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Interactive comment on "Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organisation" *by* V. Eyring et al.

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Reply to Elena Shevliakova

Thanks Elena for the helpful comments. We have now revised our manuscript in light of these and the other comments we have received. A pointwise reply is given below.

These comments are concerned with the CMIP6 description of ESM experiments, particularly a requirement of "constant" land use in the pre-industrial

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control (*piControl*) experiment and its implications for the ESM historical experiment initialization. Echoing a comment by the reviewer #3 (regarding perpetuating a myth of an equilibrium preindustrial 1850 physical climate), we would like to raise a concern that the proposed *piControl* for the CO_2-emission-driven ESMs and inferred fluxes in CO_2-concentration-driven ESMs will promote an unjustified assumption, that the pre-industrial 1850 carbon system, particularly land, was in equilibrium.

It appears that the manuscript focuses mainly on the CO_2-concentration driven experiments under the assumption that the additional CO_2-emission-driven *piControl* and historical experiments will require a simple switch from CO_2 concentration to CO_2 emissions as is typically done with short-lived atmospheric species. The DECK experiments, including those with ESMs, are expected to remain unchanged in future CMIPs. However, the experimental design of the CMIP6 ESM spin-ups, controls, and historical runs have a number of specific challenges, often not considered in AOGCMs experiments, and which are not discussed in the manuscript. I hope that the authors could expand and comment on such challenges in the manuscript.

Specific comments

1. The authors could clarify that the state of land carbon in the ESM *piControl* (i.e. equilibrated climate and carbon cycle) ignores the long term impacts of several centuries of secular change in vegetation and soil carbon storage and sustained land-use carbon emissions prior to 1850 due to land use practices such as clearing of primary lands for croplands and pasture, shifting cultivation, logging, fuel-wood extraction, and associated regrowth.

Previous CMIPs have initialized historical AOGCM simulations from a pre-

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industrial control. In this manuscript the authors describe the period chosen as ". . .prior to the onset of the large-scale industrialization. . ." with ". . .no secular changes in forcing, so the concentrations/or sources of atmospheric constituents (e.g. GHGs and other forcing) are held fixed. . ." (p 10548, l26-29). Unlike emissions of fossil fuels and cement production, CO_2 emissions from agricultural activities, biomass burning, and wood harvesting were not fixed and were not small prior to 1850, particularly in the Northern hemisphere. It's well established in the literature that in the 1850s the land was a sustain source of carbon (0.6 PgC/yr) based on a number of modeling approaches (Houghton 2010). This imbalance is well outside of the proposed "equilibrium" tolerance of 0.1 PgC/yr in the comment by Chris Jones, and thus represents an inconsistency for initialization of historical runs.

Furthermore there was secular changes in both agricultural expansion and in the amount of wood harvested for fuel and logging and those trends are documented in CMIP5 land-use change reconstruction for 1500-2005 (Hurtt et al, 2011). While one could argue that the implications of such changes (i.e. biophysical feedback, mostly from agricultural conversion) on the physical climate was small globally, these changes have major carbon cycle implications for vegetation, litter and soil carbon storage which were not in equilibrium before the onset of the industrial revolution in the 1850s. Therefore, it is only in a highly idealized context that one can interpret the state of land carbon from an ESM control run with constant land forcing as pre-industrial (before 1850).

The reference year for the piContol was discussed in detail at the WGCM meetings and the conclusion after long community consultation was not to move backward in time for computational reasons at this stage. Rather it was decided that single model simulations should be used to further quantify the omission of pre-1850 CO_2 emissions from land use and land use changes on the historical and present-day climate. Results

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from such studies could be used to give further guidance on the interpretation of the CMIP DECK and CMIP6 historical simulations and further recommendations for future efforts could be given. CMIP6 includes many different research topics and many model groups with different scientific foci. Compromises like this have to be made. To consider this comment, we have extended the text and now further address the caveats of a 1850 *piControl* choice explicitly, also for ESMs.

2. Because i) a large diversity in implementation of ESMs' land components, including land use and its interactions with carbon components, and ii) a lack of detailed analysis of how such differences may affect initialization and evolution of global carbon cycling in historical simulations, the authors should add discussion about whether the historical ESM experiment initialization should or should not follow the AOGCMs' practice of initializing historical runs from a proposed ESM equilibrated control and how much flexibility modeling centers may have in deviating from that AOGCM practice. Our experience is that a discontinuity in land carbon between a control and historical simulation is necessary to "bridge" an idealized control to accurate historical carbon cycle evolution (Sentman et al., 2009). How a modeling center could document such discontinuity and how to archive possible "bridge" experiments, could be added in the discussion section.

