We thank the two reviewers for providing precise and valuable feedback on our manuscript. Our complete response with a point-by-point reply to the comments is below in this document. The reviewer's comments are indicated in black text, and our answers follow in blue text. The revised sentences in the manuscript are indicated in red text.

We have applied major changes in the experimental design based on reviewers' suggestions. In the phase after snowball onset (subsection 2.4 Experimental design 2: post-snowball onset), we apply three changes to the model settings to obtain more realistic snowball climates.

1. Wind stress over the ocean was turned off after the snowball onset (TSI091 and TSI094).
2. All land grid (except modern Greenland and Antarctica) was set to bare soil after the snowball onset.
3. The minimum turbulence coefficient in the atmospheric boundary layer over the ocean was increased by a factor of 50 (same experimental design of TSI094mod in the original preprint). This change is applied solely to prevent a model crash.

We were able to get the transient evolution of snowball ocean circulations in this setting. We found that the meridional overturning ocean circulations resumes in ~500 years after the snowball onset because of salinity flux at the sea surface (Figure 2), and found that the MOC streamfunction in the steady-state snowball were different from the originally submitted manuscript (Figure 5c).

Still, the simulated atmospheric circulations (Hadley circulation and precipitation patterns) differed from those in previous studies. We address this issue by conducting an additional experiment (TSI094SENS) by reducing the snow albedo. We find that the reduced snow albedo leads to the Hadley circulation and net precipitation pattern that more closely match those of previous studies.

In summary, we apply major changes in the manuscript:

- All figures including TSI094 or TSI091 were changed using this new experimental design.
- We have deleted previous experiments with the presence of air-sea momentum flux and prescribed ice sheet over the whole continents.
- We have changed the method, results, and discussion sections accordingly.

Response to reviewer #1:

The authors investigated the evolution of climate and ocean circulation towards a modern snowball Earth in MIROC4m, and found some phenomena that are quite different from those in previous studies, especially when the Earth has entered a hard snowball. I like the study in that their model can be continued for thousands of years after a snowball Earth has been initiated, which was not possible in CCSM3; the model would just crash in most cases (Yang et al., 2012; Liu et al., 2013). It is unclear whether this was achievable in ECHAM5/MPI-OM (Voigt and Marotzke, 2010). Stable snowball simulations are certainly possible in ICON-ESM (Ramme and Marotzke, 2022), but it has not been used to investigate in detail the evolution of oceanic and atmospheric circulation. Therefore, there is an opportunity to find something new from the simulations done by the authors using MIROC4m. However, to my understanding, the important phenomena found by the authors so far are mostly artefacts due to inappropriate settings in the model. These problems will be listed in detail below and because of which, I think they will have to redo some of the experiments and the corresponding analyses.

Thank you for carefully reading and providing us with valuable comments. We have addressed concerns by changing experimental design in the revised manuscript:

1. Wind stress over the ocean was turned off after the snowball onset (TSI091 and TSI094).
2. All land grid (except modern Greenland and Antarctica) was set to bare soil after the snowball onset.
3. The minimum turbulence coefficient in the atmospheric boundary layer over the ocean was increased by a factor of 50 (same experimental design of TSI094mod in the original preprint). This

change is applied solely to prevent a model crash.

1. They found that there would be a strong nearly hemispherically symmetric MOC (Fig. 5c) even if the thickness of sea ice is more than 200 m thick (Fig. 4). I think this is due to the unrealistically large wind stress felt at the ice-ocean interface. This wind stress will cause large poleward Ekman transport off the equator and thus strong upwelling at the equator, which will drive strong and deep MOC when vertical stratification is absent. This MOC is an enlarged version of the wind-driven subtropical cell (called STC), which is only ~500 m deep under normal conditions (e.g., Fig. 3d). The authors recognized the limitation in this stress but probably did not realize how much their results would be affected by this drawback. I do not know under how thick sea ice the ocean should not feel the wind stress anymore, but sea ice of 200 m thick (like ice shelf around Antarctica) will certainly not move with wind anymore. Thus, they should better re-do the TSI094 and TSI091 simulations by fixing this limitation, in order to provide to the readers realistic results. When fixing the limitation on wind stress at the ice-ocean interface, it is probably also necessary to make the sea ice stagnant. This is still unrealistic (thick sea ice moves slowly) but would be better than the spatial distribution of ice thickness shown in their Fig. 4a (TSI094); one would expect that ice is thicker over the high latitudes than over the low latitudes as in Ashkenazy et al. (2014).

We agree that the original experimental design, which involved wind stress felt at the ice-ocean interface in the hard snowball was an extreme setting. We have changed the main experiments with the wind stress over the ocean was turned off after the snowball onset, as previous studies (Pollard et al., 2017; Ramme and Marotzke 2022). The results show the deep MOC resumes after 500 years of the snowball onset (Figure 2), indicating the salinity flux due to the sea ice production in the snowball climate is the driver of the ocean circulation. The sea ice thickness distribution exhibits more zonal than the previous setting (Figure 4), closer to Ashkenazy et al. (2014).

We have revised the method by creating a new subsection 2.4 (Experimental design 2: post-snowball onset) to clarify the experimental design:

Method (L122-129):

2.4 Experimental design 2: post-snowball onset

The climate turned into snowball state at year 430 in the TSI091 experiment and at year 1330 in the TSI094 experiment (Fig. 1). In the phase after snowball onset, we apply several changes in model settings to get reasonable snowball climates. First, the wind stress over the ocean was turned off after the snowball onset. This experimental design is in line with previous stuides, where turning off the air–sea momentum flux when the sea ice thickness exceeded 6 meters Pollard et al. (2017) or in a deglaciation stage Ramme and Marotzke (2022). The sea ice is not fully stagnant in this setting; it can move due to ocean circulation. Note that the maximum sea ice velocity under globally sea ice covered snowball climate is ~ 2cm/sec, which is one-tenth of the modern climate.

