Answer to the Anonymous Referee # 1

1. **Anonymous Referee # 1**

   LOVECLIM model with data assimilation is one of the more novel aspects of the paper. The authors write on page 3965 that although some improvement is obtained in proxy-model comparison due to data assimilation, it is not expected to have a model state which displays values fully consistent with proxy records. I am not a specialist in data-assimilation issues, but is it not natural that the data-model consistency increases if you force the model with the data and why is it not possible to force the model to be fully consistent with the data? There probably is an explanation for this, but I failed to fully comprehend it with the way it is described in the paper.

   Mairesse and co-authors:

   Indeed, the goal of data assimilation is to increase the model-data consistency but this objective is not necessarily reached in all the experiments, for all the proxy-based reconstructions. Limitations come first from the method itself and its implementation. For instance, we use only 96 particles which appears fine in the test we have performed (Dubinkina et al., 2011; Goosse et al., 2006) but is still relatively small and could be not enough. In some cases the physics of the model or its resolution may also be inadequate to reproduce the signal of the proxy. The interpretation of the proxy-based reconstructions or the estimate of their uncertainties may also be biased leading to inconsistencies with other records or with the model physics. The conclusion of the experiment could then be that, using the proposed methodology and the estimated uncertainties, no model state fully consistent with all the proxy-based reconstruction can be found. Ensuring this consistency would require including additional degrees of freedom in the system, which is out of the scope of the present study. In order to avoid confusion, we have modified this section in the revised version of the manuscript.

   Although some improvements are due to data assimilation, the obtained model state is still not fully consistent with all the proxy-based reconstructions. This would require including additional control parameters in the data assimilation process, for instance perturbation of some model parameters, or alternative estimates of the uncertainty of the proxy-based reconstructions. This specific experimental design is out of the scope of this paper, as we would like to focus, in this first study of the mid-Holocene climate, on an estimate of compatibilities between models and proxy-based reconstructions using the standard model configuration and interpretation of the proxy-based reconstructions.

2. **Anonymous Referee # 1**

   The second major issue is the proxy dataset. The authors write that "the proxy dataset used in the simulations with data-assimilation results from a selection

among more than 300 Holocene records..." and later on, that "on the basis of these criteria, we have selected 50 records". A critical question is how did the authors end up with only 50 records for the whole northern hemisphere and why where these records selected and so many excluded, including many which would fulfill the criteria given in the text? Why are so few continental records used from North America and northern Europe compared to, for example, the 6 ka dataset used in Bartlein et al. 2011 paper? Why so few marine records from the Atlantic and the Pacific? Why only Agassiz and Renland ice core 18O records, but not the 18O records of the other Greenland ice cores and why not the direct temperature records from the GRIP ice core based on 18O data and borehole temperature measurements? Why is only one speleothem 18O record used from Europe, where the real number of Holocene time-series speleothem records is probably over 10 these days?

Mairesse and co-authors:

Our goal is to be as objective as possible when selecting the proxy records for this study. For this purpose, we have established strict criteria of selection that sometimes put aside a proxy-based reconstruction that may have appeared suitable. When reviewing the criteria we have seen that one of them was missing and we have therefore changed the following sentence: "*... the record ... (iii) has a mean temporal resolution of at least 250 yr for the mid-Holocene time-slice (*6 ± 0.5 *ky BP) and for the reference period (950 to 450 yr BP) ...*" to " *... the record ... (iii) covers the full mid-Holocene time-slice (*6 ± 0.5 *ky BP) and the reference period (950 to 450 yr BP) with a resolution of at least 250 years. ...*". The strictest criterion is certainly the fact that we want a continuous record through mid-Holocene period and the reference period. Therefore, as the oceanic top core is often missing, several oceanic proxy-based reconstructions have not been selected. The proxy of Calvo et al. (2002) is for instance put aside because of this strict criterion since it is not continuous over the reference period (see Fig 1).

Also, as we want to have a reasonable balance between the different types of records, we have preferred to include large-scale reconstructions as the ones of Davis et al. (2003) and Viau and Gajewski (2009) that include most of the individual pollen records rather than the complete set used for instance in Bartlein et al. (2011). We have then add the following in the "The proxy-based dataset" section: *Our goal is not to include all the available local proxy-based reconstructions. When a choice has to be made, we prefer to use regional scale reconstructions such as the ones of Davis et al. (2003) and Viau and Gajewski (2009) rather than the individual records that were included in those reconstructions.*

Finally, we have selected only two air surface temperature reconstructions derived from the $\delta^{18}O$ of the Agassiz and Renland ice core because according to Vinther et al. (2009) the Greenland Ice Sheet elevation change influences trends in the $\delta^{18}O$ records except for these two air surface temperature reconstructions as they are uplift-corrected.

