Explicit modeling of cloud electrification and lightning in the COSMO model

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1/ Motivation

Thunderclouds mostly include deep convection, severe weather and lightning. Although lightning causes casualties worldwide, its explicit description in models remains complex.

Within the project CRREAT (2016-2022) which deals with **C**osmic **R**ays and **R**adiation **E**vents in the **At**mosphere and is supported by European Regional Development Fund, we have developed a **M**odel of **C**loud **E**lectrification (MCE), which explicitly describes the processes related to cloud electricity, and we are on the way to extend it by including explicit lightning.

2/ Description of MCE

MCE includes explicit description of:

- **Ion concentration** & ion interaction with hydrometeors.
- **Charge concentration** bounded to 6 kinds of hydrometeors.

MCE is implemented in COSMO non-hydrostatic NWP model that enables for explicit convection and computes with 2-moment cloud microphysics.

The modelled processes in MCE (Fig. 1):

- **Advection of charges** bounded to hydrometeors is performed within the advection of hydrometeors
- **Changes in charge concentration** are computed in the cloud microphysics in COSMO.
- **Ion equation***

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

- **Charge separation and transfer** are based on collisions of hydrometeors.
- **Lightning** proceeds from bidirectional concept of the leader of flashes. The propagation is given by probabilistic branching from dielectric breakdown concept (Barthe et al., 2012).
- **Electric field** is given by net volume charge density.

* $n_\pm \boldsymbol{V}$ … advection (monotonic flux scheme)
$K_m \nabla n_\pm$ … turbulent mixing
$n_\pm \mu_\pm \boldsymbol{E}$ … ion drift motion
G … background ion generation rate by cosmic rays
$\alpha n_+ n_-$ … ion recombination rate
S_{att} … ion attachment to hydrometeors (sink)
S_{pd} … point discharge current from the surface (source)
S_{evap} … release of any charge as ions from hydrometeors that completely evaporate

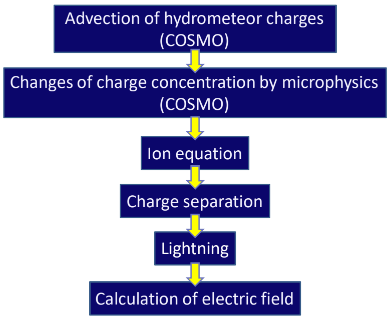

Fig. 1 *Modelled processes looped in MCE that has been implemented to COSMO NWP model.*

3/ Model configuration

Time step (MCE): 1 s
Integration time (COSMO): 6 s
Simulation time: 1 hour
Horizontal resolution: 2x2 km (81x61 grid points)
Vertical resolution: 40 non-equidistant levels
Non-inductive charging scheme:
Gardiner/Ziegler with reverse temperature -16 °C (Mansell et al.)
limited charge transfer due to collisions (20 fC graupel-ice, 50 fC graupel-snow)
Atmospheric data:
Weisman and Klemps' profiles (1982)

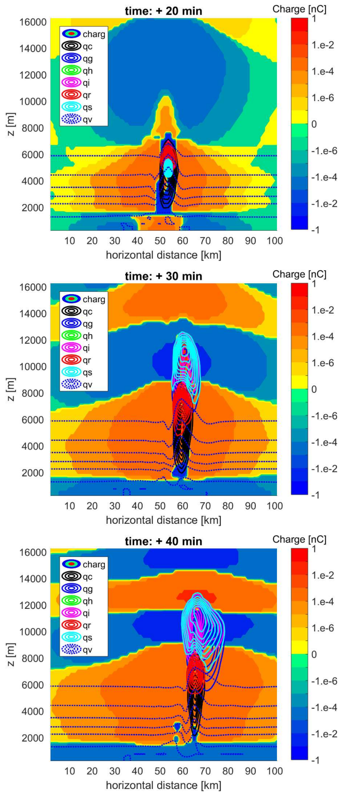

Fig. 2 *Vertical profile [m] of electric charge [nC] and distribution of hydrometeors in a thundercloud at simulation time (from top to bottom) 0 + 20, +30 and +40 min. The positively and negatively charged regions are depicted in orange & blue, respectively.*

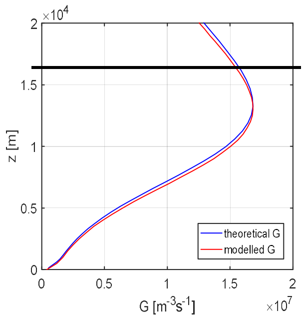

Fig. 3 *Theoretical & modelled ion generation rate by cosmic rays.*

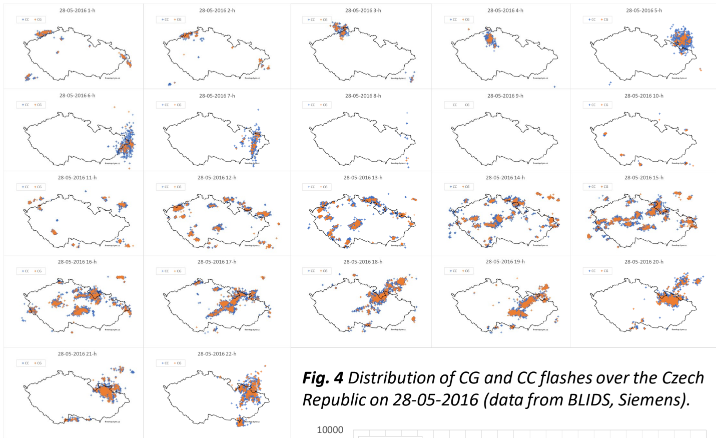

Fig. 4 *Distribution of CG and CC flashes over the Czech Republic on 28-05-2016 (data from BLIDS, Siemens).*

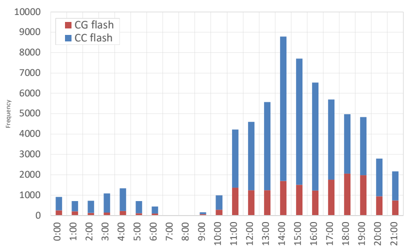

Fig. 5 *Hourly lightning distribution on 28-05-2016 over the Czech Republic (data from BLIDS, Siemens).*

4/ Results

Simulating the development of a thundercloud results after 40 min in a typical tripole charge structure (Fig. 2): two positively charged layers are separated by a negative layer. The negative layer corresponds to high concentration of graupel, ice and snow; the hydrometeors that participate the most on charge transfer through collisions. The ion generation rate by cosmic rays (Fig. 3), a parameter in the model, influences the results of simulations, while its maximum is related to the upper positive layer at an altitude of around 13 km asl.

5/ Conclusions and Future Perspectives

Conclusions

MCE satisfactorily simulates the structure of charge in the thundercloud.
The negative layer is related to graupel, ice and snow hydrometeors, whereas the upper positive layer is bounded to the maximum of the ion generation rate.

Future Perspectives

MCE has been extended by lightning scheme and is under testing.
MCE will be tested on a real thunderstorm that occurred on 28-05-2016 in the Czech Republic (Central Europe), during which the lightning intensity was high (Fig. 4, Fig. 5).

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.
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Weisman, ML, Klemp, JB., 1982: The dependence of numerically simulated convective storms on vertical wind shear and buoyancy. *Mon. Wea. Rev.*, 110, 504–520.

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