An Estimate of the Minimum Distance to Lightning Events Associated with Cosmic Ray Enhancements during Thunderstorms

N.S. Khaerdinov, A.S. Lidvansky, V.B. Petkov, Yu.P. Surovetsky, and A.F. Yanin

Institute for Nuclear Research, Russian Academy of Sciences,
60th October Anniversary pr.,7a, Moscow, 117312 Russia

The experiment made with the Baksan air shower array discovered two types of pre-lightning enhancements of the soft component of cosmic rays. We present the preliminary results of an experiment in which the distance to lightning events associated with such enhancements is estimated acoustically using a simple microphone system. During observations in the autumn of 2002, we have succeeded in finding some events, for which it was possible to measure minimum distances to lightning channels. These distances turned out to be fairly large.

Introduction

The pre-lightning enhancements of the intensity of soft cosmic rays (10–30 MeV) were observed by the Baksan air shower array [1] and interpreted as a direct confirmation of the theory of runaway electron breakdown [2]. In order to reconstruct a more detailed picture of the phenomenon under study we supplied our experiment with a simple microphone system, which allows us to derive some data about the distance to lightning channels. In the season of 2002 this system was in operation from August to November, and below we present some results of this experiment.

Experimental

Figure 1 presents a diagram illustrating the principles of distance measurements. The signal from a microphone M is divided and after passing through high-frequency and low-frequency filters feeds a coincidence circuit. The output signal of the coincidence circuit stops the counter of pulses CP that counts 50 Hz pulses from a generator G being started by the signal from an antenna A. Recording device R stores these data. The microphone M is put under a heavy metal plate in order to protect it against the sounds of noise produced by rain droplets. Unfortunately, this turned out to be possible to do within some limits, since extremely heavy rain results in the system malfunction (see Fig. 3 below for

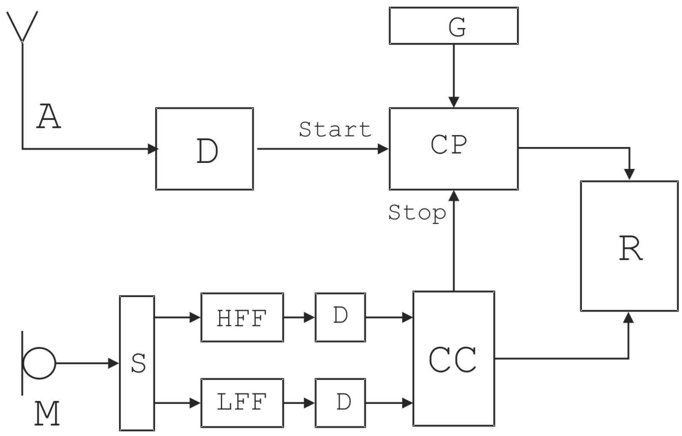

Fig. 1. A block diagram of measuring the distance to lightning channels. A and M are, respectively, an antenna and a microphone. D means discriminator, S is splitter, HFF and LFF represent high-frequency and low-frequency filters, CC is the coincidence circuit, G is generator, CP is the counter of pulses, and R is the recording system.

an example). The system of two filters is used in order to avoid the echo effect, which is especially important in a narrow mountain valley. The underlying idea is that the echoed signal contains mainly low frequencies, thus the necessary high-frequency component in the scheme of Fig. 1 essentially reduces reflected sound signals. Thus, the measurements of time delays of only direct sound signals should become possible.

Results

From August to November as many as 44 thunderstorm events were detected (we define a thunderstorm events as an event when the electric field strength exceeds 2 kV/m for at least 15 min, a separate events should be separated from another one by at least one hour). Among these events only five can be considered as real thunderstorms with strong lightning activity. No pre-lightning enhancements so bright as examples presented in [1] were detected, though some modest events of the same type (increases of a few percent amplitude) are obviously present in the data. Figure 2 presents an example: a short episode of a thunderstorm on August 1, 2002. The data of the electric field meter (upper panel) show three well-pronounced lightning events in the center. There are increases of the soft component intensity before each lightning stroke; the largest (about 4%) is before the third lightning. The bottom panel of Fig. 2 presents the result of measurements according to the scheme of Fig. 1.

