The ALERT signal of ground level enhancements of solar cosmic rays: physics basis, the ways of realization and development

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***Abstract*. Using the data from neutron monitor network observation the system of the ALERT signal generation is elaborated about, as ground level proton enhancements, so for search of solar neutron increases. On this basis the service with the emergency notification by e-mail about the onset of such increase is organized. Possibility of self-testing of system is provided.**

***Keywords*: Alert, Solar protons, Solar neutrons**

I. Introduction

Space vehicles in the near Earth space are subject to influence of many constantly varying factors of environment, but a special role play the charged particles of high energy, for example, protons with energy >100 MeV. Such particles are capable to penetrate radiating protection of space vehicles and cause any failures of the electronic equipment or even completely to put it out of action. Streams of high energy protons of solar flares reach huge sizes (>1000 pfu) and, hence, the forecast and an estimation of such streams is extremely important practical problem. Sometimes the streams of high energy protons are observed on the Earth, (GLE Ground Level Enhancement) that testifies to arrival of particles much bigger energies and at the earlier time. A possibility of prognosis of the particle fluxes in such events has been firstly considered in [1, 2]. Indeed, having defined according to ground level cosmic ray stations of the spectra of particles responsible for GLE, it is possible to estimate streams and behaviour of the protons, in particular, >100 MeV, outside of magnetosphere on some tens hours forward (Fig.1) since duration of GLE is only several hours whereas the satellite proton enhancement may last from ten hours to several days. However for automatic start of corresponding programs on spectra definition and the decision of this problem in real time, it is necessary to have a signal (ALERT), specifying in the beginning of ground level enhancement. In Fig.1 the response to solar events at Earth and scale of prognosis accordingly NOAA are shown. The system of generation of the ALERT signals by the X-ray radiation and solar proton flux for >100 MeV is developed in NOAA and may be found on the site [15]. However system of alert signal development, being based on the data about higher energy solar particles, was not created in NOAA. The scale in Fig. 1, concerning high energy particles, is added by two sources: solar neutrons and the solar protons observed on the Earth (GLE). One more acknowledgement of expediency of the forecast according to ground level observations is visible from a Fig. 2. On the Earth we receive the first information on event in X-ray radiation. Considerably after the Earth reach particles of enough big energies (>1 GeV), then, with some delay, on satellite the protons with energy >100 MeV or >10 MeV having more difficult trajectories because of interaction with interplanetary magnetic fields are registered. Last years some researches on working out of a technique of the alert signal allocation appeared. One of the early concerns works [1, 2] in which the algorithm of formation of alert signal on the basis of the neutron multiplicity data received by the neutron monitor at one point of measurement has been realized. In [3, 4] the proposed method was expanded on the data from world wide neutron monitor network. Very close method was considered in [5] where the technique has been approved on the last 10 events GLE. The present work is development of a method [3], and became possible with creation of a database of the neutron monitor network in real time. GLE is more often purely proton event, but can precede such increase by increase of intensity of solar neutrons, as, for example, in the event on May 24,1990 (GLE-048) or in general without observable proton increase, for example, on August 25, 2001. As principles of discrimination of proton and neutron increases are absolutely various, we created two independent Internet projects for detection of such events and formation alert signal which are named as Alert of Solar protons and Alert of Solar neutrons.

II. ALERT of Solar protons

A. Set of detectors for elaboration of the Alert signal

For formation of the earliest alert signal analysis of the increase is necessary to make at the earliest stage, when, as a rule, a stream of solar particles is strongly anisotropic. In fig. 3 the profiles of CR intensity registered by a network of stations during GLE in April,

