Features of the flux of gamma-radiation in the lower atmosphere during precipitation

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Abstract. We are carrying out observations and studies of increases of gamma radiation intensity in a ground atmosphere layer during precipitations. Measurements have been carried out in two high-altitude points: Apatity (Murmansk) and Barentsburg (Spitsbergen). Scintillation detectors on the basis of NaI(Tl) crystals are used. Continuous radiation detection is made as the count rate in integral channels with threshold values >20 keV, >100 keV. There are more than 500 events of increase in gamma-ray background during precipitation. Average profiles of X-ray radiation increases in a ground level and the related with them increases of intensity of precipitations for stations in Apatity and Barentsburg have been built up. In Apatity the average increase profile in the gamma-ray flux and accompanying with profile of precipitations rate have been obtained. A time gap between peaks of precipitation and increase one is 30-40 minutes. A barometric coefficient of each component of radiation has been calculated. The barometric coefficient has a zero value on gamma-ray. The charged component of the secondary cosmic rays has a typical value ~0.18 %/mB. The lack of the barometric effect on gamma-ray indicates on the local origin of this radiation.

1. Introduction
During the past three years, the study of variations of surface gamma-ray background in the cosmic ray station in Apatity and Barentsburg. At both stations used the same scintillation detectors (SD) based on the NaI(Tl) crystal the size of Ø63×20 mm. The detectors have two outputs channels: > 20 keV and > 100 keV and placed on continuous registration. A more detailed description of the complex installation, which also includes lead-free section of the neutron monitor (NM bare), detectors of charged components (electrons and muons), precipitation gauge, barometer and temperature sensor can be found in [1, 2]. During the given period a large database has accumulated. It contains hundreds of events of increases 5-50 % gamma-ray and the duration of 2-3 hours to a day or more. Events taking place all year round, the vast majority of these events are accompanied by solid or liquid precipitation. These increases are not connected with the presence of radioactivity in precipitation, or an additional release of radon from the soil. More details about the additional experiments performed to clarify the nature of the observed increases, described in [2].

In the last six months a complex installation in Apatity was additionally equipped with a new scintillation detector based on the crystal NaI (Tl) the size of Ø150×100 mm. Measurements of gamma-ray background complemented by channels > 200 keV and > 1000 keV. In addition, the analog output from this detector is used for continuous measurement of the differential energy spectrum of gamma-ray background in the range of 200-4000 keV. Connection diagram of the devices and methods of data collection of the spectrum is described in [3]. The presence of a large database on the various
components of radiation (neutron, electromagnetic, charged components) on the ground level allows conducting a comprehensive analysis. Comparison of data for small and large detectors showed that the increase in channels and variations > 20 keV, > 100 keV and > 200 keV in the range of measurement accuracy are the same, and only in the channel > 1000 keV are much smaller. Therefore we used a single channel > 100 keV, the results from other similar.

2. Measurements

2.1. Variations into different components of radiation and its relation

The daily variation in cosmic rays is well known and studied fact [4]. The reason for it is the anisotropy of primary cosmic rays and the Earth's daily rotation. This variation is observed both in the neutron and in the muon components. Study was performed to find daily variation in the surface gamma-ray background. Everywhere below to find any variations in the data the superposed epoch method has been used. The description of that method can be found in [5]. In quiet geomagnetic conditions the daily variation in the neutron monitor data (NM) is easily observable. It is an average about 0.5%, while hourly data accuracy NM ~ 0.05%. NM data were used as the primary source. From these data, we selected the days used to search for variations. Further, these data were processed using the superposed epoch method. As a result, average daily profiles were obtained. In Fig.1a shows the results. Used data from NM, NM bare and SD for 153 days in 2009-2011 It should be noted that the variation of gamma-ray background is in antiphase with the variation in the NM's. Lead-free section is sensitive to neutrons of lower energies and the variation of it is about 1.5 times greater. So far we have not enough information for explain the observed daily variations in SD. Perhaps an increase in the flux of cosmic rays leads to an increase in the conductivity of the air and this leads to a decrease in intensity of the electric fields in the atmosphere.

![Figure 1](image)

**Figure 1.** a) Average day variation of radiation flux on different detectors. NM day variation is typically for Apatity. b) Average variation of radiation flux on different detectors during X-ray increase events. Data of NM and NM bare are multiplied on 10. Data of SD is multiplied on 3.

There were also studied variations connected with precipitation. In this case, data were taken as a basis for SD. A maximum of increase was taken as a reference point, in both directions from which the interval is set at 12 hours. Similarly, the method of superposed epoch has been used. The 75 summer increases with approximately equal duration was selected. Data from SD, the detector of charged components, NM and NM bare has been used. For the charged component detector is used the channel of the upper meter (UP), registering the charged particle and the gamma-rays (with small efficiency), and the coincidence channel (DN), sensitive only to charged particles [2]. The result is shown in Fig.1b. Variation in SD provides the actual increases in the average profile. A small increase in the channel UP is explained by the minor contribution of the gamma-rays. This conclusion is confirmed by the fact that the channel DN (which registers only charged particles) has no increase there. This
clearly indicates that the increases on the SD detector provided only by photons of gamma radiation. The negative variation in NM is the result of the appearance in precipitation of additional matter above NM. It is known [5] that by NM counting decrease by 0.7% with increasing amount of matter above the NM by 1 g/cm². If we take the average values of intensity of precipitation, rain cloud thickness [6] and calculate the mass of additional matter, imparted to the atmosphere by rain, it will be about 0.4 g/cm². This amount of additional matter can reduce the neutron flux of 0.3%. A variation on the NM bare has three times more amplitude. It can be explained by the fact that after the rain neutrons is more effectively moderating by an environment saturated by hydrogen atoms (soil saturated with water), which leads to a significant increase in the flux of neutrons of moderate energies. The second decrease in the profile of NM bare is near the maximum of increase, when the maximum rate of precipitation is reached (it will be shown below).

