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Studying the Effect of Meteorological Parameters on the Concentration of Thermal Neutrons, Based on Data from the NEUTRON Setup

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Abstract—The effect meteorological parameters have on the concentration of thermal neutrons is studied using data from the NEUTRON setup in the period May 2015 to February 2019. Daily and seasonal variations in the neutron count rate are obtained. Such variations are associated with changes in temperature. The effect the depth of the snow cover has on the neutron count rate for four winter periods is estimated. It is shown that meteorological parameters have a considerable impact on the concentration of neutrons near the surface. The total contribution from pressure, temperature, and the depth of the snow cover can be more than 30%.

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INTRODUCTION

Studying the natural flux of neutrons near the Earth's surface is currently of great interest. The main sources of neutron flux near the Earth's surface are the atmosphere and the Earth's crust itself [1]. Information on how the neutron flux in the near-ground atmosphere changes as a result of different environmental effects is needed to investigate qualitatively.

A number of factors affect the neutron flux at low altitudes above the Earth's surface. These include atmospheric parameters (pressure, temperature, and accumulated precipitation); the altitude above the ground; the content of water in the environment (steam, snow, vegetation); the content of radon; seismic activity; exposure to the Sun and the Moon; and changes in the cosmic ray flux [2–4].

This work presents results from processing data obtained on the NEUTRON setup [5] for the period May 2015 to February 2019 to study the effect of different meteorological parameters which have on the thermal neutron flux in the surface atmosphere.

NEUTRON SETUP

The NEUTRON setup, designed to monitor the neutron background under and above the Earth's surface, has been operating since 2010 as part of the unique experimental complex NEVOD [6]. It consists of four identical detectors based on ZnS(Ag) + ^{6}LiF inorganic scintillators. Each detector of the setup is a pyramidal metal housing case that contains a scintillator with an effective area of 0.75 m^2 viewed by a single FEU-200 photomultiplier. The setup operates in the continuous mode and records the count rate of thermal neutrons every 5 min. The detectors are kept inside the NEVOD building at different heights of −3 to 10.5 m from the ground's surface. The first detector is positioned in the basement, making it more sensitive to variations in neutrons from the natural radioactivity due to the underground accumulation of radon. The second detector is in a glass-covered passage between buildings, and the third and fourth detectors are on the second and third floors of the building.

RESULTS OF EXPERIMENTAL DATA PROCESSING

Barometric Effect

One of the main meteorological parameters affecting the neutron flux is pressure, so we must introduce a correction into current count rate $N(t)$ before studying the effect of the ambient temperature which has on the concentration of neutrons:

$$N^{\text{corr}}(t) = N(t) + B\cdot(P_0 - P(t)),$$

where P and P_0 are the current and average atmospheric pressure, respectively, and B is the barometric coefficient. To calculate B, we construct the dependence of the count rate on pressure, and coefficient B of the fitting equation is determined. Barometric coef-

