Spatial Distribution of the Auroral Precipitation During Magnetic Cloud on 10 January 1997

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The dynamics of the electron precipitation boundaries was examined using the DMSP satellite data and empirical model in which the boundary location depends on the geomagnetic disturbance level expressed by the AL- and Dst indices. The solar wind parameters were defined by Wind satellite data. The planetary pattern of the auroral precipitation for event on 10-11 January 1997 was studied. The magnetic storm with the maximum intensity in the Dst index of -80 nT was driven by interplanetary magnetic cloud. A typically long-lasting, steady depression of the Dst index was characteristic for this event. An analysis of the planetary distribution of auroral precipitation demonstrates that the width of auroral oval precipitation in the morning – evening sectors depends on the Dst index value and the latitudinal displacement of all precipitating boundaries is controlled by the AL index. It is shown that during long-lasting steady depressed Dst index maximum shift of precipitation boundaries occurs in the morning – evening sectors.

Introduction

It is known that the solar wind flow can vary depend on the state of the solar activity. Thus, during a solar minimum, the recurrent streams (RS) originating from coronal magnetic holes, characterized by a 27-day recurrence, are predominant [1,2]. During a solar maximum, most common are the sporadic flows associated with coronal mass ejections (CME) ([3]). Near the Earth they are observed as magnetic clouds (MC) (e.g. [4]). It should be noted that magnetic clouds are one of sources of geomagnetic storms (e.g. [5]). During storm the sharply variations of solar wind parameters and geomagnetic field are accompanied by the intensifications of auroral precipitation in high latitude ionosphere. The location of the auroral oval and characteristics of the auroral precipitation within it are main elements in definition of a state of the magnetosphere.

In the paper [6] the analytical expressions relating the precipitation boundaries to magnetic disturbances during which the Dst and AL values did not exceed 150 and 1000 nT for all 3-hour sectors of the local magnetic time (MLT) were reported. This model was tested on events in which the level of magnetic distributions was higher than indicated above. So, the auroral precipitation dynamics in the night-time and day-time sectors during strong magnetic storms on 08-09 February, 1986 and on 13-14 March, 1989 with maximum Dst=–300 nT and Dst=–600 nT respectively was investigated [7]. Feldstein et al. [8] used these analytic expressions for investigation of the precipitation boundary locations during the magnetic storm on 24-27 September, 1998 with maximal Dst value about -207 nT. For all investigated events a enough good agreement of the calculated locations of precipitation boundaries with DMSP satellites observations were obtained. Thus, the obtained analytical expressions for determination of precipitation boundary positions in different MLT sectors allow us to construct the planetary distribution of auroral precipitation during the storms of different intensity.

Aim of this study is the investigation of the electron precipitation boundaries and the creation of planetary pattern of auroral precipitation during magnetic storm driven by the magnetic cloud. The magnetic storm with a minimum in Dst of - 80 nT on 10 January, 1997 was under investigation. During this event a typically long-lasting, steady depression of the Dst index was characteristic. We investigated the locations of auroral precipitation boundaries from DMSP F10, F12 and F13 spacecraft data and compared to those obtained by means of empirical model [6], in which the location of the boundaries depends on the magnetic activity expressed by AL and Dst indices.

Data

To investigate the planetary distribution of auroral precipitation during the strong magnetic storms the DMSP F10, F12 and F13 observations and empirical model [6] were used. In this model the different auroral precipitation regions were determined by the statistical treatment of DMSP observations according to the geomagnetic activity level expressed by the AL- and Dst indices. The boundary locations in the morning and evening MLT sectors were studied. The classification of the regions of electron penetrations suggested by Starkov et al. [9] was used in our paper and is presented in Figure 1. Three zones of electron precipitations are determined:

