ON THE RELATIONSHIP BETWEEN CORONAL MASS EJECTIONS, SOLAR FLARES, SOME MAGNETOSPHERIC PARAMETERS AND AURORAS OF DIFFERENT TYPES, DURING GIANT MAGNETIC STORMS

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Abstract. There were analyzed 7 giant magnetic storms, during which the minimum value of Dst variation $< 250$ nT: Febr. 8-9, 1986; March 13-14, 1989; Oct. 21-22, 1989; March 24-25, 1991; Oct. 28-29, 1991, Nov. 8-9, 1991 and Febr. 10-11, 1958. All of these superstorms were preceded by solar flares and, in some events, by the Coronal Mass Ejections (CMEs) as well. During these superstorms, over large areas of the Earth, there were registered bright auroras, the luminosity spectrum of which depended on the type of heliospheric source responsible for one or another type of superstorm as well as on different properties of the upper atmosphere. In some events bright green auroras, while in others the type A red ones, were observed. Some suggestions have been made as to the nature and mechanisms of origin of similar types of luminosity. On the basis of the temporal Dst variation, there were restored values of IMF Bz-component, as well as the estimates of the voltage difference across the Polar cap were performed. Quite large values of the voltage difference were obtained which agrees fairly well with the results of some experiments.

Introduction

Magnetic storms, during which the minimum value of Dst variation $< 250$ nT, are now commonly called giant ones or just superstorms /1/. It was just recently that it became clear, that a most important source of space weather disturbances were immense mass ejections from the Sun’s corona, i.e. coronal mass ejections (CMEs) /5/. The amount of the mass, ejected by the solar corona makes the value of $\sim 10^{15}$ $10^{16}$ gram, the energy it carries approaches $10^{32}$-$10^{33}$ erg. It is well known now, that a geomagnetic storm usually develops on the condition of an intense and long enough southern component of the interplanetary magnetic field (IMF). Coincidentally with geomagnetic storms in the Earth’s atmosphere there occur ionospheric disturbances, short wave communication blackouts, intense auroras, both in auroral and in the middle and lower latitudes as well as technogenic hazards /7/.

Yet relatively a long while ago it was known that the red type A auroras (luminosity, in the spectrum of which 630.0-636.4 nm emissions prevail) occur mainly in the years of high solar activity, whereas the red auroras of type B (basic emissions in their spectrum are PGN2) occurred in years of low activity of the Sun. The recent statistic studies /8/ showed, that in the period from 1749 to 1992 the frequency of occurrence of red type A auroras agrees well with the 11-year cycle of the solar activity. Such auroras always appear in the years of high solar activity and almost disappear in the years of minimum solar activity. The paper /9/ considers the spectra of low latitude auroras (these used to be mainly the red type A auroras), registered during the last 60 years, and there were determined their basic spectrum regularities: (1) excitation of emissions of the first negative system N$_2^{-}$ with high vibrational development bands, (2) a large value of the ratio of forbidden lines intensities of 630.0 nm atomic oxygen to 557.7 nm, (3) the prevailing presence in the spectra of atomic and ion O, O$^+$, N and N$^+$ lines compared to molecular bands.

Concerning the red type A auroras, observed in auroral regions, spectrum characteristics of auroras of that kind are similar to the ones, observed in the middle latitudes as well /10,11,12/.

Heliogeophysical situation, connected to the considered superstorms

There were picked 6 superstorms in order to enlarge our knowledge about the nature of giant magnetic storms and causes of auroras, accompanying them, as during those superstorms instrumental observations of auroras were possible, at least, at Loparskaya station (autumn, winter, spring, moonless nights with clear enough atmosphere), as well as there was at least minor possibility to obtain information about such non-typical solar phenomenon as coronal ejection of mass (CMEs). These turned out to be storms, that took place during the 22-d cycle of solar activity. For comparative analysis there was also picked the superstorm, which took place in the IGY 10-11.02.1958 at the maximum of the 19-th abnormally high cycle of the Sun activity, when numerous world observatories were registering very intense red type A auroras (see, for instance, /8, 15, 17, 22, 23/). The list of these storms, as well as phenomena, preceding their appearance, and some parameters of the solar wind, magnetosphere and atmosphere of the Earth are all included in Table 1.

