Earth Syst. Dynam. Discuss., 6, C305–C314, 2015
www.earth-syst-dynam-discuss.net/6/C305/2015/

Earth System Dynamics
Discussions
Open Access

ESDD
6, C305–C314, 2015

Interactive Comment

Interactive comment on "Climate and carbon cycle dynamics in a CESM simulation from 850–2100 CE" *by* F. Lehner et al.

F. Lehner et al.

lehner@climate.unibe.ch

Received and published: 18 May 2015

The manuscript 'Climate and carbon cycle dynamics in a CESM simulation from 850-2100 CE' by Lehner et al. describes the evolution of climate and the carbon cycle from the last millennium to the end of the current century as simulated by CESM model. The authors investigate the response of the climate and the global carbon cycle to the role of orbital forcing and volcanic eruption. They take advantage of this modelling framework to determine climate-carbon cycle sensitivity over several periods. The authors employ a quantitative methodology comparing the response of CESM model to previous simulations of CCSM and MPI-ESM and to available reconstruction and observational data. This manuscript is well written and the analyses are sounds. As such, this manuscript is a good documentation of the climate and carbon cycle evolution dur-

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

ing the last millennium as simulated by CESM. Therefore, I recommend its publication after the following minor issues are addressed. General comments: Referee: (1) The paper is too long and might be shorten if results & discussion are re-arrange.

Reply: Some sections have been condensed, some needed to be expanded in order to satisfy referee comments.

Referee: (2) Several mechanisms rely on the role of the ocean. However, few analyses are provided in terms of ocean physics and ocean marine biogeochemistry.

Reply: In response to a number of referee comments we provide more details on the some of the processes (see specific comments).

Referee: (3) It is unclear if the ocean component of the CESM model has benefited from a proper spin-up.

Reply: We have mentioned in the original version of the manuscript that the ocean is likely not in equilibrium. We have now expanded the discussion on model drift and provide more diagnostics on this topic (see specific comments).

Specific comments: Referee: P352 L14 what do you mean by “potentially” ?

Reply: What we intend to say is that only because we cannot detect a forced signal that does not mean there might not be one. The sample size might be too small to detect it. We changed the text to “might mask” instead of “potentially masks”.

Referee: P352 L16 please cite the adequate references here.

Reply: Including references in the abstract is to our knowledge not common practice. However, the adequate references (Kaufman et al., Esper et al.) are given in the introduction and respective section.

Referee: P352 L17-18 in regards of the results/discussion section, few words are needed to indicate that the climate-carbon sensitivity in CESM is lower than that estimated by Frank et al., 2010.

ESDD
6, C305–C314, 2015

Reply: We extended the sentence to read "The climate-carbon cycle sensitivity in CESM during the last millennium is estimated to be about 1.3 ppm/°C, lower than recent proxy-based estimates."

Referee: P353 L24 usually the envelope refers to 1xsd (66% confidence interval) while that used in the manuscript is 2xsd (95% CI).

Reply: It is unclear to us why the referee notes this for this specific location in the manuscript (maybe there was a mix-up in page and line reference?). We usually apply the same uncertainty estimate as the reconstruction we compare to.

Referee: P354 L21 please add (Tjiputra and Otterå, 2011) to the reference list

Reply: Done.

Referee: P355 L9 please remove 'fully'. Your experimental design implies that the carbon cycle is coupled only with biogeochemical components not the climate. Or, maybe add few lines on how biogeochemical responses of the interactive carbon cycle may impact the climate (e.g., evapotranspiration in response to rising xCO2 in CLM4). I seems this setup might bias the determination of climate-carbon sensitivity. Maybe add few words on this in the discussion.

Reply: We agree with the referee, removed "fully" and included the following sentence into the discussion of these results: "Further uncertainty arises from the experimental setup used here that does not incorporate feedbacks from the carbon cycle to the climate, such as changed surface energy and water fluxes due to local changes in atmospheric CO2."

Referee: P357 2.2 experimental setup I think that description of the ocean biogeochemical inititial condition is omitted here. Please provide a description. What are the drift in ocean transport metrics like the AMOC, ACC, AABW flow in CESM?

