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Earth's Transient Lightning Events: A Possible Factor for Solar Terrestrial Relationship

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ABSTRACT
When lightning discharges or sprites occur it emits significant amounts of energy in the ELF/VLF frequency range which is efficiently guided by the earth-ionosphere waveguide. Identification of SFERICS in VLF data is important for correlating observed effects with lightning and also to determine the location of lightning strikes. This study can provide a further insight for approaching a possible solar terrestrial relationship. This paper considers basic physics of lightning discharges occurring in the earth's troposphere and the mysterious sprites and ELVES producing in the upper atmosphere, creating a tropospheric-ionospheric coupling and thus causing a variation of electron density.
***Keywords* -** Lightning, SFERICS, ELVES, ELF/VLF frequency.

I. INTRODUCTION

Lightning producing electromagnetic radiation is the most prevalent source of ELF/VLF waves on Earth. At any instant, there are at least hundreds of active thunderstorms and about 40 lightning flashes on an average occur every second [1,2]. This paper considers basic physics of lightning discharges occurring in the earth's troposphere and the mysterious sprites and ELVES producing in the upper atmosphere, creating a tropospheric-ionospheric coupling and thus causing a variation of electron density. A SFERICS or the so-called radio atmospheric is the signature of a lightning flash as can be recorded by sensitive VLF receiver. When lightning discharges or sprites occur it emits significant amounts of energy in the ELF/VLF frequency range which is efficiently guided by the earth-ionosphere waveguide. SFERICS is clearly recognized in both broadband and narrowband data as large transient changes in amplitude and both amplitude and phase in the case of narrowband data. SFERICS are sometimes followed by a slower tail, which is indicative of strong ELF frequency content, as opposed to the VLF content in the first transient. Identification of SFERICS in VLF data is important for correlating observed effects with lightning and also to determine the location of lightning strikes [3,4]. This study can provide a further insight for approaching a possible solar terrestrial relationship.

II. NATURAL LOW FREQ. TO HIGH FREQ. NOISE

Natural electromagnetic noise amplitude is generally decreased in intensity with frequency and is affected by ionospheric condition. As LF/MF/HF frequencies are used in radio communication and broadcasting, in this frequency range natural radio noise has been the object of scientific studies. The electromagnetic waves radiated by impulsive lightning discharges cannot escape the ionosphere border. Radio waves are reflected by the upper layer of the atmosphere up to a critical frequency depending on local ionospheric condition. Non-ionizing Radiation (NIR) frequency bands and the main natural radio noise sources are presented in Table 1.

Table 1. Non-ionizing Radiation frequency bands and the main natural radio noise sources

Name of frequency	Frequency Range	Wavelength (in m)	Natural Radio Noise Sources	Primary Mode of Propagation	Environment
VLF	3–30 kHz	10^5 - 10^4	Propagation in the ionospheric cavity of the atmospheric discharge radiate energy	Between ground and lower ionosphere. It is a ground wave and uses wave guide also.	Ionospheric cavity
LF	30–300 kHz	10^4 - 10^3	Atmospheric noise	Wave guide, ground wave	Ionospheric cavity
MF	300–3000 kHz	10^3 - 10^2	Atmospheric noise	E – region of the ionosphere reflection (might). Ground wave.	Ionospheric cavity
HF	3 – 30 MHz	10^2 – 10	Atmospheric and cosmic noise	Reflection from E and F region of the ionosphere.	Ionospheric cavity
VHF	30 – 300 MHz	10 – 1	Atmospheric and cosmic noise	Line of sight, scatter from ionosphere. Reflection by active satellites.	Earth surfaces (mainly due to the cosmic noise that penetrates the ionospheric layers)

III. TRANSIENT LUMINOUS EVENTS

Fig. 1 reveals images of the same lightning flash. The left photo [Fig. 1(a)] was taken with a stationary camera while the right-hand side photograph [Fig. 1(b)] was taken with a camera that was moving horizontally during the flash (time advances from right to left). This is a downward flash as indicated by the downward direction of the branches. This figure appears to show at least seven separate individual strokes following the same path from cloud to ground, with the first stroke being on the far right [5-7]. In Fact, Transient Luminous Events (TLEs) are the optical signature of energetic processes in the upper atmosphere, of which sprites are the best known. 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. Though sprites have received very careful attention, recent optical observations have shown that elves are far more common than sprites. Similar to sprites, blue jets appear above a thundercloud, but are not unlike sprites and elves. Blue jets are not directly associated with a lightning flash.

