On the organization of passive shallow cumulus clouds

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Introduction

The shallow cumulus clouds are ubiquitous in the atmosphere, populating a large part of the subtropical oceans. They may play a strong climate feedback due to their cooling effect on the Earth's atmosphere. As a result, a large number of studies investigated the organization of cumulus clouds and their interaction with the climate [e.g. 1, 2]. However, the organization of passive shallow clouds and their impact on the atmospheric convection and climate change received very limited attention. In this work, we investigate how the organization and the total cloud cover depend on the relative humidity of the environment.

Conceptual model

We hypothesise that organization of non-precipitative passive shallow cumulus is controlled by the interaction between the old passive cumulus and the new plumes that reach the lifting condensation level, leading thus to a larger passive cloud. Based on this hypothesis we formulate a conceptual model schematically displayed in Figure 1.

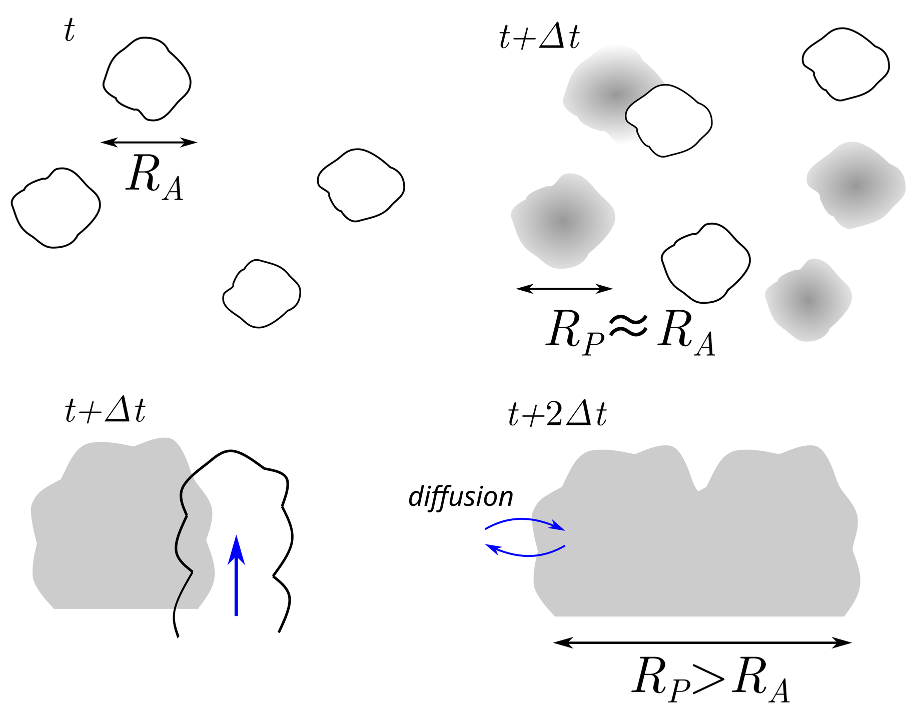

Figure 1: Schematic interaction between passive and active cumulus clouds leading to the organization of passive shallow cumuli. Here R_A is the area of the active cloud cores (plumes).

Two opposing mechanisms are identified here: (1) The growth of the passive clouds which is given by the probability of the interaction between the passive clouds and the active plumes, and is proportional with the area of the passive cloud $A_P = \pi R_P^2$, in which R_P is the radius of the passive clouds, and (2) The decay of the passive clouds due to the diffusion with the dry environmental air. Thus, we may write:

$$\frac{dA_P}{dt} \sim A_P \frac{\sigma}{t_*} - D_v(1 - RH),$$

where σ is the cloud cover of the active cloud cores, t_* is the lifetime of the active plumes, D_v is the diffusion coefficient, and RH is the relative humidity of the environment.

Methodology

To test our hypothesis, we perform a series of five large-eddy simulations (LES) for the BOMEX case with the MicroHH model [3] at a resolution of 50 m and a horizontal domain of 32 km × 32 km. A constant horizontal wind of 1 m/s is considered, and the profiles for the total water mixing ratio q_t are modified in the cloud layer in order to have different values for the RH, as shown in Figure 2. All five simulations are run for 8 h with an adaptive time step.

