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Ground level enhancement of the solar cosmic rays on January 20, 2005.

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The January 2005 brought unexpectedly giant proton event toward the end of solar cycle. The flux of relativistic protons reached the Earth at ~ 6:50 UT on 20 January and was recorded by neutron monitors as ground level enhancement which at southern polar stations was about several thousands of percentages. The characteristics of the cosmic ray energy spectrum, anisotropy, differential and integral fluxes as well, were obtained by the data from about 40 neutron monitors using anisotropic and compound models of solar cosmic ray variations. Anisotropy contribution dominates during the first 15-20 minutes of effect and quickly decreases along the time. First particles came by narrow beam from south-west direction. The flux along the IMF force line started to dominate only some time later.

1. Introduction

A new GLE was recorded on 20 January 2005 by the worldwide network of neutron monitors. It was associated with the flare X7.1 on 20 January in AR720 (N12 W58) started at 6:36 UT. This ground level event (GLE69) took place during a recovery phase of the Forbush effect series, on the background of relatively quiet geomagnetic activity (Kp changed from 2 to 4). It is remarkable that this event occurred in a descending phase of the 23rd cycle at a time-period very close to the minimum of solar activity. Nevertheless it exceeds all previous events of this solar cycle and may be comparable by order of magnitude to the greatest GLEs over the history of observations. The flux of the first relativistic protons reached Earth at 6:50 UT by very narrow beam and had a very hard spectrum. The peak of the cosmic ray (CR) variations on 20 January 2005 reached several thousands of percentages at southern polar stations. In Figure 1 the profiles of three biggest GLEs are plotted by the data from neutron monitors recorded the maximum effect. It is seen that the last event shows even higher amplitude than the famous GLE05 on 23 February 1956 [1, 2]. At the same time in GLE69 there was much less high energy particles than in 1956 or in 1989 and majority of high latitude stations recorded effect an order less (~100-300%) and at mid- latitude stations with cut off rigidity more than 6GV it was very small or absent at all. The most outstanding feature of these both proton enhancements seems to be an extremely high anisotropy and narrow and intensive beam of ultra relativistic particles arriving at Earth during the first minutes after the onset.

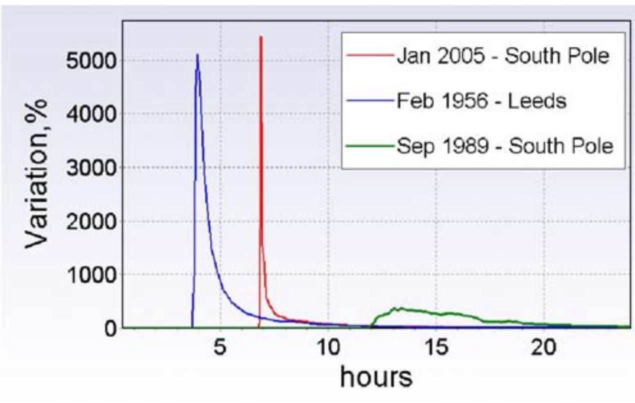

Figure 1. The time profiles of the greatest GLEs.

2. Data and Method.

The model of CR variations described in [1, 2, 4] has been used for the estimation parameters of this GLE. Counting rate at each ground level detector during a GLE may be written as [1, 2]:

$$\frac{\Delta N}{N_0}(t,t_0)=\frac{\int_{E_c}^{E_u} W(E,t_0,h)\frac{\Delta I}{I_0}(t,E)dE}{\int_{E_c}^{E_u} W(E,t_0,h)dE}$$

where I_0 is the galactic cosmic ray flux causing N_0 counting rate at the detector, h is the atmospheric depth of the point of observation in mb and E_u is the lowest value of the upper energy limit [5]. Function $W(E, t_0, h)$ is the coupling coefficient [3, 6]. The primary CR intensity variations $\Delta I(t, E)$ were supposed to consist of an isotropic part and an anisotropic one, characterized by an angular distribution function taken as $\Psi = \exp(-0.5n_a^2 \sin^2(\chi-\chi_0))$, where χ_0 corresponds to direction at which Ψ_1 equals to maximal value 1. For $\Delta I(t, E)$ we used power law spectra E^{γ}. 5-minute data from 37 neutron monitors has been processed and analyzed in order to find the behavior of solar CR.

