Journal of Atmospheric and Solar-Terrestrial Physics 107 (2014) 60–67

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

# Ground-based observations of the relations between lightning charge-moment-change and the physical and optical properties of column sprites

Roy Yaniv [a], Yoav Yair [a,*], Colin Price [b], Jo'zsef Bór [c], Mitsutero Sato [d], Yasuhide Hobara [e], Steve Cummer [f], Jingbo Li [g], Adam Devir [h]

[a] The Open University, Ra'anana, Israel
[b] Tel-Aviv University, Tel-Aviv, Israel
[c] Geodetic Observatory, Sopron, Hungary
[d] Hokkaido University, Sapporo, Japan
[e] University of Telecommunication, Tokyo, Japan
[f] Duke University, Durham, NC, USA
[g] Intel Corporation, Hillsboro, Oregon, USA
[h] IARD—Sensing Solutions Ltd., Yagur, Israel

ARTICLE INFO

*Article history:*
Received 6 January 2013
Received in revised form
19 August 2013
Accepted 29 October 2013
Available online 11 November 2013

*Keywords:*
Sprite brightness
Charge moment change
Winter thunderstorms
Calibrated observations

ABSTRACT

Optical observations of 66 sprites, using a calibrated commercial CCD camera, were conducted in 2009–2010 and 2010–2011 winter seasons as part of the ILAN (Imaging of Lightning And Nocturnal flashes) campaign in the vicinity of Israel and the eastern Mediterranean. We looked for correlations between the properties of parent lightning (specifically, the charge moment change; CMC) to the properties of column sprites, such as the measured radiance, the length and the number of column elements in each sprite event. The brightness of sprites positively correlates with the CMC (0.7) and so does the length of sprite elements (0.83). These results are in agreement with previous studies, and support the QE model of sprite generation.

© 2013 Elsevier Ltd. All rights reserved.

## 1. Introduction

Sprites are one of the most familiar types of Transient Luminous Events (TLEs) which occur in the upper atmosphere above thunderstorms. They are spectacular and beautiful, exhibiting complex structures and shapes (Pasko et al., 2011; Bór, 2013). Sprites are likely generated by the quasi electrostatic field (QSF) induced by a parent lightning flash, most often of positive polarity (+CG) (Pasko et al. 2007). During such discharges, large amount of positive charge is lowered to the ground, and the remaining charge of opposite sign above the thundercloud generates the QSF in atmospheric layers below the ionosphere, for a very short time periods ~1–50 ms. The charge-moment-change (CMC) is a parameter of the parent lightning and is defined as the product of the charge and the height from which it was lowered (Cummer et al., 2006). The CMC threshold for sprite generation is varying and no single value can be considered as the lower limit. Hu et al. (2002) found that the probability for parent flashes with CMC > 1000 C km in less than 6 ms to generate sprites was above 90%, while it was below 10% for lightning with CMC < 600 C km. In an "exceptional case" (to use their words) Hu et al. (2002) reported that a lightning flash with a CMC as low as 120 C · km was sufficient to generate sprites. Cummer and Lyons (2005) reported threshold values of 350 C km, and 600 C km on two different nights, reflecting the inter-night variability in mesospheric conductivity. The impulsive CMC (iCMC) is an empirical definition, referring to the amount of charge lowered within the first 2 ms of the onset lightning's return stroke multiplied by the original height above the ground from which it was lowered (Cummer and Lyons, 2005; Lu et al., 2012). For short-delayed sprites (less than 5 ms), a 75% probability for the generation of sprites required an iCMC larger than 300 C km (Lyons et al., 2009). The smaller values of CMC for sprite generation were explained recently with a numerical model by Qin et al. (2012). They showed that sprites can be produced even by weak flashes with CMC values ~200 C km, provided that vertically elongated inhomogeneities in the electron density exist in the ionosphere at altitudes near 90 km. Adachi et al. (2004) studied the possible correlation between the properties of the parent lightning

* Correspondence to: Department of Life and Natural Sciences, The Open University of Israel 1, University Road, Ra'anana 43107, Israel.
Tel.: +972 9 7781217; mobile: +972 52 5415091; fax: +972 9 7780661.
*E-mail addresses:* yoavyair@gmail.com, yoavya@openu.ac.il (Y. Yair).

1364-6826/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jastp.2013.10.018

(e.g peak current and CMC) and the properties of column sprites (number of column elements and length of columns). They found correlation between the CMC values and the lengths of column sprites and between the peak current values to the number of column elements of a sprite event.

Strong +CGs that exceed a threshold CMC are frequently produced in summer-time mesoscale convective systems (MCSs) (Lyons et al., 2009), and also by smaller winter-time thunderstorms, like those that are found west of Japan's coastline (Matsudo et al., 2007; Suzuki et al., 2011) and in the Eastern Mediterranean (Ganot et al., 2007; Yair et al., 2009a, 2009b). Winter thunderstorms are often characterized by small convective cells embedded in a large stratiform area, with a vertical scale of few km (Yair et al., 2009a, 2009b). A typical synoptic situation is shown in Fig. 1, where a cold front of a deep low is situated near Crete, west of the Israeli coastline, such that a clear line of sight exists to the thunderstorm cells. Lightning locations are based on the WWLLN data for ranges outside the coverage of the Israeli Lightning Detection Network, which is operated by the Israeli Electrical Corporation. For such meteorological conditions, thunderstorms produce lightning with large CMC which should suffice for sprite generation. Similar conditions exist in winter over the Sea of Japan (Takahashi et al., 2013). In Eastern Mediterranean winter thunderstorms CMC values for sprite generation were found to be in the range 600–2800 C km (Greenberg et al., 2007).