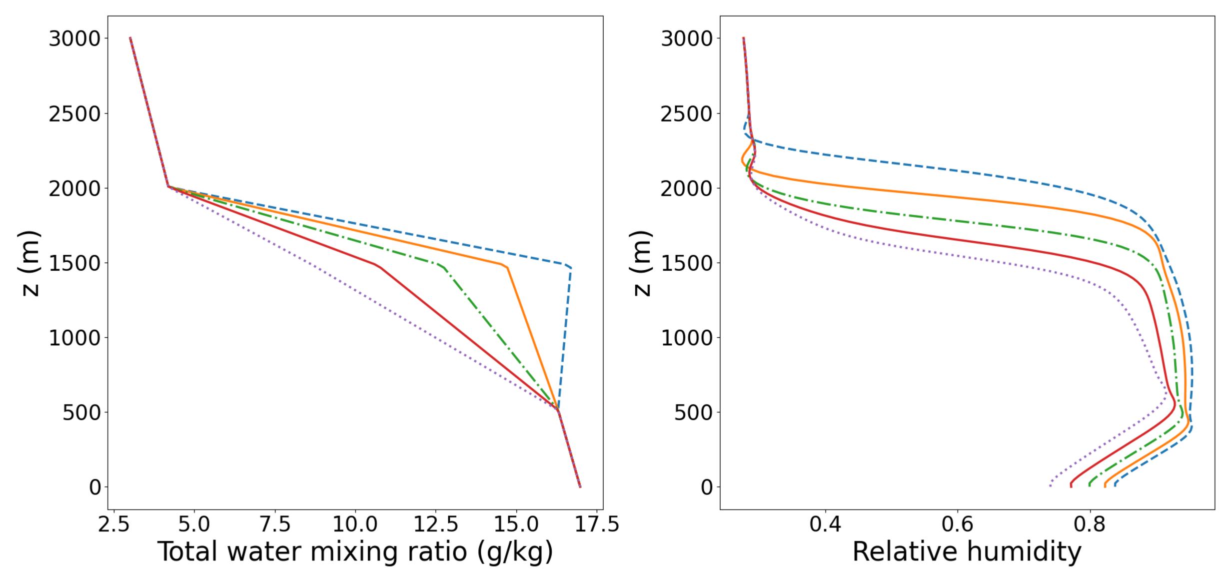

Figure 2: Chosen profiles for initial q_t (left) and for the RH at the end of the simulation (right).

We define a cloud cell as the cell in which the liquid water is above a threshold of 10^{-6} g/kg, and an updraft cloud cell as the cloud cell in which the vertical velocity is above 0.5 m/s. The passive clouds are given then by the clouds cells with a vertical velocity below 0.5 m/s.

Results

As visible in Figure 3, the average radius of clouds increases with the RH, while the average radius of active clouds keeps almost constant. Moreover, the maximum radius for clouds strongly increases with the RH, unlike the maximum radius of active clouds, which increases only slightly. Furthermore, the updraft core cover shows a much weaker dependence on the RH than the passive cloud cover, as one can see in Figure 4.

