Response to reviewer comments on "The relative importance of macrophysical and cloud albedo changes for aerosol induced radiative effects in stratocumulus" by Daniel P. Grosvenor et al.

Comments from anonymous Referee #2

We sincerely thank the Referee for taking the time to review our paper and for providing constructive suggestions for improvement. We hope that we have fully addressed the Referee's comments – our responses are listed below in non-bold font.

1. The title should reflect the fact that this is a numerical study.

In response to this comment, and also one made by Referee #1, we have changed the title to :

"The relative importance of macrophysical and cloud albedo changes for aerosol induced radiative effects in closed-cell stratocumulus: insight from the modelling of a case study."

, to include the fact that this was a modelling/numerical study of a case study and that we primarily are concerned with closed-cell stratocumulus.

2. Thorough validation of the model results against various observations is a key part

of the paper to put more confidence in the simulated aerosol impacts. Therefore, environmental

conditions simulated by the model should be validated as well. I suggest

the authors to show the ship-borne sounding comparisons.

Thank you for the suggestion, which has led to a nice comparison that supports the arguments made concerning the CFAD results (i.e. the boundary layer being too low). We have now included a figure to show the comparison to the radiosondes :-

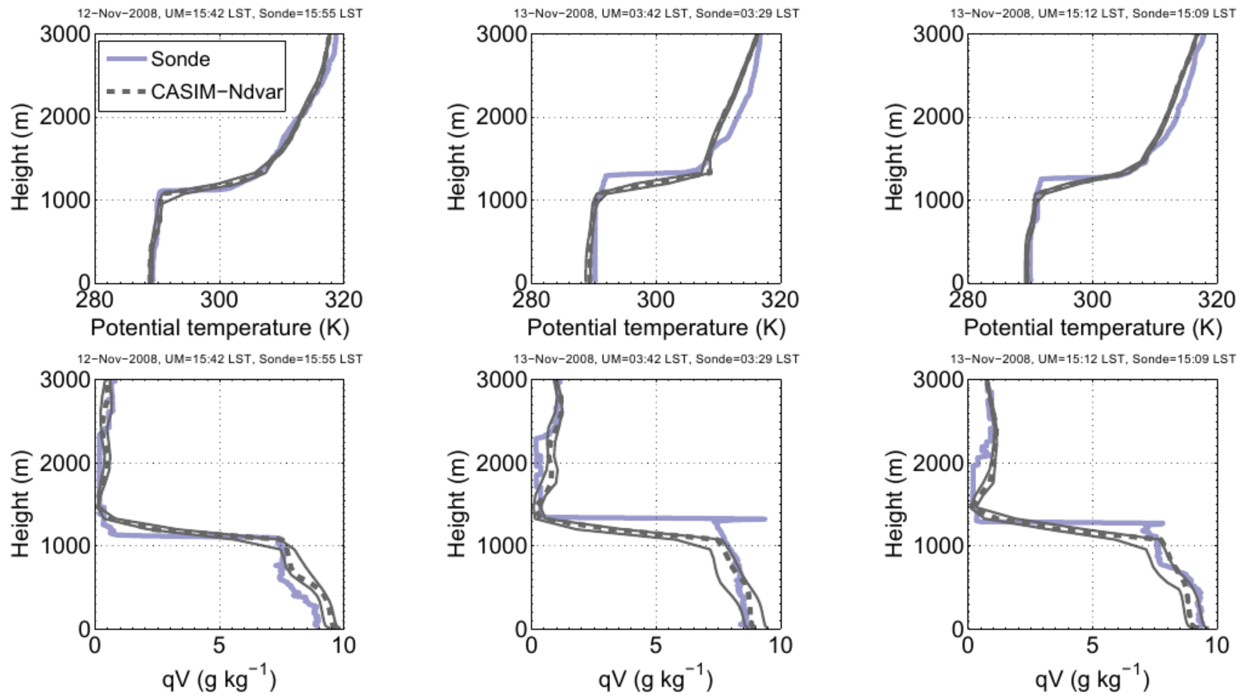

Figure 13. Profiles of potential temperature (top row) and water vapour mixing ratio (bottom row) from radiosondes released from the RH Brown ship (labelled "sonde") and from the control UM run (CASIM-Ndvar). Three different radiosonde times are shown; 15:55 LST on 12th Nov (left), 03:29 LST on 13th Nov (middle) and 15:09 LST on 13th Nov (right) with the closest available UM time being used (see titles of each sub–plot). The closest profile in the UM to the ship location is shown as the dashed grey line and the surrounding thin grey lines show the 10th and 90th percentile at each height from all of the profiles in a $1\times1^{\circ}$ region around the ship.

