

Electric field disturbances in the summer-time atmosphere and associated variations of CR intensity

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Abstract. The data on short-term variations of the intensity of secondary cosmic rays during thunderstorms are presented. The effect is studied separately for soft and hard components (the data of 11 and 14 thunderstorms, respectively, are analyzed). In both cases the correlation with the near-earth electric field is represented by a regression line with linear and quadratic terms. It is shown that, generally, the behavior of soft and hard components is reasonably well described by electron and muon mechanisms of electric field influence on cosmic ray particle fluxes. However, some irregular enhancements of soft component just before lightning discharges are observed, which cannot be explained by electric field variations. The maximum of such an enhancement reaches 20% during a thunderstorm on September 7, 2000.

1 Introduction

Short variations of cosmic ray intensity during rain and thunderstorm events (meteorological cosmic ray effects) were observed at Baksan two decades ago by Alexeyenko et al. (1984). Still earlier, many experiment had been made to measure cosmic ray intensity during thunderstorms. The results were, however, contradictory. Sometimes, the observed effects were ascribed to pressure and temperature effects (for example, Attolini et al., 1971). In the above paper by Alexeyenko et al. (1984) the correlation with the electric field strength was established. An attempt was also made to construct the theory of this phenomenon; in particular, the effect of the so called "muon mechanism" was estimated in Alexeenko et al., (1987). However, no complete quantitative description of the effect was obtained, and the experiments were terminated after the untimely death of V.G. Sborshikov who was their main

protagonist.

Now we have started the observations again, trying to study the effect more carefully, including various components at different energy thresholds. In the summer season 2000 (the effect is of a clearly pronounced seasonal character) more than a dozen of thunderstorms were recorded with simultaneous measurements of the near-earth electric field.

2 Measurements

The Carpet-2 air shower array is capable of recording many components of secondary cosmic rays. This array includes 400 m² of scintillators under a roof 21 g/cm² thick and 6 huts with 9 m² of scintillators practically without roof, a standard neutron monitor, and a large area muon detector with an energy threshold of 1 GeV. For this experiment, intensities of all these components were recorded permanently. In addition, the atmospheric pressure P , electric field strength D , and electric current of rain I were recorded every second. Temperatures inside and outside the building were recorded once in every four minutes. The soft component was isolated by measuring the intensity of uncovered scintillators at two different thresholds. We plan in the future to analyze the intensity of neutrons and muons with an energy of 1 GeV. But in this paper we have analyzed only the soft (10-30 MeV) and hard (> 80 MeV) components of secondary cosmic rays. Special measures were taken to control powerful electric interferences during thunderstorms (a separate noise channel, high-frequency filters, etc.)

3 Results

The mean counting rates of the hard and soft components were 40000 and 4000 s⁻¹, respectively. Their relationship with the electric field intensity is clearly seen by eye (Fig. 1 shows an example for the hard component). The regression

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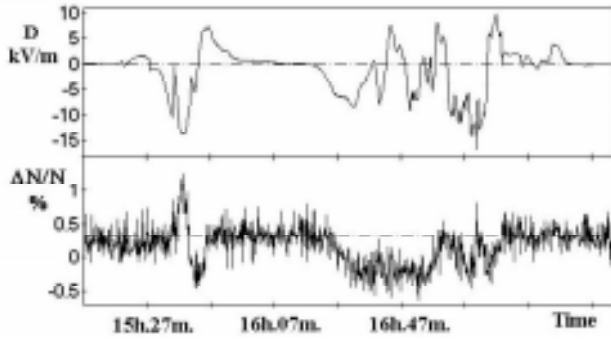


Fig. 1. Correlation of the CR hard component ($E > 80$ MeV) with the near-earth electric field of the atmosphere during a thunderstorm period on September 24, 2000.

lines for relative variations of these counting rates as functions of the local electric field were determined in the following form

$$\frac{\Delta N}{N} = A \cdot D + B \cdot D^2$$

where D is the electric field strength in kV/m. The results are shown in Fig. 2 (soft component) and Fig. 3 (hard component). One should say that the bulk of the data presented shows the behavior that was expected (see, for example, calculations for the muon mechanism in Alexeenko et al., (1987). For the hard component, the

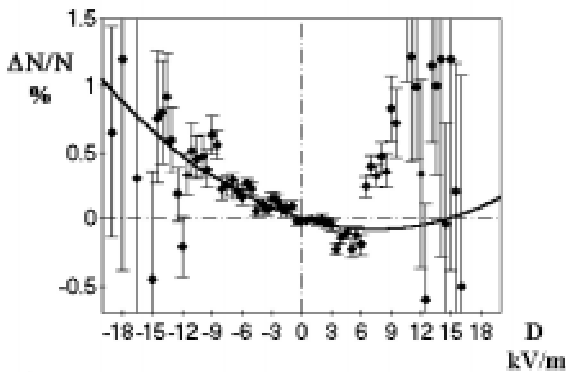


Fig. 2. The amplitude of the soft component variation versus the electric field strength. Observations of eleven thunderstorm periods are included in the analysis.

