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Polar
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SUPER GLE OF JANUARY 20, 2005

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Abstract. The characteristics of relativistic solar cosmic rays during the superevent on 20 January 2005, second in power after the famous GLE of 23 February 1956, have been explored based on the ground level observations. The data of 32 neutron monitors of the worldwide network, including the new opened stations of Barentsburg (N 78.08 E 14.12), Spitsbergen and Baksan (N 43.28, E 42.69) at Baksan Neutrino Observatory (BNO), Northern Caucasus, Russia, as well as the data of EAS arrays in BNO were used in the analysis. By the least square (optimization) technique, the parameters of relativistic solar protons, namely, the rigidity (energetic) spectra, anisotropy directions and pitch-angle distributions were found and their dynamics during the event was studied.

1. Introduction

Super GLE 69 of 20 January 2005 has been the greatest event since 23 February, 1956. The parent solar flare 2B/X7.1 had heliocoordinates N14 W61. Type II radio onset was reported at 06.44 UT. As observed by ground based cosmic ray detectors, the GLE was extremely anisotropic. The worldwide neutron monitor (NM) network may be considered as a joint multidirectional solar proton spectrometer in the relativistic energy range. By modeling the ground based detector responses to an anisotropic solar proton flux and their comparison with the observations, the parameters of primary solar protons outside the magnetosphere can be obtained by the least square technique (optimization) and their dynamics can be studied (Vashenyuk et al., 2003). In this study, for the first time, the data of EAS arrays Carpet (200 m^2, 1700 m a.s.l.) and Andyrchi (37 m^2, 2050 m a.s.l.), as well as of the Baksan Muon Detector (190 m^2) in BNO, Northern Caucasus, were used. These instruments have better than standard neutron monitors sensitivity to solar cosmic rays at geomagnetic cutoff ~ 6 GV (Karpov et al., 2005).

2. Ground based observations and modeling results

By modeling the NM responses to an anisotropic solar proton flux and comparing those with observations, the parameters of primary solar protons can be derived with the least square technique [1]. Thus the parameters of modified power rigidity spectrum with variable slope $J_{||}(R) = J_0 R^{-\gamma^*}$, $\gamma^* = \gamma + \Delta\gamma\cdot(R\text{-}1)$, are J_0 , the normalization constant, γ, the power-law spectral exponent at R = 1 GV, $\Delta\gamma$, the rate of γ increase per 1 GV. Other parameters are the coordinates Φ and Λ, determining the anisotropy axis direction in the GSE system; and parameter C, characterizing the pitch-angle distribution (PAD) in the form of a Gaussian: $F(\theta(R)) \sim exp(-\theta^2/C)$. That is, 6 parameters are to be determined: $J_{0,}$, γ, $\Delta\gamma$, C, Λ, Φ [1]. As the GLE of 20 January 2005 was very complicated, we had to use a model with two completely independent particle fluxes, accordingly, the number of parameters in the model grows up to 12. In Table 1 the parameters of these two fluxes are presented for 4 times in the period from 7.00 to 8.00 UT. After this interval, the anisotropy dropped, so that a unidirectional flux model was adequate. Figure 1a shows the increase profiles, as registered by a number of neutron monitor stations and the EAS array "Carpet". The increase at McMurdo was of the order of 3000 % that exceeded 30 times the corresponding effect on the NM in Apatity, which, in its turn, was significant (>100 %).

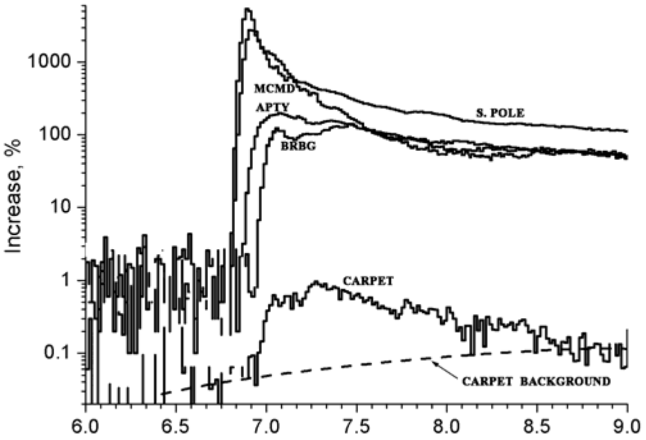

Figure 1. Increase profiles of ground based detectors: neutron monitors at Apatity (APTY), Barentsburg (BRBG), McMurdo (MCMD), Southern Pole (S.POLE), EAS array "Carpet".

