"Physics of Auroral Phenomena", Proc. XXV Annual Seminar, Apatity, pp.37-40, 2002

Polar Geophysical Institute

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

L.S.Yevlashin, Yu.P.Maltsev (*Polar Geophysical Institute, Apatity, Murmansk region, Russia)*

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 (CME) /5/. The amount of the mass, ejected by the solar corona makes the value of ~ 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 $1PGN_2$) 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 (CME_s). 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:

$$I_{630.0} = \int_{h=0}^{\infty} n_e n(O) A(T_e) dh \quad ,$$

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.

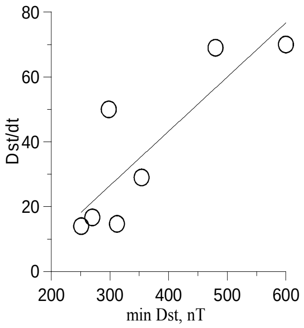

Fig. 1. Dependence of the depression of the magnetic field on min Dst.

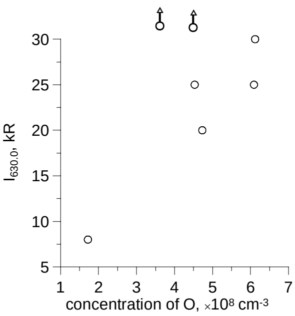

Fig. 2. Dependence of $I_{630.0}$ on the concentration of O at the height of 350 km

Table 1. Solar, geophysical and some other parameters

№ №	1	2	3	4	5	6	7
Date of storm	08-09.02.86	13-14.03.89	21-22.10.89	24-25.03.91	28-29.10.91	08-09.11.91	10-11.02.58
$F_{10.7}$ 10^{-22} W m^{-2} Hz^{-1}	102	235	216	235	250	200	285
Flares	3BX1,7 2BM5,2	3BX4,5	4BX13,0	3BX9,8	3BX6,1	SNM1,2 1BM2,8	2B
Association with CME	no	yes	yes	Yes	Yes	No	?
Min Dst, NT	-312	-600	-270	-298	-251	-354	-480
DDst/dt nT/hr	-14.7	-70.0	-16.7	-50.0	-14.0	-29.0	-69.0
SSC UT	11^h13^m 7.02	02^h15^m 13.03	08^h47^m 21.10	03^h42^m 24.03	-	06^h47^m 8.11	01^h26^m 11.02
V km/s	up to 1200	1000	800	-	-	-	-
B_z Measur.	-20	-	-20	-	-20	-5	-
U_{max} restor. KV	800	1200	>300	700	>300	>300	-
Equator. Boundary Φ^o	40	40	45	50	-	40	~35
LT hr.	23	01	19	23	19	19	06
Concentr. O part./cm^3	1,72(8)	3,65(8)	6,09(8)	4,53(8)	6,12(8)	4,73(8)	4,55(8)
$I_{630.0}$ kR	8	200	25	25	30	20	~2500
$I_{557.7}$ kR	300	20	10	10	12	8	~1000

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/:

$$Bz(t) = 0.443 - 0.265\ Dst(t) + 0.306\ Dst(t+1) + 0.00263\ Dst(t)^2 - 0.0046 \times Dst(t)\ Dst(t+1) + 0.00196\ Dst(t+1)^2 \pm 2.92,$$

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/.

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

where U_{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 middle intensities of the 630,0 nm emission, the ion temperature should reach the value of about 5000^0 at heights around 200 km, the fact, that has never been observed, even during very large auroras. Krassovski /15/ suggested the excitation of the red emission took place at the expense of intense heating of the upper atmosphere higher than the F_2 layer maximum near exosphere by infrasound waves, appearing in the region of jets, i.e. in the region of common auroras. This hypothesis is partly confirmed by the reported appearance of higher than usual temperature during observations of large red type A auroras /9,16,17/. Unfortunately, all those hypotheses, implying the excitation of 630.0-636.4 nm emissions by electrons of very low energies (2-4 eV) can not explain the appearance of the red type A auroras spectra, where, as said above, there were practically always present $1NGN_2^+$ emissions, which require the availability of energetic enough electrons (~ 20 eV) for their excitation.

Concerning the possibility of luminosity spectra excitation of the red type A aurora, precipitated as fluxes of aurora protons, for the corresponding red lines 630.0-636.4 nm intensities, reaching tens of kilorayleighs to be provided, proton fluxes of such density are needed, which would undoubtedly be found in the region of middle latitudes by the increase of intensity of Hα and Hβ hydrogen lines /9/. In the upper latitudes, although, coincidentally with the observed forms of red type A auroras there were registered proton fluxes of sufficient intensity in the first event /18/ or an intense Hα hydrogen emission in the second one /19/, it should be noted, that in both of those events, the studied phenomena were separated by large distances, which excluded their possible connection.

Thus, it remains to suggest, the most probable source of the red type A aurora generation are low energy electrons. Electron fluxes within the wide energy range had previously been observed in abundance in the Earth’s magnetosphere, but in a recent paper /20/ the authors tried to connect the fact of the presence of electrons of the large range of spectrum (30 eV<E<30 keV) to observations of middle latitudes red auroras. In a paper /21/ there was reported a large amount of superheated electrons found (100 eV - 1500 eV) by ACE satellite, that was at the distance of 1AU, due to the coronal mass ejection (CME_s).

There was analyzed and generalized 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 (CME_s). 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 (CME $_s$), accompanying them.

