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Interactive Comment

Interactive comment on "A two-habit model for the microphysical and optical properties of ice clouds" *by* C. Liu et al.

C. Liu et al.

pyang@tamu.edu

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Response to Reviewer #2 (ACP MS No.: acp-2014-441)

We would like to thank the reviewer for the valuable comments and constructive suggestions. In the revised manuscript, we have accommodated all the suggested changes.

Anonymous Referee #2

Major comments: 1) While this paper does address ice cloud microphysics, it is only addressed to the extent necessary for obtaining optical properties from a given ice particle size distribution (PSD). This point needs to be made more clearly in the paper.

Thus the content of the paper may be more appropriately expressed using a title like "A two-habit model for the optical properties of ice clouds". After all, the model conserves two microphysical properties but does not predict them.

Response: The motivation of building a new ice cloud model is to represent both its microphysical and optical properties, and this is also the most important and unique highlight of the paper. We have a full section, i.e. Section 3, to discuss the microphysical properties of the THM. For a given PSD, it is straightforward to use the THM to calculate the ice water content and medium-mass diameter for a given PSD. Furthermore, in the revised manuscript we have added an expression of particle volume as a function of particle maximum dimension. Thus, we prefer not to change the title of the paper.

2) Page 19555, lines 6-7: Since D = ice particle maximum dimension, it is not possible for both Vc(D) and Va(D) to be proportional to D3. Numerous papers show Va(D) to be roughly proportional to D2, and the exponent on D for Vc(D) lies typically between 2.5 and 3. So what expressions were used to represent Vc(D) and Va(D)?

Response: The V-D relationship is given in Eq. (4). For particle sizes between 100 μm and 1500 μm, V is proportional to the D2. In smaller or larger size regions, V is proportional to D3.

3) Page 19555, lines 13-15: Here it states that Eqns. 1 and 2, using the THM habit fractions, can be used to calculate IWC and Dmm from the observed PSD. A research paper should provide the necessary information that allows other investigators to test the study's findings. This is not possible for this study since the relationships for Vc(D) and Va(D) are not reported, but evidently these volumes are calculated as described in Appendix A. It could be very useful to the cloud physics community if these volumes could be related to their maximum dimension D in log-log space, with V-D power laws given. For example, this may allow other investigators to generalize the results reported in Fig. 4 to other cloud physics applications.

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Response: In the revised manuscript, detailed information about the aggregate particle geometry used in the two habit model is presented (see Table A1). In addition, the V-D relation is also given (see Eq. 4).

4) Page 19555, lines 13-15: Do these calculations use the gamma PSD fits noted above in lines 10-11? One might assume that they do, or else why are the gamma fits mentioned? Nonetheless, this point should be clarified.

Response: Yes, the dataset provides two parameters of each fitted gamma distribution, and we clarified this point in revised manuscript.

5) Page 19556, lines 3-11: The agreement between measured and computed IWC in Fig. 4 is remarkable; so remarkable that it is hard to believe if taken at face value since. That is, direct in situ measurements of IWC (e.g. CVI or CSI probes) compared against IWC calculated from collocated PSD measurements, using either ice particle mass-dimension (m-D) or mass-area (m-A) power law relationships, show a great deal of scatter; see for example the comparison in Fig. 6 of Lawson et al. (2010, JGR). This is the best agreement I have seen between direct measurements of IWC and IWC calculated from measured PSD & m-A expressions, and still there are differences of a factor of 2 or even 3. Questions that naturally arise when inspecting Fig. 4 are: a. What are these measured IWCs? Are they direct measurements from probes like the CVI, or are they calculated from PSD measurements assuming some m-D or m-A expression(s)? b. If they are calculated from PSD measurements, what m-D or m-A expressions were used? c. What are the expressions for Vc(D) and Va(D), used to calculate IWC in the THM? If the measured IWC was calculated from observed PSD, then what is actually being compared in Fig. 4 are two calculations; one based on observed PSD and some undisclosed m-D or m-A expression(s) and the other based on Eq. 1 in the THM. If this is the case, then the agreement observed in Fig. 4 is plausible since much of the natural variability will be removed by invoking the m-D or m-A expression(s). The same concerns noted above for IWC also apply to the Dmm comparisons.

