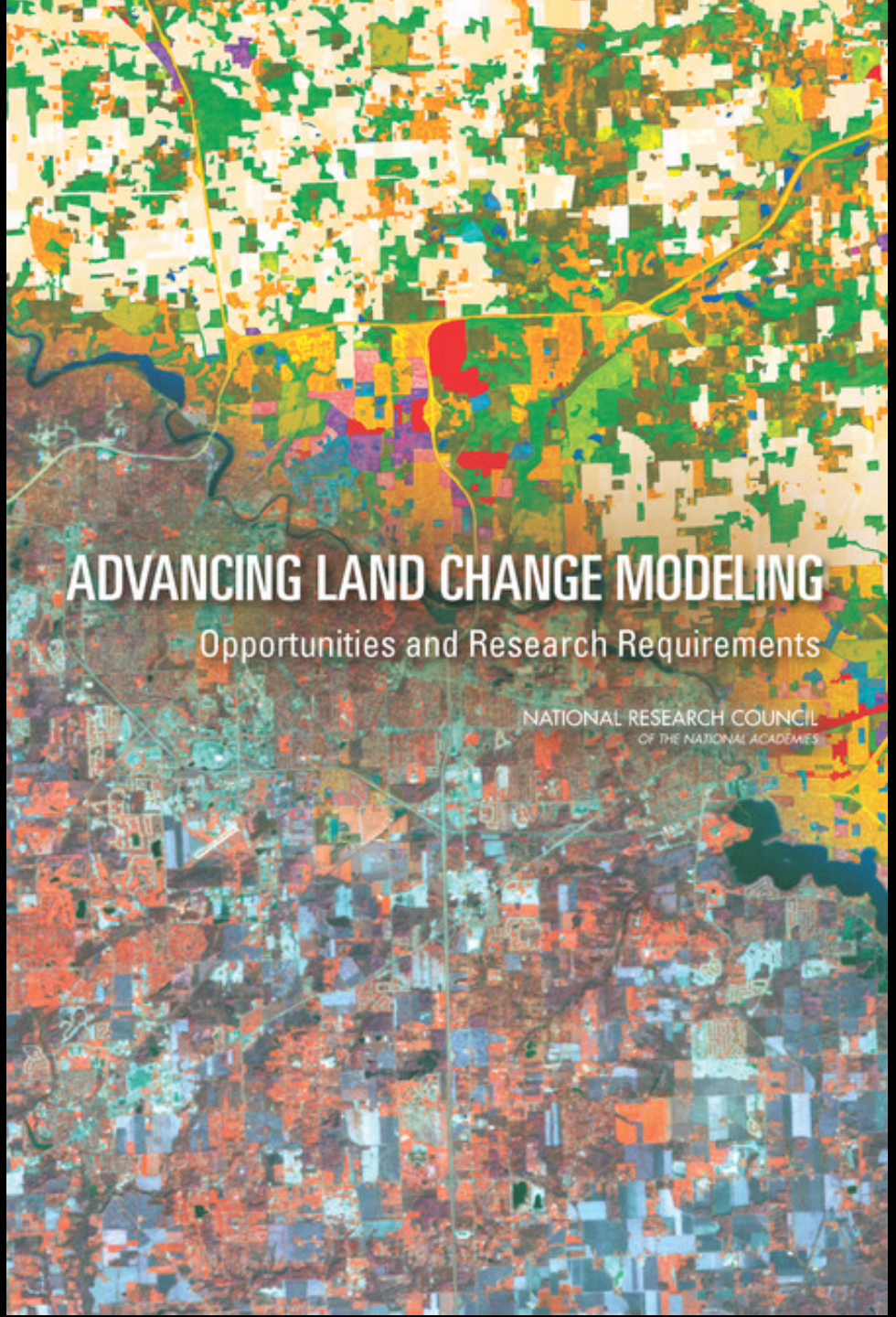
ADVANCING LAND CHANGE MODELING
Opportunities and Research Requirements
NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

Committee Membership

- Larry Band, UNC Chapel Hill
- Dan Brown (Chair), Michigan
- Kass Green, Kass Green and Associates
- Elena Irwin, Ohio State University
- Atul Jain, University of Illinois
- Eric Lambin, Stanford and Louvain
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- Karen Seto, Yale
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- Peter Verburg, Vrjie University Amsterdam
- Mark Lange (Study Director), NAS

Statement of Task, Goals

- Assess the analytical capabilities and science and/or policy applications of existing modeling approaches.
- Describe the theoretical and empirical basis and the major technical, research, and data development challenges associated with each modeling approach.
- Describe opportunities for improved integration of land observation strategies (including ground-based survey, satellite, and remote sensing data) with land-change modeling to improve land-change model outputs to better fulfill scientific and decision making requirements.

