Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 54 (2014) 517–527

ADVANCES IN SPACE RESEARCH
(a COSPAR publication)

www.elsevier.com/locate/asr

The Earth's magnetosphere response to interplanetary medium conditions on January 21–22, 2005 and on December 14–15, 2006

V.V. Kalegaev *, N.A. Vlasova

Skobeltsyn Institute of Nuclear Physics of Lomonosov Moscow State University, Moscow 119991, Russia

Abstract

The Earth's magnetosphere response to interplanetary medium conditions on January 21–22, 2005 and on December 14–15, 2006 has been studied. The analysis of solar wind parameters measured by ACE spacecraft, of geomagnetic indices variations, of geomagnetic field measured by GOES 11, 12 satellites, and of energetic particle fluxes measured by POES 15, 16, 17 satellites was performed together with magnetospheric modeling based in terms of A2000 paraboloid model. We found the similar dynamics of three particle populations (trapped, quasi-trapped, and precipitating) during storms of different intensities developed under different external conditions: the maximal values of particle fluxes and the latitudinal positions of the isotropic boundaries were approximately the same. The main sources caused RC build-up have been determined for both magnetic storms. Global magnetospheric convection controlled by IMF and substorm activity driven magnetic storm on December 14–15, 2006. Extreme solar wind pressure pulse was mainly responsible for RC particle injection and unusual January 21, 2005 magnetic storm development under northward IMF during the main phase.

Keywords: Geomagnetic storm; Charged particle precipitations; Ring current; Magnetosphere–ionosphere coupling

1. Introduction

The Earth's magnetosphere is a self-consistent system, dependent on the level of solar activity and on the conditions in the interplanetary medium. Earth's magnetosphere responses to external influence reveal themselves in geomagnetic activity: mainly, magnetic storms and magnetospheric substorms. Magnetospheric magnetic field depression at the Earth's surface is the main manifestation of magnetic storms. It is caused by storm-time development of the magnetospheric current systems: ring current (RC), geomagnetic tail currents, currents on the magnetopause, and, insignificantly, by field-aligned currents (Alexeev et al., 1996). Though, the intense discussion lasts during two decades, the relative role of magnetospheric current systems during a magnetic storm is not quite clear.

The Dessler–Parker–Scopke (DPS) relation (Dessler and Parker, 1959; Sckopke, 1966) is usually used to study RC development. It is obtained in approximation when currents in plasma do not produce a significant disturbance of the magnetic field, and connecting axially symmetrical disturbance of the field in Earth's centrum with RC particle energy. Greenspan and Hamilton (2000)calculated the trapped particle total energy obtained from particle fluxes measured by AMPTE/CCE satellite during more that 70 magnetic storms and showed that RC magnetic field perturbation calculated from DPS equation corresponds well to the magnetic field depression measured at the Earth's surface. Also, they mentioned that the positive effect of Chapman–Ferraro current in the inner magnetosphere can compensate the significant contribution of the magnetospheric tail current system to Dst-variation. Magnetopause current contribution into magnetic field disturbance at the Earth's surface can be described by the empirical relation obtained in (Burton et al., 1975)

---

* Corresponding author. Tel.: +7 495 9391915.
E-mail address: klg@dec1.sinp.msu.ru (V.V. Kalegaev).

0273-1177/$36.00 © 2013 COSPAR. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.asr.2013.11.015

$\mathrm{Dcf} = b\sqrt{P} - c$, where P is solar wind dynamical pressure, b and c are obtained from statistical analysis. Pressure corrected Dst-index is often used to represent the RC and tail current joint effect in the on-ground magnetic field variation: $\mathrm{Dst}^* = \mathrm{Dst} - \mathrm{Dcf}$. Investigations based on the models of magnetospheric magnetic field show that contributions of RC and magnetospheric tail current to Dst-variation are comparably for moderate geomagnetic storms (Alexeev et al., 2001; Tsyganenko and Sitnov, 2007). Kalegaev and Makarenkov (2008)reported that the stronger the storm, the larger the relative RC contribution to Dst.

Particle distribution inside the magnetosphere reflects the features of the magnetic field structure. The study of particle fluxes at low polar orbits can shed additional light on relative dynamics of large-scale magnetospheric magnetic field sources.

