Geophysical Research Abstracts, Vol. 7, 09821, 2005
SRef-ID: 1607-7962/gra/EGU05-A-09821

Velocity scales associated with different entrainment-contributing mechanisms in the sheared atmospheric convective boundary layer

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Entrainment in the sheared atmospheric convective boundary layer (CBL) is an example of an atmospheric process that has to be parameterized in most larger-scale numerical weather prediction and air quality models. Parameterization is commonly done within a zero-order jump model framework where the entrainment layer is represented by a discontinuity interface at the CBL top, and the master length scale of the problem is the CBL depth. Given the coexistence of buoyant and mechanical turbulence production mechanisms in a sheared CBL and the varying proportions between them in different sublayers within the CBL, three velocity scales are considered in the problem: convective velocity scale, the surface friction velocity, and a velocity scale associated with the entrainment-zone shear. Implementation of these scales in the turbulence kinetic energy (TKE) balance equation and integration over the CBL depth result in six (universal) constants. Output of large eddy simulations (LES) of 24 atmospheric CBL cases with varying surface buoyancy flux, outer stratification, and wind shear was used to evaluate these constants. Surface friction velocity was found to be relatively unimportant for the entrainment due to mutual cancellation of corresponding shear production and dissipation terms in the integral TKE budget. On the other hand, the constant for scaling the dissipation rate of TKE produced by entrainment-zone shear turned out to be larger than reported in earlier studies. The revised scalings improve performance of the zero-order entrainment equations under conditions of strong shear, where they had earlier failed.