Answer to comments on "Effects of long-range aerosol transport on the microphysical properties of low-level liquid clouds in the Arctic"

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The authors thank the reviewers for their interest in the article and their comments. We have considered each comment and have made the following adjustments to the manuscript.

1 Answer to an editorial comment.

"I notice that you use the terminology IE to define microphysical responses. I take full responsibility for coining this acronym, but as was pointed out to me soon after that publication, the indirect effect is about radiative responses, not microphysical responses. I therefore suggest that you consider changing your terminology.":

Many articles currently use the terminology ACI standing for aerosol-cloud interactions to calculate the same parameter. Here we use CO rather than aerosols to represent a pollution plume. The question is how pollution plumes affect cloud properties, allowing for the possibility that pollution aerosols may have been scavenged en route to the Arctic. Thus, we propose to replace the term IE with PCI standing for pollution-cloud interactions.

We have added a sentence on page (33-12) in Section 3.2 *The indirect effect parameter*: "We do not directly consider the effect of CCN or aerosols on clouds but rather the extent to which a pollution plume interacts with cloud microphysical properties. Often what is evaluated is aerosol-cloud interactions (or ACI). However, if aerosols have been scavenged en route to the Arctic then pollution may be present but its impact on cloud properties weak. Thus, we employ the term PCI instead standing for pollution-cloud interactions." Accordingly, we have replaced in the figures and text the term IE with PCI.

1.1 Main review points

"I am uncertain about the statistical significance and thus reliability of the IE values reported — no p values are reported for the slopes used as the basis for IE, so the statistical significance and accordingly physical meaning remains unclear. There is a paragraph pertaining to uncertainties (36-9 and following), but I am not sure if this is related":

95% confidence bars are already provided. A few aerosol-cloud interaction studies have used a p-value to evaluate the robustness of a linear fits. Accordingly, we have added for the reviewers, the p-values in the Figure 5 from the article, shown here in Fig. 1. The p-value is calculated for each fit, and each dot is proportionately color-coded. A low p-value means that we can reject the null hypothesis that the slope is 0.

In Fig. 1, if the confidence interval includes 0, then the p-value is high. Otherwise the p-value is low. The authors prefer to keep the PCI values with the confidence intervals, because graphically it is both more clear and more familiar to the readership than using p-values.

1.2 Details

- 25-25 *"In your summary of the IE parameters reported elsewhere for the relationship between aerosol and cloud-droplet effective radius you provide values greater than zero. This appears counter-intuitive as an inverse relationship is expected (radius decreases with increasing number of cloud-condensation nuclei). Please add explanatory detail to this paragraph"*:

  We add a sentence which explains how we consider only the negative of the value of the ratio for the effective radius "Where a parameter is expected to decrease with increasing CCN concentrations (e.g. the effective radius), the ratio is multiplied by negative one so that the PCI is positive."

- 25-25 *"It appears hard to compare the numbers compiled here, as the parameter used as reference (denominator) varies between the studies cited"*:

  Many of the prior studies cited in the article have calculated IE or ACI parameters using the aerosol index, the aerosol optical depth, the aerosol concentration, or the CCN concentration. The focus here is on pollution-cloud interactions rather than aerosol-cloud interactions, where we use concentrations of carbon monoxide instead. In the absence of wet scavenging, a linear relation exists between aerosols and CO since both are a by-product of combustion (Longley et al., 2005). Since calculation of the PCI employs a log scale, under these conditions relative changes in either quantity should be expected to be similar.

We add the to the article at 26-19: " In the absence of wet scavenging, a linear relation exists between aerosols and a passive tracer since both are a by-product of combustion (Longley et al., 2005). Under these conditions relatives changes in either quantity should be expected to be similar."

- 26-9 *"Another common assumption is that observed aerosol and cloud exist at the same altitude."*:

  We add to the article the following: "The assumption is made that plumes are horizontally homogeneous both within and without the cloud, and that they are vertically co-located with cloud top."

- 27-24 *"Please explain why you consider these parameters to be of particular importance."*:

  We add in the text the references Matsui et al. (2006) and Mauger et al. (2007).

