Thermal neutron variations of interplanetary, atmospheric and lithospheric origin

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Abstract:
Results of detecting of thermal neutron variations caused by sources of an interplanetary, atmospheric and lithospheric origin in Tien-Shan mountains by installations with the different site are presented. Comparison with data of the standard neutron monitor 18NM64 is carry out. Identity of the response of detectors of thermal neutrons and high energy (18NM64) on disturbance of the interplanetary environment by coronal mass ejections and change of atmospheric pressure is established. The additional thermal neutron flux was registered during seismic activity. The method of selection of thermal neutrons of lithospheric origin is offered.

Keywords: cosmic rays, thermal neutrons, seismic activity

1 Introduction

At the global network of cosmic ray stations the neutron component has been registered from the middle of the past century with neutron supermonitors based on proportional counters, the gas filling of which includes boron trifluoride enriched in the $^{10}$B isotope. Boric detectors are included in lead in order to increase the count rate due to the local generation of neutrons and in polyethylene in order to reflect thermal neutrons and decelerate fast neutrons. Neutron monitors are mainly used to study variations in the galactic cosmic ray (GCR) intensity and the space outside the Earth’s atmosphere. Thermal neutrons were measured episodically. Interest to measurements has increased after registration of thermal neutrons bursts in the Pamir during extreme gravitational impact from the Moon and the Sun [1-3]. At the high altitudes station of cosmic rays (3340 m above sea level, Tien-Shan) near the Earth’s crust fault, we created the stationary installation for registering thermal neutrons, which was put into operation in November 2006.

The aim of this work is to study the nature of variations in the intensity thermal neutrons registered with the created installation, under different heliogeophysical conditions and to detect the flux of thermal neutrons from the Earth’s crust.

2 Experimental installation

A detector of thermal neutrons (DTN) is composed of two modules. Either module includes six proportional counters filled with the mixture of helium-3 gases and argon. The thermal neutron registration effectiveness is ~60%. One module (DTN1) is installed in one room with an 18NM64 standard neutron monitor; the second module (DTN2), 10 m from the building in a light plywood container at a height of ~30 cm from the ground. The modules are fed separately and are independent. The data bank is formed with a 1-min time resolution separately for each channel (counter), which makes it possible to effectively trace instrumental errors. The count rate of the module installed within the building is ~6.8·10⁴ pulse/h, and that of the external module is ~4.9·10⁴ pulse/h.

A considerable advantage during an analysis of the thermal neutron detector variations consists in the possibility of comparing these variations with the data of the 18NM64 neutron monitor, the variations of which are well studied. The data have a high statistical accuracy (the count rate is ~5·10⁶ pulse/h). The monitor registers neutrons with an energy ≥ 200 MeV. The barometric coefficient, used to correct data, is 0.72 % /mbar. Thermal neutrons caused by sources of the atmospheric origin should also have the same coefficient.

3 Comparison of variations of high energy and thermal neutrons under different heliogeophysical conditions

By December 2006 the installation has been debugged and operated stably. In spite of the fact that 2006 belongs to the solar activity minimum, December was unusually reach in outstanding heliogeophysical events: solar flares,
coronal mass ejections (CME), considerable variations in atmospheric pressure, and seismic activity. The response of these events in the neutron monitor data is easily identified; the events are isolated except the last one. We consider the response of these events in the variations in the thermal neutron flux and compare this response to the variations in a standard neutron monitor.

3.1 Atmospheric Pressure Variations

Tien Shan station is located at an altitude of 3340 m above sea level. The average atmospheric pressure is 675 mbar. Figure 1 (from top to bottom) presents the following values in December 2006: the atmospheric pressure, data of the neutron monitor and of thermal neutrons from DTN2 and DTN1 detectors.

![Figure 1. The hourly values of the (a) atmospheric pressure, (b) 18NM64 neutron monitor, (c) external detector of thermal neutrons (DTN2), and (d) internal detector of thermal neutrons (DTN1).](image1)

The neutron intensity is given in percent with respect to the average monthly value and without correction for atmospheric pressure. It is evident that the intensity variations are similar in all plots, corresponding to the 18NM64, DTN2, and DTN1 detectors, independently of the energy of registered neutrons except December 25. All detectors identically respond to a change in the atmospheric pressure; an increase in the pressure results in a decrease in the count rate of high-energy and thermal neutrons within and outside the building. A decrease in the pressure results in an opposite effect in the neutron intensity. During December 2006, the intensities of thermal and high-energy neutrons varied in the same range (about ±8%).

