Journal of Atmospheric and Solar-Terrestrial Physics 179 (2018) 34–39

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Time-Frequency Analysis of vertical and horizontal electric field changes of lightning negative return strokes observed in Sri Lanka

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ABSTRACT

Simultaneously captured vertical and horizontal (total) electric field signatures of lightning negative Return Strokes (RS) were analyzed to obtain Time-Frequency (TF) variation using Stockwell Transformation (ST). In the study, ST was utilized since it is known to possess comparatively better time resolution at high frequency regions compared to other available TF methods. The data were obtained during the monsoon season of April–May 2014. The vertical and horizontal component of fifty negative RSs was utilized in the study. The resultant ST spectrum was analyzed and the regions of interest were demarcated based on the color which represented their relative power output intensities for different frequency components of the signal. The spread area was identified as the region of frequencies which consisted of power intensity equal or above 90th percentile when compared to the maximum possible value. The spectral area was identified as the area of frequencies in the borderline to the natural background noise. The spread region for the vertical E field had a range between 10 kHz and 650 kHz. Its average values were in between 126 kHz and 331 kHz. The spectral region of the vertical electric field change spanned from 1 kHz to 1020 kHz. Its average distribution was 44 kHz–660 kHz. Horizontal electric fields had a range of 20 kHz–1940 kHz in the spectral region. The same for the spread region was 80 kHz–910 kHz. The averages of the horizontal E field's spectral region were 46–1112 kHz and its spread region varied between 227 and 599 kHz. The results display a higher frequency range for all aspects of the horizontal E field changes which implies that its influence on the high frequency radiation is much higher than its vertical counterpart.

1. Introduction

The measurement and analysis of lightning generated electromagnetic fields has a history spanning more than a century. Majority of these studies were done in the time domain where time - amplitude representations were the primary result. It provided the basic shape and magnitude details which were helpful when identifying and segregating different lightning event types. Yet the knowledge of the physical process that takes places inside these lightning events is much more important, especially when designing mechanisms to mitigate or avoid damages caused by them. Frequency spectra information of lightning may add more knowledge on understanding the lightning process. The frequency range of 1–15 MHz is considered to be the most crucial in designing lightning protection solutions, since most of the physical structures are affected by signals within that range (Weidman and Krider, 1986). When resonant frequency radiation couples with these structures, serious damages can be incurred on systems. This was identified by Weidman et al. (1981) where such resonations created electric transients in sensitive electronic components that were found to be a result of radiation from various lightning events.

Studies on frequency spectra of lightning have a history which dates back to the early 1950s. Initially, the spectra were obtained by studying the power response for each frequency value obtained through a narrow bandwidth recorder. This method was found to be accurate for frequencies up to a maximum of 1 MHz (Nanevicz et al., 1987). In the late 1980's the Fourier Transformation (FT) methodology became the most sought method in obtaining the frequency spectra. Lightning signal radiation were obtained by using wide bandwidth recorders and these were subjected to FT. Although FT provides the complete frequency spectra details, it loses all time information of the signal during the process. Thus FT cannot convey details on at what time these frequency components existed in the signal. This inability is the direct result of the uncertainty principle which presides over all types of signals in nature. Therefore, pure time and frequency domain analysis of transient signals such as lightning will result in incomplete information. Although this limitation persisted, in earlier lightning studies (Serhan et al., 1980; Sonnadara et al., 2006; Weidman et al., 1981; Weidman and Krider, 1986; Willett et al., 1989, 1990) FT was utilized intensively.

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https://doi.org/10.1016/j.jastp.2018.06.015
Received 4 May 2018; Received in revised form 15 June 2018; Accepted 26 June 2018
Available online 28 June 2018
1364-6826/