2. Another peculiar phenomenon they found is the net precipitation at the equator two are related and can be considered as one). This phenomenon is opposite to what was found in the previous study by Abbot et al. (2013). However, this is also an artefact in my opinion because they set the land surface to be glacier once the ocean is completely covered by ice. When they do this, the land surface will have smaller surface albedo (Fig. 4b) and thus higher surface temperature (not shown but can be inferred). Moreover, the land surface will become an infinite source of water vapor. This is why the land surface has a strong net evaporation (Fig. 14) while the ocean has a net precipitation. A reasonable guess is that this also causes the air to rise over land and sink over the ocean, the latter will produce a strong temperature inversion over the ocean. Therefore, I do not feel that this temperature inversion should be attributed to the turbulent coefficient in the atmospheric boundary layer, and indeed, their test with a different coefficient could not remove the inversion (Fig. 14).

Another effect of the warm land surface is to shift the rising branch of the annual mean Hadley circulation to the north of equator, clearly seen in Fig. 12. Therefore, it is not actually a good idea to set the land surface as glacier when the sea ice closes off at the equator, just letting snow to accumulate on the land surface (i.e. do not do any special treatment) is probably more realistic. The authors do not need to worry about the glacier formation on the tropical lands, they will remain thin after even a few thousands of years because the net precipitation rate is small in a hard snowball Earth. That means, the authors need to redo the simulations without setting the land surface to glacier in order to show to the readers proper picture of atmospheric circulation.

We agree with the points that net precipitation and Hadley circulation was very different from the previous study (Abbot et al. 2013). We also agree that the prescribing ice sheet over the land grid (experimental design in the originally submitted manuscript) became infinite source of water by sublimation of ice. We have changed the experimental design of post-snowball simulations (TSI094 and TSI091) by prescribing bare soil instead of ice sheet.

Method (L129-132):

Second, we set all vegetation over the land grids with bare soil after snowball onset, while the present-day ice sheet over Greenland and Antarctica were kept unchanged. The experimental design setting bare soil rather than ice sheet is preventing infinite source of water via sublimation of the ice sheet, which impacts conservation of water in the climate model.

Further, in section 3-4, we have conducted additional experiment (TSI094SENS) to further investigate the cause of the weaker sublimation in the equator. TSI094SENS experiment branches from the TSI094 at the snowball onset, and the maximum snow albedo is reduced to 0.7. The results showed that the precipitation pattern got closer to the multimodel results (Abbot et al., 2013), with sublimation in the equatorial region and precipitation strengthened in the low latitudes (Fig. 13a right). The Hadley circulation was also strengthened (Fig. 13b right). The results of the TSI094SENS suggest that the spatial non-uniformity of albedo in the current land-sea distribution can result in a different atmospheric circulation than that obtained in multi-model studies (Abbot et al., 2013), which assumed a constant albedo of 0.6.

L256-266:

The net precipitation exhibits sublimation of sea ice near the equator and precipitation in mid- and low-latitudes (Fig. 13a left). Substantial positive net precipitation occurs in mountainous areas across the continent, whereas inland areas far from the ocean experience very sparse precipitation. While multimodel studies showed net sublimation of sea ice near equator and stronger Hadley Circulations than the modern climate (Abbot et al., 2013), but our TSI094 showed net sublimation near equator is very weak and the strength of the Hadley Circulation is weaker than the modern simulation (Fig. 13 left). In the additional experiment with reduced snow albedo (TSI094SENS), the precipitation pattern got closer to the multimodel results (Abbot et al., 2013), with sublimation in the equatorial region and net precipitation in the low latitudes (Fig. 13a). The Hadley circulation was also strengthened (Fig. 13b). Overall, the simulated precipitation pattern and Hadley circulation were closer to the multimodel study, suggesting that spatial heterogeneity in the surface albedo can lead to atmospheric circulation that differs from that obtained in multi-model studies using a constant surface albedo (Abbot et al., 2013).

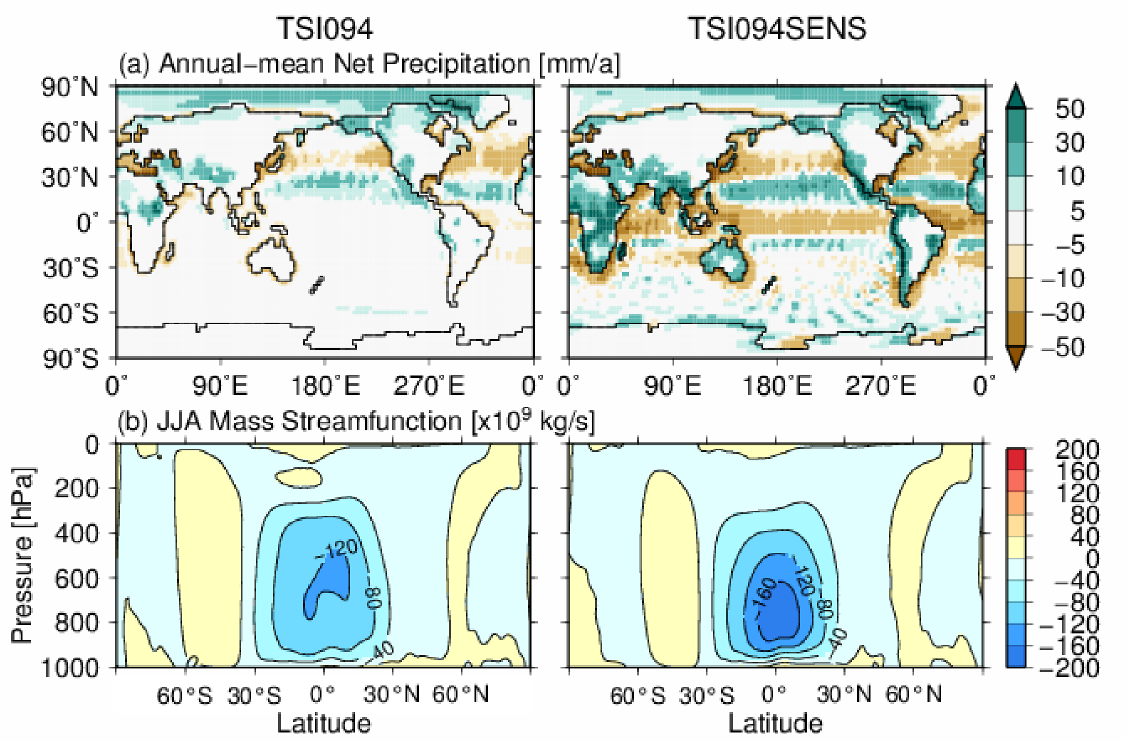

Figure 13: (a) Net precipitation, defined by precipitation minus evaporation (includes ice sublimation), (b) boreal summer meridional atmospheric mass streamfunction (10^9kg/s, positive indicates clockwise circulation) in the TSI094 and TSI094SENS experiments.

