## Point-to-point response to reviewers' comments

*The comments are in black, and our answers are in blue.*

## Reviewer #3:

Review of Zheng et al.

Zheng et al. has made substantial revision to their manuscript and improved the writing and the clarity of the presentation. I appreciate the authors' detailed reply to my comments. For example, the addition of the definition of "anomaly" is essential for the interpretation of Fig. 5 and Fig. 9. Some of my questions on the linearity of the attribution method and the Pliocene experiment setup are still not well explained. I suggest the authors to add an uncertainty estimate to the attribution method. The differences in boundary conditions between the preindustrial run and the Pliocene run will introduce perturbation fluxes not included in the attribution framework. The implication for current results should be considered. I recommend a substantial-minor revision of the current manuscript before it can be accepted for publication.

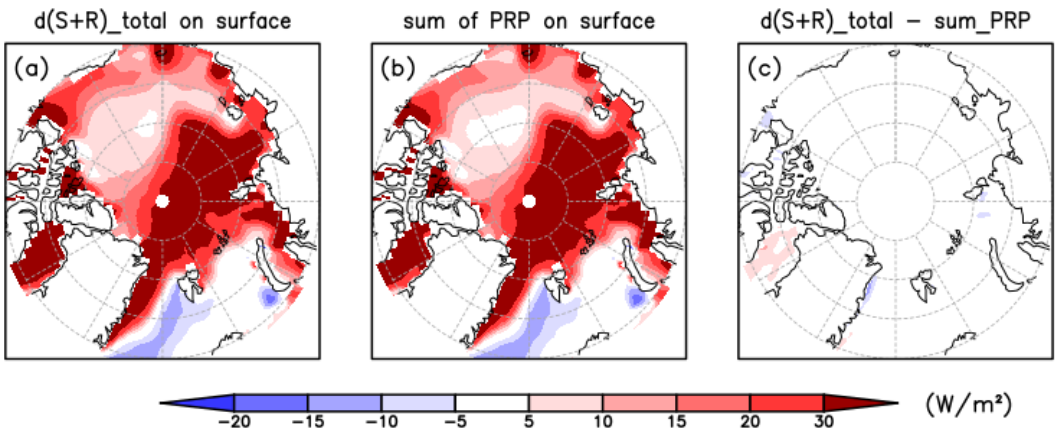
We are very grateful for the positive evaluation and detailed comments that follow. Below are our responses, and we have revised the manuscript accordingly.

Major concerns:

1. The linearity of CFRAM

The author mentioned the "albedo and insulation interact in a nonlinear way" in line 72-73 and then apply an attribution method with linear assumption without giving clear estimate of the role of nonlinearity. The authors suggest the linearity of the CFRAM can be examined by comparing the total radiative perturbation and the sum of all the partial radiative perturbation terms. The provided figure has very confusing titles and does not seem to be related to the "total vs partial perturbation" comparison. Even if the figure is indeed a comparison of the total vs partial perturbations, it does not show the residual well. A comparison of the residual, total minus sum of partial perturbation, with the total is more informative of degree of nonlinearity. Maybe this can also be used as a measure of the uncertainty in the linearity assumption? Please show clear evidence to support the assumption of linearity and provide an uncertainty estimate of this assumption.

The figure below shows the total radiative perturbation (a), the sum of all the partial radiative perturbation terms (b) and the residual (c) over the Arctic Ocean. It appears that the total radiative perturbation and the sum of all the partial radiative perturbation terms are almost identical. The residual can explain about 2.6% of the variance of the total radiative perturbation. Therefore the nonlinearity might be negligible and it is reasonable to linearly decompose radiative perturbation into individual contribution with CFRAM. The validation of linearity is added in the text and the Supplement (Figure S4).




2. The boundary condition differences between preindustrial and Pliocene runs

I would like to thank the authors for providing clearer description of the Pliocene experiment setup. After reading the authors' clarification in the revision, I realized that it is important to note the boundary condition differences between preindustrial run and the Pliocene run. The PRISM conditions are not used in the preindustrial run. This choice is understandable for model evaluation purpose using proxy data. However, it does introduce additional uncertainties in your attribution analysis. The adoption of PRISM may introduce radiative perturbation that are not included in Eq (1). How important is this factor compared to albedo and insulation effects of sea ice?

