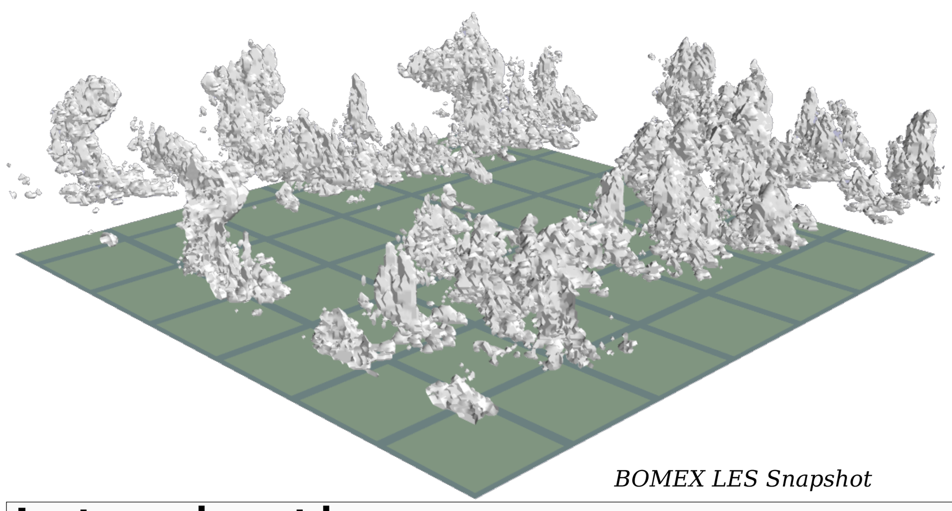

BOMEX LES Snapshot

Direct entrainment and detrainment statistics from a field of individually tracked cumulus clouds

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Introduction

Question: What controls entrainment and detrainment rates in a field of shallow cumulus clouds?

Approach:
1) Use a pattern matching algorithm to automatically track thousands of shallow clouds in a 3 hour SAM (Khairoutdinov and Randall, 2003) BOMEX equilibrium simulation

