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Transient Luminous Events and Its Electrochemical Effects to the Atmospheres

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ABSTRACT: The bi-directional discharges from thunderclouds corresponding to numerous splendid mesospheric discharges known as transient luminous phenomena are considered at length. The quasi-static electric field model of sprites with the formation of a giant parallel plate capacitor by positive ionosphere and negative shielding layer is examined.

KEYWORDS: TLE, quasi static electric field, mesospheric electron density

I. INTRODUCTION

The complex charges build up with time developed in thunderstorms leads to both upward and downward lightning discharges. These discharges are occasionally associated with Optical emissions commonly called Transient Luminous Events (TLEs), identified as sprites, elves, jets, blue starters, etc. and are usually associated with thunderstorms rousing at high altitudes in the Earth's atmosphere [1-4]. Amongst TLEs, sprites are frequently observed phenomena. Sprites, possessing huge amount of charge, are induced by positive cloud-to-ground (+CG) lightning strokes. Blue jets, on the other hand, consisting of leaders and a return stroke are discharges propagating upwards into the stratosphere from the top of the cloud like the same way of that of the lightning but they may or may not be associated with cloud to ground lightning activity whereas, Elves, another category of TLE, are concentric rings of optical emissions escaping horizontally outwards at the bottom edge of ionosphere, formed by the electromagnetic pulse radiated by the cloud-to-ground discharge current [5-9].

II. TRANSIENT LUMINOUS EVENTS

Transient Luminous Events (TLEs) are the optical signature of energetic processes in the upper atmosphere, of which sprites are the best known [10]. Sprites are short lived (a few ms), large luminous discharges that appear in the altitude range ~40 to 90 km above vigorous thunderstorms. Sprites arise from the quasi-electrostatic (QE) field causing removal of a significant amount of charge in a large lightning stroke. Whereas sprites are initiated by the QE field above a large lightning discharge, elves are the optical signature of the interaction between the lightning electromagnetic pulse and the lower atmosphere. Sprites are associated with +CG lightning discharges which lower positive charges from a cloud to the ground. Blue jets are discharges propagating upwards into the stratosphere from cloud tops in a similar way to classical lightning, consisting of leaders and a return stroke. They may or may not be associated with cloud to ground lightning activity [11]. Elves are concentric rings of optical emissions propagating horizontally outwards at the bottom edge of ionosphere at ~ 90 km altitude [12], which are caused by the electromagnetic pulse radiated by the CG discharge current of CG lightning of either polarity [13].Gigantic jets seem to be a discharge where a blue jet triggers a sprite, creating electrical breakdown of the atmosphere from the thunderstorm clouds directly up to the bottom of the ionosphere [14-16]. Lightning discharges radiate intense electromagnetic pulses ~ 20 GW peak power for ~ 1 ms to ~ 1 s duration as measured by electric and magnetic sensors on the ground or in space [17]. Table I illustrates a comparative study of the characteristics of various Transient Luminous Events [2, 18-19].

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TABLE I
A COMPARATIVE STUDY OF THE CHARACTERISTICS OF TRANSIENT LUMINOUS EVENTS

Type of TLEs	Sprites	Elves	Blue jets	Blue starters
Color	Red	Red	Deep Blue	Deep Blue
Minimum altitude in km	50	75	20	17
Maximum altitude in km	90	105	40-50	25.5
Width in km	25-50	100-300	3	2
Span in ms	5-300	<1	~250	100s ms
Spatial features	Top diffuse, bottom structured	Diffuse	Structured	Diffuse
Apparent Motion	Top upward, bottom downward	Lateral expansion	Upward	Downward
Association with lightning	Positive CG	Intense positive CG	often follow blue starters	Intense negative CG lightning
Time of onset	3-30 ms after lightning onset	<500ms after lightning onset	Quiet periods	Quiet periods
Avg. Energy /events (MJs)	22	19		
Global occurrence rate (events/min)	~1	72		
Energy deposition rate (MJs/min)	22	1370		

Recent observations show that early VLF amplitude perturbations for 90% cases were associated with + CG discharges which triggered sprites [20-23]. On the other hand numerous + GG and – CG discharges which did not trigger sprite were seldom associated with amplitude perturbations.

III. THE QUASI-STATIC ELECTRIC FIELD MODEL OF SPRITES

The quasi-static electric field model of sprites is outlined below.

