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Lightning Observatory in Gainesville (LOG), Florida: A review of recent results

V.A. Rakov*, S. Mallick, A. Nag[1], V.B. Somu

Department of Electrical and Computer Engineering, University of Florida, Gainesville, FL 32611, USA

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ABSTRACT

A review of several recent studies conducted at the Lightning Observatory in Gainesville (LOG), Florida, is given, including (a) evaluation of field-to-current conversion equations, (b) lower positive charge in the cloud and lightning type, (c) positive lightning, (d) compact intracloud lightning discharges, (e) lightning interaction with the ionosphere, and (f) X-rays produced by first and subsequent strokes in natural lightning. The results serve to improve our understanding of the physics of lightning with important implications for lightning detection and lightning protection areas.

1. Introduction

In this paper, we review several topics recently studied at the Lightning Observatory in Gainesville (LOG), Florida. The LOG is part of the International Center for Lightning Research and Testing (ICLRT), which also includes the Camp Blanding (CB) lightning-triggering facility. The LOG was established on the University of Florida campus in 2004 primarily for measuring electromagnetic fields produced by lightning. Over the years the experimental setup has undergone upgrades, modifications, expansions, and relocation. It is currently located on the roof of the five-storey New Engineering Building (29°38′32″ N 82°20′50″ W). The LOG includes a glass cupola providing over a 180° unobstructed view of the horizon. The cupola houses digitizing oscilloscopes, computers, and high-speed video cameras, with the various sensors and associated electronics being located nearby on the roof. The sensors currently include electric field antennas, electric field derivative (dE/dt) antennas, magnetic field derivative (dB/dt) antennas, and an X-ray detector. Signals from all the sensors are relayed by fiber-optic links to the glass cupola, where they are recorded. All records are GPS time stamped. An overview and photographs of LOG are shown in Figs. 1 and 2, respectively.

The LOG was originally designed to respond to both natural lightning flashes during local storms over Gainesville and natural and rocket-triggered flashes at CB, at a distance of about 45 km from LOG. Accordingly, there are two modes of operation: single-station (for local measurements) and two-station (for recording CB events). For single-station measurements, the system is triggered when the electric field exceeds a set threshold level. For two-station measurements, a dedicated phone line is used to transmit a trigger signal from CB to LOG in the event of a lightning discharge at CB. The single-station mode of operation was also used for recording distant (up to 350 km or so) flashes. In 2011, an additional field measuring station was set up in Starke, at a distance of about 3 km from CB, to allow three-station (LOG, Starke, and CB) measurements. Detailed descriptions of LOG are given by Nag [1] and Mallick et al. [2].

The following selected topics studied at LOG are reviewed in this paper:

- Evaluation of field-to-current conversion equations.
- Lower positive charge in the cloud and lightning type.
- Positive lightning.
- Compact intracloud lightning discharges.
- Lightning interaction with the ionosphere.
- X-rays produced by first and subsequent strokes in natural lightning.

* Corresponding author at: 553 Engineering Building #33, P.O. Box 116130, Gainesville, FL 32611-6130, USA. Tel.: +1 352 392 4242; fax: +1 352 392 8381.
E-mail address: rakov@ece.ufl.edu (V.A. Rakov).
[1] Present address: Thunderstorm Systems and Data Division, Vaisala Inc., Louisville, CO 80027, USA.

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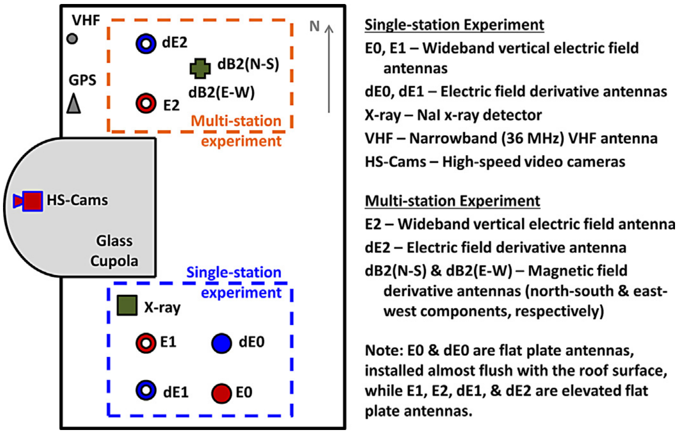

Fig. 1. An overview of the Lightning Observatory in Gainesville (LOG), Florida. E1, dE1, VHF, and X-ray detector were used in the single-station mode of operation, E2 and dE2 in the two-station mode, and dB2 in both modes. The VHF antenna is presently not utilized and additional electric field (E0) and dE/dt (dE0) antennas were added in 2011 for very close lightning field measurements. Recently, two high speed cameras were installed in the glass cupola.

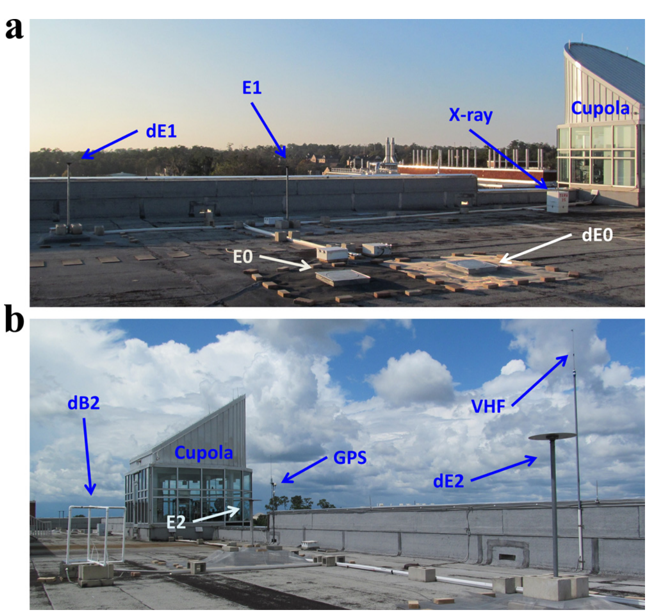

Fig. 2. Photographs of the Lightning Observatory in Gainesville (LOG), Florida (a) single-station experiment and (b) multi-station experiment.

The results serve to improve our understanding of the physics of lightning with important implications for lightning detection and lightning protection areas.

2. Evaluation of field-to-current conversion equations

Return-stroke peak current is one of the most important measures of lightning intensity needed in different areas of atmospheric electricity and lightning protection research. It can be estimated from the corresponding electric or magnetic radiation field peak. Electric fields of 89 strokes in lightning flashes triggered using the rocket-and-wire technique at CB in 2008–2010 were recorded at LOG. Peak currents were estimated from the measured electric field (or integrated electric field derivative) peaks using the empirical formula of Rakov et al. [3] and the field-to-current conversion equation based on the transmission line model (Uman and McLain [4]). The empirical formula of Rakov et al., based on data for 28 triggered-lightning strokes acquired by Willett et al. [5] at the Kennedy Space Center (KSC), Florida, is given by:

$$I = 1.5 - 0.037rE \tag{1}$$

where I is the return-stroke peak current in kA and taken as negative; E is the electric field peak, is positive, and in V/m; and r is distance to the lightning channel is in km. The field-to-current conversion equation based on the transmission line model is given by:

$$I = \frac{2\pi\varepsilon_0 c^2 r}{v} E \tag{2}$$

where ε_0 is the permittivity of free space, c is the speed of light, and v is the return-stroke speed (assumed to be constant). The return-stroke speed is generally unknown and its range of variation from one event to another is typically from $c/3$ to $2c/3$. Both I and E are absolute values. Perfectly conducting ground is assumed.

These estimates, along with peak currents reported by the U.S. National Lightning Detection Network (NLDN), were compared with current peaks directly measured at the lightning channel base (at CB). The empirical formula tends to overestimate peak currents (see Fig. 3) with the mean and median absolute errors being 24% and 22%, respectively. The NLDN-reported peak currents are on average underestimates and exhibit more scatter than those predicted by the empirical formula (compare Fig. 4 with Fig. 3), but they are (on average) in a better agreement with the ground-truth data. Indeed, for the NLDN, the mean and median absolute errors are 16% and 13%, respectively, lower than those for the empirical formula. The field-to-current conversion equation based on the transmission line model gives the best match with directly measured peak currents for return-stroke speeds between $c/2$ and $2c/3$, where c is the speed of light (see Table 1). Possible reasons for the discrepancy in the peak current estimates from the empirical formula and the ground-truth data include an error in the field calibration factor, difference in the typical return-stroke speeds at CB and at the KSC (considered to be the most likely reason), and limited sample sizes, particularly for the KSC data.

These results are presented by Mallick et al. [6].

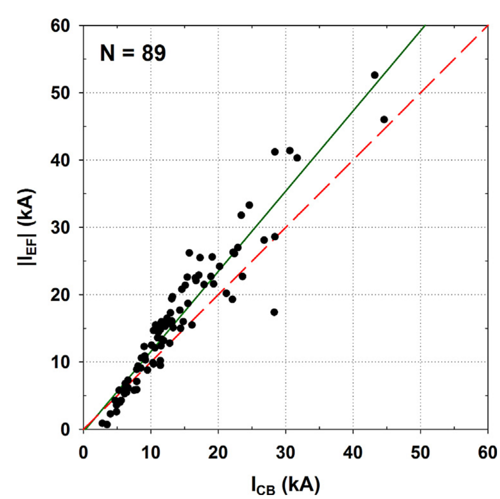

Fig. 3. Magnitude of peak current estimated from the empirical formula of Rakov et al. [3] (I_{EF}) vs. directly measured peak current (I_{CB}). The solid green line is the best (least squares) fit to the data, while the broken red line represents the ideal situation when $|I_{EF}| = I_{CB}$.

Adapted from Mallick et al. [6].