3. **Anonymous Referee # 1**

Another proxy-related issue is the nature of the records. First, the way to authors use the term "proxy" is wrong. The term "proxy" refers to any biological, physical or chemical type evidence that provide indirect palaeoclimate data. "Proxy" does not mean an individual palaeoclimatic record. It is therefore misleading to write in the abstract that ". . .the comparison of the LOVECLIM simulations with and without data assimilation has also objectively identified 16 proxies whose reconstructed signal is either incompatible..." A correct way would be to write that "...has also objectively identified 16 proxy-based palaeoclimate records whose reconstructed signal is either incompatible. . ." There is a fundamental difference of meaning.

Mairesse and co-authors:

Yes, we agree with the comment and are sorry about our potentially misleading word use. The term proxy indeed refers to any type of archive from which a physical variable describing the past climate can be reconstructed with the help of different transfer functions. And thus, we acknowledge that it is important to remind the reader that a distinction has to be made between these two types of information. This the reason why we use mainly the explicit wording "proxy-based reconstruction" in the revised version. However, to improve the readability of this manuscript, we have made the choice to sometimes refer to the reconstructed physical variable (the air or sea surface temperature) with the word "reconstruction" when in the same paragraph or page we use already many times the words "proxy-based reconstruction".

We have then added the following in the introduction:

In particular, the mid-Holocene, corresponding to 6 ky BP (thousand years before present), is a standard period in the Paleoclimate Modelling Intercomparison Project (PMIP) for which boundary conditions have been specified to facilitate the comparison between models results and with proxy-based reconstructions (hereafter often referred to as reconstructions, for simplicity).

4. **Anonymous Referee # 1**

In many reconstructions the climate parameter is annual temperature. But the models simulate winter and summer temperatures. How were the annual mean temperature records handled in the data-model comparisons?

Mairesse and co-authors:

We agree with the comment. This point was not clear in the submitted manuscript. It is now specified in the revised version in the data-assimilation section.

As the methodology does not allow taking into account different time resolutions (Mathiot et al., 2013), the annual proxy-based reconstructions are compared to model values twice a year: to the mean value of December to May during a "winter" step of assimilation, and to the mean value of June to November during a "summer" step of assimilation (when the model is propagated from July until November).

5. **Anonymous Referee # 1**

   It is understandable that the quantitative temperature data from biological proxies are suitable for this type of data-model comparison, but what needs to be explained is how the non-quantitative climate records, such as the Greenland ice core 18O data or the speleothem 18O data were used for this comparison?

   Mairesse and co-authors:

   We had to clarify this in the paper as well: we do not assimilate the $\delta^{18}O$ records, we assimilate the surface temperature derived from the $\delta^{18}O$ of the ice core and the speleothem. This is now specified in the revised version in the data-assimilation section.

6. **Anonymous Referee # 1**

   The title of the paper is misleading because in reality there is no investigation of consistency between proxies in the paper. And it is good that it does not exist, because it would require a more complete and extensive proxy dataset.

   Mairesse and co-authors:

   We have changed the title following the reviewers suggestion. It is now: *Investigating the consistency between proxy-based reconstructions and climate models using data assimilation: a mid-Holocene case study*

7. **Anonymous Referee # 1**

   Page 3954 line 9: " ... pattern but the models underestimate ..."

   Mairesse and co-authors:

   We have added the colored text in the following sentence: *" ... on the large-scale spatial pattern but the models underestimate the magnitude ... "*

8. **Anonymous Referee # 1**

   Page 3954 line 14 "all the 50 proxy records ..."

   Mairesse and co-authors:

   For more consistency with the third comment of the reviewer we have change the sentence "*... all the 50 proxies ...*" to "*... all the 50 proxy-based records ...*"

9. **Anonymous Referee # 1**

   Page 3958 line 6: why is the mid-Holocene period 5500-5000 y BP here, but 6000±500 y BP elsewhere in the study?

   Mairesse and co-authors:

   We have changed: "*... as the difference between mid-Holocene (the period 5500–5000 y BP) and modern conditions ...*" to "*... as the difference between mid-Holocene (the period 6 ± 0.5 ky BP) and modern conditions ...*"

10. **Anonymous Referee # 1**

    Page 3956 lines 20-24: this paragraph is unnecessary

    Mairesse and co-authors:

    The following paragraph has been removed: " *The methodology is presented in*

Sect. 2, including a description of LOVECLIM, the data-assimilation method, the proxy dataset and the experimental design. This is followed by the analysis and the discussion of the model results without and with data assimilation in Sect. 3. The conclusions are drawn in the Sect. 4."

