Answer to the Anonymous Referee # 2

1. **Anonymous Referee # 2**

   I agree with the comments made by referee 1. I also feel more discussion should be introduced to precisely diagnose whats happening while data are assimilated. For example, I would have appreciated some more basic information/description of the model behavior when, once data are assimilated, atmospheric and/or oceanic circulation patterns are shifted. Are there key records that push or pull North or South some of the atmospheric/oceanic features towards some kinds of directions, in a way that it can be easily described with an extra figure? Having a kind of example to put things more into context might help the reader who is not familiar with data assimilation to better envision what is occurring in the model once data are assimilated. In the same vein, there is a lack in the description of the assimilation procedure of some firm explanation on how strongly the data assimilation forces the model to drift from an unperturbed response. Can you please specify a little more how data assimilation weight in the model run? In other words, can data assimilation be considered as a kind of forcing, or does it modify only the likelihood that a model falls into one state or another? Such kinds of things are still unclear to me, and I think the authors should try to explain it in a way which can be easily understood by people not involved in climate modeling.

   Mairesse and co-authors:

   As suggested by the reviewer, we have entirely rewritten the data-assimilation section to provide more details and we hope that it will help the reader not involved in climate modeling to understand the procedure. In particular, the way data assimilation is implemented here does not allow us to estimate clearly the role of individual proxy-based reconstruction. This requires specific sensitivity studies. We have made some for disentangling the influence of oceanic and land records but it would be prohibitively expensive to investigate the influence of each (group of) record. Furthermore, the particle filter does not provide any forcing in the model, it just modifies the posterior distribution of model states after the selection of the ones that have the highest likelihood according to the proxy-based reconstruction. This is now explained in the modified description of the method as follow:

   The results of a simulation performed with a climate model depend on (i) the physics of the climate model, (ii) the initial conditions used to initialize the simulation and (iii) the forcing used to drive the model such as, for instance, the amount of solar radiation received by Earth. Here, in order to obtain an ensemble of simulations that represents possible mid-Holocene climate states, we change only the initial conditions by adding a small noise to the sea surface temperature, while the physics and the forcing are kept unchanged.

Due to the chaotic nature of the climate system, even small perturbations in initial conditions result in trajectories that quickly deviate from each other. These different trajectories are called particles or ensemble members. Starting from different initial conditions and using the LOVECLIM climate model, we propagate 96 particles forward in time for an interval of six months: from December until May and then from July until November, thus with a restart each 1st December and 1st July. This is repeated during 400 years. The interval of six months (the assimilation frequency) has been chosen to follow more precisely the seasonal signal embedded in reconstructions as more than 60% of the selected proxy-based records represent a month or a particular season (mainly winter, summer, the hottest month or the coldest month). The amount of 96 particles has been chosen because it provides a satisfactory climate range at an affordable computing cost (Dubinkina et al., 2011; Goosse et al., 2006).

After the propagation step and before another restart, the 96 climate states are evaluated according to their agreement with the air and the sea surface temperature reconstructions inferred from the proxies. This evaluation is derived from the comparison of a likelihood of each particle estimated as a function of the difference between the climate state of the particle and the proxy-based reconstructions. It is based on the surface air and sea surface temperature anomalies obtained from both model and proxy-based reconstruction as the difference between mid-Holocene (the period 6 ± 0.5 *ky BP) and modern conditions (the period 950–450 y BP). This difference is computed for all the locations and months for which proxy-based reconstructions are available (Table 1). For instance, during a "winter" step of data assimilation (when the model is propagated from December until May), one of the proxy-based reconstructions that is taken into account in the computation of the likelihood is the reconstruction number 21 (hereafter N21) for which its mean winter anomaly value is compared to the anomaly of the winter (December to February) sea surface temperature of the corresponding LOVECLIM grid point while the proxy-based reconstruction N20 is not taken into account at this step because it represents a summer anomaly. 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).*

The particles that have highest likelihood are retained while the particles with small likelihood are eliminated. The remaining particles are resampled a number of times proportional to their likelihood so that the total number of particles is kept constant. This resampling step is necessary to avoid a collapse of an ensemble of particles to one single particle. Then, a small perturbation of the surface temperature is added to the initial conditions of the ensemble members and the particles are propagated forward in time for the next 6 months of assimilation using the climate model. For more details about the methodology, which has been applied in several recent studies (e.g., Goosse et al., 2012; Mathiot et al., 2013), please refer to Dubinkina et al. (2011).

2. **Anonymous Referee # 2**

page 3954, line 15-16: the sentence suggests that the fact that data assimilation improves the agreement between data and models. As it stands, it sounds like something not obvious, but my understanding of the procedure is that, by design, constraining models with data are done to improve model-data comparison. Would it be better to state "This assimilation leads to improving the consistency ..." in such case?

Mairesse and co-authors:

Thanks for the suggestion. We have changed "*This assimilation improves the consistency between model results and the reconstructions*" to "*As expected, data assimilation leads to improving the consistency between model results and the reconstructions*".

3. **Anonymous Referee # 2**

page 3955, line 21-27: Schneider et al., 2010, Paleoceanography, not Lohmann 2012, were the first to observe this model-data mismatch in terms of magnitude, and so should be cited as well.