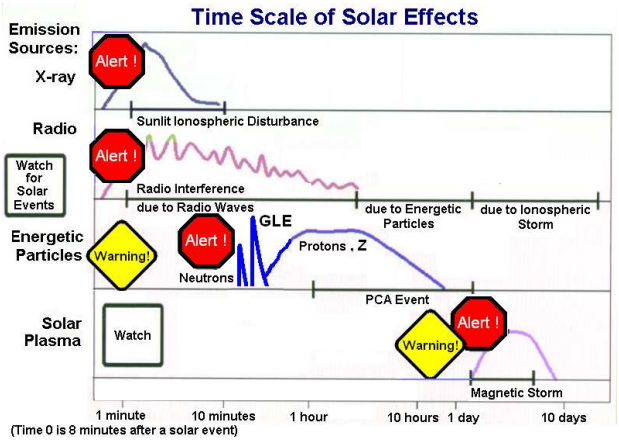

Fig. 1: Time scale of the response to solar disturbances at Earth and scale of prognosis by NOAA

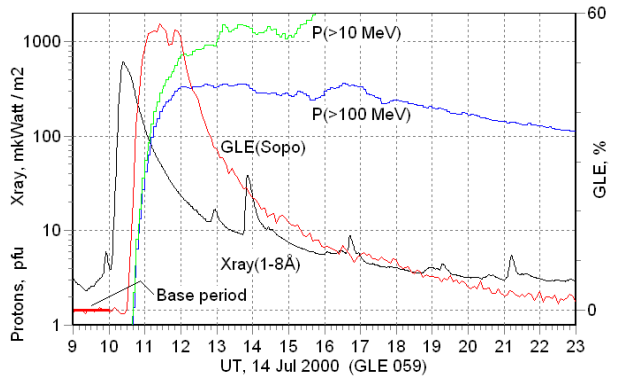

Fig. 2: Illustration of the time delays relatively to the onset of flare for X-ray for event on July 14, 2000

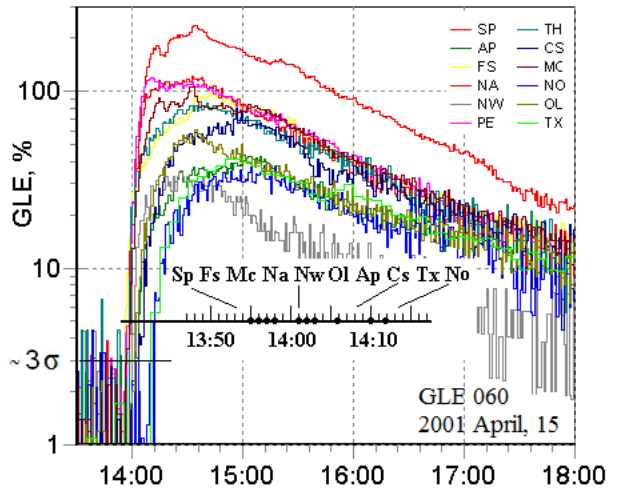

Fig. 3: The onset of GLE60 at different polar stations; Insertions at a level of 5% shows the onset

2001 are presented. There is a wide spacing in time of the beginning of event at different stations is visible and if to be limited by any local set of stations a delay in formation of alert signal can reach 10 minutes and more. Hence, in the analysis stations from all latitudes, both northern, and southern hemisphere should be presented.

B. Selection of base time

We are interested in an increase of particles of a solar origin over a background of the galactic origin, which itself does not remain to constants. Therefore it is important to choose the base period relatively which the amplitude of increase of solar CR is defined, directly ahead of increase. It is accepted at formation of a GLE file as the base period to choose the first full hour interval previous increase. Full list of GLEs and the base periods can be found in a database [11]. We also selected as a base period the first full hourly interval preceded to current time, i.e. time delay of the base period varies from 0 to 60 minutes. If it is established that increase has begun, the base period remains to constants till the end of registered GLE. Other decisions are possible also [2,5].

C. Choice of threshold level and criteria of the alert signal formation

The choice of threshold of events at formation alert signal is very important and critical. The aspiration to lower selection level (for example, 2.5σ) creates problems with false events. The choice of high level of selection (for example, 5σ) leads to the admission of small on amplitude GLE. Indeed, statistical accuracy of the minute data of 18NM64 is about 1%. We choose a selection level as 3%. In other works this level was chosen as 2.5σ [1,2], 3σ [3,6], 4σ [5], but herewith the criteria of the alert signal formation a little differed.

