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DAYTIME AURORAL PRECIPITATION DURING SUBSTORM DEVELOPMENT

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Abstract. The database of DMSP F6 and F7 satellites for 1986 was used to investigate the pre noon (09-12 MLT) auroral precipitation during a substorm. We examined the dynamics of different auroral precipitation boundaries and simultaneous changes in maximum electron precipitation energy and energy flux in different precipitation regions during all substorm phases as well as the IMF and solar wind plasma conditions during a substorm. It was found that precipitation boundaries are shifted to lower latitudes during the growth and expansion phases of substorm and then they are restored to their pre substorm position during substorm recovery. An enhancement of electron fluxes in all precipitation regions (*SDP* - soft diffuse precipitation, *AOP* - auroral oval precipitation and *DAZ* – diffuse auroral zone) begins during the substorm growth phase. The most pronounced enhancement occurs in the *SDP* and *AOP* regions.

Data used and technique of processing

DMSP F7 spacecraft observations in the period from 09 MLT to 12 MLT were used to study auroral precipitation features during the substorm. The substorm phase was determined from 1 minute averaged variations of AE, AL and AU indexes at the time when the satellite encountered the equatorial *CPS* boundary. Magnetic activities were divided into four classes: 0 –magnetically quiet time; 1 - the growth phase of substorm; 2 - the substorm expansion phase; 3 - the recovery phase of substorm; 4 - another type of magnetic activity. The objects of investigation are *CPS, BPS* and *LLBL* boundaries.

Topology of various zones of plasma precipitation in daytime was investigated in /Newell and Meng, 1992,1994/ from the results of DMSP satellite observations. In these papers different types of precipitation regions are distinguished by corresponding magnetospheric domains, such as *CPS* - the central plasma sheet, *BPS* - the boundary plasma sheet, *LLBL* – the low latitudinal boundary layer, etc. However, for the nightside /Newell et al., 1996/ the terminology *b1e*, *b2i*, *b2e, b5e* etc. based on identification of auroral precipitation boundaries is used. Thus auroral precipitation boundaries, revealed by the same satellites for the nightside and the dayside sectors, are not actually coordinated with each other. Starkov et al. /2002/ proposed a new classification, based on comparison of the precipitation and respective auroral luminosity structure. This enables to describe in the same manner the phenomena both in the nighttime and daytime sectors.

The point of the new terminology is as follows. The zone of structured auroral precipitation both in the night- and day- sides is nominated as "precipitations of the auroral oval" (*AOP*, auroral oval precipitation). Since the auroral oval, by definition, is a high latitude zone, at which discrete auroral forms are observed, the auroral oval position should be typically coincident with the zone of *AOP* type precipitations.

The diffuse luminosity band referred to as "a diffuse auroral zone" (*DAZ*, diffuse auroral zone) is associated with structureless precipitations and located equatorward of the *AOP*. To the pole from the auroral oval the high-latitude band of soft electron precipitation nominated as "soft diffuse precipitations" (*SDP*) is located.

In the present paper we present the empirical model of the substorm in the pre noon auroral precipitations. The model includes dynamics of different auroral precipitation boundaries during all substorm phases and simultaneous changes in maximum electron precipitation energy and energy flux in different precipitation regions as well as the IMF and solar wind plasma parameters during substorm.

The dynamics of different auroral precipitation boundaries during substorm in 09-12 MLT sector (a) and 21-24 MLT sector (b) is illustrated in Figure 1. The notations of various auroral precipitation zones (*SDP, AOP, DAZ*) are shown in the right part of the Figure. The substorm, as displayed in the midnight auroral precipitations, was discussed by us earlier /Vorobjev et al., 2002/.

