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Some peculiarities of longitudinal distribution of proton fluxes at high latitudes

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Abstract

Dynamical features of proton fluxes at high and middle latitudes were studied based on data measured by Sun-synchronous low-altitude (800 km height) polar-orbiting three NOAA series satellites: POES 15, 16, and 17 during the geomagnetic storm on January, 21–22, 2005. Data from three satellites that passed the Northern hemisphere along different MLTs allow reconstructing the longitudinal distribution of the proton fluxes. Measurements of protons with energies of 30–80 keV and 80–240 keV (the ring current energy range) by 0- and 90-detectors were used to evaluate and compare the longitudinal asymmetry of proton flux distribution measured in the regions equatorward and poleward of the isotropic boundary. It was found that during all the phases of the geomagnetic storm distribution of the maximum flux of precipitating protons (0-detector data) is sufficiently asymmetric. The maximal flux position along MLT is moving from pre-midnight sector in quiet time to post-midnight one before and during SSC and moving back during recovery phase. The longitudinal distribution of precipitation maxima demonstrates the local increase in afternoon sector (approximately at 13:30 MLT) and decrease in the dusk one during SSC. These features are evident consequence of the magnetosphere compression. To identify the origin of the particles, the locations of maximum fluxes have been projected to the magnetosphere. It was determined that during geomagnetic storm main and recovery phases maximum fluxes were measured at latitudes poleward of the isotropic boundary. To evaluate the trapped particle flux asymmetry, the particle fluences (90-detector data) were calculated along the satellite orbit from $L = 2$ to the isotropic boundary. The total fluences of trapped particles calculated along the satellite orbit show regular asymmetry between dusk and dawn during main and recovery phases. The maximal intensity of proton fluxes of both investigated populations located poleward and equatorward of the isotropic boundary is achieved during SSC. The total flux measured during crossing the anisotropic region can be considered as a proxy for ring current injection rate.

Keywords: Earth's magnetosphere; Geomagnetic storm; Charged particles; Ring current

1. Introduction

Measurements of particle fluxes onboard low-altitude polar-orbiting satellites provide considerable information about the spatial dimension, location, and population of magnetospheric domains: tail plasma sheet, ring current, and radiation belts (Winningham et al., 1975; Morozova et al., 1982; Søraas et al., 2002). Charged particles registered in the magnetosphere originate from the Sun and the Earth's ionosphere (as for high-energy cosmic rays, i.e. anomalous and galactic ones, they are also indirect sources of radiation belts), their motion is controlled by magnetic and electric fields, so the measured particle fluxes reflect the features of current state of the magnetosphere. Temporal and spatial variations of particle fluxes result from the magnetospheric magnetic and electric field changes and can be used to describe electrodynamics processes taking place in the near-Earth's environment (Alfvén and Fälthammar, 1963; Tverskoy, 1972).

The most significant changes in particle flux variations arise during geomagnetic storms. Geomagnetic storms are

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the most powerful phenomena in the Earth's magnetosphere. It is currently believed that there are two major types of geomagnetic storms: coronal mass ejection (CME) driven storms and corotating interaction (CIR) driven storms (Borovsky and Denton, 2010). Geomagnetic storms are caused by specific conditions taking place during solar wind – magnetosphere interaction. The major external "triggers" of storms are: enhanced solar wind pressure and southward turning of IMF (Gonzalez et al., 1994; Lee et al., 2007). The magnetic field structure, location of the magnetopause, dimensions of the magnetosphere, as well as the population of the charged particles in the near-Earth's environment considerably change during geomagnetic storm in response to the external driving.

Under prolonged southward IMF conditions during a geomagnetic storm, and enhanced cross-tail electric field in the magnetosphere energizes the particles convecting to the Earth from the magnetospheric tail. Enhanced magnetospheric convection and local particle accelerations in the magnetospheric tail during substorms are the main processes responsible for particle injections from the central plasma sheet to the inner magnetosphere, where the trapped particle population resides (Tverskoy, 1972; Kozyra and Liemohn, 2003).

