DYNAMICS OF SUBSIDING SHELLS IN ACTIVELY GROWING CLOUDS WITH VERTICAL UPDRAFTS

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The dynamics of a subsiding shell at the edges of actively growing shallow cumulus clouds with updrafts is analysed using direct numerical simulation with grid sizes of up to 3072 x 1536 x 1536. The actively growing clouds have a fixed in-cloud buoyancy and velocity. Turbulent mixing and evaporative cooling at the cloud edges generate a subsiding shell which grows with time [1].

A self-similar regime is observed for first and second order moments when normalized with their respective maximum values. Internal scales derived from integral properties of the flow problem are identified [2]. Self-similarity analysis conducted by normalizing using these scales reveal that contrary to classical self similar flows, the Turbulent Kinetic Energy (TKE) budget terms and the velocity moments scale according to the buoyancy and not with the mean velocity.

The shell thickness is observed to increase linearly with time. The shell buoyancy scale remains constant as it thickens and is set by the initial thermodynamics of the cloud and environment. The shell accelerates ballistically with a magnitude defined by the saturation value of the buoyancy of the cloud-environment mixture. In this regime, the shell is buoyancy driven and independent of the in-cloud velocity. The shell thickness and the velocity continue to grow indefinitely and could possibly be limited only by the lifetime of the cloud or thermal.

Relations are obtained for predicting the shell thickness and minimum velocities by linking the internal scales with external flow parameters. The values of shell thickness and velocities calculated using these derived relations are consistent with the values of a typical shallow cumulus cloud [3].

The entrainment coefficient, which is predicted by studying the rate of growth of the shell thickness, is observed to be a function only of the initial state of the cloud and the environment. This coefficient is linked to the fractional entrainment rate used in cumulus parameterization schemes for large scale models and is shown to be of the same order of magnitude [4].

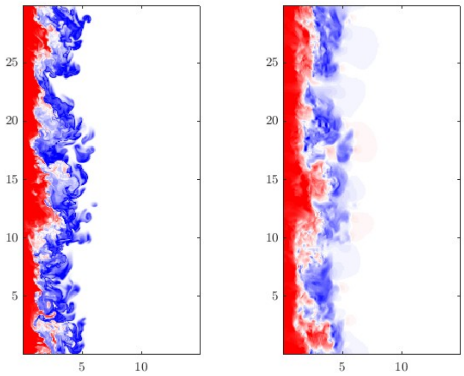

Figure 1. Instantaneous plots of the vertical cross-section of (left) buoyancy and (right) vertical velocity at cloud edge.

References

[1] Heus, T., and H. Jonker, 2008: Subsiding shells around shallow cumulus clouds. Journal of the Atmospheric Sciences, 65, 1003–1018.
[2] Craske, J., and M. van Reeuwijk, 2015: Energy dispersion in turbulent jets. part 1. Direct simulation of steady and unsteady jets. Journal of Fluid Mechanics, 763, 500537.
[3] Rodts, S., P. Duynkerke, and H. Jonker, 2003: Size distributions and dynamical properties of shallow cumulus clouds from aircraft observations and satellite data. Journal of the Atmospheric Sciences, 60,1895–1912.
[4] Romps, D., 2010: A direct measure of entrainment. Journal of the Atmospheric Sciences, 67, 1908–1927.