DYNAMICS OF THE AURORAL PRECIPITATION ZONES DURING RECURRENT STREAM OF SOLAR WIND

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***Keywords**: solar wind, auroral oval, storms*

***Abstract:** Dynamics of the electron precipitation boundaries during magnetic storms on 19-22 February, 2006 were investigated. The magnetic storm with a minimum in Dst of -40 nT was driven by solar wind high-speed recurrent stream. The locations of auroral precipitation boundaries from DMSP spacecraft observations were compared to those obtained by an empirical model (http://apm.pgia.ru/). In this model the locations of different auroral precipitation regions depend on geomagnetic activity level expressed by the AL- and Dst indices. It is shown a good agreement between the observed with DMSP spacecraft and calculated data for different MLT sectors. This allows us to use the model to examine the dynamics of auroral precipitation during the different intensity magnetic storms. The significant latitudinal displacements of the diffuse auroral zone (DAZ) and the auroral oval precipitation (AOP) along with an increase in magnetic activity were observed. The broadening of zones was more significant in the night sector (21-24 MLT). It has been shown a noon-midnight symmetry, which is controlled by an AL index. On the contrary, any differences in dawn-dusk widening (i.e., asymmetry) of the DAZ and AOP zones were not observed which were demonstrated during magnetic storms associated with solar wind magnetic clouds.*

Introduction

Solar wind is not a uniform flow, various large-scale structures and streams exist within it (e.g. [1]). A part of these non-homogeneities originate in the solar atmosphere, while another part is a result of dynamic processes in the interplanetary medium [2]. The streams and structures in the solar wind could be two types: quasi-stationary and disturbed. Quasy-stationary is the heliospheric current sheet, fast streams from coronal holes, and slow streams from the coronal streamers. To the disturbed type the interplanetary manifestations of coronal mass ejections belong which can include magnetic clouds (MC) and EJECTA (or interplanetary coronal mass ejection). Disturbed structures are also structures generated in the interplanetary medium along solar wind propagation - compression regions in the front of incoming fast recurrent streams (CIR) and magnetic clouds (Sheath) (see for example [3], [4], [5], [6], [7]).

Changes in the interplanetary medium associated with the large-scale structure of the solar wind, and a direct impact on geophysical phenomena are registered on Earth and satellites. However, in the chain: the solar wind - magnetosphere of the Earth - the manifestation of this interaction in the ionosphere, still many gaps exist. For example, the impact of the different streams and structure of the solar wind on the spatial dynamics of precipitation particle zones, in particular, the position of the auroral oval. The influence of individual parameters of the solar wind on the boundaries and distribution of auroral precipitation particle zones is studied since the 70's of the last century (e.g., [8], [9], [10]). But the solar wind parameters were considered separately, without connection with the solar wind streams and structures, which they belong.

Recently the dynamics of auroral precipitation during magnetic storms caused by solar wind magnetic clouds have been studied [11]. It was shown that the planetary pattern of auroral precipitation indicated an asymmetry - different dawn-dusk widening of the diffuse auroral zone (DAZ) and auroral oval precipitation (AOP).

In our work, we will continue to study the effect of different streams of solar wind on the spatial distribution of precipitation zones, namely, the impact of solar wind recurrent streams on the dynamics of particle precipitation. More precisely, the purpose of this study is the investigation of the electron precipitation boundary locations and the creation of planetary pattern of auroral precipitation during the magnetic storms driven by the solar wind recurrent streams.

Data used

To investigate the planetary distribution of auroral precipitation during the magnetic storms with a minimum in Dst - 40 nT on 19-22 February, 2006 the DMSP F13,15,16 observation data (OMNIWeb, http://nssdc.gsfc.noaa.gov), the AL- and Dst- indices (http://swdcdb.kugi.kyoto-u.ac.jp), and the empirical model (http://apm.pgia.ru/) ([10], [12]) were used. The solar wind and interplanetary magnetic field parameters were taken from the WIND satellite (http://cdaweb.gsfc.nasa.gov/cdaweb/istp_public/).

The model (http://apm.pgia.ru/) used here allows us to construct the planetary distribution (geomagnetic latitude - local geomagnetic time) of different types of auroral precipitation depending on the level of the geomagnetic activity determined by AL and Dst indices. The following classification of the regions of electron penetrations suggested by Starkov et al. [13]) was used in our paper:

DAZ (diffuse auroral zone) is the region of diffuse precipitation, located equatorward of auroral oval and spatially coincided with a zone of diffuse aurora. This is the zone of hard electron precipitation formed by the electrons injected into the near-Earth region on the night side and then drifted around the Earth. The typical energy of electrons here exceeds 1 keV.

