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Sabine Hittmeir

University of Vienna

Scale Analysis for Atmospheric Flows

Model reductions in meteorology by scale analysis are inevitable and therefore have a long history in meteorology. One prominent example for larger scale dynamics in the midlatitudes thereby are the quasi-geostrophic equations. Moreover, under the assumption of hydrostatic balance, the full compressible governing equations reduce to the so-called primitive equations, which often build the basis for weather-forecasting and climate models. As was proven in Cao and Titi (2007) these primitive equations are globally well-posed, where the proof relies on the fact that the pressure enters the equations only as a two-dimensional surface.
A unified framework for the derivation of such reduced models for atmospheric flows was introduced by R. Klein (2004), which in particular also provides the appropriate setting for performing multiple scale asymptotics. The latter is the key technique for a systematic study of complex processes involving the interaction of phenomena on different length and time scales and is therefore of special interest for phenomena involving clouds and cloud systems.
Due to their major contribution to the energy transport of particular interest are hot towers, which are large cumulonimbus clouds that live on small horizontal scales. In comparison to existing studies we not only incorporate moisture into the model via additional balance equations for water vapor, cloud water and rain water, but also refine the thermodynamics by taking into account the different gas constants and heat capacities for the water

components in contrast to dry air. This refined setting was demonstrated in Hittmeir and Klein (2017) to be essential by leading to different force balances in the considered scaling regime.

Such deep convective clouds furthermore constitute the building blocks of intermediate scale convective storms, which we study in a next step by incorporating the setting of organised convection into the multiscale approach. This requires systematic averaging procedures, allowing to quantify the modulation of the larger scale flow by the moisture processes in the small scale regions.