Journal of Atmospheric and Solar-Terrestrial Physics 113 (2014) 39–43

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

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

Modification of lightning quasi-electrostatic signal by mesospheric halo generation

A.J. Bennett [a,b,*]

[a] Bristol Industrial and Research Associates Limited (Biral), P O Box 2, Portishead, Bristol BS20 7JB, United Kingdom
[b] Department of Electronic and Electrical Engineering, University of Bath, Bath BA2 7AY, United Kingdom

ARTICLE INFO

Article history:
Received 27 January 2014
Received in revised form
21 March 2014
Accepted 24 March 2014
Available online 3 April 2014

Keywords:
Lightning
Thunderstorm
Mesosphere
Ionosphere

ABSTRACT

Current induced by the electrostatic component of lightning on a conductor exposed to the atmosphere was measured at 100 Hz by detectors at two sites in southern England. These detectors were separated by 120 km and capable of lightning detection to a range of approximately 100 km. Signals from the same flash detected by both receivers were generally of the same shape, as expected if the source was charge neutralisation by lightning of relatively small horizontal extent. For approximately 1% of flashes detected the signal shape received at both sites was considerably different, indicating that the small vertical dipole approximation was not sufficient to explain the detected charge reconfiguration during the flash. This discrepancy was explained by the addition of a short pulse of horizontally extensive charge above the flash, consistent with a mesospheric halo. The effect of this halo superimposed on the signal from the parent lightning is described. The observations support previous evidence that quasi-static current measurement can be used to identify flashes which produce halos and so complement existing optical halo detection instrumentation.

1. Introduction

The neutralisation of electrical charge during a lightning flash produces a quasi-electrostatic field change most noticeable at frequencies between 1 and 20 Hz (Wilson, 1920; Wormell, 1939; Pierce, 1955). At these frequencies the surface can be considered a perfect conductor and the image of the lightning charge results in the signal amplitude reducing proportional to the inverse cube of range (Pierce, 1955). This effect limits the range of electrostatic lightning detection to typically less than 100 km. In contrast, electromagnetic detection provides a range of several thousand kilometres using the Earth-ionosphere waveguide (MacGorman and Rust, 1998) due to the attenuation with distance being two powers lower. The sensitivity to distance of quasi-electrostatic measurements is however useful in estimating distance to lightning from a single site (Pierce, 1955; Bennett, 2013). The quasi-static current measurement technique described by Bennett (2013) operates at frequencies between 1 and 50 Hz and produces signals proportional to the rate of change of atmospheric electrostatic field. A 200 Hz low pass filter effectively removes the electromagnetic (radiative) component of electric field change associated with lightning of any significant amplitude. This technique is therefore favourable for the separation of small and rapid quasi-electrostatic field changes which may otherwise be difficult to distinguish amongst radio-wave emissions or lower frequency variability of similar magnitude associated with wind-blown space charge.

Short-lived (~1 ms) ionised electrical perturbations at an altitude of approximately 80 km referred to as halos are sometimes produced by lightning strokes, typically of large peak current (Barrington-Leigh et. al., 2001, Wescott et al., 2001). Halos are considered to have a major influence on mesospheric chemistry and behaviour (Bering et al., 2004a; Parra-Rojas et al., 2013), although their fundamental characteristics such as size and charge are still subject to ongoing research. Halos are usually detected from satellites or on the ground during clear nights by their weak luminous pulse visible with sensitive, high speed video cameras (Williams et al. 2012). Bennett and Harrison (2013) reported signals consistent with that expected from halos using an alternative quasi-static induced current measurement (Bennett, 2013). The detector is capable of receiving signals from Transient Luminous Events 1000 km away (Füllekrug et al., 2013). The halo produces a rapid change in electric field due to the rapid horizontal redistribution of charge in the lower ionosphere as a result of charge neutralisation by lightning in the thunderstorm

---

* Correspondence address: Bristol Industrial and Research Associates Limited (Biral), P O Box 2, Portishead, Bristol BS20 7JB, United Kingdom. Tel.: +44 (0) 1275 847787.
E-mail address: alec.bennett@biral.com

http://dx.doi.org/10.1016/j.jastp.2014.03.010
1364-6826/© 2014 Published by Elsevier Ltd.

below (Barrington-Leigh et al. 2001, Bering et al., 2004b). Ionisation at ~80 km results in an increased electron density and visible halo (Kuo et. al. 2013). There may also be the opportunity for vertical charge transfer to the ionosphere directly via sprites, but not all halos are associated with visible sprite streamers (Williams et al. 2012). Although the total electric field change from an overhead halo is small, the rapid change produces a distinct current spike lasting <10 ms induced on a suitable receiver (Bennett and Harrison, 2013). Due to the horizontally extensive nature of the lower ionospheric electron density enhancement associated with halos, the characteristic current spike from a halo can be detected several hundred kilometres from the parent lightning flash.

The quasi-static current signals from suspected halos analysed by Bennett and Harrison (2013) were from storms located over the sea, producing flashes generally too remote for their signals to be detected. The objective of the work described here was to capture the signals from halo-producing flashes at close range and determine how the shape of the signal changed with distance, testing the concept that a halo signal should become more apparent over the lightning signal with distance, as proposed by Bennett and Harrison (2013).