Secondly, I understand that the authors followed the standard protocol in PlioMIP2, but a brief explanation of the justification of some setup choices are beneficial to readers who are not very familiar with the PlioMIP2. For example, the choice of equilibrium runs depends on the small $CO_2$ concentration and orbital forcing changes during this period.

The application of the boundary conditions from PRISM may affect various climatic variables, such as temperature and precipitation, so the influence of boundary conditions can be captured in the changes of air temperature, cloud, water vapor and other factors. That is to say, the radiative perturbations in Eq (1) contain not only the effects of sea ice but also effects of the boundary conditions. In this study we focus on the effects of sea ice, which can explain part of the variance of the partial radiative perturbations in Eq (1). The residual variance includes the contribution of the boundary conditions and other factors, and it is difficult to obtain the contribution of the boundary conditions and compare with the effects of sea ice.

Thanks for your suggestion! A brief explanation of the justification of some setup choices are added in the "experimental design" section. That is, "These two experiments proposed in PlioMIP2 core experiments may assess the dependence of climate sensitivity on the radiative forcing and the boundary conditions."

Minor concerns:

1. The Pliocene climate "anomalies"

It is very confusing to refer to the differences between the Pliocene run and the preindustrial run as "anomalies", which is usually used to describe the deviation from a climatological mean or spatial averages. I guess this is why another reviewer is asking whether the trend is removed when calculating the "anomalies". Please try to find another way to describe it or be sure to explicitly remind the readers that the "anomalies" is defined differently here.

The definition of "anomalies" has been emphasized in Section 2.1 in the revised version to remind the readers.

2. Tables.

This is just a suggestion. The tables listed these variables for all 12 months. It might be less intimidating and easier to digest the information if they are shown in plots instead, unless there are some particular numbers that are important to the readers. This is just my opinion though.

Thanks for your suggestion! We think it might be more quantitative and easier to present some features, such as the significance of correlation coefficients if tables are used.

Specific comments:

Line 29-30: Something is not right about this statement. In addition, 2005 is not in the last decade.

The sentence has been modified in the revised version.

Line 31: "ice-free Arctic Ocean" in summer or all year around?

"ice-free Arctic Ocean" in September. It's specified in the text

Line 47-48: Is this a target for this study to produce a more significant Arctic amplification?

Koenigk et al. (2013) had suggested that the EC-Earth simulations show a strong Arctic amplification compared to most CMIP3 models. It's not a target for this study to produce a more significant Arctic amplification.

Line 52: It is not clear what the "sea ice effect" is referring to.

The "effects of albedo and insulation" is specified in the revised sentence.

Line 68: Why does the sea ice thinning lead to enhanced insulation? This is confusing. Please rephrase.

The "enhanced insulation" should be "weakened insulation" and it has been corrected in the text.

Line 72-73: So nonlinearity is important. Does this contradict the choice of linearity for attribution later?
As the result mentioned above (Major concerns 1), the nonlinearity exists but is not important in this study.

