PARAMETERIZATION OF SPRITES AND THEIR PARENT DISCHARGES

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ABSTRACT: Analysis of a close sprite-producing positive CG indicated that it had a total charge moment change of 460-740 C·km. Analysis of high speed video observations have determined that the initiation altitude of sprites is within the altitude range of 70-85 km with a mean of ≈75 km. These results are consistent with a conventional breakdown mechanism for sprite initiation. Once initiated, corona streamer characteristics are clearly visible in developing sprites.

INTRODUCTION

In spite of measurements of current moments at ELF frequencies [*Cummer and Inan*, 1997], very little is known about the parent positive cloud-to-ground (CG) discharges which are responsible for most sprites. Basic CG parameters such as the height, horizontal extent, rate, and quantity of charge transported to ground should be determined in order to accurately address the various sprite theories. There is also a critical lack of knowledge of the initiation altitude, sequence, speed, and nature of sprite development. This paper will highlight measurements of various sprite parameters and will briefly discuss the implications for a conventional corona streamer breakdown mechanism.

INSTRUMENTATION

In mid-May through mid-July of 1997, the NMT high-time resolution Interferometer system was operated from the Kennedy Space Center (KSC). The New Mexico Tech (NMT) Interferometer acquired 2D radio-frequency interferometry and electric field data simultaneous with 3D lightning maps obtained by KSC's Lightning Detection and Ranging (LDAR) system. Sprite-producing positive CG discharges (some within 100 km range) were observed by both systems on several nights.

During early October of 1997, a light-intensified high speed video camera system was operated from Langmuir Laboratory, NM, to observe sprite phenomena. The high speed camera was operated at frame rates of 1000, 2000, 3000, and 4000 s^{-1}. Image sequences of 42 sprite clusters and several elves were captured with the camera system.

PARENT DISCHARGE OBSERVATIONS

Figure 1 shows a sprite-producing lightning discharge (1:42:57 UT, June 22nd, 1997) overlaid onto NEXRAD reflectivity contours at an altitude of 5-8 km MSL. The 20 dbZ region of the anvil is about 50 km on a side with an estimated area of 2500 km^2. Almost all of the discharge is confined within the 20 dbZ region, but is significantly smaller with an approximate total area of 1600 km^2.

The discharge began as a bi-level intracloud within a main thunderstorm cell. The upper portion of the discharge propagated up through the cell and then out through the anvil. Figure 2 shows that the upper portion of the discharge dropped several kilometers in altitude as it propagated into the anvil. A positive CG was produced about 400 ms into the discharge and is evident as an upward step in the electric field change data. The descent of the positive leader to ground is not visible in the LDAR data.

A sprite was observed in the same video frame as that of the positive CG. The total electric field change of the sprite-producing positive CG return stroke and continuing current was about 25 V/m and had a total duration of just under 20 ms with about half of the field change amplitude

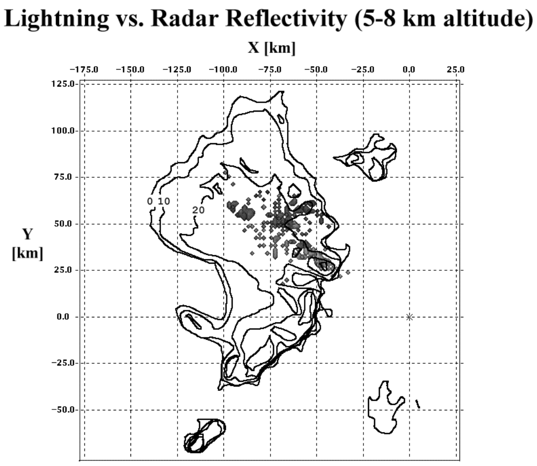

Figure 1: A sprite-producing discharge is overlaid onto NEXRAD reflectivity contours through the upper portion of the storm. The discharge is almost entirely confined within the 20 dBZ reflectivity contour.

being reached in the initial millisecond. The total field change can be used to estimate the total charge moment for the parent discharge by approximating the positive CG to a dipole:

$$\Delta E = \frac{2\,\Delta Q\,Z}{4\pi\varepsilon_o r^3}$$

where ΔE is the electric field change, $\Delta Q\,Z$ is the charge moment change, ε_o is the permittivity of free space, and r is the radial distance to the dipole. Ionospheric image charges are ignored in this calculation since their contribution would be less than that due to the range uncertainty. The estimated mean radial distance to the charge source for the positive CG (and hence to the dipole) is 75±6 km. Thus, the total charge moment for the CG was 460-740 C·km. If the charge was lowered from an altitude of ≈7.5 km, as indicated by the concentration of points at that altitude in Figure 2, then the CG lowered 60-100 C of charge to ground.

