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Simultaneous transients in the auroral zone and the equator as observed with SuperDARN and magnetometers: A correlation with equatorial counter electrojet (CEJ) event

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Abstract: An equatorial counter electrojet (CEJ) event characterized by a large amplitude (~150 nT) and a short duration (~15 min) magnetic disturbance occurred in the dayside region at 0053 UT, 23 October 1994. This event was detected by the ground magnetometers along the dayside dip-equator. The CEJ current, with local westward ionospheric currents, was located to the north of the normal eastward current (equatorial electrojet: EEJ) that existed prior to the CEJ event. Simultaneously with the occurrence of the CEJ event, an enhanced plasma convection with very high velocity (~2000 m/s) was observed by SuperDARN in the dusk sector of the auroral zone. These simultaneous occurrences in the auroral zone and at the equator may suggest that such an impulsive CEJ event could be interpreted as a violation of the shielding of the high-latitude potential pattern.

1. Introduction

An equatorial electrojet (EEJ) is a localized ionospheric current flowing at the dip-equator, with higher current intensity during the daytime. The current is supposed to be enhanced locally by the secondary vertical electric field together with the primary eastward electric field associated with the global *Sq* current system (Hirono, 1952; Baker and Martyn, 1953). Such a current enhancement is interpreted by the local enhancement of the ionospheric conductivity referred to as the Cowling conductivity. For these reasons, EEJ is confined to narrow latitudes over the dip-equator showing a diurnal change of the amplitude with a remarkable peak at local noon. The diurnal change is sometimes obscured in such a way that the amplitudes are suppressed with irregular fluctuations that have comparable amplitudes to the EEJ itself, or in such a way that the daytime values become sometimes below the nighttime level. The former case is suggested to appear often during substorms (Onwumechili *et al.*, 1973; Saka *et al.*, 1998). The latter case referred to as equatorial counter electrojet (CEJ) appears during the morning or afternoon hours (Gouin, 1962). Such abnormal depressions of EEJ have been attributed to the magnetic effects of the ring currents in the inner magnetosphere

(Akasofu and Meng, 1968; Onwumechili *et al.*, 1973), to an acceleration of the plasma convection in the nightside magnetosphere, an equatorial part of the DP2 current system (Nishida, 1968), to the disturbance dynamo effect in the local ionosphere (Blanc and Richmond, 1980), and to a modification of the tidal waves depending on lunar phase (Mayaud, 1977). In addition, the response time of the EEJ to the triggering mechanisms outlined above add the complexities in the interpretation of the EEJ responses (Scherliess and Fejer, 1997).

In this report, we present a large amplitude (~150 nT) and transient (duration ~15 min) CEJ event recorded with our magnetometer network stations across the dipequator. The associated transient ionospheric convection in the auroral zone observed with SuperDARN is compared with the equatorial signatures in the magnetometer data.

2. Observations

2.1. Magnetometer observation at dip-equator

A fluxgate magnetometer observation with high-time accuracy (100 ms) and high sensitivity (0.01 nT/bit) was carried out in the equatorial region in 1994 (Kitamura *et al.*, 1988). At 0053 UT of 23 October 1994, a large negative geomagnetic impulse (~150 nT) occurred at the dayside equator. This impulsive event can be classified as a counter electrojet (CEJ), as the field disturbances on the ground are attributed to the overhead ionospheric currents flowing westward (see below). Magnetograms of the H component at the dayside stations (POH; 0.09°N, 229.19°, CRI; 3.09°N, 273.49° in geomagnetic coordinates) are presented in Fig. 1, covering a five-day interval, 21 through 25 October, 1994. The impulsive CEJ event is marked by arrows in the figure, along with the station locations at 0100 UT. Concurrent Dst-index is shown for reference. From these, it is seen that the decrease of the Dst index occurred at ~0900 UT, 22 October prior to the onset of the CEJ event. The impulsive event at 0053 UT occurred with depressed magnitude (an order of magnitude smaller than that of POH) at the dayside low-latitude station, Kakioka. We suggest that such an impulsive event may be confined only along the equator.

Let us look at the CEJ event closely in Fig. 2 with an enlarged time scale. It is shown that the onset of the first sharp drop of the H component occurred at 0053 UT as marked by the vertical bar. Then, the recovery of the drop-off is followed in a similar manner at both POH and CRI. The duration of the CEJ was of the order of ~15 min. Note that the amplitudes of the CEJ at POH was 150 nT, while it was 40 nT for CRI. Such a discrepancy in the amplitude may be explained by taking account of the local time and latitude of CRI, which was in the afternoon sector and slightly north of the dip-equator.

