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Atmospheric
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Discussions

Interactive comment on "Examining aerosol indirect effect under contrasting environments during the ACE-2 experiment" *by* H. Guo et al.

H. Guo et al.

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We thank anonymous referee #1 for many useful comments and suggestions. We will incorporate the corrections and modifications in the revised version.

General remark:
1. Is a 24-h simulation enough? For example, over this time period, is there sufficient information on the moisture flux to rule out possible effects that it may have on the boundary layer?

Our total simulation time is 30 hours and our analysis focuses on the last 24 hours, which is enough to examine the (important) diurnal cycle of the marine boundary layer.

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The boundary layer heights are ∼1500 m and ∼1000 m for the clean case (on June 26) and for the polluted case (on July 9), respectively. The magnitude of the vertical velocity within the boundary layer is about 0.2 m/s (Guibert et al., 2003). The time scale for the surface moisture flux to be transported to the top of the boundary layer is about 1500 m/(0.2 m/s) ∼ 3 hours. Therefore, a 30 hour simulation is long enough for the moisture flux to be well distributed within the boundary layer which is what we are mainly concerned with in this study.

Of course a simulation over a longer time period, for example, a few days, may be desirable, but the computational cost would be very expensive for 3D simulations. Also, there are not enough observations over several consecutive days to validate the model results.

Reference:
Guibert, S., J.R. Snider and J.-L. Brenguier, Aerosol activation in marine stratocumulus clouds 1. Measurement validation for a closure study, J. Geophys. Res., 108(D15), 8628, doi:10.1029/2002JD002678, 2003.

The following minor revisions would help clarify some points:

1.Page 11563, line 10: Remind the reader of the magnitude of currently accepted total forcing from greenhouse gases plus natural causes.

The total forcing from greenhouse gases plus natural causes is about +2.7 W m^{-2} (IPCC 2001; Boucher and Haywood, 2001). (we will add this to line 10 on page 11563).

Reference:
Boucher, O. and J. Haywood, On summing the components of radiative forcing of climate change, Climate Dyn., 18(3-4), 297-302, 2001.

IPCC, Intergovernmental Panel on Climate Change, Climate Change 2001, The Scientific Basis, Cambridge University Press, 2001.

2.Page 11564, line 21: The abbreviation "(CF)" should be placed after the first mention of "cloud forcing" on line 20.

The abbreviation "(CF)" in this study refers to cloud fraction, not cloud forcing (see line 21 on page 11564).

3.Page 11565, line8: "The two aforementioned studies had different (or even contradictory) conclusions" is a repetition of line 5-6 "However, Xue and Feingold (2006) presented opposite results". These two sentences can be combined or one can be omitted.

The second sentence will be deleted (see line 8 on page 11565).

4.Page 11569, line 1: Clearly state the height of the cloud base.

We will add the computed clouds bases ($\sim$ 1.2 km for the ’CACM’ case and $\sim$ 0.8 km for the ’PAPM’ case, respectively); (see line 1 on page 11569).

5.Page 11569, lines 1-2: The LWC increases with height above cloud base and N_d is constant only to a height of approximately 1.4 km for CACM, and 0.9 km for PAPM. Some words about what is happening at higher levels would be interesting.

The rate of increase of LWC with height is smaller and N_d also decreases near cloud top because of the entrainment of dry air, which leads to the evaporation of some cloud droplets.

There is already some discussion of this issue in the current paper that will be revised as

follows:
N_d decreases at cloud top (~1.45 km for the CACM case and ~0.95 km for the PAPM case, respectively), due to the entrainment of dry air from above the cloud. We also note that the difference between d_v and the adiabatic d_v (solid lines in Figures 3-4 (c) and (f)) is small from cloud base to cloud top in both the ATHAM results and airborne measurements. This might suggest that the mixing between cloudy air and dry air above clouds tends to be heterogeneous because N_d becomes smaller but d_v remains close to the adiabatic d_v at cloud top. However, this convergence of d_v towards the adiabatic d_v is less evident in ATHAM than in the measurements. This might be because ATHAM treats mixing as homogeneous rather than heterogeneous (Guo et al., 2006), a problem that many CRMs or large eddy simulation models share (Grabowski et al., 2006).

6.Page 11569, line 11: Clearly state the height of the cloud top.

We will add a sentence to the computed cloud top (~1.45 km for the CACM case and ~0.95 km for the PAPM case, respectively) (see line 11 on page 11569).

7.Page 11569, lines 8-10: Is the discussion pertaining to CACM or PAPM, or both?

Both.
We will add: In both the CACM and PAPM cases the simulated N_d is slightly higher than the observed N_d near cloud base (Figures 3-4 (b) and (e)), which is partly due to the fact that the lower size limit of the Fast-FSSP (Forward Scattering Spectrometer Probe) measurement is 1.3 μm in radius (Brenguier et al. 2003). (see lines 8-10 on page 11569)

8.Page 11569, lines 19-21: This sentence seems rather ambiguous. The standard deviation "might" be larger due to the limited representation of heterogeneous mixing in ATHAM. Is it possible to be more clear as to why the standard deviation is larger?

