Author Response to Reviewer 1

We thank the reviewer for her/his thoughtful and detailed comments, which helped improve this manuscript. Please note: Reviewer's comments are listed in blue fonts. And responses are italicized text below each reviewer's comments.

This study applied an automated parameter optimization algorithm subject to TOA radiation balance constraint to improve the performance of the Community Atmospheric Model in climate simulations. Results showed that the optimized parameters evidently improve the model performance while the energy balance principle can always hold across the entire optimization iterations. This paper conforms the importance of radiation balance constraint for optimization applications in climate models. The manuscript is well organized and the presentation is generally good.

Thank you very much for your recognition. We also appreciate your following comments and suggestions.

However, there are some aspects need to be improved before considering of publication.

1. The optimization results using the constrained algorithm are quite different from the unconstrained results (Fig. 2). Does this indicate that the better model performance based on the synthesized metric (eq. 3) often leads to more serious radiation imbalance at TOA? This issue might be related to the structural inadequacy in the model physics as discussed in Qian et al. (2018) and Yang et al. (2019).

Reply: No. The better model performance based on this synthesized metric does not necessarily lead to serious radiation imbalance problems, which depends on the specified model as well as the parameter impacts and sensitivities. For example, the same metrics used in Zhang et al. (2015). The best parameter configuration in the paper can not only improve the model performance of the Grid-point Atmospheric Model of IAP LASG version 2 (GAMIL2), but also ensure the radiation balance. However, our experimental data on CAM5 shows that the best parameter configuration of the model is very likely to introduce radiation imbalance. This may indicate that it is difficult to optimize multiple variables under radiation balance constraint in a well-tuned model, due to the structural inadequacy in the model physics. As mentioned in Qian and Yang's papers, the structural and parametric problems associated with physical parameterizations are often tied together in weather and climate models. And the difficulty of simultaneous optimization of multiple variables also highlights the need of characterizing model structural uncertainty. Moreover, we add the recent paper Yang et al. (2019) in our reference list.

2. The penalty term applied in the cost function (eq. 6) is a key element of the optimization method the authors presented here. I am wondering what the optimization results will be if the net radiation budgets at TOA are directly included in the synthesized metric that is used for optimization. I think by doing this, the best members would be located in some areas between

the red and black markers in Fig. 2. The authors can check the results by using the experiments that have already been completed with constrained or unconstrained algorithm.

Reply: Thanks for your comments. It is critical for optimization results. In this work, our idea is to use radiation balance as a strong constraint, since only when it is satisfied the model can run stably for a long time. If the net radiation budgets at TOA are directly put into metrics, it is possible that the overall performance indicators will be improved, but the radiation is still unbalanced. The importance of radiation balance has not been emphasized. As for the tuning process, the searching path for optimization with the method the reviewer suggested is different from that of our algorithm (as mentioned in the review), and the final optimization results need to be evaluated carefully. In the future work, we will continue to pay attention to the impact of different constraint forms. For example, the multi-object optimization method by using radiation constraints as one separated optimization object, or using a smoother constraint expression (such as an index or a quadratic expression) and designing smart searching strategy to avoid the balance-broken optimized results.

3. P2L31-32, please check the grammar.

Reply: We change it to "This paper takes radiation balance as an example. According to the Earth's energy conservation theory, the absorbed solar radiation is approximately equal to outgoing longwave radiation at the top of model."

4. P3L18, "into to"?

Reply: We change it to "into".

5. P4L15, "it has been identified as the second most influential parameter in climate", second most influential parameter for which aspects of climate?

Reply: The cloud ice sedimentation velocity has been identified as the second most influential parameter in climate sensitivity experiment, in which the simulated performance of Surface Temperature (TAS), Seasonal Cycle in TAS (JJA - DJF), SW upward radiation at TOA, LW upward radiation at TOA, Total Precipitation, etc. is used as the criterion (Sanderson et al., 2008). This sentence is revised as follows: "it has been identified as the second most influential parameter in sensitivity experiments related to temperature, radiation, and precipitation, etc (Sanderson et al., 2008)."

6. P4L22, is 1.9*1.9 a standard option of resolution in CAM5? F19 should correspond to a resolution of 1.9*2.5.

*Reply: Thanks for pointing out this problem. We are very sorry for this mistake. In the experiments, we use the "-compset FAMIPC5 -res f19_f19". And we have corrected the description of the resolution to 1.9*2.5.*

7. P4L26, The synthesized metric was based on MSE, while the abstract (i.e. P1L15) said it used global mean values. Please make the statements consistent.

Reply: Thanks for pointing out this problem. We change abstract to "in terms of a synthesized *performance metric using normalized mean square error of radiation".*

8. Eq. 3, outputs from the control run were used to normalize model errors for different variables. So will the optimization results be different if a different set of parameter values were used in the default configuration?

Reply: The model performance optimization percentage of this paper is relative to the current default experiment. If the default parameter configuration is changed, the percentage of performance improvement may be different. The intent of the optimization method in this paper is to further improve the performance of the model under the current configuration conditions. This uncertain parameter optimization method generally improves the performance of the model by about 5% to 10% under the default parameters provided when the model was released. For example, we have increased the radiation balance constraint here, and the performance of CAM5 has been improved by about 6%. In Zhang et al. (2015)'s paper, GAMIL2 performance have been enhanced by about 9%. These results prove that the effectiveness of our optimization method is not accidental. Especially for a new model, our method can help the model experts to find a set of better parameters and can also promote the development and improvement of the model.

9. P6L10, "leading" or "leading to"?
Reply: We change it to "leading to".

10. P7L7, "When the time scale is shorter with unchanged cloud bottom convective mass flux", what is the meaning of "unchanged cloud bottom convective mass flux"? Shorter time scale should lead to stronger mass flux at cloud base.

Reply: *Nice insight! Yes, the shorter time scale should lead to stronger cloud-base mass flux based on the closure in deep convection parameterization. We are sorry for this mistake, and what we were going to state is that shorter time scale with unchanged CAPE would lead to the stronger cloud-base mass flux. This sentence has been revised as follows: "When the time scale is shorter with less changed CAPE, the increased cloud-base mass flux would help to enhance the convective precipitation."*

Reference

Zhang, T., et al. (2015). An automatic and effective parameter optimization method for model tuning, Geosci. Model Dev., 8, 3579–3591, doi.org/10.5194/gmd-8-3579-2015, 2015.

Sanderson et al.(2008). Towards constraining climate sensitivity by linear analysis of feedback patterns in thousands of perturbed-physics GCM simulations, Clim. Dyn., 30, 175–190, 2008.