

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

E. Crespin et al.

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We would like to thank very much the first referee for his very interesting suggestions that will help us to present more clearly the main points of our study in the revised version of the manuscript.

General

Regarding the main point of the reviewer, we would like to recall the advantages of our method compared to more standard ones. In the classical model studies analyzing the climate of the past millennium, simulations are performed (ideally an ensemble) over that period with models and then the consistency between model results and available observational data from proxy records is tested. Because of the internal variability of

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the system, which is largely of chaotic nature, this can only be checked on a statistical point of view, not for a particular period. The goal of the present study is to propose an alternative method for analyzing the climate of the past. In our reconstruction of past climate, we take into account all the information available from proxies, model results and the forcing applied. We can thus try to analyze some specific events using all the information available (see also point 14). This new and innovative method was positively welcomed by the two other referees. Although some limitations of the method can still be improved, we think we have obtained some interesting results up to now. Those limitations will be more extensively discussed in the revised version following the comments of the reviewers.

We agree with the reviewer that additional validation exercises for the Arctic will help to convince the readers who are the most skeptical about the interest of the method. The referee proposed two different aspects to take in consideration: the first one, to constrain the model with the full instrumental record and with instrumental records located only at the points where proxy series are available, and the second one, to nudge it towards a simulation from another model. We have chosen to follow the first alternative suggested by the referee because of the direct link with real observations and the test of the ability of the model results to follow the real changes. We are thus performing new simulations, nudged towards the instrumental record, and will present the results in the revised version of the paper. The second idea is also very interesting, but it is out of the scope of the present study. Validation exercises of the method have been and will be conducted continuously to improve the method.

As suggested, we have included a comparison with additional proxies. We have added a new paragraph devoted to this point in the validation part of the paper.

Specific

1. We have followed the suggestion of the referee.
2. The sentences using the word 'warmth' incorrectly have been modified.

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3. We have included one sentence explaining what we mean by internal variability: it is the internal variability related to the internal dynamics of the climate system, i.e. the one that would be present in the absence of any change in the external forcing (see for instance Goosse et al. 2005).

4. Bengtsson et al. states that temperature averaged for the 1940s is 1.7°C higher than for the 1910s. We have cited in the revised version the paper of Johannessen et al. (2004), which is based on observations, instead of Bengtsson et al., which looks at the causes of the increase.

5. The paper of Kuzmina et al. (2008) does not use more data than in Trenberth et al (2007), but it offers an alternative way to present them, and is very helpful in Arctic studies since the spatial coverage is enhanced in the high latitudes. So, we consider that it is useful to cite both of them.

6. We agree that the link between the two different scales (the Northern Hemisphere and the Arctic) may be confusing and will thus be removed. We have changed the paragraph by : By contrast, during the early 20th century, when anthropogenic forcing was considerably weaker than today, the observed Arctic warming was likely due to the internal variability of the climate system. Variations in solar and volcanic forcings could have played some role in this early warming, but it is difficult to assess in which proportion, because of the uncertainties in the different forcing reconstructions. It has been proposed that the early 20th century warming was caused by increased southwesterly winds and oceanic heat transport into the Barents Sea region (Bengtsson et al., 2004; Overland et al., 2004; Rogers, 1985).

7. The world 'corals' has been removed.

8. We thank the reviewer for this reference. We have added to the phrase 'The absence of direct instrumental data before the mid-19th century...'; the parenthesis 'even though we can find some records reaching back to the late 18th century'; , and cited the paper of Vinther et al. (2006).

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9. We have corrected the time period of the so-called Medieval Warm Period, extending from approximatively the 10th to the 12th centuries. The referee has suggested to discuss according to years, but this is not easy, as the timing of this warm episode differs in the different reconstructions available. Those reconstructions however agree that it happened around those centuries.

10. We have removed ADs as suggested by the referee.

11. 'relatively warmth' has been changed to 'relative warmth'

12. The method has some clear limitations but we consider that it can bring some useful information on the climate of the last millennium as discussed in the general point above. Indeed, the advantage of the data assimilation technique is that the model tries to stay as close as possible to the reality, and is able to give information about dynamical processes which are not available directly from proxies.

13. The typo has been corrected.

14. As suggested by the referee, we have included a figure in the revised version of the paper presenting the proxy series used to constrain the model averaged over the Arctic. This series has actually two maxima of temperature during the years 1400-1450 and 1470-1520. The two peaks observed in our reconstruction are clearly related to the signal recorded in the proxies. We agree that it is thus not surprising to find it in the simulations with data assimilation. This is not the most original and interesting point of this study. We do not add any information by reproducing these peaks of temperature, and we consider that it is only a kind of validation of the method to prove that we are able to reproduce the observed signal. However, our results allowed giving some light on this period that was not much discussed before. Furthermore, we can provide additional information on a plausible large-scale pattern associated with the warming recorded in the proxies in some regions and on the processes that were responsible of the warming (in particular here the atmospheric circulation).

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15. The locations where proxies are available can be seen in Fig. 2. We use 23 proxy series north of 55° . We have added this number in the revised version. A reference to the figure was stated.

16. The principal uncertainty associated with our result is the absence of a clear response in the ocean. This could be considered as a limitation but also as a conclusion of the study allowing to underline where additional work is needed, both on the data assimilation technique and on the inclusion of additional proxy. This will be explained more clearly in the revised version of the manuscript.

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