Workshop Report: Linking Earth System Dynamics and Social System Modeling

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Organizers: Human Dimensions Focus Research Group, CSDMS

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Context

Aim. *To bring together a diverse group of researchers from multiple disciplinary backgrounds to push forward the boundaries of global-scale, coupled social and biogeophysical modeling*. The workshop was used to develop a strong research plan and timetable for the integration of human systems models with Earth system models. This was based on establishing a distributed network of researchers with the cross-and trans-disciplinary skills to implement this ambitious project. The workshop began the process of developing a joint modeling effort that represents the effects of human activities on environmental change in better ways than is done currently.

Purpose: *To assess the intellectual, informatics, and material resources needed to develop global models of human systems dynamics and couple them with models of Earth system dynamics in order to further understanding of the interactions and feedbacks within the integrated human-environmental system that dominates the globe today*. Coupled human and Earth system models will help us better understand and anticipate consequences of changes in both social and natural drivers of coupled social/natural systems (e.g., climate, policy changes, etc.). The workshop was used to establish an interdisciplinary scientific network with the expertise needed to build integrated Human-Earth System Models (HESMs) to carry this initiative forward.

Outcomes: *A three-year research plan and timetable written into a White Paper to identify the most tractable components for modeling of the coupled Human-Earth system that can be scaled up from the local to the global.* In addition, the workshop supported further development of a US national center for advanced social informatics and analytics.

Output: *Recommendations for modeling priorities and resource needs, and a new community of modelers of global-scale coupled human and Earth system models*. The workshop agenda is given in Annex 1, and the full participant list in Annex 2.

Background

Projections indicate that the global population may grow to 9-14 billion by 2100, with global GDP per capita increasing from an average US$10,000 today to US$35-155,000 in 2100(1), increasing global demands for water, food and energy. Global demand for crops is expected to rise 60-110% by 2050 (2, 3) fueling a projected 50% increase in water demand (4) while at the same time, the use of crops or crop area for the production of bioenergy creates an additional pressure. Climate change and associated increases in extreme weather events will also impact the availability and quality of water resources (5), agricultural production and associated demands for irrigation (6), and ecosystems, resulting in total economic losses estimated to reach 5-20% of GDP by 2100 (7). These losses could be reduced significantly if the global mean temperature rise were to be constrained to 2°C above pre-industrial levels (8). On the other hand, the collapse of states, the chance of major pandemics in addition to erratic climate events may throw this business as usual scenario into disarray. Against these alternative background scenarios, the UN has proposed sustainability goals including "Ensure availability and sustainable management of water and sanitation for all" (goal 6); "End hunger, achieve food security and improved nutrition and promote sustainable agriculture" (goal 2); and provide "access to affordable, reliable, sustainable and modern energy for all" (goal 7); whilst at the same time reducing "climate change and its impacts" (goal 13) and ensuring "sustainable consumption and production patterns" (goal 12) (9). This raises the question: what can the scientific community provide in terms of knowledge and modelling tools in support of achieving these goals?

The Earth system (coupled processes of the atmosphere, geosphere, and biosphere) is increasingly dominated by human action, and at the same time Earth system processes continue to significantly impact human life and well-being (10). This creates an urgent need for closer coupling of social simulation models representing human behavior with Earth system models (ESMs) that focus on biogeophysical process representation (11). Advances in ESM science is giving us invaluable insights into Earth system dynamics and helping us better plan for future conditions. But, existing models typically consider humans as external to the Earth system, allowing for few (if any) feedbacks based on the diverse human decisions and activities that might amplify or dampen environmental changes. Human managed land-cover is initialized in land components of ESMs and estimates of anthropogenic greenhouse gases (e.g., Representative Concentration Pathways) are injected into ESMs at different time intervals. At the same time, most current global models of human action focus on the social world of economic markets, resource extraction, agriculture, energy production/consumption, etc.; biophysical phenomena are considered as externalities or as boundary conditions 2.

Yet we know that Earth system processes have effects on human societies, and social response to these dynamics (e.g., climate change or ocean circulation) impacts biophysical systems; we need to acknowledge and understand the bidirectional feedbacks between them (11). Thus, it is important to develop a new generation of integrated human and Earth system models (HESMs), coupling the dynamics of both biogeophysical and social systems of human decisions and actions (12). This is essential for new insights into the multi-scale interactions among markets, atmospheric physics, energy consumption, terrestrial hydrology, water use, soil biochemistry, land-use, and other societal and biophysical processes (11, 13). To accomplish such a goal requires a diverse set of social, natural, and computational scientists to work together, to learn one another's languages, and integrate methods from these different disciplines.

Fortunately, there is a growing awareness of the importance of considering social and biogeophysical processes as a single, complex, global system. For example, the National Flood Interoperability Experiment is collecting and synthesizing data at a continental scale on the impacts of the atmospheric component of the Earth system on human systems, so that local and regional authorities can better anticipate and plan for extreme weather. However, only the one-way effects of weather on society is considered. There is not yet explicit consideration of the feedbacks of human actions back to the climate system, or how those feedbacks would, in turn, affect weather hazards. The new NSF-wide Food Energy Water Nexus initiative is a more comprehensive effort to begin to capture the two-way interactions between some of the human and natural components of the modern Earth system. However, there is no indication in the initial 'dear colleague' letter for this program of an intent to support research on the evolution of current ESMs into HESMs.

Hence, the overall aim of this workshop was to bring together a diverse group of researchers from multiple disciplinary backgrounds to push forward the boundaries of global-scale, coupled social and biogeophysical modeling. The workshop was used to develop a strong research plan and timetable for the integration of human systems models with Earth system models. An international network of researchers with cross- and trans-disciplinary skills are needed to implement this ambitious project. The workshop began the process of establishing such a scientific community and developing a next-generation modeling effort to better represent the complex interactions of human activities and environmental change. Participants in this workshop included leading representatives from computational social science communities and Earth system modeling communities in the US and internationally. This involved collaboration among national laboratories, research centers, and university programs that have a common interest in the human dimensions of the Earth system (see list of participants in Appendix 2).

It is important to recognize that much of the current development and application of biogeophysical ESMs within the US takes place in national facilities such as the National Center for Atmospheric Research or Oakridge National Laboratory. Indeed, facilities developing and managing ESMs are aware of the importance of human processes to the Earth system, as evidenced by the CESM Social Dimensions Working Group at the National Center for Atmospheric Research, and the iESM group at Pacific Northwest, Oakridge, and Lawrence Berkeley National Laboratories. However, while these centers employ small numbers of social scientists, their primary missions and scientific expertise focus primarily on the biophysical components of the Earth system. Thus, it is not surprising that we still lack models at the global scale that represent human behavioral processes. This underscores the need for a new national initiative, with specialized knowledge and capacity in social informatics and human systems, to develop and maintain global-scale models of decisions and behaviors that could be integrated with existing biophysical model code for the Earth system. Scientists engaged in building these more comprehensive HESMs could also lead the creation of science-based scenarios to support decision makers in identifying robust strategies for societal sustainability in a changing world.

