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STUDY OF GAMMA-RADIATION CONNECTED TO ATMOSPHERIC PRECIPITATION

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Abstract. Increases in the intensity of gamma - radiation in the surface layer of the atmosphere during precipitation in the arctic and subarctic regions were studied. A clear link between rising and rain (snow) cloud was found out. The mechanism of generation of X-rays during precipitation is supposed. Preliminary evaluations are obtained.

1. Introduction

The existence of excess radiations associated with precipitations and thunderstorms is a well known fact [1-2]. It was shown that the main cause of the excess radiation during thunderstorms is the particles accelerated by strong electric fields within thunderclouds [2]. We organized monitoring of low-energy gamma (X-ray) background on the ground level and recorded increases, usually associated with precipitations. It should be noted that in the subArctic (Apatity) and Arctic (Spitsbergen) regions, where observations were made, thunderstorms are almost not observed. 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

2.1. Scintillation spectrometer

To monitor gamma (X-ray) - background at the ground level, we used the scintillation spectrometer based on the NaI (Tl), crystal of 6 cm in diameter and 2 cm thick. The instrument was previously developed and used to measure the auroral X-rays from balloons in the stratosphere [3]. The signal after the photomultiplier and the amplifier comes to the input of 4096 channel pulse analyzer V4K-SATSP-USB, based on the high-speed spectrometric ADC for 4096 channels.

The signal after the photomultiplier and the amplifier also is continuously recorded in 4 integral channels with a threshold photon energies> 20,> 60,> 100 and> 200KeV. Outputs of these channels enter a computer through through the interface module and a special programmed extension card AD LINK 7233. Detection in integral channels allows us continuous estimation of the integral spectrum of gamma (X-ray) radiation.

Power supply for photomultiplier and an amplifier for it is made using a special circuit of voltage converter with pulse-width modulation, providing good stability of high voltage supply for photomultiplier. Measures are taken for stabilize the temperature inside the instrument container, which is made of aluminum and hermetically sealed.

Photomultiplier output pulse enters the amplifier. Parameters of the input amplifier circuit were chosen in such a way that for each 1 KeV at the photomultiplier input had to be 1 mV at the amplifier input. The gain of amplifier was set to 10. Thus, the photon with energy of 100 keV causes at the amplifier output a pulse with amplitude of 1 V.

The spectrometers were tested with a source of gamma radiation Am^{241}, which has a weak line at 27 KeV and the main line at 60KeV. The detector is installed in Apatity on the loft, right under the 1 mm thick iron sheet roof. Along the sides and bottom it is surrounded by lead bricks 5 cm thick, for shielding them from the surrounding radiation from buildings and the ground, and placed inside a polyfoam box with a wall thickness of 8 cm. The detector in Barentsburg was installed in the housing of the central section of the neutron monitor and placed inside cylindrical steel "cup" with a wall thickness of 8 mm, which allows registration of arriving X-rays only from the top hemisphere.

2.2 Additional equipment

Together with spectrometers in Apatity a precipitation gauge was installed that allowed us to evaluate the intensity of precipitation in the form of rain and snow.

The neutron monitor housing in Barentsburg also incorporates sensors outside and inside temperatures.

3. Observations

Continuous monitoring using gamma spectrometers in Apatity and Barentsburg (archipelago Spitsbergen) were started in the summer-autumn period of 2009. The data is continuously registered by the neutron

monitor data collection systems at these stations with a frequency of 1 times per minute.
During the observations spectrometers detected sporadic increases of 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.
There were observed 99 X-ray increase events from June 2009 to April 2010. The intensity increased from 5 to 45% 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 25%.
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 were accompanied with an increase. Most of the increase events were accompanied by heavy rains or snowfall with no strong wind.

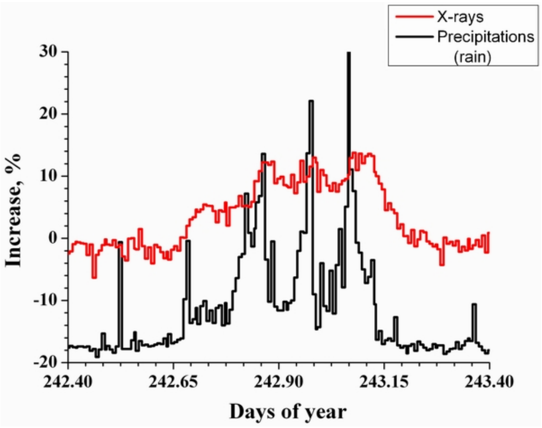

Fig. 1. X-ray increase and precipitations (rain) in the event of September 16, 2009, Apatity

