A Lightning Parameterization for the COSMO-DE Model

Johannes M. L. Dahl[1], Ulrich Schumann, Hartmut Höller, and Christian Keil
[1]*Deutsches Zentrum für Luft- und Raumfahrt, Institut für Physik der Atmosphäre, Oberpfaffenhofen, Münchner Strasse 20, 82234 Wessling, Johannes.Dahl@dlr.de*
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I. INTRODUCTION

A new lightning-frequency parameterization has been developed, which is used in the convection-resolving COSMO-DE model to simulate the spatio-temporal distribution of lightning. The approach used in this work is a multi-parameter approach, which is in contrast to popular univariate approaches that set flash rate linearly proportional to, e.g., storm generator power (Williams, 1985; Price and Rind, 1992; Yoshida et al, 2009), or to charging current or charging current density (e.g., Blyth et al., 2001; Deierling et al., 2008; Yoshida et al, 2009). These assumptions entail certain predictions about the amount of charge that is transferred during a discharge, which are not necessarily realistic (see also Boccippio, 2002).

Apart from the new parameterization, existing ones, based on linear relations between flash rate and storm-generator power have been implemented in the COSMO-DE model. The model domain covers Germany and parts of adjacent countries, and it is run in operational mode with about 2.8 km horizontal grid resolution. The vertical resolution varies between 50 m close to the ground and 1000 m at the upper domain boundary, which is at 22000 m. The temporal resolution is 25 s, and the lightning routine is called every 900 s.

II. FORMULATION OF THE PARAMETERIZATION

In order to avoid any assumptions about the discharge behavior, as is implicitly done in single-parameter approaches, a more general approach has been chosen. The idea is, that after a discharge has occurred, the electric field needs to be restored to critical strength before the next discharge can occur. The time between the discharges depends on the rate at which the field is replenished, and on the strength of the first discharge. The larger the rate of increase of the electric field, and the smaller the discharge strength, the smaller the time between two flashes, and the larger the flash rate. If it is assumed that lightning is the only way that charge is neutralized, this may be formulated as

$$f = \frac{1}{\eta E_c} \frac{\partial E}{\partial t}, \tag{1}$$

where f is the discharge rate, η is the field-neutralization efficiency, E is the vertical component of the electrostatic field, and E_c is the critical field strength at which the discharge occurs. A field-neutralization efficiency equal to one implies that the entire field has been neutralized by the discharge, and a neutralization efficiency close to zero implies that the field has not weakened appreciably during the discharge. If eq. (1) is applied to a circular, two-plate capacitor, which exhibits positive charge on the upper plate and negative charge on the lower plate, this equation becomes

$$f = \frac{\gamma}{2\epsilon} \frac{\rho_c v_s}{\eta E_c} \left[\frac{d}{\sqrt{R^2 + (\frac{d}{2})^2}} - 2 \right], \tag{2}$$

where ϵ is the permittivity, ρ_c is the charge density in the charging current, v_s is the difference of the sedimentation velocities between glaupel pellets and ice crystals, d is the separation distance between the capacitor plates, and R is the radius of the capacitor plates. The parameter γ has been introduced to describe the contribution of lightning current to the total discharge current.

It is assumed that the non-inductive graupel-ice charging process is dominating (e.g., Saunders, 2008), and that the positively-charged region is associated with cloud ice and snow, and that the negatively-charged region is associated with graupel. These regions are considered to represent the capacitor plates. The field-neutralization efficiency is determined via the charge that is dissipated during a flash. It is assumed that the bigger the space-charge region, the longer the channels, and the stronger the discharge. This is supported by laboratory experiments and theoretical considerations (Williams et al., 1985, and the references therein). The actual amount of charge is based on measurements by Maggio et al. (2009). The critical field is considered to be the breakeven field which is determined as in Marshall (2005).