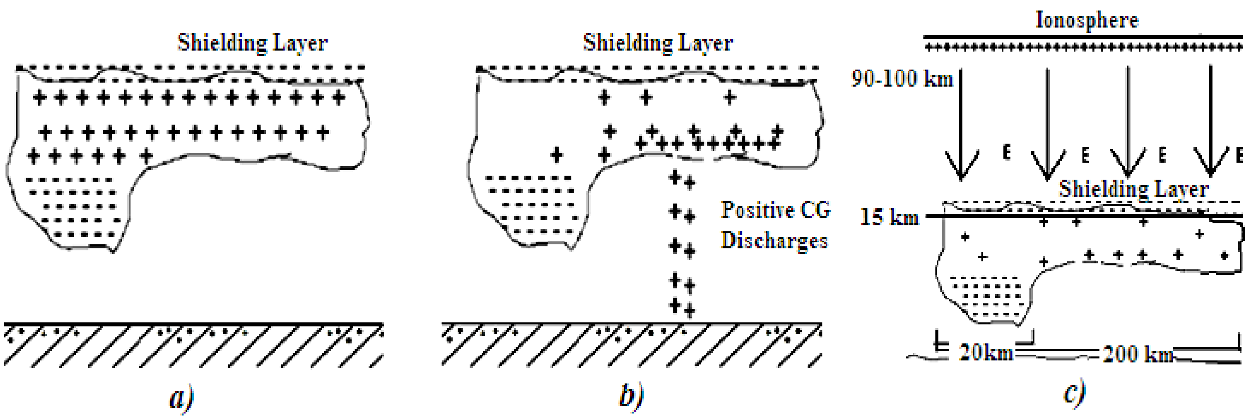

Fig. 1 *a*) The cloud charges up before the lightning discharge including a negative shielding layer, *b*) the positive CG removes positive charge, keeping the negative shielding layer for a longer time, and *c)* Giant parallel plate capacitor with positive ionosphere and negative shielding layer

Figure 1*a)* describes that the cloud charges up before the lightning discharge including a negative shielding layer while Figure 1*b)* describes how the positive charge is removed by +CG discharges, which in turn keep the negative shielding layer for a long time. The negative shielding layer persists even after the discharge causing polarization in the atmosphere and a quasi-static E-field. This can be compared to a giant parallel plate capacitor as illustrated in Figure 1*c)*. This strong E-field is responsible for the electrical breakdown and eventually produces the sprites.

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IV. EFFECTS ON MESOSPHERIC ELECTRON DENSITY DUE TO TLE

The wide spectrum of electromagnetic waves generated during lightning discharges couple the lower atmosphere with the ionosphere/magnetosphere. Transient events like sprites are short-lived (a few ms), large luminous discharges that appear in the altitude range ~40 to 90 km above large thunderstorms. Sprites arise from the quasi-electrostatic (QE) field resulting from removal of a significant amount of charge in a large lightning stroke. Terrestrial gamma rays and runway electrons are noticed at a height of about 50 km from Earth's surface. Positions of red sprites, ELVES, and blue jet are also the mysterious phenomena coupling the troposphere with the ionosphere [24-26]. The variation of electron density due to all these transient events reported at different parts of the globe when critically examined exhibit a variation of density with altitude as illustrated in Figure 2.

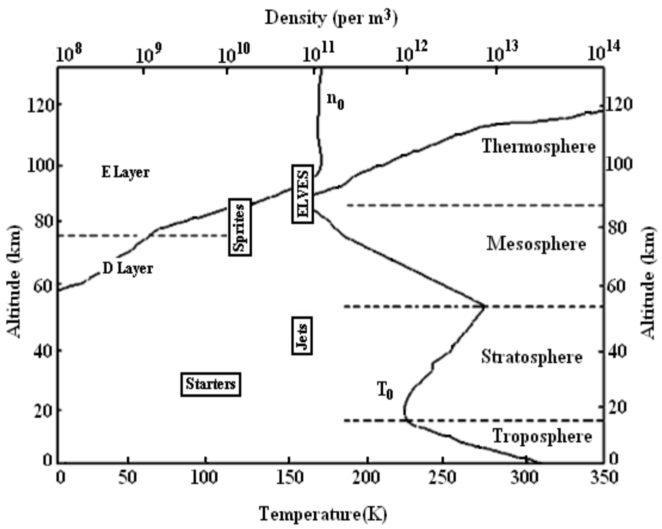

Fig. 2 Variation of electron density with altitude related to luminous events

Observation of repeated sprites occurring at the same location, it is observed that the high altitude plasma associated with a sprite or ELVE could exist for nearly 2 to 5 minutes [27-29]. Since the occurrence rate of ELVEs is much higher than those for the other TLEs, only the free electron contribution of ELVEs to the lower ionosphere is considered. Mende et al. [30] reported that the free electron density inside an ELVE can be eminent by more than 100%. The fractional local electron density change is defined as

