Improvement of convection parameterization in high resolution limit

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In operational weather prediction models, the effect of subgrid phenomena on the large scale flow is usually evaluated with parameterizations. The resolved condensation is obtained from the mean grid-box conditions together with some hypotheses on the subgrid variability. To treat deep convection, that implies significant vertical transports, mass-flux schemes are very popular. They generally assume that the grid-boxes are sufficiently large to contain a wide variety of clouds at different stages of evolution, and that the fraction of the grid-box area occupied by these is small, so that the properties in the updraft area have small impact on the resolved properties. The scheme is closed by writing some steady-state diagnostics.

For grid-box length between 10 and 1km, used together with relatively short time-steps, these hypotheses are no longer satisfied. The resolved vertical velocity becomes significant, while the resolved condensation includes a significant part of the one associated to updrafts; it becomes difficult to combine fully separate contributions from the resolved and the updraft schemes. A common practice is then to suppress the convective parameterization, but the resolution is often not sufficient to completely resolve the convective cells at all stages of their evolution.

The relevant issues to improve parameterization include the time-evolution of the updraft vertical velocity, of the updraft horizontal extents and of its vertical extent (gradual raise of the cloud, while no steady-state is reached), and preventing concurrence between resolved and subgrid. In the point of view of modeling, the two first items can be handled by memorizing respectively an updraft velocity variable governed by a prognostic equation, and an updraft mesh fraction evolving at each time step. Both variables are advected by the mean flow. This technique was applied in the 3MT scheme [Gerard et al., 2009], together with a sequential organization of the parameterizations to make them complementary. The updraft condensation was combined with the resolved condensation before entering a single microphysics. This solution produced encouraging results down to 4km resolution, but the auto-extinction of the parameterization at higher resolution was not obtained.

In theory, using small grid-boxes implies that the mesh fraction could reach 100%; but in this case the construction of a buoyant subgrid updraft looses its pertinence, and in addition it is very difficult to get the subgrid contribution falling back to zero when all updrafts are resolved.

To get out of the deadlock, we developed a new scheme based on the concept of *virtual unresolved cloud*. It considers that physical updrafts can already be partly represented by the resolved motion and the resolved condensation scheme, and that parameterization should simply produce a complementary contribution to these.

We take as prognostic variable $\omega_u^\diamond = \omega_u - \overline{\omega}$, the difference between absolute updraft velocity ω_u and resolved vertical velocity $\overline{\omega}$. The subgrid mesh fraction σ_u represents the total fraction occupied by the updrafts only when the resolution is coarse and $\overline{\omega}$ is small. At high resolution, it is associated with a virtual updraft, complementing the resolved one. The virtual updraft condenses with $\sigma_u\omega_u^\diamond$, transports and entrains with $\sigma_u(\omega_u - \omega_e)$

where ω_e is the velocity in the grid-box updraft environment, and rises with the absolute velocity ω_u.
The virtual updraft is necessarily confined in a grid column. An upwards motion of the updraft parcel (wrt the mean grid-box motion) is compensated by a downwards motion of the dryer environment. Following e.g. Asai and Kasahara [1967], the subsiding motion is accompanied by a dry adiabatic heating reducing the net buoyancy. This effect is accounted for in our formulation, and depending of the vertical dry and moist lapse rates, the maximum consumption of energy by the subgrid updraft occurs for $\sigma_u = 0.4$ or less; subsequently σ_u will never be greater than this value.
The short time-steps make it necessary to allow a gradual rise of the updraft top; the vertical equation also accounts for the fraction of the time-step a given level is reached by the rising updraft. The mesh-fraction evolution is currently estimated with a diagnostic of the steady-state value (not reached) and an evolution equation towards it.
Preliminary tests at varying resolution in three-dimensional model show a significant decrease – though not a complete extinction – of the convective contribution when the mesh-size decreases from 8 to 1km. The figure below shows that the subgrid-scheme share remains important mainly for low total precipitation amounts. Additional refinements are studied to further improve the convergence towards explicit convection.
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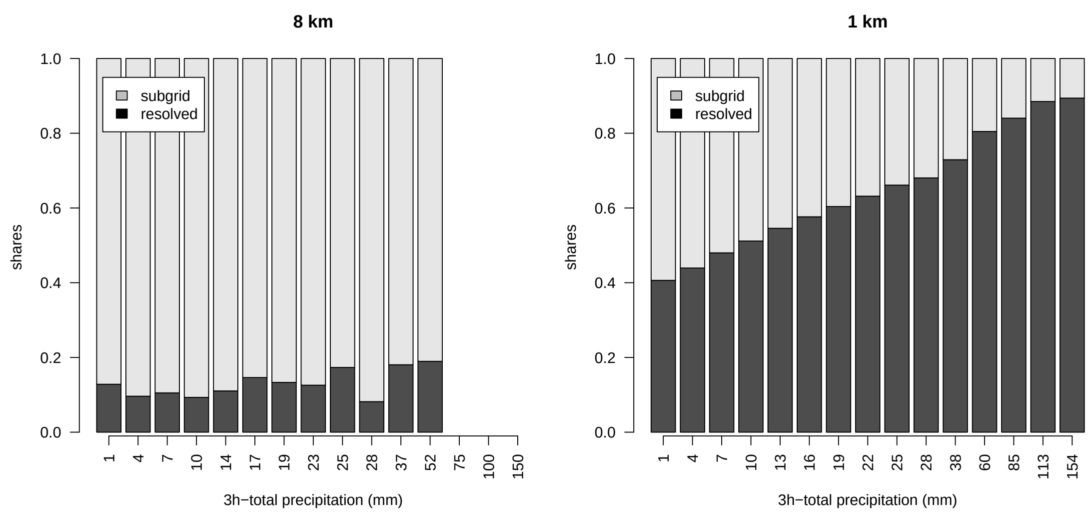

Figure 1 : Resolved and subgrid respective proportions for several classes of forecast surface precipitation intensities. Convective event over Belgium (10-09-2005). Left: 8km-, right: 1km-mesh-size

References

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