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A brief study on thunder claps

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ABSTRACT

Thunder is the acoustic emission associated with lightning discharges. In describing the features of thunder, a few subjective terms such as clap, roll and rumble have been used in the literature with no proper definitions. In this study the features of pressure pulses and their relative amplitudes were analyzed to understand claps of thunder. The subjective term clap was quantified along with relative pulse amplitudes and confirmed by listening to the recorded thunder signals carefully. The pulses with amplitudes greater than 40% of the peak amplitude were identified as claps. The most significant contribution to the sound in a thunder flash is due to claps and has been investigated separately in this article. The number of claps in a thunder flash, their frequency variation, time to start first clap, clap duration, and there pulse characteristics have also been studied. The frequency of pressure oscillations within these claps has been found to be less than 300 Hz. Besides, this study has revealed that 62% of the flashes consist of 1 to 2 claps. While it has been observed that the activity of the thunder signal is higher in the initial half than in the latter half.

1. Introduction

Thunder is the acoustic emission associated with a lightning discharge. The pressure created inside a rapidly heating lightning channel generates a shock wave. After propagating a few meters, the shock wave turns into a thunderflash. Investigating the different sounds associated with thunder is essential to recognise them from ambient noise. It is worthy to note that in describing thunder, subjective terms such as clap, peal, roll, and rumble have been used in literature without proper definitions.

Peals or claps are the sudden loud sounds that occur against a background of prolonged roll or rumble, which are separated by time intervals of 1 sec or more. A clap is sometimes considered to be less intensive and of shorter duration than a peal. Duration of claps is about 0.2–2 sec [1], and are (apparently) produced when individual thunder signals from portions of sufficiently long sections of a lightning channel arrive more or less simultaneously at the observer's location [2–4]. Thus, a clap is produced from a section of the channel having a relatively high overall length that is oriented or partially oriented to the observer's line of sight. The time interval between claps has been reported to be typically 1–3 sec [1], and there are about two to four claps per flash [1,5,6]. Details of relative clap amplitudes are found in [1,5], and [6]. In Florida, Uman and Evans (1977) reported approximately 2 or 3 claps per ground flash [7]. They further revealed that the first clap in ground flashes is generally the largest, the second clap the second largest, and the third clap the third largest. However, this result is not consistent with the data of Latham (1964) for a combination of cloud and ground flashes [1].

According to [8] and [9], the formation of thunderclaps has three contributory effects. A macro tortuous segment of a lightning channel will direct the acoustic radiation from its constituent meso tortuous pulse-emitting segments into limited annular zones. An observer located in this zone (near the perpendicular plane bisecting the macro tortuous segment) will perceive the group of pulses as loud as a clap of thunder, whereas another observer outside the zone will perceive this same source as a lower-amplitude rumbling thunder. This has been confirmed by experiments [2] and in computer simulations [10]. A second effect, which occurs only very close to the plane, is the juxtaposition of several pulses in phase, which increases the pulse amplitude to a greater extent than would be a random arrival of the same pulse. The third effect contributing to thunderclap formation is merely the bunching effect in time of the pulses. In a given period of time, more pulses will be received from a nearly perpendicular macro tortuous segment of a channel than from an equally long segment perceived at a higher angle, owing to the overall difference in the travel times of the composite pulses.

Again, [3] and [4] discussed in detail the generation of thunderclaps that are to be associated with the sound emitted by relatively long sections of the main channel and by channel branches that are approximately perpendicular to the line of sight of the observer.

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This fact that had been was verified experimentally by Few (1970) [2]. It is reasonable to expect the branches of first strokes to be powerful sources of sound, since, according to the data of Malan and Collens (1937), branches may be instantaneously brighter than the main channels above those branches [11]. It is interesting to note the presence of approximately as many claps per thunder as there are branches in a first stroke [12], so the branches may well account for a significant fraction of the claps. Several attempts have been made in the literature to discuss the thunderclaps recently [13–15].

The main objective of this study was to quantify the thunder sound called "thunderclap" in a more consistent manner. Relative amplitudes and pulse occurrence characteristics of thunderclaps have been analysed, and the number of claps in a thunder signal, their frequency variation, duration of claps, time interval between two claps, time taken to start the first clap, mean number of pulses in a clap, and the variation of relative amplitudes of claps are investigated.

2. Material and methods

The experimental set-up for this study consisted of Bruel & Kjaer type 4198 free-field ½" microphone that is stable under a variety of conditions, a 2669C preamplifier with wide frequency and dynamic range with low noise, 2690 Nexus conditioning amplifier, and NI 4472, 24 bits resolution, high-performance, high accuracy dynamic signal acquisition device. The ambient wind noise was reduced using a wind screen. About 260 thunder signals were recorded with the sampling rate of 100 kS/s in 30 s windows for a three-year period in Hambanthota (81^0 0′E, 6^0 10′N), located close to the southern coast of Sri Lanka.

