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Automated analysis and statistics of lightning leader speed, local flash rates and electric charge structure in thunderstorms✉

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ABSTRACT:

We introduce new methods for the analysis of complex three-dimensional lightning data produced by Lightning Mapping Arrays and illustrate them by cases of a mid-latitude severe weather producing thunderstorm and a tropical thunderstorm in Colombia. The method is based on the characteristics of bidirectional leader development as observed in LMA data (van der Velde and Montanyà, 2013), where mapped positive leaders were found to propagate at characteristic speeds around $2 \cdot 10^4$ m s^{-1}, while negative leaders typically propagate at speeds around 10^5 m s^{-1}. We fit slopes (t-x, t-y, t-z) to approximate leader speed, which can be used to determine the polarity, and summarize flash rate and polarity characteristics in a 3D grid over time. The summarized data can be used to follow charge structure evolution over time, as well as climatological studies comparing lightning parameters with the meteorological environment of storms.

INTRODUCTION

A Lightning Mapping Array (LMA) maps radio pulses emitted by lightning leaders, displaying lightning flash development in the cloud in three dimensions. Since the last 10 years about a dozen of these advanced systems have become operational in the United States and in Europe, with the purpose of severe weather monitoring or lightning research. The tools for analysis and operational output are quite limited. Typical plots consist of plan views, side views and time-altitude views of the data, which contain thousands of points from subsequent overlapping flashes. In active storms this can make it hard to distinguish the evolution of subtle features within, such as charge layers and subregions in storms with enhanced rates of tiny flashes. Flashes are typically separated per convective cell by 150 ms or longer silent intervals and can be grouped by size. Surges in intracloud flash rates also known as "lightning jump" (e.g. Schulz et al. 2009) have been succesfully used for predicting severe weather production, including tornadoes and large hail. Gridded activity is often also presented, counting the number of

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sources in a horizontal grid.

METHODS

Data comes from the Ebro and Colombia Lightning Mapping Arrays. Below we outline the general procedure, more detail will be provided in a journal paper.

We determine leader speed for every 1.5 x 1.5 x 0.75 km grid box in 3 ms time steps, using two time intervals (e.g., 9 ms and 27 ms) and circles (4.5 km and 2.5 km wide) in which a robust Theil-Sen fitting of the slope is performed for fast and slow leaders. The two are then merged such that important speed characteristics are optimally maintained in negative and positive leaders, and labeled with positive or negative polarity according to the resulting velocity (e.g. $< 3.5 \cdot 10^4$ m s^{-1} for positive leaders).

The method also counts how often leaders from a lightning flash initiate or pass through each grid box. This "3D local flash rate" may be used in severe thunderstorm or NO_x production studies and shall be more meaningful than LMA source density which is biased by the detection efficiency and does not represent a physical metric. Based on activity of surrounding boxes, it is determined also whether the leader initiated in the box or came from elsewhere, determining 3D initiation rates.

Additionally, in each grid box the median x, y and z components of the leader propagation vectors of all flashes result in a 3D vector grid which may be compared to vectors in numerical models of leader propagation in response to cloud charge structure.

Finally, the active charge region altitudes, layer thickness and rates are summarized from multiple maxima in vertical profiles of positive and negative leader rates.

RESULTS

Figure 1 shows an example of a flash where leader speed is displayed on the color scale.

