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Efficiency of mixing across the entrainment zone capping the convective atmospheric boundary layer

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Turbulent mixing by convective cells prevails throughout the bulk of the convectively-driven atmospheric boundary layer, referred to as the mixed layer. Here the turbulent quantities scale with the depth of the mixed layer z_i, the convective velocity scale $w_\star$ (which is typically in the order of $1 - 2$ m s^{-1}), and the temperature scale $\mathcal{F}_s/w_\star$, where $\mathcal{F}_s$ is the heat flux at the ground surface. Both velocity and temperature gradients are close to zero within the mixed layer and the heat flux decreases nearly linearly with height. Results from a high-resolution large-eddy simulation will be presented in order to characterize the convective motions which force the buoyancy interface between the mixed layer and the stably-stratified air above. Both deterministic and statistical properties of the mixed layer will be detailed. For penetrative convection, the heat flux becomes negative within the interfacial layer (referred to as the entrainment zone) due to entrainment by convective motions. The entrainment ratio $\mathcal{R}$ of the minimum heat flux $\mathcal{F}_i$ to the heat flux at the ground surface $\mathcal{F}_s$ is found to be around 0.2 in the regime of equilibrium entrainment, namely when the mixed-layer evolution is quasi steady. The value of about 0.2 for $\mathcal{R}$ was retrieved from the large-eddy simulation outputs using different approaches, which will be discussed. Note that this value is in good agreement with the mean value obtained in previous experimental and numerical studies. Within the interfacial layer, quantities are governed by the characteristics of this layer and the stable region above, as well as those of the mixed layer. As a result of both encroachment and entrainment of air from above, the mixed layer deepens. The rate of growth of the mixed layer, *i.e.* the entrainment velocity, is determined by the energy balance within the entrainment zone. The entrainment law across

this interfacial layer will be revisited in light of the concept of mixing efficiency of the entrainment process. A parameterization for $\mathcal{R}$ in terms of mixing efficiency will then be derived, yielding a new formulation of convective entrainment. Finally, its applicability for an explicit treatment of the entrainment process in classical boundary-layer parameterization schemes implemented in mesoscale models will be discussed.

Further reading: Chemel, C. and C. Staquet, 2006. A formulation of convective entrainment in terms of mixing efficiency. *J. Fluid Mech.* Under revision.