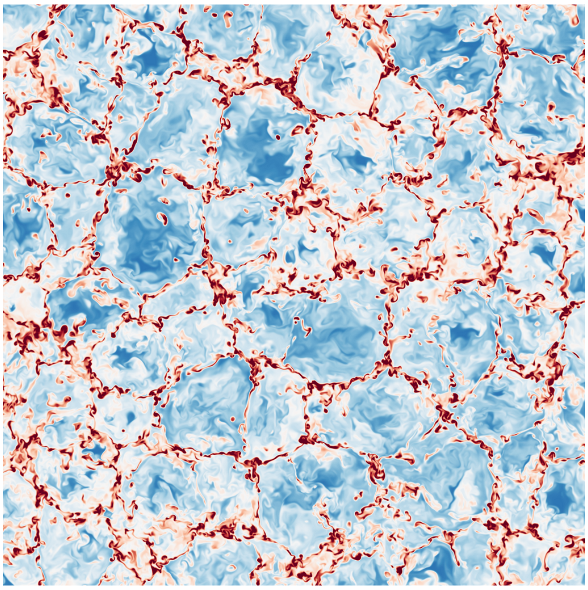
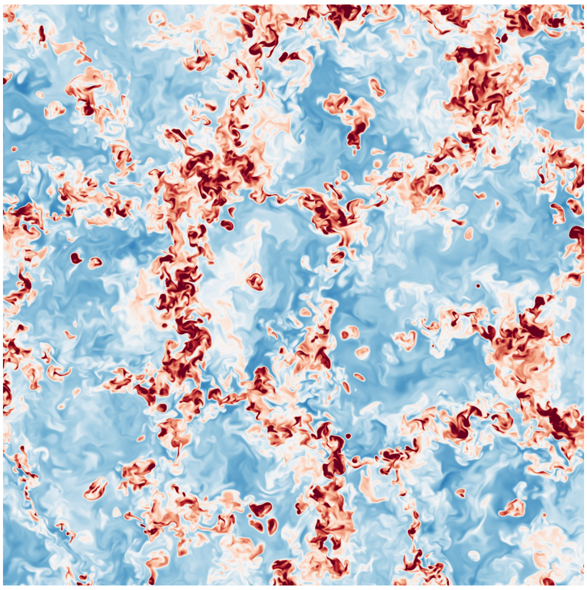
Convection Cells in Planetary Boundary Layers: Origin and Reduced Modeling

Under convection conditions, the flow in planetary boundary layers is organized in long-lived, large-scale cellular motions, which are referred to as convection cells. The diameters of these convection cells can have several kilometers, and these cells can persist for more than an hour. These convection cells are the turbulent superstructures that we want to investigate. In particular, we want to ascertain how important the surface and free-troposphere properties are for their formation and evolution, and how we can represent them in simple atmospheric models. As an example, the horizontal cross sections in the figures below make the convection cells visible by means of the temperature: red color indicates narrow regions of warm, ascending air (moving out of the plane), and blue color indicates cold, descending air (moving into the plane). We can see that the width of the convection cells strongly depends on the buoyancy stratification in the free troposphere above the planetary boundary layer. How does that occur and what are the consequences of this dependence? We want to answer these questions. We will employ data from direct numerical simulations. Starting from Rayleigh-Bénard convection, we will incrementally modify the boundary conditions to design and study convective boundary layers, which are idealized configurations that reproduce key aspects of planetary boundary layers, like convection cells. The aim is to understand the dependence of these convection cells on the boundary conditions and on the Rayleigh number. For the detection of the convection cells and the analysis of their interaction with the small-scale turbulence, we will use coarse-graining and Lagrangian techniques. In collaboration with other groups in the DFG Priority Programme, we will also develop and analyze reduced models describing the evolution of these superstructures, our project focusing on the implications for planetary boundary layers. As an outcome of this work, we will comprehensively learn how efficient these techniques are to represent turbulent superstructures in the atmosphere. Besides, this project will bring together Rayleigh-Bénard convection and atmospheric convection in one single analysis, assessing thereby to what extent we can transfer knowledge between the two fields.



Cells below a weakly stratified troposphere



Cells below a strongly stratified troposphere