Authors' Response to Anonymous Referee #2 Comments

The authors would like to thank the anonymous Referee for her/his helpful comments. Please find below a detailed point-by-point replies to each comment. Referee's comments are in blue and authors' replies in black.

In this article, ice particle complexity was derived from field campaigns spread over the globe, and it was further compared to chamber study. Angular light scattering functions from measurements were compared to Ping Yang's models, and it was concluded that roughened column aggregates model is the best representative of measurements. The new asymmetric factor derived from roughened column aggregates was explored in changing cloud radiative effects using a climate model. Overall, this article is well constructed and novel. Particularly, comparison of phase function between measurement and theoretical model will benefit other research areas such as model parameterization or remote sensing. My general comments: 1) explain how to obtain SWCRE from ECHAM model; 2) indicate how large biases of phase function exist between smooth and roughened particles.
We thank the Referee for her/his encouraging comments. To address the general comment (1) we have added a detailed description on how SWCRE was obtained using the ECHAM model. Please see the answer to the specific comments below for more details.

In the general comment (2) the Referee asks to address the differences between the phase functions and asymmetry factors of smooth and severely roughened particles. For the database used in this manuscript, this difference is discussed in the original study of Yang et al. (2013). In Fig. 13 of their paper a comparison is shown of phase functions and asymmetry factors for smooth and roughened particles. The phase functions of smooth particles show minima and maxima peaks at certain angles whereas as the roughness is increased, these peaks are more smoothened out (please also see the answer to the specific comment below). Also, the intensity at the sideward angles is the highest for the roughest particles, which leads to lowering of the asymmetry factor as seen in the lower panels of Fig. 13.

These biases between the phase functions of smooth and roughened particles are discussed in several occasions in this manuscript (please see answers below) and in the cited research (e.g. in Yi et al. (2013)). We think that the given discussion together with the references give the reader a good overview of the effects of roughness on the phase function and on the asymmetry factor.

Suggestion is to accept after a minor revision.

Specific comments:

Page 2

Lines 15-17: ' reduce the SWCRE by 1-2 W m-2' is confusing. It reads like that the magnitude of SWCRE is reduced, i.e. SW cooling is reduced by lowering g. This is conflicted with your conclusion. Please double check Yi et al. 2013 and make it clear.
We agree that the wording online 15-17 is confusing, so we reformatted the sentence as: "*Yi et al. (2013) showed that by assuming severely roughened ice crystals and, thus, lowering the cloud short wave (SW) asymmetry factors between 0.01 and 0.035, can cause additional SW cooling by 1-2 W m^{-2}*".

Line 29: Please indicate what are 'two instruments'.
We added the names of the two instruments: *"The observations of the ice crystal mesoscopic complexity are linked with measurements of the ice particle angular light scattering function at various geographical locations in the southern and northern hemisphere performed with two polar nephelometers, the Particle Habit Imaging and Polar Scattering (PHIPS) probe and the Polar Nephelometer (PN)."*

Figure 1” upper penale->upper panel ; In lower panel, some scales are not clear.
We corrected this and increased the font of the scales in the lower panel.

Page 5 line 29: ‘In these campaigns’, do you mean all arctic campaigns ? Are there mixed phase clouds in SOCRATES campaign or midlatitude campaigns such as ARISTO 2017 and CONCERT with relatively high temperatures?
Yes, we mean all arctic campaigns. We changed in the text *“In these campaigns”* to *“In the arctic campaigns”*.

We measured mixed-phase clouds in the SOCRATES campaign but in the midlatitude campaigns only measurements in fully glaciated clouds are included. To make this more clear we added the term “mixed-phase” on line 1 (page 6).

Page 6, section 2.5: Could you explain clearly how do you obtain SWCRE from ECHAM? Is it a parameter output from ECHAM, or do you run a radiative transfer model using ice clouds output from ECHAM?
We have added a detailed description of how SWCRE was obtained from the ECHAM model in the chapter 2.5.

