CHAPTER 3

EXAMINATION OF THE ROLES OF SOLAR GEOMAGNETIC FACTORS
ON TOTAL ELECTRON CONTENT FEATURES

3.1. Introduction:

Total Electron Content (TEC) of an ionized medium may be readily received through GPS by making use of Faraday Rotation (FR) as discussed in chapter-2. TEC gives the columnar electron content of the ionosphere is directly controlled by the solar radiation and geomagnetic conditions. Therefore, contributions of such factors to TEC features need to be examined so that Physics and dynamics of the atmosphere can be understood in variant solar geomagnetic ambiances. Therefore, it is important to identify TEC features like its peak value and the profile shape at different geomagnetic environment. For this purpose one has to characterise diurnal and seasonal features of TEC as a first step and then to filter out the solar geomagnetic contributions to these factors. Therefore, in this chapter an extensive analysis on diurnal and seasonal variation of TEC over Guwahati is presented covering both high and low solar activity conditions.

It is well known that the radiations emitted by sun include X-rays, EUV, UV, visible and IR. These radiations while thread their way to earth via interplanetary magnetic fields then the intensity changes during disturbed conditions of the sun, TEC also shows large changes from its normal daily patterns. These disturbed day situation of the sun as is reflected in geomagnetic field, it has become a normal practice to monitor geomagnetic parameters regularly.
The three magnetic elements whose records are usually kept (in a magnetic observatory) are H, the horizontal intensity; Z, the vertical intensity and D, the declination. According to international standard, the days of quiet magnetic condition are characterised by a figure 0, while days of strong and moderate disturbed situations are given by figure 2 and 1 respectively. The geomagnetic field generally remains fairly steady over short periods, however it has a regular variation pattern ranging from $50\gamma$ in low latitudes to $150\gamma$ at equator. This disturbance factor is defined by a parameter $K_p$, a three hour range index that measures the intensity of geomagnetic disturbances, depending on the variation range of the three magnetic elements (H, Z, D) or for the rectangular field components x (northward), y (eastward) and z (downward). The $K_p$ index may vary between 0 to 9.

If the total $\Sigma K_p$ indices is less than 20 the day is marked as Q-day. If that value exceeds 20 that day is termed as D-day. Besides this the magnetic disturbance has two more components. One component has certain regular feature (Dst) and the remaining component is totally irregular (Di). The regular component modifies the daily mean value of the elements (e.g., decreases H). This part can be obtained by subtracting the mean values of the elements of quiet days or mean value of the disturbed days (or all days). This difference on average is denoted by Dst, the storm time variation. The storm is a violent disturbed condition of the sun when density of solar wind (a gas of charged particles continuously flowing from the sun) may go as high as $10^9$ atoms per cc from its quiet condition of 1-10 atoms per cc at the earth’s orbit and its velocity may also go to as high as $10^3$ km/s as compared to 400 km/s during quiet
environment. However, in this work TEC variation during storm time will not be considered.

3.2. **Aim of the Chapter:**

The aims of this chapter are

- To extract TEC seasonal characters at high and low solar activity periods with Rz varies from 10 to 100.

- To extract the Profile features in different geomagnetic environments.

- To describe the approaches for filtering the effects of geomagnetic disturbances on TEC.

- These TEC features extracted from the approaches 1 and 2 above are then utilised for formulating a reference TEC profile while identifying EQ precursor as will be presented in details in chapter-4.

- To understand the Physics and dynamics of the ionosphere through analysis as described above.

3.3 **Data analysis:**

TEC diurnal and seasonal profiles are analysed during high and low solar activity periods. Fig 3. shows Rz variations covering ten cycles among which cycle number 8 and 10 are analysed in this chapter.
3.4. Diurnal features during Low and high solar seasons:

Fig. 3.1 Variation of $R_z$ recorded from 1900 to 2010

Fig. 3.2 Daily variation of TEC peak
Fig. 3.3(a) TEC Noon peaks for the month of August, 2009

Fig. 3.3(b) TEC Noon peaks for the month of September, 2009
The figures 3.3 (a) and (b) indicate that TEC peak value has a complex character even in a defined season. The variation may be as large as 30% even in the low solar activity period where average Rz value lies within 10. Similarly TEC variations with geomagnetic disturbances are also complex as can be seen in the figure 3.4 where a sample case of day to day variation of TEC noon peak with Kp are shown. It is shown that though there is an apparent relation between noon TEC peak with Kp, the relation is complex and it is also necessary to examine the variation in seasonal context. Therefore, it is important that one has to analyse TEC for each season separately for both low and high solar activity period before a normalized character on TEC seasonal feature could be evolved. Such analysis are presented in the following sections.
3.4.1. Characteristic Features of Diurnal TEC Profiles during the Low and High Solar activity period for Q-days:

The TEC profile features that will be extracted here confined to mainly Q-days. The disturbed days (D-days) and the magnetic storm events are not included in the analysis. The profiles are drawn separately for four seasons as defined below, as defined earlier by this group (Rahman 1987).