Reply: The linear trends over the whole control simulation for those three quantities are: AMOC: -0.22 Sv 100 yr-1 ACC: 0.70 Sv 100 yr-1 AABW: 0.01 Sv 100 yr-1 We

ESDD

6, C305–C314, 2015

mention them in the Experimental Setup section along with numbers for the DIC drift (-0.01% 100 yr-1).

Referee: P358 L18 you mean that there is no background volcanoes over the future scenario period ? How does this impact the simulated natural variability compared to previous period (in terms of detrended signal) ?

Reply: It will reduce natural variability. This is why we did not analyze the 21th century in terms of synchronization (Figs. 5, 7, 8). We extended the already existing reasoning for this to read: “Thereby, we focus on the preindustrial period, as the twentieth and twenty-first century are dominated by anthropogenic trends, which are non-trivial to remove for a proper correlation analysis. Also, the omission of volcanic forcing during the twenty-first century would likely bias the natural variability estimate low.”

Referee: P360 L3 If I’m right, the experimental design in IPSL model is not similar to yours since impacts of volcanoes is computed offline and added to the variation of the solar constant (see Dufresne et al., (2013; Swingedouw et al., (2013)).

Reply: Yes, indeed. But the forcing is based on the same reconstruction. The point we want to make is that there are such large differences in how models implement the same reconstructed volcanoes (what summarize as structural model differences) that it becomes difficult to separate uncertainty due to forcing from uncertainty due to forcing implementation. We included the following sentence to clarify this: “Note, however, that the technical implementation of those forcings into the two models are different, giving rise to structural model uncertainty even in presence of identical forcing timeseries.”

Referee: P364 L15 please provide quantitative information here. A table might help.

Reply: We now provide a table with the cumulative carbon fluxes over different time segments. Upon doing that we discovered a small bug in our previous summing over the years 1750-2011, which is why those numbers (which were already in the text before) changed slightly, although not discernable (see the new Table 3).

ESDD

6, C305–C314, 2015

Interactive Comment

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

Referee: P365 L28 please cite (Schwinger et al., 2014)

Reply: Done.

Referee: P366 L5 please cite (Wunsch and Heimbach, 2007; 2008). Quantitative information on the Southern Ocean ventilation might help (AABW flows, winter mixed volume etc. . .)

Reply: We now cite Wunsch's work and further make reference to Long et al. (2013), who provide extensive documentation of CESM's ventilation and mixed layer depth bias.

Referee: P368 L17 Weaker correlations in the high latitudes domains were expected since you apply a 5-year smoothing filter. You could eventually assess the correlation in high-latitude domains with filter bow larger than 5 years.

Reply: We tried filters of 10 years (moving window length = 200 years) and 20 years (moving window length = 400 years), the conclusions are not affected. With larger filters there start to be too few independent values to reach significant correlations anymore. Or in other words, the length of the moving window reaches the length of the entire simulation.

Referee: P369 L5 please cite Geoffroy et al. (2015) which show how land-sea ratio warming differs between CCSM4 and MPI-ESM.

Reply: Done.

Referee: P369 L17 To my point of view the penetration depth of the signal must refers to heat fluxes not solely to changes in ocean temperature. Please check whether the results are consistent using the ratio between OH [W m-3] and Hflx [W m-2].

Reply: We are not entirely sure how the proposed analysis resolves this issue. Maybe we also do not fully understand the reviewer's comment. Apologies if this is the case. In a global mean perspective, as we have it in Figure 7, the surface heat fluxes will pre-

ESDD

6, C305–C314, 2015

dominantly determine the decadal temperature anomalies and their penetration depth after volcanoes. Circulation changes will play a minor role at best. Of course, regionally this can be a different story. However, we do not see significant changes/phasing in, for example, the AMOC. However, we constructed a composite of the strongest three volcanoes in CESM and show the heat flux at different depth in the ocean in Figure 1 (attached to review response). It confirms that there are significant changes in heat flux across a surface of 50 m, 100 m, 150 m, and 200 m. In the tropical Pacific there is increased heat loss (positive anomalies) in the upper layers, while there is reduced heat uptake (negative anomalies) in the Southern Ocean and North Atlantic. Both of these processes will act to cool the global ocean down to depth of at least 200 m.