AOP (auroral oval precipitation) is the region of structured precipitation, whose equatorward boundary spatially coincides with the equatorial border of the oval.

SDP (soft diffuse precipitation) is the region of soft diffuse precipitation poleward of the AOP region.

Recurrent streams are determined as high-speed streams, which reappear in each solar rotation, thus giving 27-days periodicity in the occurrence of these streams. The recurrent streams are characterized by an increased solar wind velocity (> 500 km/s), and lower (than the average) density; the duration of these streams is ~ 3-4 days. In front of the recurrent stream there is a region of the interaction with slower streams (CIR). CIR is determined as a region with a magnetic field and plasma compression.

In this work we present an event connected with the magnetic storm caused by the solar wind recurrent stream – the event on 19-22 February, 2006.

Results

1) Comparison of the model and observed with DMSP satellites precipitation boundaries

We investigated the locations of auroral precipitation boundaries from DMSP F13, 15, 16 spacecraft and compared them with those obtained by an empirical model. Results are presented in Figure 1.

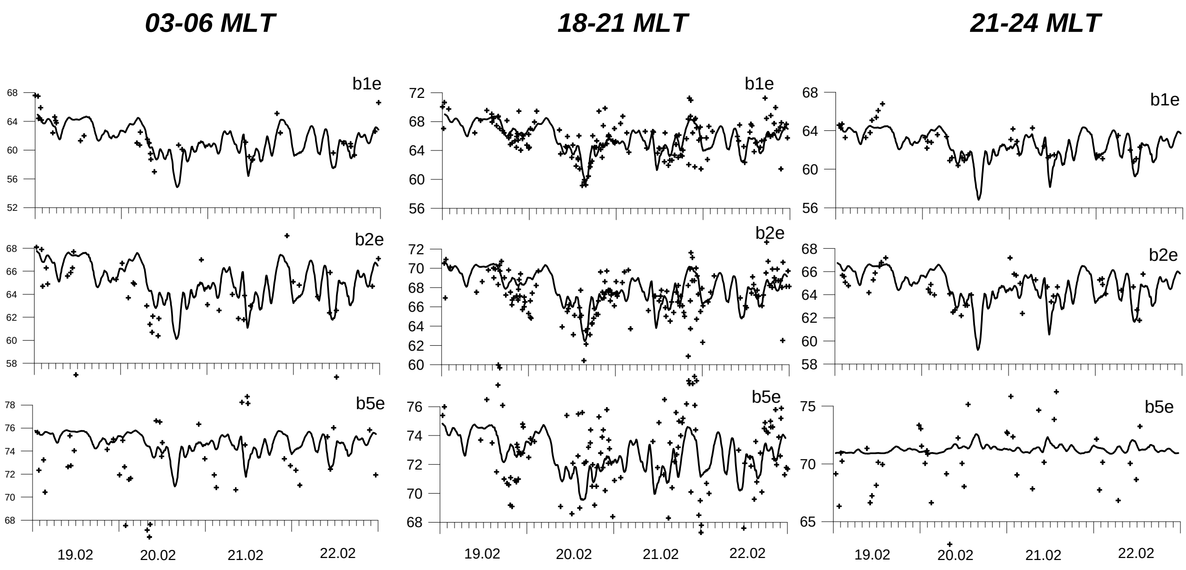


Fig. 1. Dynamics of the precipitation boundaries in the morning (03-06), evening (18-21) and night (21-24) MLTs. The solid lines indicate the model positions of b1e (DAZeq), b2e (AOPeq), b5e (AOPpol); the symbol (+) marks the boundary locations observed with the spacecraft DMSP-F13,15,16.

Figure 1 illustrates the precipitation characteristics in the morning-evening-night sectors (03-06 MLT on the left panels, 18-21 MLT on the middle panels and 21-24 MLT on the right panels). From top to bottom the variations in the position of b1e - the equatorward boundaries of the zone of diffuse auroral precipitation (DAZ); of b2e - the equatorward boundary of auroral oval precipitation (AOP eq); of b5e - the poleward boundary of auroral oval precipitation (AOPpol) are shown. The solid lines show the dynamics of the calculated boundary, the marks show the satellite DMSP F13, F15 and F16 observations of the boundaries investigated. As seen from Figure 1 the boundary positions observed by the satellite experience considerable latitudinal variations at adjacent experimental points. Although the discrepancies between the experimental and calculated precipitation characteristics are sometimes considerable, the model calculations are generally in a good agreement with the experiment.

