Journal of Electrostatics 67 (2009) 507–512

Contents lists available at ScienceDirect

Journal of Electrostatics

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

On the lightning hazard warning using electrostatic field: Analysis of summer thunderstorms in Spain

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ARTICLE INFO

Article history:
Received 15 September 2008
Received in revised form
14 November 2008
Accepted 18 January 2009
Available online 5 February 2009

Keywords:
Lightning warnings
Atmospheric electric field
Electric field mill
Electric field threshold
Polarity reversal
Forecasting verification

ABSTRACT

This work presents an analysis of lightning warnings based on atmospheric electrostatic field measurements achieved in the city of Terrassa (northeastern Spain). Seven summer thunderstorms were analyzed. Lightning location data were obtained from two lightning detection networks that provide cloud-to-ground (CG) and intra-cloud (IC) flash information. Warning behaviour was studied on the basis of the "two area method" using both electrostatic field (EF) thresholds and polarity reversal detection. The study of the total lightning locations (CG + IC) with respect to the electric field mill (EFM) site lets investigate the possible EF threshold and EF polarity inversion values useful for warning. The probability of detection (POD) and the false alarm ratio (FAR) were evaluated in both cases obtaining slightly better results by using polarity change criteria. The paper also includes a discussion about the lead times (LTs) obtained between the trigger of a warning and a CG located in the area of concern (AOC).

1. Introduction

In many countries lightning activity is one of the major causes of weather related human injuries and death. In the United States lightning causes an average of 62 fatalities and hundreds of people suffer some kind of injury each year [1]. In Colombia, a tropical country with approximately ten times less population than the United States, it is estimated from reports in the media that around 100 people per year are killed by lightning and the number of injured people could be close to 1000.

Warnings due to lightning have been commonly developed from the detection of cloud-to-ground (CG) flashes (e.g. [2–4]), and more recently, the addition of intra-cloud (IC) lightning detections forming total lightning warning algorithms (e.g. [5,6]). On the other hand, meteorological radar provides valuable information about the reflectivity and location of convective cells which can become thunderstorms. Since radars were commonly available some works added the radar information to their alarm methods (e.g. [7–9]). Finally other lightning warning methods have taken into account the atmospheric electrostatic field (EF) (e.g. [10–13]). Nowadays electrostatic field measured by single field mill sensors (EFM) are widely used to warn sport fields, leisure parks and many other outdoor activities [13]. All of the introduced warning methods are still improving their performance. The case of warnings based on EF, the optimal thresholds and warning criteria are still not well defined.

In fair-weather conditions the electrostatic field (EF) averages 120 V/m. The environmental EF is directly affected by the presence and motion of electric charges into the thunderclouds reaching values, at flat ground, up to 15 kV/m [14–16]. Depending on the charge magnitude and their location, the cloud field could be detected in a range close to 20 km. In addition, when an electrified cloud is approaching a site, an EF polarity reversal due to the mid-level negative charge in the cloud typically occurs. Then, the high EF amplitudes and polarity changes are the main indicators of storm evolution useful for warning. The probability of detection (POD, portion of observed events that were correctly forecast) based on EF warning thresholds was recently studied in Florida – USA [12], where a POD value of 34.4% was found considering an EF threshold of 1 kV/m. As the authors pointed, the low POD value was probably due to the relatively large distance between the cloud charge and the EF measurement at ground which tends to result in not very high EF before lightning was produced. However, higher POD values would be observed in other sites where cloud charges are

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doi:10.1016/j.elstat.2009.01.023

typically closer (e.g. New Mexico; see Krehbiel [15], Japan winter storms; see Brook et al. [17]).

This paper introduces the EF polarity change criterion for warning and presents a comparison of lightning warnings based on both EF thresholds and polarity changes. First, in Section 2, the data used to study the warning methods employed in this work are described. Next, Section 3 describes the analysis of EF warning methods used in this work. Section 4 presents the results for warnings based on both EF thresholds and polarity changes. Section 5 makes a comparison of both EF warning criteria and discusses the results. The conclusions summarize the results and give guidelines for future studies.

2. Data

Lightning detections were obtained from two networks which operate at the region of study. The Spanish Lightning Detection Network (SLDN) provided CG lightning characteristics (time, location, polarity and peak current) for the cases. The SLDN is composed by fifteen low-frequency (LF) combined magnetic-direction-finding and time-of-arrival (MDF/TOA) sensors over the Iberian Peninsula [20]. The second network is the Catalan Lightning Location Network (XDDE) which is operated by the Meteorological Service of Catalonia. The XDDE is composed by three VHF interferometers [18,19] that cover the northeastern region of Spain corresponding to the studied region. This network provides sources associated with the total lightning activity (CG + IC).

