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THE INFLUENCE OF HIGH-SPEED SOLAR WIND STREAMS ON THE AURORAL BULGE PARAMETERS

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Abstract

In the present paper we investigate the difference of characteristics of the auroral bulge developing during substorms related to the CME and recurrent high-speed streams. It is shown that the CME related substorms start at lower latitudes in comparison with the substorms during the recurrent streams. The longitudinal dimension of the auroral bulge is larger, but latitudinal dimension is smaller for the CME-related substorms. The influence of the solar wind parameters (solar wind velocity, V, and southward component of interplanetary magnetic field, Bs) on the bulge development is different. During the recurrent streams, the larger are V and Bs the higher is the maximal latitude of the auroral bulge. During CME the increase of V and Bs leads to decrease of the substorm maximal latitude. We suggest that these features can be explained by the different configuration of the magnetotail during solar wind streams of different nature. The results are in agreement with some earlier studies, which demonstrate that preferable conditions for the substorms to appear at very high latitudes are the recurrent high-speed solar wind streams occurred at declining stage and minimum of the solar activity cycle.

Introduction

The high-speed streams in the solar wind are associated with the recurrent streams from coronal magnetic holes and with the flare streams connected with coronal mass ejections (CME) (e.g., *Krieger et al., 1973; Burlaga et al., 1982; Pudovkin, 1996*). During solar cycle minimum the recurrent streams are typical, while during solar cycle maximum the streams connected with CME prevail (*Wang and Sheeley, 1994; Webb and Howard, 1994*). The high-speed streams contribute up to 80% of geomagnetic activity (as measured by *aa*-index) through the solar cycle. The recurrent high-speed streams contribute ~70% of *aa* outside of solar maximum and ~30% at solar maximum. CME-related structures account for ~50% of *aa* at solar maximum and <10% outside of maximum (*Richardson et al., 2000*).

Magnetospheric substorms are an important contributor to the geomagnetic activity. During the expansion phase of substorm the auroral bulge propagate poleward (*Akasofu, 1964*). In some events this propagation may be continued from auroral zone up to very high latitudes (CGLat >75-80°). Some authors relate the expansion of auroras to high latitudes with the high velocity (V) of the solar wind and strong southward component of the interplanetary magnetic field (Bs) *(Gussenhoven,, 1982; Dmitrieva and Sergeev, 1984; Weatherwax et al., 1997; Zverev et al., 1979*). It was also shown that such "high-latitudinal" substorms occur more frequently during the solar cycle minimum *(Dmitrieva and Sergeev, 1984; Despirak et al., 2007)*, and they correlate with the solar wind recurrent streams *(Sergeev et al., 1979)*. The reason why the "high-latitudinal" substorms are rare at solar cycle maximum (in spite of the CME-related high-speed streams) remains unclear.

The purpose of this paper is to investigate of how the solar wind streams from different sources, including the high-speed streams, affect the substorm expansion (namely, on the auroral bulge development). For this purpose the optical observations substorm development from the Polar satellite are compared with the interplanetary medium parameters from the Wind satellite.

Data

The auroral bulge development was studied on the basis of the Polar UVI data in LBHL band (1600-1800 Å). To distinguish from the background (non-substorm) luminosity, the auroral bulge was determined at the level above the background for 3-5 photons*cm^{-2}*s^{-1}. Typically, this criterion corresponded to level of the photon flux of 10-25 photons*cm^{-2}*s^{-1}. On the chosen level of luminosity the onset and maximal latitudes as well as latitudinal and longitudinal sizes of the bulge were defined. The onset latitude of bulge was determined as the latitude of the low boundary of the luminosity spot at the moment of substorm onset; the maximal latitude of the bulge as the maximal latitude of the bulge poleward edge in the course of the substorm development.

