Relationships between cosmic ray neutron flux and rain flows

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Abstract—**The registration of secondary cosmic ray neutrons is a convenient tool for investigation of primary cosmic ray variations and for meteorological effects as well. At present a large network of neutron monitors exists, aiming the studies of cosmic ray variations which are related to the interplanetary conditions and geomagnetic activity. At the same time cosmic ray variations may be related to some atmospheric processes. In this connection, using the data from two neutron monitors (standard and lead free one) and gamma detector from Moscow station and lead free neutron monitor at BEO Moussala, we studied the correlations between rain flows and neutron flux. In this study we used daily averages on the basis of 10 min data for the neutron flux, corrected for barometric pressure and data from local meteo-stations. The preliminary analysis indicates a correlation between rain flows and neutron flux in several cases. To explain observable correlations the calculations of neutron and gamma absorption and albedo neutron spectra have been performed on the basis of universal software package FLUKA-2006, FLUKA, 2008**

1. Introduction

The The neutron monitor (NM) is the main detector of CR ground level measurements. The purpose of the neutron monitor is to detect, deep within the atmosphere, variations of intensity in the interplanetary cosmic ray spectrum. Interactions of the primary cosmic rays with the atmosphere produce, among other secondaries, a lower energy component, in particular neutrons. The neutrons are not slowed by ionization loss. These secondary particles fall in the energy range of a few hundred MeV up to about 1 GeV. Because of the falling energy spectrum of the primary cosmic rays, the neutron monitors are most sensitive to the low energy (1-20 GeV) part of the spectrum. These nucleons in turn produce further nuclear interactions, either in the atmosphere, or in lead target material surrounding the monitor. The interaction rate may be measured most conveniently and reliably by detecting the reaction product neutrons rather than by detecting the charged fragments directly.

Neutron monitor and other CR detectors are constructed by a way to minimize the influence of local meteorological conditions. Thus, for example, polyethylene reflector in NM cut off the neutrons with energy < 20 MeV, lead in muon telescope absorbs soft component of secondary cosmic radiation with the energy <400 MeV since it is the particles of this energy diapason that most sensitive to the changes of local meteorological parameters.

However, simultaneously with CR monitoring by a standard NM the measurements of epithermal neutrons (0.025 MeV<E<0.5 MeV) by lead free monitors are conducting on some stations now. And these measurements strongly undergo to the local meteorological factors, in the first turn to content of water in the surface soil layer or above it, to the air humidity, existence of thunderstorm clouds above detector and so on. These effects are necessary to be estimated quantitatively both for their excluding from the observable data and for a solution of some applying [1 and references there] and fundamental [2, 3, 4] tasks.

During the last several decades the high mountain observatories have been exploited for astrophysical, environmental studies and of the Sun-Earth relations as well. The advantages of high-mountain observations are connected with a possibility to register with better statistics the secondary cosmic ray particles comparing to ground level observations that permits to investigate different processes of the environment and atmosphere with big precision. The Basic Environmental Observatory (BEO) Moussala is located on the top of the highest mountain at Balkan Peninsula, at 2971 m above sea level. A powerful tool used there for measurements of cosmic ray variations is lead free neutron monitor which was run only recently and still needs some verification of data.

One of important problems in the CR physics is the relationships between CR intensity and the rain flows. Stozhkov [5], Veretenenko and Pudovkin [6] and other authors discussed cosmic ray influence on precipitation in the periods of big magnetic storms (and Forbush decreases as well) and solar CR events. The increasing of atmospheric ionization leads to increasing of the density of charge condensation centres which cause increasing of total cloudiness and

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atmosphere turbulence. As a result of cloudiness increase, increase of total precipitation is also expected.

Really, during big solar CR events, when the CR intensity and ionization in the atmosphere significantly increase, an increase in the precipitation level is observed. The amplitude of the positive increase was found by Stozhkov [5]: +(13.3 ± 5.3)%. Our aim in this work is to explain the registered changes in the cosmic ray intensity at ground level during the rain flows.

