Lead free Neutron Monitor at Basic Environmental Observatory Moussala- first measurements

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Abstract—**.The developed at Basic Environmental Observatory Moussala lead free neutron monitor based on proportional counters type SNM-15 filled with BF_3 is described. According the initial design the detector complex is connected with cosmic ray variations, space weather studies and the impact of cosmic rays on atmospheric processes studies at Basic Environmental Observatory Moussala-Bulgaria. Several preliminary measurements are shown and comparison with Monte Carlo simulations is carried out. The detection of the barometric attenuation is shown, as the barometric coefficient obtaining. The scientific goals of the described complex are discussed, precisely the possibility to register solar proton events, ground level enhancements and Forbush decreases. The potential of the device for study the possible connection between cosmic ray measurements and the environmental parameters, precisely atmospheric ones is widely discussed.**

1. Introduction

During the last several decades the high mountain observatories have been exploited for astrophysical and environmental studies and observations of the Sun-Earth system as well. The advantages of high-mountain observatories are connected with the possibility to register with better statistics the secondary cosmic ray particles compared to lower observation levels.

The small anthropogenic influence gives the possibility to investigate different environmental and atmospheric processes with big precision. The Basic Environmental Observatory (BEO) Moussala is located on the top of the highest mountain at Balkan Peninsula, Rila mountain, namely at 2925m above sea level. Complex, high precision measurements of different atmospheric and environmental parameters are provided at the observatory.

Presently we study different changes and processes in the Earth atmosphere, atmospheric physics and chemistry, aerosol physics, radiation processes. Simultaneously we measure different components of secondary cosmic ray, namely the atmospheric Cherenkov light, muon component, in attempt to study different problems of cosmic rays, space weather and connections of the Sun-Earth system.

The detailed analyses of the collected data permits to study the possible relation between different kind of parameters and factors connected with environment, atmospheric processes and the system Sun - Earth. Generally the following specific objectives are pursued, in attempt to provide basic information for analysis of the connection between cosmic ray variation and atmospheric parameters. The aim is the detailed, precise and contemporary measurements of cosmic ray intensity especially the muon, electron, gamma and neutron component and the atmospheric Cherenkov light. Obviously, at the same time it is necessary to provide precise measurements of atmosphere parameters in different conditions.

One of the most existing topics in the area of Sun-Earth system, especially the relations between solar variability, respectively cosmic ray variability, is the possible influence of cosmic ray on processes in the Earth atmosphere. Changes in the large-scale atmospheric circulation are associated with solar activity phenomena [1] and long term cosmic ray intensity variations [2]. The possibility that galactic cosmic rays (GCR) are related to Earth's cloud cover [3, 4] and have an important impact on the Earth's radiativ climate forcing, has become a leading candidate to explain the observed sun–climate connection [5].

A powerful tool for investigations from Earth the variation of cosmic ray flux is based on registration of secondary cosmic ray neutrons [6]. Among the different proposed mechanisms, as example the UV heating of the stratosphere [1] or change of the solar irradiance [7] the influence of cosmic ray to cloud formation [8, 9] seems to be most promising at experimental point at BEO Moussala [10] mechanism for exploitation. The main purpose of recently developed lead free neutron monitor at BEO Moussala is the registration of the secondary cosmic ray neutrons and study of cosmic ray variations.

2. Neutron monitor

A neutron monitor is an instrument that measures the number of high-energy particles impacting Earth from space and provides continuous recording of the hadronic component in atmospheric secondary radiation. The purpose of the

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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 secondary particles, 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 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.

Because the intensity of cosmic rays hitting Earth is not uniform, it is important to place neutron monitors at multiple locations in order to form a complete picture of cosmic rays in space.

The primary cosmic ray that reaches the Earth's atmosphere is governed by the geomagnetic cutoff, which varies from a minimum at the magnetic poles to a vertical cosmic ray cutoff of about 15 GV in the equatorial regions.

As a consequence the ground-based neutron monitors detect variations in the approximately 500 MeV to 20 GeV energy range of the primary cosmic ray spectrum. In high latitude regions of the Earth, where the geomagnetic cutoff is low, the lower threshold response of the neutron monitor is controlled by the atmospheric mass. This limits the response threshold of the neutron monitor to primary radiation of about 430 MeV.

In some regions as example the South Pole, where the surface is 2820 m above sea level, the reduced atmospheric mass lowers the primary radiation detection threshold to about 300 MeV. At mid-latitudes or equatorial latitudes, the detection threshold is controlled by the geomagnetic cutoff. Neutron monitors at high altitudes have higher counting rates than neutron monitors at lower altitudes because of the atmospheric absorption of the cosmic ray secondary particles generated near the top of the atmosphere. Usually the neutrons are moderated and then counted using BF_3 or He proportional counters which are efficient thermal neutron detectors.

