Comments on “Investigation of ice cloud modeling capabilities for the irregularly shaped Voronoi models in climate simulations” by Li et al.

Anonymous Referee #1

General comments

The paper assesses the performance of the Voronoi ice crystal model on the broadband radiative transfer simulations as well as climate simulations with CAM5 through the comparisons to other four ice cloud parameterizations including Mitchell, Fu, Baum–Yang, and Yi schemes. The Voronoi scheme exhibits relatively lower asymmetry factor and higher single-scattering albedo in the visible to near-infrared wavelength domain, than the other four schemes, resulting in more reflective ice clouds in shortwave radiative transfer simulations. The comparisons of the net cloud radiative effects between CERES observations and 10-yr CAM5 simulations among these ice cloud parameterization schemes suggest that the Voronoi scheme outperforms the other four parameterization schemes. The authors conclude that the Voronoi scheme can minimize the differences of the global TOA SWCF between the satellite-based measurements and the CAM5 simulation counterparts compared to other four schemes. This paper sufficiently describes the background and introduction, and methods. However, the result section contains inadequate discussions in the interpretation of the results. In particular, the authors should add more detailed descriptions on the five parameterization schemes. Also, there are numerous grammatical/language errors, and several sentences need to be rephrased. The topic presented in this study is suitable for Atmospheric Chemistry and Physics, and therefore I recommend Major Revisions for publication.

Response: Thank you very much for your significant comments.

Major comments

1. First of all, there are lots of grammatical errors throughout the manuscript. A proofread is strongly recommended.

Response: According to the suggestions, we have proofread the manuscript.

2. Second, the authors briefly describe the five parameterization schemes. Although the description of the Voronoi scheme is sufficient, those of the other four schemes are not adequate. In particular, the authors should address/clarify the followings:

1. Fu (2007) established two ice cloud property schemes (smooth ice crystals and roughened one), both of which allow the variation of the aspect ratio. Which schemes and aspect ratio did the authors use for the present analyses (Figs. 3-9)?
2. Yi et al. (2013) included two ice cloud schemes (smooth ice crystals and roughened one) as similar to the Fu scheme. Which scheme did the authors use for the present analyses?

If the case the authors use smooth ice crystal schemes for both Fu and Yi schemes, then the authors evaluate the capabilities of the Voronoi scheme against the four schemes that are based on smoothed-surface ice crystals. This would not be a fair comparison as numerous studies have already clarified that incorporating some roughness effect into the ice cloud schemes is essential. Therefore, the authors should add one more scheme that incorporates the surface roughness (such as Yi et al. 2017ab; the MODIS C6 ice cloud scheme) for the present analyses.

These above-listed items need to be clarified before the publication of the manuscript.

Response: According to the suggestions, we have added more illustrations about the other four schemes in section 1 paragraph 3 (page 4). Modified descriptions of Fu and Yi schemes are as follows: "Fu (1996) derived an ice cloud optical parameterization (referred to as Fu scheme hereafter), in which optical properties have been parameterized as functions of ice water content and generalized effective size based on the randomly oriented hexagonal ice particle. …Yi et al. (2013) developed a parameterization (referred to as Yi scheme hereafter) based on a general habit mixture model that includes nine pristine habits with severely surface roughness."

In the study, we have accounted for the effects of roughened ice particles in scheme of Yi et al. (2013).

Specific comments

1. Line 47: "Hulst, 1957" should be "van de Hulst, 1957".

2. Line 49 "Macke et al., 1996": Macke's work do not include aircraft observations, and may be irrelevant to cite this here.

3. Line 65 "Bi et al., 2013a, 2013b": Yang et al. (2013) database did not use II-TM but used the T-matrix method (Mishchenko et al., 1996).

Response: According to the suggestions, we have corrected the wrong citations.

4. Line 94: "…, and results" should be "…, and there results".

5. Line 133 "… is strong": It should be rephased to be "high".

Response: According to the suggestions, we have modified the irrational expressions.

6. Fig. 1: It would be better to show the single-scattering albedo (SSA) or the single-scattering co-albedo, instead of the scattering efficiency as it is hard to recognize the absorptivity from this particularly for weakly absorptive particles. Also, Fig. 1 indicates a second peak at the size parameter at which the transition of the computational methods between FDTD and GOIE. Is this due to a different combination of the computational methods or what occurred physically?

Response: According to the suggestions, we have changed the scattering efficiency to the single-scattering albedo (SSA) in Fig. 1. And the main reason is that the second peak is caused by transitions of different computational methods in visible and near-infrared wavelength.

7. Lines 224 – 226 "As shown in Figure 3, …": The authors try to explain the low mass extinction coefficients at wavelengths 3.08 – 3.85 μm with an atmospheric window region. However, the single-scattering albedo at the corresponding wavelengths are relatively low (e.g., 0.6 – 0.8; Fig. 3b). Therefore, this cannot explain the low mass extinction coefficients. I suggest to check the extinction efficiency and complex refractive index of ice at corresponding wavelengths.