Process

- *Meeting 1:* Washington, DC – briefing by USGS and NASA, discuss statement of task
- *Meeting 2:* Chapel Hill – public input session on modeling approaches and suitability for particular applications
- *Meeting 3:* Washington, DC – report outlining, construct email survey
- *Meeting 4:* Woods Hole – review survey results, report drafting

Chapter 1

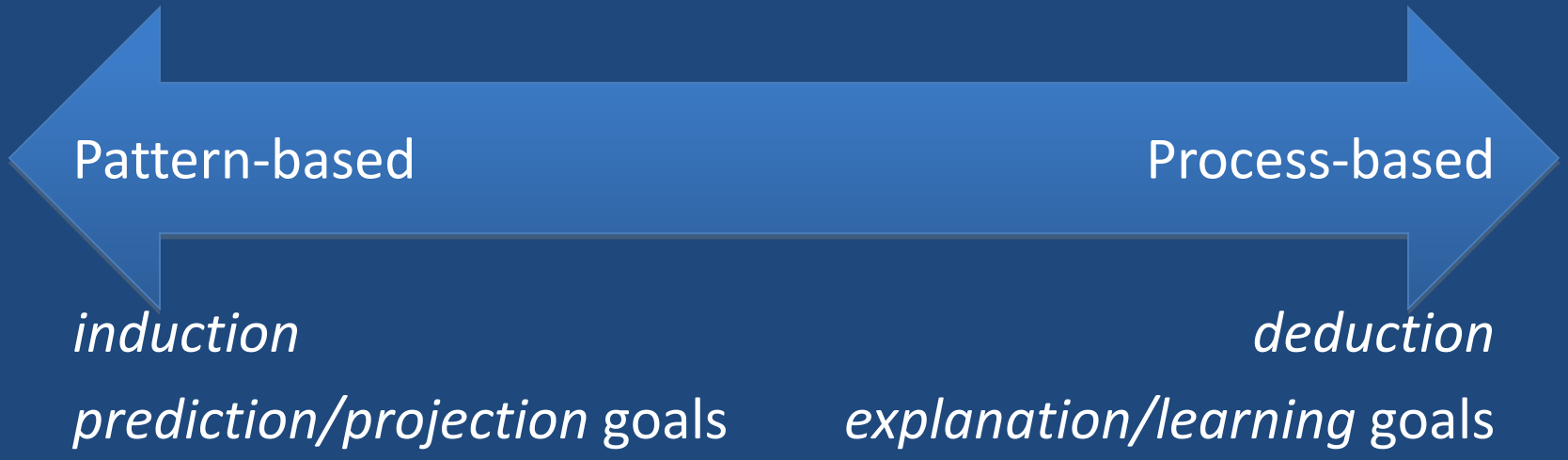
Application Domains for LCMs

- Land-climate interactions
- Water quantity and quality
- Biotic diversity, ecosystem function, and tradeoffs among ecosystem services
- Food and fiber production
- Energy and carbon (sequestration)
- Urbanization, infrastructure, and the built environment

Data Characterizing Land Change

- RS observational advances create opportunities
  - Increasing depth of Landsat archive
  - Increased temporal, spatial and spectral detail

