High-altitude observations of high-energy gamma rays and electrons from thunder activity

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High-energy radiation bursts have been observed by space observatories as well as ground-based detectors. Those bursts are thought to derive from relativistic electrons that are accelerated by strong electric fields in thunderclouds and lightning discharges. From observational viewpoints, there are two types of events that can be classfied according to their duration; one has duration with milli-seconds or less, while the other lasts for a few seconds to a few minutes. Thus, they can be called as short and long bursts. In addition, the constitution of the two bursts varies according to events. Some events consist only of gamma rays. Others comprise charged particles. For the purpose of investigating the production mechanism of those bursts and understanding the underlying electric-field particle acceleration, we installed, on the Norikura Cosmic-Ray observatory located at an altitude of 2770 m, a new radiation detection system between 2008 September and 2008 October, together with electric field and optical sensors.

As a result of almost the one-month observation, we observed three short bursts, and one long burst. All the short bursts, lasting within 1 sec, were clearly associated with lightning discharges, and consisted only of electrons. On the other hand, the long burst, detected at 15:48 UT on 2008 September 20 (UT), was not associated with lightning, but thunderclouds. This burst, lasting for 90 sec, was composed of gamma rays and electrons. The photon spectrum, clearly extending to 10 MeV, can be well described by a power law of the form aE^{-b}, with the source distance being 90 m, where a and b becomes (2.4 +- 0.4)X 10^8 $MeV^{-1}sr^{-1}$ and -1.15+-0.09, respectively. These spectra features as well as its clear relation to the thunderclouds strongly suggest that the observed gamma rays were produced by bremsstrahlung from accelerated electrons in an acceleration region in the nearby thunderclouds.

The estimated source distance, 90m, is shorter than a range of 20 MeV electrons, 110 m, at an altitude of 2770 m. Because of this short distance, primary electrons accelerated to 20 MeV would escape from the thunderclouds and then arrive at our detector. In addition, since MeV gamma rays suffer mild Compton scattering in the atmosphere, secondary electrons, produced by the Compton scattering, are minor, compared with the escaping primary electrons. Thus, we concluded that the observed electrons are highly likely to be dominated by the escaping primary ones from the acceleration region in the thunderclouds.

Given both gamma-ray and electron observations, we can estimate the size of the acceleration region in the thunderclouds. Utilizing the number of the observed MeV gamma rays and that of the primary electrons, we evaluate the vertical length of the acceleration region of 120 m corresponding to air mass of 11 g cm^{-2}. In addition, from the burst duration t_b = 90 sec, the width of the acceleration region is calculated as vt_b = 750 m, using an average velocity of thunderclouds,v = 500 m min^{-1}. Thus, the acceleration region seems to horizontally extend like a pancake.