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Natural thermal neutron flux long-term variations at 4300 m a.s.l.

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Long-term variations in the natural thermal neutron flux in Tibet at an altitude of 4300 m above sea level are studied using scintillation electron-neutron detectors (*en-detectors*) developed at the Institute for Nuclear Research, Russian Academy of Sciences. Substantial growth (on the level of several percent each year over the last 3.5 years) in the thermal neutron flux recorded by the detectors is observed. The effect is explained by an increase in the low-energy cosmic ray flux, due to decreasing solar activity in the current solar cycle. Seasonal variations in anti-correlation with the rain season were also established.

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1. Introduction

One of the main tools for monitoring solar activity is the worldwide network of neutron monitors [1]. The counting rate of neutrons generated in the monitor's lead by cosmic ray hadrons is proportional to the flux of high energy cosmic rays, which in turn anti-correlates with solar activity. The threshold for cosmic ray hadron recording by a neutron monitor is ~100 MeV for neutrons and ~1 GeV for protons thus making it insensitive to outside thermal neutrons. In our work, the background thermal neutron flux is monitored by special electron-neutron detector (*en-detector*) array PRISMA-YBJ located in the mountains of Tibet at an altitude of 4300 m above sea level. The array is a part of our global net of such detectors [2]. Unlike neutron monitors, these detectors are not shielded and are sensitive to thermal and epithermal neutrons produced by cosmic rays and natural radioactivity.

2. Experimental array

The PRISMA-YBJ array is situated on the Yangbajing high-mountain plateau (Tibet, 4300 m above sea level) in the hangar of the ARGO-YBJ experiment [3]. It consists of four electron-neutron scintillation detectors with areas of 0.35 m2 each; these detectors record both thermal neutrons and multiple charged particles as well. The signal from a charged single particle lies below the recording threshold of approximately three particles in a detector. The detector is based on a special inorganic ^{6}LiF + ZnS(Ag) scintillator made of an alloy of lithium fluoride in which the lithium is enriched to 90% by ^{6}Li with zinc sulfide. This scintillator is widely used, and is most appropriate for detecting heavy charged particles. When a thermal neutron is captured due to the ^{6}Li(n, α)^{3}H reaction releasing 4.78 MeV, triton and alpha particle lose it in the ZnS(Ag) layer. The scintillator has several time components. This allows us to separate the signals originated from neutron capture and the simultaneous multiple passage of relativistic charged particles through the scintillator, by means of pulse shape digitization. The leading front of the integrated over 5 μs signal from neutron capture is smooth, since heavy nonrelativistic particles move slowly and excite slow scintillation components, while relativistic charged particles excite mainly the fastest component, equal to approximately 40 ns.

The scintillator consists of thin layers of granulated phosphor powder, laminated on a white paper substrate with a layer thickness of about 30 mg/cm^2 corresponding to that of one granule; it lies at the base of the detector's cylindrical housing. The light emitted by the scintillator is recorded by a FEU-200 photomultiplier with a cone of reflecting material for better light collection. A plastic cylinder 70 cm in diameter and 60 cm tall (200 L commercial water tank) is used as the detector housing. The numbers of recorded and separated by On-line pulse shape selection procedure neutron and short background pulses are written each five minutes as a time series. The array was operated continuously since August 30, 2013 until March 2, 2017.

3. Results and discussion

Variations in the natural thermal neutron flux at an altitude of 4300 m in Tibet were observed over a period of approximately 3.5 years. The results are presented in the figure 1, left panel. The histogram line shows neutron counting rate, averaged as 10 days points; the red line shows the best fit including sinusoidal seasonal variation wave with period equal to one year add a delayed rise trend shown also in right panel for explanation the fitting parameters. The decrease in the intensity of thermal neutron flux coincides with the rainy season, since water is a good neutron moderator and absorber [4, 5]. The drop of background pulses counting rate during the rainy season was also established. The latter would be due to the smaller amount of dust that can carry the heavy beta-active nuclides (Bi-214 and Pb-214) produced during Rn-222 decay in air. During the dry period, dust particles can penetrate the shelter and be deposited on the plastic housing of the detector. Electrons emitted during the beta decay of these nuclides and accompanied by gamma-ray cascades, can create signals above the three-particle threshold [6]. Along with sinusoidal seasonal variations, long-term variations (trends) were detected with a regression of ≈5.1%/year. We assume this is associated with the current 11-year solar activity cycle. Solar activity is known to decrease since 2015 when maximum of the 24th cycle occurred; this is usually accompanied by growth in the low-energy cosmic ray flux in the vicinity of the Earth. If so, then further growth of the thermal neutron flux would then be expected for next 1-2 years and later it would return to the starting level. The data of neutron monitors (see for example [7]) confirm our result showing increase of counting rate since April 2015.