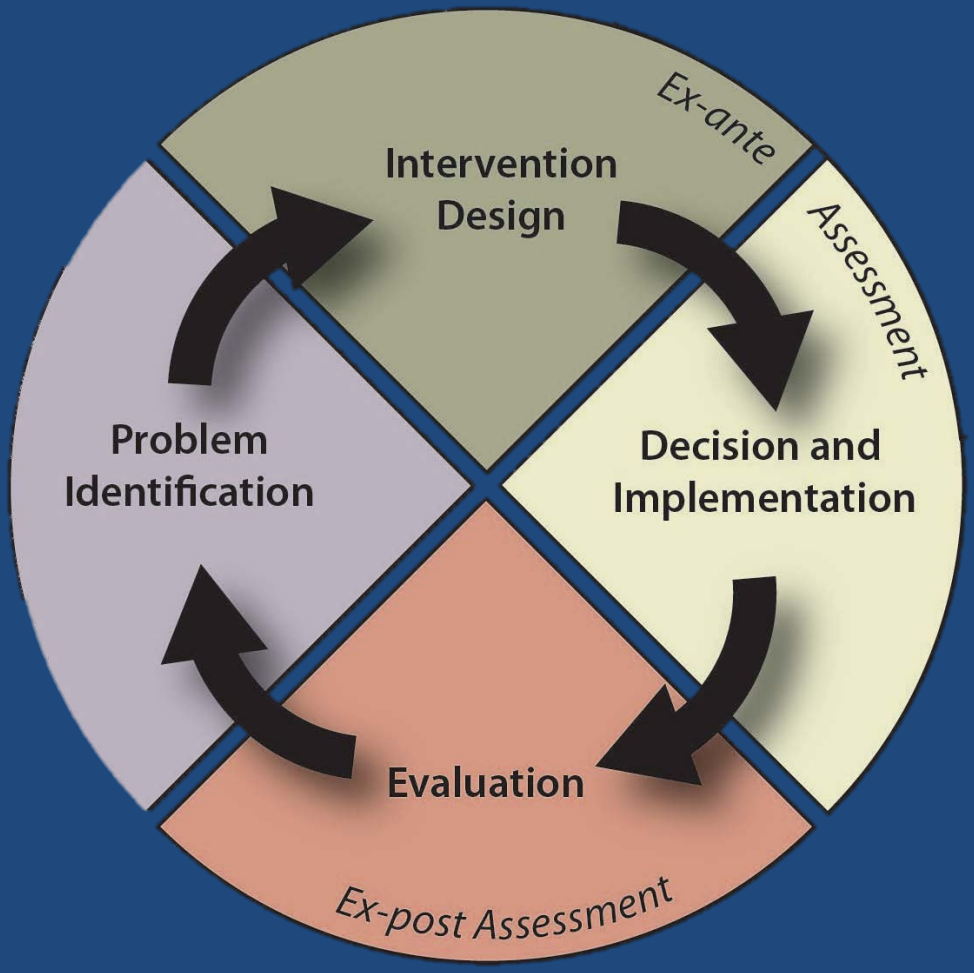
Modeling Concepts



- Most operational models fall somewhere in between
- Process identification challenged by equifinality (different processes produce similar patterns) and multifinality (same process produces multiple patterns)
- Projection challenged by non-stationarity, complexity, and path dependence in processes

Needs in Science and Practice

- Science uses tend to focus on explanation and learning goals.
- Policy and decision-making uses have varying goals depending on when they are used in the policy process, described here in four stages.



Based on Vedung (1997) *Public Policy and Program Evaluation*

Chapter 2: Modeling Approaches

Five overlapping approaches and hybrids were identified to evaluate their analytical capabilities and science and policy applications

- Machine learning
- Cellular
- Economic
  - Sector-based
  - Spatially disaggregated
- Agent-based

Machine Learning Models

- Focus is often on reproducing or predicting patterns, without formally describing processes.
- Patterns fitted to data (e.g., using ANNs, CARTs) and evaluated at some subsequent time.
- Appropriate for situations where data concerning pattern are available and theory concerning process is scant.

Cellular Models

- Also focused on patterns, but with spatial processes considered explicitly.
- Incorporate historical trends, land suitability, neighborhood interactions, and cross-scale interactions between land supply and demand.

Economic Models

Focus is on describing land use in economic terms

- assume profit or utility maximization of decision makers and market equilibrium
- based on a structural model of behavior

- Sector-based approaches focus of flows of goods and services among industries that create demand for land inputs over some geographic area. Use *representative agents* to represent aggregate sectors and regions.
- Spatial disaggregated approaches reduced-form econometric equations from spatial and temporal data, describing variables associated with land use changes.

Economic Models

Advantages

–Econometric models provide means to test hypotheses about specific effects.

–GE and PE models account for inter-regional and inter-sectoral interactions that lead to demands for land uses of different types.

Disadvantages

–Spatial resolution of GE and PE models is generally low.

–Don’t represent non-economic decision making well.