A possible structure of the equatorial ionospheric current system associated with the CEJ can be deduced by examining together the horizontal (H) and vertical (Z) components of the magnetic records on the ground. Figure 3 shows field variations at the dayside stations, POH and CRI. Note that the H component is positive northward, while the Z component is positive downward. For the normal equatorial electrojet (EEJ) event for these stations (as can be seen on 22 October), the vertical variation was upward while the H component increases northward. It is suggested that the eastward ionospheric

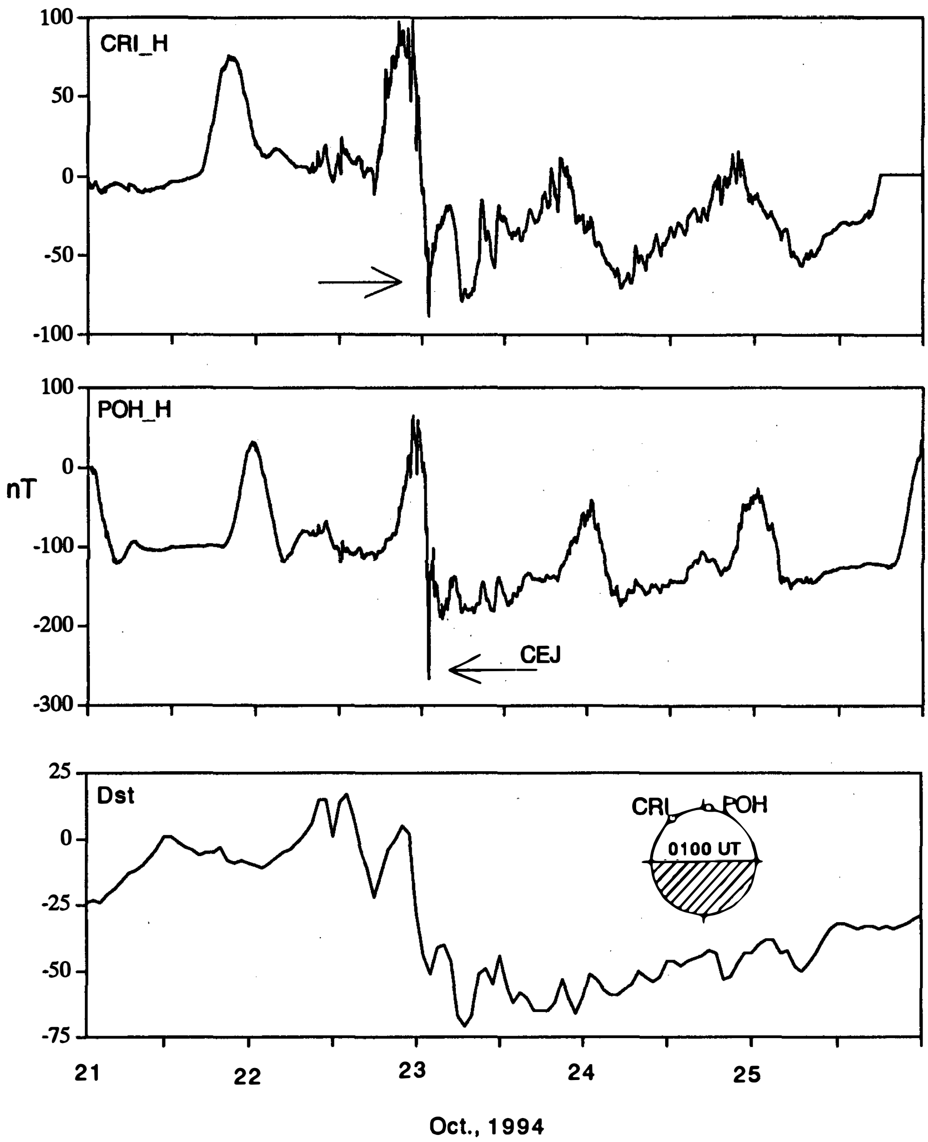

Fig. 1. Five-day plot of the H component of the equatorial magnetometer data, POH, and CRI in Pacific region. In the bottom panel, the Dst index is shown. The counter electrojet event (CEJ) at 0053 UT, 23 October 1994 is marked by arrows in the figure. The local time distribution of the equatorial magnetometer stations at 0100 UT is also shown. The vertical scale is in nT for magnetometer data and Dst index.

current of the EEJ system may be located to the south of these stations. On the following day, 23 October, a similar behavior can be seen for the H and Z components, which was then followed by the onset of the CEJ event at 0053 UT. The Z component associated with the CEJ onset depends on the observing station, namely a further enhancement was observed at POH, while the Z-field decreased at CRI. An enlarged plot of the Z component during the CEJ event can be seen in Fig. 2. It is apparent that the westward ionospheric current of CEJ event could be located at a latitude between these two stations (3.09°N–0.09°N), though they are separated by ~3 hours of local time. We note that the loci of the ionospheric current seemed to shift northward during the CEJ event.

