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Letter to the editor

Electric field fluctuations (25–35 min) in the midnight dip equatorial ionosphere

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Abstract. Measurements with a HF Doppler sounder at Kodaikanal (10.2°N, 77.5°E, geomagnetic latitude 0.8°N) showed conspicuous quasi-periodic fluctuations (period 25–35 min) in F region vertical plasma drift, V_z in the interval 0047–0210 IST on the night of 23/24 December, 1991 (A_p = 14, $K_p < 4^-$). The fluctuations in F region vertical drift are found to be coherent with variations in B_z (north-south) component of interplanetary magnetic field (IMF), in geomagnetic H/X components at high-mid latitude locations both in the sunlit and dark hemispheres and near the dayside dip equator, suggestive of DP2 origin. But the polarity of the electric field fluctuations at the midnight dip equator (eastward) is the same as the dayside equator inferred from magnetic variations, contrary to what is expected of equatorial DP2. The origin of the coherent occurrence of equatorial electric field fluctuations in the DP2 range of the same sign in the day and night hemispheres is unclear and merits further investigations.

Key words: Ionosphere (electric fields and currents; equatorial ionosphere; ionosphere-magnetosphere interactions)

Introduction

DP2 is a global ionosphere equivalent current system proposed to account for quasi-periodic (QP) fluctuations in the geomagnetic field that occur coherently at high latitudes and dayside dip equator and in the B_z (north-south) component of interplanetary magnetic field, IMF (Nishida *et al.*, 1966; Nishida, 1968a, b). The twin-vortex DP2 current system is thought to be driven by the IMF-controlled magnetospheric convection electric field. The recent case study of Kikuchi *et al.* (1996) using EISCAT radar observations showed that DP2 magnetic fluctuations at auroral latitudes are due to ionosphere Hall current caused by the convection electric field. Their work further suggests that the magnetospheric electric field penetrates almost instantaneously through the polar ionosphere to the equatorial ionosphere and drives the current system responsible for equatorial DP2. The noteworthy enhancement of DP2 amplitude at dayside dip equator compared to low latitudes is believed to be due to the Pedersen current amplified by the Cowling effect.

Most of the earlier studies of equatorial DP2 are limited to the dayside and there is an acute paucity of information on DP2 at the evening and nightside dip equator. Detailed evaluation of the local time dependence of the characteristics of equatorial DP2 will help advance our understanding of the substorm phenomenon as a whole (Rostoker, 1993) and of related equatorial ionospheric disturbances (see, Fejer, 1997 and references therein). We have very recently found evidence for DP2 electric field fluctuations (period ~25 min) at the duskside dip equator which supports the view that the magnetospheric electric field responsible for DP2 penetrates to equatorial ionosphere on the duskside as on the dayside and leads to electric field perturbations of the same polarity (eastward) as on the dayside (Abdu *et al.*, 1998). We present and discuss the characteristics of an event of electric field variations in the DP2 period range (25–35 min) evidenced in the midnight dip equatorial ionosphere.

Results and discussion

A HF Doppler sounder is regularly operated on 4 MHz at Kodaikanal, India (10.2°N, 77.5°E, geomagnetic latitude 0.8°N) to monitor the Doppler velocity, V_d of F region reflections at normal incidence in the evening-night hours. V_d represents the F region vertical plasma drift, V_z $(=V_d/2)$ due to zonal electric fields at this location over the local time period mentioned. The details of the experimental set-up were published

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elsewhere (Sastri *et al.*, 1985). The HF Doppler data of Kodaikanal have proved useful, in addition to other investigations, in studies of equatorial electric fields associated with transient geophysical phenomena like storm sudden commencements (*ssc*), sudden impulses (*si*) and substorms (Sastri *et al.*, 1993, 1995, 1997). Doppler measurements made on the night of 23/24 December 1991 (A_p = 14, K_p < 4^-) showed a distinct train of quasi-periodic variations in V_z just after local midnight as can be seen from raw V_z data (one minute resolution) presented in Fig. 1. The presence of three distinct cycles of QP fluctuations (labelled 1 to 3, period 25–35 min) over the interval 0047–0210 IST (1917–2040 UT) is obvious from the figure. We have explored whether this disturbance in F region vertical plasma drift is a signature of DP2 activity by analysing Kodaikanal V_z data in conjunction with geomagnetic field variations elsewhere and with B_z component of IMF.

