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Evaluation of multiple ground flash charge structure from electric field measurements using the local lightning detection network in the region of Warsaw

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ABSTRACT

During three summer months from 16 June to 16 September 2009, the Local Lightning Detection Network (LLDN) set up in the Warsaw region was successfully operated. Seventeen events of multiple cloud-to-ground (CG) lightning flashes have been recognized which caused E-field variations recorded simultaneously by all the LLDN six stations. A dedicated software package has been developed for the purpose of the E-field analysis and calculations of the three-dimensional location of the lightning point electric charge source. The location has been determined by the source coordinates x, y, z in a local Cartesian coordinate system and besides the magnitude of the electric charge, Q, involved in a CG return stroke or continuing current, has been obtained. Several examples of the spatial and temporal development of the multiple CG flashes initiated in different meteorological situations are presented and discussed in the paper.

1. Introduction

A method using simultaneous multi-station ground-based measurements of lightning-generated electric field variations, ΔE, for the purpose of the lightning flash location and analysis of the lightning charge structure was applied and described by Krehbiel et al. (1979). They used a network of 8 slow antennas to perform precise spatial and time analysis of the development of CG lightning flashes observed in New Mexico (USA). Mathematically, the coordinates x, y, z of the electric charge center and the charge Q transferred to the ground by a CG stroke are related to ΔE variations measured at one station and form one linear equation. In theory, to determine four unknown variables, four stations are sufficient to obtain the unique solution for a set of four independent equations. The role of redundant measurements at additional sites is to increase the confidence in the searched solutions. In addition, in order to find the location and the charge value from ground-based ΔE measurements it is necessary to assume the electric charge geometry. The simplest model of a point electric charge located above a perfectly conducting Earth's plane surface has been taken into account both in Krehbiel et al. (1979) and this work. The validity of such a model is limited to the cases when the electric charge reduced by a CG flash is assumed to be spherically symmetric and of much smaller dimensions compared to the charge distance from the ground (Krehbiel, 1986; Williams, 1989). More remarks and additional information on using such techniques to localize CG lightning can be found in (Rakov and Uman, 2003). It is also worth noting that a multi-site network of slow E-field antenna systems, synchronized individually by GPS units with 1 μs time resolution, is at present successfully operated in the Chinese Inland Plateau region and used

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for detection of intra-cloud (IC) and CG discharges, and for studies of thundercloud charge structure (Cui et al., 2007).

More recently, Stolzeburg and Marshall (2009) reported some examples of complex thunderstorm charge structures retrieved from in situ balloon electric field measurements. However, although such balloon soundings have brought many valuable and essential data about the complexity of charge structure in specific types of storms in the US such as mesoscale convective systems, supercells, and New Mexico mountain storms, they are expensive and difficult to perform routinely in thunderstorm observations beyond the US. Therefore, ground-based multi-station measurements of E or ΔE, applied to obtain the 3-D location of lightning initiation source and evaluation of its charge magnitude seem to be an acceptable solution which can be used more widely and which provides a practical and relevant indirect method of acquiring important information about the charge structure and its changes in space and time in any types of thunderstorm systems (see e.g., Rison et al., 1999; Maggio et al., 2005; Weiss et al., 2008), with high time resolution.

Loboda et al. (2009) have underlined some scientific and operational advantages that can especially be obtained in Poland from the employment of small and mobile local lightning detection network operating in low LF frequency range. The important lightning parameters such as the altitude and the amplitude of the electric charge source involved in particular lightning flashes cannot be determined from data gathered by standard large lightning detection systems that perform real-time monitoring of thunderstorm activity over Poland, e.g., the Polish national PERUN (SAFIR) system working in VHF/LF frequency range (Maciazek and Bartosik, 2004; Baranski et al., 2006) or the European commercial LINET network working in VLF/LF regime (Betz et al., 2009). Although these two wide range lightning location systems are designed by their producers for continuous and routine operation their lightning detection quality should be checked using long-term real damage strike statistics but also validated during short-term field campaigns of independent small local lightning detection networks equipped with own recording devices and computer algorithms for data processing.

2. Local lightning detection network (LLDN) in Warsaw region

2.1. Configuration and performance features of the LLDN

Each LLDN observation station is designed to record variations of the vertical component of the electric field coming from a lightning flash. The stations have been equipped with an E-field antenna with a triggering circuit, two-channel data recording device, commercial GPS receiver and a power supply system with battery backup.

The LLDN dedicated data recorders were based on the standard PC/104 built-in computer (AMD LX800 at 500 MHz) run on Linux operating system. Each recording device has been designed as a stand-alone station working without assistance during a measurement session. The built-in internal hard drive (of ~150 GB data buffer) allowed to store recorded data for 3 days maximum, i.e., 72-hour continuous recordings in the fast mode with bandwidth up to 100 kHz. The functional block diagram of the station is shown in Fig. 1.

The electric field variation ΔE generated by a lightning discharge is received by the antenna system equipped with preamplifiers. To obtain a high dynamic range of the acquired signal, the antenna preamplifiers have two outputs of different amplification factors (sensitivities). This solution gives a relatively good signal-to-noise ratio and avoids signal distortion or saturation. Additionally, an analog triggering circuit has been included. A block diagram of the electric antenna is shown in Fig. 2a.

An additional element of the station, dedicated to this particular project, is a dual channel data recorder (the block diagram shown in Fig. 2b). The functionality of the board includes analog-to-digital signal conversion (14 bits, 40 MHz), digital signal processing and data sample buffering in internal memory. The recorder control electronics provides precise data sample time synchronization to Coordinated Universal Time (UTC). A commercial GPS receiver's one-pulse-per-second output (1 pps) has been used as a reference for the data sample time tagging (accuracy $\pm$ 1 μs). Digital signal proces-

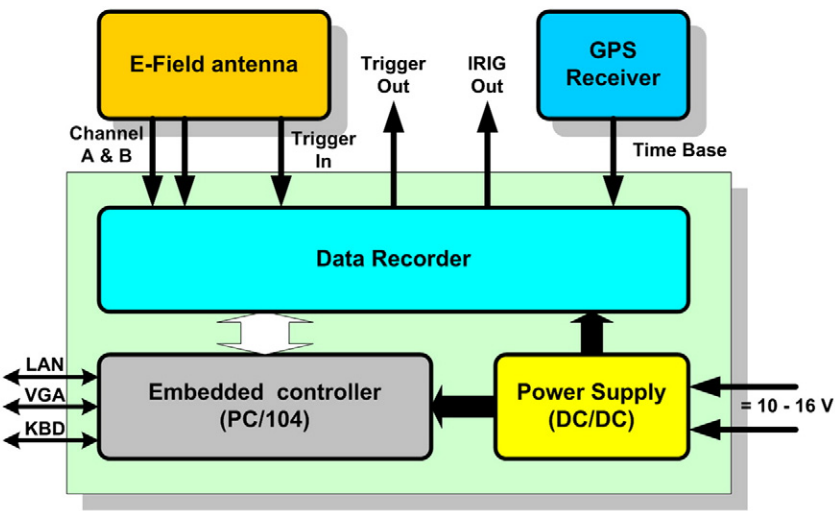

Fig. 1. Block diagram of an LLDN recording station.