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STUDY OF RADIATION RELATED WITH ATMOSPHERIC PRECIPITATIONS

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Abstract. We suggest that increases during precipitations are caused by the bremsstrahlung X-rays, created by the electrons accelerated in an electric field of clouds. It is necessary to emphasize that our results differ from similar results of works related with thunderstorm clouds. In the arctic (Spitsbergen) and subarctic (Apatity) regions where observations are carried out, thunder-storms are almost not observed. The NaI(Tl) detector is sensitive not only to the gamma and X-ray radiation, but also to the charged particles. Besides, the instrument can register a gamma radiation from the atmospheric radionuclides scavenged by precipitations. We carried out additional studies to estimate the contribution of hindering factors (charged particles, radioactivity) in the data of NaI(Tl) detector for deriving true data on X-rays. Simultaneous with NaI(Tl) detector measurements by the instrument on the basis of Geiger counter tubes showed the insignificant contribution of charged particles to composition of the radiation caused the increases. The radiochemical analysis of precipitations collected during a number of great increase events showed only trace amounts of the natural and induced radio nuclides. And anyway they could not cause the X-ray increases registered. A possible mechanism of the electron acceleration and generation of X-ray photons is suggested and simulations of the X-ray spectra compatible with observations have been carried out.

1. Introduction

The existence of excess radiations associated with thunderstorms is a known fact [1-3]. It was shown that the main cause of the excess radiation during thunderstorms is the particles accelerated by strong electric fields within thunderclouds [1,2].

Another very interesting phenomenon, related with generation of energetic particles by thunderstorm clouds, is "Terrestrial gamma-flashes" or TGF events [4]. Short bursts of energetic gamma-ray quanta are observed above thunderstorm clouds during discharges between a cloud and an ionosphere. TGF events are interesting to us in connection with the developed theory of acceleration of charged particles in a discharge [5] at the presence of so-called runaway electrons [6]. However, energetic photons studied in the given work are born not in a thunderstorm, but in "quiet" rain clouds.

We organized monitoring of low-energy gamma (X-ray) radiations on the ground level and recorded increases, usually associated with precipitations. It should be noted that in the subarctic (Apatity, Murmansk region) and arctic (Barentsburg, Spitsbergen) areas, where observations were made, thunderstorms are observed extremely seldom. Nevertheless, as the cause of the increases associated with precipitations, we assume the electric field of the clouds (though not as strong as in thunderstorm clouds), which accelerates electrons and creates the bremsstrahlung radiation penetrating to the ground level.

2. Instrumentation

To monitor gamma (X-ray)-background at the ground level in Apatity and Barentsburg, we used the scintillation spectrometer based on the NaI(Tl) crystal of 6 cm in diameter and 2 cm thick. The signal after the photomultiplier and the amplifier is continuously recorded in 4 integral channels with a threshold photon energies > 20, > 60, > 100 and > 200 KeV. Detection in integral channels allows us continuous estimation of the integral spectrum of high energy photons. Besides it, the spectrometer in Apatity is equipped with the 4096-channel pulse-height analyzer V4K-SATSP-USB, based on the high-speed spectrometric ADC. It allows us to produce accurate measurements of energy spectrum.

The instrumental complex in Apatity includes also the second NaI(Tl) spectrometer for the check experiments, a detector of charged particles, temperature and pressure sensors, and a precipitation gauge. All these instruments are installed at the loft right under the 1 mm thick iron sheet roof. The precipitation gauge allows us to evaluate the intensity of precipitation in the form of rain and snow. The principle of its operation includes measuring of intensity of the scattered back on particles of precipitations radiation from the infrared source. The detector of charged particles is a telescope on G-M counter tubes and permits detecting charged component of the secondary cosmic rays.