3. If the authors are willing to redo the simulations, the authors may want to look at how the snow cover changes with time over both land and sea ice; how the ocean stratification and MOC evolve, both the timescale and pattern could change significantly from those shown in the current manuscript; the gradual evolution of atmospheric circulation and how long it takes to reach equilibrium.

Thank you for your suggestion. We have analyzed land snow cover in the steady states (Figure 4). The land snow cover advances to low latitudes, but there was a substantial area without summer snow cover even after the snowball onset, since summer melting of snow exceeds snowfall. As the MIROC4m tends to have a warmer surface air temperature over the continent, we carefully discuss the potential model dependency of the simulated snow cover changes and potential impacts on the atmospheric circulations.

L191-197:

Expansion of the sea ice and perennial snow cover over the continents (Fig. 4a) also contributed to the reduction in surface albedo (Fig. 4b). In the TSI094 experiment, the global ocean was totally covered with sea ice and snow cover, which resulted in an albedo of approximately 0.85 (Fig. 4b right). By contrast, the albedo over the continent was notably smaller, with a value of ~ 0.3, corresponding to that of the bare soil. This indicates an absence of perennial snow cover over most parts of the continent, as seen in (Fig. 4a). Note that the surface air temperature over the continent, primarily in the Northern Hemisphere, is above 0 ◦C during boreal summer, which prevents perennial land snow cover.

L318-325:

Furthermore, not all land surfaces were covered with perennial snow cover in snowball climate in our TSI094 result. This is consistent with a study using the same AGCM as this study (Abe et al., 2011), which found that land snow cover requires a lower solar flux than that required for global sea ice cover. Substantial land-snow free area of snow cover can be found in previous studies with the modern snowball (Yang et al., 2012a) and paleotopography (Benn et al., 2015), though the atmospheric CO2 concentration were not necessary the same. The lower albedo of the land due to the absence of snow cover contributes to the warmer surface temperature and the sublimation of ice, which contributes to positive feedback for further warming over the land. We note that MIROC4m tends to exhibit warmer summer surface air temperature over the land, therefore the extent of land-snow free area would depend on climate models used.

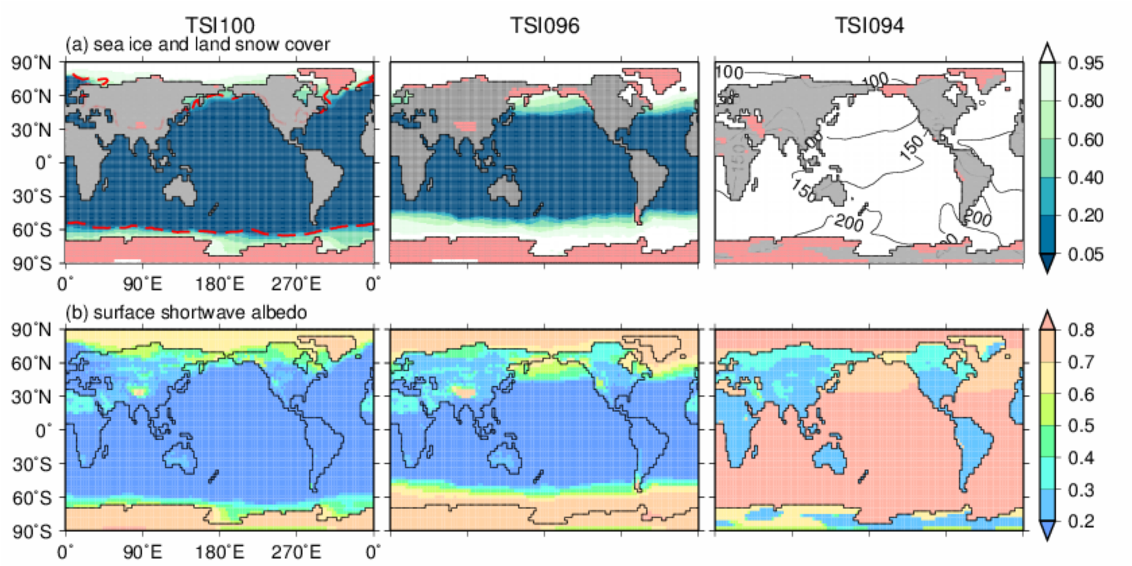

Figure 4: (a) Annual mean sea ice concentration and sea ice thickness at the end of the simulations. Red lines in TSI100 indicate the present-day winter sea ice edge (Hirahara et al., 2014), and the contour in TSI094 indicates the simulated annual mean sea ice thickness (unit: m). The red shades on the land grid indicate that the monthly minimum snow depth exceeds 1 cm. (b) Annual mean surface shortwave albedo.

4. Although land surface is assumed to become ice once the ocean is completely covered by sea ice, the land seems to have much lower albedo than the ocean. This is the major reason that the results here are very different from previous simulations. Abbot et al. (2013) did not include any continent explicitly, so they avoided this complexity. In your case, the snow is hard to accumulate on land, which creates a positive feedback that makes the land even warmer. If you prescribe the land as ice with thick snow, the results may look similar to previous modeling results. I am not asking for more sensitivity test but something you can discuss.

Thank you for the suggestion. We agree that the lower albedo of the land compared to the ocean contributes to the warmer surface temperature and the sublimation of ice, which contributes positive feedback of the further warming over the land. In the additional experiment used in the revised manuscript (TSI094SENS), the reduced maximum albedo of snow (over the sea ice) reduces the contrast in the surface albedo between the ocean and land, which finally reduces the positive feedback above.

L322-324: The lower albedo of the land due to the absence of snow cover contributes to the warmer surface temperature and the sublimation of ice, which contributes to positive feedback for further warming over the land.

5. Fig. 7 shows something interesting. Around the year 1280, sea ice starts to grow near 30°S while the higher latitudes are still having a net melting. This process seems to trigger the runaway effect, why does this happen?

Precisely, the net sea ice production is occurring near 30S around year 1280. According to the map of net sea ice production at this time slice, the sea ice was mostly positive at around this latitudinal band, which can be associated with oceanic circulation.