$$\mu_{local} = \frac{V_{elve}\, \Delta n_e r_{local}\, l_{life\ time}}{V_{local}\, n_e} \qquad (1)$$

where ne is the mean nighttime free electron density
Δne is the increase of the free electron density in an ELVE [103],
and V_{local} is the volume between 80 km and 90 km above the region of observation
The ambient electron density N_e at altitude h is

$$N_e(h) = 1.43\text{X}\, 10^7 e^{[(-\frac{0.15}{km})h']}\, e^{[(\beta - 0.15/km)(h-h')]}\, cm^{-3} \qquad (2)$$

For h' = 85 km and h' = 100 km the variation of electron density with β = 0.5 and β = 1 for different altitudes is depicted in Figure 3. From the figure it is clear that the electron density for tropical countries is greater initially but over 80-100km it is greater for non-tropical countries.

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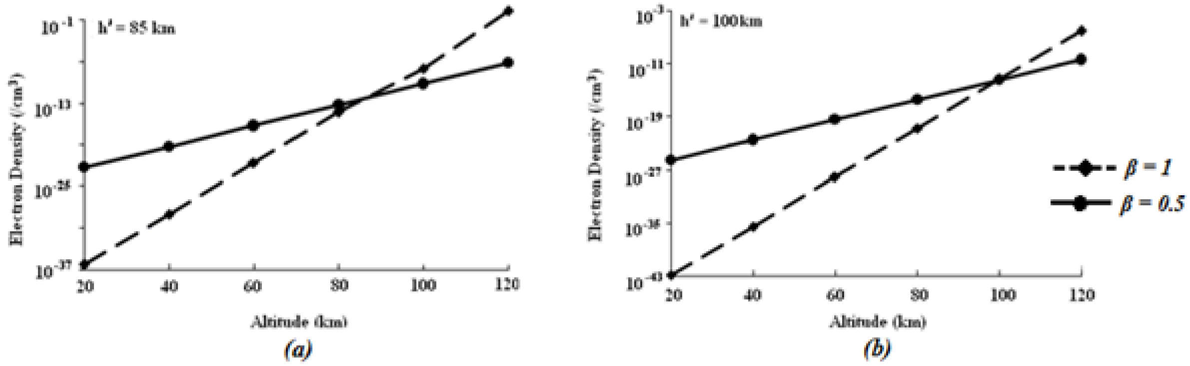

Fig. 3 Variation of electron density with β = 0.5 and β = 1 for different altitudes with *(a)* h' = 85 km and *(b)* h' = 100 km

V. DISCUSSION

The study of high altitude discharges is very useful for energy transfer between lower and upper atmosphere [31-32]. In this paper, we have summarized certain aspects of electrical discharges in thunderstorms and associated phenomena. Both the evolution and electrification of thunderstorms are briefly discussed. The bidirectional discharges from thunderclouds correspond to several magnificent mesospheric discharge (TLEs) phenomena. Observations show an asymmetry in CG discharges which generate sprites; negative CG discharges are rarely associated with sprites. The upward discharge creates a conducting path in the upper atmosphere so that the role of sprites and TLEs in the global electric circuit becomes important. The electric fields established in the mesosphere following a lightning discharge are not properly understood, and the relaxation time scale of quasi-electrostatic fields and its dependence on the ambient parameters of the medium are not well known. A complete understanding of the electric fields generated during intra-cloud, cloud-to-cloud, cloud-to-ground and cloud-to-ionosphere discharges remain a problem which requires both experimental and theoretical modeling efforts. Thunderstorm electrification process and downward lightning discharges play a significant role in the Earth's climate. They also couple the troposphere to higher regions of the atmosphere and to the ionosphere and magnetosphere.

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