2. Data and methods

Using the data from Moscow (latitude 55 degree) neutron monitors (standard super monitor NM64, lead free monitors 6nmF and 23nmF) , gamma and ionization component detectors and lead free neutron monitor at BEO Moussala (latitude 42 degree and altitude 2971 m), we studied the correlations between rain flows and neutron, gamma and ionization component behavior. We also involved data of local meteo-stations. To explain observable correlations the calculations of neutron and gamma absorption and albedo neutron spectra have been performed on the basis of universal software package FLUKA-2006, FLUKA, 2008 [7] accounting all interaction processes of neutrons and gamma radiation with a substation. In result all spectra are obtained in dependence on the soil content, its humidity (from 0 to 30%) and amount of water above the soil (from 0 to 80 m) for generated monochromatic downward neutron flux of 10 or 100 MeV energy. Calculations are made for cylindrical 3D geometry under source distance above the soil 2.5 m. The cylinder radii is 1 m, its length is by 1m above and below of the soil surface. The soil composition was used as: O – 52,8%, Si – 28%, Al – 10%, Ca – 1,65%, H – 0,675%.

3. Results – discussion

Experimental results.

In Fig. 1 the measurements of CR secondary radiation by different detectors from IZMIRAN are presented for July-October 2007. Two lead free NMs (counters surrounded only by 2.5 cm of polyethylene) recorded mainly a behavior of epithermal neutrons and its behavior is compared with the data from standard NM (6nm64) which is practically not undergone to the environmental meteorological effect (because of its specific construction). In the low panel the data on gamma radiation and total ionization component are plotted. For gamma measurements two NaJ detectors (Ш=63 mm) are used, and for ionization component the telescope on the proportional counters is employed (S=1.5 m^2).

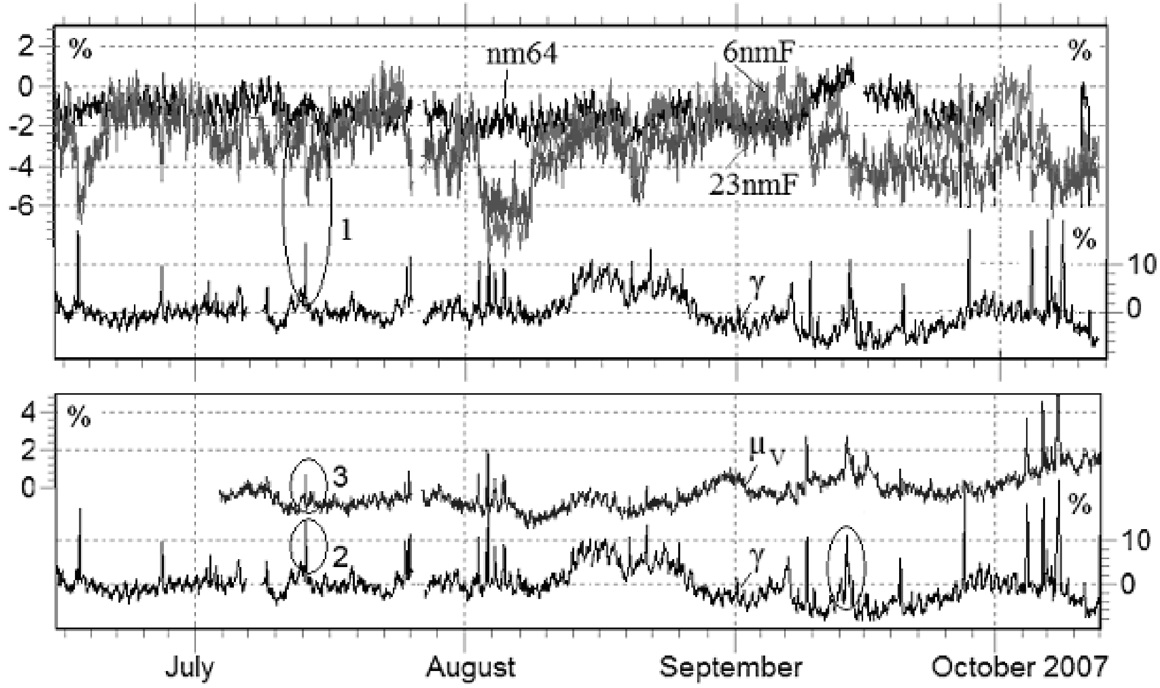
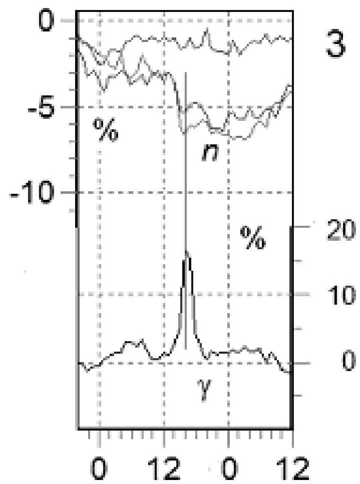


Fig. 1. Data from lead free NMs (6nmF and 23nmF) and standard NM (6nm64) in comparison with behavior of photon (gamma) and ionization components (muon) of radiation.

