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Earth System Dynamics
Discussions

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.

Referee #2

The authors present a review of 4 approaches to representing interactions between humans and the environment in land systems using coupled models. Based on the review of these approaches, the authors provide discussion and recommendations for repre-

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Discussion paper

senting human-environment interactions in land systems using coupled models. The subject of the article is interesting but work is required to restructure the manuscript, improve writing style and provide novel insights based on the review provided.

REVIEWER COMMENT

1. The 4 approaches are presented in an inconsistent way in Section 2.

a. My recommendation is that in section 2, in each case, introduce the type of model coupling you are referring to, the motivation of the original researchers for coupling the models and how they are coupled. Following this, as you have done, outline the interactions/feedbacks each model captures between human and natural systems.

A case study is useful, as you have done. I recommend following the case study with a subsection explicitly outlining the strengths and weaknesses for each of the 4 approaches. These should be summarised and combined in a table in the discussion section of the document so the reader has a clear impression of how each of the 4 approaches compare. A diagram illustrating the differences in coupling or how feedbacks are captured may be instructive.

RESPONSE

We appreciate the pressure applied on us by the reviewer to create additional diagrams illustrating the differences in coupling or how feedbacks are captured. As mentioned in our response to Reviewer 1, we have created two conceptual figures (Figures 1 and 2) and included them in our introduction to coupling at the front of manuscript. In addition to these diagrams/figures, each of the four examples now relates back to these conceptual figures and identifies how their approach relates to those figures. Furthermore, each example model provides a new figure that is a combination of the architecture of the presented model and the sequence of interactions between the models. This new figure provides more insight into the coupling process and makes the example more transparent for the reader.

Prior to submission we attempted a lessons learned and strengths and weaknesses table with each of the four examples, which did not work well given similar outcomes from each project. We attempted this again, with similar results and therefore leave the lessons learned section within the Discussion. However, as noted in our response to Reviewer 1 each lesson will have an example from presented model accompanying it.

REVIEWER COMMENT

b. Section 2.1 and 2.2 headings sound like case studies and therefore this should be the sub-section title related to case studies. Since you are comparing 4 approaches, the main title of section 2.1, 2.2, 2.3 and 2.4 should illustrate the approach you are addressing in each section as you have done in section 2.3 and 2.4. c.

RESPONSE

Agreed. We swapped different approaches to these headings several times among model names, purposes of the models (as submitted), and others. We have amended the manuscript to describe the example as an approach AND the scientific purpose. This makes the heading lengthy, but much more informative.

While within the manuscript we illustrate different coupling approaches, we do not perform a rigorous comparison of different coupling approaches. This comparison would be best done with different instantiations of the same model(s) using the same data for it to be effective. Instead we seek to demonstrate that with coupling we can answer research questions that cannot be answered without coupling AND that these approaches couple specific process models rather than general models. These specific models provide a level of transparency and depth that are not typically found in more general model integration efforts and therefore facilitate and enable new perspectives and questions to be generated in the science of coupled human-natural systems. Each of the examples illustrates the consequences of modeling feedbacks between human and natural systems at different spatial and temporal scales using different coupling architectures, frequency of communication, and level of coordination. We have clarified

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Discussion paper

these scalar and architectural differences in the manuscript, but we do not seek to outline a lengthy literature review and meta-analysis of the different possible approaches to coupling models. In summary, we appreciate this point and have used it to improve the focus and clarity of the manuscript by explicitly describing the coupling architecture for each example including how the models interact with each other, data, and how they are scheduled.

REVIEWER COMMENT

The cases provided in section 2.1 and 2.2 are new models or approaches. As a review paper, I find this somewhat problematic as the idea, I would think, is to appraise pre-existing approaches rather than adding two new approaches. If there are pre-existing approaches that are consistent with those presented in section 2.1 and 2.2, then these should be reviewed. If the authors feel that the approaches they are presenting here are novel and address some of the shortcomings of the approaches in section 2.3 and 2.4, then by all means present your approaches as novel frameworks. However, if they are not, then this article does not strike me as the appropriate platform to present new work (as it is now structured).

RESPONSE

Thank you for drawing attention to some differences in the case study between sections 2.1 and 2.2 with sections 2.3 and 2.4. We face a trade-off in wanting to demonstrate some of the results to the reader to illustrate what types of results are acquired and how they may differ from results not acquired from a coupling (and different types of coupling) between human and natural systems. These results would enable the reader to think about her or his own results and how they may differ under a coupled model. The display of results also provides tangible material for illustrating the lessons learned from the coupling experiences of the group of coauthors. To better align the examples we have edited the example sections to focus explicitly on 1) Model definition and description and 2) Feedback implementation. We have moved the results to supple-

mentary material. In the Feedback implementation section, of each example, we link back to new conceptual Figure 1 and Figure 2 and explicitly outline the architecture of the example.

Neither of the models presented in Section 2.1 or Section 2.2 are new and both have been published (as illustrated by the provided citations). However, all case studies presented illustrate a new approach to modeling human and natural systems. To accommodate the reviewers suggestion we have placed the model case study results in the supplementary material to give the reader further information about the types of results acquired from each model and the types of research questions they can be used to answer.

