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Interactive Comment

Interactive comment on "Potential causes of 15th century Arctic warming using coupled model simulations with data assimilation" *by* E. Crespin et al.

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We would like to thank very much the second referee for his positive and constructive comments and suggestions.

The method proposed in this study is new, and has been used only a few times up to now. The development of the method is then not accomplished yet and we are expecting to improve it continuously. In order to answer the first comment of the referee, we would like to discuss the different pros and contras of the method. When combining proxies and model results, as we are doing here, we benefit from the advantages of both proxies and models, but this also leads to some limitations. Proxies allow us to be close to the real evolution, by constraining internal variability in our model simulations, and the model allows us to be coherent with physical and dynamical processes included in the model. But data alone cannot tell us why changes are happening. So, we can propose, thanks to model results, the mechanisms that coherently explain the observed changes, but unfortunately we are unable to explain why those anomalies are taking place at a particular time, or why they are persistent. Our results can tell us if the observed changes are consistent with the model response to the forcing. In such a case, it appears reasonable to attribute those changes to the forcing variations (although this does not constitute a proper detection/attribution exercise per se). If the observed changes are apparently not related to the forcing, the most reasonable hypothesis is to attribute them to the internal variability of the system, although we can never totally rule out a bias in the forcing time series used or in the model response to the forcing. When analyzing the internal variability simulated by the model with assimilation during a particular period, the climate system components with a fast response, such as the atmosphere, and the ones that have a longer memory, like the ocean, play a role. We have clearly underlined in our manuscript the role of the atmospheric circulation during the warm period studied. This is, to our point of view, an important step in the analysis of the causes of the mechanism responsible for the warming. On the other hand, both for methodological issues and because of the lack of data over the oceanic areas in the compilation of proxies we use, the potential role of the ocean cannot be studied yet. If we look at the patterns of sea surface temperature (SST), the anomalies are too small to be responsible for changes in the atmospheric circulation. For instance, in the Pacific, the different experiments show mostly homogeneous SST anomalies from -0.1°C to 0.1°C. It seems improbable that those anomalies could trigger the observed changes in atmospheric circulation. The same conclusion can be drawn for the Atlantic. On the other hand, some hypotheses can be made about sea ice, and we have decided, as suggested by the referee, to add in the revised version some information about the pattern of changes in sea ice. We observe a decrease of 2% in sea ice area and 6% in sea ice volume in the Arctic during the period 1470-1520 compared to 1250-1300. A figure of the pattern of sea ice concentration anomaly has been included for our period of interest. An almost general decrease in sea ice concentration can be observed, with a minimum in the Barents Sea (-4%). A link between the Barents Sea ice coverage and the atmospheric circulation has been observed previously in our model (Goosse et al., 2003). Bengtsson et al. (2004) proposed as well that the anomaly in atmospheric circulation during the early 20th century warming in the Arctic was most likely due to a reduced sea ice cover, mainly in the Barent Sea. So, in conclusion, we can suspect a feedback with sea ice during our period of interest, but no SST anomaly can help us to understand the atmospheric circulation anomaly.

Rather than being speculative on the reasons why the anomalies are persistent during several decades, we prefer not to discuss too much this point. However, we agree with the reviewer that it is an important question that we will address as a follow up of our study. This limitation will be described in more details in the revised version of the manuscript. We think that, despite this downside, we have obtained and interesting result. The main point to retain is that we have been able to provide an evolution of the surface temperature for the last millennium that is based on both model physics and the information available from proxy data. The originality of this study is that we have been able to put in evidence a particularly warm period taking place during the years 1470-1520, that have not been given much attention until now, and we were able to associate it to a particular pattern of atmospheric circulation.

We thank the referee for the references provided. We have compared our model results with reconstructions that have not been used to constrain the model, and have added some references to the validation part of the paper. In particular, qualitative comparisons show that some reconstructions agree pretty well with our warm conditions during the 15th century and early 16th century. For instance, a record of temperature based on sedimentary diatoms from a lake in Northern Fennoscandia (Weckström et al. 2006) shows a warm period during 1470-1500, which suits very well to our results. Bird et al. (2009) identified two relatively warm periods from 1350 to 1450 and 1500 to 1620 in a varve-based record from a lake in Alaska. The climate record inferred

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from varved lake sediments on Northeast Baffin Island studied by Thomas and Briner (2009) also suggests that the warmest pre-twentieth century interval during the last millennium occurred between 1375 and 1575.

Technical issues

The typos have been corrected.

Additional references

Bird, B.W., Abbott, M.B., Finney, B.P. and Kutchko, B.: A 2000 year varve-based climate record from the central Brooks Range, Alaska, J. Paleolimnol., 41, 25-41, 2009.

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