Proceedings of the Tenth EGS4 Users' Meeting in Japan, KEK Proceedings 2002-18, p.89-94

COSMIC RAY ELECTRON ACCELERATION AND BREMSSTRAHLUNG GENERATION IN THE STRONG ELECTRIC FIELD OF THUNDERCLOUDS

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Abstract

Using an EGS4 user code by which the effect of the external electric field was combined in the EGS4 code, the acceleration of the cosmic ray electrons and the generation of the bremsstrahlung photons are calculated under the electric field simulated a thundercloud. The photon flux increased greatly in the region of 280 kV/m whose field strength is the maximum value in the electric field. Moreover, the energy spectra of photons showed a large increase in the energy region of several MeV, and were almost same distribution that had been observed on the ground during a winter thunderstorm.

1 Introduction

Increases of dose and dose-rate are occasionally observed during the thunderstorm generated on the coast in winter by the radiation-monitoring instrument around a nuclear facility facing the Sea of Japan [1, 2].

Since over 75 years, the charged particles in the atmosphere may be accelerated under the electric field of the thundercloud, and the possibility that the bremsstrahlung is generated has been pointed out [3]. In order to confirm the generation of radiation, in addition to the measurement on the ground, the observations are carried out from the inside/upper part of the thundercloud to the ionosphere by various procedures, and the radiation burst thought to actually originate in the lightning activity is observed [4, 5, 6]. However, neither the radiation source of these radiation bursts nor the mechanism of the radiation burst generation is cleared yet.

In this research, aiming to elucidate the radiation generation mechanism in thundercloud electric fields, we have made an EGS4 user code combined the effect of the external electric field [7] into the EGS4 code [8], and analyzed the possibility of the generation of the bremsstrahlung photons in the thundercloud, besides the radiation measurement during winter thunderstorms.

Here, we report on the calculated result of the bremsstrahlung generation from the cosmic ray electrons/positorns accelerated by the electric field of the thundercloud.

2 Acceleration of cosmic ray electrons and positrons in the electric field of thunderclouds and the generation of bremsstrahlung photons

In strong external electric fields, the cosmic ray electrons seem to be accelerated, and it is possible that the secondary electrons generated subsequently by the collision of energetic electrons with air molecules increase rapidly. Consequently, this phenomenon will produce the shower of electrons and photons. In order to calculate the transport of energetic electrons by such electric fields, we have modified the subroutine ELECTR of the EGS4 code, and obtained total flux and energy spectrum of the bremsstrahlung photons generated under the electric field in the thundercloud. In this calculation, since the secondary electrons generated are also accelerated and the number of electrons may be increased, we adopted the Russian roulette method to set the bias for the calculation of electron transport.

Here, we made the calculation model simulating a thundercloud (see Figure 1). Furthermore, the following points were taken into consideration in calculation.

- The spectrum of the cosmic ray electrons/positrons made based on the observed data reported in a review paper [9], and these charged particles were emitted downward at an altitude of 6 km above the ground (see Figure 2).
- We used the air density of each height based on the United States standard atmosphere [10], and applied the density correction option of the EGS4 code.
- The field strength distribution of the electric field is determined from a typical charge distribution with the tripole structure of thunderclouds (e.g., see Ref. [11, 12]) by using the finite element method (see Figure 3). Here, main electric charges were assumed to be $\pm 50\ C$ (charge densities: about $+1\ nC/m^3$, $-3\ nC/m^3$).

3 Results and Discussion

Figure 4 shows total photon flux from the vicinity of the ground to 5 km in height. The photon flux shows the maximum value at the altitude of $1km$, and it can be seen that the flux has increased in the region with the maximum field strength ($D_{max} = 280\ kV/m$). The flux at 1 km in height is about 20 times higher than that in the case without any external electric field ($D = 0\ kV/m$). Moreover, although it is a direction of the moderation for positrons in that region, the photon flux in the case of positron emitted has increased in the region, as well as in the case of electron emission, as shown in this figure. It seems that the yield of the bremsstrahlung photons increased since many positrons emitted at the high altitude became electrons and photons in this region and the electrons produced were accelerated.

In the calculation, main electric charges are assumed to be $\pm 50\ C$, but there is a possibility to exceed this greatly in local and a short duration. At that time, the photon flux is probably increased rapidly, and the radiation burst will be occurred. Furthermore, there is a possibility that the yield of the bremsstrahlung photons increases in the area with short distance between the cloud base and the ground level, such as mountaintops, because of the strong electric field compared with the case of the plain.