Winter : 16\textsuperscript{th} November to 15\textsuperscript{th} February

Vernal : 16\textsuperscript{th} February to 15\textsuperscript{th} May

Summer : 16\textsuperscript{th} May to 15\textsuperscript{th} August

Autumnal : 16\textsuperscript{th} August to 15\textsuperscript{th} November

For this purpose TEC profiles for each day for two solar activity periods as mentioned earlier are drawn. A few such diurnal profiles covering different seasons are shown in fig. 3.5.

![Figure 3.5 (a) Winter Months](image1)

**Fig. 3.5 (a)** Winter Months  
*High Solar Activity condition*  
*Low Solar Activity condition*
Fig. 3.5 (b)  Vernal Months  
High Solar Activity condition  
Low Solar Activity condition

Fig. 3.5 (c)  Summer Months  
High Solar Activity condition  
Low Solar Activity condition

Fig. 3.5 (d)  Autumnal Months  
High Solar Activity condition  
Low Solar Activity condition
In figure the Q-day profiles of low solar activity period (2009) are presented along with those of high solar activity period (1980). It is seen that the TEC peak is significantly high during high solar activity period specially during winter and equinoctial months. The difference may be as high as 90% in some of the cases of winter months.

On examining the shape of the profiles it is seen that during vernal months of low solar cycles TEC profiles maintain a comparatively sharp peak as shown in sample representative profiles of fig. 3.5. but during summer months the TEC profiles shapes are found to be relatively broad and in comparison to other months of the year the TEC values are the lowest. But in high solar activity period no distinct change in the profile shape could be detected as displayed in representative plots of figure 3.5.

Table: 3.1

<table>
<thead>
<tr>
<th>Serial No.</th>
<th>Season of the Year</th>
<th>% enhancement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Winter</td>
<td>70%</td>
</tr>
<tr>
<td>2</td>
<td>Vernal</td>
<td>50%</td>
</tr>
<tr>
<td>3</td>
<td>Summer</td>
<td>27%</td>
</tr>
<tr>
<td>4</td>
<td>Autummal</td>
<td>58%</td>
</tr>
</tbody>
</table>

46
Fig. 3.6  Seasonal variation of TEC peaks are shown with the help of representative profiles of four seasons

Thus on examination of the profile features like TEC peak and shape it is seen that

(1)  TEC peak may go to 70% high during high solar activity period compared to the situation when Rz is low.

(2)  The TEC peak always reaches maximum during vernal equinoctial months irrespective of solar ambiance.

(3)  TEC Profile has two distinct features in low solar activity periods i.e., in one case the profile shape is sharp while in the other it is flat, but in high solar activity period the TEC always maintains a relatively well defined sharp with a distinct peak value irrespective of seasons.
3.5. Relation between TEC and Kp:

Next it is important to examine the TEC peak value and profile shape with respect to the geomagnetic disturbed conditions. For this purpose we first plot the TEC peak variation with Kp at different seasons of the year and two solar activity conditions are considered here.

In Fig 3.6 TEC peak values are plotted against Kp for both high and low solar situations considering all the four seasons of the year. It is seen that during autumnal equinoctial months of high solar activity period TEC peak value decreases with increase in Kp. It is also observed that TEC peak is independent of low Kp values but to receive the disturbed day TEC features, the Kp value should exceed a value of 25. The depletion in TEC peak with increase in Kp has also been detected in winter season of high solar activity period but here the threshold value of Kp lies around 10 i.e., the TEC disturbed day feature is likely to be seen even at low Kp values compared to those that will affect the TEC profiles of the autumnal months.

During the summer season of high solar conditions the relation between TEC peak and Kp though is not very clear, an enhancement in TEC with Kp is noted. Here such changes are detected for Kp exceeding 15. The analysis thus shown that there is a threshold of magnetic disturbance parameter (Kp) for modifying a Q-day TEC profile to its D-day pattern.