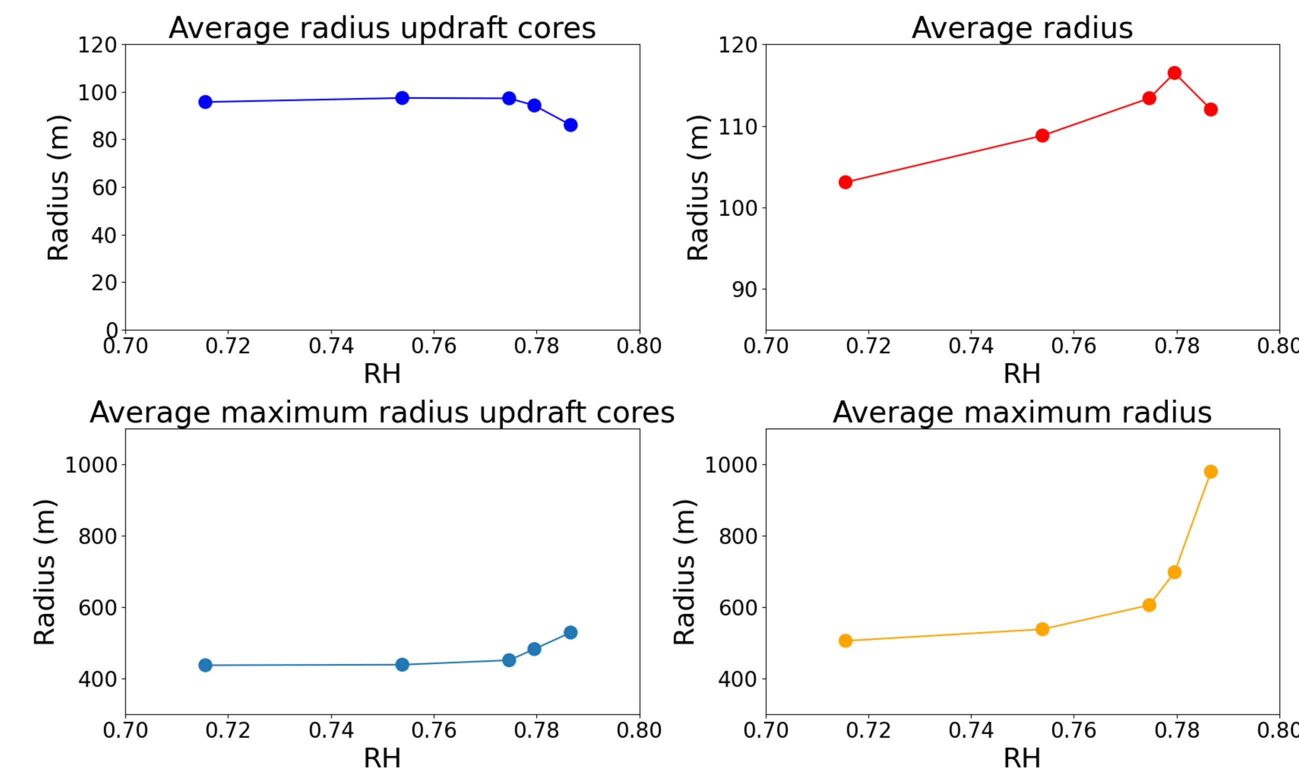

Figure 3: Dependence of average radii for clouds on relative humidity

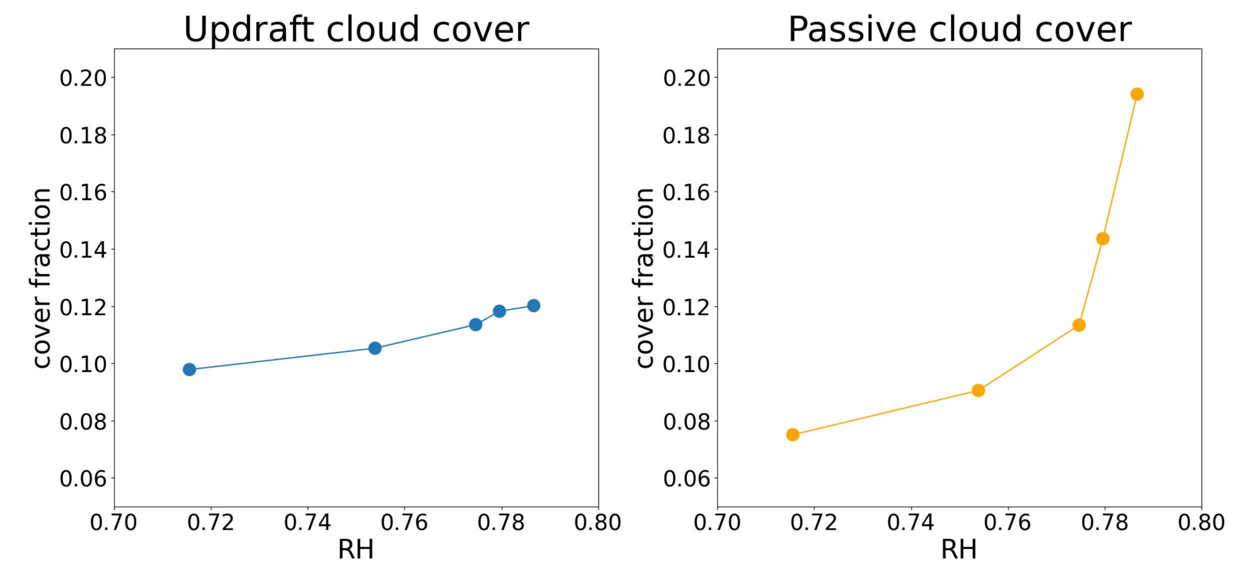

Figure 4: Dependence of average cloud cover on relative humidity

Conclusions

- A conceptual model for the organization of passive cumulus is proposed;
- We show that the horizontal dimension of clouds increases in time, while the characteristic radius of updraft cores remains steady;
- The total cloud cover increase with the RH cannot be explained through an increase in updraft cloud cover, but through the organization of passive cumuli.

References

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