Modeling the melting of graupel and hail in a bulk microphysics parameterization

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Outline

- The challenge of melting in standard bulk schemes
- An improved conceptual model of melting from a bulk point of view
- The melting equation for individual particles
- Challenge 1: particle temperature
- Challenge 2: shedding of melt water
- Implementation in ICON and the COSMO model
- Preliminary results for a idealized supercell storm
- Conclusions and Outlook

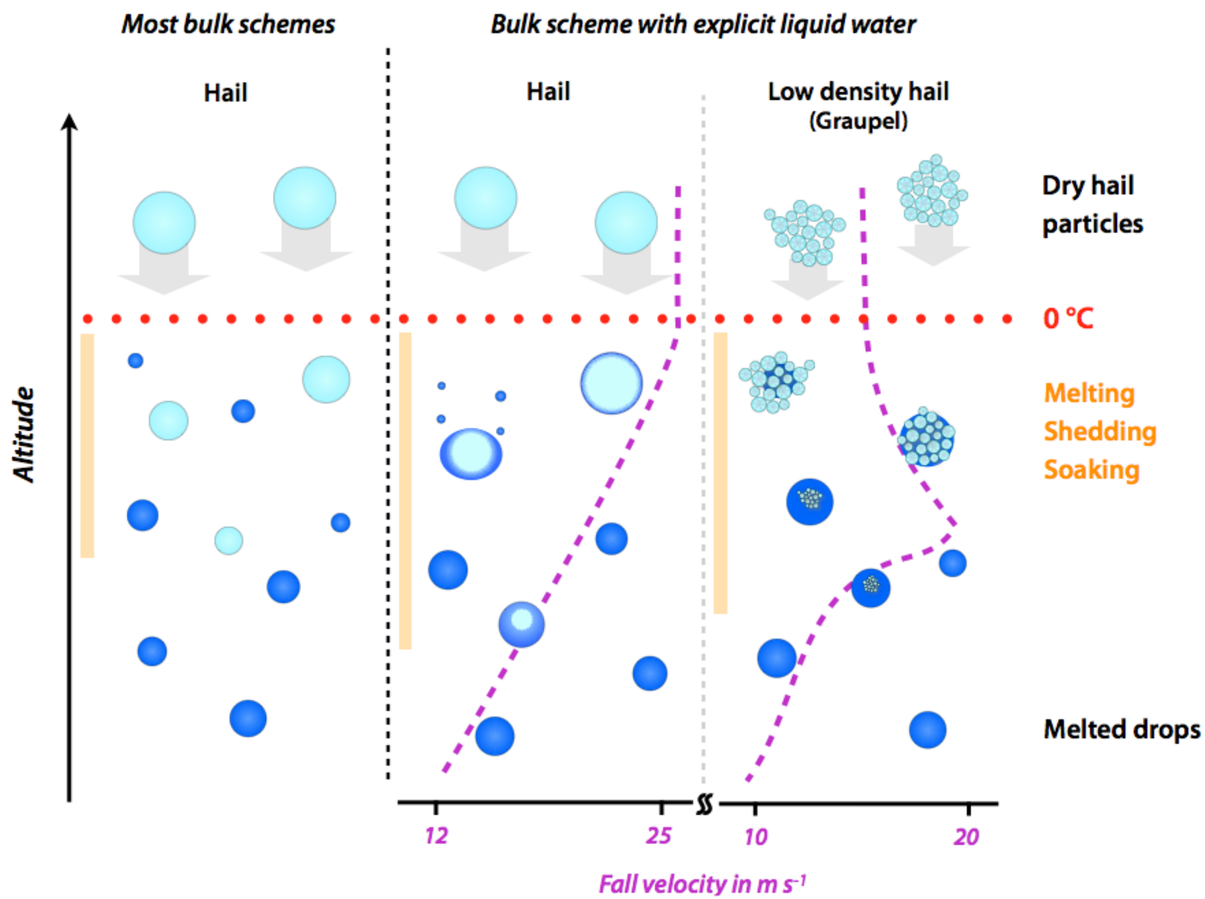
Melting in bulk microphysics schemes:

Issues of standard schemes:

- Particles are either liquid or ice, but no mixed-phase particles.
- Meltwater is immediately transfered to rain category
- No information about internal structure of melting particles.
- Fall speed of melting particles is wrong, and melt water falls with terminal velocity of rain.
- Melting layer is often too shallow.