We have also added a new section to describe these comparisons :-

3.2.7 Thermodynamic profiles

Regular radiosondes were released from the RH Brown ship allowing a comparison of the model to observations for thermodynamic profiles. Fig. 13 shows this comparison for the potential temperature (θ) and water vapour mixing ratio (q_v) for the control run only (CASIM-Ndvar); except for q_v for the CASIM-Ndvar-0.025 run, all of the runs showed very similar results and so are not shown. CASIM-Ndvar-0.025 was likely anomalous due to the lack of cloud cover in that run. Three times are shown that are close to the peaks and troughs of the diurnal cycle of LWP (see Fig. 4), but excluding the first peak at 03 LST on 12th Nov to allow for model spin–up.

For the first time shown (15:55 LST on 12th Nov, i.e. daytime) the θ profile from the model matches that observed almost exactly, including the height of the sharp inversion, but the q_v profile is around 1 $\mathrm{g\,kg^{-1}}$ too moist in the boundary layer.

The decrease in q_v associated with the inversion is also not as sharp as in reality. The model biases for both of the other two times shown (13th Nov; nighttime, 03:29 LST; daytime, 15:09 LST) are similar to each other. In the model boundary layer, the modelled θ and q_v agree with reality within 1 K and 0.5 $\mathrm{g\,kg^{-1}}$, respectively, but the sudden changes associated with the inversion are too low by around 200 m. Above the inversion the model is also too warm by a maximum of around 3 K and slightly too moist in the region 500–600 m above the inversion by a maximum of approximately 1 $\mathrm{g\,kg^{-1}}$. Overall, the results suggest that the model is matching reality very well in terms of the thermodynamic conditions, except for a tendency for the inversion to be too low by around 200 m.

3. LES simulations driven by mesoscale models than incorporate large scale dynamic and thermodynamic structure are not that uncommon now. Chow et al. (2006) demonstrated the approach. Xue et al. (2014, 2016) showed that LES simulations of actual events reproduced observational features very well. Therefore, discussions about LES v.s. regional model in pages 3 and 32 should be adjusted.

We have added some sentences to describe such simulations on p.3 and p32.

p. 3 (last two sentences added) :-

A compromise between LES and GCMs is a coarser resolution (~ 1km) regional model that can simulate larger domains for the same or less computational cost as an LES. Regional models have the advantage over LES in that they are driven by meteorological analyses that can capture the relevant large scale dynamic and thermodynamic structure, allowing results to be more easily compared to real observations. Aerosol effects can also be considered relative to dynamical forcing or meteorology effects. However, we also note that many models have the ability to nest down from regional model resolution to LES resolution (including the one used in this study), although the computational cost for high resolution nests can be prohibitive for large domains. Techniques for the better coupling of (non–LES) atmospheric models to high resolution LES nests (with non–periodic boundary conditions) now exist and have been shown to compare well to observations (e.g. Chow et al., 2006; Xue et al., 2014, 2016).

p. 32 (last sentence) :-

The use of lower resolution paves the way for larger area, longer timescale simulations than has been previously possible with very high resolution LES models, or may even allow global simulations. Domain size could be important to allow the representation of large meteorological features and dynamical feedbacks between large area features such as between open–cell and non–open–cell regions, as well as for examining the wider scale dynamical impact of cloud–aerosol interactions. Thus, the realistic meteorology of our model represents an important advantage over LES models, which are generally run over smaller domains and employ idealised set-ups that do not allow spatially inhomogeneous meteorological forcing (although there are noted exceptions to the latter limitation: e.g. Chow et al., 2006; Xue et al., 2014, 2016). Since the likelihood is that meteorology

4. What type of data from UM N512 was used to drive the 1-km simulations, analysis or forecast data (Section 2.1)?

The global model used to drive the 1km simulations was a 2-day forecast run, which was initialized using global UM analysis. Fields used to initialize the 1km nest and to force the boundaries included wind, temperature and condensed water fields. Section 2.1 has been modified as follows :-

> equator for $dx \times dy$) with 70 vertical levels below 80 km that are quadratically spaced giving more levels near the surface. This is run in forecast mode for two days (12-14th November) based on an initial field from the UM global operational analysis. The global run provides the initial conditions and forces the lateral boundaries for the wind, moisture, temperature and condensed water fields for a single 1 km resolution nest centred at 20^o S, 76^o W of size 600×600 km (Fig. 1). This places the domain near

5. The model data should apply the same way as how GOES-10 gets the 2D Nd field to calculate the 2D Nd field (Section 3.2.1).

