Atmos. Chem. Phys. Discuss.,
https://doi.org/10.5194/acp-2018-825-AC1, 2018

Atmospheric Chemistry and Physics Discussions
Open Access

Interactive comment on "Subsiding shells and vertical mass flux in warm cumulus clouds over land" *by* Christian Mallaun et al.

Christian Mallaun et al.

christian.mallaun@dlr.de

Received and published: 28 December 2018

We would, first of all, like to thank the reviewers for their thoughtful and detailed comments to our manuscript. The major concern of both Referees is about the novelty of our results. We cite some of their key comments in the following and discuss them in detail below.

Referee #1: "The results are consistent with other published observational and modeling works, and the topic fits the scope of ACP. However, in general, this manuscript lacks novelty and originality and does not provide new contributions to the studies of cumulus clouds."

Referee #2 "After reading the manuscript, I have the impression that quite similar anal-

Printer-friendly version

Discussion paper

ysis already published in the cited papers has been applied to just another set of cloud data without really new aspects or findings. Therefore, this manuscript does not give new insight in cloud dynamics and unfortunately lacks of any novelty. . ..."

Both referees thus claim the lack of novelty. This is, strictly speaking, indeed true if only one data set is considered to be 'original' (and thus publishable) for anyone topic and thus a confirmation of earlier findings is not considered to be publishable. If 'novelty', however, includes analysis methods and research focus, it doesn't apply for the present paper. The overall goal of the present paper was to confirm (or otherwise) the existence of a subsiding shell – which were first postulated based on Large-Eddy Simulation (LES) results - in real clouds. Furthermore, the study was aimed at investigating the cloud-to-cloud variability of the subsiding shell characteristics and the associated mass transfer. The first aspect has indeed previously been done. To our knowledge the existence of the subsiding shell has experimentally been investigated by Heus et al. (2009), Wang et al. (2009), Katzwinkel et al. (2014). And indeed, Wang et al. (2009) include also shallow convection over land in their analysis. We feel that a confirmation of those results over land would be a valuable additional contribution to the field. In our study, we investigated target clouds under different conditions throughout their life-cycle and carefully selected the cloud transects. Therefore, our results first confirm earlier results and second add further information about the characteristics of the different transect classes.

If we move to the methodological aspects, it seems that our paper is indeed the first to investigate the relation between individual clouds (i.e., transects through individual clouds) and a statistical ensemble of clouds with respect to the characteristics of the subsiding shell. Heus et al. (2008) define the subsiding shell of an average cloud as a shell of subsiding air that is frequently observed around cumulus clouds. They investigate the origin of this shell, which is associated with an area of negative buoyancy (with a lateral size of 50–100 m), while the pressure gradient is again positive at cloud edge. Finally, they suggest a three-layer model where the subsiding shell surrounds the cloud and separates it from the environment. Katzwinkel et al. (2013) divide the subsiding shell, again of an average cloud, into a turbulent and humid inner shell adjacent to the cloud interior and a non-buoyant, non-turbulent outer shell. All these considerations suggest the existence of a subsiding shell in terms of a thin layer enveloping the cloud. These studies have investigated the statistical properties of clouds – as it corresponds to the output of a LES. The question whether an instantaneous 'snapshot' of an individual cloud - what we obtain when flying a transect through an individual cloud - exhibits those characteristics as well – as suggested in some of the 'sketch plots' (e.g., our Fig. 1) – or to what degree and for which development stage, is at least valuable and addressing it offers new insight in the 'turbulent character' of the subsiding shell. Therefore, in our paper we analyze the number of occurrences of the mean characteristics of a subsiding shell in many individual clouds. We find that in most of the individual clouds (about 85 %) with different development stage, these are not present on both sides of the cloud. Thus, the characteristics of a subsiding shell cannot be discerned from the individual clouds (over land), at least not from a single (instantaneous) cross-section. However, we can confirm the subsiding shell as a statistical (average) property of the cloud, since - similar to earlier results - we find the signature of the subsiding shell in the median distribution of the vertical velocity. This statistical property is the result of frequent downdrafts in the near surrounding of the clouds. These findings are new and considered important. We conclude that in order to explain the subsiding shell (the statistical property) it is necessary to understand the distribution and origin of the individual downdrafts in the vicinity of the cloud. Additionally, from analyzing the vertical mass transfer in the vicinity of the cloud we can estimate the thickness of the subsiding shell (some 20% of the cloud diameter) for what no clear definition had been available previously.

Additionally, Referee 2 raises the question whether the distinction between maritime cloud dynamics and that over land should be made in principle.

Referee #2 "Why should maritime cloud dynamics should significant differ from conti-

Printer-friendly version

Discussion paper

nental clouds?"

