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HIGH-LATITUDE ELECTROJETS, AURORAL LUMINOSITY AND AURORAL PARTICLE PRECIPITATIONS

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Abstract. The mutual location of high-latitude electrojets, typical regions of the auroral luminosity and regions of auroral energy particle participations into the upper atmosphere under substorm conditions are considered. Three electrojets exist at high latitudes during substorm intervals: WE - westward electrojet, EE - eastward electrojet and PE – polar electrojet. Geomagnetic latitudes of the WE/EE and PE location vary depend on local time and magnetic activity level, respectively. It is shown that the WE is located within the limits of the auroral oval precipitation (AOP), the EE in the evening sector is located within the diffuse auroral zone (DAZ) and the PE near noon is located at the poleward AOP boundary shifting poleward with decreasing the magnetic activity level. The relationship of electrojets with different plasma domains in the magnetosphere is discussed.

1. Introduction

The close connection between magnetic disturbances and aurorae makes it necessary to consider them as two manifestations of the same phenomenon, i.e. precipitation of energetic particle fluxes into the upper atmosphere. The magnetic disturbances are of the highest intensity in the auroral region, becoming less intense poleward and at subauroral latitudes. The irregular character of geomagnetic field disturbances was mentioned by Birkeland [1908], who proposed their classification. At high latitudes the positive and negative perturbations were identified, and are known as polar elementary storms.

Alfvén [1950] proposed his electric field theory, utilizing Birkeland's idea concerning the relation of both the aurorae and magnetic disturbances with solar corpuscular fluxes. Alfvén showed that magnetic disturbances in the near-Earth space are due to a 3D current system. At ionospheric altitudes, the field-aligned currents flow into and out of latitudes of the auroral zone along these latitudes intense eastward (evening hours) and westward (morning hours) currents flow. Chapman [1935] derived a 2D current system that explains the regular features of polar magnetic disturbances. This equivalent current system at ionospheric altitudes is called the DS current system. The basic concept is that DS consists of two concentrated currents along the auroral zone, westwards/eastwards currents at dawn/dusk hours, which Chapman called the electrojets. Harang [1946] described the existence of a discontinuity between the westward (WE) and eastward electrojets (EE) at pre-midnight hours. In the dusk sector intensive currents overlap each other, and the WE is located poleward from the EE.

The modification of the spatial-temporal pattern of auroral electrojets took place just after the transition from the concept of the auroral zone to that of the auroral oval in the early 1960's (Feldstein [1963], Akasofu et al. [1965], Feldstein and Zaitzev [1965]). In a new large-scale model of the current distribution at high latitudes the electrojet with westward current flows along the auroral oval with intensity depending on local time. Our analysis of the extent to which these models are in accord with observational data presented below.

Svalgaard [1968] and Mansurov [1969] revealed two characteristic types of geomagnetic field disturbances in the polar regions at $\Phi \geq 78°$, controlled by the IMF sector structure. Friis-Christensen et al [1972], Sumaruk and Feldstein [1973] have shown that these disturbances in the polar region are controlled by the direction of the azimuthal By IMF (east-west) component. The current system of this type of geomagnetic field variations is considered to be due to the polar electrojet (PE). The direction of the PE current is westward when By<0 nT and eastward, when By>0 nT.

2. The high-latitude electrojets

We investigate variations in the location and intensity of the high-latitude electrojets during magnetic substorms on 24 September 1998 using a numerical method for estimating the equivalent ionospheric currents based on H and Z components data from three meridian chains of magnetic observatories: the IMAGE along the 110° CG (corrected geomagnetic) longitude, the GWC along the 40°longitude, and the CANOPUS along the 330° longitude. Local magnetic midnight is at 2100 UT, 0230 UT and 0630 UT, respectively. A detailed description of the method used, both accuracy and spatial resolution, was given by Popov et al. [2001]. Interplanetary and geophysical conditions for the time intervals analyzed and some results on the interrelation of auroral electrojets in the evening sector with precipitations of auroral particles were discussed by Feldstein et al. [2006]. Below we compare the location of auroral electrojets with statistical data on the location of the auroral oval, with boundaries of structural regions of auroral energy electrons and ions precipitations.

