

Response to the Interactive comment by Anonymous Referee #1 (given in *italic* below)

Brovkin et al. present the results of two transient simulations covering the period 6000 BCE to pre-industrial 1850 CE with the Earth system model MPI-ESM-LR. The goal is to constrain the processes leading to the changes in atmospheric CO₂ concentration during that period. The conclusion of the study is that a surface alkalinity decrease, for example due to enhanced carbonate accumulation on continental shelves, is necessary to explain the Holocene atmospheric CO₂ trajectory.

This is an interesting and very valuable study.

We thank the reviewer for the positive evaluation of our study.

Please find some comments below that should be addressed before publication.

1) Experimental set up:

The model was equilibrated under 6000 BCE conditions, with an atmospheric CO₂ concentration lower (260 ppm) than during the pre-industrial. If the global alkalinity concentration was kept constant, then the ocean would have lost carbon during the spin-up phase. Then forced with a transient increase in atmospheric CO₂, all else being equal, the ocean should take up carbon. This is apparently what is happening as changes in SST, ocean circulation. . . are small. Potential bias due to imposing an atmospheric CO₂ concentration should be briefly mentioned.

The global alkalinity in the spin-up experiments was not constant, as the carbonate chemistry was slowly responded to new boundary conditions. In the spinup experiment 8KAF (more than 1,000 years), the weathering flux has not been changed comparing to pre-industrial conditions. The change in the boundary conditions led to different sedimentation fluxes, which resulted in the slow decline of alkalinity in this experiment.

In the TRAFc experiment, which has interactive carbon cycle the weathering fluxes and surface alkalinity were adjusted to changes in the boundary conditions. The equilibration procedure in HAMOCC followed the same rules as in CMIP5 spin-up experiments (Ilyina et al., JAMES, 2013): “Throughout the equilibration process, weathering fluxes and CaCO₃ content in sediments have been changed, which led to changes in total alkalinity (TA). This would have occurred naturally, without leading to excess TA, had the biogeochemistry model been given a long-enough spin-up time to equilibrate its sediments. Along with change in TA, also DIC changed (with the molar ratio 2:1) in order to maintain the correct pCO₂.” This equilibration procedure was applied in the spinup of the TRAFc experiment. In particular, first the system was switched to interactive carbon mode using the same weathering rates as in 8KAF for ~300 years, then it was stabilized the system by increase all of the weathering fluxes (Si, OM, CaCO₃) which led to a stabilization of the surface alkalinity, afterwards the alkalinity was increased to keep the target pCO₂. For the last few hundred years, a weathering was adjusted that lead to alkalinity stabilization. In total, equilibration spinup 8KAFc for the TRAFc experiment took more than 1,000 model years.

We will discuss different equilibration procedure and implications for interpretation of model results in the revised manuscript. In particular, if the TRAF simulation would start from the same initial conditions as the TRAFc, the ocean would not be a source of carbon from the 8

kyr BP, and at the end the ocean carbon uptake and mismatch of carbon budget would be higher than 166 PgC obtained in the TRAF experiment.

2) Justification of surface alkalinity decrease and comparison with previous studies:

The authors have previously done extensive work on the topic of global carbon cycle changes on glacial-interglacial cycles. They are therefore well aware of the literature on the topic, on the rationale behind decreasing surface alkalinity during the Holocene, and on the results from previous studies. However, given that here it is given as the main mechanism controlling Holocene atmospheric CO₂, I would have expected a more in depth introduction of the topic and discussion with respect to previous studies. There is no mention in the introduction of the timing and magnitude of carbonate sedimentation on shelves, as well as on the results of previous modelling studies on the topic. There are only a few words on the topic in the introduction (p2, L.13-14), a few words in the method without any quantification (p4, L.17-18). As a side note, the introduction given in Kleinen, Brovkin et al., (2016) was much more informative. The results and a rapid comparison to Vecsei and Berger (2004) is given p7, L 23-25, but there is no comparison with results from previous studies. In addition, the magnitude of the necessary alkalinity change and its equivalent change in carbonate sedimentation could also be discussed in the context of the simulated changes in land carbon (see section 3).

Introduction: It is always difficult to decide how much of previously written overviews should be repeated in the next paper. As we extensively wrote on state-of-the-art of the Holocene carbon dynamics in the recent papers by Kleinen et al, Brovkin et al., (2016), we limited current introduction to discussion of key old papers (which choice is, of course, a bit subjective) and novel studies appeared after the recent reviews. One of original papers we definitely missed is the study by Elsig et al. (2009). We will refer to it in the revised manuscript, including comparison of their and our results. In particular, from the Fig. 3 in Elsig et al., one can conclude that the deconvolution approach resulted in the land uptake of ca. 140 PgC from 8 to 5 kyr BP, divided rather equally into ca. 70 PgC from 8 to 7 BP and 70 PgC from 7 to 5 kyr BP. The land CO₂ uptake from 8 to 7 BP deduced from the increase in atmospheric $\delta^{13}\text{C}$ by Elsig et al. could not be reproduced in our experiments because of equilibrium model assumptions at 8 kyr BP. Such a non-equilibrium response can be captured only in transient simulations during the last deglaciation. In our TRAF and TRAFc experiments, land accumulates about 60 PgC between 7 and 4 kyr BP. One can conclude that from 7 kyr BP, the land carbon dynamics (uptake of 60 PgC by 4 kyr BP, release of 80-100 PgC by 1850 mainly due to landuse) is similar to the land carbon changes provided by Elsig et al.

3) Changes in terrestrial carbon:

Using a mass balance approach and high-resolution atmospheric CO₂ and d13CO₂ records, Elsig et al., 2009 suggest a land carbon uptake of 290 GtC between 11ka and 5 ka B.P. I am surprised to see no reference/discussion to this study. As far as I can see this result seems supported among others by Stocker et al., (2017), Menviel & Joos (2012) ... Here, the model suggests a terrestrial carbon uptake of 50 GtC between 8 and 2 ka B.P, which is much smaller and with a different timing. A discussion should be added on the results of this study, compared to the estimates of Elsig et al., (2009). The authors should discuss how their results could be reconciled with the atmospheric d13CO₂ record, as also shown in other modelling studies, which included carbon isotopes.

See our response above. We will add comparison with results by Elsig et al. (2009) into the revised manuscript.