3. Observations

Continuous monitoring using gamma spectrometers in Apatity and Barentsburg were started in the summer-autumn period of 2009. During the observations we detected sporadic increases in the intensity of X-ray radiation. It was also noted that the increase events almost always were accompanied by intense precipitations, with dense and low altitude (200-600 meters) cloudiness, so called “nimbostratus clouds”, data on [http://rp5.ru/1122/ru].
Figure 1 shows typical profiles of the count rate increase in the X-ray channel > 20keV and precipitations for the Apatity and Barentsburg stations. The good correlation between the strengthening of rain and increases of the X-ray intensity in Apatity is seen in Figure 1a. Similarly, the good correlation is observed between the X-ray increase and snowfall in Apatity, Figure 1b. Curve 3 is the data of Geiger telescope channel which shows no any increase. It can specify lack of charged particles in the event, connected to precipitations.
There were observed over 280 X-ray increase events from June 2009 to June 2011. The intensity increased up to 50% of the background and duration of an increase varied from one hour to two days. 97% of these events were accompanied by precipitations of varying duration and intensity. The amplitude of increases differs for different seasons. In winter the amplitude of increases was on the average less and there was not fixed any increase greater than 30%.

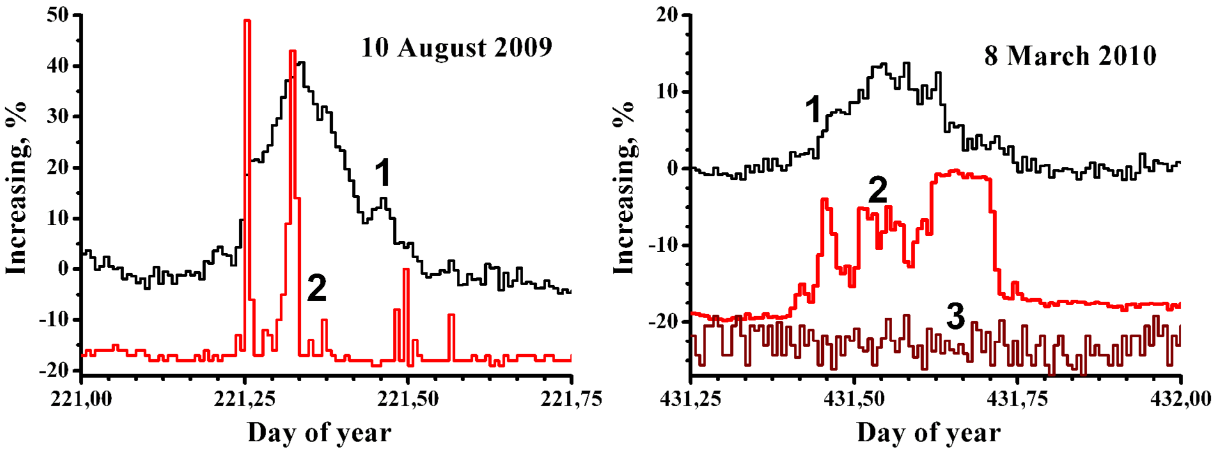

Fig.1. Typical events of X-ray increases (1) related to precipitations (2). a) rainfall event of 10.08.2009 in Apatity; b) snowfall event of 8.03.2010 in Apatity, 3 is the G-M telescope channel.

In addition, the connection of the type of precipitation with the increase amplitude was noted. Fine, dry snow with the wind (blizzard) or permanent drizzling rain rarely was accompanied with an increase. Most of the increase events were accompanied by heavy rains or snowfall with no strong wind.
During 2010 in Apatity only 3 thunder-storms in the summer season were observed. Increases of photons in these thunder-storms were small, < 5-10 %, that is quite low for the summer season. The low bound of cumulus clouds in these thunder-storms exceeded 1000 m (http://rp5.ru/1122/ru), that we consider a reason, why X-ray increases were so small.

