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DRIFTS OF AURORAL STRUCTURES AND THEIR RELATIONSHIP TO GEOMAGNETIC ACTIVITY

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Abstract: Accurate motion of some auroral structures, such as pulsating and non-pulsating patches and discrete auroral arc fragments is studied on the basis of all-sky TV observations of auroras. It is shown that the general drift pattern of these auroral structures correspond, on a gross scale, to magnetospheric convection, namely westward in the evening sector and eastward in the morning sector. The drift velocity ranges from 50 to 2000 m/s, corresponding to the electric field intensity from 3 to 120 mV/m at the ionospheric level and from 0.1 to 4 mV/m in the magnetospheric equatorial region at an L value of about 6.5. The general drift pattern locally fluctuates, when new magnetic (and auroral) activities occur. Temporal and spatial changes in the drift of the patches are related to the evolution of a substorm. Clear enhancement in the drift velocity associated with increase in the westward electrojet is observed at a different local time region from the center of the electrojet. These results indicate that the convection electric field temporarily and spatially changes when a new substorm expansion of aurora occurs in the midnight sector.

1. Introduction

Movements of auroras have been studied since early 1970's based on all-sky camera observations (*e.g.*, DAVIS, 1971). It has been suggested that the movements could indicate $\boldsymbol{E}\times\boldsymbol{B}$ drifts due to magnetospheric electric field, $\boldsymbol{E}$. Based on TV observations, SCOURFIELD *et al.* (1983) compared the drift of some pulsating auroral forms with the electric field estimated from the radar measurement in the postmidnight period and showed that the drift is consistent with $\boldsymbol{E}\times\boldsymbol{B}$ drifts assuming that the ionospheric electric field is the projection of the magnetospheric electric field.

It has been suggested that the form of pulsating patches correspond to the thermal plasma irregularities in the magnetosphere, where pitch angle scatterings can take place. As these irregularities are displaced with $\boldsymbol{E}\times\boldsymbol{B}$ drift, we will see the drift of the auroral patches as a projection of the magnetospheric irregularities onto the ionosphere. On the other hand, movements of the main body of discrete aurora (such as poleward expansion aurora or westward traveling surge) will be associated with changes in magnetic configuration rather than with drift due to magnetospheric electric field, since these discrete auroras are very likely to be mapped to the tail current sheet (LYONS and EVANS, 1984) where abrupt changes in the magnetic field are observed at the substorm expansion onset (*e.g.*, RUSSELL and MCPHERRON, 1973). Therefore, we did not discuss in this study the motion of the main body of the discrete aurora. From detailed examination of all-sky TV data, however, it has been shown that some discrete arc fragments detach from the poleward moving main body of the discrete aurora and start pulsating after several minutes (YAMAMOTO, 1984). Therefore, dispite the transition from discrete arc fragments into pulsating patches the magnetospheric source properties could be quite similar to each other in these auroras; both originate from cold plasma irregularities and hence likely to move with $\boldsymbol{E}\times\boldsymbol{B}$ drift. In order to examine this viewpoint we analysed also the motion of the discrete arc fragments.

There have been many statistical studies of magnetospheric electric fields based on radar measurements, polar-orbiting satellite measurements, and *in situ* measurements near the equatorial plane. However, only a few studies have dealt with time variations of the magnetospheric electric fields with satellite measurements because of the difficulty to separate spatial and temporal variations from the data obtained at a single moving point. Some radar measurements showed ionospheric electric field structures along a meridian line during magnetic disturbances (*e.g.*, HORWITZ, 1978; HORWITZ *et al.*, 1978) with 16-min time resolution, which is still insufficient for a substorm study. Two dimensional distribution of ionospheric electric field associated with break up aurora (BAUMJOHANN *et al.*, 1981), westward traveling surge (INHESTER *et al.*, 1981), and omega band (ANDRE and BAUMJOHANN, 1982) has been obtained with 20-s time resolution at locations where the electuricfield ma gnitude exceeds a threshold value of about 15 mV/m.

Since we can get two dimensional information with a high temporal-spatial resolution (100 ms sampling time and spatial resolution of roughly 2×2 km^2) by means of an all-sky TV camera and the TVIP (Television Image Processor) system, the measurements of auroral drift allow us to study precisely time-dependent magnetospheric electric fields. Moreover, measuring the drift of the auroral patches, that is measuring the drift of the irregularities in the magnetosphere, is a more direct way to infer the magnetospheric electric field structures than to measure the ionospheric irregularity drift by radars.

