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Outline

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

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: $0.025^\circ \times 0.025^\circ$
- 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

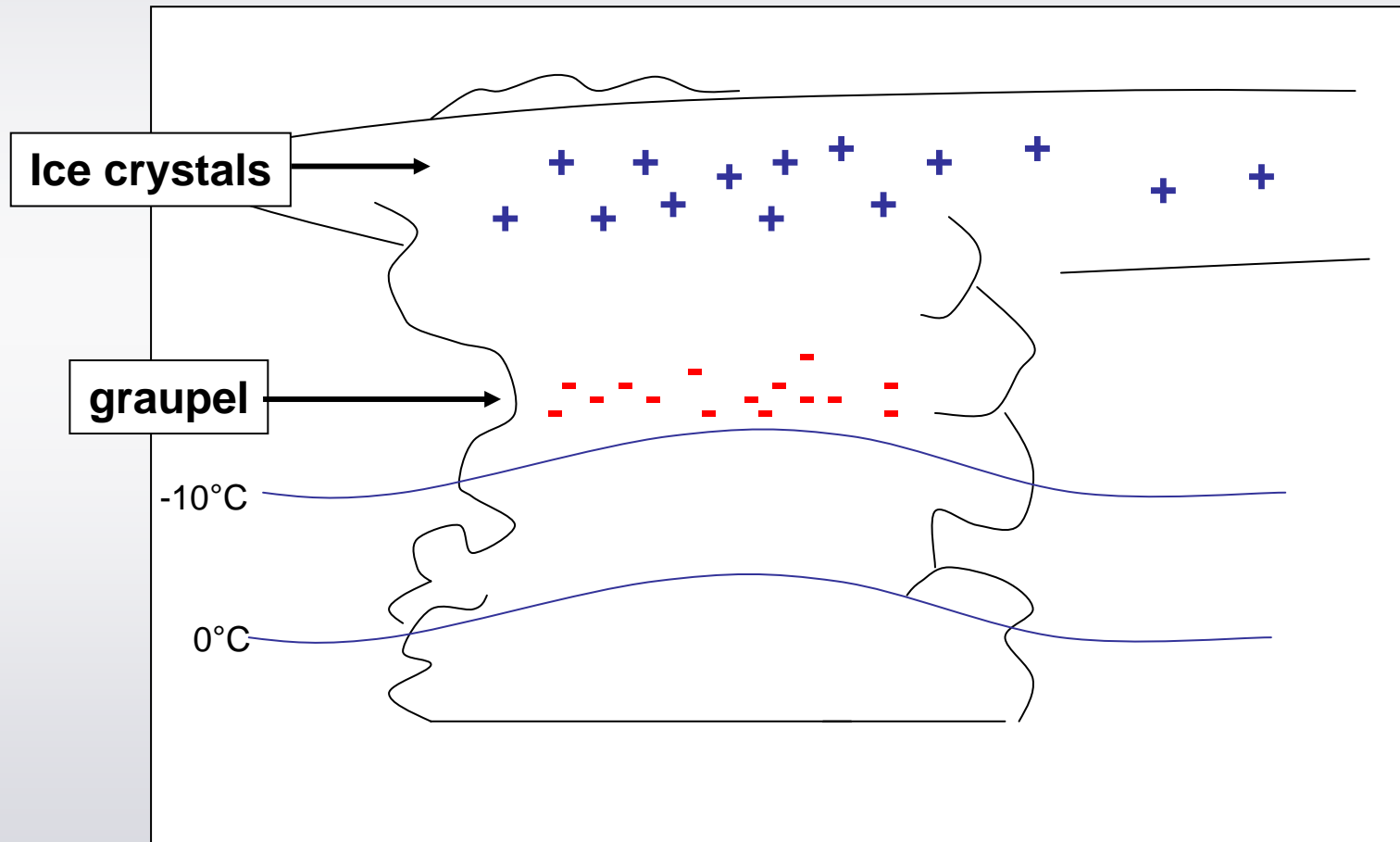
Very sophisticated schemes

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

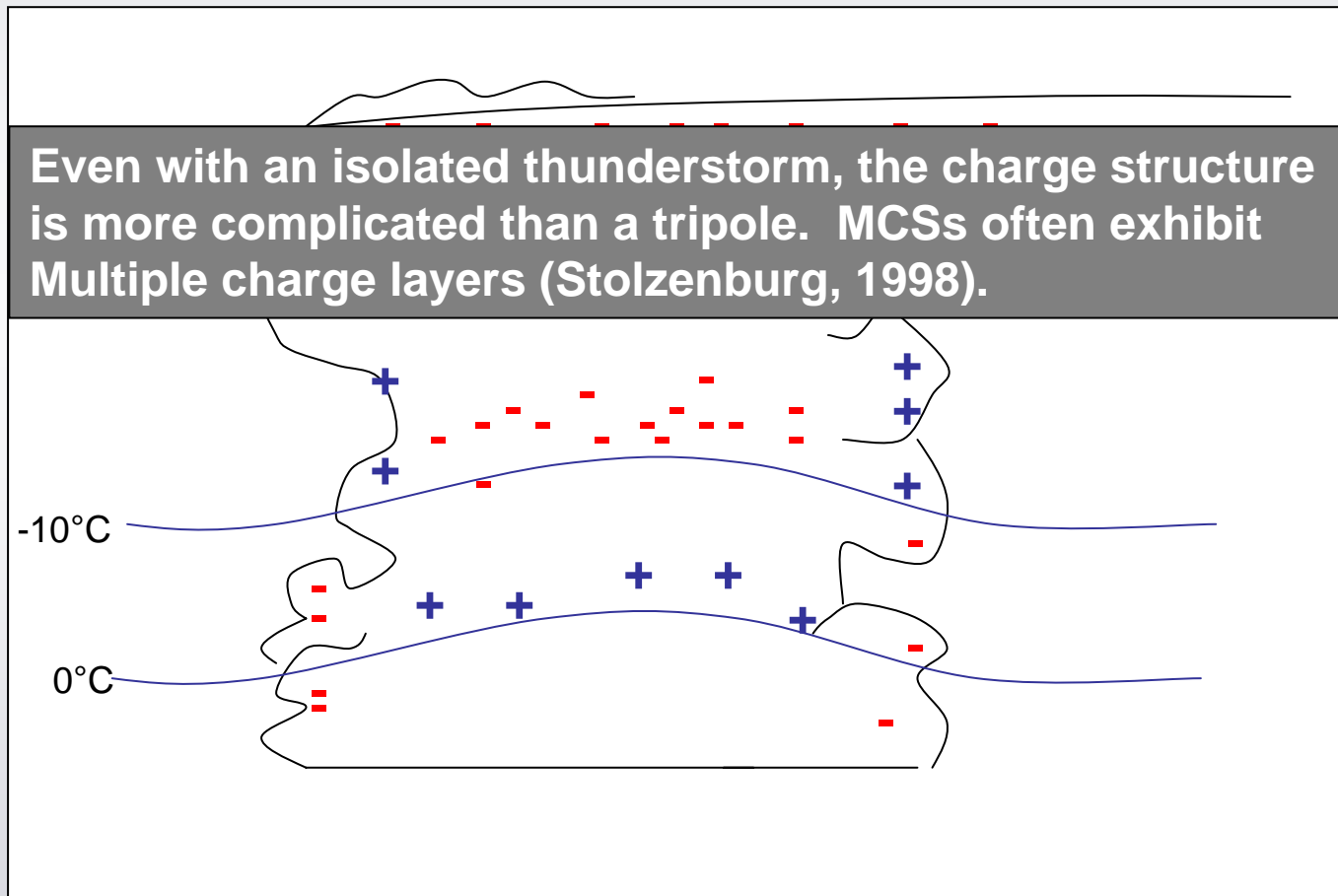
The scheme currently developed falls somewhere between these two

