

Spatial Modeling of Land Use and Land Cover Change

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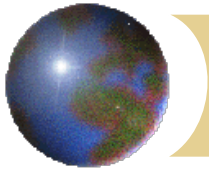
Synthesis Products

- ✦ Modeling Chapter in LCLUC book
- ✦ Modeling Section in CCSP Land Use Land Cover Change Science Plan
- ✦ Reference: Brown, D.G., Walker, R., Manson, S., Seto, K. In Press. Modeling land use and land cover change. In G. Gutman, B.L. Turner et al., Eds. *Land Change Science: Observing, Monitoring and Understanding Trajectories of Change on the Earth's Surface*. Dordrecht: Kluwer.



LULCC in Climate Change Science Plan (CCSP)

- ⊕ CCSP Question 6.1: What tools or methods are needed to better characterize historic and present land-use and land-cover attributes and dynamics?
- ⊕ CCSP Question 6.2: What are the primary drivers of land-use and land-cover change?
- ⊕ **CCSP Question 6.3: What will land-use and land-cover patterns and characteristics be 5 to 50 years into the future?**
- ⊕ ...



Sub-Question 6.3.1

- ✦ What are the major feedbacks and interactions between climate, socioeconomic, and ecological influences on changes in land use and land management?
- ✦ Feedbacks between land use, climate, socioeconomic and ecological influences can lead to surprising dynamics that improved land-use/cover models can help identify; this has implications for the resilience, vulnerability, predictability and adaptability of land use and land cover to climate and other changes.



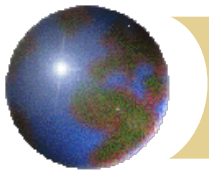
Sub-Question 6.3.2

- ⊕ What spatial and temporal level of information and modeling are needed to project land use and land management and its impacts on the Earth system at regional, national, and global scales?
- ⊕ Model characteristics will need to vary to meet the needs of the various questions within the CCSP agenda. It is possible to identify, through needs assessment, uncertainty assessment, and sensitivity analysis, the appropriate processes, spatial scales and time steps for land-use and land-cover models in the context of specific scientific decision making objectives.



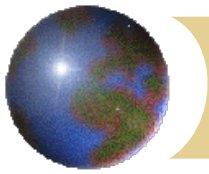
Scale and Timeframe

			<i>Timeframe for Projection</i>	
<i>Spatial Extent</i>	<i>Spatial Resolution</i>	Short (5yr)	Medium (20yr)	Long (50yr)
Local	10 - 100m	XXX	XX	X ?
Regional	100m - 1km	XXX	XXX	XX
National	1-10km	X?	XX	XXX
Global	>10km	X ?	XX	XXX (CLCM)



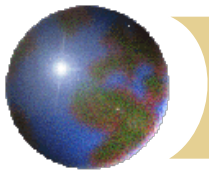
A Community Land-Cover Model

- ✦ Might we, as a community, contribute to global change research through development of a model or models of land use and cover that couple to and interact with general circulation models and ecosystem process models?
- ✦ Such models should build on the experience of this community.



Sub-Question 6.3.3

- ✦ Given specific climate, demographic, and socio-economic projections, what is the current level of skill and what are the key sources of uncertainty and major sensitivities in projecting characteristics of land-use and land-cover change 5 to 50 years into the future?
- ✦ Predictive ability of models will decrease with longer time horizons, finer spatial detail coupled with increased spatial extent, and increased thematic detail (e.g., including more detail in land characteristics requirements); increased information about model uncertainty will improve the usability of the models and their outputs.



Reviews of LCLUC Models with Foci

- ✚ Baker (1989) – land cover only
- ✚ Lambin (1997) – tropical deforestation
- ✚ Kaimowitz and Angelsen (1998) – economics of tropical deforestation
- ✚ Irwin and Geoghegan (2001) – economic vs. non-economic models of land use
- ✚ Agarwal et al. (2002) – describe model complexity in space, time, and decision-making
- ✚ Parker et al. (2003) – agent-based models



Model Categories in Our Review

These are not mutually exclusive categories, they describe differences in emphasis

- ✦ *Empirically Fitted Models* – emphasis is on fitting a statistical model to observations.
- ✦ *Dynamic Process Models* – emphasis is on describing system processes and encoding it in a simulation.



I: Empirically Fitted Models

- ✚ Focus is on accounting for spatial and temporal patterns in data or empirically testing hypotheses
- ✚ Theory informs selection of explanatory variables and structure of relationships
- ✚ Predictions outside the range of observed conditions are problematic



Estimation Challenges

- ⊕ Temporal non-stationarity
- ⊕ Spatial autocorrelation and non-stationarity
- ⊕ Non-linearity in relationships
- ⊕ Heterogeneity in household/agent characteristics
- ⊕ Aggregate vs. disaggregate data
- ⊕ Endogenous interactions and feedbacks

