Geoscientific
Model Development
Discussions

Interactive comment on "Setup of the PMIP3 paleoclimate experiments conducted using an Earth System Model, MIROC-ESM" *by* T. Sueyoshi et al.

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Reply to the comment by anonymous referee 2

We sincerely thank the referee for providing a thorough review and constructive comments. We are also very grateful for pointing out our many language mistakes in the paper. We agree that changes and clarifications are necessary to improve the manuscript. We propose to make the revisions outlined below for submission to Geoscientific Model Development.

In the following answers, all reviewer's comments are in blue, and our answers are in black.

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Discussion Paper

As for language correction, all correction will be made as reviewer's suggestion in the revised manuscript, and then will ask to the professional English proofreading service again.

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Answer to the Specific comments

1 Introduction

The term "ESM" means many different things. Some models are considered an "ESM" even if carbon cycling is prognostic in vegetation but prescribed CO_2 in atm, etc. Somewhere in this first section please describe better what you mean by it. . .I believe (but am not certain!) you mean only models for which all CO_2 cycling (including atmospheric CO_2) is prognostic.

We considered that "ESM" or "Earth System Model" is a synonym for coupled climate models with biogeochemical components, but after considering the referee's indication, we agree that the capability of prognostic carbon cycle treatment is essential. We probably don't call the climate models with diagnostic biogeochemical component.

So following the suggestion, we revised p.2529 l.1-3 as follows:

> In this paper, we consider the ESM as coupled climate models with biogeochemical components, which are capable of treating carbon cycle on-line with other climate component, in other word, climate models which can predict the atmospheric CO_2 concentration. Among such ESMs, the models of higher complexity, which are Atmosphere-Ocean general circulation models (AOGCMs) coupled with biogeochemical components, are now available for paleoclimate simulations.

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The discussion of the LM (p. 2531) leaves out all references to volcanoes!?! This was a very important part of this time period. It may be that decadally paced volcanic activity beginning 13th century helped start the Little Ice Age (e.g. Zhong, Y., G.H. Miller, B.L. Otto-Bliesner, M.M. Holland, D.A. Bailey, D.P. Schneider, and A. Geirsdottir, 2011: Centennial-scale climate change from decadally-paced explosive volcanism: A coupled sea ice-ocean mechanism. Climate Dynamics, doi:10.1007/s00382-010-0967-z.).

Following the suggestion, we add the sentences as follows in p.2531 l.10:

> Several very large volcanic eruptions occurred during this period, causing the global cooling as a response to the radiation changes. Combining with the reconstructions, they serve as ideal test cases to investigate the response of climate models. Volcanic activity may also play a key role to reproduce LIA cooling, by decadally paced volcanic activity starting around 13th century (Zhong et al., 2011).

2 Model and common settings

This section (pp. 2532-2534) reads essentially like a string of acronyms. These might be necessary for anyone who wants to look up a specific component of this complex model. However the section is lacking a overview paragraph describing a basic lineage of the MIROC-ESM or similarities/differences to preceding version and thus all the acronyms lack a context. Why not just use older version? What changes were implemented (generally - with references for those who want the details) and why?

Following the suggestion, we revised the sentences p.2532 l.6-9 as follows:

> Based on MIROC3.2, which is previous version of MIROC used for the

CMIP3 experiments, two versions are now available as AOGCM: bug-fixed version MIROC4 and new generation model MIROC5. MIROC-ESM is another brach of MIROC series based on MIROC4, in which ecosystem components are introduced as an ESM. MIROC-ESM consists of an atmospheric general circulation model (MIROC-AGCM 2010), including an on-line aerosol component (SPRINTARS 5.00), an ocean GCM with sea-ice component (COCO 3.4), land surface model (MATSIRO), and terrestrial and marine ecosystem components. These are interactively coupled as illustrated in Fig. 1.

3.1 Pre-industrial control experiment

The setup lists details (e.g. orbital parameters and GHG levels) but lacks a sentence or two putting them into context. For example, these orbital parameters result in higher/lower solar irradiance compared to 20thC, Holocene, LM, etc.

