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

Anonymous Referee #3

General comments

This study focuses on the comparison of Voronoi model with four other ice cloud models. For the validation purpose, authors used CERES data. Authors conclude that Voronoi model-based results are closer to CERES data than results obtained from other cloud schemes. The overall goal of the study looks interesting; however, the paper is poorly organized with several mistakes in English writing, literature reference, equation citation, and so on. The discussion part is also poor.

Response: Thank you very much for your significant comments.

Specific comments

1. Figure 1 shows single scattering properties of only Voronoi model, though Figure 3 shows band averaged values for all cloud models. Why not to show the single scattering properties for all models in Figure 1? It can make easy to understand Figures 3 and 4 as well as other results.

Response: The main reason is that we don't have access to the database of single-scattering properties for all ice particles utilized in other four ice cloud optical property schemes.

2. It may be better to show the difference in terms of percentage (relative values) in Figure 4.

Response: According to the suggestions, we have redrawn the Figure 4 changing from absolute differences to relative percentage.

Page 31:

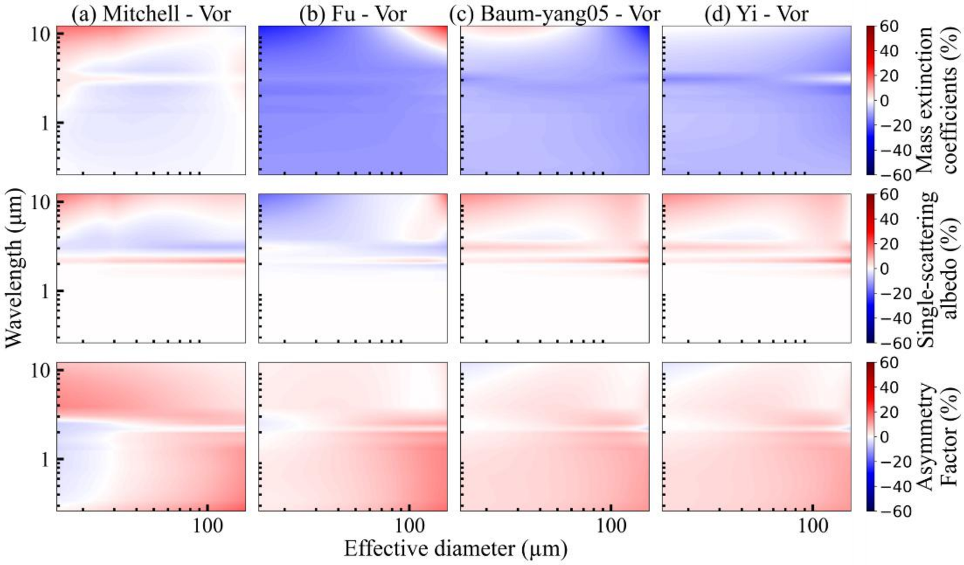

Figure 4. Relative percentage of differences of (top row) mass extinction coefficients, (second row) single scattering albedo, (third row) asymmetry factor as functions of ice particle effective diameters and shortwave bands in CAM5 between the other four schemes and Voronoi scheme.

3. There is an unclear description about particle size distribution (PSD) of ice clouds. Authors state that they utilize 14408 groups of microphysical data. Do authors use a single or multiple PSD function in this paper? For clarity, it is important to describe how PSD function is derived from 14408 groups of data to use in this study. If possible, PSD is suggested to be shown. If not possible, authors may tabulate the parameters of PSD function(s) used in this study.

Response: According to the suggestions, we have added the figure of PDSs (Figure 2 on page 28) as shown below and corresponding descriptions in section 2.2 on page 7.

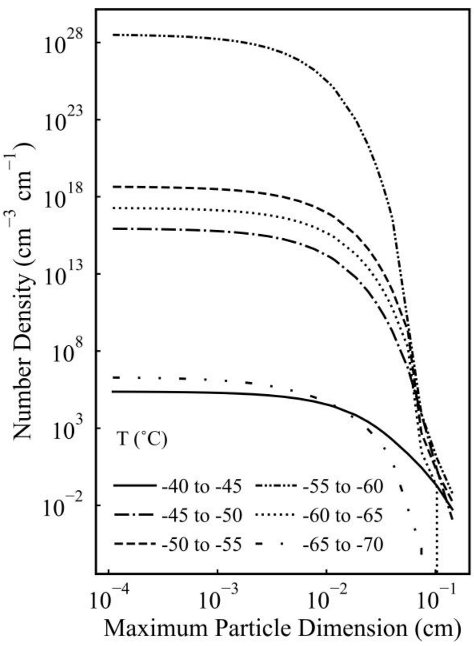

Figure 2. Ice cloud particle size distributions based on in situ aircraft observations.

4. Figure 2 is not clear. It may be removed or improved. The methodology is well understood even without Figure 2.

Response: According to the suggestions, we have redrawn the flowchart (Figure 3) on page 28 as shown below.

