Atmospheric Research 169 (2016) 340–344

Contents lists available at ScienceDirect

Atmospheric Research

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

A thunderstorm cell-lightning activity analysis: The new concept of air mass catchment

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ARTICLE INFO

Article history:
Received 5 May 2015
Received in revised form 17 October 2015
Accepted 22 October 2015
Available online 30 October 2015

Keywords:
Thunderstorm cell
Lightning frequency
Air mass catchment
Lagrange approach
TITAN method
LINET-system

ABSTRACT

Thunderstorm cell-lightning activity is discussed in terms of analysing a thunderstorm's lightning frequency–equipotential temperature relationship. Thunderstorms were tracked using Doppler radars in five-minute time steps. Lightning is assigned to the nearest thunderstorm cell, it is characterised by lightning frequency data using LINET. Equipotential temperature is not directly estimated, instead the notion of air mass catchment is introduced to represent it. It is shown in this paper that the thunderstorm cell with maximum lightning frequency in the current time step is almost always the so-called leading storm cell. The lightning frequency activity of the non-leading storm cells is not significant.

1. Introduction

Lightning is the most erratic weather phenomenon. It exhibits enormous variability not only in its electric features (Smith et al., 2000; Carey and Buffalo, 2007; Qie et al., 2014), but also in its environmental behaviour (Price and Rind, 1992; Rivas Soriano and de Pablo, 2002; Williams and Sátori, 2004; Qie et al., 2014; Gatlin and Goodman, 2010). Important characteristics include its frequency or surface density as well as its spatial–temporal distribution. Lightning frequency depends on many factors, all of them being more or less connected to the process of convection (Xu et al., 2010) accepting (Latham and Petersen, 2007) the hypothesis that in charge separation processes the non-inductive charging mechanisms are dominant. The effect of convective precipitation (Soula and Chauzy, 2000; Zhou et al., 2002), CAPE (convective available potential energy) (Williams et al., 1992), the combination of CAPE and convective precipitation (Romps et al., 2014), surface wet bulb temperature (Jayaratne and Kuleshov, 2006), maximum updraft speed (Price and Rind, 1992), updraft volume (Wiens et al., 2005; Barthe et al., 2010), graupel volume (Kuhlman et al., 2006; Barthe et al., 2010), ice water path (Barthe et al., 2010; Petersen et al., 2005), and cloud top height (Williams, 1985; Ushio et al., 2001; Yoshida et al., 2009) on lightning frequency has been investigated much more extensively than the effect of various land-surface features, such as the urban effect (Westcott, 1995; Farias et al., 2014; Kar and Liou, 2014), the land-surface–ocean distribution effect (Williams and Stanfill, 2002), or the effect of orography (Rivas Soriano et al., 2001; Sousa et al., 2013; Feudale and Manzato, 2014).

In most of the studies, Lagrange-based approaches are used for nowcasting purposes (Dixon and Wiener, 1993; Li et al., 1995; Johnson et al., 1998; Strauss et al., 2013; Horváth and Nagy, 2015) or recently for storm life cycle analyses (Booth et al., 2007; Lock and Houston, 2014; Lock and Houston, 2015; Kaltenboeck and Steinheimer, 2015; Wapler and James, 2015). The lightning frequency studies mostly concerned the actual values of total frequency (Meyer et al., 2013; Chronis et al., 2014; Poelman, 2014). According to our knowledge, the maximum flash rate values of thunderstorm cells have not been used in analyses to date. In this study, we focus on the maximum frequency values to characterise lightning activity as simply and efficiently as possible.

We used a Lagrange-based approach to investigate the relationship between the maximum lightning frequency and the near-surface atmosphere. A new procedure was applied to represent atmosphere by introducing the notion of "air mass catchment", an analogy to the notion of water catchment area. The study is observation-based, the used observation tools are briefly presented in Section 2, a more detailed description of the concept of air mass catchment can be found in Section 3.1, the applied methods are presented in Section 3.2, the results are discussed in Section 4, while the conclusions are given in Section 5.

2. Methodology

RADAR reflectivity data were available every five minutes in 1 km × 1 km spatial resolution in the Carpathian Basin (Szegedi et al.,

