

Interactive comment on “Modelling feedbacks between human and natural processes in the land system” by Derek T. Robinson et al.

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Earth System Dynamics Discussion Response to Reviewers

Responses from Robinson et al. incorporated.

We would like to first thank the reviewers and the editor for their insightful comments that have pushed us to produce a higher quality paper. Thank you.

Reviewer 1

This article analyses feedbacks between human and natural processes in land system models. The author describe in detail four recent models of this type and then attempt to draw general conclusions.

I do not have the expertise to comment on the technical aspects of the manuscript. At a more conceptual level, the paper does not seem particularly ambitious. It is mostly descriptive in nature and not particularly analytical.

RESPONSE

There is an important lack of integration of social science in studies of earth system sciences. Living in the Anthropocene, and trying to better understand processes of this epoch and its interactions, we should even more so define ways to connect modeling activities of social science and natural science models. This by itself is ambitious, as there are major challenges that require different disciplines collaborating with each other, scientists need to adjust their numerical models so they can communicate with each other, and we need to learn a sufficient amount of domain knowledge and perspective from each other's models to perform an integrated analysis. In the current academic incentive system this kind of collaboration is rarely rewarded.

In response the reviewer comment above, a majority of the manuscript authors responded with statements that to the best of their knowledge this is the first paper to directly address the value of modelling feedbacks between human and natural systems for representing the dynamics of the socioecological systems that now dominate our world. In most current modelling efforts these feedbacks are largely ignored.

Collating the presented four cases into a single narrative offers a unique opportunity to observe the challenges and approaches taken to couple models developed by specialists in disparate academic fields. These case studies illustrate successful research outcomes that can provide building blocks and guidance to model coupling in the future.

We agree with the reviewer that the manuscript illustrates the current capability of representing feedbacks between specialized human and natural system processes, but this in itself demonstrates significant scientific advances and progress towards community building across disciplines. However, given the challenge set forth by the reviewer to be more ambitious we

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1) Added a figure that provides a conceptual outline for the structure of coupling (Figure 1) and added a figure that illustrates different levels of coupling along a gradient of communication frequency and coordination (Figure 2). While these two figures do not cover all configurations of model structures or levels of communication frequency and types of coordination, they provide a conceptual outline that we use to describe the four examples in the paper and offer them as opportunities for other to do the same and contribute their work as comments to this manuscript or build upon and extend in subsequent manuscripts.

Figure 1: Approaches to model coupling. a) loose model integration via file / data exchange between model 1 (M1) and model 2 (M2); b) models share inputs and outputs but interact with independent data; c) models interact with the same data and share inputs and outputs directly with each other; d) a coupler coordinates run time and scheduling and may pass some information between models, models may also interact through manipulating data (files); e) a coupler coordinates the run time and scheduling of the individual models and passes information between models primarily use their own data, f) the coupler coordinates all interactions between models and data.

Figure 2. Conceptual outline of the frequency of model communication and coordination of interaction between models from no coupling to one-way and two-way feedback. Examples are not exhaustive but illustrate common approaches used. M1 = model 1, M2 = model 2, T1 = time step 1, Tn = time step n.

2) We also provided an additional subsection to the Discussion section that outlines 8 explicit lessons learned and a framework for coupling as guidance for a way forward.

REVIEWER COMMENT

As judged by the abstract, for example: the abstract is mostly a general introduction and then a vague summary of the article structure. I would like to see emphasised more clearly WHAT sorts of "lessons" are learned or "challenges" discussed rather than just that the statement THAT these things are done in the manuscript.



RESPONSE

Agreed. The abstract could better emphasize the insights and findings of our manuscript rather than providing a summary of what resides within. We will list and provide context for our 8 lessons learned

Lesson 1. Leverage the Power of Sensitivity Analysis with Models Lesson 2. Modelling is an Iterative Process. Lesson 3. Ensure Consistency Lesson 4. Reconcile Spatio-temporal Mismatch Lesson 5. Create a Common Language Lesson 6. Construct Homogeneous Units Lesson 7. Make Code Open-Access Lesson 8. Incorporating Feedback Increases Non-Linearity and Variability

We will also include text about the challenges faced in coupling and a short outline of how we suggest a way forward. Thank you.