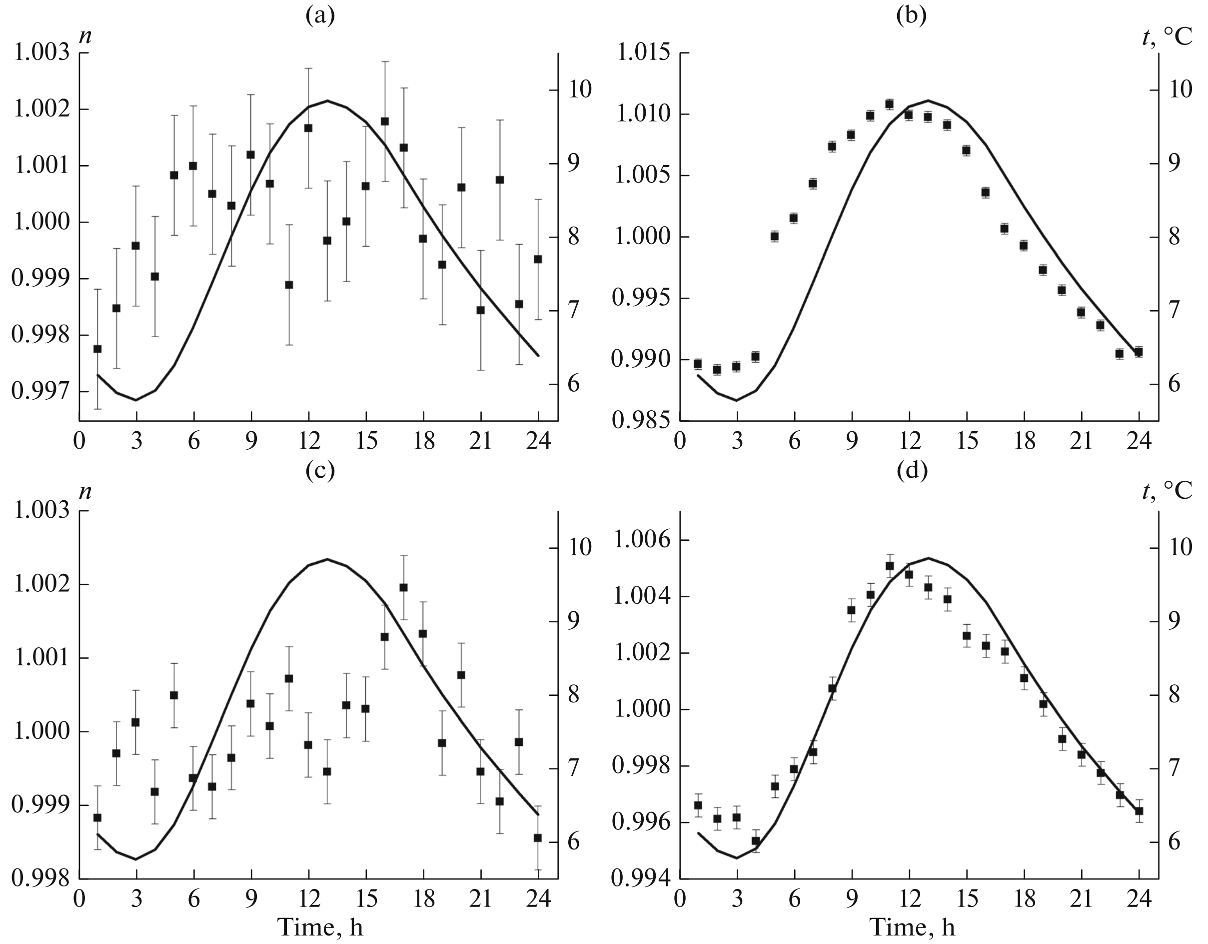

Fig. 1. Daily wave of the neutron count rate *n*, normalized to its average value, according to data from four detectors of the NEUTRON setup (points, left axes), and temperature *t* (solid curves, right axes) for the period May 2015 to February 2019: (a) detector 1, (b) detector 2, (c) detector 3, (d) detector 4.

ficient β (in %/mbar), which shows how many percent the detector count rate differs if the atmospheric pressure changes per unit, is calculated as $\beta = (B/N_0) \times 100\%$, where N_0 is the average count rate per month. The neutron count rate is in fairly strong anticorrelation with pressure before introducing the correction for the barometric effect. This correlation virtually disappears after it is introduced.

Temperature Effect

A daily wave that shows the effect temperature has on the count rate during the day (day/night) was sought by considering each day (24 h) a period. The count rate measured in 5 min in the first hour of the first day of the time series was added to those of the second day, the third day, and so on, throughout a given interval. The count rate measured in 5 min in the second hour of the first day is added to that of the second hour of the second day, the second hour of the third day, and so on throughout a given interval. The sum obtained for the corresponding hour is then divided by the number of events lasting 5 min within that hour. The daily waves of the count rate for the second and fourth detectors have the clearest shape. Figure 1 shows the daily waves of the count rate and the temperature, plotted according to the data from four detectors for the period May 2015 to February 2019.

The second detector was the one most sensitive to amplitude (2.16% versus 0.40, 0.34, and 0.97% for the first, third, and fourth detectors, respectively). This difference is largely explained by the location of each detector inside the building (due to different shielding of the detectors by its material).

Since the second detector was the one most sensitive, we considered its seasonal dependence of the count rate on temperature. The relationship between the count rate amplitude, the average temperature, and the temperature amplitude for each season was 3.5%, 19.1°C, 6°C in summer (June, July, August); 1.5%, 6.3°C, 3.1°C in autumn (September, October,