During the development of main phases of superstorms, there were observed global red type A auroras, in spectra of which the ration of $I_{630.0} / I_{557.7}$ exceeded 2. On February 11, 1958, there was registered an abnormally high value of the emission intensity630,0 nm= 10^8 rayleighs, whereas the intensity of the green line 557.7 nm made only 10^5 rayleighs.

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

1. Loewe C.A., Prolss G.W. Classification and mean behavior of magnetic storms // J.Geophys.Res. - 1997. – 102. - N A7. – P.14209-14213.
2. Gosling J.T. Coronal Mass Ejections: An Overview in Coronal Mass Ejections, editted by N.Crooker, J.A.Joselyn and J.Feynman // Geophys. Monogr. – 1997. – 99. – Amer.Geophys. Union. – P. 9-16.
3. Allen J., Sauer H., Frank L., Reiff P. Effect on March 1989 solar activity // EOS Trans.AGU. – 1989. - N 46. – P. 1479, 1486-1488.
4. Yevlashin L.S. Space-time variations of red type A auroras: Proceedings of the 25th Annual European Meeting. – Granada. – Spain. – 1999, 21-25 September. – P. 95-98.
5. Tinsley B.A., Rohrbaugh R.R., Rassonl H. et al. Low latitude aurorae and storm time current systems // J.Geophys.Res. – 1986. – 91. – N A10. – P. 11257-11269.
6. Rees M.H., Deehr C.S. The aurora of the 27 November 1959 of College, Alaska including observations of the high latitude red arc // Planet.Space.Sci. – 1961. – 8. – N 1. – P. 49-58.
7. McEwen D.J. Photometric studies of the great aurora March 13 and 14, 1989 // Can.J.Phys. – 1992. – 70. – N 2. – P. 526-531.
8. Yevlashin L.S. Spectral characteristics of great auroras during two superstorms // Phys. Chem. Earth (B). – 2000. – 25. – N 5-6. – P. 565-568.
9. Cole K.D. Magnetic storms and associated phenomena // Space Science Rev. – 1966. – V. 5. – N 4. – P. 699-770.
10. Walker J.C.C., Rees M.H. Ionospheric electron densities and temperatures in aurora // Planetary Space Sci. – 1968. – V. 16. – N 4. – P. 459-475.
11. Krassovsky V.I. Heating of the Upper Atmosphere during Geomagnetic Disturbances. Nature. – v. 217., N 5134, p.1136-1157, 1968.
12. Mulyarchik T.M. Interferometric Measurements of the Widths of the Emissions (0I) 6300 A and 5198-5200 A (NI) in the Polar Aurora, Doklady Acad. Sci. USSR, v. 130, N 2< 303-305, 1960.
13. Yevlashin L.S. Prominent Polar Aurora 11.02.1950. Geomag. And Aeronomy (in Russian), v. 2, N 1, 74-78, 1962.
14. Shepherd G.G., Brace L.H., Burrows J.R. et al. An unusial SAR arc observed during current development 4 August 1972 // Planet. Space Sci. – 1980. – 28. – N 1. – P. 69-84.
15. Yevlashin L.S. Monochomatic Morphology of Polar Aurora According to the Data of the Patrol Spectrograph in Murmansk, Polar Aurora (in Russian), Moscow, Nauka, N 19, 12-26, 1970.
16. Shiokawa K., Meng C.-I., Reeves C.D. et al. A multievent study of broadband electrons observed by the DMSP satellites at midlatitude stations // J.Geophys.Res. – 1997. – 102. – N 17. – P. 14237-14253.
17. Skoung R.M., Feldman W.C., Gosling J.T. et al. Solar wind electron characteristics inside and outside coronal mass ejections // J.Geophys.Res. – 2000. – 105. – N A10. – P. 23069-23084.
18. Manring E.R., Pettit H.B. Photometric observations of the 5577 and 6300 emissions made during the aurora of February 10-11, 1958 // J.Geophys.Res. – 1959. – V. 64. – N 2. – P. 149-153.
19. Clark K.C., Belon A.E. Spectroscopic observations of the great aurora of the 10 February 1958 – I Abnormal vibration of N_2^+ // J.Atmosph. Terrest.Phys. – 1959. – V.16. – N 2. – P. 205-219.
20. Cole K.D. Magnetospheric processes leading to mid-latitude auroras // Ann. Geophys. – 1970. – 26. – N 1. – P 187-193.
21. Hedin A.E. MSIS-86 Thermospheric Model // J.Geophys. Res. – 1987. – 92. – N A5. – P. 4649-4662.
22. Dubey S.C., Mishra A.P. Study of CME_s associated intense geomagnetic storms observed during solar maximum 1989-1991 // Indian J.Phys. – 1999. - 73B(5). – P.701-709.
23. Riley Pete, Gosling J.T., McComas D.J., Forsyth R.J. Properties and radial trends of coronal mass eject and their associated shocks observed by Ulysses in the ecliptic plane // J.Geophys.Res. – 2000. – 105. – N A6. – 12617-12626.
24. Maltsev Yu.P., and Golovchanskaya I.V. Parameters influencing the growth and fall of the regular part of the AE index (in Russian). Geomag. and Aeronomy (in press, 2002).
25. Doyle M.A., Burke W.I. S3-2 measurements of the polar cap potential // J.Geophys.Res. – 1983. – V.88. – N 5. – P. 9125-9133.