RC2: 'Comment on acp-2021-859', Anonymous Referee #2, 21 Dec 2021 reply

General comment:

This study analyzes output of LES simulations for marine stratocumulus clouds to investigate how small-scale cloud variables and their relationships to aerosols are aggregated to manifest the albedo susceptibility bias occurring at larger scales typical of satellite-based analysis with L2 and L3 datasets. For this purpose, theoretical relationships between key statistical properties are reviewed and applied to the LES output to quantify the albedo susceptibility bias as a function of several statistical properties and cloud water susceptibility for different aggregation scales. This study offers a nice demonstration of how spatial cloud inhomogeneity and non-linear aerosol-cloud relationships are a source of uncertainty in quantifying the albedo susceptibility, directly relevant to radiative forcing due to aerosol-cloud interaction. I have some minor comments mostly regarding the presentation and/or clarification as listed below and I would recommend the manuscript to be considered for publication in ACP after the authors properly address the comments.

We thank the reviewer for raising interesting questions, which have resulted in the addition of two appendices. Text additions are in blue and changes in red.

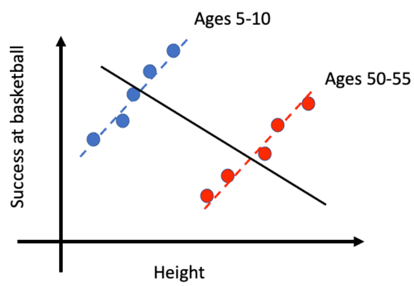
Specific comment:

Section 3.1: It is hard (at least for me) to understand in detail how the LES output variables (at the native model grid resolution) are averaged and/or aggregated into different spatial scales. In particular, I am confused with the term "aggregated" which seems to mean "averaged" for some parts and to mean "accumulated" for other parts. I would appreciate the authors to clarify if each "aggregated" means "averaged" or "accumulated". Please look at the Minor Points listed below for specific locations in the text for this clarification.

Thank you for this comment. In this work, the terms 'aggregated' and 'averaged' mean the same thing. We tend to use 'aggregated' when we speak more broadly about including data from a larger range of spatial and temporal scales. We now clarify this in the text on lines 38-40.

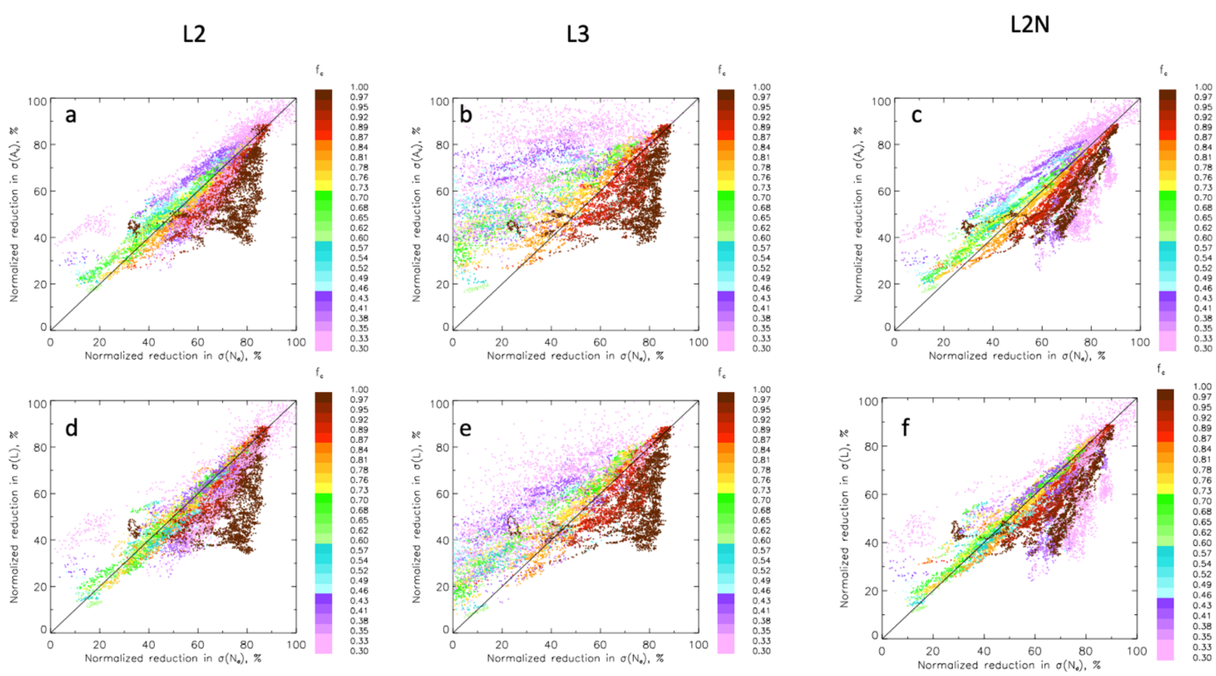
Line 188-190: "This is because L3 averaging has a stronger smoothing effect on broken cloud fields, and therefore somewhat unexpectedly reduces the averaging bias for broken cloud fields compared to solid cloud fields": Does this explain the negative values of the albedo susceptibility in Fig. 3b?