In the plasma sheet the particles are subject to intense pitch-angle scattering. This scattering depends on the ratio between the particles gyroradius and the curvature of the magnetic field. The most effectively this process takes place in the highly curved tail magnetic field. It leads to continuous loss-cone filling and consequent particle precipitations in the Earth's atmosphere (Sergeev et al., 1993; Gvozdevsky et al., 1997). The isotropic boundary location of energetic particles can be used as a proxy for the tail current strength (Asikainen et al., 2010). Particles with relatively large pitch angles reach the inner magnetosphere and become trapped by the geomagnetic field forming the storm-time ring current.

The main manifestation of a geomagnetic storm is a depression of the magnetic field's horizontal component measured at the Earth's surface. Observations indicate that this depression is global and caused by variations in large-scale currents in the Earth's magnetosphere (Chapman and Ferraro, 1930; Dessler and Parker, 1959).

Ring current, tail current, and magnetopause current account for this variation; these currents flow relatively far from the Earth and produce an approximately uniform magnetic field during quiet conditions (Alexeev et al., 1996; McPherron, 1997). During magnetospheric disturbances these currents change significantly (Alexeev et al., 1996; Kalegaev et al., 2005) and produce non-uniform magnetic field on the Earth's surface. On-ground and satellite measurements show evidence of longitudinal asymmetry of the magnetic field during magnetic disturbances (Akasofy and Chapman, 1964; Cahill, 1966). Such magnetic field structures can be represented as an effect of local current systems that exist in a limited region of space, like partial ring current, substorm current wedge etc. These currents can exist during relatively short time (1–5 h) and create the magnetic field, which distorts the magnetic field produced by large-scale current systems (Kalegaev et al., 2008). Magnetospheric magnetic field asymmetry also reveals itself in the particle flux longitudinal distribution measured onboard low-altitude polar satellites in the high-latitude region.

Several events of asymmetric injections of ring current protons were registered onboard satellite "Molniya-1" during the time interval ∼1–2 h (Kovtyukh et al., 1977) and onboard low-altitude polar-orbiting satellite "Kosmos-900" with time resolution of ∼15 min (Morozova et al., 1982). Direct observations of energetic neutral atom (ENA) fluxes, which are caused by the charge-exchange of ring current ions on atoms of the exosphere, experimentally confirm that the storm-time ring current is asymmetrical during a geomagnetic storm (Roelof, 1987; Fok et al., 2001). Mechanisms leading to ring current longitudinal asymmetry during the main phase of a geomagnetic storm are principally different in its outer and inner parts: on the outer boundary the ring current asymmetry is caused by intensifications of particle convections during substorms (Tverskoy, 1972), on the inner boundary it is caused by precipitation of particles into the loss-cone during drift from the pre-midnight sector to noon and dawn ones, owing to strong pitch-angle diffusion (Kovtyukh et al., 1978). The sharp changes of magnetopause locations, e.g. magnetospheric compression during sudden storm commencement, are also responsible for localized particle losses on the dusk magnetopause.

An evaluation of ring current asymmetry degree was made using proton flux maximum measurements onboard low-altitude polar satellite "Kosmos-900" (Morozova et al., 1982). Data from low-altitude polar-orbiting satellite NOAA are used to study the precipitation of energetic (30–80 keV) protons, several degrees equatorward of the he isotropic boundary (this precipitation is called low-latitude proton precipitation – LLPP) (Gvozdevsky et al., 1997). Poleward the isotropic boundary (IB) the pitch-angle distribution of proton fluxes is isotropic, equatorward IB it becomes anisotropic with the reduced flux of precipitating particles (Sergeev et al., 1993). Probably, the isotropic boundary divides not only two populations of particles but also closed magnetic field lines with different topology in the night-side: quasydipole and tail-like. The total power of precipitating protons in the midnight/evening local time sector using data from NOAA 15 is used to estimate the energy injection rate into the ring current due to energetic protons (Søraas et al., 2002). Ring current dynamics was studied using low latitude ENA particle observations onboard NOAA 15 and 16 (Søraas et al., 2003). Global 30–240 keV proton precipitation patterns during the geomagnetic storm were generated using data from the NOAA 15 and 16 satellites (Fang et al., 2007). In this study the change of energetic proton precipitation patterns is quantified in terms of three aspects: hemispheric integrated total particle energy input, midnight proton oval equatorward