

**The Global land Project Nodal Office on
Integration and Modelling, Aberdeen, UK**



GLP Workshop on

**'The design of integrative models of natural and social
systems in land change science'
28 Feb – 02 March 2008**

Programme and Pre-Workshop Input





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GLP Workshop on

'The design of integrative models of natural and social systems in land change science'

Programme

Wednesday 27/02/08 Arrival

Thursday 28/02/08 Field Trip - Drivers of land use in Tarland and surrounding area.

08:45	Depart Norwood Hall in small coach Travel out of Aberdeen to Ballater then onto South Deeside road
10.00	Arrive at Royal Lochnagar Distillery for visit hosted by Stewart Adamson and Donald Renwick Coffee Welcome and brief history of whisky distilling in Scotland (15 mins)
10.20	Tour of distillery What is used to make malt whisky and how do different whiskies acquire their distinctive appearance and tastes?..... "Peat, barley, oak casks, sherry and bourbon....time and angels!"
11.20	"Nosing and Tasting" session A tour of Scottish whiskies through sensory evaluation including a discussion of the historical links between people, land use, raw material supplies and the whisky industry in different parts of Scotland.
12.00	Open discussion and visit to distillery shop
12.30	Depart Royal Lochnagar Distillery Travel to Crathie and back to Ballater on main road
13.00	Lunch in the Commercial Hotel Tarland Followed by short presentation by Simon Power
14.00	The MacRobert Estate at Tarland (visit hosted by Simon Power) Land use changes in rural Scotland from the perspective of a Deeside estate - A short history of the estate and feudal system - Contemporary issues and approaches (visits to environmental schemes) - Looking forward: challenges for the future
16.00	Reflections and summary of the day
16.30	End visit
17.30	Arrive back in Aberdeen
20.00	Dinner at The Olive Tree, Queen Street

Friday 29/02/08

8.15	Pick-up from Norwood Hall to The Macaulay Institute	
9.00	Introductions, welcome and overview of the workshop aims and objectives	Eleanor Milne
Session 1. What are we trying to model?		Chair – Eleanor Milne
9.30	Integration through modelling for the Global Land Project	Richard Aspinall
10.00	Linking landscape patterns with ecological and social processes	Dan Brown
10.30	Coffee break	
11.00	Developing integrative models using spatial and regional economic models and methods	Elena Irwin
11.30	Group discussion and plans for break – out sessions in the afternoon.	
12.30	Lunch	
13.30	<p>Break out discussion sessions for Session 1.</p> <p><i>1.1 The goal of the Global Land Project is to measure, model and understand the coupled human-environmental system as a whole. In a modelling context how should this differ from previous initiatives which considered land use and land cover change only?</i></p> <p><i>1.2 What should we be working towards for full integration?</i></p> <p><i>1.3 Emergence; how important is it and how do we deal with it?</i></p>	
15.00	Coffee break	
15.30	How the biophysical mitigation potentials from ecosystem / land surface models are used to assess economic potential (with economic models) at different future carbon prices	Pete Smith
17.00	Transport back to Norwood Hall	
19.00	Workshop dinner at Norwood Hall	

Saturday 01/02/08

8.15	Pick-up from Norwood Hall to The Macaulay Institute	
9.00	Reports from Friday PM group discussions	
Session 2. Which modelling approaches should we take and why?		Chair - Colin Polsky
9.45	Conceptual strengths of ABM/LUCC models as integrative tools	Dawn Parker
10.15	MAS as a component of integrated modelling systems	Thomas Berger
10.45	Coffee break	
11.15	Break out discussion sessions for Session 2 <i>2.1 Should we go beyond model purpose dictating model structure?</i> <i>2.2 How do we represent a multi-scale/multi-structure approach in an integrated model?</i> <i>2.3 What are the pros and cons of taking a framework approach?</i>	
12.30	Lunch	
13.30	Continue break out discussions for Session 2	
14.30	Feedback from groups	
15.30	Coffee break	
Session 3. What should the design of an effective integrated model include?		Chair - Peter Verburg
16.00	Integrated socio-ecological models in land systems research: combining agent-based with stock-flow approaches in a participatory process on the municipal level	Helmut Haberl
16.30	Towards a new generation of integrated land system models – a review of modelling approaches	Rüdiger Schaldach
17.30	Transport to Norwood Hall	
19.30	Dinner at the Stage Door, City Centre	

Sunday 02/02/08

8.15	Pick-up from Norwood Hall to The Macaulay Institute	
9.00	Recap of Session 3 from previous day	Richard Aspinall
9.20	Break out discussions for Session 3. and setting of a Research Agenda <i>3.1 What characteristics are required for an integrated model?</i> <i>3.2 When does 'coupling' or 'linkage' stop and integration begin? Do we need a formal definition for integration?</i> <i>3.3 How do we identify and model feedbacks?</i> <i>3.4 Should complexity in all subsystems of an integrated model be comparable?</i>	
11.00	Coffee break	
11.30	Report back from groups	
12.30	Lunch	
13.30	Publications / Next Steps	
15.00	Coffee break	
15.30	Publications/Next steps	
16.30	Transport back to Norwood Hall	
19.30	Dinner at Howies, Chapel St., Aberdeen	

Monday 03/02/08 Departure

Abstracts Session 1.

Integration through modelling for the Global Land Project

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Presentation at GLP Workshop on “The Design of Integrative Models of Natural and Social Systems in Land-Change Science” Session 1.

Abstract

Models provide an important capability for understanding and projecting changes in land systems. The Global Land Project seeks to integrate the dynamic interactions of human and environment systems to assess vulnerability, resilience and adaptation towards sustainable land systems. This talk identifies some challenges for developing integrated models and provides a suite of possible design criteria for models of land systems. . These include developing models that are effective in satisfying both scientific and policy goals, and that have an ability to represent the spatial, temporal and process dynamics of both human and natural systems, and the interaction of these systems, in order to describe, explain, and predict change and its consequences. A capacity for adaptation may also be valuable to represent and detect change in the importance of underlying drivers. Finally, I argue that integration will benefit from recasting the driving factors used in land change science as processes.

Linking Landscape Patterns with Ecological and Social Processes

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Presentation at GLP Workshop on “The Design of Integrative Models of Natural and Social Systems in Land-Change Science” Session 1.

Abstract

Patterns on the land affect ecological and human well-being, and structure the adaptive capacity of communities and ecosystems to environmental change. Understanding the relationships between land-change patterns and the ecological and social processes with which they interact is critical, therefore, to understanding and responding to the consequences of environmental change. This talk will consider the role and relative merits of models of various types in linking patterns and processes in land-change science. Consideration is given to productively defining pattern and process, developing formal links between them, and approaches to testing their interactions. Models of land change can take a wide range of forms, trading off such characteristics as spatial detail, temporal specificity or process fidelity in service of multiple objectives that include forecasting, process understanding, and integrated assessment. Spatially aggregate models are useful for characterizing and projecting dynamics in land-use or land-cover quantities; data-based spatial models covering long temporal intervals are useful for projecting; and system dynamics models are useful for understanding interacting system dynamics. Cellular automata and agent-based simulations provide flexible platforms that can balance these demands, but pose empirical and scaling challenges. The issues presented pose to the land-change community the trade-offs we face in the context of modeling land change for regional and global-scale assessment and analysis.

Developing integrative models using spatial and regional economic models and methods

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Presentation at GLP Workshop on “The Design of Integrative Models of Natural and Social Systems in Land-Change Science” Session 1.

Abstract

This presentation reviews economic location and land use theories and spatial economic modeling methods in light of their usefulness in developing integrated models of human and natural systems. Traditional economic models of location and land use are elegant, but limited in their usefulness for developing models in which multiple forms of spatial heterogeneity are important. Theories of individual household and firm behavior can account for key sources of agent and spatial heterogeneity, but are limited in their ability to describe spatially-explicit outcomes. Empirical methods and data analysis tools, including geographic information systems and spatial econometrics, are extremely useful for model development. Spatial correlation analysis and landscape metrics are critical for describing observed spatial heterogeneity and patterns, which is important for model validation; spatial econometric modeling is essential for uncovering causal relationships among spatial variables. However, empirical analysis alone does not provide a full description of the system dynamics over time and space and can be limited in other ways. For example, estimated parameter values may not accurately capture important sources of heterogeneity across different types of agents or structural changes over time. Thus, while statistical modeling of land use outcomes can be very useful in uncovering spatial relationships and testing specific causal effects, empirical analysis should be used in conjunction with dynamic, process-based models. This underscores the importance of primary data on agent preferences, behaviors and decisionmaking processes.

How the biophysical mitigation potentials from ecosystem / land surface models are used to assess economic potential (with economic models) at different future carbon prices

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Presentation at GLP Workshop on “The Design of Integrative Models of Natural and Social Systems in Land-Change Science” Session 1.

Abstract

Agricultural lands occupy about 40-50% of the Earth’s land surface. Considering all gases, the global technical mitigation potential from agriculture (excluding fossil fuel offsets from biomass) by 2030 is estimated to be ~5500-6000 Mt CO₂-eq. yr⁻¹. Economic potentials are estimated to be 1500-1600, 2500-2700, and 4000-4300 Mt CO₂-eq. yr⁻¹ at carbon prices of up to 20, 50 and 100 US\$ t CO₂-eq.⁻¹, respectively.

About 70% of the potential lies in non-OECD/EIT countries, 20% in OECD countries and 10% for EIT countries. In addition, agriculture can supply feed-stocks for bio-energy.

The economic mitigation potential for agricultural bio-energy in 2030 is estimated to be 70-1260, 560-2320 and 2720 Mt CO₂-eq. yr⁻¹ at prices up to 20, 50 and above 100 USD t CO₂-eq.⁻¹, respectively.

These potentials represent mitigation of 5-90% of all other agricultural mitigation measures combined. An additional mitigation of 770 Mt CO₂-eq. yr⁻¹ could be achieved by 2030 by improved energy efficiency in agriculture.

This talk will focus on how results from ecosystem / land surface models can be used to drive uncoupled economic models. Results will be compared to estimates from Integrated Assessment Models.

Abstracts Session 2.

Conceptual strengths of ABM/LUCC models as integrative tools

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Presentation at GLP Workshop on “The Design of Integrative Models of Natural and Social Systems in Land-Change Science” Session 2.

Abstract

Agent-based models of land-use and land-cover change have often been developed with the express purpose of integrating the drivers of land manager decisions with their biophysical consequences. Several previously identified factors that favor ABM as a tool for integration include the ability of ABM to operate at the scale of LUCC decision making, and thus the opportunity to link local LUCC decisions to spatially explicit biophysical models through spatial identifiers; representation of diverse agent types; and representation of agent-and-environmental heterogeneity. ABM/LUCC were also viewed as a means of both knowledge discovery and knowledge synthesis, through the process of model building (potentially including stakeholder participation) and through analysis of model results. As the field has matured, these general conceptual advantages can be articulated more concretely through examples of successful completed projects and ongoing work. I will present several examples that illustrate how ABM can be used to explore the drivers of land-use change and land manager behavior, how both factors interact to affect land cover and ecosystem services, and how the heterogeneity of land manager resources, demographic profiles, and individual characteristics may affect environmental outcomes. I will also discuss the role that qualitative analysis can play in model development, drawing on ongoing work in Uganda with Berger and colleagues. Finally, I stress that integrative agent-based models are almost always hybrid models that draw on many other standard LUCC modeling tools (statistics, cellular automata, mathematical programming), and thus are beginning to be viewed as an integrative simulation modeling framework, rather than a distinct modeling method that is a pure substitute for other methods.

MAS as Component of Integrated Modeling Systems

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Presentation at GLP Workshop on “The Design of Integrative Models of Natural and Social Systems in Land-Change Science” Session 2.

Abstract

Multi-Agent Systems applied to land-use modeling (MAS/LUCC) are highly suitable for integration into larger modeling systems. MAS/LUCC are implemented at fine resolution in a spatially explicit manner, typically based on raster cellular component. This cellular component could then be used as an interface to biophysical software, for example hydrology or crop growth models.

The challenge of integrating various model components is, of course, not only relevant for land system modeling, but also for numerous business applications. Computer science and software engineering have therefore developed methods and tools that help to achieve model integration and linking, at a manageable cost. Some of these methods are of potential interest to land system modeling, for example object-oriented concepts, component-oriented programming and software frameworks. Several research groups in Europe have started developing integrated modeling frameworks for the environmental and agricultural sciences, e.g. OpenMI for the coupling of hydrology simulation models and SeamFrame for the coupling of agricultural simulation models.

In Hohenheim we have successfully coupled the agent-based agro-economic software MP-MAS and the spatially distributed hydrology software WASIM-ETH. A component-based approach for data transfer between model components was chosen, using the software TDT, which was developed at the Potsdam Institute for Climate Impact Research. Currently, the integrated modeling system is submitted to extensive empirical testing, as part of the project “Integrating Governance and Modeling” within the CGIAR Challenge Program on Water and Food.

Abstracts Session 3.

Integrated socio-ecological models in land systems research: combining agent-based with stock-flow approaches in a participatory process on the municipal level

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Presentation at GLP Workshop on “The Design of Integrative Models of Natural and Social Systems in Land-Change Science” Session 3.

Abstract

The development of integrated models capable of simulating socio-economic processes, land use and socio-ecological material and substance flows is crucial for analysis of feedbacks between societal and natural drivers and patterns and trajectories in integrated socio-ecological systems. Here we present results from a project in which such a model was developed for a local (municipal) system in a participative process lasting over two years. We use this project as a case study for discussing the questions posed in Session 3 of the workshop. The project refers to the municipality of Reichraming in the Long-Term Socio-Ecological Research (LTSER) platform Eisenwurzen, in the Austrian Alps. The region has a longstanding history of metal mining. Around 400 years ago, the region produced ~ 15% of Europe’s total iron. In pre-fossil-fuel times there was a heavy draw on the region’s forests for fuel and agricultural land. Since the advent of large-scale coal use, railways and industrialized metal smelting, most mines have been abandoned and metal smelting is now concentrated in industrial centres at the fringes or outside the region. Most of the Eisenwurzen is of marginal agricultural productivity and is subjected to intensive forest re-growth. The region experiences the typical problems of marginalized rural areas. Reichraming is a mountainous municipality with over 80 % of forest cover, much of which is managed by Austria’s state owned forest administration.

The aim of the project was to develop an integrated model that was intended to serve scientific purposes and support local stakeholders in vision-finding and strategic orientation. The scientific objectives were to simulate (1) decisions and activities of relevant actors such as farmsteads, households, the national park, the forest administration, the municipality and private enterprises, (2) the development of land use for grassland agriculture, settlement, and forestry and (3) carbon and nitrogen stocks and flows in both socioeconomic and ecological systems. From a stakeholder perspective, the model was expected to be able to simulate future scenarios depending on changes in external framework conditions as well as on internal decisions. Consequently the model now simulates socioeconomic as well as socio-ecological/ecological patterns and processes. Outputs include indicators of overall land-use change, GHG emissions and the aggregated C or N balance. With respect to scales, the model integrates the level of individual or aggregated actors, individual

parcels of land and the terrestrial ecosystems that they support and system-level patterns and processes emerging from the interactions between these individual units.