- 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

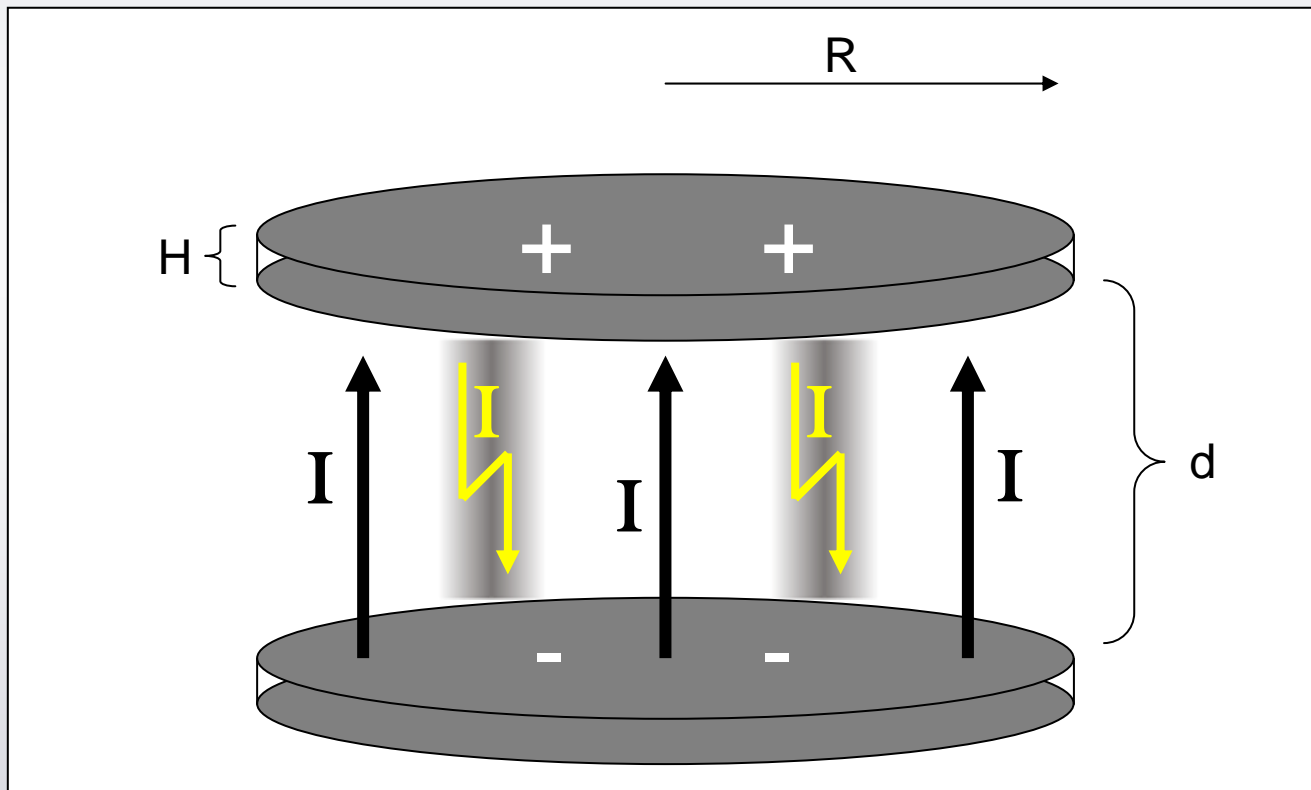


Charging processes: Charge structure

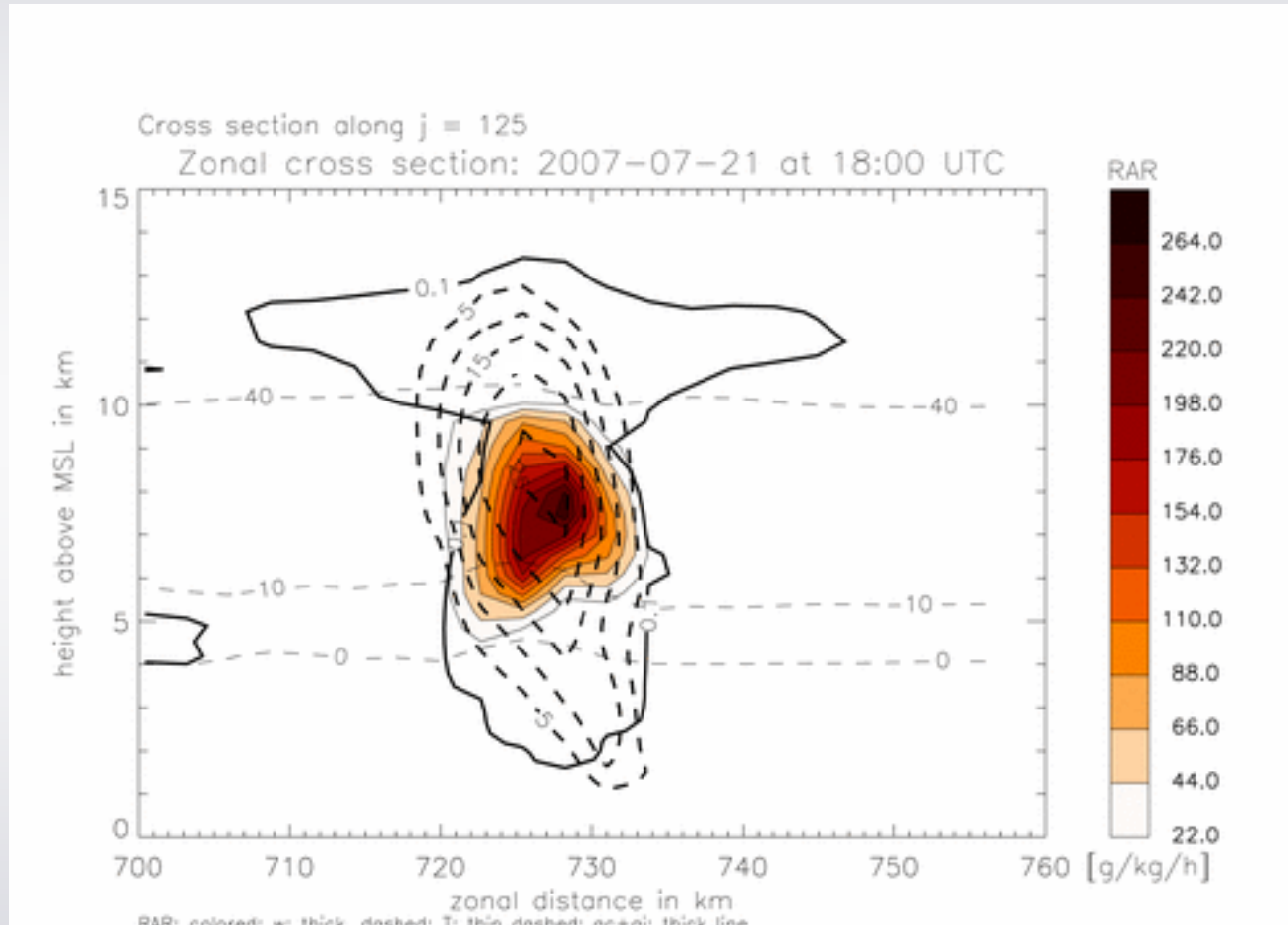


Mathematical model

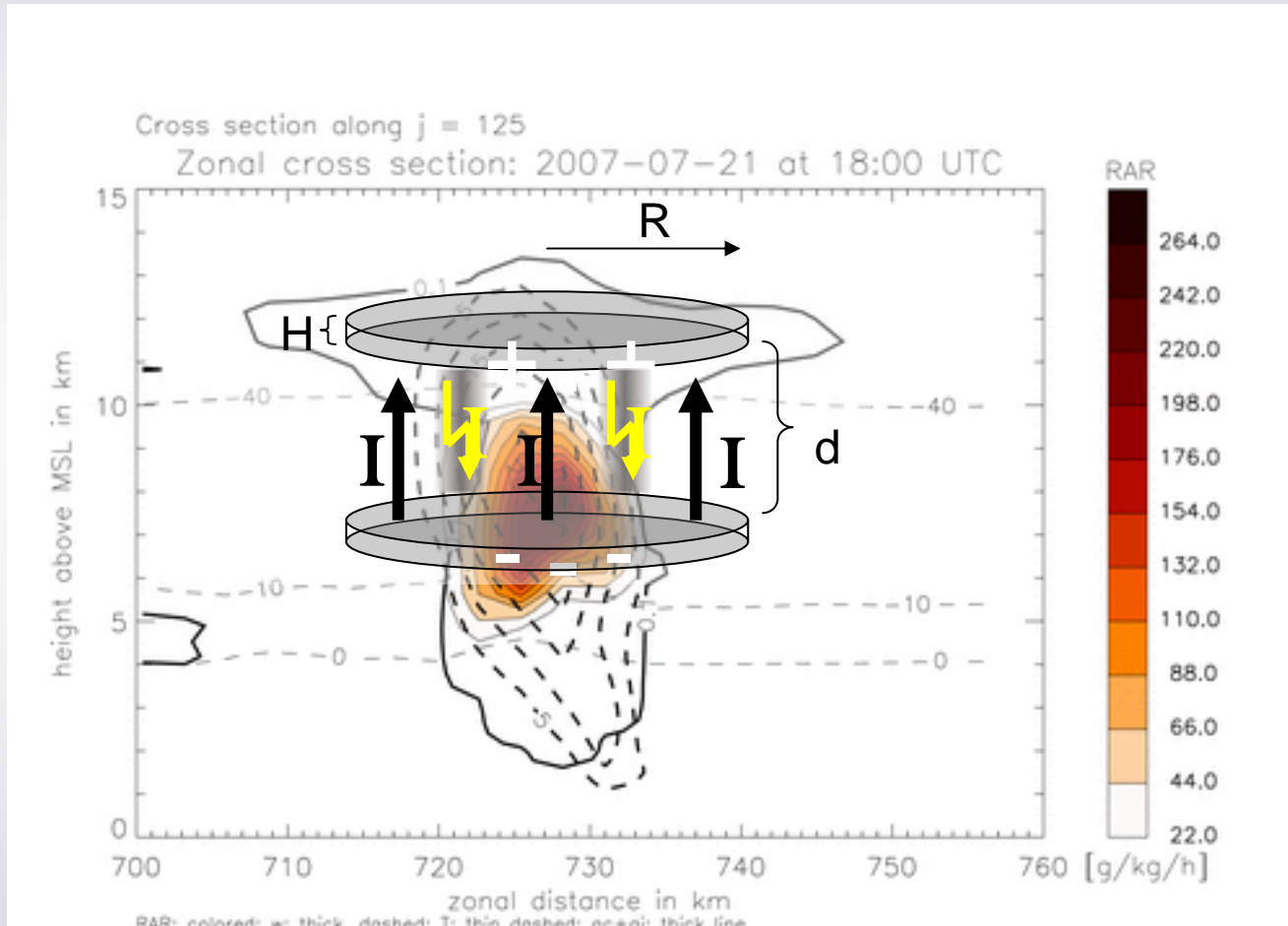
Simple generator model of the thunderstorm charge structure
Charging current is balanced by lightning (and corona, precipitation) current



Mathematical model



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.

After some algebra ...

