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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Statistical analysis of a LES shallow cumulus cloud ensemble using a cloud tracking algorithm" *by* J. T. Dawe and P. H. Austin

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The reviewer's comments are in bold, and our responses to each comment follows.

Section 3.1. This description of the cloud-tracking algorithm is difficult to follow. What distinguishes the different yellow areas that are otherwise adjacent in Figure 1? How is cloud that is connected to more than one core associated with only one core?

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We have re-written Section 3.1 extensively to try to make it clearer. We have also created a new figure to illustrate the various ways in which cloudlets may overlap with previous time steps, and modified Figure 1 from the discussion paper to show horizontal as well as vertical sections through the model and modified Figure 2 to show boundaries for the cloudlets that compose the tracked clouds in the figure.

The yellow areas that are otherwise adjacent in Figure 1 are distinguished by distance to the nearest region of contiguous core points that forms the centre of each cloudlet. Condensed regions that are connected to more than one core is associated with the nearest core, in the manner described in the algorithm.

p. 23243, lines 5-7. Are these inter-cloud or intra-cloud correlations? Does this include clouds of all heights?

These are inter-cloud correlations, done upon all clouds that reach a given height. Clouds that are not present at a given height are not included in the cross-correlations, which is why the significant correlation level changes with height. We have modified lines 5-7 to read "Cross-correlations between the horizontal mean properties of all clouds present at a given height reveal strong relationships between the mean cloud properties."

p. 23243, line 14. If a and M have near-unity correlations, this implies that variations in w can be neglected. Should this sentence read "characterized by two variables: θ_ρ and a"?

We do not agree that near-unity correlations between a and M implies that variations in w can be neglected. w has variability independent of θ_ρ and a which may be necessary to characterize the behaviour of the BOMEX cloud field.

p. 23243, lines 26-28. Please elaborate on how this can be seen or quantified from Figure 8. Also, how negative is the anticorrelation between θ_l and θ_ρ at 500 meters in the cutoff portion of Figure 7?

Upon reflection, we realize that this statement is unjustified, and we have removed it from the paper. At 500 meters, the anti-correlation between θ_l and θ_ρ is $\approx$ -0.9. We have added this information to the text.

p. 23244, line 4. Here and some other places, should this be Romps and Kuang?

Yes, this should be Romps and Kuang. We have corrected this error.

Figure 9. This figure is described inadequately. Since the dots in b are the same as in a, but connected by lines differently, why are they shown twice? In c, should these lines be labeled by the level? What correlation is being shown in d?

In an attempt to make Figure 9 clearer, we have removed the dots from (a) and removed the lines from (b), added some level labels and highlighted lines every 200 m in c), and removed every second level from the plots. We have changed the figure caption to read:

“Method used to determine correlations between lower- and upper-level cloud properties. a) Numerical particles are released once per minute from an initial level in the cloud and advected vertically with the mean vertical velocity of the cloud until the particle leaves the cloud. (Lines show the time-height trajectories of the numerical particles and colours show the cloud’s vertical velocity.) b) The times at which particles reach each model level are then identified and the cloud properties at those times are recorded. (Dots show the time each particle reaches each model level and colours show the cloud's vertical velocity. Only half the model levels have been plotted for clarity.) c) The properties encountered by the particles at a given height are then arranged by the time each particle was released, forming a set of pseudo-time series at each height. (Dotted lines show the total specific water values of the cloud at the time each particle reached a given height. The 600 m, 800 m, 1000 m, 1200 m, and 1400 m height particle values are highlighted and labeled. Only half the model levels have been plotted.) d) Correlations are then taken between the properties of the particles at release and the properties at higher levels to calculate correlation profiles. (Solid line shows the correlation between total specific humidity of the particles at release and the total specific humidity of the cloud at various heights. Dotted lines show the 99% confidence level for a correlation to be significantly different than zero.)"

Section 4.1. How do these results compare to the results in the "Nature and Nurture" paper by Romps and Kuang?