Content

Approach: Workshop participants identified a set of seven interdisciplinary scientific research issues and key questions through facilitation. Breakout groups for each of these issues were asked to address four questions to guide discussion and planning: 1) What is the scope of the scientific questions most relevant to the issue? 2) What are the methods needed to address those questions? 3) What opportunities are currently available to take the set of issues forward; what new work is needed; what funding mechanisms could support this work? The outcomes of the breakout group discussions is presented below.

1. The purpose of linking models (Chair, Hill): The purpose of developing a linked modeling effort include: to answer questions, generate questions (new realizations, discovery) and test hypotheses in order to create more representative models that are more accurate and useful. This would serve to broaden the conversation, rather than to steer the conversation, and would require the development of a new modeling community. But, we are still not clear about how to develop such models. We do know, however, that if we want to inform new model development, then we need more on the human science side; we can't simplify out humans. We also know, that without impact, this type of research will not be funded.

Comment [MOU1]: I don't see how this differs from group 3. Was this the topic the group was supposed to discuss?

Another purpose of linked models is to prioritize. For example, what information does a decision-maker need to do their job better? The process then is not just about incorporating human decision-making into ESMs, but also in providing tools to make decisions. Flint, Michigan is a good example of the breakdown between human and natural systems, arising from non-responsible government, since no model was available to test the impact of decisions taken. With better models, both problems and solutions become more visible as a guide to decision-making.

We need to be clear about why these new linked models are different. Model diversity is good, but it is also valuable to understand why models are different. Humans dimension models can produce inputs for existing Earth system models (including feedbacks) or reproduce a known human system process (e.g. agricultural intensification, demographic transition, evolution of technology, urbanization). But, we need to have clear goals concerning integration of human dimension processes in ESMs. A big advantage of models, however, is that they force people to work together and confront one another's ideas, processes, capabilities, etc. Models are often built as part of a large, governmental or corporate infrastructure. There are benefits to developing a single community model because people contribute to this collectively and are supported by the community. But this assumes that the utility of the modeling process is to produce a tool that will be used by everyone. Conversely, a new community could be an umbrella for coordinating a range of different human models. So, we need to ask ourselves whether the purpose of developing new models is to converge the science or diverge the science.

2. Land and water issues (Chair, Barton): Modeling human dimensions of dynamics in Earth's land and water systems potentially engages all critical zone systems except the atmosphere. Hence, this group tried to identify a more tractable scope for a near-term science plan. Initially, we focused on examples of land and water dynamics that could benefit most from coupling biophysical and human systems models. But, because humans now have such a significant impact on terrestrial and aquatic systems, realistically modeling very many of these systems requires consideration of the human component (see Figure 1).

We therefore selected three land/water subsystems related to important issues of human well-being in the near-term future: agricultural land-use for food security, access to surface fresh water, and the growth of urban systems. We recognize that many other dimensions of land and water systems than these could be better understood through coupling models of human and earth systems. Nonetheless, these three domains of social-natural dynamics and their broader consequences encompass much of the range of issues that could be addressed through better modeling efforts and could serve as initial proof of concept to justify subsequent expansion of modeling. Moreover, there are important interaction dynamics between each of these three subsystems.

For example, access to surface fresh water for irrigation has significant impacts on the kinds of agricultural land use practiced, and its ability to produce adequate food, especially in arid and semi-arid climate zones which are forecast to grow in extent over the next century. Conversely, agricultural land use has significant impacts on surface water availability, with irrigation reducing flows in rivers and streams and agricultural runoff affecting both sediment load and water quality. At the same time, rapidly urbanizing regions create increased demand on fresh water sources. Many of the world's largest urban areas are located on deltas at the mouths of major rivers. Urban land use is increasing rates of subsidence in deltas, agriculture can increase sediment load that increases the rate of delta formation, and damming of large rivers - to provide more secure water availability for farming and for urban use - reduces river flows and decreases the rate of delta formation. In these complex systems, the interplay between agriculture, water management, and urbanism will have significant impacts on a large fraction of the Earth's population in the coming years.

We also recognize that these three domains leave out the greatest part of the earth's critical zone, the oceans. Again, however, we have greater current knowledge and more existing modeling programs that deal with terrestrial systems than with human-biophysical coupling in marine systems. Especially for coastal environments, it will be increasingly important to support new research and modeling of human-biophysical interactions for marine systems.

For each of the three land/water subsystems chosen for more intensive focus, we discussed current modeling programs and development needs for coupling human and earth systems models.

Agricultural Land-use: There are numerous process-based models for different dimensions of the human and biophysical interactions of agricultural land-use and its consequences. These generally fall into three broad categories: economic models of agricultural commodity markets (including integrated assessment models), crop (and livestock) models that represent the growth and productivity of edible plants (and animals) under different land-use practices and edaphic conditions (weather, soil, moisture, etc), and physical models of landscape evolution (e.g., soil conditions, hydrology) and climate that can affect crop productivity. Some of models in each general class can also incorporate simplified representations of a few dynamics of other categories, but in general, the phenomena represented in each category treats the phenomena in other categories as exogenous input. That is, the components of sophisticated coupled human-biophysical models of agricultural land-use and landscapes currently exist in one form or another, but there is little in the way of dynamic coupled modeling across these components. This seems to be a domain in which scientific insight with significant benefits for food security can be realized rapidly through coordinated efforts to integrate existing modeling capacity.

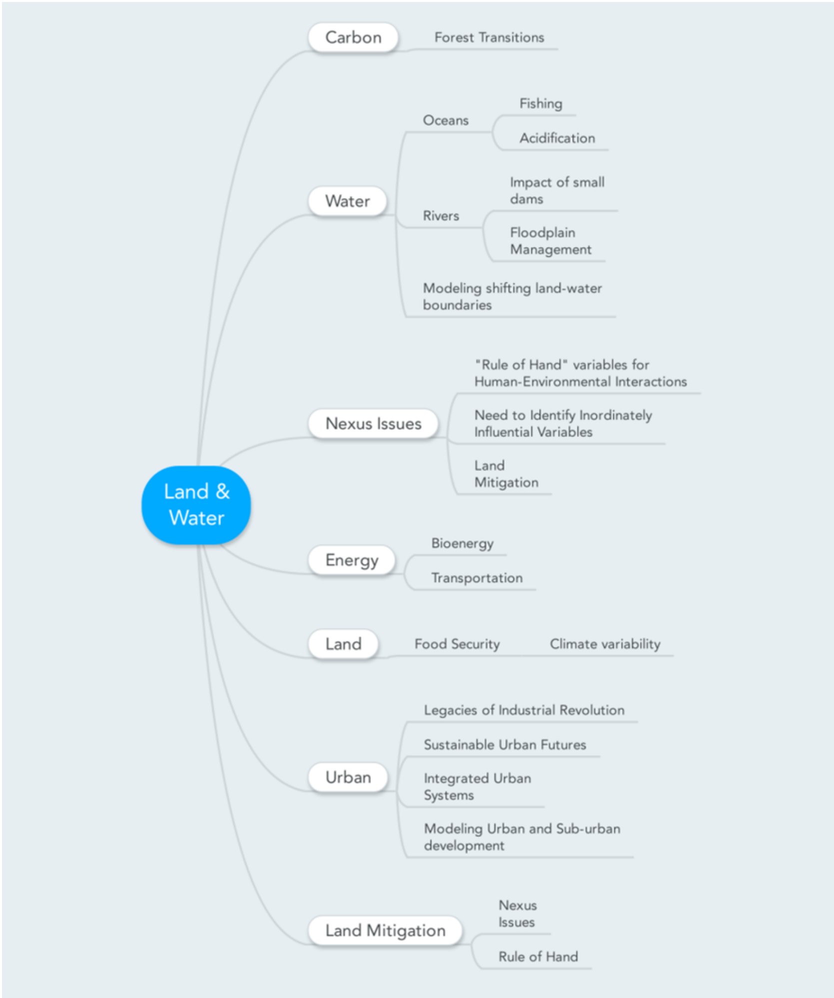

Figure 1. Examples of land and water systems where coupled biophysical and human modeling would be particularly beneficial.