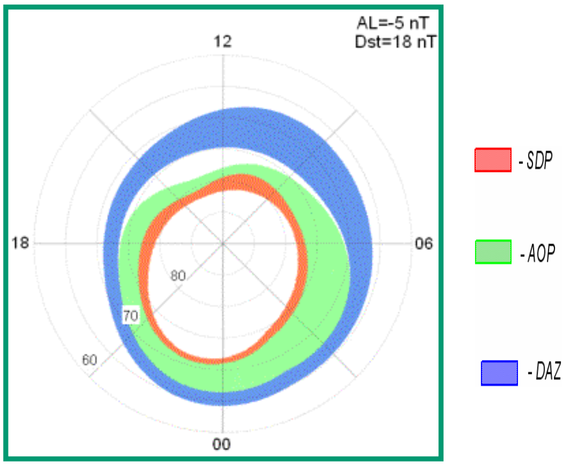


Figure 1. The determination of three zones of auroral precipitations; SDP, AOP and DAZ

1) DAZ - diffuse auroral zone, coinciding with the diffuse aurora. This is the zone of hard electron precipitations formed by the electrons injected into the near-Earth region on the night side and then drifted around the Earth. A typical energy of electrons here exceeds than 1 keV.

2) AOP - auroral oval precipitation, coinciding with the statistical discrete auroral oval. This is a region of softer precipitations with average electron energy below 1 keV. Here electron temperature is about 300 eV and the spectrum of electrons is structured both spatially and spectrally.

3) SDP - soft diffuse precipitation. This is the high-latitude band of soft electron precipitations. Average electron temperatures are usually lower than 200 eV.

The solar wind and interplanetary magnetic field parameters were taken from the WIND satellite (SWE and MFI data with 1 minute resolution were used). The solar wind and interplanetary magnetic field (IMF) parameters for MC on 10 January, 1997 are shown in Figure 2.

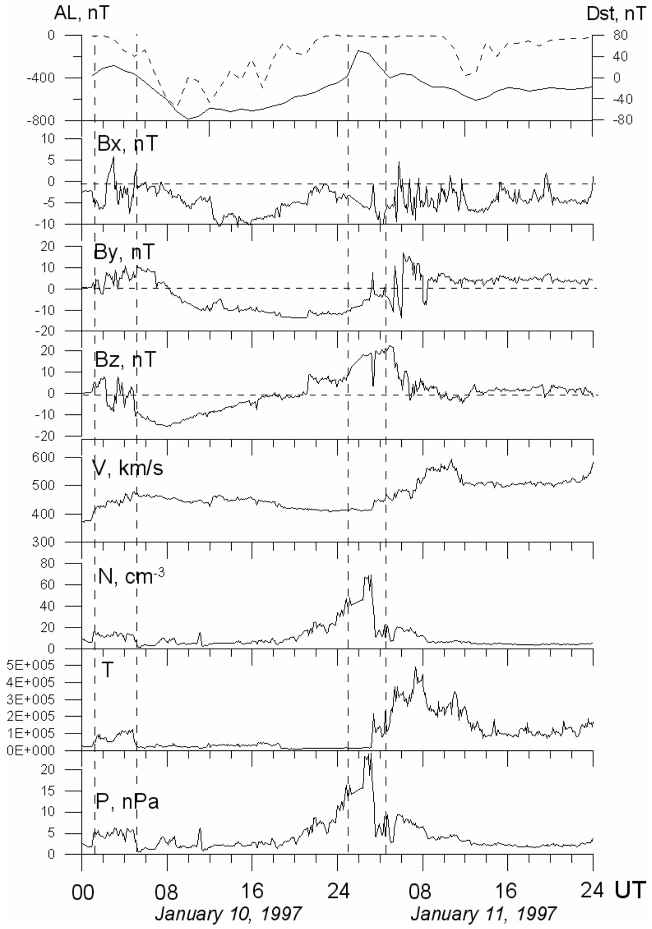


Figure 2. Solar wind, IMF parameters and geomagnetic activity on January 10-11, 1997

