Numerical analysis of turbulent superstructures in thermal convection: Long-term dynamics by Lagrangian clustering and Markov state modeling

Large-scale patterns of the time-averaged velocity and temperature fields are found for turbulent convection in a horizontally extended layer. These patterns are termed turbulent superstructures and will be in the focus of our project. We want to understand their dynamical origin from the weakly nonlinear regime, their importance for the turbulent heat transport and model transitions between different superstructure patterns in turbulence. Our investigations are based on massively parallel three-dimensional direct numerical simulations of turbulent Rayleigh-Bénard convection in large-aspect ratio domains that include very low and high Prandtl number cases. In order to answer the questions and to study the long-term evolution of superstructures, we will have to reduce the vast amount of degrees of freedom of the flow. This is done by (1) generalized Markov state models which are based on a long-term low-resolution flow trajectory in combination with short-term full-resolution ensemble simulations (see figure below) and (2) by (evolutionary) clustering in ensembles of Lagrangian tracer tracks. While method (1) gives transition probabilities between different macroscopic superstructure patterns, method (2) reveals the most persistent and longest-living Lagrangian coherent sets in the turbulent convection flow.