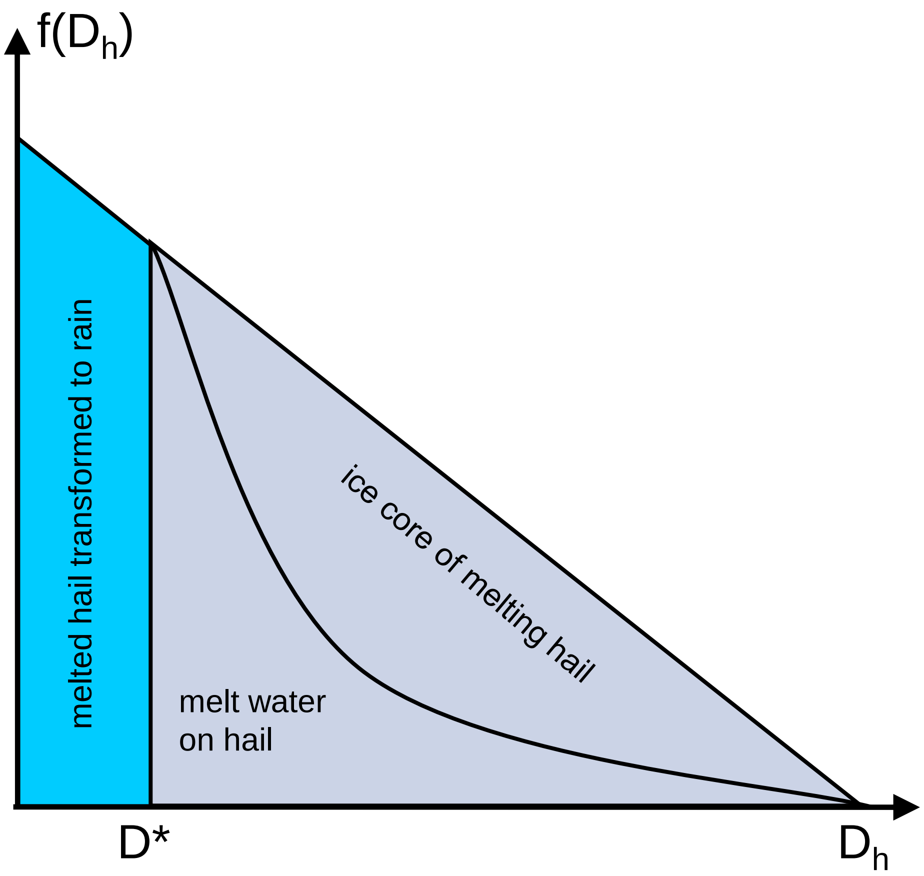
Possible solution:

- Predict melt water coating on ice as mixed-phase particles.



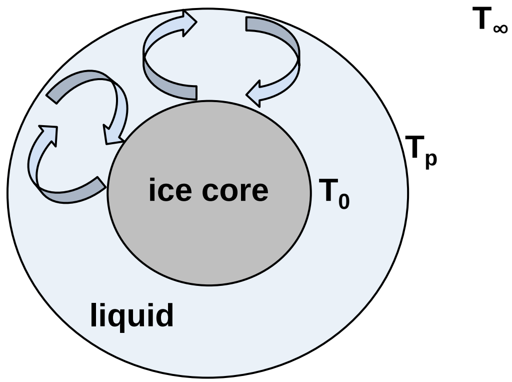
Prognostic melt water in bulk microphysics:

- We need to parameterize not only the behavior of individual particles, but the whole size distribution.
- Small particles up to D* have been melted completely and transfered to the rain category.
- The liquid water fraction decreases with increasing size.
- We predict the total bulk melt water and diagnose D* and the slope of the spectral melt water distribution.



