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Real time determination of the RSP characteristics on the base of neutron monitor data

Balabin Y.V., Germanenko A.V., Gvozdevsky B.B.

POLAR GEOPHYSICAL INSTITUTE, APATITY

INTRODUCTION

The international network of neutron monitors is still the only reliable source of data on relativistic solar protons (RSP) recorded during solar cosmic ray events. The characteristics of these particles are determined by the international network of neutron monitors (NM) through the GLE modeling. By now, systems for collecting data from neutron monitors in real time have been created. One of those systems is the NMDB. With the development of computer technology, techniques that make it possible to determine parameters of the RSP during the GLE with good accuracy have appeared. Taking into account the fact that the duration of the GLE is usually several hours, such methods allow us to carry out the dynamics of the parameters of the RSP (spectrum slope, pitch-angular distribution, anisotropy axis) during the GLE. Relativistic cosmic rays come from the Sun to the Earth with delay about 11 minutes, but the intensity of energetic cosmic rays (above 500 MeV) is quite low and does not pose a serious radiation hazard. Due to the fact that a RSP spectra have a single form from 100 MeV to 10 GeV, it is possible due to determining the spectrum by neutron monitors in the high-energy region (> 500 MeV) to predict the radiation-hazardous fluxes of particles of moderate energies, since their arrival on Earth is delayed up to several hours.

Our real-time GLE modeling technique

The parameters of RSP can be determined from the data of the ground based neutron monitor network, with the help of a GLE modeling technique. Such a modeling includes the next steps:

1. Definition of asymptotic viewing cones of the NM stations under study by the particle trajectory computations in a model magnetosphere.

2. Calculation of the NM responses at variable primary solar proton flux parameters.

3. Application of a least square procedure for determining primary solar proton parameters (namely, energy spectrum, anisotropy axis direction, pitch-angle distribution) outside the magnetosphere by comparison of computed ground based detector responses with observations.

The task to determine parameters of the RSP flux outside the Earth's magnetosphere using data of the ground based network of NMs is an 'inverse problem'. The NM response to an anisotropic solar proton flux is:

$$\frac{\Delta N}{N} = \sum_{R_C}^{R_{UP}} J(R) \cdot F(\Theta(R)) \cdot S(R) \cdot A(R) \cdot \Delta R$$

where ***ΔN/N*** is a relative increase of the NM count rate; ***R*** is a particles' rigidity; $\boldsymbol{R_C}$ is a cutoff rigidity; ***J(R)*** is a rigidity spectrum; ***F(Θ)*** is a pitch-angle distribution. Pitch-angle ***Θ*** depends on *R* because given NM accepts those particles with given *R* which had specific *Θ* outside the magnetosphere. Finally, ***S(R)*** is a Specific Yield Function. A factor ***A(R)*** is a discrete function *A(R)=1* for allowed trajectory (proton with such rigidity can reach the station) and *A(R)=0* for forbidden trajectory. Parameter A is determined at the asymptotic cone calculations.

NM data preparation for the model

1. After receiving the GLE alert signal the 1-min count rate data together with barometric pressure from all the NMDB stations start to enter the specified file. The hourly count rate and pressure data of the same stations for the hour previous to one when GLE has started are also fill in the file.

2. The recorded 1-min count rate data are corrected for the barometric effect by the two attenuation method. The pre GLE hourly count rate data are corrected for pressure with the one barometric coefficient.

3. For the majority of events operating with 1- min data result in the large errors (unless an increase is of hundreds percents). The 1-min data are summed in 3 or 5-minute meanings, which then are used in the solving of the least squares problem.

Express and full-scale optimization

For definition of RSP flux parameters in real time the cut down version of a complete technique was developed. Restrictions, imposed on accounts in real time are:

1. less number of NM stations accessible in real time: up to 25 stations NMDB in comparison with 30-35 in a complete technique;

2. limited time for asymptotic cones computations. Thus trajectories of vertically incident particles are computed only. In a complete technique the contribution of oblique incident on NM particles was taken into account;

3. larger step on rigidity (ΔR): 0.01 GV against 0.001 GV in a complete technique.
The reduction of input parameters amount also promoted reduction of operation time of the program solving a least square problem.

Examples of GLE modeling with definition of solar proton spectra from NM data with above mentioned techniques: complete and truncated one are resulted below.

Comparison of solar proton spectra obtained with the help of complete calculation model and the "truncated" one. The points show the data of the maximal flows (Time of maximum, TOM) in direct measurements of solar protons obtained at GOES series spacecrafts and balloons.

