Clim. Past Discuss., 5, S187–S193, 2009
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Climate of the Past Discussions

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.

Received and published: 3 April 2009

We would like first to thank very much the referee for his careful reading and his constructive comments that will help us to improve the clearness and the quality of our paper.

We have included numbers to the different comments for an easier reference.

Main concerns

1. As the referee has put forward, LOVECLIM is a model of intermediate complexity and, by definition, its representation of atmospheric dynamics is simpler than in more sophisticated models. We completely agree that its results have thus to be taken with

caution, in particular when analyzing the dynamical response of the atmosphere to the forcing. However, LOVECLIM has been tested and used previously in many studies devoted to the last millennium, which provided satisfactory results. Furthermore, as underlined by reviewer 2, the use of such a model offers some advantages, such as the low CPU time requirement that is compatible with the method that we have used. It would indeed be impossible to perform such an ensemble of simulations with a GCM. We thus consider that using this model is justified in the present framework. Nevertheless, we have modified the text in the conclusions to make the limitation of the methodology even clearer in the revised version.

2. There is actually no data for the central Arctic to constrain the model or compare the model results with. However, the proxies available at lower latitudes, mainly over Scandinavia and Siberia, are constraining the model and the model results in those regions are in reasonable agreement with these proxy data. Since no data show that our results are wrong, we present them as a reasonable possible pattern of change. This then provides a clear hypothesis that can be tested when new data will be available. We have included in our conclusions additional sentences stating that we are aware that the low quantity of data constitute a limitation of our study and that our results are certainly more robust in areas where a lot of proxies are available, but for now we have made what is possible.

3. During the first 4 centuries of the millennium, the number of proxies available for the data assimilation is lower than for the next 6 centuries. The uncertainties inherent to those proxies are also larger. We agree that the difference between the simulation with and without assimilation is very intriguing. We will insist a bit more on that point in the revised version of the manuscript, but we prefer, at this stage, to focus on a period for which we have more data and thus likely more robust results. Our general objective is to study warm periods, and we have chosen the warming happening during the period 1470-1520 because it is the warmest period of the millennium before the 19th century (see also point 18 below).

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4. The data assimilation technique used in the context of this study is a new method that offers many advantages, but has also some limitations, which will be described more clearly in the revised version of the paper. One limitation of combining proxies and model results is that it is not possible to explain why the anomalies responsible for the warmth are happening or why they can be maintained for a long period of time. Nevertheless, the reconstruction obtained offers some innovative results. This method allows us to obtain a reconstruction that is in agreement with the proxy records and with the physical and dynamical processes included in the model. Thanks to that, we have been able to put in evidence a particular period of warmth and to go one step further in the understanding of this warm period by proposing a mechanism that coherently explains it. We preferred not to discuss the reason of why this is happening, since we can only advance some vague hypothesis, but we agree with the referee that this is an important question that needs to be studied in the future.

The pattern of surface temperature anomaly in the simulation performed without data assimilation for our period of interest (1470-1520) is not comparable to the one observed in the simulation with data assimilation. The pattern of temperature anomaly in the simulation without data assimilation does not present an almost general warming as in the other case. Some large zones of cooling (up to -0.1° relative to the reference period) are observed in North America and Siberia. The pattern of anomaly of the 800hPa geopotential height is neither comparable. The anomalies are positive where they should have been negative. This clearly shows that, if not helping the model through constraining internal variability in the simulations, we can obtain different evolutions of the climatic situation and that the role of the forcing in the warm anomaly is minimum in our model. We have added a paragraph in the text mentioning this point, but for the clearness of the paper we preferred not to add supplementary figures, since they are not very interesting.

Further comments

1. Please refer to general comment 3 and 4.

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2. Bengtsson et al. states that temperature averaged for the 1940s is some 1.7°C higher than for the 1910s. This warming is not clear in Figure 4, because of the 51-year running mean applied to the time series. In the model, the difference between these two decades is ˜1°C. As this number may be confusing, it has been removed from the revised version of the manuscript.

3. The LOVECLIM model does not take into account explicitly the vertical distribution of the volcanic aerosols. As said in the first version of the manuscript, the volcanic forcing is imposed though solar irradiance anomalies, as it has been done in previous studies. Because of those simplifications in the forcing and in the model itself, the dynamical response of the model to the volcanic forcing must be regarded with caution. In particular, the data assimilation scheme can induce a particular phase of the NAO during some periods that would be interpreted based only on LOVECLIM results as mainly due to internal variability, while in the real world (and in some models), this can be largely attributed to a response of the system to the forcing and a much weaker contribution of the internal variability. We have mentioned this point in the conclusions. Nevertheless, the volcanic forcing did not appear to be particularly important during the period analyzed here, so we do not consider that this forbids us to discuss the role of forced and internal variabilities.