Effects in the upper atmosphere during superstorms

Cole /20/, when developing his idea about the excitation of red oxygen lines in the middle latitude auroras at the expense of suprathermal electrons, suggested a formula, using which, as he believed, one could estimate the intensity of a red oxygen line:
\[ I_{630.0} = \int_{h_0}^{\infty} n_e n(O) A(T_e) dh \]

where \( I_{630.0} \) is the height integrated red line emission; \( n_e \) is the electron density; \( n(O) \) is the atomic oxygen density; \( T_e \) is the electron temperature; \( A(T_e) \) is the rate coefficient of excitation of atomic oxygen to D-state; \( h_0 \) is the altitudes at which deactivation sets in.

According to experimental data /10,18/ the maximum of 630.0 emission intensity in the red Type A auroras is located at the height of 350 km. That is why, using the model MSIS-86 /25/ there was estimated the concentration of atomic oxygen \( O \) for the height of 350 km at the moments, when at Loparskaya station there were carried out spectrographic observations and there was registered the maximum of 630.0 nm emission intensity. The obtained results are provided in Table 1.

Fig. 1 shows the dependence of \( I_{630.0} \) on the estimated concentration of atomic oxygen at the height of 350 km. As one can see from figure below, there is a direct dependence of \( I_{630.0} \) on the concentration of \( O \). In two events, when there were obtained very high values of \( I_{630.0} \) during the experiment (10-11.02.1958 and 13-14.03.1989) the given regularity is broken. This, first, can be connected with the fact, other parameters, mentioned in the Cole formula, were not taken into consideration, or just with inapplicability of the given dependence for events of very intense precipitation of low energy electrons in the auroral zone.

![Fig. 1. Dependence of the depression of the magnetic field on min Dst.](image1)

![Fig. 2. Dependence of \( I_{630.0} \) on the concentration of \( O \) at the height of 350 km](image2)

Table 1. Solar, geophysical and some other parameters

<table>
<thead>
<tr>
<th>№</th>
<th>Date of storm</th>
<th>( F_{10.7} )</th>
<th>Flares</th>
<th>Association with CME</th>
<th>Min Dst, NT</th>
<th>( \Delta Dst/dt )</th>
<th>SSC</th>
<th>UT</th>
<th>V km/s</th>
<th>( B_z )</th>
<th>Measur.</th>
<th>( U_{max} )</th>
<th>Equator. Boundary ( \Phi )</th>
<th>Concentr. O part./cm(^3)</th>
<th>( I_{630.0} ) kR</th>
<th>( I_{557.7} ) kR</th>
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<tr>
<td>1</td>
<td>08-09.02.86</td>
<td>102</td>
<td>3BX1,7</td>
<td>no</td>
<td>-312</td>
<td>-14.7</td>
<td>11(^b)13(^m)</td>
<td>7.02</td>
<td>up to 1200</td>
<td>-20</td>
<td>800</td>
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<td>14.03.89</td>
<td>235</td>
<td>yes</td>
<td>-600</td>
<td>-70.0</td>
<td>02(^b)15(^m)</td>
<td>13.03</td>
<td>1000</td>
<td>-</td>
<td>1200</td>
<td>01</td>
<td>3,65(8)</td>
<td>200</td>
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<td>216</td>
<td>4BX13,0</td>
<td>yes</td>
<td>-270</td>
<td>-16.7</td>
<td>08(^b)47(^m)</td>
<td>21.10</td>
<td>800</td>
<td>-</td>
<td>&gt;300</td>
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<td>-</td>
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<td>250</td>
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<td>8.11</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>~35</td>
<td>4,55(8)</td>
<td>~2500</td>
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Table 1. Solar, geophysical and some other parameters
Our goal is to study the relationship between the development of superstorms and certain parameters of the Earth’s atmosphere and magnetosphere. For this purpose, we have analyzed a complex of heliogeophysical data, related to 7 giant storms, when min Dst < -250 nT: 08-09.02.1986, 13-14.03.1989, 21-22.10.1989, 24-25.03.1991, 28-29.10.1991, 08-09.11.1991 and 10-11.02.1958. All of the studied storms had been preceded by solar flares of various intensity, in most events, accompanied by coronal mass ejections (CMEs). An immediate condition of these superstorms development was the appearance of an intense enough and long-lasting southern component of the interplanetary magnetic field (IMF). During the main phase of those superstorms over the vast territories of the Earth there were registered bright auroras the spectrum of which depended on both the type of heliospheric source and the magnitude of solar activity. So, for instance, during the superstorm of 08-09.02.1986, a period of very low solar activity there were observed only green 3 IBC auroras with the ratio of emissions in the spectrum being $I_{557.7} / I_{630.0} >> 1$.

