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Comment

## ***Interactive comment on “Enhanced 20th century heat transfer to the Arctic simulated in the context of climate variations over the last millennium” by J. H. Jungclauss et al.***

### **Anonymous Referee #2**

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This study assesses the results of coupled climate simulations covering the last millennium and reaching into the 20th century. The mechanisms responsible for temperature variability in the pan-Arctic region during the last millennium are assessed. In the preindustrial time period, the simulated temperature variations in the region are found to correlate closely with ocean heat transport variations. For the postindustrial period, previous paleoceanographic reconstruction studies have indicated a dramatic warming in Atlantic Water (AW) as compared to the preindustrial period, leading to anomalous enhanced ocean heat transport into the Arctic. This has previously been suggested to be a key element in the Arctic response to anthropogenic warming, adding to the local warming and sea-ice temperature feedback. This study proposes a mechanism

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by which this could take place: anthropogenic warming results in a weakening of the deep water formation and the Atlantic meridional overturning circulation (AMOC), which leads to a strengthening of the subpolar gyre (SPG).

Assessing quantitatively the factors contributing to regional climate changes is undoubtedly of importance. The results are very interesting and contribute to our understanding of Arctic climate change in a paleoclimatic perspective, highlighting the importance of ocean circulation changes in the Arctic amplification of global warming. Although the focus of the manuscript is the 20th-century, the discussion is framed in the context of the last millennium and thus the manuscript is well suited for Climate of the Past. The paleoclimatic focus and the paper itself would both gain if preindustrial simulated variations were discussed in depth in this same manuscript, but I can understand that the authors reserve this for a future manuscript, as they mention.

The authors claim that the mechanism they describe explains the enhanced 20th century warming. However, to be totally convincing they would need to illustrate it using 20th century oceanographic observations. It is clear that for the previous period there will be no observations available, and this is where their simulations are most valid. But without current observations what they show is just a plausible mechanism as inferred from their climate model. As the authors say, ‘the model results have to be confronted with observations and reconstructions to assess in how far they reproduce the real climate evolution, both in direct comparison’. This applies also to the mechanisms. Thus, I suggest including an assessment on observational changes in ocean heat transport in the 20th century, assessing whether it is taking place and whether it responds to the same mechanism as described here. If this is not possible, it should be explained clearly why, and some of the conclusions should be rephrased.

Another point I think should be addressed is the statement that the AMOC reduction is the trigger of the SPG increase. Is an AMOC decrease really necessary to strengthen the SPG, or are the AMOC decrease and the strengthening of the SPG both a response to reduced deep water formation and local cooling? A reduction of the AMOC under

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anthropogenic warming at most only attenuates the warming. Cooling is rather only found locally, in response to reduced deep water formation. I think it would be more exact to frame their results in this way.

Other minor comments to consider are the following:

- Abstract: I find misleading the statement in the abstract saying 'Here we present results from Earth system model simulations over the last millennium that reproduce and explain reconstructed integrated quantities such as pan-Arctic temperature evolution during the pre-industrial millennium'. Besides the very low frequency variability, climate variations in the preindustrial period are not really reproduced or explained. I assume this is part of a companion paper, as the authors say.

- Page 2899, line 10: correct 'Intercomparison'

- Page 2905: why do the authors say 'a weaker overturning component is compensated by a stronger gyre'? Despite the weaker overturning the MOHT does increase, at least at high northern latitudes. This figure is however very confusing, see below.

- Page 2901, section 3: related to my comment above, the discussion of the preindustrial last millennium is limited to the comparison of the broad, low frequency variations in the reconstructed and simulated Arctic surface air temperature, sea-ice and Atlantic water temperatures. This discussion could be deepened. For example, even though figure 1b shows the simulations and reconstructions agree within the uncertainties of the latter, the simulations a priori seem to show a larger degree of agreement with each other than as compared to the reconstructions. These similarities could be a matter of chance or be related to the external forcing, but in the latter case they should also be reflected in the reconstructions, unless internal variability is strongly underestimated by the model. I understand in the case of 1c it can be partly a consequence of limited temporal resolution of the proxies.

- Page 2907, line 18: the sentence in the discussion stating the SPG intensification is

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caused by 'the weakening of the AMOC and the associated reduced heat supply' is misleading. As explained above, the SPG I understand is spun up because of local cooling due to reduced deep water formation, not because of reduced heat transport by the overturning. The AMOC does decrease, but as the authors say this does not imply reduced heat transport by the overturning. Also, is an AMOC decrease really necessary to strengthen the SPG or are the AMOC decrease and the strengthening of the SPG both a response to reduced deep water formation and local cooling? (see also the comment below).

- Page 2909, lines 8-21: the authors give arguments supporting a similar mechanism might operate during the late Holocene. They end up saying that the preindustrial millennium will be assessed separately. However, as suggested in my major comment above, they could attempt to identify this mechanism in present-day observations or explain why this is not feasible.

- Page 2011, line 16: again, is an AMOC decrease really necessary to strengthen the SPG or are the AMOC decrease and the strengthening of the SPG both a response to reduced deep water formation and local cooling?

- Figure 1: please state which of the three simulations corresponds to each colour. Also, in panels b and c, it is difficult to distinguish the thin from the thick lines. The same goes for figure 2b. I would strongly suggest using shading for the confidence intervals.

- Figure 3a is confusing: I understand there are three colors, black for the total, red for the gyre and blue for the overturning component, I assume for the ensemble as fig 2b. If so the ensemble should be explicitly mentioned. What are the dotted lines? As before, there are too many lines, I would strongly suggest using shading for the confidence intervals.

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