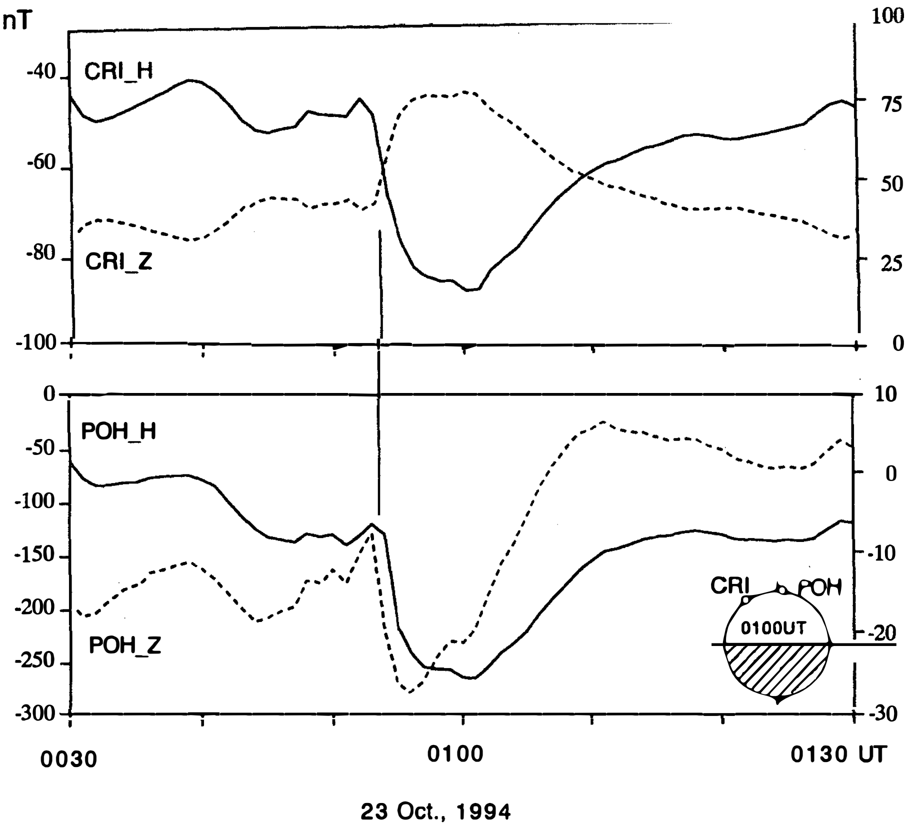

Fig. 2. An enlarged plot of the magnetometer records, H (full line) and Z (broken line) component, for the CEJ event. The amplitude scale for H and Z components are shown to the left and right ordinates, respectively, with the scale in nT. The vertical line (0053 UT) indicates an onset of CEJ.

2.2. *SuperDARN observation at high latitudes*

The radar beams from Saskatoon, Kapuskasing, Goose Bay, Stokkseyri of the SuperDARN HF radars covered the afternoon to midnight sector of the auroral zone during the CEJ event. The echoes were returned mostly from the dusk sector as can be seen in the global line-of-sight velocity map in Fig. 5. Field points of dominant echoes in the dusk sector were selected from two SuperDARN radars (Saskatoon at 1601 MLT and Kapuskasing at 1739 MLT) during the period 0030–0130 UT, October 23 and stackplots of line-of-sight velocities of these echoes are shown in Fig. 4. As demonstrated in the figure, the echoes received showed a coherent enhancement of the positive velocity (indicating motion away from the radar) in the dusk sector throughout the latitudes from 66°N to 71°N. The velocity increased quickly and its change amounted over 1 km/s within one scan interval (100-s). The SuperDARN velocity data from Saskatoon (T), Kapuskasing (K), Goose Bay (G), and Stokkseyri (W) were plotted to obtain the global line-of-sight velocity map for the intervals of 0046:40–0053:20 UT (Fig. 5a), 0053:20–0100:00 UT (Fig. 5b), 0100:00–0106:40 UT (Fig. 5c). Each map was obtained every 100-s. The coherent onset as depicted in Fig. 4 can be demonstrated again in this line-of-sight velocity map, wherein the velocity enhancement is confined in a latitude ranging from 65°N to 75°N in the dusk sector. The plasma motions after the coherent

