Entrainment rates for deep convective cores found by exploiting the linear relationship of vertical velocity to buoyancy

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Introduction

Motivations

- What determines the distribution of cloud top heights (Arakawa 2004)?
- The Giga-LES is especially well suited to studying entrainment in deep convection because of its large domain and turbulence resolving 100 m horizontal resolution.

The Giga-LES

Figure 1. SHDOM visualization of light scattering in liquid and ice water mixing ratio fields from the Giga-LES. The horizontal domain visualized above is 20 km x 20 km, about 1/100th of the total domain area.

- System for Atmospheric Modeling (SAM)
- Horizontal domain of 204.8 km x 204.8 km
- $\Delta x = \Delta y = 100$m
- $\Delta z = 50$m to 100m
- 10^9 grid cells
- A "virtual field campaign" (Khairoutdinov et al. 2009)
- Validated against observations (Lemone and Zipser 1980)

Identify 3D cloudy updrafts

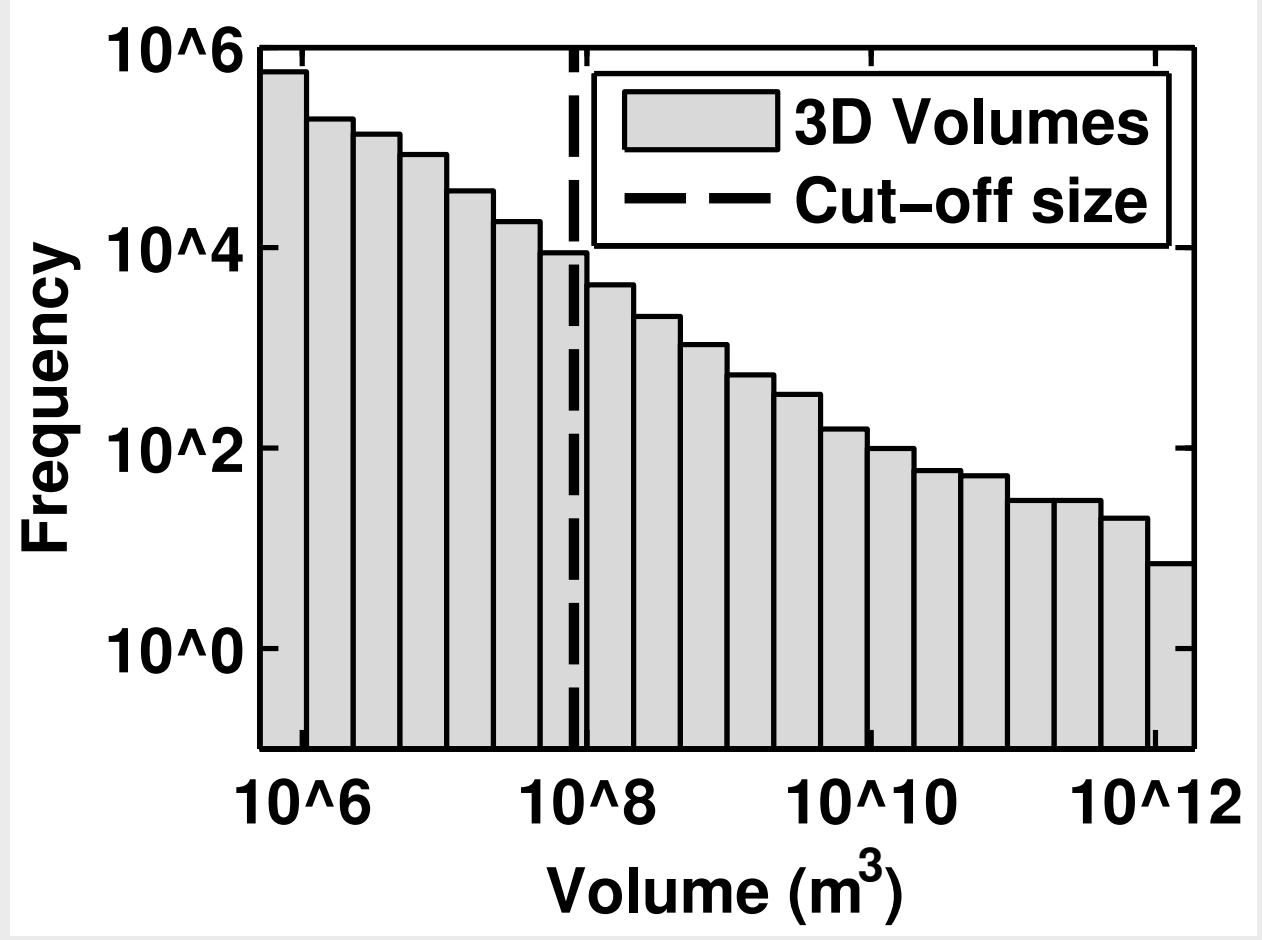


Figure 2. Log-log frequency distribution of 3D cloudy updraft volumes. We ignore the group of volumes to the left of the dashed black line as they are composed of only a few model grid points. The cut-off volume is that of a cube 450 m on each side.

- Contiguous volumes
- We use a cloudy updraft core definition similar to that used in Lemone and Zipser (1980)
- Vertical velocity (w) > 1 m/s and cloud water/ice mixing ratio (q_n) > 0.1 g/kg
- Largest volume is equivalent to a cube 10 km on each side