3. Results

Out of the recorded data, sixty-four successful signals that occurred at a distance of 1–6 km from the microphones were selected for the analysis. All thunder signals were replayed using MATLAB software and listened carefully with the aid of a powerful earpiece to distinguish the different sounds throughout the flash. The time periods of sounds of claps of each thunder flash were noted.

Fig. 1 presents the amplitude variation of one of the complete thunder signals. The microphone output amplitude is plotted as pressure perturbation with time in sec, the duration of the thunder flash being 30 sec. The amplitude was found to vary considerably during the period between +86 mV and −80 mV, from sudden loud spikes to quieter and more gradually varying parts. Five claps identified by listening to the thunder signal 1 were noted in Fig. 1, named as clap 1 to clap 5. The enlarged diagrams of the above five thunder claps with the same time scale are illustrated in Fig. 2a–e.

All above figures clearly indicate that claps and rest of the thunder signal are formed by accumulating hundreds of acoustic pulses. This analysis considered only the flashes that have amplitudes well above the noise level, which is 10% of the peak amplitude pulse. Analysing these pulses is more informative in understanding various sounds of thunder. Here, the thunder signal of each flash was split into 500 ms intervals, and all significant pulses within the range were counted, and the counted pulses were grouped according to their relative amplitudes. Pulses of relative amplitudes greater than 40% are not continuously distributed throughout the flash, and they appeared as pulse bunches. Distribution of such pulse bunches, where relative amplitudes greater than 40% for three thunder signals, were named as Thunder 1, Thunder 2, and Thunder 3, as shown in Fig. 3a–c respectively. The distributions of these groups are analogous to the above-identified clap sounds.

A brief analysis was conducted for this region since this is the dominant and significant sound of thunder flash. Throughout this analysis, pulse gatherings of relative amplitudes higher than the 40% of peak amplitude are considered to recognise the claps. The number of claps in a thunder flash was found to vary with the flash. The histogram in Fig. 4 implies the highest occurrence number of claps in a thunder flash is two and 34% of flashes were recorded with two claps, and 28% of flashes were with a single clap out of the 64 flashes. Only two flashes (0.03% out of 64 flashes) were recorded with five claps.

The clap duration or width of a clap is considered as the period in which the amplitudes of the above-mentioned bunch of pulses remain higher than 40% of the peak pulse amplitude, and which varies from clap to clap. The durations of claps were calculated with clap order for all collected thunder flashes. Fig. 5a–c, and d show the histograms of occurrences of clap durations for first, second, third, and fourth claps respectively. Fig. 6 presents the durations of all claps. The fifth clap, which recorded only two flashes, was not considered in this study.

Fig. 5a–c, and d imply that the duration of claps has no significant difference with the clap order. Only six first-order claps (10% out of 64 claps) and two second-order claps (4% out of 47 claps) lasted for more than 2.5 sec., and none of the third and fourth claps lasted beyond 2.5 sec.

The time interval between the end of a clap and the beginning of the next consecutive clap is considered as clap separation. Fig. 7 presents a histogram for occurrences of clap separations between two successive claps without considering the flash type and infers that the 70% of clap separations are less than 2.0 sec.

The first clap seems to have started with thunder in some lightning flashes, while it takes a little time to start the first clap in

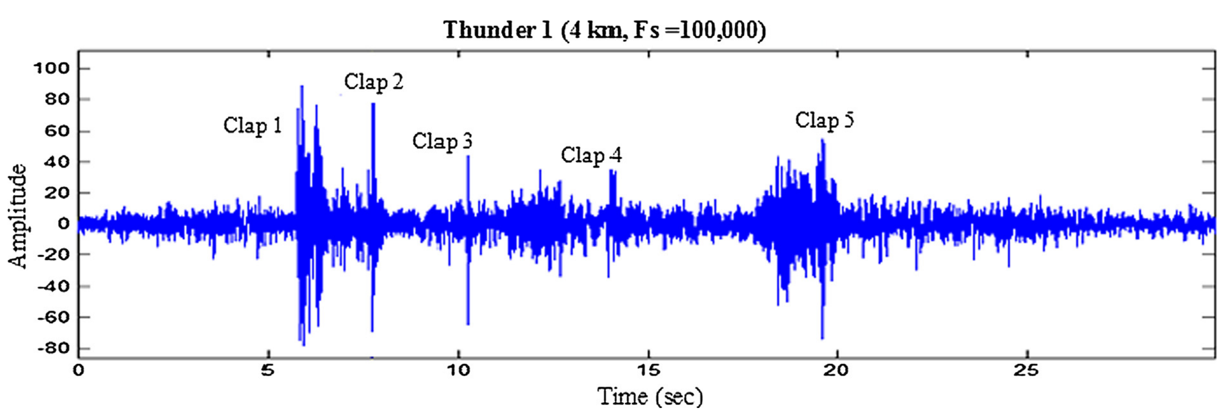

Fig. 1. A typical thunder signal (Thunder 1) with five claps recorded in this study generated by a cloud to cloud lightning flash, 4 km far from the microphone.