–Structural models difficult to estimate

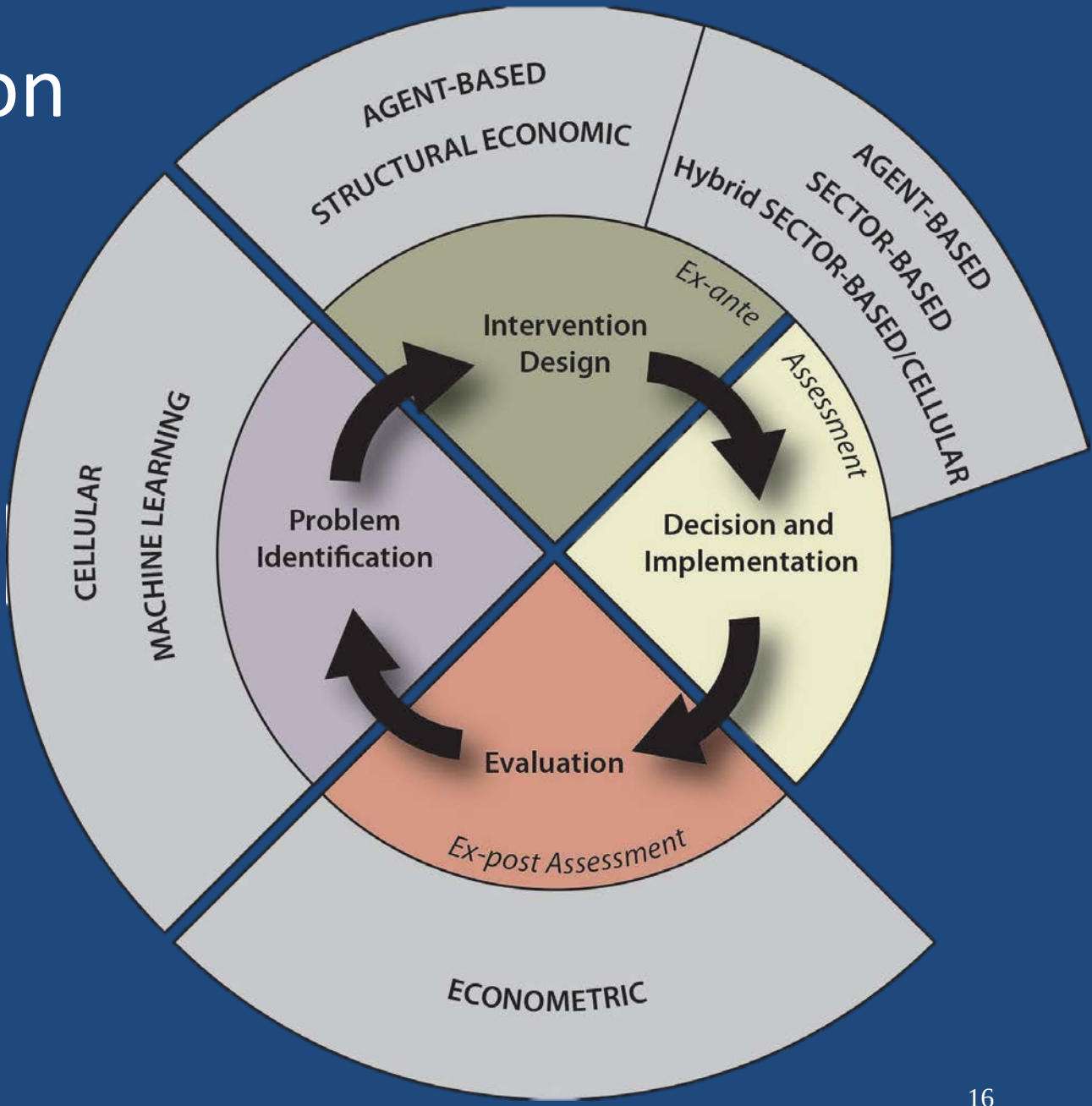
Agent-based Models

- Focus is on describing in computer code the process dynamics of change (i.e., structural models)
- Challenges include weak incorporation of economic theory, linking to statistical and data assimilation methods, high data demands, and need for better structural validation and output visualization.

Comparison

Considering the various goals of in the decision making process, different modeling approaches serve these different goals.

Model selection needs to consider match of approach to goals.



Chapter 3

Opportunities in

- LCM research
- Observations
- Cyberinfrastructure
- LCM infrastructure
- model evaluation

Opportunities in LCM Research

- *Advancement of process-based models*
  - Required for policy analyses like PES schemes.
  - Expanding models to include teleconnections and social networks
- *Cross-scale integration of models*
  - Bridging knowledge from aggregate and disaggregate approaches.
- *Cross-scale integration of LCMs and Earth System models*
  - Need models that address biophysical, like impervious to link with hydro models, albedo to link with climate models.
- *Bridging LCMs optimization and design-based approaches*
  - Simulating outcomes that are possible and those that are desirable
  - Provides links to design and planning

Opportunities in Observation

- *Improved capture and processing of remotely sensed data*
  - Better using high spatial, spectral, temporal vertical resolutions.
- *Integration of heterogeneous data sources*
  - Harmonizing multiple observation types over time can facilitate new information (e.g., management regimes, land function, land-use density)
- *Data on land-change actors*
  - Better use of land-oriented micro-data would help with process modeling
- *Making systematic land use observations*
  - Systematic land survey or observation network

Opportunities in Cyberinfrastructure

- *Crowd sourcing and distributed data mining*
  - Can be used to collected needed micro-data for econometric and ABMs
  - Pattern-based models can take advantage of ever larger data sets (finer resolution, more time points, larger areas)
  - Object-based approaches will be increasingly important for image analysis
- *High-performance computing*
  - Modeling approaches have variable need and opportunity to take advantage of multiple processors and GPUs