Figure 2 shows the temporal variation over the interval 1800–2116 UT of the B_z component of IMF (IMP-8 satellite), F region V_z at Kodaikanal and geomagnetic H/X component at Ancon, Peru (12.08°S, 77.02°W, geomagnetic latitude 1.47°), Fort Churchill (59°N, 94°W), Cambridge Bay (69°N, 105°W) and the IMAGE station, Masi (69.46°N, 23.7°E). Note that the data presented are 3-min running means of the various parameters at one minute resolution. This is done to suppress the short-period (< 1 min) fluctuations and highlight the longer period ones in the DP2 range. Further, a time shift of 17 min is introduced for IMF B_z to allow for the delay time between B_z fluctuations and their effects at ground level. IMP-8 satellite was a radial distance of 39.4 R_e over the time period studied here. The delay of 17 min which is visually assessed to be the optimum is therefore reasonable and appropriate (see Nishida, 1968b for details of delay time between changes in IMF and ground level magnetic field). Over the time interval under consideration, Cambridge Bay, Fort Churchill and Ancon were in the noon-afternoon sector, while Masi was in the dusk sector and Kodaikanal in the midnight sector. It is evident from Fig. 2 that the three cycles of QP fluctuation in F region V_z at Kodaikanal are coherent with those in B_z and the magnetic H/X components at the various stations. The amplitude of the three peaks (obtained by joining the minima/maxima of the fluctuations as shown in Fig. 2) at Cambridge Bay are 56 nT, 58 nT and 52 nT. The corresponding values at Fort Churchill are 50 nT, 42 nT and 43 nT. This near-constancy of amplitude is one of the general attributes of DP2 magnetic fluctuations on the dayside

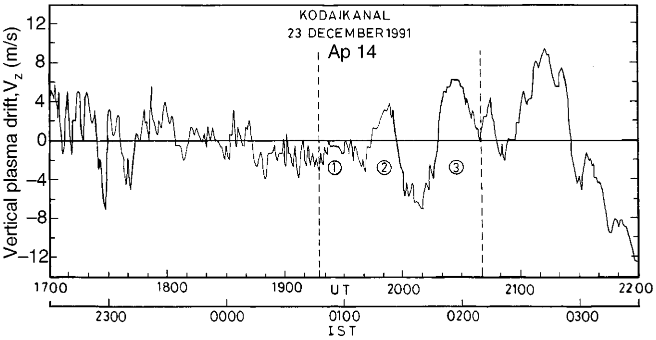

Fig. 1. Variation of F region vertical plasma drift, V_z at Kodaikanal on the night of 23/24 December 1991 (A_p = 14). Note the distinct quasi-periodic perturbations (period 25–35 min) in V_z over the time interval 0047–0210 IST (1917–2040 UT) indicated by the *two vertical dashed lines*

