Seasonal and stochastic variations in the different components of secondary cosmic rays

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Abstract: Using a complex defector unit simultaneously variations of different components of secondary cosmic rays were carried out. There are both seasonal and stochastic variations. Neutron monitor has distinct variations and was used as the reference detector at superimpose method. Due to it small variations on other detectors are found.

Keywords: gamma-rays, seasons, variations, secondary cosmic rays.

1 Introduction

In the cosmic ray laboratory of PGI during several years there has been a continuous monitoring of the different components of secondary cosmic rays. At the present time besides the conventional neutron monitor (NM) there are gamma ray detector based on the scintillation crystal (GRD), leadless section of the neutron monitor (BNM), charged particle detector (CPD) and thermal neutrons detector (TND). Analysis over the past few years has shown the presence of seasonal variations in some components of cosmic rays. Among the "NM-BNM-DTN" detectors amplitude of variation is growing with decreasing of neutron energy. Also there are gamma-ray increases up to 50% above background. Usually they are accompanying to solid or liquid precipitations during some hours. Additional experiments have shown there was absent any natural or artificial radionuclide in precipitations [1, 2, 3]. Gamma radiation on the surface layer of the atmosphere has Bremsstrahlung origin by energetic electrons produced via the muon decay [4]. Using superimpose method small variations of other components simultaneously to gamma increases have been found.

The presence of a large database of cosmic ray detectors allows the study of their different variations, including seasonal. The variations in gamma rays during precipitation are of particular interest. This phenomenon was discovered at the PGI few years ago, but there is absent a clear picture of this phenomenon till now. In this paper the results of a thorough search and analysis of variations in the different components are presented.

2 Instrumentation and results of previous studies

Comprehensive monitoring of cosmic rays in PGI have been developed. Detectors included into it have the following characteristics. Conventional neutron monitor 18-NM-64 detects neutrons with energies above 50 MeV. Leadless neutron monitor 4-NM-64 is sensitive to neutrons with energies from hundreds of keV to a few MeV [5]. Detector of thermal neutrons detects neutrons with energies up to 0.1 eV, charged particle detector (muons, electrons and positrons) has energy threshold 3-5 MeV. Gamma ray detector measures the flux of electromagnetic radiation on the 4 energy levels: >20 keV, >100 keV, >200 keV and >1 MeV. Charged particle detector consists of two Geiger-Müller counter layers which are spaced by 2 g/cm^2 matter. Upper counter layer channel and coincidence one are output. In additional there are temperature, pressure and precipitation sensors. Data from the detectors is gathered by the collection system described in [3]. At the Barentsburg station there is the shot version of the collection system including conventional neutron monitor 18-NM-64 and gamma-ray detector with output ranges >20 keV, >60 keV, >100 keV, >200 keV.

From the beginning increasing of gamma-ray background were revealed. Due to additional experiments it was later found the next [1, 2, 3]:

- increases in 95% of cases are accompanied by precipitations (rain or snow);
- increases take place whole year round;
- increase amplitude is up to 50% and the average value is ∼25%;
- increase amplitude on channels >20 keV, >100 keV, >200 keV is the same (within error) and on channel >1 MeV is less up to 2 times;
- increase duration varies from 2 hours to a day depends on the duration of rainfall;
- there is absent any radionuclide contamination of precipitation;
- increases are only in the electromagnetic component, the radiation fluxes in charged components are constant;

Among the five hundred events, gathered since starting of system operation in 2009 year, 93 short ones (no more than 4-6 hours) were selected. There are multiple randomly arranged maxima in the long events corresponding to rain (snow) intensifications. It is difficult to use our method in this case. By the superimpose method average profiles of the events and the accompanying precipitation have been obtained. A precipitation maximum was accepted as a reference point. The result is shown in Figure 1a.

