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Variations in Cosmic Rays and the Surface Electric Field in January 2016

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Abstract—Three units of neutron detectors and four blocks of gamma-ray spectrometers have been installed and started operation at Complejo Astronomico El Leoncito, CASLEO (San Juan, Argentina; coordinates 31 S, 69 W; height of 2550 m; the rigidity of geomagnetic cutoff of R_c = 9.7 GV) in May 2015 as part of the scientific cooperation between the Lebedev Physical Institute, Russian Academy of Sciences (Moscow, Russia), Universidade Presbiteriana Mackenzie (San Paulo, Brazil) and Complejo Astronomico El Leoncito, CASLEO (San Juan, Argentina). Measurements with the new detectors greatly supplement the experimental data on variations in the charged component of cosmic rays obtained by the CARPET ground-based cosmic ray detector in 2006. The first results from a joint analysis of new experimental data are presented. Particular attention is given to growing cosmic ray fluxes associated with changes in the surface electric field. The main characteristics of the events recorded in January 2016 are presented.

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INTRODUCTION

In recent decades, there has been great interest in the energetic processes that occur in the Earth's atmosphere during thunderstorm activity. These processes span the area of altitudes from 0 to 70–100 km and are observed in the form of atmospheric lighting/gamma flashes (so-called TFGs, TLEs, and so on), sprites, blue jets (at heights of 10–60 km), intra-cloud discharges, and Earth-cloud discharges observed in the near-ground atmosphere and the troposphere. There have also been reports on variations in the fluxes of charged particles, gamma-rays, and neutrons which are associated with significant variations in the surface electric field [1–7]. However, the available experimental data are contradictory, and the physical nature of the above processes and their causal relationships remain unclear.

In this work, we present experimental data obtained by Complejo Astronomico El Leoncito, CASLEO, in Argentina at a height of 2650 m in January 2016 during thunderstorm activity.

EXPERIMENTAL DEVICES

The measurement complex includes the CARPET detector of cosmic rays, a neutron detector (ND), a gamma-ray spectrometer (GAMMA) and an electric field monitor (EF) (Fig. 1).

The CARPET cosmic ray detector consists of 240 Geiger counters of the STS-6 type [4]. These counters are combined into 24 blocks. Each block

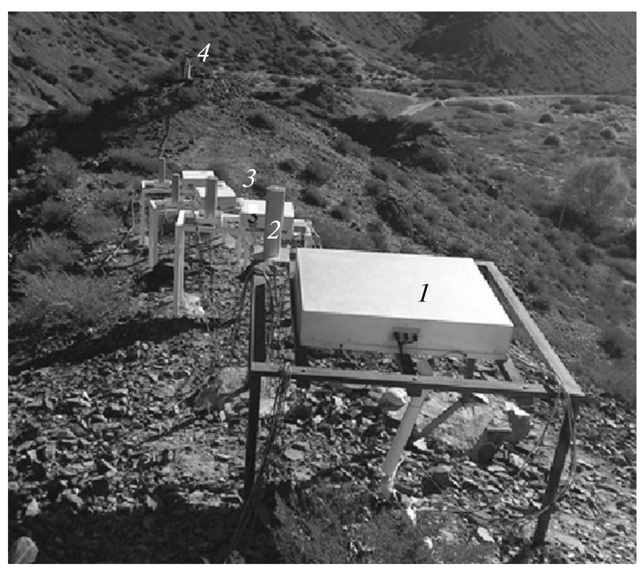

Fig. 1. CASLEO astronomical complex (Argentina, altitude 2650 m): (*1*) the CARPET cosmic ray detector, (*2*) gamma-ray spectrometer (GAMMA; 4 modules), (*3*) neutron detector (ND, 3 blocks), and (*4*) electric field monitor.

