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A formulation of convective entrainment in terms of mixing efficiency

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The entrainment law across a stably-stratified interface forced by convective motions is discussed in light of the mixing efficiency of the entrainment process. The context is that of the convectively-driven atmospheric boundary layer and we focus on the regime of equilibrium entrainment, i.e. when the boundary-layer evolution is quasi steady. The entrainment law is classically based on the ratio $\mathcal{R}$ of the negative of the heat flux at the interface to the heat flux at the ground surface. We propose a parameterization for $\mathcal{R}$ that involves the mixing efficiency and the thickness of the interface, which matches well the numerical computation of $\mathcal{R}$ from a high-resolution large-eddy simulation. This result enables us to derive modified expressions for the classical entrainment laws (the so-called zero- and first-order models) as a function of the mixing efficiency. We show that, when the thickness of the interface is ignored (zero-order model), the scaling factor in the entrainement law, denoted $\mathcal{A}$, is the flux Richardson number at the interface. This parameterization of $\mathcal{A}$ is further improved when the thickness of the interface is considered (first-order model), as direct computation of $\mathcal{A}$ from the aforementioned large-eddy simulation shows it.