In this report global drift patterns of auroral structures such as pulsating, nonpulsating patches and arc fragments detached from the main body of the discrete arc are represented. Temporal and spatial changes in drift velocities of auroral patches in the dusk sector during high geomagnetic activity are also represented and compared with the ground magnetic variations. As we will present in the following two sections, magnetospheric electric fields vary from a few mV/m to a few hundred mV/m projected onto the ionosphere depending on the magnetic activity level and on the relative local time.

2. Drift Pattern

Figure 1 shows the distribution of the drift of auroral structures obtained at La Ronge (55.2°N, 105.3°W; corrected geomagnetic lat. 64.8°, long. 311.0°) and Parksite (52.2°N, 107.2°W; corrected geomagnetic lat. 61.6°, long. 309.6°) on February 16, 1980. Methods to obtain the drift vectors are given in detail by NAKAMURA and OGUTI (1987). Most of the velocity vectors in the morning sector are from pulsating patches. Those in the evening sector, on the other hand, consist of arc fragments

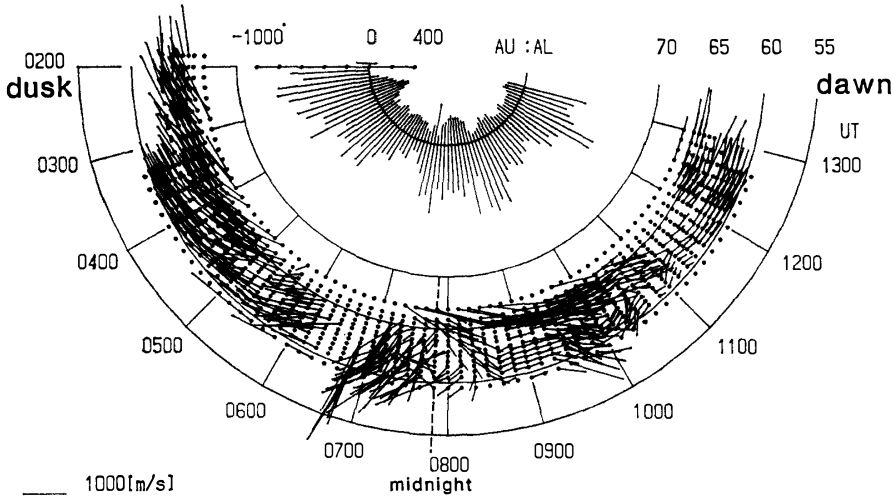

Fig. 1. Drifts of the auroral structures on February 16, 1980. The AL and AU indices are plotted along the inner circle as a reference of the magnetic activity. The drift pattern is asymmetric in the midnight sector, showing a slant line of the drift reversal similar to the Harang discontinuity (after NAKAMURA *and* OGUTI, *1987).*

in higher latitudes and pulsating patches in lower latitudes. Note that there is no clear difference in the drift pattern of these two rather different types of auroras. The drift direction is generally westward in the dusk sector. It gradually turns to southward in the late evening, then switches to eastward in the early morning. The drift reversal occurs near midnight across a slant line similar to the so-called Harang discontinuity. The drift velocity ranges from 50 to 2000 m/s, which corresponds to the electric field intensity from 3 to 120 mV/m at the ionospheric level and from 0.1 to 4 mV/m in the magnetospheric equatorial region at an L value of about 6.5. The drift pattern is consistent on a gross scale with those from other measurements of the magnetospheric convection. The result strongly supports the idea that the pulsating auroral patches are the ionospheric projections of cold plasma irregularities in the magnetosphere. Furthermore, not only the drifts of the patches but also the drifts of arc fragments are most likely due to $\boldsymbol{E}\times\boldsymbol{B}$ drifts. This observation suggests that at the substorm expansion phase when the active region (main body) expands poleward, the arc fragments detached from the main body of the discrete aurora are located on the field lines where the displacement due to the configuration change in the magnetic field is negligible compared to the drift motion of the source region. Thus both the drifts of auroral patches and detached arc fragments can be an excellent indication of magnetospheric electric fields.

The global auroral drift pattern is locally fluctuated as can be seen in the figure. These fluctuations of the drifts take place when new magnetic (and auroral) activities occur. This indicates that the convection electric field changes temporarily and spatially at the time when a new substorm expansion of aurora occurs in the midnight sector. For example, a fast southward drift at 0640 UT, a southward deflection of the drift with an increase in the velocity between 0910 UT and 0930 UT, and a reversal of the drift from eastward to westward between 1000 UT and 1030 UT in the lower latitude, are all associated with new substorm auroral expansions around the midnight sector, respectively. Note that the sudden increase in AL and the change in drift does not occur always simultaneously. This is because the change in the drift (magnetospheric electric field) does not occur along the auroral oval at the same time but propagates both eastward and westward from the midnight sector as the expansion front of aurora moves on (NAKAMURA *et al.*, 1988) and as the region of the westward jet expands, often in a stepwise fashion (WIENS and ROSTOKER, 1975).