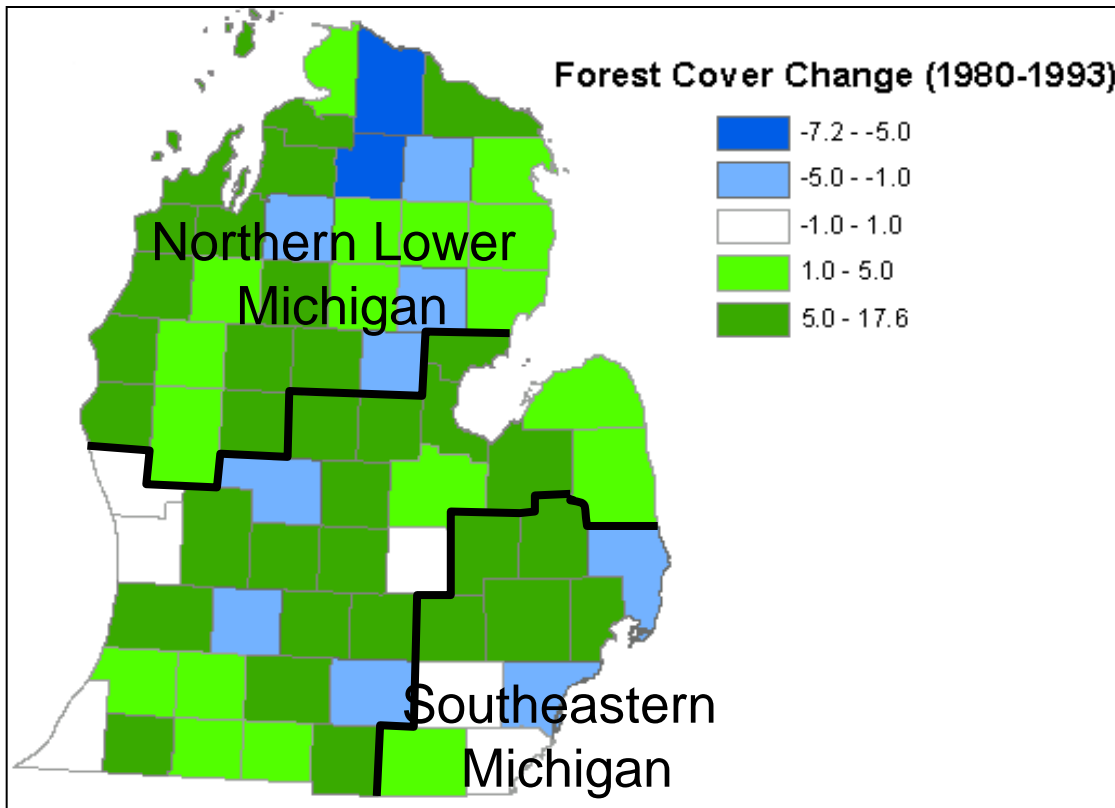


Example from Michigan

- ✚ Goal is to develop scenarios of land-cover patterns in 2010 and 2020 in select Michigan counties.
- ✚ Develop an empirical fitting approach at two distinct levels
 - ▣ County level estimation of land-cover proportions with econometric model
 - ▣ Spatial allocation of land covers using geostatistical simulation



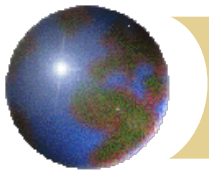
Forest Cover Change



According to the USDA Forest Service forest inventory (FIA), forest cover is increasing.

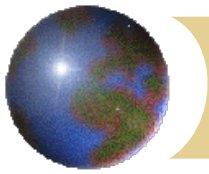
What are the differential effects of development on forest cover?

Involves interactions between land use and land cover.

