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The storm of March 1989 revisited: A fresh look at the event

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Abstract

Some new features of the well known geomagnetic storm of March 1989 are presented in this paper. They include more detailed description of the geophysical situation in the Eastern hemisphere (Siberian sector) as well as more careful consideration of the dynamics of the energetic particle precipitation during the event. More attention is given to the peculiarities of the geomagnetic activity at that time. Change of the magnetospheric configuration during active phase of the storm is especially noteworthy. Intriguing feature of this storm is the impulsive powerful solar proton event (SPE) with simultaneous impulsive intense precipitation of the protons with "soft" energetic spectra (1–40 MeV) appearing in a time interval between 02 and 12 UT of March 13 at the background of a previously existing moderate energetic proton flux. Intensity of this impulsive SPE was very high (up to 5300 pfu for protons with $E > 10$ MeV). Most probably this SPE was caused by the impulsive solar X-ray flare (N28, W02) classified as X-1.4. It is worth to note that this peak of the proton fluxes was recorded at the same time (07:45 UT) when the Quebec energetic system was collapsed. Simultaneous sharp decrease of the geomagnetic indices AU, AL and PC (Polar Cap index) with a fast recovery time was recorded. Precipitation of more soft particles ($E = 30$–30,000 eV) was studied by the data of the DMSP 8 and 9 satellites. Equatorward protrusion of the soft particles precipitation boundary reached such lower geomagnetic latitudes as 45 degrees. A specific feature of this storm was absence of the satellite measurements of the solar wind and Interplanetary Magnetic Field (IMF) during several days including active phase of the event. Under these circumstances more important became the data obtained by ground-based geophysical observations especially at the high-latitudes. A special attention was given to the elements of the storm whose peaks were close to time of technological catastrophe (07–45 UT of March 13 1989).

Keywords: Geomagnetic storm; Solar particles; Riometer; Forbush decrease

1. Introduction

Several important aspects of the ionospheric and magnetospheric disturbances during the severe geomagnetic storm of March, 1989 are reconsidered here. This event has been described in several studies previously. Among them are the excellent papers such as by Allen et al. (1989), Rich and Denig (1992) and Sojka et al. (1994).

A number of less meaningful papers describing various aspects of this unique geomagnetic storm appeared in print until 2014 when a paper by Feynman (1995) was published. All of these papers were devoted preferably to analysis of the soft electron precipitation dynamics as recorded by the DMSP 8 and 9 satellites above North-American sector. Sojka et al. (1994) compared these results with the model simulations but they admitted that discrepancies between the experimental and model data were significant. For some unknown reasons several important features of this storm remained omitted by these and others explorers. This event differs from other powerful geomagnetic storms in

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many aspects. First of all any satellite data describing conditions in the solar wind and in the IMF were absent for several days before and during this storm (from 03 UT of March 9 until 22 UT of March 14). So, it was a unique case when the ground-based ionospheric and geomagnetic observations provided the main information about the storm parameters. Secondly, many geophysical parameters (Dst, geomagnetic Polar cap (North) and Polar cap (South) indices, fluency of the solar protons with $E > 10$ MeV as well as depth of the Forbush cosmic ray decreases) reached values closed to their historical maximums in this event. Finally it was the only geomagnetic storm which caused a great technological breakdown at the ground-based electric power system. In this paper we will concentrate our attention at several topics which did not be discussed in full details in the previous studies.

Extremely intense impulsive solar proton precipitation in a comparatively "soft" (1–60 MeV) energetic spectra was recorded on March 13, 1989 in the period between 02 and 10 UT. Such great fluxes of the solar protons at 06–08 UT of March 13 ~5300 pfu (1 pfu = prt/(cm^2 s sr) for protons with energy > 10 MeV [Alert Space Environment Center, Boulder, Colorado, SDF number 072 for 13.03.1989]) produced anomalous riometer absorption at both dayside and nightside polar regions.

