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Investigation of ground level solar cosmic ray enhancements by means of Alma-Ata high-altitude neutron monitor

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Abstract. We analyze ground level solar cosmic ray enhancements (GLE) registered by means of Alma-Ata high-altitude neutron monitor during 1976-2001 years. This includes the observation at the Earth of high energy protons, generated by the powerful solar flares. It is presented the table of these events. Alma-Ata high altitude neutron monitor has a favorable location (3340 m above sea level) and very good statistics (about 1200 counts per second). The analysis of ground level enhancements and solar sources of these events connected with coronal mass ejections (CME) are carried out. It is shown that the solar activity responsible for the considered ground level enhancements extends throughout large areas on the solar disk and includes large CMEs. This may tell on the conditions of the escape and propagation of high-energy particles accelerated in flares.

1 Introduction

The observation at the Earth of solar protons generated during powerful solar flares allows us to obtain unique information on the Sun's flare process and particle acceleration mechanisms. The Alma-Ata-B high-altitude neutron monitor (Institute of Ionosphere, Republic of Kazakhstan) has a favorable location and very good statistics (about 1200 counts per second) to detect different cosmic ray effects. The combination of geomagnetic cut-off rigidity (6.7 GV) and high altitude (3340 m above sea level) makes our station enable to record GLE for the events where maximal rigidity of the protons exceeds 6.7 GV (kinetic energy 5.8 GeV). The high statistical accuracy of the 18 tube NM64 Alma-Ata neutron monitor makes space (Kahler, 1996; Cane at al., 1988, Reames at al., 1999). The most relativistic solar proton events have maximal energy possible detection GLE at this geomagnetic latitude to estimate the upper energy threshold of particles accelerated in the solar flare. These processes are connected with CME and other phenomena on the Sun and in the interplanetary of particle close to this cut-off value, so the Alma-Ata station is ideal for detecting upper energy limit in many relativistic proton events. The upper energy limits for GLE 12.10.1981, 26.11.1982 and 7.12.1982 were estimated as 9±1, 11±2 and 9.5±1.5 respectively (Zusmanovich and Shvartsman, 1989). Although recorded magnitudes of GLEs are usually very small at these geomagnetic latitudes the high statistical accuracy make possible detection of these events at this point.

2 The analysis of some events

During 1976-2001 years there were recorded 25 GLE events by means of high altitude Alma-Ata neutron monitor. The catalogue of these events with performance data are presented in Table 1.

2.1 The GLE Event of September 29, 1989

This one of the most powerful GLEs with the peak amplitude of 344.4 % is identified with the 2N/X9.8 flare (~ 11:30 UT) in the AR 5698 located behind the south-west limb (S24 W>90). On the H-alpha heliogram, the top of the optical ejection or loops is visible. The corresponding CME was observed as a large trans-equatorial loop. Therefore, the flare is only a part of much more large-scale activity involving both the south and north hemispheres. This is the most powerful GLE was recorded by means of Alma-Ata

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Table 1. Ground level solar cosmic ray enhancements by data of high-altitude neutron monitor Alma-Ata B