2) Use spatial interpolation to directly measure mass entrainment and

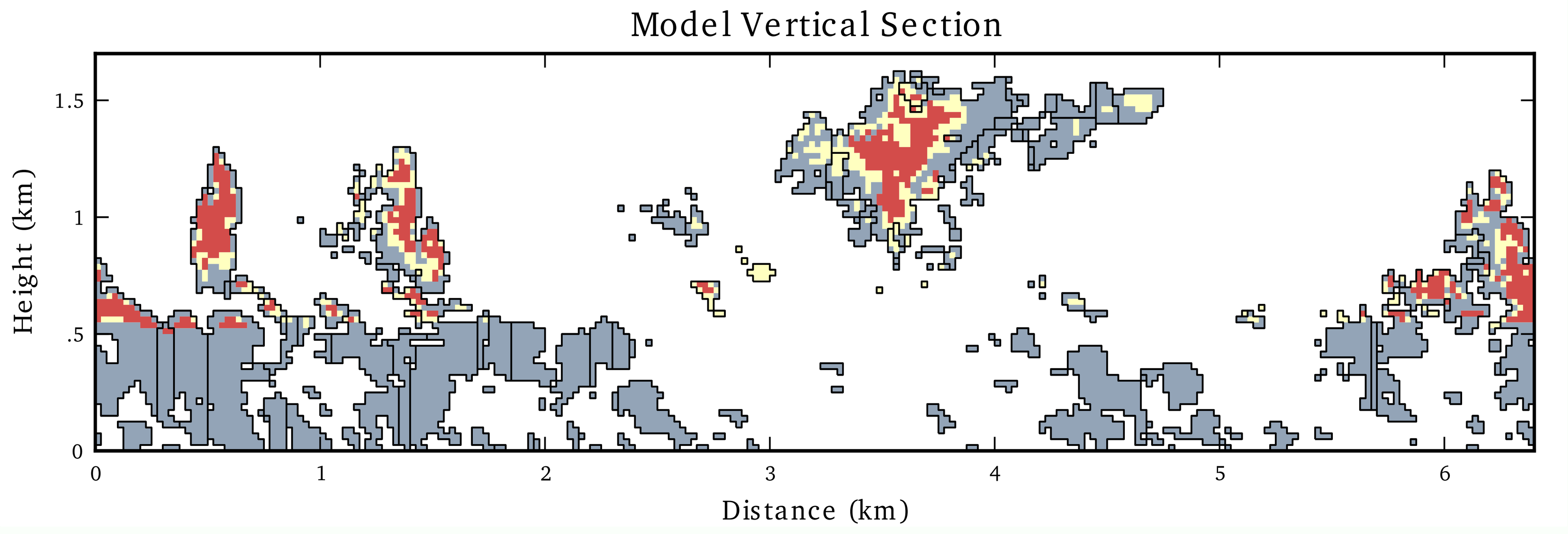
Conclusions

1) Lagrangian correlation analysis shows that cloud properties are essentially independent of sub-cloud layer perturbations in buoyancy and total water. Above cloud base, cloud properties are largely determined by the areal extent of the individual cloud cores.

2) Instantaneous mass entrainment rates are proportional to cloud core area. This is consistent with a constant entrainment timescale that is independent of cloud size. Instantaneous local detrainment rates are determined largely by the critical mixing fraction.

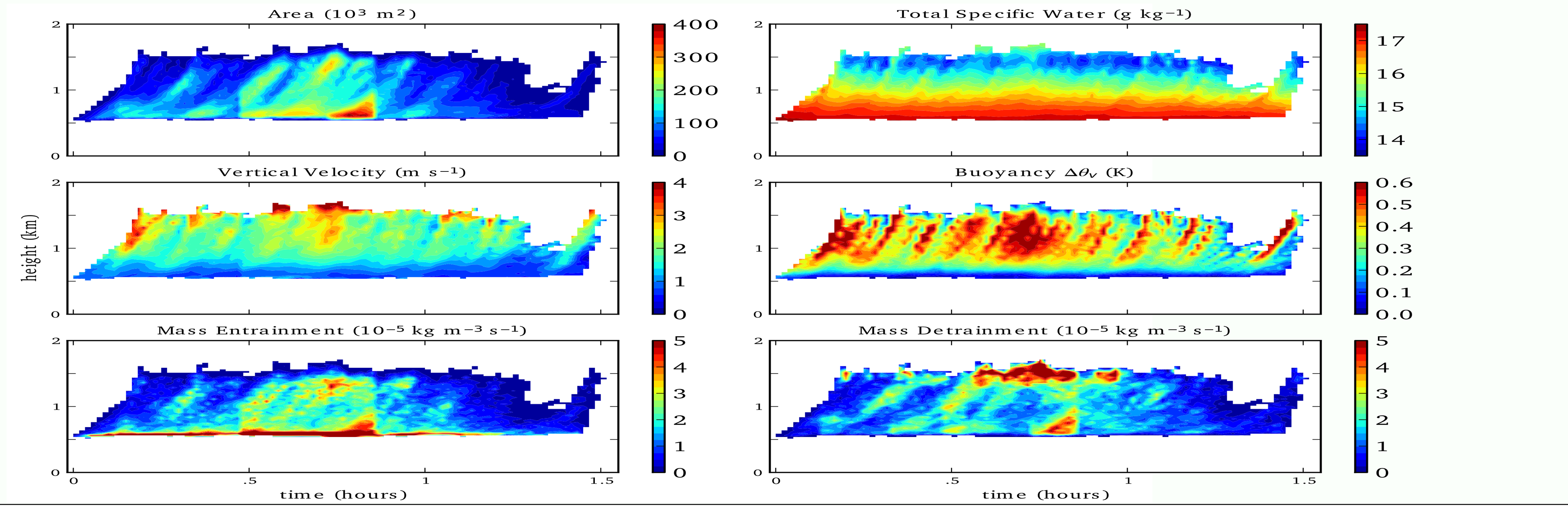
Cloud tracking

Step 1 -- identify cloud core (red), cloud (yellow), subcloud (blue)
Step 2 -- tracking algorithm identifies splits/merges and identifies 3171 clouds in a 3 hour simulation