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

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

Simplifying assumptions: $H \propto R$ $H \propto w$

$$\boxed{f \propto H^5}$$

Mathematical model

Parameterizations contained in the above formula

- $f \sim$ 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)

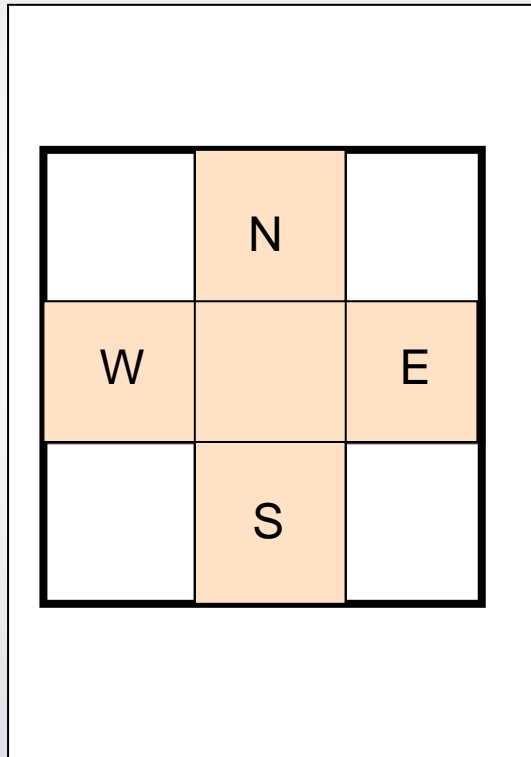
H: height of the storm in km (uppermost extension of the 2 m/s isotach)

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

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 -1 -1
- -1 0 0 0 0 0 -1 0

- Matrix after HK application

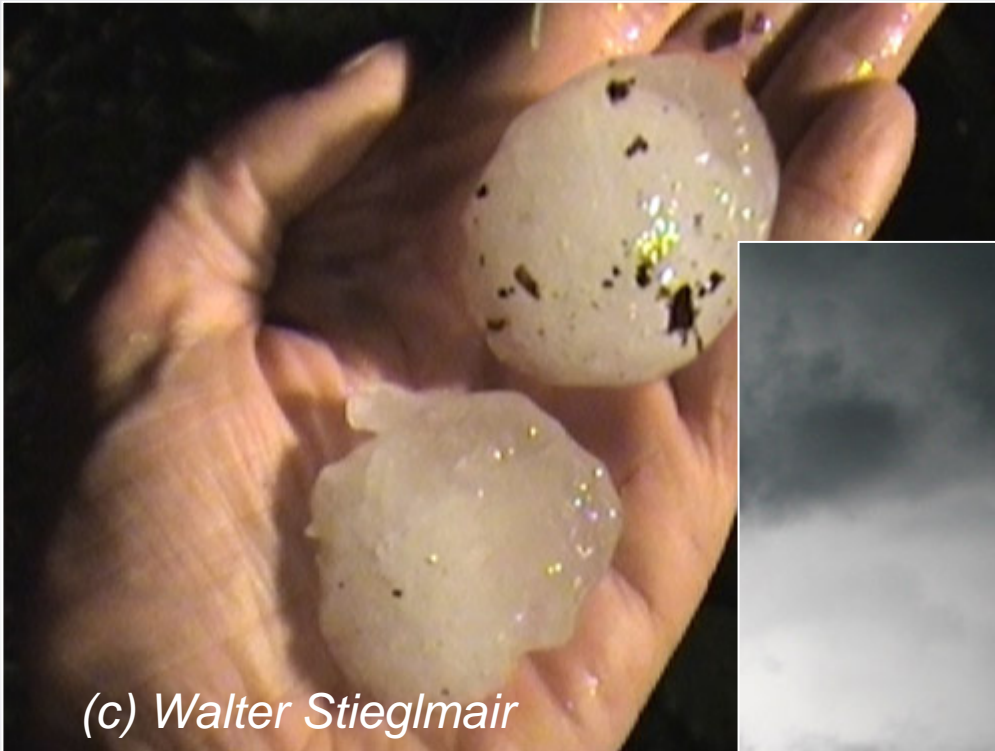
- -----
- 11 11 0 0 22 0 22 22
- 0 0 33 0 22 0 22 22
- 0 33 33 0 22 0 22 22
- 0 33 0 0 22 22 22 0
- 0 33 33 0 0 0 0 44
- 55 0 33 0 66 0 0 44
- 55 0 0 0 0 0 44 44
- 55 0 0 0 0 0 44 0

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

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)

