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EARLY FORECAST OF RADIATION HAZARDOUS SOLAR COSMIC RAY FLUXES ON THE NEUTRON MONITORS DATA

E.V. Vashenyuk, Yu.V. Balabin, B.B. Gvozdevsky, A.V. Germanenko (*Polar Geophysical Institute KSC RAS, 15, Khalturina Str., Murmansk, 183010, Russia; E-mail: vashenyuk@pgia.ru*).

Abstract. Possibility of the forecast of radiation-hazardous solar cosmic ray fluxes with energies in tens-hundreds MeV according to the neutron monitors located on a ground surface is discussed. Neutron monitors register the relativistic SCR (energies from 0.5 to a several GeV) with the minimal delay, however in a high-energy region intensity SCR is small and does not represent serious radiation hazard. At the same time, having spotted a spectrum a SCR in a high-energy region it is possible to give the forecast of radiation-hazardous fluxes of particles of moderate energies with advance time till several hours. However this forecast is possible only by data from so-called «delayed component» of relativistic cosmic rays.

1. Introduction

It is known that the maximum flux of cosmic rays in the radiation-dangerous energies of tens to hundreds of MeV are registered with a delay from ~ 1 to 10 hours in comparison with relativistic cosmic rays, which cause the increases in neutron monitors (NM). This enables real-time forecasting of radiation hazard SCR according to neutron monitors. In a number of authors in recent years the procedure of definition of parameters of the relativistic SCR according to a land network of neutron monitors (NM) has been developed [1, 2]. The method uses the inverse problem for resolve minorities' characteristics of relativistic solar protons outside the atmosphere and Earth's magnetosphere from the NM network data. In the method [1, 2] the calculated with great precision in modern models of the magnetosphere asymptotic cones of reception stations NM are also used. It has been shown, that in the flux of relativistic solar protons (RSP) are observed two components: the prompt component (PC) and the delayed component (DC) with specific properties [3, 4]. In the methods of forecasting can be used, that for the delayed component of CPR, the energy spectra in good agreement with direct measurements of solar protons of lower energies during the peak, sometimes coming within a few hours [2, 3]. Thus, identifying the spectrum of DC in the energy region with the lower limit of ~ 430 MeV (an atmospheric energy threshold for neutron monitors) can, by means of its extrapolation in the energy range of the hundreds and tens of MeV, to estimate fluxes of these particles in the absence of direct measurements, as well as give the forecast of these fluxes in the next hours.
The problems here are limited number of available data from the NM stations and deficit of time for data processing and calculations. The usual procedure of such calculations require data no less than 30-35 NM stations, detailed calculations of the asymptotic cones of accept in the modern models of the magnetosphere [1, 2]. With the advent of a network of the NM stations (23), giving the real-time data into a single database (European Project NMDB) [5] the possibility of implementing such a forecast was created. We have developed a reasonably restricted computational model using data of about 20 stations NM. It performs calculations of asymptotic cones in the model Tsyganenko 1989 and allows obtaining the spectra of relativistic solar protons (RSP) in real time with a sufficient degree of accuracy. Testing of a restricted method by comparing the data obtained with the help of the parameters of CPR with the results of the full method [1, 2] has shown the good agreement between the two. Thus, we can expect that the proposed here method of estimating the radiation hazards related with the SCR, based on data of neutron monitors, will be developed and will be used in the upcoming cycle of solar activity.
In following section in a number of examples method possibilities are shown.

1. Analysis of separate events
1.1. Event of 21 May 1990

Event SCR at ground level or Ground Level Enhancement (GLE) № 47 in the International Classification of 21.05.1990, has been associated with a solar flare of importance 2B/X5.5 and heliocoordinates N34 W37. The onset of type IV radio burst, the probable time of generation of SCR, was noted at 22.12 UT. Fig. 1a shows the characteristic profiles of increase at two neutron monitor stations: Apatity and Magadan. Profile of Apatity station has the typical for the prompt component (PC) of RSP peak at the beginning of the event. The increase at the Magadan station has a gradual profile, characteristic for the delayed component (DC) of RSP.