We suggest that the auroral bulge area relates to the magnetic flux and energy supplied in the magnetotail (e.g., *Yahnin et al., 2006a*). The flux/energy inflow is determined by the solar wind/IMF parameters. As a measure of the solar wind/IMF influence, averages of V and Bs for the two-hour interval before the maximal stage of the substorm development were chosen. Such averaging interval was selected since the solar wind/IMF parameters control the flux/energy inflow into the magnetosphere during both growth phase and expansion phase of the substorm. The 1-minute resolution solar wind and IMF parameters were revealed from the SWE and MFI instrument data onboard the WIND satellite.

The recurrent streams are characterized by a few days duration, increased solar wind velocity ($V_X > 500$ km/s), relatively low plasma density (*Pudovkin, 1996*). We selected all substorms (31 events, for which the Polar satellite data were available) during passage of the high-speed (recurrent) streams of December 1996.

Coronal mass ejections (CME) are associated with magnetic clouds in solar wind (for example, *Burlaga et al., 1982; Klein et al., 1982*). The magnetic clouds are characterized by the enhanced magnetic field strength, relatively low plasma density, the high ratio of magnetic and 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 (*Burlaga et al., 1982*).

In front of the magnetic cloud there is the region of the interaction with undisturbed solar wind. This region is characterized by increases pressure, temperature, and density of solar wind. The interplanetary magnetic field in this region is large and very fluctuated.

The list of the magnetic clouds was taken from http://lepmfi.gsfc.nasa.gov/mfi/mag_cloud_pub1.html. All available auroral substorms observed by Polar during CME for the year 2000 (20 events) were divided into two groups:

1) substorms observed during the passage of the magnetic cloud (12 events) and

2) substorms observed during the passage of the region of the interaction of CME with undisturbed solar wind (8 events).

Results

In Figure 1a the example of the auroral bulge development during the passage of the recurrent stream of 11 December 1996 is presented. This is an example of the "high-latitudinal" substorm; the poleward edge of the auroral bulge was observed at 77.3° CGLAT. The latitudinal size of this bulge was ~ 16°, and the longitudinal size was some 80°.

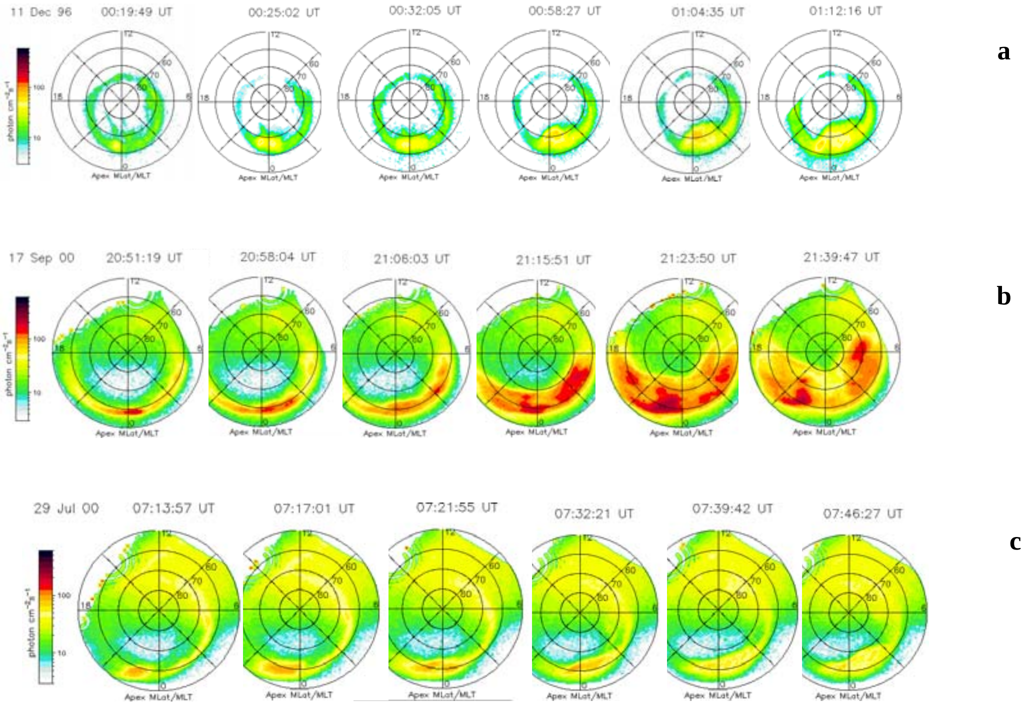

Figure 1. Examples of substorm development during the passage of the recurrent stream (**a**), region of the interaction of CME with undisturbed solar wind (**b**), and magnetic cloud (**c**).

