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Interactive comment on "Carbon cycle dynamics during recent interglacials" *by* T. Kleinen et al.

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We very much thank the reviewer for taking the time to review our manuscript. We aim to incorporate all of the reviewer's comments in the final manuscript, this will lead to a substnatial improvement over the original submission. For reader convenience we have included the reviewer's comments in full in this reply, marking them by bold font.

The goal of the study is to understand the atmospheric CO2 and d13CO2 evolution during three interglacials: the Holocene, the Eemian and MIS11 using the CLIMBER2 model. The study focuses on the role of shallow water carbonate sedimentation and peat accumulation. For that purpose CLIMBER2 is coupled to the land model LPJ and shallow water carbonate sedimentation is estimated from a simple formulation.

The roles of CaCO3 sedimentation and changes in land carbon on atmospheric CO2 and d13CO2 have been previously studied for the Holocene (including by the authors in Kleinen et al. 2010). However, changes in atmospheric CO2 and d13CO2 during the Eemian and MIS11 have received little (if any) attention. It is an interesting paper, worth publishing in Climate of the Past. Please find a few comments below.

1) Since it has been more studied, estimates of CaCO3 sedimentation and peat accumulation as well as pCO2 and d13CO2 measurements are more accurate for the Holocene. The Holocene simulation could work as a validation of the modelling approach used here. More information could thus be taken out of that simulation to inform on the other 2.

This had been our aim, but in the light of the reviews it has become clear that we need to further extend the discussion of the Holocene results. Therefore we will take this up and extend the discussion of the Holocene results, especially extending the discussion of marine C changes.

The simulated changes in peat accumulation for the Holocene are in line with previous studies (e.g. Yu et al. 2010, Spahni et al. 2013). But I wonder what are the uncertainties associated with the peat accumulation estimates and with land carbon changes in general. The authors discuss the mismatch between the simulated d13CO2 compared to the ice core measurement during the late Holocene. The mismatch almost reaches 0.2 permil at 0.5 ka B.P. Elsig et al. 2009 estimated the land carbon change occurring during the Holocene to match their d13CO2 record. They suggest a land carbon uptake of 290GtC during the early Holocene (10-6 ka B.P.), followed by a 36GtC release. The simulated changes in CaCO3 sedimentation for the Holocene are quite high. Much higher than Vecsei and Berger 2004, but roughly in line with other studies (e.g. Kleypas 1997, Ryan et al.

2001). So the mismatch between simulated and observed d13CO2 during the late Holocene could be explained by an overestimated Holocene peat accumulation, or more broadly an overestimated land carbon uptake coupled with an overestimated CaCO3 sedimentation (because pCO2 follows the observation). The mismatch starts at about 4.5 ka B.P. and as also stated by the authors, I doubt it is due to anthropogenic land carbon changes. The authors briefly mention permafrost. Would permafrost thawing occur that late in the interglacial? It might be interesting to add a few sentences on the possible role of permafrost. The same could be true for the other time periods. For example, simulated d13CO2 between ∼126-122 ka B.P. is significantly lower than observations.

A discussion of uncertainties associated with land carbon changes (and peat, please see comment below) could be added in the Discussion section. Additionally, the abstract could reflect these uncertainties.

We agree that there are substantial uncertainties with regard to the data on peat accumulation. In our 2012 paper on the peat model we have also published minimum and maximum estimates of peatland areas and peat carbon accumulation. We will use the minimum estimate and derive a second calibration for the CaCO3 model corresponding to the lower peat carbon uptake estimate. This will a) reduce the CaCO3 sedimentation required to match the CO2 record and b) bring down d13CO2 somewhat, but judging from older model results we have available, a mismatch between d13CO2 data and model results will remain.

With regard to the dynamics of the permafrost carbon, it is difficult to provide quantitative estimates of its changes in the Holocene. Assuming that the permafrost extent and C storages are linked to the temperature dynamics, one could conclude that permafrost carbon increased during the late Holocene when summer temperatures in the northern high latitudes decreased following the summer insolation decline. However, processes

of thermokarst and water erosion which disturb the permafrost C storages may require much more than several thousand years for equilibration with climate change. The amount of ice in high-latitude permafrost soils formed during the last glacial cycle is large, and disturbances could possibly release glacial-aged carbon to the atmosphere.

