



An Integrated View of Boundary Layers and Turbulence: Theories, Experimental Data, and Numerical Models

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The boundary layer near the Earth's surface is the region in which we spend most of our lives. The scales of turbulent motions in atmospheric and oceanic boundary layers are typically smaller than the horizontal grid spacing of regional and global models, calling for parameterization schemes describing the net effect of these subgrid-scale motions. My vision is to bridge the theoretical understanding of turbulent boundary layers and the demands from regional and global models.

The theoretical understanding of turbulent boundary layers cannot bypass the local integral scale that characterizes the most energetic turbulent motions. In this work, theoretical, experimental, and numerical approaches are combined to solve the puzzle of the local integral scale for typical environmental flows. A theoretical framework is established without making assumptions about temperature stratification and the balance between production and dissipation of turbulent kinetic energy (TKE). The theoretical models are confirmed for two types of boundary layers: (i) above a homogeneous surface where temperature stratification either produces or destructs TKE, and (ii) above a plant canopy where the produced TKE is efficiently transported downward.

Validating the theoretical model requires both experimental data and numerical simulations. Because the definition of time-averaged statistics used in theories require stationary conditions, this work constructs a novel approach that determines both the occurrence and the duration of stationary periods from long-term dataset sampled at multiple locations. In the presence of plant canopies, numerical simulation is needed as an intermediate method to bridge theoretical predictions and observational data. A large-eddy simulation study has shown that representing the flexibility of plants is critical to successful reproduction of turbulent fluxes carried by upward and downward events. The outcome of these theoretical, experimental, and numerical studies can be extended to various research work involving turbulent boundary layers, including turbulent fluxes in nonstationary environments, fluid-structure interactions, and sustainable agricultural practices.

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