increasing field of any sign leads to decreasing intensity. For the soft component, there is a clearly seen negative correlation (the linear term is dominant), and, contrary to the hard component, the increase of intensity takes place, as a rule. Fig. 4. shows a good example of anticorrelation of the soft component intensity and the local electric field. It is

interesting to notice that Fig. 3 demonstrates larger scatter of points as compared to Fig. 2. It is quite understandable, since muons are sensitive to the large-scale field high above the ground, while the effect for the soft component is purely local. Therefore, the correlation with the local field should be better in the soft component case.

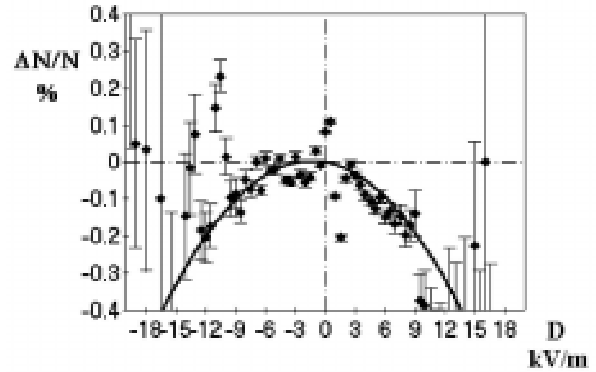


Fig. 3. The amplitude of the hard component variation versus the electric field strength. Observations of 14 thunderstorm periods are included in the analysis.

The above analysis shows fairly regular behavior of CR intensity in the thunderstorm periods. However, in addition to this well understood picture, we have observed the events of irregular enhancements of the soft components. Fig. 5 presents the recorded parameters during September 7, 2000 thunderstorm. The sharp spikes on the top and bottom panels correspond to lightning discharges. In the case of the top panel these spikes are a result of a certain reconstruction procedure. Since the field meter is not sufficiently fast device to record abrupt changes, the data of the rain current meter (shown at the bottom panel) were used to correct the field measurement data. One can suppose with a high degree of confidence that these abrupt changes are related to lightning discharges. The plot of the soft component (second from the top) shows specific intensity increases before some of these discharges (one

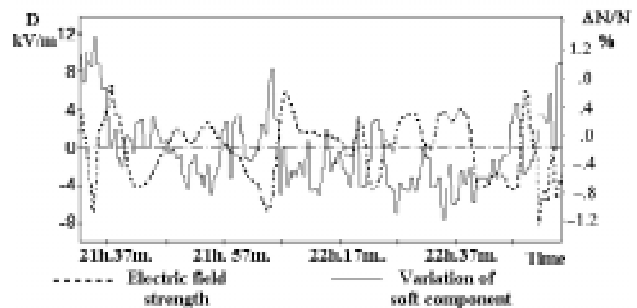


Fig. 4. An example of negative correlation of electric field and soft cosmic ray variations. The thunderstorm at Baksan on September 7, 2000. Bin width is 80 s.

is especially strong reaching 20% of intensity). The nature of this phenomenon is yet unclear, and it requires special investigation.

4 Discussion

It was mentioned in the introduction that in the first Baksan observations a strong correlation of disturbances in electric field and cosmic ray intensity was established. This, however, took place only for the time of disturbance: the duration of disturbances was nearly the same for both the quantities. As for the details, they were often quite different. Now it is clear that this was the result of poor separation of components (approximately the same two thresholds were used, but integrally, without isolating the soft component). As is clearly seen from Fig. 2 and Fig. 3, the effect is essentially different, even opposite, for the soft and hard components. First, the linear term dominates for the soft component, while for the hard component the quadratic term is dominant. Second, the quadratic terms are of the opposite sign for the soft and hard components. Accordingly, two different mechanisms are responsible for the total effect.

4.1 Muon mechanism

The effect of this mechanism was estimated in Alexeenko et al. (1987) for different vertical profiles of the electric field and several energy thresholds of muons. The general form of calculated curves is in a good agreement with that of Fig. 3. Quantitatively, the predicted effect was of the order of 1% for the electric field 200 MV. Since in Fig. 3 the order of the effect is about 0.5% for 20 kV/m, agreement within a factor of two can be achieved for the field with an extension of 10 km.