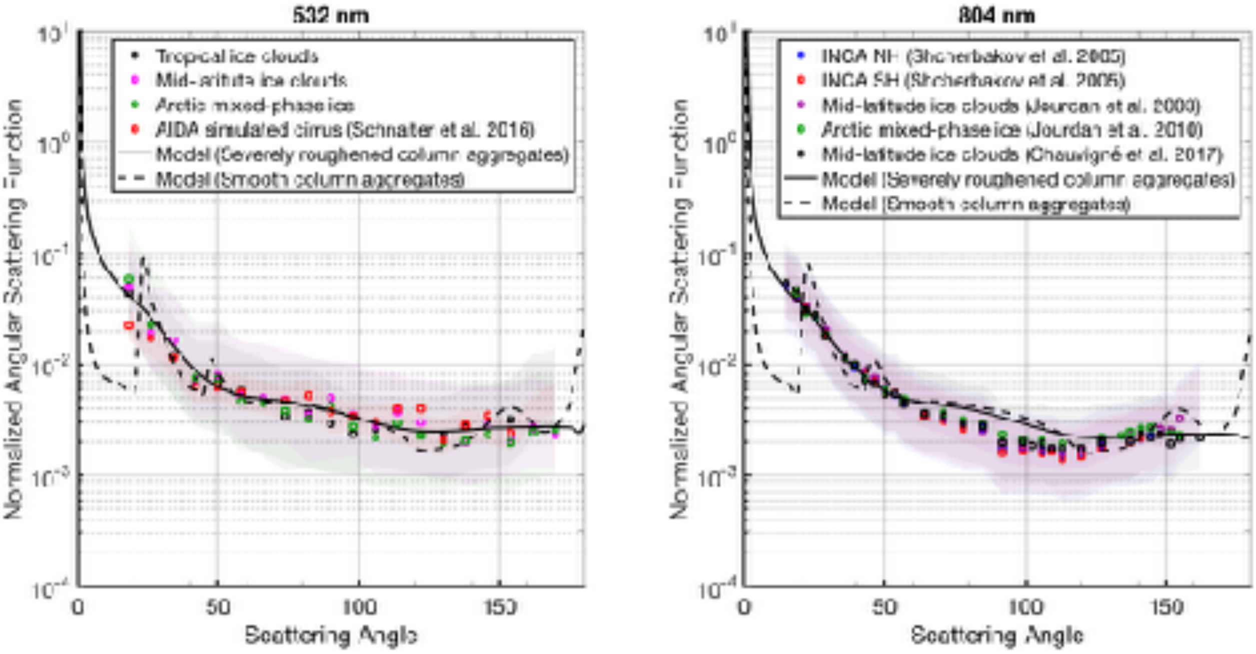
“The ECHAM-HAM model is used to calculate the SWCRE of the ice clouds, which is computed online by calling the radiation subroutine twice. The first call is with clouds (all-sky) and the second call is without clouds (clear-sky) in the atmosphere. The first call uses the standard model parameterization for the short wave asymmetry factors of ice clouds. The radiative fluxes from this call to the radiation subroutine are used to advance the model simulations. The cloud radiative effects are computed as the difference between the all-sky minus the clear-sky fluxes. To estimate the change in SWCRE by changing the short wave asymmetry factors of ice clouds an additional (third) call to the radiation subroutine is conducted. The additional (diagnostic) call to the radiation subroutine is identical to the first call except for using the new parameterization for the short wave asymmetry factors of ice clouds. The radiative fluxes from this additional call are only diagnostic. The SWCRE using the new parameterization for the short wave asymmetry factors of ice clouds is computed from the difference in SW radiative flux at the top of the atmosphere from the additional call and the cloud-free SW radiative flux at the top of the atmosphere.”

Page 8

Line 20: ‘For generation of the theoretical phase functions.....’, do you mean that the phase function here is not for only one particle, instead for integration of a series of particles like bulk property?
The theoretical phase functions are calculated for orientation averaged particles that are integrated over a size distribution - similar to the measurements that are also averaged over a particle population. To make this more clear we modified the caption of Fig. 5: *“A comparison of the measured angular light scattering functions at 532 nm (data from first panel of Fig. 4) and theoretical phase functions for different habits calculated using the database of Yang et al. (2013) and assuming a size distribution as measured during the ACRIDICON-CHUVA campaign. All calculations…”.*

Figure 4 and Figure 5: are the measured ‘angular light scattering functions’ the same in both figures? If yes, please indicate. Also, roughened particles are used here for comparison because studies indicate that they perform well in many applications. How would the smooth particle model curve look like if they are overplotted in Figures 4 and 5?
The data in the first panel of Fig. 4 is the same as seen in Fig. 5. We indicated this in the Fig. 5 caption: *“A comparison of the measured angular light scattering functions at 532 nm (data from first panel of Fig. 4)…”.*

A comparison of phase functions of smooth and roughened particles from the used database are shown in Fig. 13 of Yang et al. (2013). This figure shows that smooth particles have distinct features in the phase function that are not well represented by our measurements. Overplotting the phase functions of smooth particles to Figs. 4 and 5 would make the figures too full and could distract the reader from evaluating the difference between the measurements and the different severely roughened models (please see figure below). We think that the comparison between smooth and roughened particles is adequately discussed and shown in the cited literature so that it is not needed to show the smooth phase functions in Figs. 4 and 5. Further, the differences in the phase functions of smooth and roughened particles are described in the Introduction and in Sect. 4.