3. Results and discussion.

A great anisotropy in the event on 20 January 2005 is seen even from CR behavior at four NMs in Figure 2. The earliest onset of GLE with the biggest effect of several thousands of percentages was recorded at South Pole and McMurdo. The latest particle arrival and very low effect (for small Rc) are observed at Thule. All other high latitude stations recorded effect in between of these two: more similarly to the McMurdo it was at Nain and Forth Smith, whereas Cape Shmidt demonstrates more common with other stations behavior. The first particles came from the Sun by the narrow beam and had very hard spectrum with an index -0.7±0.2. The record enhancement is explained by an appropriate direction of the proton flux relatively to a location of the asymptotic cones of South Pole station with highest response to solar CR. In the same time there are much less a number of particles of the energy more than 3 GV: this effect is quite ordinal at the other high latitude stations (with exception for McMurdo) and is absent or small at low latitude stations.

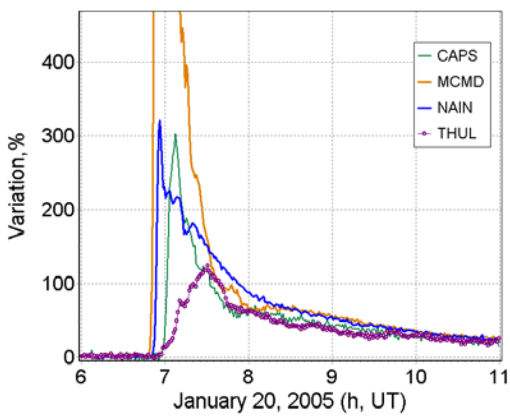

Figure 2. The visual anisotropy in CR variations at four NMs: CAPS-Cape Shmidt, MCMD-McMurdo, NAIN, THUL-Thule.

In Figure 3 the asymptotic directions for neutron monitor network are presented for the 1-st and 54-th 5-minute intervals. The parameter of model best fitted to the experimental data just after the onset are the following: γ=-0.7±0.2; E_u=7±0.5 GeV; n_a=4.7±0.2; asymptotic longitude of anisotropy source = 69±7°; asymptotic latitude = -60±3°. All these parameters essentially changed already during the next several minutes. A spectral index γ became of about -4 and remained around this level for a long time. Significantly changed the longitude of the anisotropy source and the width of anisotropic flux. The upper energy E_u

became lower, that corresponds to the spectrum softening and to the absence of the effect at mid latitude stations in the later hours.

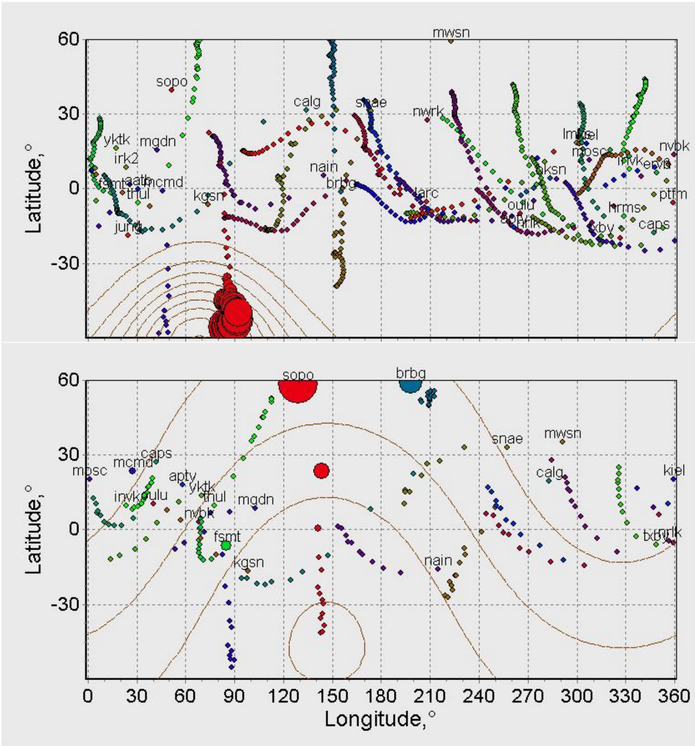

Figure 3. Asymptotic directions for particles of different energy recorded at each station at the just after the onset of GLE69 (6:50-6:55) and at