Other Comments

1) Please remove the statement about biogeochemical changes in the abstract as readers would expect much more from the manuscript by reading the abstract.

Thank you for the suggestion. We end the abstract with statements on the importance of sea ice production on the evolution of ocean circulations.

L11-14: While the evolution of the oceanic circulation would depend on the continental distribution and the evolution of continental ice sheets, our results highlight the gradual growth of sea ice and associated brine rejection are essential factors for the transient evolution of the oceanic circulation in the snowball events.

2) L16: "iron formation" to "banded iron formation" since iron formation could have many other forms and mechanisms.

We changed

L18-19: glacial deposits in low-latitude regions (Harland, 1964), banded iron formation, and cap carbonates …

3) L20: please explicitly state that the change of solar luminosity with time was estimated from solar models (i.e., not geological records) and provide relevant references.

We clarify that solar luminosity was estimated from solar models:

L20-22: Solar luminosity is estimated to have been approximately 94% of its present-day value during the latter stage of the Cryogenian Period based on solar models (Gough, 1981)

4) L22: "Thus, it is …", I cannot see the logic from the context why "thus" should be used here.

We change the sentences:

L23-25: It is one crucial question why snowball Earth events occurred during the Paleoproterozoic Era and the Cryogenian Period, but not since.

5) L24: "modelingcan" -> "modeling can"

6) L38: "AOGCM" -> "AOGCMs"

We correct them.

7) L39-40: "reconstructions of the continental distribution" is repetitive

We correct as follows:

L40-41: Subsequent studies used the same AOGCM to investigate the threshold for snowball onset under the past configuration of …

8) L57-59: In my opinion, although Ramme and Marotzke (2022) provided a nice demonstration of the ocean circulation during the snowball termination, the sea ice in their snowball state was quite thin so that the freshwater layer was easily eroded away. The simulations in Zhao et al. (2022) provide another perspective.

Thank you for telling us a valuable reference. We refer to Zhao et al. (2022) in the introduction, which estimates the quantitative timescale of snowball termination and the evolutions in ocean circulation.

L54-57: AOGCM has also studied the role of ocean circulations in the deglaciation from the snowball climate. It has been shown that the sea ice and the salinity stratification are essential factors in the timescale of snowball termination and the resumption of the meridional overturning circulation (MOC) (Ramme and Marotzke 2022; Zhao et al., 2022).

9) L98: is the shortwave albedo described here the mean of visible and near-infrared wave bands?

We clarify both of visible and near-infrared albedo values in the revised manuscript.

L94-97: "The shortwave (visible/near-infrared) albedo of snow was defined as a function of temperature to parameterize partial snow cover at relatively high temperatures, i.e., the albedo was set at a value of (0.85/0.65) for temperatures of −5 ◦C or colder, and it was reduced linearly to a value of (0.65/0.5) for temperatures up to 0 ◦C"

10) L99-101: Is snow aging considered over both land and sea ice in MIROC4m? This is important for explaining the different results between your model and other models since your model results seem peculiar. Also, I assume that the sea-ice albedo is thickness dependent and the value you provided represents the maximum.
No, snow aging is not considered in our model in both land and sea ice. The albedo of snow depends only on temperature. Also, the albedo of the sea ice is independent of thickness. We clarify in the revised manuscript.
L97-98: The aging effect of the snow and ice is not explicitly considered, and the thickness of sea ice does not affect the albedo.

11) L105-106: This is quite surprising because many models use sigma layers near the bottom because of its large variation in bathymetry and z coordinates near surface for the small variation of surface height.
The choice of vertical coordinate is the same as the original ocean model, COCO, which focuses on general ocean circulation. One merit of using sigma near the surface is that it explicitly calculates the spatial distribution of dynamic sea surface height. The flow of the ocean near the bottom, one limitation of the z coordinate model, is parameterised with a bottom boundary layer scheme.

12) Fig. 2: it will be useful to show the evolution of oceanic heat transport here; the shallow MOC is usually called STC (as mentioned above) in the field of physical oceanography; the deep MOC I guess, is driven by winds in the same way as STC, which is fundamentally different from the deep MOC in TSI100 and TSI096. Although the deep MOC in the latter is also maintained by wind driven upwelling, it's sinking is due to density anomaly. The authors may want to make it clear whether the sinking is due to density anomaly or downward Ekman pumping.
Thank you for the suggestion. While the time series of oceanic meridional circulation in the TSI094 is shown in Figure 9 with latitudinal distribution, we add the time series of maximum meridional heat transport in all simulations in Figure 2.

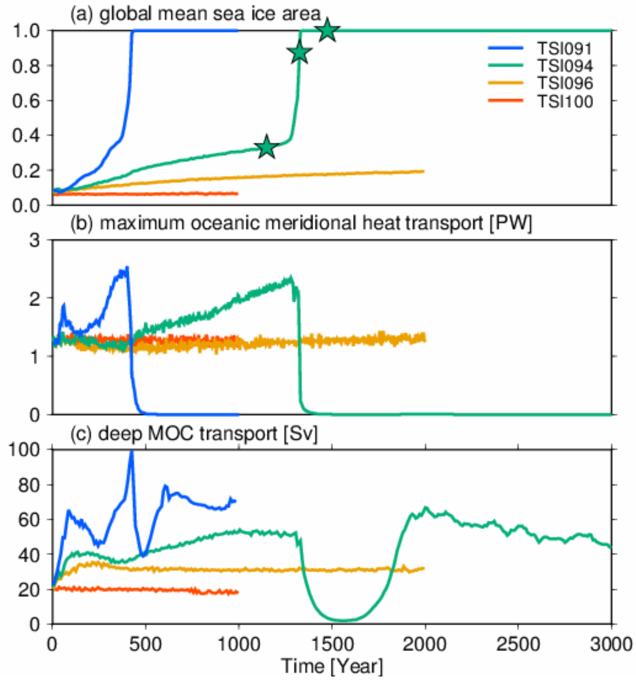

Figure 2: Time series of (a) the global mean sea ice area (as in Fig. 1), (b) maximum meridional heat transport by the ocean and (c) the deep MOC cell (depth of 3000 m to the seafloor) corresponding to AABW cell. Green stars in (a) represent snapshot states depicted in Fig. 3.