Moreover, as shown in Figures 5 and 6, the energy spectra of bremsstrahlung photons showed continuous distribution in the region of 10 MeV or less, and the flux of the energy region from several hundred keV to 10 MeV at 1 km in height, in particular, indicated about 30 times higher than that of the case without any external electric field. These are consistent with the spectrum which had been observed on the ground during a winter thunderstorm [2].

On the other hand, the dose increase has never been observed in summer thunderstorms. The base height of summer thundercloud is about 3 km or more, and it is considerably higher than that in winter. Therefore, the bremsstrahlung photons generated in the cloud are not reaching by attenuation on the ground, as presumed from Figure 4.

4 Conclusions

We have shown that the simulated result on the acceleration of cosmic-ray electrons/positrons and the generation of bremsstrahlung photons in a thundercloud by using the EGS4 code combined the effect of the external electric field. Since the observation of intense radiation caused by lightning activities is very rare, the adopting of Monte Carlo simulation in investigating the phenomenon was found to be effective.

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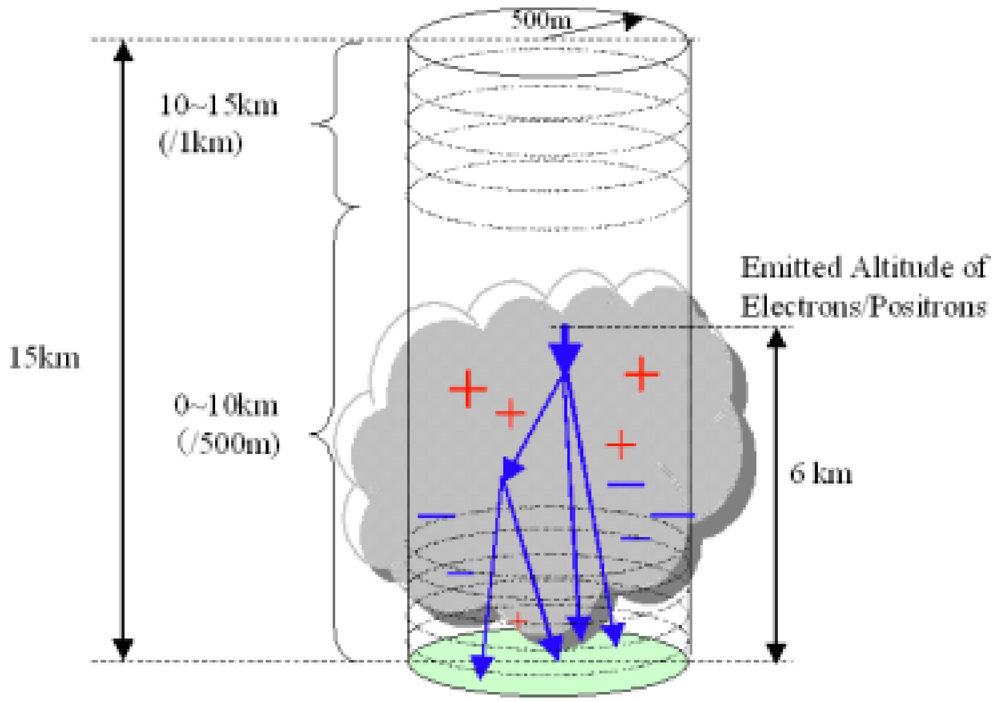

