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Maximum strength of the atmospheric electric field

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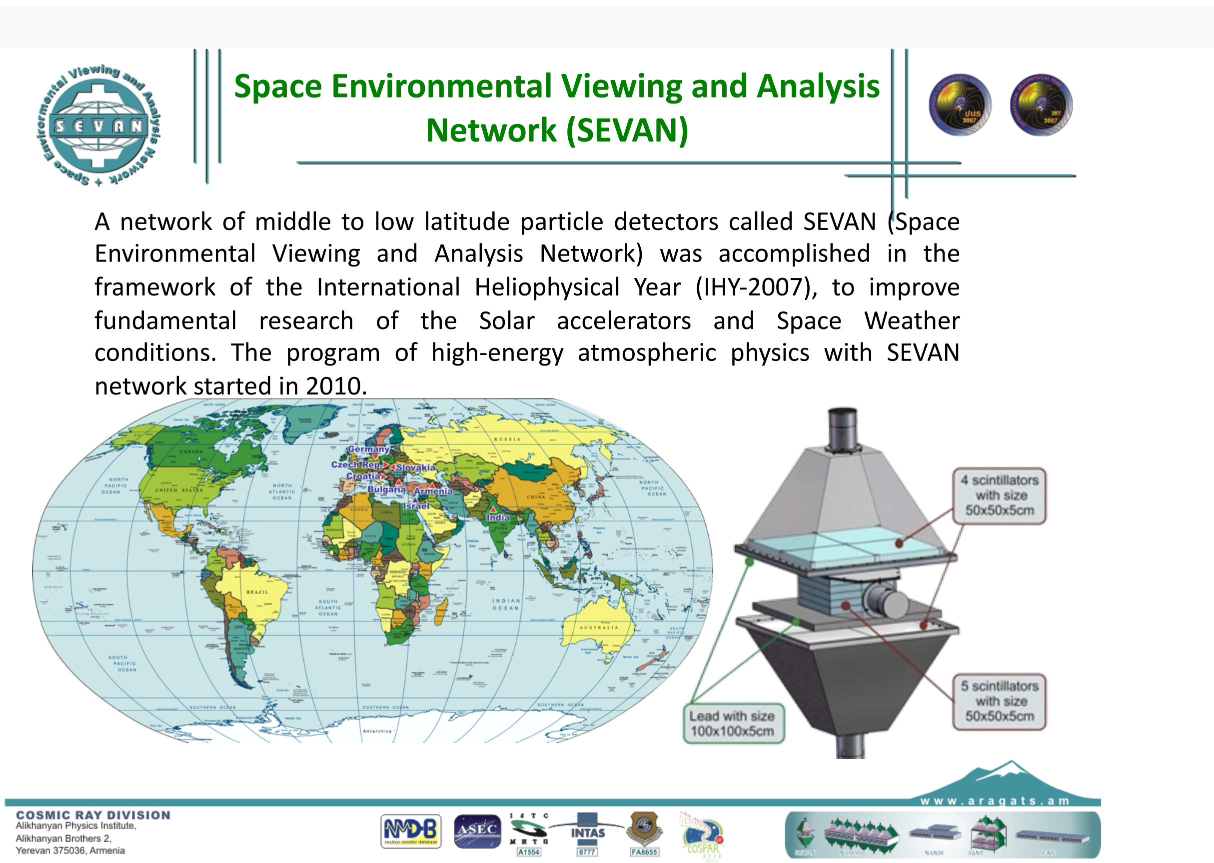
Understanding the maximum potential difference (i.e. voltage) inside thunderstorms is one of the fundamental problems of atmospheric physics directly connected with the enigma of the lightning initiation. In 1925 C.T.R. Wilson estimated the maximum potential difference in the atmosphere to be a few gigavolts: "A particle may thus acquire energy corresponding to the greater part of the whole potential difference between the poles of the thundercloud, which may be of the order of 10^9 V" [1]. In a talk at the Franklin Institute in 1929 [2] he presented detailed calculations:
"The value found for the maximum potential difference in the cloud depends on the vertical thickness, i.e., the distance through which the maximum field extends. We can hardly be wrong as to the order of magnitude if we take this height as one kilometer. If a field of 10,000 volts per centimeter extends through one kilometer the whole potential difference is 10^9 volts, i.e., one million kilovolts ". However, a potential difference as large as 1000 MV seems to be not feasible according to direct measurements: "Inside thunderstorm clouds the voltages ranged between -100 and +100 MV [5]. Though, the estimate of maximum voltage based on the balloon soundings can be biased, because, first of all, balloon flights are rare, and second, the balloon path within the thundercloud is a random walk depending on the updraft and wind speeds and hardly corresponds to the maximum possible voltage.
At Aragats we measure 50 MeV electrons reaching the earth's surface during thunderstorm ground enhancements (TGEs), intense fluxes of electrons, gamma rays, and neutrons from thunderclouds [9]. Simulations of the TGE "parents", namely, relativistic runaway electron avalanches (RREAs [3]) in the thundercloud demonstrate that electron energy in the cloud can reach up to 100 MeV. Thus, a lower boundary of the maximum voltage for the strongest TGEs measured on Aragats is 100 MV.
V. Cooray and V. Rakov derive an empirical relation between the first return stroke peak current and charge brought to the ground. If we assume the maximum extreme stroke current to be 200 kA, the maximum voltage will be approximately 200 MV [6].

Another possibility to estimate the maximum voltage is connected with the estimation of the mean electric field and its possible extent in the cloud. The electric field strength measured just before a lightning flash in balloon flights, exceeded runaway breakdown threshold, by a factor of 1.1 – 3.3 [7]. Therefore, we can assume the strength of the electric field to be 1.8-2.1 kV/cm above Aragats before a lightning flash stops the particle flux. Thus, starting from multiple simulations of the RREA and measured energy spectra of electrons and gamma rays, we come to an estimate of the maximum potential drop in the clouds above Aragats to be 350 MV [11]. Per cm? per km? Unit of field is V/cm.

Consequently, we come to large uncertainties in the estimation of the maximum voltage in the thundercloud from 100 to 1000 MV. Measurements of the modulation of cosmic ray flux traversing the electrified cloud provide a piece of ultimate evidence on cloud electrification and allow to obtain tighter limits on the maximal potential difference in thunderclouds. The big advantage of the “particle” approach is that multi-year 24/7 monitoring of different species of cosmic rays is available from the databases of high-mountain research stations. In contrast, balloon flights cannot provide continuous observations of a thunderous atmosphere and can miss extremely large voltages.

TGEs observed on mountain peaks during strong thunderstorms comprise millions of particles (electrons, gamma rays, and neutrons), enhancing the intensity of ambient flux of cosmic rays up to a hundred times [4,10]. The same field that accelerates electrons downward in the direction of the earth will reduce the flux of muons, due to the excess of positive over negative muon flux. Simultaneous monitoring of these species of secondary cosmic rays gives a possibility to select from the multi-year continuous observations of cosmic ray fluxes on Aragats in Armenia, Musala in Bulgaria, and Lomnicky Stit in Slovakia (belonging to the East-European SEVAN network of particle detectors) during the most violent storms with extreme values of the electric field. Recently, we published the analysis of the 2-year largest TGE observed on Aragats on 4 October 2010 and estimated the upper boundary of potential difference to be 350 MV [11]. The world’s largest ever TGEs observed at the sharp top of Lomnicky Stit mountain in Slovakia validates that the voltage can reach even 500 MV. This important result has now been published in Phys. Rev. D (2021) [12].



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