In all other events superstorms revealed themselves in periods of high solar activity, were caused by solar flares and, as a rule, by coronal mass ejections (CMEs), accompanying them.

During the development of main phases of superstorms, there were observed global red type A auroras, in spectra of which the ratio of $I_{630.0} / I_{557.7}$ exceeded 2. On February 11, 1958, there was registered an abnormally high value of the emission intensity $630.0 \text{ nm}= 10^9 \text{ rayleighs}$, whereas the intensity of the green line $557.7 \text{ nm}$ made only $10^5 \text{ rayleighs}$. 

**Southward IMF component and ionospheric convection**

Due to the fact, that during superstorms, as a rule, the data are either fragmentary or just absent, there were restored of some parameters, using the time dependence of the Dst variation during the storms. According to hourly data for 27 years (from 1963 to 1990) there was found a statistic relation of the IMF $z$-component with the values of Dst index for the current and subsequent hours. The relation can be approximated by the formula (24):

$$B_z(t) = 0.443 - 0.265 \text{ Dst}(t) + 0.306 \text{ Dst}(t+1) + 0.00263 \text{ Dst}(t)^2 - 0.0046 \text{ x Dst}(t) \text{ Dst}(t+1) + 0.00196 \text{ Dst}(t+1)^2 \pm 2.92,$$

where $t$ is in hours. The given formula may be used for restoration of the IMF $z$-component during the hours, when no measurements of the latter were done. There was also reconstructed the course of change of potential difference across the Polar cap by the known empirical formula (25):

$$U_{\text{pc}} = -11 B_z + 35.8,$$

where $U_{\text{pc}}$ is expressed in kV, $B_z$ in nT. The difference in potentials across the Polar cap during the considered superstorms is given in Table 1.

**Discussion and summary**

What are, in principle, conceivable mechanisms of the appearance of red type A auroras? Cole /13/ suggested a hypothesis, according to which the excitation of red oxygen emissions 630.0-636.4 nm in the middle latitudes is performed owing to high temperature electrons, energized because of electric fields or a hypothetical source, which is somewhere in the magnetosphere. The hypothesis of the luminosity excitation at the expense of electric fields was also considered by Walker and Rees /14/, but they drew a conclusion, that this idea should not be supported, as even under the expense of electric fields was also considered by Walker and Rees /14/, but they drew a conclusion, that this idea should not be supported, as even under the expense of electric fields was also considered by Walker and Rees /14/, but they drew a conclusion, that this idea should not be supported, as even under the expense of electric fields was also considered by Walker and Rees /14/, but they drew a conclusion, that this idea should not be supported, as even under the expense of electric fields was also considered by Walker and Rees /14/, but they drew a conclusion, that this idea should not be supported, as even under...
By the results of the study one can conclude, that for global red type A auroras to occur, there are, at least, two conditions needed:
1. The availability of a coronal mass ejection (CME) from the solar atmosphere and
2. A higher than usual concentration of atomic oxygen in the region of F-ionosphere, which is observed only in the years of high solar activity. The low energy electrons (E < 1 keV) should be considered an immediate source of excitation of red type A auroras luminosity.

As a rule, data on the parameters of the solar wind and the interplanetary magnetic field during these storms were either absent or fragmentary. That is why, using the available information on variations of the Dst parameter of the magnetic field and some empiric formulas, the time dependence of the Bz-component of the IMF was theoretically restored, as well as the estimation of the voltage difference across the polar cap during the main phases of the studied superstorms was carried out. There were obtained very large maximum values of voltage difference (100-1200 keV), which agrees well enough with the results of the available experiments.

References
On the relationship between coronal mass ejections, solar flares, some magnetospheric parameters and auroras of different types, during giant magnetic storms