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Interactive comment on "Cloud-Aerosol-Radiation (CAR) ensemble modeling system" *by* X.-Z. Liang and F. Zhang

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We wish to express our great appreciation for your careful review and detailed instructive comments. In the revised manuscript, we have incorporated all your comments to the extent possible. In the response below, we address each of these comments. Your comments are in quotation marks and our responses immediately follow.

"General comments: I am very impressed on how much work the authors have done to put together all those physical schemes and develop the CAR system. Although called Cloud-Aerosol-Radiation system, the CAR is basically still a radiation system, in which the original radiation schemes have been decoupled so that the parameterizations for single scattering properties of gas, clouds, aerosols, and the parameterizations for

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cloud subgrid scale structures, including vertical overlap and horizontal inhomogeneity, etc. are modularized. The original radiation schemes now mainly consist of the solver of the radiation transfer, say, two-stream or four-stream, in the CAR system. The CAR system will be a very useful tool to help identify and reduce model discrepancies in terms of the representations of some physical processes, including cloud, aerosol, and radiation. Extensive experiments have been carried out to evaluate the performance of the system. The manuscript is overall well-written and delivers the necessary information concisely. Some revisions are needed to address the following questions before the acceptance of this manuscript:"

Answer: We thank you very much for recognizing the value of our work, and clear understanding of our result as well as the compliment.

"Specific comments: 1. It is well-known and proved again by this study that the model simulations are very sensitive to the numerical representations of the cloud-aerosol-radiation processes in the models. It is also known that the most physically based schemes may not necessarily generate the best model simulation results due to the complicated interactions among the physical processes. The ultimate goal of the model development, however, is to have the most physically based representations for all the physical processes in the atmosphere. I am curious whether it is possible for the authors to provide a benchmark simulation using the most physically based parameterization among the available schemes for each physical process. It is likely that this combination wouldn't necessarily produce the best performance, but it may be able to provide some information or clues on what could possibly be the reasons."

Answer: We agree with you on the importance of identifying the most physically based parameterization schemes and benchmarking their relative performances. There are however no objective way to define what is the “most physically based parameterization”. We may be able to identify those schemes that are outdated or relatively simplistic, and thus obtain a list of remaining “sophisticated” schemes, which are many. None of these schemes is more physically based than others. Even given such a list, we would anticipate no clear dependence of their results on the levels of sophistication. On the other hand, we can use CAR to quantify the spread among the schemes in comparison and relative performance against LBL calculations or observations (which typically contain large uncertainties), as well as isolate the responsible causes. This has been done in the present manuscript, another two recent articles [Zhang et al. 2013: Cloud-Aerosol-Radiation (CAR) ensemble modeling system: Overall accuracy and efficiency, Advances in Atmospheric Sciences, in press; Zhang et al. 2013: Dominant roles of subgrid-scale cloud structures in model diversity of cloud radiative effects, Journal of Geophysics Research, accepted with minor revisions.]. Nonetheless, one of our objectives in developing the CAR system is to find an optimized ensemble that best represents observations with a credible estimate of the uncertainty range. This is an essential task, listed among our future high-priority works. In particular, we are preparing a manuscript on dimension reduction of the CAR system, in collaboration with all individuals (as co-authors) who have contributed parameterization codes and implementation assistances. In that effort, we will first select the schemes based on the fundamental physics necessary to include, the close dependence or repetition (such as the same series of several versions) to avoid, and the poor performance to eliminate. This procedure will lead to an ensemble of a computationally feasible size for future use of the research community. See also our discussion on this issue in Section 5 of the current manuscript.

"2. One important usage of the CAR system is to find out the optimal combination of the existing radiation transfer schemes with cloud and aerosol parameterizations, which would be technically useful for the climate simulations. It is my understanding that the combination could be very case dependent and therefore I am not convinced if this could be practical. Nevertheless, for the cases used in this study, do the authors find out any combinations that work the best for certain cases? Before we can get the exact solutions for the radiative transfer, it could be statistically meaningful and useful if one can use the CAR system to find out the optimal combinations under certain atmospheric conditions."

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Answer: We fully agree with you that an essential use of the CAR system is to define an optimized ensemble, which is listed as a top priority along with the dimension reduction study. We also agree that such ensemble is case dependent, obviously because any optimization must be based on statistical performance against given references, most desirable of which are reliable observations. However, as we illustrated in the current manuscript, observations are very limited in scope and contain nontrivial uncertainties. The subset of the schemes selected from the optimization against such references will be certainly limited. On the other hand, given the reduced dimension (work in progress) and the best available observation range (see Section 3), we are confident that an optimized solution is achievable. We have experiences in optimization for land surface albedo parameterization development (Liang et al. 2005), ensemble cumulus parameterization (Liang et al. 2007), and CWRF multiple physics configuration ensemble (Liang et al 2012). Similar approach can be used to do the optimization of the reduced CAR system. Our current manuscript presents in Table 4 a comparison against LBL calculations for several standard clear and cloudy cases among various combinations of radiation and cloud schemes. The result shows that smallest errors are identified generally not with the default combinations of the radiation transfer and cloud optical property schemes in the original packages. A more detailed study was given in Zhang et al. (2013, Advances in Atmospheric Sciences, in press), again illustrating that the radiation packages used in the current GCMs are not fully optimized. Figure 1 of that paper is duplicated below for your reference. We strongly believe that an optimal subset of the CAR system can be derived against certain references the community can agree on as being representative of observations. This will be our future study in a separate paper.

