Review of cp-2022-22: "Asymmetric changes of temperature in the Arctic during the Holocene based on a transient run with the CESM" by Zhang et al.

Summary

This paper argues that there was an asymmetric temperature change between the Atlantic and Pacific sectors of the Arctic from the mid- to late-Holocene. The authors find this pattern in the temp12k global Holocene temperature reconstruction and also in transient climate model simulations with CESM. They argue that this is caused by orbital modulation of the Artic Dipole pattern and the Pacific Decadal Oscillation.

Main comments:

The paper presents an interesting hypothesis with a lot of analyses to back up the main results. However, in places it seems like the results need to be better supported with evaluation of the uncertainties, while the link to the modes of variability may benefit from more elaboration. My main comments are as follows:

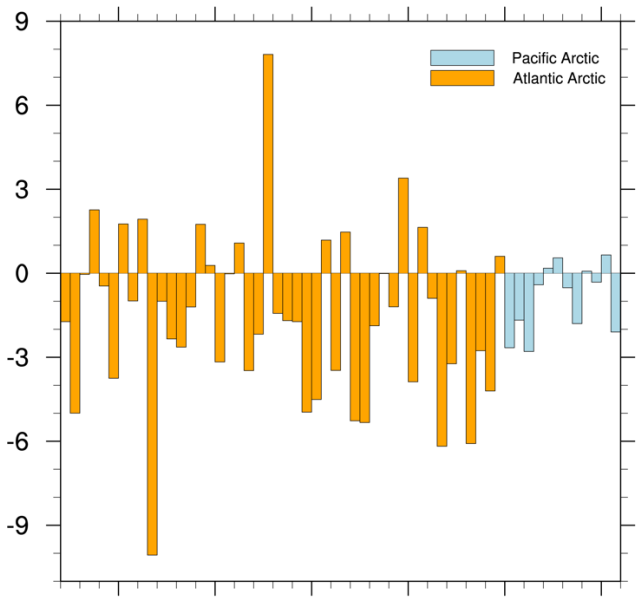
Reply: Thank you very much for your valuable suggestions and comments on our manuscript. We have carefully considered the comments and tried our best to address every one of them.

1) If I understood correctly, this Holocene simulation (AF) does not include changes in ice-sheet/sea-level forcing? It so, this might be an important caveat for the response in the Arctic. Although the global sea-level has stabilised by around 6 ka BP, this is right in the middle of the early-Holocene time window that you analyse throughout. I think some discussion of this is needed.

Reply: Thank you for your comments and suggestions. Yes, you understand correctly. The simulation doesn't include the changes of boundary conditions of ice-sheet and sea-level. It's indeed worth a discussion in the manuscript. We will add a discussion to point this out.

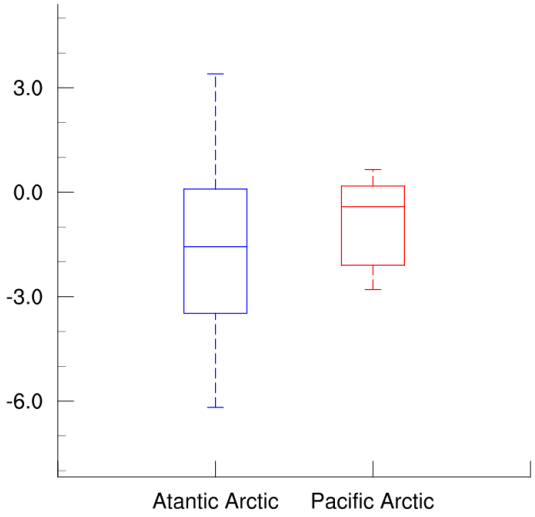
2) A more robust evaluation of the proxy-based signal is needed in section 3.1. The asymmetry is dependent on a relatively small number of points that show a stronger cooling in the Atlantic sector of Figure 1. If the coolest 2-3 of these were removed it looks like the asymmetry could likewise disappear. This makes one wonder whether the asymmetry is an artefact of the limited coverage by the proxies? Could you evaluate this in more detail? Perhaps add a histogram of the reconstructed temperature changes in the two regions?

Reply: Thank you for your comments and suggestions. The histogram of the reconstructed temperature changes is shown below. It looks more intuitive that way. There are two reconstruction records showing extreme cooling (-10.1℃) and warming (7.8℃) respectively. Although there are individual reconstructions that are outside the normal range, it is not the case that the asymmetric changes in temperature would disappears when 2-3 coldest proxies in the Atlantic Arctic region are removed. Removing individual values that are out of the norm, overall, the temperature asymmetry in the two regions is still robust ($p<0.10$).