- 28-8 *"As I understand this paragraph you use level 2 products of cloud properties. If so, please remove 'retrievals of' as the inclusion of these words might imply that you yourselves retrieve these properties. In the same vein, the next but one sentence should begin along the following lines:'In the technique applied for computation for the MODIS level 2 product, cloud-droplet effective radius..."*:

  We change the sentences as suggested to :"For the effective radius, optical depth, and cloud top temperature we use Collection 5 Level-2 products (Platnick et al., 2003; King and Platnick, 2006). (...) . Regarding the technique applied for computation of the MODIS level-2 products, cloud top temperature ..."

- 28-10 *"Do you retrieve cloud top temperature yourselves? If so, please specify how you obtain this temperature based on the 11um brightness temperature."*:

  The cloud top temperature is retrieved by measuring the brightness temperature at 11 μm by the instrument. We do not retrieve it ourselves. As explained in sentence 28-9, we use the collection 5 Level-2.

- 28-23: *"The spatial resolution for MODIS was given as a length; here (and in table 1), an area is provided. Please decide on a uniform representation."*:

  We change sentence 28-14 to : "The pixel resolution of the retrievals at nadir is 1 km$\times$1 km (...) and 5 km$\times$5 km (...)", and sentence 28-22 to: "POLDER-3 cloud microphysical property retrievals have a 36 km$\times$36 km spatial resolution."

- 32-6: *"I find it confusing that you call the 0-3 average 03:00 UTC."*:

We decide here to keep the same convention as used in the FLEXPART model which calls 03:00 UTC the 0-3 average.

- 32-15 *"I assume that altitude information refers to cloud top. Please clarify this in the manuscript. Which system is used to determine cloud top height for this classification?"*:

  POLDER-3 retrieves cloud top altitude using oxygen pressure measurements. The pressure is associated with an altitude using a pressure profile specific to this region.

  We clarify this point in the article by adding :"(...) we consider only low-level clouds (Garrett et al., 2004; Garrett and Zhao, 2006; Lubin and Vogelmann, 2006; Mauritsen et al., 2011), with POLDER cloud top altitudes between 200 and 1000 m, and between 1000 and 2000 m. The cloud top pressure is translating to cloud top altitude by a pressure profile specific to the Arctic region."

- 32-21 *"It would be much more interesting to know the area covered by each of your grid cells in your study region. Near the pole the variation in area is likely to be large."*:

  This is what we did, the article specifies: "We project data from satellites, model, and reanalysis data sets onto an equal-area sinusoidal grid such that the grid-cell resolution is $0.5^\circ \times 0.5^\circ$ at the equator corresponding to an area of $54\,\mathrm{km} \times 54\,\mathrm{km}$"

- 33-17 *"Why would this be the maximum?"*:

  This theoretical maximum is described by the studies Twomey (1977) and Feingold et al., (2001). We have added these two references in the article.

- 33-17 *"'cloud-active component' is not clear to me. Please clarify."*:

  We replace this term by cloud condensation nuclei.

- 34-23 *"I am new to robust linear models. I would assume that, as with any fit, there will be a p value of some kind, providing information on the probability that the fit identified is purely random."*:

  Cf. answer about the main review points

- 35-10 *"'more logarithmically distributed' — what does this mean? Did you perform distribution test?"*:

  The term "logarithmically distributed" is misleading here.

  We change this sentence to: "The specific humidity is distributed over several orders of magnitude. To better represent the distribution, we use a logarithmic scale for this parameter."

- 35-20 *"Sub-section 4.1 presents a lot of numerical detail. If all of this needs to be presented, I suggest a tabular formula."*:

  A table would be redundant with Figure 5. This paragraph only highlights the most important points of the Figure.

- 37-9 *"I do not understand from this sentence how the five bins/regimes are delimited."*:

  We change the sentence to : "We now present the sensitivity of the PCI parameter to 5 different ranges of meteorological parameters delimited by the percentiles values presented in Table 5."

- 37-11 *"What are the significance levels of the slopes summarized in these figures?"*:

  Cf. answer to the main review points.

- 38-4 *"Are all the values summarized here statistically significant at a level predetermined by you?"*:

  Cf. answer to the main review points.

- 38-7 *"What type of IE are you referring to here? Effective radius? Optical depth?."*:

  Here we are mainly referring to PCI for the effective radius. But if the data are sufficiently constrained for LWP, both parameters should be equal, as described by Lihavainen et al. (2009) and Sporre et al. (2012). This is also what we have shown in this study by controlling for meteorological parameters. The wide range given here -0.10 to 0.40 does not account for the difference between the two parameters, but rather the complexity of the problem.

