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Solar control of ambient ionization of the ionosphere near the crest of the equatorial anomaly in the Indian zone

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Abstract. Long term (1979-90) total electron content (TEC) data have been analyzed to show its dependence on EUV radiation from the sun. TEC observation has been made from Calcutta (22.58° N, 88.38° E geographic, dip: 32° N), situated virtually below the northern crest of equatorial ionization anomaly. Day to day changes in TEC at different local times do not show any significant correlation with F10.7 solar flux. A good correlation is, however, observed between F10.7 solar flux and monthly mean TEC when both are considered on long term basis, i.e., either in the ascending (1986-90) or in the descending (1979-85) phases. In the early morning hours correlation coefficient maximizes around 0800-1000 IST interval. The flux independent nature of diurnal TEC is prominent around the noon time hours of few months with F10.7 values greater than 150. Variation of TEC for the whole time period (1979-90) also exhibits a prominent hysteresis effect. A remarkable feature of hysteresis effect is its local time dependent nature. Solar flux normalized TEC exhibit clear seasonal dependence with asymmetrical variations in the two equinoxes. A further normalization leads to prominent local time dependent feature. Based on solar flux, seasonal and local time dependent features of TEC an empirical formula has been developed to represent the TEC variation in the early morning hours. It yields a quantitative estimate of solar flux dependent nature of TEC variation.

Keywords : solar-terrestrial relations – Sun: UV radiation – solar activity

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1. Introduction

For ground to satellite communication through the ionosphere at VHF/microwave range the parameter that has received much attention is the total electron content (TEC). The parameter is significant for phase delay of VHF/microwave ground to satellite navigation signals as well as for space weather problems. For now-casting/forecasting time delay effect study of TEC and its variability is essential. Present works involve a long term (1978-79) investigation on ionization around the crest of equatorial anomaly in the Indian zone. Total electron content (TEC) observations, made at Calcutta (22.58^0 N, 88.38^0 E geographic, dip: 32^0 N), using geostationary satellite ETS-2 have been used for the present analysis. The important feature of this data base is that it includes both the descending (1979-85) and ascending (1986- 90) phases of the solar activity. Further, the observing station, Calcutta, has a peculiar location with respect to equatorial ionization anomaly crest. It is situated virtually below the northern crest of the equatorial anomaly. TEC is the integrated effect of production, loss and transport terms in the continuity equation. Investigation on TEC therefore, requires categorization of the effects involving various geophysical parameters.

Present paper intends to study the effects of solar radiation in the variation of total electron content around the equatorial anomaly crest of the Indian zone using long term data base of TEC and 10.7 cm solar flux. Such a long- term study using TEC data base is presented for the first time to quantify the solar flux effects.

2. Results and discussions

Production of ionization is mainly controlled by the solar radiation in EUV range. In absence of proper data base of EUV fluxes, 10.7 cm solar flux is considered as a surrogate index of solar activity. Fig. 1 presents typical solar flux vs. monthly mean TEC plots at different local times pertaining to solar activity increasing and decreasing phases. TEC values are given in unit of 10^{16} electrons/m^2. A good correlation between F10.7 solar flux and TEC is evident in the plots. Correlation is found to be somewhat larger in the ascending phase than in the descending phase. Moreover, variations of ambient ionization in the equinoctial and the December solstitial months are found to be more sensitive to solar flux changes. A higher m value in the linear fit and/or higher value of correlation coefficient indicates this sensitiveness. The test of significance of the observed correlation coefficients indicates high level of significance except a few can be rejected at very low significance levels.

For a particular month correlation coefficient maximizes in the time interval 0800-0900 IST. No saturation effect is detected in the monthly mean TEC around the above local time sector.

Sometimes saturation like effect is observed in the noon time diurnal TEC variation

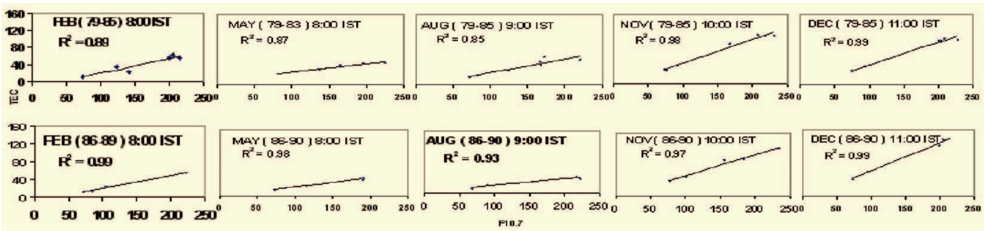

Figure 1. Plots of monthly mean TEC vs. solar flux.

