Effect of magnetic activity on equatorial F region plasma drifts

B. Engavale, K. Jeeva, K. U. Nair and A. Bhattacharyya

Indian Institute of Geomagnetism, New Panvel, Navi Mumbai- 410218, India

Abstract. Effect of magnetic activity, caused by complex interaction of solar wind and magnetosphere, on night time equatorial F region plasma drifts is studied using scintillation data recorded using spaced receivers at Tirunelveli (dip 0.4^0), for a 251 MHz signal transmitted from a geostationary satellite. Once the perturbation electric field associated with plasma bubbles are eroded, about two hours after the initiation of bubble growth, the irregularities simply drift across the signal path along with background plasma. Hence irregularity drift speed estimated from spaced receiver scintillation data is very close to the drift speed of the background plasma during this period. In order to obtain monthly average quiet time plasma drift pattern in the nighttime equatorial F region, the drifts estimated from scintillation data are averaged after 22LT for all quiet days ($Ap < 18$) of a month. Quantitative estimate of the effect of a disturbance dynamo produced by enhanced geomagnetic activity, on the nighttime equatorial F region plasma drift is obtained by removing monthly quiet time plasma drift pattern from disturbed time plasma drift pattern. The maximum effect of disturbance dynamo on equatorial F region plasma drift is observed around midnight for most of the magnetically disturbed days considered in the present study. An attempt is made here, (i) to relate the maximum deviation of the disturbed nighttime equatorial F region plasma drifts from quiet time pattern, with an empirical measure of the Joule energy input at high latitudes during magnetically active periods (ii) to investigate the time delays, which are required for obtaining the maximum disturbance dynamo effects observed in the night time equatorial F region plasma drifts, based on *AE* and *Kp* indices.

Index Terms. Disturbance dynamo, equatorial ionosphere, F region plasma drifts, time lag, Joule energy.

1. Introduction

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 enhanced magnetic activity. The neutrals thus get heated and a disturbance dynamo is set up by the changed neutral wind at high latitudes (Blanc and Richmond, 1980). Disturbance dynamo and prompt penetration of electric fields are the major sources, for modulating the ionospheric electric field and hence the dynamics of equatorial ionosphere, due to increased magnetic activity. It is known from past observations that, ionosphere shows highly variable responses during magnetically active periods (Fejer and Scherliess, 1997; Sastri et al., 2000; Basu Su. et al., 2001). The observed ionospheric effects may be associated with disturbance dynamo or prompt penetration electric field or it may be a combined effect of both (Fejer et al., 1991; Maruyama 2005). The perturbation electric field associated with the Rayleigh-Taylor (R-T) plasma instability, which produces the ESF irregularities, that give rise to the observed scintillations causes rapid changes in irregularity drift in the initial phase of development of irregularity (Bhattacharyya et al., 2001). After 22 LT, when this perturbation electric field dies down, irregularities simply drift with the background plasma. Hence drifts estimated from scintillation measurements for these periods, are close to the background plasma drifts and follow a well defined pattern for magnetically quiet days in a given month. The equatorial F region plasma drifts obtained from spaced receiver scintillation data shows the influence of magnetic activity (Bhattacharyya et al., 2002). The nature and strength of the effect of magnetic disturbances on plasma drifts 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, and in the starting time and duration of magnetic activity. Quantitative estimates of the effect of disturbance dynamo on night time equatorial F region plasma drifts are obtained by subtracting monthly average quiet time pattern of plasma drifts from disturbed time pattern, and studied as a function of empirical estimates of Joule energy input at high latitudes. The changed neutral wind resulting from enhanced Joule energy during magnetically disturbed periods takes some time to set up the disturbance dynamo. As a result disturbance dynamo associated perturbations in the equatorial ionosphere are observed with some time delays after enhancement in magnetic activity. Recently, a study done by Fejer et al. (2005) using Jicamarca radar observations, suggests that disturbance dynamo electric fields, with dominant time delay of about 3-15 hrs largely accounts for disturbed time zonal plasma drifts. In the present work the time lags, for obtaining the maximum disturbance dynamo effects observed in the

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nighttime equatorial F region plasma drifts are investigated using *AE* and *Kp* indices.