D. Selection of time resolution

The choice of time resolution of used data is close related to the choice of a threshold level. If a threshold level is 3σ one minute data can be used. As one can see in Fig.3 at this level (3%) a probability of false alert signal is high. To avoid it, we applied a procedure which demands repeated (or thrice) acknowledgement of excess of level.

E. Choice of criteria of the alert signal formation

When the alert signal is generated at some individual stations it is necessary to combine this information and produce the common signal. Can happen that at small and enough anisotropic GLEs, on a part of stations will not appear the alert signal. Therefore at development of general signal ALERT it is necessary to use soft enough conditions to consider a possible situation with anisotropy of GLE. The analysis of retrospective events has shown that at generation of general ALERT signal it is sufficient to have alert signal on 60 % of considered stations. It has proved to be true in 12 events investigated by us without formation of a false signal. Other criteria of formation of general signal are possible also.

The main principles of the generation of ALERT signal used at the program realization in real time on the site [8]: 1) Analysis is based on one-minute data of neutron

TABLE I: Outlist for Solar neutrons for 2009, May

	A		Apole		X-ray	
	%	nσ	%	nσ		
17 11:59:00	9.02	7.9	-9.30	8.3	110	TEST
17 19:25:00	4.78	4.2	-1.63	1.5	3.73 10^{-7}	No
18 11:41:00	4.64	4.1	-0.68	0.6	3.73 10^{-7}	No
18 11:59:00	9.63	8.5	-7.69	6.8	110	TEST
19 09:53:00	4.73	4.2	-0.96	0.9	3.73 10^{-7}	No
19 11:59:00	8.70	7.7	-9.77	8.7	110	TEST

monitors; 2) As the base period a full hourly time interval closely preceding the considered event is taken; 3) For decrease of a threshold of selection GLE for producing an alert signal, the level of 3 % is chosen, but under condition of repeated (or thrice) acknowledgement of excess of this level; 4) At generation of alert signal on 60 % of considered stations the general signal ALERT is formed.

F. Common description of a system on elaboration of the alert signal for proton enhancement

Block-scheme of the ALERT generation in real time is present in Fig.4. At the first stage variations of the minute data of each station which have exceeded threshold value 3σ are selected. It is supposed that an alert signal is worked out if during the following moment of time an excess of a threshold for the given station also has been fixed. In [8] we can see real time Protocol, where the cosmic ray variations for each station are presented, and on the right side a number of stations with variations exceeded 3σ is printed. At the generation of alert signal on 60% of stations a general ALERT is produced which runs a software of prognosis and estimation of the high energy solar proton fluxes.

G. Self-testing of the GLE Alert system

Considered events are very rare, so, continuous testing of software and hardware therefore is necessary to provide. With that end in view start two copies of the program. The first analyzes the real data, and the second is used for system testing. In current date a year was replaced by year in which in current month the GLE was observed. As a result within a year the program second copy will monthly generate test alert signal for GLEs: 69,59,60,61,57,53,59,64,42,65,67,70.

III. ALERT OF SOLAR NEUTRONS

Observation on the Earth the solar neutrons generated during powerful solar flares, 10 times more rare event in comparison with protons, however this data is extremely important, as they, together with the data about solar X-ray and gamma radiation, allows to receive the unique information on a source of the accelerated particles on the Sun. As solar neutrons propagate from the Sun by the straight lines, their flux at the Earth is strongly anisotropic, and the response of neutron monitors to primary solar neutrons depends on depth of atmosphere over a point of observation in the Sun direction. For observation of solar neutrons the high-mountain equatorial stations are ideal if observe the event in the summer at local midday. No other conditions play a role. In the world wide network of neutron monitors there are only about 10 equatorial high mountain stations where registration of solar neutrons is most probable. We considered only detectors which publish its data in real time: Jungfraujoch (18IGY), Jungfraujoch (3nm64), Lomnitsky Stit, Alma-Ata and Yangbajing. As selection of solar neutron increases is made with very low threshold (4σ), and increases are very short (more often one, sometimes some minutes, and such increases are practically observed only on one of a small number of the most sensitive detectors it is impossible automatically to allocate such events with sufficient high reliability. Therefore the offered system forms the small list of applicants for neutron increase which can be analyzed further. Applicants for neutron increase can be only those increases of counting rate which were accompanied by X-ray flares of a class above X1 (100 mkW/m^2). Data on X-ray channel 1-8 A from GOES are used for selection of solar neutron increases. The criteria listed above (a reception cone, criterion of selection of events and a critical stream of X-ray radiation) make physical preconditions for formation of alert signal of ground level neutron increase. Certainly, thus at polar stations it should not be observed any increase as on such high latitudes solar neutrons cannot get.