We compare our results with Romps and Kuang 2011 in the discussion in Section 4.3. However, it does make sense to address this Section 4.1, so we have added the following paragraph at the end of Section 4.1:

"Our results largely agree with the results of Romps and Kuang (2010): upper-level cloud properties are governed by the entrainment and detrainment experienced by the cloud as it rises, and cloud base properties have little influence on upper-level cloud properties, suggesting that nurture is more important than nature in determining shallow cumulus cloud properties. The exception to this is cloud area, which is correlated with cloud base area and which Romps and Kuang were not able to examine using their parcel model. Nevertheless, cloud base area and entrainment/detrainment rates still exert roughly equal influence over upper-level cloud area."

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Section 4.2. This method for calculating the cloud-top properties relies on collecting statistics on the grid cell(s) that first contains liquid water at a given height. Is this not prone to large numerical error? How can we be sure that the results from this method can be trusted to give meaningful statistics? A more robust method would be to average properties some distance (say, 100 m) below the cloud top and the same distance above the cloud top.

We have redone these calculations using environmental properties in an 125m region centred on the cloud top (5 grid cells in the vertical), and cloud properties over the top 100 m of the cloud (4 grid cells in the vertical). This does appear to remove noise from the calculation, since while the results are not significantly different, the p-values of the results are much higher.

The main differences between the calculations using the immediate cloud-top and the top 100 m are greater differences in the cloud properties between the tall and short clouds, and diminished differences in the environment properties between the tall and short clouds. The environmental vertical velocity between 550-750 m still shows a weakened effect on future cloud height, but cloud top height now appears entirely insensitive to 750-1000 m environmental properties.

We have updated the values in Table 1 with these calculations, and changed the text in Section 4.2 to reflect the new calculation method, and the slightly modified results.

p. 23251, line 7. “but not buoyancy”? Why would the upward velocity of parcels in a convective boundary layer not be controlled by buoyancy?

This was a poor choice of words. First, we should have said “the upward velocity of plumes”, not “air parcels”. Second, we intended to say that the mean vertical velocity of sub-cloud plumes is not correlated with the plume’s mean buoyancy. We have changed this sentence to read: “Conversely, the mean upward velocity of plumes in this region is uncorrelated with the plume’s mean buoyancy and plume velocity anomalies dissipate quickly as the plumes rise, suggesting the sub-cloud plume dynamics are dominated by inertia and pressure effects.”

p. 23251, lines 17-18. These lines state: “the fate of clouds... is determined by a race btw. the rate the cloud moves upward and rate the cloud is mixed away.” This is reminiscent of Neggers et al, “A multiparcel model...” Is there support for the Neggers et al theory in this paper? Please elaborate. The discussion on p. 23245 lines 24-28 seems to suggest the opposite.

The assumption made by Neggers et al. that cloud parcels enter cloud base with a wide range of properties is contradicted by our findings, as we state on p. 23245 lines 24-28. We have not attempted to examine the assumption made by Neggers et al. that fractional entrainment rate is inversely proportional to vertical velocity, although we agree that such an assumption would be consistent with our findings. However, we would say that there are much stronger correlations between the height a cloud achieves and its area than its vertical velocity. This would lead us to speculate that the inverse proportionality between fractional entrainment rate and vertical velocity assumed by Neggers et al. is actually caused by larger clouds protecting their core more effectively. Parcels in clouds with large areas are more protected from entrainment events, which allows them to achieve high buoyancies and vertical velocities. We have added the following paragraph to the discussion.

“Neggers et al. [2002] construct a theory in which fractional entrainment rate is inversely proportional to vertical velocity and cloud parcels enter cloud base with a wide range of properties. The variations in parcel properties then set the entrainment rate and thus control the future evolution of the parcel properties. Our results do not support the assumption of Neggers et al. that parcels have a range of initial thermodynamic conditions. We have not directly examined the dependence of entrainment rate on vertical velocity; however, the strong relationship between eventual height reached by the clouds and the cloud area suggests that fractional entrainment is more likely dependent on cloud area and any relationship between vertical velocity and entrainment is due to larger area clouds shielding their cores from entrainment, producing higher buoyancies and vertical velocities."

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