The latitude variations of the equivalent current distribution calculated from the magnetic field Z component (GWC chain) data on 24 September 1998 are displayed in Fig. 1 (upper panel). The intensity of component variations is calculated from the base levels at 11 UT on 24 September. The latitude variations are apparent for the WE location during 0500-1300 UT and for the EE location at 1330–2030 UT as seen in Fig. 1.

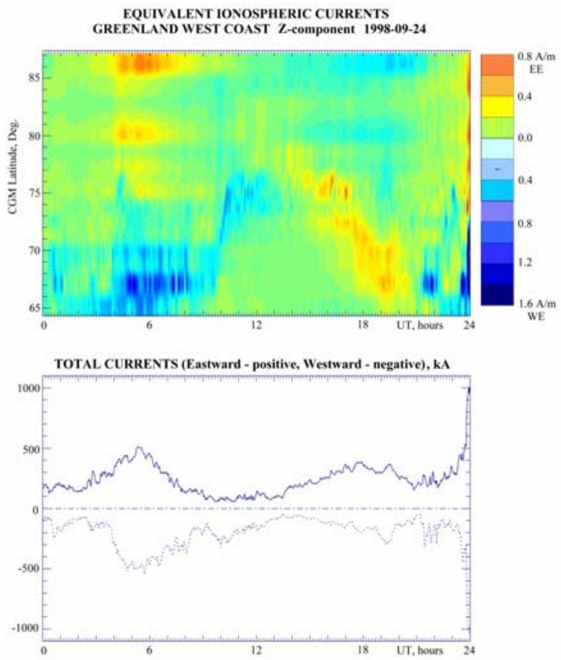

Fig.1. The corrected geomagnetic latitude vs UT plot of the eastward and westward equivalent ionospheric currents as calculated using Z component data from the GWC meridian chain of magnetic observatories (top panel) on 24 September 1998. Total intensity of the eastward (above) and westward (below) currents according to the GWC chain Z component(bottom panel).

During 1200 – 1500 UT in the day-time sector additional currents are present at Φ~78°. Their location and eastward direction under IMF By > 0 indicate these currents as a polar electrojet (PE). In Fig. 1 (lower panel) the integral intensities EE and WE can be seen.

In Fig. 2 the location of electrojet centers can be derived from data of three chains of magnetic observatories. Based on these data the averaged curves for WE (the dark blue) and for EE (the light blue) locations are also shown. The PE location can be followed using GWC data at Φ~78° (PE1, light brown) and IMAGE data at Φ~74° (PE2, brown) with no averaging. The averaged WE location covers time sectors from dusk to late morning through midnight hours. Post- and pre-noon the WE location is related to increasing latitudes and finally WE adjoins PE2. The averaged EE with monotonically increasing latitudes envelop the time sector from late evening to afternoon hours. In the evening sector the EE is located equatorward from the WE and adjoins PE2 on its equatorial side at near-noon hours. The latitudinal difference in the PE1 and PE2 location is due to the changing level of disturbances for observational time intervals for the IMAGE (0800 – 1200 UT, substorm) and GWC (1200-1500 UT, quiet).