We will extend the discussion section with regard to uncertainties in land C processes and also extend the discussion on the possible role of permafrost.

2) It has been suggested that Northern hemisphere summer insolation modulates peat accumulation (e.g. Yu et al. 2010). Apart from a slightly lower accumulation rate between 395 and 380 ka B.P., figures 4c, 7c and 10c display similar linear trends in peat accumulation rate for the 3 time periods (Holocene, Eemian and 1st part of MIS11), which is a bit surprising giving the fact that sea level variations (and thus most likely ice sheet evolution and NH insolation) are different for the 3 periods. What is the sensitivity of CLIMBER2-LPJ peat accumulation to NH summer insolation? Plotting NH summer insolation timeseries in figures 4, 7 and 10 could be useful.

Since they are a main part of the study, it would be nice to add some explanation on peat carbon changes in sections 3.2 and 3.3. In addition, maps of peatland extent and carbon density such as the ones shown in Figures 3 and 6 of Kleinen et al. 2012 would be useful.

We doubt whether maps of peatland extent and carbon density would really improve the paper, but will consider adding them.

Overall, peatland extent is mainly determined by topography in our model, with some variation determined by the land water balance P-E. Therefore, peatland extent is very similar in all interglacials. This may be a shortcoming of our peatland model, although this is hard to judge since reconstructions of past peatland extents are poor for the early Holocene and non-existent for previous interglacials.

The modulation of peat accumulation by NH summer insolation is, unfortunately, not clear with respects to the mechanisms. What Yu et al. (2010) show is a correlation between peatland *initiation* and insolation forcing. This translates to a change in total peat accumulation through the change in peatland area, but not necessarily to a change in peat accumumulation at any particular site. The increased peatland initiation could either result from increased moisture through increased precipitation, or from increased peat accumulation. For the latter it is unclear, what the exact mechanism might be. The carbon balance in a peatland is determined by productivity and respiration, i.e., NPP-Rh. NPP is dependent on both radiation and temperature, whereas Rh is only dependent on temperature. Which one of the two dominates under changed insolation is difficult to foresee. We will check in our model what the exact sensitivity of peat accumulation to insolation is, but overall the direct sensitivity of peat accumulation to insolation is relatively low in CLIMBER2-LPJ.

In the revised version of the paper will extend the discussion of the peat accumulation rates, also including the sensitivity to climate and insolation changes.

3) Why is pCO2 decreasing between 126 and 122 ka B.P. In Eem-Orb?

Carbon is taken up by both land and ocean. On land we see an uptake of carbon by the soil carbon pools. We also see enhanced weathering due to warmer temperatures at 126 ka in comparison to the Holocene. The stronger weathering leads to an increase in alkalinity, which drives oceanic CO2 uptake.

We will extend the discussion of marine C changes in the revised manuscript, discussing the differences between the interglacials further.

Minor:

- Is Figure 1 necessary?

At the time of writing we thought it would help to clarify the model parameterisation. It

is not necessary, though, so we will consider removing it from the final manuscript.

- Figure 5: The reference for the sea level should be added in the legend? i.e. why -3m

at 0 ka B.P.?

The sea level forcing we used in our experiments is the result of a forward model simulation of the last eight glacial cycles performed with CLIMBER-SICOPOLIS. Since the model does not know in advance what the final ice sheet mass will be, the sea level at the end of the experiment may differ from zero. In fact the present-day Greenland ice sheet mass is slightly overestimated by the ice sheet model. We did not correct for this when plotting the results, but we will do so for the submission of the revised paper.

We will also extend the discussion of the sea level forcing used (please, see also our reply to reviewer #2).

- Figure 9: Simulated d13CO2 could be shown.

We will be happy to show it in the revised version.

Interactive comment on Clim. Past Discuss., 11, 1945, 2015.