Important methodological issues that need to be overcome are especially those of spatial/temporal scale. Many (but not all) physical models of environmental dynamics important to crops and livestock are spatially explicit, and have variable time steps that can range from minutes to years. Many crop models are spatially explicit in only a very limited sense, representing conditions in a single farm field or pasture, but can potentially be transformed to deal with spatially more extensive, gridded landscapes.

Comment [MOU2]: This mind map is nice looking but it takes up a lot of space. If we don't have any other figures in the report, it might stand out as unusual, and could be dropped without hurting the information value of the report.

Relevant time steps range from daily to monthly to seasonal to annual. Economic models of land-use decision making are often (but not always) largely aspatial or aggregate decisions and markets at very coarse spatial scales (e.g. all of North America or western Europe). Time steps commonly range from annual to decadal. An important requirement of coupling these different modeling categories involves developing reliable and systematic ways to upscale and downscale spatially, to operate at common time steps, or to aggregate and disaggregate across different temporal intervals. In developing better ways to couple these components, it is important to note that when aggregating or upscaling, variation might be more useful than the more normally calculated mean or medians.

Availability of Surface Water: There are many, highly developed, and extensively tested, hydrological models for surface water flow at multiple scales. There is also a mature - even if less standardized and less widely used - modeling technology for representing water demand for human consumption, agriculture, and industry. However, there is very little in the way of coupling across the human and biophysical ends of these systems. Issues needed to combine these two classes of models are less clear than for agricultural land use. However, probably similar mismatches in spatial and temporal scale are equally important here. Also, water users encompass a greater range of social and economic heterogeneity than found in the agricultural sector, and will need to be represented in adequate ways. A further challenge will be addressing the importance of coupling models of water use/demand and water flow/management to agricultural land-use systems discussed above. As access to water becomes even more important in coming decades, it will be impossible to sustainably manage this critical resource without finding a way to integrating models of the primary drivers of terrestrial surface water dynamics - human social action - with models of the biophysical dynamics of streams, rivers, and lakes.

Comment [KG3]: Is this true?

Urbanization of Land: Much representation of the futures of cities is qualitative and expressed as narratives. Most extant quantitative representations primarily take the form of GIS models that are empirically-based ‘snapshots’ of future states rather than modeling the dynamics of urban systems. There are a few exceptions to this characterization, including the modeling work of Marina Alberti and Michael Batty. In all models of urbanization, however, there is little if any consideration of the biophysical dynamics of urban areas. Additionally, there is little in the way of biophysical, Earth-systems-like modeling of urban environments beyond attempts to estimate urban heat properties - currently, in very simplified and spatially coarse-grained ways.

Conversely, large and complex data sets on urban characteristics (AKA ‘big data’) are being used in innovative ways to better understand the growth of cities across large geographic regions. This ‘urban scaling’ research, best known from the work of Luis Bettancourt and colleagues, is beginning to also produce (as yet simple) generative models to account for widespread empirical patterns in the data.

The current state of affairs presents significant challenges - and significant opportunities - for modeling urban systems and the urbanization of the Earth as coupled socio-ecological systems. The limited availability of generative models for the human components of urban dynamics and the lack of biophysical models for urban regions underscores the need for considerable model development from the ground up for urban land-use. On the other hand, this same situation means that there are fewer legacy issues and path dependencies in existing modeling that need to be overcome. Finally, the use of big data for human systems seems more advanced in urban research than in the other two domains.

Taking it forward: In order to lay the ground work for a 3 to 5-year science plan, we discussed current modeling efforts that might serve as exemplars or partners in developing coupled models of human and earth systems for agricultural land-use, surface water, and urbanizing regions. Numerous research teams are working on modeling crops and *agricultural land-use*, including IPFRI (CGIAR), IIASA, PIK, and the participants in the AGMIPS program. NCAR and PNNL have land models that can potentially provide Earth system dynamics for crop models and agricultural sector economic models. The NCAR THESIS Project (NSF EaSM2 program) is developing tools for integrating data from IAM (iPETS), crop models (from UIUC), and Earth system models (CESM). At more local scales, a number of the landscape evolution and hydrology models maintained in the CSDMS Integration Facility could also be coupled with human systems and crop models.

Some of the same groups provide useful starting points for integrating human and Earth system models for surface *water accessibility*. NCAR and PNNL are applying biophysical atmospheric and land models (CESM) to water availability at global and regional scales. CSDMS also manages a suite of regional to local scale physical models for surface water. John Riley's group at MIT and Charles Vorosmarty's team at CUNY are working on integrated models for water use and availability.

Marina Alberti's research group at the University of Washington and Michael Batty's team at UCL stand out as leading modelers of *urban systems*. Urban scaling research, emphasizing empirical big data, but beginning to link this to modeling is being led by Luis Bettencourt and Geoffrey West at SFI, collaborating with Jose Lobo and others at ASU and elsewhere. The ASU Decision Center for a Desert City is also emphasizing modeling of urban areas as socio-ecological systems. These groups could provide solid starting points for developing coupled human and earth systems models of the planet's rapidly proliferating urban regions.

3. Coupling Human and Earth System Models (Chair, DiVittorio): The participants in this group represented in depth experience with the issues of model coupling in general, and integrating models of human decision/action with biophysical models in particular, and at multiple scales. The discussion began with participants briefly summarizing examples of model coupling at different scales. Allen DiVittiorio gave an overview of the iESM project to couple CESM and GCAM. Brian O'Neil reviewed the THESIS Toolkit project to rescale and integrate outputs from global scale IAM (iPETS) and Earth systems (CESM) models. Carsten Lemmen described a project integrating human land-use and land cover change at continental scales. Peter Verberg reviewed his work combining human systems and biophysical models at regional scales. Michael Barton and Isaac Ullah presented the coupled human and earth systems modeling at local scales in the MedLanD Modeling Laboratory (MML). Albert Kettner discussed CSDMS work at coupling different kinds of Earth systems models.