As the name indicates, blue jets are primarily blue in color and extend up in narrow cones which disappear at heights of 40-50 km. Early VLF events are the collective term used for describing the early/fast events with the newly reported early/slow events. Early VLF events have close similarity with LEP events in that they perturb sub-ionospherically propagating VLF transmitter signals and are due to ionospheric disturbances [6]. Fig. 2 presents the summary of Transient Luminous Events indicating sprites, elves and the blue jets.

IV. CURRENTS IN SPRITE ASSOCIATED LIGHTNING FLASHES

Measurements of SFERICS reveal that those SFERICS launched by Sprite-producing CG flashes exhibit enhanced ELF "slow tails" following the initial VLF portion. **Fig. 3** exhibits two SFERICS originating in the same thunderstorm and recorded with similar peak values of VLF magnitude but markedly different ELF "slow tail" average magnitudes. The waveform in **Fig. 3(b)** exhibits an average ELF magnitude more than 20 times greater than that of the one in **Fig. 3(a)**. The sferics with the large slow tail (b) was generated by a Sprite-associated CG flash while the one without a measurable slow tail (a) was not [7].

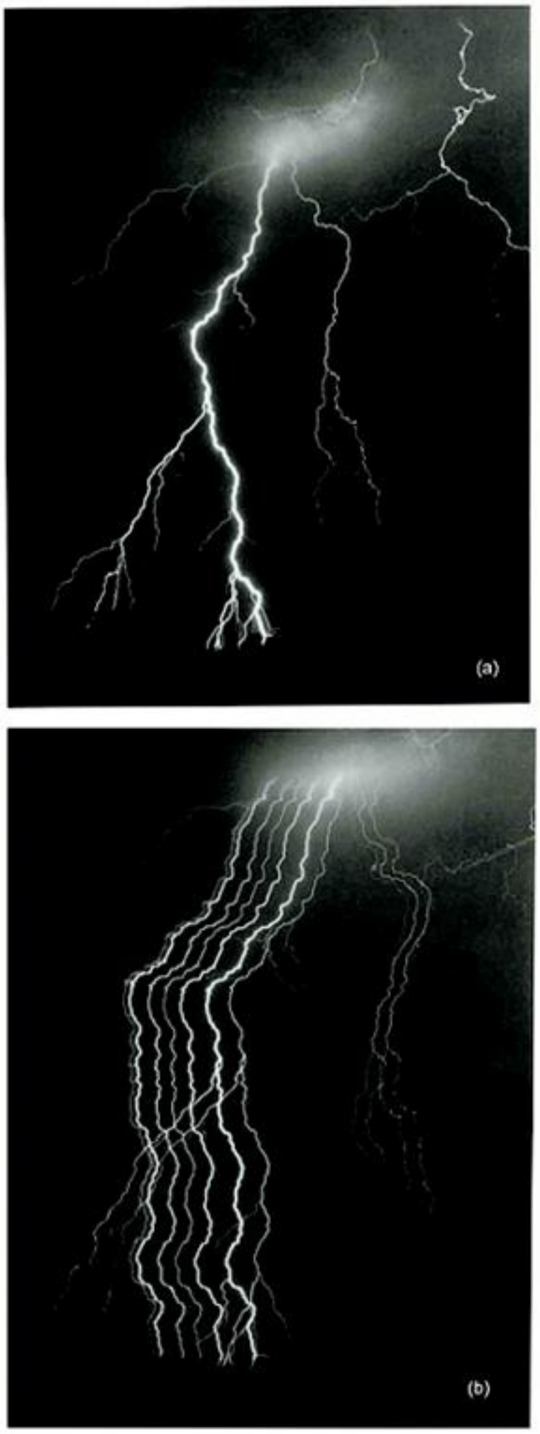

Fig.1. (a & b) Photograph of lightning flashes taken with a stationary camera (a) and horizontally moving camera (b) [5].