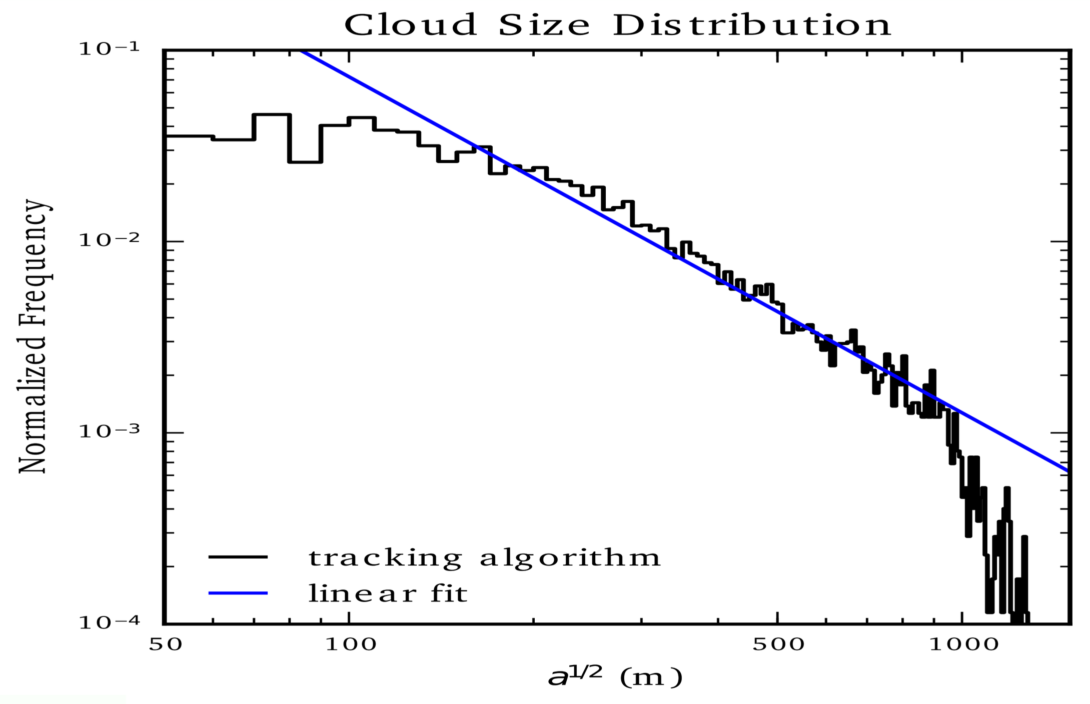
For this BOMEX simulation cloud base is at z=550 m, inversion base is at z=1300 m

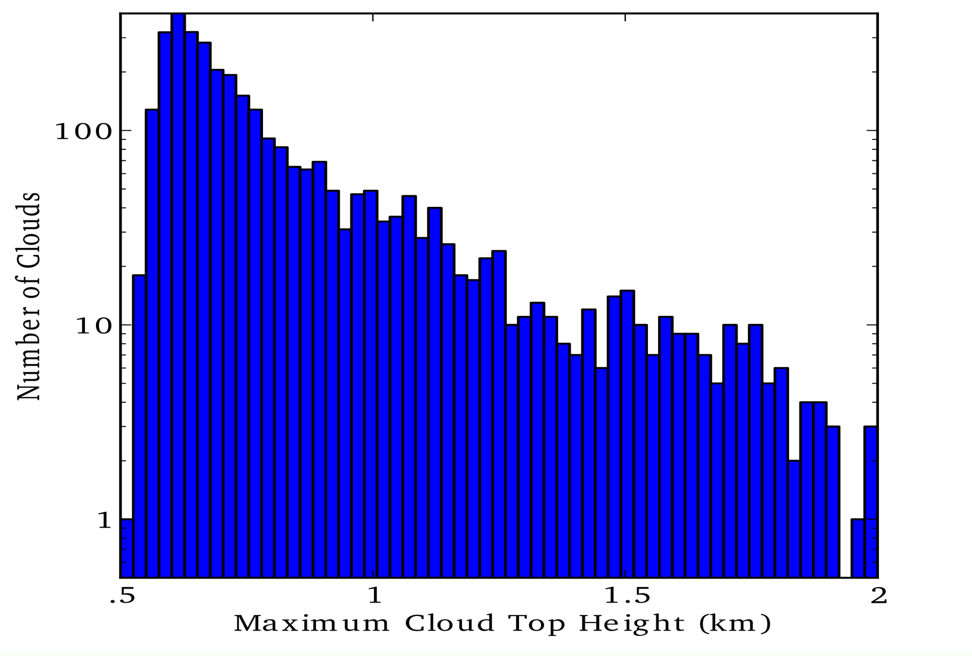
The figure below shows the 90 minute life history of one tracked cloud core



