Cloud Electrification and Lightning Model in the COSMO NWP model

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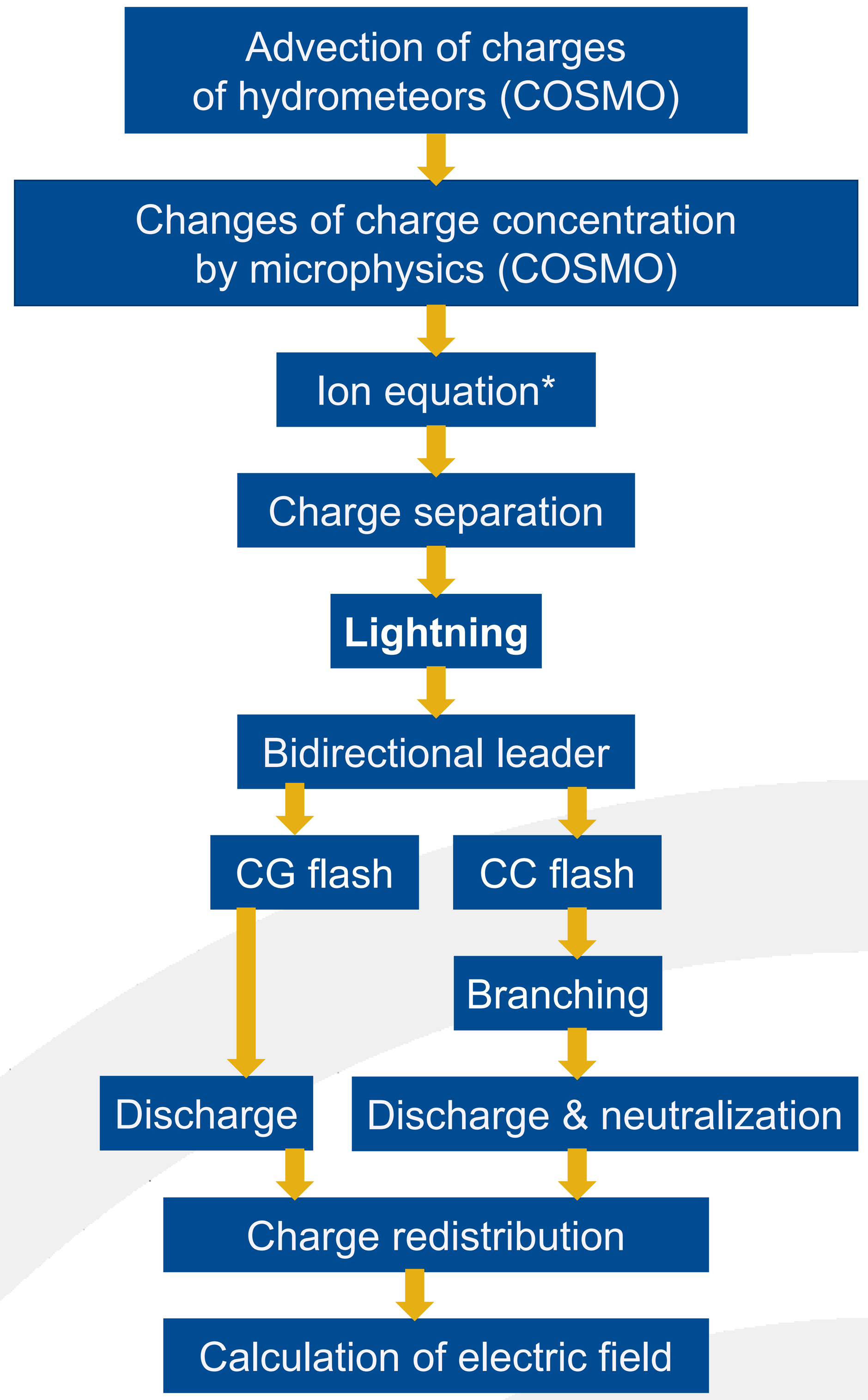


Fig. 1 Modelled processes in CELM and COSMO.

***Ion equation**

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

$n_{\pm}\boldsymbol{V}$ … 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

1/ Motivation

In the frame of the project Cosmic Rays & Radiation Events in the Atmosphere (2016-2022), which is founded by EU, we develop a model that explicitly simulates electrification and lightning in thunderclouds. The explicit modelling of cloud electrification and lightning is usually not included in Numerical Weather Prediction (NWP) models due to the complexity of the processes and high computational costs.

We call our developed model Cloud Electrification and Lightning Model (CELM) and we implemented it in COSMO non-hydrostatic convection-permitting 2-moment NWP model.

2/ Description of CELM

CELM explicitly describes the electrification of a thundercloud; it explicitly treats the ion motion including the interaction of ions with six kinds of hydrometeors (vapor, ice, graupel, rain, snow and hail). Charge concentration of the hydrometeors as well as the change of the concentration are both computed by CELM within the cloud microphysical scheme of COSMO. Basically, in CELM the charging mechanism is due to the non-inductive mechanism (Table 1), which leads to the charge separation and transfer, though the inductive charging mechanism is also considered in the model. Similar to cloud electrification, the lightning is also explicitly treated in CELM. We use the bidirectional concept of flash leader for modelling the lightning and the dielectric breakdown scheme for probabilistic branching of the leader (Barthe et al., 2012). Fig. 1 schematically depicts the processes that are treated in CELM explicitly, while Table 1 displays the simulation parameters.