This is an interesting point that we believe is a consequence of the Simpson paradox, a simple example of which is given below and included in Appendix A. In the example below, we expect basketball success to generally increase with a player's height. This is indeed the case when stratifying the data (in this case by age-group), i.e., **avoiding aggregation**. But when one averages the red points to a single value, and similarly, averages the blue points to a single value gives an *apparent negative relationship* between ordinate and abscissa. See Appendix A.



Section 4.1.3: The argument here associated with Fig. 10 is of particular importance in the context of cloud water adjustment and its impact on albedo. It is interesting to see that the tight correlation between S0 and L adjustment biases relates inversely with cloud fraction between L2 and L3. How can this reversed relation be understood? Please add some more discussion.

In response to this question, we have dug a little deeper into the model output. Based on Fig. 7 and Eq. (13), our intuition was that the change in the slope with respect to cloud fraction between L2 and L3 in Fig. 10 is likely a function of the change in aggregation-smoothing in A_c vs. smoothing in L. To test this, we repeat Fig. 7 (top row), but now also look at smoothing in L (bottom row):

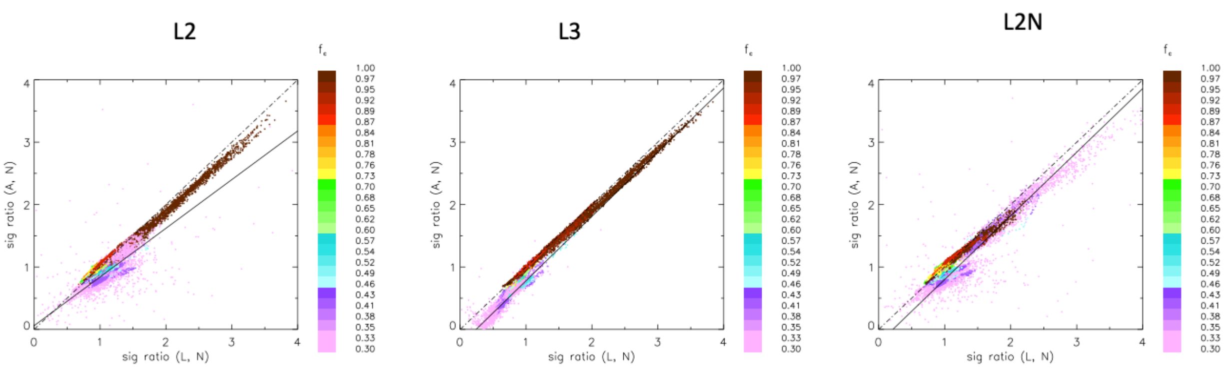


What is apparent is that for L3, there is much more smoothing in A_c than in L at low cloud fractions (the L3 points lie closer to the 1:1 line in (e) vs. (b) for low cloud fraction, f_c). For L2, more low f_c points tend to lie below the 1:1 line in (d) vs (a) but because of this migration of points from above to below the line, it is more difficult to interpret. For L2N the smoothing in L and A_c, look fairly similar, in line with our intuition that the S_o bias vs. L adjustment bias (Fig. 10) is related to the aggregation-smoothing of A_c vs the aggregation-smoothing of L (cf Fig. 10 where one sees less of a bias in the relationship for low and high cloud fraction points).

