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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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These comments are concerned with the CMIP6 description of ESM experiments, particularly a requirement of "constant" land use in the pre-industrial 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 pre-industrial 1850 physical climate), we would like to raise a concern that the proposed piControl for the CO2-emission-driven ESMs and inferred fluxes in CO2-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 CO2-concentration driven experiments under the assumption that the additional CO2-emission-driven piControl and historical experiments will require a simple switch from CO2 concentration to CO2 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-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, CO2 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.

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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).

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 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 CO2 increases, and, importantly, c) for historical simulations to be compared with observations.

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 CO2 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 CO2 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

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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 of idealized or historical experiments.

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.

Brovkin, Victor, et al. "Effect of anthropogenic land-use and land-cover changes on climate and land carbon storage in CMIP5 projections for the twenty-first century." Journal of Climate 26.18 (2013): 6859-6881.

Jones, Chris, et al. "Twenty-first-century compatible CO2 emissions and airborne fraction simulated by CMIP5 earth system models under four representative concentration pathways." Journal of Climate 26.13 (2013): 4398-4413.

Sentman, Lori T., et al. "Time scales of terrestrial carbon response related to land-use application: Implications for initializing an Earth system model." Earth Interactions 15.30 (2011): 1-16.

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.

Hoffman, Forrest M., et al. "Causes and implications of persistent atmospheric carbon dioxide biases in Earth System Models." Journal of Geophysical Research: Biogeosciences 119.2 (2014): 141-162.

Houghton, Richard A. "How well do we know the flux of CO2 from landâĂŘuse change?." Tellus B 62.5 (2010): 337-351.

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Interactive Comment