Equatorial disturbance dynamo electric field longitudinal structure and spread *F*: A case study from GUARA/EITS campaigns

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Abstract. Digisondes/ionosondes, an HF Doppler radar and magnetometers were operated in Brazil and India during the September/October 1994 GUARA/EITS campaigns. Analysis of the data for the two disturbed intervals, 2-4 October and 25-27 September provided evidence of a longitudinal structure in the disturbance dynamo (DD) electric field at low latitudes. The DD electric field which is westward in the evening, inhibited the developments of the equatorial prereversal electric field and postsunset ESF, whereas the simultaneous eastward field in the predawn sector, did not lead to ESF, contrary to what is normally expected. This non-development of ESF is suggested as evidence of the stabilizing effect of transequatorial neutral winds associated with stormtime circulation. The campaign observations clearly demonstrate that the DD electric fields could often mask the low latitude ionospheric responses to prompt penetration electric fields in the course of sustained substorm activity.

Introduction

Three basic types of electric field perturbations are now known to occur at equatorial latitudes in association with magnetospheric disturbances. These are: 1.- Transient electric fields associated with storm sudden commencements [e.g., *Sastri, et al.*, 1993]; 2.- Short-lived (≈ 2hr duration) electric fields arising from substorm development and recovery, generally associated with southward and northward turnings, respectively, of Bz component of the interplanetary magnetic field, IMF [e.g., *Fejer*, 1991; *Abdu et al*, 1995; *Abdu*, 1997] and 3.- Persistent (several hours duration) electric fields arising from the ionospheric disturbance dynamo [*Blanc and Richmond*, 1980]. While electric fields of types 1 and 2 occur almost simultaneous with the corresponding high latitude events (therefore termed prompt penetration-PP electric fields), those of disturbance dynamo (DD) set in with a delay of several hours. The limited observational evidences available to-date for DD electric fields at low latitudes are based mostly on single station measurements [e.g., *Fejer and Schirliess*, 1995; *Sastri*, 1988], and the longitudinal characteristics of the DD electric fields that remained unexplored, constitute a topic of focus in this paper. The electric field disturbances often result in significant modifications of the major phenomena of the equatorial ionosphere-thermosphere system (EITS): the ionization anomaly, the electrojet current system and the equatorial spread F (ESF)/ plasma bubble events [e.g., *Abdu*, 1997]. The influence of the DD electric field on ESF developments and on the visibility of PP electric fields events in the course of a succession of substorms are the other aspects of storm-time equatorial electrodynamics covered in this paper. The results are based on data for two disturbance intervals, obtained from digisondes/ionosondes, an HF Doppler radar and magnetometers operated in the widely separated Brazilian and Indian longitude sectors, during the GUARA/EITS observational campaign of September-October 1994. (see, *Pfaff et al.*, this issue on GUARA campaign).

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Disturbance Dynamo Electric Field Longitude Structure

Figure 1 presents in the upper three panels 15-min values of h'F (minimum virtual height of F region) and hmF2/hpF2 (height of F layer peak, hpF2 being an approximate height assuming a parabolic layer shape) for São Luís (2.33° S; 316° E; dip -0.5°), Fortaleza (4° S; 322° E, dip -9°) and Kodaikanal (10.25° N; 77.5° E; dip 4°) during the interval from 18 UT of 2 October to 09 UT of 4 October. The fourth panel shows the equatorial electrojet gross features in the Indian (75° E) sector represented by hourly values of ΔH(T) – ΔH(A) [ΔH(T,A) being the daytime magnetic field H-component variation with respect to its nighttime reference value over the electrojet station, Trivandrum (dip angle:-1.6°), and the low latitude station, Alibag (23°), respectively]. The asymmetric ring current index, ASY-H which is a good indicator of auroral substorm activity [*Iyemori and Rao*, 1996] is plotted at 1-min resolution in the bottom panel. ASY-H showed weak disturbances starting at 17 UT on 2 October followed by substorm growth and expansion phases at ~2115 UT and 2215 UT respectively. Close to 22 UT (vertical line 1) the F layer height over Sao Luis and Fortaleza showed enhanced uplift by an eastward electric field that was superposed on the normal F-layer dynamo-related prereversal height rise in progress at this time (around 2130 UT). The simultaneous response of F layer height over Kodaikanal appears to be in opposite phase. These height changes, which are indicative of eastward (westward) electric fields in the sunset (postmidnight) sector, are in agreement with model predictions for equatorward penetration of magnetospheric electric field associated with sudden increases in polar cap