The peak of this event as recorded by the riometers in both North-American and Siberian sectors coincided exactly (in limit of several minutes) with time (07–45 UT) of collapse of high-voltage power circuits in the Province of Quebec, Canada. Serious disruptions of 130 kV power lines occurred at the same time in Sweden was reported by Stauning (2002). The ground-based magnetometers located nearby of the places of technical disruptions demonstrated exactly at that time moment (07–45 UT) great sharp decreases of geomagnetic field (dB/dt) exceeding value of 10 nT/s. It is known that the latter parameter is proportional to magnitude of Geomagnetically Induced Currents (GIC) which is the primary cause of technological disruptions. It is worth to note that the main geomagnetic indices (besides Dst) reached their extremely high magnitude exactly at the same moment (07–45 UT). So, we tried to analyze all available information about geophysical situation taking place during technological disasters on the ground.

Interesting feature of this storm was intense (deviation of −15%) Forbush decrease of the cosmic rays intensity which could be manifestation of very large magnetic clouds (ICME) containing intense negative Bz component inside. This Forbush decrease recorded by ground-surface neutron monitors was traced down to very low geomagnetic latitudes.

Maximum of negative deviation of the storm-time index Dst (597 nT) took place at 01 UT of March 14 and was marked by rise of auroral AL index corresponding to intensity of western electrojet.

We carefully reexamined dynamics of precipitation of auroral electrons and protons during this storm on both day- and night sides analyzing data of the DMSP 8 and 9 satellites.

The purpose of this report is twofold: (a) we concentrate our attention on the analysis of the geophysical conditions at the moments close to technological breakdown bearing in mind that we have in our disposal preferably data of ground-based geophysical observations; (b) we tried to evaluate a spatial distribution of the geophysical disturbances caused by this geomagnetic storm.

2. Solar activity

This storm started in the period of very high solar activity which was characterized by existence of active region 5395 on the Sun. It produced several powerful solar flares among them are ones at 14.00 UT of March 6 (importance X15/8N), at 21.03 UT of March 12 (importance M6/2N) and at 03.25 UT of March 13 (importance X1/3N). It is known that the solar flares are classified according to their brightness in the X-ray wavelength (X-class-the most intensive, M-class, and C-class). Surprisingly enough only the flare of March 13 of intensity of X-rays in the range 1–8 A° with importance of 10^{-4} (W/m^2) at 03.25 UT initiated impulsive outburst of powerful flux of the solar protons which reached boundary of the Earth magnetosphere after period of $03^h\ 20^m$. According to classification proposed in Laurenza et al. (2006) a flare is considered as impulsive one if so called e-folding time (a time interval over which the flare decreases to 1/10 of its maximum intensity) is less than 1 h. Otherwise the event is a gradual one. The Fig. 1 demonstrates that our X-rays flare caused solar energetic particles. Important conclusion made in Laurenza et al. (2006) is establishing of statistically meaningful fact that impulsive flares of intensity >M 5.0 can give rise to SEPs that arrive to the Earth's orbit within no more than 4 h. Our data confirm this finding very well. So, this storm shows clearly that a powerful SEP could be evidently flare-associated phenomena in spite of many opposite points of view Laurenza et al. (2006). Unfortunately any measurements of the solar corona dynamics were absent at that period therefore it is impossible to say anything about possible birth of the coronal mass ejection (CME) event.

3. The solar energetic particles (SEP) event

Important part of the geomagnetic storm of March 13–14, 1989 was a rather unusual SEP event recorded by the GOES-7 satellite as well as by numerous riometers both in the Northern Canada and in the Russian sector of the Arctic. Weak enhancement of the solar proton flux in energy range 4.2–8.7 MeV started at 18 UT on March 8 and it lasted until 16 UT on March 14 (typical gradual SEP). A sudden impulsive outburst of the giant flux of the energetically soft protons ($Ep = 1$–50 MeV) happened in the period of 05–11 UT on March 13. Maximum of the proton flux intensity was evaluated as equal to 5300 pfu for protons with energy $Ep > 10$ MeV according