Preliminary Reports of Summer Sprite Observation Campaign at Summit of Mt. Fuji, Japan

Yuko Suzuki[1], Tomoyuki Suzuki[1], Maho nakamura[1], Tatsuo Torii[2], Masashi Kamogawa[1,*]
Story of Miracle Earth (Kiseki-no-Chikyu-Monogatari) TV Production Team[3], Kenichi Kusunoki[4]
1. Tokyo Gakugei University, Koganei, Tokyo, Japan
2. Japan Atomic Energy Agency, Chiyoda-ku, Tokyo, Japan
3. Jump Co.Ltd.,TV Asahi, Minatoku, Tokyo, Japan
4. Meteorological Research Institute, Tsukuba, Ibraki, Japan

ABSTRACT: An isolated-mountain observation was conducted at the summit of Mt. Fuji (3776 m), Japan, to detect transient luminous events (TLEs) off the coast of the Boso Peninsula, Chiba, and the east coast of Japan. Many TLEs caused by energetic positive cloud-to-ground (+CG) lightning occurred in this region during the summer of 2013. Since the summer clouds covering the ground and ocean are usually located below the summit, a 360° view from the isolated mountain along with low atmospheric pressure and unpolluted air over the summit is expected to facilitate the observation of TLEs and their vivid color images, respectively. We detected several distant TLEs with light-sensitive black-and-while CCD cameras and a color single-lens reflex camera. We analyzed the relationship between a sprite and its parent +CG lightning and storm during this study. Six sprite events were associated with +CG lightning, and their estimated amplitude was 156 ± 76 kA (89–312 kA). Sprites appeared 41.4 ± 29.8 ms after +CG lightning. The +CG lightning with sprites were located in the stratiform precipitation region.

INTRODUCTION

Sprites are subionospheric transient luminous events (TLEs) triggered by vigorous cloud-to-ground (CG) lightning. The first reported sprite was observed in North America in 1989 (Franz et al., 1990). Many investigations of TLEs, including sprites, have been conducted since the 1990s, and TLEs have since been observed all over the world. Observations of TLEs from high-altitude locations, such as satellites, aircrafts, and balloons, are ideal because the cameras are located above the line-of-sight shielded by clouds. Therefore, TLEs are more frequently detected from high altitudes than from the ground. However, these observations entail a high cost. In particular, satellite observations cover a very wide area, but do not remain in the same location. Therefore, all parent storms associated with the sprites cannot be observed continuously during the lifetime of a storm. On the other hand, the success of sprite observation from stationary observatories at ground level depends on the weather conditions between the sprite and the observer. However, the time series of sprite occurrences and the evolution of their parent storms are always observable from the ground. The cost of ground observation is lower than that associated with satellite, aircraft, and balloon observations. Sprite observation from the summit of a high mountain offers

* Contact information: Masashi Kamogawa, Tokyo Gakugei University, 4-1-1 Nukuikitamachi, Koganei, Tokyo, Japan, Email: kamogawa@u-gakugei.ac.jp

the merits of both high altitude and ground observation, namely, frequent detection and low cost. Sprite observations from mountain summits were reported by Neubert et al. (2001, 2005) and van der Velde et al. (2006) as part of the EuroSprite campaign. They collected many sprite images with a light-sensitive camera system mounted at the Observatory Midi-Pyre´ne´es on Pic du Midi in the French Pyrenees at an altitude of 2877 m.