GLE number	Date	Location	Type	Beginning, UT	Maximum, UT	Amplitude, %
27	30.04.76	S 08 W 046	1B/X2	21:35	21:50	0.5
29	24.09.77	N 10 W 120	—	06:30	06:50	0.7
30	22.11.77	N 24 W 040	2B/X1	10:00	11:00	0.6
31	07.05.78	N 23 W 072	1B/X2	03:40	03:45	2.0
32	23.09.78	N 35 W 050	3B/X1	10:25	10:25	0.4
33	21.08.79	N 17 W 040	2B/C6	06:00	06:20	0.7
36	12.10.81	S 22 E 035	3B/X3.1	06:30	07:20	1.4
37	26.11.82	S 12 W 084	SN/X4.5	02:50	02:55	0.8
38	07.12.82	S 19 W 086	1B/X2.8	23:55	00:05	1.6
39	16.02.84	W 132	—	09:05	09:15	0.9
41	16.08.89	S 18 W 084	2N/X20	02:40	07:10	2.1
42	29.09.89	S 24 W 105	2N/X9.8	11:40	12:10	151.2
43	19.10.89	S 27 E 010	4B/X13	13:35	14:25	1.2
44	22.10.89	S 27 W 031	2B/X2.9	18:30	18:40	0.6
45	24.10.89	S 30 W 057	3B/X5.7	18:25	19:30	3.3
46	15.11.89	N 11 W 026	3B/X3.2	08:05	08:10	0.8
47	21.05.90	N 35 W 036	2B/X5.5	22:40	23:00	2.3
48	24.05.90	N 33 W 078	1B/X9.3	21:05	21:15	3.4
49	26.05.90	W 010	X1.4	21:20	22:30	2.7
50	28.05.90	W 012	C1	05:10	05:40	0.8
52	15.06.91	N 33 W 069	3B/X12	10:05	10:25	4.9
53	25.06.92	N 09 W 087	3B/X3.9	23:10	23:15	0.6
55	06.11.97	S 18 W 063	2B/X9.4	12:28	13:02	1.6
60	15.04.01	S 20 W 85	2B/X14.4	13:56	14:19	3.5
61	18.04.01	W115	C2.2	03:07	04:14	1.5

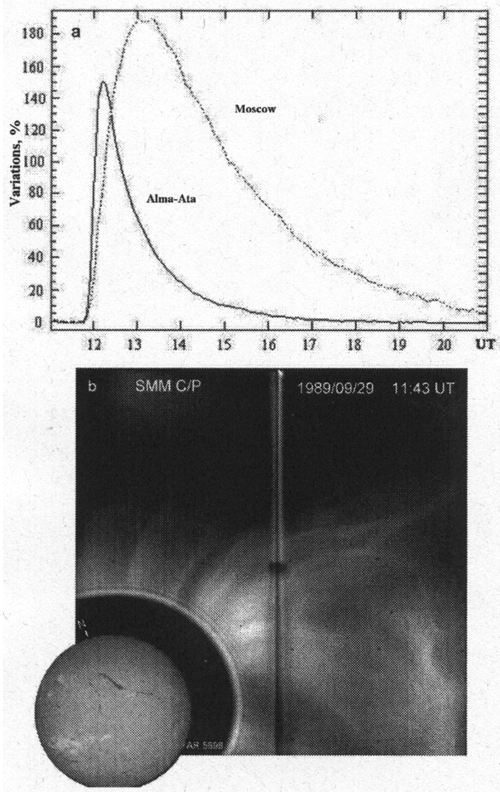

Fig.1. The GLE Event of September 29, 1989.

monitor. The amplitude of this event was 151.2 %. Figure1 demonstrates (a) – cosmic ray flux enhancement on the neutron Alma-Ata and Moscow monitors; (b) - the CME by data of SMM C/P (House et al., 1981) and the H-alpha heliogram of the Holloman observatory at 16:52 UT.

2.2 The GLE Event of November 6, 1997

This GLE which was observed by means of high-altitude neutron monitor at Alma-Ata, is very interesting. This powerful flare-transient event in the Sun and GLE of the solar cosmic rays occurred near the minimum of the solar activity and it is rather unexpected and rare event. Even much weaker proton events are observed extremely rarely throughout period of solar activity minimum. For instance similar event took place on November 4, 1997 (two days before GLE of November 6, 1997). This event is connected with activity at the same region of the disk including the 2B/X2.1 flare at the activity region AR 8100 (S14W33) with maximum at 05:57 UT and CME in form of structural halo, i.e. transient which is transported towards the Earth. The proton increase corresponding to this flare was registered only by satellites and was characterized by maximum proton flux J(>10 MeV) ~ 72 $sm^{-2}s^{-1}sr^{-1}$. The event of November 6 was more powerful by solar activity and was accompanied by considerable increase of proton flux both by GOES-9 satellite and by many ground based neutron monitors including high-altitude station Alma-Ata B. The flare corresponding to this event occurred at the region AR 8100 too. This flare was situated not far from the west limb at the region with coordinates S18W63 which is favorable for direct propagation of particles towards the Earth along spiral force lines of the interplanetary magnetic field. The 2B/X9.4 flare had the maximum at 11:53 UT. At the same time large CME in form of bright loop widening above western limb was also detected by SOHO/LASCO

