

Interactive comment on “Coupling earth system and integrated assessment models: the problem of steady state” by B. Bond-Lamberty et al.

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We thank both referees for their careful and thoughtful comments.

Response to Referee #1 major comments:

1. I am unable to understand the basic premise of how the coupling works since the GCAM model hasn't been introduced properly.

We have greatly expanded the description of GCAM (section 2.1), describing it in the methods text as well as giving additional citations, focusing in particular on the model's carbon cycle. (That said, GCAM's algorithmic complexity is similar to that of an ESM, and inevitably we have to point the reader to other references for full detail.)

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2. There are terms in the paper that probably both the ESM and the IAM communities are unfamiliar with.

Thank you for pointing this out. We now define terms consistently and carefully throughout.

3. The basic concept of the long-term pools changes hasn't been explained properly and is unclear.

This is tied to #1 above, and is now clearly—we hope—described in the GCAM model description section.

4. It is also unclear what the final iESM simulation was. Was this a 2006-2100 RCP 4.5 simulation?

We have clarified throughout the manuscript, as well as in the abstract and title, that this work does not describe a “final” iESM simulation, merely the development and testing of one half of the ESM-IAM coupling of the larger system.

5. CESM1 is not just CLM. It seems that the authors forgot about other components of the Earth system model. Is the CLM the only place in the CESM1 where it is coupled to the GCAM. What about the simulated climate in the CESM1? Doesn't it affect the behavior of the GCAM IAM.

We apologize for the lack of clarity on this point. Currently CLM is the only component of CESM1 that ties directly to GCAM (although this will change in the future). Climate does affect the GCAM IAM via its effects on the CLM carbon cycle. This is now described explicitly in the text.

6. It is also unclear how is this a problem of steady-state as the title of the manuscript suggests. . .

We have changed the title of the manuscript, per Referee #2's suggestion, to more accurately reflect the subject of the paper.

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7. In fact, if the CRUNCEP data is being used to drive the CLM model then how is this even a coupling of the CESM1 and GCAM models. In this case, it's not the ESM and IAM that are being coupled. It is coupling of CLM and GCAM models, driven offline with CRUNCEP data or climate from the CESM1 RCP 4.5 simulation. At least, that's the impression I got as a reader after reading page 1505.

That is correct, and we have clarified this in the text.

Minor comments:

8. Abstract. The opening sentence of the abstract seems a bit difficult to follow. In addition, it reads like as if a modeller is complaining – “Human activities are . . . posing a significant problem for ESMs . . .”

This has been reworded and clarified.

9. Abstract. Lines 3-4. “...which may incorporate static land-use change inputs...”. The term “static land-use change inputs” doesn't mean anything to me even as an ESM person. Maybe the authors actually mean “static land cover”.

Our intention here was to note that LUC inputs to ESMs must be specified ahead of time, and don't change during a run (e.g., in response to evolving conditions in the ESM). We have clarified this sentence.

10. Abstract. Line 10. Land use driven flux changes of what quantity?

We're unclear how the quantity is relevant here, and apologize if we have misunderstood the reviewer's question. The sentence has been reworded.

11. Page 1501, Line 5. The following sentence is not exactly true. “As a result, different policy choices vis-à-vis LUC and carbon are projected to result in greatly different configurations of the future carbon cycle and climate system.” If anything, the Brovkin et al. (2013) paper shows that the future land use change emissions and any effect on climate is much smaller compared to what the effect of historical land use change

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has been. Houghton estimates that historical LUC emissions are around 150 ± 75 Pg C. Figure 7b in Brovkin et al. (2013) shows that the effect of LUC in RCP 2.6 and 8.5 scenarios is around 10-50 Pg C, if the outlying large values from the MPI model are neglected. And, we know MPI generates such large LUC emissions because of its large initial pool sizes.

We have changed our citations here, while still acknowledging Brovkin et al. (2013) and their findings.

12. Page 1501, Lines 8-13. The sentence “Such models may incorporate static LUC inputs, but do not actively, or interactively, simulate policy options or economic forces, except for example in simple (in a policy sense) “thought experiments” ...is unclear and confusing. Again static LUC inputs doesn’t mean anything. Do the authors mean static land cover?”

