Monte Carlo simulation of runaway air breakdown in thunderstorm electric fields

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[Abstract] Intense radiations presumably associated with lightning activities have been detected in the coastal areas of the Hokuriku district in winter. In order to investigate the generation of energetic photons caused by thunderstorm electric fields, we calculate the behavior of secondary cosmic ray electrons and photons in electric fields with Monte Carlo method. The photon flux increases greatly in the region where the field strength exceeds 280P(z)kV/m-atm, and the photon energy spectrum shows a large increase in the energy region up to several MeV. These are consistent with the observed results during winter thunderstorms.

1. Introduction

Intensive gamma-rays have been observed recently inside and above thunderclouds [1,2]. The fluctuations of the cosmic ray intensity on the ground seemingly caused by thunderstorms have also been detected in mountainous areas [3]. In Addition, the gamma ray dose-rate increases associated with winter thunderstorms have been observed around nuclear facilities facing the Sea of Japan [4]. According to Gurevich et al.[5], energetic electrons such as secondary cosmic rays may be accelerated by the thunderstorm electric fields to trigger the runaway air breakdown (RAB), which is accompanied by X-ray bursts associated with runaway electrons. Therefore, using the Monte Carlo calculation code EGS4[6], modified to evaluate the effect of the ambient electric field on the electron transport, we have investigated whether the RAB and associated X-ray bursts can take place in the lower parts of thunderclouds, and whether they lead to dose-rate increases on the ground such as those we observed.

2. Results of Monte Carlo calculations

To estimate the electric field strength required for the RAB, we have calculated the flux and spectra of electrons and photons in the presence of monoenergetic electrons emitted inside a uniform electric field. The results suggest that the threshold electric field strength Eth required for the RAB is about 280P(z)kV/m-atm[7]. Here, P(z) is the atmospheric pressure at the altitude z. For example, Figure 1 shows how the electron flux varies with the distance from the emission source of 10MeV electrons and the ambient electric field in the atmospheric density corresponding to the 2km altitude. We have also found that the energetic electrons are well accelerated within several hundred meters from the emission source and produce bremsstrahlung photons with the energy over several MeV. This is consistent with our observation results [4].

Next, we have calculated the photon flux at various altitudes inside the thundercloud electric field, which is irradiated by the secondary cosmic rays (photons, electrons, and positrons). We have adopted the vertical electric field profile models of dipole and tripole winter thunderclouds. The photon flux in the tripole winter thundercloud model increases notably around 1km altitude, where the electric field strength exceeds Eth, and remains several times greater than the other results (dipole model and without electric field) even on the ground.

3. Summary

From the above results, we have found that the generation of intense radiations associated with the RAB may be triggered in the region where the electric field strength exceeds Eth, and could raise the dose-rate measured on the ground if it takes place at lower altitudes around 1km.

[References]

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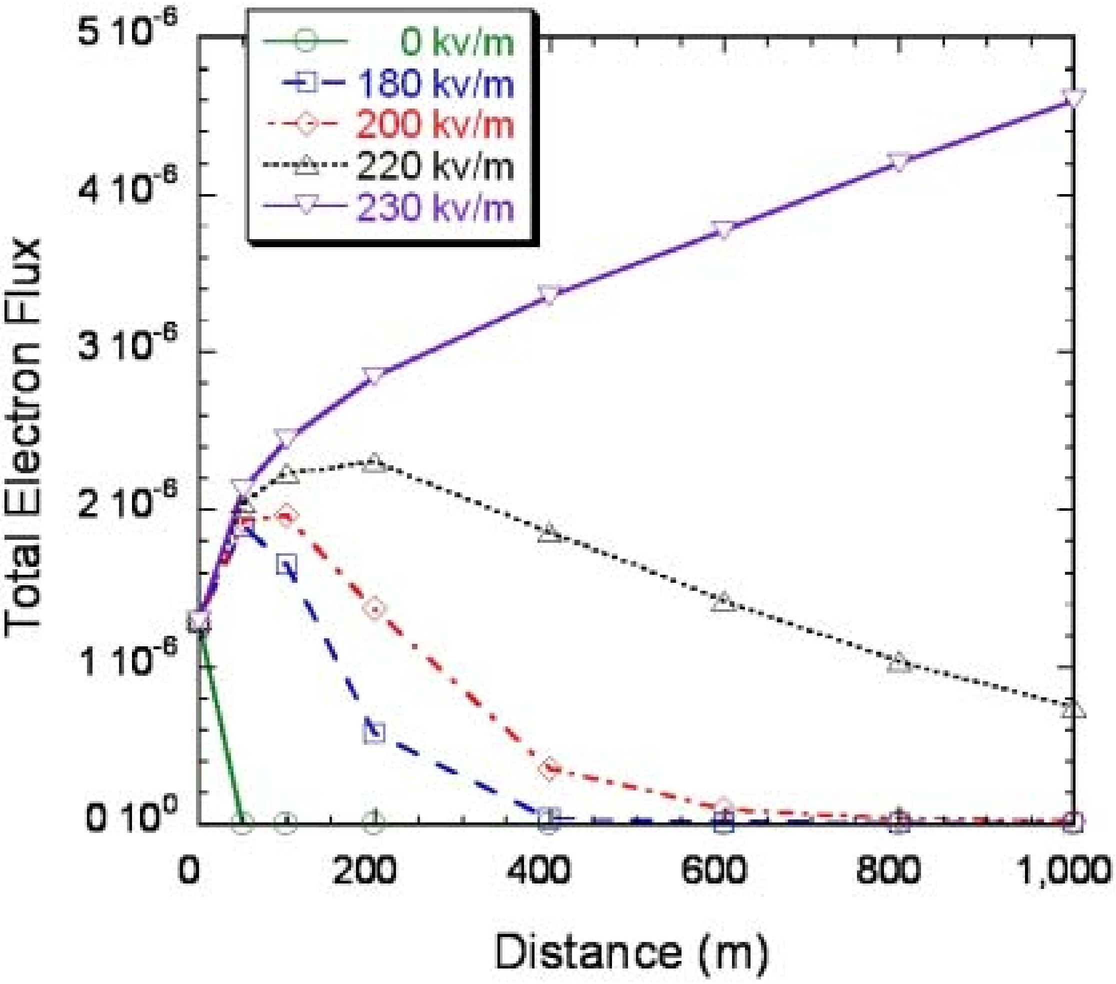

0 kv/m
180 kv/m
200 kv/m
220 kv/m
230 kv/m
5 10-6
4 10-6
3 10-6
2 10-6
1 10-6
0 100
Total Electron Flux
0
200
400
600
800
1,000
Distance (m)