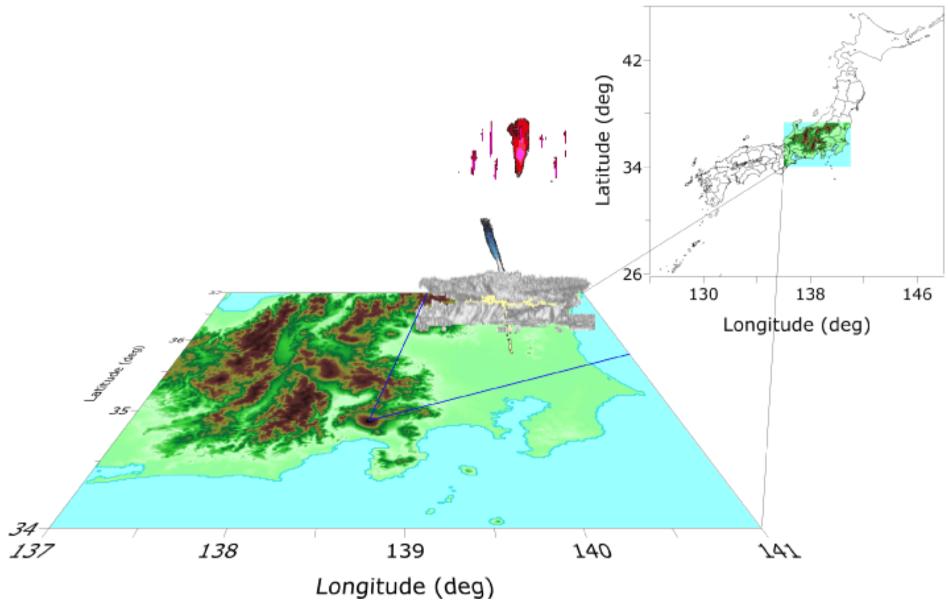

Figure 1. Schematic diagram of observation for Mt. Fuji sprite campaign 2013.

A large number of summer thunderstorms with active CG lightning strikes, which produce many sprites, appear over the Kanto Plain in central Japan. Thunderstorm occurrence in Japan during summer is associated with high relative humidity; therefore, the storms and other clouds are active and widely cover the Kanto Plain, which makes it difficult to observe summer sprites over the entire Kanto Plain. To overcome this difficulty, we conducted an observation at the summit of Mt. Fuji from the end of July to early August, 2013. Mt. Fuji, the highest mountain in Japan, is an isolated mountain. A meteorological stationary observatory (Mt. Fuji Weather Station) is located at its summit. We installed two light-sensitive cameras at the Mt. Fuji Weather Station focused toward the Kanto Plain. Moreover, we used a high definition television (HDTV) camera to collect color images of sprites. Consequently, we succeeded in capturing 10 sprites, including four sprites in color. In this study, we report a preliminary result of the summit observation.

OBSERVATION AND INSTRUMENTS

Figure 1 shows a schematic of TLE observation. Two light-sensitive monochrome CCD cameras along with one color HDTV camera were mounted at the Mt. Fuji Weather Station to detect TLEs. The camera specifications are as follows: two monochrome cameras (WAT910HX; Watec Co., Ltd.) equipped with a 4 mm and 12 mm lens and one color HDTV camera (EOS 5D MARK III). Figure 2 shows a block diagram of the monochrome CCD camera system. The WAT910HX is an ultrahigh light-sensitive dark-field CCD camera containing a 1/2 inch monochrome imager (minimum illumination: 0.000005 lx at F1.4; effective pixels: 0.38 M). Time stamps synchronized by a global positioning system (GPS) were superimposed by a GPS time imposer on the video frame. The time resolution of the GPS was 1 ms. The integration time of the video field was 16.7 ms, and the speed of the electrical shutter was 1/100 s.

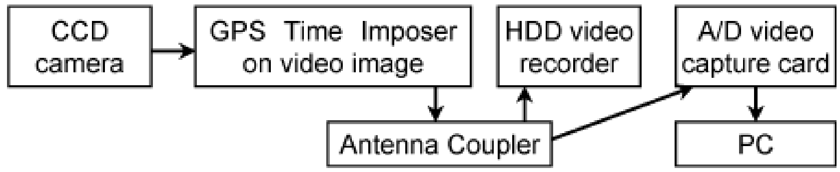

Figure 2. Block diagram of the monochrome CCD camera system.