Response: According to the suggestions, we have checked the refractive index of ice shown in Figure 1 below, and found it could because that the real part of the refractive index sharply decreases near 3 μm and reach the minimum at 3 μm (Warren and Brandt, 2008; Yang et al., 2013). This could result in a minimum value of mass extinction coefficients.

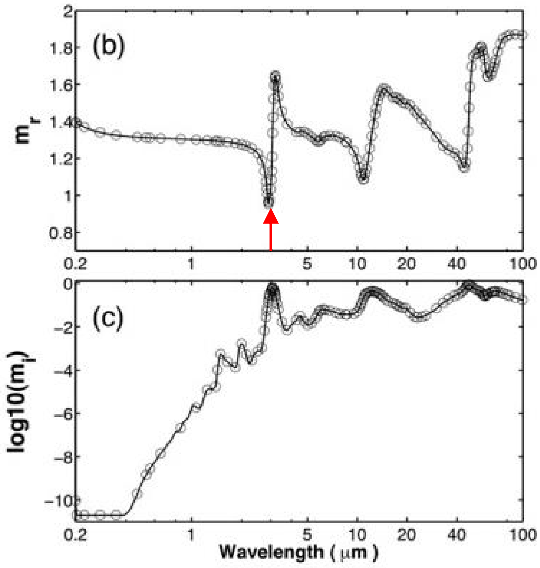

Figure1. (b) Real part of the refractive index;

(c) Imaginary part of the refractive index, cited from Yang et al. (2013).

8. Lines. 229 – 231 "… than small ice particles that are closer to Rayleigh scattering": Even for small ice particles in the near-infrared band, the size parameter is much larger than the counterpart that causes the Rayleigh scattering. I suggest the authors to simply remove "that are close to Rayleigh scattering".

Response: According to the suggestions, we have removed the irrational expressions.

9. Line 242 "it is in a good agreement with the results in Zhao et al., (2019)": Too ambiguous. Please add brief descriptions in which part of results in Zhao et al. (2019) shows the agreements with your results.

Response: According to the suggestions, we have added descriptions as follows: "This highest asymmetry factor of the Mitchell scheme is also found when comparing with other schemes in the study of Zhao et al. (2018)" in section 4.1 paragraph 2 (page 14).

10. Line 256: The downward direct flux can be different among different ice cloud parameterizations as the spectral extinction efficiency, single-scattering albedo, and asymmetry factor differ among schemes.

Response: According to the suggestions, we have modified the inappropriate expressions in section 4.2 (page 13).

11. Lines 256 – 257 "Figure 5a1 show …": This is obvious statement and can be

removed from the main text in order to let readers focus on ice cloud parameterizations.

Response: According to the suggestions, we have removed the irrational expressions.

12. Line 265 and throughout Section 4: "-10 – (-40)" should be "-10 to -40". I found the same errors in several parts in Section 4, which should be corrected.

13. Line 276: "To study the ice cloud modelling capabilities" may be rephrased to be "to study the performance of ice cloud simulations with …"

Response: According to the suggestions, we have corrected the irrational expressions.

14. Line 278: Please specify the 10-yr period of CERES data used for Fig. 6 – 7.

Response: Response: According to the suggestions, we have added descriptions in section 2.3 paragraph 2 (7). The temporal period of CERES products utilized in this study is from 2001 to 2010.

15. Line 281 "… are strong": This should be rephrased.

Response: According to the suggestions, we have corrected the irrational expressions.

16. Lines 281 – 284: This statement is true if the relative fractions of liquid and ice clouds remain unchanged. Because the authors' analysis includes both liquid and ice clouds, the interpretation of the results may be mixed up. I suggest the authors to show the liquid/ice cloud fraction from both CAM5 simulations and observations.

Response: Total cloud radiative effects are shown because the radiation scheme in CAM5 unable to treat liquid and ice clouds individually, thus we cannot separate the effects of ice clouds from the total amounts. The modifications of total cloud radiative effects can only be attributed to the difference of different ice cloud scheme adopted in radiation scheme in CAM5 with unchanged liquid cloud scheme.

17. Lines 294 – 295 and Fig. 9: The description and results are not consistent. In Fig. 9, the scheme A (Mitchell) looks the best performance. Please clarify it.

Response: Given the Mitchell scheme overestimates in the tropics and underestimates in the middle to high latitudes in both hemispheres, the positive and negative differences can produce compensating biases, which result in that the difference of globally averaged SWCF and LWCF of Mitchell scheme is closest to the zero line.

18. Fig. 7 caption: Fig. 9 should be Fig. 6.

Response: We have corrected this error in Figure 7 caption.

Reference

Fu, Q. A.: An accurate parameterization of the solar radiative properties of cirrus clouds for climate models, J Climate, 9, 2058-2082, Doi 10.1175/1520-0442(1996)009<2058:Aapots>2.0.Co;2, 1996.

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Zhao, W. J., Peng, Y. R., Wang, B., Yi, B. Q., Lin, Y. L., and Li, J. N.: Comparison of three ice cloud optical schemes in climate simulations with community atmospheric model version 5, Atmos Res, 204, 37-53, 2018.