Study of plasma pressure distribution in the inner magnetosphere using the low altitude satellite data and its relevance for magnetospheric dynamics

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Abstract. Plasma pressure distribution in the inner magnetosphere is one of the key parameters for understanding the main magnetospheric processes including geomagnetic storms and substorms. However, the pressure profiles obtained from in-situ particle measurements by the high-altitude satellites inside the plasma sheet do not allow tracking the pressure variations related to the magnetospheric dynamics, because time interval needed to do this generally exceeds the characteristic times of the main magnetospheric processes. On the contrary, fast movement of low-altitude satellites makes it possible to restore quasi-instantaneous profiles of plasma pressure along the satellite trajectory, using the precipitating particle flux data in the regions of isotropic plasma pressure. It was found that during quiet geomagnetic conditions profiles obtained from low-altitude and high-altitude satellites coincide. Nevertheless, the plasma pressure profiles change significantly during the development of storms and substorms, that indicates possibility of the interchange (storm) or modified interchange (substorm) instability development.

1. Introduction

Identification of the instabilities responsible for the development of geomagnetic storms and substorms continue to be one of the most important endeavors of Space Plasma Physics. Starting from the pioneer work of Akasofu (1964), significant number of evidences has accumulated indicating that the substorm onset takes place deep inside the magnetosphere (see Stepanova et al., (2002) for a review). On the other site, development of geomagnetic storms is related to the intensification of a ring current (Dressler and Parker, 1959) under a prolonged southward orientation of the interplanetary magnetic field (IMF). A relationship between geomagnetic storms and substorms is still not clear. However, McPherron (1997), established that during the main phase, substorms decrease the rate of strengthening of a storm. Lyons et al. (2003) showed that substorm injections lead to the decrease in the plasma pressure at the geocentric distances 10-13 $R_E$, that also decreases rate of strengthening of the storm. These results stress the importance of studying of evolution of plasma pressure profiles during disturbed geomagnetic conditions. Recently, Zaharia et al. (2006) developed a self-consistent magnetospheric model in which the magnetic forces are equilibrated by plasma pressure forces, and therefore satisfy a condition of quasi-static equilibrium, that is fundamental for description of any plasma configuration. In particular, they found that “plasma $\beta$ in the inner magnetosphere at the peak of storm activity can be significant, i.e., larger than 1. This shows that plasma pressure is crucial in influencing the magnetic field configuration” (Zaharia et al., 2006). This result points out the necessity
of developing a magnetically self-consistent approach for inner magnetosphere modeling during storms that also demands the knowledge of quasi-instantaneous plasma pressure profiles.

2. Instrumentation and data analysis

Distribution of plasma pressure in the Earth’s magnetosphere has been studied extensively during last decades. In particular, Lui et al. (1987), obtained profiles of plasma pressure using in situ particle measurements onboard the high-altitude AMPTE/CCE satellite. Later, De Michelis et al. (1999) also obtained bi-dimensional distribution of plasma pressure in the equatorial plane, using the data of the same satellite. Wing and Newell (1998) reproduced statistical bi-dimensional distribution of plasma pressure in the equatorial plane at $L \geq 10$ using the low-altitude DMSP series satellites and determined the corresponding Region 1 field-aligned current distribution. Stepanova et al. (2002) modified the technique proposed by Wing and Newell (1998), considering the presence of a field-aligned potential drop in the auroral geomagnetic field lines, and obtained footprints of plasma sheet pressure profiles in the equatorial plane for very short time intervals.

![Figure 1](image1.png)

Figure 1. April 27, 1982 event a) electron spectrogram, b) field-aligned current, and field-aligned potential drop, c) ion spectrogram, d) ion temperature, and ion concentration at the level if the satellite, e) magnetospheric pressure, and ion concentration in the magnetosphere.