4. Check experiments

For clearing up the nature of increases observed on detectors NaI(Tl) it was required to carry out a series of additional check experiments. In particular, lack of radioactivity in precipitations (rain and snow) during observation of increases has been proved. For check of connection of effect described here with a radio-activity of atmospheric precipitations we have used the data of the regional laboratory of radiochemical control. This laboratory carries out regular measurements for the last few years. Weekly samples of precipitations (all amount of precipitation, collected for the last week) are analyzed. We compared the weekly records of radioactivity in precipitations in Apatity with increases on our gamma-spectrometer. There is no regular connection of occasional radioactivity enhancements with increase events detected by our gamma-spectrometer and which we attributed to the X-ray bremsstrahlung events. In several cases of considerable X-ray increases the samples of precipitations in the form of rain and snow have been collected and analyzed with radiochemical methods. The radiometric analysis of these samples showed no excess over the background level of beta and alpha activity. The gamma-spectrometric analysis has shown usual presence of the natural radio nuclides which activity does not exceed the background level observed before and after an event. Also lack of effect of radium emanation on observed X-ray radiation has been shown. It is known, for example, that rain scavenges radon progenies efficiently and it emits gamma radiation in the energy range of hundreds keV. Increases of X-rays during precipitations in the winter season are observed with the same effectiveness as in the

summer and exclude radon origin of one.
Also lack of contamination of the charged particle component in the X-ray events has been shown. The detector is sensitive both to the electromagnetic component of radiation and to the charged one. To clarify the relative contribution of the charged component radiation to the increases is possible with the help of the charged particle detector based on Geiger counters. It is known that sensitivity of these counters with regard to the charged component of radiation is two orders of magnitude higher than to gammaray quanta. Connection of two layers of counters on coincidence, as described in Section 2, ensures detecting the charged component of radiation only. There are no charged components (electrons and muons) in the radiation causing the increase on the detector.

5. Discussion

As it was shown above, the increases in the count rate of the gamma-ray spectrometers during precipitations are not related with radioactivity of the atmosphere, including radon. They also are not caused by charged particles. Increases should be caused by photons which upper energy limit is less than 1 MeV. The probable source of these particles can be the X-ray bremsstrahlung produced by electrons accelerated in a rain (snowfall) cloud. Near the Earth's surface the electric field in quiet weather is about 100 volts per meter. Inside the rain clouds the electric field strength is much higher and may reach kilovolts per meter and even tens of kV/m [7].
The intensity of the photons is determined by the generation of energetic electrons and positrons in the form of bremsstrahlung and the alternative process of absorption in the air. When passing through the matter, the electron loses energy due to ionization and radiation losses. In our low-energy energy domain (E_e < 1MeV) a decisive contribution to the energy losses gives the ionization process. Radiation losses become significant at much higher energies [8].

6. Spectra of increases and interpretation of experimental data

At the instrumental complex in Apatity we also obtained energy spectra of photons during increases with the help of the 4096-channel pulse-height analyzer. The calibration of the spectrometer was carried out with the help of radioactive gamma-sources Am^{241} (lines of 26 and 60 KeV) and Cs^{137} (662 KeV). The spectrum of photons causing an increase was obtained by a subtraction from the measured spectrum during the increase of a spectrum of a quiet background before the increase. In Fig.2 by a thick line is shown one of the experimental spectra obtained in the event on March 8, 2010 (Fig.1b). The spectrum has a gradual form. There are not narrow peaks characters for lines of radionuclides.
We tried to simulate the observed X-ray spectra in the frames of our above suggestion about the bremsstrahlung origin.
The energy spectrum of electrons in the our energy range can be nearly approximated by an exponential law [8]

$$\frac{dN(E)}{dE} = N_0 \cdot e^{-E/E_0} \qquad (1)$$

where E0 is characteristic energy, which varies in the range from tens to hundreds keV.
At simulation we use expressions for conversion of an electron flux in a X-ray bremsstrahlung in view of simultaneous losses on ionization in air [8].

$$\frac{dN(hn)}{d(hn)} = a^{\log_2 \frac{E_0}{5}} \cdot r \cdot \left(\frac{hn}{E_0}\right)^{-3/2} \cdot \frac{dN_e}{dE} \qquad (2)$$

where $\dfrac{dN(hn)}{d(hn)}$ is spectrum of photons for a given electron spectrum with an exponent E_0.

$a = 1.63$, $r = 3.48 \cdot 10^{-4}$.