13) Fig. 3: is there atmosphere-ocean heat exchange at year 1450-1499?
Yes, there is heat exchange between the atmosphere and the ocean in the year 1450-y1499 because the atmosphere cools the ocean. and this thermal heat flux is used in sea ice growth (Figure 1b and Figure 7). We clarified it:
L181-183: Even in the globally sea ice-covered state (Fig. 3c), there is still atmosphere-ocean heat exchange that contributes to an increase in sea ice thickness (Fig. 1b).

14) Fig. 5: what do the contours show in panel f.
We removed the too fine salinity contour (0.05 psu interval) m in the revision to avoid confusion. We clarified the contour interval (0.2 psu) in the figure caption.

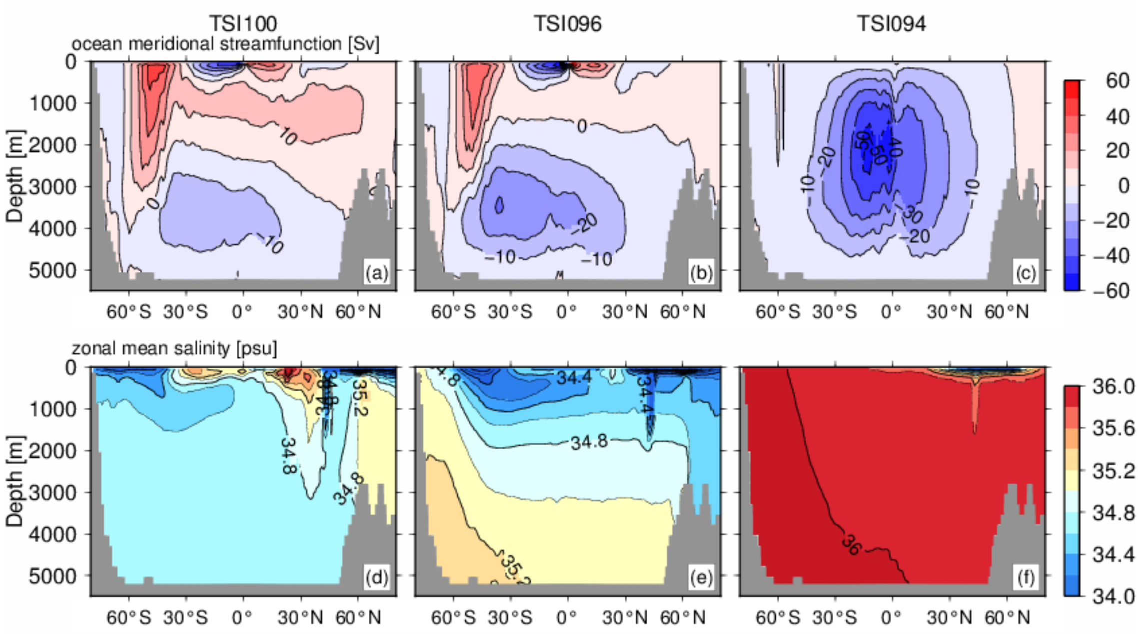

Figure 5: (a) Oceanic meridional overturning circulation (positive indicates clockwise circulation) and (b) zonal mean salinity (contour interval 0.2 psu) in the three experiments.

15) L243&L332: I think Abbot et al. used an albedo of 0.6, why do the authors think it was 0.7?
Our experiment of prescribing a uniform albedo of 0.7 was conducted independently of the Abbot et al. papers. We clarified that the multi-model study used constant surface albedo of 0.6:
L248-252:
The atmospheric circulation in a snowball climate has been investigated by multi-model study Abbot et al. (2012, 2013), with constant surface albedo 0.6 and two atmospheric CO_2 concentrations. Our snowball Earth results exhibited generally colder surface air temperatures than multi-model study, which can be explained by the different concentration of atmospheric CO_2 used, and the higher albedo of snow (0.85) in the snowball states (Fig. 4b right)

16) L267-270: The explanation provided here is very unlikely. The ocean temperature below the permanent sea ice is always below 0°C whether the AABW cell is strong or not. This is clearly demonstrated in Fig. 2 of Yang et al. (2012). I would think the high snow albedo over sea ice is more likely the reason. This can be tested but I will not ask that much.
We agree that the high snow albedo over sea ice is a likely reason. We revised the sentences.

L273-276: One possible explanation for the greater susceptibility of MIROC4m model to the snowball climate in response to insolation change is the albedo of snow. In MIROC4m, the albedo of snow can be as high as 0.85 in a colder climate (Fig. 4b), which is near the maximum value adopted in the AOGCMs used in previous studies (Yang et al., 2012a). One note is that the maximum snow albedo of 0.85 is the same as recent ICON-ESM (Ramme and Marotzke, 2022).

17) L289: A counterpart is missing for "than" in this sentence.
We correct the sentence:
L289-290: It required several hundred years to resolve the salinity stratification in our TSI094 experiment (Fig. 8a left) as opposed to TSI091 and the experiments of Ramme and Marotzke (2022).

18) L291-293: there seems to be a grammatical error around "relate"
We corrected the grammatical error:
L300-301: In MIROC4m, the surface momentum flux between the atmosphere and the ocean under the presence of sea ice is formulated using a nondimensional drag coefficient which is independent of sea ice thickness.

19) L302: "but" does not seem to be an appropriate conjunction word here.
We corrected it by dividing it to two sentences:
L307-309: Based on the balance between the vertical diffusion of heat in the sea ice and the typical value in the geothermal heat flux of the Earth, the sea ice thickness would reach a steady state of approximately 1000 m where the vertical diffusion of heat in the sea ice and the amount of geothermal heat flux are balanced.

20) L310: It should be more specific how your hydrological cycle contradicts with the geological record, not obvious to all readers.
This sentence was changed after we have revised the experimental design. Also, we revised the discussion paragraph to clarify that the verification can be done with actual continental configuration, and usage of coupled climate-ice sheet model simulations:
L348-351:
While this study clarified the timescale of the evolution of deep ocean circulation across the snowball onset, the verification of the three-dimensional ocean ciruclation is difficult because there was no snowball events in the modern configuration. The three-dimensional structure of the deep ocean circulation can be verified by the comparison with geological records and model simulations utilizing Sturtian and Marinoan configurations.