Page 10

Line 8: ' the global mean change in the SWCRE is -1.12 W m-2', please indicate that more cooling is brought in using new g parameterization.

We have modified the first sentence of paragraph 4.2 to: "*The change in the global SWCRE after applying the new parameterization to all ice clouds (cirrus and mixed-phase) is shown in Fig. 8. The global mean change in the SWCRE is –1.12 W m*$^{-2}$*, but…*"

Line 9: ' the change in global SWCRE is small compared to ....', yes, it is right. However, based on Section 2.5, SWCRE is for ice clouds only. Is the change significant relative to your simulated SWCRE with new and old parameterizations? How about compare to SWCRE by ice clouds from [Gasparini and Lohmann, 2016] and [Hong et al., 2016] where show ice cloud radiative effect using ECHAM-HAM model and from observations?

The change in the SWCRE take into account all ice clouds (cirrus and mixed-phase). To make this more clear we modified the sentence on page 10 line 7 (old manuscript) the following: *"The change in the global SWCRE after applying the new parameterization to all ice clouds (cirrus and mixed-phase) is shown in…".*

We can directly compare our estimated change in the SWCRE to the one SWCRE calculated by Hong et al. (2016) but not to the one SWCRE calculated by Gasparine and Lohmann (2016) since this was calculated for cirrus clouds only. We have calculated the change in the SWCRE also only for cirrus clouds but this estimation was not shown in the manuscript. We added this information to the revised manuscript and modified the discussion the following: *"If the new parameterization is applied only for cirrus clouds, the mean change in the SWCRE is slightly lower, –1.00 W m*$^{-2}$*. Therefore, the change in the asymmetry factor mostly affects the cirrus SWCRE and, also, the largest effect is found in the tropical regions where also the cirrus occurrence is the highest (e.g. Sassen et al., 2008). Even though the change in the global SWCRE is small compared to the* *global mean SWCRE of all clouds of about –50 W m^{-2} (Boucher et al., 2013) or to the global mean SWCRE of ice clouds of about (–16.7± 1.7 W m^{-2}) (Hong et al., 2016) it is one fourth of the global mean cirrus SWCRE of –4 W m^{-2} (Gasparini and Lohmann, 2016) and comparable to the total direct radiative effect of aerosols (–2.1± 0.7 W m^{-2}) (Lacagnina et al., 2017)"*.

Line 11: ' the decrease in SWCRE...', please indicate cooling is enhanced.
We replaced the term *"the decrease in SWCRE"* with *"The enhanced SW cooling"*.

'cirrus CRE', please explain what ice clouds have been used for CRE studied? Thin cirrus only?
The term "cirrus CRE" here refers to the CRE by cold (<-40°C) ice clouds. Here, the term "cirrus CRE" is used to generally refer to all cirrus clouds.

References

Gasparini, B., and U. Lohmann (2016), Why cirrus cloud seeding cannot substantially cool the planet, J. Geophys. Res. Atmos., 1–17, doi:10.1002/2015JD024666.

Hong, Y., G. Liu, and J.-L. F. Li (2016), Assessing the Radiative Effects of Global Ice Clouds Based on CloudSat and CALIPSO Measurements, J. Clim., (2011), In press, doi:10.1175/JCLI-D-15-0799.1.

References

Yang, P., Bi, L., Baum, B. A., Liou, K.-N., Kattawar, G. W., Mishchenko, M. I., and Cole, B.: Spectrally consistent scattering, absorption, and polarization properties of atmospheric ice crystals at wavelengths from 0.2 to 100 μ m, Journal of the Atmospheric Sciences, 70, 330–347, 2013.

Yi, B., Yang, P., Baum, B. A., L'Ecuyer, T., Oreopoulos, L., Mlawer, E. J., Heymsfield, A. J., and Liou, K.: Influence of Ice Particle Surface Roughening on the Global Cloud Radiative Effect, Journal of the Atmospheric Sciences, 70, https://doi.org/10.1175/JAS-D-13-020.1, 2013.