Atmospheric
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Discussions

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Interactive
comment

Interactive comment on "Surprising similarities in model and observational aerosol radiative forcing estimates" *by* Edward Gryspeerdt et al.

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General comment::   The manuscript covers a topic of high scientific relevance as areduced uncertainty in the aerosol forcing is crucial in order to constrain the anthropogenic impact on climate. The method the authors present may well be valid and interesting and if model and observational estimates do have a closer agreement than what have been presented so far, this is very interesting to the scientific community. Although well written, I found that lack of satisfactory explanations made it hard to fully understand their approach. The research quality is good, but modifications to how it is presented is needed before publication.
Reply: We thank the reviewer for their comments and have addressed them below in

turn. We note that a few changes have been made to the method and results in this work which are not mentioned below:

1. Correction of the bug in the LWP adjustment calculation - The original LWP adjustment calculation included scenes with no cloud as having zero LWP. This biased both the PD-PI change in LWP and the linear regression of LWP against cloud albedo. In addition, the adjusted forcing from cases with thin overlying ice cloud was applied incorrectly to the RFaci only (and not the LWP adjustment). Correcting these issues results in a small change for the RFaci and LWP adjustment in some models, but the main conclusions remain unchanged.

2. Inclusion of the constraint from Toll et al. (2019) - A new constraint on the LWP adjustment has been included in Figs. 1 and 2. This does not affect the conclusions, but provides an important new constraint that can be compared to the models.

3. Inclusion of the RFaci constraint from (Hasekamp et al., subm) - This is a new constraint based on an improved aerosol retrieval. Again, this does not affect the conclusions, but provides an important new constraint that can be compared to the models.

4. Update of the forcing values from Andersen et al. (2017) - The forcing values from Andersen et al. (2017) were incorrectly determined from the data available in the paper. These have now been updated, but do not affect the conclusions drawn.

5. Inclusion of UKESM1 - To provide an example of how the decomposition can change between model versions, UKESM1 (a descendent of HadGEM2-A and HadGEM3-UKCA) has been included.

Line numbers given are in the "track changes" version of the manuscript.

Specific comments:: *Generally, full explanations of how numbers are achieved, what experiments in what models are used etc is lacking. This needs to be fixed before publication. The text would benefit from a bit more focus on reminding the reader what you are doing - linking the results you show to the method and explaining why the results actually show and improved agreement. Not a lot is needed, just a few sentences hereand there.*
Reply: The identification of the experiments is now included in Table 1 and in Fig. 4. Changes to the text have been made to improve readability.

P1, L6:: *"different decompositions" is too vague. Suggest writing this more clearly to get the reader on board with what you are doing.*
Reply: Changes to "different methods of separating the components of aerosol forcing used in model and observational studies." (P1L6)

P3, L8:: *"...a decomposition is introduced..." Decomposition of what? The reader is left hanging here.*
Reply: This paragraph has been modified, but a relevant sentence now read "for decomposing the ERFaer" (P3L19)

P3, L13:: *"...for decomposing changes...". Suggest changing this to "...for decomposing forcing changes..."?*
Reply: Modified to " for decomposing top of atmosphere radiation changes between a PI and a PD simulation (ERFaer)" (P3L11)

P3, L17:: *"...and second from Nd changes (the RFaci)." Are you saying here that RFaci arises only because of changes in cloud droplet number. This sentence is a bit misleading.*
Reply: The sentence was intended to say that as the main controls on cloud albedo are $\mathcal{L}$ and N_d, the change in albedo can be decomposed into changes in the two quantities.

The forcing component (RFaci) is identified with the change in N_d, as this assumes that all the other cloud properties remain constant. This sentence has been modified to make it clearer. (P3L24)

P3, L26-27:: *Use cloud cover and cloud fraction interchangeably. I suggest you stick to one term to avoid confusion.*
Reply: Cover has been replaced with fraction.

P4, Eqs 3 and 4.: *I suggest labelling the terms and refer to these in the explanations from L10.*
Reply: New references to the labelled terms equation have now bee included in the text, which now reads "The aerosol direct effect or RFari can be approximated as SWari$_{cs}$+LWari$_{cs}$. This ignores changes in the surface (ΔSurf.) and the impact of aerosol above cloud (SWari$_{cld}$) but provides..." (P4L20)

P4, L11:: *Approximating RFari in this manner seems to ignore surface albedo changeas well as aerosol above cloud? (alpha_clr_NoA?)*
Reply: That is true, but these terms are small for the majority of the models and this provides a closer comparison with estimates derived from observations.