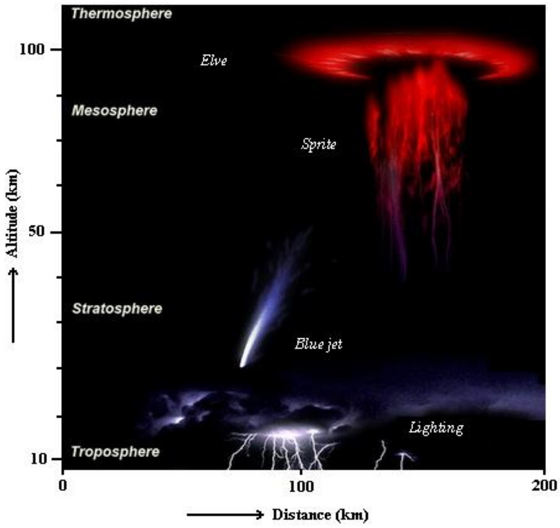

Fig. 2. Summaries of Transient Luminous Events (TLEs). The X- and Y- axes represent the distance and the corresponding altitudes respectively [6].

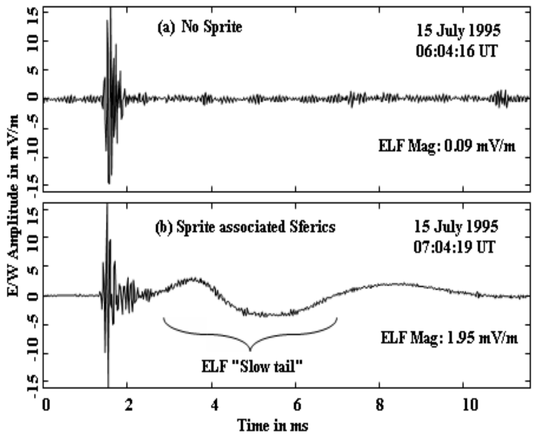

Fig. 3. Two SFERICS originating in the same thunderstorm and recorded with similar peak values of VLF magnitude but with significantly different ELF "slow tail" average magnitudes [7]

Table 2. A comparative study of the characteristics of transient luminous events

Luminous events	RED SPRITES	BLUE JETS	BLUE STARTERS	ELVES
Altitude extent	40 - 90 km	20 - 40 km	18 - 21 km	70 - 105 km
Horizontal extent	20 - 50 km diameter	3 km diameter base 10 km top	< 1 km	100 - 400 km diameter
Shape	Three bright patches separated by dark bands	Upward flaring cone 15° full width	Vertical, spark-like	Diffuse blob
Time of onset	3 - 30 ms after Lightning onset	Quiet periods	Quiet periods	< 500 ms after Lightning onset
Duration	3 ms	200-300 ms	N. A.	< 1 ms
Relationship to lightning	Follow positive CG Lightning	During periods of intense negative CG Lightning	During periods of intense negative CG Lightning	Follow positive CG Lightning

Table 2 presents comparative studies among the transient luminous events like, red sprites, blue jets, blue starters and elves. In this comparison we have emphasized altitude and horizontal extents, shape, time of onset, duration and the apparent relationship of the events to tropospheric lightning. Lightning being our special interest for examining its characteristic behavior as well as for comparison with other transient luminous events, we have drawn a schematic diagram below to illustrate the mechanism of cloud-to-ground lightning discharges (**Fig. 4**). The total charge lowered from a thundercloud at a given altitude to the ground in a lightning discharge is considered to be the most important parameter in determining its potential for producing a sprite. The charge lowered to ground can be computed by integrating the current waveform over time. Orville et al. [8] first reported a “bipolar” pattern in the distribution of positive and negative CGs in many maso-scale systems, separated by about 60-200 km. **Fig. 5** represents typical convective system associated with Sprites. Models of electrification are exhibited for the convective core on the left and stratiform region on the right (Top). Positive CG discharges are responsible for charge rearrangement in the cloud, which may induce subsequent intracloud “spider” discharges in the stratiform region (Bottom).