On the horizontal axis of this Figure the active period with unidentified substorm phase (class 4 according to the above classification) is replaced by the magnetically quiet period (class 0). Thus the disturbance being treated corresponds to an averaged isolated substorm. As D_{st} variations in the period examined were insignificant, we consider all the changes in the latitudinal location of the precipitation boundaries and auroral electron characteristics to be caused solely by substorm development. Figure 1 shows that the equatorward precipitation boundaries both in the pre noon (*cps-eq, bps-eq*) and midnight (*b1e, b2e*) sectors move during both the growth and expansion substorm phases to lower latitudes and then, during the recovery phase, return to initial positions, exhibiting good correlation with the AL index. Higher latitude precipitation boundaries (*b5e, b6*) in the nightside sector move equatorward only during the substorm growth phase. During the expansion phase the *b6* boundary returns to its undisturbed position, while the *b5e* boundary moves

about 2° further to the pole as compared to its location during the quiet period. Owing to such a difference in the *b5e* and *b6e* boundary dynamics, the region of soft precipitations between *b5e* and *b6* shrinks sharply during the expansion phase as well as the region of soft daytime precipitation between the *llbl-p* and the *bps-p*. At substorm maximum the polar cap boundary in the nightside (*b6)* and that in the dayside (*llbl-p)* are nearly coincident with the poleward boundary of the statistical auroral oval (*b5e)*
and (*bps-p)*, respectively.

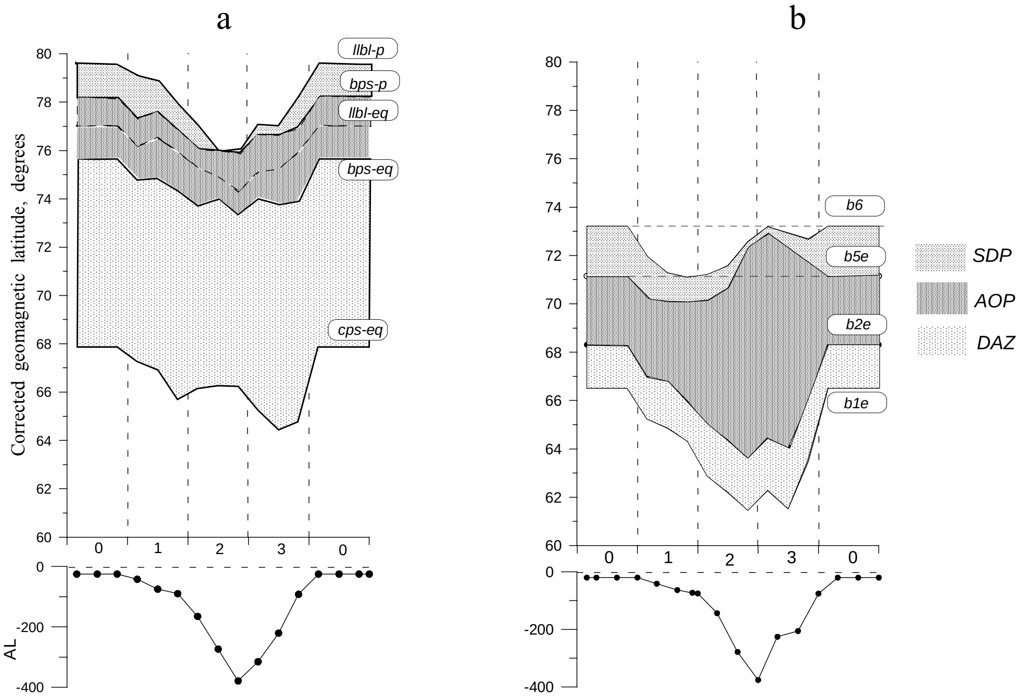

Figure 1: The dynamics of different auroral precipitation boundaries during the substorm in the pre noon 09-12 MLT (a) and pre midnight 21-24 MLT (b) sectors.

The *AOP* zone in Figure 1a is divided by the solid line into two regions: the equatorward one, where only structured precipitations are registered and the poleward one, in which structured precipitations alternate with soft precipitations.