Preliminary results: 21 July 2007

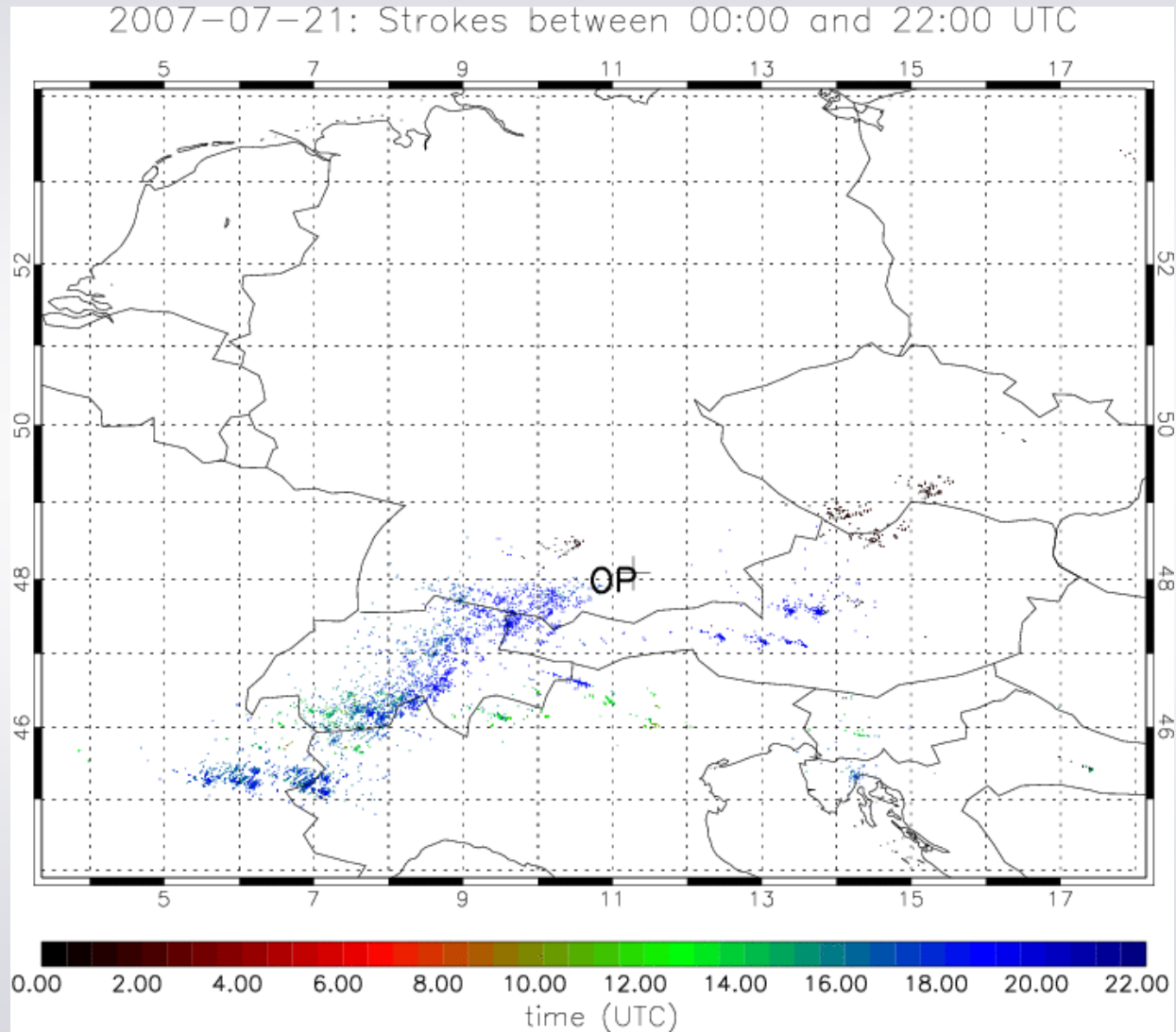


(c) Walter Stieglmair

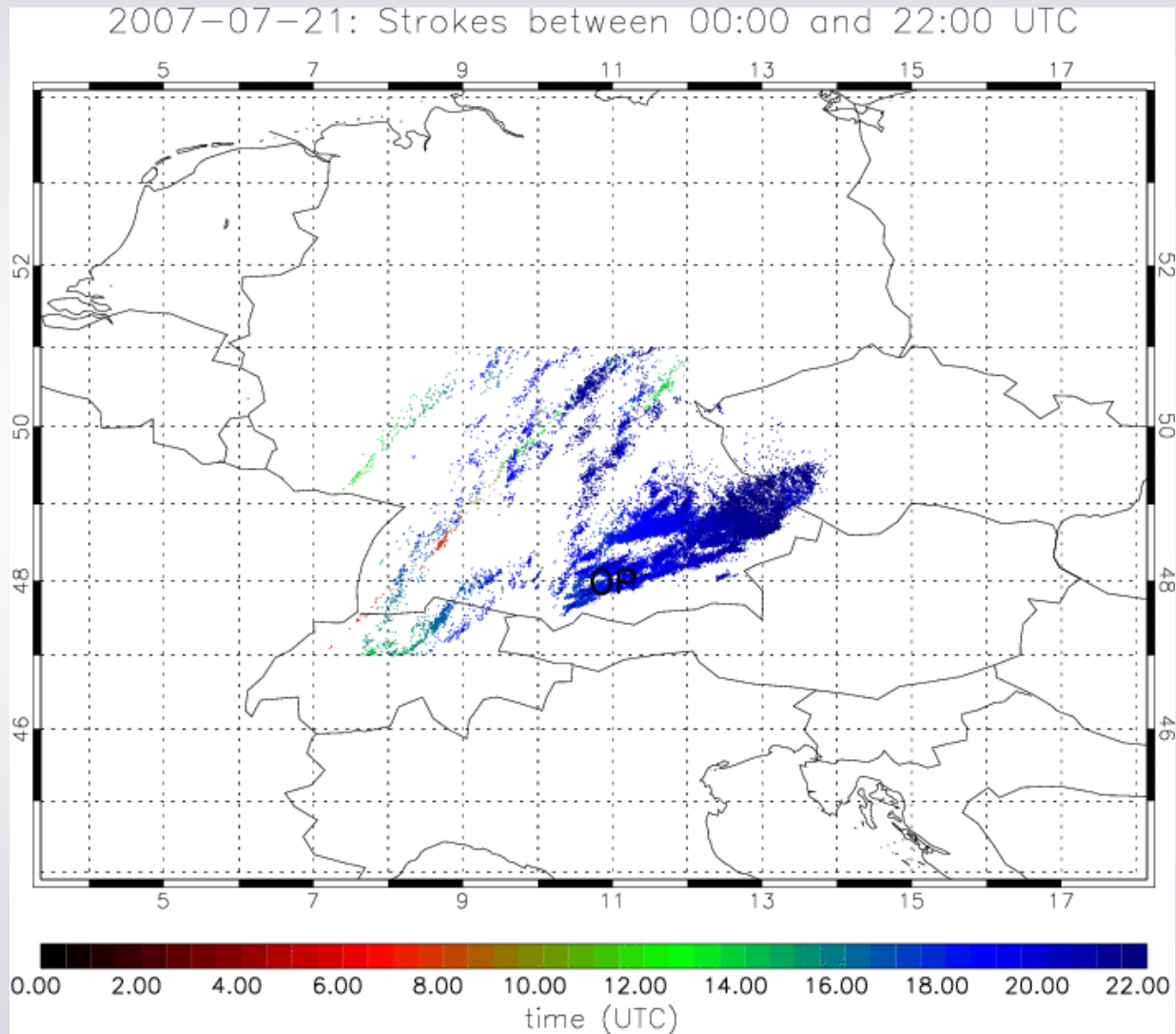


(c) Walter Stieglmair