However during low solar activity period the geomagnetic disturbances has negligible influence on TEC peak. This is due to the fact that the Kp values always lie below the threshold situation as we obtained from the analysis of high solar activity TEC data.
Variation of TEC peak with geomagnetic index Kp during four seasons of the year both for low (2009) and high (1981) solar conditions.
3.5.1. Conclusion from Relation of TEC peak with $\Sigma Kp$:

- From the relation between TEC peak and $\Sigma Kp$ it is observed that during high solar activity period the threshold value of $\Sigma Kp$ that could cause TEC modification vary with season: Summer $\Sigma Kp=32$, Autumnal $\Sigma Kp=25$, Winter no threshold, Vernal $\Sigma Kp=35$.

- In low solar activity period TEC peak has little influence with the geomagnetic parameter $\Sigma Kp$ as its value lies below threshold.

- TEC peak has both positive and negative effect with geomagnetic parameter $\Sigma Kp$ during high solar activity period.

3.6. Relation between TEC and Rz

For examining the relation between the solar control on TEC, TEC-Rz plots are made for both high and low solar ambiances. For this purpose the TEC-Rz relation for each seasons are examined separately also the average TEC peak vale is plotted against the smoothed mean of Rz and shown in the fig. 3.9 for two representative years of low and high solar conditions. It is seen from the fig. that during 1981 when Rz goes to as high as 170 TEC shows a decrease instead of enhancement as obtained in the low solar period of 2009. This decrease in tendency of the TEC with increase in Rz is known as the saturation effect as obtained by the group in earlier case also. (Devi et al 1977, Rahman 1987)
Fig. 3.8 Average relation of TEC peak with sunspot number Rz during high (1981) and low (2009) solar conditions.

Fig. 3.9 Variation of TEC peak with sunspot number Rz during four seasons of low solar activity year 2009.
• In High solar activity period Rz shows a saturation effect on TEC, were Rz lies between 90 – 170.

• In low solar situation TEC shows a gradual increase with Rz. Here Rz lies between 0 – 6.

3.7. The Study of the entire shape of the Profile or P-factor:

From the examination of the TEC profiles it is observed that the profile shape changes with solar geomagnetic activities (Fig-3.5). Therefore, it is important that the profile shape is to be examined with respect to geomagnetic activity at different solar ambiances. For this purpose a parameter called Profile factor (P-factor) is defined from the TEC diurnal variation. It is the period of the profile that maintains 70% of noon time TEC peak. Fig. 3.11 demonstrates the approach for determining the P-factor (PF) from a TEC diurnal variation plot. A large number of TEC profiles are then examined for each day of a month and P-factor is extracted for each case. This exercise is done for both high and low solar activity periods. The relation between this factor with magnetic activity at both high and low solar activity are presented in the following article.
3.7.1 Relation of P-factor with Kp:

The P-factor once it is obtained from the diurnal TEC plot, its relation with Kp is examined individually for each month. A few representative plots between P-factor and Kp are shown in the figure.-3.10.

The figs.-3.10(a) and (b) show variation of P-factor with Kp values for one of the winter months, during low and high solar activity periods respectively. No modification in P-factor with Kp when noted in the low solar activity period, a relatively strong relation of Kp and P-factor is seen during high solar activity period. However one can note a threshold value of Kp at around 20, below which no significant increase in P-factor is noted.
Similar relations between P-factor and Kp is also observed during vernal equinoctial months. As a case representation, the association to these two parameters for vernal equinoctial months are shown in fig. 3.10 (c) and (d) for low and high solar activity condition respectively. The figure shows that the P-factor is independent of Kp when Rz lies within 10, but a significant increase in P-factor with Kp is seen when solar activity increases.

The P-factor and Kp relations for the summer season of low and high solar ambiance are shown in fig. 3.10(e) and (f). As in the case of winter and vernal equinoctial months the P-factor does not bear any relation with Kp for this month of low solar activity period. But an increase in the P-factor is observed with the increase in Kp during the high solar ambiance fig. 3.10(f). However its changes in P-factor are not that significant as observed in the vernal equinoctial period.