P4, L27:: *"linear regression": A more thorough description is needed here. For what water amounts does this linearity assumption hold? Cloud albedo, like emissivity, reaches saturation, though of course at much higher liquid water paths. And what is this known change in liquid water path from PI to PD? Is this a global value?*
Reply: While it is true that cloud albedo saturates, for small changes in cloud albedo (as would be expected from aerosol-cloud interactions, the cloud albedo is approximately linear with the liquid water path. This regression is calculated at the gridbox scale (as with the other statistics) to capture the local variations in the relationship. Global averages are only taken at the final step. This has been noted in the methods

section - "Note that all of the steps in this decomposition are performed at the grid-box scale." (P4L8). After the correction of the bug in the LWP adjustment calculation, the variation between the adjustments calculated using a log or a linear regression between cloud albedo and liquid water path produces around a 10% difference in the calculated adjustment forcing.

P5, Eq 8:: *Please specify that this is to get the models to resemble the observations*
Reply: Sentence modified to read: "To get a closer agreement between models and observations, the change in liquid cloud fraction (Δf_l) is adjusted in the model output for changes in the ice cloud fraction (Δf_i) following Eq. 8, assuming that the changes in ice cloud fraction are uncorrelated to the occurrence of liquid cloud. " (P6L1)

P5, L9:: *Suggest adding a subheader here, for example "datasets".*
Reply: Amended

P5, L10:: *The descriptions of the experiments should be made clearer. Suggest separating the AeroCom and the CMIP5 explanations. As it reads now it is hard to follow. The experiment name abbreviations are explained two sentences further down.*
Reply: Paragraph has been re-worded

P5, L16.: *Please explain the set up for the anthsca simulations more thoroughly. "...whilst using the same pre-industrial simulation." This is hard to follow.*
Reply: The description has been modified to: "The "anthsca" simulations are the same as the base AeroCom setup, but with present-day anthropogenic aerosol emissions scaled by a factor given in the simulation name." (P6L20)

P5, L17:: *"This demonstrates the impact of changing only the aerosol distribution, rather than also the cloud parametrisations." But you do not change the parametrisations between the runs, do you?*

Reply: The aim was to highlight that both aerosol distributions and cloud parametrisations change between the models included in this study, but in the anthsca runs, only the aerosol distribution changes between simulations. The second clause has been removed, such that the sentence now reads: "While both the aerosol distribution and the parametrisations vary between the models used in this work, the "anthsca" simulations demonstrate the impact of changing the aerosol distribution alone.". (P6L21)

P5, L20:: *"Change is liquid" to "change in liquid"*
Reply: Amended

P5, L24:: *Are these numbers based on numbers from your decomposition method. If so, please specify this*
Reply: They are not, they are taken from the model data itself.

P5, L27:: *How do you calculate this residual? Against what?*
Reply: The residual is calculated as the total ERFaer minus the sum of the components. The sentence now reads "However, the residual of the sum of the components of decomposition compared to the total ERFaer is small (typically less than 10%).."

Caption Table 1:: *The first sentence needs to be more specific. As it reads now, this is total ERF. Also, I would argue that it is the third, not the second column that "identifies the nature...".*
Reply: Caption now reads "The ERFaer (global mean differences between the PI and PD TOA radiation) from the AeroCom (top section) and CMIP5 (bottom) models in $\mathrm{W\,m^{-2}}$. CMIP5 physics ensemble members are shown with the "-p" suffix. The third column..."

Table 2:: *Please specify that RFaci, L and fl refers to three forcing estimates in the de-composition (?). Suggest header above these column and explanation in the caption. In the caption, only RFaci is mentioned. Please add a description of the other two*

as well.

Reply: Caption now reads "The impact of ice water path thresholds on the RFaci estimate, the forcing from $\mathcal{L}$ and f_l adjustments and the $\mathcal{L}$ and f_l enhancements of the RFaci. The line in bold..."