Scaling: This initial discussion of participant experiences allowed the group to identify several key, interrelated issues related to both the technical and information quality dimensions of model coupling. Scaling was most discussed. Existing earth systems models (including vegetation and crop models) operate at point, one-dimensional (in space), two-dimensional, or three+ dimensional spatial scales, but most discussion focused on spatially explicit two+ dimensional models. These can also operate at spatial resolutions ranging from centimeters to several degrees of latitude/longitude. Many human systems models (especially economic models like IAMs and CGEs) are aspatial or semi-spatial, using a small number of irregular spatial units defined by political boundaries (e.g., GCAM has 151 units and iPETS has 9 for the entire world, while CESM has 129,600 cells at a 1° resolution). However, some human systems models are also grid based and can operate at relatively high spatial resolutions (e.g. Carsten Lemmen's project and the MedLanD project). Coupling human systems models and different Earth system models requires sophisticated aggregating or downscaling routines to produce meaningful results. The iESM and THESIS Toolkit projects are actively working through these issues for global scale models.

Scaling is not just about space, however. Different models can have different time steps. For example, CESM has a 30-minute time step and GCAM has a five-year time step. Crop models may need diurnal variation in conditions, or monthly or seasonal values. The MML landscape evolution component operates at a one-year time step, aggregating information on precipitation amount and intensity. But other surface process models run at steps of storm events. Harmonizing different time steps can be as complicated as synchronizing spatial scales.

Stochasticity: Related to issues of temporal scaling is the recognition that some models are strongly deterministic, so that the results are essentially the same for any run with the same initial parameters. This is the case for many Earth system models and some human system models (especially econometric style models). Other models have algorithms that generate stochasticity to represent uncertainty in processes. Many agent-based/individual-based models and some cellular automata fall into this category. For models with inherent stochasticity, best practice calls for repeated runs for each set of initial conditions so that a distribution of output results can be evaluated. This can be complicated when stochastic models are coupled with deterministic models. Should a coupled model system be run repeatedly or should the stochastic component of a coupled model be run repeatedly (as if it had a shorter time step) and an aggregate result (e.g. mean) be sent to the coupled deterministic model?

Feedbacks: The ability to represent feedbacks between human and Earth systems is a significant reason for coupling these different kinds of models. Such feedbacks can make models much more (or much less) dynamic and sensitive to changes in parameter values. In most cases, models of human systems and the Earth system are only loosely coupled at best. Carsten Lemmen's project and the MML exemplify the few cases of tight, dynamic coupling in these different kinds of modeling frameworks. The CSDMS also provides software tools to create different degrees of coupling between Earth science models. The scale and stochasticity issues need to be resolved in order to have information passing between human and Earth system models with sufficient reliability to study feedbacks. There also needs to be decisions about what kind of information is passed and what is not passed between models or model components. Even when these issues are resolved, allowing for feedbacks can cause previously stable models to become highly unstable as small variations become amplified in a coupled system, as learned in MML development.

Consistency: Because Earth system models and human systems models sometimes attempt to simulate similar phenomena, like land cover, coupling existing models can encounter significant problems of consistency. By making different initial assumptions and incorporating different processes into models, very different values for the same phenomenon can be generated by different models. Such consistency issues have been identified in the iESM and THESIS Toolkit projects, for example. While model coupling ultimately can help to harmonize and resolve such consistency issues, it will require decisions about which processes to represent and which to leave out when coupling models. Furthermore, other components of a model may depend on values of a phenomenon being within a given range that is not the case when the same phenomenon is modeled in a different way.

Methods: The group discussed a number of technical issues related to successfully coupling human and Earth systems models. It also discussed a number of social issues that are equally important for implementing a multi-year science plan to accomplish this. Three types of approaches to integrating human and Earth system models had the most discussion: off-line coupling by integrating data outputs, tight coupling of models in a single platform for a well-defined set of research and applications goals, and plug-and-play coupling that would allow different models to be connected for different objectives by focusing on community-standard APIs and coupling software (middleware).

Integrating Model Outputs: The NSF funded THESIS Toolkit project is an example of the off-line coupling approach. This is being done by creating software tools that can rescale data output from different kinds of human and Earth system models so that they can be analyzed in an integrated way. This provides new ways to study possible relationships between human systems and the Earth system. It also provides a way to develop pilot versions of downscaling or aggregating methods that could potentially be used to couple models dynamically. It does not, however, allow feedbacks between human and Earth systems to be explored. It also does not provide an environment to resolve consistency issues very well, although there are ongoing efforts to reduce intermodal inconsistencies. Current work is focused on global scale models.

Tight Coupling/Unitary Model Approaches: Most of the examples of coupled human and Earth system models presented by participants use the single model approach, including iESM, Lemmen's modeling system, and the MML. While distinct, stand-alone models are coupled together in such environments (at least for iESM and the MML), the models are fairly tightly 'hard-wired' together such that it would involve considerable work to switch out GCAM for another IAM in iESM, for example, although this is potentially doable. This is because knowledge of what parameters to pass between models and routines for rescaling are built into the code that connects different models into a hybrid modeling system. This means that these unitary model approaches require the scope and scale of modeling efforts to be well-defined. The MML uses a kind of middleware "Knowledge Interchange Broker (KIB)" to connect different model components, but this is insufficiently generic to allow for easy swapping between different human or Earth system models. So it is considered under single model approaches for now.

The tight coupling and built-in rescaling code means that feedbacks are operating and changing coupled model behavior in these systems - though the amount of feedback permitted can be controlled by limiting the kinds and amounts of information passed between component models or by introducing damping filters. Stochasticity does not seem to be addressed (or possibly not an issue) for iESM. For the MML, the entire modeling system is run multiple times for each set of initial conditions and aggregate results analyzed. Even though there is much less stochastic variability in the Earth system components of the MML, stochasticity in the human systems component can have a variable impact on the Earth system component - sometimes significantly altering variability and at other times not so much. Consistency issues are also handled in different ways. The iESM project attempts to resolve consistency issues between GCAM and CESM through iteratively running the coupled model until consistency is achieved. In Lemmen's system and the MML, there is no overlap in the phenomena modeled by different components, so no inconsistencies are possible.

Plug-and-Play with Common APIs and Middleware: The advantages of tight coupling and well-defined scope and scale of single model approaches are also their greatest limitations. Human systems and the Earth system are diverse, complex, and multi-scalar. By design, unitary modeling approaches can only represent a predefined subset of potentially important phenomena and only at a single scale without significant recoding of model processes, information passing (and filtering, if relevant) routines, rescaling routines, and even data structures. An alternative approach to coupling is to focus on defining common APIs and sophisticated middleware that would allow any model that conforms to a set of coding standards to be coupled with any other model that conforms to the same standards. The CSDMS has invested considerable resources in developing this approach for Earth system models. It should be noted that even CESM has a "flux coupler" middleware and the MML has the KIB. But, the goal of the CSDMS efforts go beyond these to develop generic modeling coupling approaches that could allow many different models to be plugged together to study coupled human and Earth systems in diverse dimensions and scales.

That said, even if different models conform to a common API standard, the plug-and-play approach to model coupling must still resolve issues of temporal and spatial rescaling, variation across the stochastic/deterministic continuum andpotentials for consistency problems when two different models represent the same phenomenon. There will still be the potential for feedbacks between models to introduce unexpected instabilities. While such instabilities could be informative, they can also cause model representations to deviate far from reality. Hence, while common API standards could be developed—and probably are a good way forward—middleware to couple human and Earth system models will need to deal with rescaling, consistency, and stochasticity/determinism on a case-by-case basis.