We have added the sentences to p.2534 l.23 (end of the paragraph), to explain the impact of changes in those parameters:

> Although these orbital parameters have considerable effect on longer time scale, it has had little impact on annual mean insolation in the time scale shorter than the millennium. According to IPCC AR4, summer insolation decreased by 0.33 W/m2 at 45Ňover the millennium, winter insolation increased by 0.83 W/m2 (Goosse et al., 2005), and the magnitude of the mean seasonal cycle of insolation in the Northern Hemisphere decreased by 0.4 W/m2.

Spin up procedures are not clear. For example, how was the PI run initialized? Support "linear trends became insignificant" with a plot or two. Likewise, why only use

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the last 100 yrs of a 630 yr simulation when some climate modes may need longer than that to define (e.g. thermohaline circulation, the Atlantic Multidecadal Oscillation) and particularly when you will be comparing (albeit in detail in other publications) to a 1000+yr LM simulation and presumbably would want similar basis for statistics? Likewise, the 6ka temperatures are compared to the PI starting at the branching time (yr 250 - p. 2537) so more than the last 100 yrs of the PI are used?

We are sorry for confusing explanation. Detailed spin-up procedure of PI is already presented by one of the co-author of this paper as Watanabe et al. (2011). We didn't mention the detail if it was already reported in this previous paper. We realized that the reference to this paper is missing in this section (and in the model performance section as well), so revised the p.2535 ll.2-5 as follows:

> Initial condition for PI experiment was prepared in stages. The procedure is presented in detail by Watanabe et al. (2011), the description paper of MIROC-ESM. Here we outline the procedure briefly in Fig 3a. Spin-up was started with the version of MIROC-ESM with 20 vertical layers in the atmosphere. 380-yr integration was performed as an atmosphere-ocean coupled system, followed by a 50-yr integration with an atmosphere with 80 vertical layers.

Expression of "last 100 year" is for the comparison between the time slice experiments, LGM-PI and 6ka-PI. The period for analysis is set to 100 years because CMIP5/PMIP3 protocol requires 100 years outputs for these experiments. As for PI, more than 500 years is the requirement of the protocol, and we submitted the whole 630 years time series. As the referee pointed out, it is still not long enough to compare with LM, so the extension of the PI experiment is planned for future work.

We are not yet sure if we should include the explanation of the detailed spin-up procedure of PI in this manuscript, but attached the sea-ice and 2m air temperature trend

during the last phase of the spin-up. This figure can be referred from p.2535 l.10.

A more detailed description of the model performance in the PI experiment is needed to put the results of the paleo-simulations in perspective. For example, investigating the climate sensitivity of the LGM through modeling simulations requires an understanding of the climate sensitivity of present-day model to make adequate comparisons. The authors state that the PI simulation shows a "reasonable SST distribution" that claim that global PI SST is slightly cooler than observations because it's a simulation from mid-1850s. The pattern of SST differences in Figure 4, however, suggest that differences between obs and model are far more complicated that this and must be related to ocean circulation. Furthermore, a comparison with a reanalysis based product such as that described by Hurrell et al., 2008 (Hurrell, J. W., J. J. Hack, D. Shea, J. M. Caron, and J. Rosinski, 2008: A new sea surface temperature and sea ice boundary dataset for the Community Atmosphere Model. J. Climate, 21, 5145-5153) might give a more accurate perspective of the basic differences in SST between the MIROC-ESM and observationally-based SSTs.

Again, we aplogize the missing reference to Watanabe et al. (2011). Detailed analysis on model performance is presented there, including air temperature, SST, sea ice, and other aspects. The author is wondering whether to include the similar statement on the model performance or not.