A number of publications (Hoffman et al 2013, Brovkin et al 2013, Jones et al 2013) show that the CMIP5 ESMs are dramatically diverse in their implementations of vegetation dynamics, soil biogeochemistry and, particularly, land use and management components. Most ESMs in CMIP5 have ignored harvesting of wood and shifting cultivation, which have been shown to play a significant role in altering natural forest dynamics, forest age structure, and carbon uptake on time scales from decades to centuries (Houghton, 2010). Some CMIP5 ESMs included crops as plant functional types, others pastures as plant functional

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types, and a few treated their carbon dynamics differently from natural grasslands (i.e., no harvesting or grazing). Some ESMs transferred harvested or cleared carbon from agricultural practices to the atmosphere directly, others deposited cleared or harvested carbon to anthropogenic pools, with the release time scales varying from a year to a decade or century. Still others returned harvested or cleared carbon directly to soils.

In CMIP5, differences in vegetation dynamics and land use models also led to diverse practices in ESMs' spin-ups. Examples include a fixed crop/pasture fraction from a dataset of choice, with or without wood harvesting, or potential vegetation without any land use. A similar variety of strategies was used in controls or idealized experiments. We do not expect that land models, including implementation of land use, will be less diverse in CMIP6 and future CMIPs. All such model differences have implications for a) how much carbon an ESM is going to converge to in an equilibrated state, including vegetation, litter and soil carbon pools, b) for how these pools are going to respond to warming in idealized experiments and to the atmospheric CO_2 increases, and, importantly, c) for historical simulations to be compared with observations.

These are all good points which should be considered in the analysis and interpretation of the ESM *piControl* and *historical*. We are however not commenting here on the diversity of the ESMs that we expect in CMIP6. This is something that will be described in the model documentation papers. We have noted the caveat that 1850 is not strictly speaking pre-industrial condition (see also our response above).

There are then indeed no secular changes in the *piControl* because the forcings are held constant (for AOGCMs and ESMs). To consider this comment, we have added a paragraph at the end of Section A1.2 that specifies what is done for the *piControl* for ESMs in CO_2-emission driven mode: external input of CO_2 from either

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fossil fuel or land use is prescribed to be zero in the *piControl*, to be able to remove the model drift that arises from the uptake of CO_2 by the ocean and land even in the absence of CO_2 emissions.

This then indeed creates a small discontinuity in land carbon between the control and the historical simulation when moving from 1850 to 1851 and throughout the historical simulation within the lifetime of this effect which we now state in Section A2. In Section A2 we now also comment on strategies to account for the fact that land-surface was not in equilibrium in 1850 ("bridging" experiments). Due to the wide diversity of modelling approaches for land carbon in the ESMs, the actual method applied by each group to account for these effects will differ so cannot be further specified here. But we request that it needs to be well documented.

3. As Gavin Schmidt already pointed out in his review, a clarification would be helpful about how to interpret "constant" land for *piControl*, particularly in CO_2 emission-driven simulations, especially how to implement "constant" wood harvesting and shifting cultivation (secondary lands in Hurtt et al 2011). As more models attempt to capture forest age structure distribution, which is important for simulating the rate of carbon uptake, it's not clear how to initialize that age distribution from the PI control. In a concentration-driven AOGCMs the implications of "constant" land use for physical climate are different than the implications of the same treatment of land use in an ESM for carbon storage or for simulated atmospheric CO_2 concentration. As land components of ESMs are still rapidly changing and implications of a particular "constant" land–use treatment for the DECK and historical experiments are not clear, we suggest that modeling centers should have some flexibility in how to interpret "constant" land use in AOGCM and ESMs (including an option of not having any land use in control), as long as their documentation manuscripts report clearly details of spin-up and PI controls and any extra experiments they may do for initialization

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of idealized or historical experiments.

We now give a more detailed recommendation for the treatment of land-use in the *piControl*. The land use forcing dataset will be described in the corresponding contribution to this Special Issue. We also clearly state that any deviations from the recommendations given here need to be documented, so this point is covered already.

4. A minor point, it would be helpful if the manuscript defined which models are AOGCMs and which are ESMs for the purpose of the CMIP6, as there are many definitions of ESMs in the literature. Section 3 opens by stating that the DECK comprises four base experiments plus *historical*. It would be helpful to clarify from the beginning that the above applies only to AOGCMs. For ESMs, the DECK comprises 5 experiments and 2 historical simulations.

ESM now defined and where required, the discussion has been extended with explicit mentioning that applies to CO_2-emission driven simulations.

The way we have defined this is that the DECK and the historical simulation need to be performed with all model configurations, so the number of simulations is implicit. C4MIP includes both CO_2-concentration and -emission driven experiments, so that participating in C4MIP requires repeating the DECK and the CMIP6 historical simulations with both model configurations. We stick to this definition and have not changed the text.

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Hurtt, G. C., et al. "Harmonization of land-use scenarios for the period 1500–2100: 600 years of global gridded annual land-use transitions, wood harvest, and resulting secondary lands." Climatic Change 109.1-2 (2011): 117-161.

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Interactive comment on Geosci. Model Dev. Discuss., 8, 10539, 2015.