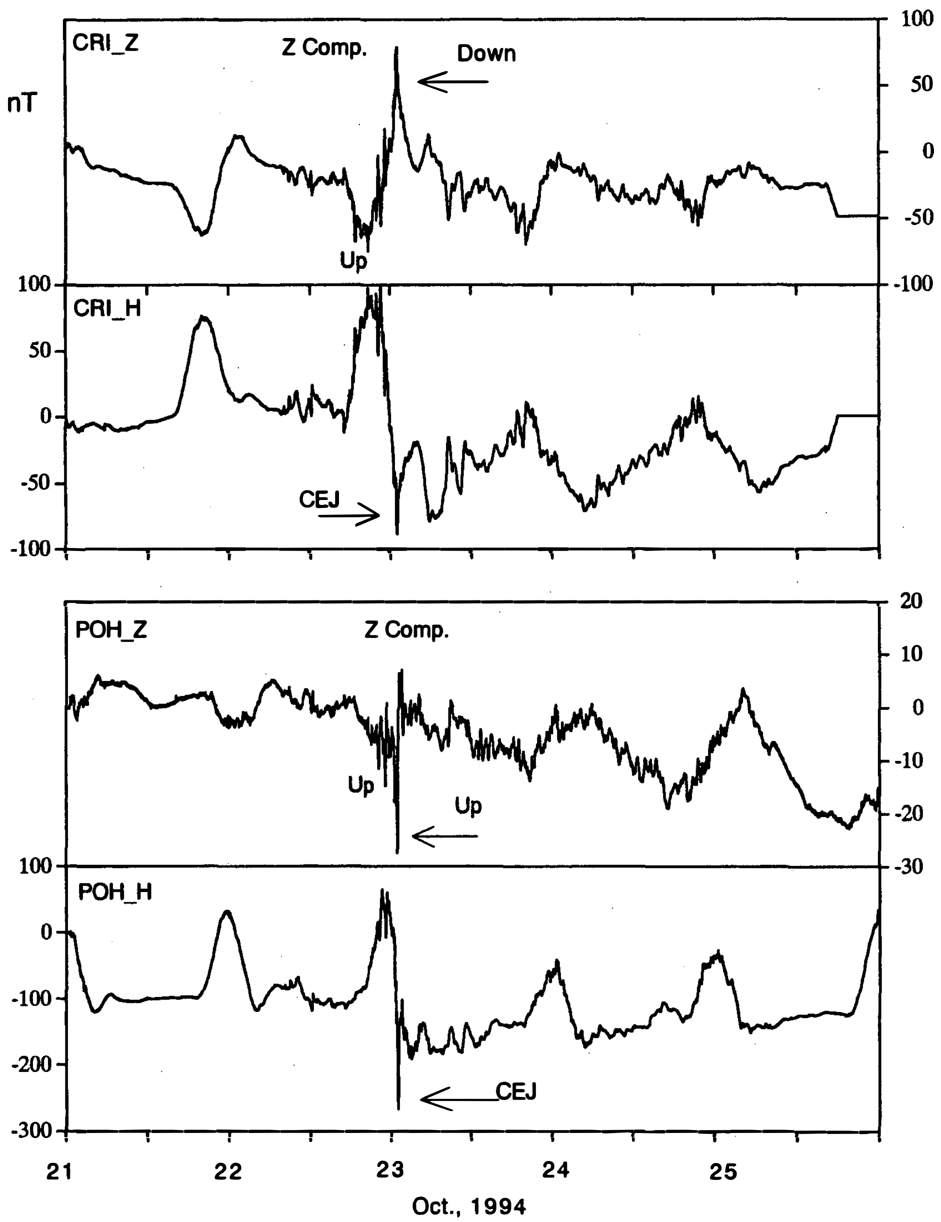

Fig. 3. *Five-day plot of the H (positive northward) and Z (positive downward) components for the stations, POH and CRI. The sense of the field changes in the Z component is noted in the figure.*

onset were characterized first by the north-westward velocity at the post-dusk sector and then by northward in pre-dusk sector (see Fig. 5b). Thereafter, the scattering region expands toward the nightside sector with decreasing convection velocity (see Fig. 5c). The onset of the velocity enhancement coincided with the CEJ onset as characterized by a sharp drop off of the *H* component (0053 UT) at the dayside equator. The enhanced velocity returned to a pre-onset level along with the recovery of the CEJ impulse. As a result, it is clear that the velocity enhancement in the auroral zone observed by the SuperDARN radars (SuperDARN high-velocity event) was correlated with the occurrence of the CEJ at the dip-equator, without any significant time delay.