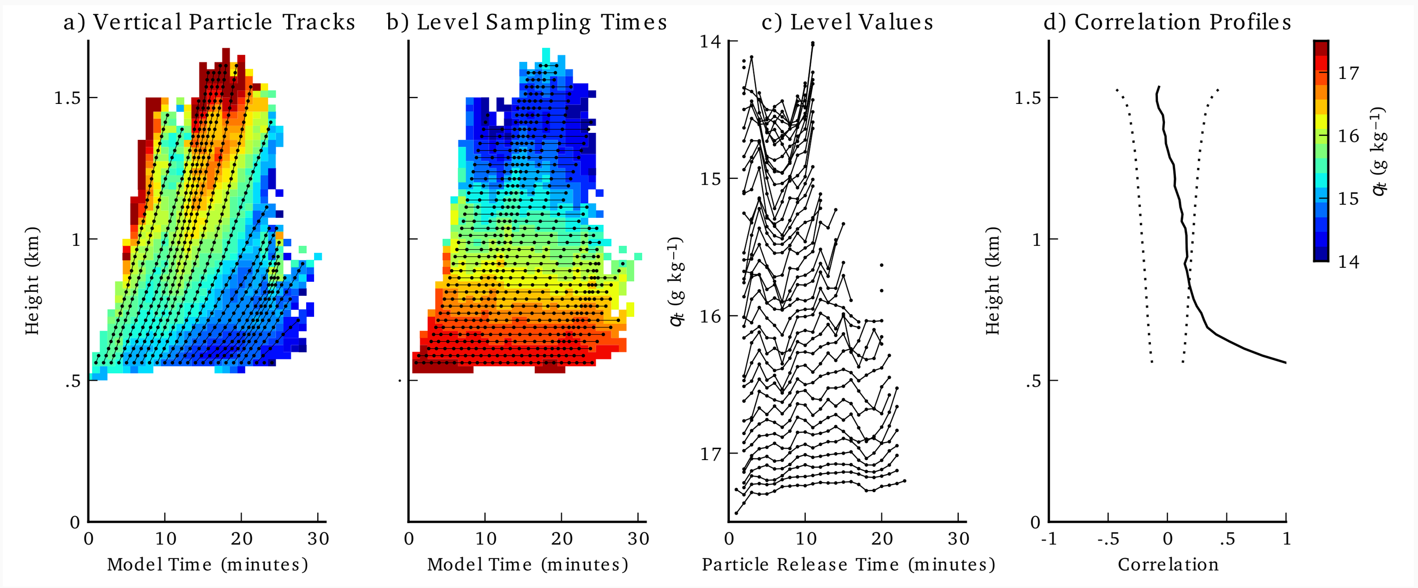
Population statistics for BOMEX

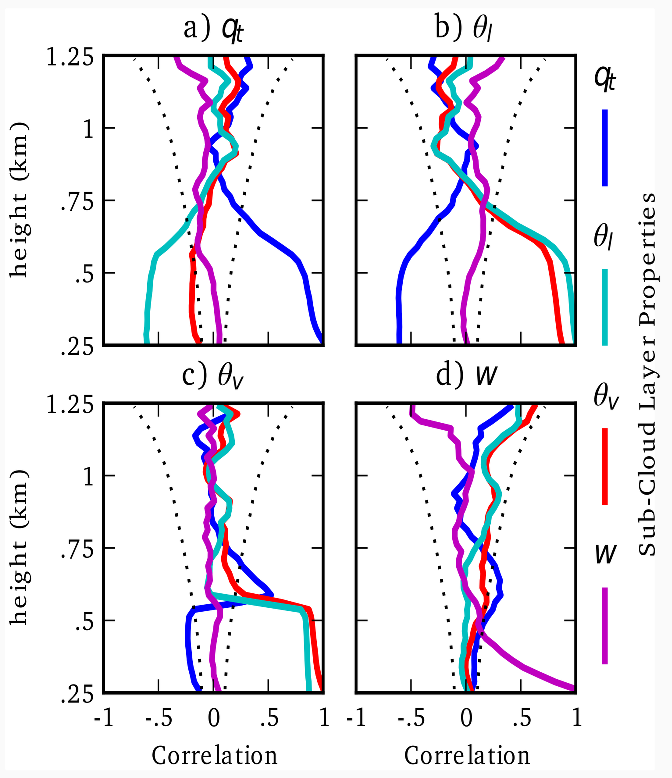
Total	New	Splits	Unknown	Dissipates	Merges	Unknown
3171	2381	609	181	2820	261	90