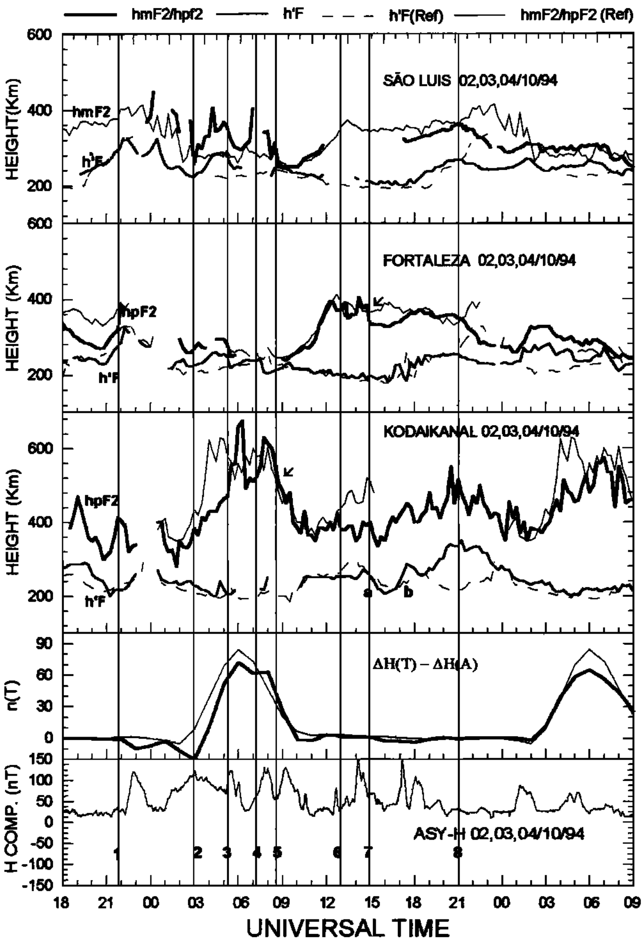

Figure 1. Variations during the magnetic storm of 2-4 October 1994 of (from the top) F layer heights (h'F, hmF2/hpF2) at São Luís, Fortaleza and Kodaikanal; equatorial electrojet, ΔH in the Indian (75°E) sector and the asymmetric ring current index, ASY-H. The corresponding quiet day variations of ionospheric and geomagnetic parameters are also shown for reference (Ref) as thin line (note that the hpF2 (Ref) curve of Oct. 1 for Kodaikanal is discontinuous).