The obtained profiles contain very important information about the nature of the increase. Firstly, there is a time gap

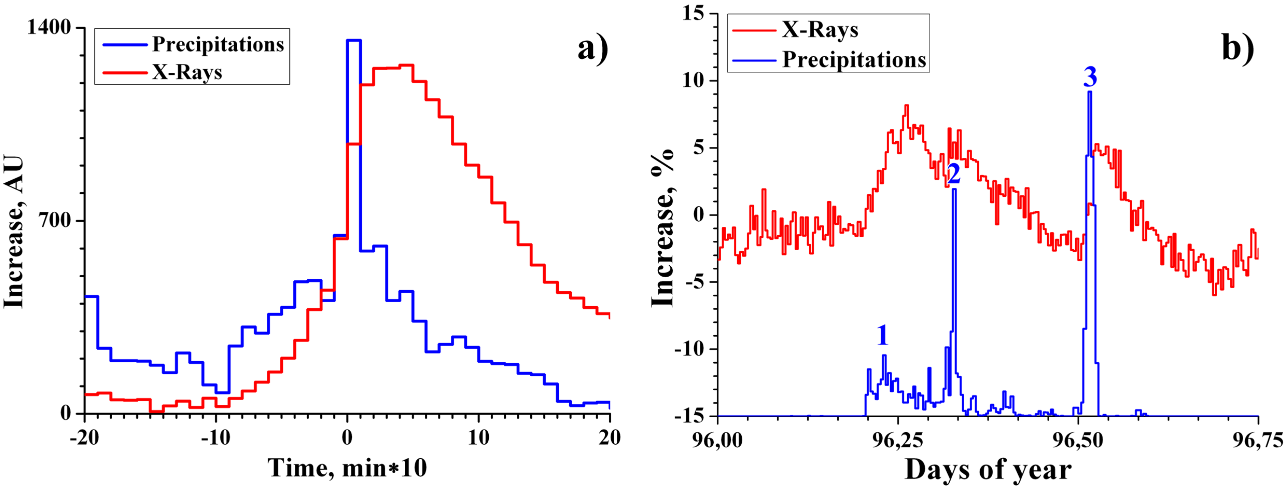


Figure 1: **a)** Average profiles of precipitation (blue) and gamma radiation increase, derived by superimpose method. **b)** Increase event example at April 6, 2012. The snow storm maxima are marked numbers. Explanation see in the text.

between the precipitation and gamma radiation peaks on 30-40 minutes. Secondly, the average precipitation profile is symmetrical about it maximum, while the gamma-profile has a significant asymmetry: the steep leading edge and a slow decay with a characteristic time of ∼100 min. Thirdly, the maximum of precipitation is at the time of maximum growth of gamma radiation. Commonly the picture is as follow: precipitation is influencing factor, and the system, which produces the background gamma radiation flux, "has responded" to the influence. It would be said the effect is like "shock" and sounding, because the "shock" is shorter in comparison with the response. To demonstrate the real fact of "shock-response" sequence it is shown real increase event in Apatity at April 6, 2012 (Figure 1b). There was −15 °C outer temperature and deep snow cover (strong winter season). The weather was windy and commonly clear, but three short (not more 20 minutes) snowstorms came sometimes. Each storm has brought about equal snow amount (1-2 cm). Differences in precipitation amplitude are due to snowflake size only. Position and the time gap between intencity profiles of precipitation and gamma rays are the like at Figure 1a. The third snowstorm is most demonstrative.

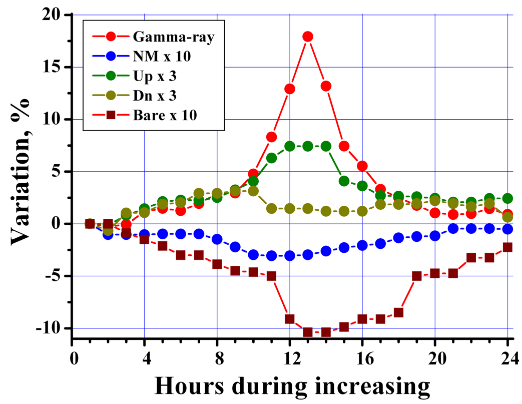


Figure 2: Small variations in different components of secondary cosmic rays accompaning gamma ray increases. Increase profile of gamma ray during precipitation is red. Variation in NM and BNM (marked as Bare) are blue and wine correspondently. Upper layer channel (marked as Up) is green. Coincidence channel (marked as Dn) is dark yellow. The scaling factors are on the figure legend.