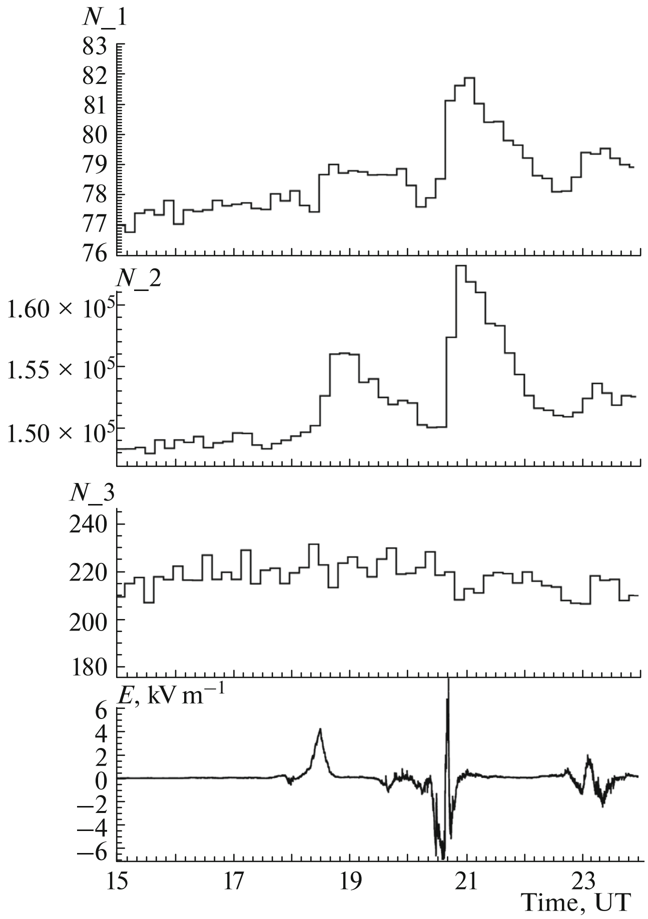

Fig. 2. Experimental data for January 20, 2016: 10-minute count rate (rel. units) the CARPET detector (N_1, UP channel), the GAMMA detector (N_2, channel >100 keV), and the neutron detector (N_3). E is the electric field (EF; 1 s. of data in kV m^{-1}).

consists of five upper and five lower counters. These layers of counters are separated by an aluminum absorber 7 mm thick. Such construction of the detector allows us to obtain information on the total count rate of all the upper counters (the UP channel), the count of all lower counters (the LOW channel), and the rate of particles which pass through the top counter, aluminum filter, and bottom counter (the TEL channel). The first two channels of data correspond to the total count rate of protons ($E > 5$ MeV), electrons and positrons ($E > 200$ keV), and muons ($E > 5$ MeV), while the third channel corresponds to the count of protons ($E > 30$ MeV), electrons and positrons ($E > 5$ MeV), and muons ($E > 15$ MeV). The detector operates in the continuous mode, and the temporal resolution of the original data is 0.5 s.

The neutron detector (ND) consists of three independent modules, each contains nine SNM-18 helium counters mounted in a polyethylene neutron moderator. The moderator is 125 mm thick, allowing effective thermalization of incident <10 MeV neutrons. The temporal resolution of the data is 1 ms.

The gamma-ray spectrometer (GAMMA) consists of four independent modules located by one on the platform close to each neutron module (see Fig. 1) and the CARPET detector. Each module is based on NaI(Tl) spectrometric crystal 80 mm in diameter and of 80 mm thickness and the Hamamatsu photomultiplier. The spectrometer was calibrated using the standard sources of Cs-137 and Co-60.

A standard EFM-100 electric field monitor (Boltek, United States) serves as an electric field sensor of the surface atmospheric layer at the location of the cosmic ray detectors.

OBSERVATIONS IN JANUARY 2016

The table below presents the list of January 2016 events at CASLEO when increases in the count rate of charged particles and concomitant increases in gamma-ray radiation in the energy range of 100 keV to several MeV were recorded. The date and time interval of observation (UTC), and the amplitudes of the increases in the count rate of the CARPET detector in the UP channel, the gamma-ray spectrometer ($E >$ 100 keV), and the neutron detector relative to the pre-event level are indicated for each event. The range of variation in the electric field (ΔE), based on the measurements by the EFM-100 electric field monitor, is also indicated.