Opportunities in LCM Infrastructure

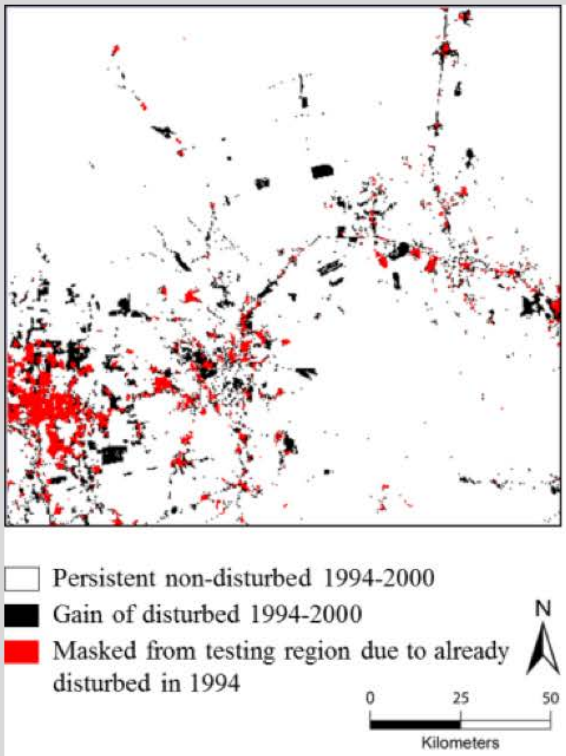
- *Model and software infrastructure*
  - Open models and development platforms should use more standard documentation
- *Data infrastructure*
  - Better compilation, curation, and comparison of heterogeneous data for LCMs needed.
- *Community modeling and governance*
  - Two possible models: CESM and openabm.org

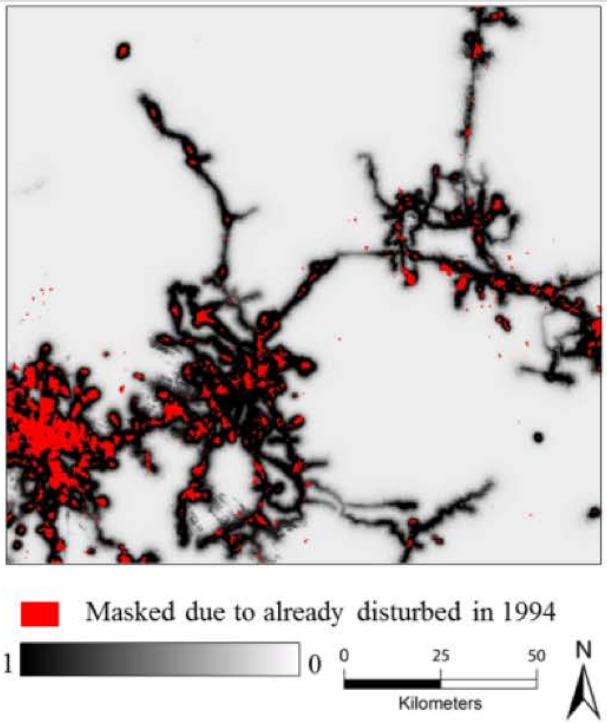
Opportunities in Model Evaluation

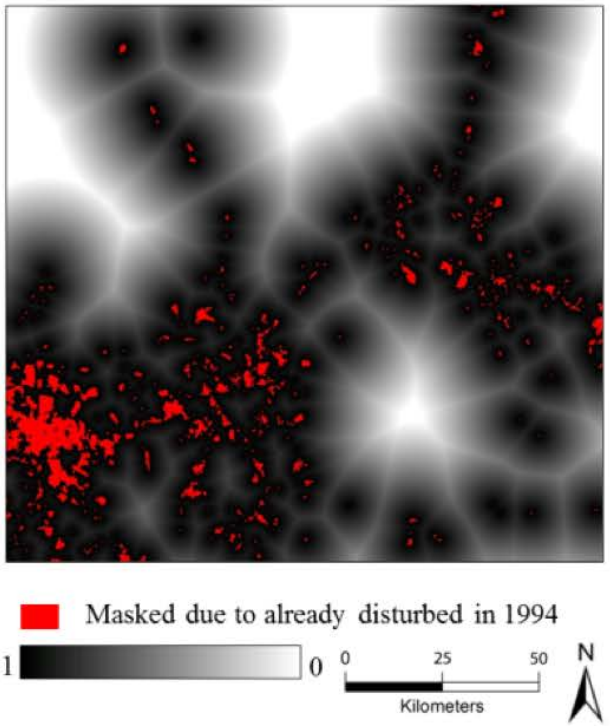
- *Sensitivity analysis*
  - Need more consistent analyses of sensitivity of models to variations in data, parameters and model structure.
- *Pattern validation*
  - Need more thoughtful use of map and pattern comparisons in model validation, considering non-stationarity, equifinality and multifinality.
- *Structural validation*
  - Need more work on the combination of quantitative and qualitative approaches to evaluating the match between model structure and real world processes.

