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RELATIONSHIP BETWEEN THE AURORAL BULGE AREA IN THE IONOSPHERE AND TOTAL PRESSURE DECREASE IN THE MAGNETOTAIL

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Introduction

The substorm explosive phase is characterized by formation of the auroral bulge in the night-side ionosphere (*Akasofu, 1964).* In the magnetosphere the explosive phase is associated with numerous processes, one of those is the formation of the near-Earth neutral line (NENL) where reconnection takes place (e.g., *Baker et al. (1996)).* Reconnection results in fast plasma flows from the NENL toward the Earth and toward the tail. On the basis of simultaneous observations onboard Polar and Geotail spacecraft, *Yahnin et al. (2005)* has recently shown that a spacecraft within the Earthward plasma flow has its ionospheric footprint within the auroral bulge, while a spacecraft within the tailward flux has the projection poleward of the bulge poleward edge. This has been interpreted as the evidence for the conjunction of the reconnection site and the poleward edge of the substorm auroras. If so, the auroral bulge area is proportional to the reconnected magnetic flux. This, indeed, has been confirmed by *Yahnin et al. (2004) and Shukhtina et al., (2005),* who demonstrated that the flux through the bulge is in average equal to the flux accumulated in the tail during the growth phase. Thus, the area of the auroral bulge is a parameter characterizing the substorm intensity in terms of the magnetic flux dissipation.

Along with magnetic flux dissipation, the substorm is characterized by the dissipation of magnetic energy in the tail lobes. A measure for magnetic energy (more correctly, for the energy density) is the magnetic pressure $B^2/2\mu_0$ (B is the magnetic field in the tail lobe) or, according to the pressure balance, the total pressure (that is, the sum of magnetic and kinetic pressure) in the plasma sheet. As known, the magnetic pressure in the tail lobes increases before a substorm and starts to decrease with the substorm onset (e.g., *Caan et al., 1978).*

The value of the total pressure decrease in the magnetotail associated with the substorm correlates with the intensity of some parameters characterizing the substorm. For instance, *Yamaguchi et al. (2004)* showed that the total pressure decrease correlates with the magnitude of the positive magnetic bay at low latitudes that characterizes the intensity of the substorm current wedge. *Miyashita et al. (2003)* analyzing several substorm events found the correlation between the total pressure decrease and latitudinal and longitudinal size of the auroral bulge. The latter result allows one to expect that auroral bulge area is proportional to the pressure decrease as well. In the present paper we consider this relationship on the basis of the data from the Polar и Geotail spacecraft.

Data selection criteria and analysis

For our analysis we selected substorms, which were observed by Polar as isolated, clear events. The double oval events were excluded. It was required that the entire auroral bulge (from the first brightening until maximum expansion) was in the field of view of the UVI imager. This should make the determination of the auroral bulge area unambiguous.

From the pressure balance condition, the total pressure is equal to the magnetic pressure in the tail lobe and, consequently, proportional to the squared plasma sheet current density. Thus, the total pressure decrease means the decrease of the current density (that is, the current disruption). The closer is the spacecraft to the disruption region, the stronger is the magnetic effect. According to the results by *Yahnin et al (2002, 2005)*, the source of the current disruption coincides with the reconnection region, that is, with the flow reversal. (This will be demonstrated in the next Section). Thus, another criterion for our analysis was the Geotail observation of the first (in the course of the substorm under consideration) tailward-to-Earthward plasma flow reversal. Only the plasma flows with the velocity V>200 km/s in the plasma sheet were considered, and the criterion $\beta>0.1$ (β is the ratio of kinetic plasma pressure to magnetic pressure) was applied for the plasma sheet determination.

Our consideration is limited by the observations made in 1996-1997 when the apogee of Geotail was about 30 R_E. The survey of the data revealed 9 substorm events meeting the above criteria.

