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DP 2 electric field fluctuations in the dusk-time dip equatorial ionosphere

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Abstract. We have studied the geomagnetic and ionospheric manifestations of the DP 2 activity that occurred on April 7, 1995 using high time resolution magnetometer data of IMAGE network in Scandinavia and of Alcantara (dip 1.2° N), Brazil, and F layer vertical plasma drift, V_z, measured by an HF Doppler radar at Kodaikanal (dip 4° N), India. Quasi-periodic fluctuations in dusk-time (1730-1900 LT) F layer vertical plasma drift (eastward electric field) occurred over Kodaikanal coherent with DP 2 type magnetic fluctuations (period ≈ 25 min) at the day-side dip equator and auroral/subauroral latitudes. This first-ever observation at the dusk-side equator is in agreement with the two-cell equivalent current system previously proposed for DP 2 fluctuations. The results strongly suggest that the magnetospheric electric field responsible for DP 2 fluctuations penetrates to equatorial ionosphere on the dusk-side as on the day-side. An additional observation is that the electric field fluctuation amplitude increases towards the nightside suggesting the influence of dusk sector electrodynamics in the observed signature of the DP 2 electric field.

Introduction

Geomagnetic fluctuations of DP 2 type are characterized by quasi-periodic variations with time scales mostly from about 30 minutes to several hours that occur coherently at high latitudes and at the day-side dip equator [*Nishida,* 1968 a,b]. They correlate well with fluctuations in the north-south component of the interplanetary magnetic field, IMF, irrespective of its direction and are thought to be produced by ionospheric currents driven by the magnetospheric electric field [*Nishida, 1968 b*]. The recent work of *Kikuchi et al* [1996] provided evidence suggesting that DP 2 magnetic fluctuations are indeed caused by a Hall current at auroral latitudes that is driven by magnetospheric convection electric field, as observed by the EISCAT radar. The enhancement of DP 2 amplitude in the dayside equator is believed to be caused by a Pedersen current amplified by the Cowling effect. It was concluded that magnetospheric electric field penetrates into the equatorial ionosphere through the polar ionosphere almost instantaneously driving the ionospheric current responsible for DP 2 fluctuations at the dayside dip equator. Studies of the equatorial DP 2 events are thus far limited to the day-side based as they are on magnetometer data and not much is known *per se* about DP 2 at the evening and night-side equator. If the current understanding on the low latitude penetration of magnetospheric electric field is valid, then DP 2 electric fields are to be seen at the dip equator on the evening and night-side as on the dayside. Thus detailed evaluation and understanding of their local time characteristics, of fo. is here, is important for advancing our knowledge of substorm processes as a whole [*Rostoker,* 1993] and of associated equatorial ionospheric disturbances in particular [see *Fejer,* 1991; *Abdu et al,* 1997]. High - time resolution data of ionospheric parameters sensitive to electric fields are necessary for such evaluations. In this paper, we present the first experimental evidence for DP 2 type fluctuations (period ≈ 25 min) in zonal electric field at dusk-time equator coherent with the magnetic field fluctuations at high latitudes as well as at day-side dip equator.

Observational Results

The present work concerns the DP 2 event that occurred during the period ~1229-1329 UT on April 7, 1995, a geomagnetically disturbed day (A_p=100; ΣKp = 49^+) corresponding to the 8th EITS (Equatorial Ionosphere-Thermosphere System) campaign under International STEP (Solar-Terrestrial Energy Program). The study is based on digital magnetometer data of IMAGE (International Monitor for Auroral Geomagnetic Effects) network in Scandinavia [*Luhr,* 1994], from Alcantara (2.31° S; 315.6° E; dip 1.2° N), Brazil and ionospheric F region vertical plasma drift, V_z, at Kodaikanal (10.2° N, 77.5° E, dip 4° N), India, measured by an HF Doppler radar. The radar provides high time resolution (1-min) data of the Doppler velocity (V_d) of ionsopheric reflections at normal incidence which represents the vertical plasma motion (V_z=V_d/2) due to zonal electric fields.