A. Total description of the alert system for solar neutron enhancements

Block-scheme of a system for selection of applicants to neutron GLE is present in Fig 5. Search for effect of solar neutron is carried independently by each station on the base of one-minute NM data with incorporating of X-ray channel data. Event is enlisted in applicants for solar neutron increase if following conditions are simultaneously satisfied: a) In the absence of increase at basic polar station at tested station increase $> 4\sigma$ is observed; b) The station is in a zone of direct visibility on the Sun within some angular cone c) The flux of X-ray exceeds the threshold ($>$100 mkW/m^2). This case is presented by line 1 in Fig.5. As in the case of GLE-Alert for proton enhancement for the base period the full preceding hour is accepted. A threshold level was chosen 4σ both for reference polar and tested stations. If thus the stream of X-ray radiation does not surpass threshold value such increase does not join in number of applicants, and is entered only in the minutes. On fig. 5 it is presented by a line 2. It is obvious that the report will contain basically such events. If increases at polar station exceed threshold, in not dependences on variations at equatorial station such event is also allocated and can be used at the analysis of quality of NM data or in general can concern proton GLE. In fig. 5 it is presented by a line 3. And, at last, if variations at basic and tested stations have not reached threshold values such events are not considered at all.

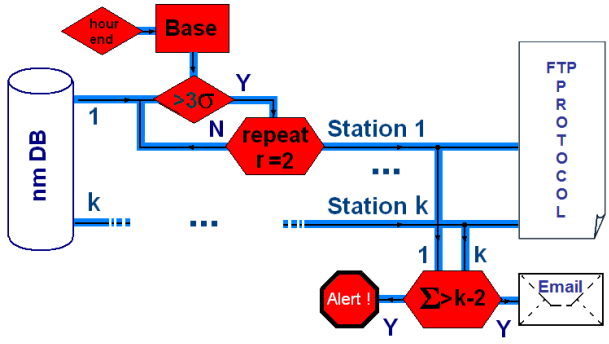

Fig. 4: Block-scheme of the system of generation of alert system for proton ground level enhancement

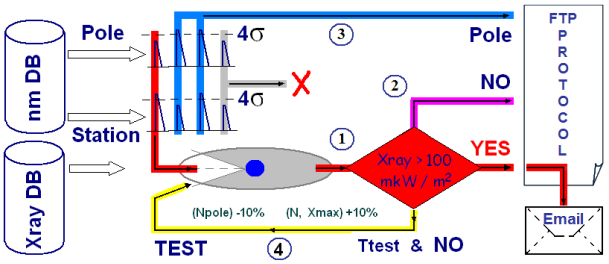

Fig. 5: Block-scheme of the system of producing ALERT signal of the solor neutron

B. Auto-testing of a system Solar Neutron Alert.

Not to break process of selection of solar neutrons, auto-testing is carried near to an exit of station from a cone of visibility of a stream of solar neutrons. With that end in view in Ttest=1:59 LT on each station provided that the stream of X-ray radiation less than threshold value, "is thrown" a false information for check of working capacity of system. This is a 10% increase of the counting rate variation at tested station and the same decrease at polar station. The X-ray flux is made also of 10% higher than threshold value. Test checking is entered in the minutes as TEST and is missed in the further processing of a signal. This case is presented by line 4 in Fig.5. The described technique is realized in the Internet project [9]. The result of the analysis is accessible in a kind ftp Protocol. Subscription possibility (or its cancellations) on post dispatch if the system has developed the applicant for neutron increase is provided. The typical Protocol which is formed for each station is presented in Table 1.

