GEOPHYSICAL RESEARCH LETTERS, VOL. 19, NO. 14, PAGES 1451-1454, July 24, 1992

TRANSIENT COMPOSITE ELECTRIC FIELD DISTURBANCES NEAR DIP EQUATOR ASSOCIATED WITH AURORAL SUBSTORMS

J.Hanumath Sastri, K.B. Ramesh and H.N.Ranganath Rao

Indian Institute of Astrophysics, Bangalore, India.

Abstract. Ionosonde data of Kodaikanal (Geog.Long. 77° 29′E, dip 3.0°N) and Huancayo (Geog.Long. 75°18′W, dip 2.0°N) are used to show the simultaneous occurrence of a transient disturbance in F region height of composite polarity in day and night sectors near the dip equator during the auroral substorm activity on 20 August 1979. At Kodaikanal which is on the nightside at the time of the substorm activity, h′F first underwent an abrupt and rapid decrease (80km in 1 hr) followed by a much larger increase (120km in 1 hr). Perturbation in hpF2 of exactly opposite polarity was simultaneously seen at Huancayo which is on the dayside. The decrease in h′F at Kodaikanal (increase in hpF2 at Huancayo) occurred in association with an increase in polar cap potential drop, ϕ (estimated from IMF parameters), and the subsequent increase (decrease at Huancayo) with a decrease in polar cap potential. The F-region height disturbance is interpreted as the manifestation of a global transient composite disturbance in equatorial zonal electric field caused by the prompt penetration of substorm-related high latitude electric fields into the equatorial ionosphere. The polarity pattern of the electric field disturbance is consistent with the global convection models which predict westward (eastward) electric fields at night (by day) near the geomagnetic equator in response to an increase in polar cap potential drop, and fields of opposite signs for a decrease in polar cap potential.

Introduction

That electric fields of magnetospheric/high latitude origin can instantaneously penetrate to low latitudes at times of sudden transitions in IMF Bz and attendant changes in polar cap potential drop (ϕ), auroral substorm activity and asymmetric ring current is now established (see Fejer, 1991 and references therein). In the dip equatorial region the prompt penetration electric field which are transient (typical duration ~ 2 hrs) and global in nature, invariably manifest in the zonal component. An aspect of transient electric fields that has not received due attention so far is the observation that they tend to appear either with an increase in high latitude convection around the onset of a substorm (due to southward turning of Bz) or with a decrease in convection during its recovery phase (due to northward turning of Bz) but not both (e.g. Fejer et al, 1979 a). This is rather disconcerting because, typically, increase in convection around the onset of a substorm will be followed by a decrease in its recovery phase and the effects of both are to prevail, at least in principle. Specific searches for the composite electric field effects due to increases and decreases in convection, however, have not been made for individual substorms especially for the dip equatorial region. Studies of composite electric field disturbances are necessary in view of their implications to the understanding of physical processes that govern the generation of disturbances in high latitude electric fields and their penetration to low latitudes at times of substorm activity.

We have quite recently found evidence for a transient composite disturbance in the equatorial zonal electric field in the midnight-dawn sector, in close association with an isolated auroral substorm of moderate strength (Sastri et al, 1992). In this paper we report the characteristics of a transient composite electric field disturbance that is simultaneously seen both in the night and day hemispheres near the dip equator in close association with an event of isolated auroral substorm activity.

Paper number 92GL01447
0094-8534/92/92GL-01447$03.00

Data

We have used F-layer height data derived from the ionograms recorded at Kodaikanal (10°14′N, 77°29′E, dip 3.0°N) and Huancayo (12°S, 75°18′W, dip 2.0°N). We have relied on hpF2 to ascertain the changes in the vertical plasma drift and hence in the zonal electric field in the dayside sector. Similarly we have made use of h′F data for information on zonal electric fields for the night sector. At night, h′F and its time derivative [d(h′F)/dt] near dip equator provide reliable information on F region vertical plasma drift, Vz (e.g. Bittencourt and Abdu, 1981). The inherent limitations in the usage of hpF2/h′F (see Batista et al, 1991; Sastri et al, 1992 for details) do not vitiate the conclusions of the present study as we are primarily interested here not in the absolute values of the vertical plasma drift but the short-term changes in it on substorm time scales.