Mentioning the comparison between PI result and modern observation, we have revised the first paragraph of section 3.1.3. as follows:

> The climate of PI experiment is briefly presented comparing with the modern climate in this section. Although PI simulation is not necessarily comparable with modern-day observations, the characteristics of the PI climate is briefly introduced, since PI is commonly used as a baseline to compare

the paleoclimate experiments with proxy data. A detailed comparison of a present-day simulation with modern observations was already presented by Watanabe et al. (2011) using CMIP5 historical experiment. PI mean value differs with the 20th century ensemble mean analyzed in Watanabe et al. (2011) by ca. 0.3°C in global mean surface air temperature, but spatial pattern of the bias is quite similar to each other. From these backgrounds, we discuss the PI-observation in the followings.

The sentence in p.2535 l.16 is revised as follows:

PI simulated reasonable SST distribution, though the biases appear in Pacific convergence zone, Kuroshio region, the eastern equatorial Pacific.

Mention to the precipitation is revised as follows (p.2535 l.22-24):

The precipitation is underestimated along the South Pacific convergence zone (SPCZ) and over Central America, whereas it is overestimated over the Maritime Continent and the north-western Indian Ocean. These shortcomings are similar to those in our previous model (MIROC3.2) because these two models have almost the same atmospheric physics components. In comparing with paleoclimate, reasonable representation of the ITCZ and precipitation distribution of the monsoon area is positive.

How is the sea ice initialized and/or set-up? This is important here as the authors state that the Antarctic sea-ice extent is reducing slowing in the model yet it isn't clear exactly what this means. A specific year in the 630-yr integration? Or from intial conditions? Also - is it reducing on an annual or season basis? A time series showing this reduction in Antarctic SIE would be helpful.

C1467

Sea ice reduction is slowly started from initial condition, superimposed by event-like decrease occurred during the integration. Reduction is on annual basis, with the very long-term trend. Time series of sea ice in the LM experiment is attached for the purpose of reference. As for the sea ice treatment in the model is described in Watanabe et al. (2011): it is based on a two-category thickness representation, zero-layer thermodynamics (Semtner, 1976), and dynamics with elastic-viscous-plastic rheology (Hunke and Dukowicz, 1997).

3.4 LM

The term "anthropogenic land use" is used often throughout the paper and in particular here in the LM section in a manner I find very confusing. Much better would be to state "land use for 1850" or "20thC land use" or whatever it was ("anthropogenic" means human-caused. It has no exact time frame - although most commony used for time period 1850-2000+ in modeling circles. . ..). It's use here is misleading - using "anthropogenic land use" - vegetation is not prognostic? Or is? Carbon cycle is but vegetation is not? Land use changes over period humans were thought to significantly modify it (maybe 1750 onwards, or maybe not ....maybe 1850....). Then at the very end on p. 2543 it is stated that "anthropogenic land use was assumed to be unchanged". Over the entire Last Millennium? 850-2005? Really?

We agree to the point that use of "anthropogenic land use" was confusing. Following the referee's suggestion, we avoid using "anthropogenic" and specify the time frame as "land use for 1850" if needed. In MIROC-ESM, this land use means the cropland, and the vegetation on crop field is calculated online. However, as described in section 2, land index is not changing on-line.

The land use is actually assumed to be unchanged, over the entire Last Millennium. Experiment with the land use change remains to be done as future work.

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Answer to the Technical corrections

We agree to the point. We have revised the manuscript as follows:

> Paleoclimate experiments using contemporary climate models are effective
> measure to evaluate climate models.

Following the suggestion, we have revised the sentence (l.6-7) as follows:

> Paleoclimate events can be a suitable benchmarks to evaluate ESMs. The
> variation in aerosols associated with the volcanic eruptions provide a clear
> signal in forcing, which can be a good test to check a response of climate
> model to the radiation changes. The variations in atmospheric CO2 level or
> changes in ice sheet extent can be used for evaluation as well.

We have revised the sentence (l.10) as follows:

> ... using MIROC-ESM, an ESM based on a global climate model MIROC
> (Model for Inter-disciplinary Research on Climate).

