Anonymous Referee #2 Received and published: 2 March 2020

In this work, the authors investigate the contribution of aerosol in cloudy skies to the magnitude of the aerosol direct effect (RFari). They results from a collection of global models to show that the contribution to the RFari from cloud skies is small. They also investigate the parameters that affect this between different models, showing that the shortwave cloud radiative effect is the biggest contributor to inter-model differences. This work is within scope for ACP and would be relevant for the readers. I have some comments, particularly regarding the notation and some of the explanation, after which I believe it would be suitable for publication.

Response: we appreciate the nice evaluation and interpretation of our manuscript and constructive comments to improve the manuscript.

Major points

Has the choice for the meaning of RFariclear and RFaricloudy been made in a previous paper? If not, a change in the notation might improve readability. My understanding is that radiative forcings usually sum, such that Eq. 1 could be written as RF ariallsky = RF ariclear + RF aricloudy rather than a cloud-fraction weighted sum. This would improve readability throughout the paper, as "contribution of cloud sky to RFari" is written much more often than RFaricloudy at the moment (perhaps RF aricloudy = AC × RF aci| cloudy). Having a linear sum of terms would also match better with the approximate linear sum ERF aer = ERF ari + ERF aci. This is somewhat a matter of taste, so I understand if the authors prefer to stick with the current notation.

Response: **We agree to the nice suggestion to improve the readability of the manuscript by simplify Eq 1. We change $RFari_{clear}$ from the earlier version to $RFari_{clear\text{-}total}$ and similar the cloudy contribution to continue illustrating the term in Fig 2.**

Second, while I like the idea of the PCA decomposition, I found it hard to interpret and ended up mostly looking at the correlogram (Fig. 4b). Some more explanation and guidance to interpretation would be useful here.

Response: PCA is a fairly well known, yet complicated, statistical technique used in exploratory data analysis. As such there is limit to how much can be explained in this paper, without making the paper about explaining PCA. What is important to understand is that PCA is a dimension reduction technique, allowing for the visualization of all the variance between the variables in a two-dimensional plot (biplot). When we use a correlogram we only get to see the one to one correlation between variables. With the PCA we can assess the relationship between multiple variables simultaneously. This allows us to get a sense of the degree of influence the variables have on each other. This cannot be seen in a correlogram. However, because the projections of the variables in the biplot are dependent on each other, it can be hard to see the one to one relationship. There is therefore pros and cons to both types of plots, but together they help in the exploratory data analysis.

We have included more description of the method and interpretation of the results, see below on response to other comments.

Does it use only the values in Tab. 1 (the global mean values)?

Response: Yes, table 1 contains all the data used in the PCA. However, as mentioned on line 122 in the ACPD paper. We have two models, LMDZ-INCA and ECHAM-HAM, which have some missing data. In PCA, no missing data can exist in the analysis. If a single record (i.e. in this case a climate model) is missing data for one variable, then the entire record must be removed for all variables. Removing two models would be fairly detrimental to this study, as we have few records (8 climate models) to begin with. For this reason, we use the technique regularized iterative PCA to fill in the missing values with estimates. As we are only using the PCA to get an overview of the relationship among the variables, and we are not trying to create a predictive model for estimating "Cloudy", the use of this imputation technique should be valid. We have added at the top of the paragraph that global mean used in the Multivariate data analysis.

What does it mean that SW_CRF has no contribution to PC1, yet has the strongest correlation to the cloudy sky contribution to the RFari in 4b?

Response: The principle components represent new dimensions created to plot the variance. This is described on line 109-119. If all variables were correlated with PC1, then all the variables would all be correlated with each other. All PC are anticorrelated with each other, which is why PC1 and PC2 are perpendicular to each other. Such is also the case between PC1 and PC3, PC2 and PC3, etc. As plotted in figure 4a) SW_CRE is near perfectly positively correlated with PC2, hence it has to be anticorrelated with every other PC. Which is why the vector is perpendicular to the PC1 axis. This is also why in figure 4c) the length of the vector is so short, as it nether correlates with PC3 or PC1. So yes, SW_CRE is correlated with PC2, and also Cloudy is correlated with PC2. The vector is just pointing in the opposite direction, which means the two variables are negatively correlated with each other. This is also what figure 4b) suggest providing negative correlation between the two variables.

We have made the following changes:

In the second paragraph in section 2.2

1) **We have replaced the following sentence: '***Each following PC in turn has the highest variance possible assuming that it is orthogonal to the previous PC, successively explaining less of the magnitude of cloudy sky RFari***' with '***All the variables relationship to each other can be to a lesser degree explained (magnitude) with each exceeding PC. In other words, it's not exclusively to RF ari$_{cloud}$***.'**
2) **This sentence is added: '***All PCs are anticorrelated with each other, which is why PC1 and PC2 are perpendicular to each other.***'**

In the result section 3.2:

3) **The following text is added: '***SW_CRE is near perfectly positively correlated with PC2 (Figure 4a), hence it must be anticorrelated with every other PCs. Therefore, the vector in Figure 4a is perpendicular to the PC1 axis. This is also why the length of the vector is so short in Figure 4c since it nether correlates with PC3 or PC1. SW_CRE is correlated with PC2 and Cloudy is correlated with PC2. The vector is pointing in the opposite direction between SW_CRE and Cloudy, which means the two variables are negatively correlated with each other. Figure 4b show also a negative correlation between the two variables.***'**

“Cloudy, FIX2 and FIX3 are plotted but don’t affect the projection of the other variables.” - I am not quite sure what this means for the interpretation of their position, is this just their correlation with PC1 and PC2? What does this shown.

