Introduction

Below convective clouds, evaporating rain cools down surrounding air, inducing negative buoyancy, and causing the cool air to form a downdraught that descends towards and impinges upon the ground. When the downdraught impacts the ground it produces radially propagating gust fronts. This can be hazardous for aviation and understanding them can be useful in the prediction of future storms.

Experimental techniques, large-eddy simulations with the Met Office NERC Cloud model (MONC), and theoretical analyses are all compared to investigate the downdraught.

Finite Duration Downdraughts

The majority of the current literature concerning downdraughts considers either a plume, a steady state continuous flow of cold air; or a thermal, an instantaneously released bubble. In reality, an actual downdraught is between both these limiting cases.

Rooney (2015) derive a similarity solution for the position of the front of a thermal, $z_0$, dependent on time, $t$,

$$z + z_0 = \left[ 2FrTm^{-1/2}\alpha^{-1}B^{1/2}\tau \right]^{1/2},$$

where $z_0$ represents the virtual origin, $Fr_T$ is the Froude number, $m$ is a shape factor, $\alpha$ is the entrainment coefficient, and $B$ is the buoyancy. The solution for the position of the front of a plume is derived in Devenish et al. (2010),

$$z + z_p = \sqrt{\frac{9}{10}} \left( \frac{\alpha^2 \pi}{B} \right)^{1/4} \tau^{3/4}.$$

Figure 1: Two different length releases of a MONC simulation with analogous experimental runs.

Raindrop-laden Downdraughts

Raindrops are neglected in most studies of the downdraught. Their effect on the flow are investigated by making the assumption of a thermal and through comparisons with a negatively buoyant bubble.

The Boundary layer

It is important to verify that the numerical simulations correctly represent the physical world in the boundary region, as this is often unresolved due to a coarse grid spacing.

Figure 2a: Height of the front of the bubble against time for experimental runs of 0.5s, 1s, 3s, and 10s releases, plotted with the corresponding curves for the plume and thermal theory.

Figure 2b: Time scaled with the buoyancy for each case.

Conclusions and Further Work

For varying durations, time of descent and length of release are inversely related. Longer releases result in a higher overall buoyancy, using this to scale time causes a collapse to the theory of a thermal with non-constant buoyancy. A downdraught can hence be approximated as a steady-state plume with a thermal-like head.

The raindrop-laden bubble falls faster than the cold. Specific values of entrainment, added mass, and drag coefficients were chosen to produce this result. To improve the model, effects of momentum transfer and evaporation of the particles should be included.

There is disparity between velocity in the boundary layer with large variance in the MONC results, although the maxima for the radial velocity occur at similar positions and are of a similar magnitude. Ongoing adaptations to the model include a more realistic release time and a surface roughness more similar to that of the lab.

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References: