

ELECTRIC FIELD IRREGULARITIES IN THE HIGH-LATITUDE IONOSPHERE

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Abstract. Having processed high resolution electric field measurements of the Dynamic Explorer 2 spacecraft in order to reveal and study signatures of rapid magnetospheric streams, we found that along with a regular large-scale electric field there exists an irregular one with amplitudes of 50–200 mV/m and transverse scale sizes varying from several to hundred km. This field behaves quite differently compared to the regular component, in particular, it is most common and of highest intensity under strong northward B_z IMF. It is typically observed at or around the convection reversal boundary. The field oscillations are accompanied by peak-to-peak variation of the corresponding magnetic field component suggesting strong field-aligned currents that must be associated with discrete auroral arcs.

1. Introduction

Through the last decade the concept of cold rapid formations which could partly perform plasma and magnetic flux transport inside the magnetosphere has been invoked in a number of works [e. g., Pontius and Wolf, 1990; Sergeev and Lennartsson, 1988, 1990; Chen and Wolf, 1993]. Pontius and Wolf [1990] who put forward this idea as a way to overcome 'the pressure balance inconsistency' in the inner plasma sheet considered these structures to be bubbles. In our earlier paper [Maltsev and Golovchanskaya, 1996] and here we expect them to be streams rather than formations of any other topology, for we suggest it is magnetospheric streams that manifest in the ionosphere as auroral arcs and are reported as strongly enhanced perpendicular electric fields of presumably magnetospheric origin adjacent to discrete auroras [Oppe-noorth et al., 1990 and references therein]. In other aspects our approach is close to that of Chen and Wolf [1993], namely, we suppose that transport of the transients is controlled by the interchange process. Its linear analysis with application to the magnetosphere was accomplished by Volkov and Maltsev [1986] and Maltsev and Mingalev [2000] where the growth rate of the interchange instability which we assume to be the source of the streams was found both for low- and high- β plasmas in the presence of the external electric field.

In this study an attempt has been made to find and examine signatures of the streams in high-time-resolution electric field measurements of the Dynamic Explorer 2 spacecraft (DE2) which were expected to manifest as strong electric field irregularities with small transverse scales. Since we suppose a streaming character is a very common feature of the magnetospheric convection and this view is supported by more and more experimental works [Baumjohann et al., 1990; Angelopoulos et al., 1992, 1993, 1994; Shiokawa et al., 1997; Amm et al., 1999] the choice of the spacecraft was only stipulated by its high-time-resolution (we used half a second data) and long period of observations (from August, 1981 to February, 1983).

2. Case Study

Already at the stage of preliminary data processing we found that along with a regular large-scale background electric field (for its detailed description see [Weimer, 1995]) there nearly always exist strong electric field perturbations with amplitudes of 50–200 mV/m and scale sizes varying from the upper resolution limit of 3.8 km to about hundred km. These perturbations are typically located at or around the convection reversal boundary, sometimes expanding towards the pole and covering the entire central polar region and sometimes shifting to lower latitudes, so that the polar cap is free of them. Though it is impossible to distinguish between spatial and temporal variations of a field by one spacecraft measurements, we'll interpret the results obtained in terms of spatial variations, since the observed values of the electric and magnetic perturbations up to 200 mV/m and 300 nT, respectively, at the spacecraft altitude of 300–1000 km can hardly be referred to any kind of geomagnetic pulsations.

Figures 1a-1d represent different extent of the high latitude electric field perturbation. The growing x -values correspond to the DE2 passing the dawn auroral zone, polar cap and dusk auroral zone along dawn-dusk meridian in the Northern Hemisphere. The sign of the electric field leading to sunward convection, i. e. background in the auroral zone has been taken as negative and that of the dawn-to-dusk electric field as positive. In fact, we found that the convection reversal boundary is nearly permanently perturbed, so the case of a smooth electric field in this region shown in Figure 1a is rather rare. If the electric field perturbations are actually caused by the interchange instability, then Figures 1a-1d can illustrate well different stages of its development: (1) an initial unperturbed state (Figure 1a); (2) emergence of perturbations (Figure 1b); (3) their growing up (Figure 1c) and (4) a strong non-linear stage when the perturbations completely destroyed the background gradients which brought them to growth (Figure 1d). For each of the passes in Figures 1a-1d are shown the corresponding hourly values of the B_y and B_z IMF in nT, solar wind velocity V in km/s, solar wind dynamic pressure variation dp in nPa and RMS (B_z variability) in nT. As we'll see further,

of all the parameters chosen only B_z IMF appears to be important for the irregular electric field formation.

It was noticed in case studying that this field doesn't obey general relationships well-known for the regular component. In particular, it is most common and of highest intensity under strong northward IMF (this feature will be clarified in the next section), i. e. when solar wind-magnetosphere coupling is the weakest and thus reflects rebuilding rather than generation of the magnetospheric electric field.

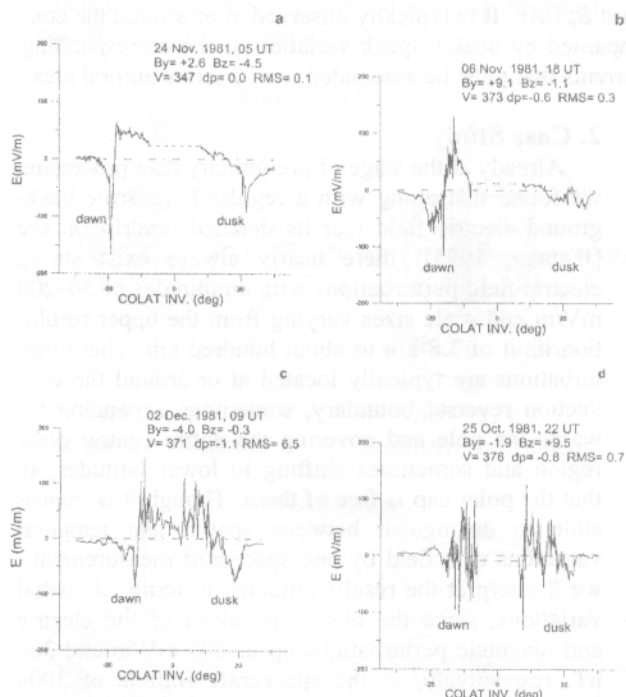


Figure 1. Examples of the observed high-latitude electric field in different passes of the DE2 spacecraft along dawn-dusk meridian in the Northern Hemisphere. E is the component along the spacecraft trajectory in mV/m taken negative in the dawn and dusk auroral zone and positive in the polar cap. The dashed lines show gaps in the measurements, the dashed-dotted lines mark the null level of the field. The average values of the solar wind parameters for the corresponding hour are given in conventional units.

3. Events of 24.11.1981 and 25.11.1981

In the observational period of the DE2 there were two days very representative with regard to whether B_z IMF is a principal factor in the phenomenon considered. These are 24.11.1981 when B_z IMF was steadily southward through the whole day and 25.11.1981 when it was strongly northward till 22 UT (Figure 2 in which the Dst behavior on these two days is also shown). The day of 24.11.81 was studied in detail in many papers [e.g. Yahnin *et al.*, 1994; Sergeev *et al.*, 1996] as a period of steady magnetospheric convection.

All the DE2 passes available for 24.11.1981 (two of them are illustrated in Figures 1a and 3a) indicated nearly unperturbed electric field in the polar cap and

auroral zone with rather smooth convection reversal boundary. At about 02 UT on 25.11.1981 B_z IMF turned to the north and in the closest pass of 03 UT one can see emergence of perturbations (Figure 3b). They reached extremely high values at 10 UT (Figure 3c) and persisted later on (Figure 3d) till 22 UT when B_z IMF turned southward again and the perturbations faded (Figure 3e). For all the cases considered we examined behavior of the corresponding magnetic field component and found that it follows peak-to-peak the electric field oscillations.

Figure 4 reproduces in more detail a fragment of the electric field perturbation in the dawn auroral zone depicted in Figure 3d with the accompanying magnetic field variation. The amplitudes of the latter up to 300 nT suggest strong field-aligned currents flowing in this region, which local values for the scales observed can be estimated as 10–100 A/km².

For the extremely strong event shown in Figure 3c we checked up if conjugacy with the Southern Hemisphere took place. It was found that with a difference in time of about 40 minutes taken by the spacecraft to reach the conjugated region the event was observed in the southern hemisphere too, though with somewhat smaller intensity. This infers that the irregular electric field is most probably attached to closed magnetic field lines. At the same time a closed magnetic field configuration is a necessary condition for interchange instability development, which may suggest interrelation of these two phenomena.

4. Relevance to discrete auroral arcs

From the above consideration it follows that the irregular electric fields being examined are obviously related to discrete auroral arcs at least those which are referred to as 'quiet' ones. Both develop at the auroral latitudes extending to the pole or shifting to the equator depending on the B_z IMF, both are accompanied by field-aligned currents of the same magnitude, both are conjugated between the hemispheres, both typically display multiple structure, etc. For the event of 25.11.1981, UT = 10 (Figure 3c) all sky camera data of Cheluskin observatory port (LAT_{geom} = 71.6°) were available and indicated quiet auroral arcs [Starkov, 1989].

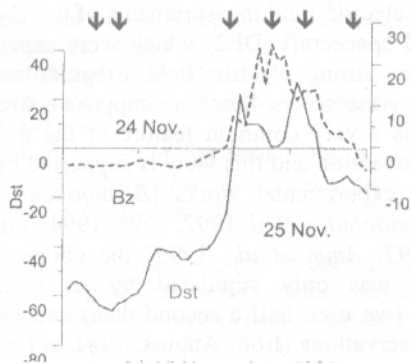


Figure 2. Variation of the B_z IMF component (nT) and Dst index on November 24, 25 1981. The arrows show the hours of the passes presented in Figures 1a and 3a–3e.

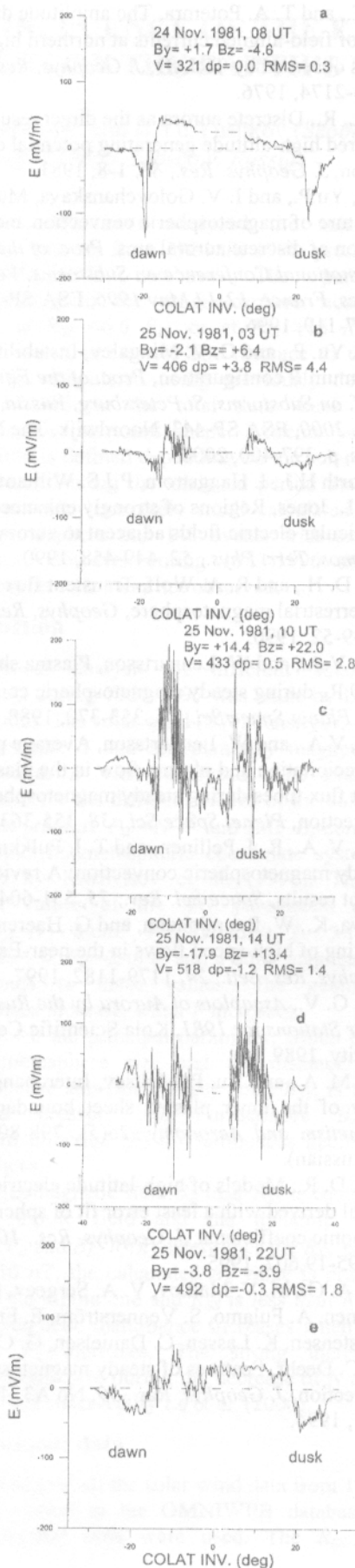


Figure 3. Evolution of the irregular electric field depending on B_z IMF conditions.

