Spatiotemporal structures of sprites observed with the FORMOSAT-2/ISUAL and electrical properties of lightning discharges

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Sprites are high-altitude electric discharges with a wide variety of forms induced by lightning discharges. Recent telescopic observations clarified that sprites consist of streamers with diameters of ˜100 m. On the other hand, a pancake-like diffuse glow referred to as sprite halo sometimes occurs on the top of streamers. Although halos and streamers often occur independently, past studies have not clarified the essential parameters of lightning discharges in the production of each phenomenon.

In this study, we analyze optical data observed with the ISUAL payload onboard the FORMOSAT-2 satellite and magnetic field data observed with the ground-based ELF network system. The ISUAL consists of an imager, an array photometer, and a spectrophotometer. We primarily analyze data obtained from the array photometer which possesses two photometers measuring the two wavelength ranges of 360-470 nm and 520-750 nm. Because each photometer has a vertical resolution of 8-13 km and a temporal resolution of 50 or 500 microseconds, we can extract spatio-temporal variations of sprite emissions by separating the contamination from causative lightning flashes. The ELF magnetic field observation system is installed at three sites: Syowa station (39.500E, 69.018S), Onagawa observatory (141.483E, 38.433N), and Esrange observatory (21.100E, 67.883N). These observation systems measure electromagnetic waves in the frequency range of 1-100 Hz which are radiated from lightning discharges. From ELF magnetic field data, we estimate the polarity and the charge moment of parent lightning discharges inducing sprites.

We analyze 77 sprite events observed during the period from July 4 2004 to November 20 2005. Based on the imager data, we classify these sprite events into three categories: 15 halo events, 29 streamer events, and 23 halo with streamer events. The remaining 10 events have unclear structures. The average charge moment values of causative lightning discharges in halo, streamer, and halo with streamer events are 400, 1100, and 1200 C-km respectively. It is clear that the halo events have smaller charge moment values compared with other two categories. Furthermore, we estimate the intensity of reduced electric fields producing sprites from blue/red emission ratios measured with the array photometer. The estimated values at the initiation of halos and streamers are 60-80 Td and 100-260 Td, respectively. Since the ionization rate coefficient exceeds the attachment coefficient at an electric field larger than the conventional breakdown field of ˜126 Td, strong ionization processes would occur in the streamer events while ionization would be negligible in the halo events.

Based on the obtained results, we suggest that lightning discharges with charge moment values smaller than 600 C-km produce relatively weak quasi-electrostatic (QE) fields above thunderstorms and halo emission without ionization processes. On the other hand, lightning discharges larger than 600 C-km would produce intense QE fields exceeding the conventional breakdown level and streamers via electron avalanche processes.