2. Data analysis

Amplitude scintillation data for a 251 MHz signal transmitted from a geostationary satellite, UFO2, located at 71.2 ^{o} E, and recorded by two spaced receivers closely aligned in magnetic E-W direction, at the equatorial station, Tirunelveli (dip latitude 0.6 ^{o} N) during the period, June 2001 to March 2005 is used in the present study. In addition to this amplitude scintillations on the same frequency signal transmitted from a geostationary satellite, FLEETSAT, located at 73 ^{o} E and recorded at Tirunelveli, for some equinoctial and summer months of 1995-2000 is also utilized. The separation between receivers is 540 m in the magnetic east-west direction. Full cross correlation analysis technique introduced by Briggs (1984) is used and maximum cross-correlation $C_I(x_0, t_m)$ of intensity fluctuations between two receivers, average drift V_0 of scintillation pattern along the receiver's base line, random velocity V_C and S_4 index, which is the standard deviation of normalized intensity variations are estimated for every 3 min from the scintillation data, which is sampled at 0.1 s intervals. Random velocity V_C is a measure of random changes in the irregularity characteristics. When the signals from spaced receivers are correlated 50% or greater, the assumption inherent in the full correlation technique have greater validity and hence V_0 and V_C are estimated only for intervals with $C_I(x_0, t_m) \geq 0.5$. In order to eliminate noisy signals from the observed scintillations, only intervals with $S_4 \geq 0.15$ are considered for the present study. In the early phase of irregularity generation, the calculated V_0 is highly variable due to presence of perturbation electric field associated with the R-T plasma instability (Bhattacharyya, et al., 1989). After 22 LT, when perturbation electric field associated with plasma instabilities is eroded irregularities simply drift across the signal path with background plasma and hence estimated drift of ground scintillation pattern, V_0 is very close to background plasma drift (Bhattacharyya et al 2001). For the geometry of incoming radio signal path, $V_0 = V_E - V_Z \tan\theta \sin\phi$, where V_E and V_Z are eastward and vertical drifts of irregularities, and θ and ϕ are zenith and azimuth angle of the signal path. The contributions to V_0, from vertical drift are $-0.13V_Z$ and $-0.1V_Z$ for UFO2 and FLEETSAT respectively, which are very small after 22LT. Hence calculated V_0, after 22LT is close to the zonal plasma drifts. The disturbed time plasma drifts can be identified after 22 LT, as magnetically quiet time plasma drift variations follow a well-defined pattern after 22LT for a given month. Fig.1 shows the zonal plasma drift for a disturbed day, 24 November 2001 superimposed on the monthly quite time plasma drift pattern for November 2001. The effect of magnetic disturbances is seen very clearly on the equatorial F region plasma drift, as an additional westward drift is imposed on the background plasma, resulting in decreased zonal drifts in the equatorial F region. The data gaps seen in the calculated V_0, are associated with scintillation events with $C_I(x_0, t_m) < 0.5$.

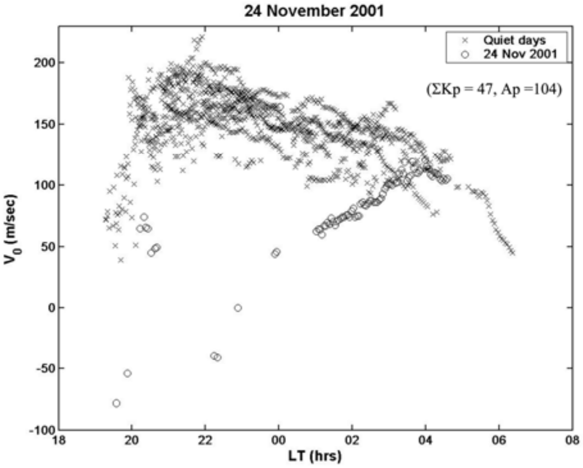

Fig. 1. Mass plot of the eastward plasma drift V_0, for magnetically quiet nights for the month of November 2001 superimposed with the plasma drift on a disturbed day, 24 November 2001.

