Solar flux influence on propagation of disturbance dynamo to equatorial ionosphere

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Abstract

On some magnetically disturbed days equatorial ionospheric electric fields are changed which affects the quiet time behavior of equatorial F layer height in the post sunset hours. The effects seen at equatorial F region are either associated with disturbance dynamo (DD) or prompt penetration (PP) or combination of both DD and PP. In the present investigation an attempt is made to identify the effects associated with DD alone, which are causing upward movement of F layer in the post sunset hours and studied separately for low and high solar flux periods. Ionosonde data recorded at dip equatorial station Trivandrum (77^0 E, 8.5^0N, dip0.5^0N) for the period of 1990-2003 is scaled to obtained local time (LT) variation of base height of F layer (h'F) in the post sunset hours. Monthly quiet time average of h'F $\left(\left\langle h'F_Q\right\rangle\right)$ is computed by taking 15 minutes average. Effect of DD electric field on h'F (ΔH) is computed by subtracting disturbed time h'F $(h'F_D)$ from $\left\langle h'F_Q\right\rangle$. The maximum enhancement seen in h'F due to DD electric field is obtained by taking minimum of ΔH and then compared with Joule energy deposited at high latitudes for different time lags. It is found that time delay required to produce the maximum effect of DD on equatorial F region height is solar flux dependent. The delay time is found to be higher for periods of high solar flux. Moreover the Joule energy required to produce same maximum upward movement of F layer as compared to their monthly quiet time pattern is found to be higher for days with high solar flux.

1. Introduction

A large amount of energy gets deposited in the high latitude ionosphere during periods of strong geomagnetic activity. Enhancement of electric field and electrical conductivity in the high latitude ionosphere causes intense currents to flow there giving rise to increased Joule heating during periods of high magnetic activity. The neutrals thus get heated and a disturbance dynamo is set up by the altered neutral wind at high latitudes [1]. Disturbance dynamo (DD) and prompt penetration (PP) of magnetospheric electric field are the sources for modulation of equatorial ionospheric electric field and hence play important roles in the dynamics of equatorial ionosphere during periods of high magnetic activity. It is known from past observations that the equatorial ionosphere shows highly variable responses during magnetically active periods [2-4]. The effect of magnetic activity observed at a given LT in equatorial ionosphere may be associated with either DD or PP electric field alone or it may be a combined effect of both [5-7]. Earlier studies have suggested that sudden change in polar cap potential may cause prompt penetration of electric field, when there is no sufficient shielding effect [8] and these PP electric fields (i) have short time duration (~1 hr), (ii) can reverse the direction of the normal electric field (iii) its effects are often observed simultaneously at all longitudes [9-12]. However, recent study suggests that PP electric field effects

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can be seen for longer duration during intense geomagnetic storm. As DD takes some time to set up, its effects are observed after some time delay at equatorial ionosphere. Sometimes the effects of magnetic activity are observed on the following day of magnetically disturbed day. It is also suggested that its effect can persist for longer time duration. Computer simulation has shown that PP electric field considerably modulates the existing DD electric field and hence it's associated effects on equatorial F region [7]. However the modulated ionospheric electric field associated with either DD or PP or DD+PP may increase or decrease the height of equatorial F layer considerably as compared to their monthly quiet time pattern in the post sunset hours, depending upon the direction and strength of disturbed time electric fields, which is superposed on ambient ionospheric electric field. The nature and strength of the effect of magnetic disturbances on h'F is found to be different for different magnetically disturbed days, which may be attributed to differences in the magnetic activity level on those days and hence in the Joule energy, in the starting time and duration of magnetic activity and in the ambient ionospheric conditions. A study done by Fejer et al. [13] using Jicamarca radar observations, suggests that DD electric field, with dominant time delay of about 3-15 hrs after a period of increased magnetic activity largely accounts for disturbed time zonal plasma drifts. These authors found that geomagnetic activity effect on zonal plasma drifts are season and solar flux dependent; however effect of solar flux on time delays is not yet examined. In the present study 18 magnetically disturbed, which shows significant enhancement in h'F as compared to their quiet time pattern, in the post sunset hours as a result of DD electric field alone are studied. The time delay required for the DD to produce maximum effect at equatorial F region is estimated for low and high solar flux periods.

