Development of Substorm Bulges During Storms of Different Interplanetary Origins

Despirak I.V.[1], Lubchich A.A.[1], Guineva V.[2]

[1]. Polar Geophysical Institute, Apatity, Russia, despirak@pgia.ru
[2]. Solar-Terrestrial Influences Institute, Stara Zagora, Bulgaria, v_guineva@yahoo.com

Different structures in solar wind are observed depending on the type of solar activity: magnetic clouds (MC), recurrent streams (RS), and regions of their interaction with undisturbed solar wind (Sheath and CIR). Three of these structures, namely, Sheath, CIR, and MC, are the sources of geomagnetic storms. Furthermore, the storms originating from these three sources differ in intensity, recovery phase duration, etc. We have searched for distinctions in the development of substorm bulges occurring during geomagnetic storms connected with the MC, Sheath and CIR. Solar wind parameters were taken from the Wind spacecraft observations and the auroral bulge parameters were obtained by data from the Ultra Violet Imager onboard Polar. We determined the longitudinal and latitudinal dimensions of the auroral bulges, the poleward aurora propagation and the onset latitude of auroral bulge. It is shown that auroral bulges "geometry" is different for these types of storms. The largest sizes of auroral bulge are found for CIR- and Sheath-storms situations. The latitudinal size of the auroral bulge during MC-storms is smaller, but the longitudinal size is larger. As consequence, the ratio between longitudinal and latitudinal sizes for substorms during MC is also larger. We suggest this latter feature is explained by different configuration of the near-Earth magnetotail during CIR- and MC-storms.

Introduction

It is known that the solar wind flow can vary depending 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]). 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 increased solar wind velocity (Vx > 500 km/s), and 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 [4]. During a solar maximum, most common are the sporadic flows associated with coronal mass ejections (CME) ([5]). Near the Earth they are observed as magnetic clouds (MC) (e.g. [6]). The magnetic clouds (MC) are characterized as regions, where the magnetic field strength is higher than the average, the density is relatively low, the magnetic pressure strongly exceeds the ion thermal pressure, the magnetic field direction changes through the cloud by rotating parallel to a plane which is highly inclined with respect to the ecliptic [6]. 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.

Recently, in paper [7] considered substorm bulge development against a background of magnetic clouds (MC), recurrent streams (RS), and regions of their interaction with undisturbed solar wind (Sheath and CIR). It is shown that the auroral bulge "geometry" differs for substorms occurring during the recurrent streams and magnetic clouds. This is evidenced by difference in the ratio of auroral bulge longitudinal and latitudinal dimensions. In particular, during MC conditions the auroral bulge is confined in latitude and extended in longitude. Authors relate this to storm-like configuration of the near-Earth magnetotail.

On the other hand, different types of solar wind mainly generate the storms: ICME including Sheath- region and body of ICME (magnetic cloud, MC) and CIR- region (e.g. [8], [9]). There are differences between storms generated by Sheath, MC and CIR (in intensity, recovery phase duration, etc.) (e.g., [10], [11], [12]). It is important to understand the difference in substorm bulge development during storms of different interplanetary origins, to find the answers to the following questions: Is the difference in auroral bulge development, described in [7], observed for all storms, or only for storms generated by MC? In this study, we are investigating the distinctions in the development of substorms bulges occurring during geomagnetic storms connected with MC, Sheath and CIR.

Data

The auroral bulge development is studied by Polar UVI data in the LBHL band (1600-1800 Å). The luminosity of the UV aurora is divided into 25 intervals according to $I = I_0 \cdot 10^{\Delta \cdot n}$, where $\mathbf{I_0}$ ~ 3.2 photons*cm^{-2}*s^{-1}, $\mathbf{\Delta} = 0.1$, and **n** is the interval number. A background level of the auroral oval luminosity for every considered substorm was determined as the luminosity observed before the substorm onset at the onset meridian. Typically, under relatively quiet (non-storm) conditions, this corresponds to level of the photon flux of 10-25 photons*cm^{-2}*s^{-1}. However, under storm-time conditions the selected level for the auroral bulge determination can reach up to 200 photons*cm^{-2}*s^{-1}. As assumed, the storms and substorms are different magnetospheric/ionospheric dynamical processes (e.g., [9]). If a substorm occurs during the storm time, it has the same typical signatures as a substorm developing during non-storm conditions. Namely, on the Polar UVI auroral images one can see: (1) the burst of luminous spot, (2) expansion of spot to the pole and in longitude, and (3) decay of spot. The development of the substorm bulge during the storm time has the same time scale as "usual" substorms, i.e., from 10 min up to an hour. Therefore we will determine the parameters of auroral bulge during storm-time conditions in the same way as for "usual" substorms, of course, taking into account the higher background level of the auroral oval luminosity during storm-time conditions.