Theory of melting hail

Based on the heat transfer equation the change in meltwater of a melting particle can be written as



$$\left.\frac{\partial m_w}{\partial t}\right|_{\mathrm{melt}} = \frac{2\pi D_p D_i k_w \Delta T_{p,0}}{L_m (D_p - D_i)}$$

$$= \frac{2\pi D_p}{L_m}\left(\bar{f}_h k_a \Delta T_{\infty,p} + \bar{f}_v \frac{D_v L_e}{R_v} \Delta q_{\infty,p}\right)$$

where the heat transfer through the meltwater layer (**internal conduction**) is balanced by the heat transfer at the particle surface (sum of **external conduction** and **latent heat**).
Note that the sub-scripts ∞, *p*, and *0* correspond to the far field, the particle surface and the 0 °C surface of the ice core, respectively. Especially for melting hail the particle surface is not at 0 °C, but warmer due to the limited external heat transfer.

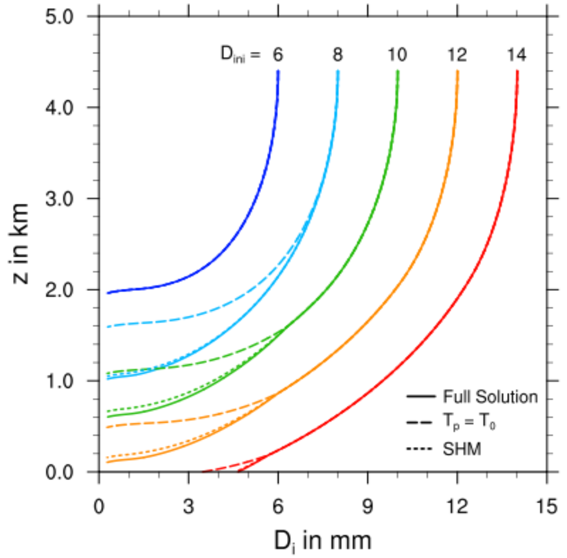
Challenge 1: Particle surface temperature

- ➔ Do we need an additional prognostic variable for particle surface temperature?
- ➔ The surface temperature depends strongly on particle size. How can we treat this in a bulk microphysics scheme

Using a detailed bin model that predicts the surface temperature in each size bin, we confirm the hypothesis that the **surface temperature deviation from 0 °C scales with the thickness of the layer of melt water** on the particles.
The latter we know, because we already make an assumption about the spectral liquid water fraction.

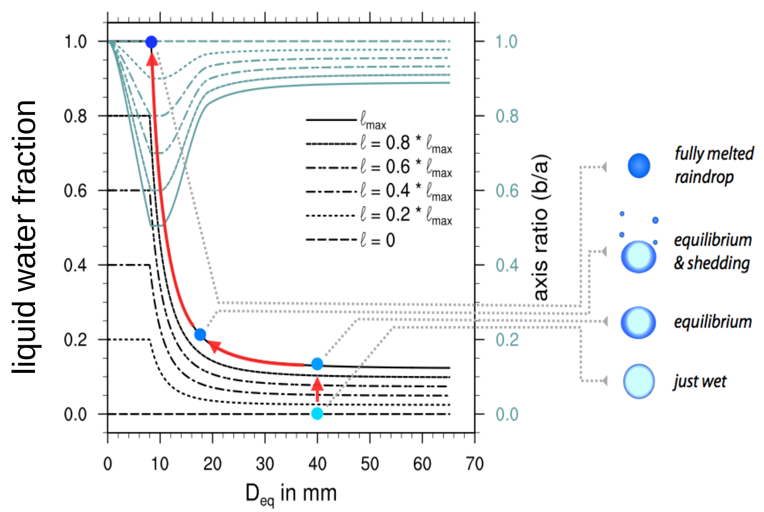
$$\frac{D_i}{D_p} \approx \frac{\Delta T_{\infty,p}}{\Delta T_{\infty,0}} \approx \frac{\Delta q_{\infty,p}}{\Delta q_{\infty,0}}$$

Simulation of melting in a 1D model. Shown is the profile of the diameter of the ice core