REVIEWER COMMENT

The bulk of the manuscript is a detailed description of the models and some illustrative results. I'm not quite sure what role the results are meant to serve. There is no space to expand on them in detail, and they are not picked up upon in the discussion.

RESPONSE

Our intention was to draw upon the results as illustrative of achievements that could not be made in the absence of coupling models together or our approaches to model coupling. These results provide tangible outcomes for reference in the lessons learned section. While we had mixed response among our author listing about inclusion of the results in the manuscript versus relegating them to the supplementary material, we have decided to align with the reviewer and have created a piece of supplementary material that contains the results for each of the model coupling examples presented.

REVIEWER COMMENT

In section 3.1, "Lessons learned" the discussion is actually rather general. Only one



model (DEED) is actually mentioned. I would like to see more discussion of what was learnt from the models that were discussed in so much detail earlier in the manuscript.

RESPONSE

Earlier drafts of the paper had the lessons learned after each example and we attempted this again; however, in both attempts we collectively agreed that the lessons were more useful and effective as a group in the discussion section. Therefore we left the lessons in the discussion but removed the consistency section and refocused the lessons learned to make them explicit and numbered. Each lesson also now refers back to and offers an example from one of the four models presented. Our draft of this section is as follows: Lesson 1. Leverage the Power of Sensitivity Analysis with Models. A powerful benefit of simulation models is that they can facilitate analysis of the effects of interventions and scenarios for which there is no precedent. Models should be leveraged, through computation across a full range of parameters and use of simulated data or expert- or theory-informed methods to evaluate the relative contribution of parameter values/ranges, missing data, or processes on model outcomes. Model sensitivity to parameters, data, or processes can be evaluated to support design and deployment of resources for new data collection.

Lesson 2. Modelling is an Iterative Process. The process of analyzing coupled human and natural system models often results in identification of needs to investigate key variables, data, or mechanisms. For example, through the coupling of DEED and BIOME-BGC (Section 2.2), it was realized that data on vegetation and soil carbon for residential land uses are grossly inadequate for model calibration. This realization fostered new data collection and analysis about the distribution of carbon stored in different residential land uses (Currie et al. 2016). New forms of measurement and evaluation are often needed to collect novel data and quantify variables and feedbacks linking human and natural systems. As these new data are collected and become available, new questions about model processes are inevitable (Rounsevell et al. 2012).

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Lesson 3. Ensure Consistency. Modelers seeking to couple natural- and human-systems models that represent similar phenomena, like land cover, can encounter significant ontological and process consistency challenges. Models with different initial assumptions and different processes can generate different values for the same phenomenon. While model coupling ultimately can provide an impetus for harmonizing and resolving such consistency issues, it requires decisions about which processes to represent and which to leave out in the coupling procedure to avoid duplication. The iESM (Section 2.4) well illustrates issues of consistency in assumptions, definitions, and processes. First, ecosystem properties from CLM were translated to impacts that could be applied to GCAM “equilibrium” yields and carbon densities (Bond-Lamberty et al., 2014). Second, a major finding that is especially relevant to all land change and ecosystem models is that the inconsistencies between land use and a land cover definitions caused CESM to include only 22% of the prescribed RCP4.5 afforestation in CMIP5 (Di Vittorio et al., 2014). Additionally, it was discovered that wood harvest was conceptually different across three of the models comprising iESM (GCAM, GLM, and CLM), with each model having its own process for determining how harvest is spatially distributed. Wood harvest is a good example of different modeling groups attempting to describe the same thing by using very different processes, with unintended consequences for CESM’s terrestrial carbon cycle.