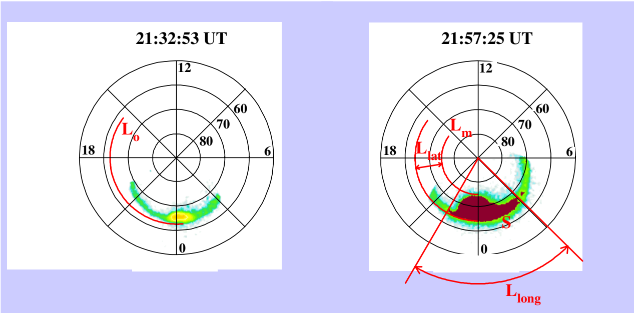

Figure 1. The determination of auroral bulge parameters

At the chosen level of luminosity, we found the onset (L_O) and maximum (L_m) expansion latitudes, as well as the latitudinal (L_{lat}) and longitudinal (L_{long}) sizes of the bulge. The onset latitude was defined as the latitude of luminous spot at the moment of substorm onset, while the maximum latitude of the bulge was considered to be the latitude of bulge polar edge at the moment of maximum substorm development.

The solar wind and interplanetary magnetic field parameters were taken from the WIND satellite (SWE and MFI data with 1 minute resolution were used). All auroral substorms observed by Polar during 12 MCs and 6 recurrent streams for the year 2000, in October 2001, December 1996 and from January to July 1997 were studied.

Results

In Fig. 2 examples of auroral bulge development during a CIR-storm and a Sheath-storm are shown. The top panel of the picture shows the auroral bulge development by Polar UVI data. The bottom panel displays the Dst index value, the times of substorms observation by Polar satellite during Sheath and CIR structures are indicated by vertical lines. The top panel of Fig.2 presents the events of substorm development during the CIR of 28 February 1997 (2a) and during the Sheath of 17 September 2000 (2b). These examples refer to the "high latitudinal" substorms, for which the poleward edge of the auroral bulge propagated up to very high latitudes (~80° CGLAT). For the event of 28 February 1997 (2a) the onset latitude L_o of the bulge was 55.3° CGLAT; the maximal latitude L_m was 82.3 ° CGLAT; the ratio between the longitudinal and the latitudinal sizes L_d/L_F was equal to ~ 8.8. For the event of 17 September 2000 (2b) the onset latitude L_o was 56.67° CGLAT; the maximal latitude L_m was 80.3 ° CGLAT; the ratio between the longitudinal and the latitudinal sizes L_d/L_F was equal to ~ 9.33. Substorms developed under high values of solar wind parameters (Vx -585 km/s, -705.3 km/s; Bz ~ -5.5 nT, -12.5 nTl). The CIR- and Sheath- associated substorms were observed during the storm main phase (Dst ~-85, Dst ~-200). In Fig. 3 examples of auroral bulge development during the MC-storm of 22 October 2001 are shown. The left picture shows the Dst index value, the vertical lines indicate the times of substorm observations by Polar, in the right panel of the picture the auroral bulge development by Polar UVI data during the MC is presented.