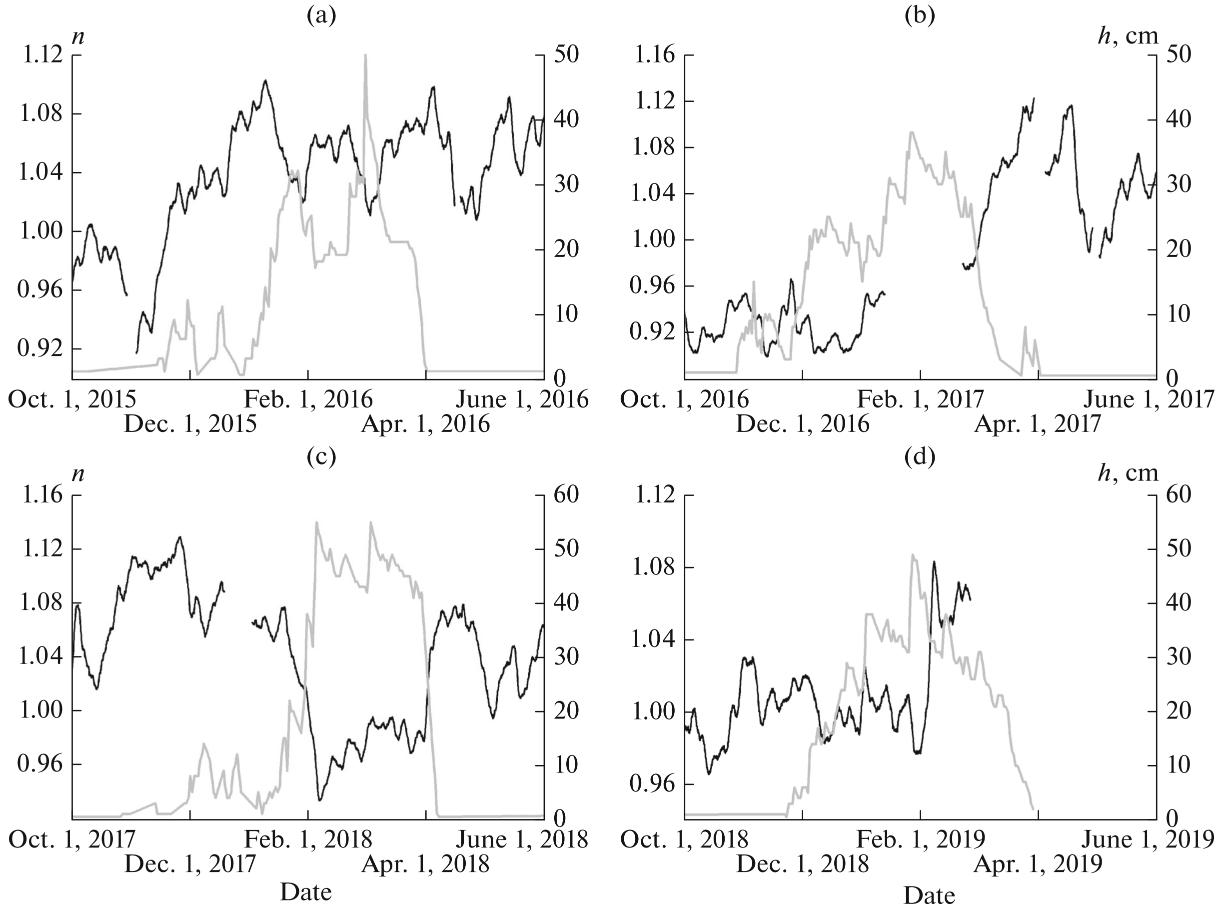

Fig. 2. Dependence of the count rate of detector 2, corrected for pressure and normalized to average value *n* (black lines, left axes) and snow depth *h* (gray lines, right axes), on time for four winters: (a) 2015–2016. , (b) 2016–2017, (c) 2017–2018, (d) 2018–2019.

November); 1.3%, −4.6°C, 1.5°C in winter (December, January, February); and 2.6%, 7.9°C, 5.2°C in spring (March, April, May). The drop in the amplitude of the daily wave for the winter and autumn seasons is explained by the smaller fluctuations in temperature, a general decrease in temperature, and the accumulated precipitation (especially snow). A time shift between waves of the count rate and temperature was observed for all seasons.

Snow Cover Effect

The dependence of the count rate on the depth of the snow cover [7] was investigated for four winters (2015–2016, 2016–2017, 2017–2018, 2018–2019) to study its effect. The count rate was corrected for pressure, smoothed over 3 days, and normalized to an average value; the snow cover data were averaged according to day. Figure 2 shows the dependences of the normalized neutron count rate of the second detector and the depth of the snow cover on time for the four winters given above. As can be seen from the figure, a visible effect of the snow cover was observed in the winter of 2017–2018, during which the count rate fell by ~20%. The effect was weaker for the rest of the detectors, (5, 10, and 10% for the first, third, and fourth detectors, respectively). The effect of temperature is also visible. The snow takes time to melt at negative temperatures and acts as a neutron shield for long periods (in the winter of 2017–2018, a snow cover of 50 cm depth remained for more than two months at temperatures of around −10°C, at the same time, the snow thickness increased and fell very quickly. The other winters were slightly warmer, the temperature varied around zero, and the depth of the snow cover changed more smoothly.

CONCLUSIONS

Our studies show that meteorological parameters have a strong effect on the neutron concentration in areas of the Earth's surface. The contribution from pressure can be as high as 0.85%/mbar; that of temperature, as high as 2.2%; and that of snow cover, as high as 20%. These contributions must therefore be considered when studying exoatmospheric processes.

The second detector of the NEUTRON setup, located in the open gallery, is best for investigating the effect of meteorological parameters.

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