Caption Figure 1: Superposed Epoch Analysis on the strongest three volcanic eruptions in CESM for heat flux (W/m2) across different depth in the ocean. Depth labeled in bottom left corner of each panel. Here, the 5 years following an eruption are subtracted from the 5 years preceding an eruption. Only values significant at the 5% value are shaded.

Referee: P369 L 26 you may also refer to Swingedouw et al., (2015)

Reply: Done.

Referee: P370 section 4.2 Further details are needed here. First the use of DIC anomaly with respect to 850-1849 might be clearly state in the text. Then, It is unclear to me whether the evolution of the distribution of the DIC anomalies in function of time is an artifact of the anomaly calculation or an effective difference of behavior between the two models.

Reply: We now emphasize the reference period at the beginning of section 4. The apparent differences between panels a and b of Fig. 8 are certainly influenced by different low-frequency trends in the two models (see also response to next comment). This is exactly why the running window correlation in panel c is useful for highlighting periods of coherent model behavior, as it is largely independent from differences in

ESDD
6, C305–C314, 2015

mean or millennial-scale drift in the two models.

Referee: If control simulation is available over such period, please assess if the patterns shown on Figure 8 also emerge after correcting the drift in DIC. Since most of the difference are due to various behavior in Southern Ocean mixed-layer depth, it might be interesting to illustrate these latter with an additional Figure. If models are identical, you could eventually refer to (Resplandy et al., 2015) which provide a quantitative comparison of several CMIP5 model including CESM-BGC and MPI-ESM over the preindustrial control simulation.

Reply: Thanks for this good comment and reference. It seems from the analysis in Resplandy et al. that CESM and MPI have a comparably weak variability in the Southern Ocean CO2 fluxes. The MPI simulation used here bases on a very long control and should be largely without drift, according to Jungclaus et al. (2010). Unfortunately, the CESM control simulation is not long enough to calculate the drift for the whole transient simulation. But we redid the analysis for Figure 8 on the part of the CESM transient simulation for which we have a corresponding control simulation. The drift in deep ocean DIC in CESM is removed, however the correlation pattern between the two models in the upper ocean remains largely the same (see Figure 2; attached to review response) and so do our conclusions. However, we make note of these new results in the revised text and refer to Resplandy et al. in the discussion.

“There appear to exist spurious trends in CESM, likely related to model drift. We repeated the analysis, but with the CESM output detrended in each grid cell by subtracting the CTRL over the corresponding period 850-1372 CE. Due to the shortness of CTRL, we cannot apply this to the whole simulation. However, these tests showed that the correlation between the two simulation is largely insensitive to the drift in CESM.”

Referee: P378 L4 please mention that the Time of Emergence framework address solely direct changes not climate-carbon cycle feedbacks.

Reply: Given the small carbon-cycle sensitivity in CESM we do not expect this to alter the conclusions discernably. We nevertheless clarify by adding the sentence: “Note, that these estimates might differ slightly for a radiatively interactive carbon cycle setup.”

Referee: Figure 4 caption: change ‘observational’ by ‘observation-derived’ since GCP data are a combination of several observational source of data plus process-based model reconstruction.

Reply: Done.

Caption Figure 1: Superposed Epoch Analysis on the strongest three volcanic eruptions in CESM for heat flux (W/m2) across different depth in the ocean. Depth labeled in bottom left corner of each panel. Here, the 5 years following an eruption are subtracted from the 5 years preceding an eruption. Only values significant at the 5% value are shaded.

Caption Figure 2: (upper panel) same correlation anaysis as in Fig. 8 of the main manuscript. (lower panel) same as (upper panel) but with the CESM values detrended by the respective segment of the control simulation.

Interactive comment on Earth Syst. Dynam. Discuss., 6, 351, 2015.