Results and Discussion

The substorm-related perturbation in F region height was seen at Kodaikanal and Huancayo on 20 August 1979, a moderately disturbed day (Ap = 42). The time histories of the auroral electrojet indices (AU/AL/AE) over the period 04-24 UT on the day shown in Figure.1 indicate the occurrence of severe auroral substorm activity (Kp = 7°) starting around 1630 UT. The relatively quiet geomagnetic conditions that preceded

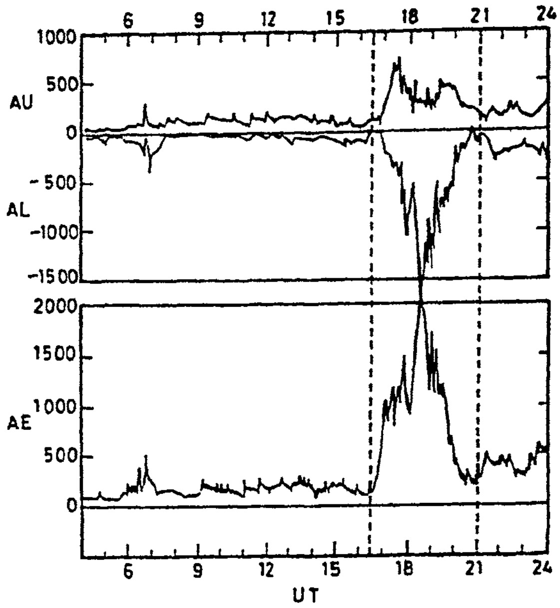

Fig.1. Time histories of the auroral electrojet indices (AU/AL/AE) during the interval 04-24 UT on 20 August 1979 illustrating the onset of an isolated, severe substorm around 1630 UT. The vertical dashed lines indicate the period when a conspicuous perturbation in F-region height prevailed simultaneously at Kodaikanal (dip 3°N) and Huancayo (dip 2°N) separated by 10 hrs in local time.

the substorm activity testify to its rather isolated nature. The wide spatial extent of the substorm activity can be inferred from the AE index which was > 2000 nT at its maximum. Figure.2 shows the variations of h'F at Kodaikanal and of hpF2 at Huancayo for the interval 13 UT of 20 August to 01UT of 21 August together with the monthly median patterns (dashed curves). Also shown are the low-time resolution (hourly averages) data of the auroral electrojet indices (AU/AL), IMF Bz (hourly values) in GSM coordinates and the polar cap potential drop (ϕ), estimated from IMF data using the empirical formula of Reiff and Luhmann (1986). We have not introduced any specific delay between Bz and ϕ, because the time lag that prevails between the changes in Bz and ϕ is usually less than the basic time resolution (1hr) of the published IMF data available with us.

On 20 August 1979, h'F at Kodaikanal displayed the usual post-sunset enhancement although the maximum in h'F is higher and the time of its occurrence earlier that the corresponding median values (Figure.2). This feature implies that though the upward V_z is higher than the normal, its post-sunset enhancement is shorter in duration on 20 August (see Figure.3). After reaching the maximum, h'F rapidly decreased indicating the prevalence of larger than normal values of downward Vz till 2000 LT (Figures. 2 and 3). This sort of departure from the median pattern is not uncommon because Vz is well known to undergo considerable day-to-day variability even on quiet days in the post-sunset period. h'F and Vz recovered to the median values by 21LT, but beginning at 2130LT (1630UT) there was a sudden and anomalous reduction in h'F from 340 km to 260 km at 2230 LT (i.e.80 km in 1 hr). The time variation of [d(h'F)/dt] shows that a downward vertical drift of