The video signal from the CCD camera was separated by an antenna coupler, and the two separated video lines were connected to a hard-disk video recorder and PC via a video capture board. The two monochrome CCD camera systems were operated only from 9 UTC to 20 UTC, and the hard-disk recorders continuously captured images during these times. Automated event detection software (UFO capture V2) stored the video images within 5 s before and after the detection of an event. Cameras protected by camera housing were fixed to the outside of the Mt. Fuji Weather Station and focused toward the Kanto area. The EOS 5D MARK III color camera was focused off the coast of the Boso Peninsula, Chiba, to manually capture the TLEs.

To investigate the properties of the parent CG lightning, we used VHF/LF lightning mapping data constructed by the Lightning Detection Network (LIDEN) operated by the Japan Meteorological Agency (JMA) (Observation department of Japan Meteorological Agency, 2001). The LIDEN is a hybrid system consisting of interferometry and time-of-arrival (TOA) measurements based on VHF and LF signals received by a VHF array and LF detector, respectively. These systems have been developed at 30 sites in Japan (http://www.jma.go.jp/jma/kishou/know/toppuu/thunder1-2.html). At each site, we estimated the azimuth of the VHF radiation source from a lightning channel by interferometry. Several properties of the CG lightning, such as location, detection time, electric field peak amplitude, and electric field rise/decay times, were also analyzed through the TOA measurements. Using the data of the azimuth of the VHF radiation source and the detection time of CG lightning observed at 30 sites, two-dimensional (2-D) locations of the VHF radiation sources and CG lightning were estimated. The location of the VHF radiation source generated from intra-clouds were triangulated by at least two VHF arrays. The 2-D locations of CG lightning detected by several LF detectors were estimated from TOA measurements.

Parent storms were imaged using the radar-echo composite maps by merging all weather radar echo operated by JMA. The radar-echo composite maps include the echo top altitude at a resolution of 2.5 km × 2.5 km and the precipitation near the ground at 2 km altitude at a resolution of 1 km × 1 km.

RESULTS

During this study, we detected the first sprite image from the summit of Mt. Fuji on July 22, 2013. We succeeded in observing a total of 10 sprite images (six monochrome sprite images on July 22 and four color sprite images on August 1). Figure 3 shows the color HDTV and monochrome video images of sprites along with the location map of the parent CG lightning. The sprites of July 22 appeared above the region of CG lightning located approximately 200 km north of Mt. Fuji. The sprites on August 1 appeared above the region of CG lightning located 400–1000 km east of Mt. Fuji.