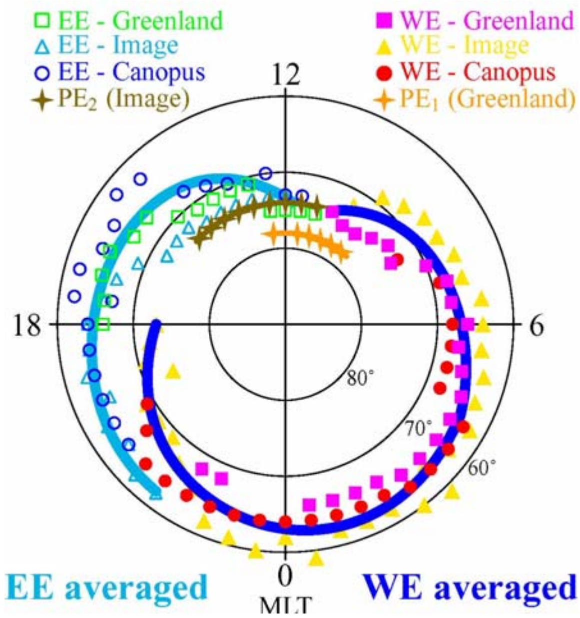

Fig. 2. The PE, EE, and WE location during substorms on September 24, 1998. Averaged EE (blue) and WE (dark blue) curves are obtained using observational data from three chains of magnetic observatories (circles, triangles, and squares corresponding to CANOPUS, IMAGE and GWC, respectively, using corresponding colours as shown). Data from IMAGE and GWC (stars) are only used for the PE. Co-ordinates: corrected geomagnetic latitude and MLT.

3. Electrojets and auroral luminosity

Fig. 3 illustrates the mutual location of auroral electrojets and typical regions of the auroral luminosity. Both the auroral oval (AO) with discrete auroral forms (green) and diffuse auroral zone (DAZ, yellow) luminosity just equatorward of the AO can be seen. The AO boundaries correspond to that proposed by Feldstein and Starkov [1967] for different values of the magnetic activity Q-index. The DAZ equatorial boundary corresponds to that proposed by Gussenhoven et al. [1983] as being dependent on the Kp index. To describe both the AO polar/equatorial boundaries and DAZ equatorial boundary Starkov [1994a, b] proposed approximation relations using three harmonics of the Fourier series. The amplitudes and phases of harmonic were considered as dependent on the AL index. The luminosity regions shown in Fig. 3 were calculated for AL = –450 nT, corresponding to the magnetic activity conditions during the substorms on 24 September 1998.

According to the data used the WE is located at AO latitudes practically for all MLT, reaching the AO polar boundary in early evening (~ 18 MLT) and late morning (~ 10 MLT) hours. In the near-noon sector the polar electrojet (PE2) is also located at these latitudes. Between late evening and afternoon hours the EE can be seen at DAZ (near its polar boundary) latitudes. Only about near-noon hours the EE shifts to AO latitudes adjoining the PE2. During magnetic disturbances the PE2 is located in the vicinity of the AO polar boundary.

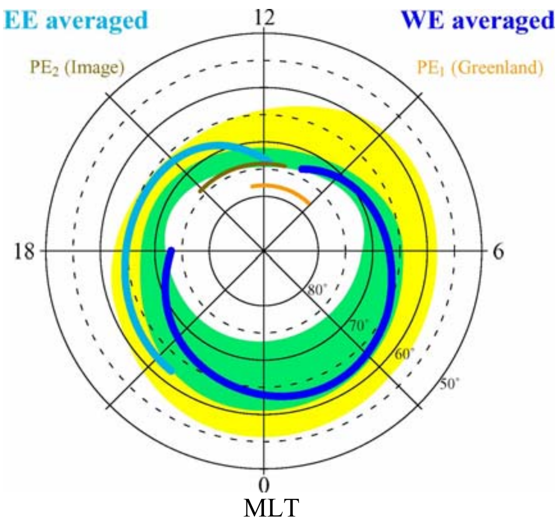

Fig. 3. The mutual location of characteristic regions of the auroral luminescence (Auroral Oval green and Diffuse Auroral Zone yellow) and high-latitude electrojets (averaged curves for WE and EE) under disturbed conditions during the substorms on 24 September 1998.