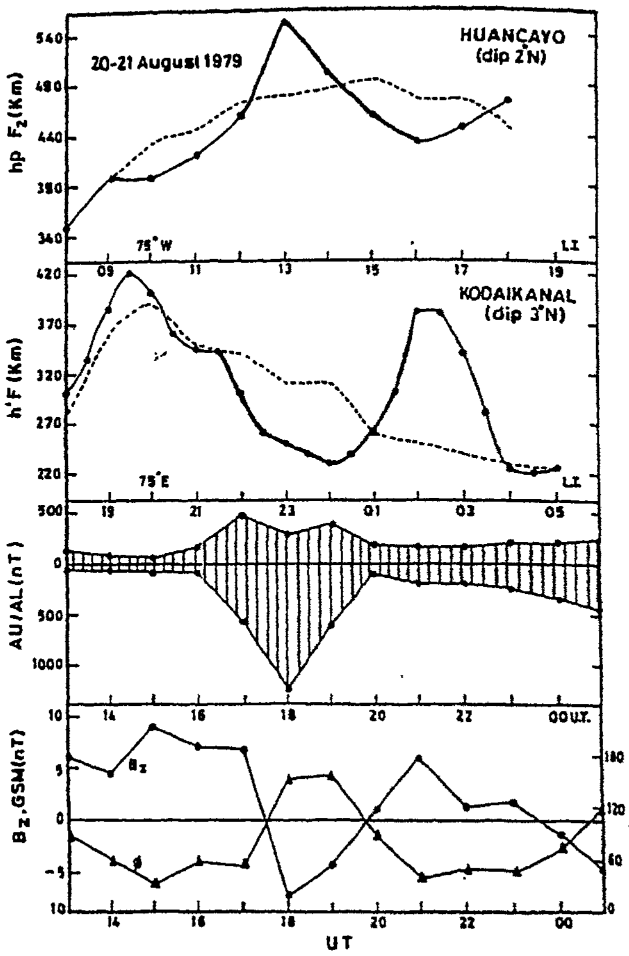

Fig.2. Time variation (hourly values) of the north-south (Bz) component of IMF, auroral electrojet indices (AU/AL) from 13 UT of 20 August 1979 to 01UT of 21 August 1979 (bottom and middle panels). The variations in the polar cap potential drop (ϕ) estimated from IMF parameters is also shown. The top panels show the variation of h'F at Kodaikanal (on the nightside), and of hpF2 at Huancayo (on the dayside) on 20 August 1979 with the monthly median patterns (dashed curves) superposed for reference.

about 22 ms^{-1} prevailed for an hour while the median pattern is a much smaller drift ($\leq$ 8.3 ms^{-1}) at the time (Figure.3). The strong downward drift eased a bit by 2230 LT and moved closer to the median values. Subsequently the F- region height at Kodaikanal experienced another conspicuous perturbation in the form of an increase beginning at 00LT (Figure.2). The increase was slow and small initially but was rapid and substantial later such that h'F rose from 260km at 01 LT (20UT) to 380 km by 02 LT (21UT) i.e. an increase of 120km in 1 hour or a gross upward drift of 33.3.ms^{-1}. Vz estimated from the time derivative of h'F (Figure.3) indeed shows the presence of significant upward drift for about 90 min starting from 0300 LT in contrast to the median behaviour of a downward drift. These values of Vz represent correct ones except for the interval (0015 - 0115 LT) when h'F was < 300 km, when they get overestimated due to the contribution of height increases due to chemical loss. A similar perturbation in F region peak height of mixed polarity prevailed at Huancayo on the dayside simultaneous to the one in h'F Kodaikanal on the nightside,

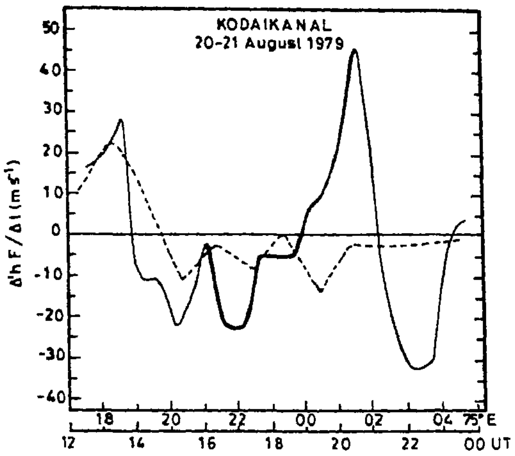

Fig.3. F-region vertical drift velocity at Kodaikanal (derived from h'F data) on the night of 20-21 August 1979 along with the monthly median pattern (dashed curve). The transient disturbance in vertical drift associated with the substorm is indicated by the heavy line.

