**Potential New Project**: Under Consideration by the Geographical Sciences Committee of the National Research Council's Board on Earth Sciences and Resources.

# National Needs and Research Requirements for Land-Change Modeling

## ABBREVIATED STATEMENT OF TASK

A National Research Council committee will review the present status of land-change modeling approaches and describe future research needs so that model outputs can better assist the science, policy, and decision-support communities. Future needs for higher resolution and more accurate predictions will require improved coupling of land-change models to climate, ecology, and biochemistry models; improved validation of land-change models; and improved estimates of uncertainty associated with model outputs. The study will provide guidance on the verification strategies and research requirements needed to enhance the next generation of models.

## CONTEXT

Policy Context:

Understanding changes in land-use and land-cover over time provides a means to evaluate complex interactions between human and biophysical systems and to project future impacts of human activities on land-use and land-cover. Consequently, land-change science has evolved into a foundational element of climate, environmental, and sustainability science (see, e.g**.,** *Populations, Land Use, and Environment* (NRC, 2005), *Down to Earth: Geographic Information for Sustainable Development in Africa* (NRC, 2002), *Grand challenges in the Environmental Sciences* (NRC, 1999), *People and Pixels* (NRC, 1998), *Research Pathways for the Next Decade* (NRC, 1997), *Global Environmental Change: the Human Dimensions* (NRC,1992)). Land-change models provide a central analytical and forecasting tool for land-change science. They illuminate gaps in understanding, the processes and feedbacks acting on land change, and help to identify environmental and human consequences of this change (*Our Common Journey: Transition towards Sustainability* (NRC, 1999)).

In addition to supporting fundamental science, land-change models support decision making and policy analysis and development in applications at federal to local agencies and among stakeholders from international to local organizations. Understanding and projecting land change is pivotal to responding to questions on a broad range of topics, including ecosystem services like food and fiber production, biodiversity, carbon and water cycles, wildlife habitat, climate change, hazard mitigation, urban and regional studies, natural resource management, and transportation impact assessments. How much additional land will be needed to feed a growing population, especially in the developing world? What ecosystem services are lost, or could be gained, in the tradeoff with additional cropland? The Climate Change Science Program (CCSP) has defined five strategic questions that all demand attention to land-change models: (1) What tools or methods are needed to better characterize historic and current land-use and land-cover attributes and dynamics? (2) What are the primary drivers of land-use and land-cover change? (3) What will land-use and land-cover patterns and characteristics be 5 to 50 years into the future? (4) How do climate variability and change affect land use and land cover, and what are the potential feedbacks of changes in land use and land cover to climate? (5) What are the environmental, social, economic, and human health consequences of current and potential land-use and land-cover change over the next 5 to 50 years (CCSP, 2003)?

Rapid landscape change, driven by unprecedented global populations and rates of urbanization – for the first time over half of the world's population will live in urban areas by the end of the current decade (McGee 2001) – and consequent requirements for infrastructure, agricultural intensification and other resources, has created a growing demand in all domains for spatially explicit forecast models to provide improved information. A diverse range of land-change models already explain, predict, and project the type and location of change in land cover and land use. Individual agencies have evaluated the strengths and weaknesses of particular subsets of land-change models (e.g., EPA, USFS, USGS), but there are disparate programs and projects across the federal government that develop and/or use land-change models, and there is no systematic assessment of the efficacy and maturity of these modeling approaches relative to the objectives of national and international programs such as the CCSP, Global Change Research Program (GCRP) and the Global Earth Observation System of Systems (GEOSS) program. In addition, some work has been done on evaluating existing land-change models (e.g., Southworth 1995; U.S. E.P.A. 2000; Agrawal et al., 2002), but there is no unified national research agenda for developing the next generation of land-change modeling approaches despite the benefits in terms of efficiencies through pooling of resources, unearthing methodologies already in use that could have broader applicability, etc.

<u>Technical Context:</u>

Land-change models have become increasingly sophisticated in the last decade, with Europe taking the lead on applying models to policy questions. Nonetheless, land-change modeling is in its infancy compared with climate, water, and ecosystem modeling. Although there has been much research that contributes to our understanding of the dynamics of land-use and land-cover change from an observational or empirical basis, there is a need for (1) a synthesis of the state-of-art that can provide a roadmap for future model development, and (2) further development of approaches to model land-use and land-cover changes at spatial scales from local to global, and time scales from short (<5 years) to long (> 50 years), so that they are relevant to pressing societal and environmental problems.

Many modeling approaches are used to encode our understanding of land change in order to make forecasts and other analyses. These approaches include Markov, econometric, micro-simulation, dynamic spatial simulation, cellular automata, agent-based, and statistical-empirical models (see references in Appendix 1). With a focus on the spatially explicit models (also called "geographically enabled models"), this study will provide guidance to a diverse set of science- and application-based model users on the **strengths and weaknesses** of the various approaches and the appropriate contexts in which they can be applied. To date, comparisons have been limited in scope and such guidance is not widely available.

Modeling land-use and land-cover change dynamics across space and time requires **coupling** land-cover models with models of physical processes in such fields as climate, ecology, and biochemistry, and to models of social and economic dynamics that affect and are affected by environmental processes. Attempts to couple land-change models with these other models face a number of challenges. For example, the spatial and temporal scales and level of process detail of land-change models need to be compatible with both the driving processes of land change and broader models of environmental systems in which land-change is an important driver. So far, success in achieving such coupling has been ad hoc and on the basis of individual projects. In addition, the models must share semantic, ontological, and technical specifications to ensure inter-model communication.

Model **verification** also remains a challenge. Whatever the intended application, land-change models need to be sufficiently robust and rich in process-level detail that they are credible. Model comparisons and evaluations need to include evaluation of both their structure and performance in prediction. Land-change modelers have begun to develop metrics for model evaluation and apply them to suites of models (e.g., Pontius et al., 2007), but it is necessary to further consider model validation approaches in the context of land-change models developed for many different purposes.

Lastly, the capabilities of some models are challenged with the requirement to spatially forecast future states of land use and cover. Increasing attention is being paid in the ecological and social scientific communities to the effects of heterogeneity and patterning in space on the processes that are affected by land-change (like ecosystem productivity and human quality of life). Land-change models need to provide spatially explicity outputs so these effects can be evaluated. Land-change modeling can benefit from cross-fertilization and expansion among different modeling approaches. For example, some non-spatial models (like many economic forecasts of land-use shares) might be extensible in space, or could be used to constrain with existing spatial models. An evaluation of the future directions and opportunities in this regard is needed.

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