Figure 1: Geometry of Calculation

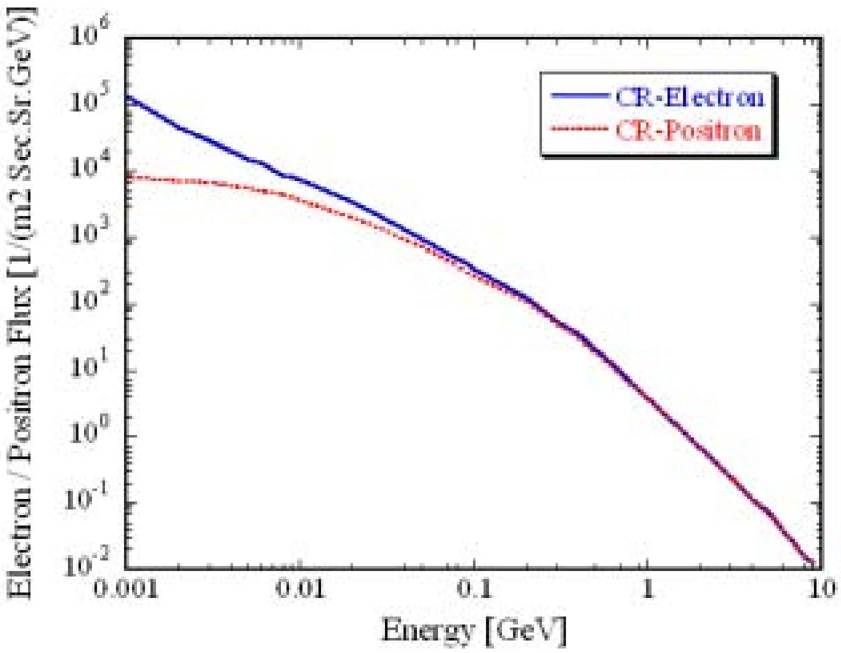

Figure 2: Energy Spectra of Cosmic Ray (CR)-Electrons / Positrons at the altitude of about 6 km (500 g-cm^{-2})