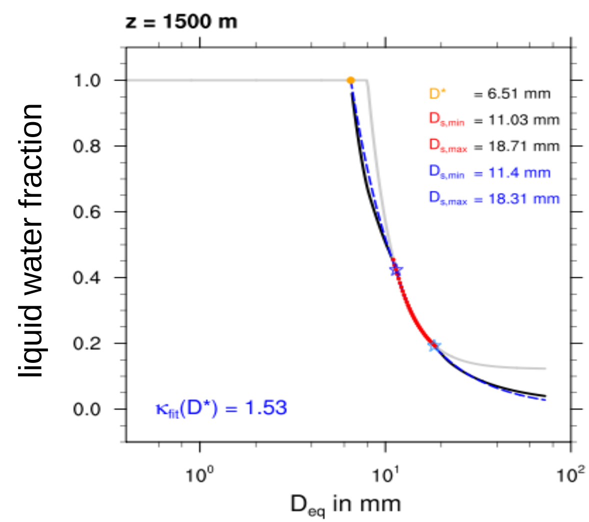


Challenge 2: Shedding

- ➔ Large ice particles cannot become hydrodynamically unstable during melting and loose melt water by shedding.
- ➔ A treatment of shedding is crucial for a consistent treatment of melting and rain, because raindrops large 8 mm diameter are unstable, too.



Illustrating the evolution of the hail liquid water fraction and aspect ratio during melting.



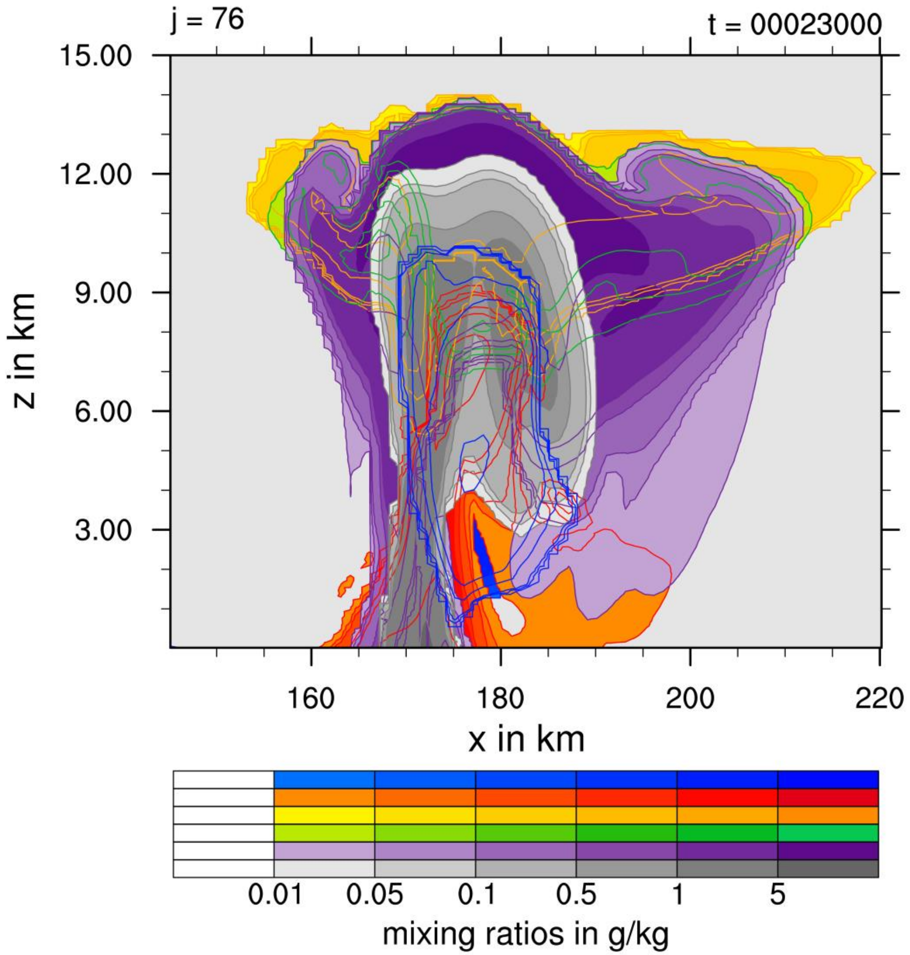
Example of shedding for medium sized melting hail