11. **Anonymous Referee # 1**

    Page 3964 lines 1-5: this should be in the methods

    Mairesse and co-authors:

    This section is very short and relatively simple. We have included it to help the reader and we consider that it is better to keep it in section 3 rather than in the methods.

12. **Anonymous Referee # 1**

    Page 3969 line 26: Gulf Stream

    Mairesse and co-authors:

    We have changed: "*The first is associated with an intensification of the gulf stream current at around ...*" to "*The first is associated with an intensification of the Gulf Stream current at around ...*"

13. **Anonymous Referee # 1**

    Figures are in principle good and informative, but too small.

    Mairesse and co-authors:

    We will ensure with the editor, before the publication, that all the figures are readable in the final format.

1 figures

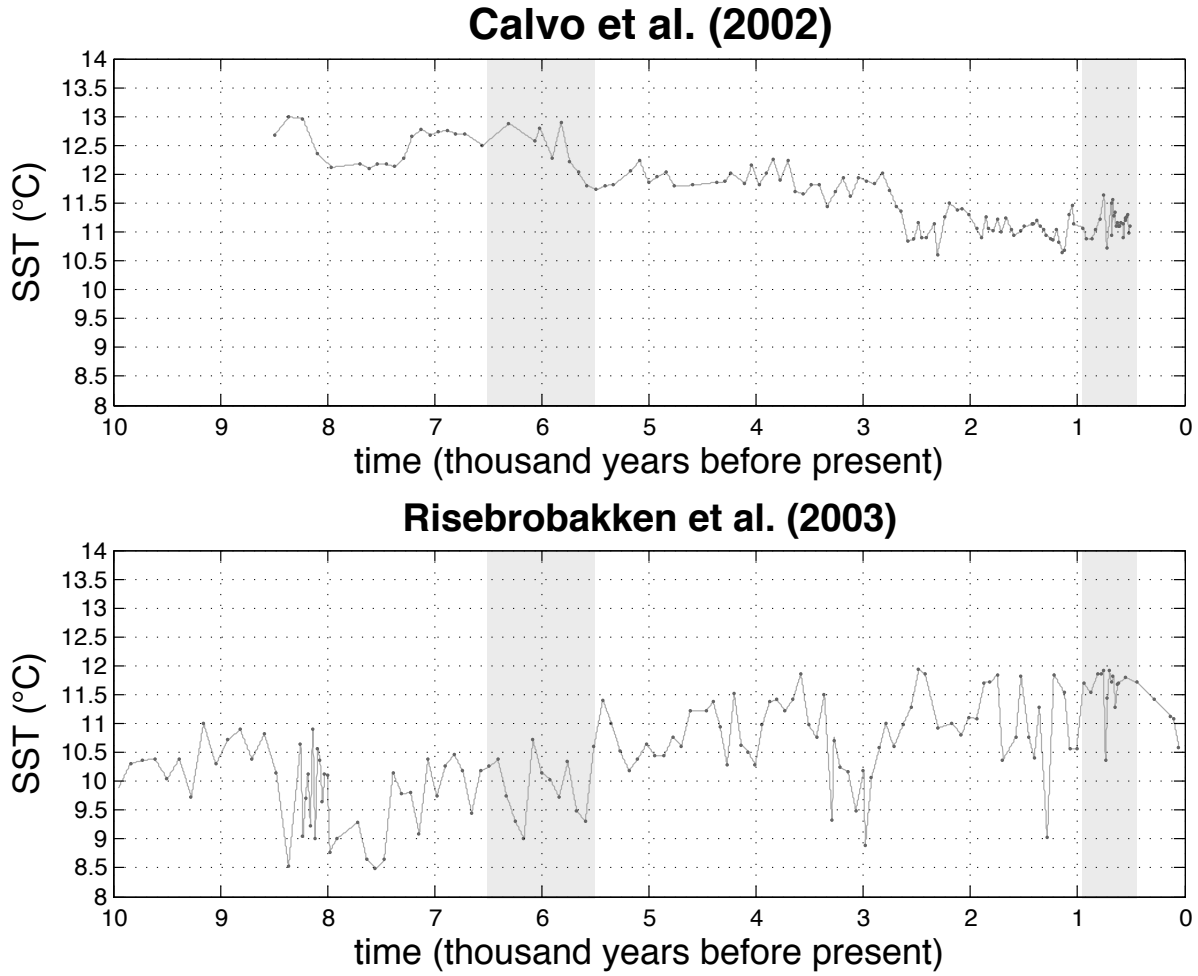

Figure 1: Sea surface temperature reconstructed from the IMAGES core MD95-2011:
- top panel: by Calvo et al. (2002) on the basis of alkenone.
- bottom panel: by Risebrobakken et al. (2003) on the basis of foraminifera.
The grey shaded area are the mid-Holocene period and the reference period.

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