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Biogeosciences Discussions

Interactive comment on "Climate and marine biogeochemistry during the Holocene from transient model simulations" *by* Joachim Segschneider et al.

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Response to Rev#2

We wish to thank Reviewer#2 for the kind words and thoughtful comments that we intend to address as outlined below. In addition we plan to divide the Discussion into subsections for better readability as it was already fairly lengthy and will now have to further increase in length.

1) Mismatch with observations/regard experiments as sensitivity study

We find that a particularly useful suggestion of Rev#2 that we are happy to follow. Also, Rev#1 pointed us to the study of (Liu et al., 2014, The Holocene temperature conundrum), who investigated this mismatch of proxy-based warmer and model simulated colder mid-Holocene than late-Holocene in some detail. They found this to be a consistant feature for the three investigated coupled climate models. So this is a more widespread issue that we can not resolve here. See also response to Rev#1 FC11.

We will revise the Abstract, Introduction, and Discussion to describe our study as a sensitivity experiment to the prescribed forcing, with known deviations to the Holocene climate evolution estimates from proxy data.

2) Relatively large CH_4 variations during the Holocene but CH_4 not included in forcing

We admit that due to a misunderstanding between authors we stated that KCM was forced with only CO_2 as time-varying greenhouse gas. However, the experiments were in fact also forced with transient CH_4 and N_2O according to the PMIP protocol (https://www.paleo.bristol.ac.uk/ ggdjl/pmip/pmip_hol_lig_gases.txt).

We apologize for this error, and will rewrite section 2.2.1 accordingly. We will also add the data source, and the reference to Augustin et al. (2004) that describes the EPICA ice core as data source for the Holocene greenhouse gas concentrations.

Since the CH_4 variations were relatively large (about 100ppbv leaving aside the land use change related increase during the last 500 years), however, it still seems useful to estimate the effect of Holocene CH_4 change on simulated temperature. We plan to do this based on already existing idealized KCM experiments. Such experiments were carried out with a 1% p.a. CO_2 increase, and with/without a 1%/2% p.a. CH_4 increase (Biastoch et al., 2011, supplementary material Fig. S3). From the 1%p.a. CH_4 until +25% CH_4 increase experiment (from around 800 to 1000 ppbv) we diagnose a temperature increase of 0.2C over 100 years, from the 2% p.a. until +225% CH_4 (800 - 2600 ppbv) a temperature increase of 0.75C. It is difficult to estimate, however, what the climate sensitivity on longer time scales would be without actually performing the experiments, but a contribution on the order of 0.1C to the simulated Holocene global mean SST variation from the prescribed CH_4 seems a reasonably conservative estimate.

We will revise Fig. 1a, Sec.2.2.1, Sec. 3.1.1 and the Discusssion to include time series of atmospheric methane and the potential impacts on SST-evolution.

3) Are planetary and cloud albedo included in the radiation calculation?

Both planetary and cloud albedo are included in the radiation scheme of ECHAM5 (sections 6.1.1 and 11.3.2 in the Technical Report (Roeckner et al., 2003). A more detailed analysis of the atmospheric variations in the KCM-experiments is planned to be published in a separate manuscript in a more climate focussed journal.

4) Comparison with proxy reconstructions would be nice to see (AMOC, $\delta^{15}N$)

A more detailed analysis of the physical ocean variations, possibly including a more in

depth comparison of the model results for the North Atlantic and the tropical Pacific with proxy data would likewise be the topic of a separate study. But we will try to address the issue within our current limitations.

4.a) AMOC (Atlantic Meridional Overturning Circulation, data from Hillaire-Marcel et al., 2001, Hoogakker et al., 2011, 2015, Thornalley et al., 2013)

Here we would like to refer to the work of Blaschek et al. (2015), who describe a set of experiments with the earth system model of intermediate complexity "LOVECLIM" and compare their results with various proxies for AMOC (including those investigated by Hoogakker et al. (2011), see Table 2 in Blaschek et al. (2015)). Since the temporal evolution of AMOC in our experiment KCM-HOL is similar to that of experiment 'OG' (Orbital and Greenhouse gases as forcing) in Blaschek et al. (2015), we can assume that their findings are also valid for our experiments: Additional forcing with the 8.2 kyr BP fresh water pulse and also ice sheet topography changes seems to be required to simulate the weak early Holocene AMOC derived from proxies. As those forcings are not included in our model experiment, there is a further reason to discuss our experiments as a sensitivity experiment to orbital and GHG forcing.

4.b) Oxygen minimum zones/ $\delta^{15}N$ records in the Arabian Sea and the Eastern Equatorial Pacific

Arabian Sea (AS):

Here we would like to refer to the study of Gaye et al. (2017) in which an earlier version of the accelerated experiment BGC-HOLx10 was compared to observation based estimates of Holocene OMZ evolution in the Arabian Sea. Based on $\delta^{15}N$ records,

Gaye et al. (2017) find that the AS OMZ has intensified since the last LGM, and that most of this increase occured throughout the Holocene (their Fig. 6). The model results presented here show a more modest increase in AS OMZ-volume than the one in Gaye et al. (2017) even in the non-accelerated experiment, and a rather constant OMZ volume in the accelerated experiment.

Eastern Equatorial Pacific (EEP):

Comparing our results with the proxy-derived estimates of OMZ intensity in the Eastern Tropical South Pacific (Salvatteci et al., 2016), we find an indication of stronger denitrification towards the late Holocene in the proxy data. This would likely support our result of an expanding EEP OMZ, but this could also be a more local decrease in O_2-concentration, rather than a general expansion of the OMZ. Moreover, the proxy-data for the early Holocene show a decrease in $\delta^{15}N$, indicating increasing oxygen concentrations, which is, however, not simulated by our model.

In summary, as we do not simulate nitrogen isotopes (or other proxies), a direct comparison between proxies and model results is somewhat limited. To address Rev#2's comment, we will add the above attempts to the Discussion and point out the limitated nature of that comparison. A more comprehensive comparison of proxy data and our model results has been planned for the future.

Response to minor comments

p15, ln 6: should indeed be -0.4 GtC/yr

p16, ln 20: double 'relevance' will be removed

p19, ln 24: 'seaice' will be corrected to 'sea-ice'

p22, ln 28: 'effect' will be corrected to 'affect'

p24, ln 23: 'pysical' will be corrected to 'physical'

p24, ln 23: 'extrema' will be corrected to 'extremes'

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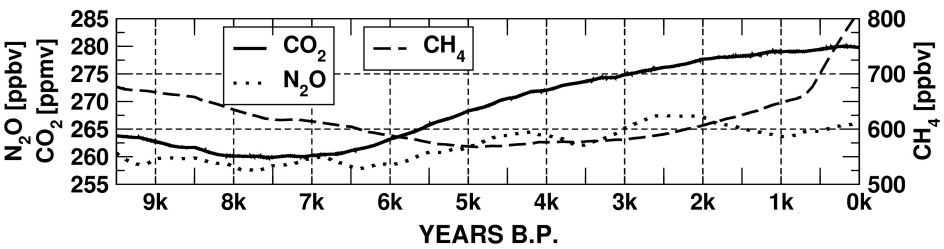

Fig. 1. Revised Fig. 1a