Taking it Forward: Overall, while developing algorithms to better rescale and integrate outputs of human systems models and Earth systems models was considered to be an essential development step, the general consensus was that evidence from existing coupled modeling projects suggest it would be valuable to create modeling frameworks that could represent bi-directional feedbacks between human systems and the Earth system. Multiple initiatives already in progress could be leveraged to create proof-of-concept for the returns for science and policy of integrating models of human systems and the Earth system, and also provide testbeds for developing solutions to the coupling issues described above, as well as others not discussed. The fact that in-progress initiatives are taking place at multiple scales is a valuable asset for these objectives. The iESM project (PNNL and collaborators) is not currently funded, but new work could build on that code. There is also a new Social Dimensions Working Group for CESM that could also help guide and accelerate tests of modeling integrated systems at global scales. Breakout participants Carsten Lemmen, Jed Kaplan, and Peter Verberg are all working at regional scales in Europe and could help guide model coupling tests at that scale. The MedLanD project's MML operates at local scales and could also serve as a proof-of-concept project at that scale.

All of these ongoing efforts are best thought of as effectively *tight coupling/unitary modeling* approaches. The CSDMS, however, has committed significant resources to the development of API standards and middleware that could provide the framework for creating a more flexible *plug-and-play* approach. So far, the CSDMS has focused almost exclusively on coupling different kinds of Earth system models, but its cooperative agreement with CoMSES Net (Network for Computational Modeling in Social and Ecological Sciences) and CSDMS' new Human Dimensions Focus Research Group offer the possibility of applying CSDMS technologies to human systems models so that they could be integrated with Earth system models. Most CSDMS (and CoMSES Net) models operate at local to regional scales, but solving plug-and-play integration of human and Earth systems should be scalable to a global level. The group suggested that deltas-agriculture-urbanism or hydrology-water demand/use could be tractable starting places for this work.

Several participants expressed concern that, if it became too easy technically to couple different kinds of models, then some users might do so in ways that would lead to misleading or meaningless results. They suggested that we consider some form of control that would encourage or force users to carefully consider the consequences of spatial/temporal scale, parameter passing, stochasticity, consistency, and related issues when coupling models of human and Earth systems. There are potential ways to design APIs for model communication that can communicate different model requirements in this regard. However, as we know from experience, there is no way to design software that can completely prevent people from using it in inappropriate, stupid, but also innovative ways. The best way to resolve this issue is to also support better training of human and Earth system scientists, and to encourage collaborations between domain experts in different fields.

Related to the importance of interdisciplinary collaboration for successful integration of human and Earth systems modeling, several participants noted that it is currently not a level playing field. There are many more resources and, hence, active modeling efforts in the Earth sciences than in human systems science. Some of the participants have encountered Earth science modeling groups that seem to only want to add human systems as a required, but insignificant appendage to large biophysical models. Thus, Earth system scientists need to work closely with human system scientists to understand the kinds of information needed and the kinds of information that can be provided by models of human systems. Moreover, the most scientifically and socially valuable results of integrated modeling require that both Earth system models and human systems models be modified and enhanced to work together. The collaborative model development that this entails involves social interactions, two-way communications, and mutual respect for needed domain knowledge as well as technical solutions. In this regard, there need to be scientific, professional, and policy incentives for <u>all</u> members of the interdisciplinary teams needed to develop successful integrated modeling. In this respect, another dimension that was not discussed, but also important is the value of both Earth and human systems scientists working with members of the computer science community, particularly those with expertise in modeling and simulation, informatics, and cyber infrastructure.

Finally, participants felt that the discussion, and comparison of ongoing projects that are coupling models of human and Earth systems was of significance, not just for themselves, but also potentially for the wider scientific community. For this reason, the participants are planning to write a joint paper for a major scientific journal outlining challenges and potential returns of integrated modeling of human and Earth systems.

4. Extreme events and migration (Chair, Arneth): Extreme events (either social or biophysical) can trigger major LUC decisions and affect the vulnerability and resilience of societies. Past extreme events triggered by climate change or other natural or social stresses have been demonstrated to have had considerable consequences for human and biophysical systems. An initial goal in modeling extremes could be to explore the effects of biophysical and social extreme events on agricultural responses to climate variability. In doing this, consideration of both the level of complexity and uncertainty is important. There is also a need to differentiate between extreme events, probabilities and surprises. For example, there was little or no probability of the breakup of the Soviet Union, which came as a complete surprise. We also need to address a number of factors associated with the nature of extreme events themselves and how to model them. This includes deep uncertainty (i.e. unknown processes/drivers of change), scenarios versus process models of extreme events, variability versus state-change, rates of change (including intensity, duration and frequency), social institutions helping or hindering resilience and the role of influential outlier agents (people) leading to constructive or destructive amplification

Comment [MOU4]: Need to spell out the first time an acronym is introduced. LUC=Land-use/Land-cover? Or something else?

Population migration: Demographic feedbacks are currently hard-wired into scenarios. But, if we are going to simulate a human dominated world, we need to know where people are located and how they move around. We also know that modeling feedbacks can drastically change outcomes. Issues of importance here include the dynamic nature of cultures and their effects on decision making, gender issues, and the use of coupled models to understand whether/when human migration is adaptation. The key questions include, how large of a climate change induced migration is plausible? What are the impacts of migration on ecosystems, agriculture, etc.? Do we need novel prognostic models of population or are dynamic demographic models needed or important? What can we learn from the past? Will the past help us to understand the drivers of migration and the effects of migration on society and natural system feedbacks? There are numerous examples from the past of how social unrest and wars have been triggered by inequality and have led to migration. We can also speculate about how future changes in obesity, malnourishment and changing mortality rates might affect population movements.

Scoping/Issues: What is an extreme event in a socio-economic-natural system? We need to address both natural events and human-induced events, as well as exploring the effects of cascading events, i.e. where one event leads to another. What are the timescales of events and how does cultural memory affect this? What are risks/disasters - expected versus unexpected risks? For example, what is the impact of climate change on agriculture over different timescales? Who is responding and how? Are those responding individuals or groups? Do droughts in livestock agricultural systems lead to increased migration and re-greening of pastures? What do we understand about rural to urban migration? Overall, we need to understanding how/when extreme events and surprises fundamentally change coupled systems as well as understanding the sensitivity of the system to shocks. Can environmental change plausibly drive large-scale migration? If yes, then how can we scale-up these processes from the local/national level to econometric modeling at global scale levels?

Methods: Methods should address emergent properties that happen after thresholds are crossed, and drivers that occur in human/natural systems, but are not currently modeled. As part of this we need to decide what to internalize in a model and what to treat exogenously through scenarios. The impact of an asteroid (as a shock event) should clearly be treated as an exogenous force, but what of other potential shock drivers, e.g. economic collapse, geopolitical change, …? We also need to take advantage of large amounts of local data from case studies. Such cases could be the basis for an extreme events meta-analysis, as well as helping us to embrace the Big data community. Overall, however, we will need to design new research methods to address the impacts of extreme events.