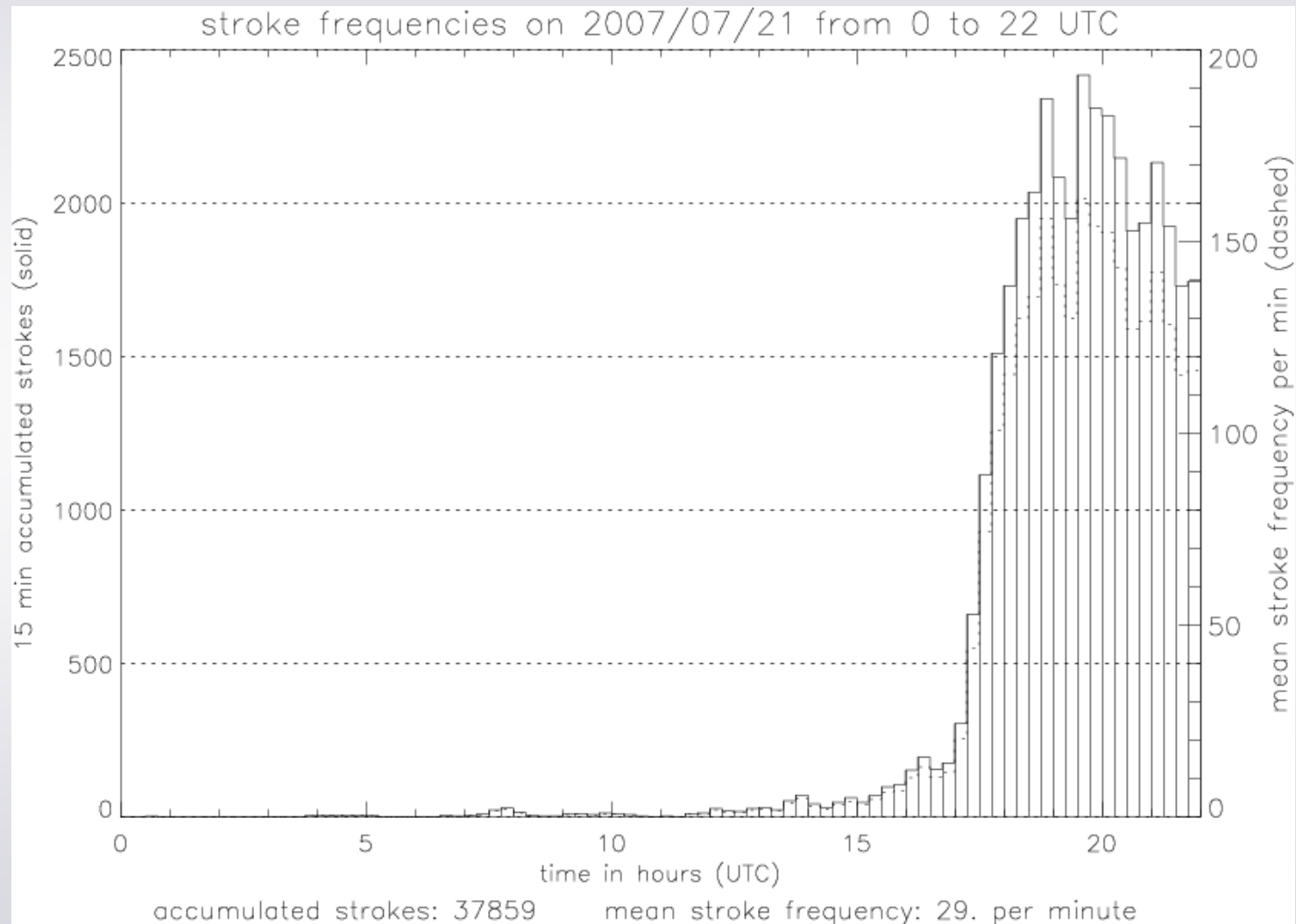
Preliminary results: Simulated flashes



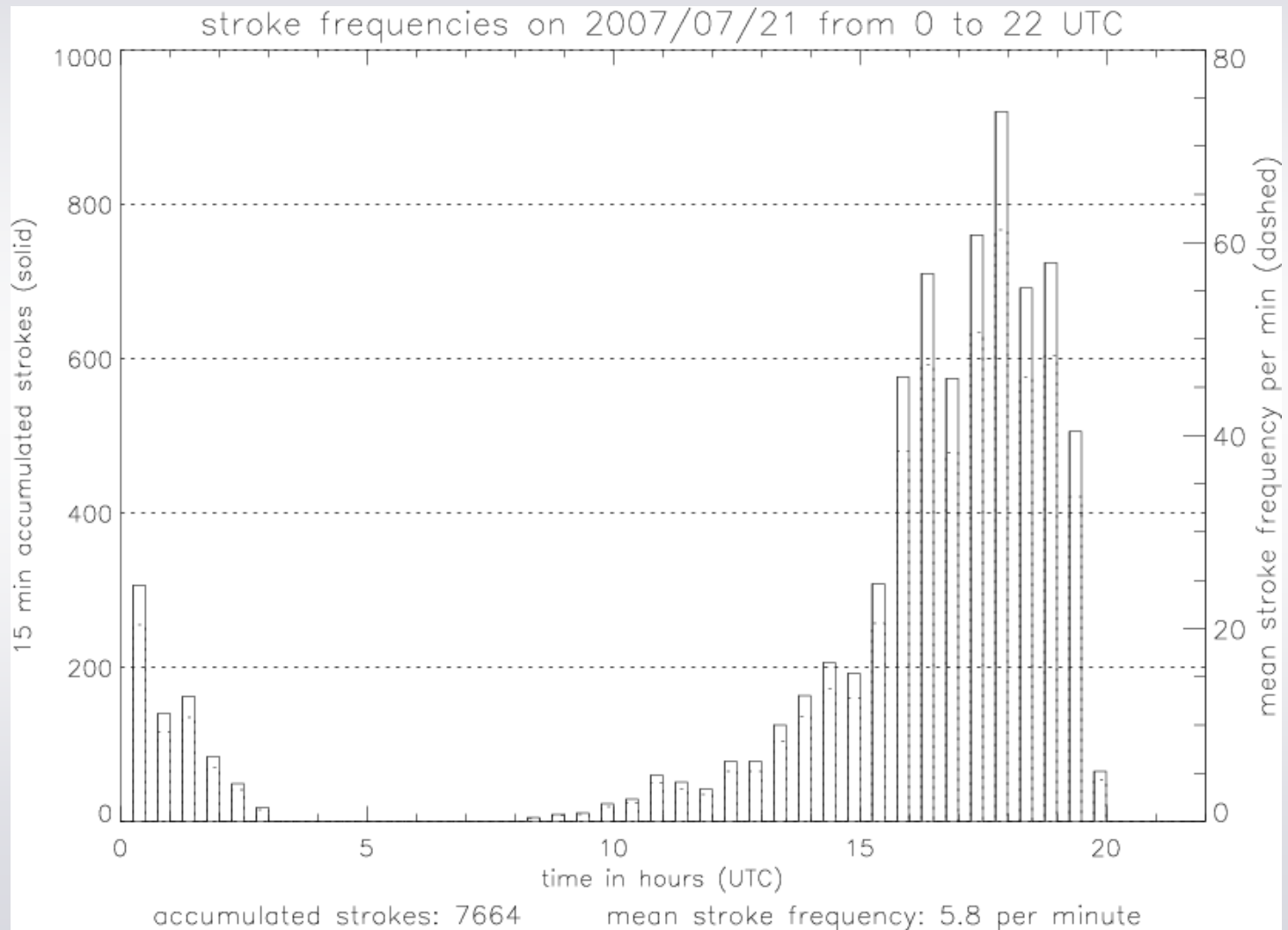
Preliminary results: Flashes (LINET) 21 July 2007



Preliminary Results: Temporal evolution (LINET)



Preliminary Results: Temporal evolution (COSMO)



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!