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Ground Level Enhancement of December 13, 2006 by the ground measurement data

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Abstract: On the basis of neutron monitor world network data the GLE event of December 13, 2006 is studied. Taking into account the initial differential spectrum of galactic cosmic rays, viewing cones of the detectors, integral multiplicity of secondary neutrons at various latitudes and observation levels the GLE spectrum is estimated. It is noted that at the Yakutsk station this event has also been registered with the ionization chamber ASK-1..

Introduction

In spite of the fact that an amplitude of the current 23–rd solar activity cycle is below than for the two previous cycles, nevertheless there is one remarkable peculiarity. Of 92 solar energetic particle (SEP) events (with peak flux exceeding 10 $cm^{-2}s^{-1}sr^{-1}$ for more than 10 MeV solar protons), 16 ground level enhancements (GLE) ($\sim 15\%$) have been registreted. It is interest to study the last ground increase (GLE70) of cosmic ray (CR) flux on December 13, 2006 which occurred near solar minimum.

Results and discussion

The flare (importance $X3/4B, 02.40$ UT) and the accompanying halo–CME (02.54 UT) originated from the active region NOAA 10930 with coordinates S05W23 (http://umbra.nascom.nasa.gov/SEP/seps.html).
It has been detected with network station monitors (Figure 1). To determine the spectrum for the GLE70 event on December 13, 2006, we used 1-min data of 20 neutron monitors of network CR stations (ftp://cr0.izmiran.rssi.ru/Cosray!/FTP_GLE).
The stations were selected in such a way that their asymptotic receiving cones of solar particles were rather uniformly distributed in direction. As is seen from Figure 1, the essential difference in onset and maximum time of the event is observed. Besides, the noticeable difference in the intensity profile is also observed. This points to the presence strong anisotropic effects which are not considered in this paper.

Table 1 presents a list of stations, data of which are used in the analysis, count rate for each station, threshold rigidity, amplitude of CR intensity at a maximum and time moment 15, 30 and 60 min from the beginning of particle flux increase at the station.

The estimation of CR flux spectrum (without anisotropy) by using neutron monitor data was carried out by the method suggested in [1, 2]. The integral intensity of secondary particles observed on the Earth is given in the form:

$$N(p) = \int_{p_{min}}^{\infty} p^{-\gamma} m(p) dp, \qquad (1)$$

where $m(p)$ is an integral multiplicity of the secondary particle generation from a primary particle with the impulse p at the atmosphere boundary, $p^{-\gamma}$ is a galactic CR spectrum. Calculations of the $N(p)$ will be carried out, if integral multiplicities are known. Conditions of CR registration at different stations essentially differ from each other, therefore, $m^i_(p)$ is separately calculated for each i-station. To determine the integral multiplicity for

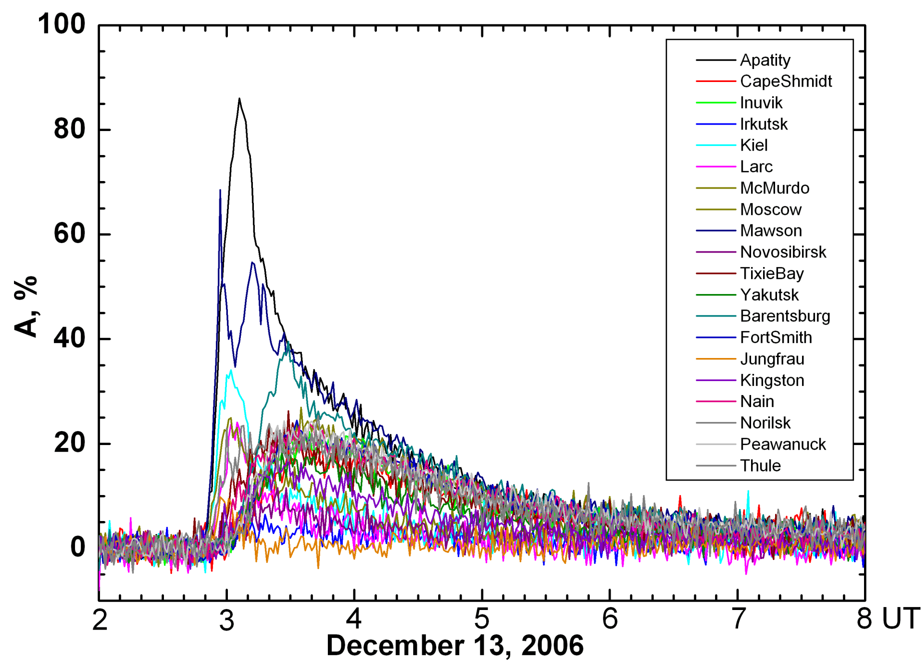

Figure 1: Temporal profiles of GLE70 by 1-min data of 20 neutron monitors.