3. Quantitative estimate of disturbance dynamo

The identification of disturbed equatorial F region plasma drift before 22 LT is difficult, due to presence of perturbation electric field associated with plasma instability on disturbed days as well. Hence magnetically quiet time monthly average of plasma drift $\langle V_0 \rangle$ and disturbed time average plasma drift $\langle V_D \rangle$ for each disturbed day is computed after 22LT for every 6 minute.

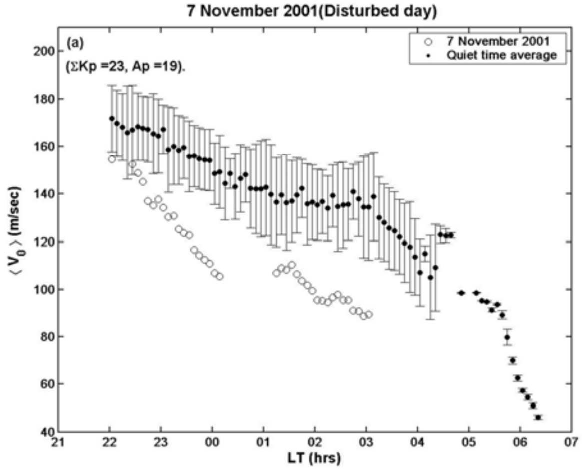

Fig. 2(a). Monthly quiet time average eastward plasma drift with error bars for the month of November 2001 and plasma drift on a disturbed day: 7 November 2001, are shown as a function of local time.

The maximum departure of the disturbed plasma drift from the monthly average quiet time pattern is obtained; $\Delta V = \langle V_D \rangle - \langle V_0 \rangle$. Distribution of ΔV with local time is fitted with a 6th order polynomial and maximum value ΔV_{max} of $|\Delta V|$ is obtained for each disturbed day studied. Fig. 2(a) shows the monthly average quiet time plasma drifts for November 2001 along with plasma drifts for a disturbed day: 7 November 2001. The absolute value of the difference between quiet and disturbed time plasma drift for the same day, |ΔV| is shown in Fig. 2(b). It is seen that the |ΔV| has a local maximum around midnight, and perhaps another one at about 03 hrs LT.

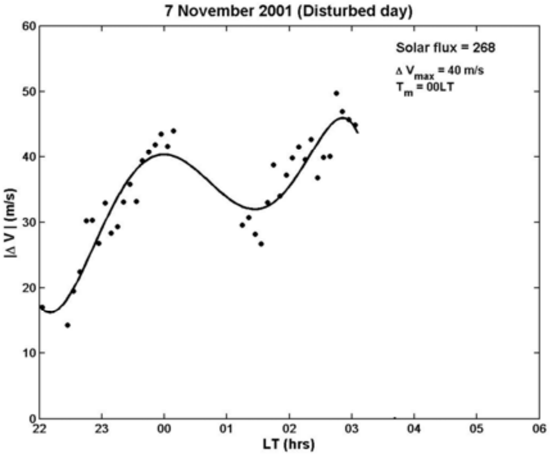

Fig. 2 (b). |ΔV| as a function of local time fitted with 6th order polynomial.

Most of the disturbed days considered in the present study, show maximum effect of the disturbances around midnight, however on some magnetically disturbed days second peak is also seen in the post midnight hours. Magnetic activity affects not only the zonal drift but also the vertical drift of plasma in the equatorial F region. As a result sometimes fresh ESF irregularities are generated, during periods of high magnetic activity, and estimated maximum cross-correlation of intensity variations, $C_I(x_0, t_m)$ is found to be low during those periods (generally below 0.5) (Bhattacharyya, 2002). A low decorrelation at the time, when maximum disturbance dynamo effect is observed indicates that the observed effect in plasma drift is associated with changes in the ambient electric field and it is not influenced by the presence of any perturbation electric field of irregularities.