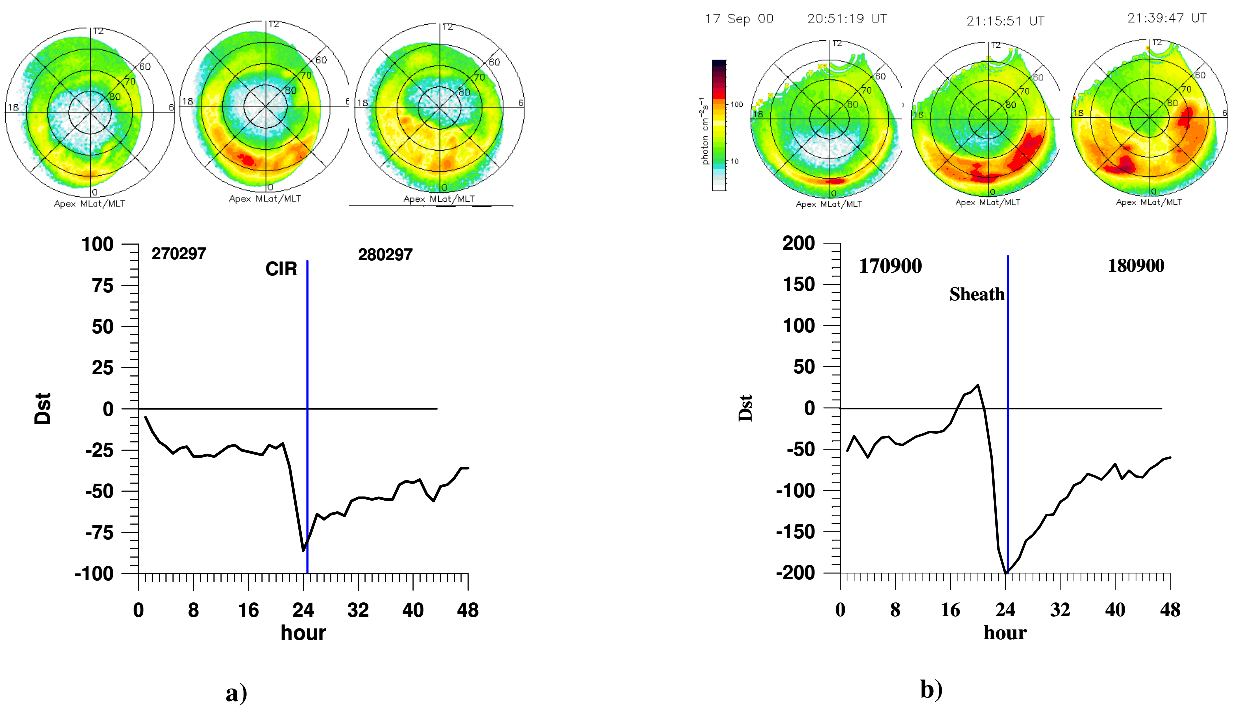

Figure 2.The top panels show examples of substorm development by Polar UVI data and the bottom panels display the Dst index during the CIR-storm (2a) and during Sheath-storm (2b).

It is shown that the auroral bulge was formed at very low geomagnetic latitudes during MC. The onset latitudes (L_o) for the three examples presented in Fig.3 were 56.7º CGLAT, 53º CGLAT and 54.7º CGLAT, respectively. The maximal latitudes (L_m) were 72.3º CGLAT, 73º CGLAT and 66º CGLAT; the ratio between the longitudinal and the latitudinal sizes L_d/L_F was equal to ~ 11.4, 12.4 and 9.9, respectively. The substorms were observed during the storm main phase (Dst ~-140, -135, -160). The substorms developed under high values of solar wind parameters (Vx ~ 551; -530; -525 km/s; Bz ~ -6.7; --9.3; -3.5 nT). As it is seen from Fig.2 and Fig.3, the latitudinal and longitudinal dimensions of the auroral bulge of substorms, occurred during MC-storm and during CIR- and Sheath-storm, are different. The auroral bulges of substorms observed during MC are, in average, wider in longitude and narrower in latitude than those related to CIR and Sheath.

This difference is manifested more clearly in Fig.4, where these dimensions are compared. Here are presented the median values of latitudinal and longitudinal sizes, first and third quartiles of their distributions. On the top panel, one can see the bulge sizes for the substorms during MCs, CIRs and Sheaths, on the bottom panel – the ratio of longitudinal to latitudinal bulge sizes.

