TRANSIENT LUMINOUS EVENTS STATISTICS, SOURCE STRENGTH ENERGETICS DURING THE 1999 SPRITES BALLOON CAMPAIGN

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ABSTRACT

Historically, the process of TLE detection has required an alert human observer on a low light level television (LLTV) monitor, either in real time or playback. The payloads had all-sky upward looking photometers not sensitive to events below the balloons. We cross-checked our photometer data with National Lightning Detection Network (NLDN) data to find TLEs that were missed visually. We have analyzed 3622 events in 4.1 hours of storm time to estimated energy deposition in mesosphere due to the TLEs and the threshold value of the charge moment of the TLE itself.

INTRODUCTION

Transient Luminous Events (sprites, elves, sprite halos) are short lived luminous phenomena associated with large thunderstorms that occur above clouds. They are basically recognized as electrical discharges and are associated with large thunderstorms. Sprites (Sentman et al., 1995) are vertical large scale luminous glows occurring for 1-10 ms above thunderstorms at altitudes ~50-100 km, exhibiting predominantly red color. They have a lateral extent of few a tens of kilometers and are preceded by a large cloud-to-ground (CG) lightning discharge. Elves (Emissions of Light and Very low frequency perturbations from Electromagnetically pulsed Sources) (Fukunishi et al., 1996) are ring like flashes centered on the vertical channel to ground that immediately follow the CG stroke and are very fast ($\leq$1ms). They are believed to be caused by electromagnetic pulses from lightning. Previously, sprites halos were confused with elves. Recently they have been found to be an upper diffuse region of the sprites. -CG events, ground flashes with negative polarity, predominate in most storms, +CG events are less frequent and are more energetic. Our primary focus will be on the estimation of energy deposition by the events in mesosphere. Though there are number of issues to be resolved for the better understanding of these upper atmospheric phenomena and their effects in energy budget of the atmosphere, this paper will provide general idea of possible mesospheric effects of TLEs. We used the simple idea of considering sprite as a free space dipole and its image formed by the highly conducting earth surface, to calculate the dipole charge moment of the TLE event itself. Using the distance of the event from the balloon provided by NLDN data and vertical electric field measured by balloon payload in the stratosphere, we are able to estimate average energy input to mesosphere per luminous event to be • 82kJ. Considering 1400 km of viewing radius, power per unit area delivered by TLEs comes out to be 0.16×10^{-9} W/m^2. We also found the charge dipole moment threshold for +CG events as 200C-km, which was not true for a relatively large number of -CG events.

INSTRUMENTATION

The 1999 Sprites Balloon Campaign involved simultaneous observations of the sprites by instruments on the balloon and by observers at three ground stations. Three ground observing stations were located at Yucca Ridge Field Station, Ft. Collins, Colorado; Wyoming Infrared Observatory on Jelm Mt., Wyoming and Bear Mt. Fire Lookout in South Dakota.

Balloon Payload

The balloon payload contained instruments that measured the vector electric field, the vector magnetic field, X-ray counting rate, light emissions from the events, vertical current density, conductivity, temperature and balloon location. A more detailed description of the instruments can be found at http://www.uh.edu/research/spg/Sprites99.html.

Ground-Based Optical Observations

Low-Light-Level video observations of sprites, jets, halos and elves were made from three locations on the eastern edge of the Rocky Mountains. Simultaneous multiple site video recording permitted the use of triangulation methods to establish the location and size of some of the observed events. The observation was carried out by the teams from the Geophysical Institute at the University of Alaska and FMA Research.

FLIGHT OPERATIONS

1999 Sprite Balloon Campaign conducted three high altitude balloon flights, one from Palestine, Texas and two from Ottumwa, Iowa, USA. Flight 1, was launched From Palestine at 01:14:31 UTC on 07/06/1999 and cut down at 09:45:00 UTC on same day. Flights 2 and 3 flew from Ottumwa at 23:57:30 UTC on 08/14/1999 to 12:35:00 UTC on 08/15/1999 and at 00:39:32 UTC on 08/21/1999 to 11:12:00 UTC on the same day respectively.

FORMULATION

TLEs can be modeled as a free space dipole, with an image below the ground assuming ground to be a conductor. Static electric field due to such a dipole is,

$$\vec{E}_{static} = [3\hat{n}(\hat{n}.\vec{p}) - \vec{p}]\frac{1}{R^3} \quad \text{(1)}$$

Here R is the distance from the balloon to the stroke, $\vec{p}$ is the dipole moment. The radiation field is,

$$\vec{E}_{radiation} = \frac{\omega^2}{c^2}(\hat{n}\times\vec{p})\times\hat{n}\frac{e^{i\frac{\omega R}{c}}}{R} \quad \text{(2)}$$

Here ω is the radiation frequency, c is the velocity of light. In far zone, we can approximate for frequency f,

$$\left\| \frac{\vec{E}_{radiation}}{\vec{E}_{static}} \right\| \approx \frac{\omega^2 R^2}{2c^2} = \frac{2\pi^2 f^2 R^2}{c^2} \quad \text{(3)}$$

thus, total vertical electric field is,

$$\Delta\vec{E} = \vec{E}_{radiation} + \vec{E}_{Static} \quad \text{(4)}$$

which can be solved for the moment,

$$\vec{p} = \frac{4\pi\varepsilon_0 \Delta\vec{E} R^3}{\left(\frac{2\pi^2 f^2 R^2}{c^2} + 1\right)} \quad \text{(5)}$$

Considering potential energy due to two separated point charge, energy can be written as,

$$Energy = \frac{1}{2}\frac{(0.55p)^2}{4\pi\varepsilon_0 r^3} \quad \text{(6)}$$

In our calculation we took, r =100 km. This formulation will give us the base for the further extension of the energy estimate using more appropriate approximation as done by Wait in his classic paper (Wait, 1962).