Lesson 4. Reconcile Spatio-temporal Mismatch. Many natural system models operate at finer temporal and coarser spatial resolutions than human system models (Evans et al. 2013). Often, these discrepancies cannot simply be dealt with by aggregation of the variables because they represent mismatch in spatial and temporal dynamics that may also happen in reality. Human responses to environmental change may show significant time-lags or may be related to cycles of management (e.g. cropping cycles) rather than showing an immediate response. Similarly, while the ecological models are strongly place-based, coupling human and natural systems at the pixel level may not always be appropriate due to complex spatial relations in the human dimensions (e.g. distant land owners) or responses across different levels of decision making (e.g. policy



responses) that are not linked to the exact place of the ecological impact. Reconciling these mismatches involves balancing detail and computational tractability within existing model structures and scheduling the frequency of communication between models. As an example, the DEED ABM (Section 2.2) used an annual time-step to reflect the timing of land management decisions, whereas the ecosystem model BIOME-BGC represented vegetation growth and biogeochemical cycles daily. To reconcile these differences, irrigation decisions were made annually, but implemented one day a week during the growing season by modifying the daily precipitation file used by BIOME-BGC. In contrast, other management activities were implemented once annually, before (for fertilization) and after (for removals) the growing season. These limitations could have a significant effect on estimated carbon storage and have fostered additional fieldwork for further validation (e.g., Currie et al. 2016) and additional efforts to tightly couple the two models.

Lesson 5. Create a Common Language. Coupling human and natural systems brings social and natural scientists together that often have a different understanding of the meanings commonly used terms. Both technical and conceptual aspects of the coupling process can be improved when a common language is used. For example, traditional coupling between the ocean and the atmosphere in Earth System Models typically uses the Climate and Forecast conventions (Eaton et al. 2011). A controlled vocabulary in these conventions assists understanding of model processes and facilitates their coupling among models or replacement in new models. With a similar goal but different approach, CSDMS introduced rules for creation of unequivocal terms through their standard names system that functions as a semantic matching mechanism for determining whether two terms refer to the same quantity with associated predefined units. This concept is currently undergoing transition to a Geoscience Standard Names ontology that reaches out to include social science terms (David et al. 2016), which can benefit communication between communities (i.e., natural and social science) that may have different terms and descriptions of similar processes (Di Vittorio et al. 2014). With a common language, data can be more easily and unambiguously communicated



between components in a coupled system.

Lesson 6. Construct Homogeneous Units. Coupling models increases computational overhead and thus requires increases in computational efficiency, which always come with trade-offs. One approach to improving efficiency is to classify and generalize components of the model such as agent types in the human system (e.g., Brown and Robinson 2006), types of vegetation (e.g., plant functional types, Díaz and Cabido 1997, Smith et al. 1993, Smith et al. 1997), or landscape units. Landscape units are not typically constructed to structure spatial variability in land use science, but are used regularly in hydrological modelling; for example the Soil Water Assessment Tool (SWAT, Neitsch et al. 2011) uses hydrological response units (HRUs) that have a soil profile, bedrock, and topographic characteristics that are assumed homogeneous for the entire spatial extent of the unit. Similar concepts have been used to identify management zones or units, and two of our examples employed this approach (Robinson et al. 2013, Collins et al., 2015). However, the variability among management activities and land-cover types can lead to a large combination of outcomes, and the delineation of these units directly contributes to uncertainty in model projections (Di Vittorio et al., 2016).

Lesson 7. Make Code Open-Access. Many ecosystem and Earth-system models have mass, energy, or other balance equations that constrain the processes to the laws of thermodynamics and can be used to ensure that they are working correctly. For example, the ecosystem model LPJ-GUESS has a routine to ensure balance between influx, efflux, and storage of carbon. Similar checks and balances are used in human system models with respect to population change (e.g., births, deaths, immigration, and emigration) or economic trade (e.g., production, consumption, imports, and exports) at macro levels and budget or labour constraints at household or individual levels. However, in many natural-system models these balance equations are not accessible for coupling and the representation of human perturbations and modifications to the factors in balance equations are either not included or done so indirectly and make the coupling less flexible and tractable.

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Lesson 8. Incorporating Feedback Increases Non-Linearity and Variability. Results from the four examples provided span the supplementary material and a number of publications. Among these coupling efforts, it has been found that the incorporation of two-way feedbacks (Figure 2) between models of the human and natural system typically produces non-linear results and a greater range in model outcomes than are observed when the models are isolated or one-way prescriptions are used. For both the MML and DEED models, changes in the natural system were relatively linear when one-way human perturbations were prescribed. However, when feedbacks between the systems were incorporated then non-linear outcomes were observed and frequently a greater variation in model outcomes (e.g., Supplementary Material 1.2).

