Cloud Electrification Model (CEM) in the COSMO Numerical Weather Prediction Model

Zbyněk Sokol, Jana Minářová*

*jana.minarova@ufa.cas.cz

1/ Motivation

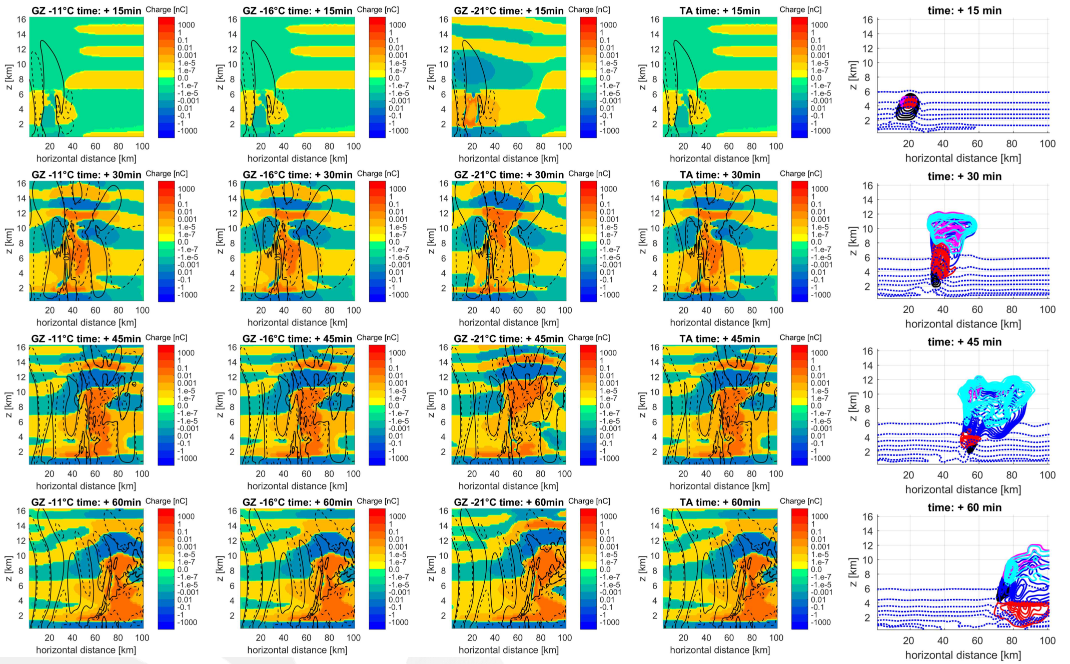
Cloud electrification is a complex process, which is mostly related to thunderclouds and lightning. The modelling of cloud electrification and lightning is usually not explicit in the Numerical Weather Prediction (NWP) models.
Thus, we present a Cloud Electrification Model (CEM), which enables to explicitly treat the electrification and lightning. CEM has been developed thanks to the CRREAT project (2016-2022) which is focused on the **C**osmic **R**ays & **R**adiation **E**vents in the **At**mosphere and founded by EU.

Advection of charges of hydrometeors (COSMO)
↓
Changes of charge concentration by microphysics (COSMO)
↓
Ion equation*
↓
Charge separation
↓
Lightning
↓
Calculation of electric field

Fig. 1 Processes modelled in CEM & implemented in the COSMO NWP model.

2/ Cloud Electrification Model

CEM is implemented in COSMO non-hydrostatic 2-moment NWP model. It explicitly describes the ion motion including the interaction of ions with 6 kinds of hydrometeors. CEM takes into account of the charge concentration of the hydrometeors. The charges are carried along with the hydrometeors and their change is computed within the cloud microphysics in COSMO NWP model. Collision among the hydrometeors is the principal process, which leads to the charge separation and transfer in CEM. Modelling of lightning is based on the bidirectional concept of flash leader which probabilistically bran-ches using the dielectric breakdown scheme (Barthe et al., 2012).
The modelled processes are schematically depicted in Fig. 1.