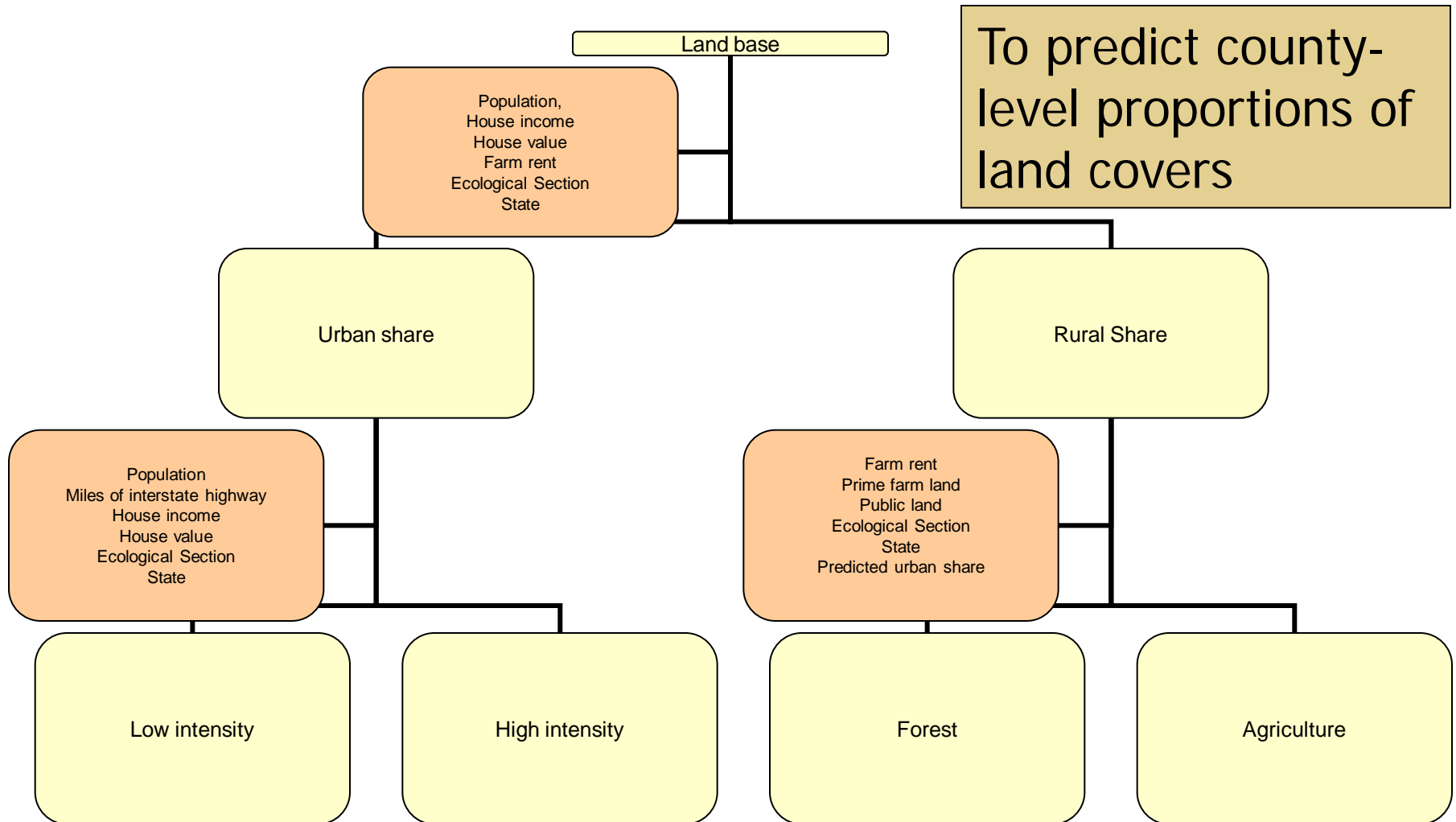


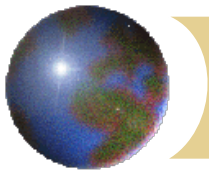
Project Team

- ✦ Dan Brown, U Michigan
- ✦ Pierre Goovaerts, PGeostat, LLC; BioMedware
- ✦ Dave Wear, USDA Forest Service
- ✦ Kathleen Bergen, U Michigan
- ✦ Amy Burnicki, PhD Student
- ✦ Lalith Narayan, Programmer



Econometric Model Structure





Challenge

- ✚ Estimate area-base model with a relatively small sample size ($n=75-82$)
 - ▣ Lower Peninsula Michigan
 - ▣ + 14 counties in Northeastern Ohio
- ✚ Suggests returns to simple models
 - ▣ Parsimony wins...



Estimation Results

✚ Model of Urban Proportion

- ✚ Model is significant (Log likelihood test)
- ✚ Population density is dominant explanatory variable
 - Effects differ between two ecological subregions
- ✚ Pseudo R-squared
 - ~0.8
- ✚ Heteroscedasticity
 - Specification issues?



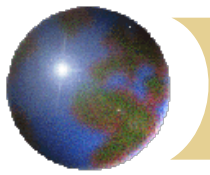
Estimation results

- ✚ Rural: Model of Forest Proportion
 - ▣ Model is significant (log likelihood test)
 - ▣ Most variables are significant
 - ▣ Pseudo-R-squared
 - ~0.65



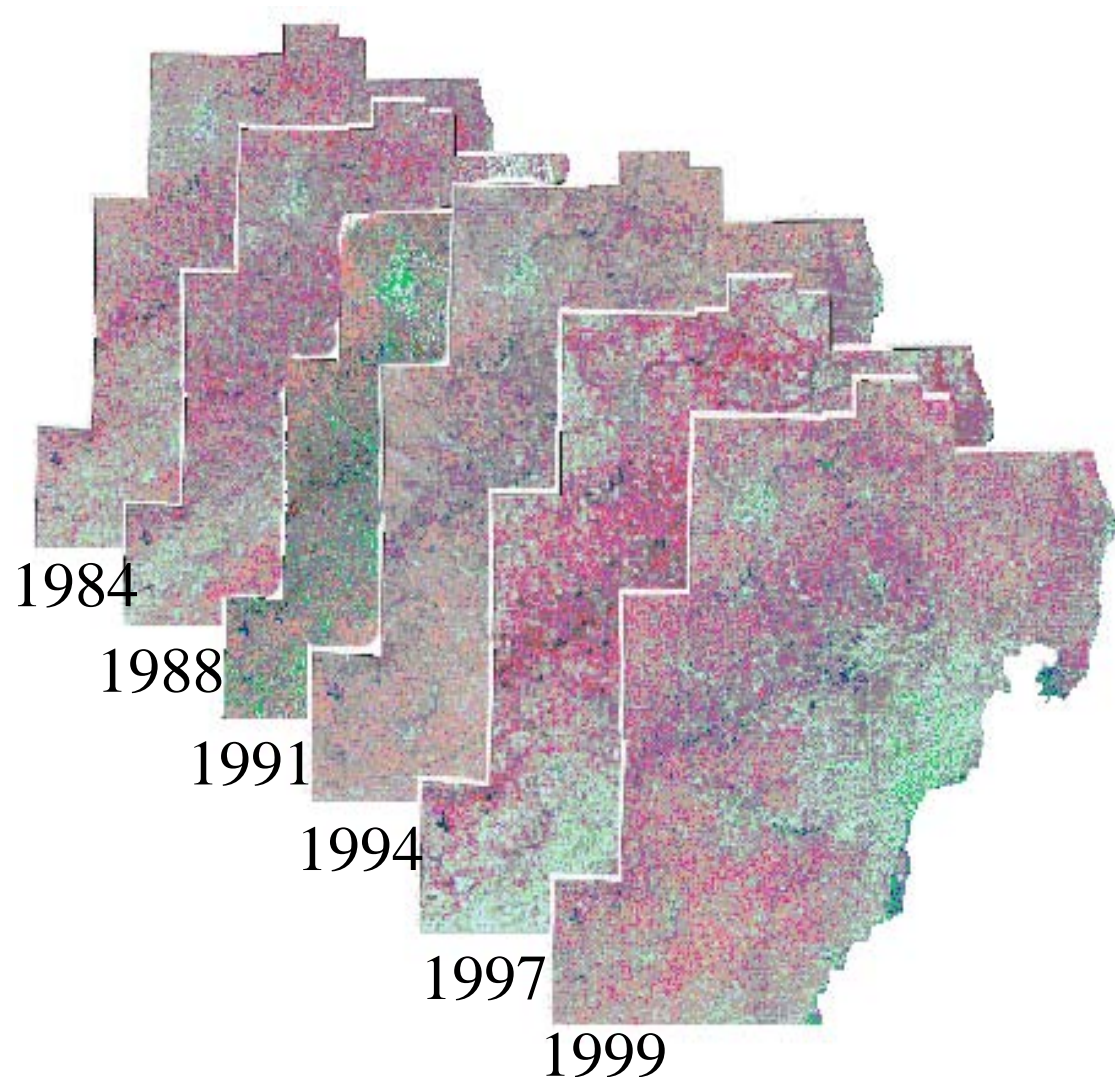
Geostatistical simulation of land cover

- ✦ Projects of land-cover patterns within a county, given amounts from econometric model
- ✦ Approach is to stochastically generate spatial patterns that meet three objectives:
 - ✦ locations of likely change
 - ✦ spatial patterns of change
 - ✦ amount of change, based on county-level econometric model
- ✦ Reference: Brown, D.G., Goovaerts, P., Burnicki, A., Li, M.Y. 2002. Stochastic simulation of land-cover change using geostatistics and generalized additive models. *Photogrammetric Engineering and Remote Sensing*, 68(10):1051-1061.



