GLEs as a warning tool for radiation effects on electronics and systems: A new Alert System based on real-time Neutron Monitors

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Abstract— **Ground level enhancements (GLEs) are the manifestation of short-time solar energetic particle radiation near Earth causing damage to electronic devices carried above the satellite platforms. A test alert system based on a real-time ground level Neutron Monitor Network is proposed in order to protect devices and electronics from space weather radiation effects.**

Index Terms—**Cosmic rays, Extraterrestrial phenomena, Solar radiation**

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I. Introduction

Unexpected bursts of solar energetic particles (SEP) are one of the major constraints on the operation of space systems and further technological utilization of near-Earth space [1]. The US National Security Space Architect report on Space weather referees that during the last years about one or two satellites per year have suffered either total or partial mission loss due to space weather [2]. Electromagnetic fields as well as radiation of different kinds are usually the most common factors that influence the satellite operation. Since spaceships and satellites are not protected by the atmosphere and to some extent neither by the magnetosphere, they are exposed to constantly varying parameters of surrounding environment. Therefore space weather changes can be extremely hazardous for the devices carried above their platforms. Especially, the high-energy charged particles play an essential role resulting in different kind of failures in the electronic equipment, even rendering them completely inoperative. In case of a sever radiation storm satellites may be rendered useless since they experience memory device impacts, orientation problems, serious noise in image data and permanent damage to solar panels. Moreover, blackout of high frequency radio communications over high latitude regions as well as increased number of navigation errors over several days are likely to appear.

The high-energy proton fluxes from solar flares reach gigantic values (>10000 pfu). Therefore, estimation and prognosis of such fluxes is a practical task of extreme importance. One of the ways to protect devices and electronics from space weather radiation effects is to elaborate accurate prognosis methods for the detection of possible dangerous periods for the near Earth environment. These methods should be built in such way as to allow the undertaking of a set of preventive measures for decreasing the probability of space born equipment operation during periods of severe radiation storms. A prognosis and evaluation of the high-energy solar proton flux may be feasible if Ground Level Enhancements (GLEs) are simultaneously recorded at different points of observation on the Earth. A GLE is a sharp increase in the counting rate of a ground based cosmic ray detector, caused by solar particles of sufficiently high energies to propagate along the interplanetary magnetic field and reach the Earth surface. A possible solution of such a problem has been considered by [3], [4]. According to this approach, it is possible, during a GLE, to define the high-energy protons spectra on the boundary of magnetosphere using the ground level neutron monitor data. The duration of a GLE is usually of a few hours – much shorter than that of >10MeV and >100 MeV energy proton enhancements detected by GOES (Fig. 1). Therefore, after defining the spectra of these particles and calculating their behavior during the proton event, an estimation of the lower energy proton flux, as well as the time of their maximum, will be attainable. The accuracy of this forecasting depends on the accuracy of the spectra obtained. However, to run automatically corresponding spectra calculation program, we should get an alert signal showing the onset of GLE.

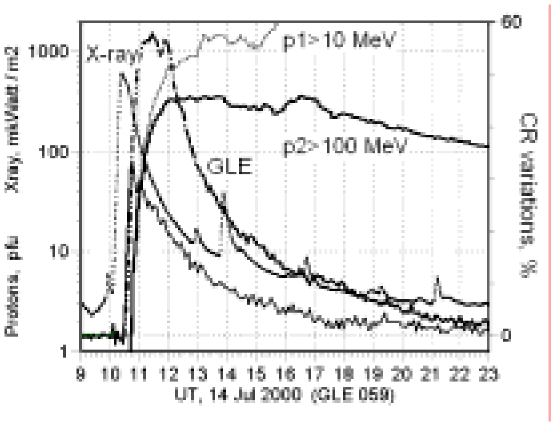

Fig. 1: Illustration of the time delay relatively to the flare onset for X-ray increasing, the ground level comic ray enhancement recorded by neutron monitors and the increase of the protons (>10 MeV and >100 MeV) on the example of the event of 14 July, 2000.

