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GEOPHYSICAL ACTIVITY DURING TWO SUPERSTORMS ASSOCIATED WITH DIFFERENT HELIOSPHERIC DISTURBANCES

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Abstract. We compared situation on the Sun, in the solar wind, in the Earth magnetosphere and ionosphere during two superstorms: 8-9 February 1986 (minimum *Dst* = - 312 nT) and 13-14 March 1989 (minimum *Dst* = - 600 nT). The equatorward edge of the night side auroral oval according to particle measurements descended to the latitude of 43 degrees for superstorm-86 and to 40 degrees for superstorm-89. The green 557.7-nm emission dominated in the auroras of superstorm-86. The precipitation electron spectrum was comparatively hard (1-30 keV). During superstorm-89, the intensity of the red 630-nm emission exceeded essentially the 557.7-nm emission; the electron spectrum was soft (150-800 eV). An exclusively severe coronal mass ejection (CME) occurred on March, 10, 1989. There were no CMEs on 3-7 February 1986. IMF measurements during these storms were practically absent. One can restore the IMF z-component by using the temporal dependence of *Dst*(t). According to our computations, the average BzIMF was -12 nT during the main phase of superstorm-86 and -31 nT during the main phase of superstorm-89 with spikes down to -100 nT. The electric convection potential drop in the magnetosphere seems to reach sometimes 1000 kV during superstorm- 89.

1. Introduction

A geomagnetic storm develops on the condition of an intensive and long enough southward component of the interplanetary magnetic field (IMF). This component is close to zero in the quiet solar wind. This component appears only if there is an inhomogeneity in the solar wind.

Just recently it was assumed that the main sources of streams of particles in the Sun, provoking the appearance of storms, are solar flares, coronal holes and disappearing filaments [Marubashi, 1989]. However, still bigger number of scientists tend to believe, the source of the space weather disturbance and, in particular, the geomagnetic storms occurrence is so called coronal mass ejection (CME), generated in the solar atmosphere [e.g., Gosling, 1997]. The mass, ejected from the solar corona, amounts to 10^{15}–10^{16} grams, the energy it carries, amounts to 10^{30}–10^{32} ergs, and the velocity of the mass propagation reaches 2000 km/s and more [Zhang and Matsumoto, 1998].

One may expect that different solar sources cause substantially different physical events during geomagnetic storms. For instance, when the Earth is involved into the magnetic cloud (SMC), which is an interplanetary analog of the coronal mass ejection (CME) [Bothmer and Rust, 1997], electrons precipitating into the Earth atmosphere have considerably less energy (~500 eV) than usual [Sivjee and Shen, 1997]. When a geomagnetic disturbance occurs as a result of the solar flare or coronal hole the precipitating electrons and protons have energies of several keV. So various types of aurora luminosity can occur. In the first case, atomic lines prevail in the radiation spectrum, where as in the second case, the main components are neutral and ionized molecule bands. As reported by Gosling [1997], the coronal mass ejection is usually a source of large non-recurrent magnetic storms. In a recent study, Yevlashin and Maltsev [1998] have shown, that red auroral arcs, stipulated by the 630.0 nm emission's luminosity are revealed at the storm main phase, when *Dst* drops quickly, which is usually attributed to the southward IMF component and to intense magnetosphere-ionospheric convection.

The purpose of this study is to find out the nature of auroral luminosity during two geomagnetic superstorms, that were provoked by various heliospheric sources, as well as the estimation of some magnetospheric parameters, in particular, the value of the electric potential drop in the Earth magnetosphere during these geomagnetic superstorms.

2. Experimental auroral research results

Two geomagnetic superstorms were chosen for the analysis of geophysical situation: February 8 – 9, 1986 and March 13-14, 1989. The 1-st one was observed during the period of intense minimum of the solar activity, when the monthly smoothed sunspots number was equal to 15, the second one was revealed during a comparatively high maximum of the solar activity (160).