21) L310-313: I don't understand why vapor condensation can induce a strong temperature inversion near the surface since condensation gives off large amount of heat to the surface.
We revised the sentence to clarify that the atmospheric vapor condensation is a result of a strong temperature inversion. As we have integrated this experimental design into the main results after snowball onset, we have revised the method to clarify the relationship between water vapor condensation and strong temperature inversion in MIROC4m.
L132-137: Third, the minimum turbulence coefficient in the atmospheric boundary layer over the ocean was increased by a factor of 50. This change is applied solely to prevent a model crash, as we found the model crashed in a snowball climate very early. This can happen due to negative atmospheric water vapor content, caused by substantial atmospheric water vapor condensation over the sea ice. We found that substantial atmospheric water vapor is caused by an unrealistically strong atmospheric inversion layer over the ocean (i.e., a 2-m air temperature difference of up to 20°C relative to the surface temperature).

22) Fig. 14: It will be useful to also show surface temperature here.
Based on comparison of skin temperature in TSI094, the increase in minimum turbulence coefficient lead to reduced surface temperature between land and ocean.

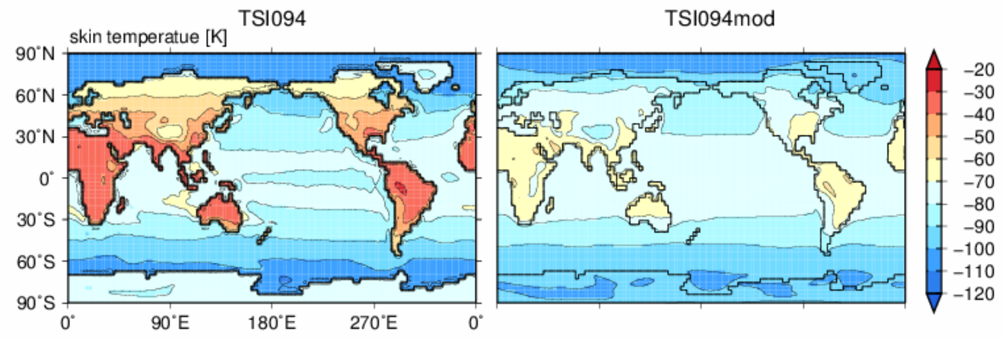

Figure: annual-mean skin temperature in the TSI094 and TSI094mod (minimum turbulence coefficient in the atmospheric boundary layer over the ocean was increased by a factor of 50) experiments.

Response to reviewer #2:
The manuscript by Takashi Obase and colleagues presents simulation results from climate experiments of transitioning from a modern-day climate state to a snowball-Earth state in response to an abrupt reduction in incoming solar radiation. The authors use the MIROC4m atmosphere–ocean general circulation model (AOGCM), which—in principle—seems a good choice for this kind of study and enables them to investigate the evolution of ocean and atmosphere during and after that transition. I think the study is interesting especially with regard to the ocean dynamics and the results are discussed in an enlightening way. However, I would suggest a few general and a number of specific minor revisions before publication.
Thank you for carefully reading and providing us with valuable comments. We have addressed concerns by changing experimental design in the revised manuscript:

1. Wind stress over the ocean was turned off after the snowball onset (TSI091 and TSI094).
2. All land grid (except modern Greenland and Antarctica) was set to bare soil after the snowball onset.
3. The minimum turbulence coefficient in the atmospheric boundary layer over the ocean was increased by a factor of 50 (same experimental design of TSI094mod in the original preprint). This change is applied solely to prevent a model crash.

Minor revisions (general)
The authors acknowledge that their results differ from previous studies in some important points, which is not a problem in its own right, of course. However, two assumptions appear very critical to me, as outlined below. Ideally, a study would mostly cover the sensitivity of the results to these assumptions, but seeing that the scope of the paper would considerably grow and the discussed results do not need to be "most realistic", I would suggest an even deeper discussion of the following points.

I think it is a strong assumption and maybe a large perturbation for the model to abruptly replace all land surface with ice sheets once the oceans are fully covered in sea ice. The effect of this assumption on the results (especially regarding the hydrological cycle) should be discussed.

We agree with the points that replacing all land surface with ice sheets is an extreme setting assumption. We have changed the experimental design by prescribing bare soil instead of ice sheet in the revised manuscript. In the above setting, we get different precipitation and Hadley circulations from the originally submitted manuscript (Figure 13 left). We also conduct additional experiment (TSI094SENS) to address the impact of snow albedo parameters on the Hadley Circulation and precipitation (Figure 13 right)

Method (L129-132):
Second, we set all vegetation over the land grids with bare soil after snowball onset, while the present-day ice sheet over Greenland and Antarctica were kept unchanged. The experimental design setting bare soil rather than ice sheet is preventing infinite source of water via sublimation of the ice sheet, which impacts conservation of water in the climate model.