In addition to the auroral precipitation boundary co-ordinates, the DMSP database contains information on maximum and average precipitating electron energy as well as on energy flux in different precipitation regions. Such kind of data are available for the three precipitation regions being considered in the present study: *DAZ* - precipitations equatorward of the auroral oval (diffuse auroral luminosity); *AOP* - precipitations of the auroral oval (auroral oval luminosity); and *SDP* - soft electron precipitation region poleward of the auroral oval. Precipitating electron characteristics in these regions are shown in Figure 2. To compute these characteristics we have distinguished one more time interval in the magnetospheric substorm development, i.e. 1-3 phase. At the 1-3 phase, corresponding to the final stage of the substorm growth phase, we have chosen the satellite passes closest to the substorm onset, the time of which has been estimated as (T_0 - 5)± 5 min. In Figure 2 maximum electron precipitation energy and energy flux are standardized to those corresponding to magnetically quiet conditions, which levels in keV for maximum energy (Em) and in erg/cm^2 s for energy flux (Fm) are shown in the right part of Figures 2a and 2b, respectively. The average electron precipitation energy and energy flux are standardized to those during magnetic quiet time and indicated in brackets.

Figure 2a illustrates variation of maximum electron precipitation energy in different regions during substorm. As seen from the Figure, an increase of energy in the *SDP* and *DAZ* zones begins at substorm growth phase. During this period the energy of precipitating electrons in *AOP* gradually decreases, exhibiting much sharper decrease before the substorm onset. Right after the growth phase, the energy of precipitating electrons in *AOP* sharply increases again and though the energy flux remains rather low, one can expect occurrence of sufficiently bright discrete auroral structures. The energy decrease in two low latitude auroral regions can be related to the fading of both discrete and diffuse auroras before the substorm onset revealed by Zaitseva et al. (1976), Pellinen and Heikkila (1978) and Kornilova et al. (1989).

Figure 2b displays changes of the maximum electron precipitating flux in the same precipitation zones. One can see that during substorm growth phase the maximum energy flux increases in all precipitation regions. The most essential (factor 2-2.5) increase of the flux occurs in the most polar *SDP* and *AOP* zones.

Before the end of the growth phase (T_0-5 min.) and right after the onset of the expansive phase (T_0+5 min.) the energy fluxes sharply decrease in the *AOP* and *DAZ*, and sharply increase in the *SDP*. In the *DAZ* the most essential increase of energy flux occurs during the recovery phase of the substorm. This increase, as well as additional displacement of all zones to lower latitudes, is apparently connected with the occurrence in the dayside of the electrons injected during substorm development in the midnight sector.