We agree that this would be an ideal way forward, but in order to fully simulate the satellite it would be necessary to perform 3D radiative transfer upon the model fields in order to calculate reflectances at the relevant wavelengths and then to perform the retrievals of effective radius and optical depth on these (since these are used to obtain Nd). Unfortunately, this is a capability that we do not have available currently and which would also be very computationally costly. Observations in the region of our study (Painemal, 2011 & 2012) show that the satellite retrieval generally performs well against in-situ observations of Nd suggesting that a direct comparison to model Nd is justified. The satellite retrieval assumes that Nd is constant throughout the cloud depth and this assumption is well validated by the studies just mentioned. Such an assumption is consistent with the model fields for this cloud and so the choice of height used should not be very important. Therefore, we choose the height at which the liquid water content is the highest since this is likely most representative of a cloudy part of the profile. We also only consider columns with LWP>5 g m^2 in order to exclude non-cloudy columns. Given that there are reasonably large uncertainties in the observations for this quantity we feel that errors introduced by these methods are of secondary importance.

6. Sections 3.2.3 and 3.2.4 should be simplified. Too much detail now.

We have simplified Section 3.2.3 and especially 3.2.4 to remove a lot of the unnecessary detail. In section 3.2.3 we have removed some of the detail regarding the different POC regions. In Section 3.2.4 we have changed some of the details due to the new figure being implemented (see response 7) and have cut out the detail regarding the Poisson errors and some of the quantitative quotes, which we deemed a little too complicated and did not add much beyond what could be ascertained from the figure itself. Please see the revised manuscript for more details.

7. Why don't you use all available satellite data to plot the LWP PDF in Fig. 8? The

data sample in current Fig. 8 is very limited based on just one snapshot.

Thanks for the suggestion - we have now revised Fig. 8 to include 9 snapshots from the REMSS microwave satellite instruments for the nighttime (the time centred around the maxima of the LWP diurnal cycle) PDF (no GOES data available). For the daytime (surrounding the LWP minima) there are only 4 available REMSS snapshots, but we have also sampled the GOES LWP (available every 30 minutes) for a longer period and for both of the days available. Here is the revised figure and caption :-

