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On two different geomagnetic manifestations of solar flare November 4, 2003

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Abstract

Investigations during the last decade revealed the presence of important qualitative distinctions in a spatially temporal pattern of geomagnetic response to solar flares featuring harder radiation spectra (photon wavelength <0.05 Å). These distinctions cannot be adequately described by the classical theory of flare-terrestrial coupling implying ionization growing on E and D ionosperic layers and intensification of S_q-current system. In this respect, flare on November 4, 2003 characterized by existence of two separate (time lag ~45 min) spectral maximums, first one in X-rays range (average quantum energy <100 keV) and second one in γ-rays range (average quantum energy >100 keV), represents convenient proving ground for study of specifics a geomagnetic response to bursts marked by different hardness. This paper deals with analysis of magnetometer, riometer, and satellite data collected during flare November 4, 2003 with emphasis on examination of unusual magnetic respond in ULF frequency range (1–10^3 mHz) supposedly related to stirring up of γ-rays flux. Feasible physical mechanisms responsible for observed magnetic response are discussed and theory model is considered.

Keywords: ULF disturbance; Solar flare; Electromagnetic radiation; Gamma emissions; Diffusion equation; Plasma diamagnetism

1. Introduction

Solar flare activity is one of the most powerful factors affecting the processes in Earth's ionosphere (Mitra, 1974). The arrival of flare electromagnetic radiation (mostly UV- and soft X-emissions) causes a drastic increase of the ionization on altitudes of E and D layers of dayside middle and low latitude ionosphere. The entire spectrum of the ionospheric effects caused by enhancement of electron density and intensification of S_q-current system is usually termed sudden ionospheric disturbance (SID) (Mitra, 1974). SID is a predominantly daytime event and its longitude distribution is controlled by the sun's zenith angle. The well-known geomagnetic manifestation of SID is a gradual (characteristic scale ~1 h) disturbance resembling a hook on ground based magnetograms, so called "crotchet" or solar flare effect (SFE) (Rishbath and Garriott, 1969). In a high-frequency domain, SFE appears as trains of irregular geomagnetic pulsations P1-3sfe with period T~0.5–400 s (Kato et al, 1959). The source of P1sfe pulsations (period ~0.5–60 s) is

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thought to be connected with small-scale current vortices (Sorokin and Yashenko, 1990). Pulsations P2sfe (period ~60–150 s) resembling well-known pulsations Pi2, link with magnetosphere hydromagnetic waves generated from the drastic change of ionosphere conductivity (Rosenberg et al., 1981). Pulsations P3sfe (period ~150–400 s) are rather caused by slow MHD-waves originating from the impulse heating of ionosphere plasma (Gutop and Sorokin, 1984).

Along with that, a numbers of researchers have reported that the hardening of flare radiation (appearance of photons with wavelengths <0.05 Å) comes with changes in the above mentioned traditional structure of the geomagnetic "crotchet". In his pioneering work (Pinter, 1957) paid attention to specifics of the geomagnetic signatures of hard spectrum flares. Sastri and Murthy (1975) described a burst of hard radiation flux on balloon (stratosphere) heights and daytime geomagnetic disturbance that was being monitored ~15 min later. This geomagnetic disturbance manifested itself as a sudden impulse in the horizontal component of magnetic field with amplitude ~14 nT and length ~20 min. After analyzing the VLF records, Fishman and Inan (1988) reported the emergence of ionospheric disturbance following detection of hard flare emissions near earth's orbit. Parkhomov (1992) investigated the geomagnetic field response to solar γ-bursts and showed that it is different from effect of X-bursts in terms of the impulse component, extension of frequency spectrum, and increase in pulsations Psfe activity. Dovbnya et al. (1995) described the occurrence of a high-frequency (up to 2 Hz) branch in P1sfe spectrum that is supposed to be excited due to γ-emissions on the lower atmospheric layers.

Because of the lack of a commonly accepted mechanism for converting the energy of a γ-radiation flux into that of geomagnetic disturbance, the possible relationship between the γ-flare and magnetic perturbation itself seems ambiguous and needs to be proved. Matronchick (1994) conducted an analytical investigation and proposed the concept of a double electric layer as a response to the intrusion of the γ rays into an originally neutral atmosphere. Following this, he suggests an electric field of double layer to govern the horizontal diffusion of ionospheric currents and invoke the appropriate geomagnetic effect. Moldavanov (2002) studied the response of the global atmosphere–ionosphere circuit to double layer appearance. The possibility of electric discharge between the stratosphere double layer and ionosphere base as a source of magnetic disturbances possessing a broad spectrum has been also analyzed (Moldavanov, 2003).

Despite the above-mentioned experimental research and a few results from theoretical studies, the question about the causal relation between γ-rays flares and geomagnetic disturbances still remains open. The uniqueness of the flare on November 4, 2003 is explained by the fact that temporal pattern of flare development is characterized by the presence of two maximums, in the X-ray (average quantum energy <100 keV) and the γ-ray ranges (average quantum energy >100 keV). Moreover, the spectral maximum in the γ range was observed in ~45 min, on the phase of actual X-rays flux decaying, which indicates the existence of separate X- and γ-phases for this flare. Because these phases occurred at different times and did not overlap each other, it presents an opportunity for the independent study of the magnetic field response to the X- and γ-component of flare radiation.

In this article, following experimental analysis, the authors will try to construct the physical model for transfer of γ-rays flux energy into that of geomagnetic perturbation in a frequency range 1–10^3 mHz, and in this framework, consider relevant theoretical mechanism.

2. Presentation of the data

The dataset used in this study consists of three main components: spacecraft, magnetometer and riometer data. The spacecraft data include X- and γ-rays flux measurements made by two satellites, GOES 10 and Hessi, during the time interval ~1900–2100 UT on November 4, 2003. GOES 10 operated in the Earth's geographic equatorial plane, in a geostationary orbit at a radial distance of 6.6 R_E. It was located within a few degrees of 135°W longitude (geographic) while the magnetic latitude was close to the equatorial zone throughout that year. During the flare GOES 10 was positioned in midday sector (10–12 MLT).

The Hessi satellite was launched into a circular orbit on February 5, 2002. The orbit had an inclination of 38° to the equator plane, an altitude of 600 km and a period of 96 min. The satellite carried nine germanium detectors that permitted X- and γ-ray spectra of cosmic sources. Hessi detectors covered the energy range approximately from 3 keV