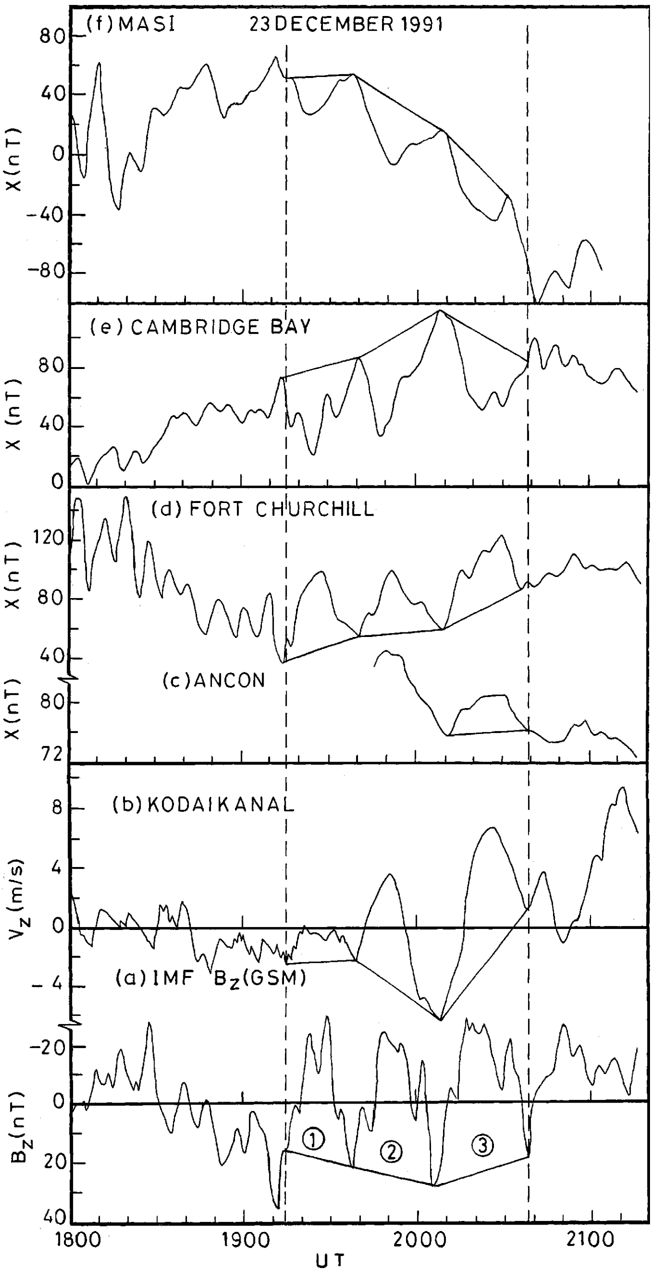

Fig. 2a–f. Variation during 1800–2120 UT on 23 December 1991 of **a** IMF B_z, **b** F region vertical plasma drift at Kodaikanal in the midnight sector, **c–e** geomagnetic H/X component at Ancon, Fort Churchill and Cambridge Bay on the dayside and **f** at the IMAGE station, Masi in the dusk sector. Note that a time shift of 17 min is introduced for IMF B_z to show the temporal coherence of quasi-periodic fluctuations (labelled *1–3*) in the parameters at the various locations over the time interval 1915–2038 UT marked by *vertical dashed lines*

(Nishida, 1971). The unfortunate data gap at Ancon till 1946 UT precluded estimation of the amplitudes of the first two peaks near the dayside dip equator. The magnitude of the third peak around 2025 UT is 2.6 nT which is reasonable keeping in view that it corresponds to a time of rapidly decreasing electrojet strength. It is to be noted here that the amplitude of DP2 magnetic variations in the dayside hemisphere (a) decreases rapidly with decrease in latitude but increases again near the dip equator and (b) varies with local time to be highest around noon compared to other times at the dip equator (Nishida, 1986b; Kikuchi *et al.*, 1996).

The amplitude of the three peaks (1 to 3 in Fig. 2) in F region V_z at Kodaikanal estimated by the same procedure is 2 m/s (0.08 mV/m), 7.4 m/s (0.3 mV/m) and 8.6 m/s (0.34 mV/m) in that order. This suggests a tendency for the amplitude to increase towards the early morning side. Note that the ambient vertical plasma drift of equatorial F region is generally downward (westward electric field) in the nighttime. The virtual height of the bottomside F region over Kodaikanal to which the 4 MHz Doppler observations correspond to was in the range 265–285 km prior to and during the interval of QP fluctuations (1800–2030 UT). At altitudes less than 300 km the chemical recombination induces an apparent upward drift, V_c that makes the true downward plasma drift. This is the reason for the absence of an apparent downward drift over Kodaikanal prior and during the QP fluctuations. Corrections for chemical loss effects are not made for V_z data because they are basically a *d.c effect* and fluctuations with periods <40 min of specific interest here are unlikely to be influenced by the altitude-dependent changes in the chemical loss or in the ionization scale height (Sastri, 1995). The sense of the perturbation peaks in V_z is to be positive (upward drift) in view of their close temporal association with IMF B_z and magnetic variations elsewhere (see Fig. 2).