Table 1

Time step (CELM): 1 s

Integration time (COSMO): 6 s

Simulation time: 1 hour

Horizontal resolution: 0.56 x 0.56 km (101x61 grid points)

Vertical resolution: 50 non-equidistant levels (0-22 km a.s.l.)

Atmospheric data: Weisman and Klemps' profiles (1982)

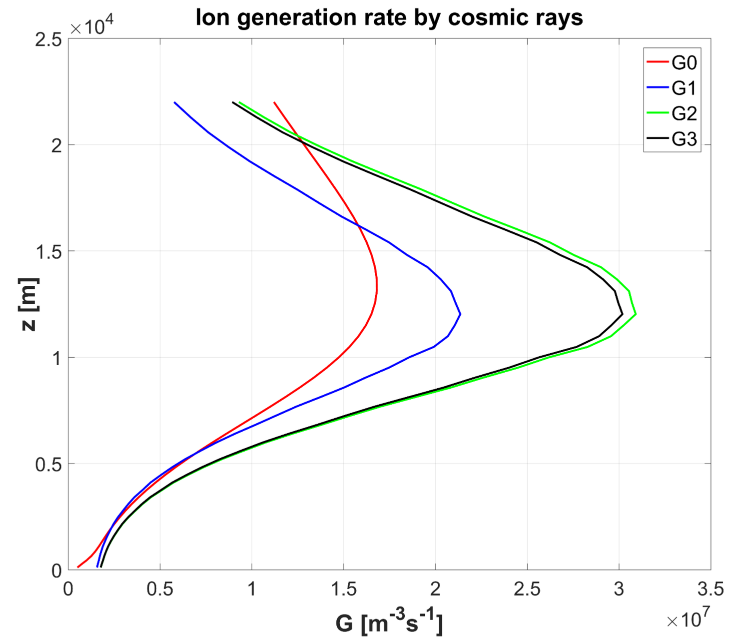
Electrical boundary conditions:

Ground level: $\Phi_E = 0$, else Neumann's conditions $\delta\, \Phi_E / \delta\, n = 0$

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

Gardiner/Ziegler (GZ16), Takahashi's (TAK),

Saunders/Peck's scheme (SP98)



G0 analytical solution
G1 max solar activity June 1991
G2 June 2016, 51° N
G3 June 2016, 50° N, Prague

Fig. 2 Vertical profile of G; ion generation rate by cosmic rays.

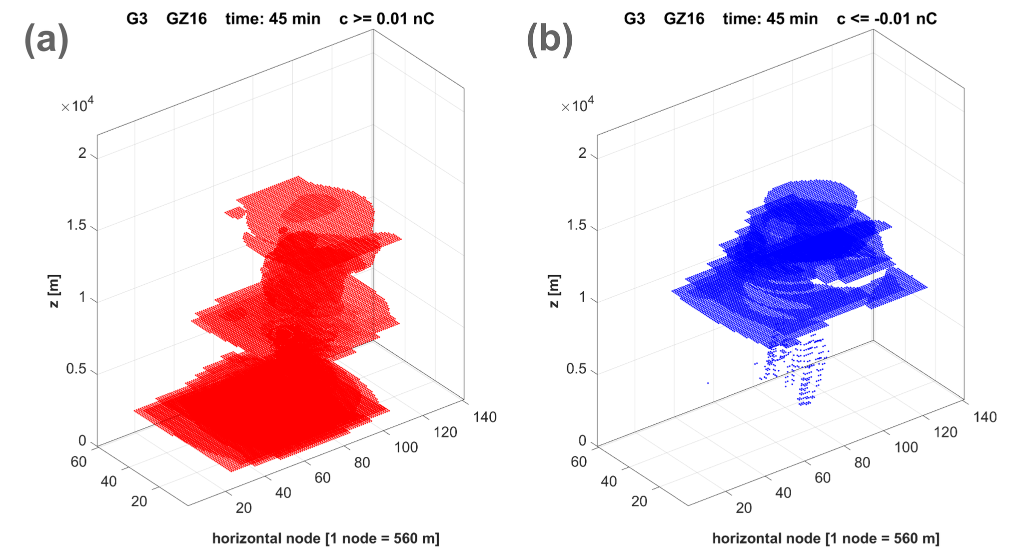


Fig. 3 Distribution of (a) positive and (b) negative charges for GZ16 scheme and G3 at 45 simulated min.

4/ Conclusions and next?

In CELM, the charge structure significantly depends on G:

- **Analytical solution (G0) differs the most from others**
- **Negligible differences between G2 (51°N) & G3 (50°N)**

The selected non-inductive charging scheme has minor influence.