Thank You

Machine Learning Example







a) Train *Idrisi*'s Multi-Layer Perceptron on past pattern of disturbance

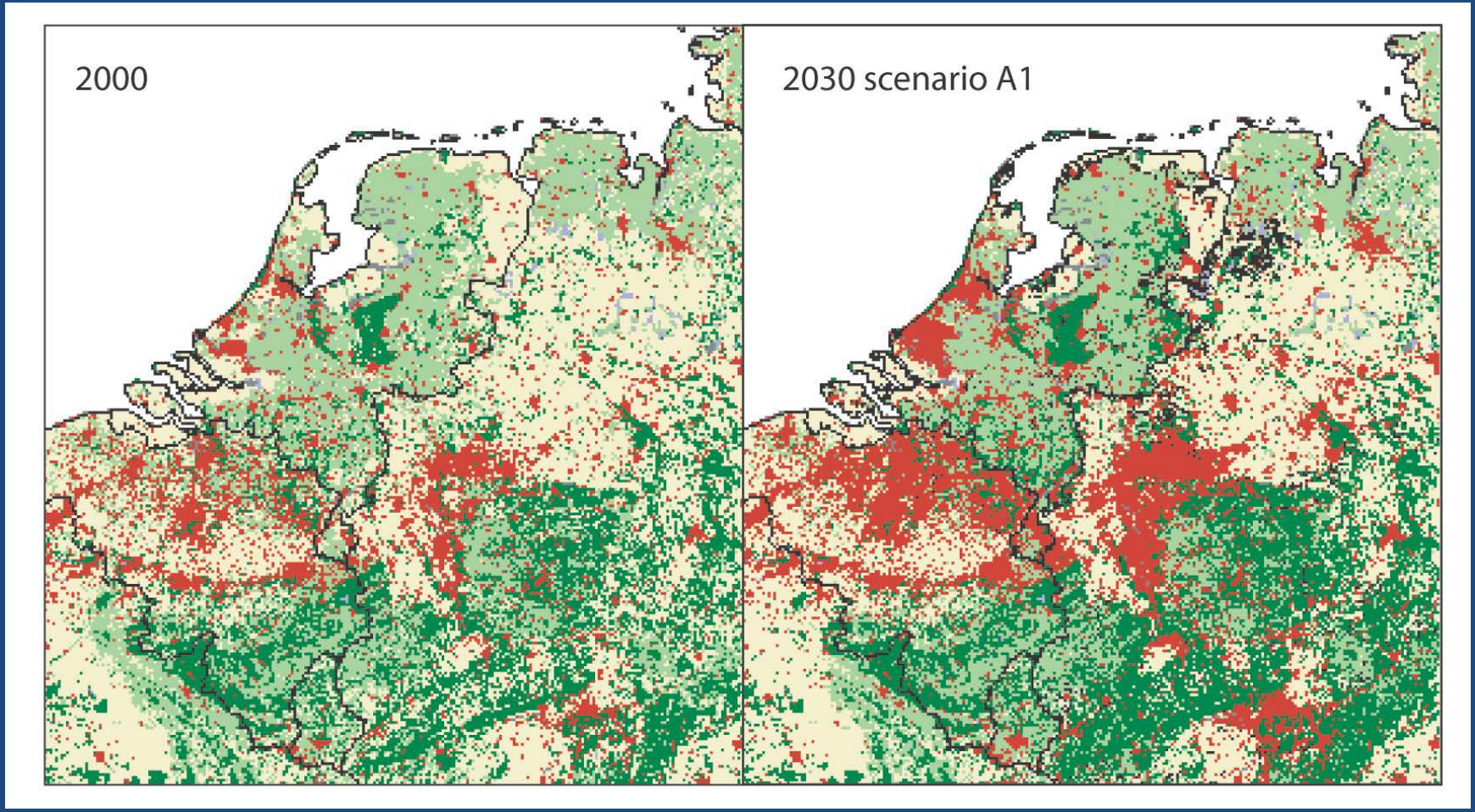
b) Use model to identify locations of future disturbance