- 38-7 *"I am not convinced that IE values using different parameters in numerator and denominator can be directly compared"*:

  Cf. answer for the comment 25-25.

- 38-12 *"To claim that you found greater pollution-dependence you would have to consider exactly the same time period using your refined methodology. Otherwise differences between years could distort the picture"*:

  The results are not shown in this paper but if we perform the results for just one year (2008) values of PCI are generally greater. Below is Table 3 but considering only 2008 data between 21 March and 20 July 2008 (the same time period used in Tietze et al. (2011) study). The conclusion is the same. PCI values are still generally higher than the results shown in Tietze et al. (2011)

Table 1: IE parameter calculated for the optical depth and the effective radius considering all clouds, graybody clouds, blackbody clouds, averaged from values presented in the article in Fig. 5. The results are presented considering data from 2008 to 2010 and 2008 only.

		All LWP	Graybody	Blackbody
2008 to 2010	PCI_{r_e}	0.12	0.10	0.14
	PCI_{τ}	0.16	0.13	0.17
2008	PCI_{r_e}	0.01	0.05	0.05
	PCI_{τ}	0.34	0.09	0.25

- 38-15 *"Likewise, this comparison is only possible if the same period is considered."*:

  Cf. answer 38-12

- 40-10 *"eightieth percentile bin of 23 K' — I do not understand what you mean here."*:

  We change the text to "greater than 23 K"

- Figure 3 *"Figure text does not include information on lower bound of cloud altitude range considered here (1000 m given in the main text)."*:

  We have added to the figure's caption "(...) with cloud top altitudes between 1000 m and 2000 m, (...)"

- Figure 6 and 7 *"A two-dimensional binning would be of great use I think — e.g. with LTS on one axis, humidity on the other, and color codes for IE."*:

  If we control for LTS and specific humidity within narrow ranges then the number of data points is low and this weakens the statistical significance of the results.

  In Figure 6 we still control for LTS, but we determine the range so as to maximize the number of data points. It is difficult to control for both LTS and specific humidity at the same time in a two-dimensional histogram. The figures show a general trend between the PCI and meteorological parameters. The same argument can be applied to Figure 7.

1.3 Technical suggestions

All the technical suggestions have been considered by the authors and are changed in the final manuscript.