2. Methodology

In the present study ionosonde data recorded at Trivandrum (77^0 E, 8.5^0N, dip0.5^0N) for the period of 1990-2003 is used. For each day the base height of F region, h'F is scaled from ~17 to 08LT of the next day. Despite of day-to-day variability in the post sunset evolution of F region the apparent base height of F layer, h'F, generally follow a well defined pattern for magnetically quiet days in a given month. A monthly average quiet time pattern is obtained by taking 15min average for magnetically quiet days of a month. For each magnetically disturbed day effect of magnetic disturbance on h'F (ΔH) is obtained by subtracting disturbed time h'F $(h'F_D)$ from monthly quiet time average pattern of h'F, $(\langle h'F_Q \rangle)$. Figure1 shows the monthly quiet time average pattern for July 1999, superimposed with h'F for magnetically disturbed day 2 July 1999 as a function of LT in upper panel and ΔH as a function of LT in lower panel. It is clearly seen that on disturbed day; 2 July 1999, F layer moves upward considerably as compared to quiet time average pattern of h'F and maximum increase of ~ 156km is seen around 01.7LT. The minimum of ΔH provides the estimate of maximum effect on h'F resulting from disturbed time eastward electric field that is superimposed on ambient quiet time electric field in the post sunset hours. It should be noted that the $\Delta H_{\min}$ is considered as the quantitative measure of maximum effect of magnetic disturbance on h'F, however it is not known that observed effect is associated with DD or PP or combination of DD and PP both. A method based on three hourly geomagnetic activity index ap is used to identify the magnetically disturbed days on which observed effects on h'F are caused due to DD electric field alone. To carry out this exercise, for each nth day three values namely Ap0, Ap1, Ap2 are calculated from three hourly geomagnetic activity index ap such that Ap0, Ap1 and Ap2 respectively represents the average of 6 ap values in sequence starting from 00UT of n-1th day. The ap and AE values starting from 00UT of previous day to 06UT of next day are plotted for 2 July 1999 in figure2. It should be noted that effect of magnetic activity on h'F in the post sunset hour through the night i.e ~17-32LT are studied here, hence 32LT represents the 08LT of next day. Ap2 indicate the average magnetic activity for the period starting from ~17.5LT for the nth day to 11.5LT of following day. Ap0 and Ap1 jointly indicate the average magnetic activity for 36hrs prior to the starting time of Ap2 (i.e 17.5LT). The magnetically disturbed and quiet days are chosen on the basis of Ap0, Ap1 and Ap2. The days with (Ap0+Ap1)/2<18 and Ap2<18 are considered as magnetically quiet days, whereas remaining days are consider as magnetically disturbed. This criterion is chosen as it assures that (i) the period when effects of magnetic activity are observed (i.e 17-08LT) on h'F is magnetically quiet (ii) 36hrs prior to this period of Ap2 is magnetically quiet. The magnetically disturbed days with (Ap0+Ap1)/2 $\geq$ 18 and Ap2<18 are considered in the present study as the effects seen on these days can be attributed to DD electric fields alone. It should be noted that as Ap2<18 the time when effects of magnetic activity is observed on h'F in post sunset hours, 17-08LT is on an average magnetically inactive. Secondly, condition (Ap0+Ap1)/2 $\geq$ 18 ensures that the period prior to the time when maximum effects of magnetic activity is observed on h'F, was magnetically disturbed. Hence combining these two conditions safely one can say that the observed effects of

magnetic activity at equatorial F region height are associated with DD electric field alone and hence can be compared with energy input at high latitudes.