c) Compare pattern to simple proximity model

Economic Models

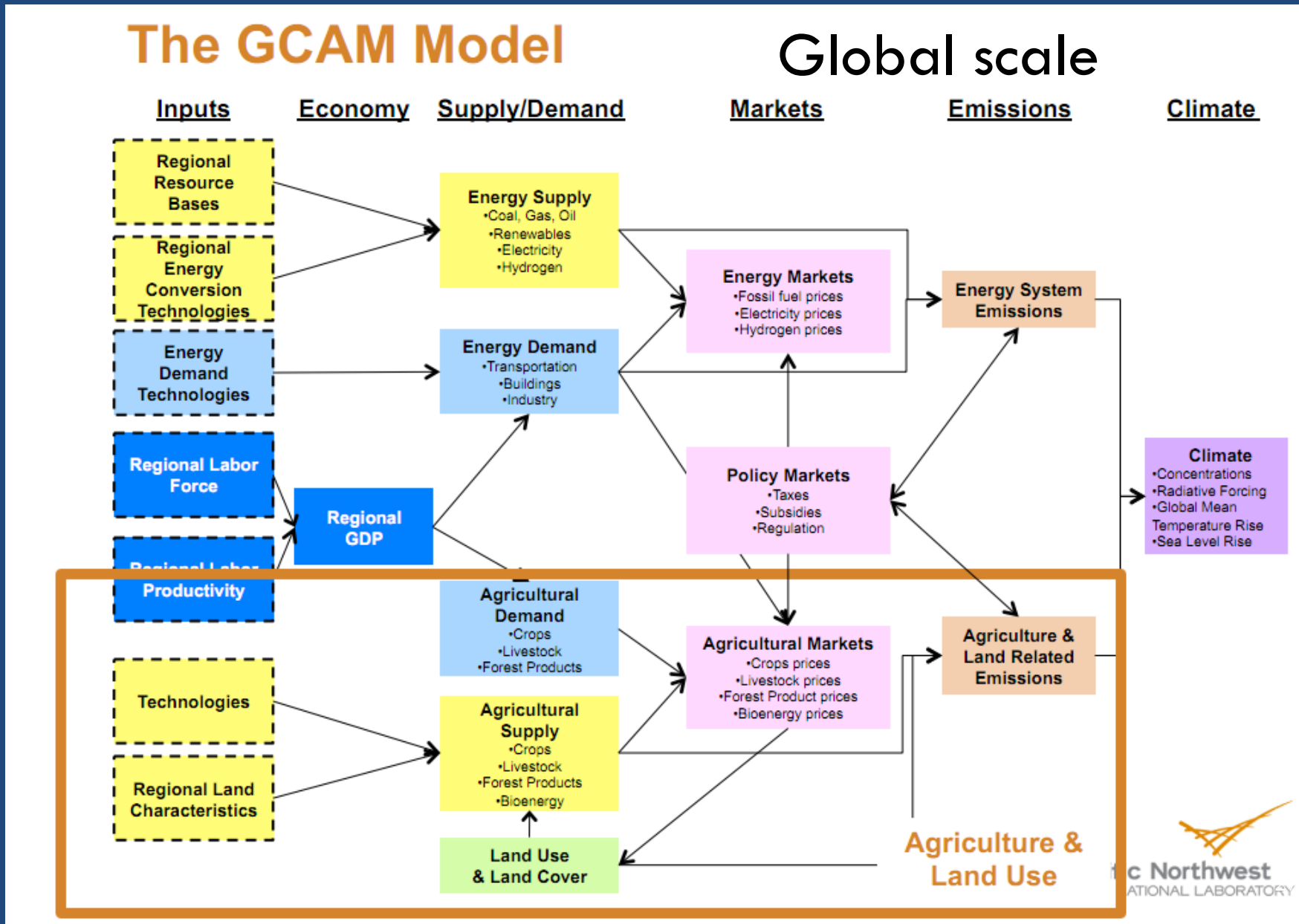
Modeling Approach	Key assumptions	Land Use/Cover	Typical Data Requirements	Recommended Uses
Sector-based	Utility or profit maximizing Representative agents	Land Use	Land-use or land-cover maps from at least one point in time Maps of explanatory variables Any other required instrumental or socioeconomic variables. Prices of commodities and values of trade.	Forecast land changes under a variety of market-based changes that can affect demand and supply.
Spatially disaggregated	Utility or profit maximizing Often homogeneous agents	Land Use	Land-use or land-cover maps from at least one point in time Maps of explanatory variables Any other required instrumental or socioeconomic variables.	Identify the influence of spatial and temporal variables on land change Simulate effects of policy changes on pattern outcomes

Cellular Model Example



CLUE models used to support policy discussion and ex-ante evaluations of policy alternatives.