The correlation between bursts in gamma radiation and ionization component takes an attention. Such bursts are always observed when thunderstorm cloud approaches, often without rain. By the data from spacecraft, aircraft and ground level observations it was found by different researchers ([8, 9, 10, 11] that thunderstorm cloud and lightening discharges may lead to a generation of high energy particles. This means that electrons are accelerated up to relativistic energies in the electric field of thunderstorm clouds with the consequent generation of photon component. Herewith the short (or longer) increases of several minutes duration are recorded by detectors of gamma and ionizing radiation. Unfortunately, we have no direct measurements of the electric fields. The neutron component reveals quite different behavior. Effect in NM data is always much longer than the rain or gamma burst duration (see Fig.2). This effect of long decrease in the neutron component intensity badly correlates with the air humidity.

The humidity effect is less than temperature effect by order and is estimated as -0.005 %/g/cm^2.



Fug. 2. Comparison the effects in neutron and gamma components in 2007-07-17.

We assumed that observable effect is caused by the amount of moisture in near ground layer that requires the measurements of moisture content in the ground level soil. To explain the presented experimental data the spectra albedo neutrons were calculated by Monte-Carlo method (as it described above) for energies from10^{-11} up to 20 MeV. The obtained results can be used for the estimates of the water stores in the mountains by means of snow cover monitoring. They can be also useful for analysis the results of planet scanning by the spacecrafts equipped by the neutron detectors.

Discussion of results for neutron component

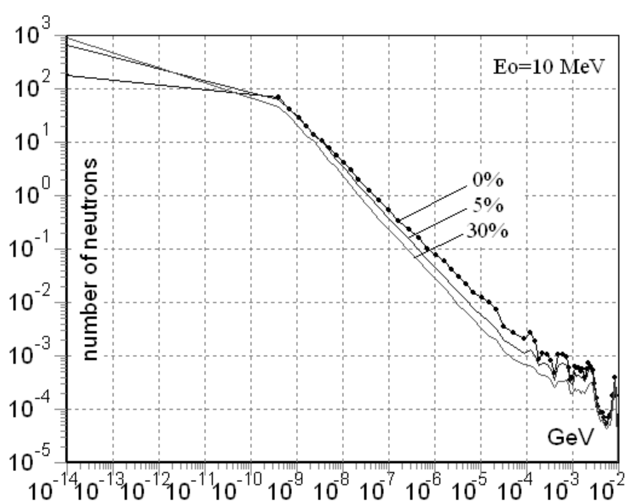


Fig. 3. Calculated spectra of albedo neutrons: for dry soil, soil with 5% and 30% of moisture content. The energy of incident neutron is 10 MeV.

These spectra for thermal, epithermal and fast albedo neutrons for incident neutron flux of 10 MeV energy are depicted in Fig. 3. Neutron spectrum marked by the points and corresponded to dry soil (0%) is compared with two other spectra for 5% and 30% moisture content calculated. One can see that the increase of H2O substation leads to an increase of a number of neutrons which in result of deceleration go into a thermal part of energy spectrum.

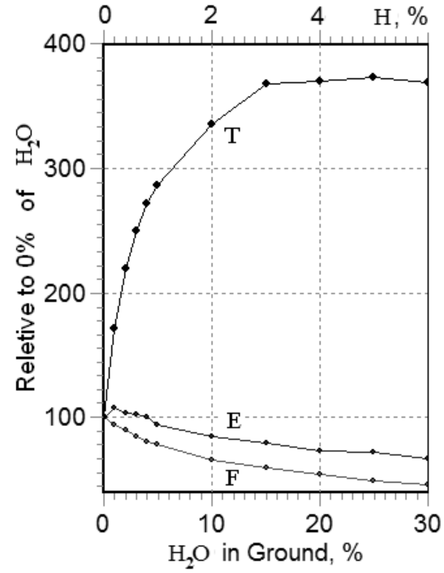


Fig. 4. Dependence of albedo fluxes for thermal (T), epithermal (E) and fast (F) neutrons on the hydrogen content in the soil.. E_0=10 MeV.