The coherence of the QP fluctuations in V_z at Kodaikanal with IMF B_z and magnetic variations at the various stations is evaluated through correlation analysis. The correlation coefficient between V_z and IMF B_z for the period 1915–2038 UT covering the three cycles is −0.671 and for the subperiod 1939–2038 UT covering the last two cycles (2 and 3) is −0.667. The corresponding values for X-comp at high latitude stations on the dayside, at Fort Churchill (Cambridge Bay) are 0.805 and 0.915 (−0.723 and −0.84) in that order. For Masi the values are −0.541 and −0.688. All the correlation coefficients are statistically significant confirming the temporal coherence of the QP variations in F region V_z at Kodaikanal with magnetic fluctuations at high latitudes on the dayside as well as nightside. The correlation coefficient between V_z and H-component at Ancon is 0.43 (statistically significant) for the period 1947–2040 UT for which data are available. The correlation coefficient increased to 0.897 when the H-field is detrended for the diurnal variation. This excellent temporal association can clearly be seen from Fig. 3. But the most noteworthy feature in Figs. 2 and 3 is that the QP fluctuations at the two dip equatorial stations bear an *anti-phase* relationship with IMF B_z such that the southward turning of B_z is associated with an increase in H-field (increase of electrojet strength) on the dayside (Ancon) and a predominantly upward F region plasma drift (eastward electric field) on the nightside (Kodaikanal). The first of the features is in agreement with the earlier work of Nishida (1986b) while the second one is the new fact brought to light by the current study.

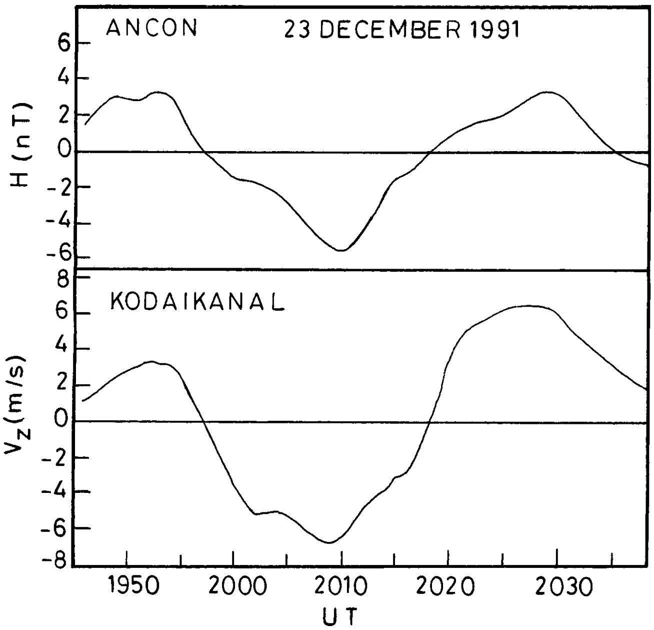

Fig. 3. Variation of geomagnetic H-component and F region vertical plasma drift, V_z at the dip equatorial stations, Ancon, Peru (dayside) and Kodaikanal, India (nightside) respectively over the interval 1916–2038 UT of 23 December, 1991. Note the *in-phase* relationship of the quasi-periodic fluctuations in the parameters at the two stations

It is known that DP2 activity generally develops during the growth phase of the substorm and persists even during the expansion phase (Clauer and Kamide, 1985). Careful scrutiny of the one-minute resolution data of the auroral electrojet index, AE (courtesy T. Iyemori) showed that auroral activity was low (AE $<$ 200 nT) during the time interval of DP2 type QP fluctuations. An increase in AE index indicative of substorm activity began only from 2105 UT which peaked (570 nT) at 2130 UT. The QP variations in F region vertical plasma drift at Kodaikanal as well as in geomagnetic field at the various stations studied here are therefore unlikely to be effected by the longer period (2–3 h) disturbances associated with substorms.