Figure 1 shows the temporal variation at one-minute resolution of the geomagnetic field X-component at IMAGE stations: Soroya, SOR (70.5° N, 22.2° E, mag. lat. 66.08° N); Pello, PEL (66.9° N, 24.08° E, mag. lat. 62.4° N) and Nurmijarvi, NUR (60.5° N, 24.65° E, mag. lat. 56.16° N), and that at Alcantara, ALC, Brazil, for the time interval 12-14 UT. The IMAGE stations are in the post-noon sector, while ALC is in the forenoon sector. Also shown are the asymmetric (ASY) and symmetric (SYM)/ring current (D_{st}) indices for the period [*Iyemori and Rao,* 1996]. It is evident from Figure 1 that quasi-periodic (QP) fluctuations with a period of ≈ 25 minutes (or even less) are coherently present at all the stations over the period 1229-1329 UT. Fluctuations of smaller amplitude and shorter duration at all stations are centered around 1234 UT. But we shall focus attention on the two dominant peaks readily recognizable at ALC and NUR at 1250 UT and 1316 UT (marked as 1 and 2 in the figure). At the auroral stations the first peak stands out but the second peak is distorted

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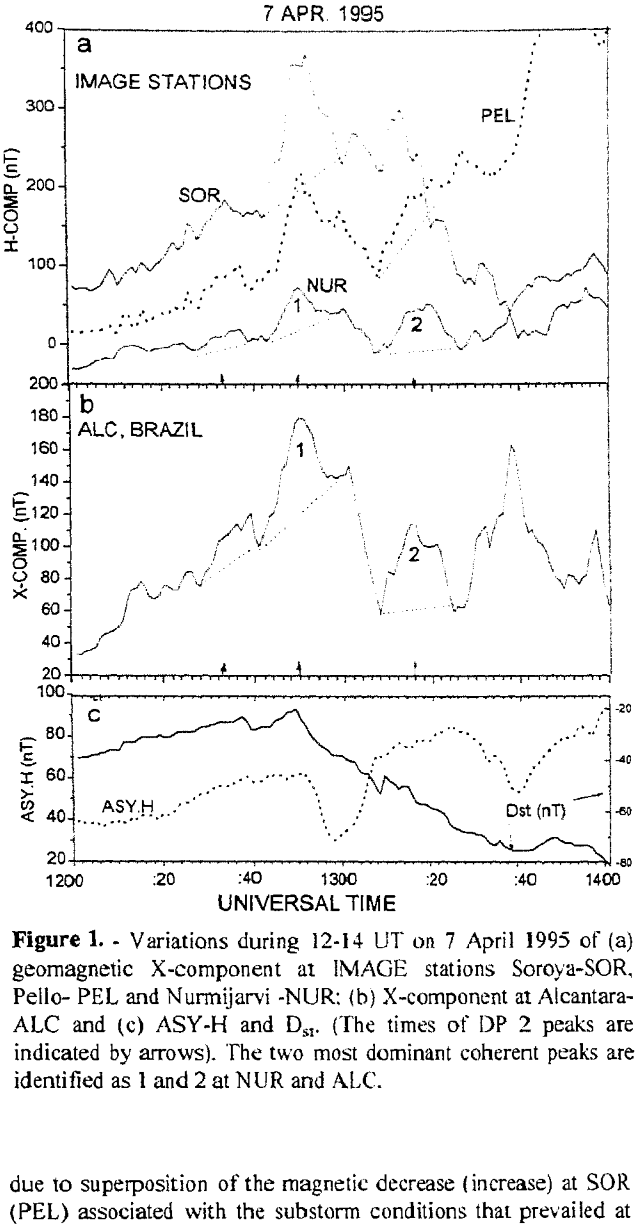

Figure 1. - Variations during 12-14 UT on 7 April 1995 of (a) geomagnetic X-component at IMAGE stations Soroya-SOR, Pello- PEL and Nurmijarvi -NUR; (b) X-component at Alcantara-ALC and (c) ASY-H and D_{ST}. (The times of DP 2 peaks are indicated by arrows). The two most dominant coherent peaks are identified as 1 and 2 at NUR and ALC.

due to superposition of the magnetic decrease (increase) at SOR (PEL) associated with the substorm conditions that prevailed at this time as indicated also by the D_{st} and ASY-H indices of the bottom panel. The amplitudes of the two peaks at Alcantara are 50 nT and 52 nT, and those at the subauroral station, NUR, are 50 nT and 58 nT. Such relative constancy of amplitude is a general attribute of DP 2 magnetic fluctuations [*Nishida*, 1971]. The amplitude of the first (1250UT) peak at the auroral stations, SOR and PEL is higher being 162 nT and 102 nT respectively. It is clear that the amplitude of the coherent QP magnetic fluctuations rapidly decreases with decrease in latitude but gets enhanced at the dayside dip equator (ALC) to be almost equal to that at subauroral latitude (NUR). This feature is consistent also with the latitudinal profile of DP 2 amplitude reported by *Kikuchi et al* [1996].

