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Evaluating cloud processes in large-scale models: Of idealized case studies, parameterization testbeds and single-column modelling on climate time-scales

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Boundary-layer schemes have always formed an integral part of General Circulation Models (GCMs) used for numerical weather and climate prediction. The spatial and temporal scales associated with boundary-layer processes and clouds are typically much smaller than those at which GCMs are discretized, which makes their representation through parameterization a necessity. The need for generally applicable boundary-layer parameterizations has motivated many scientific studies, which in effect has created its own active research field in the atmospheric sciences. Of particular interest has been the evaluation of boundary-layer schemes at "process-level". This means that parameterized physics are studied in isolated mode from the larger-scale circulation, using prescribed forcings and excluding any upscale interaction. Although feedbacks are thus prevented, the benefit is an enhanced model transparency, which might aid an investigator in identifying model errors and understanding model behavior. The popularity and success of the process-level approach is demonstrated by the many past and ongoing model inter-comparison studies that have been organized by initiatives such as GCSS/GASS. A red line in the results of these studies is that although most schemes somehow manage to capture first-order aspects of boundary layer cloud fields, there certainly remains room for improvement in many areas. Only too often are boundary layer parameterizations still found to be at the heart of problems in large-scale models, negatively affecting forecast skills of NWP models or causing uncertainty in numerical predictions of future climate. How to break this parameterization "deadlock" remains an open problem. This presentation attempts to give an overview of the various existing methods for the process-level evaluation of boundary-layer physics in large-scale models. This includes i) idealized case studies, ii) longer-term evaluation at permanent meteorological sites (the testbed approach), and iii) process-level evaluation at climate time-scales. The advantages and disadvantages of each approach will be identified and discussed, and some thoughts about possible future developments will be given.