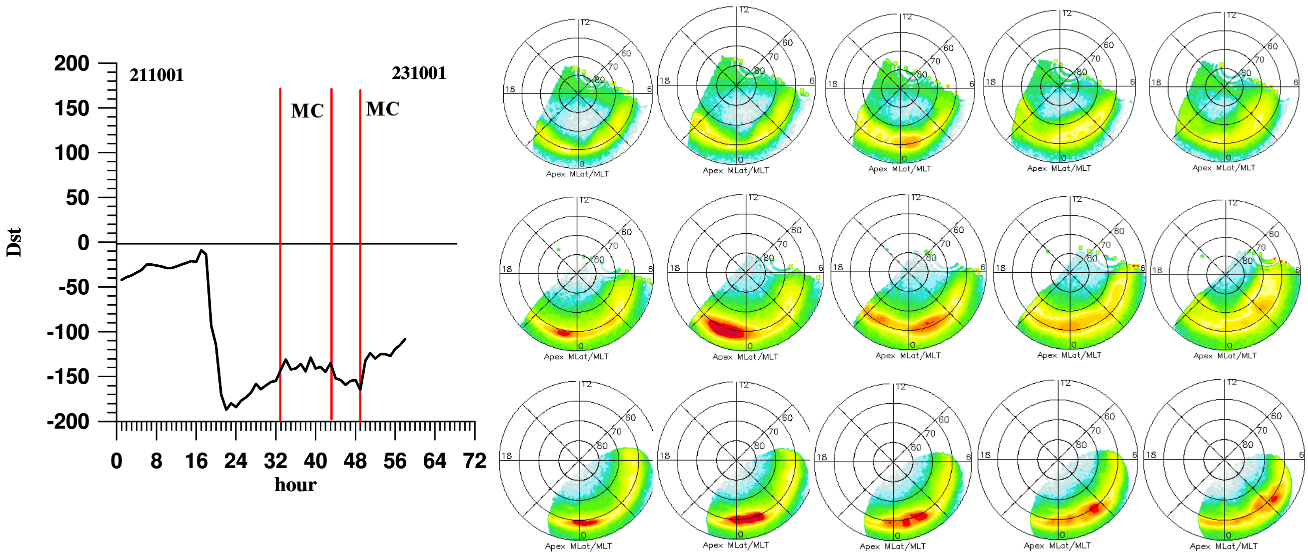

Figure 3.Eexamples of substorm development by Polar UVI data during MC- storm (right panel) and the Dst index (left panel). Vertical lines indicate the times of substorm observations by Polar.

As it is seen from Fig. 4, the auroral bulge sizes are maximal for substorms during Sheath and CIR. At the same time, the ratio of longitudinal to latitudinal sizes is maximal for substorms during MC, the averaged value of relationship being higher for MC –associated substorms.

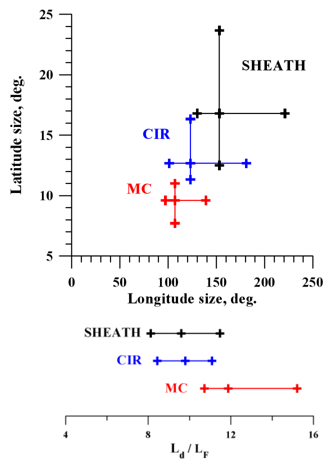

Figure 4. The median values, first and third quartiles of distribution of the sizes of the bulge for MC, CIR and Sheath (top panel). The bottom panel presents the ratio of longitudinal to latitudinal sizes.

Discussion and conclusions

It is shown that during MC-storms and during CIR- and Sheath-storms the substorm behaviour differs. This is evidenced by the difference in the auroral bulge longitudinal and latitudinal dimensions. The ratio of longitudinal to latitudinal dimensions of the bulge during MC-storms is rather stable and always higher than the one during CIR- and Sheath-storms. The area of the auroral bulges associated with Sheath- and CIR-storms is the largest. Such bulges are most extended in both latitude and longitude. Perhaps, this is due to the influence of the compressed, highly dense solar wind plasma [13]. The auroral bulge area can be considered as a measure of the magnetic flux dissipated in the magnetotail during substorm and also as a measure of energy dissipation both in the magnetotail and the ionosphere [14]. Hence one can expect that larger dissipated flux and also larger energy dissipation in the magnetotail must occur during substorms associated with Sheath and CIR than during substorms in the course of MC when the input energy and driving are largest. This result is in accordance with the conclusion of the recent paper [15]. In this paper, the solar wind – magnetosphere coupling efficiency as response to the solar wind dynamic pressure impulses was investigated. It was shown, that the magnetosphere uses the energy of a weaker driver more efficiently, whereas during the stronger drivers the energy is more inefficiently used. However, the consideration of this effect is beyond the scope of the present paper and requires further investigations.

During MC- storms the auroral bulge is confined in latitude and extended in longitude. However this effect is not observed during substorms occurring during CIR- storms.The reason for such different ‘geometry’ in the development of the auroral bulge may be in different configuration of the geomagnetic tail. The configuration of the geomagnetic tail strongly changes under storm conditions. As it was shown in [16], the storm-time geomagnetic tail is more stretched. In [16] the substorms occurred during the passage of MC on 22 October 2001 were considered and it was shown that under MC-associated storms, an intense thin current sheet forms that occupies a wider MLT sector of the near Earth tail. The magnetic field lines are highly elongated in the tail not only in the night sector, but also in the evening and morning sectors. This means, that there is an intensive current sheet near the Earth in a wide longitudinal area. The formation of an intense thin current sheet provides favorable conditions for driving magnetic reconnection in this region, which may be a cause of substorm (e.g., [14]). Therefore, the substorm can develop in a wider longitudinal sector, and for energy dissipation not needed the propagating far down the magnetospheric tail, i.e. along latitude.

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