Interactions between social, economic and ecological aspects were at the core of model development from its inception. All three of the model's modules – actors, land use/cover and substance flows – include social, ecological and economic parameters, so the model is not an “addition” of models that have to be “coupled” in a second step.

Towards a new generation of integrated land system models – a review of modelling approaches

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Presentation at GLP Workshop on “The Design of Integrative Models of Natural and Social Systems in Land-Change Science” Session 3.

Abstract

Processes of land-use change are the result of complex interactions between human and environmental driving factors. One approach for capturing this complexity is the analytical framework of land systems as coupled human-environment systems, a concept that is a central component of the science plan of the Global Land Project. Starting point of this presentation is a first definition of key elements that characterize integrated land system models and distinguishes them from land-use change models. Then, it is analyzed how these key elements are implemented by state-of-the-art model approaches for the regional and global scale levels. Here, the focus lies on the representation of the human and environmental sub-systems as well as on the modeling of interactions and feedback between these two components. Based on these results, further research needs for the development of a new generation of integrated land system models are identified.

The design of integrative models of natural and social systems in land change science

Pre-Workshop Input

Introduction - Eleanor Milne

Thank-you to everyone for taking the time to produce the requested pre-workshop input. We have had some really interesting responses which will serve as a good starting point for the discussion sessions. The purpose of the exercise, in addition to serving as a catalyst for the discussions was also to give all participants, especially those not giving presentations, an opportunity to refer to their own work and many of you did this. The questions under each of the session headings were given as examples of some of the types of things we may want to consider during the workshop sessions. People were encouraged to list other questions/issues that could be considered and many of you did this. I have given a few examples of these below (the list is a small sample only and is by no means definitive), many more will hopefully come up during the workshop. I have also taken a few quotes from the GLP science plan which may be relevant to each of the sessions as I think it will be useful for us to refer to the GLP science plan throughout the workshop, in terms of understanding what the GLP sets out to do and providing feedback to the GLP steering committee (three of whom will be attending the workshop). Unfortunately we will not be able to provide copies of the science plan at the workshop, but the science plan can be downloaded from

<http://www.globallandproject.org/documents.shtml>

Selected notes and quotes from the GLP Science Plan

Session 1. What are we trying to model?

‘A model that focuses on the interactions within a human-environment system’
‘processes operating at different spatial and temporal scales’
‘interactions between drivers, especially major policy shifts’
‘GLP should put a significant effort into developing and experimenting with a wide range of models that integrate societal and natural dynamics’
‘A more complete understanding of complex land system-dynamics will require better integration of component level understanding’

Selected notes and quotes from the GLP Science Plan

Session 2. Which modelling approaches should we take and why?

‘The approach should consider the vulnerability and resilience of land systems’
‘The approach should be able to identify and model the coping capacities of land systems and how these change’
‘Advances are needed in the development of integrated decision making models and dynamic global land models’
‘Advances in agent based modelling permits complex factors to be treated systematically and holistically’

Selected notes and quotes from the GLP Science Plan

Session 3. What should the design of an effective integrated model include?

- Model human-environment interactions in terms of the interactions themselves rather than from the perspective of one domain or the other.
- If possible they should utilise 'discipline neutral' terms.
- Should be able to model processes operating at different spatial and temporal scales.
- Should account for the interactions between different drivers.
- Should be able to model thresholds in the human-environment system as it changes structure and function.
- Should identify and be able to model critical pathways of change in land systems.
- It should have a structure that allows uncertainties to be recognised and quantified.
- The ability to incorporate second order dynamics of change.
- It should be designed to be policy relevant.
- It should work towards a fully developed understanding of the impact of institutions on the land system.

Selected excerpts from the input exercise

Session 1. What are we trying to model?

'Land use systems and ecosystem function – the integrated land system'

'Integration of socio-economic processes, land use and socio-ecological material and substance flow'

'Multiple processes across spatial and temporal scales'

'Land use and land cover need to be separated as concepts and focus needs to be put on the interactions'

'The new generation of integrated models should move beyond traditional approaches of spatial models which focused very much on land use and land cover change and might have been too much dominated by available data and techniques, such as the availability of remote-sensing data'

'Comprehensive representation and analysis of multiple land use types, their link to land functionality, their inter-dependencies in modelling and the relationship between change in individual land uses and the overall landscape change'

Selected excerpts from the input exercise

Session 2. Which modelling approaches should we take and why?

'The approach should consider integration from the conceptual stage'

'Pay attention to the proper time/space scales, and create communication points appropriately'

'An approach that explicitly includes feedback mechanisms in land change models'

‘Full integrated assessment models like IMAGE with all the feedbacks but without too much detail - or detailed bottom up models’

‘An approach that involves a multidisciplinary team’

‘Given the strong potential contribution of empirical models in complex integrated modelling it is important that we capitalise on the strengths and turn the weaknesses into opportunities’

Selected excerpts from the input exercise

Session 3. What should the design of an effective integrated model include?

- be spatially explicit
- well tested system feedbacks
- more modelling of the ecological/biophysical effects of land-use and land-cover change, rather than just on the character of land-use change
- be able to integrate the best and most appropriate of existing models, knowledge and data
- have an internally consistent ontology
- should be released under an appropriate licence
- include conceptual and methodological differences
- include drivers and underlying causes as well as impacts on the human environmental system

Some questions posed in the input exercise

- How are changes in land use over time properly correlated to other processes – a) lag effects of physical and social processes b) spatial vs. temporal?
- How are case study materials being most useful in extrapolating more large scale or general processes? Dangers and strengths.
- How can drivers to land- use change be assessed?
- Is there certain data that cannot be used in integrating work?
- When is an integrating model effective?
- Where does simplicity and clarity ends and inaccuracy begin?
- How can we make sure that patterns are linked to processes (linked to the issue of equifinality)?
- Are we actually able to understand and model human (and species?) behaviour?
- How do we address the issues of ABMs calibration and validation, which seem far from being solved and are a prerequisite in order for ABMs to gain credibility?
- What is the meaning of the term “full integration” and we should aim to build models that are fully integrated?
- What are the different meanings of “integration” on the conceptual and technical level?
- Should we even be trying to reinvent another integrated model?

Inge Aalders
The Macaulay Institute, Aberdeen, UK

Session 1. What are we trying to model?

1.1 The goal of the Global Land Project is to measure, model and understand the coupled human-environmental system as a whole. In a modelling context how should this differ from previous initiatives which considered land use and land cover change only?

- Comprehensive representation and analysis of multiple land use types, their link to land functionality, their inter-dependencies in modelling and the relationship between change in individual land uses and the overall landscape change (actual & perceived change). This will have to deal with improving our understanding about the way different land uses in a particular location interact (either complimentary or conflict) as well as the complex of land functionalities.

1.2 What should we be working towards for full integration?

- A trans-disciplinary environment for the development of models and modelling methodologies, which will be organised in an iterative process cycle and which may adopt appropriate modelling methodologies for different stages of the process.
- We should appreciate that models in the broadest sense are abstract representation of reality, which can assist us in enhancing our understanding of natural & social systems in land change science. Models can take many different shapes and forms. The key challenge is to find effective ways of using the knowledge gained from specific models (simple or complex), and although full integration may be the ultimate objective, it may not always be appropriate.

1.3 Emergence; how important is it and how do we deal with it?

Session 2. Which modelling approaches should we take and why?

2.1 Should we go beyond model purpose dictating model structure?

- I do believe we should, because it often seriously constraints the development and application of the model beyond that particular purpose.

2.2 How do we represent a multi-scale/multi-structure approach in an integrated model?

- Different phases, i.e. as a route through the model rather than all at the same time.

2.3 What are the pros and cons of taking a framework approach?

- Pros – flexibility; facilitates trans- & interdisciplinarity model development.
- Cons – encourages coupling/linkage rather than full integration.

Session 3. What should the design of an effective integrated model include?

3.1 What characteristics are required for an integrated model?

3.2 When does ‘coupling’ or ‘linkage’ stop and integration begin? Do we need a formal definition for integration?

- Only if that definition can clarify the nature of the sliding scale that integration is, in that it can take place at different levels of intensity and that it can use different methods.

3.3 How do we identify and model feedbacks?

3.4 Should complexity in all subsystems of an integrated model be comparable?

- No not necessarily

Richard Aspinall
The Macaulay Institute, Aberdeen, UK

Session 1. What are we trying to model?

1.1 The goal of the Global Land Project is to measure, model and understand the coupled human-environmental system as a whole. In a modelling context how should this differ from previous initiatives which considered land use and land cover change only?

- Processes should be represented and included in models
- Feedbacks and interactions of human and natural systems should be a focus of models
- Consequences of land use and land cover change, for example on ecosystem services, would be a valuable extension beyond capabilities of previous initiatives

1.2 What should we be working towards for full integration?

- Models that focus on the coupled human and natural system rather than on each separately or only one
- Models based on process understanding

1.3 Emergence; how important is it and how do we deal with it?

- Emergence is important for evaluation of model outputs and outcomes in providing additional metrics of change in land systems. It should be viewed as a relevant consequence (or by-product) of a successful model

Session 2. Which modelling approaches should we take and why?

2.1 Should we go beyond model purpose dictating model structure?

2.2 How do we represent a multi-scale/multi-structure approach in an integrated model?

- I would address this with an approach based in spatial and temporal scaling where scales are identified and prescribed by the relevant spatial and temporal scales of processes representing underlying and proximate drivers of change

2.3 What are the pros and cons of taking a framework approach?

- Pros include a structured approach to model construction, management and documentation that may facilitate use and comparison of models in multiple case studies.
- Cons arise from too rigid a framework structure

Session 3. What should the design of an effective integrated model include?

3.1 What characteristics are required for an integrated model?

- I shall describe characteristics I see in integrated models in a presentation in the first session

3.2 When does 'coupling' or 'linkage' stop and integration begin? Do we need a formal definition for integration?

- To me this relates to the framework approach noted above (under 2.3) and refers to use of the terms coupled, linked, and integrated in a computing sense rather than in a sense that relates to outcomes and products of modelling using an integrated approach. For example, a loosely coupled suite of programmes and procedures may provide an integrated model if the components provide outputs that meet requirements and characteristics that define integrated around the linked human and natural systems (under 1.2 above).

3.3 How do we identify and model feedbacks?

- By addressing the connections and interdependence of land use and land cover (and I would add land function) and their responses to processes that produce change.
- In all senses, a desire for, and expectation of, plausible answers to this question are the motivation for this workshop and will provide a metric of success in focusing a research agenda for integrated modelling of land systems.

3.4 Should complexity in all subsystems of an integrated model be comparable?

- Not necessarily – models, including of subsystems, should be as simple as possible and no simpler (thank you Einstein!). To me complexity of the model is not the issue; representation of processes for land use as a coupled human and natural system and a focus on outputs and outcomes is more important.

Martha Bakker
Wageningen University, The Netherlands

Dealing with uncertainties, confounding factors, interactions and feedbacks in integrated empirical models

With increasing model complexity, empirical modelling will remain an important tool. The main reason is that the observed reality is the starting point in empirical modelling, and that the observed phenomenon of interest is the result of all processes affecting the phenomenon, regardless whether or not these processes have been taken into account by the modeller.

Empirical modelling has important advantages, but there are disadvantages as well. Advantages are: (i) it tends to produce results that are likely to be realistic; (ii) it is very flexible in terms of input and output; (iii) process-knowledge can be incorporated to any given extent; and (iiii) it helps in identifying the gaps in current knowledge. The disadvantages are that (i) the applicability of the obtained models is limited to the spatial and temporal spans for which the model parameters were assessed; (ii) causality cannot be inferred from statistical associations; (iii) in complex models with many variables, residuals can often not be clearly attributed to either stochasticity, data inaccuracy, inherent system properties, omitted variables, and/or to wrong postulations concerning the form of the functional relationships. Furthermore there is the problem of confounding variables that may lead to misinterpretation (particularly when scientists aim at obtaining parsimonious models by means of stepwise selection methods), and interacting variables that may often appear as so-called emergent properties of land systems.

Given the strong potential contribution of empirical models in complex integrated modelling, it is important we capitalize on the strengths and turn the weaknesses into opportunities. Below the most important advantages and disadvantages, and how one often follows from the other, are discussed:

- (i) Advantage: process-knowledge can be incorporated to any given extent. The extent to which process knowledge can be incorporated may vary from totally no process knowledge, to capturing the entire process in rules and equations. In the first case, the scientist will make a very wide selection of variables and let the software select the best variables (data-mining), whereas in the second case the outcomes of a process-based model are compared to reality by means of a regression between observed and predicted Y-data. Most of the time an empirical modelling exercise is situated somewhere in between: on the one end incorporating process knowledge starts by making an informed selection of variables for the regression. (Entering too many variables without scientific basis is never appropriate, as when one simply has abundant observations ($n \rightarrow \infty$), any variable will become significant. Furthermore, some meaningless variable may obscure another meaningful variable (e.g. latitude obscuring the role of temperature)). At the other end, many of the processes may be captured by pre-calculated variables (e.g. potential productivity computed from temperature and latitude), but the exact parameterization is done by the regression analysis. Combining process knowledge and empirical modelling can be seen as a combined top-down – bottom-up approach: the process

- knowledge enters the model from the bottom in an upward direction, while the empirical observations enter the model from the top in a downward direction. In order for the two to meet halfway, the fine-tuning of parameters is required.
- (ii) Advantage/disadvantage: Regression models are very flexible in terms of input and output, as the relationships are identified at the scale of the given Y variable. From this advantage follows the disadvantage that the applicability of the obtained models is limited to the spatial and temporal spans at which the model parameters were assessed. This raises the question of universality and stationarity of empirically derived relationships. Understanding can be greatly improved on these issues: relationships observed in different agro-ecosystems and on different spatial scales can be compared and analyzed in, say, a meta-model; much more investigation can be done on the (lack) of stationarity in relationships (how relationships change through time); a more structural method on projecting relationships over different spatial scales can be developed by investigating the distribution of both the X and Y variable with different aggregation levels; etc.
 - (iii) Disadvantage: It should always be acknowledged that causality cannot be inferred from statistical associations. Covariates and omitted intervening variables may lead to false interpretations, and so may feedback mechanisms and dependent X-variables. Methods exist that are currently hardly explored, such as path-analysis, which allow unravelling the roles of several covariates and intervening variables. Also the sampling strategy can be adjusted so that potential covariates can be controlled for. Involving X-variables that are not truly independent from the Y variable may lead to a form of auto-regression, with high model fits but no predictive power. Interaction analysis provides insight in how subpopulations respond differently to variations in certain X-variables, which can form a considerable contribution to process understanding.
 - (iv) Advantage/disadvantage: The disadvantage of a possible lack in explanatory power (indicated by residuals in the regression) has the potential advantage that it can be used to identify gaps in current knowledge. Residuals on the expected Y-value (given the matrix of X values and the vector of regression coefficients), be it land cover change, population density, N-surpluses or bird-occurrences, will tell you if you have missed important explanatory factors in your process description. Residuals of the regression may be spatially auto-correlated, and therewith reveal an omitted variable. Also when residuals are not spatially auto-correlated, they point at some level of inherent uncertainty, something that should not be “modelled away”. The true nature of the residuals should be identified, and their extent and spatial organization should be maintained in model predictions. This will result in non-reproducible results, so that end users of such models should become used to results indicating the probability on a certain (change of) state per pixel, rather than only the state. However, information that some areas show much less uncertainty than others is valuable information in itself.