The introduction of the neutron monitor as a continuous recorder of the primary cosmic-ray intensity resulted from the design by Simpson [11] of a neutron monitor pile. He discovered [12] that the latitude variation of the secondary hadronic component is considerably larger than muon component. As a result the response of a neutron monitor is more sensitive to lower energies of primary spectrum. On the basis on the obtained results was constructed 12 tube neutron monitor during International Geophysical Year (IGY) 1957-1958 [13]. The IGY neutron monitor was used world-wide as detector to study cosmic ray variations.

Hatton and Carmichael [14] carried out a long series of measurements, in order to determine experimentally optimal design for a neutron monitor with larger size than the IGY neutron monitor. In their studies they used different geometrical arrangements, thicknesses of lead and moderator. In addition they used paraffin wax and polyethylene instead of paraffin wax, as moderator. The main result of these studies was the considerable increase per unit area of the lead producer of the counting rates that of the IGY neutron monitor. The improved efficiency is due generally to the use of larger counters.

A good summary of the work is given in [15] and for the different NM designs and improvements in [16]. On the basis of theoretical [17, 18] and Monte Carlo studies [19, 20] with corresponding experimental studies, H. Debrunner and E. Fluckiger contributed significantly to new designs and improvement of neutron monitors. The main difference between IGY and NM64 is related to reflector thickness, which is 30 cm of paraffin wax for IGY monitor, respectively 7.5 cm polyethylene for NM 64. The small reflector thickness of 7.5 cm makes the NM64 more susceptible to environmentally produced neutrons than the 30 cm reflector thickness of the IGY neutron monitor.

In addition bare $^{10}BF_3$ counters, without lead and no moderating polyethylene cylinders are used to record thermalized low energy neutrons produced in the atmosphere and nearby matter by cosmic rays. Such type of counters, are the basis for different neutron monitor configurations and lead free neutron monitor designs. Usually the response function of lead free neutron monitors shows larger sensitivity to low rigidity primary cosmic-rays from 2 to 8 GV [21].

Recently was developed neutron monitors based on ^3He counters for latitude survey [22]. The response functions of such neutron monitor are obtained on the basis of Monte Carlo simulations [23] and are discussed in [24]. It was founded that the efficiency and energy response of the ^3He detector is identical to BF_3 detector, and ^3He tubes can be used in a standard NM-64 monitor.

3. LEAD FREE NEUTRON MONITOR AT BEO MOUSSALA

The solar activity can affect atmospheric processes and climate in different aspects, timescales trough large diversity of mechanisms. Taking into account that the secondary cosmic ray neutrons are connected with cosmic ray variations it is possible to study such effects on the basis of secondary cosmic ray flux measurements [6].

In this connection, with principal aim to study the variations of primary cosmic ray, a lead free neutron monitor is recently developed at BEO Moussala (Fig.1). The lead free neutron monitor at BEO Moussala is mid latitude 42.11 N, mid rigidity 6.5GV and high altitude (2925m above sea level) neutron monitor. The principal aim of the device is to investigate the cosmic ray variations and to study the possible connection between cosmic ray and atmospheric processes, simultaneously with other equipment at BEO Moussala [10]. In addition lead free neutron monitor of different design are useful for analysis of ground level solar cosmic ray events [25]. The monitor represents system of six BF_3 detectors type SNM-15.

Neutron monitors are very sensitiv to external climatic conditions and ambient neutron production. The detectors has to be shielded by sufficient thickness of moderator against variable neutron production and moderating effects outside the assembly. A key point in the construction of neutron monitor, is the estimation of several important characteristics, such as moderator layer, geometry, efficiency, expected counting rates etc…