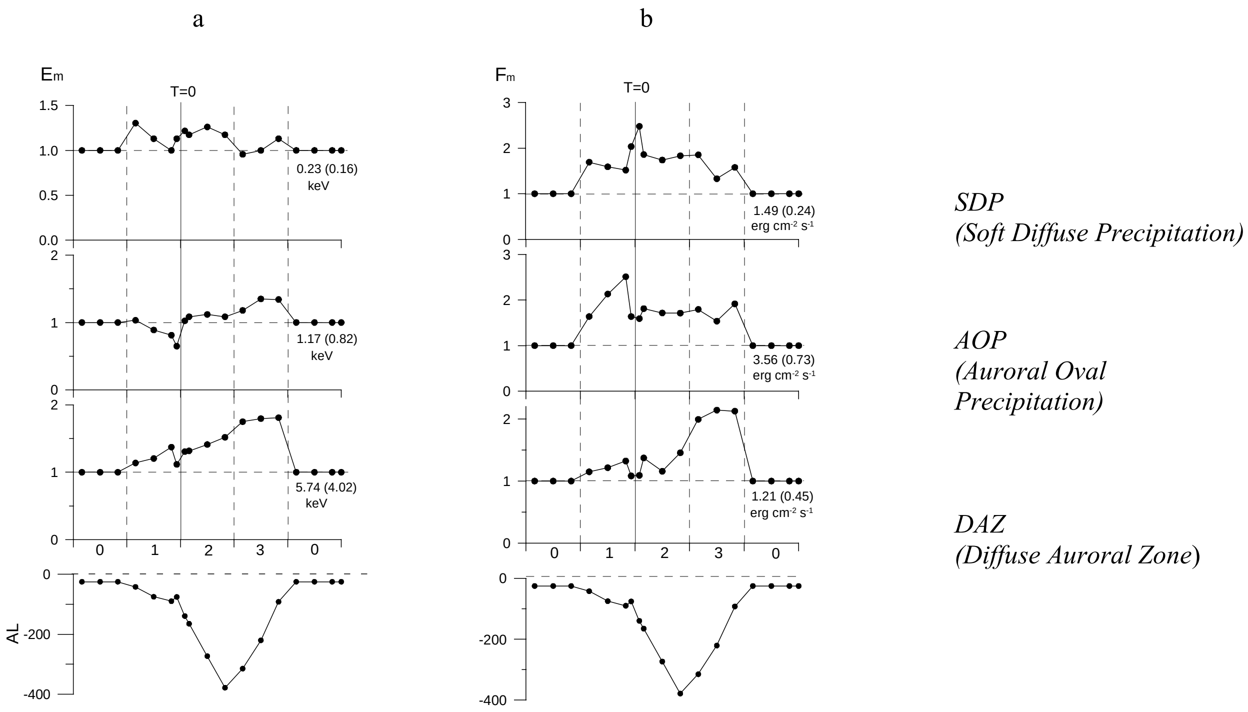

Figure 2: The maximum electron energy (a) and energy precipitation flux (b) in various precipitation regions during the substorm.

Simultaneous decrease of energy (even at maximum it appears to be lower than 1 keV) and energy flux before the substorm onset can result in fading and disappearance of discrete auroras. One can expect a simultaneous slight fading of luminosity in the diffuse auroral zone (*DAZ*) to the equator from discrete auroral forms. Some decrease of both precipitating electron energy and flux is observed here too.

It is interesting that in the *SDP* zone to the pole from discrete auroral forms before the substorm onset there is an increase in energy and fluxes of precipitating electrons similar to that observed in the midnight sector.

Analysis of interplanetary conditions demonstrates that, on the average, the solar wind dynamic pressure is a little bit higher during the substorm than during the magnetically quiet period. In winter substorms were generally observed under positive interplanetary B_y, and in summer they occurred during negative B_y.

Substorms occurred predominantly under southward IMF orientation, with substorm onsets being often not associated with the northward turn of the interplanetary B_z.

Conclusion

DMSP F7 satellite observations for 1986 in the range from 09 to 12 MLT were used to examine auroral precipitation boundary dynamics and precipitating electron features during all substorm phases. The general results can be summarized as follows:

1. An empirical model of the substorm as displayed in the pre noon auroral precipitation is suggested. The model includes dynamics of different electron precipitation boundaries during all substorm phases along with simultaneous changes in maximum electron precipitation energy and energy flux in different precipitation zones as well as IMF and solar wind plasma behavior during substorm.
2. It has been found that the precipitation boundaries shift to lower latitudes during the growth and expansion phases of substorm and then restore to their pre substorm position during substorm recovery. Under magnetically quiet conditions and just before the onset of substorm expansion the latitudinal width of auroral oval precipitation in the pre noon sector is about 2°CGL.

3. An enhancement of electron fluxes in all precipitation regions (*SDP* - soft diffuse precipitation, *AOP* - auroral oval precipitation and *DAZ* – diffuse auroral zone) begins during substorm growth phase. The most pronounced enhancement is observed in the *SDP* and *AOP* regions.
4. For about 5 min prior to the substorm onset a decrease in precipitating electron energy and energy flux in the *AOP* and *DAZ* zones is observed. Simultaneously, an increase in both maximum precipitating electron energy and energy flux is registered in the *SDP* zone.
5. On average, during the substorm the solar wind dynamic pressure is increased by factor 1.5 compared to magnetically quiet time. Substorms occur predominantly under southward IMF orientation, the substorm onset being mostly independent of the northward turn or decrease of the southward interplanetary B_z. For the northern hemisphere in winter, substorms generally occur under positive interplanetary B_y, while in summer they are more frequent when the interplanetary B_y is negative. For the southern hemisphere the opposite situation takes place.

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