Taking it Forward for migration: There is a lot of current work on migration, so how can we better interact with the migration/hazards/risk community? Are there existing funded research efforts on climate induced migration? Large scale migration has been occurring in delta urban regions, but can we model this? What are the potential consequence of sea level rise for the coastal population? What are the important aspects that are not currently modeled? For example, what is the role of gender issues in forced or economically induced migration? Modeling efforts that may be useful in addressing these questions include the NCAR/CSM climate induced migration project. The UMich Ryan Kellogg residential location choice model with climate, and the EPA model. There are also lots of case studies with modeling such as demonstrated at the Migration Modeling workshop on climate & migration (France, Dec 2016), the CESM Social Dimensions Working Group linking physical and social science in ESMs, Future Earth, which has 8 pilot projects such as the pilot Urban Extreme events from climate to society and the ABM/IAM EMF Snowmass meeting. Possible funding for research in this field includes NSF (CNH has a RCN track), the Belmont forum, and SESNYC synthesis.

5. Decisions, Behaviors, and Institutional Change (Chair, Janssen): A set of issues emerged around the modeling of processes, such as how to include feedbacks and human decisions/needs in ESM models; how to deal with complexity, that is, the community of modelers is not able to capture global scale complexity at the moment. A need was identified to build models that are simpler to test, with a simple logic and which can be nested and up-scaled from the local to the global. There are also issues of scaling in outcome measures and other scaling issues such as temperature being smooth while irrigation falls along gradients. There are also issues of experimental and scenario testing quality.

There are also issues concerning the science and theory of decision making. This includes the challenges associated with, for example, the heterogeneity among agents, but also the need to accommodate Keystone Actors. Keystone Actors represent an agent type that functions in a particular way, has a disproportionate impact on a system (relative to their numbers), and that may or may not yet be represented theoretically. We also need to identify what are the other key behaviors besides 'rationality' in agents. There are many large-scale actors that are not influenced by nations (nongovernmental actors) for example. Traditional social science models may be outdated due in part to the limitation of theory. Furthermore, there is the problem that documentation of behavioral processes may be lacking as well as a lack of quantitative data more generally (this is changing, but not yet at the level of Earth sciences). Finally, we need to address how to build capacity in the social sciences and how to break down the old schisms between, e.g. human and physical geographers.

Issues (Methods): A series of general methodological issues emerged and include the need to first identify where disconnects are between different communities. There is a qualitative understanding of human processes, but is there a way of bridging the gap to models by having ES modelers say "here is a problem we want to understand, what are the relevant human systems"? This could perhaps be achieved by identifying the relevant human or physical processes and scales of processes in linked research questions. Second, how to connect input to outputs? Do the results make sense, given the input data (e.g. population data sets at multiple scales)? How to get around the disconnect between the social science communities and the physical world? Once we identify this, we may come to understand what is missing. Third, conduct a meta-analysis of social survey work, rules, actors, important ecosystem processes, as a part of project. For example, there is a need for information about how to optimize for prestige, risk-avoidance, maximization of economic returns, and changes to all of these.

Regarding modeling itself, emerging ideas included developing a human dimensions 'module'; potentially an agency module, and; develop infrastructure to link the social science and ESM communities: Michael Barton is actively seeking funding to build such an infrastructure. Do we need an NCAR for Social Science? Should there be a Standardized classification scheme for agents? Should we encourage people who are willing to rewrite their code to match social science models (if the idea is to build upon what is there, rather than starting from the ground up)? A possible model for this is to identify what is relevant for ESMs that impacts/reflects on human decision making, e.g. Land use and land cover change. We would then need to explore the human decisions around these themes that go into ESMs, and what are the questions that social scientists are interested in?

Taking this forward: We need to explore the different formulations of decision making and the different goals of actors within our models. For this, we need different groups of people doing the testing. We could develop decision making modules that plug and play to support model comparison (e.g. fishery to pastoralism livelihoods). We might develop a COMMUNITY framework to inform the construction of a model that scales from individual agency and behavioral types. But, we should certainly attempt to build capacity in early career social science students to do modeling. This would require funding for the development of interdisciplinary models and the training of modelers.

Vital questions remain. How important are the spatial configurations of the individual factors included in the model? How do we match input variables to the question? What direction is energy transferred in the models including edge effects and micro-climates. In Global Models change is typically located in particular regions, i.e. biomes. The basic rules in the Global Scale Human models (e.g. economic) are fundamentally flawed. We need to ask instead, what are the mechanisms occurring at each scale that are producing the outcomes that we observe? Governance occurs at many levels: how does it influence the outcome? How do you include the impacts of governance across scale levels (both spatially and temporally)? What are the ecological influences that are meaningful to the population/agents we want to include? What is the lag time for policy uptake and influence? When do we assume rational agents? When does rationality hold true, when does it not? What are the assumptions behind our choices of modeling about the rationality of our agents? Rationalism and optimism are under the same umbrella; how to write algorithms…what are you trying to optimize? What are the decision-making algorithms? What are the tradeoffs? When do we assume policy suggestions (or policy in general) makes a difference? How do we translate these behavioral mechanisms and social norms into modeling code? How do we incorporate barriers to behavior in our models? A critical constraint is how to link those who collect data to those who run the models? Would it be simpler to start with rural planning rather than urban planning?

Needs Identified: We need to identify what social dynamics are currently NOT included in land use models. We also need to identify and classify human-natural system interactions and feedbacks. For example, ESMs have delivered output, but they do not currently capture interactions. Can we identify a human decision-making process that determines how the natural system responds? Should there be basic training of Earth system modelers in understanding the human decision making process in order to produce models that are useful for policy application (e.g. for adaptation, resilience and capacity building in vulnerable communities). There is a need to better understand one another's languages to improve communication, as well as more respect between Earth system modelers and the human systems communities.

6. Multi-scalar, impact assessment methods (Chair, Lawrence): Impact assessment is important in order to explore, holistically, a wide range of the effects of global environmental change. From an ESM perspective impact assessment is done very simply, with a limited number of variables. Assessment is based primarily on the outcomes of physical models (e.g. of the climate system) being applied to sectors (usually one sector at a time without consideration of the effects of cross-sectoral interactions or indirect impacts). We need to move away from these rather simplistic approaches to explore impacts on people, societies and their well-being. This requires more insight into, and definition of, the concept of well-being, and the identification of appropriate metrics to assess it. Impact assessment also needs to address scale and extent issues, identify the key processes of interest, explore connectivity across spatial and temporal scales and processes and understand cascading effects across scales.

Scoping: There are a number of critical issues that need to be addressed to advance impact assessment methods. Uncertainty in ESMs is important, but so to is the effect of this uncertainty for human impact models and the propagation of errors in coupled systems. There may be a need for alternative modeling approaches, compared with what we have now to deal with the uncertainty propagation issue. But, we also need to be confident that we are able to evaluate the success/utility of human system impact models. This includes how we address aspects such as risk, vulnerability, exposure, feedbacks, the limits to aggregation and temporal lags.