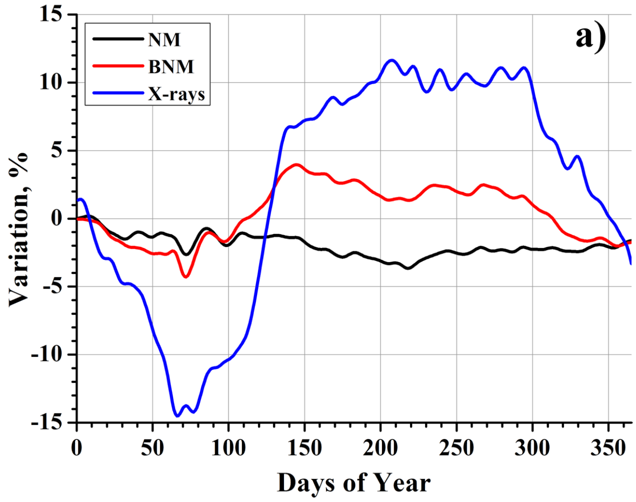
3 Search and study of small variations in the other components

The influence problem of cause (or causes), which produces gamma-ray background increase, is opened: does this cause influence on the other cosmic rays components? This problem is important because it determines a physical way of increase. There is no significant increase in the charged component, as well as in neutron, but it may be due to they are lost against the background fluctuations.

To clarify this problem, studies have been conducted. Events lasting no more than 6 hours and the amplitude increase of at least 15% have been selected. The last condition was set to cut off numerous but small increases, origin of which is under doubt. Such events are about a hundred. The special technique based on the superimpose method has been applied. Maximum of gamma-ray increase was accepted as a reference point. The result is shown in Figure 2. It can be seen, synchronous variations with gamma increases are really present in the other components. They are small and only due to a special technique they were able to visible. Let us consider these variations.

The variation in the neutron component of 18-NM-64 is about 0.3%. According to [6] average amount of rain water (in a form of drops in clouds) is ∼0.4 g/cm^2. It is known [7] that the barometric coefficient for NM is 0.72%/mb. 1 mb of atmospheric pressure is equal to 1 g/cm^2. In this case, reduction of the NM counting rate due to water in clouds is approximately ∼0.3%. Thus, the variation on the NM accompaning by the increase of gamma-ray background is due to the appearance above NM additional substance brought by precipitation in clouds. Such small value of the variations is usually not observable at NM; they sink in the fluctuations and variations caused by the conditions in the space. The new technique reveals this small effect.

Variation in the neutron component on leadless sections 4-NM-64 has greater amplitude. This can be explained by the fact that BNM is sensitive to middle-energy neutrons.



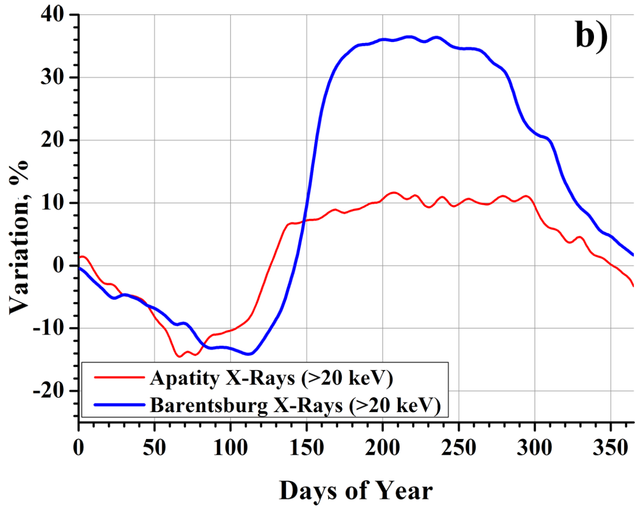


Figure 3: **a)** Average annual variation in different components of secondary cosmic rays on Apatity station. The snow cover melts away in May and restores at November. At the warm period there is a raise on the BNM count rate due to radom emisson. **b)** Average annual variation in gamma radiation on Apatity and Barentzburg stations in comparison.

Due to precipitation there is more hydrogen atoms in the environment (both in the atmosphere and the soil), which effectively moderate neutrons till thermal energy.

Variations on the charged particles detector are demonstrative. The variation on the upper layer channel is clear and beyond doubt. At the same time the variation on the coincidence between the upper and lower layers channel virtually absent. It is having single meaning result. The variation on the upper layer is caused by gamma rays. The matter is that the Geiger-Müller counter has a slight sensitivity to gamma radiation [8]. Such sensitivity is caused by δ-electrons emission from the tube material or surrounding objects.

Thus, small variations, associated with precipitations, in other radiation components are actually present. However, variations on the neutron component are caused by changes in the amount of matter above NM. The variation ratio on the charged particle detector indicates on that the additional flux of charged particles (both electrons and muons) with energies above 5 MeV is absent. It is experimentally confirms that only gamma radiation increases during precipitation.