Implementation in ICON and the COSMO model

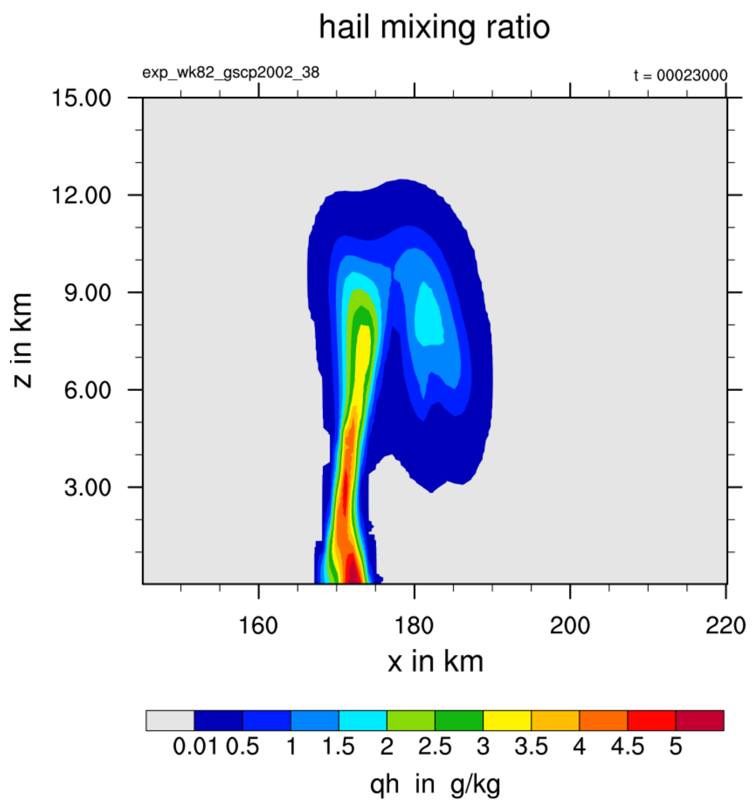
- The new melting scheme has been implemented as an extension of the two-moment microphysics scheme of ICON and the COSMO model.
- A version for the one-moment scheme is not planned.
- So far only idealized test have been done. More detailed case studies with COSMO-DE need to be performed and validated before the scheme will be released (hopefully later this year).
- The implementation relies on pre-calculated tables or rational function fits. This makes parameter studies more difficult, but is necessary due to the complexity of the melting (and shedding) process.

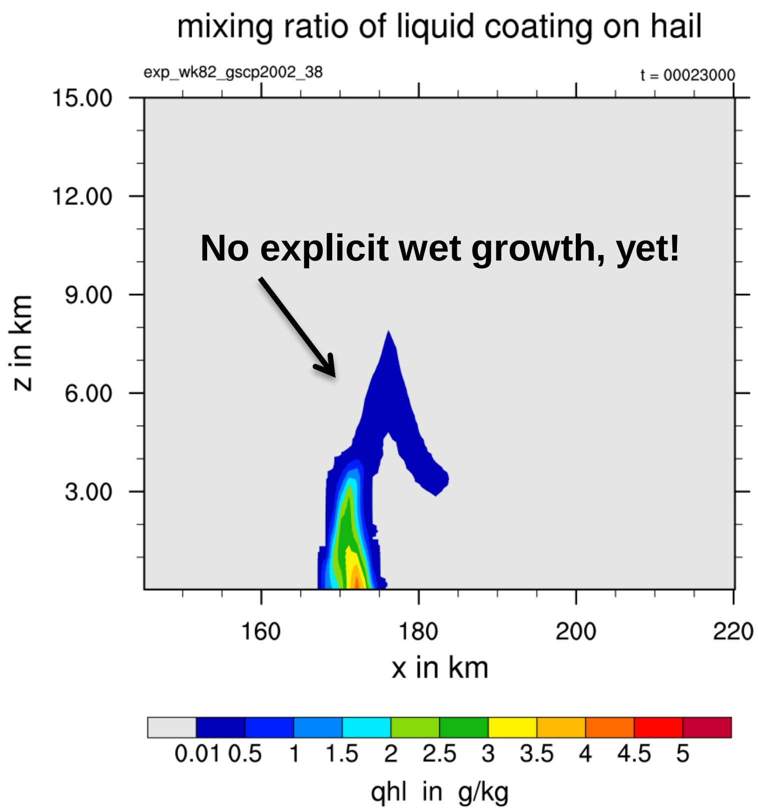
Simulation of an idealized supercell storm