During autumnal months of high solar activity conditions it is seen that a significant increase in P-factor with Kp is noted. In low solar activity period the relation between P-factor and Kp remains same as observed in other seasons.
Fig. 3.11 Relation for $P$-factor with geomagnetic parameter $Kp$ during high and low solar conditions.
3.7.2. Relation of P-factor with Rz:

It is noted from the earlier study of past worker over this station (Devi et al., 1984, Rahman 1987) that TEC magnitude as well as growth and decay rates varies significantly with Rz.

Fig. 3.12(a) Relation for P-factor with sunspot number Rz during winter months of high solar conditions.

Fig. 3.12(b) Relation for P-factor with sunspot number Rz during Summer months of high solar conditions.
So it is necessary to examine the variation of P-factor with Rz, both for high and low solar activity situations. For this purpose Rz for each day of a month is associated with the corresponding value of P-factor and the relations so obtained are presented by a few representative plots in Figs 3.12 for high solar situations. However during low solar situation no such relations exist between P-factor and Rz as can be seen from Figs 3.13.
Fig. 3.12(a) Relation of P-factor with sunspot number Rz during vernal equinoctial month of low solar condition.

Fig. 3.12(a) Relation of P-factor with sunspot number Rz during summer month of low solar condition.

Fig. 3.12(a) Relation of P-factor with sunspot number Rz during autumnal equinoctial month of low solar condition.
3.7.3. **Discussion and Conclusion:**

The chapter focuses a few features of TEC like the noon peak values and profile factor and tries to understand the role of solar geomagnetic aspects on their modifications. The observation is based on data collected at Guwahati, an anomaly crest station where solar geomagnetic influence on ionization density are found to be complex because anomaly width itself undergoes fluctuations at different solar geomagnetic ambiances. The analysis also shows that no significant changes on TEC peak or P-factor occur with Rz or Kp during solar minimum condition when maximum Rz values go up to 10 and some Kp rarely exceeds 20. It is also noted that during high solar activity period TEC noon peak is modified by magnetic disturbances after the Kp value crosses a threshold limit. Thus influences of Rz and Kp on TEC modifications are practically absent during low solar activity conditions when both solar and geomagnetic factor lie below the threshold limit. However one cannot neglect the day to day fluctuation of TEC and P-factor even on Q-days as shown in fig. 3.13. And these aspects will have to be considered while framing Q-day TEC template for extraction of EQ precursor which will be discussed in the next chapter.

![Graphs](a) (b)
Fig. 3.13 Some profiles of Q-days with different profile shape during the low solar ambiance days of 2009

The complexity in understanding the changes in TEC with solar and geomagnetic variation in equatorial anomaly region is mainly associated with modification in the electric field a significant component in controlling ionization density of equatorial region (Devi et al. 2002) because the E field working with the magnetic field generates an ExB process could transport ionisation from the equator to off equator region there by causing density minimum at equator and a relatively high density at around 20° geomagnetic latitude. This is the well known equatorial anomaly phenomena. It is also well known that the anomaly width changes with solar geomagnetic environment (Huang et. al., 1987; Walker and Chen, 1989, Min-Yun and Chang-Shou, 1991 Anderson et. al., 2006; Devi et. al., 2006). The width may go beyond to anomaly crest zone in cases. As Guwahati lies in the crest of the anomaly there are situations specially in the equinoctial seasons where TEC post noon peak may be higher than the noon peak as an example shown in the fig. 3.12. There fore, it is important that while we try to compare Q-day TEC features with those modified by a process like EQ we have to consider not only TEC peak but also profile shape.
Fig. 3.14  TEC profile showing post noon peak higher than noon peak.

3.8. Conclusion:

- From the relation between TEC peak and Kp it is observed that during high solar activity period the threshold value of Kp that could cause TEC modification vary with season. These are - for Summer Kp=32, Autumnal Kp=25, Winter no threshold, Vernal Kp=35.

- In low solar activity period geomagnetic disturbances have little influence on TEC peak value. This observation is in conformity with our observation as
discussed above because Kp values lie below threshold limit in this solar minimum condition.

• Role of solar geomagnetic factors on modification of P-factor is found to be insignificant when Rz lies below 10.

• Solar and geomagnetic control on profile shape during high solar activity period is found to be very significant.

• The above results support that any variation on TEC caused by factors other than solar geomagnetic disturbances will be more easily detectable during low solar activity period compared to the high solar ambiances. This is due to the fact that TEC undergoes large modifications by attaining a saturation value during high Kp conditions, thereby suppressing any effect by non solar and geomagnetic origin.