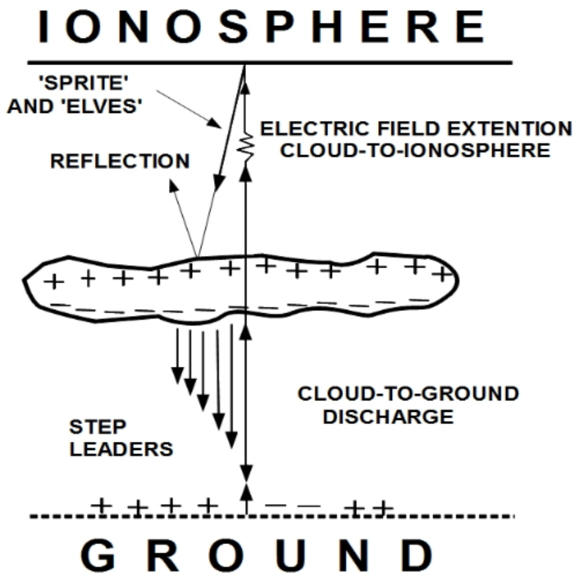

Fig. 4. Schematic diagram of cloud-to-ground lightning discharge

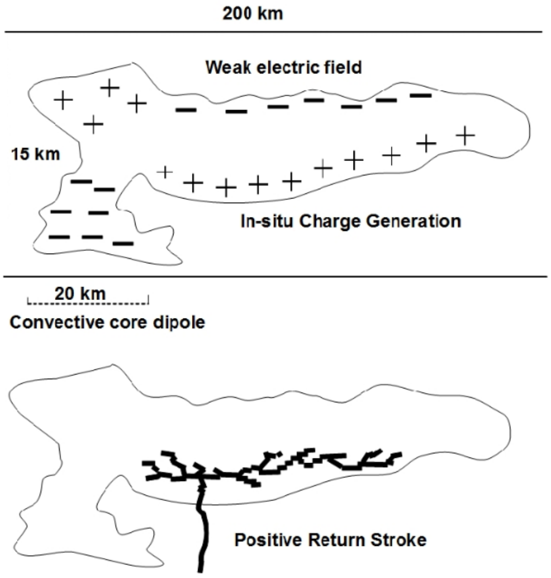

Fig. 5. Schematic of the typical convective system associated with Sprites.

V. LIGHTNING IN THE FORM OF SFERICS

The electromagnetic radiation radiated during lightning discharges may be received by sensitive receivers as SFERICS. Integrated field intensity of SFERICS is the resultant of a large number of individual impulses. The impulses numbering several thousand per second and are received directly as well as by reflections through the ionospheric layers. The sensitive receivers developed and constructed at Kalyani (lat. 22.98°N, long. 88.46°E) for recording SFERICS at 27 kHz is being operated round-the-clock. At the time of vigorous charge activity due to local cumulonimbus clouds causing lightning discharges we noticed an enhancement in the noise level of SFERICS which after the disappearance of repetitive lightning occurrences come down to the normal level. This we have noticed several occasions during the pre-monsoon months of 2010. One of such typical records is presented in **Fig. 6** for illustration.

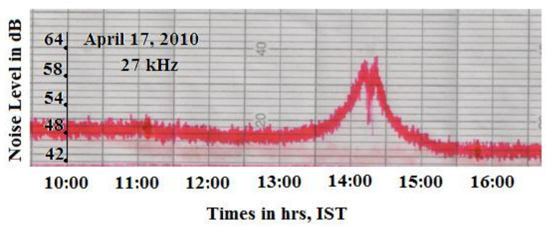

Fig. 6. Typical record of SFERICS showing enhancement in the noise level during vigorous charge activity causing local lightning discharges. The ordinate is in dB above 1μV/m.

The variation of electron density due to various transient events reported at different parts of the globe when critically examined [9, 10] clearly represent a significant change in density with altitude as illustrated in **Fig. 7**.

