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Pressure drag for shallow cumulus clouds: from thermals to the cloud ensemble

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This study takes the first step to bridge the gap between the pressure drag of a shallow cloud ensemble and that of an individual cloud composed of rising thermals. It is found that the pressure drag for a cloud ensemble is primarily controlled by the dynamical component. The dominance of dynamical pressure drag and its increased magnitude with height are independent of cloud lifetime and are common features of individual clouds except that the total drag of a single cloud over life cycle presents vertical oscillations. These oscillations are associated with successive rising thermals but are further complicated by the evaporation-driven downdrafts outside the cloud. The horizontal vorticity associated with the vortical structure is amplified as the thermals rise to higher altitudes due to continuous baroclinic vorticity generation. This leads to the increased magnitude of local minima of dynamical pressure perturbation with height and consequently to increased dynamical pressure drag.