Under southward orientation of the interplanetary magnetic field (IMF) during a magnetic storm, the intensified "dawn-dusk" convection electric field in the magnetospheric tail accelerates particles moving to Earth. Another mechanism of such acceleration in the tail is induced electric fields developing during substorm activations (Tverskoy, 1972; Kozyra and Liemohn, 2003). Particles experience strong pitch-angle scattering at the curved field of the magnetosphere tail. This process contributes to a continuous filling of the loss-cone and following precipitation of particles into the Earth's atmosphere (Sergeev et al., 1993). Particles with relatively large pitch-angle achieve the inner magnetosphere and become trapped forming the RC.

Particles transport to the inner magnetosphere taking place due to a sudden compression of the magnetosphere after SC is another cause of acceleration during a magnetic storm (Li et al., 2003; Shi et al., 2008). Magnetospheric convection intensification, local particle acceleration due to substorm activity, and transport of particles after SC are main fundamental processes that cause particle injection into the inner magnetosphere, the particle trapped region, and subsequent RC formation.

Particle flux measurements give possibility to better understand RC dynamics during disturbances. RC proton asymmetric injection was studied, for example, using Molniya-1 satellite data (Kovtyukh et al., 1977). RC dawn-dusk asymmetry development was investigated based on proton flux maximum measurements made onboard low-altitudinal polar satellite Cosmos-900 (Morozova et al., 1982). Researches of proton fluxes at low altitudes by Cosmos-900 satellite data showed that isotropic fluxes are observed on average at higher latitudes in the day- and dawn-sectors than in night- and dusk-ones during magnetically-quiet intervals (Panasyuk et al., 1985). The total energy of precipitating protons was used to estimate velocity of the energy injection to RC in the dusk/night-sector by POES 15 satellite data (Søraas et al., 2002). Precipitating particle flux intensity increases during geomagnetic disturbances: the stronger the magnetic field depression the higher the intensive flux value (Søraas et al., 2002). A global picture of 30–240 keV proton precipitation was obtained using POES 15, 16 satellite data during a geomagnetic storm (Fang et al., 2007). Data from low-orbiting polar satellites of NOAA series were used to study the energetic proton precipitations at latitudes lower than the isotropic boundary (IB, Sergeev et al., 1993) and low-latitude proton precipitations (LLPP, Gvozdevsky et al., 1997).

The RC dynamics can be studied using measurements of energetically neutral atoms (ENA). Their source is charge exchange of RC ions on geocorona's neutral hydrogen, as suggested by Dessler and Parker (1959). Roelof (1987) reported that ENA flux measurements are an experimental verification of RC asymmetry during geomagnetic storms.

Moritz (1972) supposed that ENA originating near the equator can transit from high L to low ones, where they can be ionized due to a secondary charge exchange with ionospheric particles and be trapped by the magnetic field as ions. A close connection during disturbances between particle flux increases at $L = 3$ and at low altitudes near equator was shown (Moritz, 1972). Due to the large geocorona density at low L-shells these ions will drift very slowly and their lifetime is relatively short. Søraas et al. (2003) studied RC dynamics during different phases of geomagnetic storms using variations of low-latitudinal proton fluxes called the storm time equatorial belt (STEB) measured by POES 15, 16 satellite.

The goal of the present work is to study the causes and main sources of magnetic storms on January 21–22, 2005 and December 14–15, 2006, along with their similarities and differences. We will use particle flux measurements in order to gain a better understanding of the response of magnetospheric current systems to external drivers. This research is based on complex analysis of the experimental data from LEO satellites and calculations in terms of paraboloid model (A2000) of the magnetospheric magnetic field (Alexeev et al., 1996, 2001).

2. Experimental data

The Earth's magnetosphere, magnetospheric currents systems, plasma domains, and energetic particles trapped in the magnetosphere are influenced by solar wind parameters. Complex studies of experimental data obtained from interplanetary medium and measured inside the Earth's magnetosphere provide information about the dynamic processes taking place in the Sun-solar wind-magnetosphere coupled system.

Solar wind density and velocity, as well as IMF components, are crucial parameters characterized external influence on the magnetosphere. These data can be obtained from ACE spacecraft measurements. Geomagnetic indices Dst, ASY/H and SYM/H, AL (World Data Center C2 for Geomagnetism, Kyoto (http://wdc.kugi.kyoto-u.ac.jp/)) and magnetic field measurements from GOES satellites can be used for descriptions of geomagnetic conditions inside the magnetosphere. More information on the