We had placed this explanation in the wrong place. It was meant to explain why d_v from the model diverged from the adiabatic d_v more than the measurement did. We will add:
However, this convergence of d_v towards the adiabatic d_v is less evident in ATHAM than in the measurements. This might be because ATHAM treats mixing as homogeneous rather than heterogeneous (Guo et al., 2006), a problem that many CRMs or large eddy simulation models share (Grabowski et al., 2006). The standard deviation of the simulated d_v is about 2$\sim$5 μm, which is larger than that of the observed d_v (2$\sim$3 μm) (Pawlowska et al., 2006). This might be partly due to sampling strategies. We sampled over all cloudy cells within the numerical domain, while the observations sampled over the traverse of the aircraft through a cloud.

9.Page 11570, line 18: "evenly-spaced" rather than "evenly-divided".

This will be changed from "evenly-divided" to "evenly-spaced". (see line 18 on page 11570).

10.Page 11571, line 6: The discussion of Figures 7 and 8 would be much clearer if Table 1 and the description of CAPM and PACM were introduced first, rather than in Section 4.

The PACM and CAPM will be introduced in Section 2.1 as noted below (see lines 3-4 on page 11567):
Two sensitivity tests were also conducted, which were denoted as PACM and CAPM and are discussed in detail in Section 4 (see Table 1).

11.Page 11572, line 16 and 17: Add in the word "respectively":($\sim$100% and $\sim$95%, respectively, and $\sim$75% and $\sim$45%, respectively).

Two respectively will be added (see lines 16-17 on page 11572).

12.Page 11574, line 13: "first" rather than "1st".

This will be changed to ’first’ (see line 13 on page 11574)

13.Page 11574, line 15: Explain ρ_w and describe β.

We will change this to: (see lines 15-18 on page 11574)
where ρ_w is the liquid water density (1000 kg m^{-3}), and β is a parameter that measures the ratio between the droplet effective radius (e.g., the ratio between the third and the second moment of the droplet size distribution) and the droplet volume mean radius. β is ~1.08 for maritime clouds (Martin et al., 1994).

14.Page 11575, equations: Explain F_{net}

We will changed this to
F_{net} is the net incoming radiative flux (shortwave plus longwave, where downward is positive) (see line 24 on page 11574)

15.Page 11575, line 21-25: This seems a bit confusing. The authors state that the magnitude of the magnitude of $\delta F_t(CM)$ is smaller than that of $\delta F_1(CM)$ and results in a positive $\delta F_2(CM)$, but the positive $\delta F_2(CM)$ is dominated by a negative $\delta F_1(CM)$, So, which is the cause and which is the cause and effect?

The sentence will be deleted.

16.Page 11576, line 4: Add "W m-2, i.e. " 0 W m-2"

This will be added (see line 4 on page 11576).

17.Page 11584, Table 2: Why is this table not discussed in the CACM/PACM section, Section 4.1.1?

We will add a discussion of Table 2 in the CACM/PACM section, Section 4.1.1 (see lines 20-24 on page 1572).
At local noon when the solar radiation is strong, the CF in the ’CACM’ case is about twice of that in the ’PACM’ case; the in-cloud LWP in the ’CACM’ case is about 40% larger (Figure 7). On the daily average, the CF in the ’CACM’ case is larger than that in the ’PACM’ by 12% and the in-cloud LWP in the ’CACM’ case is about 27% larger (Table 2).

18.Page 11588, Figure 3c, f: How different is the curve if N_d is set to 40 cm^{-3} rather than 50 cm^{-3}, which seems closer to the observations? Similarly, what if N_d? is set to 25 cm^{-3} above a height of 1.4 km?

For a given LWC, the volume mean cloud droplet diameter (d_v) is inversely proportional to $N_d^{1/3}$. A 20% (or 50%) change in N_d will give rise to a 7% (or 20%) change in d_v. So we expect there is no significant change for the curves in Figure 3c, f.

We are not quite clear about what the reviewer wants to know:
If we assume that the reviewer wants to know the difference from the adiabatic profile, then we can compare the adiabatic volume mean droplet diameters using $N_d = 50cm^{-3}$ and using $N_d = 40cm^{-3}$ or 25 cm^{-3}.
we have the plot at the web-address:
http://athlon1.engin.umich.edu/hguo/ACPD-2006-0331-rp_ref1_pic/ref1_Q18_fig1.jpg

The red curves in (c) and (f) of the above plot are the vertical profiles of the adiabatic droplet diameter with $N_d = 40cm^{-3}$ for z from 1.2 to 1.4 km and with $N_d = 25cm^{-3}$ for z>1.4 km. The blue curves in (c) and (f) are the same as in Figure 3 (c), (f) in our manuscript (i.e., $N_d = 50cm^{-3}$ for z from 1.2, to 1.45 km). You can see that the difference between the red and blue curves is small near cloud base largely because the adiabatic LWC is small and the adiabatic diameter (d_{va}) is calculated from $d_{va} = (\frac{6LWC}{\pi\rho_w N_d})^{1/3}$, however, this difference becomes larger with the height above the cloud base due to larger adiabatic LWC.