Modeling from Satellite Time Series

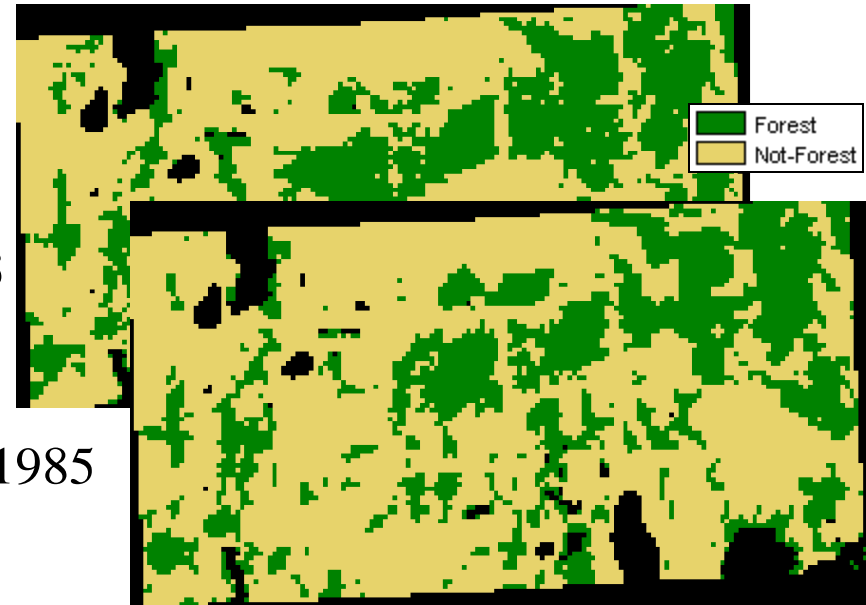
- ✦ Based on land-cover classification.
- ✦ Overall accuracy 78 – 85%
- ✦ PhD thesis underway spatial-temporal patterns of error in classification and change detection.



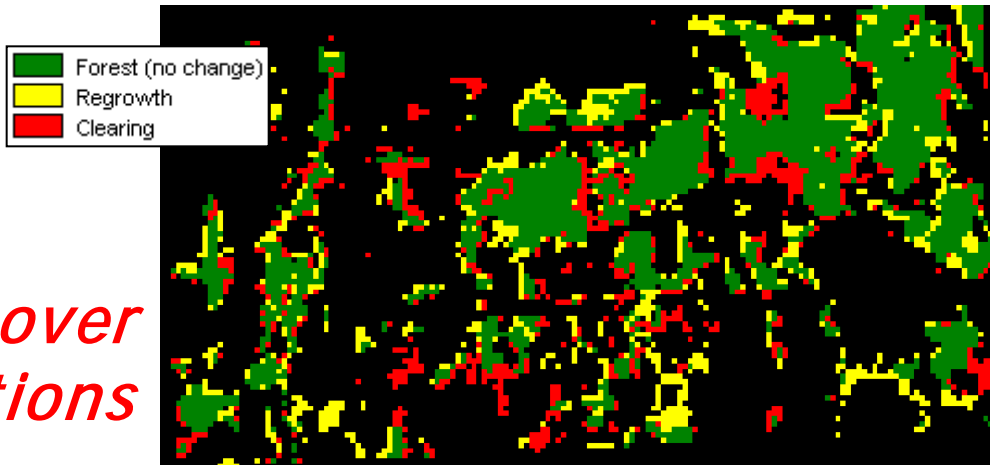


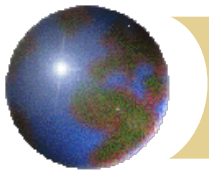
Dependent Variables

Land Cover States



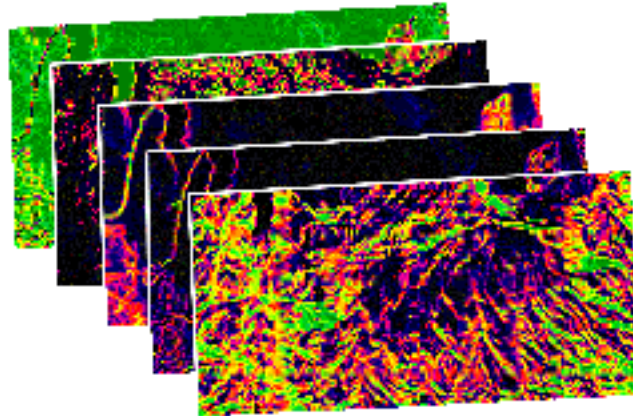
Land Cover Transitions



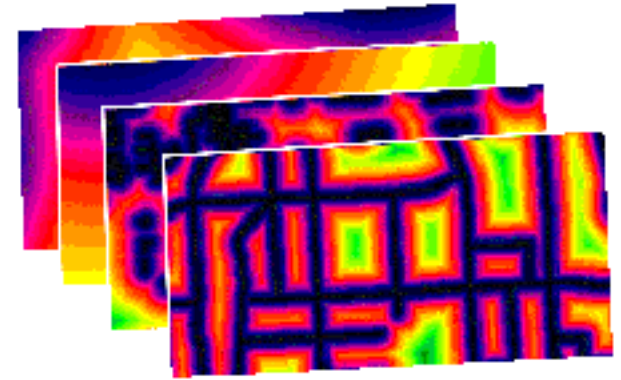


Predictor Variables

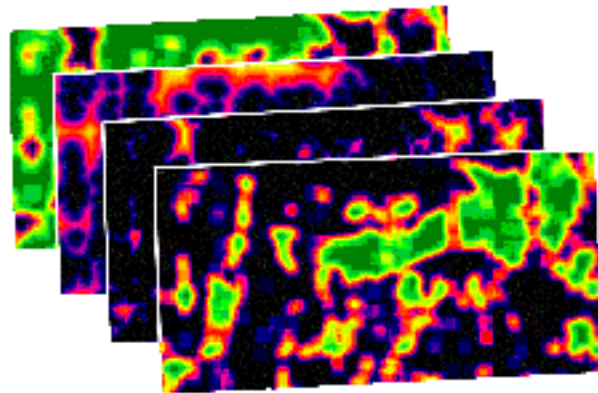
- ✦ Location of changes are modeled relative to predictors using generalized additive models (GAMs).
- ✦ Represent hypotheses of correlates of land-cover change.