2) Global distribution of auroral precipitation on February 19-22, 2006

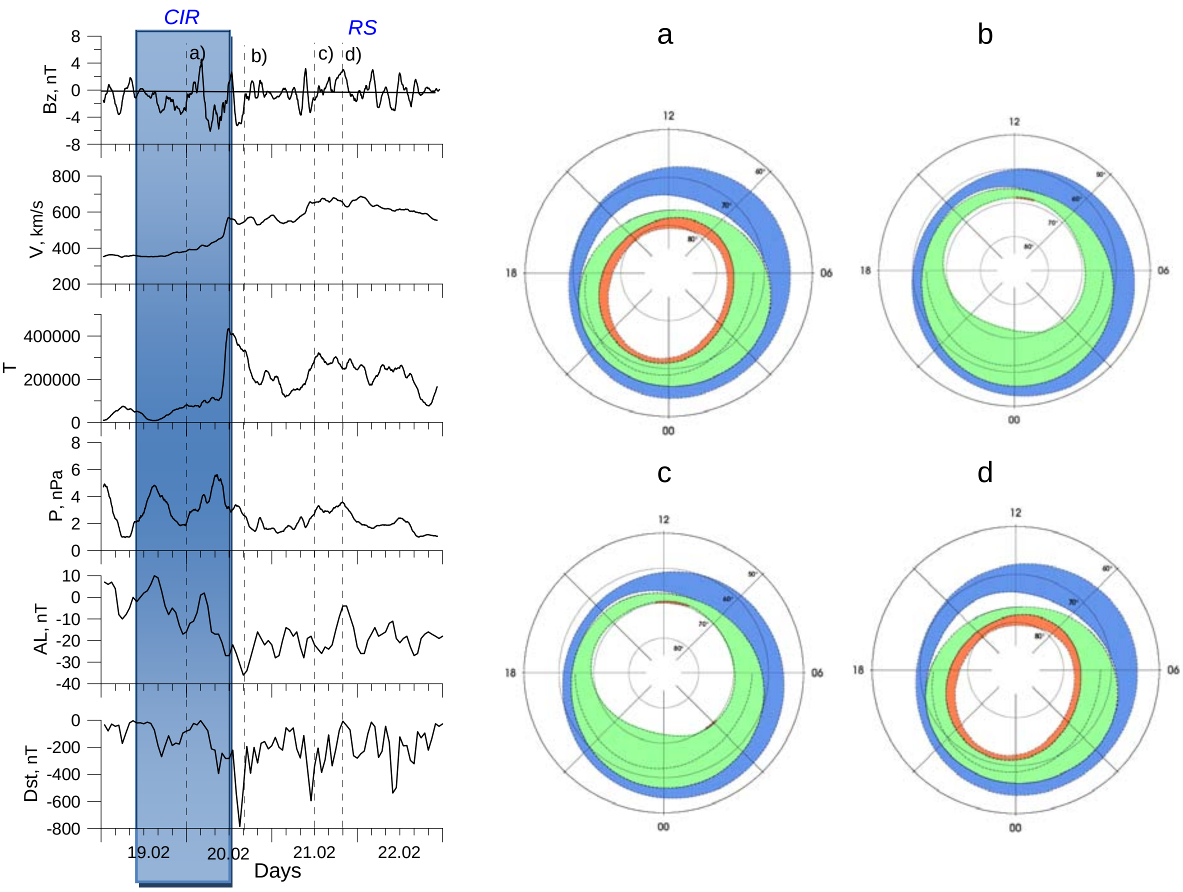


Fig. 2. On the left panel - the solar wind conditions and the indices of geomagnetic activity (AL and Dst indices) during the storm on 19-22 February, 2006; on the right panel - the dynamics of the global precipitation for four intervals marked by the dashed black lines ((a), (b), (c), and (d)).