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p. 2530 line 9 verb tense 9 - I recommend keeping the same tense ("are" rather than "were")

As suggested, we have revised the sentence as follows:

> The LGM is characterized by a very cold and dry climate. The Laurentide and Fennoscandian ice sheets cover North America and Northern Europe (e.g. Denton and Hughes, 1981), atmospheric greenhouse gas (GHG) levels are reduced, and dust transportation is enhanced. (e.g. Barnola et al., 1987; Petit et al., 1981). Land vegetation responds as well: subtropical deserts expand and forests generally regress (Colinvaux et al., 1996, 2000; Marchant et al., 2009). At high latitudes, boreal forests migrate southward, replaced by tundra and grassland (Prentice et al., 2000; Tarasov et al., 2000; Ray and Adams, 2001; Harrison and Prentice, 2003). Due to these significant differences from today, various aspects of the climate can be investigated.

p. 2529 line 17 "vegetation" or "vegetation activity"? "activity" unusual word choice with "vegetation"

As suggested, we used "vegetation".

p. 2529 lines 23-24 delete "enhancement" and replace with something like "sufficiently high Holocene precipitation to . . ."

Following the suggestion, we have revised as follows:

> ... but most of the models failed to simulate sufficiently high Holocene precipitation to maintain a vegetated Sahara.

p. 2532 lines 5-6 This definition of MIROC should come at first use and deleted here

We have revised as suggested.

p. 2532 lines 21-24 It's not at all clear what the differences or similarities are between the "full version" MIROC-ESM and the "CHASER" are except one uses more computational resources. . .
We agree that the sentence is not clear. We have revised as follows:

> Due to the limited computational resources, part of the CMIP5 experiments were performed with full version of MIROC-ESM, in which atmospheric chemistry component (CHASER) is coupled. Other experiments, including the paleoclimate experiments described in this paper, were performed without CHASER.

p. 2535 lines 5-9 Had to read this sentence a couple of times. . .2nd half is incomplete. Reorder such that the list of "cycle components" comes in parenthesis after "components".
We apologize for poor writing. We have revised the sentence as follows:

> In the course of the spin-up runs, representative states and fluxes in the physical climate (surface air temperatures, radiation fluxes at the top of the atmosphere, strength of the thermohaline circulation, sea-ice extent) and carbon cycle components (soil and vegetation carbon storage) were monitored.

p. 2536 line 9-10 I believe you mean that no volcanic activity was used in forcing 6 ka simulation, not "volcanic changes" which imply constant, but not necessarily zero, volcanic activity?
Following the suggestion, we have revised the sentence as follows:

> No volcanic activity was considered in forcing 6 ka.

p. 2536 lines 17-19 This is confusing. PI I thought was forced at constant (non-transient) conditions, including land use types, yet these sentences imply that land use changed during this simulation. "initialized" and "steady state" are at odds - "initialized" means a one-time initialization, whereas "steady state" implies keeping at a steady state with time. . . I'm guessing initialized with land-vegetation types assumed relavant to 6 ka and derived from ?

We are sorry for confusing explanations. PI is forced at constant conditions as you mentioned. The sentence here is saying about the land surface type "cropland". MIROC-ESM has "cropland" as one of the surface type, and PI condition has it in some grids. Here the initialization is aiming to eliminate them.

> As the land surface condition in the PI experiment is referring the condition in year 1850, some grids are classified as cropland. To perform the 6ka experiment, we need to replace such grid with the natural vegetation and to spin-up the terrestrial ecosystem to a steady state without such anthropogenic land usages.

p. 2536, lines 21-24 to p. 2537 lines 1-2 Very confusing and Figure 3 doesn't help at all. . .I don't understand at all how vegetation was initialized or carbon-cycle spun up for 6 ka.

We have revised the sentences (p. 2536, l.21 to p. 2537 l.2) as follows.

