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Anisotropy of proton fluxes in neutral sheet region measured by DOK2 on Interball-1

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Abstract

The anisotropy of proton fluxes measured by DOK2 in a wide energy range (20–400 keV) during four crossings of the neutral sheet is discussed. In two cases, the satellite moves earthward whereas it moves tailward in other two. The bipolar proton fluxes are observed in the whole energy range. All events are observed during quiet geomagnetic field intervals with the predominate IMF B_x component and in the course of the growth phase of a small geomagnetic substorm, when the Interball-1 satellite was located in the plasma sheet and crossed the neutral line at a distance of $\sim 26R_E$. Changes of proton energy spectra during the crossings were observed. Observations indicate a crossing of the region where reconnection of magnetic field lines takes place. The positions of the neutral point were consistent with the NENL model.

Keywords: Magnetotail; Neutral sheet; Near-Earth's neutral point; Energetic particles

1. Introduction

The magnetotail is a dynamic entity where mass and energy from the solar wind are stored and later released, generating disturbances like substorms. Its temporal variations occur primarily in a direct response to variable conditions in the solar wind and interplanetary magnetic field. Energetic particles accelerated in the magnetotail extensively influence processes in the inner magnetosphere.

The plasma sheet with central part, the neutral sheet, is the most dynamic region of the magnetotail. It is a very important region for many magnetospheric processes, most of which are related to substorms. The state of the Earths magnetosphere is strongly affected by the solar wind dynamics and by the orientation of the interplanetary magnetic field (IMF). The transport of mass, momentum and energy from the solar wind into the magnetosphere as well as the role of the ionosphere in populating the near-Earth tail are not completely understood yet.

Magnetospheric substorms are the main sources of energetic particles in the tail plasma sheet region. Substorms are defined as intervals of intense energy dissipation lasting from about 30 min to several hours. The temporal and spatial evolutions of the substorms were studied by many authors, e.g., Mukai et al. (2000), Ashour-Abdalla et al. (2000), Petrukovich et al. (2000), Petrukovich (2002), Slavin et al. (2002), Ohtani et al. (2002) and others using the measurements from IMP-8, ISEE, Wind, Geotail, Interball-1, and other satellites.

Hones (1984) attributed dissipation of the magnetotail energy during substorm growth phase to a formation of the near-Earth neutral line. His idea is known as the (near-Earth neutral line NENL) model, which is now widely accepted as one of the most comprehensive frameworks for ordering the global and complex signatures of substorms (Baker et al., 1996).

The tail current disruption and near-Earth reconnection are the two main processes controlling the substorm dynamics in the magnetotail. Recent observations

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suggest that the near-Earth neutral line is formed between $X = -22R_E$ and $-30R_E$ (Nagai et al., 1998). Miyashita et al. (2000) obtained the location of the near-Earth neutral line in $X = -19.6R_E$ at onset time. Baumjohann et al. (1998) used Geotail data to show that the NENL is located around 20–30R_E during substorm expansion phase with a tendency to be closer to 20R_E at the substorm onset.

Lui (2002) presented a detailed examination of current disruption events in which magnetic reconnection plays no significant role for particle acceleration. Independent studies have suggested that tail current disruption can be initiated much closer to the Earth, perhaps within 12R_E from the Earth. Since tail current disruption and the NENL formation take place at different radial distances, it is reasonable to consider them as different processes.

Petrukovich et al. (1999) analyzed Geotail observations in the near-Earth magnetotail at $X = -11R_E$ and found a small-amplitude bipolar (first tailward, then earthward) ion flow during the growth phase of geomagnetic substorm on August 30, 1996. The interval of the tailward flow contained spikes of negative IMF B_z (in GSM) while the earthward-flow interval included transient B_z increase and subsequent dipolarization. The authors interpreted this phenomenon as a tailward propagating reconnection event.

A statistical analysis of the ion flow in the plasma sheet and its boundary layer at radial distances from the Earth between 10R_E and 50R_E was done by Paterson et al. (1998) using the Geotail data. Lopez et al. (1989) examined the relation between the energetic particle flux morphology and the change in the magnetic field magnitude during substorms in the near-Earth magnetotail. It was found that the particle flux morphology is organized by the sign of $\Delta|\mathbf{B}|$. Nishida (2000) summarized the current state of knowledge in the physics of the magnetotail.

Interball-1 crossed the magnetotail for three months every year. During the 5-year period of active measurements, the DOK2 spectrometer accumulated a lot of information about proton and electron fluxes in plasma and neutral sheets accordingly. In the paper by Slivka and Kudela (2002), the existence of bipolar fluxes of protons with energy 20–26 keV during the growth phase of a small substorm on December 3, 1996 is discussed. We have concluded that the anisotropy changes are probably caused by reconnection of geomagnetic field lines.

In this paper, the anisotropy of proton fluxes measured by the DOK2 spectrometer during neutral line crossings in course of the growth phase of small geomagnetic storms (substorms) is investigated. During two of them, namely on December 3, 1996 and November 28, 1997, the satellite was moving earthward. The crossings on November 19 and December 5, 1998 correspond to the tailward motion of the spacecraft.

2. Experimental data

The data on energetic proton and electron fluxes measured by DOK2 spectrometer onboard the Interball-1 satellite, are analyzed. The DOK2 spectrometer (Kudela et al., 1995; Lutsenko et al., 1995) is a monitoring device for the measurement of (i) fine time structure of proton and electron fluxes at three selected energy ranges and (ii) the detailed energy spectra with a longer time resolution. The detector D1 is oriented in the $-X_{GSE}$ direction (along the spacecraft spin axis), while D2 detector is declined on 62° from $+X_{GSE}$ direction and spins with 2 min period. The proton data presented here are from both detectors (D1 and D2), on the contrary to the electron data, which are from D1 only. The abbreviations D1P1, D1P2 and D1P3 correspond to energies 20–26, 45–59, and 101–132 keV respectively for the D1 protons; D2P1, D2P2 and D2P3 with similar energy limits for protons measured by D2. The electron fluxes abbreviated by D1E1, D1E2 and D1E3 are measured by detector D1 at 22–26, 39–48, and 76–95 keV ranges, respectively.

The energy spectra of protons (~20–800 keV) and electrons (~20–600 keV) are measured simultaneously, with the accumulation time depending on the sum of fluxes. The proton energy spectra were averaged into 14 channels denoted as ch1–ch14 in the further text. The corresponding energy ranges of these channels are presented in Table 1 for both proton detectors. These data are complemented with 2-min averaged data from two other instruments onboard Interball-1, namely CORALL (ion temperature and bulk plasma velocity) and MIF-M (magnetometer).

Table 1
Proton energy channels ranges of DOK2 detectors (energy is in keV)

Channel no.	Detector 1 energy	Detector 2 energy
1	20.2–26.1	19.3–25.1
2	26.1–33.6	25.1–32.5
3	33.6–43.4	32.5–42.3
4	43.4–56.1	42.3–55.1
5	56.1–72.8	55.1–71.9
6	72.8–94.7	71.9–94.2
7	94.7–123	94.2–124
8	123–161	124–163
9	161–211	163–215
10	211–276	215–284
11	276–362	284–375
12	362–476	375–496
13	476–625	496–657
14	625–821	657–871