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Session 2. Which modelling approaches should we take and why?

2.1 Should we go beyond model purpose dictating model structure?

A model is built in order to answer to some questions about a system. The model building requires analysing and describing the objects of the real world in a formal framework and using a structure. To build efficiently his model, the designer has to answer to do some choices:

1. What **variables** to take into account?
2. What **scales** (individual, global, space) of description to take into account and how to **organize** them?
3. What **interactions** to take into account and how **organize** them?
4. What are the sub-systems and how to organize them?

These choices are dictated by the purpose of the model i.e. the initial questions to answer. According these choices, the designer will conceptualize and implement the model using a specific structure. For example, if the model requires taking into account the individual actions and their interactions between them and with the environment, a structure based on IBM is required. But, if the designer is interested to apprehend only what happen at global level, an aggregate structure such mathematical model is relevant.

But the model structure does not depend only on model purpose. The model complexity can also dictate the model structure. In the case where the model is composed of several sub-systems, the designer can use different formalisms to represent the sub-systems according to their complexity which dictates how to structure each sub-system. Then, a platform allowing multi-model and multi-formalism integration is necessary to deal with the system complexity.

2.2 How do we represent a multi-scale/multi-structure approach in an integrated model?

The management of renewable resources requires the comprehension of the interactions between **social** and **ecological** dynamics. The dynamics of a renewable resource is the object of triple complexity: (1) ecological dynamics of the renewable resources, (2) the social practices (3) the **interactions** between these two dynamics on which depend economical, social and ecological **viability** of the system.

The problems which emerge are the representation of **complex system** which is the place of a certain number of dynamics at several spatio-temporal scales. A “complex system” is considered here as a set of non-linear interacting components which produce at the global level a behaviour irreducible to the composition of the individual behaviours (Müller, 2004a).

Generally, the problem of the comprehension and the management of a complex system are based on the **articulation** of at least two **levels** of description: that **local** of the components of the system, and that, **global** of the collective behaviour which results from it.

The representation of such system is not satisfied an only one type of formalism nor of only one scale of representation of the phenomena (Müller, 2004b). Thus the individual behaviours can indifferently call upon processes of **optimization of the utilities** such as **rules of behaviours**. The interactions between the individuals and the resources are more easily represented by the **multi-agents systems (MAS)**. Finally the global level can emerge from the local interactions or be described by **models with compartments** according to the stability of the system or the more or less large number of the implied individuals.

Toward a multi-point of view analysis

Complex system analysis requires multi-points of view (POV) analysis to deal fully with the system complexity. For example, the organic matter management at village territory level requires analysing (1) crop management, in order to study the crop production effect on carbon dynamics, (2) the carbon transport to study carbon transfer between different entities (plant, atmosphere, soil, etc.), (3) the carbon decomposition and (4) the organic matter market to analysis the economical factor of carbon dynamics. Crop management, carbon transport, carbon decomposition and organic matter market points of view do not concern necessary same entities and the entities representation varies from a POV to another POV. For example, Human according to crop production context is a producer; the soil represents a production site and organic matter a fertilizer. But, in decomposition context, the soil is an organic matter decomposer. In organic matter market, organic matter is an economical good exchanged between human which are organic matter seller and buyer. Taking into account these different points of view requires to analyse their relationship and how they can be linked and to form a global and coherent system. In this case a modelling framework allowing multi-point of view analysis and integration is important. Most modelling approaches proposed do not handle easily multi-point of view analysis and integration.

In MAS, two modelling approaches have been proposed : ACMAS (Agent-Centered MAS) and OCMAS (Organization-Centered MAS) approaches (Ferber *et al.*, 2003). The ACMAS approach is based on agent-oriented point of view. *“In that view, the designer of a multi-agent system is only concerned with agents’ individual actions, and it is supposed that social structures come from patterns of actions that arise as a result of interactions”* (Ferber et Gutknecht, 1998). Models based on this approach assume that the global behaviour emerges from agents interactions. In ACMAS, a system is decomposed directly into agents. Each agent is defined by its internal state and set of operations defining its behaviour. Then, it is difficult to express explicitly the system points of view. There are implicitly defined across the agents properties and behaviour making difficult the system comprehension.

Unlike ACMAS models, OCMAS models treat MAS as organizations interacting through agents playing roles. OCMAS models assume that the social structure must exist a priori and constraint the agents behaviour (Hübner et al., 2002). OCMAS

model introduces the notion of organization, role and agent to represent a system structure (Ferber et Gutknecht, 1998). An organization defines a collection of roles and their relationship. A role is an agent function; it is related to an organization and can be played by several agents. Agents are active, autonomous objects interacting with each others agents through their roles. OCMAS models allow dealing easily with the **local** and **global** representation and their interactions. The organizations and their relationship represent the global level and the agents the local level.

An organization can be viewed as a sub-goal or a particular functionality providing a “high-level analysis” (Jennings, 2000) and in consequence a POV of the designer. Most OCMAS allow multi-organization analysis, then considering an organization as a POV, OCMAS can be used for multi-point of view analysis. Then, using AGR model extension, we proposed OREA model for multi-point of view analysis and used it for carbon dynamics modelling from plot to territory level (Belem, 2007b ; Belem, 2007a).

Unlike most models, OREA model allows environment integration in the organizations. Then, considering a scale as an organization or a point of view, an OREA model allows a multi-scale representation.

An OCMAS model using in carbon dynamics modelling allows to fully express the individual and global level in carbon management as the multi-scaling in carbon dynamics modelling.

To conclude, to deal efficiently with 1) individual and global representation and articulation, 2) multi-point of view analysis and 3) multi-scale representation, OCMAS models are more relevant than most of modelling approaches.

What are the pros and cons of taking a framework approach?

Taking a framework approach present some advantages. It makes easier:

1. Communication between researchers of different disciplines
2. Knowledge sharing
3. Tools use and integration.

As long as, each discipline can find its easiest way of expression, hence our multi-formalism proposal.

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On The Design of Integrative Models of Natural and Social Systems in Land-Change Science

I have been working on modeling various aspects of land change for the past ten years or so. Approaching the question of how to represent the role and dynamics of human-activity in changing landscape structure in ways that affect environmental quality led me early on to recognize the key difference between *land use* and *land cover* as distinct phenomena. This distinction is obvious, conceptually, but when doing data-based modeling, which my early work focused on, we are consistently confronted with data in which they are either imperfectly represented or completely conflated. Oddly, I think that separating these two key concepts is essential to forward progress in integration; it gives the ability to focus on the interactions between land use and land cover as an essential subject of integrated modeling. We have found this to be especially true when looking at heterogeneous, human-dominated landscapes.

Pursuing data-based modeling, I worked with others to implement and elaborate on land-cover modeling approaches that are based on transition probabilities. We did this initially using “global” transition probabilities applied to small sections of landscape to describe the processes of deforestation and afforestation (Brown et al. 2000). Comparing transition probabilities among landscape sections revealed clear differences (i.e., non-stationarities) in the rates. These non-stationarities are where the interesting information about process differences lie. Elaborating on this process, we developed geostatistical simulation approach that incorporated spatial variables that predict these variations in transition probabilities (Brown et al. 2002). The general idea is that we can use these approaches to modeling land-cover transitions in conjunction with other methods for describing land-use change processes, which rely on social, political and economic explanations and processes. One approach to coupling these representations of process is by nesting land-cover transition models within models that forecast demand for land-covers based on econometric or other types of models. This is not unlike the approach taken in CLUE-S (Verburg et al. 2002), but isn’t particularly clear about the distinctions between land-use and land-cover, modeling land cover directly and skipping any representation of land-use.

In order to get a bit more explicit about the distinctions between land use and land cover and their implications in both use of land data sets and in coupling or integrating models, we described a framework for “semantic translation” between land use and land cover, based on a simulated annealing approach (Brown and Duh 2004). A big motivator behind this work was to see how far pursuing the distinctions between land use and land cover, and modeling the interactions between them, might get us in integrating social and environmental processes.

Ultimately, while all of these efforts, and those of the broader scientific community to which they contributed, have taken us further in describing and projecting landscape changes, they have been based on process descriptions that are largely devoid of actually physical or social processes. For example, the Markov chain or simulated annealing processes, while useful, do not have a direct link to process as

environmental or social scientists might recognize them. I view these processes as useful for project, but to make more progress on integrated modeling, I think we need a means of representing these processes so that we can evaluate the consequences of various interventions in system dynamics.

The modeling approaches from complex systems, including system dynamics models, cellular automata (CA) and agent-based models (ABMs), provide a couple of ways of representing process dynamics that are more analogous to biophysical and social processes. On reflection, CA models are a spatially interactive form of the transition probability models we were working with before, so do not take us much further than we were before. System dynamics models and ABMs, on the other hand, provide stronger approaches to representing process. We argued that by coupling ABM with geographic information systems (GIS) we can gain from the spatial representations in GIS and the process representations in ABM (Brown et al. 2005). Because of their flexibility, we have taken an approach to agent-based modeling that starts with simple models that we can understand and that represent critical processes about which we have an interest, and gradually add detail as we come to understand the dynamics of the models we have. The key advantage of integrating social and environmental process models is that we can include feedbacks between these two systems into the dynamics. This suggests, however, that the interactions need to be built into the system from the beginning and not tacked on as a later “coupling” of models.

As we investigate the interactions between social and environmental processes and the patterns of land use and land cover, these process models give us the ability to pose process descriptions from theory and evaluate the implications of that theory (Brown et al. 2006). This approach to modeling relates to data in different ways from traditional statistical or data-based model (Brown et al. In Press). We need better micro-level data about land change processes, especially those driven by human decision making. Also, the feedbacks and complex dynamics that can result mean that we may need to rethink the measures that we use to evaluate our models. By evaluating the consequences of dynamic interactions we can learn something uncertainly inherent in the outcomes of the system, resulting for example from path dependence (Brown et al. 2005b).

Ultimately, I believe land-change science faces a challenge of taking the lessons from process-based dynamic descriptions of land-change and scaling them to regional and continental scales, such that they can be used in concert with models in other domains. I don't think a completely integrated model of the entire earth system is a worthy goal, but that models of land change that can couple with atmospheric and biospheric models would be a fruitful goal. I am a fan of developing multiple competing models of the same phenomenon, in order to make process comparisons, but we might want to discuss the possibility and necessity for a community model of land change that could be used in regional and global assessments. It wouldn't answer all questions, but might be a valuable contribution to global-change science. A proliferation of land-change models is probably necessary for local assessments of vulnerability and adaptation. Nonetheless, a discussion of a community land model would contribute to a fuller evaluation of the merits of multiple modeling approaches.

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Session 1. What are we trying to model?

1.1 The goal of the Global Land Project is to measure, model and understand the coupled human-environmental system as a whole. In a modelling context how should this differ from previous initiatives which considered land use and land cover change only?

Most previous models of land use and land cover change have considered the human and environmental systems as two separate systems. This means that one of these two systems was considered exogenous to the system under study.

I believe that future models of land use change (and ABMs in particular) should seek to fully integrate human decision-making and biophysical processes. They should treat the landscape as a dynamic entity, as in many cases human-environmental interactions are non-linear, with the environment being affected by individual decisions, which in turn impact on the environment. It is essential to correctly understand and represent these feedback loops within integrated models of land use change. In order to achieve its goals, the GLP should focus on developing fully integrated models like, for example, the PALM model (Matthews, 2007). This will require the participation of scientists and stakeholders from different fields and strong programming skills.

1.2 What should we be working towards for full integration?

I think the key challenge will be to get people from different backgrounds involved in this multi-disciplinary process. Geographers, socio-economists, field ecologists, ecological modellers, soil scientists, hydrologists, programmers and many others should really commit to this exercise because no single expert has the required knowledge to model complex systems.

Likewise, stakeholders should be involved and the communication among scientists of different fields and between scientists and stakeholders should be improved.

Session 2. Which modelling approaches should we take and why?

2.2 How do we represent a multi-scale/multi-structure approach in an integrated model?

As an example, a flowchart of a conceptual framework for a multi-structure ABM that aims at providing indicators of the evolution of Ecosystems Goods and Services (EGS) is represented in the figure below.

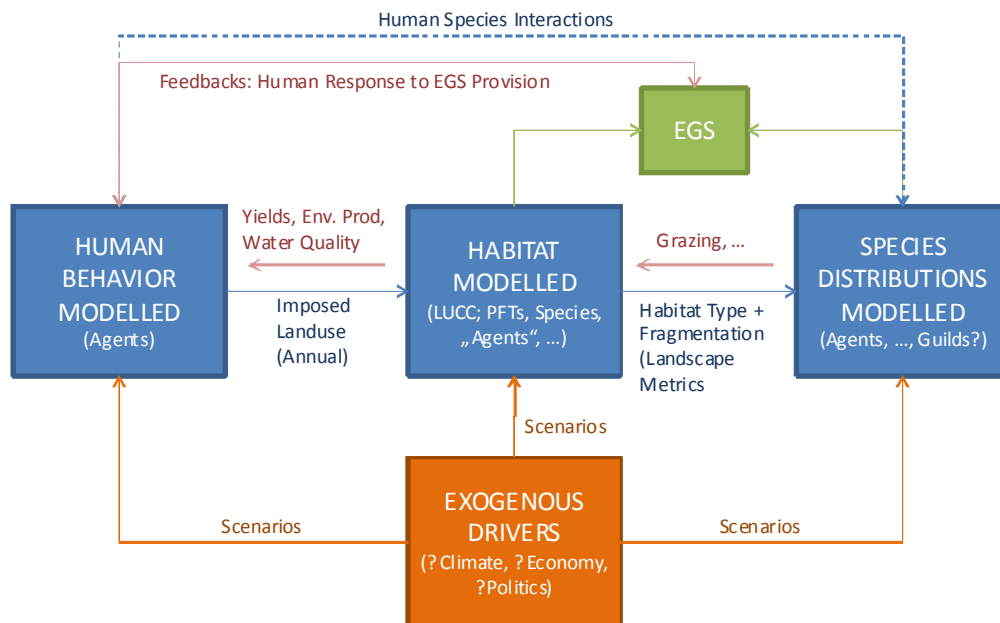


Figure 1: Flowchart of a conceptual framework for a multi-structure ABM – source: Johannes Fruemann, EC-funded ECOCHANGE project.

