Self-similar energy-containing eddies in a turbulent natural convection boundary layer immersed in a stably stratified medium

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This study investigates the statistical nature of turbulence in a natural convection boundary layer immersed in a stably stratified medium using three-dimensional direct numerical simulations. Numerical simulations were performed using an in-house collocated finite volume code at three different Grashof numbers (2400, 2800 and 3600) and at a constant Prandtl number of 0.71. At certain wall-normal locations in the outer layer, the shear-production of turbulent kinetic energy approximately balances viscous dissipation, and there is an equilibrium layer in the sense of Townsend[1]. In this layer, the energy-containing eddies (anisotropic eddies whose dimensions are smaller than the boundary layer thickness) are statistically self-similar and are solely governed by local flow properties. The energy-containing eddies' length and velocity scales only depend on the local mean shear ($S = \partial U/\partial x_2$) and Reynolds shear stress ($\langle u_1 u_2 \rangle$) despite the presence of buoyancy and stratification. Fig. 1 shows the unscaled and scaled premultiplied streamwise energy spectra of streamwise velocity fluctuations at five wall-normal locations in the equilibrium layer. Fig. 1(b) shows an excellent collapse of data in the scaled variables, indicating that the energy-containing eddies are self-similar and are only governed by local mean shear and Reynolds shear stress. This self-similarity is observed for all three components of velocity fluctuations. These results indicate that the turbulence in the equilibrium layer is statistically similar to shear-driven turbulence[2] despite the flow being driven by buoyancy.

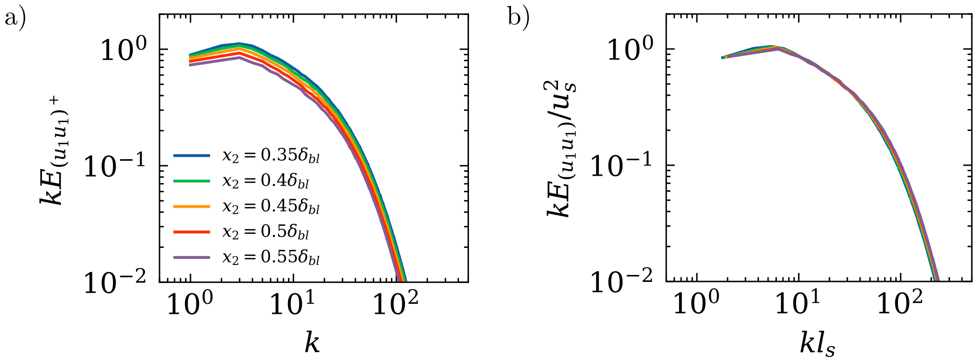

Figure 1: (a) Unscaled and (b) scaled premultiplied streamwise energy spectra of streamwise velocity fluctuations in the equilibrium layer. Here, $u_s = \sqrt{\langle u_1 u_2 \rangle}$ and $l_s = u_s/S$.

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[1] Townsend, *The Structure of Turbulent Shear Flow*, Cambridge University Press (1976).

[2] Lozano-Durán and Bae, *J. Fluid Mech.* **868**, 698–725 (2019).