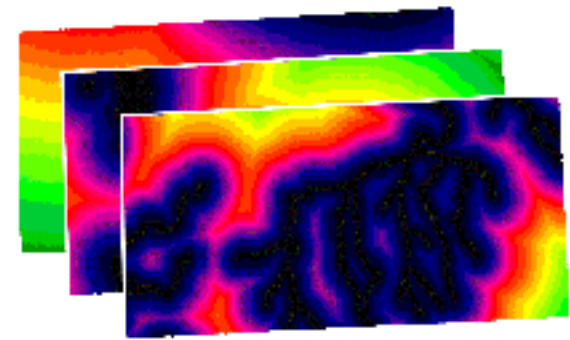
Soil and Terrain



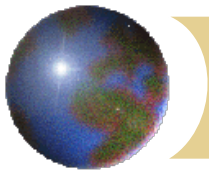
Road and City Access



Existing Land Cover

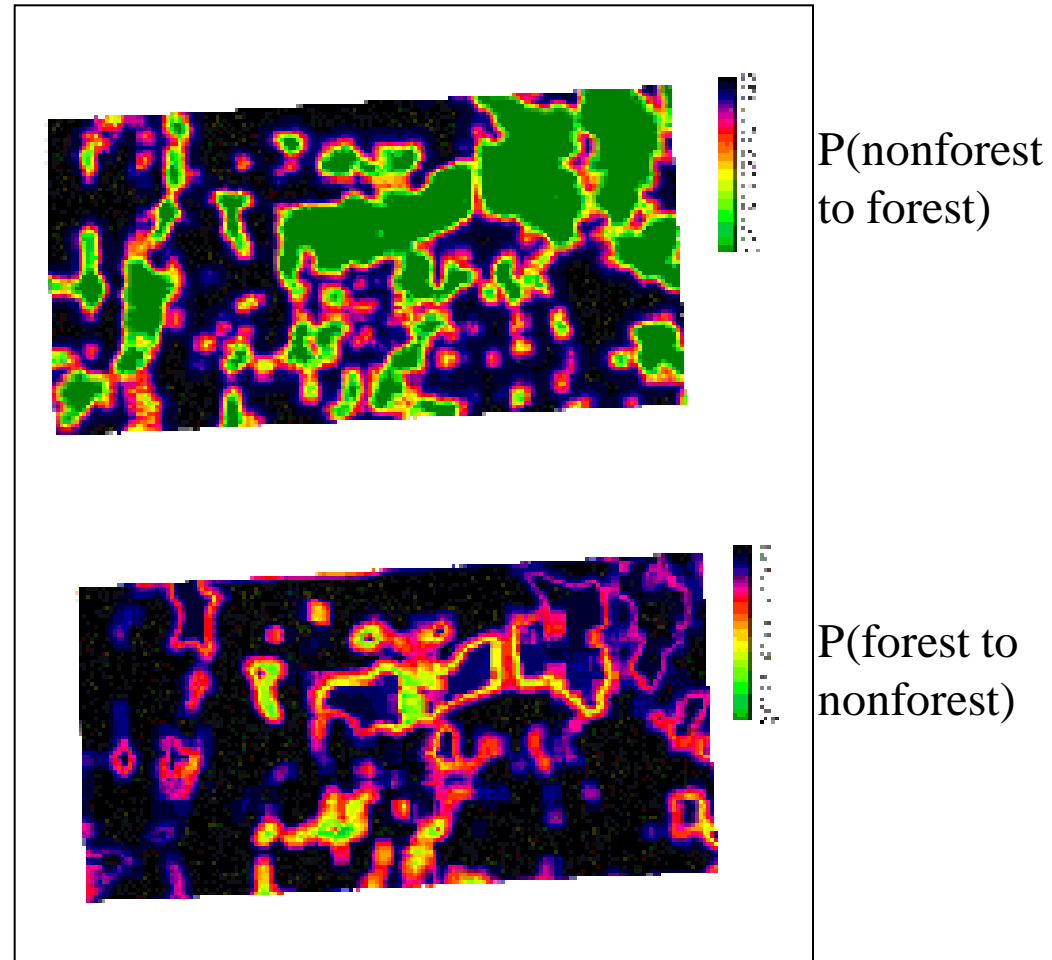


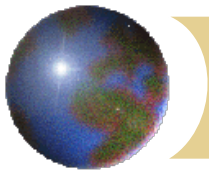
Distance to Water



Transition Probabilities

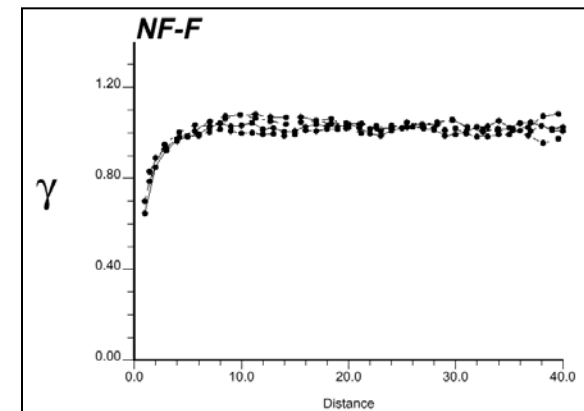
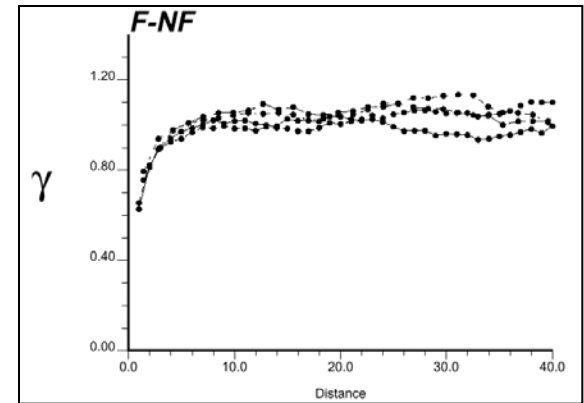
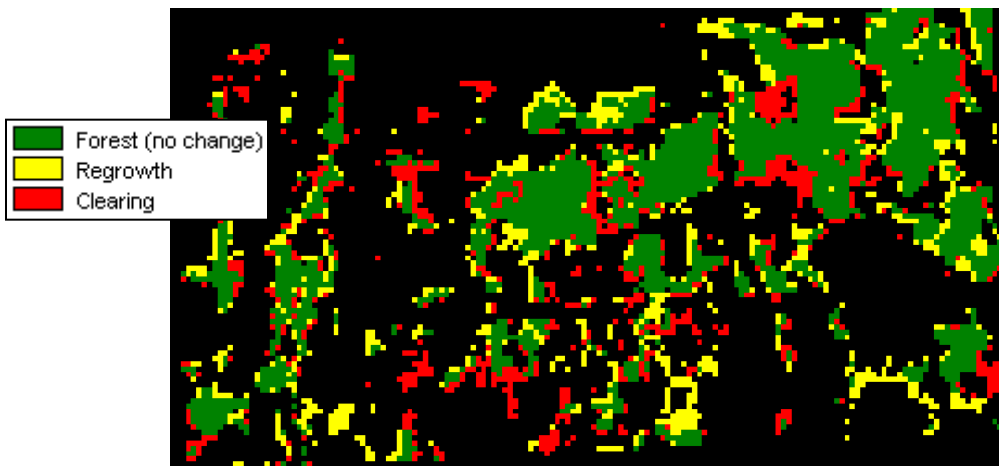
- ⊕ Estimated from GAMs.
