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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Microphysical controls on the stratocumulus topped boundary-layer structure during VOCALS-REx" *by* I. A. Boutle and S. J. Abel

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General comments:

- Following modification of the manuscript to address comments raised by both reviewers, we have given it a careful read though and made some changes aimed at improving clarity.
- Our initial focus for the control simulation was to take an operational NWP model, in this case as is used over the UK, and run the same science settings over the VOCALS region, and we have stated this more explicitly in Section 2. The Smith

(1990) cloud scheme is still used operationally at these resolutions, hence it's inclusion here. The question of what to do with a cloud scheme at these resolutions is still very much an open question, and a topic for future research, as we discuss in the paper when mentioning the artefacts introduced by this scheme. In fact, the work shown in this paper has demonstrated quite clearly the need to modify/replace/remove the cloud parametrization in our high-resolution models. We did actually try a run in the 1km simulation with the scheme effectively switched off (an RHcrit value of 0.95 was used everywhere), and the resultant simulation had very little cloud present, more like open-cellular convection. This makes us feel that some cloud parametrization is still required at these resolutions. We have added some comments in Section 3 and the conclusions to address the fact that the cloud scheme is a weakness of the simulation, and further work is needed to produce an adequate replacement.
- We have added citations to a couple of the later references which are particularly relevant to this article.

Specific comments:

- We have clarified that the cloud layer is decoupled if the turbulent eddies do not span the entire boundary-layer depth.
- This is really what we meant, that cumulus rising into stratocumulus is often linked to the diurnal cycle. We have re-worded the sentence to clarify this.
- We have removed this sentence.
- It is something of a mixture of the two. In our experiments, the global model is simply re-started from the 00 UTC analysis on the 13th. However, this analysis is constructed from the initial analysis (00 UTC on the 12th) and standard data

assimilation procedures, in this case 4 updates at 6 hourly intervals using the Met Office 4D-Var system. We have compared the T+24 forecast fields from 00 UTC on the 12th with the 00 UTC analysis on the 13th, and the differences in the VOCALS region are very small.

- We have changed the word “resolution” to “grid-length” in this instance to make our meaning more explicit, and do discuss this issue in Section 5 when pointing out that the scale of the convection is larger in the model, due to its necessity to be resolved on the 1km model grid, forcing cells to be at least several km in diameter.
- The referenced paper (Lean *et al*., 2008) describes how the modified CAPE closure scheme used at 4km performs better than either of the two extreme cases (no convection parametrization or a full convection parametrization) in tests over the UK. This is because, as mentioned, 4km is only “convection permitting” and not “convection resolving”. It allows the model to generate convection explicitly in situations where the scale is large enough to be resolved on the grid, but still allows the convection scheme to represent the weaker clouds that would otherwise be missed, as their scale is smaller.
- We have clarified that the increased entrainment and rise in inversion height is due to increased turbulence generated by cloud top radiative cooling.
- This assertion is based on the greater number of decoupled profiles shown in Figure 2a. Although we do not have space to show all the profiles during this period, they do look more decoupled and the measure of decoupling used (Δz_b) is also greater on the 2nd day. This has been clarified in the text.
- Yes, we do mean cloud fraction and have changed the sentence accordingly.
- We agree that the change in dewpoint is much more pronounced than that in temperature, although our point was really that the stratification in the model is

greater than what was observed, and this is noticeable in both the temperature and dewpoint. We have modified the sentence to clarify this. In terms of conserved variables, there is no change in this stratification because the model cloud base is around 600 m/940 hPa, as shown in Figure 5. We appreciate that making comparisons like this was not easy due to the use of pressure as the vertical coordinate on the tephigrams and height on the other plots, and therefore have now included the approximate height of the pressure surfaces on the tephigrams.

- The Lock *et al.* (2000) boundary-layer scheme parametrizes 4 separate types of unstable boundary layer, depending on the presence/absence of cumulus convection and the presence/absence of decoupled stratocumulus. Therefore decoupled stratocumulus over cumulus convection includes some area of CAPE above the lifting condensation level, allowing the parametrized convection scheme to act, with this convective cloud spreading into a stratocumulus deck near the top. The sentence has been re-worded slightly to clarify that the lower resolution models are attempting to simulate cumulus convection beneath the stratocumulus, something which was not observed on this day.
- We believe that it is the latter, and have modified the sentence accordingly. Vertical velocity skewness would be very useful, but unfortunately the doppler lidar on the Ron Brown research vessel was not working during this two day period. Looking at some data from other periods during VOCALS, the cloud base skewness is often negative, especially during the night time, suggesting that the turbulence is mainly driven from the cloud top. Fig. 1 (below) shows the surface sensible, latent and total buoyancy flux as measured by the Ron Brown during this two day period. As shown, during the period of inversion rise (00 to 03 UTC on the 13th), there is a decrease in the surface buoyancy flux, suggesting that surface driven turbulence will have reduced during this period, meaning the cloud top driven component must be dominant.

- This sentence was confusing and we have modified it accordingly. What we were trying to say is that even though the surface sensible heat flux becomes negative during the night-time, this does not shut off the surface driven turbulence because the surface latent heat flux remains large and positive, forcing the total surface buoyancy flux to remain positive throughout the diurnal cycle. This is shown in Fig. 1 (below).