Partition cloudy updrafts into two groups

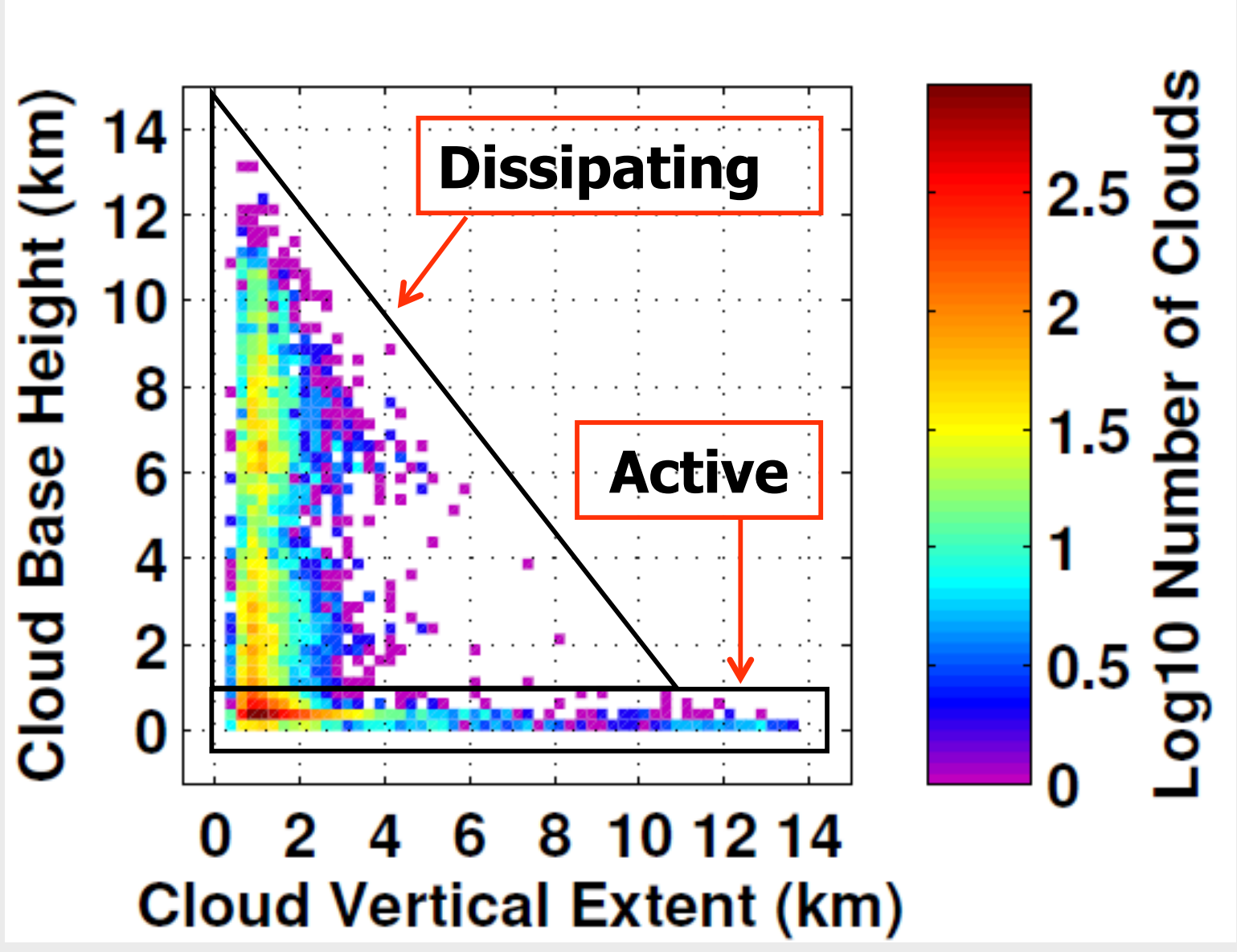


Figure 3. Log frequency of 3D cloudy updrafts vertical extent vs. cloud base height. The clouds outlined in the lower black rectangle are representative of active cumulus convection, with bases below 1 km.

- Life-cycle stage of the convection?
- Low cloud bases: growing and mature convective updrafts
- Elevated cloud bases: dissipating stage of updraft