Figure 1b show the example of auroral bulge development during the passage of the interaction region of 17 September 2000. During this event the poleward edge of the auroral bulge prorogated up to very high latitude (~80° CGLAT); this is also the example of the "high-latitudinal" substorm. The latitudinal size was ~ 22°, the longitudinal size was 221°.

Figure 1c presents the example of the auroral bulge development during the magnetic cloud passage of 29 July 2000. The maximal latitude of bulge was 69.0° CGLAT, the latitudinal size was ~ 8°, the longitudinal size was 107°.

The dependences of the onset and maximal latitudes of the auroral bulge on solar wind parameters are shown in

Figure 2. At the left (right) column the dependences on B_S (Vx) is shown.

The upper (bottom) panel of Figure 2 shows the dependencies for recurrent (magnetic cloud related) streams. The middle panel represents the dependencies for the CME/undisturbed solar wind interaction region. In the bottom the dependencies are shown for the magnetic cloud related streams. It is seen that the substorms (both onset and maximal latitude) during high-speed recurrent streams develop at higher latitudes in comparison with those related to the magnetic clouds. During the recurrent streams the maximal latitude of the auroral bulge increases with the increase of the B_S and V_X, while the onset latitude decreases. In contrast, during the magnetic cloud passage the maximal latitude of the bulge does not increase and even tends to decreases. The onset latitude also decreases.

The dependences on Bs and Vx for the situation of the interaction region passage look similar to those for the recurrent streams. Besides, the “high-latitudinal" substorms can be also observed during such intervals.