Fig. 1 BEO Moussala 2925 m above sea level

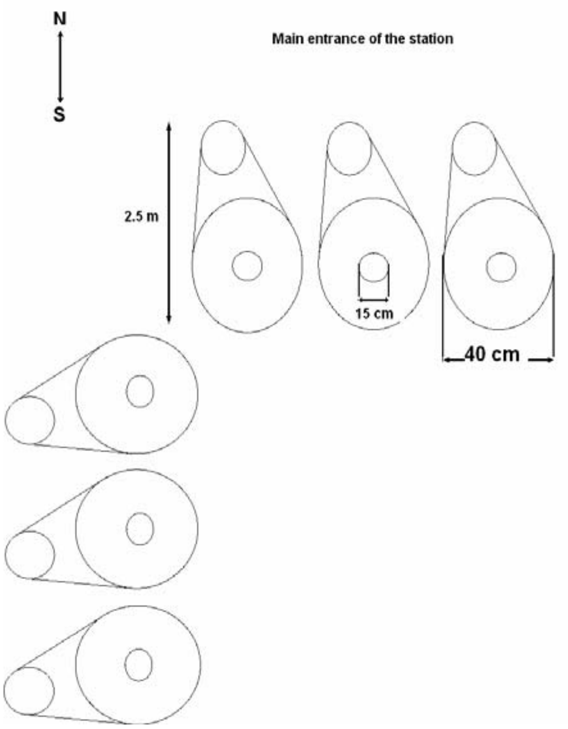

Fig. 2 Sketch of the lead free neutron monitor at BEO Moussala

For these purposes a detailed Monte Carlo simulation of the detector response is carried out. The simulations are made for a neutron monitor pile. The result is the estimation of moderator layer to 12.5 cm. In this study we used the measured at Testa Grigia neutron spectrum [26] as input for the simulations. This spectrum is in a full agreement with measurements [27, 28]. The simulations are carried out with MCNP code [29]. This permitted to assure proper accuracy of simulations of detector response. In this case was we used a simplified geometric model of the detector (planar geometry) and uniform spherical neutron source.

The total neutron current, function of the moderator layer is obtained for different moderator thickness (4cm, 7cm, 10cm, 15cm, 20cm, 25cm, 30cm, 35cm and 40cm). The proposed 12.5 cm moderator of glycerin permits, to render the monitor essentially opaque to low energy background neutrons due to interaction of high energy cosmic rays with the ground and detector surroundings. At the same time we assure high counting rate, which results on a good statistics of the measurements.

4. PRELIMINARY MEASUREMENTS

In this section are described several preliminary measurements carried out with the lead free neutron monitor at BEO Moussala. The detector complex is operational since April 2007. The estimation of measurements accuracy is obtained on the basis of statistical analysis of one week data, when the barometric pressure is relatively constant, (the variation of the pressure is lees than 2 hPa). The estimated accuracy of the measurements of the neutron flux is 0.014. This corresponds to about 1% statistical accuracy for 10 min measurements. The measured data are fitted with Gaussian (Fig. 3) with mean value of 5260 and σ=250. The latter analysis shows good statistical quality of the measured data.

The impact of atmosphere on neutron monitor counting rates is well known. The atmospheric corrections are based on both, theoretical and experimental investigations of meteorological phenomena related to passage of particles through the atmosphere [15, 30, 31]. Generally the meteorological effects are associated with changes in the air mass overburden. During stable atmospheric conditions, the barometric pressure recorded at the monitor site is related with air overburden.

Thus one of the first tests for the recently operational lead free neutron monitor at BEO Moussala is the observed anti correlation with barometric pressure. An example is shown in Fig. 4.

Usually the attenuation coefficient at given neutron monitor is determined empirically. In addition the barometric coefficient is a function of latitude and altitude [32] which increases with altitude below 600mm Hg and decreases with altitude above 600 mm-Hg and also varies with the solar cycle [15]. The obtained barometric coefficient for BEO Moussala lead free neutron monitor is 0.21% per HPa.

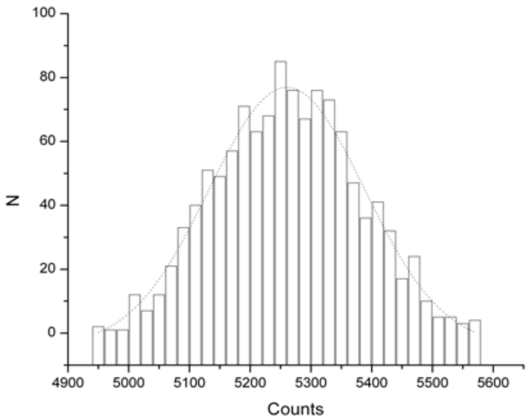

Fig. 3 Counts distribution of measured data with lead free neutron monitor at BEO Moussala