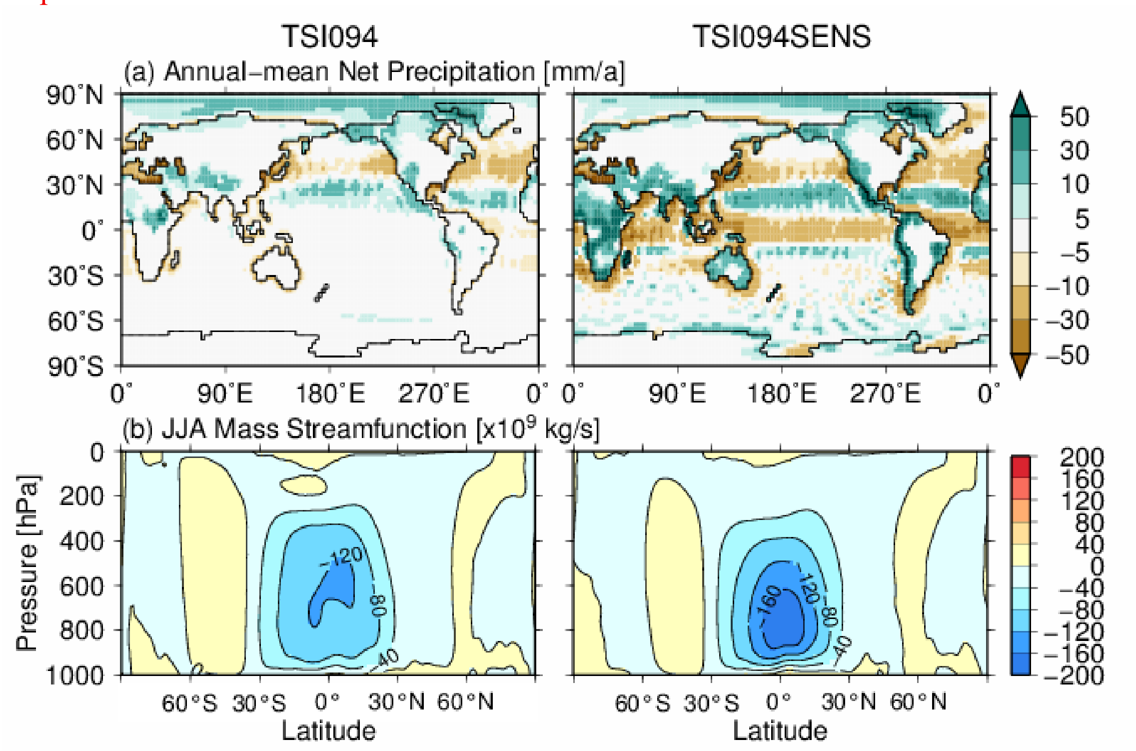

Figure 13: (a) Net precipitation, defined by precipitation minus evaporation (includes ice sublimation), (b) boreal summer meridional atmospheric mass streamfunction (10^9kg/s, positive indicates clockwise circulation) in the TSI094 and TSI094SENS experiments.

The comparatively strong momentum transfer from the wind to the ocean in the case of very thick sea ice is already discussed. Ideally, one would need a sensitivity run to see the differences in the model. This is not absolutely necessary from my point of view, but it should be stressed at a prominent point of the manuscript that the assumption is probably unrealistic.
We agree that the original experimental design, which involved wind stress felt at the ice-ocean interface in the hard snowball was an extreme setting. We have changed the main experiments with the wind stress over the ocean was turned off after the snowball onset, as previous studies (Pollard et al., 2017; Ramme and Marotzke 2022). The results show the deep MOC resumes after 500 years of the snowball onset (Figure 2), indicating the salinity flux due to the sea ice production in the snowball climate is the driver of the ocean circulation. The sea ice thickness distribution exhibits more zonal than the previous setting (Figure 4), closer to Ashkenazy et al. (2014).
We have revised the method by creating a new subsection 2.4 (Experimental design 2: post-snowball onset) to clarify the experimental design:
L122-129:
2.4 Experimental design 2: post-snowball onset
The climate turned into snowball state at year 430 in the TSI091 experiment and at year 1330 in the TSI094 experiment (Fig. 1). In the phase after snowball onset, we apply several changes in model settings to get reasonable snowball climates. First, the wind stress over the ocean was turned off after the snowball onset. This experimental design is in line with previous stuides, where turning off the

air–sea momentum flux when the sea ice thickness exceeded 6 meters Pollard et al. (2017) or in a deglaciation stage Ramme and Marotzke (2022). The sea ice is not fully stagnant in this setting; it can move due to ocean circulation. Note that the maximum sea ice velocity under globally sea ice covered snowball climate is ~ 2cm/sec, which is one-tenth of the modern climate.

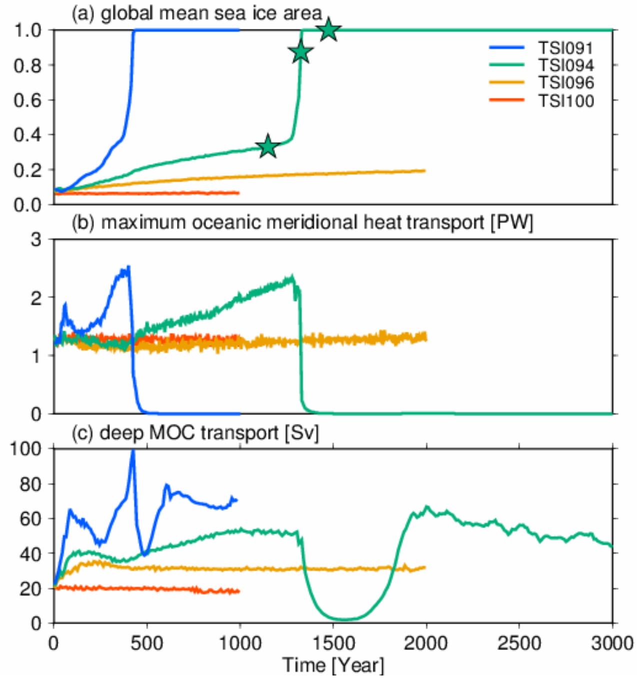

Figure 2: Time series of (a) the global mean sea ice area (as in Fig. 1), (b) maximum meridional heat transport by the ocean and (c) the deep MOC cell (depth of 3000 m to the seafloor) corresponding to AABW cell. Green stars in (a) represent snapshot states depicted in Fig. 3.

That said, it is notable that the authors included a discussion and sensitivity test regarding the minimal thermal diffusion coefficient over the ocean surface, because this is another critical point.

The experimental design changing minimal thermal diffusion coefficient over the ocean surface is now integrated to the main experimental design:

L132-137: Third, the minimum turbulence coefficient in the atmospheric boundary layer over the ocean was increased by a factor of 50. This change is applied solely to prevent a model crash, as we found the model crashed in a snowball climate very early. This can happen due to negative atmospheric water vapor content, caused by substantial atmospheric water vapor condensation over the sea ice. We found that substantial atmospheric water vapor is caused by an unrealistically strong atmospheric inversion layer over the ocean (i.e., a 2-m air temperature difference of up to 20°C relative to the surface temperature).

Minor revisions (specific)

L8: I find it not clear what is meant by “necessary”. Maybe replace the formulation by “the duration between the change in solar constant and snowball onset” or something similar.

We revise the sentence:

L7-8: By contrast, such salinity stratification was absent if the duration between the change in solar constant and snowball onset was short.

L17f.: “iron formation” is too general.

We changed

L18-19: glacial deposits in low-latitude regions (Harland, 1964), banded iron formation, and cap carbonates …

L20: "… 94% of its …" without "that"
L27: "… equilibrium solution of the climate" instead of "planet"
We correct them.

