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Influence of subgrid-scale turbulence parameterization on the mean flow properties and characteristics of individual convective cells

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The design of subgrid-scale turbulence parameterizations which work well across the entire range of the so-called "terra incognita", i.e. the scales between the mesoscale limit (no turbulence resolved) and the large-eddy simulation limit (energy-containing eddies resolved), is a big challenge for convection-resolving modeling. Despite several attempts, there is still disagreement on which approach is the best to adopt with regard to turbulence treatment at the kilometer scale. This study aims at investigating the sensitivities stemming from the formulation of subgrid-scale turbulent processes with respect to both the mean flow properties and the characteristics of the single convective cells at horizontal grid spacings Δx = 8.8, 4.4, 2.2, 1.1 km and 550 m. A 1D TKE-based turbulence scheme devised for mesoscale modeling with grid-independent but tunable asymptotic Blackadar turbulent length scale l_∞ and a 3D Smagorinsky turbulence closure devised for LES are compared. Real-case simulations over the Alps and over Central Germany are conducted to compare the results over mountainous and flat terrain.

Results show that the mean flow properties are more sensitive to the subgrid-scale turbulence parameterization than to Δx, whereas the opposite is valid for the characteristics of the individual convective cells. Smaller values of l_∞ in the 1D model are associated with lower diffusion, stronger convective cells, reduced cloud cover but thicker clouds, lower cloud base and increased precipitation. These sensitivities are generally more pronounced at coarse resolutions and over flat terrain. Changing the value of l_∞ has little impact on cloud-scale statistics such as the number of grid-scale clouds and the average distance between the cloud clusters, but larger l_∞ reduces the mean updraft velocity of the convective cores. The employment of a 3D Smagorinsky closure at the kilometer scale generally yields similar results of a 1D model with very large values of l_∞, indicating that 3D closures are too diffusive and should not be applied to simulations with Δx = 1.1 km or coarser resolutions. However, the two become comparable at subkilometer scales, suggesting that 3D closures yield reasonable performances also at scales of a few hundreds meters, and thus larger than those for which they were designed, and that they should preferably be used at scales smaller than a few hundred meters.