The isometric lines represent a distribution of solar CR intensity: central circle corresponds to 90% and outer line – to 10% of the full intensity. We see that acceptance cones of South Pole (sopo) and McMurdo (mcmd) stations fall down directly to a location of the anisotropy source. At the beginning of event the particles came from a direction far enough from the IMF force line, but with the time a direction to the flux maximum and the IMF line became close to each other. Already in several minutes there is appeared an isotropic part of enhancement. In some minutes after the onset a spectrum of the solar CR jumped to become soft and during the next 5 hours its index changed only within -3.5 - -4.0 range. In Figure 4 two spectra for solar CR in this event are presented: for the first 5-min interval and for the second one, which is practically the same for all other intervals. It is clearly seen that in the first interval high energy particles dominated in the flux whereas just before the 7:00 UT the number of low energy particles essentially enhanced. The anisotropic beam was expanded along the time and in a few hours it became like a usual (for galactic CR) anisotropic flux, which can be described by the first spherical harmonic. Changes of the longitudinal dependence of the flux width in a projection on the Earth equator are shown in Figure 5. In Figure 3 (lower panel) we placed a map of asymptotic directions for the stations at the moment corresponding to 54-th 5-minute interval (11:17 UT) when the flux became rather isotropic. Anisotropy is already small at this time but it remains sufficiently noticeable during several hours after. Isometric lines in the asymptotic map

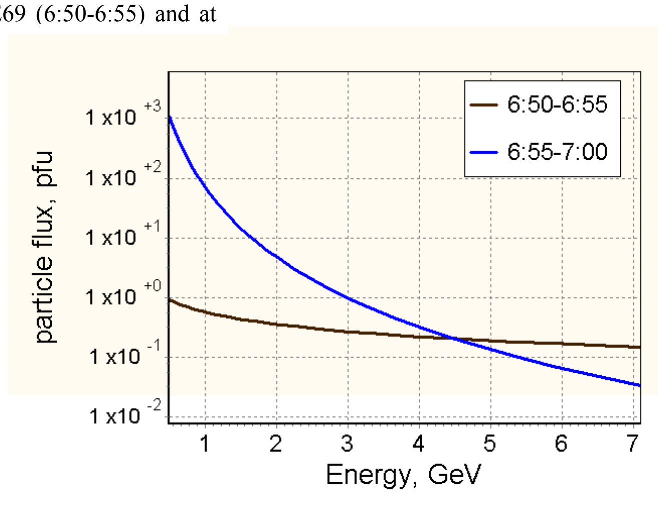

Figure 4. Spectra of the solar CR during the first and second 5-minute intervals after the onset.

(Figure3) at 11:47 UT meaning the same ratio of anisotropy (90, 80, 70 %) illustrate also, that anisotropic flux became essentially wider at this moment.

4. Conclusion

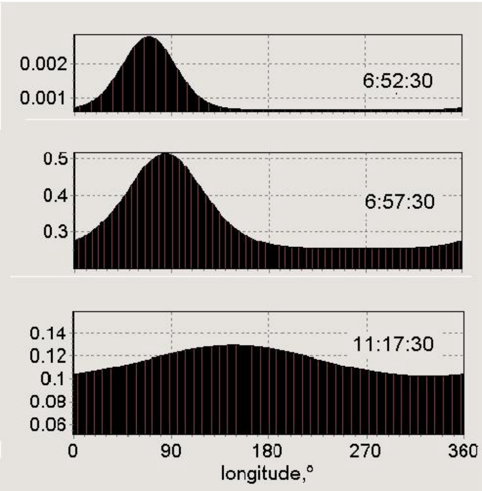

Figure 5. Changes of the longitudinal distribution of the solar CR flux at Earth's equator at 1-st, 2-nd and 54-th 5-minute intervals, the flux is plotted in pfu/Mev

The Sun prepared several surprise toward the end of the cycle 23. One of them was the record enhancement in the counting rate at some southern polar NMs on 20 January 2005 which ranges this event among the greatest GLEs. Nevertheless, high energy particles (>3 GeV) turned out to be of much less amount than in 1956 and 1989 events.

The first particles came by very narrow beam and had a very hard spectrum. Already in some minutes after the onset the spectrum became soft and kept its form during the several hours with index -3.5--4.0.

Anisotropy remained for a long time but in some hours after the onset it became of the usual form like the first spherical harmonic.

The source position, remote from the IMF force line at the first moment, soon assumed a direction close to the IMF force line direction.

Despite the event in January 2005 yields in main parameters to the greatest enhancements in former time (in 1949, 1956, 1989 etc.) but it is more valuable for the analysis because of many kind of relevant data and measurements during this event available in different sources.

5. Acknowledgements

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