Sensible and latent heat fluxes are crucial for the formation of convective clouds and they are definitely different over land and sea surfaces. Similarly, the depth and diurnal variability of the boundary layer is different. This is particularly true for the boundary layer structure over mountainous terrain (e.g., Serafin et al. 2018, Lehner and Rotach 2018, Rotach et al. 2017) and hence the cloud regimes we investigate among others. Differential heating of the surface is responsible for triggering convective clouds over land (e.g, Cotton, 1992), which is less important over the sea. Investigating the characteristics of individual and average cloud properties over different surfaces thus reveals the impact of the different factors mentioned above on the structure of convective clouds. Moreover, Stevens and Feingold (2009) have suggested that the complex processes in shallow convection need to be investigated for the different cloud regimes so that they eventually might be combined to a common picture. Therefore, an extension of the investigation on the subsiding shell on shallow convection over land – and different land characteristics – seems to be a logical consequence. Even if we do not find important differences between the overall characteristics of convective clouds over land and those reported in the literature over the ocean – not over ‘flat land’ and neither over mountainous terrain – we think that it is important to conclude that apparently boundary layer characteristics, despite their overall relevance for cloud formation, do not have a significant impact on the average and individual cloud characteristics.

Finally, referee 2 raises the question

Referee #2 "How can you come up with robust conclusions based on only six flights?"

The measurement flights in shallow convection were conducted during two 3-week-long measurement campaigns in two consecutive years. This resulted in 6 successful measurement flights including 191 cloud transects – and we think it is rather the number of investigated clouds and to a lesser degree the number of flights (as long as they cover a substantial range of conditions) that determine the robustness of the results.

Printer-friendly version

Discussion paper

With ‘order 100’ the number of realized transects is clearly not the ‘large number’ (order ten thousand, say) one usually demands for statistical significance. Still, practical restrictions (flight endurance, etc.) and the comparably large effort for each sample set certain limits. Also, it is noted that our sample size is comparable to that from other investigations in this context (e.g., Katzwinkel et al., 2014, Perry and Hobbs, 1996). It is clear that certain sub-samples in our study, such as ‘transects for inactive clouds over mountainous terrain’ (see Tab. 4) are much too small - so that we refrain from drawing any conclusions.

We realize that we have not sufficiently emphasized all these aspects in the manuscript and hope that our response could clarify our intention. Furthermore, we are convinced that the manuscript presents novel and important findings about the nature and characteristics of the subsiding shell. The referees will hopefully follow our argumentation and agree to the preparation of a revised version, where we will certainly attempt to improve the manuscript as discussed above. We will be more than happy to also address the remaining (relatively) minor comments by the referees in the revised manuscript.

References

Cotton, W. and Anthes, R.: Storm and Cloud Dynamics, vol. Volume 44, Academic Press, 1st edition edn., 1992.

Heus, T. and Jonker, H. J. J.: Subsiding Shells around Shallow Cumulus Clouds, J. Atmos. Sci., 65, 1003–1018, http://dx.doi.org/10.1175/2007JAS2322.1, 2008.

Heus, T., J. Pols, C. F., J. Jonker, H. J., A. Van den Akker, H. E., and H. Lenschow, D.: Observational validation of the compensating mass flux through the shell around cumulus clouds, Quarterly Journal of the Royal Meteorological Society, 135, 101–112, http://dx.doi.org/10.1002/qj.358, 2009.

Katzwinkel, J., Siebert, H., Heus, T., and Shaw, R. A.: Measurements of Turbulent Mixing and Subsiding Shells in Trade Wind Cumuli, J. Atmos. Sci., 71, 2810–2822, http://dx.doi.org/10.1175/JAS-D-13-0222.1, 2014.

Lehner, M. and Rotach, M. W.: Current Challenges in Understanding and Predicting Transport and Exchange in the Atmosphere over Mountainous Terrain, Atmosphere, 9, https://doi.org/10.3390/atmos9070276, http://www.mdpi.com/2073-4433/9/7/276, 2018.

Perry, K. D. and Hobbs, P. V.: Influences of Isolated Cumulus Clouds on the Humidity of Their Surroundings, J. Atmos. Sci., 53, 159–174, http://dx.doi.org/10.1175/1520-0469(1996)053<0159:IOICCO>2.0.CO;2, 1996.

Rotach, M. W., Stiperski, I., Fuhrer, O., Goger, B., Gohm, A., Obleitner, F., Rau, G., Sfyri, E., and Vergeiner, J.: Investigating Exchange Processes over Complex Topography: The Innsbruck Box (i-Box), Bulletin of the American Meteorological Society, 98, 787–805, https://doi.org/10.1175/BAMS-D-15-00246.1, https://doi.org/10.1175/BAMS-D-15-00246.1, 2017.

Serafin, S., Adler, B., Cuxart, J., De Wekker, S. F. J., Gohm, A., Grisogono, B., Kalthoff, N., Kirshbaum, D. J., Rotach, M. W., Schmidli, J., Stiperski, I., Vecenaj, Z., and Zardi, D.: Exchange Processes in the Atmospheric Boundary Layer Over Mountainous Terrain, Atmosphere, 9, https://doi.org/10.3390/atmos9030102, http://www.mdpi.com/2073-4433/9/3/102, 2018.

Stevens, B. and Feingold, G.: Untangling aerosol effects on clouds and precipitation in a buffered system, Nature, 461, 607–613, http: //dx.doi.org/10.1038/nature08281, 2009.

Wang, Y., Geerts, B., and French, J.: Dynamics of the Cumulus Cloud Margin: An Observational Study, J. Atmos. Sci., 66, 3660–3677, http://dx.doi.org/10.1175/2009JAS3129.1, 2009

Interactive comment on Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2018-825, 2018.