Fig. 2 shows the derived from ground based observations energy spectra of RSP, recalculated from rigidity spectra (Table 1), for 2 moments of time. Spectra 1 and 2 correspond to Flux 1 and Flux 2, 7.00 UT, when a strong anisotropy and intensity maximum at South Pole and McMurdo were observed. Spectrum 3 is derived for 8.00 UT, in a period after intensity maximum with weak anisotropy. The spectra of two fluxes at 7.00 UT differ considerably. Spectrum (1) flattens at its low energy part and, as can be shown (Vashenyuk et al., 2005), has an exponential form in energy. Spectrum (2) has a power-law form and extends with the constant slope into the region of moderate energies (of tens-to-hundreds MeV), as evidenced by direct solar proton data. Also, in Fig. 2, are shown the data of direct solar protons measured by GOES-10 spacecraft and balloons launched in Apatity (joint Lebedev Physical Institute and Polar Geophysical Institute balloon experiment), for details see (Bazilevskaya and Svirzhevskaya, 1998). It is seen that spectrum (1) has no extension to low energies. Spectrum 3 (8.00 UT) has a power-law form and may be extended into moderate energy range.

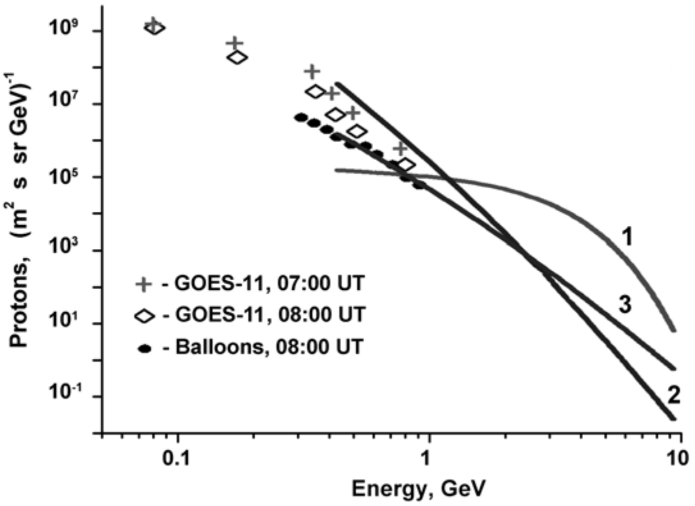

Fig. 2. Derived energy spectra of RSP: 1 - 7.00 UT, Flux 1; 2 - 7.00 UT, Flux 2; 3- 8.00 UT.

Table 1. Derived parameters of relativistic solar protons: model of two independent fluxes

		Flux I						**Flux 2**					
No	Time	**$\gamma 1$**	**$\Delta\gamma 1$**	**C1**	**Θ deg**	**$\Phi 1$ deg**	**J1**	**$\gamma 2$**	**$\Delta\gamma 2$**	**C2**	**$\theta 2$ deg**	**$\Phi 2$ Deg**	**J2**
1	06:57	-2.51	0.72	0.24	-26	-105	$1.2\ 10^6$	-3.5	0.6	0.55	6	0	$3.5\ 10^4$
2	06:69	-0.70	1.12	0.26	-25	-108	$2.9\ 10^5$	-6.6	0	1.0	-20	-11	$2.0\ 10^6$
3	07:00	-0.20	0.43	0.20	-26	-118	$3.5\ 10^4$	-9.0	0	1.2	-45	-28	$2.3\ 10^7$
4	07:05	-0.18	0.43	0.28	-25	-121	$1.1\ 10^4$	-7.7	0	1.7	-69	-14	$1.6\ 10^7$
5	07:10	-0.66	3.6	0.10	-24	-117	$7.4\ 10^3$	-7.6	0	1.3	-67	-20	$2.0\ 10^7$
6	07:30	-4.40	1.9	0.16	17	-77	$1.1\ 10^6$	-7.6	0	25	-7	0	$5.1\ 10^6$
7	07:45	-5.69	0	5.71	-30	-29	$6.4\ 10^5$						
8	08:00	-6.1	0	14.7	-35	9	$9.8\ 10^5$	-	-	-	-	-	-

Fig.3 shows the map of asymptotic directions for 7.00 UT with anisotropy axes and corresponding pitch angle grids for Flux1 (a) and Flux2 (b) in accordance with Table 1. The symmetry axes of Flux 1 pass through the asymptotic cones of South Pole and McMurdo stations that registered the maximum increase. Flux 1 was extremely anisotropic, as the stations with asymptotic cones out of 30^0 limits (Thule, Fort Smith, SANAE, Barentsburg) did not respond to it (Fig. 2 a). Flux 2 (Table 1) with a steep power law spectrum had the PAD wider than that of Flux 1 and caused an increase at the majority of neutron monitor stations during the anisotropy phase (up to 7.30 UT). We should note a large deviation ($\sim 60^0$) of the symmetry axis of Flux 1 from the IMF direction. The symmetry axis of Flux 2 is more aligned with the IMF, and did not change so noticeably as its direction after 07.30 UT when Flux 1 disappeared.