Figure 1 illustrates the mains steps to follow for determining the plasma pressure profiles. It shows electron precipitating fluxes (a), field-aligned currents and potential drops (b), ion precipitating fluxes (c), ion temperatures and concentrations (d), and finally plasma pressure at the level of ionosphere and in the magnetosphere (e), obtained April 27, 1982. Particle data with a time resolution of 1.6-3.6 s was provided by the SPECTRO instruments within the 0.02-22 keV energy range (Bosqued et al., 1982). Field-aligned currents and potential drops were obtained by fitting and integrating the electron flux data, ion concentration and temperature were obtained from ion flux data. Finally the pressure was calculated taking into account the presence of field-aligned potential drops (see Stepanova et al., 2002 for details).

In the next step it is necessary to map the pressure into the equatorial plane using some geomagnetic field model. Figure 2 shows magnetic field lines, obtained using Tsyganenko 1996 and 2001 geomagnetic field models. As can be seen, the T96 is much more overstretched than the T01.
This fact is reflected in the behavior of plasma pressure (Figure 3). It reflects a relationship between the plasma pressure and the volume of the magnetic flux tube per unit flux \( W = \int d l / B \).

The fits of pressure by \( W^{-T} \). It can be easily seen, that in case of T01 model, pressure decreases much faster. This fact is very important for the analysis of possible development of interchange instability. According to the Kadomtsev criterion, any plasma configuration is stable only when

\[
\frac{dp}{dW} \geq -\kappa \frac{p}{W}
\]

(1)

where \( \kappa \) is the polytrophic index.

Results of Stepanova et al (2002) show that during substorms plasma apparently is stable with respect to the ordinary interchange instability, however interchange instability, modified by azimuthal pressure gradients, can develop.

3. Plasma pressure behavior during storms.

Analysis of inner magnetosphere pressure behavior during the March 1-8, 1982 intense geomagnetic storm (minimum Dst=-211 nT) showed that the plasma pressure profile became steeper, especially
near the end of the main phase, having the value near and even exceeding (in IGRF mapping) the maximum steeping value $\gamma = -7$ necessary for the development of an interchange instability.

Figure 4 shows the relationship between the position (in Earth’s radii) and the corresponding value in maximum of radial pressure distributions, obtained using International Geomagnetic Reference Field (IGRF), Tsyganenko 2001 (T01) and 2004 (T04) geomagnetic field models (Macmillan et al. 2003, Tsyganenko 2002, Tsyganenko et al. 2005). IGRF model gives a standard mathematical description of the Earth’s main magnetic field and does not consider their distortion caused by magnetospheric current systems. T01 and T04 models represent the expected statistical response of the geomagnetic field to the orientation of the Earth's dipole axis, solar wind pressure, interplanetary magnetic field, and appropriate geophysical indices. In can be seen, that according to all models used, strong values of the plasma pressure maxima were observed deep inside the magnetosphere only ($L < 7$). This fact agrees with the results of Zaharia et al., (2006) showing that “plasma $\beta$ in the inner magnetosphere at the peak of storm activity can be significant, i.e., larger than 1. This shows that plasma pressure is crucial in influencing the magnetic field configuration”.

It was also found, that the closest position of the pressure maximum, ($L_{max} = 3.0 \, R_e$ for IGRF, $L_{max} = 3.5 \, R_e$ for T01, $L_{max} = 3.2 \, R_e$ for T04) and the maximum value of Dst $- variation |D_{st}|_{max} = 211 \, nT$, follows well the results of Tverkaya et al. (2003) $|D_{st}|_{max} = 2.75 \cdot 10^4 L_{max} \, nT$, that provides the additional support of the theory of magnetic storm developed by Tverskoy (1997) and Antonova (2005).

![Fig. 4 Relationship between the position and the value of pressure in the maximum (IGRF (black), T04 (grey), and T01 (white)).](image)

### 4. Conclusions

Our results demonstrated that the use of low-altitude satellites for studies of inner-magnetosphere plasma pressure dynamics is very efficient. This makes it possible to obtain the radial plasma pressure profiles quasi-instantaneously and in the nearest future to use them for development of self-consistent magnetospheric models, under magnetostatic equilibrium.

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