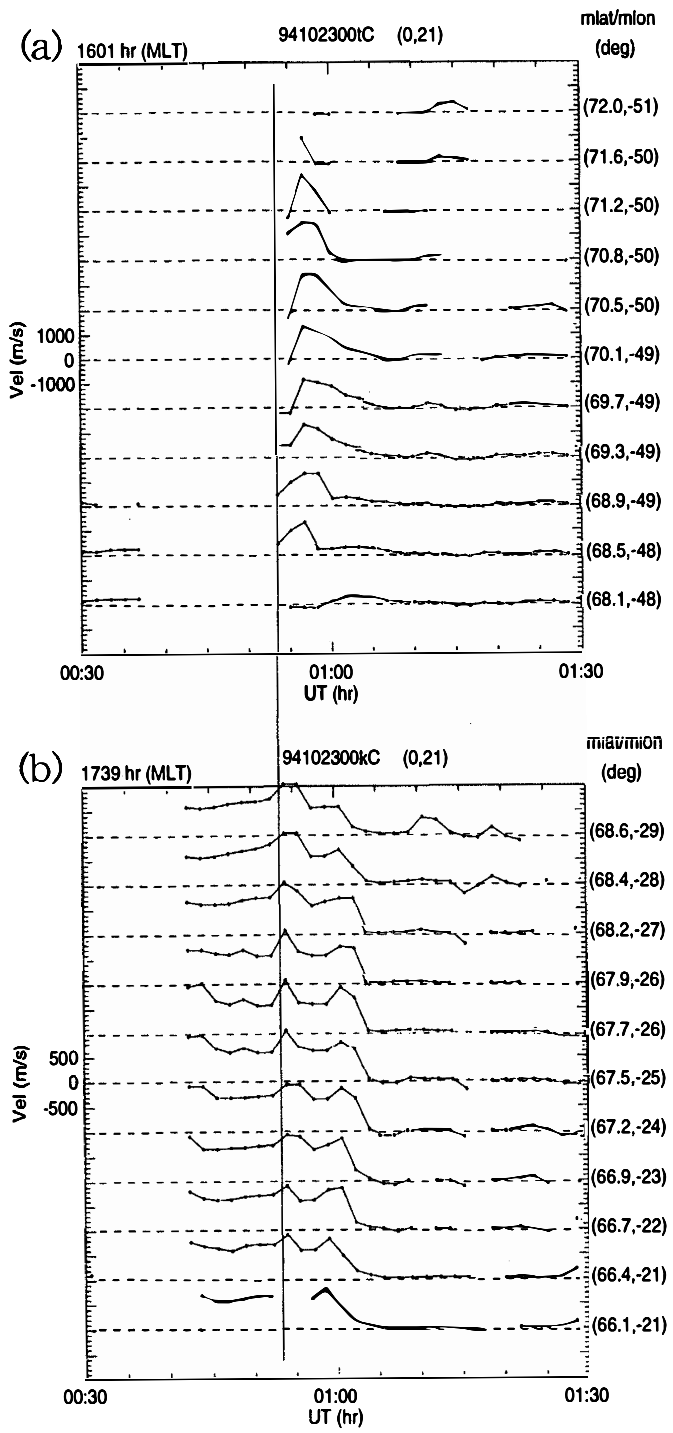

Fig. 4. Stackplots of line-of-sight velocities recorded by two SuperDARN radars over selected beam and range gate intervals during the period October 23, 1994, 0030–0130 UT. For each plot, the positions of field points in magnetic coordinates are shown at the right ordinate and the MLT of the central field point at the start of the period (0030 UT) is indicated at the top left. (a) Saskatoon, (b) Kapuskasing. The vertical line is at 0053 UT (see text). See the velocity scale to the left.