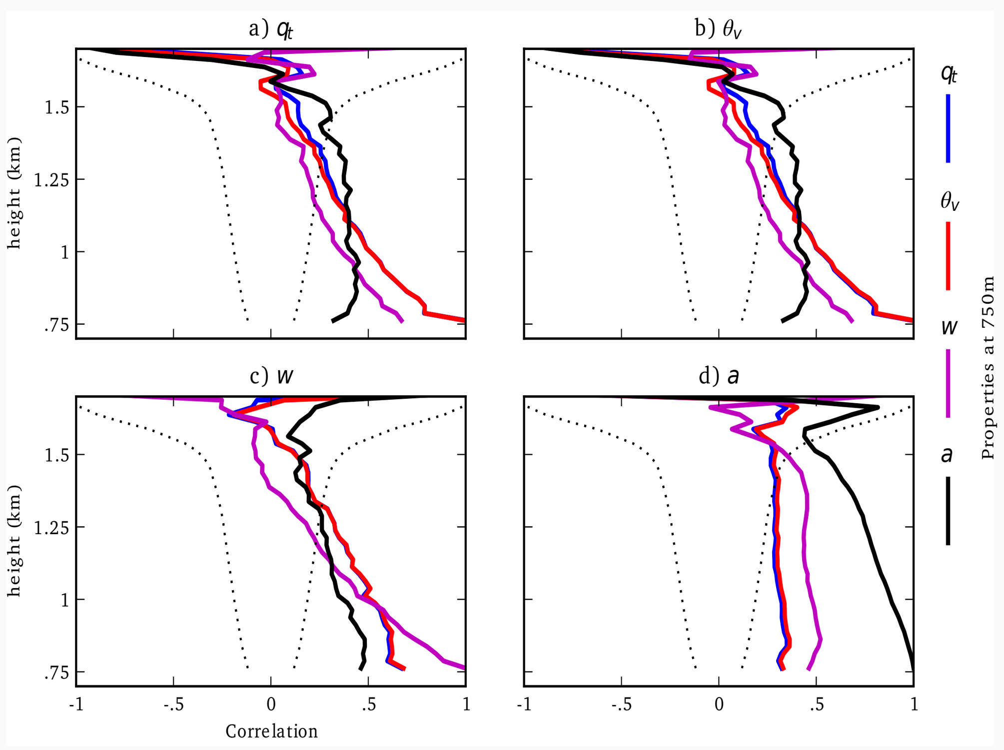




Vertical correlations





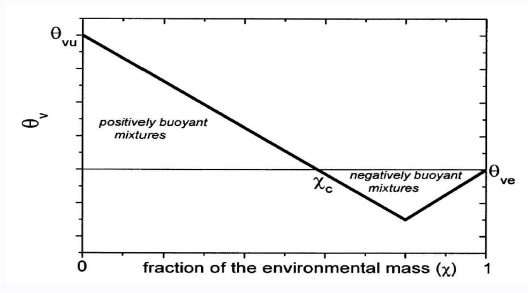


We use Lagragian particles released at sub-cloud, cloud base (550 m),and the lower part of the cloud layer (750 m) to tag grid-cells for lagged correlation. The middle figure (for particle release at 250 m) shows that there is essentially no correlation between conditions in the sub-cloud layer and air above cloud base for total water, buoyancy, entropy or vertical velocity. The right figure shows that the cloud core area at 750 m is well correlated with cloud thermodynamic properties in the upper part of the cloud layer.