- Define "active" as 3D cloudy updrafts with cloud base < 1 km

Best fit entrainment rate given B and W

Parcel Model for Vertical Velocity

- Consider the buoyancy and vertical velocity profiles for each active 3D cloudy updraft
- What fractional entrainment rate for a parcel gives the best fit to the 3D cloudy updraft profile of vertical velocity?

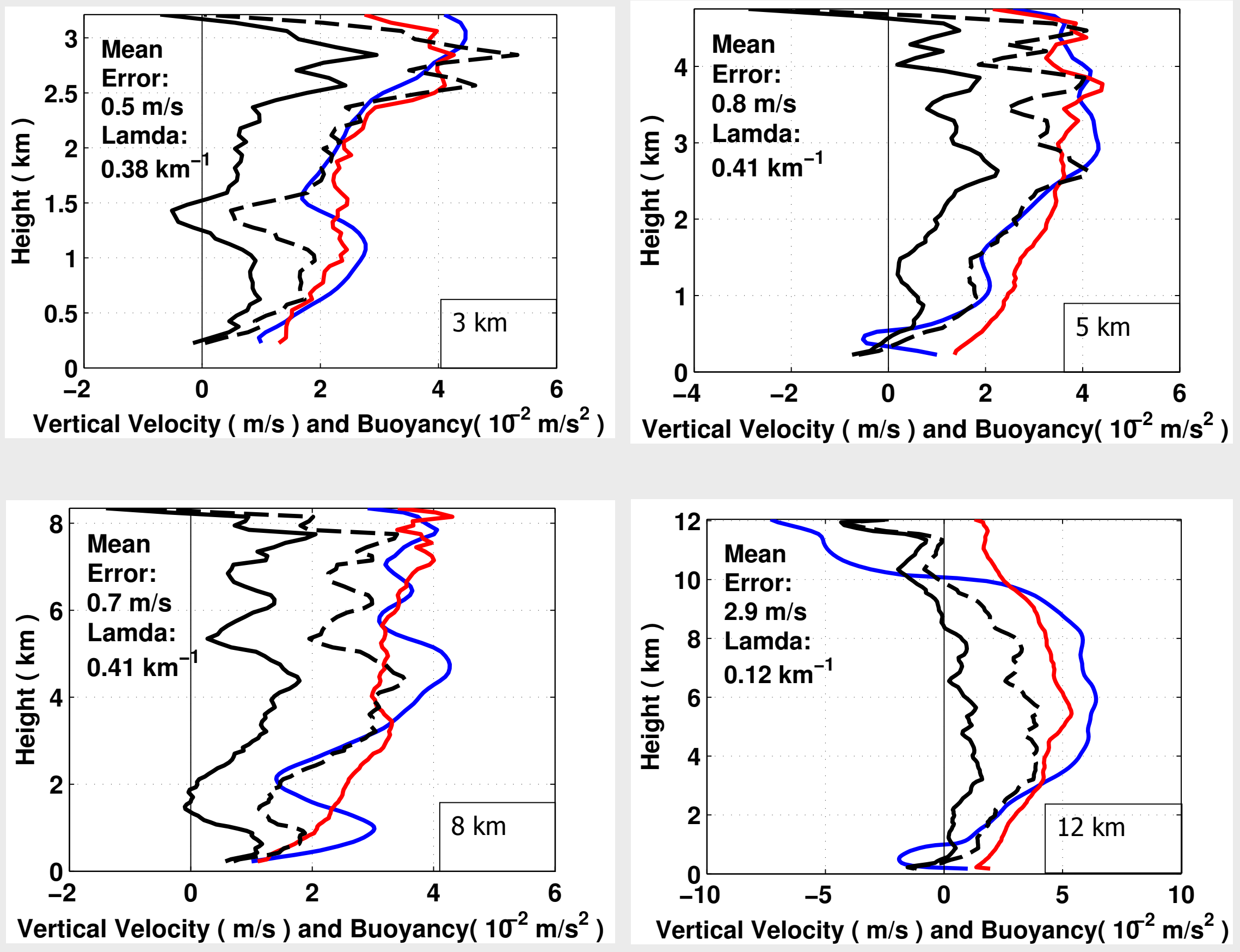
$$\frac{1}{2}\frac{dW^2}{dz} = aB - b\lambda W^2$$