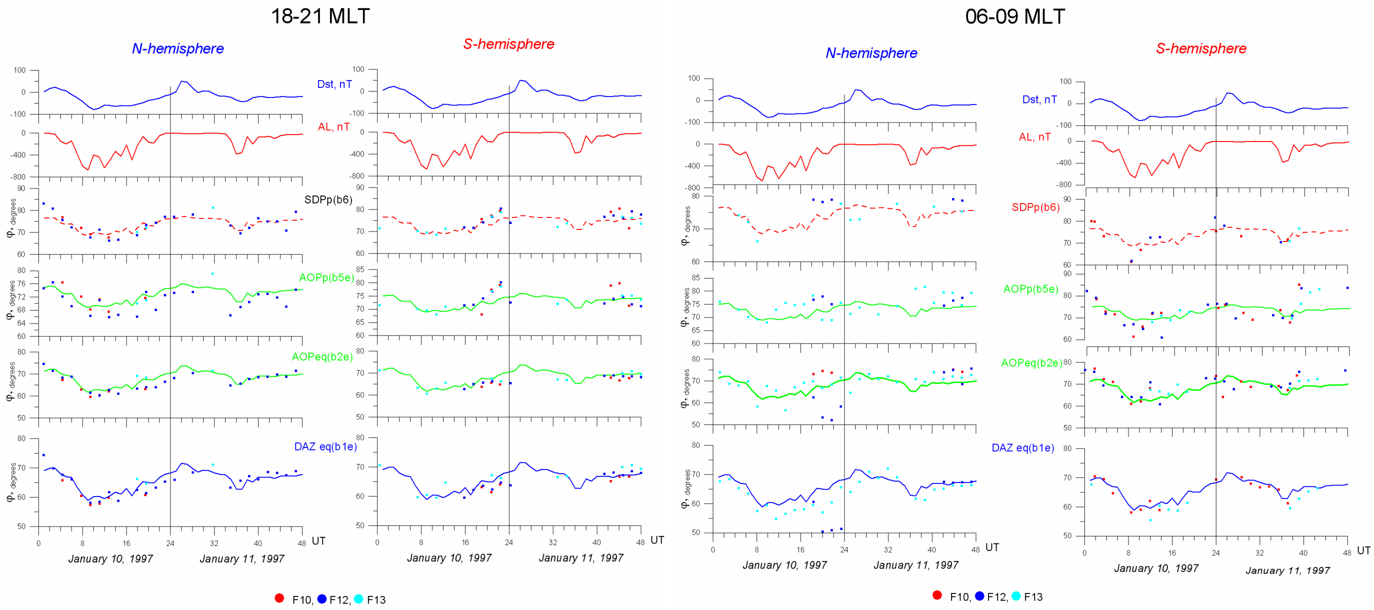
From top to bottom the AL- and Dst-indices, the magnetic field components (B_X, B_Y, B_Z), the solar wind velocity, density, temperature and dynamic pressure from WIND spacecraft are shown. The shock onset was registered at 01.29 UT. The magnetic cloud existed from about 05.40 UT to about 01 UT January 11. Inside the magnetic cloud B_Y and B_Z components slowly rotated. To the end of the magnetic cloud IMF B_Z was positive. Ahead of MC, the region of interaction with undisturbed solar wind (Sheath) is known to form, which is characterized by high density, increased pressure and strong IMF variability. The vertical dashed lines show the time of Sheath region which was during from 01.29 UT to 05.40 UT on 10 January. In the Sheath region the IMF components were variable. After magnetic cloud the solar wind recurrent stream was monitored. The recurrent streams are characterized by increased solar wind velocity ($V_x > 500$ km/s), and the lower (than the average) density; the duration of these streams is ~ 3-4 days (e.g., [3]). In front of the recurrent stream there is a region of the interaction with slower streams (CIR). CIR is determined as a region with magnetic field and plasma compression [10]. The CIR was registered from 01 to 05 UT on 11 January; the vertical dashed lines show the time of CIR. The solar wind dynamic pressure within CIR was large and reached 20 nPa and the B_Z reached 20 nT and then sharply decreased after 06 UT on 11 January.

In this period two storms are observed: the first stronger storm was on 10 January and the second weak storm was 11 January. The first storm initiated at 05.40 UT when the Sheath- region reached the magnetosphere. During this storm the AL- and Dst indices were -600 nT and -80 nT, accordingly. The second storm initiated when solar wind velocity rose up to 600 km/s during recurrent stream. The value of AL-index was -400 nT and atypically long-lasting, steady depression of the Dst index was characteristic for this period.