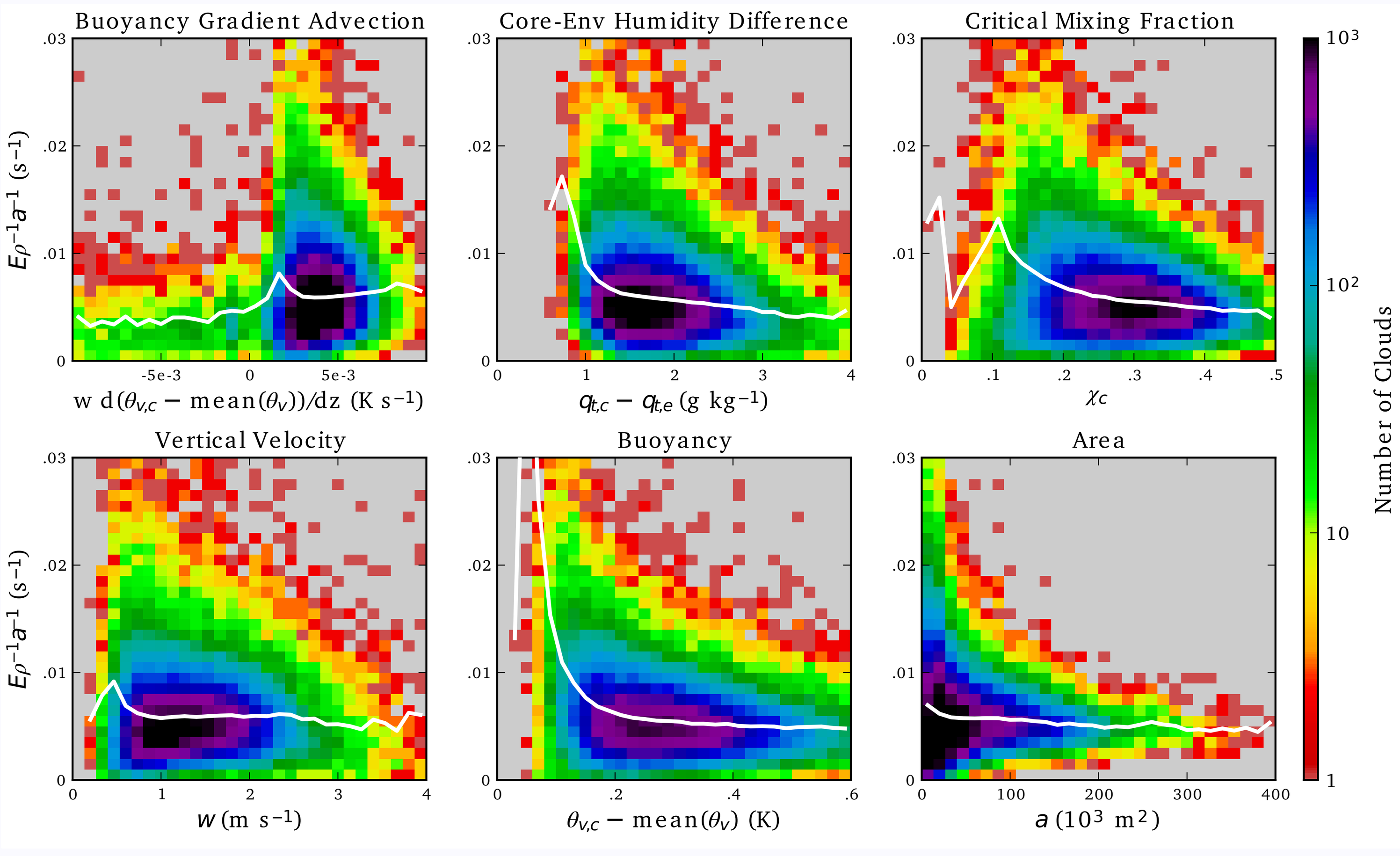
Direct measures of entrainment/detrainment