as can be seen from the behaviour of hpF2 shown in Figure.2 (top panel). The polarity pattern of the disturbance in hpF2 is exactly the opposite of that in h'F. At the time of the sudden and rapid decrease in h'F at Kodaikanal (indicating the onset of strong downward drift) beginning at 2130LT (1630UT), hpF2 at Huancayo experienced a rapid and significant rise from 458 km at 12 LT (17 UT) to 551 Km at 13 LT (19 UT) i.e. an increase of 93 Km in 1 hr. Thereafter the F-layer underwent a continuous and anomalous descent for 3 hrs so much so that hpF2 decreased from 551 Km at 13 LT (18 UT) to 432 km by 16 LT (21 UT). These rapid and significant change in hpF2, which are in marked deviation to the general trend of a steady and slow increase (6km/hr) around noon (see Figure.2), constitute signatures of a transient disturbance in F-region vertical plasma drift. In view of the known sensitivity of F-layer peak electron density near dip equator (trough region of the equatorial ionization anomaly) to the zonal electric field through the EXB plasma drift (basic ingredient of the 'fountain' process responsible for the anomaly), we have also examined the day-

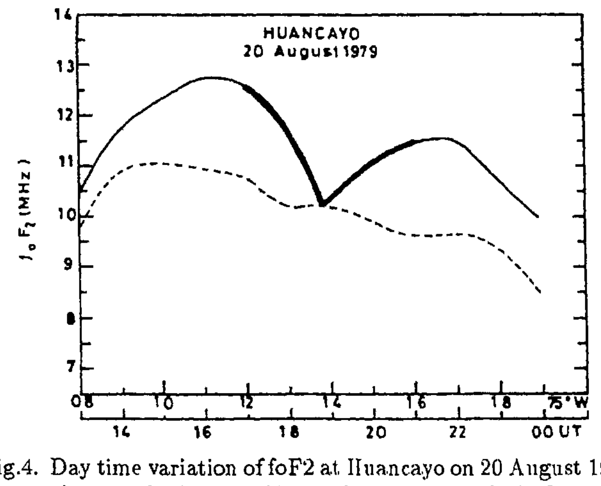

Fig.4. Day time variation of foF2 at Huancayo on 20 August 1979 along with the monthly median pattern (dashed curve). The perturbation associated with that in hpF2 and the substorm is indicated by the heavy line.

time behaviour of foF2 at Huancayo on 20 August 1979 for a plausible response. The data presented in Figure.4 clear show a prominent disturbance in foF2 of the expected nature in association with that in hpF2 namely, an initial decrease (by 2.4 MHz over the period 12 -14 LT) and a subsequent increase (by 1.2 MHz over the period 14 - 16 LT). These changes in foF2 indicate that the perturbation in hpF2 is a manifestation of that in vertical plasma drift. This conclusion also draws support from the study of Batista et al (1991) which showed that a downward drift (westward electric field) during daytime causes a lowering of F-region peak height and a sharp and rapid rise in peak electron density. Transient changes in foF2 and hpF2 of opposite polarity will prevail if an increase in the ambient upward drift (eastward electric field) were to occur.

The geomagnetic, interplanetary and ionospheric data presented in Figures.1 and 2 demonstrate the excellent coincidence of the simultaneous disturbance in F-layer height of composite nature at Kodaikanal and Huancayo with the substorm activity and related changes in IMF Bz and polar cap voltage (ϕ). The unambiguous temporal relationship strongly suggests the substorm origin of the disturbance in equatorial F-region height and hence in the zonal electric field. The contribution of substorm-related neutral winds and waves to the observed height changes can be discounted on several points: (a) the known insensitivity of F-region height near dip equator to horizontal neutral winds (b) the wind and wave effects will manifest at equatorial latitudes with a delay from the onset of the substorm (a wave disturbance originating at 65° geomag.lat. for example, would reach Kodaikanal after ~ 2 hrs even if it propagates at 1000m/s and (c) the substorm-generated winds being equatorward can only cause an increase in F-region height in the northern hemisphere but not the observed increase and decrease.