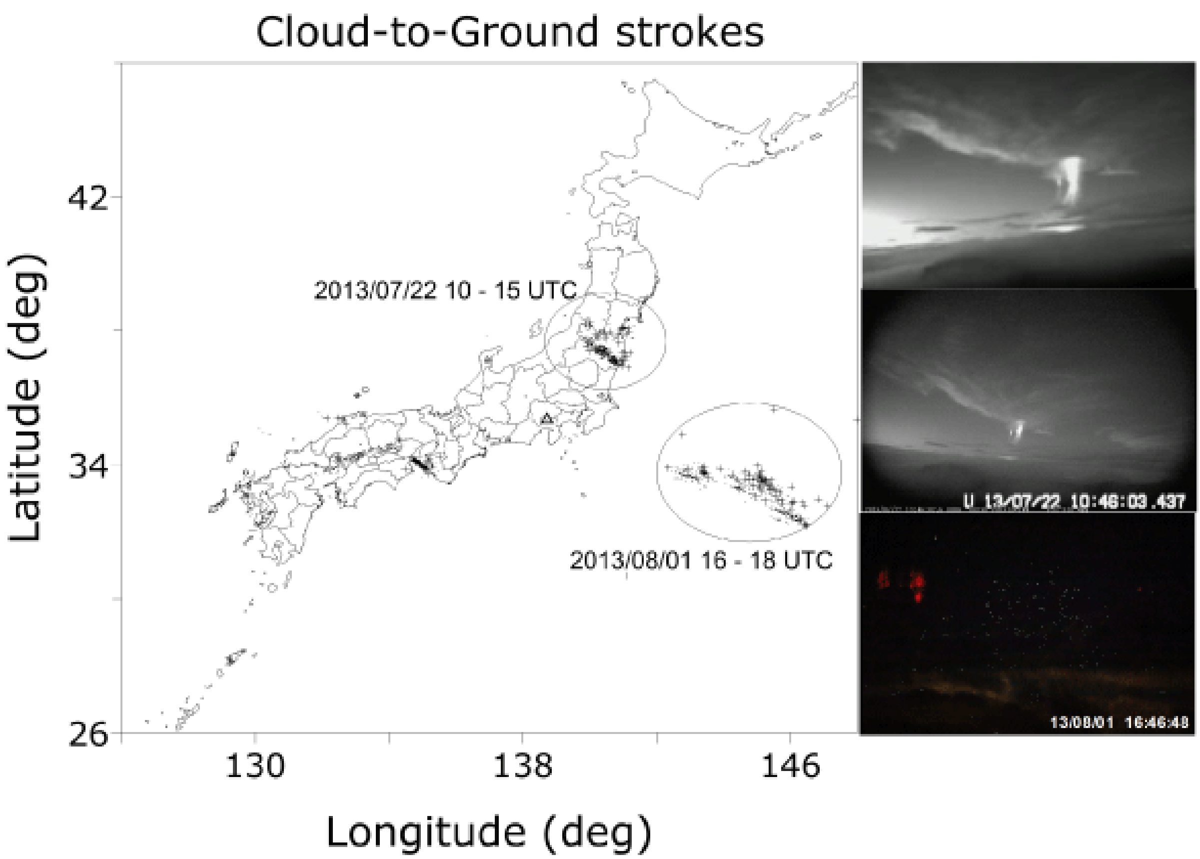

Figure 3. Map of CG lightning under parent storm on 22 July and 1 August 2013 (left panel). The plus and minus signs show positive and negative CG lightning, respectively. The triangle sign indicates the location of Mt. Fuji. Examples of red sprite (right panel): Sprites on 22 July (top and middle) and sprites on 1 August (bottom). Top and middle image shows the same event and they were captured by cameras with 4 mm and 12 mm lens, respectively. Bottom shows a color image of red sprite.

Table 1 Property of sprites and sprite-associated +CG lightning. The average values of lifetimes, time intervals, and amplitudes are shown.

No.	Date	Time (UTC)	Lifetime (ms)	Time interval between +CG lightning and sprite (ms)	Amplitude of +CG lightning (kA)
1	July 22, 2013	10:46:03.437	17	−30	132.77
2	July 22, 2013	11:21:06.371	50	−25	311.69
3a	July 22, 2013	11:38:11.320	33	−25	179.71
3b	July 22, 2013	11:38:11.520	17	−26	96.79
4	July 22, 2013	11:43:37.944	33	95*	123.67*
5	July 22, 2013	14:24:45.240	17	−101	88.91
			27.83 ± 12.23	−41.4 ± 29.8	161.97 ± 81.45

* Theses values are excluded for taking the average.

The time of sprite appearance, sprite lifetime, time interval between the sprites and the lightning, and lightning current estimated by LIDEN were investigated. Table 1 shows a list of the July 22 sprites and parent CG lightning. Five of the observed sprites followed positive CG (+CG) lightning, whereas one preceded +CG lightning, possibly because of a wrong selection of parent CG lightning. The lifetimes of the six sprite events ranged from 17 to 50 ms with a mean of 27.83 ± 12.23 ms. The time interval between the sprites and the lightning ranged from −101 to −25 ms with a mean of −41.4 ± 29.8 ms. [Remark 1] The estimated current amplitude ranged from 88.91 to 311.69 kA with a mean of 161.97 ± 81.45 kA. The number of negative CG (−CG) and +CG lightning at 10–11 UTC, 11–12 UTC, and 14–15 UTC were 10 and 33, 7 and 7, and 12 and 142, respectively. Most importantly, sprites were frequently observed at 11–12 UTC, when lightning activity is very low. The rates of +CG lightning during this period were relatively high, and four of seven +CG lightning events were associated with sprites. In contrast, CG lightning was very active during 10–11 UTC and 14–15 UTC. In particular, −CG lightning was vigorously generated, whereas sprite occurrences were inactive.