DP2 type magnetic and electric field fluctuations are one of a class of disturbances that originate from global-scale current systems set up by sources in the polar regions, the other being the storm sudden commencements (*ssc*) and sudden impulses (*si*). The detailed case study of Kikuchi *et al.* (1996) demonstrated that the transient component of the electric field set up by region 1 and 2 field-aligned currents (FAC) flowing in and out of the polar ionosphere is responsible for DP2 at auroral latitudes (see Fig. 9 of their paper). The coherent occurrence of magnetic fluctuations all over the globe with a conspicious enhancement near the dayside dip equator that characterises DP2 activity implies that the usually prevalent shielding of the low latitude ionosphere from polar cap electric fields by region 2 FAC breaks down facilitating the low-latitude penetration of polar electric fields. Based on analysis of magnetometer data, Araki (1977) proposed that the simultaneous appearance of the preliminary impulse (*PI*) of storm sudden commencement (*ssc*) at the dayside dip equator and at high latitudes is due to the extension to the dayside equator of DP2 type ionospheric current system driven by the dusk-to-dawn electric field imposed on the polar ionosphere. Theoretical studies showed that the Earth-ionosphere wave guide facilitates the instantaneous transmission of a suddenly imposed polar electric field to the dip equator as a zeroth-order transverse magnetic (TM) electromagnetic wave (Kikuchi *et al.*, 1978; Kikuchi and Araki, 1979). The subsequent numerical simulations of the two-dimensional current system by Tsunomura and Araki (1984) lent support to the wave guide model and provided an insight into the latitudinal profile and local time pattern of penetration electric fields and associated currents. Very recently, Tsunomura (1999) obtained a realistic solution of the polar-originating current system including the equatorial enhancement which showed that one of the non-diagonal terms of the conductivity tensor in the dip equatorial region significantly influences the equatorial electric fields. For the *initial phase* representing an enhancement in magnetospheric convection brought by a southward turning of IMF B_z, the new simulations show the equatorial zonal electric field to be eastward between 06 and 22 LT with a broad morning maximum between 08 and 09 LT and an evening maximum at 19 LT. The electric field is westward at other times with a broad maximum in the presunrise hours (see Fig. 5 of their paper).

The polarity in *H*-field (increase of electrojet strength) of the QP fluctuations at Ancon near the afternoon dip equator, their small amplitude and neagative correlation with IMF B_z are in accordance with the model results of Tsunomura (1999) as well as of Senior and Blanc (1984) and Tsunomura and Araki (1984). All of these models consistently show that the penetration electric field for the *initial phase* is eastward during daytime and changes in magnitude to attain low values in the afternoon around 16 LT. The sign (upward drift indicative of eastward electric field) of the QP fluctuations in F region vertical plasma drift at Kodaikanal near the postmidnight dip equator, is however, inconsistent with the model simulations all of which show a westward electric field in the midnight-sunrise sector (see Fig. 5 of Tsunomura, 1999). In otherwords, the present observations show the *simultaneous* presence of QP fluctuations of the *same polarity* in parameters representative of equatorial zonal electric fields in the afternoon and postmidnight sectors, instead of *opposite polarity* expected from the current understanding of equatorial DP2. The tendency for the magnitude of the QP fluctuations in F region V_z at Kodaikanal to increase towards the early morning side is nevertheless in agreement with the local time dependence of penetration electric fields in the midnight-sunrise period. In our knowledge, there is only one documented event of similar quasi-periodic electric field fluctuations of eastward polarity at the nightside (22-04 LT) dip equator. This event of February 17–18, 1976, studied by Gonzales *et al.* (1979) as well as Earle and Kelley (1987), is characterised by fluctuations with significant power at ≈1 h period in IMF B_z as well as in electric fields at auroral and dip equatorial stations. But this event too does not seem to be of DP2 origin because the day-to-night polarity of the equatorial electric fields (eastward on nightside and westward on dayside) is at variance with the theoretical pattern of DP2 electric fields.

In conclusion, the present case study brought to light that quasi-periodic fluctuations in the DP2 range (period 25–35 min) do occur in F region vertical plasma drift (zonal electric field) near the postmidnight dip equator coherent with magnetic fluctuations near the dayside dip equator and auroral/subauroral locations both in the sunlit and dark hemispheres. The electric field fluctuations do not, however, seem to be signatures of DP2 activity since they exhibit the same eastward polarity as those seen at the dayside equator, although they possess most of the other known characteristics of DP2. The origin of the distinct electric field variations in the midnight dip equatorial ionosphere reported here is enigmatic and merits further studies.

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