In Figure 2 (left panel) the solar wind conditions and the indices of geomagnetic activity during the storm on 19-22 February, 2006 are shown. From top to bottom Bz-component IMF, solar wind velocity, temperature and dynamic pressure from OMNI database are presented. Two bottom panels show the values of indices of magnetic activity (AL and Dst indices). The recurrent stream is characterized by a higher solar wind velocity (V > 500 km/s) and lower pressure (density) (than the average); the duration of these streams is ~ 3-4 days (Pudovkin, 1996). In front of the recurrent stream there is a region of the interaction with slower streams (CIR). CIR is determined as a region with the magnetic field and plasma compression (Balogh et al., 1999). The CIR was registered from 11 UT on 19 February to 12 UT on 20 February; the blue region shows the time of CIR. After CIR, a solar wind recurrent stream was monitored; recurrent stream was observed from 12 UT on 20 February to 12 UT on 23 February. This recurrent stream caused a magnetic storm; the magnetic storm was initiated at ~ 20 UT on 19 February when the CIR region reached the magnetosphere. During this storm the AL- and SYMNH indices (1 min data) were -1400 nT and -40 nT, accordingly.

Figure 2 (right panel) illustrates the global pattern of auroral precipitation in the CGL – MLAT coordinates during the storm. The dashed black lines mark the four intervals - (a), (b), (c), and (d) during different magnetic storm phases, for which the planetary distributions are shown. In the model calculations, the 1-hour indices of magnetic activity (AL and Dst) were used.

From Figure 2 we can see a significant displacement to lower latitudes of the auroral precipitation and a change in the size (the broadening) of the precipitation zones with an increase magnetic activity. The broadening is more significant in the night sector (21-24 MLT). Max displacement and widening of AOP and DAZ are visible in 15:40 UT on 20 February (great values of Dst and AL, (b) picture).

3) The size of widening of AOP (a) and DAZ (b) in the morning (03-06 MLT), the evening (18-21 MLT) and the night (21-24 MLT) sectors

