Plumes, thermals and chains: A critical examination of the various conceptual models for moist convection

Hugh Morrison (morrison@ucar.edu)
National Center for Atmospheric Research,
Mesoscale and Microscale Meteorology Laboratory

Since the 1950's two primary conceptual models have served as a basis for understanding the structure and behavior of moist convection in the atmosphere. The first is the steady-state plume, and the second is the isolated rising thermal. These models have markedly different structural and flow characteristics, and debate has continued as to which one provides a better framework for understanding and parameterizing moist convection. Based on theory, high resolution large eddy simulations, and observations, we argue that moist updrafts have characteristics of both plumes and thermals, with neither alone providing a satisfactory description. More plume-like versus thermal-like updrafts occur as conditions vary (e.g., environmental relative humidity), and the transition between thermal-like and plume-like updrafts is characterized by a succession of rising bubbles which we call a "thermal chain". Although thermal chains share common features with both plumes and thermals they also have several unique characteristics, particularly with regard to entrainment. We derive approximate analytic solutions to the governing momentum, mass continuity, and cloud thermodynamic equations for a cloudy updraft, and show that thermal chains are a characteristic feature of these solutions under a wide range of conditions. Although dry convective updrafts can also occur as thermal chains under certain conditions, they are primarily a feature of moist convection owing to the feedback between entrainment, evaporation, buoyancy, and flow structure. A conceptual model based on these ideas will be presented, and implications for improving convection parameterizations and interpreting results from nonhydrostatic convection-permitting models will be discussed.