GLE 59, 14 July, 2000 ("Bastille day GLE")

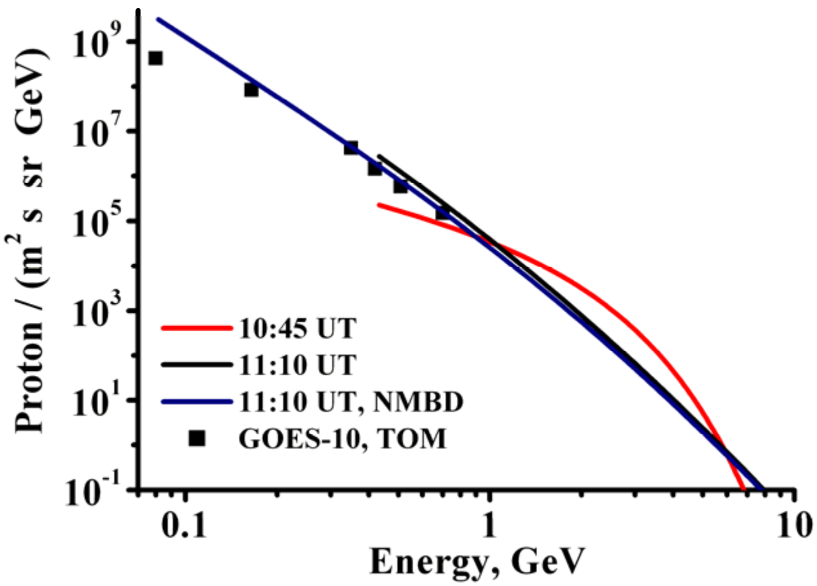

Fig.1. RSP spectra derived from NM data:
Red line is prompt component, complete model.
Black line is delayed component, complete model.
Blue line is delayed component, "truncated" model.
Points are TOM spectrum of direct solar proton data on the GOES-10 spacecraft

GLE 60, 15 April, 2001 ("Easter GLE")

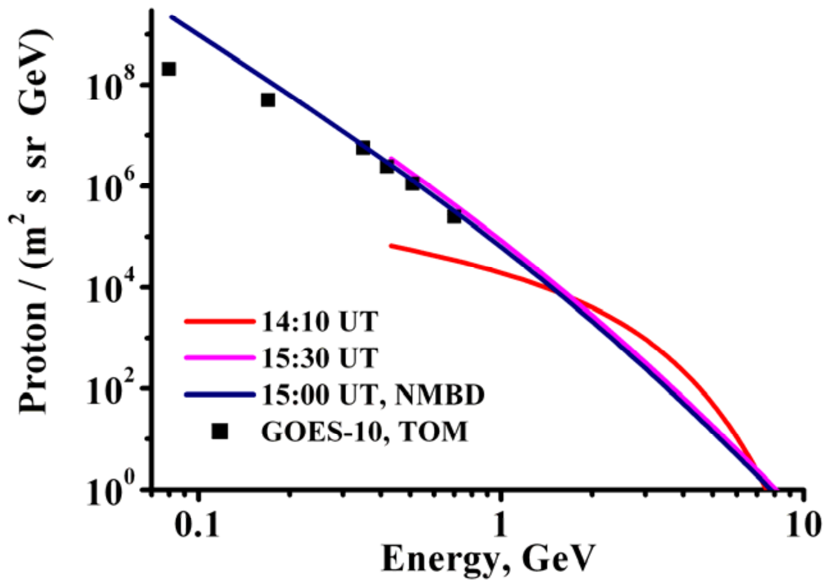

Fig.2. RSP spectra derived from NM data:
Red line is prompt component, complete model.
Magenta line is delayed component, complete model. **Blue** line is delayed component, "truncated" model. **Points** are TOM spectrum of direct solar proton data on the GOES-10 spacecraft

Comparison of solar proton spectra obtained with the help of complete calculation model and the "truncated" one. The points show the data of the maximal flows (TOM) in direct measurements of solar protons obtained at GOES series spacecrafts and balloons.