Response: In the 4 caption we have added: ‘This requirement is made since cloudy, FIX2scat and FIX3abs already depends on the other variable and see their correlation.**’**

Also, Fig 4c does not appear to be referenced in the text at all. Is this intentional?

Response: It is added that global mean values from Table 1 is used in PCA analysis. Reference to Fig 4c is now included. SW_CRF, FIX2 and FIX3 have been changed to SW_CRE, FIX2scat and FIX3abs, respectively as suggested by the reviewer.

We have added the following text in the result section 3.2: ‘*A biplot with PC1 and PC3 (Figure 4c) can explain more about a variable than PC1 and PC2. For example, CL_ALT has a slightly stronger projection in the PC1 and PC3 biplot and suggest that there is an anticorrelation with FIX2scat. However, in the PC1 and PC2 they are positively correlated with each other. This suggest that there is partial correlation and Figure 4b shows there is a weak positive correlation between these two variables.***’**

We have added this sentence in section 3.2: ‘*Adding PC3 this number increases to 89.2%.’*

Third, how do these value fit in with the “error in the cloud radiative forcing” calculated using the method in Ghan (ACP, 2013)? That method would suggest a contribution to the RFari from aerosol above cloud of +0.40 Wm−2 . Higher values (although not as large as this) are also found in Gryspeerdt et al. (ACP 2020), which uses essentially the same method. Finally, a few more commas would be nice to improve readability and there are a few typos which could be caught in the next round (I have identified some of them below)

Response: From Table S2 in Gryspeerdt et al. (ACP 2020) the mean SWaricloud is +0.01 W m^{-2} of 8 models. The residual among a large set of simulating the ERFaer (direct and indirect aerosol effects) is weak indicating that SWaricloud is likely weak in all 17 models from AeroCom and CMIP5. We have had the following to the discussion section:

‘The simulations used in this study only include the RF of the aerosol-radiation interaction. In a recent multi-model study, a decomposition of all aerosol effect (including aerosol-cloud interactions) provides weak $RFari_{cloud}$ for all models, of magnitude and multi-model mean similar to this study (Gryspeerdt et al., 2020). A separate single-model study however found it to be substantial (Ghan, 2013).’

Minor points L28 - Why are SSA and SW_CRF called out here, when they control PC2?

Response: These two factors have been shown in this study to play a major in calculation of the $RFari_{cloud}$ and thus emphasized in the abstract.

L68 - substantially L99 - constraint L102 - FIX2scat, FIX3abs? These acronyms are used in Tab. 1, but not elsewhere. Having the “scat” and “abs” suffixes is helpful for those less familiar with the experiments.

Response: the comment is taken into account

L121 - Not quite clear what is going on here. Why is the variable for which you are trying to explain the variance added to the list of variables in the PCA?
Response: See the additional text added to the manuscript described above.

L151 - “All sky RFari” or RFariallsky? I know these are the same, but it might help keep things clear.

Response: Simplifying Eq 1 as suggested by the Reviewer make the readability of this sentence easier and sentence is therefore made much shorter.

L161 - “present-day” instead of “current” would make this clearer that it is not referring to a current estimate.

Response: Comment is taken into account.

L184 - SW_CRE vs SW_CRF - Cloud radiative effect is referred to, but the acronym suggests radiative forcing.

Response: We agree to the comment and have change SW_CRF to SW_CRE through the manuscript.

L188 - Supplementary information seems to be missing

Response: We have changed the reference to Supplementary to Fig 4c.

L189 - FIX2 and FIX3 are hardly used. Is there more that could be said here?

Response: We have added the following: ‘FIX2scat and FIX3abs are strongly dependent on the host model clouds and their radiative effect and anticorrelated to cloud fraction and SW_CRE, respectively’

L194 - “PCA finds a weak dependence”

Response: Sentence corrected to include ‘*a*’ before ‘*weak*’

L207 - “However, when analyzing multi-model simulations, additional factors become important.”

Response: Sentence changed as suggested.

Ghan, S. J.: Technical Note: Estimating aerosol effects on cloud radiative forcing, Atmospheric Chemistry and Physics, 13(19), 9971-9974, 2013.

Gryspeerdt, E., Mülmenstädt, J., Gettelman, A., Malavelle, F. F., Morrison, H., Neubauer, D., Partridge, D. G., Stier, P., Takemura, T., Wang, H., Wang, M. and Zhang, K.: Surprising similarities in model and observational aerosol radiative forcing estimates, Atmos. Chem. Phys., 20(1), 613-623, 2020.