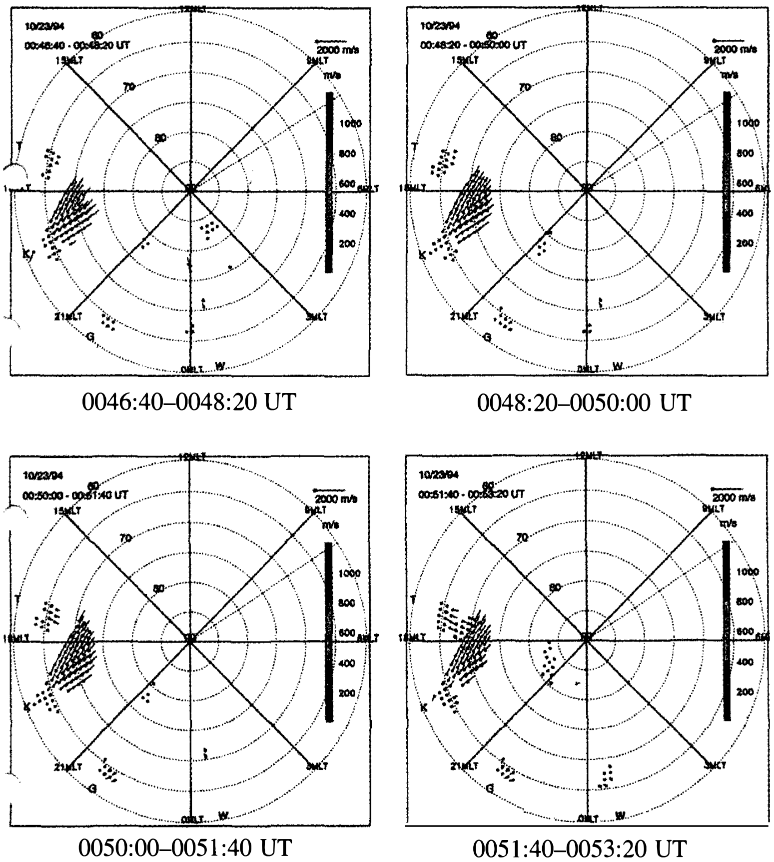

Fig. 5a. Plot of the averaged line-of-sight velocity values obtained from the SuperDARN radars on 23 October 1994. 0046:40–0053:20 UT. The longitude positions (in geomagnetic coordinates) of the contributing radars are indicated by the letters along 60°N contour; T, Saskatoon; K, Kapuskasing; G, Goose Bay; W, Stokkseyri.

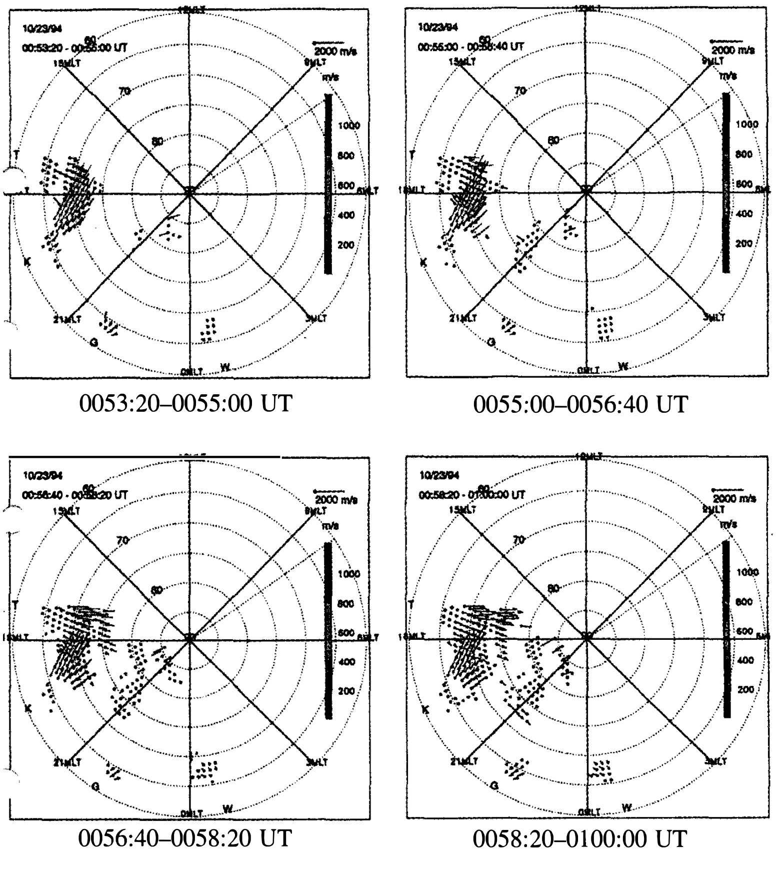

Fig. 5b. Same as Fig. 5a except 0053:20–0100:00 UT.