ESDD

6, C305–C314, 2015

Interactive Comment

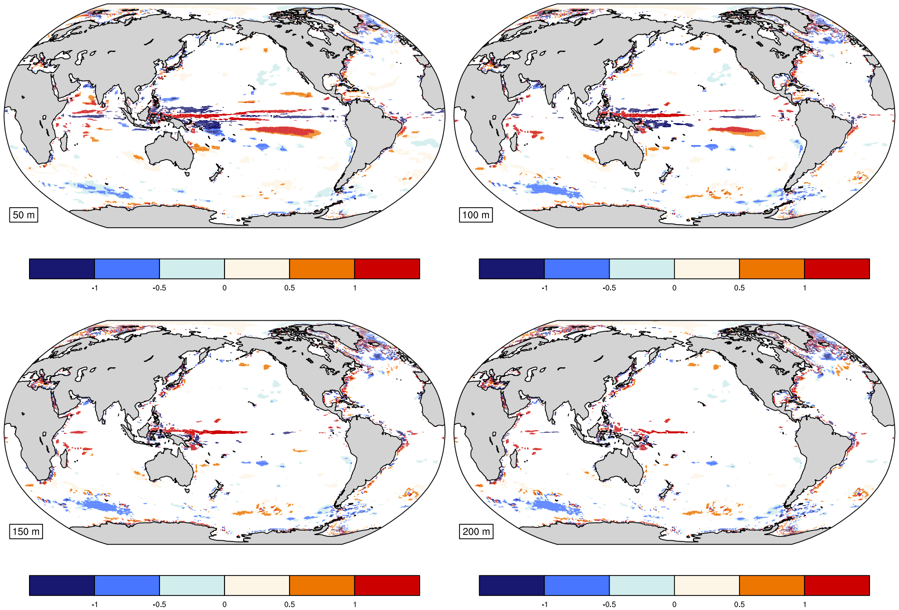
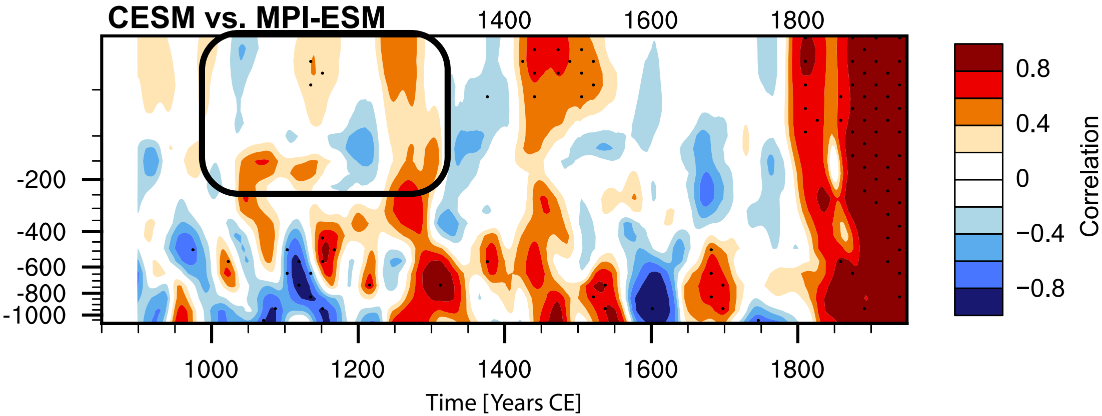
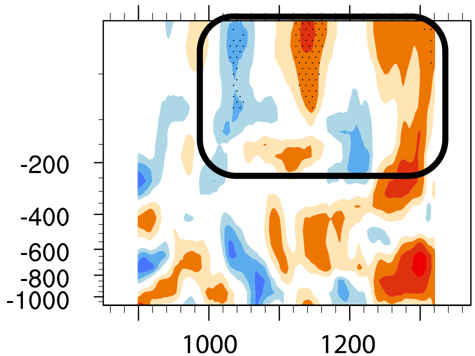


Fig. 1.





CESM detrended by subtracting the control run over the period 850-1372 CE.

Fig. 2.

ESDD

6, C305–C314, 2015