2.2. Barometric effects in different components
Availability of large amounts of data makes it possible to study the influence of on different component radiation, and of atmospheric pressure define barometric coefficients. This allows us better understand the nature of radiation and its origins. Methods of calculating the barometric coefficient is given in [5]. We are using all data arrays except the data during periods of strong geomagnetic activity. Periods of increasing of gamma-ray background that take place during precipitation are also included. In Fig.2 are shows the results of calculating the barometric coefficients.

Barometric coefficient for the NM and NM bare are the same. It is well studied and k_NM = 0.72 %/mb. It had given as a control for the validation and verification techniques. Barometric coefficient for the charged component was found to be k_CH = 0.18 %/mb, which is close to the standard barometric coefficient for the muons. This result was expected because the main component of the charged radiation on the ground level is muons. An unexpected result was found out for the gamma-radiation: k_SD ≈ 0. At least the lower part of the figure 2a shows no slope to the axis OX. The upper part of the figure a more blurred due to the inclusion of data SD during the increases.

2.3. Relation between X-ray and precipitations
The relationship between increases in the gamma-ray background and the precipitation is not in doubt. More than 95% of cases are accompanied by increasing precipitation in the form of snow or rain. However, the measurement method used in the precipitation gauge is not adapted to produce the absolute values [2]. It works on the principle of measuring the scattered IR radiation precipitation. The value of the scattering depends on the intensity and on the type of precipitation. During a particular rain with some certainty can say that the value of the signal from the precipitation gauge is proportional to the intensity of rainfall, however, it is impossible to calculate from these data the absolute values of the intensity of the two different cases of precipitation.

To work around this difficulty and to compare different cases, normalization was performed. The profile of each increase and precipitation were normalized at their maximum. Then the superposed epoch method was performed to profiles of selected events. Reference point was chosen as the time of
maximum precipitation. To study were selected 82 events with approximately the same duration, one type of precipitation (rain) and with amplitude of at least 10%. The results are shown in figure 3.

Figure 3. a) - Average profiles of precipitation (blue) and X-ray increase. There were used 82 events during warm seasons 2009-2011. b) – an example of real “shock” precipitations and relaxation response on it at gamma-ray background.

It should be noted that the profile of precipitation quite sharp and symmetrical, while the profile of gamma-ray background significantly asymmetrical (steep leading front and a slow decline). It is also noteworthy that between the maximum rate of precipitation and maximum of increase delay for 20-30 minutes is present. Also the maximum increase in amplitude in X-ray has a maximum rate of precipitation. The ratio of profiles is similar to some “shock” effect (precipitation) and the response of an inertial system (gamma-background.) on it. From figure 3a can obtain the average relaxation time of ~ 100 minutes. In figure 3b shows an example of a real "shock" effect. If we look at figure 3b, we can see that it is such a relaxation time of recovering gamma-ray background in the real events. These features of the profiles (and adjusted to [1] experiments) should be considered when developing a model of generation of additional gamma radiation by charged particles when they have extra accelerating in electric fields.

3. Conclusions
Daily variations in different components of radiation in the atmospheric surface layer using the different type of detectors (neutron monitor, lead-free neutron monitor, a charged component detector gamma-detector) have been studied. The daily variation of the gamma background is in antiphase with the variation in the NM data. Variations in the other detectors at the time of increases in the gamma-ray background are clearly show that all the additional flux of radiation, recorded by SD, caused only by gamma rays. Found no barometric effect in the data by gamma-ray detector. That indicates the local origin of this radiation. Finally, on the basis of the average profiles of precipitation and increases in gamma-ray background, we can conclude that an increase in the average is delayed with respect of precipitation for 20-30 minutes.

4. References
[1] Germanenko A V, Balabin Yu V, Vashenyuk E V, Gvozdevsky B B and Schur L I 2011 High-energy photons connected to atmospheric precipitations Astrophys. Space Sci. Trans. 7 471–475
[2] Gvozdevsky B B, Balabin Yu V, Germanenko A V and Vashenyuk E V 2011 Proc. of 32nd ICRC (China, Beijing, 11–18 August 2011) id 863
[3] Germanenko A V, Balabin Yu V, Maurchiev E A, Gvozdevsky B B and Vashenyuk E V 2011 Proc. of 23rd ECRS (Russia, Moscow, 3–7 Jule 2011) geo619
[4] Dorman L I 1975 Exper. and Theor. Foundations of Space Rays Astrophys. (Moscow: Nauka)
[5] Dorman L I 1972 Meteorological effects in cosmic rays (Moscow: Nauka)
[6] Chalmers J A 1974 Atmospheric Electricity (Oxford: Pergamon press)