II. GLE ALERT SYSTEM

An attempt to create a worldwide data collection system connecting all real time neutron monitor stations in a common real time network, capable of real time data processing and forecasting has been recently made by the Athens Neutron Monitor and the IZMIRAN cosmic ray groups. The system being developed watches for count rate increases recorded in real time by twenty-one neutron monitors, and gives an alarm when a Ground Level Enhancement (GLE) is detected. In order to create this alarm system the following aims have been followed: 1) utilization of retrospective data (X-Ray radiation, GLE data, solar protons and electron channels from GOES) in order to define the earliest alert GLE signal, 2) use of a large statistical material for investigating the delay of the enhancement onset in case of different kinds of radiation and

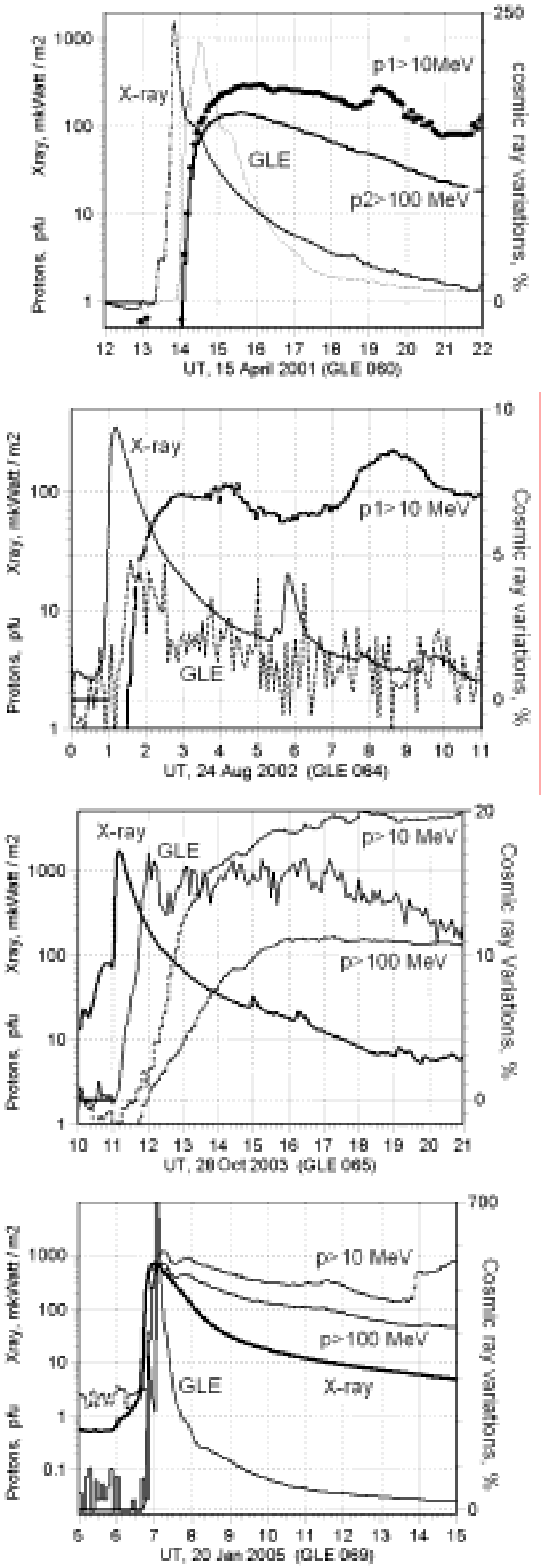

Fig. 2. Illustration of time delay relatively to the flare onset in X-ray enhancement, for GLE (Apatity NM), and for enhancement in >10 and >100 MeV protons on the example of four GLE events.

3) application of a trustworthy method of producing alert signal. A short description of the main steps of the main program solving the alert signal producing problem is presented.

In Figs 1 and 2 the time delay between solar flare onset (X-ray) and beginning of the enhancement in different particle channels (NM, and protons of >10 and >100 MeV energies) is illustrated for different proton events. It is clearly seen that in the vicinity of the Earth, the first notification of the existence of the event is obtained from X-ray radiation data. Significantly later the effect starts to appear in the high energy particle arrival at Earth, causing the onset of a GLE. More complicated trajectories because of the interplanetary magnetic field have solar protons of lower energy (>10 and >100 MeV) that leads to a bigger delay relatively to the flare onset.

