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Large-eddy simulation of organized precipitating trade wind cumulus clouds

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Reply to anonymous referee #2 (13, C623-C625, 2013)

We thanks the reviewer for the positive review and the comments that helped us to improve the manuscript.

Reviewer: *This paper showed many sensitivity tests to demonstrate that cloud organization is caused by precipitation evaporation in the sub-cloud layer. I think the authors should make it clear that precipitation evaporation in the sub-cloud layer has two direct effects: (1) temperature perturbation, i.e., cold pool; (2) moisture perturbation, i.e., moistening due to the evaporation of liquid phase. The cold pool can be clearly seen in the figures in the paper. However, the paper has demonstrated that precipitating regions often has less moisture (drying effect) in the sub-cloud layer, which seems conflicting with the moistening effect of precipitation evaporation. Therefore, the paper should add more discussion to explain the dry core in the cold pool region. I think the paper has mentioned that dryer air from higher levels are transported to the cold pool region and make a dry core. It just needs more clarification and explanation. I also think that the paper should not try to answer whether the cooling or the moistening of the sub-cloud layer is triggering the organization (page 1866, lines 4-5). Statements and analysis related to this could be misleading because the core region is indeed not moistened, as the authors have recognized (page 1872, line 16).*

Reply: We will try the extend and improve the discussion of the drying vs moistening in the revised version. The dry downdraft may be explained by detrainment and evaporation in the cloud layer and subsequent mixing with the drier air from the environment. When this air arrives in the sub-cloud layer it is much drier than the sub-cloud layer air. For the details of the cloud dynamics, e.g., the formation of the dry downdraft we would like to refer to standard textbooks on cloud dynamics. For example, sections 7.3, 7.4 and 8.6 of the book *'Storm and Cloud Dynamics'* by Cotton, Bryan and van den Heever (2011, 2nd edition, Internat. Geophys. Series 99, Academic Press) provide a detailed explanation and discussion of the formation of downdrafts, their effect on the sub-cloud layer and the formation of cold pools. Also, the paper Tompkins (2001) provides a very good and extensive discussion of the cold pool formation, the formation of the dry core and the effects on sub-cloud layer moisture in general.

Reviewer: *The authors have shown that new clouds tend to form at the boundary of cold pool. At the boundary, temperature is often warmer and air is often moister, compared to the cold pool core region. But sometimes I found statements in the paper are inconsistent with this picture. For example, page 1868, lines 6-8: clouds usually occur over the moister patches of the sub-cloud layer and even prefer colder rather than warmer areas.*

Reply: As can be seen in Fig. 7, the boundaries of the cold pools are not per se warmer than their surrounding. Due to the low Bowen ratio that is typical for trade wind cumulus convection, the contribution of the surface sensible heat to the buoyancy tends to be relatively small compared with the latent heat contribution. Also, as stated on page 1867 around line 14, a lower temperature contributes to a lowering of the lifting condensation level, which facilitates cloud formation. This behavior has been previously reported, for example by Nicholls and LeMone (1980). The details of this effect are part of currently ongoing research.

Reviewer: *In the Fourier analysis, have the authors also looked at spectra of liquid water mixing ratio at 1000m or LWP? Especially in the following section (section 3.3), the authors identify and track clouds based on LWP and cloud cores, I think it would be interesting to look at the 2D Fourier analysis of liquid water mixing ratio at some height or simply just the 2D Fourier analysis of LWP.*

Reply: The Fourier analysis presented in the manuscript is based on the total moisture, i.e., the sum of vapor and liquid mixing ratio. Using the liquid water content or liquid water path may not be such a good idea, because those fields are not smooth and contain mostly zero values with just a few clouds here and there.

Reviewer: *The introduction of the paper is too short. It does not provide enough background on the previous studies of cumulus cloud organization.*

Reply: The literature on organization of cumulus clouds is indeed vast, especially when we include deep and tropical convection. It is therefore difficult to anticipate what kind of information the readers would find most useful in the introduction to our paper. For shallow convection we have referred to the excellent review of Atkinson and Chang (1996), but we should probably emphasize more that this paper gives an extensive overview of the organization of shallow and boundary layer clouds. We might also extend the discussion on deep convection, e.g., by discussing the squall dynamics, but this is indeed covered by many standard textbooks (e.g., *'Storm and Cloud Dynamics'* by Cotton, Bryan and van den Heever). It might also be interesting to give some overview of the observations, e.g., from GATE and other field experiments, but those focused very much on the deeper modes of convection. We will consider to extend the introduction along these lines.

Reviewer: *The paper should provide more detailed description of the microphysics in the model.*

For example, how the cloud water is converted to rain water. This is very important because different microphysical schemes could result in different behavior of the cloud field.

Reply: In section 2.1 we mention that the model uses the warm rain scheme of Seifert and Beheng (2001) and refer to Stevens and Seifert (2008) for further details. A detailed and extensive discussion of the microphysical sensitivities for the RICO case is in fact provided by Stevens and Seifert (2008) using exactly the same microphysics scheme. Nevertheless, we will extend the description of the microphysical assumption in the revised version. The treatment of evaporation should indeed be given in some more detail, since that part is not described in Stevens and Seifert (2008).

Reviewer: *Fonts in all the figures are too small.*

Reply: We have increased some of the font sizes, especially of some legend labels which are better readable now. Together with the Copernicus technical staff we will also make sure that the figures are large enough in the final layout.