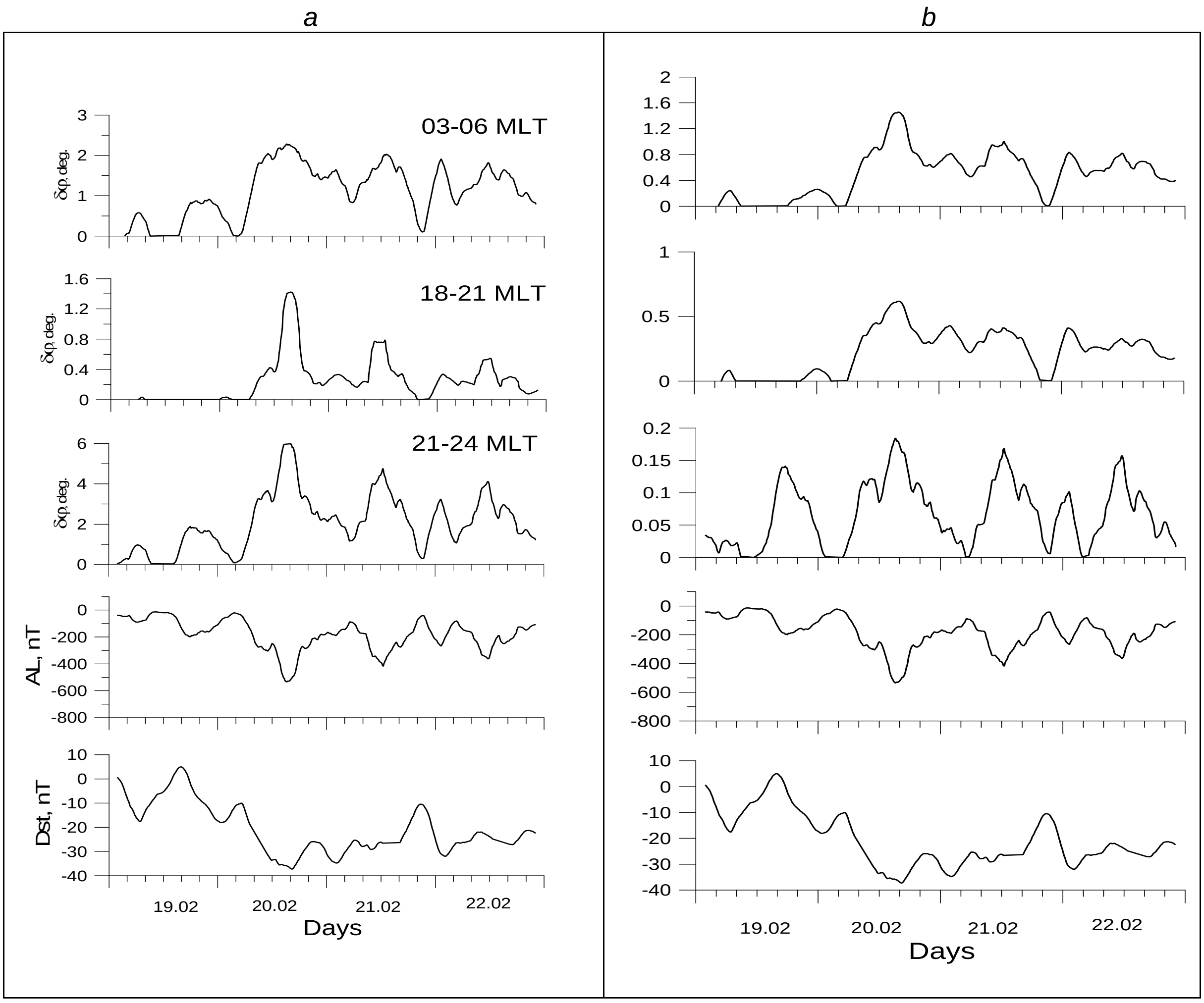


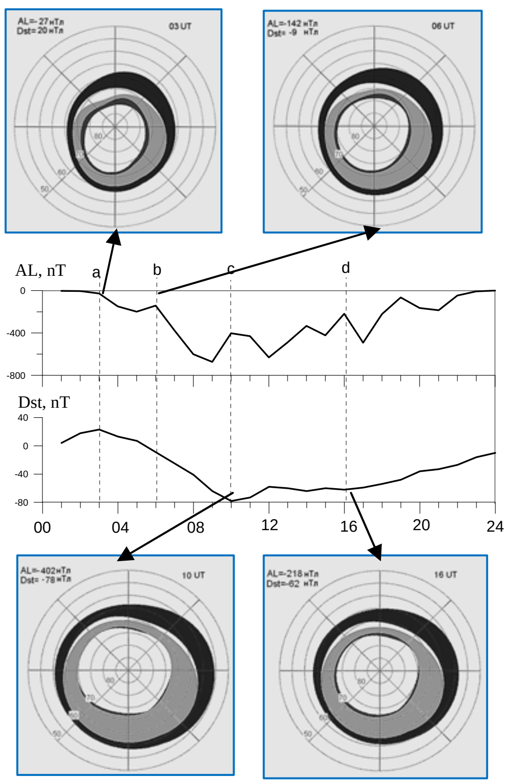
Fig. 3. Latitudinal sizes of AOP (a) and DAZ (b) in the three MLT sectors; two bottom panels show the variations of AL and Dst indices.

In Figure 3 the changes in the size of precipitation zones AOP (a) and DAZ (b) in the morning (03-06 MLT), evening (18-21 MLT) and night (21-24 MLT) sectors are presented in detail. On two bottom panels of the Figures the AL and Dst indices of the magnetic activity are shown. All the curves were smoothed using a running average for clarity.

As we can see the maximum widening of the AOP is about 6^0 CGL for the night sector, about 1.6^0 CGL for the evening sector and about 2.5^0 CGL for the morning sector. Figure shows the width of AOP in the night and evening sectors is controlled by the AL index; the width of AOP in the morning sector is controlled by the Dst index. The width of DAZ in all sectors does not change significantly. The width of DAZ in the morning and evening sectors appears to be controlled by the Dst index; the width of DAZ in the night sector is controlled by the AL index.

4) Comparison of dynamics of AOP and DAZ for storms caused by the solar wind magnetic clouds and the recurrent stream