IV. Conclusion

1) The algorithm of generation of alert signal of ground level proton increase on the basis of the one-minute data of the neutron monitor network is developed and realized. The developed Internet project [8] provides possibility of formation of the electronic warning signal and its automatic dispatch. In project development it is planned to add system with the module for an estimation of GLE spectrum and the forecast on its basis of the high energy proton fluxes from solar flares, in particular, protons with energy >10 MeV or >100 MeV. 2) The developed system of selection of applicants for solar neutron increase allows to form the list of possible increases in real time and to carry out the internal control of system. The developed Internet project [9] provides possibility of formation of the electronic message and its automatic dispatch. At the given stage the cone of reception of solar neutrons got out wide enough, namely 2 hour relatively local midday. In project development it is supposed to involve results of work [14] when such choice can be detailed taking into account probabilities of arrival of neutrons in the given point and at present days. Even taking into account very low threshold of 4σ, the number of untrue reports is quite comprehensible, as the condition of excess of a threshold of a X-ray stream is very rigid and, hence, only during these short periods the system can generate such untrue reports.

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References

[1] Dorman L., Zukerman I., *Adv. Space Res.*, 31, 925-932, 2003.
[2] Dorman L., Pustilnik L., Sternlieb A., Zukerman I., *Adv. Space Res.*, 31, 847-852, 2003.
[3] Dorman L., Pustilnik L., Sternlieb A., Zukerman I., Belov A., Eroshenko E., Yanke V., Mavromichalaki H., Sarlanis C., Souvatzoglou G., Tatsis S., Iucci N., Villoresi G., Fedorov Yu. , Shakhov B., *IEEE Transactions on Plasma Science*, 32, No 4, 1478-1488, 2004.
[4] Mavromichalaki H., Gerontidou M., Mariatos G., Planaki C., Papaioannou A., Sarlanis C., Souvatzoglou G., Belov A., Eroshenko E., Yanke V., Tsitomeneas S., *IEEE Transactions on nuclear science*, vol. 52, No 6, December 2005
[5] Kuwabara T., Bieber J., Clem J., Evenson P., Pyle R., *Space Weather*,vol. 4, S08001, doi:10.1029/2005SW000204, 2006.
[6] Souvatzoglou G., Mavromichalaki H., Sarlanis C., Mariatos G., Belov A., Eroshenko E., Yanke V. , *Adv. Space Res.*,doi:10.1016/j.asr.2008.09.018, 2008.
[7] Mavromichalaki H., Souvatzoglou C., Sarlanis C., Mariatos G., Papaioannou, A., Belov A., Eroshenko E., Yanke V., *Proc. 31th ICRC*, Poland, ID 0000, 2009.
[8] GLE Alert: http://cr0.izmiran.ru/GLE-AlertAndProfilesPrognosing
[9] Solar Neutron Alert: http://cr0.izmiran.ru/SolarNeutronMonitoring
[10] Archive SPIDR Data Base: http://spidr.ngdc.noaa.gov/spidr/index.jsp
[11] Archive GLE Data: ftp://cr0.izmiran.ru/COSRAY!/FTP_GLE
[12] Real Time X ray (1-8 *A*): http://www.sec.noaa.gov/ftpdir/lists/xray
[13] Real Time Proton Data (>10 MeV and >100 MeV): http://www.sec.noaa.gov/ftpdir/lists/particle
[14] Belov A., Asipenka A., Dorman L., Eroshenko E., Kryakunova O., Nikolayevsky N., Shepetov A., Zhang JiLong, Yanke V., *Proc. 31th ICRC*,Poland, ID 1107, 2009.
[15] NOAA Space Environment Center Website: http://www.sec.noaa.gov/alerts/index.html
[16] NOAA Space Weather Scales: http://www.sec.noaa.gov/NOAAscales/index.html