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A Wavenumber–Frequency Spectrum Model for Sheared Convective Atmospheric Boundary Layer Flows

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Turbulence in the atmospheric boundary layer (ABL) plays an important role in the weather and climate system as it governs the meteorological exchanges of momentum, energy, and moisture between the free atmosphere and the Earth's surface. Motivated by the need for conceptual physics-based models that parameterize turbulence in the ABL in terms of spectra at all spatio-temporal scales, we explore a linear random advection approach to characterize different scenarios of sheared convective boundary layer flows. As a main result, we obtain the wavenumber–frequency spectrum as a product of the wavenumber spectrum and a Gaussian frequency distribution, whose mean and variance are given by the mean advection and random sweeping velocities, respectively. The applicability of the model is evaluated with direct numerical simulations of the mixed layer and entrainment zone for the streamwise and vertical velocity components as well as buoyancy. To obtain a fully analytical formula for the linear random advection approach, we propose using a von-Kàrmàn wavenumber spectrum parameterized by the characteristic convective velocity and length scales. These scales are height-dependent and vary considerably with the relative balance of buoyancy and shear forces. The comparison of the von-Kàrmàn-based model for velocity and buoyancy to simulation results shows that the main features of the measured spectra are captured by the model.