a) b)

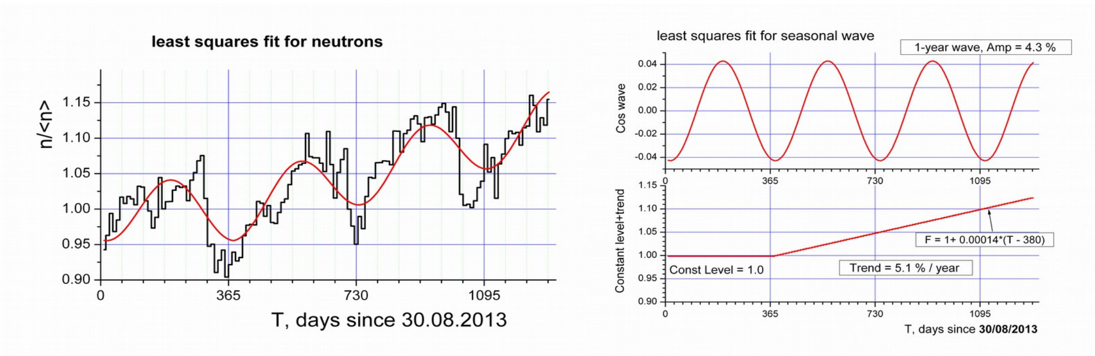

Figure 1: Natural thermal neutron flux variations at 4300 m a.s.l.

The above result can be compared with that recorded by neutron monitors. Figure 2 displays the data of Oulu monitor [7] where rising is also clearly seen but about 0.5 y later.

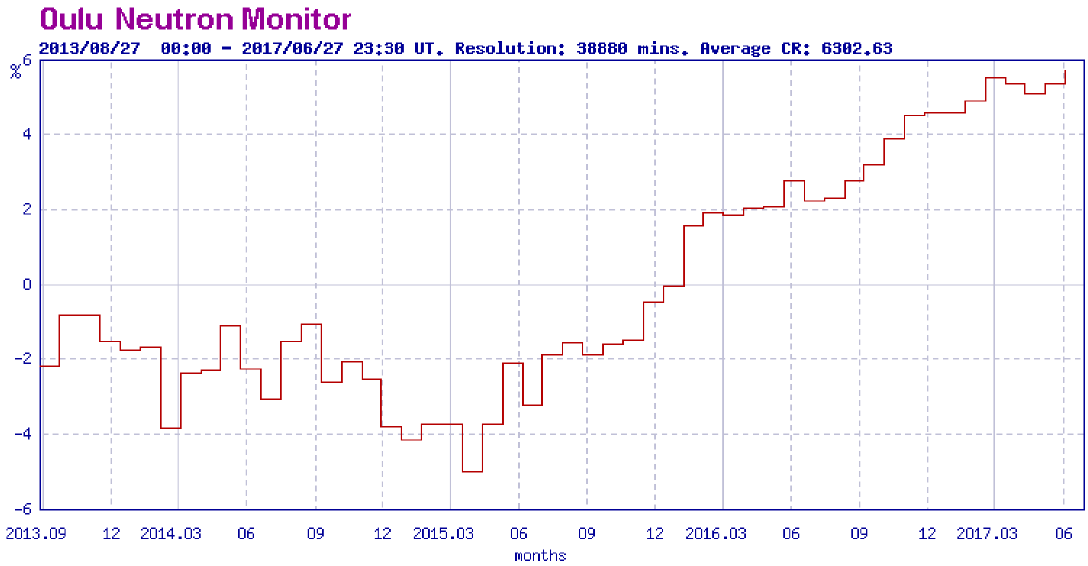

Figure 2: Cosmic ray variations measured by Oulu neutron monitor [4] at the same dates.

4. Conclusion

The natural thermal neutron flux at 4300 m above sea level was monitored and analyzed over the last 3.5 years with a small open neutron detector array PRISMA-YBJ. Long-term variations in the natural thermal neutron flux were observed along with other effects, and an assumption was made on the possible influence of the 11-year solar activity cycle on the considered neutron flux. This influence could be both direct (i.e., via neutron generation by cosmic rays in the vicinity of the detector) and indirect (via soil activation by cosmic rays, resulting in higher production and emission of different radon isotopes from the soil and the corresponding neutron flux from its (α, *n*) reactions). Our open en-detectors showed a growth of natural thermal neutron flux at high altitude starting somewhat earlier than neutron monitors show. An explanation could be probably found taking into account significantly lower threshold of our en-detectors for neutron recording, since solar activity affects more effectively to the lowest energy cosmic ray particles. The early start of cosmic ray rising at near Earth's space can be confirmed by fig.2 in [8].

Acknowledgments

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