The First GLE of the New 24th Solar Cycle

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Abstract: Ground level enhancement events in solar cosmic rays were absent from December 2006 till May 2012. The 24th solar cycle started at 2009 and the GLE71 on May 17, 2012 has become the first event of the new cycle. This paper presents the analysis of the GLE71.

Keywords: GLE, solar cycle, neutron monitor, spectrum, pitch-angle distribution.

1 Introduction

The first ground level enhancement (GLE) in the 24th solar cycle was registered by the worldwide network of neutron monitors (NM) at 17.05.2012 after 5-year pause. Besides solar cosmic rays, this event was also registered in soft X-rays as a weak eruption flare 1F/M5.1. The event was associated with a solar flare in region 1476 located at N11W76. The region was beta type and quite small (the square was 230) [1]. GLE started at 01:54 UT (Oulu), the maximum was 18% on Oulu and Apatity stations at 02:08 UT. The South Pole station, which was the third on magnitude, registered around 7% increase, as reduced to the sea level. Total duration of the GLE was about 1.5 hour. On the whole GLE71 is weak and odd.

2 Calculation method

Based on our advanced method (which was used in modeling more than four tens of GLEs) we derived main parameters of the GLE: spectrum of relativistic solar proton (RSP) flux, pitch-angle distribution and direction of anisotropy. The method is based on an inverse problem solution. The data of the worldwide network of NMs (27 stations) [2, 3] were used. To calculate asymptotic cones of the stations we used the Tsyganenko magnetosphere model T01 [4].

Spectral function $I(R)$ was taken in the common form

$$I(R) = J_0 \cdot R^{\gamma-\Delta\gamma(R-1)} \quad (1)$$

where J_0 is a flux intensity at 1 GV rigidity, γ is a spectral index, $\Delta\gamma$ is a spectral correction. $\Delta\gamma$ parameter provides variable slope of the spectral function. Note especially that the spectral function is not pure power law or exponential. However, for given pair of values (γ and $\Delta\gamma$) it is possible to obtain a near-power or near-exponential form within the rigidity range $1-20$ GV. Basic pitch-angle distribution of the RSP flux is given in the form of Gaussian function normalized to 1

$$G(\theta) = exp(-\theta^2/c) \quad (2)$$

where c is a parameter characterizing the flux width, θ is a pitch angle of a particle with rigidity R moving in the interplanetary magnetic field (IMF). To determine θ it is necessary to know the direction of the anisotropy axis. It can be defined by two angles λ and φ, latitude and longitude. So there are additionally three spatial parameters (c, λ, φ) describing RSP flux.

The final expression is

$$\Delta N(J_0,\gamma,\Delta\gamma,c,\lambda,\varphi) = \\ = \sum_{R=1}^{20} I(R)\cdot S(R)\cdot A(R)\cdot G(\theta(R,\gamma,\varphi))\cdot \Delta R \quad (3)$$

where ΔN is a derived increase at a station, $S(R)$ is a specific yield function [5], $A(R)$ is a quantized function of asymptotic cones, which is "1" for allowed trajectory and "0" for forbidden one, ΔR is a rigidity step.

Discrepancy function is

$$\Phi(J_0,\gamma,\Delta\gamma,c,\lambda,\varphi) = \\ = \sum_{L} [\Delta N_L \cdot (J_0,\gamma,\Delta\gamma,c,\lambda,\varphi) - \Delta M_L]^2 \quad (4)$$

and the least square method is used to find the minimum of Φ. More information about our method one can find in the papers, for example [6, 7].

3 Results and discussion

GLE71 was processed by the described method from 02:05 UT till 03:10 UT with 5 minute step. All 6 parameters of RSP were obtained each time. Furthermore, responses in same time points for each station of NM were calculated (see Figures 1 and 2). It should be noted that GLE71 is really odd. In this study it was found that in a given form of the pitch-angle distribution (expression 2) a suitable solution can't be found. The analysis of NM increase profiles and directions of asymptotic cones (Figure 3) has shown that at the pitch angles close to 90° an intensity gap is present. This gap can't be described by expression (2). Therefore a function has been created to add a gap into Gaussian distribution at $\sim 90°$. Due to it two parameters were added. After such fitting solutions with a satisfactory accuracy ($\sim$10-15%) were obtained. Physically, this gap is easy to explain. GLE71 occurred on extremely weak and quiet IMF. Under such conditions RSP propagation was along the magnetic field lines almost without scattering. It is obvious that in this case the particles with large pitch angles have significantly less drift velocity along the field line and reach the Earth later than the particles propagating with small pitch angles. It is noteworthy that during the GLE growth phase there are few particles with pitch angles $> 90°$. After 02:30 UT the flux at large angles has increased and the gap has been smoothed.