Mairesse and co-authors:

We agree for Schneider et al. (2010). We also have found that Lorenz et al. (2006) had similar results comparing sea surface temperature derived from alkenone (Kim and Schneider, 2004) with transient Holocene simulation realized with the AOGCM ECHO-G. Consequently, we have add the following text in the revised version.

Previous studies (e.g., Lohmann et al., 2013; Lorenz et al., 2006; Schneider et al., 2010) have found similar results when analyzing the trends of the Holocene sea surface temperature obtained mainly from alkenone data: data and models are in relatively good agreement regarding the sign of the trend while the models underestimate the magnitude of the changes.

4. **Anonymous Referee # 2**

page 3963 lines 1-4 and page 3968 lines 13-15: The paper by Risebrobakken et al. (2003) is cited many times and pointed as a SST record which might be representative of subsurface temperature. Although it is a nice test for the data-assimilation robustness - so that temperature record and the discussion associated with that record should be kept - please be aware that another alkenone record from the same site (Calvo et al., 2002) shows a temperature warmer than the one from Risebrbakken by at least a couple of degrees celsius. That paper should be cited to justify your sentence from page 3968 lines 13-15.

Mairesse and co-authors:

This comment is taken into account in the revised version. The sentence is now the following:

Another example is the oceanic proxy-based reconstruction N15 whose signal shows a summer negative anomaly opposite (i) to the positive one illustrated by the nearby continental proxy-based reconstructions and (ii) to the alkenone-based sea surface temperature reconstruction derived from the same core which

depicts a positive anomaly (Calvo et al., 2002). This incompatibility consolidates the interpretation of Risebrobakken et al. (2003) that this proxy-based reconstruction should not be considered as an estimate of sea surface temperature.

5. **Anonymous Referee # 2**

   pages 3964-3965, the two last sentences of that paragraph: please comment and describe a bit more those points, in particular by using better the figures to highlight your point.

   Mairesse and co-authors:

   We have add the following explanation.

   As this analysis is much less strict since it is less influenced by the magnitude of the anomaly, it leads to much more encouraging results than the conclusions derived from the analysis of the RMSE: LOVECLIM mid-Holocene simulation agrees with the sign of the anomaly of about two thirds of the proxy-based reconstructions (see the blue and the green markers on the Fig. 5a). This agreement displays no clear dependance on the season, on the location of the reconstructions or on the type of the proxy-based reconstructions and no dominant spatial pattern can be defined from Fig. 5a.

6. **Anonymous Referee # 2**

   I re-emphasize, as Reviewer 1, that figures are much too small, in particular the size of the markers that spot the climate records.

   Mairesse and co-authors:

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

References

Calvo, E., Grimalt, J., and Jansen, E. (2002). High resolution UK37 sea surface temperature reconstruction in the norwegian sea during the holocene. Quaternary Science Reviews, 21(12-13):1385 – 1394.

Dubinkina, S., Goosse, H., Sallaz-damaz, Y., Crespin, E., and Crucifix, M. (2011). Testing a particle filter to reconstruct climate changes over past centuries. International Journal of Bifurcation and Chaos, 21(12):3611–3618.

Goosse, H., Crespin, E., Dubinkina, S., Loutre, M.-F., Mann, M. E., Renssen, H., Sallaz-Damaz, Y., and Shindell, D. (2012). The role of forcing and internal dynamics in explaining the "medieval climate anomaly". Climate Dynamics, 39(12):2847–2866.

Goosse, H., Renssen, H., Timmermann, A., Bradley, R., and Mann, M. E. (2006). Using paleoclimate proxy-data to select optimal realisations in an ensemble of simulations of the climate of the past millennium. Climate Dynamics, 27(2):165–184.

Kim, J.-H. and Schneider, R. (2004). GHOST global database for alkenone-derived holocene sea-surface temperature records, GHOST project, Bremerhaven, PANGAEA.

Lohmann, G., Pfeiffer, M., Laepple, T., Leduc, G., and Kim, J.-H. (2013). A model-data comparison of the holocene global sea surface temperature evolution. Climate of the Past, 9(4):1807–1839.

Lorenz, S. J., Kim, J.-H., Rimbu, N., Schneider, R. R., and Lohmann, G. (2006). Orbitally driven insolation forcing on holocene climate trends: Evidence from alkenone data and climate modeling. Paleoceanography, 21(1):n/a–n/a.

Mathiot, P., Goosse, H., Crosta, X., Stenni, B., Braida, M., Renssen, H., Van Meerbeeck, C. J., Masson-Delmotte, V., Mairesse, A., and Dubinkina, S. (2013). Using data assimilation to investigate the causes of southern hemisphere high latitude cooling from 10 to 8 ka bp. Climate of the Past, 9(2):887–901.

Risebrobakken, B., Jansen, E., Andersson, C., Mjelde, E., and Hevrøy, K. (2003). A high-resolution study of Holocene paleoclimatic and paleoceanographic changes in the Nordic Seas. Paleoceanography, 18(1):1017.

Schneider, B., Leduc, G., and Park, W. (2010). Disentangling seasonal signals in holocene climate trends by satellite-model-proxy integration. Paleoceanography, 25(4):n/a–n/a.