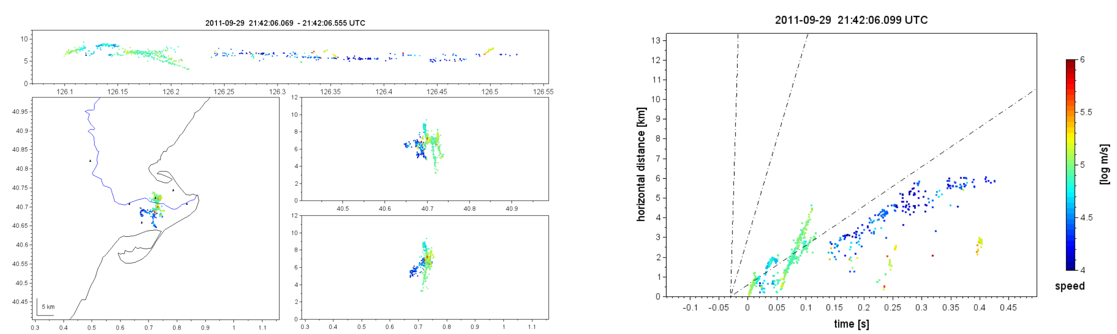

Figure 1. Leader speed of a bolt-from-the-blue cloud-to-ground flash over the Ebro Delta in Spain. The dark blue sources are slow leaders (positive polarity), the green sources typical negative leaders travelling at about 10^5 m s^{-1}. The lines in the time-distance plot to the right are 10^6, 10^5 and $2*10^4$ m s^{-1} (van der Velde and Montanyà 2013).

The data can be summarized in a 4D grid and displayed, for example, by taking the median speed per altitude in the x-y-z domain, summarized at intervals of 2 minutes, as Figure 2 shows.

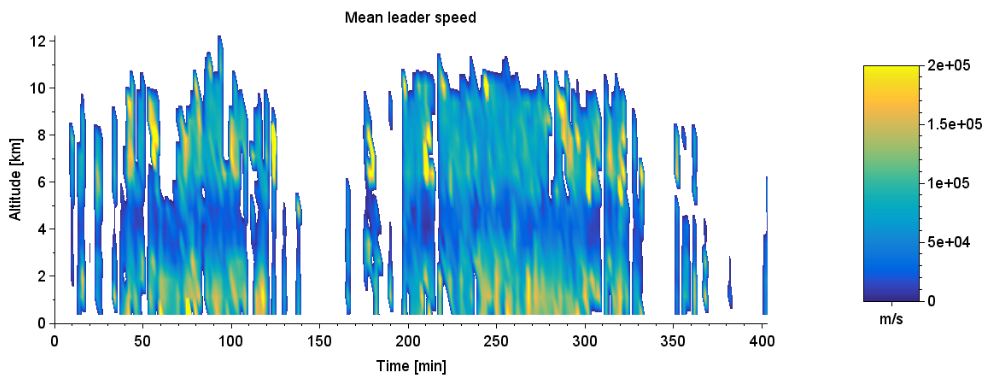

Figure 2. Leader speed evolution of a thunderstorm, summarized as the median speed per altitude layer by time, at 2 minute intervals. 20 November 2011.

The graph shows clearly the altitudes of slow positive leaders at 3-6 km and faster negative leaders (upper and lower positive cloud charge) above and below it. Some episodes occurred with much faster negative leaders in the upper layer, some of these were associated with sprites (van der Velde et al. 2014).

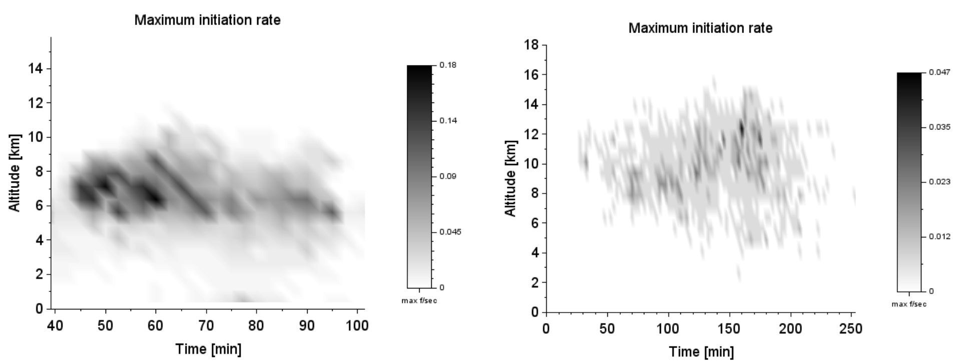

Figure 3. Maximum x-y initiation rate per altitude in a domain. Left: severe thunderstorm on 18 June 2013 in the Ebro Valley region in Spain. Right: storm near Santa Marta, Colombia.

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