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Clouds in a changing climate in decade long convection-resolving climate simulations over Europe

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Clouds are a fundamental component of the Earth's climate system, and substantially influence climate change through feedback effects, especially via the energy budget. Despite the evident need to reliably represent cloudiness in climate models, cloud processes still constitute the leading cause for the wide spread in climate projections. Current climate models indeed operate at coarse horizontal grid spacings of O(10 km) to O(100 km), are not suited to represent finer-scale cloud processes, and use parameterized cloud representations. Thanks to the advent of high performance hybrid computing facilities, it is becoming feasible to run high-resolution climate simulations over continental-scale domains with explicitly resolved deep convection. This has the threefold advantage: (i) removing uncertainties due to the parameterization of convection, (ii) improving the representation of the underlying topography, and (iii) allowing for a finer representation of cloud-microphysical and dynamical processes.

Here we present a study based on decade-long convection-resolving climate simulations at a horizontal grid resolution of 2.2 km over a computational domain with 1536x1536x60 grid points covering Europe. Such unprecedented and computationally expensive simulations have become feasible with a COSMO (Consortium for Small-Scale Modeling) model version that runs entirely on Graphics Processing Units (GPUs). We first focus on evaluating the representation of the mean summertime cloudiness in a present-day convection-resolving climate simulation driven by ERA-Interim reanalysis (Leutwyler at al., 2017 JGR). Comparisons with observations show a reduction of the positive bias in mean total cloud cover and improvements in the top-of-the-atmosphere radiation budget when convection is resolved instead of parameterized. Of particular interest is the enhanced mid-tropospheric cloud layer in the convection-resolving simulation, which is typically underestimated in conventional climate models. This enhancement can be traced back to an increased transport of moisture from the low to the mid-troposphere, generated by stronger boundary layer mixing with explicitly resolved deep convection.

Secondly, we compare the present-day simulation with a Pseudo-Global Warming (PGW) simulation to assess potential climate change effects in convection-resolving simulations. The PGW simulation is driven by ERA-Interim reanalysis, perturbed by the mean annual cycle of climate changes derived from a CMIP5 model. With this approach, resulting signals are due to seasonal circulation changes and the large-scale warming and moistening of the atmosphere. Cloud amount changes in the convection-resolving simulations are dominated by reductions of lower to mid-tropospheric summertime cloudiness over a large band covering mid-Europe, and are consistent with findings from convection-parameterizing simulations. The resulting surplus of incoming solar radiation indicates a positive cloud feedback. Although consistent in sign, the changes of the energy budget components substantially differ in magnitude, between the convection-resolving and the convection-parameterizing approaches. This is attributable to slightly differing cloud amount changes between the two approaches.