III. IMPLEMENTATION OF THE PARAMETERIZATION

In order to apply eq. (2) to a real-world scenario, the assumption is made that the interior field of a capacitor of arbitrary morphology is reasonaby well modeled by a circular capacitor of the same surface area. This way, the numerical solution of Gauss's law for every cell can be circumvented. In order to determine the radii and separation distances of the plates, first a labeling algorithm, developed by Hoshen and Kopelman (1976), has been parallelized (Constantin et al., 1997) and extended to three dimensions. This algorithm identifies contiguous regions of pixels with a certain property. With this algorithm and several utility routines, the geometry and locations of the cells are determined. Based on this, the flash rate of every cell is calculated and, along with the cells' positions, stored in a separate structure. The total number of flashes between two calls is extrapolated based on the instantaneous flash rate. A pseudo-random number generator is used to distribute the discharges in time and space around the cells' horizontal centroid positions.

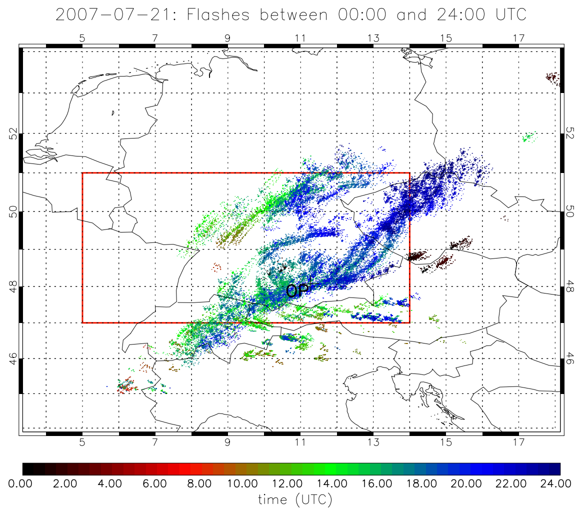

FIG. 1: Simulated flashes of 21 July 2007. The dots represent the locations of the discharges (intracloud and cloud-to-ground), colors refer to the time. The red box highlights the subdomain of the LINET-covered area used in this study.

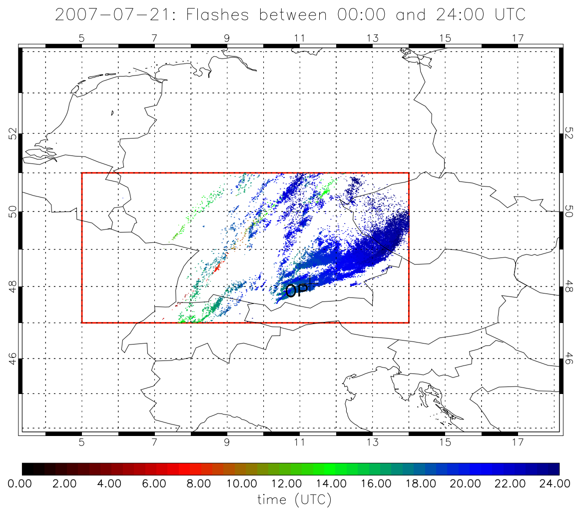

FIG. 2: As in Fig. (1), but for flashes detected with the LINET system.

IV. NUMERICAL EXPERIMENTS

Results from a simulation of 21 July 2007 are shown in Fig. (1). That day, well-organized, highly electrified severe thunderstorms crossed southern Germany in the evening hours. The dots indicate the horizontal locations of lightning flashes (both, intra-cloud and cloud-to-ground). The time of occurrence is color-coded. For comparison, the flashes detected with LINET (Betz et al., 2009) are shown in Fig. (2). It is seen that the lightning activity, including some meso- and even convective-scale details, is rather well reproduced. As errors in the modeled convection are directly inherited to the lightning scheme, the lightning forecast is expected to work well only if the convection itself is accurately simulated. Future work includes quantitative comparisons with observations and among the different parameterizations.

V. ACKNOWLEDGMENTS

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