Using level average density buoyancy from cloudy updraft core

Iterate to find the fractional entrainment rate that…

…gives the best fit to the known W profile (min. RMS error)

Cloudy Updraft Vertical Velocity
Parcel Model Vertical Velocity



- Four example cloudy updrafts are shown, note different cloud top heights
- Cloud average W profile in red
- Many possible W profiles are calculated for a range of λ, best fit plotted in blue
- "Unloaded" thermal buoyancy black dashed
- "Loaded" density buoyancy B solid black

Figure 4. Profiles of 3D cloudy updraft average loaded buoyancy (black), unloaded buoyancy (dashed black), and vertical velocity (red). Best fit parcel model vertical velocity is plotted in blue.

Entrainment rate λ from best-fit parcel model of cloudy updraft W

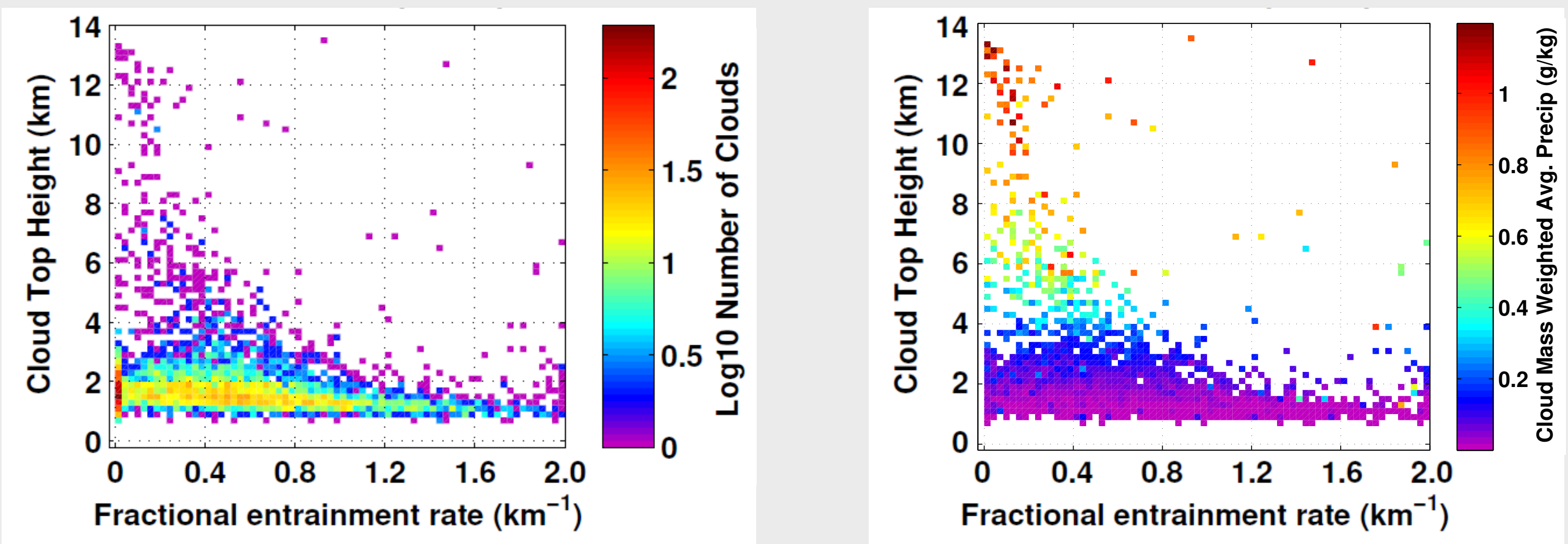


Figure 5. On the left, frequency vs cloud top height of parcel model entrainment rate that produces the best fit to the cloud W profile. On the right, the average precipitating condensate for the clouds in each λ and cloud top height bin.