3/ Configuration of CEM

Time step (CEM): 1 s

Integration time (COSMO): 6 s

Simulation time: 1 hour

Horizontal resolution: 2x2 km (81x61 grid points)

Vertical resolution: 40 non-equidistant levels

Atmospheric data: Weisman and Klemps' profiles (1982)

Non-inductive charging scheme (Mansell et al., 2005):

Gardiner/Ziegler (GZ) with reverse temperature -11, -16, and -21°C

Takahashi's (TA) with varying reverse temperature

4/ Results

The performance of CEM is illustrated on a thunderstorm prototype that was simulated during an hour. Fig. 2 shows the complex charge structure that results in the thundercloud after 30 simulated minutes. The main negatively charged layer is situated at a height of 8-10 km and mostly corresponds to 3 kinds of hydrometeors; snow, graupel, and ice. The 3 kinds of hydrometeors are the hydrometeors known to participate the most in the charge transfer due to the collisions of hydrometeors.
The charge structure does not seem to be crucially influenced by the selected scheme and the reverse temperature (in the case of GZ). Nevertheless, slight differences among the simulations can still be observed.

Fig. 2 Vertical profile [km] of electric charge [nC] and vertical velocity [m/s] (contours) in a thundercloud at a simulation time of (from top to bottom) + 15, + 30, + 45, and + 60 min (first 4 columns). Positively and negatively charged regions are depicted in orange & blue shades, respectively. GZ stands for Gardiner/Ziegler scheme (first 3 columns) with 3 tested reverse temperatures (from the left column to the right: -11, -16, & -21 °C). TA represents the Takahashi's scheme (4th column), which varies in reverse temperature.
The last column displays the distribution of hydrometeors in the thundercloud. It shows the mixing ratio of 6 kinds of hydrometeors.

$$\text{* Ion equation } \frac{\delta n_\pm}{\delta t} = -\nabla(n_\pm \boldsymbol{V} \pm n_\pm \mu_\pm \boldsymbol{E} - K_m \nabla n_\pm) + G - \alpha n_+ n_- - S_{att} + S_{pd} + S_{evap}$$

$n_\pm \boldsymbol{V}$ … advection
$K_m \nabla n_\pm$ … turbulent mixing
$n_\pm \mu_\pm \boldsymbol{E}$ … ion drift motion
G … background ion generation rate
$\alpha n_+ n_-$ … ion recombination rate
S_{att} … ion attachment to hydrometeors
S_{pd} … point discharge current
S_{evap} … release of any charge as ions from evaporated hydrometeors

5/ Conclusions & future plans

CEM is able to explicitly model the electrification of thunderclouds.
The negatively charged layer mostly corresponds to graupel, snow, and ice.
Computation-wise, the CEM is quite costly.
Thus, we currently focus our work on the parallelization of the model.
We also test the model on real storms from 2016 and are about to finish the tuning of the lightning scheme.

References

- Barthe et al. 2012. CELLS v1.0: updated and parallelized version of an electrical scheme to simulate multiple electrified clouds and flashes over large domains. *Geosci. Model Dev.* 5(1): 167–184. DOI: 10.5194/gmd-5-167-2012.
- Mansell ER, MacGorman DR, Ziegler CL, Straka JM. 2005. Charge structure and lightning sensitivity in a simulated multicell thunderstorm. *Journal of Geophysical Research: Atmospheres* 110(D12): D12101. DOI: 10.1029/2004JD005287.
- Weisman, ML, Klemp, JB., 1982: The dependence of numerically simulated convective storms on vertical wind shear and buoyancy. *Mon. Wea. Rev.*, 110, 504–520.

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research, Development and Education

MINISTRY OF EDUCATION, YOUTH AND SPORTS

INSTITUTE OF ATMOSPHERIC PHYSICS CAS

CRREAT