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Elements of modern cloud modelling

Cloud modelling deals with description of processes occurring in the atmosphere that lead to formation of clouds and precipitation. The challenges in cloud modelling stem from the myriad of couplings that link large-scale atmospheric thermo- and hydrodynamics with physicochemical properties of individual aerosol particles, cloud droplets and rain drops. Furthermore, cloud modelling faces the challenge of effectively leveraging modern computing technologies.

The thesis is structured into four introductory chapters and an appendix containing three research papers co-authored by the candidate. The introduction is aimed at guiding the reader through the three papers which constitute the substance of the thesis. Four aspects of cloud modelling are briefly discussed in the introductory chapters, namely: modelled phenomena, model formulation, model implementation and model validation. Each of the papers is focused on a different one of these aspects. All three papers, however, feature application of the Lagrangian-in-size representation of particle size spectrum. This approach is of particular applicability to studies on aerosol-cloud interactions which have been the focus of active research in last years due to their still uncertain role in shaping the Earth's climate.

The first paper entitled "Adaptive method of lines for multi-component aerosol condensational growth and CCN activation" (Arabas and Pawlowska, 2011, *Geosci. Model. Dev.* 4) is focused on the activation of cloud condensation nuclei (CCN) to form cloud droplets. The paper describes original formulation and implementation of a zero-dimensional cloud model (so-called parcel model).

The second paper entitled "Large-Eddy Simulations of Trade Wind Cumuli Using Particle-Based Microphysics with Monte Carlo Coalescence" (Arabas and Shima, 2013, *J. Atmos. Sci.* 70) is focused on validation of model formulation and simulation results against observational data. The paper describes a novel application of the particle-based simulation technique for cloud modelling. Presented simulations involve a Monte-Carlo type representation of particle collision process. The simulations are carried out using a three-dimensional Large-Eddy-Simulation (LES) modelling framework.

The third presented paper entitled "libcloudph++ 0.1: single-moment bulk, double-moment bulk, and particle-based warm-rain microphysics library in C++" (Arabas, Jaruga, Pawlowska, Grabowski 2013, arXiv e-print 1310.1905) is focused on model implementation. The paper describes original implementations of three algorithms for representing processes leading to formation of rain under absence

of ice. One of the implemented algorithms is based on the particle-based technique and uses the Monte-Carlo type scheme for solving particle collisions. The formulation of the particle-based scheme includes original elements and is presented in the paper. The algorithms are implemented in a form of a C++ library released as free and open-source software. The library design and programming interface (API) are described within the paper. Simulation examples presented in the paper are carried out using a two-dimensional prescribed-flow modelling framework.

Each paper is accompanied by a description of authors' contributions to the presented research and the paper content.