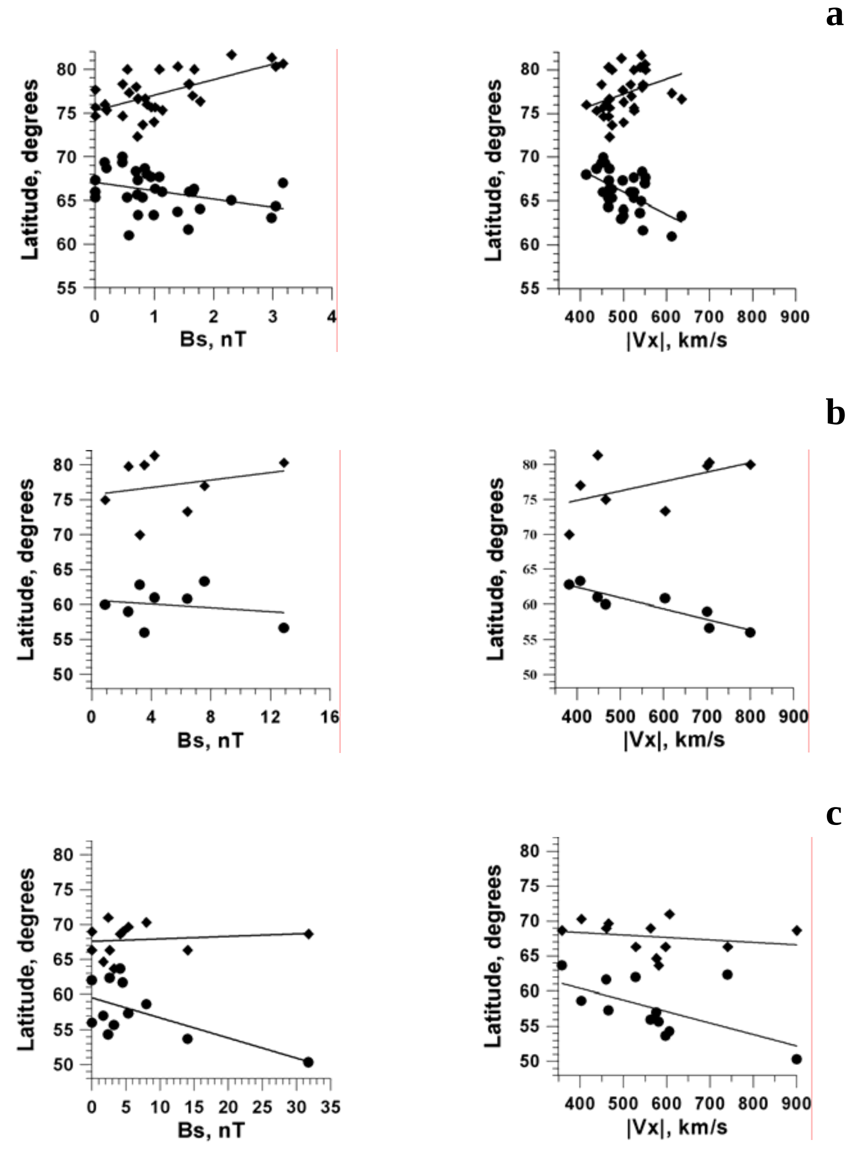

Figure 2. The dependences of the auroral bulge onset and maximal latitudes on solar wind parameters during the passage of the recurrent streams (**a**), the regions of interaction of CME with undisturbed solar wind (**b**), and the magnetic clouds (**c**).

Let us compare the latitude and longitude dimensions of the auroral bulge of substorms occurred during different solar wind streams. At the upper (bottom) panel of Figure 3 the dimensions are presented for the conditions of the recurrent (magnetic cloud) streams. In Figure 3 the sizes are indicated for every available substorm. Solid (dashed) vertical lines show the average (median) values of bulge sizes. For the conditions of the recurrent currents the latitudinal size of the aurora bulge is, in average, larger than for conditions of the magnetic clouds. Opposite relationship holds true for longitudinal sizes; the average value is higher for the magnetic cloud conditions.