REVIEWER COMMENT

2. The article states that there is a lack of suitable frameworks to guide the building of coupled models of land systems. Given the wide-ranging expertise of the coauthors here, I would expect the article to present a new framework to tackle these issues based an assessment of the strengths and weaknesses of existing approaches. I understand that you are addressing systems that operate across multiple scales. Nonetheless I would like to see the authors make an attempt to outline a framework that can be applied across scales or at the minimum a list of best practices and core knowledge gaps that are required to be filled. A call to action, if you will. These should be explicitly outlined as they will form the main novel findings of the manuscript.

RESPONSE

We would like to thank the reviewer for pushing us on this issue of providing a framework based on the wide-range of expertise among the coauthors. We hope that the conceptual figures outlining the coupling architecture (Figure 1) and the frequency of communication and level of coordination (Figure 2) address a portion of this request. The coauthors did not find it suitable and thought it was premature at this point in our experiences in model coupling to put forward a generalized framework for others to

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Discussion paper

follow, but we did come to consensus on proposing a way forward that would help expedite model coupling initiatives and ensure that the products of those initiatives are more interoperable and usable by the science community. We added a section to the Discussion title A Way Forward that contains the following text.

3.4 A Way Forward

The ability to dynamically simulate feedbacks between human decision-making and natural processes requires some kind of tight couplingâĂŤin the sense of frequent communication and high coordination (Figure 2) âĂŤ between models designed to represent these different processes. To date, this has largely been achieved through connecting models into a single modeling environment. This is true to a large extent for all the case studies presented here. Adding new models to such systems, often requires significant reprogramming and makes the expanded code base increasingly difficult to debug, verify, and validate. Additionally, any other researcher that would like to combine fewer, more, or different components will need to reprogram multiple parts of the modeling environment to decouple a model and add another. To expedite coupling, we recommend a bottom up approach to modeling, whereby 1) modellers with in-depth domain knowledge create and make available relatively small, more easily verified modules comprising a model (Bell et al. 2015) or models as components for assembly into metamodels; or 2) modellers work coupling frameworks (e.g., OpenMI, ESMF, OMS, and CSDMS) that connect or couple multidisciplinary models, both of which have the goal of preserving and building upon existing numerical code previously developed by the many subdisciplines involved in modeling human and natural systems. These are not new ideas, but they have not yet been achievable in spite of their recognized desirability. However, a suite of technologies have reached sufficient maturity that it may now be a practical way to create a new generation of modeling tools that can exploit these two avenues for modelling coupled human-natural systems. New coordinating frameworks for next generation coupled modeling of human and Earth systems are being developed within a number of relevant organizations: the Com-

munity Surface Dynamics Modeling System (CSDMS), the Network for Computational Modeling in Social and Ecological Sciences (CoMSES Net), and the Analysis, Integration, and Modeling of the Earth System (AIMES) Core Project of Future Earth. These frameworks envision a set of community-developed and promoted standards for open, platform-independent, model coupling and integration based around an interrelated set of components that build on Lessons 3, 4, 5, and 7.

i) Start with wrapper container software (e.g., Docker) to encapsulate model code and needed dependencies.

ii) Use a standardized API, like extension of the Basic Modeling Interface (BMI) developed by the CSDMS, to standardize and describe various functions (e.g., Model Control, Model Information, Time, Variable Information, Variable Getters and Setters, and Model Grids) such that a calling component in the framework is provided with the needed level of control to access other component's metadata and simulated data (Hutton et al., 2014).

iii) Incorporate Standard Names to map variables of multiple components to each other. In the CSDMS framework the Standard Names functions as a semantic matching mechanism, a lingua franca, for determining whether two variable names refer to the same quantity with associated predefined units.

iv) Adopt reproducible workflow environments to wire models together, supervise their execution and manage storage of the intermediate and final results needed for subsequent analysis.

For these elements of a framework to be maintained, a community organization is required in an open-source development environment. Models meeting these community standards would then be certified in public code libraries like those maintained by CoMSES Net and CSDMS to indicate which models could be coupled with any other certified model. Certification from a community organization and buy-in from the modelling community would create an ecosystem of open, connectable models that could

be integrated into reproducible computational pipelines in standard ways for coupled human and natural system models. The evolution of such an ecosystem is dependent on the commitment of organizations representing modeling science to support and maintain a set of community standards and to facilitate the education and adoption of those standards by the modelling community. An important advantage of the proposed framework is that it does not require scientists to significantly change the way they develop models or to commit to a particular language, platform, or operating system. The combination of this development flexibility with committed standards and adoption assistance would enhance the likelihood of reaching a critical mass of development that would greatly expedite not only the development of coupled human and natural system models, but also increase the rate of scientific discovery in this domain.

REVIEWER COMMENT

3. The writing style is very loose with statements made that are imprecise, insufficiently explained or qualified. For example, the motivation for coupling on page 5 line 16 – page 6 line 7. Page 6 line 16-17. The coupling approach enables a greater degree of transparency and accuracy in coupled models. There are examples like this throughout the manuscript that need to be made more precise, properly qualified and backed up by citations where appropriate. In addition, many of the sentences are too long and contain multiple arguments. Better to split these into shorter sentences for clarity.