Ground-based calibrated optical observations to measure the radiance of sprites were first performed by the ILAN team from Israel in the winter of 2008–9 (Yaniv et al., 2009). The calibration procedure of the cameras was similar to the one described by Yair et al. (2003) for the sprite observations conducted during the Mediterranean Israeli Dust Experiment (MEIDEX) on-board the space shuttle Columbia in January 2003. For accurate and reliable results they considered the extinction of light by absorption and scattering of the atmosphere (aerosols, water vapor, $O_2$) to obtain the attenuation of radiance and visibility. The procedure involved separating pixels illuminated by sprite from pixels belonging to the background. This was done by averaging and subtracting the background pixels, and considering the sprite spectra, atmospheric visibility and transmittance of the atmosphere computed by the MODTRAN code. The total brightness of 5 different column sprites was found to range from 183 to 350 kR.

Recently, Takahashi et al. (2010) measured the CMC – sprite brightness relationship using ISUAL/array photometer on board the FORMOSAT-2. The brightness was calculated for 14 events by measuring photon flux of $N_2$1PG and $N_2$2PG spectral bands, taking into account the background noise. Optical energies in [MJ] were found to be in the range 1.3 MJ–58 kJ, with an average value of 300 kJ. The correlation coefficients between the parent flash CMC and sprite's luminosity were 0.93 for the $N_2$1PG and 0.91 for the $N_2$2PG, showing an excellent linear relationship, further supporting QE model.

This work describes the newest results from ground-based observations of sprites employing the same calibration methodology as used by Yaniv et al., 2009, for 66 events recorded during winter campaigns conducted from Israel during 2009–2011.

## 2. Instruments and data

We used a standard commercial CCD camera–Watec 902H2 Ultimate operating with a frame rate of 33 ms/frame, that is commonly used by other TLEs research groups in Europe and in Japan (Bór et al. 2009, Soula et al., 2009). The camera was fitted with a 12 mm f/0.8 lens with a field of view (FOV) of 31°(H) × 23°(V). A special broadband filter (Archer Optx FLTR-BP720-25) was mounted on the camera. The spectral band of this filter (640–800 nm) matches the first positive ($N_2$1 P) emission of sprites (575–1187 nm). The filter transmittance, the quantum efficiency of the camera, atmospheric transmittance and sprite spectrum (Hampton et al. 1996) are shown in Fig. 2. The atmospheric transmittance was calculated using MODTRAN 4 code with mid-latitude winter atmospheric model for range from the point of observation on the ground to the sprite location of 400 km assuming an altitude is equal to 80 km (these are typical values of camera-sprite ranges for observations in the Eastern Mediterranean; (Ganot et al., 2007). The camera settings are described in detail in Yaniv et al. (2009).

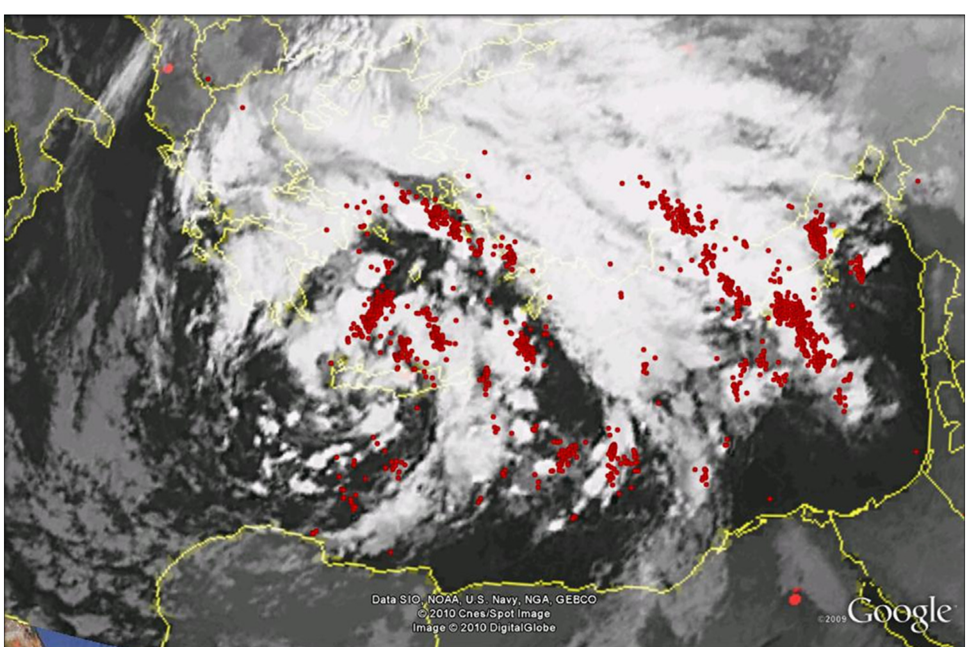


**Fig. 1.** An IR satellite image from December 11th, 2009 at 0130 UT. A deep low is situated over Crete as it moves eastward. Lightning locations are denoted by red points, based on the WWLLN data. A total of 37 sprites (columns, carrots, angels) were imaged during a 5 h period.

Download English Version:

https://daneshyari.com/en/article/1776675

Download Persian Version:

https://daneshyari.com/article/1776675

Daneshyari.com