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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Large-eddy simulation of mesoscale dynamics and entrainment around a pocket of open cells observed in VOCALS RF06" *by* A. H. Berner et al.

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We thank the reviewer for their helpful suggestions and comments. Responses to the individual points are made below.

1) "Cloud droplet number concentration (Nc)" and "cloud condensation nucleus (CCN) number concentration" are used interchangeably in the paper, which is sometimes quite confusing, for example, when seeing non-zero Nc above the boundary layer where there is no cloud. In the sub-section title 4.1, "CCN advection" is used; however, Nc is used again in the text. I guess the real issue is that the cloud microphysics scheme employed for the simulations doesn't take CCN as an input. It's fine to use fixed Nc *like in single-moment schemes, but it would be nice to make it clear upfront that Nc at some places should be viewed as CCN number concentration.*

Re1: Text has been added clarifying the role of advected N_c as an idealization of CCN in the sensitivity study, and that the N_c is regionally fixed for the control case.

2) I have some other concern regarding the treatment of Nc. As far as I know, the two-moment Morrison microphysics scheme already has the capability/option to predict Nc. Wouldn't it be nice to include that in the model simulations? Please also comment on how this treatment impacts the prognostic raindrop number concentration and derived rain rate in the simulations.

Re2: We agree that the reviewer's suggestion would have been a good idea. When we started our numerical simulations, we did not appreciate how to take advantage of this predictive N_c capability of the Morrison microphysics without explicitly predicting and evolving the aerosol size distribution. At this point, redoing two very large simulations would be impractical within the revision timescale for this paper; the advected case would require additional model modifications, as the Morrison microphysics implementation currently used applies a spatially uniform two mode aerosol distribution. Based on POC observations (e. g. Wood et al. 2011) and other modeling studies with fully prognostic aerosol (e. g. Kazil et al. 2010), the assumption of uniform aerosol concentration within the POC would in any case not be that accurate, as accumulation-mode aerosol concentrations are drastically lower in the 'ultraclean' layer which contains the patchy thin capping stratocumulus than in the subcloud layer that feeds the cumulus updrafts. Hence by using a fixed, spatially varying, or a passively advected aerosol distribution, we would still expect substantial microphysical biases in the simulated POC compared to observations. As a test of this, we have performed two additional small domain runs using identical large scale forcing and thermodynamic initialization, but allowing prognostic N_c activated from a fixed, lognormal accumulation mode with mean

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diameter of 200nm and number concentrations N_a of 30 cm^{-3} and 10 cm^{-3}. The run with N_a of 30 cm^{-3}, a value derived from the subcloud sampling of RF06 as reported in Wood et al. 2011, develops a relatively uniform cloud N_c of 25 cm^{-3} with little surface precipitation evolving over the course of eight hours. As a further test, the run in which N_a is reduced to 10 cm^{-3} develops lower cloud cover and greater surface precipitation, but maintains relative spatial uniformity of N_c from 8 to 9 cm^{-3}. This suggests that dynamically driven difference in activation alone are insufficient to account for the N_c variation observed within POC cloud systems. We are currently implementing a prognostic aerosol scheme incorporating cloud-aerosol-precipitation interaction and a simple treatment of surface and entrainment source and sink terms. This will allow us to simulate microphysical feedbacks that cannot be considered in either the fixed N_c or fixed-aerosol framework.

Because the droplet concentration does vary dramatically within the POC from 30 cm^{-3} in the cumulus updrafts to 1 cm^{-3} or less in parts of the ultraclean layer, there is ambiguity in the ideal choice of a spatially uniform N_c to use in the POC. In the revised text, we include a sensitivity study done with horizontally homogeneous N_c in the smaller 24 km x 24 km domain, in which N_c values are reduced to 5 cm^{-3} and 1 cm^{-3}. The cloud fraction declines sharply with reduced N_c with modest reductions in LWP and little change in area-averaged precipitation.