This ABM will be developed in the ECOCHANGE project and is part of a larger Integrated Sustainability Assessment (ISA) framework. It is a nice example of a model that will require input from economists, ecologists, geographers and programmers. It consists of three main modules (Human behaviour model – Habitat model (LU) – Species distribution model) that influence each other with feedbacks. It is obvious that multi-scale processes (not represented on the graph) occur within these systems, and particularly within the human system. Issues of time and spatial scales will need to be addressed.

Session 3. What should the design of an effective integrated model include?

3.2 When does ‘coupling’ or ‘linkage’ stop and integration begin? Do we need a formal definition for integration?

I believe that there is no clear-cut distinction between ‘coupling/linkage’ and ‘integration’. Perhaps the difference comes from the fact that an integrated system will model feedback between the different systems modelled (e.g. between agents and their environment) whereas coupled or linked systems barely use outputs from one system as inputs in another system and vice versa. Perhaps a formal definition of ‘integration’ (in the land use/ ABM context) would be useful to prevent it from becoming a ‘buzz-word’, without any clear meaning behind.

3.4 Should complexity in all subsystems of an integrated model be comparable?

Complexity in ABM is not predefined and should emerge from the modelled subsystems (i.e. it is bottom-up). Even if we would like it to be comparable, it is probably impossible to tell whether this will be the case.

Other issues that I would like to see addressed during this workshop are: 1) how can we make sure that patterns are linked to processes (linked to the issue of equifinality); 2) are we actually able to understand and model human (and species?) behaviour; and, last but not least 3) the issues of ABMs calibration and validation, which seem far from being solved and are a prerequisite in order for ABMs to gain credibility.

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Session 1. What are we trying to model?

1.1 The goal of the Global Land Project is to measure, model and understand the coupled human-environmental system as a whole. In a modelling context how should this differ from previous initiatives which considered land use and land cover change only?

1.2 What should we be working towards for full integration?

The GLP initiative, from a modelling perspective, should focus on building model components representing complementary aspects of the human-environment system. The land use system should be one of them.

Full integration can only be achieved if pursued since the conceptual modelling phase. Specialists from different background should work together in the initial phase of system specification, discussing common goals and integration aspects. Postponing integration discussion may lead to coupling, as discussed below, and a whole series of scale and semantic mismatches.

For instance, in the GEOMA network, we aim at constructing models of land change for the Amazonia, encompassing climate, biodiversity, wetlands dynamics, and land use change. The land use component is a central and complex piece due to the heterogeneity of the region (Aguiar et al, 2007), in terms of actors and processes (Camara et al., 2003, Escada et al., 2005). It is formed itself by the integration of multiple components, involving an inter-disciplinary team. Our aim is to analyze the effects of exogenous and endogenous processes at different scales, including the intra-regional interactions (Aguiar, 2006) of market, connectivity (Amaral, 2006), conservation policies and institutional aspects. We are using a multi-scale, multi-locality, multi-approach modelling framework (Carneiro et al., 2004, Carneiro, 2006), as discussed below. Parallel to that, we are working towards integration to the other modelling groups (Climate, Biodiversity, Wetlands) to construct combined models at different scales.

1.3 Emergence; how important is it and how do we deal with it?

We view emergence as an important issue to be considered in our models for Amazonia, especially to understand collective behaviour in response to different socio-economical and political contexts, at different scales. We intend to deal with emergence using multi-agent systems, as detailed below.

Session 2. Which modelling approaches should we take and why?

In this session, we will focus on question 2.1 and 2.2.

2.1 Should we go beyond model purpose dictating model structure?

2.2 How do we represent a multi-scale/multi-structure approach in an integrated model?

2.3 What are the pros and cons of taking a framework approach?

In our modelling projects, we are adopting a multi-paradigm approach. The same model may combine multiple spatial and analytical representations, based on different modelling techniques.

In order to explore this form of modelling, we are using the TerraME Modelling Environment (Carneiro, 2006), developed at INPE and UFOP (Ouro Preto Federal University). One of the goals of TerraME was to support GEOMA inter-disciplinary efforts, so it had to be capable of dealing with heterogeneous applications and processes, and to allow multi-scale and model integration. TerraME had three main design requirements:

- a. Ability to support real-world case studies.
- b. Extensibility to include different conceptual approaches.
- c. Capacity of representing interaction between multiple spatial scales.

To meet the first requirement, TerraME was designed using TerraLib GIS library for spatial database management, and thus a modeller has full access to real-world geographic databases. Model input and output are organized as *Cellular Spaces*. A *Cellular Space* is a regular grid of multi-valuated cells implemented as a layer in a TerraLib geographic database. The cell attribute values may be static or multi-temporal, allowing for the evolution of land characteristics at each location in time.

To meet the second requirement, TerraME has a modelling language, named TerraML, an extension of the LUA language. To facilitate the implementation of spatial dynamic models, TerraML uses LUA extensibility mechanisms to include new data types and functions. Examples of elements included are: *Cellular Space*, *Cell*, *Neighbourhood*, *Agent*, *Automaton*, etc. Different modelling approaches can then be implemented combining these elements, according to application needs, for instance: cellular automata, agent based, and statistical models.

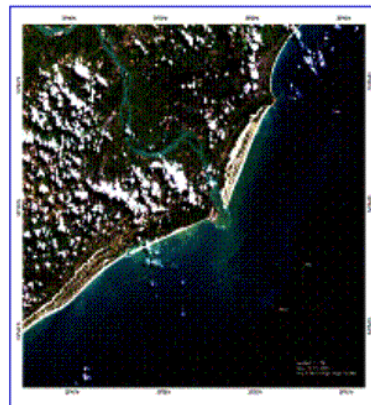
To meet the third requirement, TerraME has been designed around the core concept of an *Environment*. An *Environment* represents a spatial dynamic system in a specific extent and resolution. It encompasses all the analytical, spatial, and temporal dimensions of the system. Different modelling approaches may be combined in each *Environment*. Using this concept, TerraME allows:

- *Behaviour to be heterogeneous in space and time*. Different processes can act upon different space partitions, with different time resolutions, as Figure 1 illustrates.
- *Space to be structurally heterogeneous in terms of proximity relations*, through the use of multiple neighbourhood relationships, including network based ones (Aguar et al, 2003).
- *Spatial dynamic processes to be asynchronous*. Agents and processes can operate at distinct temporal resolutions.
- *Multiple scales to be integrated in a single model*, through the nesting of *Environments*, as described below.

Environments can be nested. This is the foundation for the construction of hierarchical multi-scale models. The models for each spatial scale are encapsulated in separated *Environments*. The necessary top-down and bottom-up linkages and feedbacks are

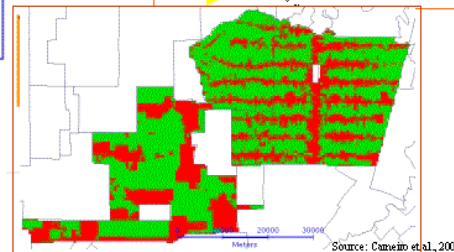
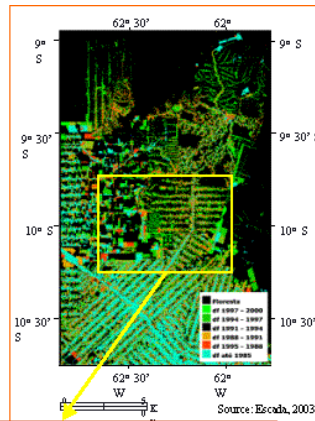
then implemented as *Spatial and Analytical Couplers* in a third *Environment* encompassing the others.

We plan to use the same principle to *integrate human-environment model components*. For instance, to integrate models of wetlands dynamics and land change, we will use different *Environments* for dry land and wetland dynamics, and a third *Environment* to integrate them.



One environment for the sea,
One for land,
One for integration

One environment for small
Farmers (500 m resolution)
One for large farmers (2500
m resolution)



Session 3. What should the design of an effective integrated model include?

3.1 What characteristics are required for an integrated model?

An integrated model should:

- Consider more than one aspect of the human-environment integrated system;
- Be constructed by inter-disciplinary teams (computer scientists, natural scientists, social scientists);
- Consider integration aspects from the conceptual model phase to avoid scale and semantics mismatches;

3.2 When does 'coupling' or 'linkage' stop and integration begin? Do we need a formal definition for integration?

As mentioned before, we believe models are integrated instead of coupled when the whole modelling process is integrated, from the conceptual phase.

3.3 How do we identify and model feedbacks?

Ideally, feedbacks should be identified in the conceptual modelling phase, from knowledge exchange. Feedbacks are modelled as part of integration components in our environment (see Session 2).

3.4 Should complexity in all subsystems of an integrated model be comparable?

Maybe this is not possible, since model construction is an iterative process. As long as interfaces are well defined, individual subsystems may grow in complexity at different paces.

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Session 1. What are we trying to model?

1.1 The goal of the Global Land Project is to measure, model and understand the coupled human-environmental system as a whole. In a modelling context how should this differ from previous initiatives which considered land use and land cover change only?

Land use planning demands managing diverse objectives, with a view to help understanding how delivering of [what are now known as] Ecosystem Services can be achieved.

From my prospective, there is a need to better model the effect of land use decisions on landscape structure, to understand how this impacts on various services, including species distribution and diversity (or Biodiversity, if you prefer). The same applies to a number of other ecosystem services, such as pollination, pollution control, recreation potential etc.. These need to be modelled and linked to some decision making framework that enables researchers and users to evaluate trade-offs between different services and policy decisions. In the case of conservation of biodiversity, for example, it would be very useful to be able to link land use change scenarios and land use change modes with models of vulnerability of species and ecosystem services to change and to landscape prioritization methods.

However, the challenge posed by question 1.1. is much bigger.

The domain proposed is huge and I am not sure whether a unique conceptual framework exists -or can exist -to model the human-environment interaction, or even some particular aspects and case studies.

Before using detailed (spatial) models, I think it is useful to use tools that facilitate a shared understanding of the problem from the point of view of different disciplines. This, in my experience can be quite difficult, and is in itself a communal learning experience. On the one hand, this enables researchers with different backgrounds to challenge each-others conceptual models of a problem, on the other, it enables them to better understand aspects of the problem they previously had not appreciated. Of course these comments extend to stake holders participation. In addition, creating a shared conceptual model helps with transparency of assumptions that all involved parties can inspect.

Ideally, to support strategic landscape/land use planning, we should make use of existing models, to capitalise on previous efforts, but the need of writing new models/modules might become apparent from the conceptual effort I mentioned above.

An approach encompassing the use of multiple tools, such as system dynamics, fuzzy cognitive map, and Bayesian Networks as well as meta-modelling, which re-uses and integrates existing (more detailed and spatially explicit) models could be useful.

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Session 1. What are we trying to model?

1.1 The goal of the Global Land Project is to measure, model and understand the coupled human-environmental system as a whole. In a modelling context how should this differ from previous initiatives which considered land use and land cover change only?

Understanding the coupled human-environmental system as a whole requires considering demographics, macroeconomics, international politics, and technological change along with land use, land cover, and ecosystem ecology: land use is one major aspect of the “socio-techno-ecosystems” we inhabit (Gotts and Polhill 2006a). For the GLP, the focus should remain on land use/land cover; the other system aspects should be endogenised in simulation models, but represented at a coarser level of detail. Modularity should be maximised, so that modelling of these aspects can be refined as and when the need and resources to do so exist.

1.2 What should we be working towards for full integration?

Simulating systems containing such a broad range of entities and processes as the coupled human-environment system requires a highly modular, interdisciplinary approach, combining fundamentally different kinds of model (see 2 below). There is no “finishing line” to cross to achieve full integration: integrated models should be built in the expectation that all components will sooner or later be superseded.

1.3 Emergence; how important is it and how do we deal with it?

“Emergence” is a slippery term, to be used with care. Defining it as the way stable or metastable macro-scale patterns arise from multiple local interactions, it is important, but human social systems are unique (so far as is known) in that the “elements” involved in such local interactions (people) can recognise, criticise and change the emergent macro-scale patterns.

Session 2. Which modelling approaches should we take and why?

Different aspects of the system will require to be represented in different ways: systems dynamics modelling for quantitative aspects that can readily be represented in “stock and flow” terms (population, food reserves, fossil fuels); agent-based modelling for local or regional “submodels” of land use (see 2.2 below), and for modelling interactions between states and corporations; specialised plant growth and climate models for those aspects of the system.

2.1 Should we go beyond model purpose dictating model structure?

I am not sure who the “we” is here, or what practical effect such “dictation” would have. However, all scientific models should be constructed solely using open-source software; code, parameters and results should be made available on-line.

2.2 How do we represent a multi-scale/multi-structure approach in an integrated model?

An “integrated model” should not be something that can only be run in an all-or-nothing fashion. “Integrated modelling” should primarily describe the process of designing and using models, rather than the models themselves. When modelling “the coupled human-environmental system as a whole” it will be essential to have model runs which do indeed

cover the whole system, at a coarse level of detail; and others which model both functionally and geographically defined parts of that system in finer detail. Thus one would probably need multiple models of a specific subsystem – each producing the same types of output (for input to other components) but differing internally. To ensure the compatibility of the suite of submodels, an underlying formal conceptual model is needed. This could be expressed in terms of formal ontologies (Polhill and Gotts 2006), and perhaps specialised spatio-temporal and causal formalisms (Gotts and Polhill 2006b).

2.3 *What are the pros and cons of taking a framework approach?*

I don't know what this means.

Session 3. What should the design of an effective integrated model include?

3.1 *What characteristics are required for an integrated model?*

Modularity, flexibility, transparency. All can be enhanced by use of open source software, and appropriate conceptual formalisms (see above).

3.2 *When does 'coupling' or 'linkage' stop and integration begin? Do we need a formal definition for integration?*

No formal definition is needed. There are multiple dimensions to linkage/integration. The key point is to design models in the expectation that they will need to be linked to other models; and to design specialised model-interface software to link/integrate them.

3.3 *How do we identify and model feedbacks?*

It depends on the feedback, and on the type of the model component. For example, in systems dynamics models, feedbacks are represented explicitly; in agent-based modelling the global pattern of feedbacks should emerge from local interactions.

3.4 *Should complexity in all subsystems of an integrated model be comparable?*

Not necessarily. see 2.2 above.

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Session 3: What should the design of an effective integrated model include?

Integrated socio-ecological models in land systems research: combining agent-based with stock-flow approaches in a participatory process on the municipal level

The development of integrated models capable of simulating socio-economic processes, land use and socio-ecological material and substance flows is crucial for analysing feedbacks between societal and natural drivers, patterns and trajectories in integrated socio-ecological (or human-environment) systems. We here present results from a project in which such a model was developed for a local (municipal) system in a participative process lasting over two years and involving a variety of relevant local stakeholders. We use this project as a case study for discussing the questions posed in session three of the workshop that can be boiled down to the question of how such integrated models should be designed.