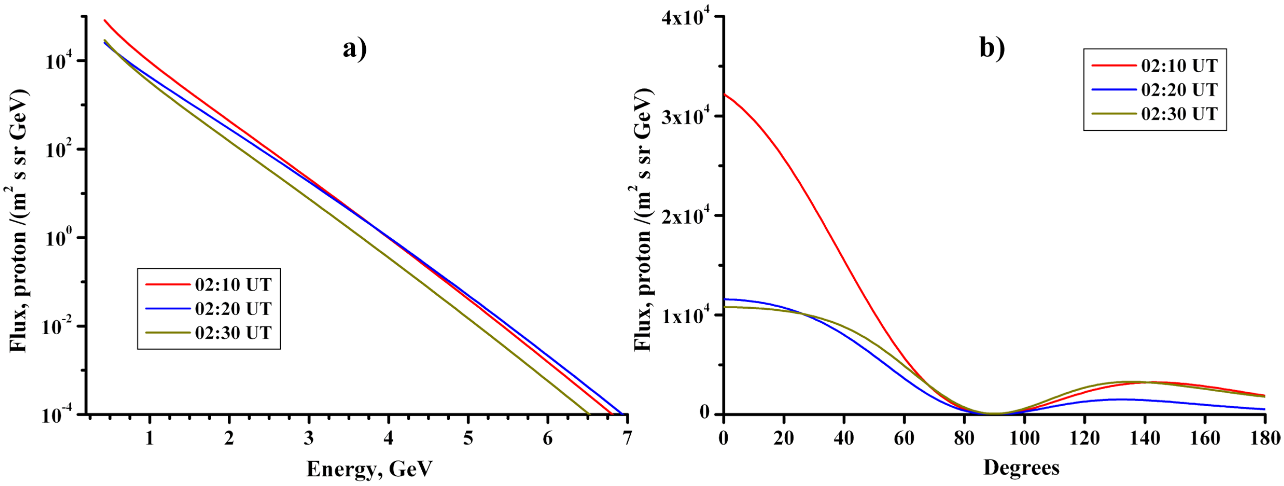

Figure 1: **a**) Derived spectra of RSP; **b**) Pitch-angle distribution for the three moments of time.

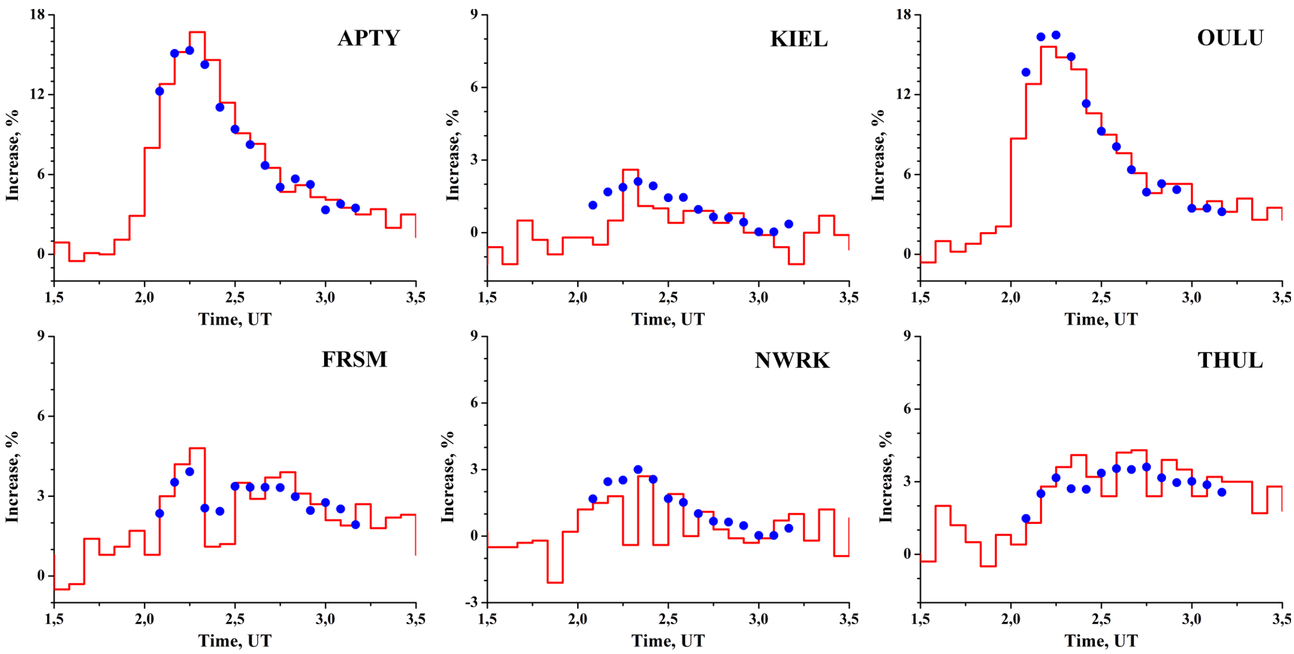

Figure 2: GLE71. Increase profiles on some NM stations (red lines) vs derived responses on these stations (blue dots). APTY - Apatity, KIEL - Kiel, OULU - Oulu, FRSM - Fort Smith, NWRK - Newark, THUL - Thule.