It should be noted that one must account effects of absorption in the air of both electrons and produced by them X-ray photons. Due to the strong absorption of electrons with energies of tens or hundreds KeV in the air, it is expected that only particles produced no higher than 1000 m can reach the ground level. This is also confirmed by the fact that almost all registered increases we observed in the overcast with the lower edge of the clouds from 200 to 600 m. According to balloon studies [7] in nimbostratus clouds, which we usually observe during the X-ray increase events, there are electric fields with intensity of vertical component: $E_Z = 1 \div 12$ kV/m and a layer width (LC) of a few hundred meters. Intensity of a horizontal component is $E_H = 0.2 \div 28$ kV/m. We suppose that presence of such electric fields in clouds in rainy weather gives extra energy $\Delta E = E_Z \cdot L_C$ to electrons, which results in the increased flux of X-ray bremsstrahlung on the ground level. We obtain the expression that describes the spectrum of X-ray radiation at the earth's surface after accounting for losses due to absorption of both electrons and gamma rays:

$$N(hn) = \int_0^l [\exp(m(hn)\cdot(l-x))\cdot \int_{hn}^{\infty} Q(E,hn)\cdot \exp\left(-\frac{E}{E_0} - (k\cdot x) + \Delta E)\right) dE]dx \qquad (3)$$

where:
l is height of generation of accelerated electrons, μ is linear attenuation coefficient of gamma – radiation, *Q(E,hν)* is differential cross section of bremsstrahlung, *k* is specific energy losses of electrons in the air, ΔE is extra energy of electrons from acceleration in electric field in clouds.

Calculations are made in the energy range of X-ray *hν* from 0 to 1000 keV (step 5 keV) and for the heights of the generation of electrons from 100 to 1000 m (step 50 m).
Figure 2 shows the results of model calculations according to formula (3) of the spectra of bremsstrahlung photons at the earth surface, produced by accelerated electrons in the atmosphere at height l for different values of this parameter from 300 to 500 meters.
Thick curve shows the spectrum of photons measured in the event of March 8, 2010 (Fig. 1b). It is evident that the measured spectrum agrees well with the model obtained for the generation altitude band of 200-300 meters with an integral exponential spectrum with E_0 = 100 keV.
According to our model calculations under the formula 3 the increase of field gradient E_Z at 1 kV/m, gives increasing of a flux of X-rays on the ground level approximately at 1%. This agrees well with the data of observations.

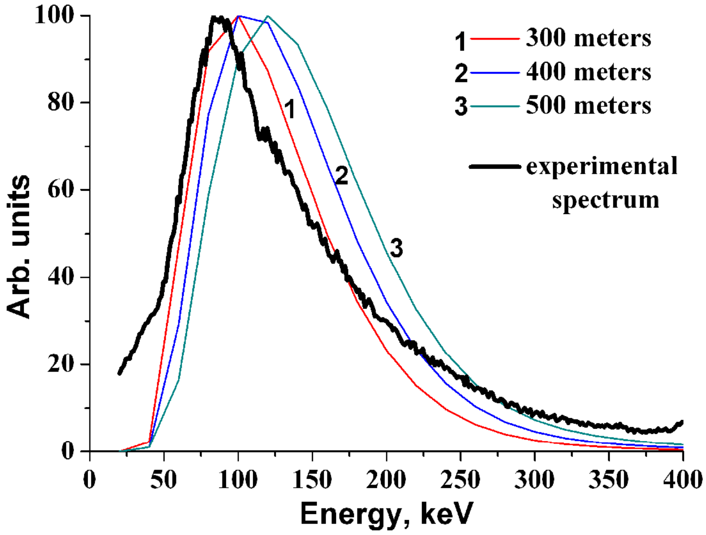

Fig. 2. Comparison of model spectra for different altitudes (1, 2 and 3) with the experimental one (black line).

7. Conclusions

Continuous measurements (monitoring) by X-ray spectrometer in the atmospheric surface layer of the arctic (Spitsbergen archipelago) and subarctic (Apatity) regions discovered systematic relationships between increases in the low-energy gamma (X-ray) background and precipitation as rains and snowfalls at a low and dense cloudiness.

As the reason of X-ray increases the bremsstrahlung X-ray radiation produced by the secondary cosmic ray electrons, accelerated in electric fields inside rain clouds is suggested. The calculated X-ray spectrum obtained in the model assumptions, are in satisfactory agreement with measurements.

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