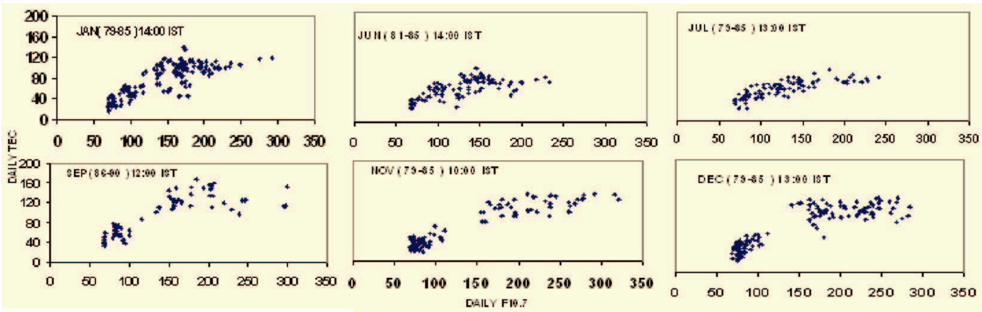

Figure 2. Plots of daily TEC vs. daily F10.7.

for F10.7>150 (Fig. 2). The feature is primarily observed in the solstitial months of descending phase, not in the ascending phase except in the months of September and December. Further, flux independent nature is absent in the other time period of diurnal TEC variation. Titheridge (1973), Bhuyan et al. (1983), Koparkar (1987), Rao et al. (1988), Dabas et al. (1993), Balan et al. (1993), Gupta & Singh (2001), found saturation effect at different solar flux values in different seasons with a linear/nonlinear fit. Present observations support saturation like effect only for few months of the descending phase. The time interval of saturation like effect is such that not only production, for which solar flux is mainly responsible, but transport of ionization is also important. Saturation effect may be due to inherent deficiency of F10.7 to represent the variation of EUV.

Although a good correlation with high significance level is observed when TEC (both diurnal and monthly mean) variation is considered with solar flux on long term basis, the day to day changes in TEC do not show any significant correlation with day to day changes in solar flux (Fig. 3). One of the reasons for short term variability is the day to day changes in the neutral winds that will give rise to fluctuations in zonal electric field. This will cause changes in the strength of anomaly and therefore in TEC at anomaly crest region.

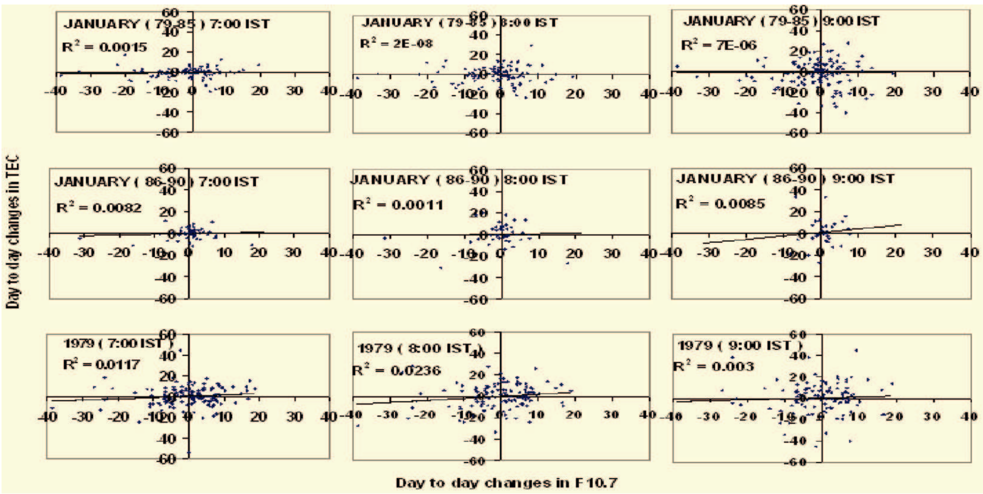

Figure 3. Plots of day to day changes in TEC and solar flux.