The project refers to the municipality of Reichraming in the emerging Long-Term Socio-Ecological Research (LTSER) platform Eisenwurzen. The Eisenwurzen covers parts of three Austrian provinces (*Oberösterreich, Niederösterreich, Steiermark*) and is located in the northern limestone alps, a mostly hilly or lower mountain region with some higher peaks and flat parts. The region has a longstanding history of metal mining and metallurgy that goes back over 500 years in time. Around 400 years ago, the amount of iron produced in that region was about 15% of the total amount of iron produced in all of Europe. In pre-fossil-fuel times there was a heavy draw on the region's forests, both due to the necessary supply of fuel wood and the requirement to feed a large non-agricultural population of miners, workers in metallurgical facilities and forestry workers based on the region's low-input/low-output agrarian land-use systems. Since the advent of large-scale coal use, railways and industrialized metal smelting and metallurgy, most mines have been abandoned and metal smelting is now concentrated in industrial centres at the fringes or even outside the region, e.g. in the city of Linz. Most of the Eisenwurzen is of marginal agricultural productivity and is subjected to intensive forest re-growth, in parts of the region to an extent that it is regarded as a burden by the local population. The region mostly experiences the typical problems of marginalized rural areas, i.e. decline of agriculture, lack of jobs, low incomes and creeping deterioration of infrastructures. Reichraming is a mountainous municipality with a high percentage (over 80%) of forest cover, much of which is managed by Austria's state owned forest administration. A considerable fraction of its 1800 inhabitants commute to their work places. Many of the c.60 farms raise cattle and produce milk. A national park (Kalkalpen, i.e. limestone alps) covers about one third of the area (c. 100 km).

Aim of the project was to develop an integrated model that was intended to (1) serve scientific purposes, above all the ability to integrate a wide variety of societal as well as natural drivers, patterns, processes, and outcomes, and (2) support local stakeholders in vision-finding and strategic orientation processes.

From a scientific perspective, the aim was to simulate (1) decisions and activities of relevant actors such as farmsteads, households, the national park, the forest administration, the municipality and private enterprises, (2) the development of land use for grassland agriculture, settlement, and forestry and (3) carbon and nitrogen stocks and flows in both socioeconomic (farms, households, companies) and ecological systems. One idea behind that was the aim to contribute to the LTSER agenda that aims to develop a long-term understanding of integrated socio-ecological systems depending on globalization and global environmental change. In particular, the model was also intended as a tool for “back-casting” studies, i.e. the reconstruction of possible past states of the system based on spotty historical data.

From a stakeholder perspective, the model was expected to be able to simulate future scenarios depending on changes in external framework conditions (e.g., economic factors such as agricultural or energy prices, political factors such as subsidies or regulations, social factors such as changes in leisure time preferences or minimum income requirements, environmental factors such as climate change) as well as on internal decisions, e.g. increased cooperation between farmers, implementation of policies to increase bio-energy production and the like. Consequently the model now simulates socioeconomic patterns and processes such as income, municipal budget, time use or the number of farms and households as well as socio-ecological/ecological patterns and processes such as land use, land cover, plant growth and harvest or fossil fuel consumption. Both external and internal factors can be modified during model runs using sliders. Outputs include indicators of overall land-use change, GHG emissions and the aggregated C or N balance.

In constructing the model we opted against the possibility of using existing ecological models to represent C and N flows in ecosystems, as this would have resulted in an extreme imbalance in the complexity of the model’s different modules (societal/natural) which we felt to be inappropriate due to our goal to focus on the interface of the socioeconomic and ecological realms. The agent-based module was constructed based on in-depth cooperation with local stakeholders, including focus groups, interviews and survey techniques, extensively using existing literature and expertise from within and outside the project team. The land-use/land-cover module simulates land-use change in a spatially explicit way based on existing GIS data and data on land-tenure going down to the level of single parcels of land and farmsteads. The stock/flow module calculating socio-ecological substance flows (C,N) uses a rather simple system-dynamic approach, but is based on model runs of a much more complex ecosystem model (Biome-BGC) that were used to determine crucial factors. Feedbacks between the agent-based module and the stock-flow module mostly proceed via the land-use/land-cover module. For example, if farmers decide to change the use of their land, this may affect the area under a defined land use (e.g., cattle grazing) or the intensity of farming operations (e.g., amount of fertilizer used). Changes in plant growth resulting from such interventions will then affect the amount of product and thereby the amount of income derived from a certain parcel of land. Direct feedbacks can also be simulated, e.g. households may switch between fuels (e.g. heating oil or wood) and thus affect the system’s C balance.

With respect to scales, the model integrates the level of individual or aggregated actors (households, for example, are modelled as one aggregated agent), individual parcels of land and the terrestrial ecosystems that they support, and system-level patterns and processes emerging from the interactions between these individual units. At present, all higher-level processes are external to the model and have to be fed into the model before or during a model run as input parameters. In principle, it

would be possible and also quite interesting to embed the model in a larger-scale model, e.g. a macroeconomic model of Austria, that would endogenously determine many of the current model's inputs and deal with its outputs. Tight limits to project resources have so far hindered any progress in that direction. The model could also be extended to consider impacts of climate change as well as of adaptation and mitigation measures/strategies. At present, such feedbacks have not been implemented due to resource constraints.

Interactions between social (e.g. time use), economic (e.g. income) and ecological (e.g. land use, C and N flows) aspects of sustainability were at the core of model development from its very inception. All three of the model's modules – actors, land use/cover and substance flows – include social, ecological and economic parameters, so the model is not an “addition” of existing social/economic/ecological models that have to be “coupled” in a second step – all modules were developed almost from scratch keeping in mind that the understanding of society-nature interaction was the main goal of the model's development. Of course we do not want to claim that such an approach were required or even useful in any particular case. It has proven useful, however, in our case as a powerful tool to integrate knowledge from different scientific disciplines in a coherent model system, thereby promoting interdisciplinary discourse and even taking it to a new level, as the formalization required in model construction has proven instrumental in making sure that all members of the team really understand what the respective others are talking about. Counter-intuitively, the use of formal models has also proven to be highly useful in promoting a transdisciplinary discourse and integrate stakeholders in the research process. Gaining data and knowledge from stakeholders, letting them flow into a model that is then put into operation before their eyes, producing all kinds of expected or maybe also surprising results, has helped in structuring and inspiring discourses between different groups on possible future developments of their region, thus also supporting the empowerment of the local population.

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Pre-workshop input: ‘The design of integrative models of natural and social systems in land change science’

There are a number of challenges to developing joint structural models of human behavior and ecological processes and their interactions across time and space. Rather than seeking to be exhaustive, the following highlights my thoughts regarding a few of the challenges that are particularly germane to developing integrated ecological-economic models:

1. Multiple processes that interact across spatial and temporal scales are an important feature of complex human/natural systems. Ecological processes may exhibit meaningful variation over the course of a day, but the relevant economic processes may evolve much more slowly and yet other ecological processes may respond only very slowly on the order of decades or centuries. Because these processes are not independent, this presents a number of modeling challenges.

Empirically, it is difficult to **estimate the structural parameters** of joint processes and often only “reduced form” parameters can be obtained. These provide information on correlation, but do not indicate causality. Without evidence of causality, however, there is nothing to guide policy and correlation analysis can generate misleading policy implications. A good example in land use modeling is the issue of roads and land use change: do roads cause urban development or does urban development cause roads? The answer is YES. A naive model that accounts only for the one-way effect of roads on land use change may overestimate the influence of roads and thus, could lead to false implications for policies that seek to manage urban growth through road development (some of these points are further discussed in Irwin and Geoghegan 2002).

Methodologically, traditional economic models rely on equilibrium-based assumptions that allow for simple models of aggregate behavior, but that make modeling dynamic processes that evolve over time and space more difficult. While this approach is able to describe the general features of the fixed points (or steady state equilibria) of the system, it cannot describe the **transient dynamics**, which are often as important if not more so in ecological-economic systems. These points are further discussed and illustrated in a recent working paper (Irwin, Jayaprakash and Chen 2007) that considers the joint system dynamics of an amenity-based regional economy with migration and endogenous ecological change.

2. Data and empirical analysis are essential for the development of meaningful models of ecological-economic systems. Without data as a guide, it is possible to develop a model that predicts any number of outcomes depending on how it is specified and parameterized. This is true regardless of whether the model is well-grounded in theory. Data analysis is essential for descriptive analysis of spatial or temporal trends that is necessary to motivate formal models (e.g., Irwin and Bockstael 2007) and that can be useful in validating models. However, empirical analysis by itself is insufficient for developing a full model because the results do not provide a description of the system dynamics over time and space. Empirical analysis and dynamic modeling methods should be used in conjunction with each other to develop meaningful models of land use dynamics (for some examples of combining statistical estimates with some very simple-minded simulations see Carrion-Flores and Irwin, 2004; Irwin and Bockstael, 2002; Irwin, Bell and Geoghegan 2003).

Lack of data on the relevant processes is often a challenge. It is often the case that we have data on outcomes, but not on the underlying processes that generate these observed outcomes. For example, we observe land use changes, but we do not have data on the farmer, firm or household-level decisions that generated these changes. Statistical models can generate inferences on causal relationships, but the resulting empirical estimates may be biased or misleading. Statistical bias can result from uncontrolled spatial autocorrelation that can arise from misspecified models that omit relevant spatial variables (Irwin and Bockstael 2002). Even if these spatial statistical issues are addressed, it is difficult to know the extent to which structural change may be present: the estimated parameter may be an average value that does not accurately reflect changes over time or heterogeneity across different types of agents. This is particularly a concern if the estimates are being used to specify an agent-based model in which heterogeneity is a key aspect. Thus, while statistical modeling can be very useful in uncovering spatial relationships and testing specific causal effects (e.g., the effect of zoning or other land use controls on land development), specification of process-based models can benefit greatly from primary data on agent preferences and behaviors.

1 Modeling human behavior requires one to wrestle with **whether and how humans form expectations over future events and outcomes**. Although sometimes humans may be truly be myopic, they most often form some kinds of expectations over the future and thus these expectations (and the factors that influence them) are a critical aspect of modeling human behavior in a dynamic model. The fields of psychology and more recently, behavioral economics, have uncovered a number of interesting cases in which human behavior and expectations formation is far from the “rational economic agent” of traditional economic models. Decision making processes are context specific and thus, information on the decision making rules or heuristics that an agent employs and under which conditions can be a critical aspect of model development. In particular, the **role of uncertainty in decision making** is key, given the inherent uncertainty of many ecological-economic systems. This once again points to the importance of primary data and on data collection and analysis methods that can uncover this kind of information. Experimental economic methods are important in this regard.

2 The challenges of **conceptual and methodological differences across disciplines** are sometimes substantial. For example, economists are often reluctant to pursue a model that relies completely on numerical or simulation methods. As far as I can tell, this lingering discomfort with numerical methods stems largely from the fact that numerical and simulation methods require a full parameterization of the model. While parameterizing cost functions may be reasonably straightforward, assigning specific numbers to a utility function goes against the grain of most economists (who are the first to admit that utility is a murky concept). Put simply, there is no a single correct way to parameterize human behavior and so many economists believe that simpler, more general models are better. Thus, they would prefer to err on the side of overly simplistic models rather than overly parameterized models. This belief, which has often served economists well, causes analytical methods to be favored over numerical and simulation methods (this also explains why equilibrium-based models are favored, since they can be solved using analytical methods). This bias among economists can create barriers to interdisciplinary collaborations, particularly with ecologists and others from disciplines in which model parameterization (which can be more readily validated in lab or field settings) and dynamic simulation models are more the norm. It is possible that with better techniques to uncover the parameters of

human behavior (e.g., experimental methods in economics) that this bias will lessen.

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Session 3. What should the design of an effective integrated model include?

3.1 What characteristics are required for an integrated model?

Up to now a lot of land-use models have included either the human or the environmental subsystem, only very rarely both are indeed integrated to address the coupled human-environment system with a holistic point of view. However, the need to do so is increasingly stressed and also proved (Lakes et al. 2007, Lakes & Müller, Lakes & Schwanghart). First of all we want to point out the importance of a spatially explicit approach for an integrated model, since spatially explicit information add a benefit for the holistic view of the coupled human-environment system, such as on spatial interactions between subsystems, neighbourhood effects (Müller et al., Lakes & Müller, Lakes et al. 2007). Secondly, we think that the new generation of integrated models should move beyond traditional approaches of spatial models which focused very much on land use and land cover change and might have been too much dominated by available data and techniques, such as the availability of remote-sensing data. In these traditional models the conceptual model of land change only rarely integrates driving factors, underlying causes and impacts within a holistic human-environment approach in an explicit way. We think that an integrated land-use model approach requires the following characteristics on the three levels of modelling, the conceptual, methodical, and data level:

- Conceptual level:

Drivers and underlying causes as well as impacts on the human and environmental system should be included in the modelling approach to get a holistic view of the land-use system. The theory and methods of the complex systems approach might offer benefits to analyse the coupled human-environmental system and not only subsystems of it (Lakes & Schwanghart). The integrated modelling approach anticipates that the aim of land-use modelling is more than a descriptive task but rather one which can help to explore and explain a system's behaviour. Modelling should as well serve as a tool to predict, forecast, and prognose future development paths and, perhaps most important, modelling can provide a means to communicate between scientists, decision-makers and people concerned with processes of land change (Lakes & Schwanghart). Hence we think that on a conceptual level it is most important to identify and describe the conceptual model and to specify the aim of modelling in a specific case study.

- methodical level:

Since the conceptual model and the modelling aim very much dominate the techniques to be used, we think we need a more careful look at the specific techniques within a certain application. Complexity of coupled human-environment system can eg. be well-represented and simplified in cellular automata (Lakes & Schwanghart), microsimulation and agent-based models instead resemble the human behaviour to a deeper extent (Lakes & Hostert 2007), while neural networks are powerful computational tools to predict likely future spatial patterns and statistical models detect and value the underlying causes and drivers (Lakes & Müller in review). As we show in Lakes et al. 2007 and in Lakes & Müller (in review) the need for coupling different modelling techniques and the evaluation of techniques should be a future

focus of work. Another good example is the successful combination of cellular automata with agent-based models. However, the integrated models need to meet the requirement to provide a well-documented measure for achieving the proposed goal (storyline, quantitative, qualitative). Hence, to document benefits but also drawbacks of different modelling techniques as well as coupling modelling techniques should be characteristics of integrated land-use models.