We have clarified this sentence.

13. Page 1502. After the introductory section, the authors delve straight into the details of the CLM model without telling the user what purpose does CLM serves in the CESM1 model. A simple sentence telling that CLM simulates land-atmosphere fluxes of energy, water and CO₂ would have been very helpful. Just throwing off big terms - carbon and nitrogen dynamics, biogeophysics, biogeochemistry etc. isn’t very helpful here. The model needs to be described in a much better way. Also note that, CLM doesn’t do the hydrologic cycle. It models the surface hydrological process. Hydrologic cycle is modeled by the full Earth system model.

We now describe CLM’s role in CESM, and have slightly expanded other parts of this paragraph. We respectfully disagree, however, that a detailed description of CLM is necessary here. Finally, the text now says “surface hydrology”, although the CLM website (<http://www.cgd.ucar.edu/tss/clm/>) does describe it as modeling the “hydrologic cycle”.

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14. Page 1502. The following sentence “The model’s C and N cycles are closely coupled and include assimilation, plant growth and mortality, allocation, and subsurface cycling.” ...is another example of a poorly written sentence. Assimilation of what? Mortality of what? Allocation of what? Sub-surface cycling of what?

We believe that “plant growth and mortality” is clear, but have clarified other terms in this sentence.

15. Page 1503, Line 5. “is a dynamic recursive economic model” Just like carbon and nitrogen dynamics mean nothing to an economic modeler, the term “dynamic recursive economic model” means nothing to me as an ESM person. The paper needs to serve both communities and this means some extra effort needs to be put to make it palatable to both.

Here, “dynamic recursive” means that decision-makers have imperfect information about the future (specifically, decisions made in one time period do not reflect future changes in population, GDP, technology, or prices). We have decided that this phrase is not relevant to this paper and potentially confusing, and have removed it from the text.

16. Page 1503, Line 13. What does “optional policy scenarios” mean?

In an IAM like GCAM, the future can be run with optional “policies”, e.g. a carbon tax at national or international levels. This has been clarified in the text.

17. Page 1503, Lines 21-25. The IAMs focus on land use change, while what is actually needed by ESMs is land cover. ESMs need to know what kind of PFT grows (or can grow) in a grid cell. The intermediate step of going from GCAM’s land use change decisions to a land cover product that CLM can use is an important coupling step. Yet, this hasn’t been explained properly and the reader is pointed to two references. In my opinion, this important coupling step must be explained properly in the manuscript.

We hope that our revisions (new title, clarified text, etc.) make clear that this manuscript

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does not aim to describe the full iESM system, but rather one specific aspect of it: the link from CLM to GCAM, and this is now noted in this paragraph. The GCAM-to-CLM link is quite complex and described fully by Di Vittorio et al. (2014), cited in the text.

18. Page 1503, Line 30. “...the former tracks real-time...”. What authors mean here is probably “time-varying” and not “real-time”. Page 1504, Line 10. “real-time” on this line and elsewhere probably also means “time varying”.

That’s a better term—thank you. Changed and/or removed.

19. I am a bit confused after reading Section 2.3 (lines 21-28). . .An introduction to a simple equation like this and somehow relating this to what GCAM needs will likely help to understand how the coupling is being performed.

We have modified and clarified section 2.3, and added a new Table 1, providing more detail on the simulations and tests performed.

20. Page 1505, Line 1. Authors say “We tested the feasibility of these proxies in two ways”. What does “these” refers to in this sentence. Is it the vegetation, litter and soil carbon pools? Again, it would have been helpful to introduce the basic equations that describe the terrestrial carbon balance in the CLM and GCAM models, so that the linkages between the two can be easily explained by the authors. I am also unclear why the primary terrestrial carbon cycle fluxes and pools are described as proxy variables.

Please see previous response.

21. Page 1505, Line 14. Please start a new paragraph when start discussing the CRUNCEP data. The way the simulations S1 through S6 are described it seems CESM1 was never run coupled to GCAM and all the simulations are offline in which CLM is driven with either CRUNCEP data or data from CESM1’s RCP 4.5 simulations.

We have clarified the extent of coupling in the simulations, here and throughout; it’s correct that they were all offline, i.e. using CLM but not the fully coupled CESM1 system.

