The Development of a Lightning Parameterization for the COSMO-DE

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Outline

• Introduction
• Cloud-charging processes
• Mathematical model
• Implementation into the COSMO-DE
• Preliminary results
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Introduction: Motivation

• No reliable way of forecasting flash rates based on standard meteorological fields (CAPE, shear, equilibrium-level temperature, only give rough trends).

• Lightning forecasts of interest:
  – Forecasting for general public, warnings
  – Forecasts suited to aviation
  – Global LNOX production rates

→ a lightning package for the COSMO-DE is being developed to enable lightning forecasts in the COSMO-DE
Introduction: Model setup

- Model: COSMO-DE, version 4.6
- Horizontal resolution: 0.025° x 0.025°
- Domain: Standard COSMO-DE domain (ie_tot = 421, je_tot = 461, ke_tot = 50)
- Real case: 21 July 2007
- Using COSMO-EU data as boundary
Introduction: Existing parameterizations

Simple (computationally inexpensive) ones using

- Cloud depth
- Updraft velocity
- Precipitation rate/reflectivity

Very sophisticated schemes

- Direct simulation of the electric field and lightning channels (Ziegler, Mansell)

The scheme currently developed falls somewhere between these two

- Electric field evolution and lightning channels are not simulated
- However, a variety of factors considered (rather than just one as in the simple schemes)
Charging processes: Basic charge structure

- Ice crystals
- graupel

Temperature levels:
- 0°C
- -10°C
Even with an isolated thunderstorm, the charge structure is more complicated than a tripole. MCSs often exhibit multiple charge layers (Stolzenburg, 1998).
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**Mathematical model**

Simple generator model of the thunderstorm charge structure
Charging current is balanced by lightning (and corona, precipitation) current
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Mathematical model

Cross section along j = 125
Zonal cross section: 2007-07-21 at 18:00 UTC

RAR: colored: w: thick, dashed: T: thin dashed: ac: oil: thick line

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Mathematical model
Mathematical model

• Observations indicate that lightning frequency is proportional to the electric power that the storm produces

\[ f \propto P = IU \quad \text{Generator power} \]

The voltage, U, (potential difference between the two plates) can be found via Gauss’s law, relating electrostatic potential to the charge distribution.

\[ f \propto R^2 \rho^2 u_g^T H \left( \sqrt{R^2 + (H + d)^2} - R - H - d \right) \]

\[ f = f(R,H,d,\rho,u_g^T) \]

Simplifying assumptions: \( H \propto R \quad H \propto w \)

\[ f \propto H^5 \]
**Mathematical model**

Parameterizations contained in the above formula

- \( f \sim \text{rain rate/reflectivity} \)
- \( f \sim w^5 \)
- \( f \sim H^5 \) (Price and Rind, 1992)

\[
f = 3.44 \cdot 10^{-5} H^{4.9}
\]

- \( f \): flash frequency (1/min)
- \( H \): height of the storm in km (uppermost extension of the 2 m/s isotach)
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**Implementation: The Hoshen-Kopelman algorithm**

- An algorithm determining the size of the „plates“ (e.g., area or depth of the volume occupied by an updraft, graupel, etc.) was needed
- Provided by: Percolation Theory (occupation by molecule clusters in crystal lattices). Hoshen-Kopelman (1976) algorithm (HK76)
- Identification and analysis of contiguous regions of certain properties (making up clusters)
- Only one pass through the array necessary to obtain cluster information (very fast)
- Can be utilized to obtain the volume or the diameter of a cluster, if grid spacing is known
- Geometric analysis of the Cb and of its components (ice-water region, graupel region, etc) possible.
- This information can be inserted into the expression for the flash frequency
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Implementation: The Hoshen-Kopelman algorithm

NEWS-neighborhood rule

- Matrix before HK application
  - -------------------------------
  - -1 -1  0  0 -1  0 -1 -1
  - 0  0 -1  0 -1  0 -1 -1
  - 0 -1 -1  0 -1  0 -1 -1
  - 0 -1  0  0 -1 -1 -1  0
  - 0 -1 -1  0  0  0  0 -1
  - -1  0 -1  0 -1  0  0 -1
  - -1  0  0  0  0  0  0 -1
  - -1  0  0  0  0  0 -1  0

- Matrix after HK application
  - -------------------------------
  - 11  11  0  0  22  0  22  22
  - 0  0  33  0  22  0  22  22
  - 0  33  33  0  22  0  22  22
  - 0  33  0  0  22  22  22  0
  - 0  33  33  0  0  0  0  44
  - 55  0  33  0  66  0  0  44
  - 55  0  0  0  0  0  44  44
  - 55  0  0  0  0  0  44  0

This algorithm had to be extended to three dimensions and parallelized!

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Implementation

- A structure array has been set up, containing pixel size, pixel number, centroid position, etc. of each cluster.

- This information is inserted into the expression for lightning frequency (e.g., fifth power of the height of the uppermost point belonging to a cluster).

- Another structure, containing cluster centroid positions and flash frequency as components, defines the thunderstorm cells.

  - Every cell object is attributed with a position and a flash frequency.

- Flashes are then randomly distributed within time interval between the calls of the lightning package …

- … and distributed spatially around the cells‘ centroids with a maximum distance of three gridpoints (and Gauss weighted).
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Preliminary results: 21 July 2007

Intense thunderstorms developed over south Germany in the late afternoon hours, and apart from severe hailfall and damaging wind gusts, they produced much lightning …

(c) Walter Stieglmair

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Preliminary results: Simulated flashes
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Preliminary results: Flashes (LINET) 21 July 2007
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Preliminary Results: Temporal evolution (LINET)
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Preliminary Results: Temporal evolution (COSMO)

stroke frequencies on 2007/07/21 from 0 to 22 UTC

15 min accumulated strokes (solid) mean stroke frequency per min (dashed)

accumulated strokes: 7664 mean stroke frequency: 5.8 per minute

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Future work

- Including more parameterizations with increasing degree of sophistication in the module
- Intercomparison between the different parameterizations
- Comparison with LINET data, evaluation of the skill of different parameterizations
- Development of three-layer model (explicit CG/IC parameterization?)
- Optimization of the code for faster processing
Thank you for your attention!