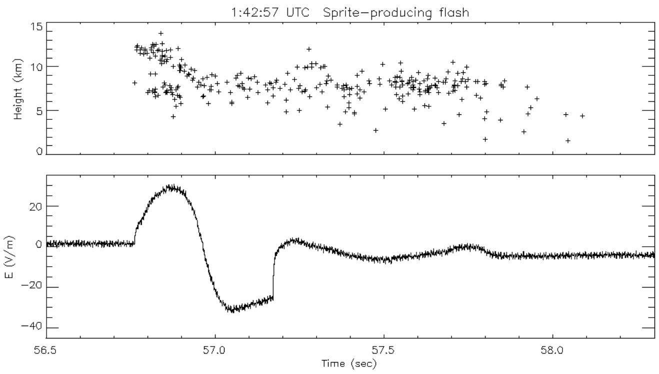

Figure 2: The time development of the 1:42:57 UT lightning discharge is shown with respect to discharge altitude (top) and electric field at the KSC observation site (bottom). The upward vertical step in electric field at 57.17 seconds was produced by a sprite-producing positive CG.

SPRITE OBSERVATIONS

Figure 3 shows a normal speed video image of a sprite cluster (8:43:57 UT, October 3rd, 1997) along with the first high speed video frame for the same region. The column visible in the first high speed video frame was at an altitude of 67-77 km and corresponded with the initial development of the carrot sprite visible in the normal speed image. The height estimate is based on the range to the associated positive CG determined by National Lightning Detection Network (NLDN) stroke-level data. The column extended primarily downwards in the second frame (not shown) and branched downwards into tendrils in the same frame. The tendrils had insignificant persistence between the 2nd and 3rd frames indicating that electrons were rapidly recombining in the region behind the downward propagating tips. This is consistent with the predictions of Pasko et al. [1998] who predicted that "corona streamers", characterized by very short persistence, are present in sprites. The tendrils were followed by upward developing structures (UDSs) which branched outwards from the main column to form the carrot shape of the sprite.

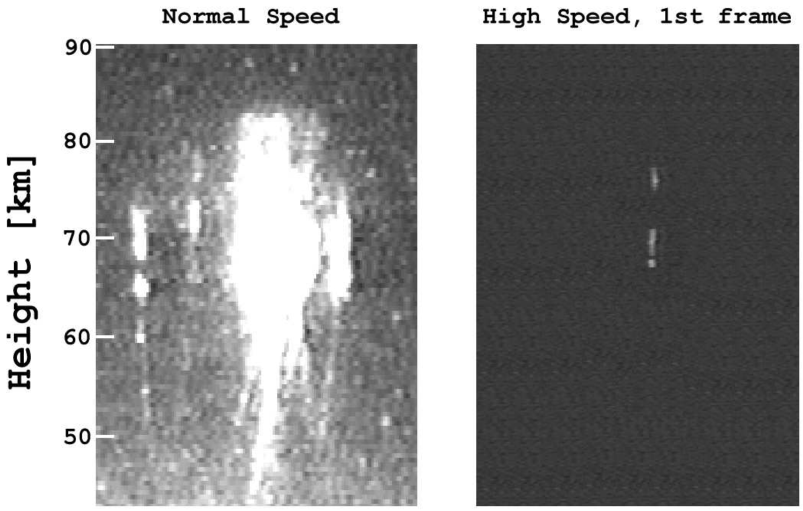

Figure 3: The image on the left was obtained at 60 fields/second while that on the right was obtained at 1000 frames/second for the same region of the sprite cluster. Both images correspond with the first one in which sprite luminosity was visible from the cluster. The carrot sprite was initiated before the columniform sprites and the carrot began as a noncontinuous column. Note that the "vertex" of the carrot sprite is below the initiation altitude region indicated in the high speed video image.

All of the sprites observed by the high speed video system started out with a columnar form (usually noncontinuous) within the first several hundred microseconds. This column appeared to extend both upwards and downwards in many cases and primarily downwards in a few others. The downward propagating portion of the column could split into 2 or more tendrils which continued to propagate downwards. The tendrils had velocities of about 0.01-0.1 c, where c is the speed of light. Based on the altitude extent of the initial column and possible bidirectional development, the initiation altitude for the sprites analyzed in this study was above $\approx$70 km with a mean altitude of $\approx$75 km.

UDSs were visible on all carrot sprites and occasionally on what was otherwise a columniform sprite. They often could be seen originating from altitudes below that of sprite initiation. These structures propagated with velocities of 0.05-0.2 c and were followed by a short and often insignificant persistence within the upper portion of sprites. This suggests that they have corona streamer characteristics within that region. However, they could be followed by significant persistence at lower altitudes within the head region of carrot sprites. It is this persistence which is in large part responsible for the brightness of the head of carrot sprites.

DISCUSSION

Analysis of high speed video indicates that sprites are initiated at altitudes of 70-85 km. Fernsler and Rowland [1996] calculated that a minimum charge moment change of 300 C·km would be needed for conventional breakdown to occur at 80 km altitude. This threshold is less than the observed charge moment change of the sprite-producing positive CG analyzed in this paper. Thus, the analyzed discharge should be capable of initiating a conventional breakdown process at altitudes where initial sprite development is observed. The corona streamer behavior visible in both tendrils and UDSs provides further evidence for a conventional breakdown mechanism.

Though the corona streamer nature agrees with predictions of Pasko et al. [1998], the velocities are significantly higher than theoretical predictions. Additional theoretical work is needed to address this discrepancy.

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