Typically, the substorm expansion consists of several activations *(e.g., Sergeev and Yahnin (1979)*). When it was possible, the bulge area and the corresponding total pressure change were estimated for each activation separately. Otherwise, when it was not possible to distinguish between different activations, the estimation of the parameters was done for the whole event. Taking this into account, the comparison was performed for 13 cases.

Determination of the auroral bulge and total pressure decrease

The development of the auroral bulge is controlled by the Ultra Violet Imager onboard Polar. Only images obtained in the LBHL (1600-1800 Å) emission with the time resolution from 0.5 min to 3 minutes were used. The area of the bulge was determined according to the luminosity level exceeding by 25% the luminosity of the auroral oval before the substorm onset. Typically, this criterion corresponds to the level of the photon flux of 10-25 photons*cm^{-2}*s^{-1}.

The total pressure P_{total} is defined from the Geotail plasma and magnetic data by $P_{total}=P_{mag}+P_{thr}$,where $P_{mag}=B^2_{obs}/2\mu_0$; $P_{thr}= nkT_{ion}*1.2$, B_{obs} is the observed magnetic field strength. (The factor 1.2 reflects the contribution of electrons).

Superposed epoch analysis of the magnetotail dynamics during flow reversal

We applied the superposed epoch analysis to obtain the average variations of the total pressure (Fig.1). The moment of the flow reversal is chosen as the reference time (bottom panel). The upper panel demonstrates a stepwise decrease of the total pressure centered at the reversal. This clearly demonstrates the coincidence of reconnection and current disruption.

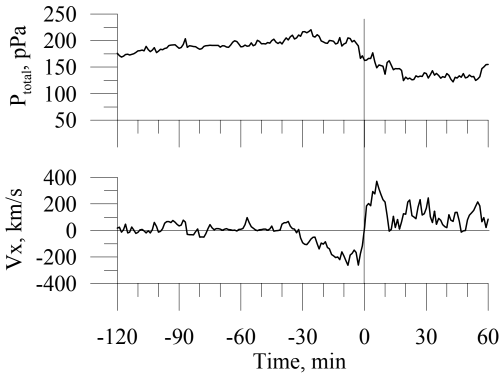

Figure 1. Averaged behavior of the total plasma pressure around the time of the flow reversal, as obtained by the superposed epoch analysis

Total pressure decrease and auroral bulge area

Fig. 2 represents the Geotail data for the event of 09 February 1997. The flow reversal occurred at around 12.28 UT. The total plasma pressure started decreasing at 12.20 UT when the tailward flow started. The minimal total pressure for this episode was observed at 12.31UT, with the value of the total pressure decrease of 62.1 pPa. The upper panel shows how the auroral bulge area developed in time. To compare the total pressure change (ΔP) with the auroral data we determined the bulge area (S) at the moment of the total pressure minimum.

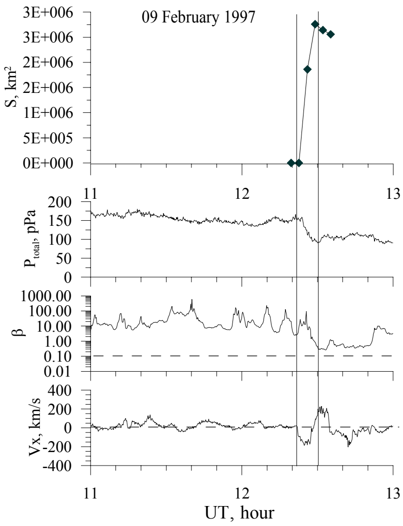

Figure 2. Variations of the plasma sheet parameters during the substorm event of 09 February 1997. The upper panel presents the dynamics of the auroral bulge area.

The relationship between ΔP and S for all considered cases is shown in Fig.3a,b. We present the relationship for both absolute values (in pPa) and relative values (percentage). The latter is determined as $(\Delta P_{total}/P_s)*100\%$, where P_s is the total pressure before the decrease. It seems reasonable to use the relative values since the absolute one depends on the distance from the Earth *(Yamaguchi et al. (2004))*. However, Fig.3 shows that both dependencies indicate a rather good relation between the studied parameters. Linear fits for these relationships are $S=2.4*10^4*\Delta P$

and S=5.1*10^4*ΔP for the absolute and relative changes of the total pressure, respectively. Note, that the fits are taken through the origin, since no dissipation in the tail should mean no dissipation in the ionosphere.