> Firstly, 100 yr of integration was performed using the 6 ka GHG concentrations and orbital forcing using MIROC-ESM. Using the last 25 years of this output, we ran the off-line model to spin-up the variables of terrestrial ecosystems for 2000 simulation years, with the cycling 25 years climate forcing. This "cycling 25 years" procedure is following the protocol of C4MIP (Fung et al., 2000; Cox et al., 2002). Then the variables were merged back

into the restart data of MIROC-ESM, followed by a spin-up of 180 simulation years under the 6ka forcings (Fig. 3b).

p. 2537 line 17 substitute "while" for "whilst"
We have revised as suggested.

p. 2540 lines 5-11 "Initialization" implies a one-time starting point, however this has "initialization process" which sounds more like a spin-up?. . ...Clean up language/description for clarification.
We have revised the usage of "spin-up" and "initialize" through the manuscript. This part is updated as follows:

> The variables of terrestrial ecosystem was spun-up using the offline land ecosystem model, as used in the 6 ka experiment. The terrestrial variables were calculated for 2000 model years under the LGM climate forcing to obtain a steady state. During this process, the land use (cropland) is also reset to the potential natural vegetation. Distribution of the ice sheets (also a forcing data) was referred for suppressing the new vegetation and accumulations of soil carbon on ice grid.

p. 2541 line 6 eliminate "peak value of AMOC"
We have revised as suggested.

p. 2541 line 7 add "as suggested by the proxies"
We have revised as suggested.

p. 2543 lines 5-19 "Spin-up", "initial state" seem to be interchanged (and should not be).
We revised the section as follows:

C1473

As is the case in the 6 ka experiment, pre-industrial physical fields (i.e. from PI experiment) of the atmosphere and ocean were used for the initial condition of LM spin-up. Since the forcing conditions (orbital parameters, solar irradiance and GHG concentrations) are quite similar between the pre-industrial period and 800s, PI can be regarded as a initial condition for the 850 AD condition.

p. 2543, lines 12-14 "CO2 concentration was set to be free" then "CO2 concentration was reset" These statements contradict one another.
We revised the section as follows:

Then CO2 concentration was set to be free, so that the model-calculated value is used in the radiation process of the atmosphere component. Initial value of the CO2 concentration for "CO2 free" experiment was reset from 298.71ppm to the level of 279.3ppm (i.e. value at year 850; Joos, 2007), as the transient simulation was started. This resetting procedure was performed to maintain consistency with the reconstructed value, and also to avoid unnecessary CO2 feedback. It breaks the conservation of the total carbon in a precise sense, but the effect is small enough to neglect in evaluating the total budget.

p. 2544, line1 Time period from which anomalies in Figure 12 are calculated are different in the text (this line) and in Figure 12 caption. Text states 1961-1990 and Figure caption states 1970-2000.
We are sorry for mistakes. Text was just wrong, and figure caption is also not precise. The period should be 1971-2000.

p. 2544, line 11 re-word "low-pass characteristics"
We have revised the sentence as follows:

Considering that the proxy data cannot record the high-frequency variations, ...

p. 2544 line 18 substitute "large" or "very large" for "huge"
We have revised as suggested.

p. 2544 lines 21-25 Reword. Solar irradiance is not "visible" at all - but the effects are! Volcanic aerosols do not "control" surface temperature but they do effect them, or influence them, etc. Likewise "flat" applies to a line segment on a graph, perhaps, but not solar forcing. Perhaps "relatively constant".
Following the suggestion, we have revised the sentence as follows:

Comparing the simulated temperature anomaly with the forcing data (panel a and b in Fig. 14), it is clear that volcanic aerosols have strong influence on the surface air temperature, while the solar irradiance has minor effects. Under the current set-up of the model, LM climate variations should depend mainly on those two types of forcing. The faint LIA is considered to be due to the relatively constant solar forcing.

Figures.

Figure 12. panels (a) and (b) are mislabeled in caption (or in reverse order). Here panel (a) is volcanic forcing and (b) is solar (and is stated the other way around in caption).
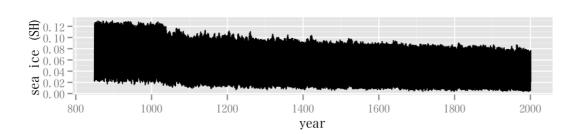We are sorry for mistake. We have corrected the figure caption.

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Fig. 1. Time series of sea ice extent in LM experiment