In our opinion, the theoretical work most relevant to the observations reported here are the semi-analytical/ numerical models which simulate the perturbations in subauroral electric fields following rapid changes in high latitude convection (Senior and Blanc, 1984; Fejer et al,1990a). These models based on the convection approach predict westward (eastward) electric fields at equatorial latitudes during night (day) for a sudden increase in polar cap potential (ϕ), and fields of opposite polarity for a sudden decrease. And this indeed is the polarity pattern observed at the dip equatorial stations during the substorm activity on 20 August studied here. The comparison of observations with theory can also be attempted with regards to the amplitude of the transient electric fields, because the estimated changes in ϕ during the substorm (Figure.2) are very close to the values assumed in the model simulations available in literature i.e. an increase and decrease in ϕ of 100 KV and 70 KV respectively. The comparison is, however, done only for the night sector because of the availability of direct information of Vz from h'F data at Kodaikanal. Assessment of the perturbation in Vz responsible for the observed changes in daytime hpF2 at Huancayo requires a numerical model-based study which is beyond the scope of this paper. To estimate the magnitude of the substorm-related electric fields, the values of Vz derived from h'F data at Kodaikanal are corrected for chemical loss effects. The upward drift induced by chemical loss, $V_\beta = \beta L$, where β is the loss rate and $L = [(dn/dz)/N]^{-1}$ is the electron density scale length. β is calculated form MSIS-86 thermospherical model (Hedin, 1987) derived values of neutral composition for the relevant geophysical conditions and local times, using the expression given by Titheridge and Buonsanto (1983) which is valid for T_n in the range 750-1300 K as is found to be the case. L is estimated from ionogram data. The corrected values of $Vz = [d(h'F)/dt - V_\beta]$ showed the maximum amplitudes of the transient westward (around 22LT) and eastward (at 02LT) electric fields at Kodaikanal to be $\sim$ 0.9 mV/m and $\sim$ 1.7mV/m respectively. The initial time response curves of the equatorial zonal electric field for $\Delta\phi = 100$ KV and $\Delta\phi =$ -70 KV show the amplitude of the westward and eastward perturbation fields for the relevant local times to be $\sim$ 0.1mV/m and $\sim$ 0.8 mV/m respectively (see Figure.5 of Fejer at al, 1990 a and Figure.10 of Fejer et al, 1990 b). The observed amplitude of the transient electric fields especially the eastward field around 02 LT is higher than the model results. The occurrence of such large eastward electric fields ($>$ 1.5mV/m) in the midnight - dawn sector at equatorial and low latitudes in association with sudden northward swing of Bz/onset of substorm recovery phase is known from recent case studies (e.g.Fejer et al, 1990 a; Sastri et al, 1992).

During the review of this paper, one of the referees drew our attention to the presence of a composite electric field disturbance in the earlier work of Gonzales et al (1983). The polarity pattern of this disturbance which was evidenced over the period 08-09UT on 11 October 1980 is the same as that presented here, namely, eastward (westward) fields near dip equator on the nightside (dayside) with a decrease in convection (at 08UT), and fields of opposite polarity with an increase in convection (at 09UT). There are noteworthy differences, however, between the two electric field disturbances. The one on 20 August 1979 discussed here occurred in close asociation with isolated substorm activity and with a natural sequence of convection changes, i.e, an increase followed by a decrease, and the comparison of its characteristics (on the nightside) with theoretical results is rather straightforward. The one on 11 October 1980, on the otherhand, manifested during the course of prolonged substorm activity (moderate auroral activity also prevailed over the preceeding 12 hrs with AE index exceeding 500nT several times), and the electric field penetration is evidenced first with a decrease and then with an increase. Scrutiny of Figure.5 of Gonzales et al shows that rapid decrease and increase in convection also occurred around 0540UT and 0625 UT respectively as at 08 and 09UT mentioned earlier. But while the latter are accompanied by unmistakable worldwide perturbations in equatorial zonal electric field, there is no perceptible response to the former even on the nightside at Jicamarca (75°W). Instead, eastward fields are seen at Jicamarca at 0500UT and 0710UT when there are no changes in IMF Bz, AL index and high latitude electric field. The lack of detectable perturbation electirc fields due to the convection changes over the period 0540-0625UT could be due to the strong local time dependence of penetration electric fields (the amplitude is smaller around midnight than in the predawn period) or enhanced attenuation of high latitude fields in penetrating to dip equator or both. The measurements of Gonzales et al (1983) for the plasmaspheric electric field campaign of October 1980 stand testimony to the complexity of the physical situation that obtains during prolonged substrom activity, and the difficulties in understanding the electric field disturbances under such geophysical conditions.