potential drop that characterize the substorm development [*Senior and Blanc*, 1984; *Spiro et al.*, 1988]. The responses to the subsequent substorm recovery (at ~23 UT) and to the onset of the next substorm at 01 UT on 3 October are undefinable (till ~03 UT) due to data discontinuities. Rather clear responses to the substorm decay starting at 03 UT (vertical line 2) are seen as marked depression in hpF2, relative to the quiet day values, and reduction in electrojet strength (indicative of westward electric field) in the Indian morning sector, and as simultaneous and significant increases in hmF2 and h'F (indicative of eastward electric field) in the postmidnight Brazilian sector. The subsequent rapid increase in ASY-H at ~0510 UT (vertical line 3) produced a conspicuous uplift of the F layer (by ~200 km in hpF2) over Kodaikanal with a simultaneous depression of hmF2 at Sao Luís and Fortaleza. Structured decay of ASY-H that followed seems to have caused height changes of opposite polarities in the two longitude sectors. Similar anti-phase relationship of PP electric field manifestation in the afternoon sector (India) and postmidnight sector (Brazil) is also evident with the rapid increase in ASY-H at ~0715 UT (vertical line 4). In contrast, there is no perceptible response in hpF2 features (at the region indicated by an arrow) at Kodaikanal to the substorm that developed around 0840 UT (vertical line 5). Note that compared to the two previous substorms, this substorm developed at the end of storm main phase with a Dst value slightly more negative (by ~20 nT) than at 0715 UT. Sunrise conditions prevented an evaluation of the corresponding response in the Brazilian sector. We consider this near-absence of a response (expected to be an eastward PP electric field) to be due to a competing influence of a westward electric field of DD origin, that seems to have set in the Indian sector just around this time, that is, ~09 UT. The time delay for the onset of this DD electric field with respect to the onset of the first substorm of the series is around 10 hours which is consistent with the model predictions of *Blanc and Richmond* [1980]. The continuing presence of the westward DD electric field is evident near 13 UT when the normal prereversal F-layer rise is not at all apparent at Kodaikanal (vertical line 6). On the other hand, the DD westward electric field seems to manifest for the first time in Brazilian sector starting around 15 UT, indicated by an arrow for Fortaleza, (vertical line 7), followed by the nearly total inhibition of the sunset height rise around 21 UT (vertical line 8) over São Luís and Fortaleza, that confirm the continuing presence of the DD electric field in this sector also. Thus, by ~15 UT the disturbed region extended to at least 120 degrees in longitude. These results show that the DD electric field is not detectable at the same time at all longitudes of the low latitude ionosphere and thus point to the existence of a longitudinal structure in it. By 21 UT when a westward electric field prevailed over Brazil, the Indian postmidnight sector showed the presence of an eastward electric field as indicated by a large F layer uplift. DD electric fields seem to influence the F layer beahviour till 09 UT on 4 October.

An excellent example of the interplay between the PP and DD electric fields during which the latter modulates the visibility of the former is presented in Figure 2. Shown are the 1-min F layer vertical drift (V_z) from HF Doppler radar at Kodaikanal and the ASY-H index on 3 October. The two events marked **a** and **b** are identified as such also in Figure 1. As discussed before, on 3 October, the DD field is already

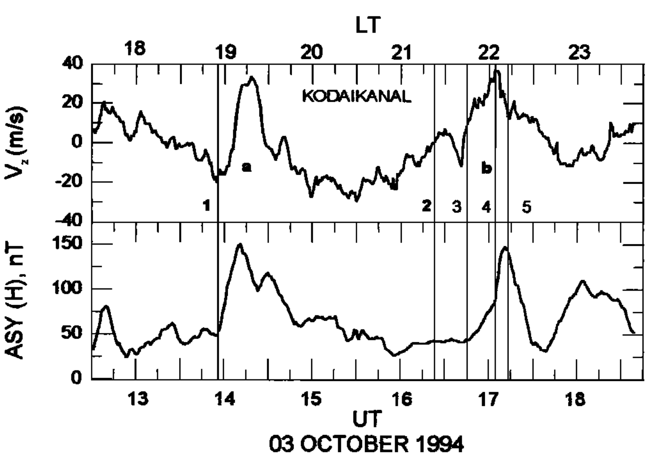

Figure 2. Variations of F layer vertical drift, Vz, at Kodaikanal and ASY(H) index over the period:1230-1840 UT on 3 October 1994. See text for futher details.

active in the local evening hours in the Indian sector. This can be seen from the low values of the evening prereversal V_z and its much earlier reversal time at ≈1330 UT (1830 LT). In comparison, on 1 October (a quiet day), the prereversal V_z peak around 1330 UT (1830 LT) reached ~23 ms^{-1} with the downward reversal around 1440 UT (1940 LT). The increase in ASY-H at 1355 UT (vertical line 1) produced a superimposed PP eastward electric field disturbance of ~ 50 ms^{-1}, the net upward drift being ~30 ms^{-1} only. Its decay into the background DD field followed closely the substorm decay. The DD electric field seems to have reversed polarity around 1622 UT (vertical line 2), (with some uncertainty due to wave activity at the time), in agreement with the model prediction by *Blanc and Richmond* [1980] and radar observations by *Fejer and Scherliess* [1995]. The response of V_z to a renewed activity starting at 1645 UT (line 3) is not well defined probably due to fluctuating background DD field. All that is apparent is the presence of an eastward electric field during the growth phase (1645-1704 UT, vertical lines 3-4), a rather well defined westward electric field during the expansion phase (1705-1712 UT, vertical lines 4-5) and again a westward field during the slower increase between 1738-1803 UT. These features are consistent with the PP field polarity reversal near midnight predicted by the models. But, as discussed with reference to Figure 1, most of the remaining response features are masked by the presence of a DD field.