RESPONSE

Thank you for pointing out these areas of improvement. We have altered the text in these sections to be more precise in some cases and qualified in others. We have also qualified other similar statements in the paper. An example to the Reviewer's point on Page 6 line 16-17 is that we changed the text from

"The coupling approach enables a greater degree of transparency and accuracy in coupled models."

To

“Because of the greater degree of openness enabled by these technologies and their modular nature, coupled models enable a greater degree of transparency in how we represent human-natural system models. Whether their relative process richness enables a greater degree of model accuracy remains to be tested.”

Furthermore, throughout the manuscript, sentences are shortened.

REVIEWER COMMENT

4. The motivation of the study (stated page 6 line 17 – page 7 line 5) is unclear to me. These are the aims are written as:

Aim 1: We present multiple approaches to coupling land-change and natural-system models to evaluate how alternative approaches to representing feedbacks add value to scientific inquiry into global change and thus generate new insights into the sustainable management of human-environment interactions.

Aim 2: Based on the current state of the science, we categorize conceptual approaches to coupling land-change models with natural-system models that differ across a range of spatial extents and coupling methods.

Aim 3: Using four case studies, we critically assess the influence of land-change processes on natural-system processes and vice versa, focusing on the implications of these feedbacks for system dynamics, the research questions that model coupling enables, and the strengths and weaknesses of the coupling approach.

Aim 4: we describe the lessons learned from the various approaches, the different types of consistency that should be maintained between coupled models as well as the feedbacks represented between the human and natural systems.

Aim 1: I thought the focus was on the land system and land system models, not global change, which is a much broader topic. Aim 2: Okay, a useful aim but I don’t think the

paper achieves this. You should make a clearer distinction of the differences between the 4 approaches presented. See comment 1 and 2. Aim 3: I thought the specific aim of the paper was to investigate how human-environment interactions in the land system are captured using coupled modelling approaches.

As it is written, it comes across as quite a verbose research aim. I recommend focusing solely on how human-environment interactions in the land system are captured using coupled modelling approaches. Aim 4: See comment 1 and 2.

RESPONSE

Agreed, we became over excited in what we would achieve with this manuscript. We refined the aims to better match the content of the manuscript and convey this focus at the end of the introduction using the following text:

"We present multiple approaches to coupling land-change and natural-system models and reflect on how their representations of feedbacks add value to scientific inquiry into the dynamics of coupled human-natural systems. We highlight four example models that explicitly represent feedbacks between land-change and natural systems, but vary in their scale of application and coupling architecture. We then present the lessons learned from the modelling research teams, discuss the challenges of representing feedbacks, and then outline a way forward to expedite model coupling initiatives and their subsequent scientific advances."

REVIEWER COMMENT

Specific comments Page 4: Avoid the use of footnotes

RESPONSE

We agree with the reviewer and typically avoid the use of footnotes in all our publications. We have included a single footnote in the submitted manuscript because we believe that the incorporation of the definitions within the text is a distraction from the narrative of the article. The purpose of the footnote is to provide definition and clar-

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Discussion paper

ification for those who are not used to the nomenclature used in the manuscript and specifically the differences between Earth, ecosystem, and land surface models. If it is acceptable to the journal we would appreciate the inclusion of this content as a footnote rather than integrating the definitions into the text.

Page 6 Line 20: State of the science is incorrect English

Agreed. Thank you for pointing out this error. We have deleted the identified text and edited the paragraph within which the referred text resides to clarify the intentions of the manuscript.

REVIEWER COMMENT

Page 28 Line 18-19. Please qualify this statement.

The statement referred to is as follows:

“These examples provide a level of transparency and detail in the represented processes that is not typically found in larger Integrated Assessment Models (IAMs).”

RESPONSE

Our teams’ collective experiential work with and knowledge of IAMs demonstrates that the specific equations and parameters for biophysical processes are often not exposed to the model user, calibrated for specific study areas, or coupled in a way that creates a direct impact-response feedback. Instead, the biophysical processes are either 1) disconnected and act as an independent measurement routine, 2) linked as is often done in climate modelling via prescribed changes in land use and land cover change, or 3) have a simplistic representation that can be useful at very large spatial extents (e.g., globally) but do not match observations well locally.

We have changed the text in this paragraph to replace the text in question with the following:

The focus on specialist-developed models offers a flexible and open approach to an-

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swering new questions about feedbacks in coupled human-natural systems, and also facilitates the identification of new types of data required to calibrate and validate the interactions and feedbacks between the two systems. Additionally, in contrast to the monolithic approach to modelling like that taken in integrated assessment models (IAMs), coupled modelling presents an opportunity for increased transparency and detail in the represented processes through more explicit identification and documentation of component interactions and processes.

REVIEWER COMMENT

Page 38 and 39. The conclusion section on interdisciplinary collaboration is valuable and insightful.

RESPONSE

Thank you for this comment and more importantly thank you for your time and effort. Again, your contribution and review is appreciated and has made the manuscript stronger and hopefully more useful for future readers.

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

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