We currently test the model on real data, i.e. convective storms of summer 2016 and 2018. We deal with the high sensitivity of electric field to orography.

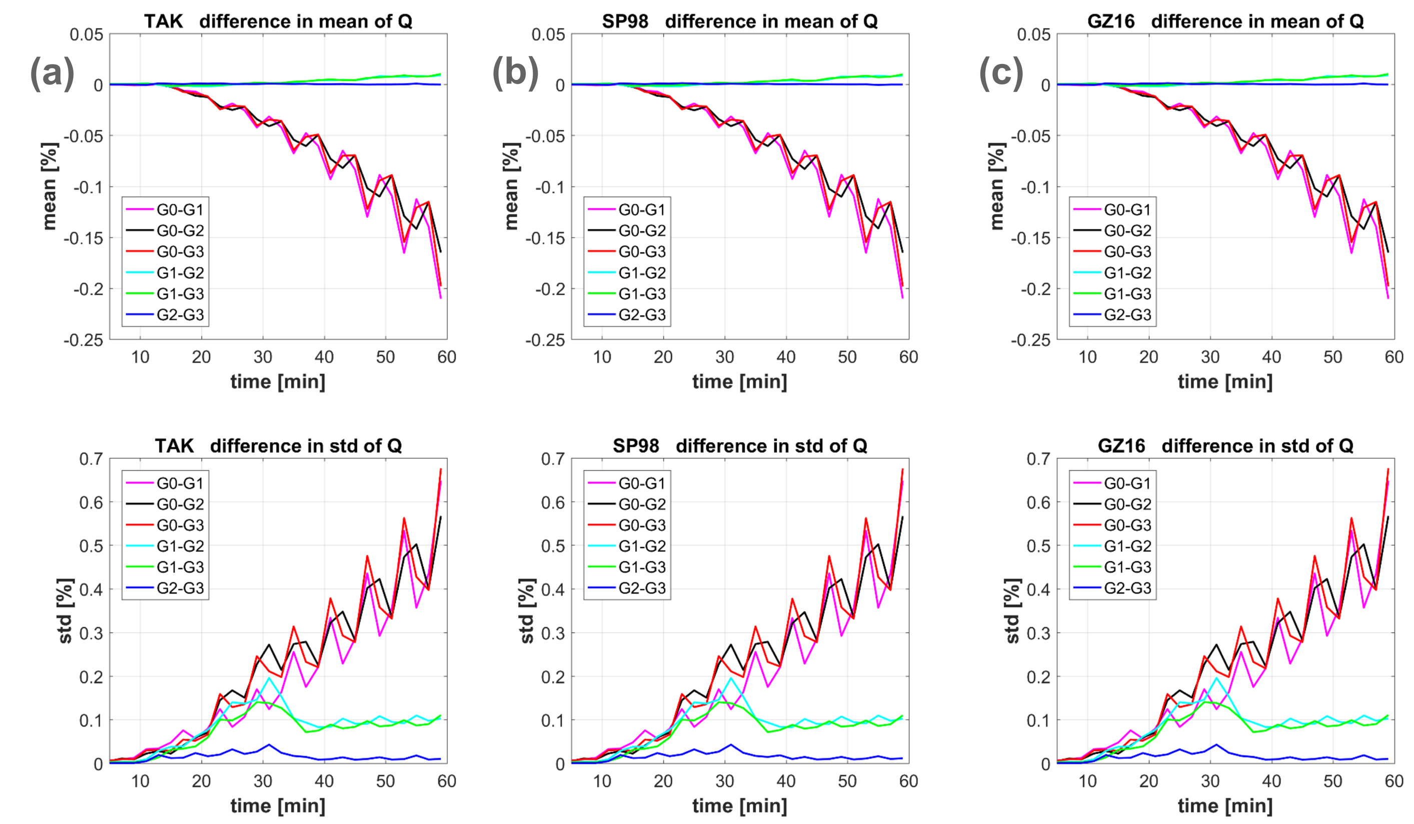


Fig. 4 Normalized difference in (top) mean and (bottom) standard deviation for schemes: (a) TAK, (b) SP98, and (c) GZ16.

3/ Methods & Results

Simulations of CELM using an artificially induced thundercloud, the warm air bubble (Weisman and Klemps' profiles, 1982), previously showed a good ability of the model to simulate realistic charge structure of the thundercloud.

Thus, we could study the dependence of the resulting charge structure on one of CELM input parameter; the ion generation rate by cosmic rays (G). We tested four G functions (Fig. 2). The charge structure for one of it is displayed in Fig. 3. We obtained various results while using the three non-inductive charging schemes and four G functions, and sought whether the various results are more related to the selected G or selected scheme. To answer the question, we conducted a sensitivity analysis: we subtracted the electric charge of one simulation using a G from that of another simulation using another G, we computed mean and standard deviation of the differences and normalized the results using the size of individual electric fields. Fig. 4 shows the results of the sensitivity analysis. It clearly suggests that the influence of schemes on the resulting charge structure is almost negligible, i.e. the charge structure depends more on G with G2 and G3 giving most similar results and G0 differing the most from the others.

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.

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