In Fig.4 a dependence of albedo fluxes for thermal, epithermal and fast neutrons on the moisture content in the soil is depicted. This result is obtained by integration of the spectra from Fig.3 within corresponding energy ranges: for thermal <0.5 eV; epithermal – from 0.5 eV up to ~0.5 MeV; and fast - >0.5 MeV. The ordinate shows a relative change of neutron fluxes for different energy diapasons, and abscissa axis corresponds to the water content in the soil. Statistical accuracy within all energy diapasons is several percentages.

In the counting rate of lead free detectors the large contribution give thermal and epithermal neutrons from the soil and atmosphere, so, data in Fig. 4 plotted explain our experimental results. With an increase of moisture the larger portion of neutrons is slowed and transferred into thermal range and a part of epithermal albedo neutrons reduces. Thus, 10% humidity leads to the same decrease of epithermal albedo neutrons. Such a content of moisture is possible even under moderate rain with precipitation of 50 mm and thickness of surface layer of tens cm.

It is important to know a response of neutron detector to the moisture amount above the surface layer. The spectra computations above the soil have been performed for different moisture layers (0, 10, 40 cm) and for two energies of incident neutrons: 10 and 100 MeV. The moisture content of the soil was accepted as 5%. On the basis of obtained spectra the flux of thermal, epithermal and fast neutrons dependence on the thickness of water-layer above the surface were derived.

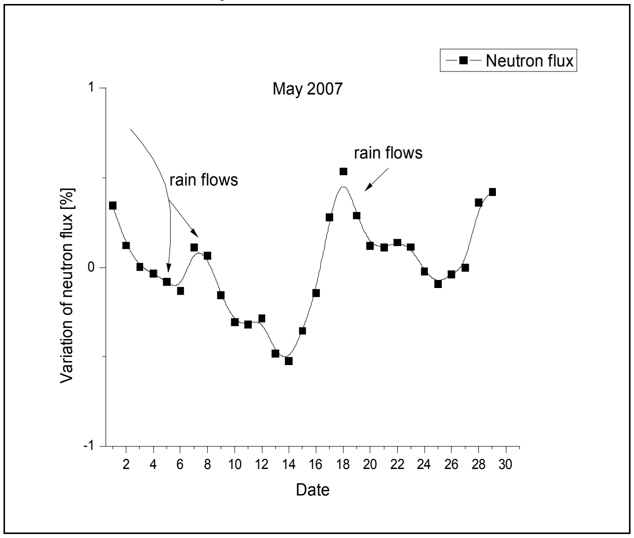


Fig. 5. The variation of neutron flux after pressure correction in May 2007 with significant rain flows at the top of Mussala.

A little different results – an increase of CR intensity during the rain period – was obtained from the data observation at Mussala lead free NM [12] (see Fig. 5). In addition the relative fluctuation of the mean flux also increases. In principle such an effect is possible to be and might be explained as due mainly to the additional moderating affects of the rain, which additionally slows the neutrons in the atmosphere. The possible relation between increasing of the flux and cloud cover is a topic of future investigation. Herewith, we should be very careful with using Mussala data in this initial period of the NM operating (It was run only on April 2007).

Conclusions

1) Secondary neutron radiation recorded by lead-free NM, and gamma radiation as well, are strongly effected from meteorological factors. The neutron component behavior depends on the moisture amount in the soil surface, and bursts of gamma radiation seems to be caused by a transformation of photon-electron component of the spectrum due to the strong electric fields in thunderstorm clouds and usually is an evidence of existence of such clouds..

2) Computations performed on the basis of universal software package FLUKA-2006 for particle interaction with substation, allow deriving of detailed spectra of albedo neutrons within three energy ranges: thermal, epithermal and fast neutrons. The moisture content of soil as 5% leads to an increase of the flux of albedo thermal neutrons in three times, whereas the flux of epithermal neutrons decreases by 6% and flux of the fast neutrons – by 22%.

3) Water layer above the soil lowers both the neutron incident to the surface and albedo neutrons. The result depends strongly on the energy of incident particles. Thus, under 100 MEV energy the flux of epithermal and fast neutrons is additionally absorbed on 70% by the layer of 10 cm. Albedo flux of gamma radiation reduces by 25% in water layer of 40 cm thickness under energy 10 MeV.

Acknowledgements

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