"3. I believe that another intended application of the CAR system is to couple it to climate models (similar to the development of WRF) and provide the users with the freedom to choose the parameterizations they want to use. However, given so many possible combinations, I guess it would be very difficult for the users, who normally only know some parts of the model system and treat the other parts as black boxes, to choose among the numerous schemes. Do the authors plan to provide the CAR system as a research tool for experts in the cloud-aerosol-radiation field or for a wider community use? If the purpose is for wider community use (such as WRF), it would be very important to identify a few default options and/or combinations that work the best for certain cases. Or would the authors suggest using ensemble modeling, which could be very time consuming?"

Answer: We plan to provide the CAR system for a wide community use, including as a research tool for experts in the cloud-aerosol-radiation field and for developers of climate models, as well as an education tool for students to explore numerical representations and structured uncertainties. The full system will be released after the publication of this manuscript and another two papers on dimension reduction and climate sensitivity that are fundamental for the CAR general application. The release will include a subset of the system based on the dimension reduction study. In addition, we will follow our approach in releasing CWRF to provide a control version of the CAR that is cost-effective for simulating the present climate. The schedule for these efforts, however, will largely depend on the availability of supercomputing resources and funding supports. Per discussion in Section 5, we will also seek the optimized physics ensemble that is computationally feasible by taking advantage of the unique advance in the structured CPU time distribution of the CAR system.

"4. Page 10194, line 4: What does the “geometry” in the cloud properties mean? Seems to me, the authors were talking about cloud vertical overlap as shown in Table 3."

Answer: We use word “geometry” to describe the configuration of clouds with subgrid variability. As discussed in Liang and Wang (1997) cited in this manuscript, for GCM parameterization the subgrid variability related to cloud-radiation interaction includes not only the cloud geometric association (vertical overlap or more general macrogrouping) and inhomogeneity (within-cloud optical property variance) that have already been built in CAR, but also broken-cloud effects (interaction between finite clouds, i.e., mutual shielding and reflection) to be developed in the future. We add this as a footnote in 3rd paragraph of Section 2.

"5. Page 10204, lines 11-13: It is my understanding that McICA does not employ any particular overlap assumption."

Answer: We agree and have now revised the sentence to "whereas McICA typically employs some stochastic cloud generators that assume all cloud types to follow the same statistical relationship such as α-weighted maximum-random overlap."

"6. Page 10205, lines 1-11: 1) The aerosol vertical profiles play very important roles in the determination of the radiation budget and TOA and surface, as well as the heating profiles within the atmosphere. What are the built-in options for the aerosol vertical profiles included in the CAR system? "

Answer: We have built the CAR system with the ability to explicitly incorporate 3D distributions of aerosol mass loading or optical depth, such as those modeled by CAM-Chem, GEOS-Chem or WRF-Chem without the need for vertical profile assumption. Only when using 2D total aerosol mass loading or optical depth, some climatology-based vertical weighting profiles are prescribed. At the moment, the CAR system includes an exponential decay with a specified scale depth and the Spinhirne vertical profile. We generally use the exponential decay with a scale depth set to 3000 m. For different aerosol types, the scale depth can be different.

"6.2) Do any of the experiments include the 1st indirect effect mentioned in this paragraph?"

Answer: This study does not include the 1st indirect effect.

"6.3) Semi-direct effect, by definition, is to describe the aerosol absorption of sunlight which heats the lower troposphere and reduces large-scale cloud cover (Hansen et al. 1997). In the designed experiment (page 10210, lines 23-25), the authors examined the semi-direct effect without changing the cloud cover. In that case, the semi-direct effect can not be investigated. I wish to point out that the semi-direct parameterization (Li et al. 2011) that the authors adopted is on the change of water cloud optical properties due to the internal mixture of black carbon. By commonly used definition, it is more related to 1st indirect effect."

Answer: We thank you for the comment and fully agree with your understanding. To reflect this point, we have now revised the text in the last paragraph of Section 4.3 as follows: "Another set of 4 similar runs is conducted except including the extra SW absorption of black carbon within clouds as represented by the perturbation approach of Li et al. (2011). These offline runs exclude the feedback from cloud cover change induced by the absorption, and hence do not account for the actual semi-direct effect. Here concerned are only the flux changes due to internal mixture of black carbon within clouds, offering a reference for future investigation on aerosol semi-direct effects in CAR-coupled climate models that predict cloud changes. On average of January and July 2004, the absorption effect for net SW flux at TOA (surface) is 1.98 (-1.76) and 1.96 (-1.67) Wm-2 as resulted from respectively the cccma and flg radiation using the same cccma aerosol optical property scheme. The result changes little when using the OPAC property scheme, with the corresponding values of 2.01 (-1.75) and 1.98 (-1.66) Wm-2. Therefore the estimate for the absorption, and likely the semi-direct effect, of black carbon has little sensitivity to the choice for the radiation and aerosol optical property schemes."

"7. Page 10213, line 15: I guess 2125 W m-2 should be 21.25 W m-2."

Answer: This is a typo from document conversion. It should be 21-25 Wm-2, representing a range.

Interactive comment on Atmos. Chem. Phys. Discuss., 13, 10193, 2013.