4.2 Electron mechanism

Unlike the muon mechanism, this mechanism is local, since electrons and positrons have the path length of the order of one radiation length (360 m at the Baksan level). The asymmetry of this mechanism is related to the excess of electrons over positrons (the result of Compton scattering at low energies). Some estimations of the effect produced by the electron mechanism were made by V.G. Sborshikov long ago. According to them, the linear regression coefficient should be about 1% per 20 kV/m, which is approximately equal to the experimental value in Fig. 2. The quadratic term is expected to be opposite in sign to that of the muon mechanism, as it is really the case in Fig. 2.

4.3 Enhancements of the soft component before lightning discharges

As far as the events similar to that presented in Fig. 5 are concerned, only some preliminary comments can be done at the moment. A pair of such events were observed in the first observation run in 1983. But then the 4-min read-out was used, and the maximum effect reached about 3%. Now

the time resolution is much better, which allowed us to see (Fig. 5) a very short increase of a fantastic value of 20%. This increase is most probably precedes the lightning discharge. One can recall in this connection a very old idea of C.T. Wilson that thunderclouds can effectively accelerate electrons to high energies (Wilson, 1925). There are also some recent models where lightning initiation goes through the so called “runaway breakdown” (Gurevich et al., 1999). The latter mechanism can have something to do with the events of the described type. In any case, more experimental data are necessary, which means both better statistics and more detailed investigations.

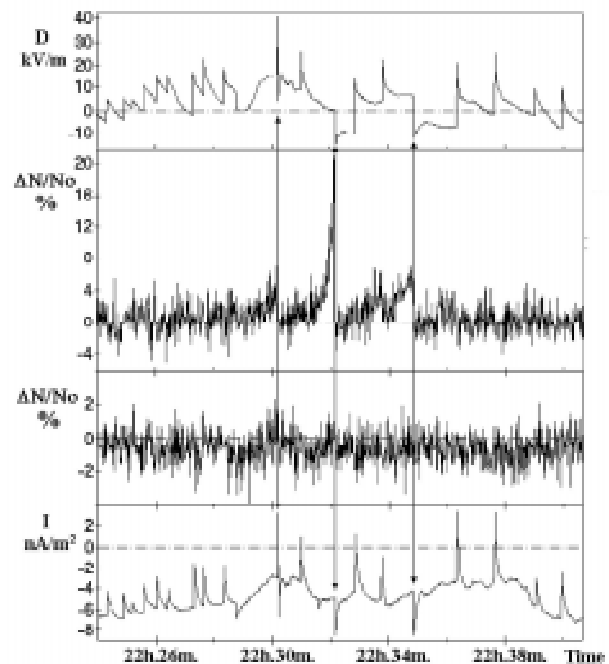


Fig. 5. Strong enhancements of the soft component (second panel from the top) during the thunderstorm on September 7, 2000. The data of the top panel (electric field) is corrected using the data of the bottom panel (the electric current of rain). No effect is observed for the hard component (the second panel from the bottom).

5 Conclusions

(1) The conclusion that the electric field variations during thunderstorm periods is the main cause of short disturbances of the intensity of secondary cosmic rays is confirmed in observations at Baksan in the summer season of 2000.

(2) The effect is studied separately for the soft and hard components. Qualitatively, the data in these two cases correspond to the electron and muon mechanisms of the electric field influence. The quantitative estimations made earlier are in a reasonable agreement with the experimental data.

(3) Sometimes, very short and very large enhancements of the soft component intensity are observed before lightning discharges. The maximum observed value of such an enhancement comprises 20%. The nature of these enhancements is unknown, and further investigations of the phenomenon are necessary.

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References

- Alexeyenko, V.V., Chudakov, A.E., Sborshikov, V.G., and Tizengauzen, V.A., Short perturbations of cosmic ray intensity and electric field in atmosphere, Proc. 19th ICRC, La Jolla, 1985, vol. 5, pp. 352-355.
- Alexeenko, V.V., Chernyaev, A.B., Chudakov, A.E., Khaerdinov, N.S., Ozrokov, S.Kh., and Sborshikov, V.G. Short perturbations of cosmic ray intensity and electric field in atmosphere, Proc. 20th ICRC, Moscow, 1987, vol. 4, pp. 272-275.
- Attolini, M.R., Cecchini, S., Galli, M., and Guidi, I., Cosmic-ray microvariations during thunderstorm perturbations, Lettere al Nuovo Cimento, 1, 716-720, 1971.
- Gurevich, A.V., Zybin, K.P., and Russel-Dupre, R.A., Lightning initiation by simultaneous effect of runaway breakdown and cosmic ray showers, Physics Letters, A254, 79-87, 1999.
- Wilson, C.T. The acceleration of β -particles in strong electric fields such as those of thunderclouds, Proc. Camb. Phil. Soc., 22, 534-538, 1925.