Example Sector-based Model

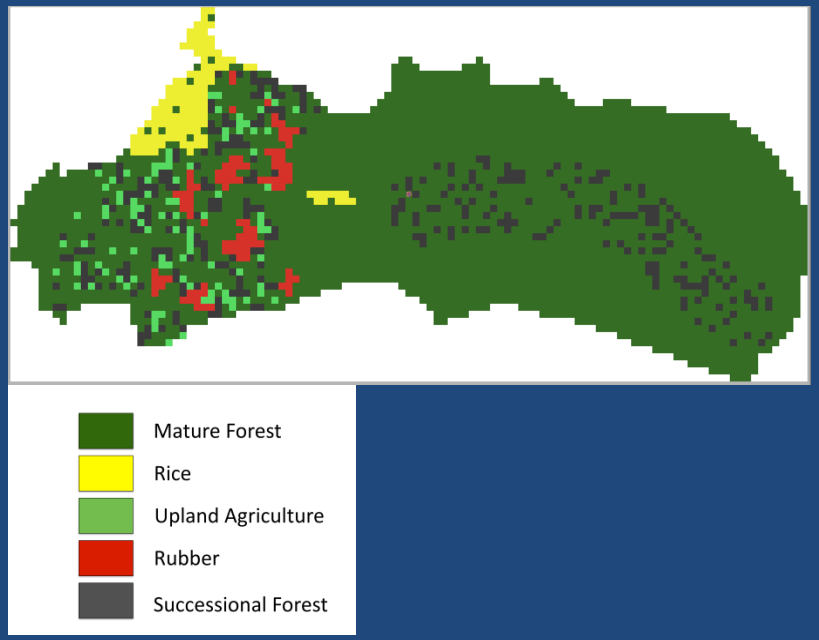


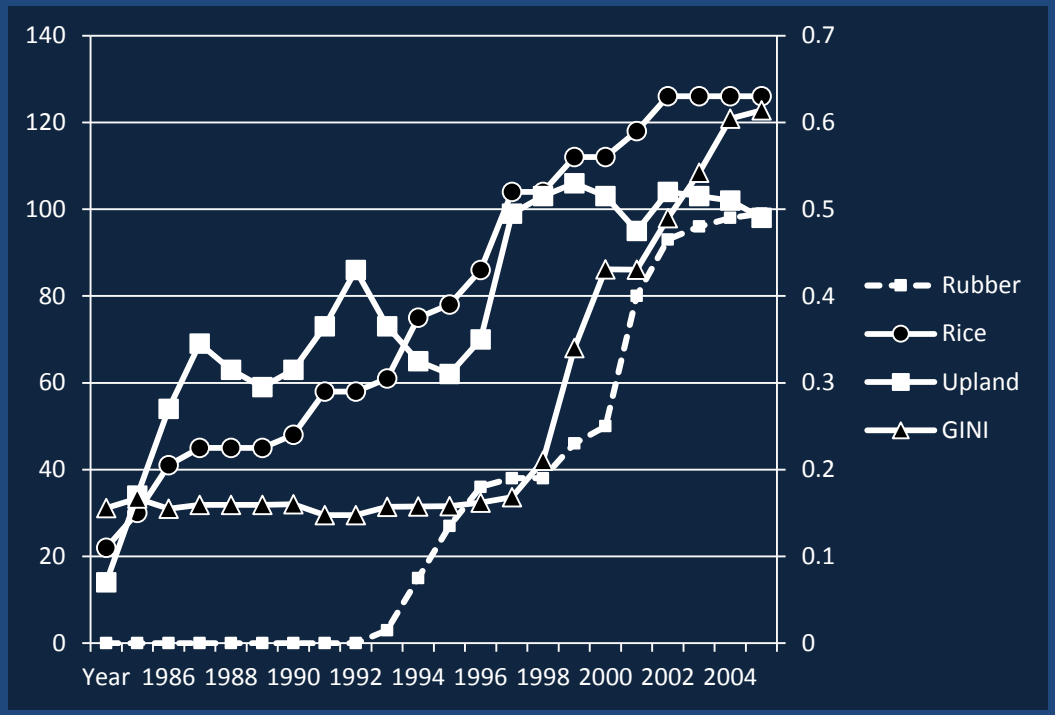
Example Spatially Disaggregated Model

Simulation Scenario	Change in Acreage (1,000s)	% of Factually Simulated Change	% of Factual Acreage Change Attributable to Variable Fixed
Factual Simulation	-41,136	100.0%	0.0%
No Change in Crop Returns	-23,477	57%	-43%
No Change in Govt. Payments	-44,670	109%	9%
No Govt. Payments	-48,626	118%	18%
No CRP	-11,825	29%	-71%
No Govt. Payments and No CRP	-16,358	40%	-60%
No Change in Pasture Returns	-48,262	117%	17%

Lubowski et al. (2006) used estimated econometric model based on NRI data to evaluate effects of PES on land use (change in acres of agriculture land 1982-1997 shown).

Example Agent-based Model





Evans et al. 2011 simulated rubber adoption in northern Laos to assess changes in household-level inqualities associated with the transition from shifting cultivation to export-oriented rubber production.

Key assumptions	Land Use/Cover	Typical Data Requirements	Recommended Uses
Strong stationarity	Land Cover	Land-cover maps from at least two times	Make forecasts of land change under stationarity
		Some number of maps of predictor variable(s)	Extrapolating past patterns

Key assumptions	**Land Use/Cover**	**Typical Data Requirements**	**Recommended Uses**
Stationarity Strong spatial control and/or interaction No market interactions	Land Use and Land Cover	A land-cover map at some point in time Some number of maps of predictor variable(s)	Forecast land-change patterns Evaluate changes in spatial controls without market feedbacks

Key assumptions	Land Use/Cover	Typical Data Requirements	Recommended Uses
Usually heterogeneous agents Variable interactions among agents	Land Use or Land Cover	Data describing characteristics of agents. Qualitative or quantitative data on decision processes. Data on land-use or land-cover at some point(s) in time.	Explore land change processes, often under stylized conditions Explore effects of exogenous change on a system, where it hasn't happened Explore future scenarios where past patterns may be poor indicators of future outcomes