Response: Yes, these IWCs are all direct measurements from probes of different kinds, and data collected from 11 field campaigns are used. Actually, the TC-4 discussed by Lawson et al. (2010) is one of the 11 field campaigns. Many more details about the in situ measurements can be found from the references we cited. To clarify, we added the final format of the relationship we found between V and D, which leads to close agreement between the theoretical and observed microphysical properties.

6) Page 19557, line 5: The convention in cloud physics for aspect ratio is to define it as more than or equal to 1.0 for columnar ice crystals and less than or equal to 1.0 for planar ice crystals (e.g. Lamb & Verlinde, 2011: Physics and Chemistry of Clouds, Cambridge; see Ch. 8).

Response: The definition of the aspect ratio is clearly given in the manuscript. Many references cited in this manuscript use the same definition as ours. So we prefer to keep this definition.

7) Page 19559, end of Sec. 4.1: Please comment on the importance of the random distribution of aspect ratio and size regarding the aggregate components. For example, to what extent do the optical properties change when a realistic fixed aspect ratio/monomer size assumption is imposed?

Response: The effect of the aspect ratio of a hexagonal column on its scattering properties has been well studied (e.g., Yang, P., and Q. Fu, 2009: Dependence of ice crystal optical properties on particle aspect ratio, J. Quant. Spectrosc. Radiat. Transfer, 110, 1604-1614), and we will not repeat those in this paper. For this study, we try to build a particle with relatively small asymmetry factor (at visible and near infrared wavelengths), and, thus, the aspect ratios of hexagonal monomers are kept close to 1. In other words, it is important to have monomers with aspect ratios close to 1, and the asymmetry factor will become larger as the aspect ratio deviates from unity. However, the random distribution is implemented by assuming that the monomers of a realistic aggregate do not have the same aspect ratio.

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8) Page 19560, line 9: Wang et al. (2014) is not referenced. Wang et al. (2013a) and (2013b) are referenced, but are not cited in this paper apparently. The Wang et al. 2013 papers do not retrieve the scattering phase function of ice clouds from satellite observations (which the Wang et al. 2014 paper allegedly does).

Response: We have the references of Wang et al. 2013a, 2013b and 2014. The citations about the three papers are checked and corrected. Thanks for pointing out the typo.

9) Page 19560, line 20: How is Deff defined in this study? Some investigators use extinction to define it, others use PSD projected area, and so on.

Response: We add the definition of Deff in the text. In addition, the paper by Foot (1988) has been cited, which introduces the definition.

10) Page 19560, lines 17-20: Mishra et al. (2014, JGR) show that Deff =100μm is also common for cirrus clouds. Please consider adding a THM bulk phase function for Deff = 100 μm to Fig. 8, showing how insensitive the phase function is to Deff.

Response: One of the most significant features of the THM is that its phase functions (as well as the asymmetry factor) at visible and near infrared channels are not sensitive to particle size, as can seen from Fig. 7. The phase function with Deff=50μm is very close to that with Deff=100μm (except for the forward diffraction peaks that are proportional to particle geometrical cross section). To better illustrate this, we added the phase function with Deff=100μm in the figure for comparison.

9) Page 19561, lines 1-3: Could another explanation be that Deff is smaller over land (relative to the oceans)?

Response: As we have demonstrated in the paper, the phase function of the THM at visible/near infrared bands does not vary significantly for different Deff (except for the forward peak) and this should not be the reason for the relatively poor agreement for data over land.

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Technical comments:

1) Page 19547, line 10: ensemble habits => ensemble of habits?

Response: Corrected.

2) Page 19547, line 29: growth, => diffusion growth, ?

Response: Modified. Thanks for the suggestion.

3) Page 19548, line 9-10: ice crystal particle => ice particle?

Response: Corrected

4) Page 19567, line 14: ranage => range?

Response: Corrected.

5) Page 19568, line 21: dada => data?

Response: Corrected.

6) Figure 7: The text within Fig. 7b refers to a wavelength of 0.804 μm, but the caption refers to a wavelength of 0.86 μm.

Response: Corrected.

Interactive comment on Atmos. Chem. Phys. Discuss., 14, 19545, 2014.