- *data level:*

The integrated land use modelling approach is of course reflected in a new type of information needed. We believe that remote-sensing data on land-use/land-cover is one important source for mapping land use and modelling land-use developments (Kümmerle et al. 2006), particularly since satellite data has become available for free (GLCF). However, it is only one data source next to data on socio-economic situation, demographics, health, environment etc. Integrating the different data sources and also quantitative and qualitative data is necessary (Lakes & Müller in review). An important characteristics of integrated models should hence be to bridge the divide between quantitative and qualitative data, to combine different data sources, and to provide an easy access not only for remote-sensing data but also additional data on the coupled human-environment system for case studies.

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Session 3. What should the design of an effective integrated model include?

My work has so far included aspects of integration at several different levels and characteristics. Firstly it has been an integration of **spatial levels** in terms of data. One such example is using remote sensing data with different spatial resolution. Secondly I have tried to work with integration of **qualitative and quantitative data**, such as mixing information from remote sensing with personal interview data. Thirdly the two first aspects usually lead to a third integration which is **linking a social process, such as a land reform, with a physical process, such as increased vegetation** where linkages are investigated. Finally, my experience is that very seldom is a land-use issue described by two parameters of data, but of a **complex web of processes** covering local, regional and global levels; personal, cultural, political, climatological, economical and geomorphological drivers. How to model this properly - I don't know. These aspects are what interest me and what I have worked with and that I would like to develop further.

From this I would like to pose a few questions that I hope to discuss with the participants at the workshop and I have also included a few references to studies that have generated these questions.

- a) How are changes in land use over time properly correlated to other processes –
a) lag effects of physical and social processes b) spatial vs. temporal?
- b) How are case study materials being most useful in extrapolating more large scale or general processes? Dangers and strengths.
- c) How can drivers to land- use change be assessed?
- d) Is there certain data that can not be used in integrating work?
- e) When is an integrating model effective?
- f) Where does simplicity and clarity ends and inaccuracy begin?

Apart from my own questions I am really looking forward to discuss the ones that Eleanor put forward:

3.1 What characteristics are required for an integrated model?

3.2 When does 'coupling' or 'linkage' stop and integration begin? Do we need a formal definition for integration?

3.3 How do we identify and model feedbacks?

3.4 Should complexity in all subsystems of an integrated model be comparable?

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Session 1. What are we trying to model?

1.1 The goal of the Global Land Project is to measure, model and understand the coupled human-environmental system as a whole. In a modelling context how should this differ from previous initiatives which considered land use and land cover change only?

It seems we probably seek greater emphasis on modelling the environmental behaviour of agents operating on the landscape, not just on the drivers of land-use change. Some of my newer and proposed work falls in this area, and in particular proposes to compare the relative environmental effects of land-use change vs. land-manager behaviour, so I have some bias already. (See for example [http://mason.gmu.edu/dparker3/Potomac Gorge Website/index.html](http://mason.gmu.edu/dparker3/Potomac_Gorge_Website/index.html).) We should probably also seek more modelling of the ecological/biophysical effects of land-use and land-cover change, rather than just on the character of land-use change. So in that sense, the extent of modelling has increased. Yet, it is probably important not to make the scope of things larger, and try to expand land-change science to look at all ecosystem services, etc. We should keep our focus grounded by making sure that LUCC questions are central to our analysis.

1.2 What should we be working towards for full integration?

Not sure what I can add here beyond 1.1.

1.3 Emergence; how important is it and how do we deal with it?

We should be diligent to not get caught up in discussion of what emergence is or isn't, and whether or not it is surprising. What is useful, I think, is the idea of identifying higher-scale (macro-scale) patterns that are a result of decisions and interactions of elements at a lower scale, such as described in Grimm et al. (2005) and reviewed in Parker et al. (2003). This is a useful perspective for modelling complex systems, and it can be useful for our modelling goals in the sense that many ecosystem services can be seen as emergent (See Daly and Farley (2004) for a very general introduction). But, I don't see the concept of emergence as the central organizing principle for a discussion of modelling coupled human-natural systems.

Session 2. Which modelling approaches should we take and why?

2.1 Should we go beyond model purpose dictating model structure?

My initial thought is no. I'm very much a proponent of building the right model for a particular research question, and teach my students that the type of model that they build should depend very much on the intent of the model, available data, resources, etc. Here is a list of questions that I suggest they answer when building a land-use model: http://mason.gmu.edu/~dparker3/lucc_class/modeling_questions.pdf

2.2 How do we represent a multi-scale/multi-structure approach in an integrated model?

This is a challenging open question. Almost without fail, multi-scale models are of a hybrid nature. (For instance, both CLUE-S (Verburg et al. 2002) and Environment Explorer (Engelen et al. 2003) use very different types of models for determining regional quantities of land-use change and local spatial allocation.) There are practical run-time considerations behind this, in some cases, in terms of having higher-scale models operate at a coarser resolution, even if actual decision making operates at a finer scale. For example, what if you wanted to create an agent-based version of something like Environment Explorer. Would it really be feasible to have all regional activities (trade flows, employment changes, migration, etc.) be modelled at the level of the individual agent? There are also practical considerations in terms of what models are already developed. Again on the subject of integrating a local (say, city level) model with a regional model, there are many regional models already developed that work at a fairly aggregated level. These may be an appropriate starting point, if a rational way could be found to create the right feedbacks (population migration, employment) between the regional and local-level model. This is a point of discussion, but the questions are not answered yet. For example, would the city-level model produce a stream of out-migrants, and receive a stream of in-migrants? Would their characteristics be preserved one-to-one as they relocated, or would they simply be part of a population with a distribution of characteristics?

2.3 What are the pros and cons of taking a framework approach?

I'm taking "framework" to mean an existing general model that can be customized for various case-specific applications. I see some benefits to developing and using frameworks when possible, as they can facilitate cross-site comparisons, speed up model development time, and enhance model communication. Again, both CLUE and the RIKS family of models are nice examples. The CORMAS code base and the many models developed from it is another very nice example (Bousquet et al. 2003). I've also been a proponent of developing a set of shared conceptual models for land-use change (Parker et al. In Press-a), which we have also used to undertake cross-site comparisons of existing models (Parker et al. In Press-b). Hopefully, this conceptual model will be instantiated in a shared code base at some point, again, providing students and researchers with a low-cost way to jumpstart model development.

There are also disadvantages to the framework approach, however. The main one is that there is a chance of using the wrong model for a particular research question and/or study site, just because the model is available and/or familiar. There is a danger of a particular approach or methods getting locked in, and the limitations of that approach not being revealed since it is universally used. However, in reality, this does not appear to be a practical danger for land-use modelling, and in fact, the existence of different frameworks can facilitate some comparisons between alternative approaches (Castella and Verburg 2007).

Session 3. What should the design of an effective integrated model include?

3.1 What characteristics are required for an integrated model? See 1.1, above.

3.2 When does ‘coupling’ or ‘linkage’ stop and integration begin? Do we need a formal definition for integration?

Again, I think this topic provides an opportunity for discussion to be diverted in the direction of definitions, to the exclusion of actually getting something done. That said, I think we need a formal definition for “integration,” but it should be very broad. Taking integration as a broad concept that includes coupled and/or linked models, it could be helpful to start with a discussion of the dimensions across which integration can occur. Certainly integration across human and natural systems is something that we are interested in. Integrated models can also be classified according to the degree of endogeneity (i.e., you can have integrated models that take either the human or natural system component as exogenous, and use that as an input to a model that determined the other component endogenously). There is the related issue of the direction and degree of linkages, and whether feedbacks are present, as we discuss Parker, Hessel, and Dasvis (In Press-c). Our approach effectively assumes that outputs of one side of modelling become inputs to other side—effectively, that the models are separable. Antle et al. (2001) describe a tighter form of integration, where as I understand it model component are not separable, but have a single set of drivers and endogenous elements for the whole model. Finally, scale is an important dimension across which integration can occur, for either/both human and natural systems.

3.3 How do we identify and model feedbacks?

I think identifying feedbacks is fairly easy. Modelling them is more difficult, due to practical considerations of scale matching (both at the data and process level), data availability, and the fact that many feedback are not direct. I also think that we might pay more attention to the issue of missing feedbacks, and how these compromise the sustainability of the modelled system (Parker et al. In Press-c). There is not a simple answer to this question.

3.4 Should complexity in all subsystems of an integrated model be comparable?

Good question. The answer is probably “no,” but the implications of having model components that are not comparable in terms of complexity has not been fully explored. There is the related issue of the extent to which model components need to have the same degree of empirical foundation (under the assumption that we are interested in building empirical models). This issue came up in recent discussions with Dan Brown’s research group, and generated some different perspectives. I am always a bit suspicious of models that are highly empirical in some dimensions (for instance, initialized with real-world land use data), but completely abstract in others (for instance, that use abstractly conceived and parameterized agent decision models). I worry that if they succeed empirically, it is in spite of, rather than because of, underlying model mechanisms, and that in fact there may be a wide range of behavioural rules that could have produced the same spatial outcome. However, to my knowledge, this question has not been investigated methodically.

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Session 1. What are we trying to model?

1.1 The goal of the Global Land Project is to measure, model and understand the coupled human-environmental system as a whole. In a modelling context how should this differ from previous initiatives which considered land use and land cover change only?

From a modelling point of view, this question seems to me to be simply to a case of broadening the domain of application: land use and land cover change being one aspect, or focus of human-environmental systems. It should thus be the case that the family of models belonging under the GLP umbrella is bigger than in previous initiatives, and there may be larger models, covering more of the human-environment system than previously; though perhaps in less detail.

1.2 What should we be working towards for full integration?

It is not particularly clear to me what the end-point ‘full integration’ precisely is. However my ideal world is one in which we have standards for understanding, sharing and reusing more transparent model components that we can build on to put together integrated models as we explore assumption space. Ken Kahn (2007) has illustrated a system in NetLogo that demonstrates the beginnings of this kind of functionality, but at a finer scale of modularisation, and confined to NetLogo only.

1.3 Emergence; how important is it and how do we deal with it?

Emergence is important from a scientific point of view in generalising findings from complex systems through identifying sets of interaction rules required to establish a particular emergent outcome, and how resilient such outcomes are. In the real world, I think emergence is unlikely to be particularly useful except in the most resilient cases (some simulated emergent phenomena might be sensitive to spatial representation or a particular scheduling sequence; see, for example, Bigbee et al., 2005), and even then, the fact that humans can observe and reflect on outcomes at the collective level could cause rule changes that would break the emergence.

Session 2. Which modelling approaches should we take and why?

2.1 Should we go beyond model purpose dictating model structure?

We should go beyond thinking of a model as a single entity in its own right, and start thinking about models as part of a family of models within a modelling framework. There is unlikely to be a generally accepted one-to-one (or many-to-one) relationship between the purpose for which a model is used and its structure. To adequately explore human-environmental systems, and attempt to factor out at least some of the arbitrary assumptions required during model construction, defining the structure of a model narrowly within the terms of a specific purpose is likely to prove too much of a constraint. It may also be desirable to look beyond the model boundary apparently

defined by a particular purpose in case bringing in extra information has a significant effect on the dynamics.

2.2 How do we represent a multi-scale/multi-structure approach in an integrated model?

This is a challenging problem, and one highlighted in a presentation to the LUCC meeting in Amsterdam in 2004 (Polhill et al., 2004). In integrating models from multiple disciplines, there can be clashes of spatial, temporal and organisational scale, and even clashes of underlying epistemological framework that need to be resolved. Addressing the challenge involves ensuring ontological consistency within the integrated model, and an approach to achieve this has been suggested by Polhill & Gotts (2006).

2.3 What are the pros and cons of taking a framework approach?

I'm not sure what this means.

Session 3. What should the design of an effective integrated model include?

3.1 What characteristics are required for an integrated model?

An integrated model should have an internally consistent ontology.

All software models claiming to be part of the scientific endeavour should be released under an appropriate licence (Polhill & Edmonds, 2007)

3.2 When does 'coupling' or 'linkage' stop and integration begin? Do we need a formal definition for integration?

Integration begins when one no longer sees submodels as separate, but as part of a whole that collectively forms a consistent ontology. In coupled systems, there is no guarantee that submodels will not be duplicating the representation of some phenomenon or other, leading to potential inconsistencies in the state of that phenomenon at some point during simulations.

3.3 How do we identify and model feedbacks?

Modelling feedbacks in computer programs is relatively trivial in that a series of statements are executed that form a loop from a variable's value at one time to its value at a later time. Identifying them empirically would be rather more challenging, as within human-environmental systems, causal chains of events may be difficult to identify with certainty. Modellers may thus be put in a position where they are representing a particular narrative thread through the system. Since the narrative thread will influence the structure of the model, it may be desirable to look at other representations, as stated in 2.1 above.

3.4 Should complexity in all subsystems of an integrated model be comparable?

No. Not least because, so far as I am aware, there is not an adequately precise definition of complexity to enable the comparison to take place meaningfully. More importantly, even in an integrated model, different subsystems are likely to be modelled at different levels of detail. What matters is that this can be done in a way that does not lead to internal inconsistencies in the representation.

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Session 1. What are we trying to model?

1.1 The goal of the Global Land Project is to measure, model and understand the coupled human-environmental system as a whole. In a modelling context how should this differ from previous initiatives which considered land use and land cover change only?

I'm not sure that it does differ from the grand statements about the "LUCC" approach, as embodied in the 1995 Science Plan. Perhaps the role of human and ecological feedbacks, which ultimately define the vulnerability/resilience of the h-e system, is emphasized more in GLP than in LUCC, but I don't think that notion was absent in LUCC. In our view, it would also be helpful to try to make the GLP science use-able for the policy community.

1.2 What should we be working towards for full integration?

A spatially distributed human model, coupled with a spatially distributed terrestrial model, linked to a spatially distributed surface water model. The latter will connect human influences on land, and human influences in water, with impacts to widely distant areas (e.g. downstream lakes, rivers and oceans). Basically it is an Earth System Model perspective. Then, as noted in the answer to Question 1.1, attention should be paid to the use-ability of the research product. This means engaging potential "users" before and during the execution of the research.

1.3 Emergence; how important is it and how do we deal with it?

Perhaps the best thing is to take pains to "capture" it in a "findings" sense, rather than attempt to model it; emergence it seems to me is a product of modelling.

Session 2. Which modelling approaches should we take and why?

2.1 Should we go beyond model purpose dictating model structure?

I don't understand this question. I think our group should try an experiment: to dictate the variables "ideal" models should incorporate. This is an exercise at the intermediate-level of abstraction. Perhaps the experiment will fail.

2.2 How do we represent a multi-scale/multi-structure approach in an integrated model?

Pay attention to the proper time/space scales, and create communication points appropriately.

2.3 What are the pros and cons of taking a framework approach?

I don't understand this question.

Session 3. What should the design of an effective integrated model include?

3.1 What characteristics are required for an integrated model?

Two features: (1) allow feedback loops to develop, and (2) a variety of types of people should be able to understand it.