NN	Station	Count Rate (imp/sec)	R_C(GV)	A_{max} (%)	A_{15min} (%)	A_{30min} (%)	A_{60min} (%)
1	Apaptity	160	0.6	86	86	48	28
2	Cape Shmidt	100	0.5	20	13	30	16
3	Inuvik	215	0.16	21	14	20	17
4	Irkutsk	220	3.6	6	6	4	3
5	Kiel	175	2.3	33	30	13	7
6	Larc	77	3	23.5	23.5	9	5
7	McMurdo	250	0.5	26	14	23	2
8	Moscow	162	2.4	25	23	13	9
9	Mawson	240	0.5	68	35	45	28
10	Novosibirsk	175	2.8	10	4	10	5
11	Tixie Bay	110	0.5	26	16	26	15
12	Yakutsk	210	1.6	16	8	16	14
13	Barentsburg	145	0.5	39	20	39	22
14	Fort Smith	290	0.5	24	15	24	17
15	Jungfraujoch	155	4.5	9.5	5	0	0
16	Kingston	205	1.8	16.5	11	16.5	12
17	Nain	205	0.9	24	16	22	19.5
18	Norolsk	108	0.64	23	23	23	20
19	Peawanuck	225	0.9	23	18	23	19
20	Thule	220	0.5	22	12	22	18

Table 1: Some characteristics of CR stations and effects of GLE observable on them.

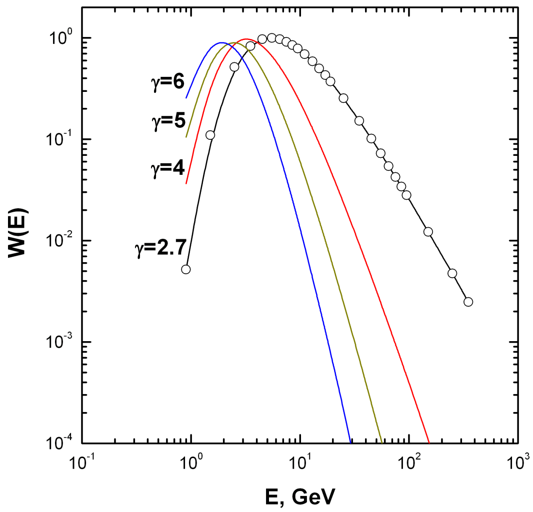

Figure 2: The normalized coupling coefficients for different γ. Observational results are shown by the open circles.

i-detector, we use the expression [2]:

$$m(p) = \frac{W_m^i(p)N^i(p)}{p^{-\gamma}}, \quad (2)$$

where $W_m^i(p)$ are coupling coefficients of neutron monitors at solar activity minimum known from latitudinal observations [3], $N^i(p)$ is a flux observed of galactic CRs at the same period.

As an example, Figure 2 and Figure 3 present calculation results of coupling coefficients and integral multiplicities for Apatity, Mawson, Novosibirsk, Tixie Bay, Fort Smith and Thule stations for the different γ.

For the case of solar particle rise, the Equation 1 can be written in the form:

$$N^i(p) = k\int_{p_{min}}^{\infty} p^{-\gamma} m^i(p,\gamma)dp, \quad (3)$$

where $m^i(p,\gamma)$ is the integral multiplicity depending on index γ.

If $N^i(p)$ is the galactic CR intensity registered at i-station before the arrival of solar particles, N_{obs}^i is the additional flux at i-station, then the coefficient $k = N_{obs}^i/N^i$ will reflect the relative density of this flux at the observation moment. In this case, to determine $m^i(p,\gamma)$, there is a need to know the coupling coefficients $W^i(p,\gamma)$ for the solar particles. To calculate $W^i(p,\gamma)$ for different γ (see Figure 2), we used the expression:

$$W(p,\gamma) = \frac{m^i(p)p^{-\gamma}}{N^i(p)}. \quad (4)$$

Thus, taking into account results obtained and according to Equation 2, we determine integral multiplicities of solar protons $m^i(p,\gamma)$ depending on the spectrum index γ (see Figure 3).