The coherence of the QP magnetic fluctuations between high latitudes and dip equator is evaluated through a correlation analysis of the magnetic data of NUR and ALC. NUR is chosen because it does not seem to be much effected by local electric field associated with substorm conditions that became dominant from ~1306 UT onwards. The correlation coefficients for the period 1241-1329 UT was 0.8, and for the two sub-periods, 1241-1259 UT and 1306-1329 UT encompassing the two dominant cycles of the QP fluctuations, were 0.96 and 0.86. These values are statistically significant confirming that the magnetic fluctuations are indeed manifestations of DP 2 activity in the sunlit hemisphere. It may be noted from Figure 1 that the DP 2 fluctuations are positive in X-comp at the IMAGE stations implying corresponding eastward current fluctuations at auroral and subauroral latitudes. At Alcantara also they manifested as increases in the X-component (that is, enhanced equatorial electrojet strength). This eastward DP 2 electric field at day- side equator is in agreement with the results of *Kikuchi et al* [1996]. Let us now consider the situation at the dusk sector.

Figure 2 shows the F layer vertical E X B plasma drift, V_z at Kodaikanal in the dusk sector along with the X -component of the geomagnetic field variations at ALC and NUR in the day sector over the period 12-14 UT. The shorter period (< 3 min) fluctuations in V_z are suppressed by taking 5-min running mean. A smoothed curve is shown (dotted line) that represents 41-minute running average of the V_z. Also shown for comparison is the smoothed V_z variation on 3 April, a nearby quiet day ($A_p = 2$, $\Sigma K_p = 2^+$). Several interesting features may be noted in Figure 2. The quiet day curve shows the usual prereversal enhancement in vertical drift (zonal electric field) with a peak value of ≈ 21 m/sec at 1315 UT (1815 LT) followed by a decrease and eventual

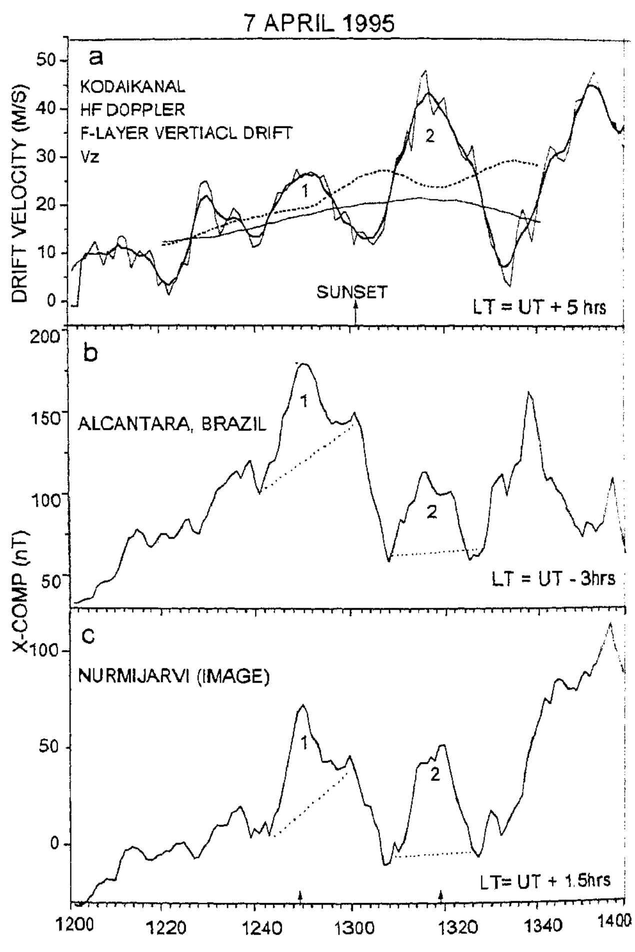

Figure 2. - Over the interval 12-14 UT: (a) the F region vertical plasma drift, V_z, over Kodaikanal (dip 4°N), India (5-min running mean -solid line , 41-min running mean - dotted line). The smoothed quiet day value for 3 April is shown as thin line, (b) and (c) X-component at ALC and NUR.

reversal to downward by 1440 UT (1940 LT, not covered in Fig. 2). This is known to be produced by an eastward electric fields arising from F region dynamo [*Rishbeth*, 1971]. The behavior of F layer vertical plasma drift on 7 April is unusual even considering the 41-minute smoothed curve which represents higher values than those of the quiet day. It may be noted that the event corresponds to an epoch of low solar activity and that the dusk-time V_z at Kodaikanal is positively dependent on solar flux [e.g., *Sastri*, 1996].