3) On page 13322 in lines 5-25, the mysterious behaviors in the model (the sensitivity of entrainment rate to horizontal grid spacing, and surface fluxes to near-surface vertical grid spacing) need more explanations.

Re3: The grid sensitivity of LES simulations to both numerical diffusion and subgrid parameterizations is well established, e.g. Bretherton et al. (1998, QJR); Stevens, Moeng, and Sullivan (1999, JAS). For stretched grid meshes such as the ones employed in this study, additional complexity arises from the interaction with surface flux schemes not necessarily conceived with high aspect-ratio grids in mind. We feel the exact nature of the interactions leading to these sensitivities is beyond the scope of the paper, and that insofar as the sensitivity is acknowledged and a configuration found for which the various parameterizations provide results in reasonable agreement with the observations, the description is sufficient. For completeness, text referring interested readers to the appropriate literature regarding grid sensitivity of LES has been added to the section.

4) For a growing boundary layer, entrainment rate is usually calculated as the sum of the growth rate of the boundary layer and large-scale subsidence rate at the top of the boundary layer. This would give the same entrainment rate for POC and OVC. However, the two methods for calculating entrainment rate used in the paper give different answers for POC and OVC. It's explained in the paper that the actual subsidence rate is an order of magnitude larger in OVC than in POC due to the circulations depicted in Fig. 12 although subsidence was prescribed as a uniform forcing across the domain. This is truly interesting. Does this suggest that the traditional way of calculating entrainment rate is not applicable to POC region? Might there be a scale-dependence (e.g., on POC size and Zi) of this kind of POC-OVC interaction and the consequent effect on subsidence rates?

Re4: The reviewer is correct. Regional modeling studies of the SEP or other stratocumulus regimes may eventually provide better insights to the scale dependence of the induced mesoscale variability in subsidence around a POC; we can only state with certainty that the behavior appears in domains on the order of the 100 km we have tested. While the horizontal divergent flows that divert subsiding air from above the POC to above the surrounding solid cloud are only a fraction of a meter per second in our case, our simulations suggests that for a POC 500 km on a side, these flows might be five times as large (a couple of meters per second) and therefore might be more observable.

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5) It's unclear to me how the two-hour mean stream function (Fig. 12 and at Zi for Fig. 14) is calculated. Was the growth of Zi during the two hours taken into consideration?

Re5: The calculation does account for the inversion deepening. Specifically, the y-averaged stream function at the nearest grid level to the domain mean Zi is calculated for each 3D snapshot (i. e. every ten minutes), and the plots average together two hours of these traces. Text to this effect has been added to the discussion of the figure.

6) It is mentioned in the paper that modeled cloud cover in POC is too large (nearly 100%) compared to observations. Is this the reason why POC and OVC have similar radiative cooling rates in the simulation? If there were no such a discrepancy, would the conclusions about entrainment rate and subsidence rate in the POC/OVC system change?

Re6: Yes, the POC radiative cooling is sensitive to the cloud cover. Our new sensitivity studies with even smaller N_c inside the POC simulate reduced cloud fraction and further reduced entrainment within the POC. If anything, the mesoscale circulations and dynamics described ought to be enhanced in the true case, as they are driven by the difference in entrainment between the POC and overcast regions. Text discussing the added sensitivity study addresses these points.

Suggestions for some minor changes:

1) It's recommended to add "REx" to the title.

Done.

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2) In the abstract, change "resolution" to "grid spacing"; also at a few other places in the text.

Done.

3) The units of temperature in "K", not "oK" (a few places on pages 13328 and 13331 and in Figs. 2 and 11)

Done.

4) On page 13331, variables in the equation in line 8 should be briefly defined.

Done.

5) Four panels in Fig. 13 are referred to as (a-d) in the text but not labeled in the figure. The order of the panels seems to be inconsistent.

Labelled in figure and made consistent in text.

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 13317, 2011.

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