3.2 When does 'coupling' or 'linkage' stop and integration begin? Do we need a formal definition for integration?

I think these terms are synonymous. But, given that our group is multi-national, perhaps we should spend a minute defining terms; we may reach quick consensus on these terms, or we may not. The reading audience for our publications is similarly multi-national so this could be a valuable exercise.

3.3 How do we identify and model feedbacks?

I think modelling a feedback can be considered an operationalization of the hypothesis that the feedback is important; validation of the model will test the hypothesis.

3.4 Should complexity in all subsystems of an integrated model be comparable?

I don't think that complexity in all subsystems of an integrated model *must* be comparable. I think the complexity of a modelled subsystem should relate to what is computationally/empirically possible.

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Session 1. What are we trying to model?

1.1. Measuring, modelling and understanding the coupled human-environmental system is not an easy task. Many studies focus on one or several aspects of the system only, depending on the disciplinary background of the researcher(s). Understanding the coupled human-environmental system as a whole requires collaboration and communication with a large group of researchers with different backgrounds.

In agricultural land use system analysis, there are few studies that adequately link the impact of biophysical conditions and the impact of management (related to socio-economic conditions and farm characteristics) on agricultural production, income and land use. It is important to take all these aspects into account when assessing the impacts of changes, e.g. of climate change (Reidsma, PhD thesis, 2007).

The SEAMLESS project (System for Environmental and Agricultural Modelling; Linking European Science and Society; www.seamless-ip.org) develops a framework for integrated assessment of the agricultural sector. A computerized framework is being developed to assess and compare, ex-ante, alternative agricultural and environmental policy options. Models are developed at multiple scales, which provide indicators in different dimensions of sustainability (economic, environmental and social). Important for the linking of models is the development of an ontology. An ontology stores information on all the variables and relationships in the given models in a computer language. This ensures the technical linking of models, but importantly, the communication and agreement between researchers on what is being modeled, improves understanding of the causal chains in the human-environmental system.

While SEAMLESS focuses on multiple scales in agriculture, the SENSOR project (www.sensor-ip.org) focuses on multiple land use sectors at regional level. In the LUPIS project (Land Use Policies and Sustainable Development in Developing Countries; www.lupis.eu) the methodologies developed in SEAMLESS and in SENSOR, which are applied in the European Union, are evaluated and adapted for application in developing countries. A methodological framework is being developed for integrated assessment of the impact of land use policies and global trends on sustainable development (SD), in the context of a range of developing countries. Land use change is an important intermediate indicator for assessing the impact of land use policies on SD, but the major challenge is to assess how land use change links to different economic, environmental and social indicators.

1.2 Full integration of computer models requires a lot of time for software development. The objective of SEAMLESS is to develop a generic tool. It is tested for several applications in the European Union, but should allow re-use for new assessments. For European case studies this will likely be possible, but as the LUPIS project revealed, currently the re-use of the whole computerized framework in other regions is not directly possible. Individual models and methods can be re-used and adapted for case studies, but the linkages between models and indicators need to be developed per case study. One of the reasons is that full integration of models requires a lot of technological and knowledge development. Interpretation of the results of an assessment is only possible if the researcher(s) fully understands the assessment, and building on developments of others can make this difficult. In LUPIS we aim for a full conceptual integration of the effects of land use policies on multiple indicators of

SD for multiple land use sectors and multiple scales, but not for an integrated modelling framework

Session 2. Which modelling approaches should we take and why?

2.2 In SEAMLESS models are developed at different scales and for different dimensions of sustainability. The different models provide input and output to each other. How outputs of a specific model provide inputs for another model is defined by the ontology. An indicator framework is developed for interpretation of results at different scales.

2.3 A framework approach is useful, as it provides guidelines on how to structure the research. As understanding of the coupled human-environmental system requires collaboration between several researchers, a clear framework can clarify the links between different models and assessments. The disadvantage of a framework approach is that often much time is being devoted to develop a framework, causing that there is little time left to do the actual modelling.

Session 3. What should the design of an effective integrated model include?

3.1 In an integrated model all drivers and all dimensions (i.e. economic, environmental and social) of a system should be considered. This may be a model at one scale (e.g. farm, region, nation, global), but taking into consideration the drivers that affect the system at other scales. It can also consider one land use sector (as for agriculture in SEAMLESS). An integrated model can be mathematically very complex, but may also be qualitative, as long all drivers and dimensions of the system are considered.

3.2 Coupling or linking refers to having different modules, which together form an integrated framework. Integration may imply that all aspects are integrated into one model. As the coupled-human environmental system is very complex, it is more desirable to link different modules and link these. An individual model can be adapted and re-used, it can be re-placed, without affecting other modules of the integrated framework. A good linking is also integration.

3.3 Feedbacks between different parts of the system are often ignored. As different parts of the system require different scientific backgrounds, models for these parts are often developed separately. Even in a large project like SEAMLESS it is difficult to identify and simulate all the feedbacks. In Reidsma (PhD thesis, 2007) we show how important the feedbacks between the biophysical conditions and management are for crop yields, farmer's income and land use. When the impact of climate change on agriculture is being assessed, often studies start with assessing changes in crop yields with crop models. These are based on biophysical relationships and do not consider management. The outputs are used for a bio-economic / land use model to assess income and land use. The outputs of these other models should however also provide feedback to the crop model, as management and adaptation largely influence crop yields. Consequently, the different output on crop yields will cause different outputs for land use and income.

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Session 1: What are we trying to model?

1.1 The goal of the Global Land Project is to measure, model and understand the coupled human-environmental system as a whole. In a modelling context how should this differ from previous initiatives which considered land use and land cover change only?

Land use and land cover change are important processes of the land-system. However, the focus of GLP research should not be limited to these activities but should also take into account material, energy and information flows within and between the different system components. From my perspective, there should be a much greater emphasis on the modelling of biogeochemical cycles, flows within human systems (industry, economy etc.) and their linkages. Nevertheless, putting the Earth surface in the centre of the system-view is a very suitable approach to define a reference for geographically linking processes. The design of our LandShift model reflects this sight by strictly distinguishing between the geographical reference system and processes which can operate on different spatial levels.

1.2 What should we be working towards for full integration?

Here we should discuss the meaning of the term “full integration” and whether we should aim to build models that are fully integrated. A classical definition for “integration” that may serve as a starting point, which stems from the field of integrated assessment is “the combination of socio-economic, environmental and technical aspects in a study or a model”. I would prefer to discuss these issues on a high level of abstraction (systems theory, definition of system boundaries etc.) instead of sticking to the level of modelling tools.

Session 2: Which modelling approaches should we take and why?

2.1. Should we go beyond model purpose dictating model structure?

Long time ago, I learned that the process of model building is driven by the underlying research question. From this point, I do not think that the model purpose dictates the model structure per-se, but that the modeller has to develop/use a model structure with an appropriate degree of complexity to answer his/her research question. Even if we would try to build a super-comprehensive fully-integrated land-system model the basic procedure of model building would be same (if we acknowledge that models can only be approximations of real world processes). But I strongly support that more resources should be spent in structuring models in a way that allows integrating them into larger contexts and adapting them for further studies. This aim should be kept in mind both for conceptual model building and software implementation of models.

2.2. How do we represent a multi-scale/multi-structure approach in an integrated model?

This is a question of software design. As mentioned before, in LandShift we separate the geographic representation (layers and linkages between the layers) from processes. Each process operates on one or more geographical levels and additionally can communicate with other processes. Currently these processes cover macro-economy, land use decision making, plant growth and hydrology. Even if it's not fully realized yet, we offer a simple framework to include and combine additional processes.

2.3. What are the pros and cons of taking a framework approach?

The suitability of software frameworks depends on the type of framework, number and qualification of scientists and time involved in the project. From my perspective it is very useful to offer the LandShift framework as a platform to integrate new sub-models as it is easier to maintain the consistency of the code base. Please note that in this case the aim is not to provide out-of-the-box tools for general model development or model coupling. Programming is still done in a 3GL language like C++. More general frameworks like RePast, OpenMI or the High Level Architecture (HLA) can drastically improve the time for software development and model communication, respectively. A major requirement for a software framework should be its availability under an open source licence. The greatest con is that frameworks might be very complex and need a substantial amount of programming skills to be used efficiently.

Session 3: What should the design of an effective integrated model include?

3.1. What characteristics are required for an integrated model?

The most important characteristic is that sub-models from multiple scientific disciplines are brought together and that the sub-models are connected in a way that represents the interactions of the components of the modelled real-world systems.

3.2. When does 'coupling' or 'linkage' stop and integration begin? Do we need a formal definition for integration?

Here we should look on the different meanings of "integration" on the conceptual and technical level. Ideas for the definition of "integration" on the conceptual level are given under 3.1. Looking at the technical level, a very first approach to separate "coupling" from "integration" might be to define an "integrated model" as a model that includes a closed specification of the modelled system, i.e. that each status variable and process has one unique representation within the model.

3.4. Should complexity in all subsystems of an integrated model be comparable?

Here we are back to the question whether model purpose should dictate model structure. I think, primarily each sub-system should implement the level of complexity that is necessary to fulfil its role in the integrated model. For example, a complex farmer decision model that needs information about crop yields and does not explicitly simulate management actions can use a relatively simple empirical yield

model (which is relatively easy to handle) whereas the simulation of impacts of fertilizer application on ground water would demand for a crop model that is able to simulate soil transport processes. Furthermore, I find it difficult to compare levels of complexity for instance between sub-models of natural systems (e.g. vegetation and soil) and economic models (e.g. number of processes, lines of code, type of modelling approach).

Shibu Ebrahim Mohamed
The Macaulay Institute, UK

Session 1. What are we trying to model?

1.1 The goal of the Global Land Project is to measure, model and understand the coupled human-environmental system as a whole. In a modelling context how should this differ from previous initiatives which considered land use and land cover change only?

Attempts to model the biophysical processes and finding the ways to manage natural resources were only a partial solution to the complex reality where human decisions are involved. Involving human decision making, which is always driven by socio-economic factors is very important to understand the land use/land cover change

1.2 What should we be working towards for full integration?

Integration of models is important, because environmental and socioeconomic systems have emergent properties which relate to the whole of the system. Modelling of the components alone does not simulate the reality. Models that address specific components of the system need to be carefully integrated in order to produce realistic scenarios.

1.3 Emergence; how important is it and how do we deal with it?

Emergence is a property of complex systems due to non-linear interactions between its various components. Emergence makes the modelling activity more complex. Agent based modelling (ABM) is a suitable approach to deal with emergence as it tries to replicate the complex nature of physical, biological and social systems that adapt over time through its non-homogenous agents, which behave in autonomous and goal-directed manner.

Session 2. Which modelling approaches should we take and why?

2.1 Should we go beyond model purpose dictating model structure?

Till now, modelling process is directed by the purpose or objective, which in turn could be very detailed comprehensive models or simple functional models. In the next generation modelling, we should be able to represent the system at different levels at different integrity (complexity) independent of their objectives in a single framework.

2.2 How do we represent a multi-scale/multi-structure approach in an integrated model?

Since different processes in different disciplines like bio-physical and socio-economic operate at different scales, representing and integrating processes across different spatial and temporal scales for the whole system is a major modelling challenge. In order to integrate these models, they should have compatible spatial and temporal scales, in the absence, an intermediate program may be required to reconcile different scales.

2.3 What are the pros and cons of taking a framework approach?

The problem is mainly of integrating different programming languages, different units, and different time steps for simulation for different models that we are trying to integrate in a single framework /integrated model.

Session 3. What should the design of an effective integrated model include?

3.1 What characteristics are required for an integrated model?

- a) An integrated modelling approach should have the best options for integrating environment, ecology, economy and social dimensions of a system
- b) The modelling framework should be able to analyse, optimise and build scenarios
- c) An integrated modelling framework must be able to integrate the best and most appropriate of existing models, knowledge and data

Pete Smith
The University of Aberdeen, UK

Session 1. What are we trying to model?

1.1 The goal of the Global Land Project is to measure, model and understand the coupled human-environmental system as a whole. In a modelling context how should this differ from previous initiatives which considered land use and land cover change only?

Yes – it should include more of the human behaviour / economics. The two approaches are to go for full Integrated Assessment Models (like IMAGE) which do all the feedbacks well but necessarily does each sector / region with not too much detail, or use detailed bottom-up models which perhaps do not do the feedbacks so well. A “dual constraint” top down and bottom approach (as per CarboEurope-IP) is probably the most informative way forward.

1.2 What should we be working towards for full integration?

See above – I like the idea of maintaining a range of approaches as each provides unique information, not provided by other approaches.

1.3 Emergence; how important is it and how do we deal with it?

Nothing intelligent to say here!!

Session 2. Which modelling approaches should we take and why?

2.1 Should we go beyond model purpose dictating model structure?

We should maintain a diversity of approaches since we have multiple questions to answer at multiple levels of detail (spatially and in terms of processes).

2.2 How do we represent a multi-scale/multi-structure approach in an integrated model?

Or the question might be, should we even be trying to reinvent another integrated model. This is a very interesting topic for discussion at your meeting.

2.3 What are the pros and cons of taking a framework approach?

Pros are the explicit allowance of feedbacks in the biophysical / economic / human system. Cons are the necessary sacrifice of some sectoral details which would be too complex to model in a fully integrated system.

Session 3. What should the design of an effective integrated model include?

3.1 What characteristics are required for an integrated model?

Well tested system feedbacks.

3.2 When does ‘coupling’ or ‘linkage’ stop and integration begin? Do we need a formal definition for integration?

No – I don’t think we really need a definition. Coupling and linkage is the first step toward integration. We might ask ourselves if, in some circumstances, ‘coupling’ or ‘linkage’ might be enough to answer a specific question.

3.3 How do we identify and model feedbacks?

We should know them when our non-integrated system fails, or where we know that a feedback is not coded in. For example, we run models to simulate GHG emissions, but unless this information is fed back into a GCM and the climate forcing recalculated, we know that we are not taking account of this feedback. I guess I am saying – in some cases we just know that the feedback is not included.

3.4 Should complexity in all subsystems of an integrated model be comparable?

In principle yes, but for answering specific questions, more detail might be required in some sub-modules than others. It all depends upon the system sensitivities – a sensitivity (and uncertainty) analysis of any such integrated model is essential to determine the level of complexity / detail required in each module (for a given use).

Diego Valbuena
Wageningen University, The Netherlands

Session 1. What are we trying to model?

I think that if we try to model the whole coupled human and natural system, the results of such model (including MAS) will primarily remain in a theoretical world. In my point of view, empirical models cannot address the whole systems, and therefore, these models need to address particular processes at specific spatial scales.

Session 2. Which modelling approaches should be take and why?

To design an integrate approach, the interaction of different disciplines is needed. I believe that the main aim of such an interaction is to give a better understanding of both human and natural systems, and how they interact. However, each discipline has its own set of relevant approaches. For me, this diversity of approaches shows the complexity of the systems we are dealing with, including ourselves as observers. So, instead of propose specific approaches and model structures, I suggest that we need to develop a simple and flexible framework that allows us to compare different approaches, while describing the model itself—including the type assumptions and level of uncertainty.