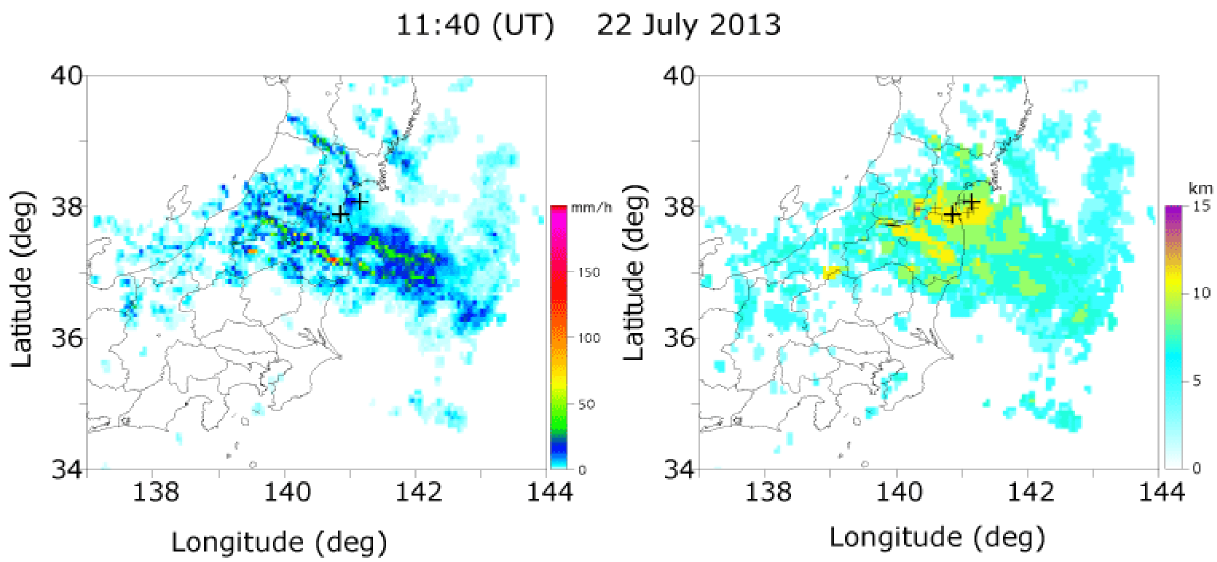

Figure 4. Storm associated with sprites at 11:38:11.320 and 11:38:11.520 UTC on 22 July 2013. Radar-echo composite map (left) and echo top map (right) at 11:40 on the same day. The plus and minus signs correspond to +CG lightning and – CG lightning. Parent +CGs lightning overlayed on the left panel and CGs occurred during 11 ~ 12 UTC plot on the right panel.

Figure 4 shows the radar-echo composite map for a parent storm at 11:40 UTC. The left panel of Fig. 4 shows the precipitation map near the ground, and the right panel shows the echo top altitude. This storm induced two sprite events at 11:38:11.320 and 11:38:11.520. Each sprite event accompanied different +CG lightning. The radar-echo tops corresponding to +CG lightning associated with sprites were at an altitude of 11 km, and the intensity of precipitation around the location of +CG lightning was at most 5 mm/h. The storm structure near the +CG lightning indicates that the stratiform precipitation region extended over the +CG lightning points associated with sprites; the storm decayed when the sprites appeared.

