Comment on "Measurement of the Electrical Properties of a Thundercloud through Muon Imaging by the GRAPES-3 Experiment"

In a recent Letter [1], a technique was suggested to estimate the atmospheric electric potential based on the measured decline of muon flux. However, our consideration shows that this technique is inconsistent, and the reported 1.3 GV potential within a gap of 2 km at 8–10 km altitude above sea level and the average electric field with a strength of $\sim$2.2 kV/cm are highly overestimated.

The emergence and evolution of the intracloud electric field and its impact on the high-energy particle flux are among the most important problems of atmospheric physics. A decrease of muon flux during thunderstorms was reported in Refs. [2,3]; models of muon flux decline in strong electric fields, and numerical simulations were discussed in Refs. [3–7]. On Mount Aragats, huge enhancements of electron and γ ray flux were measured simultaneously with the decline of muon flux (so-called thunderstorm ground enhancement, TGE [8]). Through comparison of the energy spectra of TGE particles with simulated ones for different strengths of the intracloud electric field (see details of the simulations in Ref. [7]), a simple method for the estimation of the intracloud electric field was suggested [9]. Thus, the atmospheric electric field indeed modulates particle fluxes, and several methods were suggested to probe an atmospheric electric field through its impact on the intensity of particle fluxes.

According to Ref. [1], "A uniform electric field applied between 8 and 10 km was used to provide a conservative estimate of the thundercloud potential." However, such a model is fundamentally incorrect because, due to the action of the global electric circuit [10], the formation of a cloud layer with a great electric potential at certain altitudes eventually leads to the formation of a layer with the oppositely directed electric field under this cloud, which compensates for the cloud potential and makes a total potential of about $\sim$240 kV. Therefore, a correct model should include at least two regions of the strong electric field (directed upward and downward) on the way of muons toward the ground.

The potential difference within a thundercloud is greatly overestimated in Ref. [1]. According to Ref. [11], the maximum static electric field strength achievable in the air (critical field, $E_{\max}$), assuming a length of the electric field region of 1 km at 1 atm, is $\sim$3 kV/cm. For altitudes of $\sim$10 km, this corresponds to an electric field of $3\ \mathrm{kV/cm} \times 0.33 \sim 1\ \mathrm{kV/cm}$. Above this value, the electric field is violently unstable, and the runaway breakdown will discharge the large-scale electric fields inside thunderstorms on a millisecond timescale. Surely, the 20-min depletion of the muon flux cannot be explained by a millisecond duration electric field. The results of balloon-borne measurements of the electric field within thunderclouds [12–14] (see Fig. 3.2 in Ref. [14]) strongly confirm that maximal electric field strength in extremely electrified thunderclouds can exceed the critical field only on a small scale of the order of $\sim$100 m.

A comprehensive analysis of C. T. R. Wilson's classical publications (cited in Ref. [1]), along with Wilson's research notebooks, has been made by Williams [15], who noted, "On the basis of the assumption that the 'sparking limit' for atmospheric air at atmospheric pressure (3×10^6 V/m) is applicable to the conditions in thunderclouds (scaled for air density), Wilson estimated the thundercloud potential $\sim 10^9$ volts throughout his work. Today this estimate is judged to be too large by an order of magnitude [12–14]."

Note that a 1.3 GV potential drop would require a charge $Q \geq 1100$ C for each layer. To get a rough estimate of the field that is expected at the ground, it is worth considering a simple example of the structure consisting of two equal cylinders parallel to the ground, one above the other. The resulting electric field value near the ground surface will be $E_{\mathrm{total}} \sim -30$ kV/m. This is 10 times more larger by an order of magnitude than what was measured at Outy (Fig. 6 in Ref. [1]).

It is also impossible to imagine that such a huge electric voltage would not lead to a pronounced lightning activity, which, however, was not registered by the worldwide lightning location network [16]. Numerous measurements of the thunderstorm ground enhancements abruptly terminated by the lightning flash [8,17,18] confirmed by the GEANT4 and CORSIKA simulations [7,19,20,21] prove that an electric field slightly exceeding the critical value can highly enhance the particle flux. For the more than twofold enhancement, we can expect the inevitable lightning flash following particle flux.

Measurements performed by the GRAPES-3 experiment at Outy are unique and for proper inference adequate models of the atmospheric electric field should be developed and used.

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