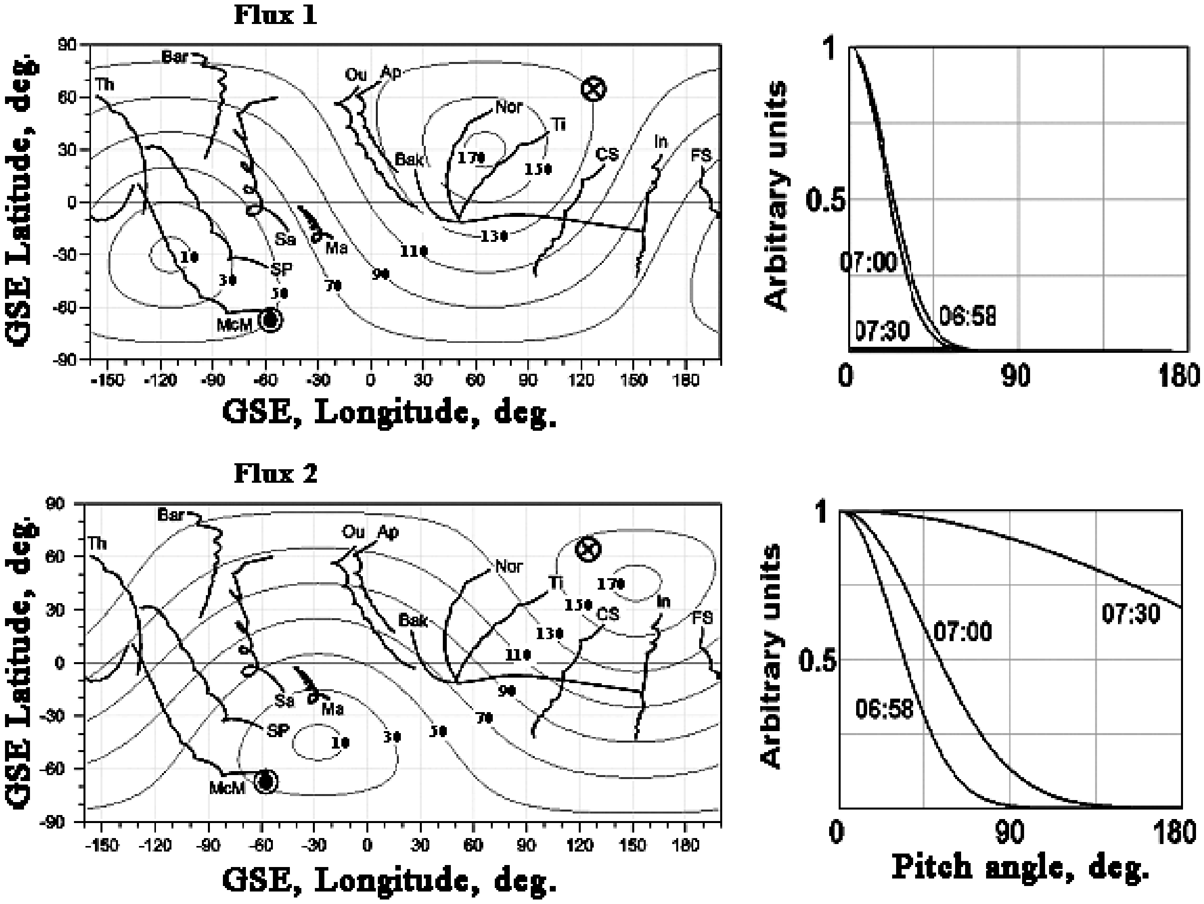

Fig. 3. Asymptotic direction maps with symmetry axes and pitch angle grid lines (left panels) and derived pitch angle distributions (right panels) for two solar proton fluxes: Flux 1 (upper row), and Flux 2 (lower row). The pitch angle distribution of Flux 1 (Table 1) was quite narrow. It caused a giant impulsive increase at South Pole and McMurdo stations. Flux 2, which is responsible for increase at most of other NM stations, had a wider PAD (lower row, right panel). The asymptotic cones (1-20 GV), the title is at 20 GV end, are shown for the following NM stations: Th-Thule, Bar-Barentsburg, McM-McMurdo, SP-South Pole, Sa-SANAE, Ma-Mawson, Ou-Oulu, Ap-Apatity, Bak-Baksan, Nor-Norilsk, Ti-Tixie, CS-Cape Shmidt, In-Inuvik, FS-Fort Smith.

