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Mesoscale impacts of explicit numerical diffusion in a convection-permitting model

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Previous studies have highlighted the effects of both numerical and sub-grid turbulent filtering in convection-permitting simulations ($\Delta x \approx O(1\text{ km})$), since both significantly modify cloud dynamics by enhancing the dissipation within moist convective plumes. In this study we are interested in impacts of the model's numerics and physics upon intermediate scales, at which energy is not primarily attenuated by the explicit numerical filter, e.g., the scale of the European Alps. Furthermore, we study the influence of numerical small-scale filtering of specific prognostic variables on the up-scaling of energy to larger scales.

Numerical simulations of a period characterized by summertime convection over Alpine terrain are performed using the COSMO-CLM mesoscale model at a grid-spacing of 2.2 km. The feedback to larger scales is explored using spectral analysis and by computing bulk Alpine heat and moisture budgets. The latter are evaluated by a recently implemented budget diagnosis tool, which extracts all physical and dynamical contributions to the net temperature and moisture scalar tendencies.

Both the peak of the mean diurnal cycle and the total amount of precipitation in a large Alpine region is reduced by up to 37 % in the case of strong numerical dissipation applied to the prognostic variables. Besides a direct impact on cloud structures, the spectral analysis and the heat budgets reveal a substantially reduced feedback of small-scale energy to the mesoscale. Less energy is contained at the Alpine scale and the bulk Alpine net heat budget is modified such that less heating occurs within the PBL during daytime and the upper tropospheric heating is reduced by ~ 30 % in the late evening. The former is mainly a consequence of reduced vertical heat advection within the PBL, while the latter is primarily a result of minimized latent heat release.

In order to determine the origin of the amplifying grid-scale energy, which is either of physical origin or the result of computational noise, we compare different moisture advection schemes. On the one hand a Semi-Lagrangian (SL) scheme, which is characterized by spurious small-scale oscillations, and on the other hand different monotonic schemes. In contrast to the monotonic schemes, energy at the shortest wavelengths is increased with the SL scheme and the up-scaling is therefore significantly influenced by explicit filtering of moisture scalars.

The results agree surprisingly well with the linear theory of convective growth, which is also used to better understand the initial period of convective growth of the numerically generated perturbations. Especially the filtering of horizontal momentum and buoyancy determines the characteristic amplification times of small-scale instabilities.