Acknowledgements. The authors are grateful to WDC-C1 for Solar-Terrestrial Physics, Rutherford Appleton Laboratory, Chilton, Didcot, U.K. for providing ionosode data of Huancayo. One of the authors (H.N.R.Rao) is grateful to Indian Space Research Organisation (ISRO) for financial support under RESPOND programme.

References

Batista, I.S., E.R. de Paula., M.A. Abdu and N.B. Trivedi, Ionospheric effects of the March 13, 1989, magnetic storm at low and equatorial latitudes, J.Geophys. Res., 96, 13943, 1991.

Bittencourt, J.A., and M.A. abdu, A theoretical comparison between apparent and real vertical ionization drift velocities in the equatorial F-region, J.Geophys.Res. 86, 2451, 1981.

Fejer, B.G., C.A. Gonzales., D.T. Farely., M.C. Kelley and R.F. Woodman, Equatorial electric fields during magnetically disturbed conditions 1. The effect of the interplanetary magnetic field, J.Geophys. Res., 84, 5797, 1979 a.

Fejer, B.G., R.W. Spiro., R.A. Wolf and J.G. Foster, Latitudinal variation of perturbation electric fields during magnetically disturbed periods: 1986 SUNDIAL observations and model results, Ann. Geophysicae, 8, 441, 1990 a.

Fejer, B.G., M.C. Kelley., C. Senior., O. de la Beanjardieve., J.A. Holt., C.A. Tepley., R.Burnside., M.A.Abdu., J.H.A. Sobral., R.F. Woodman., Y.Kamide., and R.Lepping, Low and mid-latitude ionospheric electric fields during the January 1984 GISMOS Campaign. J.Geophys. Res., 95, 2367, 1990 b.

Fejer, B.G, Low-latitude electrodynamic plasma drifts: a review, J.Atmos.Terr.Phys., 53, 677, 1991.

Gonzales, C.A., M.C. Kelley., R.A. Behnke., J.F.Vickrey., R.Wand and J.Holt, On the latitudinal variations of the ionospheric electric field during magnetospheric disturbances, J.Geophys. Res., 88, 9135, 1983.

Hedin, A.E, MSIS-86 Thermospheric model, J.Geophys.Res., 92, 4849, 1987.

Reiff, P.H. and J.G. Luhmann, Solar Wind control of the polar cap voltage, in 'Solar wind-Magnetosphere coupling', edited by Y.Kamide and J.A. Slavin, p 453, Terra.Scientific, Tokyo, 1986.

Sastri, J.H. K.B. Ramesh., and D.Karunakaran, On the nature of substorm-related transient electric field disturbances in the equatorial ionosphere, Planet. Space Sci.,40, 95, 1992.

Senior, C., and M. Blanc, On the control of magnetospheric convection by the spatial distribution of ionospheric conductivities, J.Geophys. Res., 89, 261, 1984.

Titheridge, J.E., and M.J. Buonsanto, Annual variations in the electron content and height of F-layer in the northern and southern hemispheres related to neutral composition, J.Atmos.Terr.Phys., 45, 863, 1983.

K.B. Ramesh, H.N.R. Rao and J.H.Sastri. Indian Institute of Astrophysics, Bangalore-560 034, INDIA.

(Received January 13, 1992;
revised May 7, 1992;
accepted May 31, 1992.)