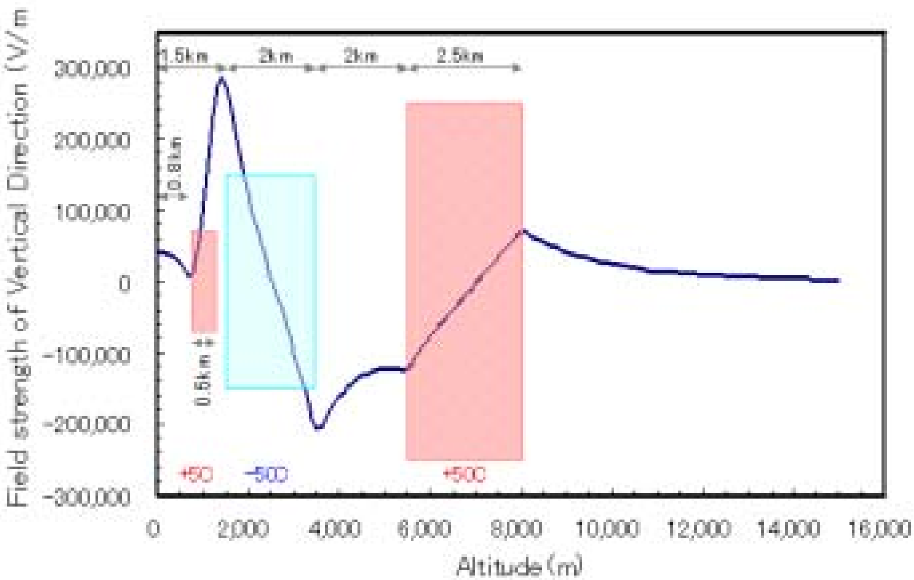

Figure 3: Charged Regions and the Distribution of Field Strength

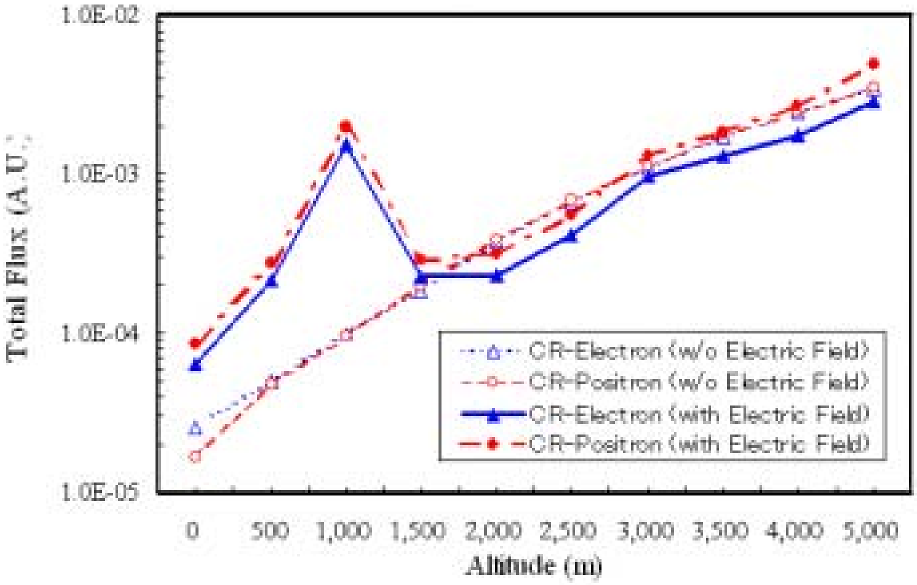

Figure 4: Total Flux of Bremsstrahlung Photons at Each Altitude

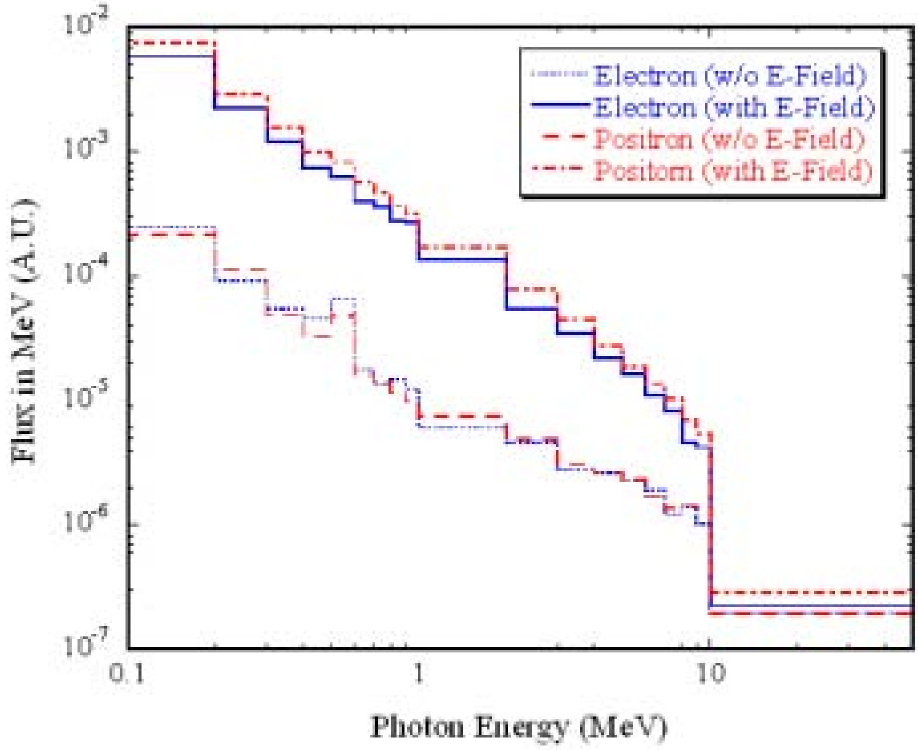

Figure 5: Energy Spectra of Bremsstrahlung Photons at 1 km in Height

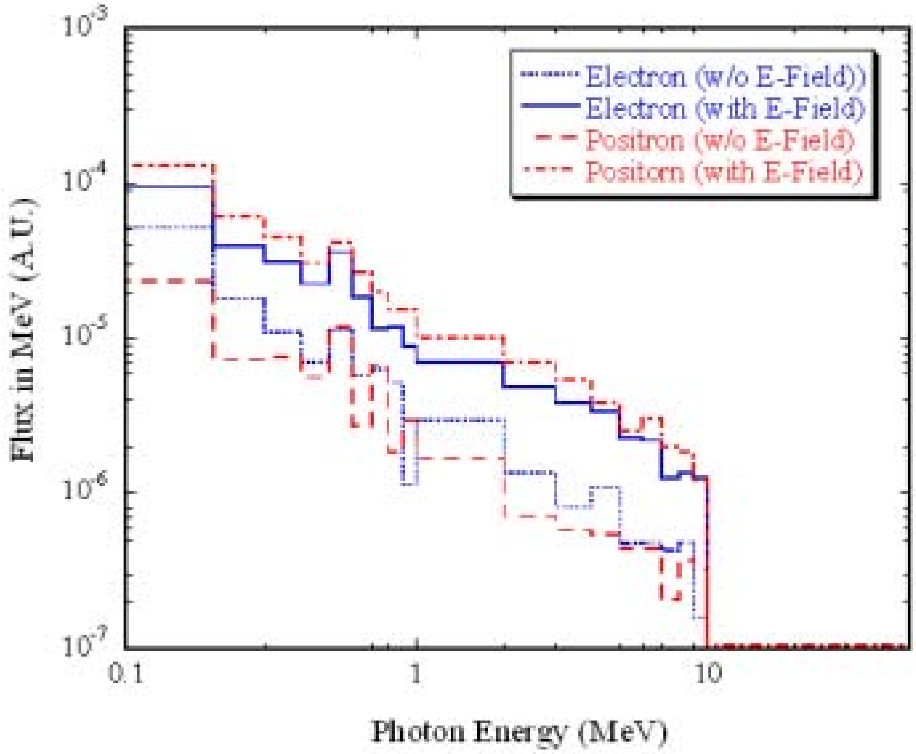

Figure 6: Energy Spectra of Bremsstrahlung Photons on the Ground