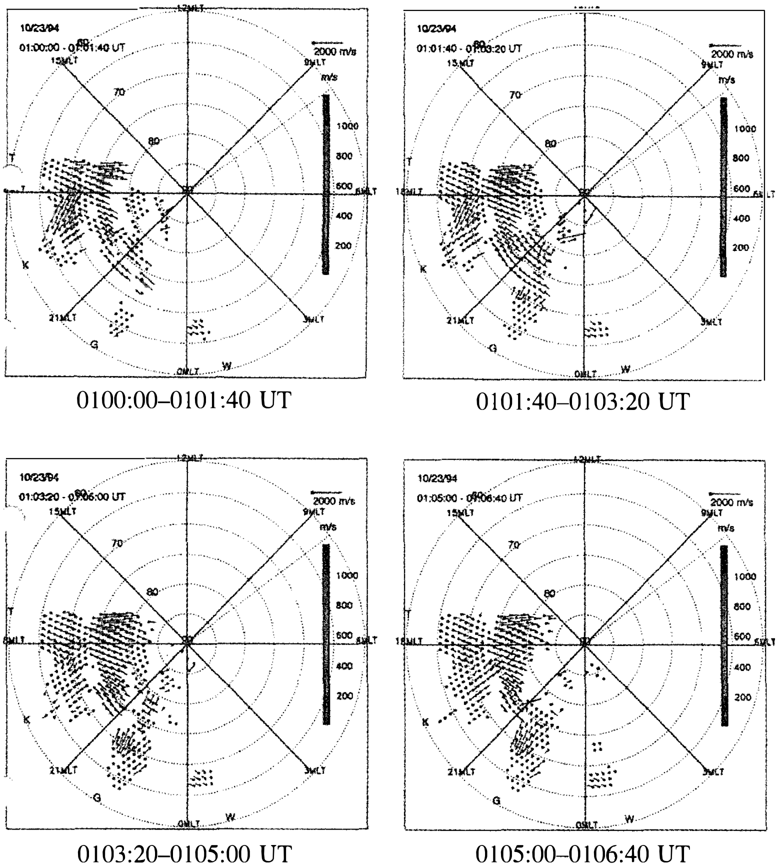

Fig. 5c. Same as Fig. 5a except 0100:00–0106:40 UT.

3. Summary

It is shown that the equatorial counter electrojet (CEJ) occurring impulsively at the dayside equator was caused by the westward ionospheric currents flowing at latitudes between 3.09°N–0.09°N. During the CEJ event, the westward current was found to move to the north of the normal equatorial electrojet (EEJ) that existed prior to the CEJ event. An intensity of the ionospheric current is higher at the dip-equator during the daytime, with the enhancement of the ionospheric conductivity. However, one single line current model may not be appropriate to describe such an EEJ current system (*e.g.*, Colqui, 1995). It is likely that the EEJ current intensity profile may have several peaks in latitudes. As the ground magnetometer observe an integrated magnetic effect of EEJ current, an overall current profile may affect the resultant ground observation. Accordingly, a major part of the ionospheric current seemed to be located to the south of the ground stations, POH and CRI, before CEJ event. Once the CEJ commenced, the profile could be modified and the current system might shift to the latitudes between POH and CRI. If the equatorial current system stems primarily from the confluence of the ionospheric currents from the northern and southern hemispheres, a balance of these two currents might change during the CEJ occurrence. This may result in a modification of the current profile in latitudes and shift the current system.

In the inner magnetosphere, the polarization field induced by net positive and negative charges along the surface of the injected plasma (Alfvén layer) shields effectively the primarily dawn-to-dusk electric fields in the solar wind (*e.g.*, Nishida, 1978). During the transient responses of the magnetosphere, however the shielding by the Alfvén layer may be insufficient to cancel out the primarily electric fields. Such a transient response of the Earth's magnetosphere due to the jump of solar wind dawn-to-dusk electric fields has been calculated using semianalytical model by Senior and Blanc (1984). The leakage of the net electric fields imposed on the high latitude may arrive at the equator and drive the ionospheric currents. This could be an equatorial part of the transient response (Senior and Blanc, 1984).

An isolated tangential discontinuity (TD) and an associated rapid decrease of plasma density were observed by Geotail spacecraft in the solar wind during the periods 0105–0115 UT. The TD was characterized by an abrupt change of the Bz component from +10 nT to −15 nT and then to +20 nT in 5 min interval (0105–0110 UT) (Fig. 6), while the decrease of the plasma density lasted for 10 min (0105–0115 UT). There was a time delay (~12 min) of the TD observed by Geotail spacecraft (XGSE=−54.7 Re, YGSE=−64.1 Re, ZGSE=−6.1 Re) with respect to the occurrence of the CEJ on the Earth. By taking account of the solar wind speed (440 km/s), these solar wind structures (TD and the rapid density decrease) passing through the interplanetary space are likely to cause the CEJ and SuperDARN high-velocity event on the Earth. If the impulsive southward IMF can be a primarily source of the CEJ event, it is supposed that the westward (dusk-to-dawn) electric field, which may trigger the CEJ event, would be imposed on the dayside equator as a result of the overreaction of the potential shielding.