Results

In Figure 3 dynamics of the precipitation boundaries in the N- and S- hemispheres for the evening (a) and morning (b) MLT sectors is shown. The top panels showed the variations of AL- and Dst indices on 10-11 January 1997. We have considered following boundaries of precipitations: the poleward boundary of soft diffuse precipitation (SDP) which coincides with the polar cap boundary; the poleward boundary of auroral oval precipitation (AOPp), the equatorward boundary of auroral oval precipitation (AOPeq) and the equatorward boundary of the diffuse auroral precipitation (DAZeq). Universal time is presented along the horizontal axis; the latitudes (φ°, CGLAT) of the auroral precipitation boundaries are shown along the vertical axis. The lines show the calculated from the model the values of the boundary positions; points show the satellite DMSP F10, F12 and F13data.

As seen from Fig. 3, the maximum equatorward displacements of electron precipitation zones are observed during main phase of the storm. The observed by the satellites the boundary positions experience considerable latitudinal variations at adjacent experimental points. For time interval from 01 UT to 10 UT on January 11 the spacecraft observations are absent. Although the discrepancies between the experimental and calculated precipitation characteristics are sometimes considerable, the model calculations are generally rather good agreement with the experiment.



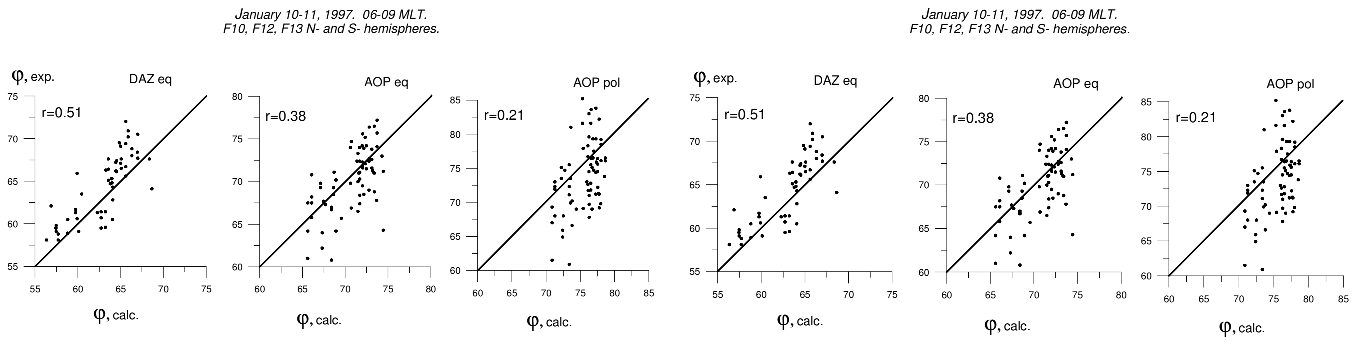
a) **b)**

Figure 3. Dynamics of the precipitation boundaries obtained from DMSP data and calculated from the model for the evening (a) and morning (b) MLT sectors in the N- and S- hemispheres.

Figure 4 shows the relation between the experimental and calculated locations of boundaries in the morning 06-09 MLT (a) and in the evening 18-21 MLT (b) sectors. The registered by the satellite (Φ´exp) the latitudes of the boundaries are represented on the vertical axis. The latitudes of these boundaries calculated from analytical expressions are shown along the horizontal axis (Φ´calc). DAZeq and AOPeq correspond to the equatorial boundaries of zones, and AOPp corresponds to the poleward boundary of aurora oval precipitation region.

In the Figure the solid lines correspond to the equality in the position of the boundaries (Φ´exp = Φ´calc). The coefficients of correlation between the calculated and experimental values are shown for each boundary.