4. Joule energy computation

The empirical relation given by Akasofu (1981) is used for the computation of Joule energy. A factor of 2 accounts for the Joule energy from both the hemisphere. Joule energy is calculated from the time integration of the power given by Eq. (1)

$$P_{Joule,\ Akasofu} = 0.2 \ * AE \ * 10^{9} \ \text{W} \quad (1)$$

Hence selection of T_1 and T_2, the start and end time respectively, for the integration becomes very important. The time at which, maximum effect of disturbance dynamo occurs is denoted by T_m. This effect is a manifestation of energy deposited in the high latitude ionosphere over a period of time. In some cases, the observed effects are associated with previous day's magnetic activity. Hence AE (or Kp) indices are plotted for a 50 hour period starting at T_0 = 00UT of the day before the magnetically disturbed day. The starting time T_1 is allowed to vary from T_0 +3 hrs to T_0 +36 hrs, in steps of 3 hours. The ending time T_2 is taken as T_m-τ, where the minimum time lag τ for the high latitude disturbances to have an effect on the equatorial ionosphere is allowed to take on values: τ = 0,1,2….15 hrs.

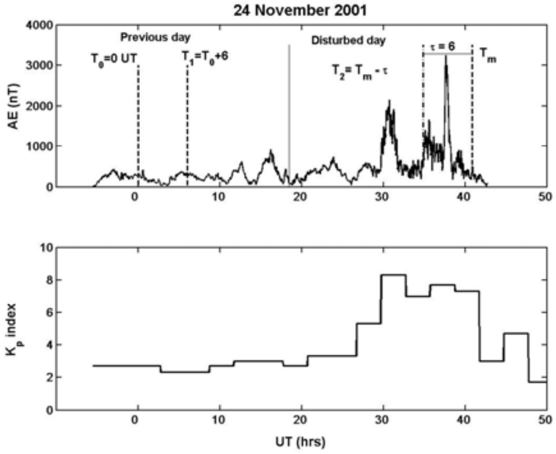

Fig. 3. Variation of *AE* and *Kp* index for 24 November 2001 and its previous day with different start time and time lags used for the calculation of Joule energy.

5. Results and discussion

The scintillation data set is divided into two groups (i) magnetically disturbed days from 1995-2001, for which *AE* and *Kp* indices are available and (ii) magnetically disturbed days from 2002-2005, for which only *Kp* indices are available. The joule energy and average *Kp* is computed using different start time T_1 and time lag τ for magnetically disturbed days from group I.

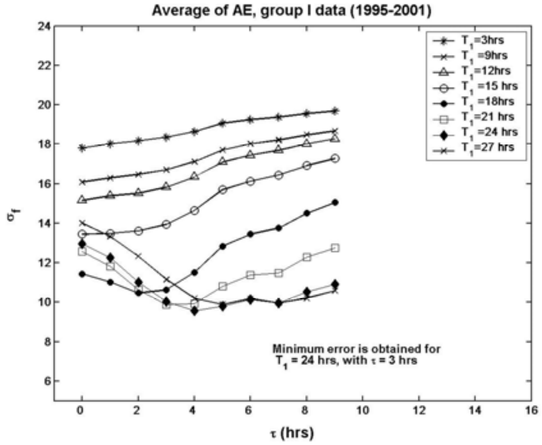

Fig. 4. Error in least square fit of the variation of $\Delta V_{\max}$ with Joule energy is plotted as a function of time lag for different start time T_1.