Solutions: Capacity building through training is paramount. This will ensure that teams of experts include the right people from the outset, i.e. people who understand model limitations, the role of stakeholders and who can identify proper data, models and variables. This would be facilitated by the creation of networks of experts that use a common language to support communication. It would be useful to foster such networks by developing guidelines to establish appropriate problem statements, as well as identifying the right people and methods. This would contribute to the further development of impact assessment methods. In this respect there is a need to do much more integrated Impact, Adaptation and Vulnerability (IAV) assessment that considers interactions across sectors for multiple drivers, i.e. moving away from the single sector/scale/driver approach that is current at present, to multi-sector/scale/driver assessments. This might be facilitated by, for example, replacing the current IPCC process with a problem-driven assessment. Hence, do we need a National Academy Panel to evaluate frameworks and priorities for coupled human natural systems? This could be useful in identifying and removing barriers to integrated, human-natural system science. It could also help to define the highest priorities for assessment, e.g. existential threats to society, ecosystems and the physical climate.

7. Model evaluation (Chair, Hill): A long-term goal (after 10 years) is for a new generation of models that reproduce human systems at least as well as we currently reproduce vegetation dynamics. Such models would make human decision-making visible and useful in evaluating, for example, whether policy measures have the desired outcomes. Thus, these models would support the translation of research into practice. An important step in advancing methods to evaluate human system models is to collate datasets on human dimension research. This could help to parametrize, but also to test the role of prices/wages, economic structures, technological development, psychology (preferences traits) and social structures.

Human system model evaluation should employ idealized experiments and scenarios, test against observational data quantitatively, and develop and use appropriate testing metrics. We also need to ensure that models work properly/as expected (verification), and accredit models that do, i.e. guarantee that the models work correctly. Model validation and testing also needs to consider input validation, as well as output validation and to use sensitivity analysis to test whether a result is achieved for the right reason. Since we are at such an early stage of human system modeling, we should do whatever we can just to incite people to become involved and try out their own approaches to model evaluation.

Summary

A number of lessons learned emerged from the workshop discussions, including:

1. It is important to understand more about the role of the heterogeneity of decision-making actors and the role of behavioral mechanisms that underpin decision making.
2. Social system models need to represent a wider range of social processes than they do now, e.g. social interaction, power and control, cooperation/communication, competition, and social learning.
3. Keystone actors can sometimes be very important in understanding human-environment systems. Other times they have limited impact. Can we understand the contexts that lead to these differences?
4. How can studies of the past (e.g. land use change) benefit, but also support, modelling of Earth system change in the future?

5. There is a need to endogenize institutions within social system models, especially as one up-scales models from the local to global.
6. Inconsistency in baseline input data, including thematic definitions, is an important limitation to modeling. This underscores the need for quantitative meta-analyses of human systems case studies of phenenomena like power, learning, decision-making by and among individuals, institutions, and governance structures.
7. There needs to be open discussion among human and earth systems scientists around issues of complexity and its representation versus simplicity in models, and when it is and is not useful to couple models with different modeling approaches.
8. Understanding the sensitivity of biophysical models to human processes such as land management, and vice versa, is critical in supporting the development of the next generation of coupled human-environment models.

Next steps

Actions. A number of actions were identified for further development, including writing a white paper that outlines a comprehensive plan to take the community forward, writing papers on issues related to modling human and earth systems, organizing follow-up US and international meetings/workshops, establishing branding and communications plans, and exploring funding opportunities for the network.

It was agreed that one US follow-up meeting should be based on the white paper, with a focus on a broader range of science presentations, including the identification of research gaps that could form the basis of a perspective paper. A possible venue for this meeting would be to hold jointly with the 2017 annual meeting of the Community Surface Dynamics Modeling System (CSDMS). Internationalisation of this meeting could be supported with funding from the NSF international office.

We have also proposed a symposium at the upcoming AGU conference in December 2016. This conference would also provide an opportunity for a sub-set of the group to: a) discuss the white paper, b) plan the agenda for the CSDMS annual meeting related workshop.

We also have international two international meetings planned. One will take place in Kyoto, Japan in September 2016, with support from Future Earth. A second is planned for 2017 in Europe.

A subset of the workshop participants has started a paper about modeling coupling methods with examples from participants. The goal is to submit this to a major journal by the end of year (contact: Derek Robinson).

Community building/identity. We agreed that the ways in which we brand and identify/communicate ourselves as a community is critical in supporting collaboration with other, existing communities. A name for the group was proposed: Computational Human and Earth System Science or Community for Human and Earth System Science (CHESS).

An initial website/wiki for the community has been set up with support from CSDMS (contact: Albert Kettner) that includes materials from this workshop, and will be expanded to also include webcast presentations, links to participant pages, links to other relevant communities, and bibliography links. In support of the CHESS identity, we will write a short summary of the workshop to be posted on the website (contact: Kimberly Rogers). This article could form the basis of a workshop report to the AGU journal (EOS) if completed within 2 months of the workshop dates.

We will also explore additional papers ideas: a Global Environmental Change editorial (CHESS community authored), a longer multi-authored, position article (perspective piece) on the issues/ways forward (it is possibly too early at present for such a paper since we need to develop the novelty and further results – wait for whiter paper outcomes). This paper should be thought-provoking, but also evidence-based. Perhaps focus on the SDG framework, which requires human dimensions research to be underpinned by better capacity building within research communities to achieve this. The paper should also discuss links with IAMs and focus on the local level in order to put individuals back into models along with associated feedbacks (the research gap need). Thus, the CHESS community needs to identify the big holes, or what we're not doing now, and provide concrete examples to resolve these gaps.

We also have the results of a short summary of the workshop participants:

https://docs.google.com/spreadsheets/d/1FD9k9_-6h86L9sYBbDmx45al3k8Pl8b9TrQYquZmxPk/edit?usp=sharing

We also identified a number of potential funding opportunities, and everyone in the CHESS community is encouraged to explore funding to support our collective aspirations (See Appendix 3).

Potential new members to include in future CHESS community activities are: Yoshiki Yamagata (http://www.cger.nies.go.jp/gcp/members.html), Navin Ramankutty (http://ires.ubc.ca/person/navin-ramankutty/) and Dale Rothman (http://www.du.edu/korbel/faculty/rothman.html).

Potential funding and endorsement opportunities. In progressing the community and its intellectual aims, we identified a number of potential funding schemes that are listed in Annex 3.

Timeline. The following was agreed for implementation of the actions discussed above:

1. Coupling paper Skype (asap) Derek
2. AGU journal (EOS) workshop report paper (within 2 months of now) - Kimberly
3. Draft report/white paper distributed for comment (30 June 2016) – Kathy, Mark, Michael
4. Video-conference to discuss white paper (1st week of August 2016) – Albert can set-up the infrastructure,
5. Final draft white paper (comments incorporated) (end September 2016) – Kathy, Mark, Michael
6. AGU sub-set meeting (December 2016) – Kimberly to follow-up on timing/rooms
7. CESM annual workshop (Feb 2017) – potential CHESS involvement
8. CSDMS annual meeting and a full CHESS meeting (May 2017)

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Annex 1: Workshop agenda

Monday 23 May (9h-17h30)

Session 1 (Kathy Galvin): Welcome and introductions (9h-10h30)

Welcome and about the workshop + Q&A, Kathy Galvin & Mark Rounsevell (20 min + 10)

Kathy: why we need to connect across global issues, e.g. SDGs, Future Earth, and social sciences processes; the need to focus on solutions; how did we get here (CSDMS etc)?