Recently the auroral precipitation boundary dynamics during magnetic storms caused by solar wind magnetic clouds have been studied and the global pattern of auroral precipitation during three magnetic storms of different intensity have been created on the basis of the empirical model (APM). Three magnetic storms (weak, moderate and strong) were examined. It is shown that there is a significant displacement to lower latitudes of the diffuse auroral zone (DAZ) and the auroral oval precipitation (AOP) in the morning and evening sectors during the main phase of the storm. The authors found that the planetary pattern of auroral precipitation showed the morning – evening asymmetry. To illustrate these results and indicate the different behavior of the precipitation boundaries during the magnetic storms driven by the different sources we present Figure 4 (Figure taken from [11]). Figure 4 demonstrates the global pattern of the auroral precipitation in CGL – MLAT coordinates and the indices of the geomagnetic activity for the weak magnetic storm on 10-11 January, 1997. The dashed lines point four intervals - the calm (a), the growth (b), and the expansive (c) and the recovery (d) magnetic storm phases for which the planetary distributions are shown. Max displacement and asymmetry are visible in 01 UT (great values of Dst and AL). From the left panel of Figure 4 it is seen the significant displacement to the lower latitudes of auroral precipitation zones and the change of their sizes along with an increase in the magnetic activity. From the right panel one can see that the planetary pattern of auroral precipitation indicates different dawn-dusk widening of DAZ and AOP (asymmetry). For all the events considered by Yagodkina et. al. [11] the following conclusions were made: (1) the width of the DAZ does not change in the evening sector and it extended up to 9^0 in the morning sector during the strong storm; (2) the AOP region expands differently in two sectors for the storms of different intensity. For the moderate and strong storms, the AOP region expansion was observed in both sectors, and for the weak storm a significant expansion occurred only in the evening sector.



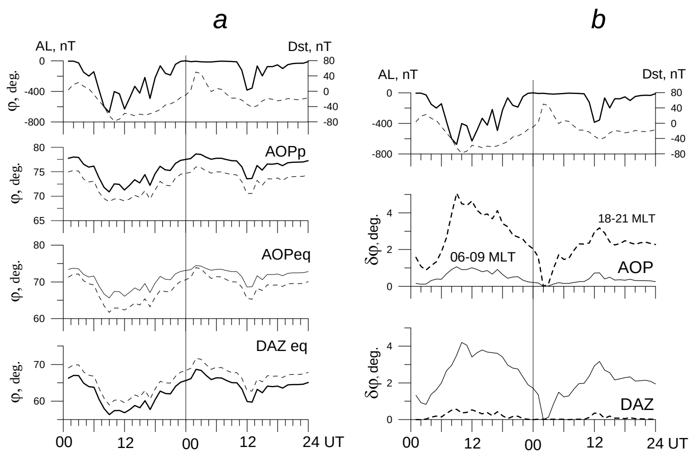


Fig. 4. On the left panel - global distribution of auroral precipitation during the storm on 10-11 January, 1997 caused by a magnetic cloud; on the right panel - the boundary displacements (a) and changes of the size of AOP and DAZ (b) in the morning (06-09 MLT –solid lines) and in the evening (18-21 MLT – dashed lines) sectors. (Figures taken from Yagodkina et. al., [11])

Thus, we see that there are differences in the dynamics of AOP and DAZ for the storms caused by the recurrent stream and for the storms caused by the magnetic cloud.

From Figure 2 and Figure 3 it is seen that with an increase in the magnetic activity and in the intensity of the storm there observed a widening of the AOP and DAZ regions. The strongest widening of AOP was observed in the night sector; the value of the expansion of AOP in the evening and night sectors was controlled by the AL index. It is shown that during the recurrent stream the symmetry in the precipitation particle was observed along the noon – midnight meridian, and there was no dawn-dusk asymmetry, which is the characteristic of the storm caused by a magnetic cloud.

Conclusions

The present study presents the model pattern of the global auroral precipitation during the magnetic storm driven by the recurrent stream (namely CIR- storm). The auroral boundary positions in the morning (03-06 MLT), in the evening (18-21 MLT) and in the night (21-24 MLT) sectors were considered in detail for two different auroral regions: the diffuse auroral zone (DAZ) and the structured auroral oval precipitation (AOP).

The following conclusions were made:

1) Model calculations describe well the dynamics of precipitation boundaries observed by DMSP satellites. This makes it possible to describe the situation of recurrent streams using the model calculations.

2) It was found that, with an increase in magnetic activity, both zones move to lower latitudes in a regular fashion and we observe their broadening. The broadening is more significant for the night sector (21-24 MLT).

3) It is shown that during the magnetic storm driven by the recurrent stream there is noon-midnight symmetry of auroral precipitation, On the contrary, during the storms associated with the magnetic clouds there is a dawn-dusk asymmetry.

*Acknowledgements***.** The paper was supported by the RFBR Grants 12-05-01030, 12-05 -00273 and Program No 22 of the Presidium of the Russian Academy of Sciences (RAS) “Fundamental problems of the Solar system exploration”.

The study is part of a joint Russian - Bulgarian Project “The influence of solar activity and solar wind streams on the magnetospheric disturbances, particle precipitations and auroral emissions” of PGI RAS and IKIT-BAS under the Fundamental Space Research Program between RAS and BAS.

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