GLE 69, 20 January, 2005

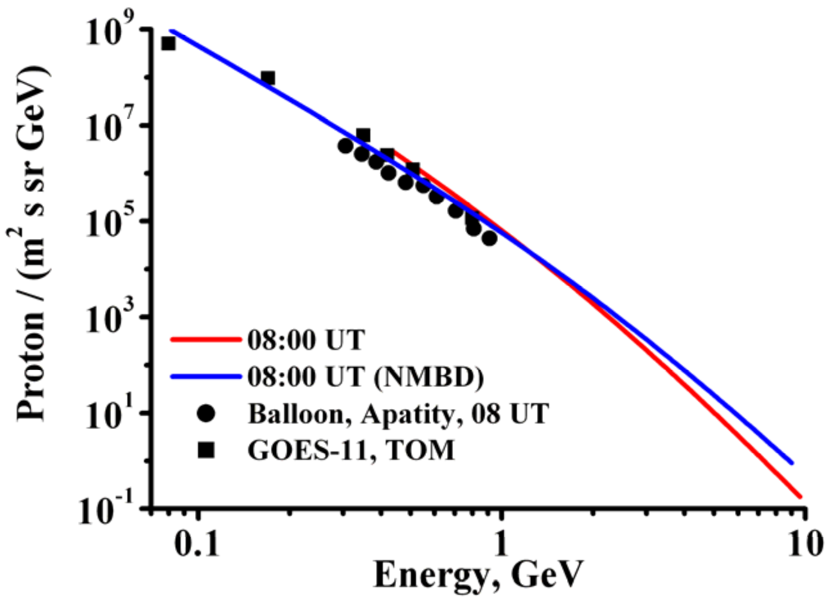

Fig.3. RSP spectra derived from NM data:
Red line is delayed component, complete model.
Blue line is delayed component, "truncated" model.
Points are TOM spectrum of direct solar proton data on the GOES-11 spacecraft

GLE 70, 13 December, 2006

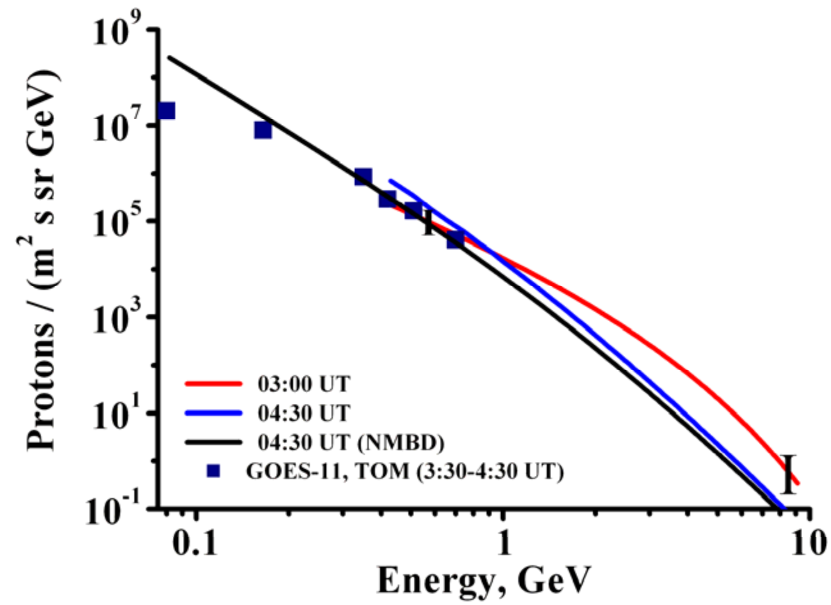

Fig.4. RSP spectra derived from NM data:
Red line is delayed component, complete model.
Blue line is delayed component, "truncated" model.
Points are TOM spectrum of direct solar proton data on the GOES-11 spacecraft

RESULTS

We developed the truncated technique of solar protons spectrum definition on the data of the limited number of neutron monitor stations and with the simplified procedure of accounts adapted for the purposes of the operative determination of the RSP characteristics on the base of neutron monitor data. The solar proton spectra obtained with the truncated technique practically do not differ from spectra obtained with a complete technique at energies less than 5 GeV. Thus the good agreement between derived from the neutron monitor data intensities of solar protons in an energy range of hundreds MeV with the data of direct measurements of solar protons at GOES-11 spacecraft is observed as well. The maximum of increase on neutron monitors outstrips on several hours (2-10) an appropriate maximum of radiation-dangerous fluxes, registered by spacecrafts of GOES series. Thus, the system of the determination of the RSP characteristics and predict the radiation-hazardous fluxes of solar cosmic rays in space on the basis of the neutron monitors data obtained in real time by the NMDB network can be created.