Electron Acceleration Above Thunderclouds

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The acceleration of electrons results in observable electromagnetic waves which can be used for remote sensing. Here, we make use of ~4 Hz–66 MHz radio waves emitted by two consecutive intense positive lightning discharges to investigate their impact on the atmosphere above a thundercloud. It is found that the first positive lightning discharge initiates a sprite where electrons are accelerated during the exponential growth and branching of the sprite streamers. This preconditioned plasma above the thundercloud is subsequently exposed to a second positive lightning discharge associated with a bouncing-wave discharge. This discharge process causes a re-brightening of the existing sprite streamers above the thundercloud and initiates a subsequent relativistic electron beam.

Transient energetic charged particle populations occur in association with thunderstorms where the lightning electromagnetic field can release electrons from the radiation belts precipitating into the atmosphere (Voss et al 1998, 1984). These electrons have typical kinetic energies ~100–250 keV in addition to their rest mass ~511 keV and occur ~0.1–1 s after the causative lightning discharge (Gemelos et al 2009). The electrons are decelerated when penetrating the neutral atmosphere and deposit their energy in ~100–2000 km large ionization patches north/south of a lightning discharge in the northern/southern hemisphere (Inan et al 2007). Electrons are accelerated to very high energies ~10–100 MeV inside thunderclouds, either in lightning leader tips (Celestin and Pasko 2011) and/or in large scale thunderstorm electric fields (Dwyer and Cummer 2013, Gurevich and Karashtin 2013, Dwyer 2012, Gurevich et al 1992). The acceleration of the electrons is accompanied by gamma rays emanating from thunderstorms (Østgaard et al 2013, Tavani et al 2011, Smith et al 2005, Fishman et al 1994) which can be used a diagnostic tool. When the gamma rays interact with air molecules and exceed an energy ~1.022 MeV, i.e., two times the rest mass of an electron, the gamma rays can disintegrate into an electron–positron pair around ~40–60 km height such that magnetized positrons and electrons are observed on board of satellites in near-Earth space (Briggs et al 2011, Carlson et al 2009, Dwyer et al 2008). Similarly, it was proposed that the lightning electromagnetic field can accelerate electrons above thunderclouds from the cosmic ray layer upwards to produce avalanching relativistic electron beams (Roussel-Dupre et al 1998, Roussel-Dupre and Gurevich 1996). Experimental evidence for such electron beams was reported by remote sensing with low frequency radio waves (Fullekrug et al 2011b, 2010). The lightning electromagnetic field also causes Joule heating above thunderclouds which results in electrical breakdown of air such that sprite streamers develop (Pasko 2010). The exponential growth and splitting of streamers results in an electron multiplication associated with the acceleration of electrons to a few eV. The accelerated electrons radiate a small amount of electromagnetic energy and the incoherent superposition of many streamers causes low frequency radio noise (Fullekrug et al 2013a, Qin et al 2012a). As a result, the remote sensing with radio waves can be used to investigate the acceleration of electrons above a thundercloud during a sprite followed by a consecutive electron beam. It is speculated that the occasional occurrence of such electron beams can be explained with mesospheric irregularities which assist the initiation of sprites. Here we report the experimental detection of a ~3–19 km^3 large mesospheric irregularity at ~80–85 km height which is illuminated by the electromagnetic field of an intense positive cloud-to-ground lightning discharge. While the lightning discharge causes a prompt group of four sprites above the lightning discharge, the mesospheric irregularity is found at a horizontal distance at least ~15–20 km away from the sprite group and it rebrightens ~40–60 ms after the sprite group occurrence. This rebrightening is driven by a local quasi-static electric field enhancement with a charge moment ~4–20 C km which causes the irregularity to develop a downward descending luminous column from ~75–85 km height. The quasi-static electric field enhancement is caused by the reorganization of residual charge inside the thundercloud during a high-level activity of intracloud discharges with ~10–20 pulses per ms.