EPSC Abstracts
Vol. 8, EPSC2013-478, 2013
European Planetary Science Congress 2013

The Discharge Characteristics of TLE-Producing Lightning

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Abstract

On 2 August 2010 and from a site located at the southern tip of Taiwan, we observed 51 TLEs over a thunderstorm near Luzon Island which featured abundant negative cloud-to-ground (-CG) lightning. The TLE events include 42 negative elves, 7 negative halos, 3 positive sprites, and 1 negative cloud-to-ionosphere (-CI; TYPE I) gigantic jet. The ULF and VLF band sferics of these TLEs were also recorded by radio stations in Taiwan. The radio waveforms of the TLE-associated lightning discharges appear to show dependence on the type of TLEs. For example, the ratio of the peak magnetic field in ULF and VLF bands appear to vary with the type of TLEs. Also based on the observed sferics, we try to find the discharge waveform for the lightning that will induce TLEs.

1. Introduction

Previous quasi-electric field modeling result shows that halo would not form when the discharge time is longer than 2 ms due to the attachment process [1]. Recently, Williams et al. used the lightning optical brightness recorded by ISUAL 777.4 nm spectrophotometer as an indicator of the lightning discharge time and found that the duration time of lightning flash for halo and sprite are less and greater than 2 ms respectively [2]. Li, et al. also suggested that the parent lightning discharge of the negative sprite accompanied by halo have at least 450 C km of charge moment change in 0.5 ms or less [3].

In this study, the image and the radio signal of many types of TLEs are recorded simultaneously. The images are recorded by WATEC-N100 cameras. Although the lightning could not be resolved in the low-light-level images, the WWLLN (World Wide Lightning Location Network) lightning data could provide precise lighting location and discharge time. Thus the associated radio signals of TLEs recorded by our ULF (Ultralow Frequency; 0.3Hz to 500Hz) and VLF (Very Low Frequency; 1.5 to 15 kHz) stations can be identified. The waveform of TLE causative lightning in different frequency bands and for different type of TLEs is examined in detail. The discharge characteristics of the causative lightning will further compare with that from the numerical simulations.

2. Observation results

The frequency band of the VLF station used in this work is between 10~15 kHz. The signals with frequency below 10 kHz are truncated due to abnormally intense noise. The VLF peak value for the elve-producing lightning is greater than 3 nT, while the corresponding ULF peak is small. Also, the ULF peak value for halo-producing lightning is much larger than that for elve-producing lightning; even though their VLF peak values are comparable. To characterize the differences between different types of TLE source discharges, one possibility is to track the ULF/VLF value which is defined as the ratio of the ULF peak magnetic pulse and the corresponding VLF peaks (Figure 1). The bar diagram shows the ULF/VLF value for lightning which induces elve, halo and elve accompanied with halo events (elve+halo), respectively. The ULF/VLF ratio of elve-lightning is between 0.15 and 0.7, between 1.2 and 2.7 for halo-lightning, and between 0.3 and 1.1 for elve+halo-lightning.

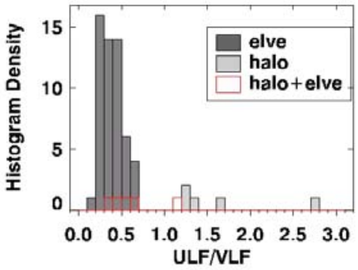

Figure 1: Histogram of the ULF/VLF value.

3. Numerical results

We use 2-D Finite-Difference Time-Domain (FDTD) method to compute the magnetic field radiated by lightning. The input lightning current is assumed to have the form of

$$\begin{cases} I_0 \dfrac{t}{\tau_r},\ t < \tau_r \\ I_0\left(e^{-\left[(t-\tau_r)/\tau_f\right]^2}\right),\ t \ge \tau_r \end{cases},$$

where I_0, τ_r and τ_f represent the peak current of lightning, the rising and the decaying time respectively. The preliminary simulation results are listed in Table 1. Under a fixed current moment and decay time, the ULF band emission appears to increase in sync with the rising time; while the VLF band emission exhibits a decrease trend. This result illustrates that the characteristics of the lightning discharges may be inferred from the observed sferics with the simulation result acting as the guide. Detailed results will be discussed further during the conference.

Table 1: Computed ULF/VLF peak ratio for lightning discharges with the same peak current.

Ip (kA)	Rising time (μs)	Decay time (μs)	ULF-peak value	VLF-peak value	ULF/VLF
60	10	100	0.94	6.81	0.14
60	30	100	1.04	4.80	0.22
60	50	100	1.15	2.53	0.45
60	80	100	1.31	1.4	0.94

4. Summary

From analyzing the TLEs occurred on the same thunderstorm system and at distance between 500 and 700 km from the observation site, the current form could be inferred from the associated sferics recorded by two pairs of magnetic field sensors operating at different wave band. The ratio of the peak ULF and VLF values seems be a good indicator and can be used in studying elves and halos independently of optical systems, which are often limited by weather and observation location.

Acknowledgements

Works were supported in part by the National Space Organization (NSPO) and National Science Council in Taiwan under grants NSPO-S-100010, NSC 100-2111-M-006-002, NSC 99-2112-M-006-006-MY3, NSC 99-2111-M-006-001-MY3, NSC 100-2111-M-006-001, NSC 100-2119-M-006-014, and NSC 100-2119-M-006-015.

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