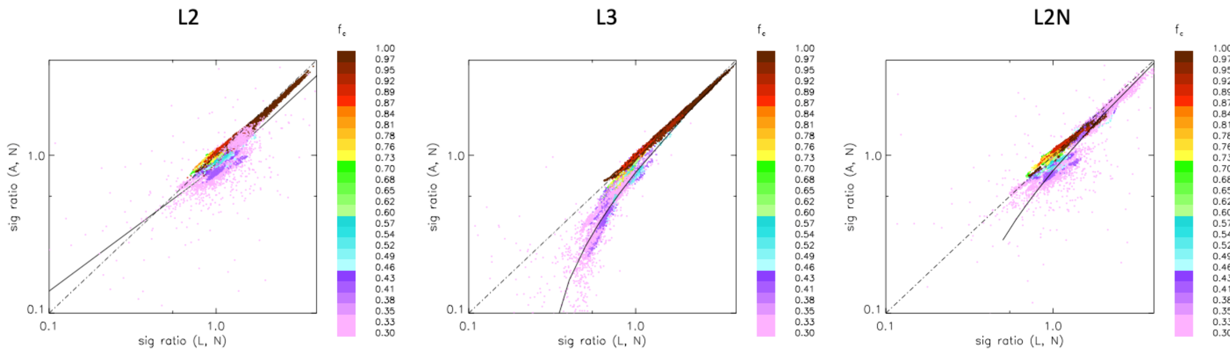
To dig even deeper, we looked more closely at the sigma-ratio (Eq. 12) for the low cloud fractions. We fit a linear relation between points for $0.3 < f_c < 0.43$ (shown on the plot below) and $f_c > 0.85$ (not shown) and obtained the following:

<u>0.3 < fc < 0.43</u>	<u>fc > 0.85</u>
L2: y = 0.06 + 0.78 x	L2: y = 0.1 +0.90 x
L3: y = -0.25 + 1.03 x	L3: y = 0.04 + 0.94 x
L2N: y =-0.22 + 1.02 x	L2N: y = 0.23 + 0.81 x

The high f_c slopes between L2 and L3 are similar (0.90 vs. 0.94, resp.) but there is a big difference in the low f_c slopes (0.78 vs. 1.03 for L2 and L3 resp.), and in the direction consistent with Fig. 10ab. Note too, the negative intercept for L3 at low f_c, which is consistent with Fig. 10b.



Differences are even clearer if one zooms in on a log-log scale to accentuate the low f_c points. (Note the linear fit is still applied but becomes curved on the log-log plot.):



Note the steepening of the low f_c points in L3. Comparing with Fig. 10 confirms that it is the differences in degree of aggregation-related smoothing between A_c and L in these low cloud fraction scenes that flips the relative sign of S_o vs L adjustment slopes between Fig. 10a and Fig. 10b. We have added text to the revised document (line 303-304) to explain this and added supporting figures in Appendix B

We note that these differences in smoothing derive from the derivations of A_c (Eq. 4) and L (Eq. 3), with A_c a (non-linear) function of τ only, and L a function of the product of τ and r_e. Anticipating how the aggregation biases play out is not intuitive, and requires, in our experience, analyses of the kind shown here.

Minor point:

Equation 6: Is this B_x inverse of the bias?

B_x is related to the bias that occurs when smoothing small scale structure. It may be an enhancement factor if $x < 1$ or a reduction factor if $x > 1$. See, e.g., https://doi.org/10.5194/acp-19-1077-2019, Eq. (14)

Fig. 1: Are the numbers labelled for contours in percent?

Yes, corrected.

Line 135: Insert 'of' between 'fields' and 'drop'

Corrected.

Line 138: "Both cloud water and rain water contribute to tau and re": Does this mean that re is computed as the ratio of third to second moments of the whole range of the bimodal size distribution? If so, is it consistent with what satellite measurement looks at given satellite measurement is sensitive primarily to the cloud mode alone?

We include both cloud and rainwater since by definition, r_e is the ratio of volume to surface area, and because rain water can on occasion contribute significantly to moments of the drop size distribution. A more rigorous calculation based on a MODIS instrument simulator might reveal some differences but we believe they would be small, and that we are capturing the most important characteristics of the system.

Line 146: "aggregated": Does this mean "averaged"?

See response to specific point above and lines 38-40.

Line 151: "at the pixel level": Does this mean the model native resolution (200m)?

Yes, clarified on line 204.

Line 162: "aggregated": Does this mean "averaged"? Namely, are tau and re first averaged to n=4 and n=30, and then Equations (2) and (3) are applied to them to derive Nc and L?

Yes, correct.

Line 201: Fig. 3 -> Fig. 4 (?)

Yes, thank you for catching this mistake. See line 221.

Line 206: Does this "aggregate" mean "average"?

Yes, see response to specific point above and lines 38-40.

Line 214: Please state that b(6km) and b(800m) are denoted as b_hat_overbar and b_hat, respectively.

Done. (line 237)

Fig. 3 etc.: Please put the panel titles as "L2", "L3" and "L2N".

Done.