4 Seasonal variations in different components

The neutron, electron and muon, electromagnetic components (with energies of tens MeV and more) of secondary cosmic rays are investigated for many years. Soft gamma radiation (up to few MeV) in the surface layer of the atmosphere is much less studied. Our 4 years data of the complex unit on the Apatity and Barentsburg stations is quit enough to carry out of studying and comparison. On the Apatity station data from detectors: NM, BNM, CPD and GRD were used. At the Barentsburg station two types of detectors were only used: NM and GRD. To reveal the annual variations, the method of superimpose method was applied. Annual profiles of variations in different components are shown in Figure 3a.

Seasonal variations on NM and CPD are absent, but are observed a monotonic decrease of intensity. This is due to the 11-year solar cycle modulation of cosmic rays in the heliosphere because the period 2009-2012 is from the Sun minimum to maximum. The same trend is observed at BNM, however, in the each warm season there is an increase of the neutron flux. With cold weather coming this flux is reduced to its previous value. It would be radon emission influence. With cold weather coming soil is freezing and snow is covering it, radon emission from the soil is reduced.

Most remarkable variation is present at GRD detector. The variation amplitude is more than 20%. It can't be explained only by the presence of radon. Relying on a variation at BNM, one can say that at the winter (from November to May) deep snow (over 1 m) and frost cut off the radon emission from the soil. However, the gamma-ray flux during a winter is falling down continuously. At mid-May snow is melting, the soil is thawing, and the radon emission to the atmosphere is restored. However, since the beginning of May until the end of July the flux of gamma-ray is going up, increasing in this period is on 10% additionally. According to BNM variation radon emission is around constant at warm season. We consider it can't be omitted the factor of radon emission, but it is not the main cause of gamma-ray background variations. Seasonal variation of gamma background in Barentsburg at latitude 78°N is more indicative. This is the permafrost zone. The radon emission from the soil in such conditions is not possible. However the annual variation amplitude at Barentsburg is twice more than at Apatity (see Figure 3b) and up to 50%. At the same time the profile shape of seasonal variations on these two stations are close enough.

5 Discussion

In this paper we present the results of new research on variations of gamma radiation associated with precipitation to determine their origin. Small variations on the other components accompanying the precipitation can be explained by the already known causes. Therefore, after this study we can conclude that the reason causing of the increase of the gamma ray background with precipitation, affects only the electromagnetic component. At least its influence on the other components is less by several orders and undetectably.

As to seasonal variation, the variation in the electromagnetic component is an order greater than in the other components. The cause of BNM increases at summer quite well explained by the seasonal variations of radon emission from the soil into the atmosphere. Now there is not enough data to determine the cause of the seasonal variation in the gamma radiation. But some of the principal points can be noted. Differential spectrum of soft gamma radiation, measured at the surface [9], is in corresponding to Bremsstrahlung form. Its origin is explained in [4, 10]. The simplest way to explain this phenomenon is seasonal variations in the temperature of the atmosphere. Because light energetic particles (electrons and positrons), producing Bremsstrahlung originate from the muon decay, the muon flux variations in the depth of the atmosphere influence eventually on energetic electron flux and gamma radiation too. Seasonal variations of muons are well known [7]. They are caused the atmospheric temperature variation. However, clear understanding of this phenomenon (gamma radiation variation) is absent now, it is necessary to continue complex measurements in the atmosphere.

6 Conclusions

Based on the superimpose method we have studied annual and stochastic variations in the different components of the secondary cosmic rays. Stochastic variations are connected to precipitation. With a good statistical accuracy small variation in charged and neutron components are found. They are concurrent with the increase in the gamma-ray radiation. It was found that these small variations are quite explained by known reasons which are not direct to gamma variations. Therefore it would be concluded that the actual reason causing increase in gamma radiation are not affected on other components.

Seasonal variations in different components of the secondary cosmic rays during 2009-2012 have been measured. Seasonal variation on the HM is completely absent, there is only a gradual decrease caused of the solar activity increase. The general trend at BNM is the same as at NM, however, in the warm season there is a slight increase. We associate it with the radon emission from the soil. Seasonal variation in the soft gamma rays is huge ($>$20% at Apatity, $>$50% at Barentzburg). A possible reason of them could be the seasonal variation in the muon flux.

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