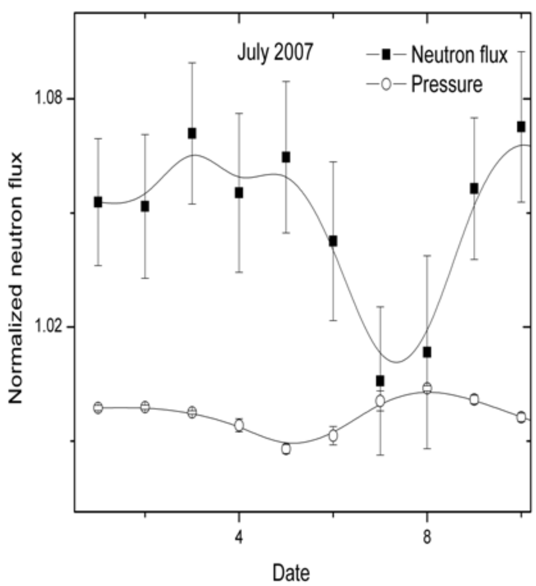

Fig. 4 Barometric effect detected with lead free neutron monitor at BEO Moussala

5. DISCUSSION

. Presently several arguments claim that the solar activity affects the global climate in different aspects and timescales. One possibility is based on climate response to changes in the cosmic ray flux and radiative budget. This is connected with tropospheric response to solar variability, precisely the heating of the troposphere during solar maximum. The latter is related with modulation of the large-scale tropospheric circulation systems. Additionally the stratospheric ozone plays important role on the modulation of the radiative influence of the climate [33]. There is a general agreement that the variations of global tropospheric temperature are partly related to solar activity.

However, the problem how exactly the solar variability can influence the climate is still open. Possible mechanism is related with change of the solar radiance [5]. Another mechanism suggests that cosmic ray fluctuations, caused by the heliospheric modulation, affect the climate via cloud formation [8]. The latter is related trough the proposed mechanism cosmic ray-aerosol-cloud interactions [34, 35,].

In general the microphysical and radiative processes involved in the interaction of cosmic radiation with aerosols in the atmosphere impacts the ion-induced formation of aerosol particles. They can act as cloud condensation nuclei. This may in turn affect the cloud droplet distribution and optical properties of clouds. Basically when solar activity is less, more cosmic rays pass through the atmosphere. They activate the aerosols, already present in the atmosphere. Hence the fluctuations in the cosmic rays due to variations in the solar activity can produce significant changes in the atmospheric environment.

In this connection atmospheric transparency changes may be associated with solar wind induced atmospheric electricity variations [36]. The variations in atmospheric transmission of several percent in clear air, accompany solar wind events associated with variations on the day-to-day timescale in the flow of vertical current density in the global electric circuit. These events occurred when there was a high loading of stratospheric aerosols. Decreases in transmission, are present when Forbush decreases of galactic cosmic ray flux occur, but only during periods of low stratospheric aerosol loading. Forbush decreases are associated with both tropospheric ion production decreases and current density decreases. Similar effects are present on the 11-year solar cycle, with climate consequences that have yet to be analyzed.

The mechanisms for these phenomena are not well understood, but the nature of the observations suggests that explanations should be sought in terms of theories of the effects of electric charge on the formation of aerosols. Therefore the simultaneous measurements of cosmic ray variations with different complementary to each other devices and atmospheric transparency is very important [10], together with development of recent precise models for cosmic ray induced ionization. In this connection the simultaneous measurements of cosmic ray variations with lead free neutron monitor at BEO Moussala and atmospheric transparency with Cherenkov telescope [10] are very important.

The variations of solar and galactic cosmic rays may be responsible for the changes in the large-scale atmospheric circulation. It is possible to associate such type of phenomena with solar activity, precisely with cosmic particles of 0.1–1 GeV. Possible mechanism of cosmic ray effects on the lower atmosphere involves changes in the atmospheric transparency, which is connected with cloud cover. This is due to changes in the stratospheric ionization produced by the considered cosmic particles, during the solar cosmic ray bursts.

The dynamics of the temperature profiles, as well as the changes of other meteorological characteristics may be associated with the solar cosmic ray bursts with the particle energy E_p>90 MeV. The effect takes place within the first 10 hours after the burst and consists in the tropospheric heating and the stratospheric cooling. Another effect is observed [37] on the third day after the event onset is opposite to the first one. The temperature changes occur at the heights 3–6 and 10–12 km. These changes seem to be due to the cloud formation that may be associated with the changes in the ionization of the stratosphere during the solar cosmic ray bursts.

Another topic is the possibility to investigate the variations of the pressure level heights, temperature profiles and wind characteristics in the troposphere and lower stratosphere during Forbush-decreases of the galactic cosmic rays [38]. The Forbush-decreases are accompanied by the pressure increase in the whole troposphere, the maximum of the effect taking place on the 3–4th day after the event onset. Simultaneously the temperature decrease is observed in the troposphere during the first few days of the Forbush-decreases. The pressure increase might be related to the changes of wind characteristics in the middle and upper troposphere.