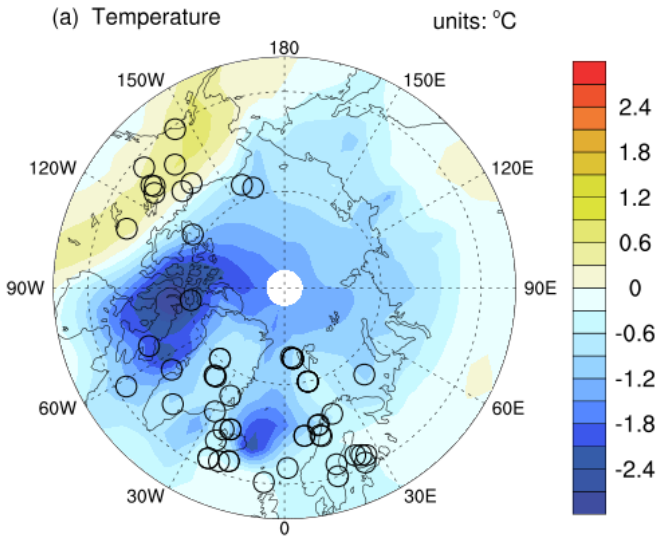
3)The reconstructed and simulated regional temperature anomalies are given to 2 decimal places which feels overly-precise. It would be more convincing if the estimated uncertainties on these values were presented.

Reply: Thank you for your comments and suggestions. We used box figure (see below) as well as t-test to help estimate the significance of temperature anomalies. Due to the small sample size of the Pacific Arctic reconstruction data, the temperature changes are only showing significance ($p<0.10$) on t-test.



4) Assuming that the reconstructed asymmetry is robust to the choice of points it is not clear on first reading that the model actually replicates the 'asymmetric' temperature response in the annual mean as only the separate seasons are shown. Since the proxies are calibrated to reflect the annual mean signal I think it would be beneficial to show the annual-mean model result.

Reply: Thank you for your comments and suggestions. We will add the annual-mean model result in temperature anomalies. The figure below shows the asymmetric temperature changes in annual-mean model output. Similarly to proxy data, it depicts the difference in temperature variation between the two regions, with cooling of -1.0℃ and -0.64℃ in the Atlantic Arctic and Pacific Arctic, respectively.



5) The analysis of the atmospheric dynamics is not easy to follow (see comments below) and it is difficult to understand precisely how the PDO/AD modes combine to produce the seasonal-mean signal in the sea-ice.

Reply: Thank you for your comments and suggestions. We apologize for not making it clearer and more understandable. We will reorganize this section in the revised manuscript. In short, the main forcing processes are: 1) the PDO's potential phase dominates the SLP, it affects the AD mode; 2) AD mode brings in warm southerly winds along the shores of the East Siberian and Chukchi seas. It favors strong sea-ice melt in these sectors and pushes the ice away from the coast, leaving open water; 3) The pressure pattern also favors the transport of sea-ice out of the Arctic Ocean and into the North Atlantic through Fram Strait. In turn, it contributes to the asymmetric change in temperature in Arctic.

6) Changes in ocean circulation are not mentioned, but given they are important for the past 2000 years (Zhong et al 2018), it would be worth evaluating.

Reply: Thank you for your comments and suggestions. Zhong et al (2018) proposed that changes in ocean salinity leading to an increase in ocean density, which further affects the transport of heat in the northern North Atlantic and contributes to asymmetric temperature changes. Our manuscript mainly focuses on the analysis of the role of atmospheric dynamics and sea ice. In the revised manuscript, we will discuss the effect of ocean circulation on asymmetric temperature changes more in the discussion section in the context of the importance of ocean circulation.

Minor comments:

Line 102: Is the Glimmer ice sheet model used in this study or is it deactivated?

Reply: Thank you for your comments and suggestions. The Glimmer ice sheet model is coupled in the model simulations. We will clarify that in the text.

Line 103: I think you should cite Hurrell et al 2013, instead of this web link.

Reply: Thank you for your comments and suggestions. We have modified it.

Line 109: It's not clear how the Gao et al reconstruction is used for the Holocene as in their paper they only discuss the last 1000 years. Please could you expand on this?

Reply: Thank you for your comments and suggestions. The reconstruction data for volcanoes during the Holocene have not yet been published, and we have revised this citation.

Line 113: I could not find Wan et al. (2020) in the reference list.

Reply: Thank you for your comments and suggestions. We've added it.

Line 138: This link does not appear to describe the Jonkers et al 2020 dataset or anything else that is mentioned in this manuscript.

Reply: Thank you for your comments and suggestions. The link is miss one number. We've modified it as "http://www.ncdc.noaa.gov/paleo/study/27330".

Line 149: "... with red indicating an increase in temperature between the late and the early-mid Holocene (0-2 ka BP and 5-8 ka BP), while the blue indicating and decreasing." This can be omitted.

Reply: Thank you for your comments and suggestions. We've removed it.

Line 154-155: These values to 2 decimal places seem overly precise. Please could you estimate the uncertainty in these two values?

Reply: Thank you for your comments and suggestions. We've modified it. Due to the small sample size of the Pacific Arctic reconstruction data, the temperature changes are only showing significance ($p<0.10$) on t-test.