The GLE71 event also has its specific spectra of RSP. First, during the event (up to 03:10 UT) energy spectrum (after solving the spectra are converted into energy units) of RSP has an exponential form, i.e. is approximated by the expression

$$J(E) = J_0 \cdot exp(-E/E_0) \qquad (5)$$

where E_0 is characteristic energy, $J(E)$ is energetic spectrum of RSP. Secondly, characteristic energy $E_0 \approx 0.36$ GeV is lower then usual one $E_0 = 0.5$-0.6 GeV [8]. In [9], we calculated the spectrum of RSP generated during the actual solar flare 14.07.2000 (the Bastille Day GLE). On the basis of the magnetograms of the Sun and measurements of plasma velocity it was modeled the magnetic reconnection region, in which protons are accelerated to relativistic energies. The modeled spectrum of RSP, leaving the Sun, had a pure exponential form. The main parameter determining the characteristic energy E_0 was the plasma velocity inflow in the reconnection region. A lower value of E_0 in GLE71 can be explained by the fact that the event GLE71 has occurred in weak eruption flare (1F/M5.1), which had lower plasma velocities.

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4 Conclusions

Analysis of the first event GLE (17.05.2012) in the new 24th solar cycle is presented. The spectra and the pitch-angle distribution of RSP during the event were obtained. Feature of this event is the exponential form of the RSP spectrum during GLE, as well as the intensity gap at pitch angles $\sim 90°$, which is observed on the initial phase of GLE.

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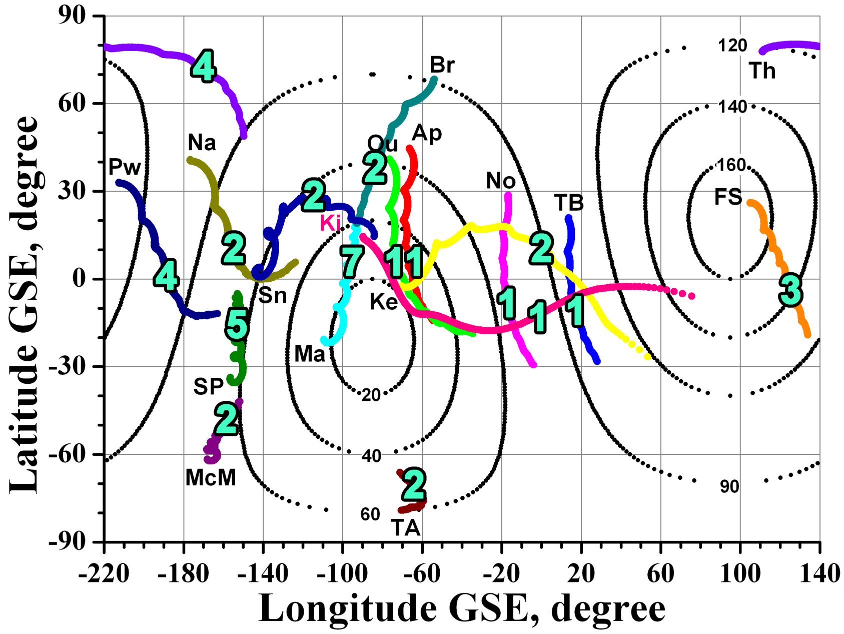

Figure 3: GLE71. Asymptotic cones of some stations. Pw - Peawanuck, Na - Nain, SP - South Pole, McM - McMurdo, Sn - SANAE, Ki - Kiel, Ma - Mawson, Ou - Oulu, Ap - Apatity, Ke - Kerguelen, Br - Barentsburg, TA - Terre Adelie, No - Norilsk, TB - Tixie Bay, FS - Fort Smith, Th - Thule. Black dot lines are isogons with its pitch angle values. Bold green numbers on the cones indicate increase magnitudes of corresponding stations. The numbers are set at station sensitivity maxima to the derived spectrum at 02:20 UT. Distribution of these numbers along the map has a gap at $\sim 90^\circ$ pitch angles.

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