We calculated the correlation coefficients between the series of the data of the thermal neutron and neutron supermonitor detectors during December 1–31, 2006. The correlation coefficient is $K_1 = 0.97$ for the detectors within the building and $K_1 = 0.84$ for the external module (DTN2). High correlation coefficients and a similar response to a change in the atmospheric pressure make it possible to conclude that registered neutrons are of the atmospheric origin and to use the known formula in order to correct neutron monitor data for pressure and to apply this formula to the data of the thermal neutron detectors.

3.2 Variations caused by sources of the Interplanetary Origin

The isolated group of sunspots, which subsequently became the source of powerful flares and CMEs, was registered on the solar disk at the beginning of December 2006. Mainly flared of December 5 and 13 affected the variations in the intensity of galactic cosmic rays registered with ground monitors.

The X9.0/2N flare of December 5, occurred on the eastern limb, and was accompanied by CME and an IMF disturbance. The neutron component intensity at Alma-Ata high altitude station started decreasing on December 7. The maximal decrease value was ~3%.

Figure 2 presents the solar wind velocity, interplanetary magnetic field (IMF), corrected for a change in pressure data of the neutron monitor and thermal neutron detectors. A decrease in the neutron component was observed at all detectors.

![Figure 2. The hourly values of the (a) solar wind velocity, (b) IMF, (c) 18NM64 neutron monitor, (d) external detector of thermal neutrons (DTN2), and (e) internal detector of thermal neutrons (DTN1). The neutron intensity was corrected for variations pressure.](image2)

The X3.4/4b flare on December 13 was the most pronounced and geoeffective event in December. This flare took place in the western part of the solar disk and was also accompanied by full halo CME. A shock wave approached the Earth on December 14. Figure 2c–2e show an identical response to a disturbance in the interplanetary space in the form of an abrupt decrease in intensity (~6%) on December 14 at all presented detectors, registered neutrons with different energies. The value of the Forbush effect in the thermal neutron intensity was not less than in the neutron monitor data. A slow recovery of intensity takes place also synchronously at all detectors. Event of
February 2011 also shows synchronous decrease of intensity in all detectors during disturbance in interplanetary space. We calculated the correlation coefficients between the series of data of thermal neutrons and high-energy, registered by standard neutron monitor for the period December 1–24, 2006, including CME events. The correlation coefficients (K2) for the module within the building (DTN1) and for the external module (DTN2) are 0.98 and 0.89, respectively. So high correlation coefficients indicate that the modulation sources of the intensity of thermal neutrons and the intensity, registered with the neutron monitor were identical during that period. The result confirms our conclusion that thermal neutrons, registered with the DTN1 and DTN2 detectors, were generated mainly in the atmosphere by galactic cosmic rays rather than in the Earth’s crust. We pay attention to a burst of intensity on December 25 at the external detector (Figure 2), which will be considered in detail in the next section.

3.3 Analysis of the Measurements during Seismic Activity

At 20:01 (UT) on December 25, 2006 according to the Greenwich Time, the earthquake occurred at a distance of 146 km southwestward from Alma-Ata. According to the seismic data of the Kazakhstan National Data Center, the earthquake parameters are as follows: the latitude is 42.10 N, the longitude is 76.03 E, the magnitude is 5.95, and the energy class is $K = 14.2$. In Alma-Ata the earthquake intensity was Mw 4–5.

We consider in more detail the variations in the intensity of high-energy and thermal neutrons (not corrected for pressure) in the last decade of December (Figure 3).

At all detectors the intensity variations before the earthquake instant are absolutely similar independently of the neutron energy, which is confirmed by very high correlation coefficients on December 20–24, 2006 (table). This coefficient is 0.98 and 0.97 for DTN1–18NM64 and DTN2–18NM64, respectively.