Line 173: again the regional average temperature anomalies should include uncertainties. I suspect 2 decimal places is overly-precise.

Reply: Thank you for your comments and suggestions. We've modified it. The temperature changes in two region showed significance ($p<0.01$) in t-test.

Line 206: This sentence starting "Many studies" makes it soucnd like these are all studies on the Holocene, but I believe that they are all focussed on the present-day. Please re-word to clarify this.

Reply: Thank you for your comments and suggestions. We've modified it.

Line 223-227: "The difference in SLP between the two periods does show a similar dipole pattern, but combined with the stronger SLP in the late Holocene than in the early-mid Holocene shown above, it can be assumed that the stronger Arctic dipole in the late period had a greater role in influencing sea ice" Perhaps I have missed something, but I don't follow this.

Reply: Thank you for your comments and suggestions. The manuscript we want to express that the Arctic dipole mode in the late Holocene is stronger than that in early-mid Holocene, and the atmospheric circulation under its influence should also have a stronger influence on sea ice. We have revised this description to make it easier to read.

Lines 236-249: It's not clear how the regressed UV winds and sea-ice on PC2 are responsible for the climatological signal. I think this needs to be elaborated on.

Reply: Thank you for your comments and suggestions. We want to illustrate by changes in UV and sea ice that changes in the SLP brings in warm southerly winds along the shores of the East Siberian and Chukchi seas. It favors strong ice melt in these sectors and pushes the ice away from the coast, leaving open water. The pressure pattern also favors the transport of ice out of the Arctic Ocean and into the North Atlantic through Fram Strait. Differences in the distribution of sea ice in turn change the heat balance through feedback, leading to inconsistent changes in Arctic temperatures. We will add more details in the text to make this part more readable.

Line 260: "The index indicates that negative PDO dominates the late Holocene, while the positive and negative PDO phases oscillate during the early-mid Holocene." This is not clear from the figure. Please can you provide a statistic that shows this.

Reply: Thank you for your comments and suggestions. We've added this analysis. The Negative phase PDO dominated the late Holocene, accounting for more than 90%. On the other hand, the PDO in the positive phase accounted for 62% in the mid Holocene.

Lines 265, 267: Please specify what you are comparing with this spatial correlation coefficient?

Reply: Thank you for your comments and suggestions. We compare the EOF leading pattern of SLP in the whole early-mid Holocene and the EOF leading pattern of SLP in the positive PDO year in the early-mid Holocene, with the spatial correlation coefficient is 0.96. And We compare the EOF leading pattern of SLP in the whole late Holocene and the EOF leading pattern of SLP in the negative PDO year in the late Holocene, with the spatial correlation coefficient is 0.99. We've modified this description.

Line 280: Your results mirror findings of Zhong et al 2018. However, they invoked a significant role of the ocean circulation. Is that important in the present model results?

Reply: Thank you for your comments and suggestions. Yes, the ocean circulation is another important aspect in Zhong et al 2018. In this article, our analysis focuses more on the importance of atmospheric dynamics and sea ice. We will add some ocean circulation analyses in the discussion section and compare out results with Zhang et al. 2018.

Comments on the figures:

Throughout the labels on figures could be tailored for easier reading of the figures. As it is one has to read the caption carefully to understand what the multi-panelled figures are showing.

Reply: Thank you for your comments and suggestions. We will modify it.

Figure 1: For clarity could you include in this caption whether this is late Holocene minus early Holocene?

Reply: Thank you for your comments and suggestions. We've modified it.

Figure 3: I would like to see the annual-mean model result as the proxies are calibrated to this if I understand correctly?

Reply: Thank you for your comments and suggestions. The annual-mean shows similar results. We've added it.

Figure 6: It would probably be helpful to have the same y-axis limits on panels (c) and (d). Also, are the timeseries of the PC 2 smoothed?

Reply: Thank you for your comments and suggestions. Yes, they are smoothed. But when regressing based on the PC time series we use the original unfiltered PC time series. This needs to be made clear. We've modified it.

Figure 9: is this the AF or the ORBIT-only simulation? Do they both look similar?

Reply: Thank you for your comments and suggestions. It is the AF simulation. Yes, they look similar.

Technical corrections:

Line 148: "while the blue indicating and decreasing." Typo here.

Reply: Thank you for your comments and suggestions. We've modified it.

Figure 10: The captions says EOF1 but the figure labels say EOF2. I assume they should both same EOF1?

Reply: Thank you for your comments and suggestions. We've modified it.

References:

Hurrell, J et al (2013). The Community Earth System Model: A Framework for Collaborative Research, Bull Am Met Soc, 94,9, https://doi.org/10.1175/BAMS-D-12-00121.1.

Wan Lingfeng, Liu Jian, Gao Chaochao, Sun Weiyi, Ning Liang, Yan Mi. Study about influence of the Holocene volcanic eruptions on temperature variation trend by simulation[J]. Quaternary Sciences, 2020, 40(6): 1597-1610. doi: 10.11928/j.issn.1001-7410.2020.06.19