- Quarter-shear idealized supercell using WK82 profiles



Simulation of an idealized supercell storm





➔ Quarter-shear idealized supercell using WK82 profiles

Simulation of an idealized supercell storm

- Surface hail is more localized and more intense in the new scheme

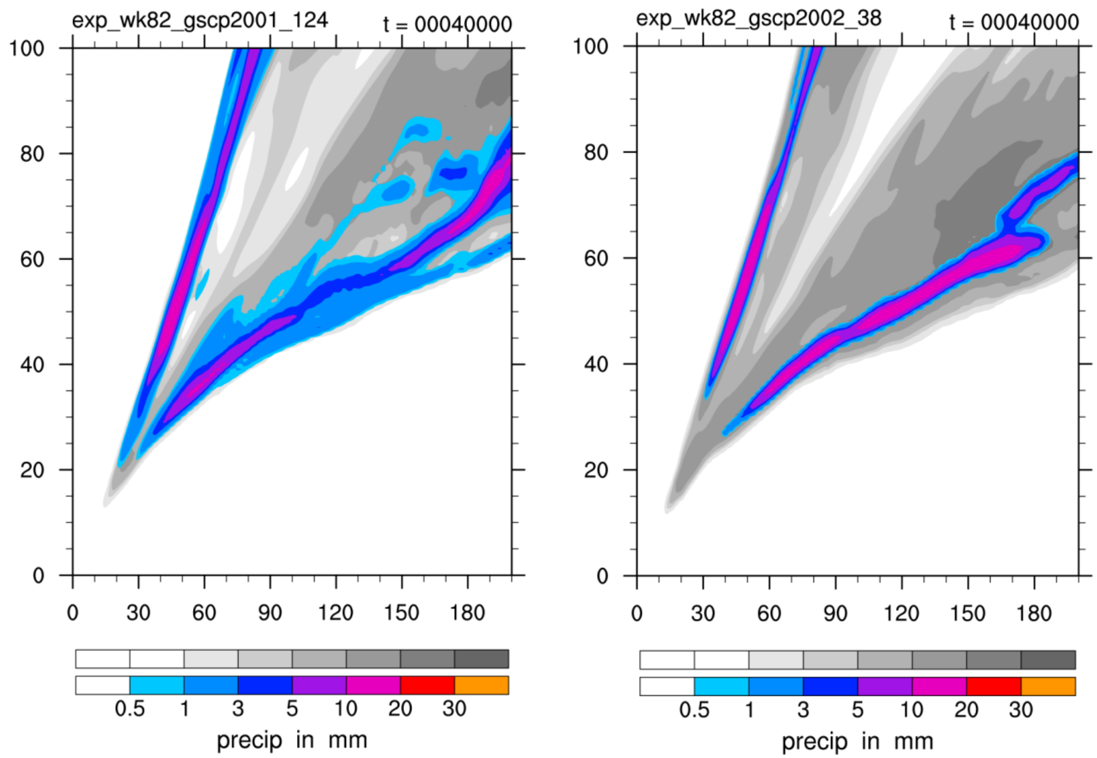


Figure: Surface precipitation (total: grey, hail: colors) for the new scheme (right) and the old scheme (left).

Simulation of an idealized supercell storm

- Storm structure is slightly different, but storm splitting and propagation are unchanged.
- Smoother low level reflectivity, because we now really have two modes for the rain and melting hail?
- Looking forward to storm-scale EnKF experiments.

