

Dear the reviewer for the manuscript entitled "Description and basic evaluation of simulated mean state, internal variability, and climate sensitivity in MIROC6" by Tatebe et al.

We would like to thank the reviewer for taking the time to carefully read our manuscript, for several very valuable suggestions and English grammatical corrections. We have much revised our manuscript and answered all the comments given by the reviewer. In the separate reply letter uploaded as a supplement, point-by-point responses to the reviewer's comments and how we revised the manuscript are described, referring to the revised manuscript and the manuscript with revision history which were also uploaded as supplements.

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**Response to reviewers' comments on " Description and basic evaluation of simulated mean state, internal variability, and climate sensitivity in MIROC6" by Tatebe et al.**

**Reply to the reviewer #1**

**General comments**

This paper describes MIROC6, a new climate model aiming at participating in CMIP6, by developing the previous climate model MIROC5 that participated in CMIP5. Following the description of the model formulation focusing on the changes from MIROC5 together with the model's tuning procedure, the model's mean climate and variability in the preindustrial experiment are presented. Furthermore, climate sensitivity of the model and reproducibility of the past climate change are also evaluated. Although the manuscript is comprehensive, it is well-constructed and well-documented. Climate variabilities of the model has also been widely evaluated, which brings many useful scientific knowledges for future studies using this model. In addition, model tuning procedure is also described in detail, which contains very useful information to be helpful for climate model developers. It is recommended that it will be published after minor revisions.

We would like to thank the reviewer for taking the time to carefully read our manuscript, for several very valuable suggestions, and English grammatical corrections. We would like to answer the questions given by the reviewer and to describe how we have revised our manuscript point by point. Please note that our replies are written in red letters in this reply letter.

**Reply to specific comments**

L.355: The main parameters...in which the uncertainty of the climate sensitivity...

Does this mean that the model is tuned for a climate sensitivity as a result? If so, it is desirable to describe what is the target climate sensitivity (2.5 K?) for the tuning.

Here, the authors just wanted to mention that parameters listed in Shiogama et al. (2012) are mainly used for a tuning procedure. Climate sensitivity was not a tuning target. In the revised manuscript, we have rephrased the sentence as "The main parameters used in our tuning procedures are chosen referring to a perturbed parameter ensemble set made by Shiogama et al. (2012) in which parameter sensitivity to cloud-radiative processes is examined". Please see the lines 374 -377 in the revised manuscript.

L.374: interactions between anthropogenic aerosol emissions and...

“emissions” do not interact with cloud-radiation processes. Do you mean “aerosolcloud interaction”? Rephrase it.

In the revised manuscript, the words are replaced by "aerosol-cloud interaction". Please see the lines 402-403. Thank you for your suggestion.

L.380: a present-day run

Is the run a fixed SST? Since the value of  $-0.9 \text{ Wm}^{-2}$  by IPCC (2013) is for ERF, it should be evaluated by radiation change under the condition that SST does not change. Please explain.

The tuning was done under a coupled mode, namely, SST is not fixed. In the revised manuscript, we added the sentence "Note that MIROC6 in a coupled mode is used in this tuning procedure, and thus the sea surface temperature (SST) is not fixed. The estimated cooling effects here are not strictly the same as the effective radiative forcing estimated in IPCC (2013). However, by the present tuning procedure, the global-mean surface air temperature (SAT) change after the mid-19th century is well reproduced in the historical runs by MIROC6 (details are discussed in Section 4)". Please read the lines 411-416.

L.397: the global-mean ocean temperature shows a larger trend of...

On average there is  $1.1 \text{ Wm}^{-2}$  heating. Are these trends consistent with the radiation budget?

Discussions on the relationship between the warming trend of the ocean temperature and the TOA radiation budget/ocean heat uptake have been added in the revised manuscript. And we also added the explanation on the heat energy inconsistency between the TOA radiation budget and the ocean heat uptake in association with the model imperfection. We have rephrased the last paragraph of Section 2.5 as "The trend of the global-mean ocean temperature in the later period suggests slight but continuous warming of the deep ocean. The radiation budget at the TOA is  $1.1 \text{ Wm}^{-2}$  downward on average (linear trend of  $9.5 \times 10^{-3} \text{ K/100 yr}$ ) and the net heat input at the sea surface is  $0.32 \text{ Wm}^{-2}$ . The deep ocean warming is explained by the net heat input. Note that there is about  $0.78 \text{ Wm}^{-2}$  inconsistency between the TOA radiation budget and the ocean heat uptake. This heat energy inconsistency is due to that internal energy associated with precipitation, water vapor and river runoff is not taken account in the atmospheric and land surface component in MIROC6 and that these waters with no temperature information implicitly set their temperature to the SST when they flow or fall into the ocean. Perpetual melting of the prescribed Antarctic ice-sheet with invariant ice thickness, which is occurred due to the warm SAT bias in the Antarctic region (details will be discussed in Section 3.1.3), is also a cause of the heat energy inconsistency".

L.477: consistent with the observed value of  $-0.81 \text{ Wm}^{-2}$ .

The observed value is  $-0.8 \text{ Wm}^{-2}$  because the system is warming in the present-day conditions. Ideally it should be  $0 \text{ Wm}^{-2}$  in the preindustrial conditions. The radiation imbalance of  $-1.1 \text{ Wm}^{-2}$  is in the marginally acceptable range.

Thank you for your comment and the authors agree with the reviewer. In the revised manuscript, we added the sentence "However, the observed value is estimated in the present-day condition. Ideally, the model value in the preindustrial condition should be  $0 \text{ Wm}^{-2}$  and is in the marginally acceptable range". Please read the lines 521-523.