As one can see from the figures presented above, the behavior of particles with different energy during the powerful solar energetic particle events clearly declares that high-energy particle profiles recorded at the Earth had ended well before the main development of the low-energy particle profiles. The distribution of the time delay between maxima in X-rays and in >10 MeV protons obtained from [5] on the large statistical material, is plotted in Fig. 3. The main maximum of this distribution corresponds to a time delay of 3-4 hours, but there are also seen other clusters of events with significantly larger time of delay. The width of the time delay distribution is caused, first of all, by different longitudinal location of the solar sources. However, even in the case of simultaneous onsets (as, for example, in the case of the event of 20 January 2005, Fig. 2) the ground level observations give a clear chance to evaluate and predict a behavior of lower energy particles and their fluencies during some later hours due to the fact that GLE profile is completely finished well before the enhancement evolving in the lower energies.

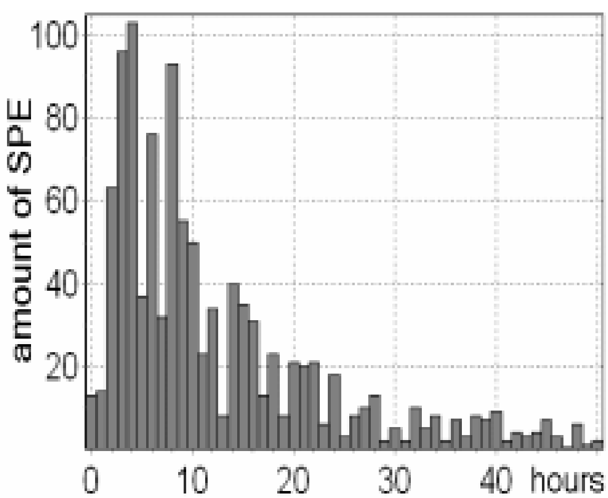

Fig.3. Distribution of the time delay of the proton (>10 MeV) enhancements relatively to the onset of the associated X-ray flares.

III. DATA AND METHOD

Data of solar radiation of different kinds (X-ray, proton fluxes) have been used from the archive of minute data enhancement [6] from 1986 to 2005. One-minute real time data of X-ray and protons have been taken from updated sources [7] and [8]. Different GLE neutron monitor data have been used from the archive soure [9]. Alert signal determining the beginning of the proton event (in our case, the GLE event) can be obtained from the X-ray data and ground level observation data, sometimes jointly with the data of >10 MeV and >100 MeV protons [10]. The methods and preliminary algorithm of such a signal elaborating were described in [3], [4], [11]. In this work special attention was paid to choosing the baseline period as well as the selection criteria of the GLE beginning. The aim was to minimize a probability of a false Alarm. Obtaining Alert signal for the onset of the event gives a start for running a special program for collecting and processing data from NM network to calculate the GLE spectrum and evaluate the behavior as well as the fluencies of the lower energy, however more dangerous, and the fluxes of solar protons. At present in the ANMODAP Center in the Athens University jointly with IZMIRAN Cosmic Ray group, essential efforts are being applied in order to elaborate this Alert forecasting program.

The method of prognosis consists of four steps:

1) Data from at least three NM stations at Earth (two high latitudinal and one/two low latitudinal, or, three high latitudinal stations located in 120^o by longitude) and two independent satellite channels, for example X-ray on GOES10 and GOES12, are processed to search for the start of ground level enhancement. If it is found, our computer elaborates an Alert signal. From about 30 considered events only one signal was elaborated as false Alert.

2) The obtained by such a way Alert signal is sent by e-mail, while simultaneously a system of minute data collection from the whole NM network is running. In this case it is very important that neutron monitor data are updated not rarer than every 5 minutes. The number of necessary stations to be used should be about 10-20.

3) While the one-minute data are collected, the program of the proton enhancement analysis is running. The proton spectrum will be derived with more and more accuracy along the accumulation of new and new data.

4) Parameters of GLE spectrum from the NM network obtained are being used for the calculation different characteristics: diffusion coefficient, fluxes at different levels above the magnetosphere, possible fluencies for different energy particles and behavior dangerous part of proton radiation during the next hours, providing some kind of forecasting for proton fluxes. In a whole, it allows prognosis time behavior of non-relativistic solar protons up to 10-15 hours.

On the basis of a very close method in [12] a creation of software of automatically sending out the alert signal is planned. Combination of two or more independent sources of alert signal will allow to get the signal on GLE onset with high accuracy and run corresponding procedures for the automatic spectra estimation and the calculation of the expected fluxes of >10 or > 100 MeV protons.

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