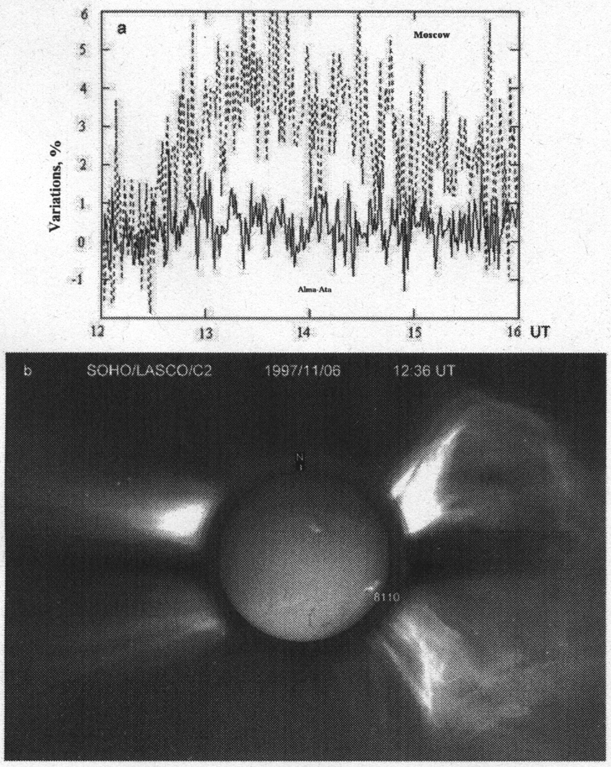

Fig.2. GLE Event of November 6, 1997.

coronographs in white light. It is important that the CME covered large region of latitudes both at the south hemisphere and at the north one, where the luminescence in white light was more intensive than above the south region. It means that large region of solar atmosphere much exceeding typical flare dimension and AR 8100 region was involved to the process of CME eruption and post-eruption energy. At centimeter range powerful microwave burst rather long (tens minutes) took place during this event according to data of IZMIRAN (Troitsk). Increase of cosmic ray flux had maximum intensity J(>10 MeV) ~ 490 $sm^{-2}s^{-1}sr^{-1}$ in the range of low energies (10 - 100 MeV). Due to hard energy spectrum this increase of proton flux gave also appreciable burst registered by neutron monitors in range of high energies. Neutron monitors of high latitudes recorded appreciable GLEs, just as it was to be expected. That was more than 10 % at the Apatity, 9.5 % at Tixie, 5 % at Moscow. Appreciable increases were observed also by neutron monitors of world-wide network: Calgary, Goose Bay 12 %, Kiel, Climax 5 %. It is necessary to note that small GLE ~ 1 % was observed also at high-altitude neutron monitor of the Institute of Ionosphere. It was detected exclusively due to high statistical exactitude of the instrument. See Fig. 2.

2.3. GLE Events of April 15 and April 18, 2001.

These recent ground level enhancement events were recorded by means of high-altitude neutron monitor at Alma-Ata. Active region 9415 was the source of the second largest flare of solar cycle 23, an impulsive X14.4/2B event at 13:50 UT on April 15. As well strong type II and IV radio sweeps, solar proton event at greater than 100 MeV and 10 MeV were recorded. Region was crossing the west limb as the period ended. In Fig.3 it is shown the increase by 1-minut data of high altitude Alma-Ata monitor and CME durind event of April 15.