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22. Page 1505, Lines 17-18. “ ... and land use boundary conditions constant at their 1850 values.” Again, probably what is meant is land cover was kept constant corresponding to year 1850.

Clarified.

23. Page 1506, Lines 1-9. I am unable to grasp the basic concept here. For example, I am unsure why the following is necessary. - “We examined the degree to which (i) NPP in the first 5 years of simulation S5 predicted total vegetation carbon in the final 5 years . . .”. In absence of equations relating the output from the CLM model to the needs of the GCAM model, I am unable to understand this. It is also possible that, as an ESM person I am unable to follow the simple world of GCAM in which only equilibrium values of the pools matter. If this is the case, then the GCAM's philosophy needs to be explained properly.

This text, and the entire section, has been extensively reworked and clarified. A new table summarizes the model runs performed, and the runs themselves have been re-named for clarity.

24. Page 1506, Line 10 reads – “The overall control run—our base reference simulation—was based on the RCP4.5 stabilization pathway. . .” Yet, on page 1505 simulation S1 was introduced as the control simulation driven with CRUNCEP data for period 1901-1920 used repeatedly. Are there two kinds of control simulations?

We agree that this text was confusing. We have deleted the second reference to a control run and clarified that simulation S1 is the control run only for the initial set of offline simulations S1-S4. In addition, a new Table 1 summarizes the simulation, some of which have been renamed for clarity.

25. Page 1506, Lines 25-26. “For the iESM, even a perfect proxy variable will be subject to both climate and LUC during a CESM run, both before the run starts. . .”. I am unable to follow this sentence.

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This text, and the entire section, has been extensively reworked and clarified.

26. Page 1507, Lines 3-5. “Conversely, significant expansion of a PFT (e.g., agriculture reverting to forest) during the iESM run might appear to have drastically lowered productivity, leading GCAM redirect resources away from that region”. First, is the agricultural productivity higher than forests in CLM because of the higher per unit leaf area maximum photosynthesis rates for crops. Second, what does “redirect resources away from that region” means. You have to keep in mind as authors that the ESM community is not familiar with the GCAM model, and vice versa.

We have clarified that these sentence refer to GCAM, not CLM, and explained in greater detail how this potential problem can happen.

27. Page 1507, Line 9-10. “GCAM will, if it sees out-of-line values, potentially pour more resources into those cells, leading to a runaway feedback”. Sorry, I have no clue what this means. What are the units of resources? Is it money (\$), energy (W/m²) or something else? Without being introduced to the basic manner in which GCAM works, very few people in the ESM community can understand what this means.

Here “resources” refers to land. In GCAM, extreme productivity values will result in high agricultural production and thus profit. Since the model allocates land based on profitability, this in turn leads to a change in land allocation towards a PFT (if its productivity is extremely high) or away (if its productivity is extremely low). This has been clarified in the text.

28. Page 1507, Line 11-12. “. . .and profit maximization is the fundamental decision-making criterion in GCAM.” What is the currency of profit, money (\$) or carbon? Profit is what context?

By profit maximization, we mean maximizing economic profit (revenue minus cost), measured in U.S. dollars; that is, landowners choose the land use that results in the largest amount of money. This is now clarified.

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29. I am unable to follow the basic premise of Sections 3.1 and 3.2.

We have made many changes to these sections, and hopefully the changes to section 2 make all the results easier to understand.

30. Page 1511, Lines 17-18. “By allowing climate effects from a full earth system model to modulate, in real time, the economic and policy decisions of an integrated assessment model. . .” I am confused if a full ESM simulation was performed in this study or not.

This is a very good point, and one we have tried to clarify throughout the text.

31. Page 1522. Figure 3. To which year of the RCP 4.5 simulation does the result correspond? Color figures are free in online journals. Please consider using a color version of Figure 3.

We now provide a color version of Figure 3. The data shown in this figure are from the year 2065; this is now made clear in the caption.

32. Page 1524. Figure 5. What are the units on x-axis? Yes, the authors have explained LUC effect equals to 1 means no LUC. But what does a value of 5 means?

We have clarified the caption describing Figure 5.

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