The $\Delta V_{\max}$ is plotted as a function of calculated average *Kp* and Joule energy for different start time and time lag. For each combination of T_1 and τ, distribution of $\Delta V_{\max}$ with estimated (i) Joule energy and (ii) average *Kp* are fitted with a linear least square fit. Error in the fit σ_F is plotted as a function of time lag for each value of start time for both the cases, which are shown in Figs. 4 and 5 respectively. The combination of T_1 and τ, which gives minimum error in the least square fit are associated with the time duration required to obtained maximum disturbance dynamo effect on night time equatorial F region plasma drifts, and the computed Joule energy and average *Kp* for those time durations are associated with the maximum disturbance dynamo effect. It is clear from Fig. 4 that, error in the fitting increases with time lag when $T_1 \leq 15\,hrs$. Minimum error is obtained for a time lag of 4 hrs with $T_1 = 24 hrs$. It implies that Joule energy from the time interval from T_1 to $T_m - 4\,hrs$ contribute the most to the disturbance dynamo effect observed in the equatorial F region. When a similar exercise is done using *Kp* indices, the minimum error in the fitting is obtained for a time lag of 3 hrs with $T_1 = 27 hrs$, which is shown in Fig. 5. The maximum effect of disturbance dynamo on equatorial F region plasma drifts is seen around midnight in most of the cases. This suggests that Joule energy deposited approximately 4-18 hrs before time T_m, when maximum disturbance dynamo effect is seen (approximately around midnight) contributes the maximum to disturbance dynamo effects observed on equatorial F region plasma drifts. Calculations made using mid latitude *Kp* indices suggest a delay of 3-15 hrs. A recent study by Fejer et al. (2005) has suggested that Jicamarca zonal disturbance drifts can be largely accounted for disturbance dynamo electric fields with dominant time delay of about 3-15 hrs. These authors also observed small westward perturbations in the post midnight hours, which are associated with time delay of about 15-24 hrs.

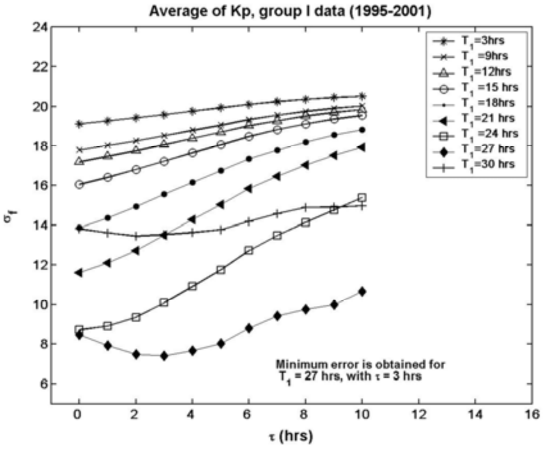

Fig. 5. Error in least square fitting to the variation of $\Delta V_{\max}$ with average *Kp* is plotted as a function of time lag for different start time T_1.

The time delay of about 3-15 hrs, based on *Kp* indices obtained using scintillation data is in good agreement with results obtained by Fejer et al (2005). However, these authors have also considered the influence of solar activity by using separate data sets for high and low solar flux periods. Due to insufficient data the effect of solar flux on disturbance dynamo is not studied in the present work. A total of 29 magnetically disturbed days from group II are studied using the same method, in order to investigate if the variation of $\Delta V_{\max}$ with average *Kp* for magnetically disturbed days from group II (2002-2005), follow the same pattern as magnetically disturbed days from group I. Fig. 6 shows the distribution of $\Delta V_{\max}$ with average *Kp* for T_1 = 27 hrs and $\tau = 3hrs$ for magnetically disturbed days from group I and group II. It is clearly seen from Fig. 6 that, the distribution of $\Delta V_{\max}$ with average *Kp* for group II follow the pattern of magnetically disturbed days from group I. The results presented here suggest that Kp and AE indices are good indicators of the extent of disturbance dynamo effects on the electrodynamics of equatorial F region plasma.

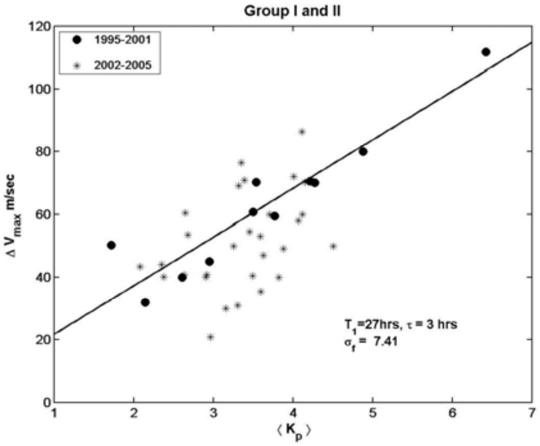

Fig. 6. Plot of $\Delta V_{\max}$ as function of average Kp for T_1=27 hrs, $\tau = 3hrs$ for magnetically disturbed days of group II and I.

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