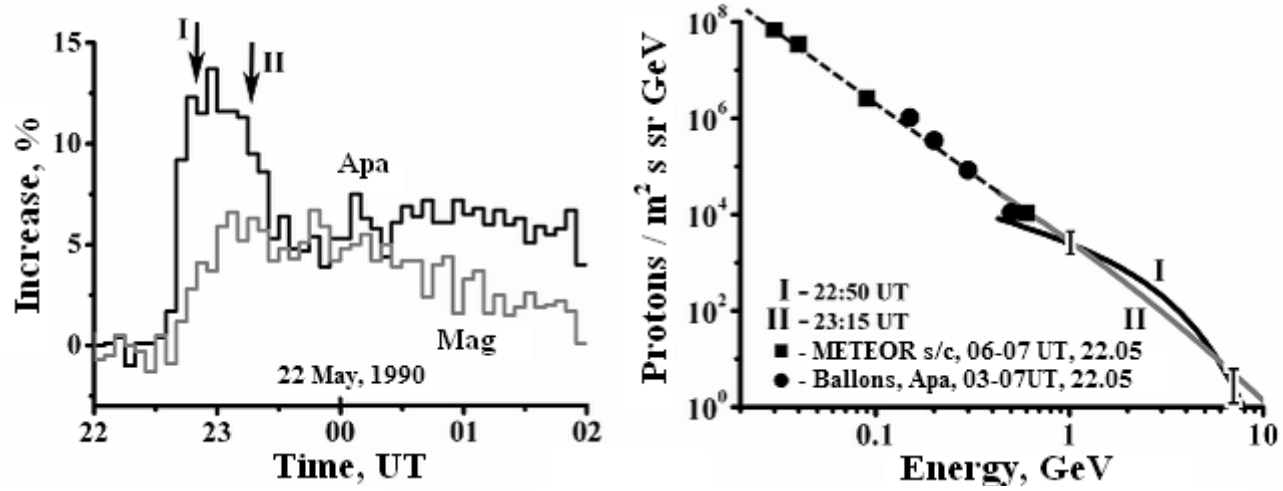

Fig. 1. a - profiles of ground level enhancements at NM stations Apatity (Ap) and Magadan (Ma). **b** - energy spectra of the RSP, gained from the NM data at times I (PC) and II. (DC). The Dotted line - extrapolation of spectrum II (DC). Points - a spectrum measured at times of maximum fluxes (TOM), according to direct measuring of solar protons on the spacecraft "Meteor" and balloons at Apatity [5].

In fig. 1 b solid lines show the spectra of the RSP, obtained from the worldwide NM data by a method of solving the inverse problem [1] at times I and II in Fig. 1a. The spectrum I correspond to the so-called prompt component (PC), which usually has an exponential dependence on energy and flattens at low energies [3]. Spectrum II belongs to the so-called delayed component (DC) and has the power law dependence on energy. Its extrapolation to lower energies (<430 MeV) is shown by a dotted line. The good agreement with the spectrum measured at times of maximum fluxes (TOM) at different energies of solar protons [6], according to the direct measurements of solar protons on the spacecraft "Meteor" and balloons (joint experiment Lebedev Physical Institute and PGI) is seen.
It should be noted, that the spectrum of the delayed component of RSP was obtained for the moment of time 23.15 UT, an hour after the start of active processes in the flare. And the TOM spectrum of solar protons was obtained at 4-5 hours after this time for the energies of 150-500 MeV (balloons) and >30, >40, >90, >600 MeV, at the spacecraft "Meteor". Thus, the possibility is clearly demonstrated of early (4-7 hours) forecast of maximum solar proton fluxes in the energy range from 30 to 90 and 300-500 MeV.using the ground based neutron monitors data only.

1.2. Event of 14 July 2000

GLE event № 59 (14.07.2000, the "Bastille Day") has been associated with the solar flare of importance 3B/X5.7, and heliocoordinates N22 W07. At 10.19 UT the onset of a radio burst of type II, probable time of acceleration of particles, was noted. In figure 2 the profiles of the increase at the NM stations Apatity and Mawson (Antarctica) are shown. Arrows I and II designate the moments of time when the PC (I) and DC (II) was dominate in the in flux of relativistic solar protons (RSP). Accordingly, in fig. 2 b spectra PC (I) and DC (II) are designated. As in the first case, the spectrum of PC is flattens to lower energies [7,8], and extrapolation of the power law spectrum of the DC II (dashed line) well agrees with direct measurements of solar protons up to energies of 150 MeV. At lower energies (<100 MeV) the spectrum of direct measurements of solar protons is bent toward lower energies. It should be noted, that the maximum intensity of cosmic rays of moderate energies in this case have been achieved within an hour and half after the maximum increase on the NMs. As can be seen from Fig. 2b there is a satisfactory agreement between the extrapolated spectrum of the DC obtained in one hour after the start of a solar flare and simultaneous direct measurements of solar protons on the spacecraft GOES-10. in the energy range from 700 to 150 MeV. At energies <100 MeV the spectrum of solar protons is bent and the forecast gives approximately 10 times overestimated values. Despite this, there is the advantage of such forecasts, which in the absence of direct measurements can give a rather accurate estimation of SCR fluxes at energies inaccessible to ground observations.