- Maximum cloud top height at a particular λ decreases with increasing λ
- What explains the range of cloud top heights for the same λ? Life-cycle stage? Are those clouds still growing?

- Average precipitating condensate is a strong function of cloud top height, but not of λ

Can method be applied to observations?

Solve for B assuming W = (B - Drag) * 120 s

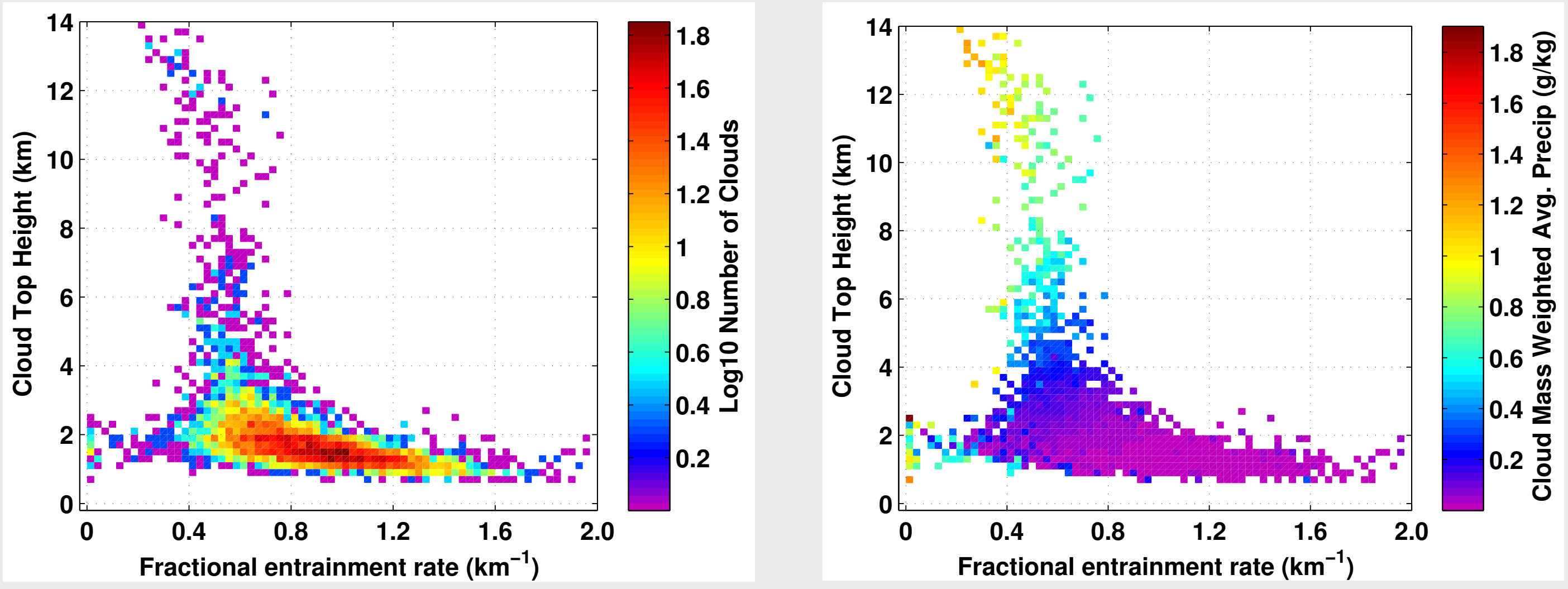


Figure 6. Same as Fig. 5, but instead of the known buoyancy profile we use B=W/(120 s) + Drag. The known drag profile is used to illustrate a best possible case of using this method.

- An estimate of the drag force is essential for this method

- It is encouraging that precip. mixing ratio varies nicely with CTH

Summary

- 3D cloudy updrafts are defined in a large domain LES of deep convection. We select those with cloud base < 1 km as "active clouds"
- We show that a simple entraining parcel model for each active cloud can partially explain the distribution of cloud top heights
- After Alison Stirling of the Met office and others, we note average vertical velocity profile is proportional to average unloaded buoyancy profile in the active clouds
- Using this estimate for unloaded buoyancy, dual doppler radar retrievals of vertical velocity could theoretically then be used to solve for λ, given an estimate of drag
- Using the known drag as a "best case" gives encouraging results

References

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