<table>
<thead>
<tr>
<th>Detectors</th>
<th>K1</th>
<th>K2</th>
<th>K3</th>
<th>K4</th>
<th>K5</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTN1-18NM64</td>
<td>0.97</td>
<td>0.98</td>
<td>0.97</td>
<td>0.74</td>
<td>0.90</td>
</tr>
<tr>
<td>DTN2-18NM64</td>
<td>0.84</td>
<td>0.89</td>
<td>0.90</td>
<td>0.57</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Table. Correlation coefficients between the detectors of thermal neutrons and the standard neutron monitor.

In all three detectors, the intensity decreases due to an increase in the atmospheric pressure on December 25. During that period, IMF was absolutely quiet (Fig. 2). The solar wind velocity decreased to the minimal values at the end of the month. The intensity at the neutron monitor continued decreasing up to December 27. The situation is absolutely different in the lower plot, where the data of the external detector of thermal neutrons are presented: the intensity started increasing exactly at the earthquake instant. An increase in the intensity at the external detector of thermal neutrons corresponds to 4%. After the earthquake, the correlation between the data of the external detector and the neutron monitor was disturbed from December 25 to December 31 (K4 = 0.57, table). We should note that the intensity variations after the earthquake also differed from the variations at the neutron monitor at the internal detector of thermal neutrons. The correlation coefficient between the DTN1 internal detector and the neutron monitor became slightly lower (0.74) than before the earthquake. At the beginning of January, 2007, the correlation coefficients between the thermal detectors and the neutron monitor increased again.

An exact coincidence of the earthquake time with an increase in the flux of thermal neutrons at the external detector, a disturbance of correlation with the neutron monitor data, and an increase in phase with the atmospheric pressure in the absence of disturbances in the interplanetary medium indicate that the source of the additional neutron flux at the DTN2 detector during the earthquake fundamentally differed from the sources of the variations considered above. We assumed that the additional flux of thermal neutrons was caused by the Earth’s crust. The earthquake of December 25, 2006, probably caused a considerable escape of radon due to deformations of faults in the Earth’s crust or the formation of micro cracks. Both factors could result in the generation of the additional flux of thermal neutrons from the Earth’s crust.
3.4 Separation of Thermal Neutrons flux, caused by sources of the lithospheric origin, from the Variations of Neutrons Produced in the Atmosphere by GCR

We indicated above that the variations in the data of the neutron monitor and thermal neutron detectors are of the same order and have the same modulation sources except the period of seismic activity at Tien Shan station. We have the unique possibility of separating the flux of thermal neutrons from the Earth’s crust from the variations in neutrons produced in the atmosphere by galactic cosmic rays. Taking into account that the probability of registering external thermal neutrons with the neutron monitor is extremely low (lower than 0.01) and the variations, caused by sources of the atmospheric and interplanetary origin are similar at all detectors, we subtract the data of the neutron monitor from those of the DTN2 thermal neutron detector. Thus, we eliminate the general variations. Figure 4 presents the result of this procedure with the data not corrected for atmospheric pressure. Correction on change of atmospheric pressure doesn’t influence result as it is identical in all detectors.

The low-frequency intensity trends and the daily variations in neutrons, which are observed in Fig 2, are absent in Fig. 4, but an increase in the flux of thermal neutrons during the first hours after the earthquake by more than 5% is evident. An additional flux of neutrons was received during ~1.5 days.

The presented event of December 2006 isn’t unique. On Fig. 5 results of detecting high-energy and thermal neutrons are presented during earthquakes: (a) November 1-2, 2008, (b) May 1-3, 2011.

We propose to use the method for detecting the flux of thermal neutrons from the Earth’s crust, using the simultaneous registration of high-energy neutrons for the purpose of forecast of seismic activity. However, this method requires further development.

4 Conclusions

It is established that intensity of the thermal neutrons registered on a surface of the Earth, is modulated by disturbance sources of an interplanetary, atmospheric and lithospheric origin. Variations of thermal neutrons intensity of an interplanetary and atmospheric origin are equal to variations high-energy neutrons registered with a standard neutron monitor.

During seismic activity the additional flux of thermal neutrons from Earth’ crust is registered. We assume that this flux is caused by the escape of radon and disturbance of the Earth’s crust structure with the formation of micro cracks during earthquakes.

We proposed the method for detecting the flux of thermal neutrons from the Earth’s crust, using the simultaneous registration of high energy neutrons.

References