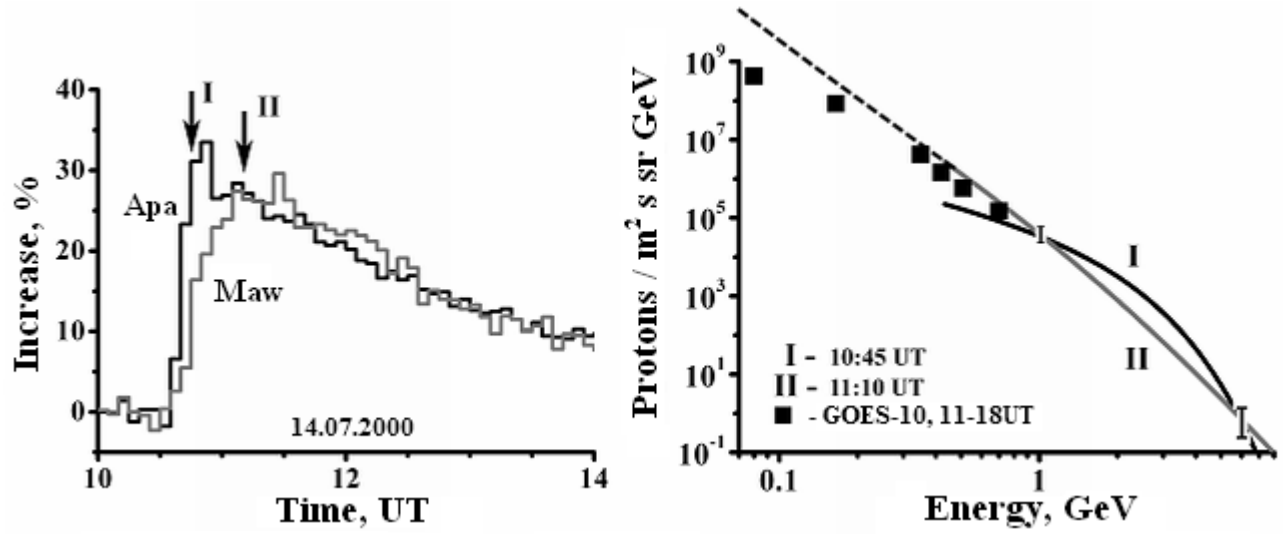

Fig. 2. a - profiles of ground level enhancements at NM stations Apatity (Ap) and Mawson (Ma). **b** - energy spectra of the RSP, obtained from the NM data at times I (PC) and II. (DC). The dashed line is extrapolation of the spectrum II (DC). Points is a spectrum of the time of maximum (TOM) spectrum, according to direct measuring of solar protons on the spacecraft GOES-10.

1.3. Event of 15 April 2001

GLE event No 60 (15.04.2001) was associated with the solar flare 2B/X14.4, heliocoordinates S20 W85. At 13.48 UT the onset of a radio burst of type IV, probable time of acceleration of particles, was noted. In fig. 3 profiles of increase at the NM stations Cape Schmidt and Oulu, are shown. Arrows I and II designate the moments of determination of the spectra given on fig. 3b. As well as in previous cases, the spectrum measured at the moment I have the characteristics of the prompt component (exponential dependence on energy). The spectrum II belongs to the delayed component (DC). Its extrapolation (dotted line) well agrees with the TOM spectrum of maximal fluxes at moderate energies (up to 200 MeV). At lower energies forecast gives overestimated values of intensities. It should be noted, that in this case the maximum range of fluxes was taken almost simultaneously with the increase on NM, and the maximum in the energy <100 MeV are simply not been achieved. Therefore, the forecast based on the extrapolated spectrum of the DC of the relativistic solar protons is quite justified.