When compared to the observations, the blue curve (with $N_d = 50cm^{-3}$) seems to be closer to the observations than the red curve (with $N_d = 40cm^{-3}$) for z **from 1.2 to 1.4 km**. This is because the observed LWC is generally smaller than the adiabatic LWC. For z >**1.4 km**, neither blue nor red curve is closer to the observations.

Nevertheless, due to the dilution or evaporation after mixing with dry air above the clouds (or the entrainment near cloud top), the observed LWC is smaller than the adiabatic LWC (see (d)). We also note that the observed N_d decreases near cloud top (see (e)), while the observed d_v is still close to the adiabatic d_v (blue curve in (f)) and is not significantly affected by the entrainment. This feature suggests that the dilution of N_d is more significant than the evaporation of droplets (d_v), which implies that the mixing between cloudy and clear air here is largely heterogeneous here and that the representation of heterogeneous mixing in cloud models will be desirable.

The over-estimation of N_d from the model (see (b)) compared to observations is partly due to the measurement artifact at cloud base and the lack of representation of heteorogeneous mixing at cloud top in the model, respectively. This discussion has been presented in Section 3.1 in our manuscript.

If we assume that the reviewer wants to know the difference from the computed profile from ATHAM, then when we use the average computed liquid water content from ATHAM (Figure 3a) and $N_d = 40cm^{-3}$ for z from 1.2 to 1.4 km and $N_d = 25cm^{-3}$ for z $>$ 1.4 km to calculate volume mean droplet diameter, we get the plot at the web-address (green curve in (c) and (f) of the following plot):
http://athlon1.engin.umich.edu/hguo/ACPD-2006-0331-rp_ref1_pic/ref1_Q18_fig2.jpg

The blue curve is the vertical profile of adiabatic volume mean droplet diameter with $N_d = 50cm^{-3}$. For z from 1.2 to 1.4 km, there is good agreement between the green and blue curves. For z >1.4 km, there is a kink in the green curve due to the sudden change of N_d from 40 cm^{-3}

to 25 cm^{-3}. Nevertheless, the green and blue curves still compare well with each other, and with observations as well.

19.Page 11589, Figure 4: What causes the large difference in modeled and observed N_d around a height of 0.75-0.8 km?

It is due to the uncertainty of the estimate of the altitude of cloud base.

20.Page 11589, Figure 4c, f: How would the curve vary if N_d was set to 200 cm^{-3} when the height is above 0.9 km?

Similar to Q. 18, we plot the vertical profile of the adiabatic volume mean droplet diameter with $N_d = 300cm^{-3}$ for z from 0.75 to 0.9 km and with $N_d = 200cm^{-3}$ for z $>$0.9 km (red curves in (c) and (f) of the following plot at the web-address:
http://athlon1.engin.umich.edu/hguo/ACPD-2006-0331-rp_ref1_pic/ref1_Q20_fig1.jpg).

We also plot the vertical profile of the volume mean droplet diameter using the average computed liquid water content from ATHAM (Figure 4a) and $N_d = 300cm^{-3}$ for z from 0.75 to 0.9 km and $N_d = 200cm^{-3}$ for z $>$ 0.9 km as shown in the following plot (green curves in (c) and (f) of the following plot at the web-address:
http://athlon1.engin.umich.edu/hguo/ACPD-2006-0331-rp_ref1_pic/ref1_Q20_fig2.jpg).

The discussion is similar to that in Q.18 and omitted here for simplicity.

21.Page 11589, Figure 4: A comment about why modeled LWC and N_d compares well to the adiabatic LWC and N_d around 0.8-0.85 km when the observations are higher would be interesting.

The higher observed LWC than the adiabatic LWC reflects the observational uncertainty, for example, horizontal inhomegeneity, the uncertainty in the cloud base altitude estimation (Brenguier et al., 2000).

Reference:

Brenguier, J.-L., H. Pawlowska, L. Schuller, R. Preusker, J. Fischer, and Y. Fouquart, Radiative properties of boundary layer clouds: droplet effective radius versus number concentration, J. Atmos. Sci., 57, 803-821, 2000.

22.Page 11591, Figure 6: "evenly spaced" rather than "evenly-divided".

This will be changed to "evenly-spaced". (see Figure 6 on page 11591).

23.Page 11592, Figure 7: "with "" and vertical error bars" would be clearer than "with "*" and vertical bars".*

This will be changed to "‘vertical bars" in Figure 7 on Page 11592.

24.Page 11593, Figure 8a: What is the strange black line/symbol? It does not appear to be an asterisk with error bars.

It is the measurement of cloud fraction from CASI (Compact Airborne Spectrographic Imager) in Figure 8a on Page 11593, and we will re-plot it.

25.Page 11596, Figure 11: Please enlarge this figure so that it is easier to read.

Figure 11 on Page 11596 will be enlarged.

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