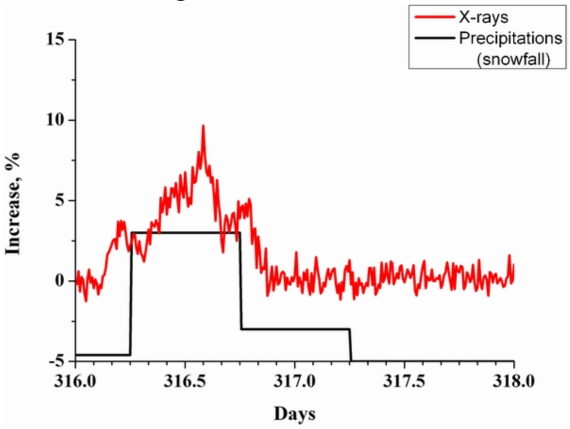

Fig. 2. X-ray increase and precipitations (snowfall) in the event of November 12, 2009, Barentsburg

Figure 1 shows typical profiles of the count rate increase in the X-ray channel > 20keV and precipitations (rain) for the Apatity station. The good correlation between the strengthening of rain and increases of the X-ray intensity is seen. Typically, a peak of a rainfall occurs 10-40 minutes prior to the corresponding increase in X-rays.
Figure 2 shows the typical profiles of X-rays > 20keV increase and the precipitations (snow) for the station Barentsburg. Unfortunately, here we were only available data on precipitation averaged for 3 hours, but still it is seen the link between the X-ray increase with a period of snowfall.

4. Discussion

We assume that the increase in a count rate of gamma-ray spectrometers is caused by the X-ray bremsstrahlung produced by electrons accelerated in a rain cloud. Near the Earth's surface the electric field in quiet weather is about 100 V/m. Inside rain clouds the electric field strength is much higher and may reach of kilovolts and even tens of kV/m [4]. This is enough to accelerate electrons up to such energies, that produced by them X-ray quanta could reach a terrestrial surface and cause appreciable increases of the count rate of gamma - detectors.
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 [3]. 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 [2].
The energy spectrum of electrons in the energy range (E < 1MeV) can be approximated by an exponential law [3].

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

where E_0 is characteristic energy, which varies in the range 10-100 keV.
Number of photons with energies *hν* in the range *d(hν)*, produced by an electron with energy *E* when changing it on *dE* on distance *dx*, is equal to:

$$dN(hn, E) = \frac{ds\,(hn, E)}{d(hn)}\, d(hn) \cdot N\, \frac{dx}{dE}\, dE\,, \qquad (2)$$

where $\frac{ds\,(hn, E)}{d(hn)}$ is differential bremsstrahlung cross section; N is density of atoms of matter.

The total number of photons with energy *hv* in interval *d(hv)*, produced by electrons with initial energy E_0 are equal to (when E > hv):

$$\frac{dN(\mathrm{hn}, \mathrm{E}^0)}{d(hn)} = \int_{hn}^{E^0} \frac{ds\,(hn, E)}{d(hn)} \cdot \frac{N}{\left(-\frac{dE}{dx}\right)} dE\,, \qquad (3)$$

For all electrons with energies 20keV < E < 100keV the value of $(-dE/dx)$ in formula (3) will be dominated by ionization losses. The expression for them is [5]:

$$\left(-\frac{dE}{dx}\right)_{HOH} = \frac{2ne^4 N}{E} \cdot z \cdot \left(\ln \frac{E}{\sqrt{2} \cdot I} + \frac{1}{2}\right), \qquad (4)$$

Where *I* is ionization potential; *z* is average charge of the nucleus. For the air, *I* = 80.5 eV, *z* = 7.22.
Integrating expression (3) over the electron spectrum, we have:

$$\frac{dN(hn)}{d(hn)} = \int_{hn}^{\infty} \frac{dN(hn, E^0)}{d(hn)} \cdot \frac{dN_e}{dE^0} dE^0 = \int_{hn}^{\infty} \frac{dN_e}{dE^0} dE^0 \cdot \int_{hn}^{E_0} \frac{ds\,(hn, E)}{d(hn)} \cdot \frac{N}{(-dE/dx)} dE\,, \qquad (5)$$

For the differential cross section of bremsstrahlung X-rays it was taken the expression [6]:

$$Q(E, hn) = \frac{ds\,(hn, E)}{d(hn)} = \frac{8e^2 h}{3p^2 m^2 c^3} \cdot \frac{h_i h_f}{hn} \cdot \frac{1 - e^{-2h_i}}{1 - e^{-2h_f}} \cdot \ln \frac{h_f + h_i}{h_f - h_i}\,, \qquad (6)$$

where $h_i = az\sqrt{\frac{mc^2}{zE}}$; $h_f = az\sqrt{\frac{mc^2}{z(E - hn)}}$; $a = \frac{1}{137}$.

Substituting expressions (1), (4), (6) into (5) and calculating the integral, we obtain $\frac{dN(hn)}{d(hn)}$ - a spectrum of photons for a given electron spectrum with an exponent E_0.
Expression (5) had been numerically integrated previously [1] and was taken as a first approximation to our data. On the results of calculations the empirical expression for the transition from the spectrum of photons to the spectrum of electrons was found [3]:

$$\frac{dN(hn)}{d(hn)} = a^{\log_2 \frac{E_0}{5}} \cdot r \cdot \left(\frac{hn}{E_0}\right)^{-3/2} \cdot \frac{dN_e}{dE}\,, \qquad (7)$$

where $a = 1.63$, $r = 3.48 \cdot 10^{-4}$. This expression in the energy range 20-500 keV coincides with the results of calculations within 10%.

