Remote observations of runaway electron production inside thunderclouds

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Relativistic runaway electrons are expected to occur inside thunderclouds when the rate of energy gain from the ambient electric field exceeds the rate of energy loss experienced by the electrons in air due to ionization. For sufficiently strong electric fields, avalanches of runaway electrons can be produced, resulting in large amounts of ionization and x-ray, gamma-ray and RF emissions. The threshold electric field for such runaway electron avalanche multiplication is E_{th} = 284 kV/m×(n/n_o), where n and n_o are the densities of air at that altitude and at sea level, respectively. Because thundercloud electric fields have never been observed to reach the conventional breakdown field, E_b = 3000 kV/m×(n/n_o), but are sometimes observed to exceed the runaway electron avalanche threshold, E_{th}, it has been suggested that runaway electrons, possibly in conjunction with extensive cosmic-ray air showers, may play some role in lightning initiation. Evidence that runaway electrons are produced in large numbers inside thunderclouds comes from terrestrial gamma-ray flash (TGF) measurements made from space and from x-ray and gamma-ray measurements made *in situ* and on the ground. Such measurements are of great interest, because they can be used to infer properties of the runaway electrons and the conditions inside the thunderclouds that produced them. In this talk, techniques for remotely measuring runaway electrons and their effects inside thunderclouds will be presented. In particular, the role of extensive cosmic-ray air showers and relativistic feedback in runaway electron production will be presented, and measurements of x-rays and gamma-rays emanating from thunderclouds as well as accompanying RF emissions will be discussed.