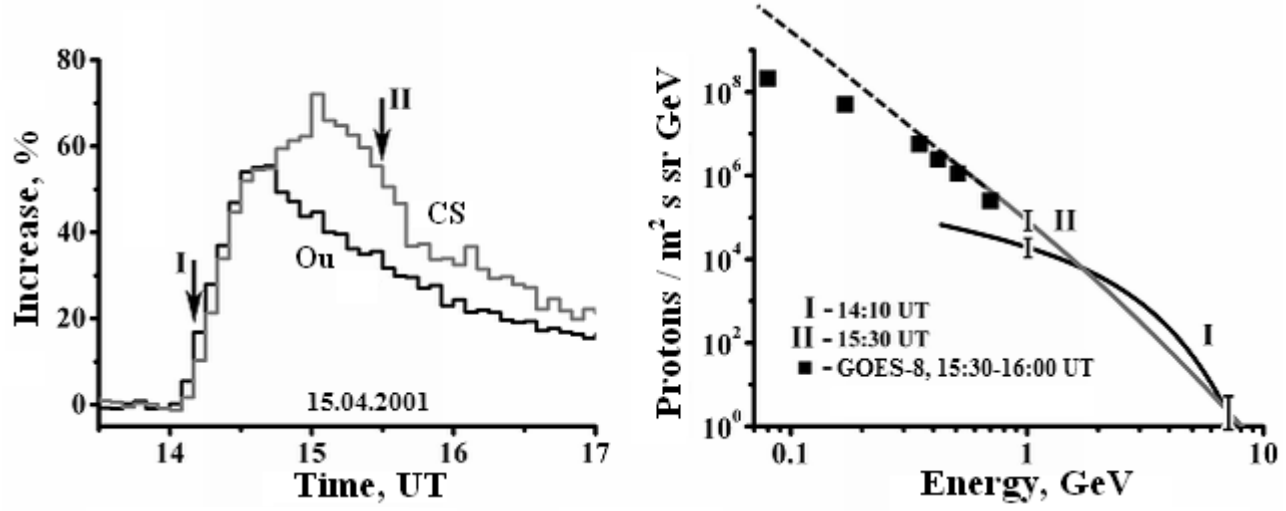

Fig. 3. a - profiles of ground level enhancements at NM stations Cape Schmidt (CS) and Oulu (Ou). **b** - energy spectra of the RSP, obtained from the NM data at times I (PC) and II. (DC). The dashed line is extrapolation of spectrum II (DC). Points are the TOM spectrum of the maximum fluxes, according to direct measurements of solar protons on the spacecraft GOES-8.

3. Discussion

The considered above examples are typical and are chosen from 12 analysed cases. By present time we have 35 analysed SCR events at ground level during 1956-2006 with the calculated energy distributions. It shuld be noted,

that for such analysis as in the above-stated examples, it it is necessary to have data on about time of maximum (TOM) spectra in the range of moderate-energy SCR (tens to hundreds MeV). Sets of TOM spectra are available in the "Catalogues of Solar Proton Events" [6, 9, 10], covering the period from 1970 to 1996. Attraction of data from these Catalogues will permit to significantly expanding the base of the present study. For the events of recent years data of available measurements of solar cosmic rays on the spacecrafts and balloons measurements will be involved.
The observed accordance spectra of thedelayed component of RSP, and the TOM spectra of the maximum fluxes of solar protons of moderate energies, we can assume as a consequence of unique mechanism of acceleration on the Sun. Thus for PC the mechanism of acceleration by an electric field in the area of magnetic reconnection of solar flare [3, 7, 8] is essential. This mechanism gives an exponential energy spectrum, which flattens at moderate and low energies. Rather, probable mechanisms of particles acceleration of DC can be a stochastic acceleration by plasma turbulence [8] or the acceleration at a shock wave. Both of these mechanisms provide a power energy spectrum and are effective enough both at low, and at high energies.
Therefore, the energy spectra of solar cosmic rays at high and low energies coincide, although the high-energy particles come from the sun and reach the maximum intensity before the low-energy.
From here also it is clear, that for the forecast of fluxes of SCR of moderate energies on ground level measurements it is necessary to use only data of the delayed component of relativistic SCR.

4. Conclusions

In this paper, on a number of concrete examples the possibility of the forecast of radiation-hazardous fluxes of SCR in the energy range of tens to hundreds of MeV, according to spectra of the relativistic solar protons obtained by means of an author's methods from data of ground based neutron monitors is shown. In events with relativistic cosmic rays there are usually observed two populations (components) of particles: prompt component (PC) with an exponential energy spectrum and the delayed component (DC). It is shown, that for the forecast of fluxes of SCR of moderate energies (tens and hundreds of MeV) it is necessary to use the spectra of the delayed component of relativistic solar protons. The proposed here technique allows us to evaluate the fluxes of solar cosmic rays of moderate energies in lack of the direct measurements, as well as provide forecast for these fluxes in the next few hours. This technique may also find application in the created by now database of neutron monitors (NMDB) [5] which is working in real time and carrying out in a automatically mode a number of problems of space weather and forecasting of the natural-hazards phenomena.

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