Table 2 and text:: *Please explain how you got the numbers in the table, what model and experiments were used*

Reply: The text now links to this table where the IWP limit is discussed and ECHAM-HAM is mentioned in the caption.

Page 7, L2:: *"...aerosol-dependent cloud adjustment (CND)..." The notation used here is misleading. I assume the CND refers to an experiment where these adjustments are removed? Please rephrase and specify with what model and how these simulations were carried out*

Reply: This sentence has been modified to provide a quick explanation of the method, with a longer description included in the methods section: "By removing the aerosol-dependent cloud adjustments using a climatological N_d(CND), .." (P8L6)

P7, L1-3:: *Yes, RFaci is within 10% for the CND runs, but the L and fl are not. Please discuss this in the text.*

Reply: The sentence has been modified to read: "... within 10% of the value calculated through the decomposition in this work, with the forcing from the cloud adjustments decreasing to close to zero as the adjustments are removed (Tab. 2)" (P8L7)

P7, L10-12:: *Does it show that this is a suitable method or that the method is not very sensitive to the choice of threshold?*

Reply: Sentence modified to read: "showing that this method is relatively insensitive to the choice of threshold and hence is a suitable method to account for the effect of thin ice clouds." (P8L20)

Figure 1:: Please separate the panels more so that the axis labelling becomes more clear.
Reply: Done

Figure 1, caption:: Please add "are shown" or similar to "other estimates...".
Reply: Done

P8, L8:: You use Delta alpha_c here but this is the same as Delta In AOD in Figure 1a?
Reply: The $\Delta\alpha_c$ is the forcing from the change in cloud albedo, in this case only liquid clouds are considered. It has been changed to $\Delta\mathrm{SW}_c$ for consistency with Eq. 4.

P9, L1-3:: Is this shown somewhere? Fig 1.b?
Reply: This section is modified to read "...observational constraints (Fig. 1a - cross-bars). However, when the forcing due to $\mathcal{L}$adjustments is removed, the variability is reduced, with a lower bound of $-1.26\,\mathrm{W\,m^{-2}}$and many of the models producing an RFaci estimate around $-0.75\,\mathrm{W\,m^{-2}}$or smaller (Fig. 1a - markers)." (P9L2)

P9, L4-6:: Is this shown somewhere? Figure in supplementary?
Reply: Sentence now reads: "A stronger relationship between $\Delta N_d$and the RFaci is seen for the individual models (Fig. 1a), ..." (P9L7)

Figure 2::   Is there a residual cloud albedo change? Does the positive value in 2a indicate a negative change in cloud droplet number?
Reply: There is no residual cloud albedo change, as the Twomey effect/RFaci is the difference between the total cloud albedo change and that from changes in $\mathcal{L}$. The positive values have been removed with the bugfix to the decomposition of the liquid cloud.

P9, L13-14:: *"However, uncertainties from both S1 and S2 are shared with the RFaci estimate." Please write this more clearly.*
Reply: Changed to: "However, uncertainties from both S1 and S2 apply to both the RFaci and the adjustments." (P9L15)

P10, L17:: *"The overall pattern of the forcing from fl changes..." Please add "in the models" or equivalent.*
Reply: Done

P10, L10:: *A bit harsh to state that liquid water path decreases with increased N in observations. This is much debated and state and cloud type dependent. This should be reflected in the text here.*
Reply: This has been softened to read "Several studies have found a $\mathcal{L}$decrease with increased aerosol or N_d, suggesting a negative adjustment (Chen et al., 2014; Christensen et al., 2017; Sato et al., 2018). However, recent work has suggested that..." (P12L1)

P11, L18:: *The variability of...*
Reply: Amended

Figure 4:: *Please separate the panels more so that the axis labelling becomes more clear.*
Reply: Done

Figure 4:: *Mark which models are AeroCom and which are CMIP?*
Reply: Done

Figure 4:: *Caption (Delta SWc) is this the Delta SWalpha used earlier? If so, chose one notation.*

C9

Reply: The notation has been changed to be consistent. $\Delta\alpha_c$ now refers to the change in cloud albedo, whereas ΔSW_c refers to forcing resulting from that change.

Figure 4:: "longwave changes from cloud properties..." is microphysics a more fitting term here? Fraction is also a cloud property?
Reply: Changed to "Longwave changes from changes in intrinsic cloud properties"

References

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