Remote observation of a continuous glow of the night-time atmosphere during thunderstorms and analysis of the high-altitude electrical field dynamics according to the data on cosmic ray variations

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Baksan Air Shower Array (BASA)

**Central Carpet**
(400 liquid scintillators)

**Six huts**
(108 liquid scintillators)

**Muon Detector**
(175 plastic scintillators under 2 m of rock).
Energy threshold 1 GeV
Amplitude spectrum from a layer of scintillators

Two thresholds are used to separate soft and hard components:

Soft component is detected by huts between low (Al) and upper (Ah) thresholds. Electrons – 20%, positrons – 10%, γ-rays – 50%, admixture of muons is less than 20%.

Hard component is measured by Carpet detectors (under concrete roof 29 g/cm²) above upper threshold (muons 90%)
Correlation the intensity of soft CR component with near-earth electric field as measured and calculated (on the left panel). The difference (not explained by the spectrum transformation in the field near the ground surface) is shown on the right panel.

Accelerated near the ground

Electrons  Positrons

Accelerated in the clouds

Positrons  Electrons
Muons with $E_\mu > 100$ MeV, deviation from the mean intensity as a function of near-ground electric field strength (weighted average curve, summation over separate thunderstorms).

Solid circles correspond to distribution after exclusion of ±300-second periods of active thunderstorm phase. Variations with large dispersion have no effect on the regular variation with the near-ground field.
Events on June 18, 2008 (left, averaged over 15 s) and July 18, 2008 (right, averaged over 30 s)
Motivation for optical observations

- Model calculations of intensity of low-energy muons during thunderstorm conditions
- Estimation of the stratosphere field during muon disturbances to be supercritical
- Estimation of heights of regions of accelerating electron-positron component
- As a result – hypothesis of a new type of slow runaway breakdown between the thundercloud top and ionosphere - analog of glow discharge produced by relativistic electrons
Potential difference $\Phi$ between the muon production level (11.4 km a.s.l.) and the observation level (1.7 km a.s.l.) and amplitude of count rate disturbance (%) of 100 MeV muons as a function of cloud boundary zenith angle $\theta$. Percent isolines are shown in the figure.
Position of the remote video camera relative to the Carpet EAS array
The field of view of the remote video camera and atmospheric regions under analysis.
Thunderstorm on August 31, 2013. Data are averaged over 15 s intervals. From top to bottom:

1. Lightning detector (arbitrary units proportional to the amplitude of lightning electromagnetic signal).

2. Variations of the soft component intensity.

3. Variations of the hard component intensity.

4. Precipitation electric current.

5. Mean illumination of the near video camera (relative units: $1 \sim 10^{-7}$ lx), the data are averaged over 4 s intervals.

6. The ratio of the brightness in the troposphere region to the average brightness over the matrix for the remote camera, one-second values.
Three snapshots of the sky at a sharp disturbance of the muon flux during thunderstorm on September 15, 2013
Thunderstorm event on September 15, 2013. Interval of averaging is 15 s in all cases except for two upper panels. From top to bottom: 1. lightning indicator (arbitrary units proportional to amplitude of electromagnetic noise from lightning discharges), 2. mean brightness of different sky areas on distant camera images (red colour for ionosphere, violet for stratosphere, and blue for troposphere), 3. pressure, 4. variations of the soft component, 5. variations of the hard component, 6. precipitation electric current. Units of optical data in the second panel 10^{-7} lx (data are presented with one-minute intervals averaged over four adjacent frames).
Thunderstorm event on September 15, 2013. Moments characterizing the dynamics of glow evolution in the atmosphere. Brightness is amplified by a factor of 25.
A new method of analysis with muon angular separation

Equi-partition of four count rate ranges gives four independent parameters. Maximum spectrum position, average potential difference above the array and at the periphery, with angular boundary between them. The typical muon generation level being known, one can represent the angular boundary as a radius on the plane (for vertical field model).
Thunderstorm event on 24-25.07.2014

Pressure

Electric field strength

Precipitation electric current

Electron-photon component

Total muon intensity

Variations of vertical muons

Variations of peripheral muons
Analysis of correlations

Earthquakes around the globe

Potential difference in the troposphere above the array (5 min averaging)

Potential difference in the troposphere at the periphery

Variations of electron-photon component

Relative sky brightness (at the distance of 75 km)

World data on geomagnetic field variations

Relative sky brightness (at the distance of 0.5 km)
Thunderstorm event 10.06.2015
Spectral intensity of the glow

- Background luminosity of the ionosphere region above thunderstorm in three colors: red (R) = 2.5 kR, green (G) = 8.1 kR, blue (B) = 23.5 kR. Or in photometric units, respectively, R = 1.1 \cdot 10^{-4} \text{ cd/m}^2, G = 1.3 \cdot 10^{-3} \text{ cd/m}^2, B = 6.8 \cdot 10^{-5} \text{ cd/m}^2. These values are comparable with brightness of moonlit cirrus clouds, ~ 10 kR. The amplitude of luminosity variations correlating with potential difference in the stratosphere:
  - R: 0.42 kR, G: 1.58 kR, B: 4.33 kR. These values are comparable with Milky Way brightness (1 kR).
  - See poster 126 presenting a case study for the thunderstorm event on 24-25.07.2014.
Conclusions

- Hypothesis of existence of a new type of high-altitude discharge, based on experimental data of muon variations during thunderstorms, has got some confirmation in optical observations.
- These observations include a variety of phenomena on the local and even global scales.
Universal instrument for measuring the near-ground electrostatic field of the atmosphere and precipitation electric current

Measurements of electrostatic and slowly variable field in the range from from -40 kV/m up to +40 kV/m with an accuracy of ~ 10 V/m.

Precipitation electric current is measured in the range from -50 nA/m² up to +50 nA/m² with an accuracy of ~ 10 pA/m².

The instrument allows one to measure not only thunderstorm field but also the background (fair weather) electric field by a single method.
Continuous glow in maxima of relative amplitudes
Record enhancement during thunderstorm on October 11, 2003

Estimates of minimal distance to two lightning strokes exerting strong effect on the intensity are 4.4 and 3.1 km. Other lightning discharges, including very near, give no such an effect.
Two strong variations of muons on one day of a year separated by seven years: September 24, 2000 and 2007. In the latter event sharp variations associated with lightning discharges are observed.
The event on October 15, 2007

Classification of geomagnetic pulsations (amplitude from some tenth to tens of nT): regular Pc and irregular Pi

<table>
<thead>
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<th>$P_c$</th>
<th>Period, s</th>
<th>$P_i$</th>
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<td>Pc1</td>
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<td>Pi 1</td>
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