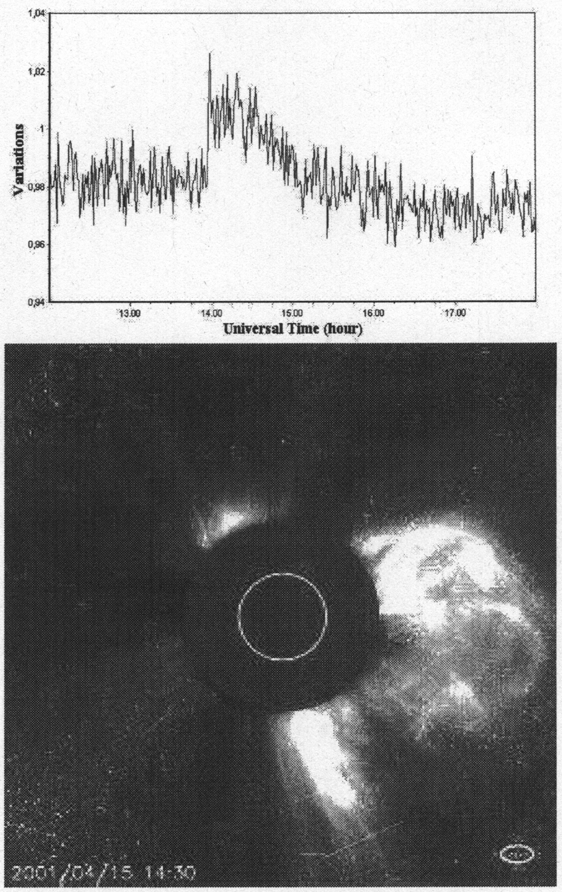

Fig.3. GLE Event of April 15, 2001.

The GLE event on April 18 is connected with a C2.2 flare at 02:14 UT with an associated strong type II sweep, it has origin in region 9415 well behind the southwest limb. A radiation storm began shortly after the flare. In Fig.4 we can see fast bright loop front with complex helical streamers on disk disrupted and the increase by 1-minut data observed by means of high-altitude neutron monitor at Alma-Ata.

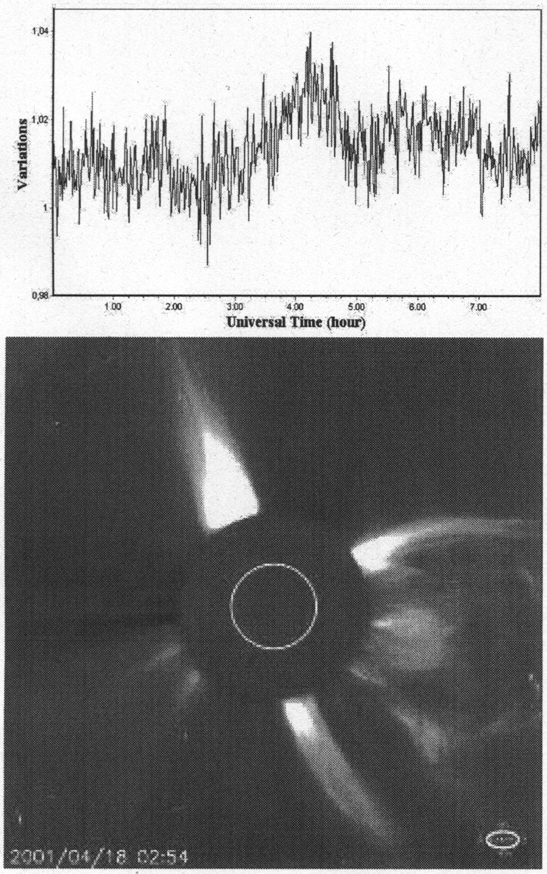

Fig.3. GLE Event of April 18, 2001.

Conclusions

The analysis of these events and also the GLE events of August 16 and October 24 1989 by means of comparison of galactic and solar cosmic rays flux were registered at the high-altitude Alma-Ata neutron monitor and SMM C/P and SOHO/LASCO observations allows to make the following conclusions:

- The solar activity responsible for the considered GLEs extends throughout large areas on the solar disk and includes large CMEs.
- Even at comparatively small distances from the Sun, the CME sizes much exceed those of optical flares, active region, and filaments which are considered usually as sources of the accelerated particles and geospace disturbances.
- The situation is rather typical when the corresponding flare or filament are located near one of the legs of the large loop-like CME in the north or south solar hemispheres while another (sometimes much more bright and developed) leg of the CME leans on a remote region in the opposite hemisphere.
- It is concluded that the activity, accompanied by GLE, has usually a large-scale character and, besides the corresponding active regions, involves highly extended structures of the global solar magnetosphere, particularly in the different solar hemispheres.
- This may tell on the conditions of the escape and propagation of high-energy particles accelerated in flares, current sheets and coronal shock waves. It should be taken onto account also under determination of the geoefficiency of the solar events.

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