The solar proton fluxes N_{exp}^i expected are calculated for the GLE70 event at t=15, 30 and 60 min from the beginning of intensity rise. To find the spectrum index, we determined, according to [2], a ratio $a_i(\gamma)$ of theoretical expected values N_{exp}^i to observatianal values N_{obs}^i. In this case, the value $A(\gamma)$ is a characteristic of constancy of this ratio:

$$A(\gamma) = \frac{1}{20}\sum_{i=1}^{20} |\lg a_i(\gamma) - \overline{\lg a(\gamma)}|, \quad (5)$$

where

$$\overline{\lg a(\gamma)}| = \frac{1}{20}\sum_{i=1}^{20} \lg a_i(\gamma). \quad (6)$$

Here, the value γ is considered to be the most real, when $A(\gamma)$ is minimum.

The estimation of the spectrum index for the solar protons in the event GLE70 shows that during the first hour after the beginning of the event, the effective index is enough hard: $\gamma_{eff} \approx 5$. This is consistent with data of the ionization chamber ASK-1 ($R_c \sim 6$ GV) at the Yakutsk station, which is registered a small ($\sim 0.6\%$) increase of CR intensity, although the ground–based muon telescope ($R_c \sim 3$ GV) no increase is registreted. Note that the ionization chamber registers, on the whole, the CR muon component, but the secondary neutrons also make the small contribution. The small GLE ($\sim 1\%$) was observed at the Alma-Ata neutron monitor station ($R_c \sim 6.6$ GV).

Conclusion

The above analysis shows that the event GLE70 considered is characterized by the enough hard energy spectrum with $\gamma \approx 5$.

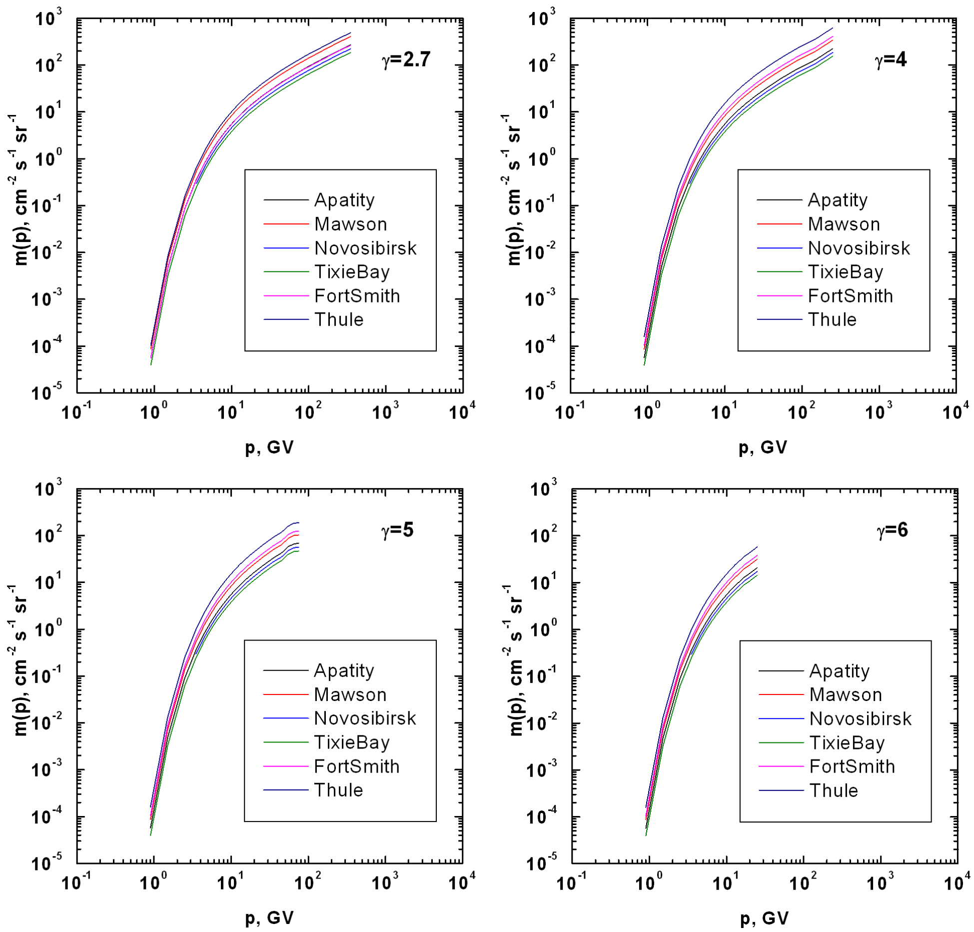

Figure 3: Integral generation multiplicities for six CR station selected.

Acknowledgements

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