4. Electrojets and auroral particles precipitations

Fig. 4 shows the mutual location of auroral electrojets and typical regions of the auroral particles precipitations. The auroral oval precipitations (AOP), soft diffuse precipitations (SDP) just poleward and diffuse auroral zone (DAZP) precipitations equatorward of the AOP can be seen. The SDP, AOP and DAZP boundaries are identical with those considered by Vorobjev et al. [2000], Starkov et al. [2002], and Starkov et al. [2003]. Those are obtained using analytical relationship for location of precipitation region boundaries under changing AL and Dst indices as follows from DMSP F6 and DMSP F7 measurements [Vorobjev and Yagodkina, 2005, 2007]. During night hours AOP is located between b2e and b5e boundaries, while DAZP is between b1e and b2e boundaries and SDP is found between b5e and b6e boundaries [Newell et al., 1996]. During day hours AOP is located between polar boundaries of traditional CPS and BPS. DAZP is between equatorial and polar boundaries of the traditional CPS, while SDP is located between polar boundaries of traditional BSP and LLBL. These traditional CPS, BPS boundaries and LLBL boundaries mentioned for day hours are calculated using algorithms reported by Newell et al. [1991]. As seen in Fig. 4, the WE is located within the AOP region, EE location corresponds to the DAZP and PE is poleward of the SDP.

Conclusions based on comparison of location of high-latitude electrojets during substorms analyzed, on the one hand, and of the statistically determined regions of auroral luminosity and/or auroral energy electron precipitations, on the other hand, need additional confirmation using satellite plasma and

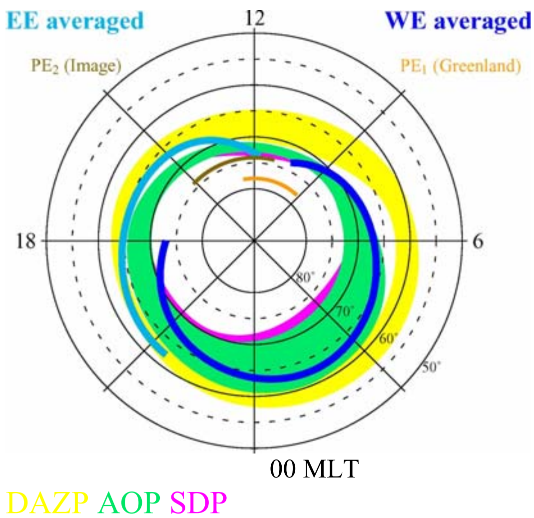

Fig. 4. Characteristic location of precipitation regions for auroral energy electrons into the Auroral Oval Precipitation (AOP, green), Diffuse Auroral Zone (DAZ, yellow) and Soft Diffuse Precipitation (SDP, violet). The curves for the location of high-latitude electrojets are also shown.

electromagnetic measurements. Measurements during the DMSP F14 satellite pass from evening to near-noon sector through high latitudes in the Northern Hemisphere, namely at 0952–1013 UT on 24 September 1998, are shown in Fig.5. The satellite intersected the evening and near-noon auroral sectors. Time of near-noon sector intersections by the satellite coincided with the period of PE2 observations by the IMAGE

The pass occurred during the substorm with AL ~ -450 nT. The location of selected boundaries is indicated by vertical lines. The satellite intersected the DAZ between the b1e (62.9°, 1900 MLT) and the b2e (65.8°, 1840 MLT) boundaries (in the evening sector) and AOP between the b2e and the b5 (74.0°, 1650 MLT) boundaries. Then the DMSP F14 entered the polar cap and crossed the CUSP polar/equatorial boundaries at 75.3° (MLT 14.0)/72.5° (1250 MLT) latitudes. Intense fluxes of soft ions were seen at these latitudes. Structured fluxes of electrons with energies up to 1 keV were also observed. Those are likely to be responsible for discrete auroral forms (the AOP). The DAZ polar/equatorial boundaries were intersected at (69.6°, MLT 11.7) / (61.0°, MLT 10.8). As seen, the AOP and DAZ boundaries specified above correspond reasonably well to those defined from the auroral luminosity observations (see Fig. 3). Note that within the day-time sector the PE2 location corresponds to the CUSP polar boundary.