The storm of February 8-9, 1986, with minimum value of *Dst* = - 312 nT is one of the largest for the last 50 years, of those recorded during solar activity minimums. It was presumably provoked by a series of solar flares of moderate intensity during February 3-7, not accompanied by the coronal mass ejection (CME) [Watanabe, 1989]. The geomagnetic storm main phase is revealed a few hours later, after a considerable increase of the solar wind velocity and the turn of IMF B_z component southwards. The solar wind velocity on February 8 reached a very high level, probably, more than 1200 km/s. [Yamoto et al, 1989; Hamilton et al., 1988]

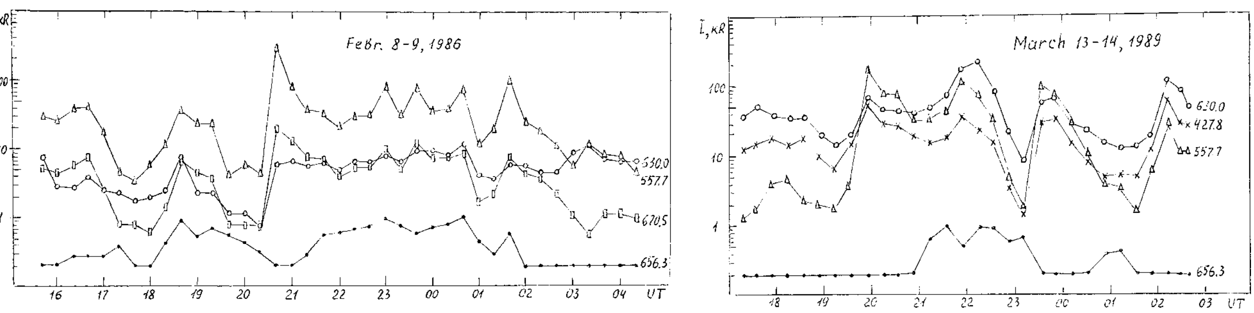
The superstorm of March 13-14, 1989 with minimum value *Dst* = - 600 nT is, in fact, the largest over the last 130 years, if it is estimated after *AA* scale (*AA* = 450) [Allen et al., 1989]. This storm was provoked by considerable solar flare X 4,5/3B, occurred on March 10, accompanied by exceptionally bright coronal mass ejection (CME), the average solar wind velocity being 770 km/s [Feynman and Hundhausen, 1994].

During the storm main phase on February 8-9, 1986 ($\Phi = 64^0$) the transparence of the atmosphere over Loparskaya observatory was good enough, and instrumental and visual observations of auroras were carried out all the night.

The patrol spectrograph C 180-S was used for visible part of the spectrum. The sensitivity of the device made 200 Rayleigh under spectrum exposure for 20 minutes. Fig. 1a represents results of the photometry of basic auroral emissions in spectra for zenith area of Loparskaya observatory. As one may see from Fig. 1a and records from visual observation register during all night of February 8-9, 1986, there were observed bright green of the IBC 3 aurora. Intensity of the green line 557.7 nm constituted a value of ~100 kR, sometimes exceeding it. The intensity ratio $I_{557.7}/I_{630.0}$ was much more than 1. From time to time red type B auroras (with red lower edge) were observed. During this time the 670.5 nm $N_2$1P band intensity exceeded the red oxygen line by 630.0 nm [OI] intensity. There are almost no any data on optical observations of auroras by the world ground-based stations network during the storm 8-9.02.86. Another paper, Rich et al. [1990] reports on bright auroras, observed in the auroral zone and polar cap. The same paper shows, after the DMSP F7 particle measurement data, the equatorial edge of the auroral oval night part reached 43^0 of geomagnetic latitude. Particles flux observations by DMSP F6 and F7 satellites during the of February 8-9, 1986, storm showed that in different sectors of the MLT the precipitating fluxes of comparatively hard electrons and ions (1-30 keV) within broad latitude range prevailed, reaching values of 10^7 cm^{-2} s^{-1} sr^{-1} and 10^6 cm^{-2} s^{-1} sr^{-1}, correspondingly [Swider, 1990].

During the main phase of March 13-14, 1989, storm, instrumental control in Loparskaya observatory ($\Phi = 64^0$) has been taken by the C-180-S patrol spectrograph all the night, as well as visual observations were carried out. The device parameters and shooting conditions remained the same as they used to be during the February 8-9, 1986 storm.

The atmosphere transparency during that night was not good enough, which, however, did not prevent the photographing of aurora spectra. Fig. 1b shows the results of the main aurora emissions photometering in spectra for the Loparskaya zenith area. As one may see from the given figure, mainly red type A auroras were observed during the night of March 13-14, 1989 from 17 UT till 03 UT.



a b

Fig. 1. The zenith intensity of auroral emissions recorded by patrol spectrograph in Loparskaya.
o – λ630.0 nm [OI], Δ – λ557.7 nm [OI], □ – λ670.5 nm $N_2$1Pg, • – λ656.3 nm H_α.