4. If we look at the 1400-1450 warm period, we have a maximum of temperature, which is preceded by a maximum (0,5 W/m2) of the solar forcing. On the other hand, the second maximum of temperature taking place at the end of the 15th century, corresponds to a minimum (-0.3 W/m2) in the solar forcing. Unless a very complex feedback took place leading to a warming of the region, it is thus hard to attribute this warming to a solar effect. Furthermore, to our knowledge, no study has proposed a large warming of the Arctic such the one described in Fig. 5 as a response to a decrease in solar forcing.

5. As expected, the evolution of the sea ice is in good agreement with the evolution of the temperatures: minima in sea ice area can be observed during our periods of warm-

ing, and vice versa. This will be mentioned in the revised version of the manuscript in a new paragraph concerning the changes in sea ice. A new figure showing the pattern of sea ice concentration anomaly is added for the period 1470-1520. We also suggest a possible influence of the decrease in sea ice concentration on the atmospheric circulation anomaly observed during our period of interest.

6. The constraints in the data assimilation are applied on annual means, since the proxy series used here comes from the recent compilation of Mann et al. (2008), which were calibrated using annual mean values. It would be very interesting to carry out the exercise for seasonal means when an seasonal equivalent of the compilation of Mann et al. (2008), in which all the proxies will be screened in order to select only those which display a clear signal for one particular season, will be available.

7. We wanted around a hundred simulations in order to have a statistically significant number of realizations of the internal variability of the system. For technical reasons, we chose to run 96 simulations as this is easier to run in parallel (3 groups of 32 simulations each of them on 32 CPUs of a cluster). This will be mentioned in the revised version of the manuscript.

8. We made use of the University of East Anglia Climate Research Unit instrumental surface air temperature data. (http://www.cru.uea.ac.uk/data/temperature). We have added this reference in the text.

9. Because of the smoothing of the proxies, it is not possible to follow the observed interannual variability of the system. However, previous studies (Goosse et al. 2006) have shown that when using a 1-year mean in the evaluation of the cost function, we can adequately follow the decadal changes of the system. Anyway, tests with different averaging periods are presented to show that this value is not critical in our analysis.

10. The typo has been corrected.

11. The typo has been corrected.

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12. The typo has been corrected.

13. As suggested by the referee, Figures 1 and 2 have been modified.

14. At the time scale of the last millennium, the role of the orbital forcing is weak. Other LOVECLIM studies have shown that the effects of this forcing are not significant for the last millennium (Goosse et al. 2006b). The value of the orbital parameters changes each 1000 years. For the year 1950 we have: eccentricity = 0.016724, obliquity = 23.446°, longitude of the perihelion = 102.04°, climatic precession = 0.01636; and for the year 950: eccentricity = 0.017116, obliquity = 23.575°, longitude of the perihelion = 84.96, climatic precession = 0.01705.

15. We have changed the colorscale in Figure 2.

16. We have increased the thickness of the lines in Figure 3.

17. This has been discussed in the 4th point of the main concerns.

18. This has been discussed in the 3th point of the main concerns. The 1000-1400 period is not analyzed because of the uncertainties and the low number of proxies used in the data assimilation technique. The analysis of other special events was not included in this paper since we decided to focus on the particular 1470-1520 warm period. The difference between the runs with and without data assimilation for that period is of 0.2°C. A second period is showing as well high values of the temperature for the run with data assimilation, that is the early 19th century cold period. As this period is known to have increased volcanic activity, it is probable that here the data assimilation technique is correcting the response of the model to the volcanic forcing, which, as commented by the referee (point 3 above), must be regarded with caution.

19. This comparison is done in Fig 2a. The figure on the right in Fig. 2a is the same than Fig. 5, but we have kept from the model results only the points where the proxies were available for an easier comparison. So, we do not think it will add much more by putting it again in Figure 5.

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20. This has been discussed in the 2th point of the main concerns. The central Arctic has actually no data, so the comparison between model results and proxy series is not possible. But the comparison at the location where proxies are available show a good agreement, with high values of temperature in Scandinavia and Siberia.

21. Studies about the early century 20th warm period suggest that an atmospheric circulation anomaly was responsible for this warming. This anomaly has clear similarities with the one of the late 15th century warming. What we wanted to say in that paragraph is that even if the warming is higher in the first one, the atmospheric circulation seems to be acting in the same way.

22. The increased inflow of warm air coming from the south is responsible for the warming in the Canadian Archipelago. This is indeed a somewhat broad definition of the AL and has been removed.

Additional reference

Goosse, H., Arzel, O., Luterbacher, J., Mann, M.E., Renssen, H., Riedwyl, N., Timmermann, A., Xoplaki, E. and Wanner, H.: The origin of the European "Medieval Warm Period", Clim. Past, 2, 99-113, 2006b

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