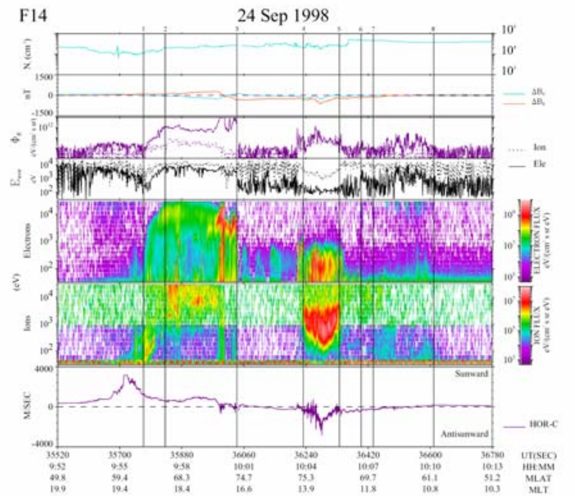

Fig. 5. Plasma measurements during the 0952–1013 UT on 24 September 1998 from the DMSP F14 pass over high latitudes. From top to bottom: ion density (first panel); variations of the magnetic field east-west (Bz) and north-south (By) components (second panel); energy flows and mean energy of electrons and ions (third and fourth panels); energy spectrogram for electrons and ions (fifth and sixth panels); plasma drift velocity horizontal component (seventh panel)**.** The intersections of auroral precipitation boundaries are indicated by vertical lines 1-8.

5. Discussion

The analysis of the spatial-temporal distribution of auroral electrojets presented above makes it possible to return to the issue of a high-latitude current system pattern responsible for substorms once more. As known, Akasofu et al. [1965] proposed the one-vortex current system: the WE along the AO and the eastward current in the evening sector as a return current from WE. The two-vortex current system includes the WE along the AO and EE in the evening sector was proposed by Feldstein [1963], Feldstein and Zaitsev [1965]. The EE in this system is an independent electrojet, not closure (return) currents of the WE. There are more arguments in favor of the two-vortex substorm current system: (i) the eastward current integral intensity (in the evening sector) can exceed that of the westward current, which is located on the same longitude at higher latitudes; (ii) bay-like disturbances of the magnetic field H component at subauroral and middle latitudes (on the EE meridian) are described by the equivalent westward current (EE return current); (iii) the WE and EE are independent since they are associated with different types of auroral luminosity: WE with AO, EE with DAZ; (iv) the WE and EE are independent since they are associated with different types of auroral particles precipitations: WE with AOP, EE with DAZ. Distinctions in characteristics of auroral particles precipitations at different latitudes are connected with their relationship with various magnetospheric plasma domains: central plasma sheet in case of the WE, Alfvén layer located between plasmopause and central plasma sheet in case of the EE.

The first two arguments supporting the two-vortex current system were reported earlier [e.g. Feldstein and Zaitsev, 1968]. The higher EE intensity (in comparison with that of the EW) is confirmed when determining the equivalent ionospheric current intensity from the magnetic field measurements by the CHAMP satellite [Ritter et al., 2004]. Keeping in mind the observed features in the WE and EE locations, on one hand, and different types of auroral particle precipitations, on the other hand, the third and forth arguments appear are most decisive.

6. Conclusions

From the analysis of the spatial-temporal distribution of auroral electrojets we conclude:

1. Three electrojets exist at high latitudes during substorm intervals: WE - westward electrojet, EE - eastward electrojet and PE – polar electrojet. Geomagnetic latitudes of the WE/EE and PE location vary depend on local time and magnetic activity level, respectively.
2. WE is located within the limits of the auroral oval (AO) between evening and before noon hours, the lowest latitude of WE location occurs in the early morning hours near AO boundary, reaching the poleward AO boundary at 18 MLT and 10 MLT.
3. EE in the evening sector is located within the diffuse auroral zone (DAZ) reaching lowest latitude at 15-17 MLT near the DAZ equatorial boundary, while reaching the poleward boundary before midnight and after midday MLT hours.
4. PE is located at the poleward AO boundary near noon shifting poleward with decreasing activity level.
5. Comparison of the characteristic regions of plasma precipitation observed by the DMSP satellites with the location of electrojets made it possible to determine the relationship of electrojets with magnetospheric plasma domains in the magnetosphere: (i) EE is located at latitudes of the

Alfvén Layer mapped to the ionospheric altitudes (along magnetic field lines); (ii) WE is located at latitudes of the central plasma sheet; (iii) PE is found in daytime hours at cusp latitudes

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