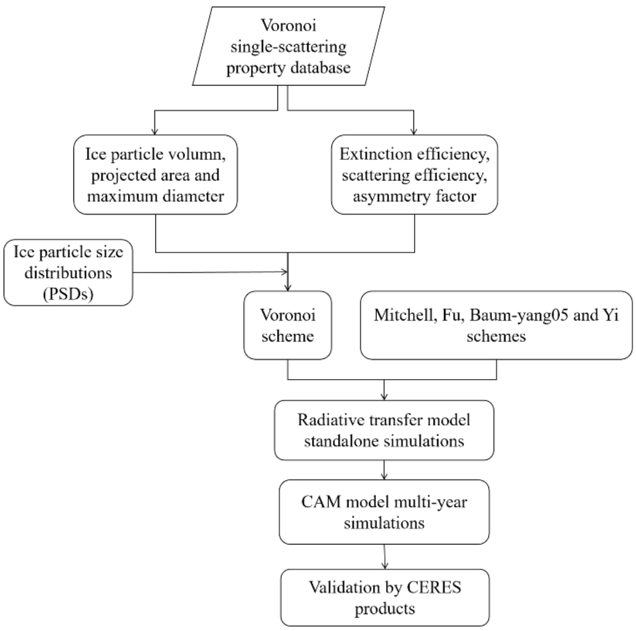

Figure 3. Flowchart of the study

5. Equations are described in the text very randomly. For example, in section 3, Eq. 7 is described after Eq. 2. Equations and Figures are needed to appear in the text ascending order.

Response: According to the suggestions, we have reorganized the layout of equations in section 3 (page 8-10).

Page 8-9:

"To better understand the ice cloud modelling capabilities of …to the extinction coefficient in the form of Eq. (4), respectively.

$$\beta_{e,s,a} = \int_{L_{min}}^{L_{max}} \sigma_{e,s,a} n(L) dL \ , \quad (3)$$

$$\varpi = \frac{\beta_s}{\beta_e} \text{ ,or } 1 - \varpi = \frac{\beta_a}{\beta_e} \quad (4)$$

where $\sigma_{e,s}$ is the…can be defined by Eq. (5).

$$\tau = \int_z^{\infty} \beta_e \, dz \ , \quad (5)$$

where z is … can be given by Eq. (6).

$$J(\tau;\mu;\phi) = \frac{\varpi}{4\pi} \int_0^{2\pi} \int_{-1}^{1} I(\tau;\mu';\phi') P(\mu,\phi;\mu',\phi') d\mu' d\phi'$$

$$+ \frac{\varpi}{4\pi} F_{\Theta} P(\mu,\phi;-\mu_0,\phi_0) e^{-\tau/\mu_0} + (1-\varpi) B[T(\tau)] \ , \quad (6)$$

where P is the phase function … expressions of ice cloud bulk optical properties as functions of D_e are obtained...."

6. What is the necessity to integrate over wavelength in Eq. (7)?

Response: As you mentioned, effective diameter D_e is invariant with wavelength. We have modified Eq. (7) as below,

$$D_e = \frac{3}{2} \frac{\int_{L_{min}}^{L_{max}} V(L) n(L) dL}{\int_{L_{max}}^{L_{max}} A(L) n(L) dL}$$

7. Eqs. 11-13: Equations corresponding to long wavelength bands need to be rewritten or a symbol to represent S and J may be used and stated below those equations.

Response: According to the suggestions, we have utilized a parameter E in Eq. 11-13. In shortwave and longwave spectrum, E is assigned by solar constants and Planck functions, respectively.

8. Authors state that the wavelength range is from 0.2 micron to 15 micron for Voronoi database and they assumed unchanged properties for wavelength larger than

15 microns. What about database for other cloud models? Do they also have such assumption? If such assumption is only for Voronoi database, what are the effects in results shown in Figure 3 and onward?

Response: As you mentioned, to ensure consistency for all schemes, we only used parameterized coefficients between 0.2 and 15 μm for the other four schemes. The wavelength range from 0.2 micron to 15 micron is sufficient for remote sensing and climate modelling applications (Yang et al., 2018; Yang et al., 2015).

9. Authors discuss about cloud forcing in Eq. (14). Can authors also discuss about the comparison of downwelling and/or upwelling fluxes for cloudy scenario between CERES and each cloud scheme? I guess comparison of fluxes rather than cloud forcing may help to better understand the performance of each model.

Response: According to the suggestions, we have added global average downwelling surface shortwave fluxes and top of atmosphere upwelling fluxes for all cases. As you mentioned, difference in net radiative components owing to different ice cloud schemes can help us to understand the performance of different schemes.

10. How water cloud is treated here is not clear. Authors may describe a more about water cloud properties and how they are merged with ice clouds in the simulation. Authors may add information (height, properties etc) related water cloud in Table 2.

Response: According to the suggestions, we have added input parameters related to liquid clouds in RRTMG simulations in Table 3, including liquid cloud top height, liquid water path, liquid effective radius.

11. What is Downward flux in Figure 5. Is it Direct+Diffuse flux? please clarify. If it is Direct+diffuse flux, why is it largely different than Difdown flux for a cloudy condition? Are clouds optically very thin for such difference?

Response: According to the suggestions, we have added more descriptions of Figure 5 (section 4.2, page 11). As you mentioned, the downward is the combination of direct and diffuse fluxes. The large difference between the downward and diffuse fluxes could be related with absence of water clouds in the RRTMG simulations.

Reference

Yang, P., Hioki, S., Saito, M., Kuo, C. P., Baum, B. A., and Liou, K. N.: A Review of Ice Cloud Optical Property Models for Passive Satellite Remote Sensing, Atmosphere, 9, 2018.

Yang, P., Liou, K. N., Bi, L., Liu, C., Yi, B. Q., and Baum, B. A.: On the Radiative Properties of Ice Clouds: Light Scattering, Remote Sensing, and Radiation Parameterization, Advances in Atmospheric Sciences, 32, 32-63, 2015.