STATISTICS

Table 1. Statistics of the events. Sprites, elves and halos were recognized from the ground observations for flight 3. Third and fourth column gives the NLDN current based number of events, fifth and sixth column gives the photometer based number of luminous events and seventh and eighth column gives vertical electric field based number of the events. *(T stands for TLE)

						No Light	No Light				
	Total	+CG	-CG	+T*	-T	+• E	-• E	• E=0	Sprites	Elves	Halos
Flight 1	1650	181	1469	5	43	102	1367	133			
Flight 1(No NLDN	8	0	0	2	6	0	0	0			
Flight 3	1919	86	1833	24	113	57	1547	178	29	15	117
Flight 3(No NLDN)	23	0	0	15	8	0	0	0			
Flight3(Ground with NLDN)	51	0	0	0	0	0	0	0			
Flight3(Ground w/o NLDN)	22	0	0	1	0	11	4	6			
Total	3622	267	3302	47	170	170	2918	317			

RESULTS AND DISCUSSION

Global cloud to ground lightning flash rate is estimated to be between 10-14 per sec (Mackerras et al., 1998). From statistics we found that the positive events are less than 10% of the total lightening flashes and about 1.3% have positive flashes, again every positive flash is not producing sprites (Table 1). So, if we assume that the global sprite distribution is similar to a global lightning distribution, there is occurrence of 1 positive event in 1 sec and 1 sprite in 10 seconds. This, of course depend on the lightning and sprites spatial distribution all over the world. We examined electric and magnetic field vectors and photometer data at NLDN stroke time, using 100 ms plot of 1 kHz data.

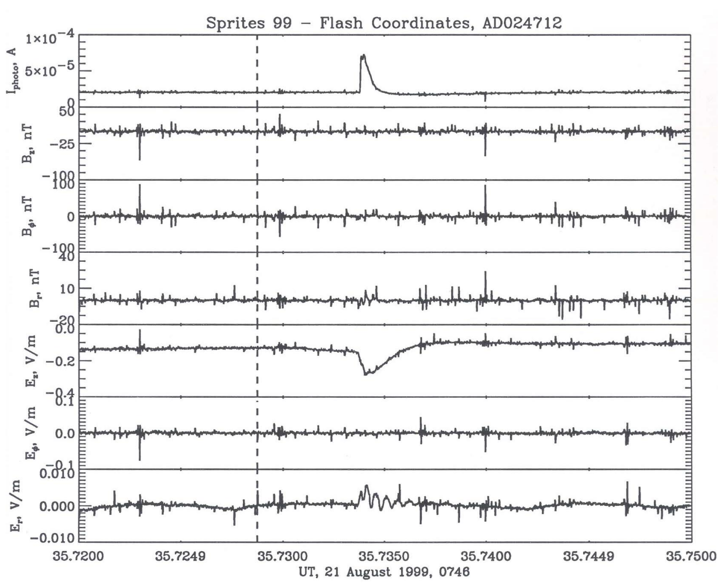

Figure 1 Figure shows a negative halo, confirmed by ground observation. From top to bottom, high speed data plots show photometer current, magnetic and electric field in stroke centered cylindrical coordinates. This event has an apparent radius of 300 km in the Yucca Ridge video and look like an elve. However the time delay between the VLF sferic and the TLE suggests strongly that the event was a halo.

We recorded vertical electric field, range, light/no light, and time of the event. According to our criteria we have calculated energy per positive flash to be • 82 kJ. The energy deposited in sprites has been estimated from 1MJ to as much as 1GJ (Heavner et al.,1999). Assuming that power is distributed with in an area of viewing radius 1400 km of the balloon, the power per unit area from the positive flashes comes out to be $1.6x10^{-10}$ W/m^2. Positive flashes are generally very big and are main cause of sprites. We did not find any positive flash with charge moment less than about 200 C-km. But There is no such kind of threshold limit for the negative flashes, which are far much greater in umber than positive. Most of these negative flashes which looked like elve during ground observation had a large time delay equivalent to that of sprites, and therefore were negative halos ("Fig1"). We found that the sprite halos and sprites produce almost same electric and magnetic field pulses. Thus halos, which are far greater in number than other luminous events, cannot be ignored in energy calculations due to mesosphere phenomena. It is clear from the figure that this particular event has vertical electric field of 150 mV/m, certainly there is energy contribution from these events. This amount of energy is significant because the number of such events is much larger than the big events like sprite, so they can not be ignored. We assume that inclusion of these events will raise the estimated energy input by a factor of ~2-5. Inclusion of non luminous CGs, which are very large in number (Table1) will further increase the estimated energy by another factor of 5. Since we assumed very simple model for the charge moment calculations, which practically is far from the actual conditions, we are extending the study using the more real models of wave propagation, using the wave guide nature of the earth-ionosphere system (Wait, 1962).

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