One should have in mind that the electronic circuits of Fig. 1 are not zeroed after each lightning. So, the distance to a previous lightning is conserved in the recording device until the next lightning (horizontal line segments in the bottom panel of Fig. 2). Note also that the plot presented possesses a property of self-checking: long delays of the first and second lightning strokes correspond to their large distance (5 km), while the smaller distance of the third lightning (2 km) is associated with a shorter delay. Thus, one can see from Fig. 2 that the simple scheme of Fig. 1 yields reasonable data.

Fig. 2. A short interval of a thunderstorm on August 1, 2002 with pre-lightning enhancements of the soft component (middle panel) and minimum distances measured to lightning events (bottom panel).

Figure 3 presents another example of a longer duration, a thunderstorm on September 5, 2002. This figure contains an additional plot where the data of measuring the electric current of rain are presented (bottom panel). It is clearly seen in this figure that, when at 23:07:30 rain is greatly intensified, the distance in the preceding plot goes to zero. This is, obviously, the effect of system's malfunction during heavy rain.

Figure 3 also illustrates other peculiar features of our system. One can see that lightning effect in the field and current measurement systems does not directly correlate with probability of detection in the acoustic channel. For example, it does not 'hear' strong lightning at 22:58. On the contrary, very weak electric signal at 23:00:20 resulted in a measurable acoustic signal.

The distance distribution of all detected events is given in Fig. 4. All individual events are represented in the same figure by the points whose ordinates correspond to percent amplitude of a pre-lightning increase (right scale). It is clearly seen that the interval 2-5.5 km includes the overwhelming majority of events. The amplitude of increase was determined as the difference of mean intensities over 20-s periods after and before lightning. The maximum effect thus determined is equal to 4%, while the average value for 37 events is 0.915 ± 0.056 %.

Fig. 3. Thunderstorm on September 5, 2002. Heavy rain at 23:07:30 sets distance to zero.

A sharp spike at 22:59:50 deserves a close examination. Figure 5 presents this event scaled up. For lightning representation we have used the current of rain (right scale). The deviation of the soft component counting rate (left scale) from the daily mean value is given in the same plot. Horizontal bars represent 20-s averaged intensity. Double vertical dashed lines show the gaps in data. In the first case the gap was associated with some kind of irregularity (the data did not pass selection criteria). The second gap is due to presence of lightning (one or two seconds near the lightning is always excluded from the data, since no measurements are possible in this case). The bottom panel of Fig. 5 presents the deviation from the mean value of the ratio of two halves of the data in order to illustrate the absence of noise effects. The last second (before lightning) in the soft component intensity demonstrates a large (almost 12%, eight s. d.) increase that is quite significant. In addition, it is worthwhile to note that the scale of Fig. 5 allows one to see that the acoustic signal at 23:00:20 in Fig. 3 was really connected with a small lightning.

Fig.4. Distribution of distances and individual events with their increases. Distance to a nearby mountain peak is shown by vertical dashed line.

Discussion

Thus, we deal mainly with rather distant lightning events (Fig. 4). This is, perhaps, reasonable if we take into account that our air shower array is located in a rather narrow mountain valley at 1700 m above sea level. Very close to the array a mountain slope begins with an angle of inclination of about 30°. The height of a nearby mountain peak is about 3900 a. s. l., i.e., more than 2 km above the level of observation (the approximate distance to this peak is shown in Fig. 4 by vertical dashed line.

Under these conditions, the cloud-to-ground lightning is more probable to the mountain peak and slope. We can then hypothesize that we regularly observe the effects of strong field of a thundercloud, which is switched off by

Fig. 5. The lightning at 23:00 in Fig. 3 on a large scale (see text for details). Below is the ratio of counting rates of two halves of the soft component detectors.

lightning. This situation is quite different from that taking place, for example, in the experiments where the immediate radiation of lightning (X-rays) are searched for in order to confirm the theory of runaway electron breakdown, either on balloons [3] or on the ground [4, 5]. We believe that our data are mainly concerned with the strong field effects, since the estimated minimum distance to lightning channel is rather large (Fig. 4). May be the event of Fig. 5 is a more rare event of a nearby lightning (according to Fig. 3 the distance to this lightning is 700 m). It is interesting to note that precisely this event of rather close lightning has a hint on some very fast increase immediately before the lightning instant.

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