2. Discussion

As observations and modeling study show, the GLE on 20 January 2003 was formed by two fluxes of relativistic solar protons (RSP) with different characteristics. The short-lived and extremely anisotropic Flux 1 with very hard, exponential energetic spectrum caused a giant impulse-like increase at two southern polar stations, namely, South Pole and McMurdo. We also note a noticeable deviation of Flux 1 from the estimated IMF direction. Flux 2 had an energy spectrum of power law form that could be extended into moderate energy range, covered by direct solar proton measurements on balloons and spacecraft. Flux 2 had rather wide pitch angle distribution, being responsible for the increase effect at the majority of NM stations. The increase onset at these stations was delayed as compared to South Pole and McMurdo, on average, for 10-15 min. As one can see, the properties of Fluxes 1 and 2, on the whole, correspond to the prompt and delayed components of relativistic solar protons (Vashenyuk et al., 2005). According to the scenario proposed in that work, the prompt component (PC) of RSP is produced during the initial energy release in a low-coronal magnetic null point. This process is associated with the H-alpha eruption, onset of CME and type II radio emission (Manoharan and Kundu, 2003). The particles of the PC, presumably accelerated in an impulsive process of magnetic reconnection, have exponential energetic spectrum and leave the corona along open field lines with diverging geometry, which results in strong focusing of the bunch. The DC particles are originally trapped in magnetic arcs in the low corona and accelerated by a stochastic mechanism related to MHD turbulence in expanding flare plasma. The accelerated DC particles can be then carried to the outer corona by an expanding CME and released into interplanetary space after the magnetic trap is destroyed. As for the deviation of PC particles flux from IMF direction (Fig.2a), it may be related to IMF irregularities observed in Phi component from about 8.30 to 10.20 UT (Fig. 4). This may indicate sharp kinks of the IMF line, arising on the way of collimated particle Flux 1 just in front of the Earth. The curvature radii of these kinks are of the order of 10^6 km, being comparable with the Larmor radii of relativistic protons in the 5 nT field. As our trajectory calculations indicate, a collimated particle beam is strongly deviated at such IMF kinks. On the contrary, the particles with large pitch angles are little scattered at the kink and pass through it keeping the direction of movement along the magnetic field. A similar situation was observed in GLE on 28 October 2003 (Vashenyuk et al., 2005, this issue).

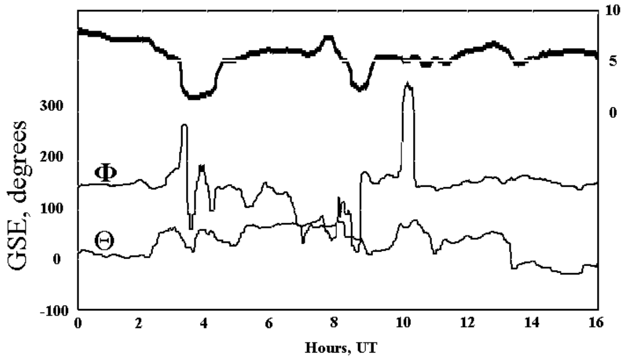

Fig. 4. IMF |B|, Phi, Theta (GSE) variations by 5 min data of ACE spacecraft around the onset of the 20 January, 2005 GLE. Note the strong variations in Phi indicating the kinks in IMF at distances 2-6x10^6 km ahead of the Earth at GLE onset.

Conclusions

Relativistic solar cosmic rays responsible for the GLE 20 January, 2005 were presented by two components: the prompt and delayed ones. The prompt component (PC) was very short-lived and extremely anisotropic. It had an exponential energetic spectrum and caused a giant impulse-like increase effect at the Antarctic NM stations South Pole and McMurdo. PC arrival direction was noticeably declined from the IMF direction. A possible cause of this effect could be scattering of narrow particle beam on the sharp kinks of IMF existing in front of the Earth during the GLE onset. The delayed component had a power-law energetic spectrum and a wider pitch-angle distribution. It was responsible for the increase effect at most NM stations of the worldwide network. The PC disappeared at about 7.30 UT. After that, the delayed component was dominating in the RSP flux.

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