DD Electric Field and ESF Development

During the interval from 15 September till the GUARA high altitude spread F rocket launch on 9 October, postsunset ESF did not occur over Sao Luis and Fortaleza only on 3 October, which corresponded to near total absence of the prereversal F layer height rise, under the influence of the DD electric field (Figure 1). Concurrent with this, strong eastward DD electric field was present over Indian longitude centered around 21 UT(02 LT) resulting in the F layer uplift by ~140 km, with h'F reaching ~340 km. However, this did not produce ESF although the generalized Rayleigh-Taylor (R-T) instability growth rate calculation using local values of the relevant parameters predicted ESF development. This contrasts with the cases of positive relationship between disturbance eastward electric fields (considered to be PP type) and ESF reported by *Fejer et al.*[1976] which were modeled by *Kelley and Maruyama* [1992] using field line integrated quantities. The variation of hmF2 at the low latitude station, Ahmedabad (not shown here) in the same longitude sector as Kodaikanal, however indicated the presence of significant meridional wind (probably transequatorial) during this DD field disturbances, which might have offered stabilizing conditions against the ESF growth. Additional evidence in support of this possibility is presented in Figure 3. Here the onset of a magnetic storm at 18 UT (vertical line 1) on September 25 produced DD electric field starting around 06 UT on September 26 (delay ~12-hr) which is seen as an abnormal increase in F layer height (between the vertical lines 2 and 3) over Sao Luís (dip angle: -0.5°), similar to a few other cases recently reported by *Abdu et al.*[1996]. This layer rise represents a vertical drift of ~16 ms^{-1}. However, no such vertical drift is perceivable over Fortaleza (dip: ~ -9°). We believe that the difference in response of the F layer height between São Luís and Fortaleza can safely be considered as due to a transequatorial wind, because the height over São Luís, with close to zero dip angle, is practically unaffected by meridional winds. The wind and electric field distributions over the restricted longitude range covered by the two stations can be considered to be uniform so that the difference in the dip angle at the two sites produces the different degree of the F-layer uplift observed at the two sites. This difference can be explained if a poleward meridional wind of ~ 100 ms^{-1} acted against the layer uplift over Fortaleza. The fact that no postmidnight ESF was generated during this event points to the important stabilizing role played by a transequatorial wind [*Maruyama*, 1988], as on the night of 3-4 October. ΔH data from Indian sector is plotted in Fig. 3 to indicate that DD field in the noon sector is manifested as a westward electric field (reduced electrojet current intensity) when the concurrent DD field in the postmidnight sector over Brazil is eastward.

Discussion and Conclusions

Joule heating from energy deposition at high latitudes produces disturbance in global thermospheric circulation pattern. The disturbance spreads equatorward and acquires significant westward velocity in the middle and low latitude regions due to the action of coriolis force. The resulting equatorward Pederson current and poleward electric field are the basic driving forces responsible for the establishment of DD electric field over low latitudes [*Blanc and Richmond*, 1980]. A uniform high latitude energy input predicts the establishment of a global dawn-to-dusk electric field. The idealized energy input function used by *Blanc and Richmond* may not strictly apply for our cases. However, it is pertinent to note that the predicted delay of the DD electric field over low latitudes (6-12 hours) is in reasonable agreement with the ~9-10 hr delay observed by us. The observed polarity of DD