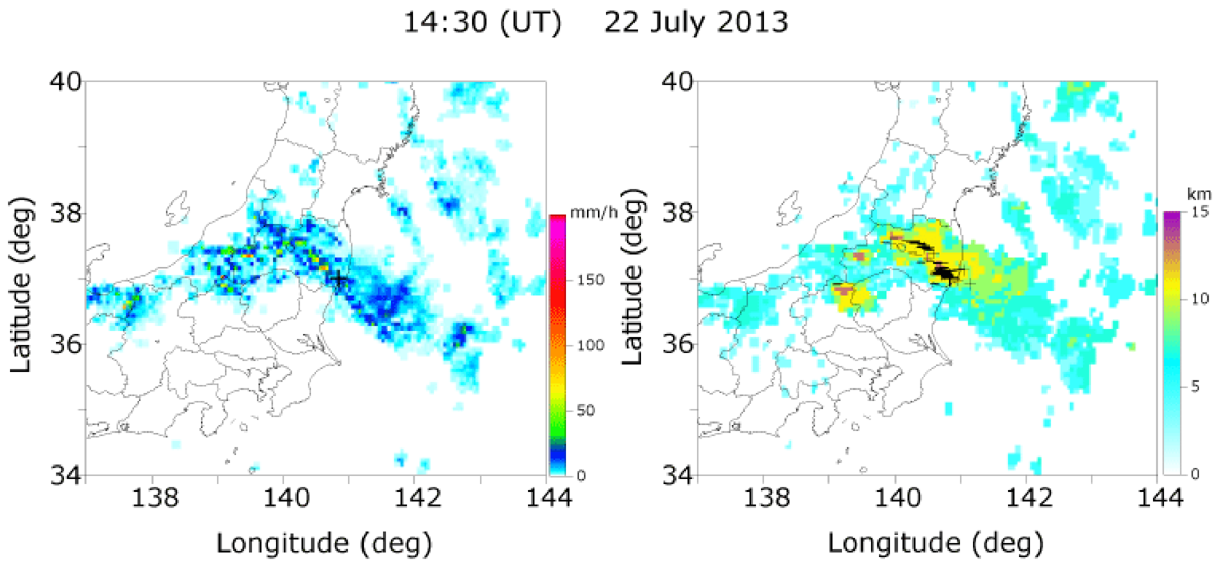

Figure 5. The same as Figure 4 but for sprites at 14:24:45.240 UTC on the same day.

Figure 5 shows the same information as Fig. 4 but for the parent storm at 14:30 UTC corresponding to the sprite event at 14:24:45.240 UTC. The storm is the same as the one in Fig. 4; it redeveloped in this period. The storm contained convective lines, and the strong convective echo core in the convective lines corresponding to a precipitation intensity of more than 100 mm/h. The convective core was located at the northwest side of the parent +CG lightning point (downwind side of the convective core). The +CG lightning was located at the point with less than 10 mm/h precipitation, and the echo top reached an altitude of 13 km. The structure of the storm over the foot of the +CG lightning point may correspond to the stratiform precipitation region. Only the +CG lightning around the parent +CG lightning occurred in the stratiform precipitation region.

We found that the sprite-associated +CG lightning on July 22 occurred in the stratiform precipitation region with a large amount of positive charge. These results related to the summer sprite-associated +CG lightning and parent storm in Japan agree with those of other studies [e.g., Lyons, 1996]. Sprites seem to be generated above the startiform precipitation cloud.

CONCLUSIONS

The 2013 Mt. Fuji Sprites campaign in Japan was conducted from the end of July to early August. Sprites were clearly observed above the clouds around Mt. Fuji; therefore, we expect that a significant number of sprites could be detected from Mt. Fuji because its altitude is higher than that of low clouds. Ten sprite images were detected from the Mt. Fuji Weather Station during the campaign. In this paper, we analyzed six sprite events on July 22, 2013. We concluded the following about sprites, parent +CG lightning, and parent storms. All observed sprites were associated with +CG lightning. With the exception of one case, sprites appeared −41.4 ± 29.8 ms after the +CG lightning. The mean estimated amplitude of +CG lightning associated with sprites was 161.97 ± 81.45 kA. The +CG lightning with sprites were located in the stratiform precipitation region. Four out of seven +CG lightning events occurring from 11 to

12 UTC were associated with sprite appearances. Sprites frequently occurred during periods of inactive −CG lightning but active +CG lightning.

ACKNOWLEDGMENTS

This work was performed during the period when the NPO Valid Utilization of Mt. Fuji Weather Station maintained the facilities. This research was partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Scientific Research (B), No. 24360399, 2012-2014 (T. T. and M. K.).

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