Figure 2 presents the experimental data for January 20, 2016, 15:00–24:00 UTC as an example of such events. We can distinguish three increases whose duration exceeded one hour in the count rate of charged particles (the CARPET detector) and gamma radiation in four channels (see table). It should be noted that short-term variations in the electric field were observed at the beginning of each increase, and the field strength was close to the undisturbed background level until the end of the event. If we assume that the sources of the observed long-lasting events are strong electric fields, these fields must exist for a long time (from tens of minutes to hours) in the atmosphere at a large distance from the surface detectors. In that case only powerful sharp well distant electric discharges or lightning in the atmosphere could be observed as significant short-term electric field variations in the surface atmosphere. At the same time, such events could be observed as well-known TLE, TGF events in the atmosphere at altitudes above 15–20 km.

The energy spectra of of gamma-ray emission for each event listed in the table were determined using the GAMMA detector data. The shape of these spectra, especially at the maxima of the events, agrees satisfactorily with those of gamma-ray bursts observed during the TGF events described in [5]. This may suggest that powerful thunderstorm activity observed in the near-ground atmosphere is also accompanied by

List of events observed at CASLEO in January 2016

Date	Time, UTC	CARPET , A%	GAMMA, A%	ND, A%	ΔE, kV m^{-1}
5.01.2016	~1–19	11	22	–	–10…+13
	~21–22	10	8	–	–12…+2
7.01.2016	~8–10	6	5	–	–8…+4
	~18–20	5	7	–	–4…+3
8.01.2016	~7–8	–	2	–	0…+0.04
	~10–12	–	2.6	–	0…+0.04
20.01.2016	~18–20	2	5	–	–1…+4.5
	~20–22	5.5	8.5	–	–7…+8.5
	~23–24	2	2	–	–2…+2
23.01.2016	~1–3	2	2.6	–	–11…+4
	~4–6	3	1.3	–	–7…+9
	~6.5–14	5.8–4.2	9.2	–	–7…+2
	~22–24	3.9	8.8	–	–7…+5
24.01.2016	~1–2	4.1	6.5	–	–9…+15
	~3–4	2.1	1.3	–	–5…+3
31.01.2016–1.02.2016	~21–04	21	28	–17	–15…+17
					–12…+2

The date and the time interval of observation (UTC), the amplitude of the increases in the count rate of the CARPET detector in the UP channel, the gamma-ray spectrometer (E > 100 keV), and neutron detector relative to the undisturbed level are indicated for each event. The range of variation in the electric field (ΔE) is also indicated, based on the measurement data using the EFM-100 electric field monitor.

similar phenomena throughout the Earth's atmosphere and the global electric circuit.

CONCLUSIONS

Experimental data on charge particles flux, gamma-ray emission, neutron flux, and electric field variations obtained at Complejo Astronomico El Leoncito, CASLEO (Argentina) in January 2016 were analyzed. The measurements were made with the CARPET cosmic ray detector, a neutron detector, gamma-ray spectrometers, and an EFM-100 electric field monitor. Particular attention was given to cosmic ray flux increases associated with changes in the electric field in the surface level of the atmosphere. The main characteristics of the events recorded in January 2016 are listed below:

(1) The duration of increases in the count rate of the integral flux of charged particles and gamma-ray emission (E > 100 keV) ranged from tens of minutes to several hours. No increase was observed at the neutron detector.

(2) The amplitudes of the count rates increases of the detectors did not exceed 30%, relative to the quiet pre-event background. We observed short-term changes in the electric field strength of the surface atmosphere in the interval from –15 to +17 kV m^{-1}.

(3) The energy spectra of gamma-ray emission in the range of ~100 keV–5 MeV were determined for all events. These spectra were consistent with the average spectra of gamma ray flashes in the atmosphere at altitudes of 20–70 km as observed by satellites [5].

The data suggest that powerful thunderstorm activity in the surface layer of the atmosphere is accompanied by similar phenomena throughout the Earth's atmosphere and the global electric circuit. The sources of additional fluxes of low-energy charged particles and gamma-ray emission might be extended and long-lived regions of enhanced electric field (up to several hundreds kV/m) at altitudes above 15–20 km in the atmosphere. Secondary cosmic rays can be accelerated in such regions. These regions could also be sources of short-term (discharge or lightning) variations in the electric field strength observed in the surface atmosphere. They can simultaneously be seen as powerful sources of well-known TLE, TGF-events observed in the Earth's atmosphere at altitudes above 15–20 km.

The complex experimental study of similar events observed simultaneously at all altitudes from ground level to the ionosphere by different instruments should continue in the future.

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