REVIEWER COMMENT

I'd also like a broader discussion of research gaps. Although combining human and natural processes is an important subject, the models discussed here still only address a subset of human processes. In section 2.3, for example, societal and cultural level processes of norm formation regarding food consumption for example are discussed. How else to describe changes in food consumption patterns? Such models probably don't exist in any form, and so can't be expected to be included in this paper, but the authors should indicate that there are still significant research gaps out there.

RESPONSE

The reviewer addresses an important point, what are the research gaps, when integrating human and natural processes. However, coupling existing models does not necessarily mean that all processes are included for each domain. Indeed there are major elements of social systems or natural processes that are not well represented in available and existing models.

Here we focus on land use because it is a widely studied human-environment relationship that offers some examples of human-environment coupled models, which is the emphasis of this manuscript. Thus, we demonstrate how the authors have layed

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the groundwork for increasing the complexity in subsystem models. The case studies demonstrate how the inter-system coupling is extremely important in addition to how the inter-system coupling affects estimates and our understanding of the coupled system. Once we know the implications of coupling models, then we can start coupling different types of models, and social scientists can create models of dynamics that have not been represented before, and connect it with natural system models (e.g., models of energy or transportation systems with climate models) and visa versa.

Through the manuscript we try to emphasize that there is considerable value in coupling models of other dimensions of human systems, created by social scientists, with relevant biophysical models. We do not seek to discuss different kinds of models of human decisions and actions. Many such models already exist (e.g., see model library at www.comses.net). However, most of these models have not been coupled with models of natural systems such that they impact and are impacted by the natural system. The main focus of this paper, which we intend to clarify, is to show what new insights can be gained when we create modeling environments that can dynamically simulate interactions and feedbacks between different components of human and natural systems.

REVIEWER COMMENT

Minor comment: page 20 line 5: which land management activities were identified?

RESPONSE

Thank you for drawing attention to the mentioned text. We have revised the sentence to include the following land management activities: irrigation, fertilization, biomass removal.

Again. Thank you for your time and effort in providing a very helpful review.

Interactive comment on Earth Syst. Dynam. Discuss., <https://doi.org/10.5194/esd-2017-68>, 2017.

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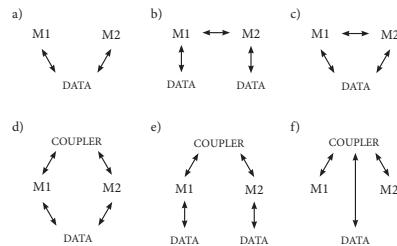


Fig. 1. Figure 1: Approaches to model coupling.

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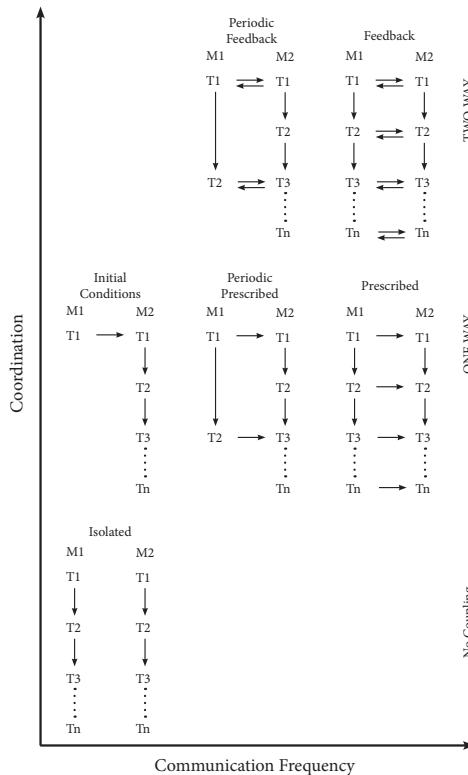


Fig. 2. Figure 2: Conceptual outline of the frequency of model communication and coordination of interaction between models from no coupling to one-way and two-way feedback.

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