- ⊕ One for each type or transition (e.g., forest to nonforest).
- ⊕ Estimates likely *locations* of change.





Spatial Patterns of Change

- Land covers and changes are clustered.
- Semivariograms describe the *patterns* of types or of change.

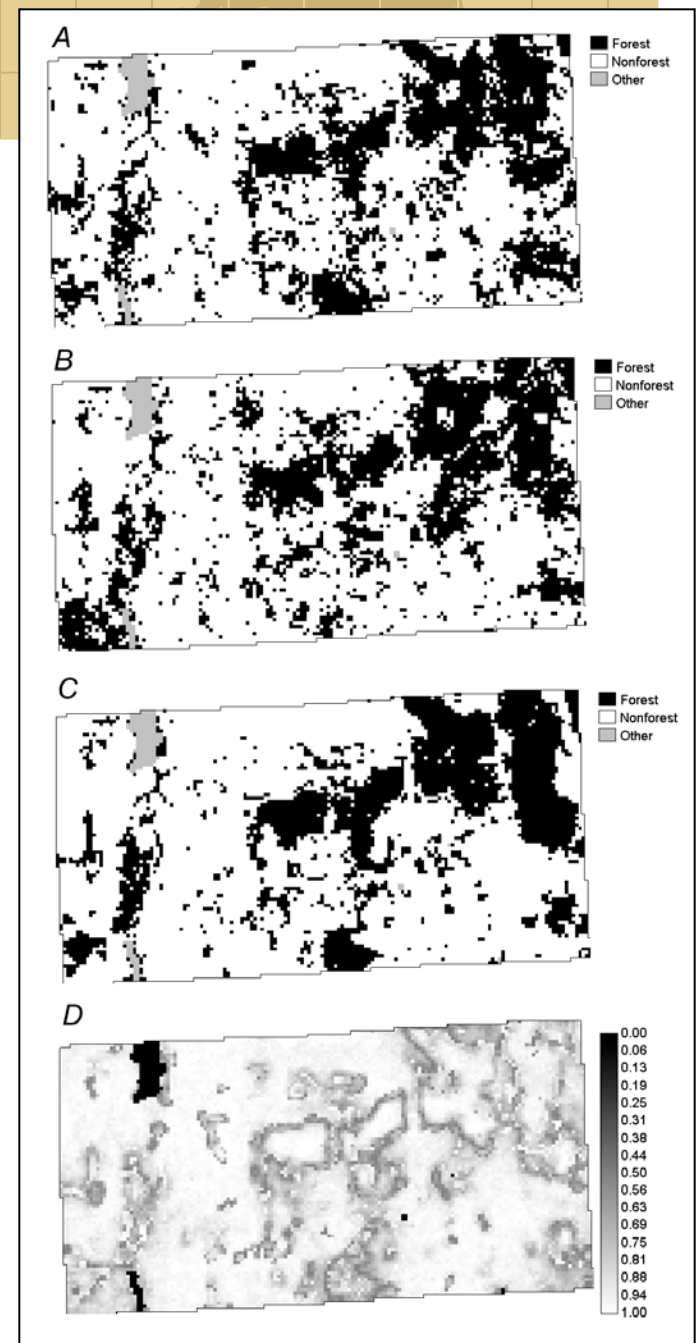


Semivariograms serve as pattern descriptors to guide geostatistical simulation or for model-data comparisons.