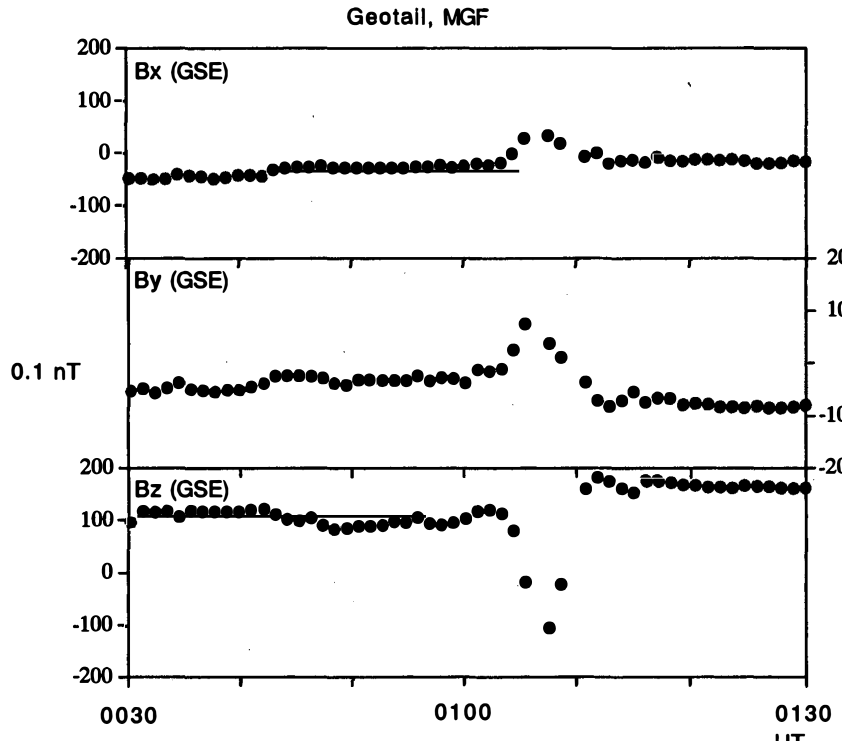

Fig. 6. Geotail MGF key parameter plot (one minute resolution) for the interval 0030–0130 UT, 23 October 1994. Three components, Bx, By, Bz are in GSE coordinates. The vertical scale is in 0.1 nT.

Acknowledgments

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References

Akasofu, S.-I. and Meng, C.-I. (1968): Low latitude negative bays. J. Atmos. Terr. Phys., **30**, 227–241.

Baker, W.G. and Martyn, D.F. (1953): Electric currents in the ionosphere, Part 1. Philos. Trans. R. Soc., London, **246**, 281–294.

Blanc, M. and Richmond, A.D. (1980): The ionospheric disturbance dynamo. J. Geophys. Res., **85**, 1669–1686.

Colqui, R. (1995): Two dimensional EEJ current system deduced from the Brazilian network. Msc. Thesis, Kyushu University.

Gouin, P. (1962): Reversal of the magnetic daily variation at Addis Ababa. Nature, **193**, 1145–1146.

Hirono, M. (1952): A theory of diurnal magnetic variations in equatorial regions and conductivity of the ionosphere *E* region. J. Geomagn. Geoelectr., **4**, 7–21.

Kitamura, T.-I., Saka, O., Shimoizumu, M., Tachihara, H., Oguti, T., Araki, T., Sato, N., Ishitsuka, M., Veliz, O. and Nyobe, J.B. (1988): Global mode of Pi 2 waves in the Equatorial region–Difference of Pi 2 mode between high and equatorial latitudes. J. Geomagn. Geoelectr., **40**, 621–634.

Mayaud, P.N. (1977): The equatorial counter-electrojet–a review of its geomagnetic aspects. J. Atmos. Terr. Phys., **39**, 1055–1070.

Nishida, A. (1968): Coherence of geomagnetic DP-2 fluctuations with interplanetary magnetic variation. J. Geophys. Res., **73**, 5549–5559.

Nishida, A. (1978): Geomagnetic Diagnosis of the Magnetosphere. New York, Spriger-Verlag.

Onwumechili, A., Kawasaki, K. and Akasofu, S.-I. (1973): Relationships between the equatorial electrojet and polar magnetic variations. Planet. Space Sci., **21**, 1–16.

Saka, O., Kitamura, T., Tachihara, H., Shinohara, M., Trivedi, N.B., Reeves, G.D. and Hansen, T.L. (1998): Amplitude modulation of equatorial electrojet (EEJ) during magnetospheric storm. J. Atmos. Solar Terr. Phys., **60**, 1129–1137.

Scherliess, L. and Fejer, B.G. (1997): Storm time dependence of equatorial disturbance dynamo zonal electric fields. J. Geophys. Res., **102**, 24037–24046.

Senior, C. and Blanc, M. (1984): On the control of magnetospheric convection by the spatial distribution of ionospheric conductivities. J. Geophys. Res., **89**, 261–284.

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