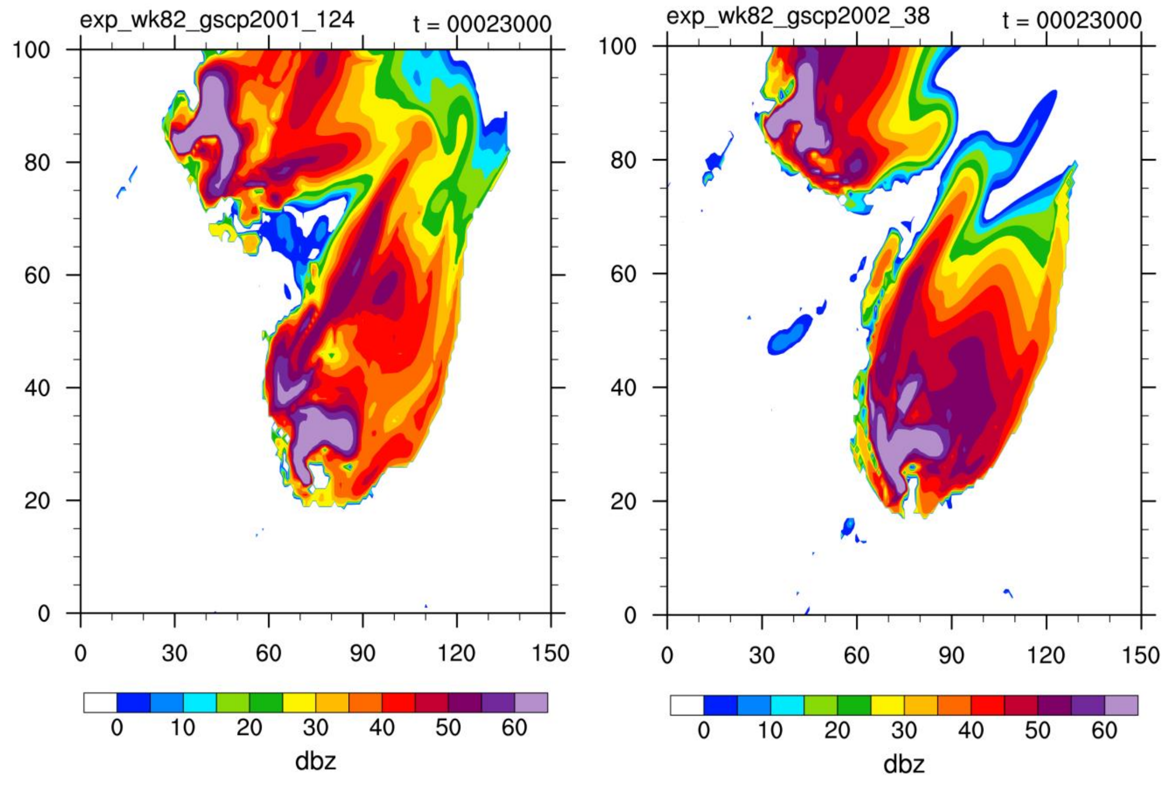


Figure: Horizontal cross sections at of radar reflectivity at 3 km height for the new scheme (right) and the old scheme (left).

Summary and Outlook:

- ➔ Melting of graupel and hail is poorly treated in most bulk models (including the current schemes of the COSMO model).
- ➔ Explicit prognostic melt water can help to overcome some of the deficiencies of the simple schemes.
- ➔ Challenges are, for example, the non-equilibrium surface temperature during melting and the shedding of melt water.
- ➔ Uncertainties remain due to a lack of detailed laboratory studies. The new model relies basically on a single wind tunnel study of melting graupel and hail made in the late 70s in Pruppacher's lab at UCLA.
- ➔ This is not (yet) a fully explicity treatment of wet growth of hail. Wet growth is still implicit and not considered for the new liquid water on hail variable.
- ➔ The new scheme will be made available to the community later this year and will hopefully improve the prediction of hail and graupel.