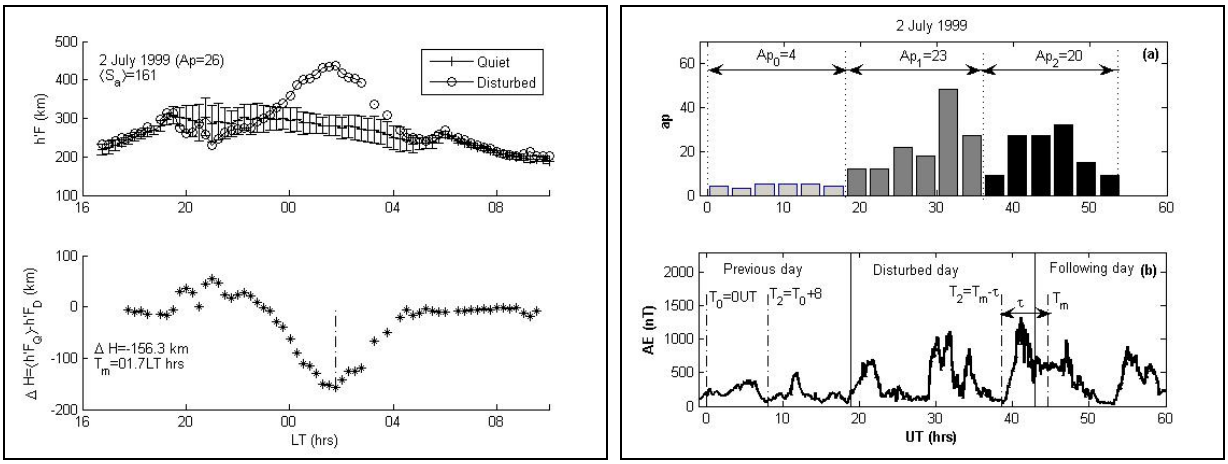


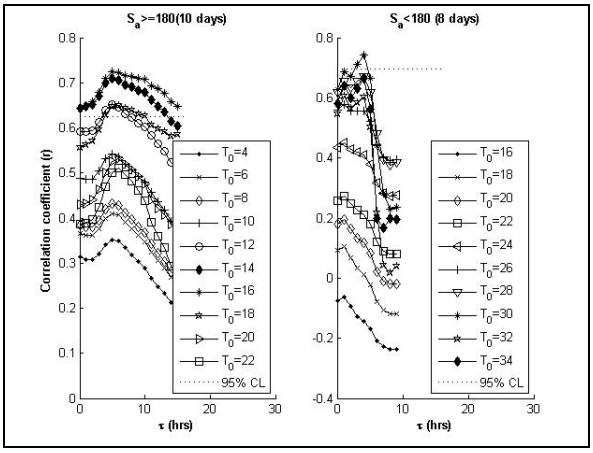
Fig1. (a) Monthly quiet time average pattern of h'F for July 1999 along with h'F for disturbed day 2 July 1999 as a function of LT. (b) ΔH as a function of LT for 2 July 1999. Fig2. Geomagnetic activity index (a) ap and (b) AE is plotted starting from 00UT of 1 July 1999.

For each magnetically disturbed day Joule energy deposited at high latitude is computed using empirical relation given by Akasofu [14]. Joule energy is calculated from integration over time of the power given by $P = 2 * (2 * AE * 10^8)$ W. A factor of 2 accounts for the energy from both hemispheres. Let T_1 and T_2 be start and end time for integration. The maximum effect of magnetic activity on h'F is observed at time T_m and this effect is a manifestation of energy deposited in the high latitude ionosphere over a period of time prior to this time T_m. Let T_0 is the start time of AE considered in the present study for integration i.e 00UT. T_1 is allowed to change from T_0 to T_0+40 in steps of 2hrs. The end time T_2 is considered as $T_m - \tau$, where τ is the minimum time lag for the high latitude disturbances to have an effect on the equatorial F region and allowed to change from 0, 1, 2...15 hrs. Figure 2b shows the variation of AE index for 2 July 1999 starting from previous day 00UT, with different (i) start time and (ii) time lags used for the computing energy deposits at high latitudes.

3. Results and discussion

Magnetically disturbed days with (Ap0+Ap1)/2 ≥ 18 and Ap2<18 are separated into two bins depending on the 10.7 cm solar flux (S_a). There are 10days with $S_a \geq 180$ and 8 days with $S_a < 180$, which shows significant effect of DD (i.e $|\Delta H_{\min}| \geq 80$ km). The empirical estimates of Joule energy, E_{Joule} for different start time T_1 and τ are computed and compared with $|\Delta H_{\min}|$. Correlation coefficient between E_{Joule} and $|\Delta H_{\min}|$ are estimated for each combination of T_1 and τ. Figure3 shows the correlation coefficient as a function of τ for different start time T_1 separately for days with (i) $S_a \geq 180$ and (ii) $S_a < 180$. It should be noted that maximum correlation 0.72 is obtained for T_1=16 and τ=5hrs for the magnetically disturbed days with $S_a \geq 180$. Whereas maximum correlation of 0.74 is obtained for T_1=30 and τ=4 hrs. The maximum effect of DD electric field on h'F are seen at $\langle T_m \rangle$= 21.8 ± 2 LT and 25 ± 2.4LT (01LT) respectively high (236 ± 44) and low (121 ± 40) solar flux period. Hence the maximum and minimum time delay required to get the maximum effect of DD on equatorial F region are found to be 24.3-5 and 13.5-4hrs for high and low solar flux respectively. Result suggest that the Joule energy deposited 5-23.5 hrs (14.5-4hrs) prior to the time $\langle T_m \rangle$ when maximum effect of DD is observed at equatorial ionosphere i.e around 21.8 LT (02LT) during high (low) solar flux is attributed to observed effect on h'F. Figure4 shows the $|\Delta H_{\min}|$ as a function of Joule energy deposited at high latitude for these time durations for high and low solar flux period. It is found that the energy required to produce the same enhancement in h'F in the post sunset hours as

compared to their monthly quiet time pattern is lower during low solar flux as compared to periods of high solar flux.



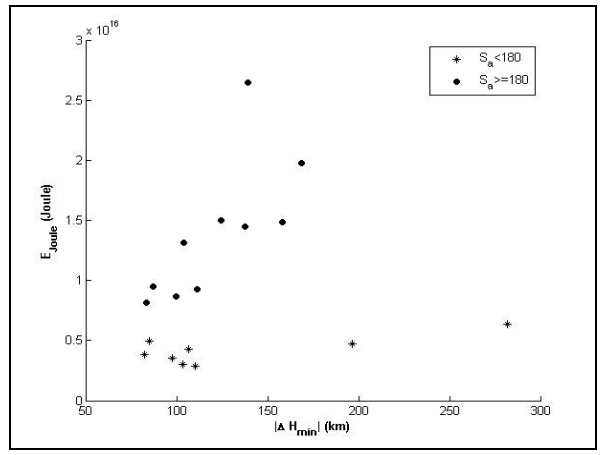


Fig3: Correlation coefficient as a function of time delay for different T_1 for low and high solar flux period. Fig4: $|\Delta H_{\min}|$ as a function of Joule energy E_{Joule} for low and high solar flux.

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