The most noteworthy feature of Figure 2 is that the QP fluctuations of large amplitude superposed on the sunset V_z enhancement at Kodaikanal bear excellent temporal coherence with the magnetic fluctuations at ALC and NUR representing DP 2 activity in the sunlit hemisphere. The correlation coefficients between the 5-minute averaged V_z values at Kodaikanal and the X-component at Alcantara for the same two subperiods (1241-1259 UT and 1306- 1329UT) are 0.85 and 0.87 respectively. The corresponding values with NUR are also high, being or 0.75 and 0.93. The sense of the QP fluctuations in V_z is predominantly positive or upward (with respect to the quiet day curve of 3 April, although the precise reference curve for this day in unknown) implying that the causative zonal electric field fluctuations are predominantly eastward. Thus the observations presented here clearly show eastward electric field fluctuations at the dusk-side dip equator coherent with magnetic fluctuations indicative of the same polarity at the day- side dip equator. Further, as a significant finding, it may be noted that the amplitudes of the DP 2 fluctuation peaks (1 and 2) at ALC on the day side are of comparable amplitude. But the amplitude of peak 2 in vertical drift at Kodaikanal is significantly larger than that of peak- 1, their respective amplitudes being 13.0 m/sec (0.52 mV/m) and 33.0 m/sec (1.3 mV/m).

Discussion and conclusions

The DP 2 activity develops during the growth phase of a storm and sustains even during the expansion phase (*Clauer and Kamide*, 1985). Ionospheric Hall current generated by the transient component of an electric field set up by region 1 and 2 field-aligned currents (FAC) flowing in and out of the polar ionosphere, is shown to be responsible for DP 2 at auroral latitudes [*Kikuchi et al.*, 1996] (see the sketch in Fig.3). Generally the low latitude ionosphere is shielded from the polar cap electric field by region 2 FAC. But the coherent occurrence of magnetic fluctuations at all latitudes [*Nishida*, 1968 a, b; 1971] implies that the polar electric field penetrates to lower latitudes driving ionospheric Pedersen current leading to equatorial DP 2 on the day- side. The mechanism of electric field penetration is transmission through the Earth-ionosphere waveguide invoked by *Araki* [1977] to explain the simultaneous appearance of the preliminary impulse (PI) of geomagnetic sudden commencement (sc) at the day-side dip equator and high latitudes [see also, *Kikuchi et al.*, 1996]. Numerical calculations by *Tsunombura and Araki* [1984] supported the waveguide model, and provided additional information on the latitudinal profile and local time pattern (as eastward during 08 -23 LT and westward during 23-08 LT) of penetration electric fields. The latitude variation of the DP 2 amplitude we have observed is in conformity with these results. So is the polarity of DP 2 fluctuations in dusk-time equatorial F layer vertical drift which imply (predominantly) eastward electric field.

The period range we have observed is close to the time constant for shielding (≈ 30 min) by region 2 FAC [*Vasyliunas*, 1972]. The period above which shielding becomes effective for low latitude penetration of DP 2 electric fields is an interesting unsettled