L38: "… the same AOGCM[s]" is not correct. E.g., the study by Poulsen et al. (2002) used FOAM, which the studies mentioned before did not employ. Voigt (2013) used an AGCM. The study by Eberhard et al. (2023) differs from the ones mentioned before, as they used a model of intermediate complexity (which is not an AOGCM) and focused on a large set of sensitivity runs instead.
We agree with this. As the focus of this sentence is on previous studies that have examined the role of continental distribution, we remove the phrase "the same AOGCMs" from this sentence.
L40-41: Subsequent studies used AOGCMs to investigate the threshold for snowball onset under the past configuration of the Sturtian (720–660 Ma) and Marinoan (650–630 Ma) periods

L39: The terms "Marinoan" and "Sturtian" have to be switched. The Marinoan is the younger one.
We correct the mistake: "Sturtian (720–660 Ma) and Marinoan (650–630 Ma)"

L65 and other instances: It appears that sometimes the names MIROC and MIROC4m are synonymous. Are they? If not, please make a clearer distinction.
MIROC and MIROC4m are used interchangeably in this article. We unify the wording to "MIROC4m" throughout the manuscript.

L95: I think this value of the ECS is for doubling CO2 in a modern climate state, right? If so, please mention this, as for states with more ice the ECS is sometimes expected to be much higher.
Yes, the ECS is defined in the modern, pre-industrial climate. We clarify ECS can change depending on the reference climate.
L90-91: One note is that the global mean surface air temperature with a doubling of the atmospheric CO2 depends on the reference states (e.g. continental distributions).

L112f.: Is it likely that this nonconservation of global water volume and salinity introduces any artificial long-term salinity trends for "stable" climate states which could be relevant for the snowball simulations? One could, e.g., check the discussed TS100 run for the long-term evolution of total salinity. I ask because sometimes this can happen in the case of nonconservative schemes.
We have checked the global-mean salinity trends in TSI100 experiment, and found the global-mean salinity trend is 0.002 psu per 1000 years.
L112-114: Note that the global-mean salinity trends in the pre-industrial simulation in this revised model is 0.002 psu in 1000 years, which is of the same magnitude as the original simulation.

L120: What is the reason for using this value for the solar constant? Basically, I am wondering where the .12 comes from.
The solar constant value (1366.12) is the same as the description paper of the MIROC4m (Nozawa et al., 2007), which was submitted to the Fourth phase of the Coupled Model Intercomparison Project (CMIP4). We opted to use the same value because all model tuning for the pre-industrial simulation has been conducted with this solar constant. We have added the reference.

L120: "changed from 91 to 100%" or "set to 91–100%"
We correct it.

L135ff.: I realize the difficulty to run the TS096 simulation for even longer, but it is not evident for me that this one will stay in a non-snowball state forever. Sea-ice area and SAT still have considerable

trends and might reach the transition point eventually. I suggest to at least mention this in the manuscript and, for example, weaken the statement in L139f: "… was determined to be between 94 and 96%".
We agree that the equilibrium state of TSI096 may be a snowball state, given the gradual trend observed at the end of the simulation. We change the sentences to clarify that the 94% is a sufficient condition:
L153-154: There are still gradual trends in sea ice area in the TSI096, therefore, the solar flux of 94 % is a sufficient condition for a modern snowball climate in MIROC4m.

L155: "Fig. 2c blue"—Please check whether you indicated the right color.
We correct it as "Figure 2c green".

L190f.: "The sea ice formation …" is a repetition of a similar statement in L184ff.
We changed it:
L208: "The increase in total sea ice volume contributes to the increase in global mean salinity".

L192: It would make sense to add a reference to Fig. 5c, as well.
We revise the sentence by referring to Figure 5c as well as Figure 5f.

L196: "maximum sea ice thickness along the western side of the Pacific Ocean"—This is difficult to see in the figure.
This sentence was changed as we utilize an experiment without air-sea momentum flux in the snowball condition:.
L197-198: The sea ice thickness also exhibits a latitudinal gradient; it reaches a maximum in the Antarctic Ocean and a minimum in the Northern Pacific (Fig. 4a right).

L203f.: This last sentence is partly a repetition of a similar earlier statement in L199f.
We agree with this. However, as we utilize an experiment without air-sea momentum flux in the snowball condition, the statement about wind was removed.

L246: ".. from that in a multimodel study", similar in L249f.
We correct it:

L284: "… depends on radiative forcing"—This sounds as if the radiative forcing directly influenced the salinity stratification. Maybe: "depends on the rate of cooling"?
L284f.: Please specify what you mean with "external forcing", this could even be early in the paper. Some people describe the insolation itself as a forcing, and then it would sound strange to speak of a stronger external forcing for reduced insolation.
We agree with this. As the focus of this sentence is the duration required for snowball onset, we revise the sentence without using external forcing:
L283-285: We also found that the strong salinity stratification at snowball onset is present in the TSI094 experiment but absent in the TSI091 experiment, suggesting that the presence of salinity stratification before snowball onset depends on the rate of cooling

L289: "as opposed to" instead of "than"?
We change it as suggested:
L289-290: It required several hundred years to resolve the salinity stratification in our TSI094 experiment (Fig. 7a left) as opposed to TSI091 and the experiments of Ramme and Marotzke (2022)

L347: "… coupled with an EBM"

We correct it

L359: Please carefully revise the values given. Liu et al. (2013) find thresholds between 80 and 150 ppm, but thresholds even below 80 ppm for another aerosol parametrization. Feulner and Kienert (2014) find thresholds of 100–110 ppm for the Sturtian and 120–130 ppm for the Marinoan.
We carefully revise the sentences according to each reference:
L344-347: Specifically, Liu et al. (2013) estimated the threshold of atmospheric CO2 as 80 ppm for the Sturtian and 150 ppm for the Marinoan configuration, and it can change by ~30 ppm depending on the optical depth of the aerosol parameterisation. Feulner Kienert (2014) estimated the threshold of atmospheric CO2 concentration as 110 for Sturtian and Marinoan configurations.

References
Nozawa, T., Nagashima, T., Ogura, T., Yokohata, T., Okada, N., Shiogama, H., Climate Change Simulations with a Coupled Ocean-Atmosphere GCM Called the Model for Interdisciplinary Research on Climate MIROC, CGER's Supercomputer Monograph Report, Vol. 12, (2007). https://www.cger.nies.go.jp/publications/report/i073/I073.pdf