The effects of solar variability on regional climate time series were examined using a sequence of physical connections between total solar irradiance modulated by galactic cosmic rays and ocean and atmospheric patterns that affect precipitation and streamflow. The solar energy reaching the Earth's surface and its oceans is thought to be controlled through an interaction between total solar irradiance and galactic cosmic rays, which are theorized to ionize the atmosphere and increase cloud formation and its resultant albedo. High galactic cosmic rays flux may promote cloudiness and higher albedo at the same time that total solar irradiance is lowest in the solar cycle which in turn creates cooler ocean temperature anomalies. Respectively low galactic cosmic rays flux leads to clear skies and lower albedo, when the total solar irradiance is highest in the solar cycle. It's in turn creates warmer ocean temperature anomalies [39].

Even such type of effects are global in the majority of the models, presently it exist evidence for physical linkage between galactic cosmic rays and regional climate time series [39]. Therefore the mentioned above complex i.e. the lead free neutron monitor measurements at BEO Moussala can provide for better understanding of the physical processes.

Several characteristic signatures in cosmic rays may be used for space weather applications on the basis of secondary cosmic ray neutron data. Major disturbances of the interplanetary medium have a significant impact on cosmic ray flux and anisotropy, affecting the first harmonic as well as higher-order terms. Cosmic ray phenomena are observed not only during solar wind disturbances, but also prior to their arrival at Earth. Thus they are of major importance to forecasting space weather. Good examples are the solar proton events and geomagnetic storms.

The space weather refers to the dynamic, variable conditions in the on the sun, solar wind and Earth's magnetosphere and ionosphere, that can diminish the performance and reliability of spacecraft and ground-based systems. The relativistic cosmic rays galactic and solar registered by neutron monitors can play a useful key-role in space weather storms forecasting and in the specification of magnetic properties of coronal mass ejections, shocks and ground level enhancements on the basis of real-time data from a neutron monitor network.

The geomagnetic and radiation storms are significant elements of space weather. The forecasting of such type of events is very important for orbiting flights. In fact the geomagnetic storms are driven by magnetized plasma clouds. They reach the Earth from few hours till several days. During their propagation they interact with galactic cosmic rays. The result is the modulation of galactic comic rays till energies of thousands of GeV. The change of the intensity is possible to detect by surface detectors (neutron monitors, muon telescopes, muon hodoscopes).

In addition the data from neutron monitors complementary to muon detector network can provide powerful tool for better understanding the space weather in the vicinity of Earth. Sudden correlated measurements and analysis of the variation of secondary muon, neutron and electrons could be good basis for indication of upcoming geomagnetic storms. The solar cycle variations of modulation parameters are derived from cosmic-ray anisotropy can be observed by a network of detector complexes. These data gave possibility to make prediction of expected part of global climate change, caused by long-term cosmic ray intensity variation. Using a convenient modelof cosmic ray modulation in the Heliosphere, based on a relation between long-term cosmic ray variations with parameters of the solar magnetic field it is possible to predict cosmic ray intensity for 1–6 months by using a delay of long-term cosmic ray variations relatively to effects of the solar activity and to predict cosmic ray intensity for the next solar cycle.

6. Conclusion

The precise measurements with lead free neutron monitor give excellent possibility to understand the role of cosmic ray variation of the Earth climate and to check different mechanisms of such type of influence. Moreover this gives the possibility to check at experimental point of view different proposed models.

This permits to study the influence of galactic cosmic rays on the solar radiation input to the lower atmosphere, especially increases of the total radiation fluxes associated with Forbush-decreases in the galactic cosmic rays, the possible influence of different helio and geophysical factors such as solar flares, galactic cosmic ray variations, auroral phenomena on the solar radiation input to the lower atmosphere, as well as the as the latitudinal dependence of such effects.

It is clear that the scientific potential of detector complex is promising. Starting from estimation of the dose rate and finishing with space weather applications. The relativistic cosmic rays both galactic and solar play a useful key in space weather storms forecasting and in the specification of magnetic properties of coronal mass ejections, shocks and ground level enhancements.

In this connection is presented one of main BEO Moussala activity, which is connected with secondary cosmic ray registration i.e. the neutron component. The presented activities are both theoretical, based on Monte Carlo simulations and experimental. The lead free neutron monitor is described with estimations concerning the final design. The presented detector complex has the advantage to be placed at high mountain altitude and to have large sensitive area, which permits to provide measurements with good statistics and to study different problems. Obviously the high quality data can be useful as a basis to check several models on the influence of high energy particles on the middle atmosphere.

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