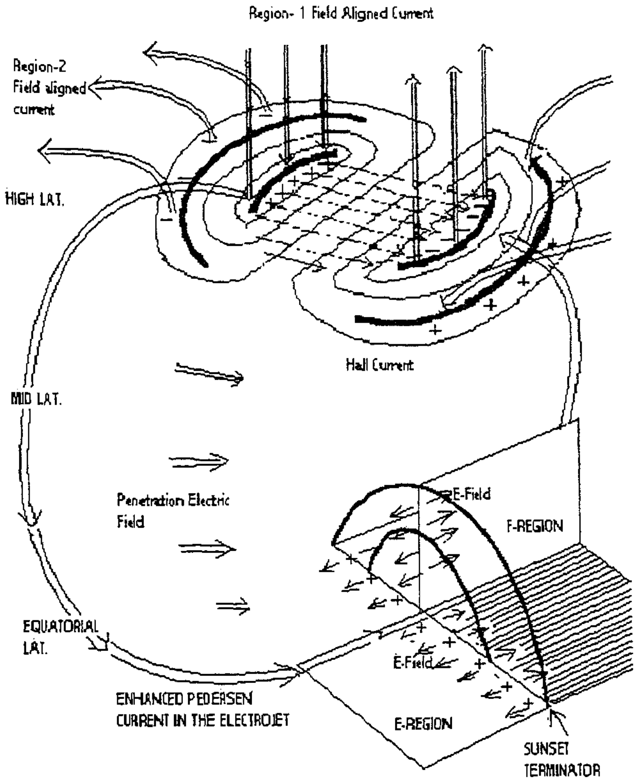

Figure 3.- A sketch of the DP 2 current system closing at dusk side dip equator. The high latitude part of the sketch is adapted from *Kikuchi et al.* (1996). Over the low latitude the EEJ, shown in the horizontal plane E-region, flows towards the terminator (aligned with the magnetic meridian, indicated by the geomagnetic field -thick- lines) where the strong Pedersen Conductivity longitudinal gradient produces positive charge build up with associated westward and eastward electric fields on the day and night sides, respectively, that are mapped along magnetic field lines on to the F region shown in vertical equatorial plane.

question. From spectral analysis of multi-site electric field data during an event *Earle and Kelley* [1987] showed QP fluctuations of ≈ 1 hr period in IMF B_z and in electric fields at auroral latitudes and at dip equatorial stations. However, the day-to-night polarity pattern of this event, as described by *Gonzalez et al* [1979], does not fit in with the present results, the results of *Kikuchi et al* [1996] and the model calculations of *Tsunomura and Araki* [1984]. Therefore this event does not seem to characterize itself as DP 2 fluctuations. This could be due in part to the accompanying disturbances of longer periods (2-3hrs) associated with substorm/ring current activity. In the present case also, after the second cycle of DP 2 such disturbances drastically reduced the coherence between the magnetic field changes at different latitudes. Further studies are needed to ascertain the critical period above which shielding becomes very effective and to evaluate the phase relationship between DP 2 electric fields on the day- side and in the midnight-morning sector.

A very interesting feature of the dusk time DP 2 fluctuation reported here is the significant increase of the electric field amplitude going towards the night side of the terminator (by comparing the fluctuation peaks 1 and 2). An explanation to this feature can be sought in the electrodynamic conditions peculiar to the dusk side. The daytime eastward current in the low latitude E layer is a Pedersen current driven by the dynamo eastward electric field . Enhancement of this current under the effect of Cowling conductivity produces the equatorial electrojet (EEJ). For a discussion of what happens to EEJ current at sunset see *Haerendel at al* [1992]. We have here a situation of DP 2 eastward electric field acting across the sunset terminator where the Pedersen conductivity decreases from its large daytime value to negligible night side value. The DP 2 component of the eastward Pedersen current and its enhanced EEJ component are interrupted at the terminator that could result in positive charge build up that opposes the current flow. The associated electric field divergence is characterized by a westward and an eastward electric field on the day and night side respectively of the terminator that are mapped by the equipotential geomagnetic field lines on to the F region as sketched in Fig.3. The consequent downward (upward) plasma drift on the day (night) side subtracts from (adds to) the F region plasma drift driven by the imposed primary DP 2 electric field, producing thereby the plasma drift pattern observed by the radar in the dusk sector.

In conclusion, we have presented the results of a case study to show that DP 2 type fluctuations (period ≈ 25 min or less) manifested themselves in the vertical plasma drift of dusk time equatorial F layer, coherent with magnetic fluctuations at auroral/subauroral latitudes and at the day side dip equator. This is first time that DP 2 electric fields at the dusk-side dip equator is identified. The amplitude of the observed electric fields is in the range 0.52- 1.30 mV/m and the polarity is eastward as it is at the day-side equator, in agreement with the equivalent current system proposed for DP 2 and the theoretical predictions of the local time pattern of penetration electric fields at the dip equator due to region 1 FAC . The dusk sector Pedersen conductivity gradient seem to modify the primary DP 2 electric field to cause its reduced amplitude on the day-side and enhanced amplitude on the night side of the terminator. The present work demonstrates clearly that the magnetospheric/polar electric fields do contribute to the temporal fine structure of equatorial zonal electric fields under disturbed geomagnetic conditions.

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