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http://dx.doi.org/10.1016/j.atmosres.2015.10.017
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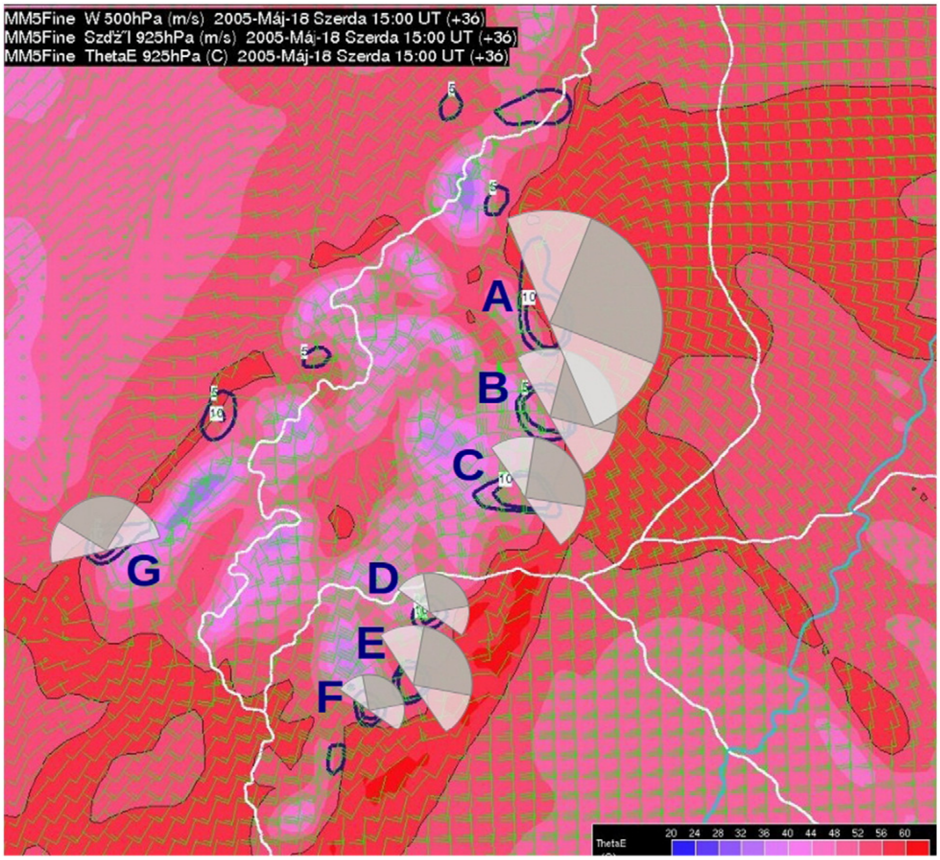

Fig. 1. Schematic illustration of the physical bases of the air mass catchment concept (Horváth et al., 2006).

2014). The composite maps are constructed by using their column maximum values.

Lightning data were available from the Hungarian part of the LINET system. LINET is a VLF/LF lightning detection system (Betz et al., 2009), which uses the time of arrival method for detecting total (cloud-to-ground + cloud-to-cloud lightning) lightning activity at a 150 m resolution.

2.1. Storm cell identification, tracking and lightning assignment

In our studies, we use a RADAR cell identification and tracking system based on the globally used TITAN method (Dixon and Wiener, 1993; Han et al., 2009; Horváth et al., 2008; Sánchez et al., 2013; Horváth et al., 2015). The algorithm can easily isolate stormy parts from the radar reflectivity image of the observed area. The method is based on counting the number of adjacent pixels above a certain radar reflectivity threshold value. An ellipse is constructed over areas where at least 8 pixels exceed 45 dBZ. The identification is carried in each time step. The tracking possesses more steps: the algorithm checks every cell in a 10-km range, and if in the next time step a cell with a very similar size and radar reflectivity is there, the algorithm connects them.

Lightning is always assigned in a 5 min interval (±2.5 min with respect to radar image time) to that cell which is the closest to the lightning location. There are also lightnings which are not taken into consideration at all. These lightnings are located more than 30 km from the nearest cell. We do not differentiate between cloud-to-ground and cloud-to-cloud lightnings. In our investigation, only the fact of lightning is used as information.

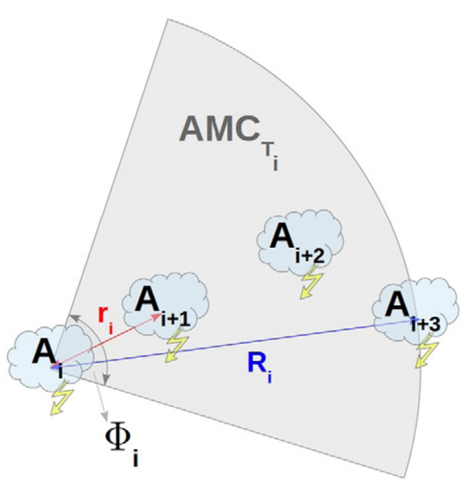

Fig. 2. Schematic figure for illustrating how the territory of the AMC (AMC_{T_i}) of a storm cell in time step i (A_i) is obtained.

3. Air mass catchment–lightning activity approach

3.1. Concept

A storm is a complex, highly non-linear system converting thermodynamic energy into electrical activity. Its functioning can be compared to vacuum cleaner with remark that warm and humid air supports its intensity. A storm's electrical activity is proportionate to the physical state characteristics (e.g., air mass size, heat and water vapour content) of the air mass used by it (Deierling and Petersen, 2008). The similarity to vacuum cleaner motivated us to introduce the new concept of air mass catchment (AMC) to unify and quantify these two important features. By introducing it we can distinguish between the leading and the non-leading thunderstorm cells, which is an important point of view in the subject discussed. Otherwise, the concept is closely related to