Geostatistical Simulation

- ❖ Stochastic simulation approach allows generation of multiple realizations and to assess effects of uncertainty in the models.
- ❖ First two figures are realizations of 1985 forest cover map. Third is the maximum likelihood map.
- ❖ Fourth figure shows probabilities of change based on multiple runs.





Progress

- ❖ Automated entire simulation process
 - ❖ Estimation of generalized additive models
 - ❖ Fitting of variograms
 - ❖ Generation of realizations
- ❖ Extended simulation approach to >2 classes.
- ❖ Allow choice of modeling transitions versus modeling types.
- ❖ Next step, to evaluate spatial and temporal variability (stationarity) in the models.



II: Dynamic Process Models

- ✚ Iterative – including CA and ABM
- ✚ Focus is on describing the process of change rather than data on the outcomes of process
- ✚ Lend generative insights to dynamics and possible effects of shocks and unobserved variation.
- ✚ Predictions can be difficult to interpret in presence of non-linear dynamics.



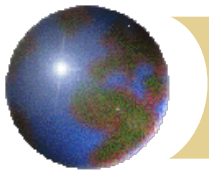
Example from Michigan

- ✚ Goal is to understand human-environment interactions at the urban-rural fringe
- ✚ Combines agent-based modeling with spatial data, surveys and choice experiments to characterize
 - ▣ effects of landscape on human decisions
 - ▣ effects of human decisions on landscapes



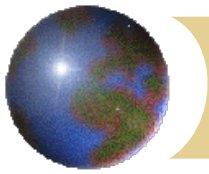
Project Team – U. Michigan

- ✦ Dan Brown
- ✦ Scott Page
- ✦ Rick Riolo
- ✦ Joan Nassauer
- ✦ Bobbi Low
- ✦ Bob Marans
- ✦ Dave Allan
- ✦ Kathleen Bergen
- ✦ Li An
- ✦ Bill Rand
- ✦ Moira Zellner
- ✦ Derek Thompson
- ✦ Greg Claxton



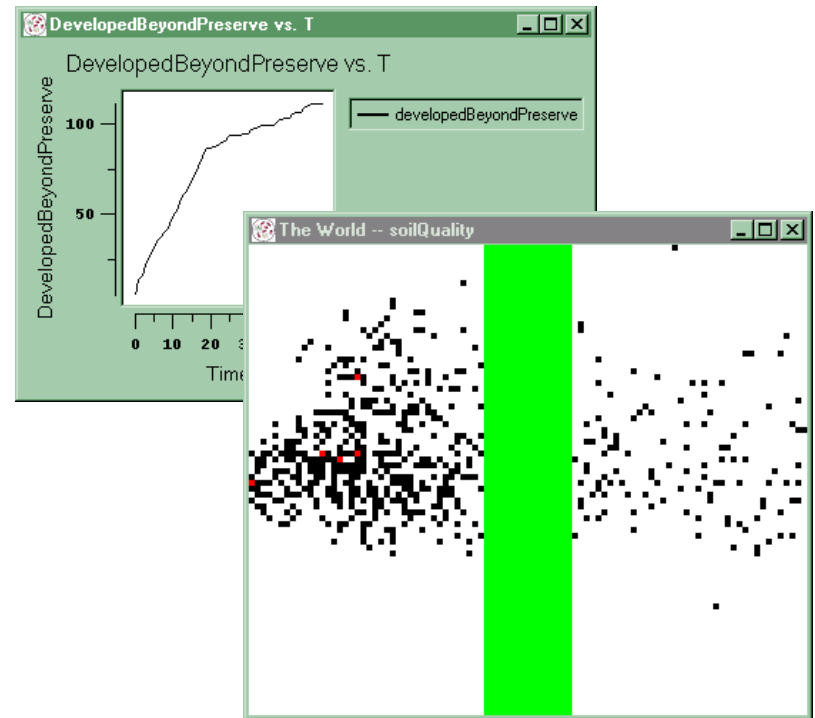
Agent-Based Modeling of Development

- ✚ We start with simple models to understand system, then make them more realistic.
- ✚ We want to evaluate approaches to achieving desirable landscape patterns by coupling land use decisions with landscape outcomes.
- ✚ Models based on agents with bounded rationality, using landscape perception literature and including policy agents.

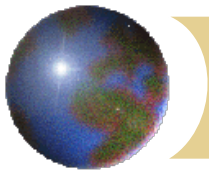


Evaluating Effects of Greenbelts

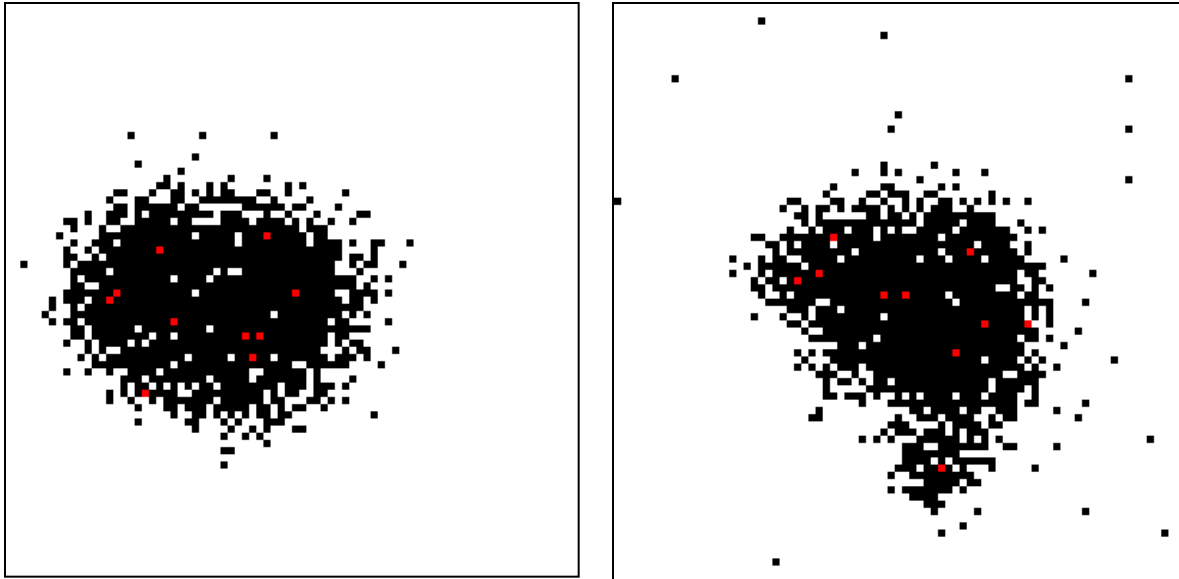
- ⊕ Compares mathematical model with ABMs to examine the ability of a greenbelt to delay sprawl.
- ⊕ Results depend on assumptions about whether city services follows residents and on patterns of aesthetic quality.