(a) Suppression of the perturbations under prolonged southward B_z IMF.

(b), (c), (d) Perturbation emergence and growing up after B_z IMF turning northward.

(e) Returning to the unperturbed state after restoring southward B_z IMF.

The observed shape of the electric field spikes is another point worth to draw the reader's attention to. The spikes appeared to be symmetric only in 20 percent of the cases. More frequently they are asymmetric with one edge steeper than the other (Figure 5a). This asymmetry, however, not always can be interpreted in terms of a discrete auroral arc arising on a respective side of the perturbation and fading the electric field. We would like to mention a strong resemblance both with respect to the electric field magnitude and spike shape of the perturbation shown in Figure 10a to that observed by EISCAT and reported as adjacent to a discrete auroral arc (Figure 5b taken from [Oppe-noorth *et al.*, 1991]). The arc was reported to be located from the smooth side of the perturbation.

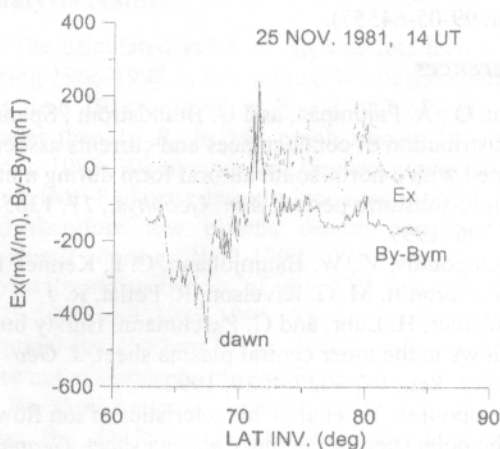


Figure 4. Correspondence between the electric and magnetic field variations in the event of strong irregular electric field. The directions of the E_x and B_y in the dawn auroral zone are southward and westward, respectively. From the observed B_y the model geomagnetic field B_{ym} is subtracted.

We complete this section by returning to the event of 25.11.1981, UT = 10 (Figure 3c). Extremely strong field-aligned currents developing in this case must lead to what is called discrete 'polar cap' arcs, which are known to cover the entire central polar region under strong northward B_z IMF [Gusev and Troshichev, 1992]. It should be noted that here the term 'polar cap' can hardly refer to a region with open magnetic field lines, since the magnetosphere is considered to be closed under much smaller and less prolonged northward B_z IMF [Fairfield, 1993]. Conjugacy between the hemispheres found for this event as well as four-cell large-scale convection pattern (Figure 3c) prove in favor of this view.

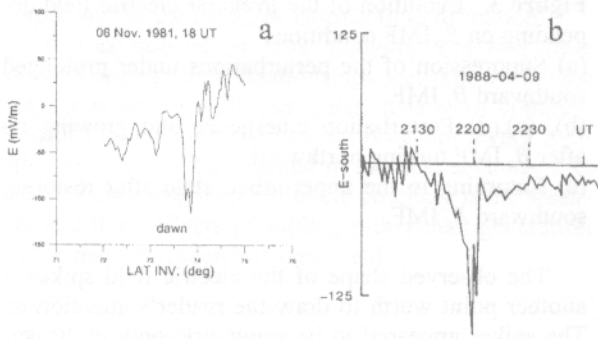


Figure 5. (a) A fragment of the DE2 electric field measurements in the event of 06 November 1981, 18 UT illustrating a typical shape of the spikes and (b) a postmidnight electric field enhancement observed by EISCAT and reported as adjacent to a discrete auroral arc [Oppeanoorth et al., 1991].

Acknowledgements. The Dynamics Explorer2 and solar wind data have been taken from NSSDC CD-ROM. We are obliged to J. King and N. Papitashvili for providing us with the data. This work was supported by the Russian Basic Research Foundation (grant 99-05-64557).

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