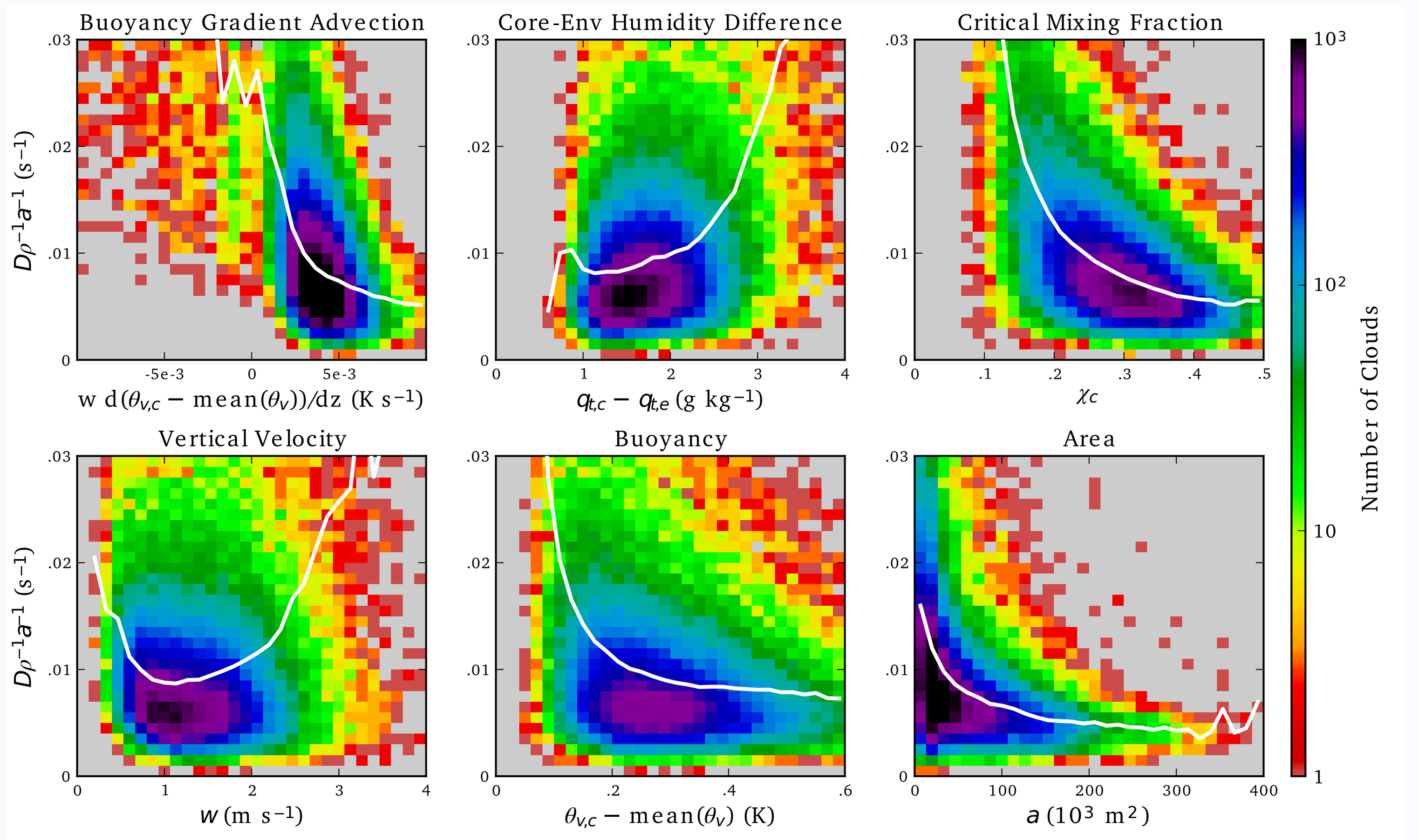
We can calculate the entrainment/detrainment mass fluxes for the the tracked cloud cores using Dawe/Austin (MWR, 2011). The panels below show histograms of the mass entrainment flux E divided by the density ρ and cloud area *a to* make a mixing timescale. As the bottom right (area) panel shows, this mixing timescale is independent of cloud size. Our value of 1/0.005=200 seconds is about half the value of 400 seconds found by Neggers et al. (2002) using bulk tracer budgets.

Detrainment is most sensitive to the critical mixing fraction χ, the fraction of environmental air required to produce neutral buoyancy



de Rooy and Siebesma, 2008





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All figures were generated using the matplotlib library in the Python programming language.