Atmospheric EF measurements were obtained from an EFM station located in the city of Terrassa (Barcelona, Spain). The employed EFM was similar to that described by Montanyà et al. [21]. The EFM measurements were not done over a perfect flat ground, therefore the electric field measurements could be affected by the environment introducing some uncertainty. The EF measurements presented in this paper correspond to a particular installation over a building where an estimated correction factor was used. In order to observe the slow electric field variations due to the presence of the thunderstorm, sudden electric field changes due to lightning are smoothed by using a 60 s average method applied in previous works such as Murphy et al. [12]. Fig. 1 shows the smoothed EF, cloud-to-ground (CG) and intra-cloud (IC) lightning distances to the EF measurement point during one of the thunderstorm cases. The EF polarity reversals and magnitude increments can be observed during the storm approach.

The analyzed cases correspond to seven summer storms during 2004 and 2006. In general, the cases were related with typical ordinary convective storms which usually are triggered over higher terrain or in larger scale convergence zones associated with fronts.

3. Analysis

Taking into account the two area method [2,7], the analysis was implemented in order to study the effectiveness of lightning warnings produced from EF measured at a point of interest (PI). The so-called area of concern (AOC) is a region that surrounds the point of interest (PI) where lightning risks and damages should be prevented. In the two area method the outer area is named warning area (WA) and surrounds the AOC. Then, warnings are triggered when the lightning-related information (e.g. CG location) is detected within the WA. In the implemented method, lightning warnings are only triggered by analyzing the EF measured at the PI. The two areas and the PI are illustrated in Fig. 2. The first triggering method is merely an EF threshold (Section 4.1) because the EF during thunderstorms is much higher than during fair weather, whereas the second one corresponds to the detection of EF polarity reversals (Section 4.2) that is commonly observed when a thunderstorm is growing or approaching. Warnings are evaluated on the basis of the following four parameters: (i) Effective alarm (EA) is a warning that was previously triggered before a CG flash in the AOC; (ii) the lead time (LT) is the time between the start of the alarm and the first occurrence of a CG flash at the AOC; (iii) in the case that the first CG flash is produced into the AOC without a previous warning it corresponds to a failure to warn (FTW); (iv) false alarm (FA) is a triggered warning without the subsequent occurrence of a CG flash in the AOC. Additionally, by using a simple dichotomous method, the forecast verification is made on the basis of the contingency table described in Table 1. Two categorical statistics are used in this study: the probability of detection POD, Eq. (1), and the false alarm ratio FAR, Eq. (2).

$$\mathrm{POD} = \frac{\mathrm{EA}}{\mathrm{EA} + \mathrm{FTW}} \tag{1}$$

$$\mathrm{FAR} = \frac{\mathrm{FA}}{\mathrm{EA} + \mathrm{FA}} \tag{2}$$

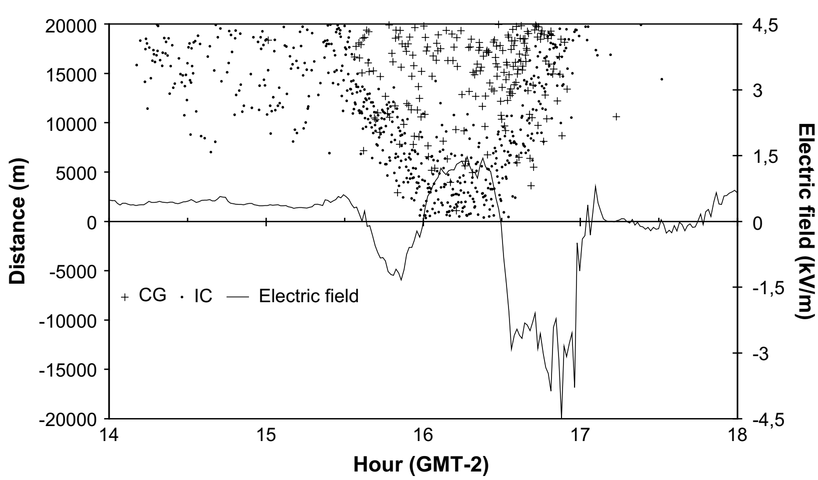

Fig. 1. Electric field signal and nearby CG and IC lightning activity in Terrassa on August 8, 2006.