3. Seasonal variability of TEC

When TEC is normalized with respect to F10.7 solar flux and seasonal variation is considered an asymmetrical double peak response results. Typical plots of solar flux normalized TEC values vs. months are shown in the Fig. 4. Important feature of this semiannual variation is the local time dependence of the asymmetrical peak amplitudes and its temporal flip-over. Vernal equinoctial peaks are found to be larger compared to the autumnal equinoctial peaks in the time interval 0700-1100 IST of ascending phase (1986-90). From 1200 IST onwards autumnal equinoctial peaks show greater values and the trend continues up to 2300 IST. The double peak nature ceases to exist during 0400-0500 IST of ascending phase. A similar semiannual asymmetrical double peak response is detected in the descending phase (1979-85) also but vernal equinoctial values indicate larger peak through out the day up to 1900 IST contrary to that observed in the ascending phase. It may be mentioned that there is a data gap for the month of March in the descending phase (1979-85) for satellite eclipse period. The semiannual variation registered minima in both the phases at the summer solstitial months (June, July) with winter solstitial months (November, December, January) exhibiting higher values (winter anomaly) compared to the summer case. Thus both the phases exhibit seasonal/winter anomaly.

Seasonal anomaly is explained in terms of variation of thermospheric composition (Rishbeth & Setty 1961). Near the equatorial anomaly not only composition changes, equatorial fountain effect also affects the ionization. In F2 layer ion production is related to the concentration of atomic oxygen and loss of ions depends on the molecular gasses (N_2, O_2). The density of atomic oxygen increases near the equinoxes reducing the diffusive loss and increasing ionization/TEC (Titheridge & Buonsantu 1983). A higher atomic

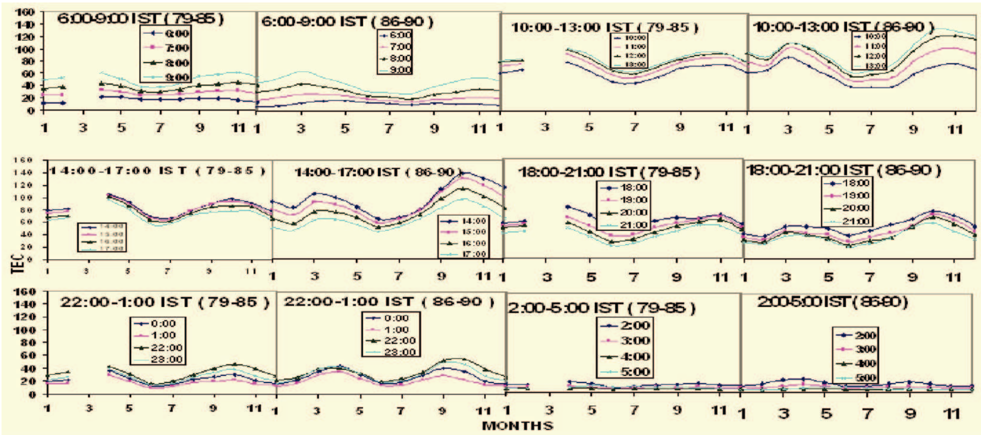

Figure 4. Seasonal plots.

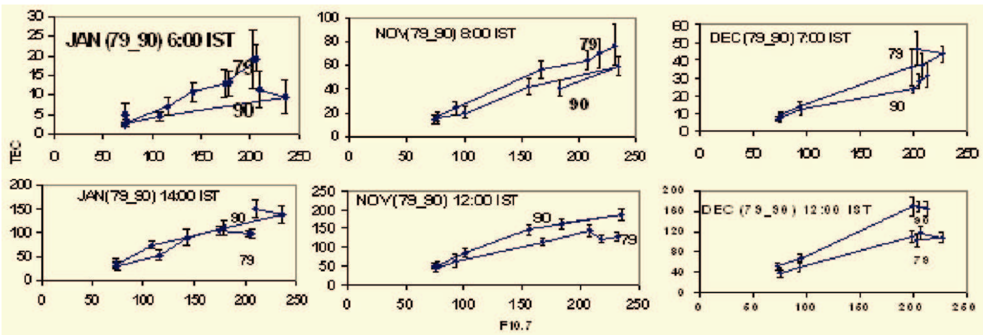

Figure 5. Plots of TEC vs solar flux showing hysteresis.

to molecular ratio in winter than in summer could account in principle for the difference in solstices. A summer to winter trans equatorial wind produces an increased peak density, and hence the large winter increase (Titheridge and Buonsantu 1983; Fuller-Rowell 1998; Rishbeth et al. 2000; Rishbeth 2000). Though seasonal anomaly is well documented, its local time dependence needs further investigation combining wind dynamics and equatorial electrodynamics.