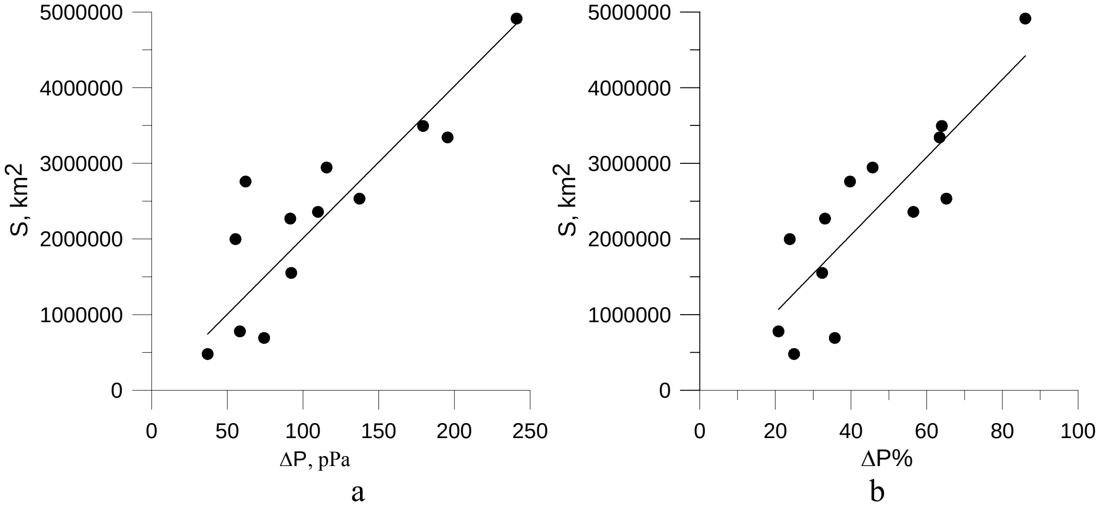

Figure 3. Relationship between the auroral bulge area in the ionosphere and the total pressure decrease in the magnetotail

Discussion and Conclusion

We considered 13 cases of the total pressure decrease in the magnetotail correlated with the auroral substorm development. We found a close relation of the total pressure decrease with the auroral bulge area determined at the moment of the total pressure minimum. This confirms the result of *Miyashita et al. (2003*), who, using a small number of events, came to a similar conclusion, but in regard to the linear dimensions of the bulge.

Since the total pressure characterizes the magnetic energy density in the tail lobe, its decrease during the substorm is a measure of the dissipated magnetic energy. Thus, the relationship we have found between the total pressure decrease and auroral bulge area means that the latter is a good ionosphere measure of substorm intensity. A similar relationship has been recently obtained for the magnetic flux through the bulge (assumed to be equal to the flux dissipated in the magnetotail during the reconnection process) and the flux accumulated in the tail during the growth phase (*Shukhtina et al. (2005)).* Also, an integral of the photon flux, revealed from observation of the LBHL emission taken over the bulge area, characterizes the precipitated electron power, and further integration in time gives the energy of the precipitated electrons producing the bright auroras (see, for example, *Chua et al. (2004)*, who used this method to estimate the precipitating electron energy over the whole oval during substorm).

One can see that the same parameter (the area of the auroral bulge) can be used to characterize three rather different manifestations of substorm process. This fact stresses the importance of auroral bulge observations for quantitative characterization of substorms.

It is worth noting that *Uritsky et al. (2002)* showed that the area of a "patch" of enhanced auroral intensity integrated over its life time is proportional to the energy of precipitated electrons. This result has been obtained statistically and independently of the nature of a "patch". In future, it would be interesting to check if this holds true for such a specific object as the auroral bulge.

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