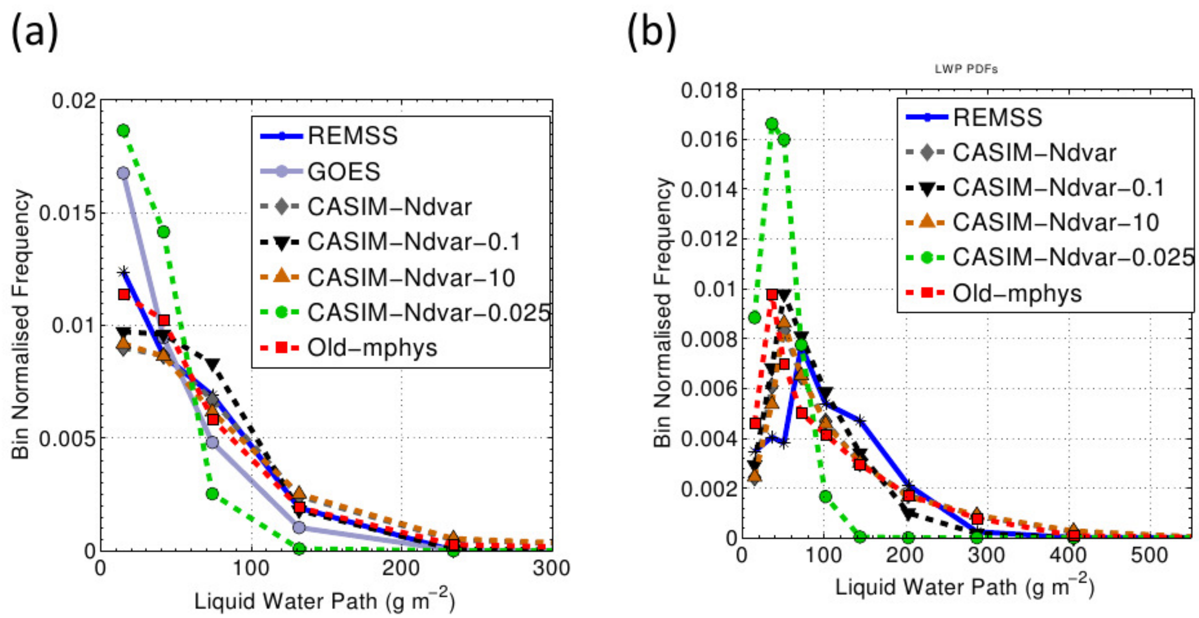

Figure 8. PDFs of LWP for daytime (left) and nighttime (right) time periods for the model and for satellite observations. "REMSS" refers to the several available REMSS microwave instruments, each of which provides a snapshot LWP field. For the daytime, the times surrounding the minima in the LWP diurnal cycle (see Fig 4) are used (10-18 LST on both 12th and 13th November; overall 4 REMSS snapshots). For the nighttime, only the REMSS satellites are shown; times are chosen surrounding the maxima of the LWP cycle, but the surrounding period is reduced compared to the daytime in order to match the limited available REMSS times as closely as possible (03-09 LST on 12th Nov, 20 LST on 12th Nov to 10 LST on 13th Nov, 18:30 - 20 LST on 13th Nov; contains 9 REMSS snapshots). The model and GOES-10 data have been coarse grained to the AMSR-E resolution of 0.25°.

The description in Section 3.2.4 has also been adjusted accordingly (and simplified as requested in the previous comment).

8.The 1X1 degree region in the model is too large to compare with the ship-borne radar CFAD. The W-band radar will not cover such a big area. A cloud regime matching technique can be used to choose the right area in the model results.

We acknowledge that a 1x1 degree region is much larger than the size of the region sampled by the ship radar in a single profile. However, the radar is sampling continuously over time and thus will be capturing some spatial variability of the clouds as they move with the wind over the ship. The model data is available every 30 minutes (ship data every 0.3 seconds) and so given the limited time frequency of the model some spatial sampling is warranted (assuming that spatial sampling can make up for a lack of temporal sampling). Using a wind speed of 10 m/s the cloud field will move by 18km in 30 minutes and so our choice of 1x1 degree is likely to lead to a larger sampling region than was the case in reality. However, tests using smaller sampling regions (down to 3x3km; not shown) for the model show very little change in the patterns of frequencies for the CFADs indicating that this choice of sampling scale is not very important for this comparison.

We have added a comment on this in the paper at p21, line 1 :-

Tests using smaller sampling regions (down to 3×3 km; not shown) show very little change in the patterns of frequencies for the 2D PDFs indicating that the choice of sampling scale is not very important for this comparison.

9. The RHcrit in the sub-grid cloud scheme should be a function of aerosol loading so that the aerosol impact on sub-grid cloud can be addressed.

We are a little unclear about what is meant here. The RHcrit parameter and the cloud scheme is intended to simulate the extra condensation of vapour into cloud liquid due to sub-grid variability of relative humidity. The condensation of vapour into cloud does not depend on aerosol for the resolved scheme and so this is also the case for the sub-grid cloud scheme. The sub-grid cloud allows a response to aerosol via the microphysics, which takes into account any sub-grid cloud fraction, so that the in-cloud droplet concentrations (and liquid water contents) are enhanced relative to the grid-box mean, if the cloud fraction is less than one. This allows the aerosol to affect the sub-grid precipitation formation for example.

<u>Some technical suggestions:</u>

Page 1, lines 18 to 19 and later in Page 24: ... to within delta fc = 0.04 ... It is the fc

difference not the fc itself.

Fixed.

Page 5, line 23: ... since the presence of some liquid ...

Fixed.

Page 7, line 2: ... investigate its impact. You shouldn't know whether it is important or

not.

Fixed.

Page 8, caption of Figure 2: should the box be blue not white?

Fixed.

Page 17, line 20 and page 19 last line: ... for the entire of the ...

Fixed.

Page 20, line 5: ... similar to those observed by CERES.

Fixed.

Page 20, line 6: ... unlikely to be the result of cloud fraction ...

Fixed.

Page 20, line 7: ... distribution for this and higher ...

Fixed.

Page 26, line 6: ... and that leads to lower boundary layer.

Fixed.

Page 31, line 16: Please reword this sentence.

Done.

Page 31, line 30: , which was responsible ...

Fixed.

References

Painemal, D. and Zuidema, P.: Assessment of MODIS cloud effective radius and optical thickness retrievals over the Southeast Pacific with VOCALS-REx in situ measurements, JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES, 116, doi:10.1029/2011JD016155,2011.

Painemal, D., Minnis, P., Ayers, J. K., and O'Neill, L.: GOES-10 microphysical retrievals in marine warm clouds: Multi-instrument validation and daytime cycle over the southeast Pacific, Journal of Geophysical Research: Atmospheres, 117, n/a–n/a, doi:10.1029/2012jd017822, http://dx.doi.org/10.1029/2012JD017822, 2012.