The red oxygen 630.0 nm line intensity reached the value of 300 kR under emissions intensity ratio $I_{630.0}/I_{557.7}$ >> 2.

In the northern part of Canada at Rabbit Lake observatory ($\Phi = 65{,}3^0$) the auroras luminosity during the storm of March 13-14, 1989 was analogous to the one, observed at the Loparskaya observatory [McEwen, 1992].

The red type A auroras appeared above the Rabbit Lake observatory at 03 UT on March 13 and were recorded till 07 UT on March 14. The red 630.0 nm emission intensity reached the value of 130 kR right after the storm beginning at 03.47 UT on March 13. During the following night the red oxygen line intensity did not exceed 30 kR. The HILAT satellite, passing over the Rabbit Lake observatory at 04.15 on March 14, registered the increase of electrons within the interval of 150-800 eV. The integral flux of electrons reached the value of 10 erg s^{-1} cm^{-2} sr^{-1}. The proton flux, judging by the hydrogen emission intensity measurment of 486.1 nm (maximum value on March 13 was 350 R and on March 14–200R), was not large.

An exclusively broad area of aurora luminosity was registered by ground-based stations in the middle and lower latitudes and by the DE-1, DMSP satellites as well [Allen et al., 1989]. The bright types were observed over the US territory during the nights of March 12-13 and March 13-14. The observers noticed auroras in the states of New York, New Jersey, Colorado, Texas, New Mexico, Arizona, California, Florida. Bright green, blue and white types of auroras were observed over the eastern part of the US, and the red ones, type A auroras were mainly observed in the southern states. In England, auroras were observed southwards of London as red diffuse luminosity. The southern Australia was covered with clouds, and just over its northern part on the night of March 13-14 it was possible to observe red type A auroras. Over the former Soviet Union auroras were observed in Georgian republic [Toroshelidze and Fishkova, 1989] and in the Crimea [Levina, 1989]. In the night of March 13-14, 1989, after Abastumani astrophysical observatory, the luminosity appeared at about 01 Moscow Time. It spread from the north-west north-eastwards, reaching the zenith distance of 45^0, it was uniformly diffuse, its brightness differing from one part to another, its color varying from lightred (as a fire glare) to dark-red. The quality estimation of the luminosity intensity revealed the value of a few dozens of kilo Rayleighs in emission of 630.0 nm.

In the Crimea, bright luminosity similar to a fire glow was observed. The luminosity was covering half sky, shining with bright yellow and red rays, coming from far away (00.45 till 01.15 Moscow Time).

The equatorial edge of auroral oval night side, after the data of particles measurements by DMSP F7 satellite shifted till 40^0 of geomagnetic latitude [Rich and Denig, 1992].

3. Magnetic field in the solar wind

The information on the solar wind parameters on March 13-14, 1989 is not available. During the storm on February 8-9, 1986, only single IMF measurements are available. The IMF southward component can be approximately restored with the help of empiric equation [Rezhenov and Maltsev, 1998]

$$\frac{dDst_0}{dt} = 1.2B_s - \frac{Dst_0 + 20}{12.5} \qquad (1)$$

where

$$Dst_0 = Dst - 0.02\sqrt{nV^2} + 20 \qquad (2)$$

is the ram pressure corrected *Dst*-index, in nT.

The proton density in the solar wind n is in cm^{-3}, the velocity V in km/s, the southward IMF component B_s in nT ($B_s = B_z$ for $B_z < 0$; $B_s = 0$ for $B_z > 0$), t is time in hours.

The joint contribution of the last two components in (2) constitutes several percents during strong storms, that's why we assume

$$Dst_0 \approx Dst \qquad (3)$$

In the top panel of Fig. 2, the behavior of *Dst*-index during the main phase of two superstorms on February 8-9, 1986 and on March 13-14, 1989 is shown. In the middle panel of the same figure the conduct of the southward IMF component is shown, as restored by equation (1), taking into consideration the (3). Squares stand for the measured values of IMF Bz component. It is obvious, that the computations do not differ much from the measurements. The positive Bs do not carry any physical sense and give a picture of computation accuracy.