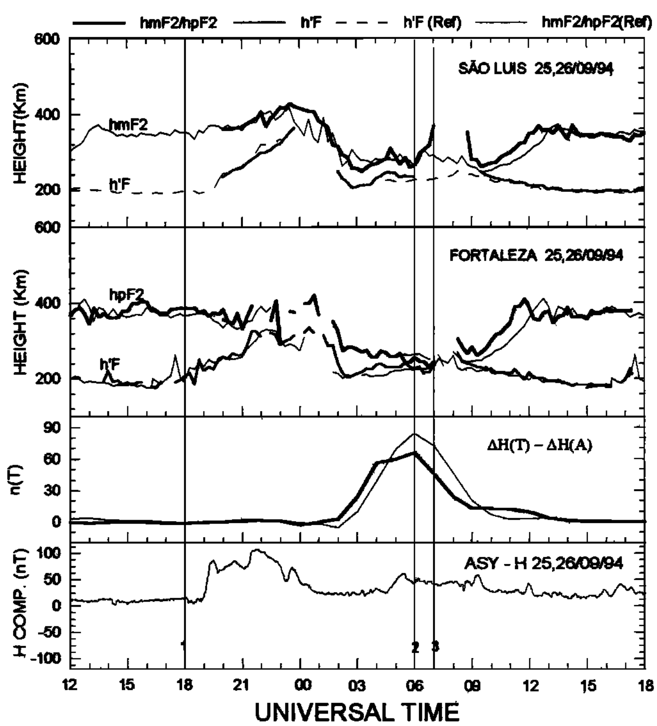

Figure 3. Same as in Figure 1 (excluding Kodaikanal ionosonde data) but for the disturbance period 25-26 September 1994.

field is also consistent with the model results. However, our observations seem to show the existence of significant longitudinal structure in it. This might suggest that the DD electric field involves thermospheric disturbance circulation cells with restricted longitudinal extension (depending upon the spatial size of the auroral energy input source) that seems to predominate, at least initially, in preferred longitudinal sectors of the low latitude ionosphere. With increasing time (within ~17 hrs of the first substorm, see Figure 1) the longitudinal extension becomes >120. The earlier magnetometer results of *Mazaudier and Venkateswaran* [1990] on the daytime manifestation of DD electric field in three longitude sectors (Trivandrum, Adis Ababa and Huancayo) are consistent with our results. But the evidence of simultaneous of DD electric fields of opposite polarity in the dusk and predawn hours is presented here for the first time.

The present work indicates that the PP electric field is easily detected during the initial few hours of an extended substorm activity, but eventually the onset of DD field could severely cloud its visibility. Some clear cases of this effect are identified in this paper which lead us to successfully identify the existence of longitudinal structure in the DD electric field. DD field which is westward in the sunset sector [*Fejer and Scherliess*, 1995] thus reduces or totally inhibits the normal prereversal enhancement in eastward field [*Abdu, et al.*, 1995]. As a result ESF development is inhibited as shown in this paper. The DD field reverses to eastward just before midnight and rather large eastward electric fields have been observed during the postmidnight hours [see also *Abdu et al.*, 1996]. In the cases analysed here, the resulting F layer height rise did not however produce any ESF even though the local R-T growth rate suggests favourable conditions. This contrasts with the ESF developments in association with anomalous eastward electric fields studied by *Kelley and Maruyama* [1992]. Comparison of the height responses at equatorial and off-equatorial stations suggests an association of the DD electric field with significant meridional winds that are possibly transequatorial winds. This seems to provide an important evidence on the stabilizing effect of such winds on the R-T instability process that otherwise could have lead to ESF development [*Maruyama*, 1988; *Sultan*, 1996]. Based on case studies carried out with the multi-site database of GUARA/EITS campaign, we may conclude that DD electric fields present longitudinal structure, effect visibility of PP electric fields, and inhibit postsunset ESF development but do not necessarily lead to ESF in the predawn period. Further, transequatorial winds seem to play the role of a stabilizing factor in the ESF processes in the predawn period just like in the.postsunset period [see also, *Abdu, 1997*].

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