L.542: increase in precipitation (Figs. 8ce)

Increase in precipitation is found only in the North Pacific.

In the revised manuscript, the corresponding sentence is rewritten as "is accompanied by an associated increase in precipitation, especially in the North Pacific (Figs. 8ce)". Please read the lines 594-595.

Fig. 13 and 14: It is easy to understand if the biases are indicated by color shadings.

Following the comments, we have redrawn Figs. 13 and 14, and corresponding descriptions on ocean climatological hydrography have been rephrased partly in the revised manuscript. Please read the 1st and 2nd paragraphs of Section 3.1.2. Also, the revised manuscript with revision history is useful for checking the revision.

L.595: the Pacific sector (Figs. 13a-c) → "the Atlantic sector (Figs. 13a-c)" or "the Pacific sector (Figs. 14a-c)"

Carefully checking zonal-mean ocean temperature and salinity in the Pacific sector, the authors considered that representation of the northward intrusion of Antarctic Intermediate Water in the Southern Hemisphere in MIROC6 is not better than in MIROC5. In the revised manuscript, we deleted the sentence "Meanwhile, the northward intrusion of Antarctic Intermediate Water in the Southern Hemisphere around the 1000 m depth is better simulated in MIROC6 than in MIROC5, especially in the Pacific sector (Figs. 14a-c)".

L.622: better representation of cloud physics

How does cloud physics relate to trade wind? It seems to me that they are incoherent.

In the revised manuscript, we have described the details about the relationship between the stronger trade

wind and cumulus processes referring to the stand-alone AGCM experiments as "However, the thermocline depths in the western tropical Pacific are still larger in the models than in observations and are attributed to the stronger trade winds in the models. When both of MIROC6 and MIROC5 are executed as stand-alone AGCMs with the prescribed SST obtained from observations, the overestimate of the equatorial trade winds also appears due to overestimate of the upward winds over the maritime continent associated with deep cumulus convection and the resultant strengthening of the Walker circulation over the equatorial Pacific. Better parameterizing deep cumulus convection in the models could be required". Please read the lines 677-684.

L.648: present-day conditions. Specify the years of the observation. (1980-2009)?

In the revised manuscript, the years are specified as "while observations are taken in present-day conditions of 1980–2009...". Please read the lines 7070-711.

Figure 18: Adding a plot for the observed sea surface height will be helpful.

A figure of observed sea level height has been added as Fig. 18a and the reference for the observation data has been written in References (please see Rio et al. 2014).

L.687: strengthening of the Aleutian low lead to increase in southward transport...

I could not understand why the strengthening of the Aleutian low lead to increase in southward transport along the west coast.

We have rephrased the corresponding sentence as "Warm SAT and SST biases along the west coast of the North America are smaller in MIROC6 than in MIROC5. The reason is that an increase of southeastward Ekman transport in the eastern subarctic North Pacific due to the strengthening of the mid-latitude westerly jet (Fig. 10) and the Aleutian low tend to cancel out the relatively warm water supply from the subtropics to the subarctic region by the surface geostrophic current". Please read the lines 7555-759.

L.919: first 20 years

By the CMIP6 protocol, 150 year-long simulations are requested. ECS may change according to the length of analysis period. Describe why you made analysis for the first 20 years.

The authors agree that analysis for the first 20 years is not consistent with the CMIP6 protocol. Following the comment, we repeated the analysis using the first 150-yr-long data, and confirmed that the results were similar to the ones based on the first 20-yr-long data. The manuscript is updated based on the present

analysis. Please read Section 3.3 of the revised manuscript. Also, Figures 30, 31 and Tables 2 and 3 have been replaced by the revised ones.

L.939: are consistent with...→ “are correlated with”

In the revised manuscript, "are consistent with.." was replaced by "are correlated with". Please read the lines 1015-1019.

L.998: subarctic (tropical) region are underestimated (overestimated) in MIROC6 (MIROC5)

“subarctic (tropical) region are underestimated in MIROC6 (MIROC5)” or “subarctic region are underestimated (overestimated) in MIROC6 (MIROC5)”

Following the reviewer's comment, we have rewritten the sentence as "Signals associated with AMO in the subarctic (tropical) region are underestimated in MIROC6 (MIROC5)". Please read the lines 1073-1074. Thank you very much.

L.1053: which is consistent with...in observations → which is in the acceptable range.

In the revised manuscript, the corresponding sentence is rewritten as "the global TOA radiation imbalance in MIROC6 is about  $-1.1 \text{ Wm}^{-2}$ , which is in the acceptable range of observations". Please see the lines 1128-1130.

## Technical corrections

L.185: is insufficient → delete : Deleted.

L.229: in order to to → in order to : Fixed.

L.433: , which has a shallow...: It is unnecessary as it already described in section 2.1.

The corresponding sentence was deleted in the revised manuscript.

L.481:  $2.9 (3.1) \text{ Wm}^{-2}$  in MIROC5 →  $2.9 (-3.1) \text{ Wm}^{-2}$  in MIROC5: We have added "-" in front of "3.1".

L.490: better simulated in MIROC5 → better simulated in MIROC6 : Fixed.

L.922:  $-1.5 \text{ Wm}^{-2}$  →  $-1.5 \text{ Wm}^{-2}\text{K}^{-1}$  :Fixed. Thank you for your comment.

L.987: , qualitatively → delete. : Deleted.