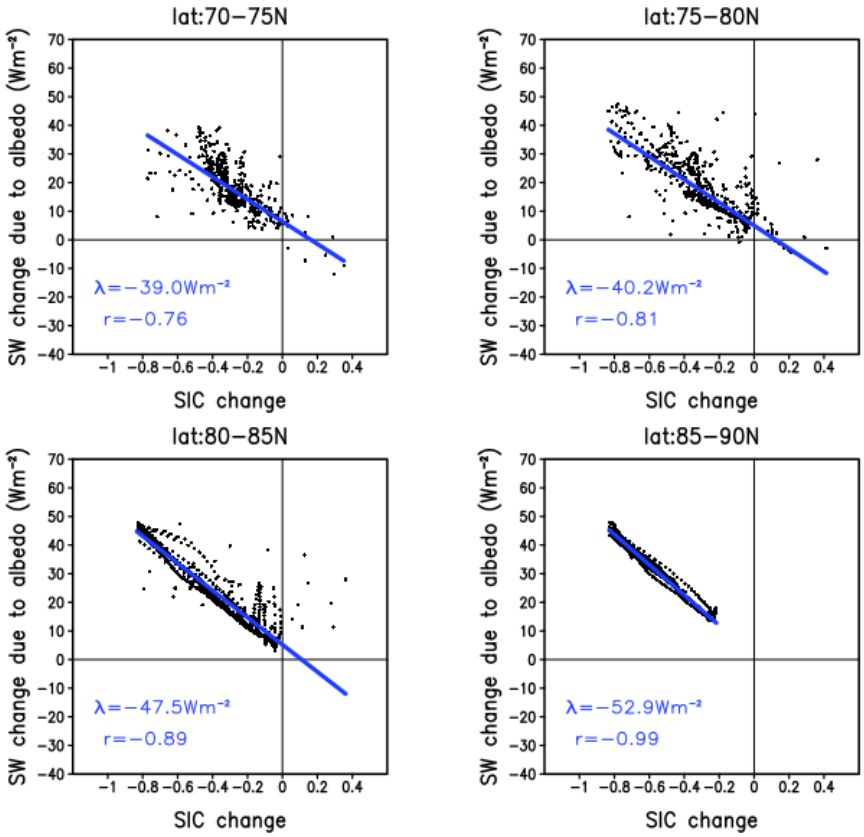
Line 118-120: This statement is confusing. It gives the impression that although it is actually late Pliocene but called mid-Pliocene because the mid-Pliocene is studied more. Do you mean this term "mid-Pliocene warm period" is frequently used for this period in literature although it is actually late Pliocene? Please rephrase.
Yes, we mean this term "mid-Pliocene warm period" is frequently used for this period in literature although it is actually late Pliocene. Thanks for your suggestion! The sentence has been modified in the revised version.

Line 146: Again, does the differences in boundary conditions contribute in this equation?
The radiative perturbations in Eq (1) contain not only the effects of sea ice but also effects of the boundary conditions. In this study we focus on the effects of sea ice, which can explain part of the variance of the radiative perturbations in Eq (1), and the boundary conditions can explain part of the residual variance.

Line 147: Is the "perturbation" here refer to the differences between the Pliocene run and the preindustrial run? Please clarify.
Yes. The "perturbation" is specified in the text for clarity.

Line 208-213: As is mentioned by another reviewer, the constant SST under sea ice is also a contributing factor here. Please add it here.
Done.

Fig. 5: Because each dot represents a grid point in the model, then the latitude can be very important for the total SW insulation and the SW changes with albedo. Will you get a different regression coefficient if subsetting the data by latitude? Can you calculate similar contribution to variance for the other factors in Eq (1)? Will they add up to 1?
To find the role of latitude, the data are divided into 4 subsets by latitude and shown below. The higher the latitude, the stronger is the response of the net shortwave radiation change caused by albedo to the change of sea ice concentration.
The contribution to variance can be calculated for other factors, but it just represents the variance of each term in the right hands of Eq (1) explained by the sea ice change, e.g. 71% for SW change due to albedo, 31% for LW change due to water vapor, so they will not add up to 1.




Line 260: What is the "response coefficient of albedo to SIC"?

The phrase "response coefficient of albedo to SIC" is unclear, so it is changed to "response coefficients of net shortwave flux to the albedo effect of sea ice".

Line 324-327: Following Clausius–Clapeyron, in the colder Arctic, the saturating mixing ratio of water vapor is much smaller, so the latent heating and the responses are also smaller.

Thanks for your helpful comments! The explanation is added in the revised version.

Line 336: I don't think it is conduction. Heat transfer by conduction does not rely on the wind speed or the amount of turbulence.

Conduction is efficient at the sea/ice surface when the molecules are tightly constrained, while convection occurs much more efficiently in the atmosphere by mixing. The sensible heat is transferred through convection and conduction. So the "convection" is added in the text.

Koenigk, T., Brodeau, L., Graversen, R. G., Karlsson, J., Svensson, G., Tjernström, M. and Wyser, K.: Arctic climate change in 21st century CMIP5 simulations with EC-Earth, Climate dynamics, 40(11-12), 2719-2743, doi: 10.1007/s00382-012-1505-y, 2013.