Session 3. What should the design of an effective integrated model include?

I think models are tools that help us to simplify, analyze and explore the patterns and dynamics of coupled systems. In that sense, integrated models need to be preceded by an integrated conceptual approach that make the link, instead of coupling or linking two models that were developed based on different approaches.

Although theory in complex systems and/or theoretical models might help us to identify where the potential feedbacks between systems and scales are, it is still necessary to test and illustrate such suppositions with real case studies. Otherwise, research on these topics will keep having an impact mainly on research itself, and not on decision-making processes.

Anne van der Veen
ITC and University of Twente, The Netherlands

Land use change and Agent Based Modeling

What are we trying to model in Twente?

We model agglomeration processes, trying to understand why land use changes from nature/agriculture to urban. Starting from Regional Economics we open the black box of so-called external economies of scale and model location behaviour of firms and households. We have chosen an Agent Based Modelling approach. Some call it Agent Based Computational Economics. Interactions between households and between firms establish complex systems that lead to emergent patterns. The specification of these interactions is of paramount importance for the ultimate results.

What should be working towards for full integration?

Full integration is a long-term goal from a science philosophical point of view; it implies a radical change, or shift in paradigms of the underlying scientific fields. A shorter-term goal is multidisciplinary collaboration.

How important is emergence and how to deal with it?

By definition, if we specify interactions between our agents the result will be any form of emergence. The success of integrative models of natural and social systems will depend on the specification of these interactions.

Which modelling approach?

Integrative models of natural and social systems have to recognize the problem of spatial and time scales. Socializing the pixel is the buzzword, however, the social sciences, especially economics have big problems in aggregating from micro to macro. Explicit modeling in spatial economics is in a baby phase. Moreover, in opting for an ABM modeling framework, the connection between GIS and ABM is perhaps a bridge too far.

When does coupling stop and integration begin?

Integration starts where overarching paradigms are beginning to develop. In some sciences this is a success (medical sciences), but in our field we experience huge challenges; the experiences within ecological economics show how difficult the process is. The idea of so-called environmental services seems to be a novelty that may lead to integration between economics and ecology.

Peter H Verburg
Wageningen University, The Netherlands

Session 1. What are we trying to model?

–The challenge of moving from land cover change to land use change and land(scape) function change

It is important to distinguish the different ways in which we may characterize the land surface in land change studies. Commonly we characterize the land surface by distinguishing different land cover types. Land cover addresses the layer of soils and biomass, including natural vegetation, crops and human structures that cover the land surface. Land cover is thus directly observable, both in the field as well as from remote sensing images. Land use in contrast refers to the purposes for which humans exploit the land cover. Land use is not always easily observable, although, in many cases, land use may be inferred from observable activities (e.g., grazing) or structural elements in the landscape (e.g., the presence of logging roads). When different land uses are systematically linked through either temporal (e.g. crop rotations) or spatial interactions we are dealing with land use systems. Detection and analysis of land use systems is often impossible based on land cover observations only, supplementary socio-economic information is needed to make a good assessment of land use system changes possible. At the level of the landscape a myriad of different, interacting land use systems may be present supplying a wide variety of goods and services to society. If we refer to the capacity of landscapes to provide goods and services we speak about land(scape) or ecosystem functions¹ (Groot, 1992; MEA, 2005; de Groot, 2006). Although the capacity of a landscape to provide landscape functions is related to land cover, many other factors including the spatial arrangement and temporal intensity of land use in the landscape may be important. Our common observation techniques and available maps and spatial datasets provide little information about the spatial variation in landscape functions.

Therefore, most land change models have focused on land cover dynamics, sometimes including land use types that are directly linked to observed land cover. This approach has limitations in properly assessing changes in the integrated land system. Land function may drastically change without any change in land cover and vice versa. Also in the coupling of different models problems originate from addressing land cover instead of land functions. When commodity based models (e.g., macro-economic projection models) are linked to land cover assessments (such as in the <http://www.eururalis.eu> modeling system) changing demands for commodities need to be translated into changes in land cover areas. Alto the demands for other land functions are expressed in units that cannot directly be translated in land cover areas. Multi-functionality of land use can cause one particular land cover to fulfill the demand for several land functions. On the other hand, fallow agricultural land or recently abandoned farmland may still be classified as agricultural land cover while its new functionality is not explicitly linked to a demand from society.

Similar considerations apply to the use of data to calibrate and validate models of land cover change. Large inconsistencies between statistical databases (census) and remote sensing data are frequently reported. Although some of these inconsistencies can be attributed to aggregation errors (e.g., neglecting linear features and small scale landscape elements, figure 1) and observation problems the main difference may be

attributed to the reporting of respectively area used for production (land use/land function area) and the observed areas of a land cover type possibly associated to that land function.

In this paper we will use the term landscape functions when referring to the goods and services provided by the ecosystems and land use systems within the landscape. Policy formulation and land use planning is often aiming at enhancing specific or multiple functionalities of the land. Therefore, insight in the changing functionalities of the land is essential. Land cover models are not always capable providing these insights.

Based on these recommendations, both from a technical/data perspective and a policy perspective, it seems obvious that a move toward land function change modeling would be a useful step. The largest challenge is however the quantification and mapping of land functions since these are not directly observable.



Figure 1. Examples of landscape composition in two areas (left: South-West UK; right: North-West Netherlands) that are entirely used for agriculture according to remotely sensed land cover datasets at 100x100 meter resolution (CORINE database, EEA). Landscape elements that cause a lower actual surface area of agriculture are indicated (images based on Google Earth, accessed January 2008).

Session 3. What should the design of an effective integrated model include?

3.3 How do we model feedbacks?

-Some notes from Verburg, P.H. (2006) *Simulating feedback in land use and land cover change models*. *Landscape Ecology*, 21(8): 1171-1183.

A further integration of the social and biophysical systems in land change models could be achieved by explicitly including feedback mechanisms in land change models. Feedbacks are seen as an important feature of complex systems such as land use systems and a key characteristics of the deterministic complexity of such systems. Three types of feedbacks in land use systems are frequently mentioned in a number of recent reviews of land use change models. These three different types of feedbacks include:

- Feedbacks between the driving factors and the effects of land use change (impacts).
- Feedbacks between local and regional processes of land use change.
- Feedbacks between agents of land use change and the spatial units of the environment.

These three types of feedback are interrelated and all address the interaction between decision making structures and the spatial organization of the landscape.

Most feedback mechanisms between the impacts and driving factors of land use change can only be made operational when a link between the land and the people is established. It is therefore essential to know over which scales and which levels of spatial and social organization such feedbacks occur. The inclusion of system feedbacks will also challenge the techniques we have for model parameterization and calibration. When e.g., land use change and erosion/sedimentation process models are connected both models need to be calibrated independently. Calibration of the coupled system is more difficult because interdependencies may lead to multiple possible solutions and make it difficult to trace the influence of different variables. Feedbacks cause strong path-dependence in models and a high sensitivity to initial conditions. In land use systems initial conditions, such as land use history are largely uncertain, leading to high potential of error propagation and bifurcation. These problems ask for new techniques of model parameterization, focusing on dynamic analysis of land use trajectories and calibration/validation techniques that are suitable for such systems.

Abdoulaye Wélé
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Session 1. What are we trying to model?

1.1 The goal of the Global Land Project is to measure, model and understand the coupled human-environmental system as a whole. In a modelling context how should this differ from previous initiatives which considered land use and land cover change only?

I think in most of previous patterns, the human factor is taken into account but not directly as we are trying to do in our workshop. For instance in case of modelling the vegetation evolution, we can say that the tree cover, the density, the bare soils and so on are the consequences of a given type of resource management. These factors are very closed to human actions and are the expressions of their acts. The destruction of woody vegetation for cropland for example is not a natural process but reflects the need of human beings to access to the land, cultivate it in order to live. The immediate consequence is the tree cover reduction, the physiognomy change and the destructions of species. These list of responses is not complete but shows the human effects are indirectly considered. In modelling, these aspects are often focused.

1.2 What should we be working towards for full integration?

For full integration we must think about how to integrate human factors in modelling so that the used patterns reflect a situation which will be conform to the reality. That is the challenge in the context of climate change and the necessity to respect the sustainable development. Socio-economics activities are also taken in consideration in a lot of models but the data are quantitative. How integrate in models the qualitative aspects, the populations practices, which are very important, sometimes more important than the quantitative ones and explain the main trends and expected situation. Some factors are essential since we work in land field such as the tenure, area, land use, land occupation, population growth, erosion with loss of land, slope, type of soil, soil structure, rainfall, vegetation cover, wind speed and direction, bushfire, overgrazing, spatial needs, development planning policies especially in fact of territorial management at different scales national and local level.

Session 2. Which modelling approaches should we take and why?

2.1 Should we go beyond model purpose dictating model structure?

A good model is theoretically based on the objectives assigned to it and it dictates the structuration of the model to be undertaken. The **availability** and **reliability** of data are also very important to determine the kind of model and finally the model has to be tested to see the level of accuracy with relevance to field reality.

2.2 How do we represent a multi-scale/multi-structure approach in an integrated model?

We can represent a multi-scale/multi-structure approach in an integrated model by using an participatory approach where man has a core role to play. Since the understanding of global land is very complex and requires many disciplines, different scales, spatio-temporal dynamics, different models (hydrological model, forest model,...etc.). All these elements and their interactions must be considered and

integrated. That is a big problem to master this complexity which is the distinctive feature of most natural processes. Simulation can lead to a virtual situation where experimentation could help to better represent the evolution, the dynamics by adding or stopping, modifying some data at a given time and waiting for a new virtual reality. An opportunity to focus on training must be found by experimenting a series of exercises on landscape changes simulation which might improve, strengthen our ability to model and predict an event. . Where, when and How ?

2.3 What are the pros and cons of taking a framework approach?

The framework approach can be motivated by:

- the need of focusing on a limited number of fields;
- the need to address global change
- to have one tool for monitoring use and change landscapes, ecosystem....etc.

The elements against this approach are:

- it does not focus on the specificities;
- some important factors can intentionally be neglected
- The information derived from this approach should not be representative of small areas at a local scale

Session 3. What should the design of an effective integrated model include?

3.1 What characteristics are required for an integrated model?

Powerful, Adapted, Easily understood

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A Multi-Grid Method for Earth Surface Systems

The earth surface environment is at the interface of the lithosphere, atmosphere, hydrosphere and biosphere, which is marked by webs of interrelations, mutual adjustments, chain reactions, flows and cycles of energy and matter, feedbacks and complex responses. An earth surface system is a set of interconnected components of the earth surface environment that function together as a complex whole (Phillips, 1999). Earth surface systems invariably reflect the interactions among the four spheres of the earth surface environment. Despite the variety and complexity of earth surface systems, there are some general principles about the way in which they function, and about the ways in which the interactions of the biosphere, lithosphere, hydrosphere, and atmosphere manifest themselves at the surface of the earth. These general principles make surface modeling become possible. Although geographical information systems (GIS) have proven to be extremely powerful and have been applied to almost all kinds of earth surface systems and components of earth surface environment, there are still error problem and multi-scale problem, which have been accepted as research challenges of geographical information science (Usery and McMaster, 2005).

Issues on errors of surface modeling have been important research topics since the late 1960s and many methods for analyzing and measuring errors have been developed. However, these methods lack their theoretical foundation. The error problem is not attacked at the root.

Surface modelling is involved in various scales. Scale issue is an inherent part of surface modeling since 1960s. Solution of multi-scale problems has become the new frontier of ecology and geography since 1990s.

Thus a new method of surface modelling based on the fundamental theorem of surfaces (YUE-HASM) is presented (Yue et al., 2007, 2008a, 2008b). Numerical tests and the real world studies, such as construction of DEM and simulation of climatic change surfaces, show that YUE-HASM is much more accurate than the classical methods such as TIN, IDW, KRIGING and SPLINE. Spatial resolution has little impact on YUE-HASM accuracy, which means that YUE-HASM has given a solution to the multi-scale problems. YUE-HASM has given solutions to error and multi-scale problems that have long perplexed surface modelling. However, YUE-HASM has a much longer computing time because it must use two partial differential equations to simulate each lattice of a surface, which made YUE-HASM difficult to be widely applied in practice.

The two partial differential equations of YUE-HASM are evidently elliptic. It is found that multigrid works excellently for nicely elliptic problems (Trottenberg et al., 2001). The multigrid is generally accepted as being the fastest numerical method for the solution of elliptic partial differential equations. Thus, YUE-HASM is developed by means of the multigrid method and is used to simulate spatial patterns of climatic change in Jiangxi province of China on the basis of digital elevation model (DEM).

A promising and challenging trend in numerical simulation and scientific computing is the use of parallelism in numerical algorithms because most high performance computers are now parallel systems. In parallel multigrid, the given grid is partitioned

into a number of subgrids. Each processor works on the subgrid and communicates with the other processors. All multigrid components that have to be specified should be as parallel as possible and as efficient as possible. Parallelization of YUE-HASM is of particular importance. For many applications, even today's supercomputers are not powerful enough even if the multigrid methods were used. It is generally agreed that further accelerations in the supercomputer range will principally be achieved by an increasing degree of parallelism since possible improvements of single processors seem to be much more limited. Methods lacking either parallelism or numerical efficiency will not be suitable for the challenging problems of the future. How to design an ideal parallel multigrid algorithm depends on the concrete parallel architecture to be employed: whether a parallel system with shared, distributed or some hierarchical memory is used, whether it consists of vector, cache or scalar processors and which type of interconnection network is used.

Defining a global grid for the discretization of a given problem independently of the solution process is often insufficient. Adaptivity of grids principle is one of the major trends in numerical simulation and scientific computing. In the adaptive multigrid process finer and finer grids are not constructed globally. They are only constructed in those parts of the domain where the current discretization error is significantly large. An adaptive simulation approach with grid selection strategies is highly significant for YUE-HASM, which is a very desirable feature for an accurate analysis and an efficient simulation. The adaptive approach can be distinguished into predefined refinement and self-adaptive refinement. In predefined refinement, the refinement is determined before the solution process is started; in self-adaptive approaches, the grid refinements are carried out dynamically during the solution process. In practice, the predefined refinement and self-adaptive refinement may be combined (Trottenberg et al., 2001). The adaptive grid selection strategies generally have to provide a discretization approach with a domain partitioning method capable of adapting the size of the discretization cells locally and to supply an adaptive simulation approach with a method for the evaluation and control of the discrete approximation errors during simulation. In addition, construction of adaptive grids and the control of the discrete approximation accuracy should be performed both in space and time dimensions. Adaptive grid structures should allow for easy and efficient local modifications without introducing unnecessary refined domain areas and be as regular as possible in order to supply an acceptable order of consistency and to minimize the errors introduced with data transfers between different grid structures (Joppich and Mijalkovic, 1993).

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