Reference: Brown, D.G., Page, S.E., Riolo, R.L., and Rand, W. In Press. Agent based and analytical modeling to evaluate the effectiveness of greenbelts. *Environmental Modelling and Software*.



Homogeneous vs. Heterogeneous Preferences



- ✦ Heterogeneity in the landscape preferences of residents increases sprawl by 6% compared to a model with homogenous preferences.

Reference: Rand et al. 2002. The complex interaction of agents and environments: An example in urban sprawl. *Proceedings, Agent 2002: Social Agents: Ecology, Exchange, and Evolution*. Chicago, IL, October 2002.



Charactering Heterogeneity

- This finding highlights the importance of understanding heterogeneity in preferences and behavior (a strength of ABM)
- We are evaluating heterogeneity in agents empirically by
 - Analyzing survey of stated preferences (n = >4000)
 - Developing choice experiments



Dynamic Process Models Summary

- ✚ These approaches can reveal path dependence in systems, due to feedbacks, and help identify “lever points” to which system is responsive to policy interventions.
- ✚ Can reveal difficulties in prediction that result from these path dependencies.
- ✚ Notoriously difficult to calibrate, in the sense of empirically fitted models.



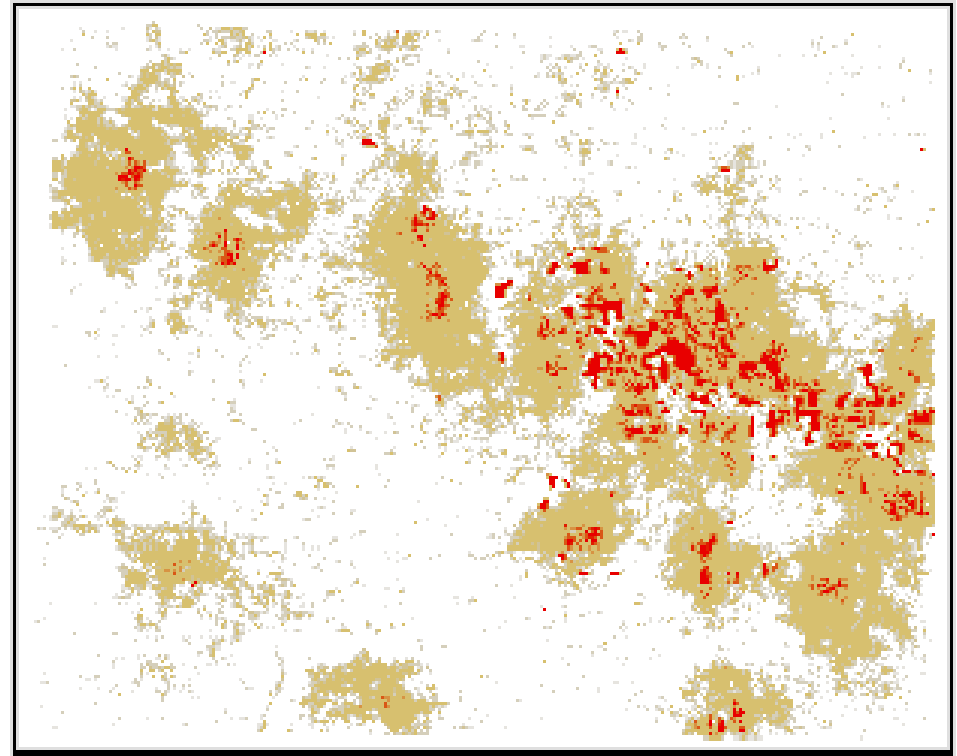
Calibration and Validation

- ⊕ Data on micro-level processes needed to calibrate process models.
- ⊕ Calibration of CA models more advanced than ABM.
- ⊕ Validation requires comparing model outcomes with data in known cases (i.e., the past).
 - ⊞ Aggregate characteristics, e.g., amount of development, degree of fragmentation
 - ⊞ Spatial locations, e.g., percent of locations correctly predicted



Model Validation

- ❖ Path dependent models require methods for identifying how well the model predicts, but also when uncertainty in the prediction is high.
- ❖ Our method divides map into variant and invariant regions and compares with reference map within each.



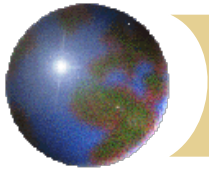
The figure segregates model results into invariant (red and white) and variant (tan) regions.

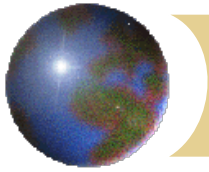
Reference: Brown, D.G., Page, S.E., Riolo, R.L., Zellner, M., and Rand, W. In Press. Path dependence and the validation of agent-based spatial models of land-use. *Int. J. of GISc.*



Summary

- ✦ Various modeling approaches can serve different purposes.
- ✦ CCSP calls for predictions and scenarios on regional and global scales, which could build on existing modeling approaches.
- ✦ We can continue to learn from models about the drivers and processes of land use and cover change.





Empirically Fitted Models - Summary

- ✦ Offer solutions for hypothesis testing and prediction in the short term.
- ✦ Spatial and temporal non-stationarity needs to be understood and managed (I.e., in what situations is any given model applicable).