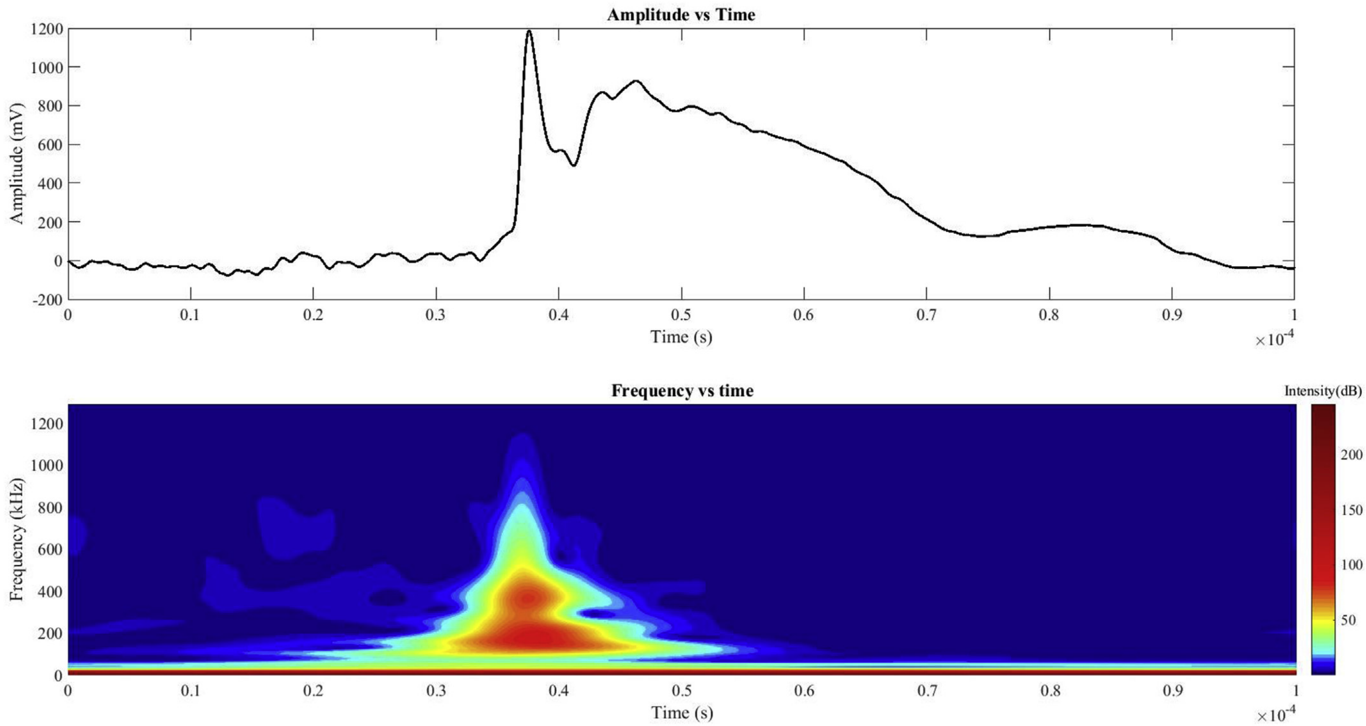

Fig. 1. S-Transform spectrum of the vertical electric field change of a Lightning Return Stroke.

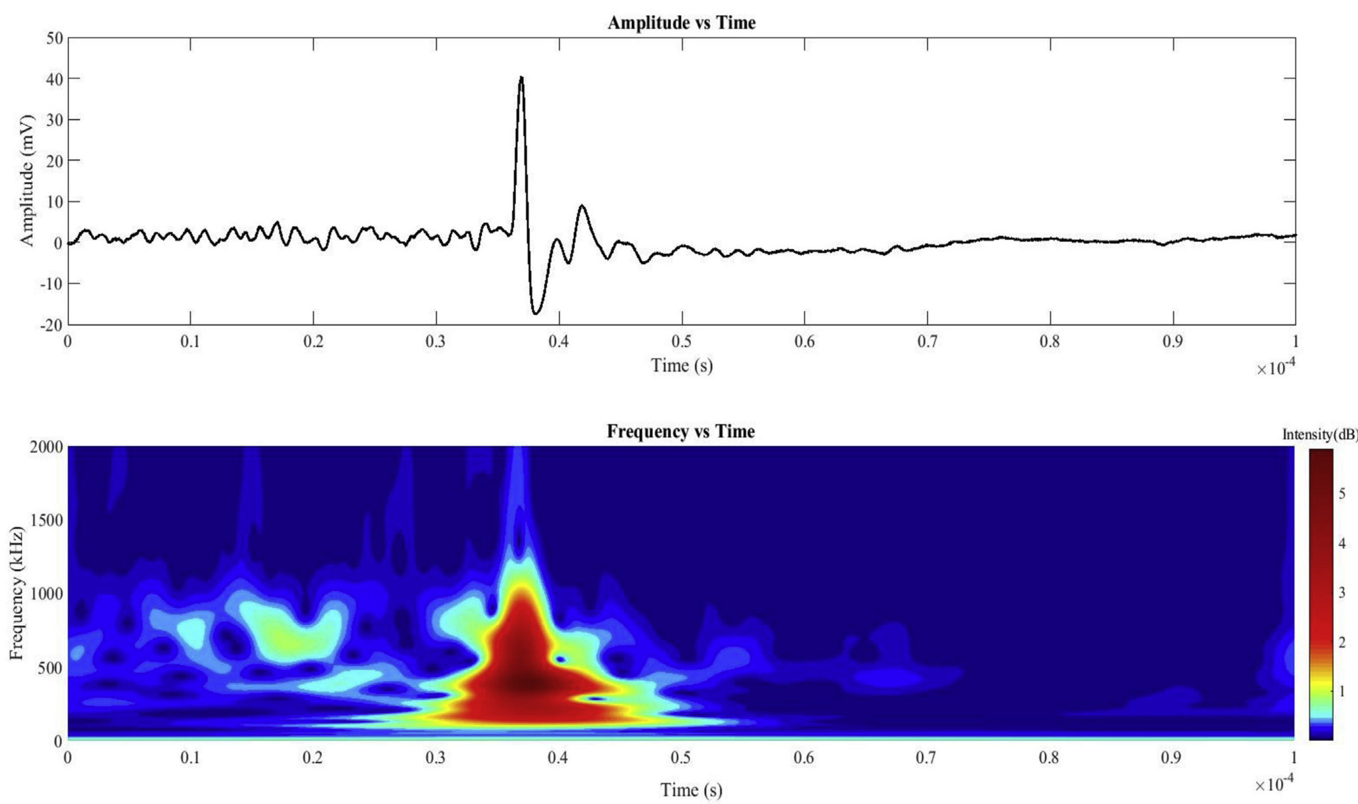

Fig. 2. S-Transform spectrum of the horizontal electric field change of a Lightning Return Stroke.

To overcome this issue, the Time-Frequency (TF) analysis is considered to be the suitable approach. It is in fact a combination of time-domain and frequency-domain analysis where both are applied simultaneously on the signal. The output is the TF distribution, which gives the intensity or the energy concentration of a signal at given time and frequency in a color code. This can be used to identify at what time interval the highest intensity of a signal is present with its corresponding frequency range. Since the uncertainty principle presides, the resultant time and frequency resolution cannot produce the exact values. Instead, both domains will be limited to a time interval and a