During the main phase, on the average, each superstorm makes $<B_z>$ = -12 nT for February 8-9, 1986 storm and $<B_z>$ = -31 nT for March 13, 1989 storm. The increase of southward IMF component up to ~−100 nT occurred by the end of the 89' storm main phase.

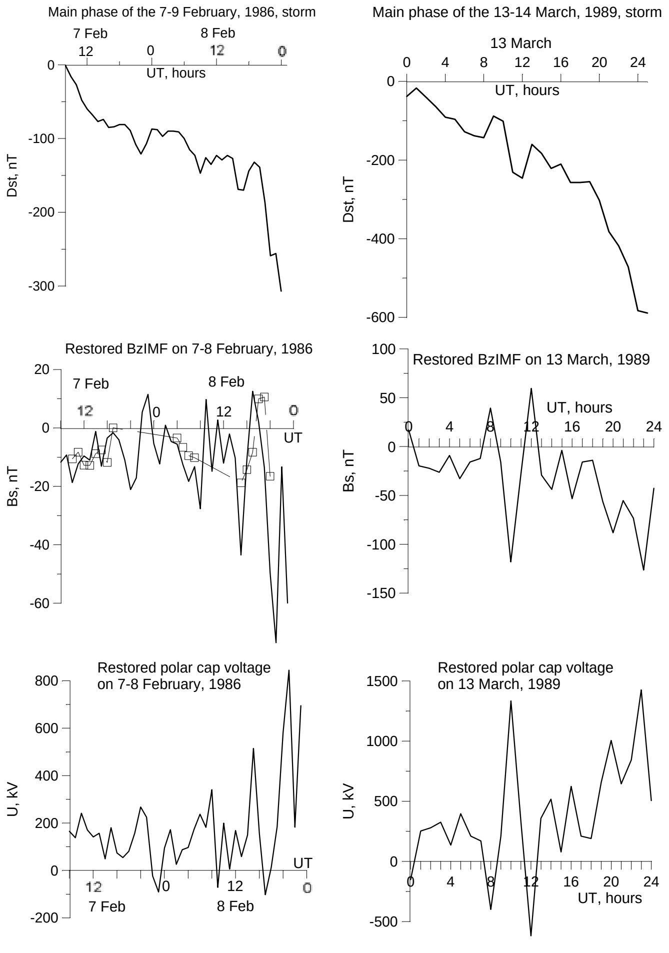


Fig. 2. *Dst* variation as well as the restored B_zIMF and the convection potential.

4. Ionospheric convection

Doyle and Burke [1983] obtained an empiric relation of the U_{pc} potential difference between the morning and evening sides of the polar cap with IMF Bz component:

$$U_{pc} = -11B_z + 35.8 \qquad (4)$$

where U_{pc} is in kV, B_z is in nT.

In the bottom panel of Fig. 2, the probable conduct of potentials difference during two superstorms, restored from the middle panel of the figure and equation (4). One can see that the ionospheric convection at the end of the main phase of the storm on March 13-14, 1989 could reach extreme values ($U_{pc} \approx$ 1000 kV). The typical potential difference between the dawn and dusk sides of the polar cap under quiet conditions is ~50 kV.

The potential difference of 1000 kV could have provoked the dramatic change in the ionosphere. In scientific periodicals, we managed to find information on the ionospheric electric fields only for UT ≈ 1110 – 1130 [Okada et al., 1993]. According to the middle right panel of Fig. 2, a short-time U_{pc} leap, of about 1200 kV, occurred at 10 UT, however at 11 UT the convection potential difference dropped a few times. Nevertheless, the convection at 11.30 UT is featured as an intense one by Okada et al. [1993].

We should note, there were reports on the very strong electric field during other storms. For instance, Wygant et al. [1998] discovered, that during the storm of March 24, 1991 electric field in the magnetosphere at distances L = 2-6, increased by 60 times compared to the quiet level. During observations of the strong field, *Dst* fell quickly ($dDst/dt \approx$ -50 nT/hr).

The storm of February 8-9, 1986 was not accompanied by an extreme increase of convection, because of the comparatively slow intensification of geomagnetic depression (-300 nT during 40 hours). Depression on March 13-14, 1989 was increasing much faster (-600 nT in 24 hours).

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