A further normalization of TEC on the seasonal basis yields the variation of TEC with local time. A minimum is generally observed around 0400-0500 IST with maximum at 1300-1400 IST. Nature of variation is same in both the solar phases. There is a signature of secondary enhancement at pre midnight time sector for the equinoctial months.

One important feature of long term TEC variation with F10.7 cm solar flux is the hysteresis effect. When monthly mean TEC values are plotted against mean solar flux, TEC in the ascending phase follows a path different from that of the descending phase similar to the hysteresis effect shown by the ferromagnetic material. Fig. 5 is a plot of monthly mean values of TEC vs. F10.7 solar flux. The vertical bars represent corresponding standard deviations. The effect is more prominent in the high solar activity period than in the lower one. The hysteresis may be classified as positive or negative according as TEC in the descending part of solar cycle lies above or below the ascending part. In most cases during the time interval 0600-0900 IST TEC shows positive hysteresis effect. The hysteresis effect observed with TEC is similar to that observed in foF2, M(3000)F2 and ypF2 (semi thickness of F2 layer) with sunspot number (Huang 1963; Rao & Rao1969, Huang & Bor-Shenn 1976; Smith & King 1981; Apostolv & Berca 1995). Rao & Rao (1969) reported the hysteresis effect in foF2 as the cumulative influence of magnetic storms on the noon time foF2.

One remarkable feature of hysteresis phenomena is its local time dependence. TEC variation for more or less the same solar flux shows positive as well as negative effect at different local time. For better realization of phase reversal, long term temporal effects of anomaly parameters and of wind system on TEC variability are to be considered other than solar flux.

4. Development of an empirical formula

Considering the solar flux, seasonal and local time variation of TEC an empirical formula has been developed for the time interval 0700-0900 IST. This may give an indication of solar control of ionization in morning sector. The formula empirically developed may thus be written as

$$\begin{aligned}\text{TECcal} &= [\{(m+12)/(m+6)\} * \{(F10.7-1)/(F10.7+200)\}] \\ &\quad *[S.F. + m * (\text{Sea}/12) + t * (\text{Temp}/24)]\end{aligned}$$

where m = months, t = local time, F10.7 = value of 10.7 cm solar flux, S.F. = contribution of solar flux obtained from solar flux vs. TEC plot, Sea= seasonal contribution obtained from solar flux normalized TEC plot, Temp= local time contribution obtained from temporal plot.

A validation of the estimated TEC values has been made using TEC data for the year 1978 (Fig. 6). F10.7 solar flux has been taken as a matching parameter. Here calculated values agree with the original TEC values except for the months of September and October when deviation is observed to be 30-40% from experimental values.

5. Conclusion

Long-term study of TEC and solar flux reveals that ionization around the local morning time is mainly controlled by solar radiation. Seasonal and local time contributions are

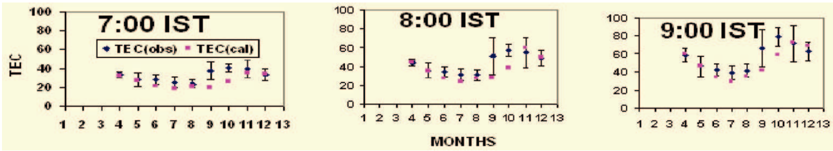

Figure 6. Calculated and observed values of TEC for 1978.

observed to be much less. The ascending phase of the solar cycle is found to be more sensitive in controlling the ambient ionization around the present location. The apparent saturation like effect in the TEC variation with solar flux, for certain months of the descending phase, needs further investigation relating to equatorial electrojet strength and wind parameters. A prominent hysteresis effect observed in the variation of TEC with solar flux and its local time dependence requires further analysis concerning transport parameters.

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