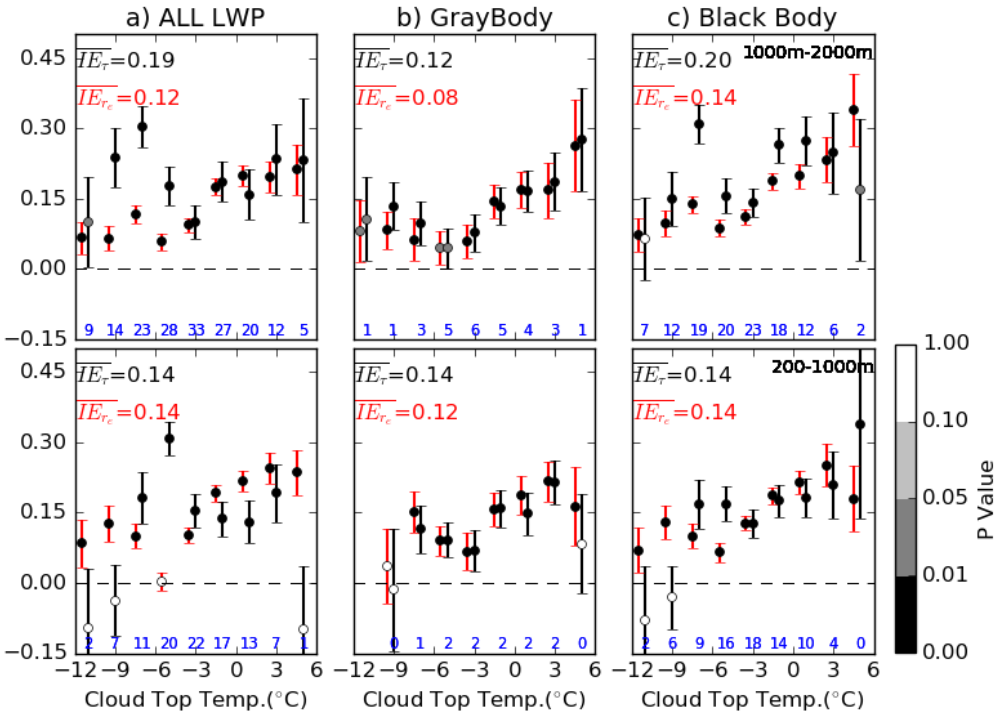

Figure 1: PCI parameter for the effective radius (r_e) (red) and optical depth (τ) (black), as a function of temperature calculated for liquid clouds between 200–1000 m (lower row) and 1000–2000 m (upper row). The bars indicate the 95 % confidence limit in the calculation of the mean PCI value. Each column corresponds to different thresholds for LWP (blackbody: LWP $> 40\,\mathrm{g\,m^{-2}}$, graybody: LWP $< 40\,\mathrm{g\,m^{-2}}$). Blue numbers indicate the number of grid-cells, in hundreds, that are used to calculate each PCI value. In each figure, the PCI value averaged over temperature, and weighted according the inverse of the uncertainty, is indicated. The shade of gray for each dot represents the p value.

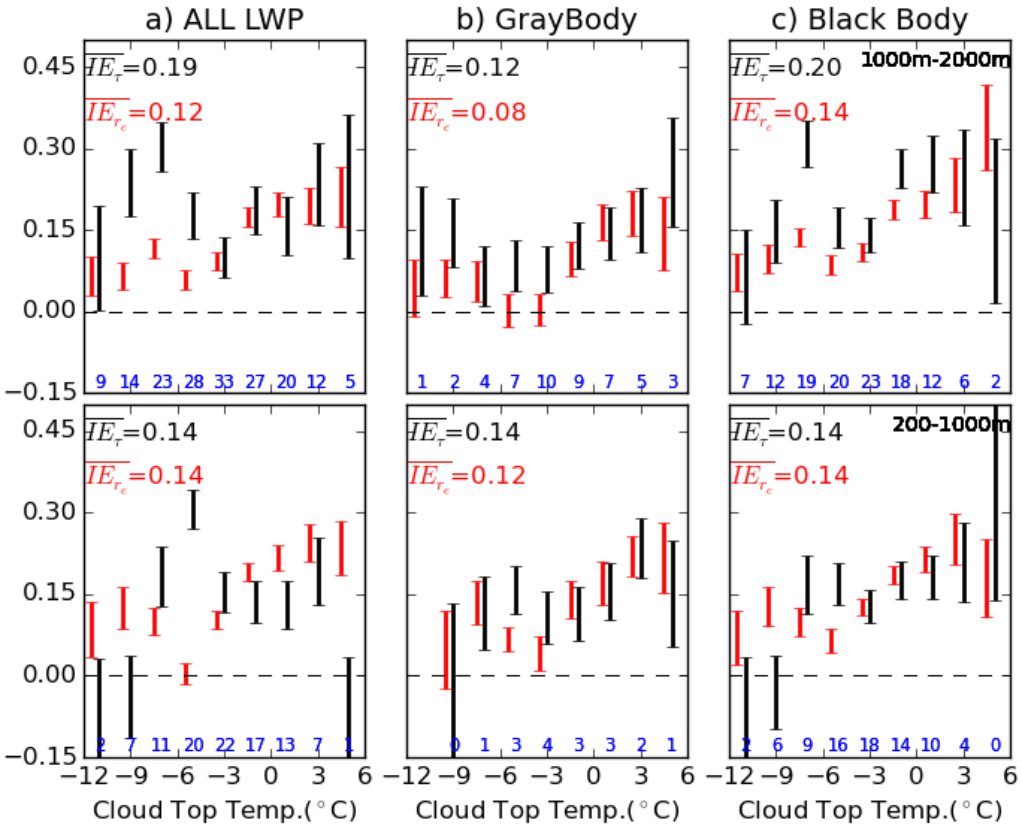

Figure 2: PCI parameter for the effective radius (r_e) (red) and optical depth (τ) (black), as a function of temperature calculated for liquid clouds between 200–1000 m (lower row) and 1000–2000 m (upper row). The bars indicate the 95 % confidence limit in the calculation of the mean PCI value. Each column corresponds to different thresholds for LWP (blackbody: LWP $> 40\,\mathrm{g\,m^{-2}}$, graybody: LWP $< 40\,\mathrm{g\,m^{-2}}$). Blue numbers indicate the number of grid-cells, in hundreds, that are used to calculate each PCI value. In each figure, the PCI value averaged over temperature, and weighted according the inverse of the uncertainty, is indicated.