Mark: the major gaps in upscaling human decision processes (in models) to global scale levels; goals of the meeting; a walk through the agenda, and objectives of the meeting

Introduction to the participants: tour de table (10 mins)

Community Surface Dynamics Modelling System (CSDMS), Focal Research Groups (FRGs), funders, white paper, James Syvitski (5 mins)

Scene setting talk 1 (15 min): The Network for Computational Modeling for Socio-Ecological Science (CoMSES Net), Michael Barton

Scene setting talk 2 (15 min): Perspectives from Future Earth (Josh Tewkesbury via Skype)

Q&A (15 mins)

Coffee break (10h30-11h)

Session 2 (Michael Barton): where are we now? An overview of current major global modelling types (11h-12h30)

An overview of current global human dimension methods: Land use and land cover change models, Peter Verburg, GLP (15 min)

An overview of current global human dimension methods: integrated assessment models, Brian O'Neill, NCAR (15 min)

Recent developments in Digital Global Vegetation Models (DGVMs): C/N dynamics and crops yields, Almut Arneth, KIT (15 mins)

The spectrum of Earth system dynamics models, James Syvitski (15 min)

Panel discussion: what we do well now and what could we do better? (30 mins)

Lunch (12h30-14h)

Session 3 (Mark Rounsevell): where are we now? Examples of specific modelling approaches (14h-15h15)

Agent-Based Modelling of rural and urban land systems at the landscape scale, Dan Brown (15 min)

The human dimensions of reconstructing past land use and land cover change, Jed Kaplan (15 min)

Global scale agricultural systems: the role of diet, trade and food waste, Peter Alexander (15 min)

Panel discussion: what do we do well now and what could we do better? (30 mins).

Coffee break (15h15-15h45)

Session 4 (Kathy Galvin): where are we heading? (15h45-17h30)

How can social science methods and models and methods be scaled to global levels, Marco Janssen (15 min)

Extending ABM approaches to national and continental scales, Mark Rounsevell (15 mins)

Massive Agent-Based Models, Rob Axtel (15 mins)

Panel discussion: what can we learn from these and other approaches? (30 mins)

General discussion: What have we learned from the day so far? (30 mins)

Tuesday 24 May (9h-17h30)

Session 1 (Mark) Identifying key issues/questions (9h-10h30)

Recap and introduction to the day (15 mins), Kathy, Mark

Facilitated session on emerging issues/questions for discussion: collecting ideas, clustering and prioritizing these and planning the subsequent breakout sessions (75 mins)

Some possible issues/questions include:

1. Coarse-graining/scaling social processes to tractable scales for global modelling. What ARE tractable scales? Maybe they are not so coarse.
2. What aspects of human systems give the most ROI to start with? What are the low hanging fruit? Possibilities include land use and its impact on land cover, GHG emissions, energy use, water use, health and epidemiology. What about economic markets? These are generally treated at national or supranational scales. Is there a benefit to downscaling this to 1 degree or less? Not sure.
3. To what extent do we want to model human systems components as emergent properties that respond to ESMs vs. researcher-specified parameters to set up and run experiments of different socio-ecological scenarios?
4. What modelling frameworks/"formalisms" are most useful for integrating with ESMs? My guess is CA of some kind. Are there other candidates? Should mobile agents be considered, at least for some things? Stick with a single global

framework or integrated different ones for different aspects of human systems (e.g., like atmosphere, land, ocean models)?

5. How can human systems models be coupled with earth systems models? Currently, there are some human systems components embedded into the land models of ESMs. But these are generally static. Should they be pulled out and moved to a HSM? Can we have couplers (or APIs) that allow a community human systems model (CHSM) be coupled to different ESMs like CESM, ACME, Hadley, etc?
6. How best can we represent social processes in models that emerge from individual behaviour and choices?

Coffee break (10h30-11h)

Session 2 Discussion of key issues/questions (11h-12h30)

Break out groups on 3 key issues/questions (chairs to be nominated in Session 1) (75 mins)

Group report backs (max 5 mins each group)

Lunch (12h30-14h)

Session 3 Discussion of key issues/questions (14h-15h30)

Break out groups on a further 3 key issues/questions (chairs to be nominated in Session 1)

Group report backs (max 5 mins each group)

Coffee break (15h30-16h)

Session 4 Outcomes of discussions on key issues/questions

Further breakout sessions with report back (if needed), and general discussion on outcomes and setting research priorities

Weds 25 May (9h-12h30)

Session 1 (Michael) Developing a research plan, the distributed network and the timetable (9h-10h30)

What we need, e.g. resources, person power, infrastructure, meetings. What kind of social/technical infrastructure is needed to develop and maintain a CHSM? Some things might include: versioning server(s), software engineering, organization to vet code and decide what does and does not get into CHSM, organization to oversee integration with ESMs and decide which experiments are run

Financing: what do we have now? What do we need in the future? What are the funding sources?

Establishing a network of researchers (communication and interaction)

Coffee break (10h30-11h)

Session 2 (Kathy/Mark) Planning continued with wrap-up and actions (11h-12h30)

Discussion on BC21 and CSDMS 3

The research plan and timetable

Actions: who does what and when?

Close of workshop

Lunch and depart (from 12h30)

Annex 2: Participant list & contact details

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Annex 3. Potential funding and endorsement sources

1. CSDMS3 (logistical support, meeting/workshop support, software design…) – need to contribute to funding proposal
2. Future Earth (KANs, AIMES, GLP, iLEAPS, …)
3. NSF programmes, e.g. joint US-UK grants
4. NSF STC (Science and Technology Centre) (potential for a human dimensions part, physically located, as part of a broader CSDMS proposal), 10 years max (up to $50m)
5. NSF RCN (Research Coordination Network) – CNH track possible (dynamics of Coupled Natural Human systems)
6. National Institute of Health (NIH) - Office of behavioural and social science research (under NIH)
7. USDA – unique calls on food security, including the need for international collaboration
8. COST Actions – networking grants within the EU (meetings, database development, infrastructure, synthesis)
9. European Commission Horizon2020 – consortia research grants (call-based)
10. European Commission Framework 7 grants (on-going, potential funding for workshops, supporting webinars)
11. European Research Council (ERC) – individual starter, consolidator and advanced grants with international collaboration (fundamental research €1.5-2M)
12. European National research councils (UK, Germany, Netherlands, etc)
13. Belmont Forum grants
14. Rockefeller Brothers Foundation (www.rockefellerfoundation.org/our-work/initiatives)
15. Hoover Foundation; Sloan Foundation (urban); Hewlett Foundation; Clinton Foundation (environmental degradation); Gordon Moore Foundation (Conservation International) – need to be focused on Foundation aims
16. Wellcome Trust call – European and global challenges (environment and Health) - https://wellcome.ac.uk/funding/europe-and-global-challenges
17. International Social Science Council – global reach (no national limitations), e.g. social transformations call, and human-environment interactions
18. Global Carbon project (outreach to non-North American/European researchers)
19. Graduate students, Masters, PhDs, … - NRT funding for groups of grad students
20. Student winter/summer School's (Marco's, Peyresq, …)