2. Measurement technique

Two identical detectors measuring induced current between 1 and 50 Hz were installed at different sites in southern England from 29 May 2012. One (TD1), was at Reading University Atmospheric Observatory (51.442°N, 0.938°W) and the other (TD2) approximately 120 km west at Biral headquarters in Portishead (51.483°N, 2.769°W). Further details on the detectors are described by Bennett (2013). Lightning stroke location data were purchased from the LINET lightning detection network, operating in the VLF/LF band (Betz et al., 2008), which also identifies the type (cloud-to-cloud or cloud-to-ground), polarity and peak current of the return strokes. In some cases, signal timing by the detectors varies by up to 2 s between sites due to crystal oscillator timing drift between daily GPS synchronisations, although this uncertainty was sufficiently small to allow identification of signals originating from the same flash. Power line interference at 50 Hz (and harmonics up to 200 Hz) represents the noise floor for the plots discussed in this work. The interference was not removed by software notch filters to avoid any distortion of the shape of the flash and halo signals, which were usually clearly identifiable above the noise.

With an assumption that horizontal charge transfer distances by lightning are small compared to the horizontal distance to the receivers, a lightning flash can be considered a point source or vertical dipole, imaged by the ground. The shape of the signal will therefore be conserved with distance from source, aside from the reduction in overall intensity. Two examples of this are shown in Fig. 1, where induced current from the same lightning flash is recorded by both detectors. Relative current is used here to emphasise the shape of the signals. The shapes from each flash are broadly consistent at both sites, indicative of a typical flash where charge redistribution occurs within the thunderstorm cell and underlying surface.

Compared to those from lightning flashes, halo signals are of short duration (within 10 ms) and importantly for their distinguishment from flashes, have no detectable recovery curve immediately afterwards, since the electrical relaxation time at halo altitudes is only ~1 ms (Kuo et. al. 2013) and do not have the same charge separation process which restores the electrostatic field after a flash as found in thunderstorms (Wormell, 1939). An example of a suspected halo signal with its parent flash is shown in Fig. 2. The flash shown in (b) is characteristic of a positive cloud-to-ground. The main difference between the flash and halo signals

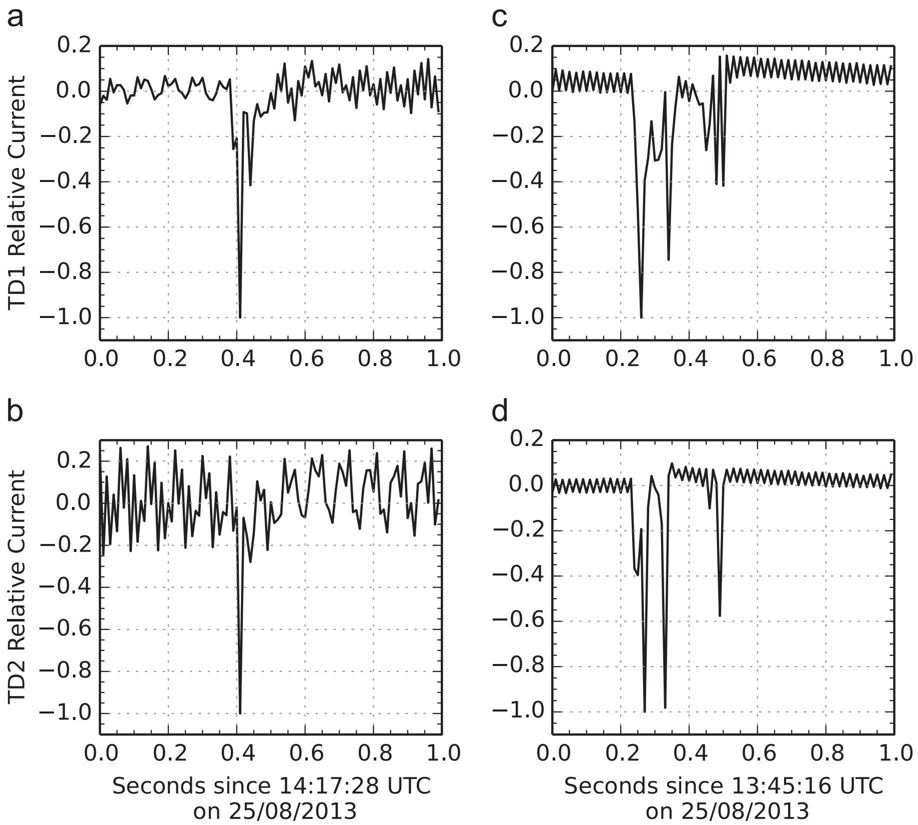

Fig. 1. Relative current signals from two lightning flashes that did not produce a halo. Graphs (a) and (b) are for a −19 kA flash 66 km and 62 km from TD1 and TD2 respectively. Graphs (c) and (d) are for a −53 kA flash 56 km and 72 km from TD1 and TD2 respectively.