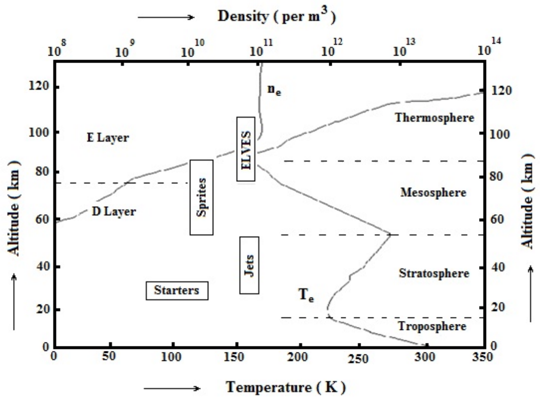

Fig. 7. Variation of electron density with altitude related to luminous events like sprites, elves, jets etc. corresponding to different atmospheric layers from troposphere to thermosphere.

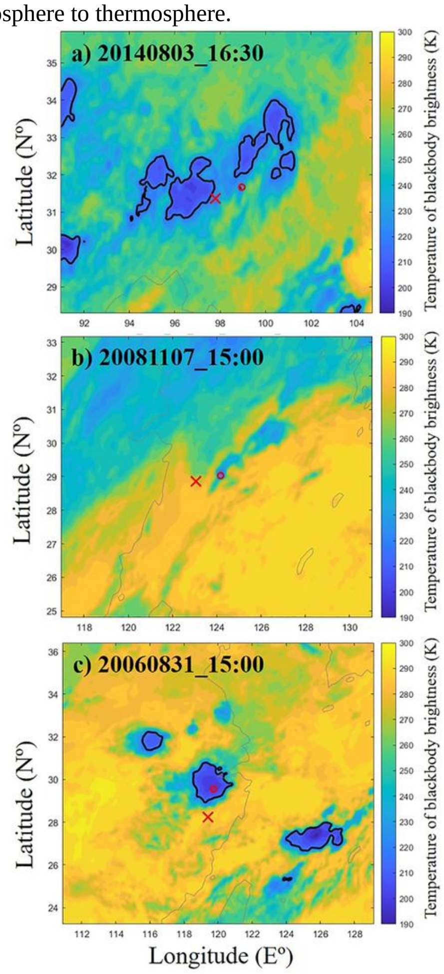

Fig. 8. The examples of positioning results of Imager of Sprites and Elves (in cross) on a map of Black Body Temperature (TBB).

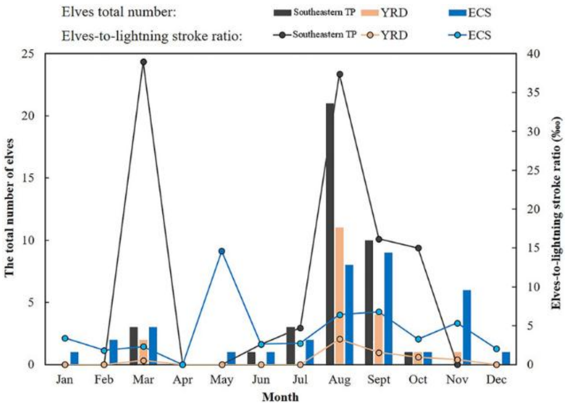

Fig. 9. The monthly total number of elves (in histogram) and elves- to- lightning stroke ratio (‰ , in line- dot) over the regions of the southeastern Tibetan Plateau, Yangtze- River Delta, and East China Sea.

VI. CONCLUSION

During flare events X-ray flux is emitted from the sun and causes photo ionization to neutral atoms in the lower atmosphere. Due to this, concentration of electron increases in the ionospheric D-region. As a result, the character of the earth-ionosphere waveguide will change and propagation of VLF signals will also be affected. Comparing the amplitude and phase of the signals in the disturbed and stable undisturbed condition detection of X-ray flare is possible [11]. In the lower ionospheric D-region production and loss of electron continues. The production is mainly due to photo ionization processes induced by hard X-rays, galactic cosmic rays etc. for some other region of the D-layer. During solar flare and also during the period of quite sun ionization by X-rays is the predominant source of electron production. On the other hand, loss of electron is mainly due to recombination with positive ions. At equilibrium, rate of production of electron is equal to the rate of loss of electron. Since electrons are not only the one negative charge present in the D-region thus recombination of positive ions with the other negative ions is also possible and thus there is a decrease in the ionization level in the D-region due to the 'effective recombination' [12].

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