3. Temporal and Spatial Variations during Magnetic Activities

We further show an example which reveals a close relationship between temporal and spatial variations of magnetospheric electric field deduced from auroral drifts and those of substorm activity.

Figure 2 shows the auroral luminosities along 8 E-W lines in the time interval from 0230 UT to 0456 UT (1830 MLT to 2056 MLT) on February 17, 1980. The location and number of each E-W line are given in the attached all-sky picture. These E-W lines are the parallels of geomagnetic latitude circles which pass through (1) 150 km, (2) 100 km, (3) 50 km north, (4) zenith, (5) 50 km, (6) 100 km, (7) 150 km, and (8) 200 km south of La Ronge. The upper and the lower boundaries of these E-W position-time displays are the easternmost and westernmost sampling points along the sampling lines. These boundary points are located at a distance 150 km away from the meridian line passing the zenith of La Ronge. Standard AL and AU indices are also given in Fig. 2. The auroral luminosities are represented in negative images; the dark streaks (some examples are indicated with arrows in the plot (4)) going down with time indicate westward drift of the auroral patches, while the nearly straight lines designated as S in the plots (6) and (8) the star lights. Assuming that the geomagnetic field is a dipole field, and that there is no electric potential drops along field lines, westward drift velocity of 100 m/s at La Ronge latitude, $L=6.5$, corresponds to a radial electric field of 0.2 mV/m in the magnetospheric equatorial plane.

An increase in westward drift velocity of several auroral patches can be clearly seen starting from 0340 UT associated with the substorm which broke out at 0326 UT. The equivalent current system obtained from 24 geomagnetic stations shows a DP1 type pattern with an intense westward electrojet centered around Great Whale River (corrected geomagnetic lat. 68.0°, long. 353.7°) located near the midnight meridian (see Fig. 6 of NAKAMURA *et al.*, 1988). The drift velocity increases and decreases on average with a time lag of about ten minutes behind the development and decay, respectively, of the westward electrojet. The increase of the drift velocity is larger in higher latitude region. Particularly at the maximum stage of the electrojet evolution, this latitudinal dependence of the electric field intensity is most clearly observed.

Two possible mechanisms are discussed to explain this observational results. One possibility is that the change in the electric field is caused by the energetic particles, which are injected at the substorm onset in a localized region near GWR and drift to the meridian where we observed the electric field. It is natural to think that the injected protons produce in the dusk sector northward electric fields at higher

