Cosmic rays and thunderstorms at the Tien-Shan mountain station

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Abstract. Experimental work of the past few years has shown that runaway breakdown determines the maximum electric field strength in thunderclouds and is behind a variety of phenomena newly observed in thunderstorm atmosphere, such as TGFs, TLEs, etc. The necessary condition for the occurrence of runaway avalanche is the existence of high-energy electrons. In the atmosphere, these are the cosmic ray secondary electrons. Therefore the observed effects reflect close relationship between cosmic rays and electrodynamic processes in a thunderstorm atmosphere. The Tien-Shan high-altitude cosmic ray station is a unique site for investigations effects of cosmic rays and thunderstorm discharge. "Thunderstorm" detector complex is designed especially for a systematical study of atmospheric discharges by the means of simultaneous recording of the different kinds of radiation. The presence of a widespread extensive air shower trigger set-up at the Tien-Shan station permits to study the role of energetic cosmic ray particles in lightning development. Overview of main results, obtain during last several years at the Tien-Shan are presented. A phenomenological description and theoretical vision of the cosmic rays role in atmosphere processes during thunderstorm are discussed.

1. Introduction

The influence of cosmic rays (CR) at the ionization of atmosphere and consequently on the formation of the clouds including the thunderclouds is well known. During two last decades new more deep connections between thunderstorm processes and low energy components of CR are revealed. First of all a discovery of intensive fluxes of gamma emission, accelerated electrons and even positrons and neutrons in thunderstorm atmosphere should be emphasized. These high-energy emissions are observed at high-altitude atmospheric discharges TGF (terrestrial gamma flashes) and at the discharges between atmosphere and ionosphere TLE (transient luminous events) as well as in the conventional thunderstorm discharges. The observations of the last effects at the height 3 − 4 km is the goal of the report.
2. Connection of cosmic rays and runaway breakdown phenomena

The existence of high-energy emissions is connected with the runaway breakdown (RB) phenomena. The strong decrease in friction scattering of electrons in atmosphere gives rise to the possibility of electron acceleration in thundercloud electric field. These runaway electrons colliding with air molecules could generate new runaways. That leads to RB: the avalanche growth of the number of both runaway and low-energy electrons. The RB excitation conditions is: 

\[ E > E_c = 2.2 \frac{p_0}{p} \text{kV/cm} \]

where \( p_0 \) is the normal atmospheric pressure and \( p \) is the pressure at a given height (Figure 1). The presence of fast seed electrons above the critical runaway energy 0.1 – 1 MeV is also necessary. The seed electrons are effectively generated by cosmic rays. That determines the deep connection of RB and CR. Note that in a very strong electric field \( E > 200 – 300 \text{kV/cm} \) seed electrons are not needed for RB excitation. Such conditions could be fulfilled in lightning leaders or streamers.

The different forms of radiation during thunderstorm were observed at the high-energy cosmic ray station of P.N. Lebedev Physical Institute installation “Groza” located at Tien-Shang mountain at the height 3400-3860 meters. “Groza” consists of the following separate setups: an EAS registration system, two independent radio systems, a system of scintillation NaI detectors, a system of plastic detectors, a system of neutron detectors and recorder of the quasi-static electric field and its variations. The maximum distance between detectors of the facility in horizontal plane reaches 2 – 2.5 km and in the height 440 m what allows to study both temporal and spatial distributions of the intensity of various radiation types.

![Figure 1. Height dependence of critical field \( E_c \) in atmosphere. Curves - balloon measured electric field, arrows – mark lightning events.](image1.png)

A long period of measurement of gamma emission is presented at Figure 2. The significant enhancement of gamma emission in thunderstorm time is clearly seen.

![Figure 2. A long period of measurement of gamma emission at Tien-Shan.](image2.png)

3. Experimental results

The observed gamma emission in accordance with its duration could be classified as follows:

a) a very short gamma ray flashes lasting less then 200 µs. The flashes are usually widespread sometimes correlated with EAS [2];

b) short gamma-flashes lasting 600-800 µs [3];

c) long-lasting gamma ray bursts 100-600 ms. The burst consists of multiple random flashes and it is directly connected with atmospheric discharge. The duration of bursts is very close to the duration of the discharges [4];

d) background gamma ray emission (GRB) registered both in clear and thunderstorm days. All the above events are seen over GRB during thunderstorm only. In clear days GRB is stable, during thunderstorm it varies in a minute time scale [5].

The strong growth of GRB emission in thunderclouds generated by energetic electrons was observed. The number of energetic electrons is grown up by an order in comparison with the number of CR secondaries under the action of thundercloud electric field. The growth of gamma emission is
well correlated with electric field. The GRB jumps during atmospheric discharge are revealed (Figure 3). The jumps give the direct evidence of a strong affect of the thundercloud electric field on a number of CR secondaries in atmosphere [5].

![Gamma ray intensity](image)

**Figure 3.** Gamma ray intensity. The atmospheric discharge and gamma-ray burst last from -300 ms to 150 ms. The intensity distribution during the burst is extremely non-uniform consists of numerous flashes. The GRB jump during atmospheric discharge is clearly seen. The gamma-counts average value before the discharge (in the area before - 300 ms) is 1.42 counts, after the discharge (in the area after 150 ms) is 0.53 counts.

The prolonged (100 ms-600 ms) gamma radiation (GR) bursts are found and identified with electric atmospheric discharge. GR burst completely fill up the whole time of atmospheric discharge. The observed average radiation intensity during the burst exceeds the background level more then an order of magnitude. The temporal distribution of intensity in a burst is extremely non-uniform consisting of numerous flashes of the GR intensity (Figure3). The intensity in the short flashes can reach the values three orders of magnitude higher than that of the background. Extremely strong dependence of the GR on the height (what means on the distance to the radiation sources) should be especially noted [4].

At the extensive atmospheric showers (EAS) the number of CR secondaries is growing strongly. As they serve the seed electrons for the RB that naturally leads to a strong amplification of RB avalanche -RB EAS effect. This effect being generated by the energetic CR particles of $10^{15}$ eV and $10^{13}$ eV has been observed in [2] and [6].

The CR of low energies $10^{7} - 10^{12}$ eV and CR secondaries with energy $10^{7} - 10^{9}$ eV could serve the initiation of multiple random pulse discharges (PD) observed during the atmospheric discharge by the radio emission [7]. PD are the localized discharges of special type: the ionization front velocity of the discharge is close to the velocity of light (much higher than that of conventional streamer or leader). The average growth-time duration of PD is about 100 ns – same as the RB growth-time. The time interval between pulses is 10-30 µs (Figure 4).

![Localized pulsed discharges](image)

**Figure 4.** Localized pulsed discharges observed during:
top – 1 ms of atmospheric discharge initiated at -133.251 ms before the returned stroke,
bottom – 1 ms before the middle of the atmospheric discharge.
The full number of pulses during one atmospheric discharge reaches $10^4$. Observations demonstrate correlation of PD with gamma emission, high energy electrons and even neutrons. All the correlations demonstrate close connection between cosmic rays and lightning initiation process (Figure 5).

![Figure 5. Correlations during the atmospheric discharge. Up to down: a) field b) radio pulse discharges c) gamma emission d,e) gamma+electrons f) high-energy electrons g) neutrons](image)

4. Conclusion
The observations at Tien-Shang mountains demonstrate:
   a) strong influence of thunderstorm electric field on the low-energy component of CR and EAS,
   b) influence of CR on the lightning (atmospheric discharge) initiation process.

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