- The diurnal cycle is poor in the control model because of the excessive drizzle production, and it is significantly improved in the modified microphysics experiment because there is no longer excessive drizzle production. This is shown in Section 5, although we have modified the sentence to tell the reader that we will show this in Section 5.

- The droplet concentrations we quote are those measured by the research flights of the BAe-146 and NSF C-130 during the case-study period. We have modified the text to make this clearer, and now show the observations from the 12th in a sub-panel of Figure 5. The reference given (Allen *et al.*, 2011) also shows droplet number concentrations from the entire VOCALS period.

- We agree that the CFADs are more persuasive, but feel that the time-reflectivity snapshots give a different perspective, as they show the character of the drizzle in the region surrounding the ship, rather than just whatever happened to drift over the ship. They show the spatial extent of the excess drizzle surrounding the ship in the control simulation, and how this is much improved in the modified simulation. As mentioned, they do also give the reader an appreciation of the observed vs simulated cell size, hence why we did not degrade the radar plot to the model grid scale. They show that even at 1km horizontal resolution, the model is not fully resolving the scales of cloud and precipitation present in this region.

- This was partly the reason for the comment. Even with a 1km grid length, the

model can only resolve convective activity that is at a larger scale than this, yet the radar scan is clearly showing drizzle cells that are similar to, or less than this size. If the model cannot resolve features of this scale, then some parametrization of them is required, and hence it is a question for future research at what scale a shallow convection parametrization is really not needed. We have modified the end of this paragraph to explain this better.

References

Allen, G., Coe, H., Clarke, A., Bretherton, C., Wood, R., Abel, S. J., Barrett, P., Brown, P., George, R., Freitag, S., McNaughton, C., Howell, S., Shank, L., Kapustin, V., Brekhovskikh, V., Kleinman, L., Lee, Y.-N., Springston, S., Toniazzo, T., Krejci, R., Fochesatto, J., Shaw, G., Krecl, P., Brooks, B., McMeeking, G., Bower, K. N., Williams, P. I., Crosier, J., Crawford, I., Connolly, P., Allan, J. D., Covert, D., Bandy, A. R., Russell, L. M., Trembath, J., Bart, M., McQuaid, J. B., Wang, J., and Chand, D. (2011). South East Pacific atmospheric composition and variability sampled along 20° S during VOCALS-REx. *Atmos. Chem. Phys.*, **11**, 5237–5262.

Lean, H. W., Clark, P. A., Dixon, M., Roberts, N. M., Fitch, A., Forbes, R., and Halliwell, C. (2008). Characteristics of High-Resolution Versions of the Met Office Unified Model for Forecasting Convection over the United Kingdom. *Mon. Weather Rev.*, **136**, 3408–3424.

Lock, A. P., Brown, A. R., Bush, M. R., Martin, G. M., and Smith, R. N. B. (2000). A New Boundary Layer Mixing Scheme. Part I: Scheme Description and Single-Column Model Tests. *Mon. Weather Rev.*, **128**, 3187–3199.

Smith, R. N. B. (1990). A scheme for predicting layer clouds and their water content in a general circulation model. *Q. J. R. Meteorol. Soc.*, **116**, 435–460.

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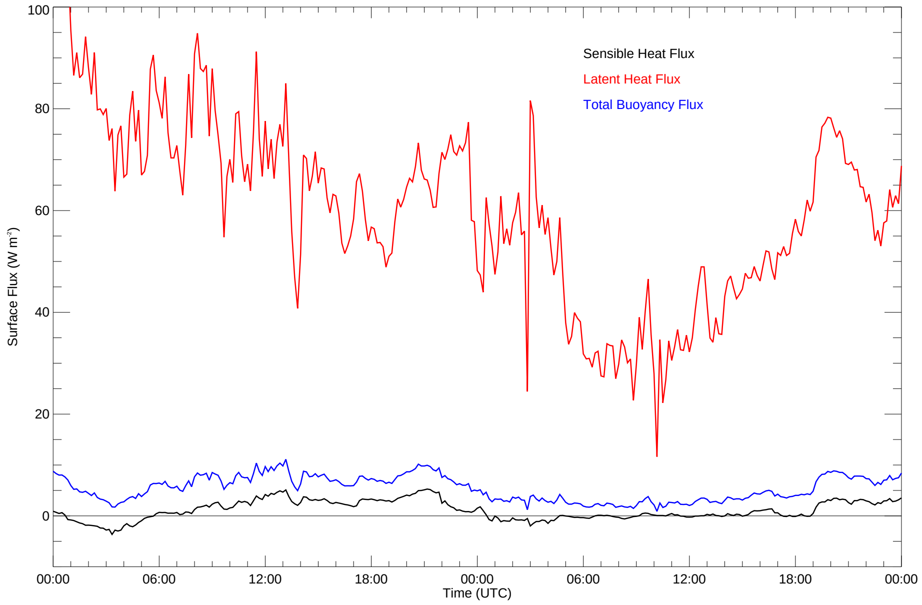

Fig. 1. Time-series of surface flux measurements taken at the Ron Brown during 12 and 13 November 2008.