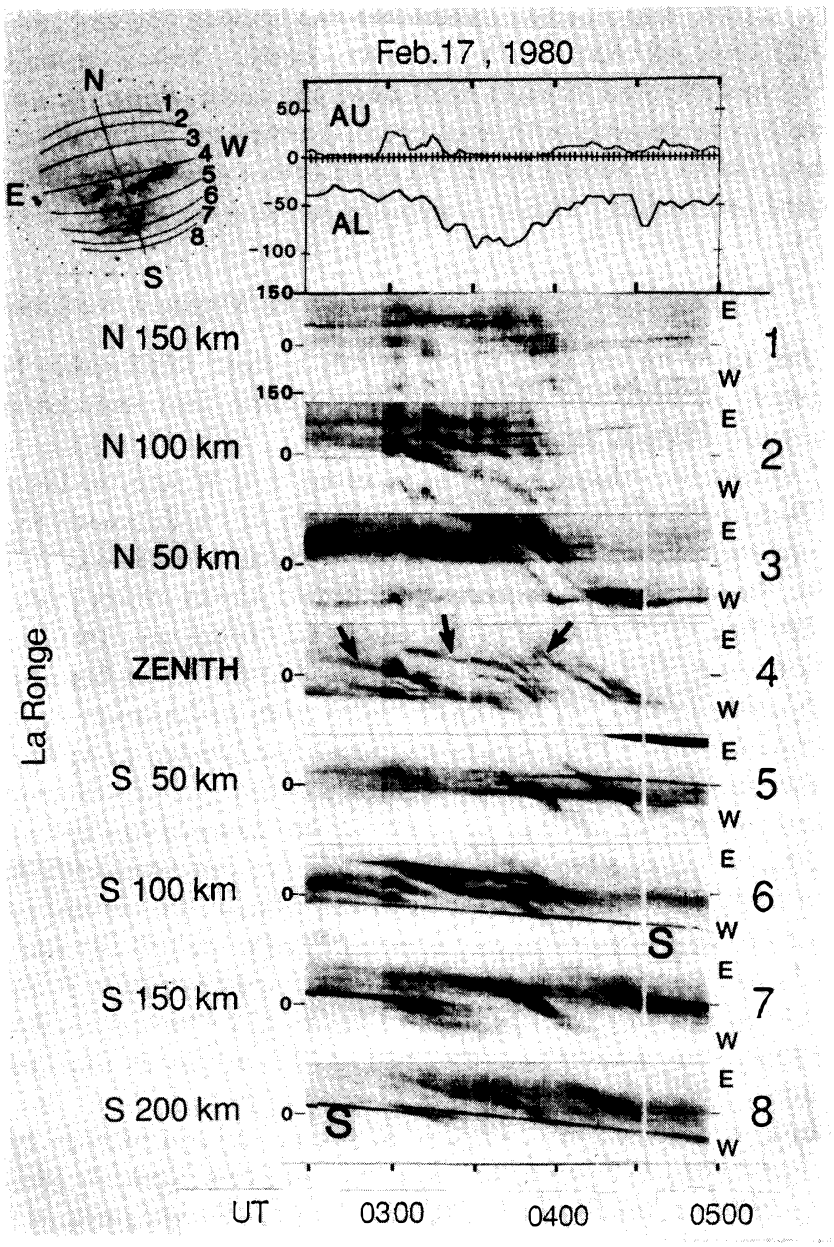

Fig. 2. Auroral luminosities in negative images sampled along 8 E-W lines and the geomagnetic AL and AU indices from 0230 UT to 0456 UT (1830 MLT to 2056 MLT) on February 17, 1980. The location and number of each E-W line are given in the attached all-sky picture. The auroral luminosities are represented in negative images. The dark streaks (some examples are indicated with arrows in the plot (4)) going down with time indicate westward drift of the auroral patches (after NAKAMURA *et al., 1988).*

latitudes and southward electric fields in lower latitudes. Since the drift trajectory is energy dependent, the total electric field will then be produced by the protons distributed at different radial distances from the earth. This distribution causes radial gradient of electric field, which explains the latitudinal gradient of the northward electric field observed at La Ronge. The 14-minutes delay between the substorm onset and the electric field response at La Ronge could be interpreted as the drift time of energetic particles which produce the electric field if we neglect the Alfvén transit time of less than half a minute. Then 14 minutes corresponds to the proton energy of about 60 keV in a dipole magnetic field drifting from GWR meridian. The electric field magnitude expected for a particle to penetrate to La Ronge latitude is estimated to be about 0.134 mV/m.

Another possibility is that the observed electric field is caused by a newly induced electric field associated with a disruption of the tail current at the substorm onset. As mentioned in the previous section the onset region expands westward and eastward from the initially localized break up region. The lag-time of the drift then could be the expansion of the dipolarization area. The estimated maximum velocity from our observation is about 5.4 km/s at the ionospheric level. This is a value comparable to the velocity of a westward expansion front of discrete aurora. Since the mechanism of the auroral expansion is yet an unsolved problem, it is unknown if an expansion front accompanies a latitude dependent electric field in the lower latitude region. INHESTER *et al.* (1981) observed also a northward electric field at the southwest region of a westward traveling surge. Since there was actually no discrete aurora within the field of view in our observation we cannot directly compare our inference of the electric field structure with their results.

Relationship between the magnetospheric electric field and the motion of the injected particle as well as the displacement of the dipolarization area front could be more quantitatively examined with a simultaneous observation of auroral drift and particle flux in the equatorial plane. The results of such an analysis will appear elsewhere.

4. Conclusion

Global drift pattern of the auroral structures, such as pulsating and non-pulsating auroras as well as discrete arc fragments detached from the main body shows on a gross scale a typical two-cell convection pattern. This result supports the idea that these auroral structures could be the ionospheric projection of thermal plasma irregularities in the equatorial plane, and therefore move mainly with $\boldsymbol{E} \times \boldsymbol{B}$ drift.

The global convection pattern shows local and temporal fluctuations with new substorm activity. The characteristic response of the magnetospheric electric field during the disturbed period on Feb. 17, 1980 was an enhancement in its intensity with a steep latitudinal dependence and its time delay of about 10 minutes behind the electrojet evolution. The result suggests the longitudinal development of a substorm associated disturbance caused by newly injected particles and/or the longitudinal expansion of the dipolarization region.

This study shows that the drift of auroral structures is useful information to investigate variations of magnetospheric electric fields, since this method allows us to examine temporal change as well as spatial structures of the electric fields with high resolutions.

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