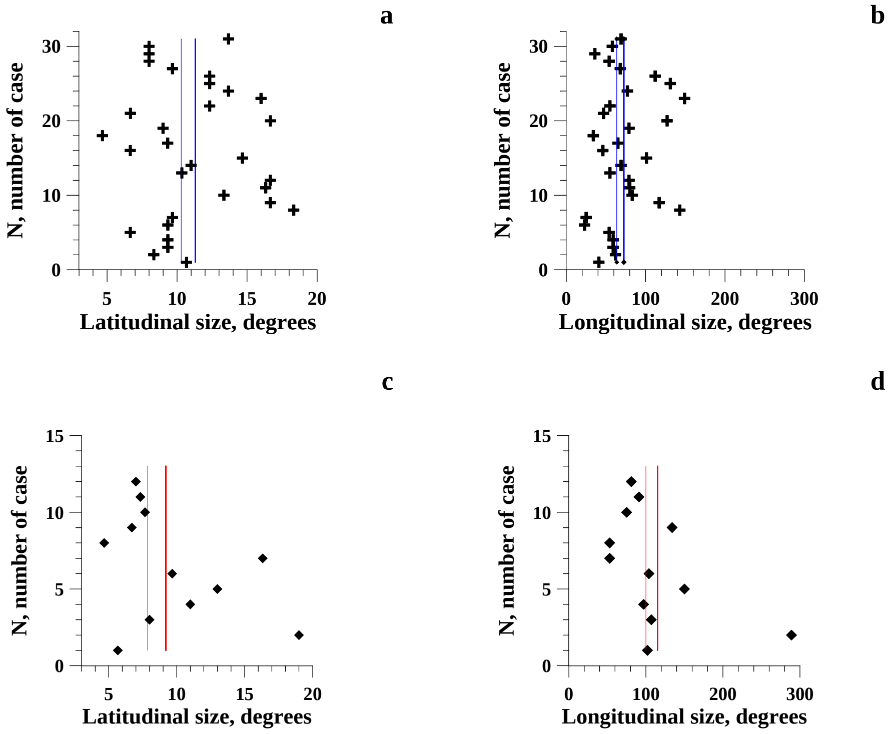

Figure 3. The latitudinal (**a** and **c**) and longitudinal (**b** and **d**) sizes of the auroral bulge during the recurrent streams (**a** and **b**) and magnetic clouds (**c** and **d**) passage.

Discussion

On the basis of comparison of auroral observations from the Polar satellite with data from the Geotail spacecraft in the magnetotail, *Yahnin et al. (2006b)* concluded that poleward edge of the auroral bulge map onto the vicinity of the near-Earth neutral line. This means that the reconnected magnetic flux in the magnetotail is equal to the flux through the auroral bulge, that is, proportional to the auroral bulge area. *Shukhtina et al. (2005)* demonstrated that reconnected flux is equal to that accumulated in the tail before the substorm expansion onset. In turn, the accumulated flux is proportional to the merging electric field. Thus, one can expect that under the same conditions in the interplanetary medium the auroral bulge area is the same independently on the solar cycle stage. Indeed, *Yahnin et al. (2004)* showed that under the same values of the merging electric field and Bs, the auroral bulge area is approximately the same during both solar cycle minimum and maximum.

During the magnetic cloud conditions the substorms start at lower latitudes comparing with recurrent streams (Fig. 2, see also *Yahnin et al. (2004), Gerard et al. (2004)* who noted the same for the conditions of the solar cycle maximum and minimum, respectively). This fact along with the equality of the auroral bulge area under the same Bs and V could explain the lack of the “high-latitudinal” substroms during magnetic clouds in comparison with recurrent streams. However, those magnetic clouds associated with extremely large Bs, which are not typical for recurrent streams, are expected to have much larger bulge area. It is not clear *a priory* why such bulges remain at low latitudes.

Figure 3 can shed a light on this problem. It shows that the substorms related to the magnetic clouds are, in average, wider in longitude and less in latitude than those related to recurrent streams. In addition, we found that for magnetic clouds the ratio of latitudinal and longitudinal dimensions of the bulge is rather stable and always less than that for recurrent streams (not shown). In other words, during the magnetic cloud conditions the bulge of the greater area has a relatively small latitudinal size because it is more extended along longitude.

The reason can be in the configuration of the magnetotail. The magnetic clouds are usually associated with magnetic storms (for example, *Wilson, 1987*). The magnetotail configuration during the storms differs from that during non-storm intervals. The magnetotail is more stretched during the storm time (e.g. *Pulkkinen et al., 1996*) and the intense and thin current sheet (conditions suitable for reconnection) occupies a wide (wider than during non-storm time) MLT sector of the near-Earth tail. As consequence, during CME/storm intervals reconnection develops in the wider region. This prevents expansion of the auroras to the high latitudes.

The “high-latitudinal" substorms can be observed during passage of the CME/quite solar wind interaction region. However, this does not significantly affect on the general occurrence of the “high-latitudinal" substorms during solar maximum conditions (*Despirak et al., 2007*) since the duration of such intervals is small in comparison with the duration of the magnetic clouds.

Conclusion

Thus, our results suggest that preferable conditions for the substorms to appear at very high latitudes are the recurrent high-speed solar wind streams typically occurring at declining stage and minimum of the solar activity cycle. The lack of “high-latitudinal" substorms during the magnetic cloud events (mainly related to the solar cycle maximum) is, probably, due to more stretched configuration of the near-Earth magnetotail under such conditions. This is in agreement with the behavior of the magnetotail stretching in the course of the solar cycle found by *Yahnina et al. (2005).*

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