The global pattern of the auroral precipitation in CGL – MLAT coordinates for three time intervals 02-03, 09-10 and 15-16 UT during the magnetic storm is shown in Figure 5. For its creation the empirical model of the auroral precipitation was applied. In the calculations the 1-hour values of the magnetic activity (AL and Dst indices) were used. In the bottom part of Figure the magnetic activity variations are displayed. The vertical solid lines note the intervals for which the global patterns are constructed.



a) **b)**

Figure 4. The correlation between the experimental and the calculated boundaries on January 10-11, 1997

As can see from the Figure the growth (a), expansive (b) and recovery (c) storm phases were under investigation. It is seen the significant displacement to lower latitudes the diffuse auroral zone (DAZ) and the auroral oval precipitation region (AOP) along with the increase of magnetic activity. In the main phase of the storm (maximum of the magnetic activity) the region of the soft auroral precipitation (SDP) located poleward the AOP disappears. During the event the change of the size of the precipitating zones is registered. The width of the evening sector (18-21 MLT) DAZ precipitation does not change significantly while in the morning sector (06-09 MLT) the width of the DAZ increases. The AOP region displays the opposite pattern: weak widening of the precipitation in the morning and expansion of the structured precipitation in the evening sector. The width of the DAZ and AOP regions depends on Dst variations course. The planetary pattern of auroral precipitation shows morning – evening asymmetry in the auroral precipitation.

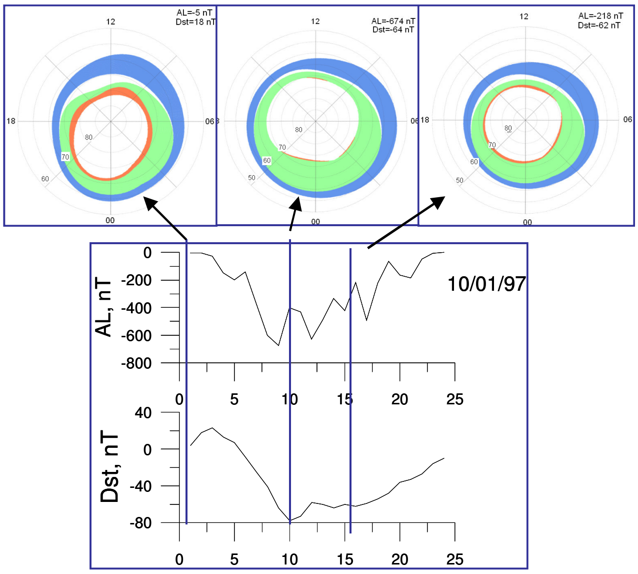


Figure 5. The planetary distribution of auroral precipitation during onset, main phase and recovery phase of storm

In paper [11] it was shown that during this event the particle injections occur simultaneously at all MLTs. And we can see a global auroral reaction in the magnetic storm driven by the magnetic cloud. Thus, from the planetary pattern of auroral precipitation one can see the morning–evening asymmetry: expansion of the width zones in the morning sector and their narrowing in the evening.

Conclusion and discussion

We used the empirical model for study auroral precipitation during magnetic cloud on 10 January 1997. The AL- and Dst-indices of magnetic activity were used to construct the planetary pattern of precipitation for event under investigation. The following conclusions were made:

•Comparisons between the precipitation boundary position observed by DMSP and the calculated precipitation characteristics show a good correlation.

•An analysis of the planetary distribution during MC- storm indicated the equatorward displacement of electron precipitation boundaries. It was shown the change of the width of the DAZ and AOP regions depending on the magnetic activity increase.

•The latitudinal sizes of AOP and DAZ are controlled much more strongly by the Dst variations than the AL index value and the latitudinal shift of boundary positions depends on the AL index course more strongly.

It is known that the configuration of the geomagnetic tail considerably changes under storm conditions. As shown by [11] the storm-time geomagnetic tail is more stretched in this condition. Authors considered MC on 22 October 2001 and showed that an intense thin current sheet are formed and occupied a wider MLT sector of the near Earth tail. This configuration of current sheet can explain the different "geometry" of auroral bulges during MC obtained in paper [12]. The auroral oval is confined in latitude and extended in longitude during MC. We consider that configuration of magnetotail during MC-storms is displayed in dynamic of precipitation zones as morning – evening asymmetry.

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