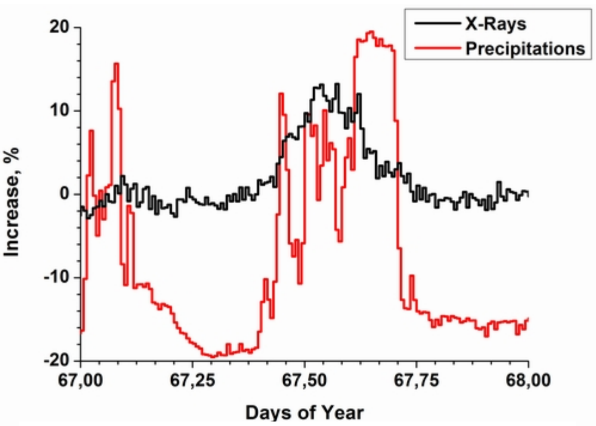

Fig.3. X-ray increase and precipitations (rain) in the event of March 8, 2010, Apatity

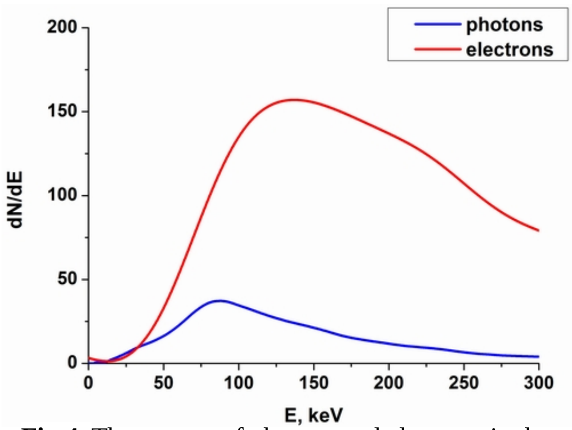

Fig.4. The spectra of photons and electrons in the event of March 8, 2010

With this expression the electron spectrum from the measured photon spectrum can be calculated. The profile of the increase registered on March 8, 2010, is shown in Figure 3. The measured spectrum of photons and calculated from it using (7) the electron spectrum are shown in Figure 4.
It should be noted that the above consideration does not take into 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 of KeV in the air, it is expected that only particles produced no higher than 300-600 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. 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 is

$$N(hn) = \int_0^l \left[\exp\left(\frac{m(hn)*(l-x)}{10} \right) \cdot \int_{hn}^{\infty} Q(E,hn) \cdot \exp\left(\frac{-E+(k \cdot x)}{E_0} \right) dE \right] dx, \quad (8)$$

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 losses of electrons in the air (220 keV/m).
Calculations are made in the energy range of X-ray *hν* from 0 to 1000 keV (step 4 keV) and for the heights of the generation of electrons from 100 to 1000 m (step 50 m).
Figure 5 shows the results of model calculations according to formula (8) of the spectra of bremsstrahlung photons at the earth surface, produced by accelerated electrons in the atmospheric layer of thickness l for different values of this parameter from 450 to 650 meters. Thick curve shows the spectrum of photons measured in the event of March 8, 2010 (Fig. 5). It is evident that the measured spectrum agrees well with the model obtained for the generation altitude of 500 m with an integral exponential spectrum with $E_0 = 100$ keV.

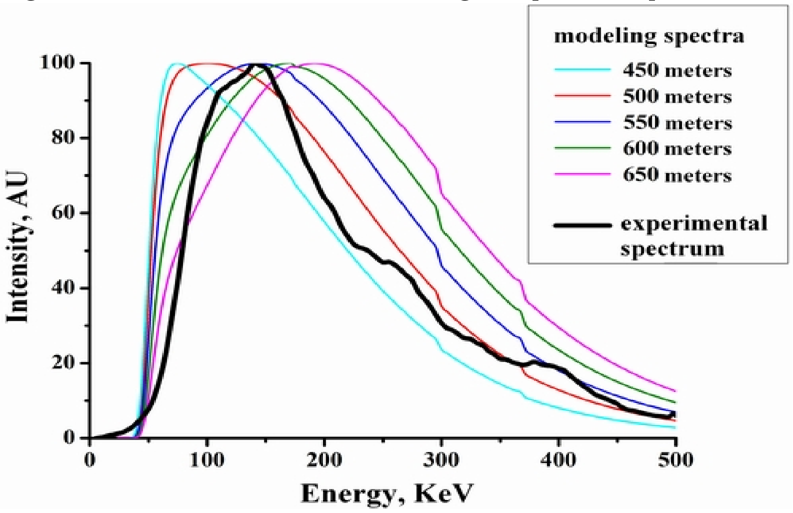

Fig.5. Comparison of model spectra (color curves) with the experimental one (black line)

5. 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 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.

References

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