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Land Cover Land Use Change
Year 2 Progress Report
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Modeling Strategies for Adaptation to Coupled Climate and Land Use Change in the United States

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Project overview

The overall science goal of this project is to leverage work that has generated both climate and land use forecasts that are consistent with the IPCC Special Report on Emission Scenarios (SRES) and, importantly, prepare for next generation regionally focused IPCC scenarios that better incorporate the influences and feedbacks of land use change. Our specific objectives are to spatially predict future land use change, initially in the eastern United States, and to incorporate those predictions under different SRES scenarios into an established state-of-the-art modeling system that assimilates data from a variety of sources and drives a set of coupled ecosystem and hydrology models. We are simulating the influence of potential mitigation and adaptation actions by predicting land use change scenarios that incorporate a range of best management practices (BMPs) associated with land cover and land use change. Our overriding hypothesis is that any of a number of land use BMPs will mitigate additional climate warming by increasing carbon sequestration via changes in primary productivity and reducing radiative forcings associated with energy cycle feedbacks to climate. While the forcings are not a primary focus of the project, the implications of trade-offs in productivity versus radiative forcings are implicit to the mitigation and adaptation scenarios upon which we will focus.

The research falls under three major categories: (1) Spatial predictive modeling of land use change; (2) Terrestrial Observation and Prediction System (TOPS) simulations under climate change scenarios; (3) TOPS Predictions under Land Use Change Scenarios. Under the latter two topics we will produce simulations of (a) carbon exchange and productivity, (b) hydrological and energy fluxes.

Spatial Predictive Modeling of Future Land Use Change

Whereas the SLEUTH-3d modeling report last time marks a substantial advance in the development of the cellular automaton approach to urban change modeling, it is difficult to run a model at this level of spatial detail at a nationwide scale or to incorporate socioeconomic data sets. As a result, the majority of the work we are conducting using the TOPS modeling framework (described below) makes use of future projections of urbanization we have developed during this second year of the project using the Spatially Explicit Regional Growth Model (SERGoM). The model is based on changes in housing units as estimated from census data projections of population change (Bierwagen et al. 2010; Figure 1). We used these housing density changes to also estimate associated changes in impervious surface area (ISA) (Theobald et al. 2009).

We applied the housing density and impervious surface data in scenarios consistent with those used to produce the climate scenarios for the IPCC Fourth Assessment Report (AR4). These scenarios were produced for the eastern U.S. at a resolution of 1ha and resampled to a resolution of 1km to match the other inputs to TOPS, and to reduce the computational requirements to a reasonable level. A total of four housing density and ISA scenarios were produced for the period from 2010 to 2100 for SRES scenarios A1, A2, B1, and B2. ISA estimates were generated for each scenario at a decadal time step.

Since TOPS does not accept ISA as a direct input to the component ecosystem models, the ISA scenarios were used to adjust the soil properties to provide a representation of the likely impacts of ISA on soil water holding capacity and runoff. TOPS usually requires soil texture and soil depth information derived from the STATSGO soil database (see Nemani et al. 2009), and the ISA scenarios were used to modify the soil depth following the simplifying assumption that increasing ISA linearly reduces percolation and soil water holding capacity. Corresponding adjustments were made to TOPS to provide for utilization of dynamic soil depth information updated on a decadal time step.

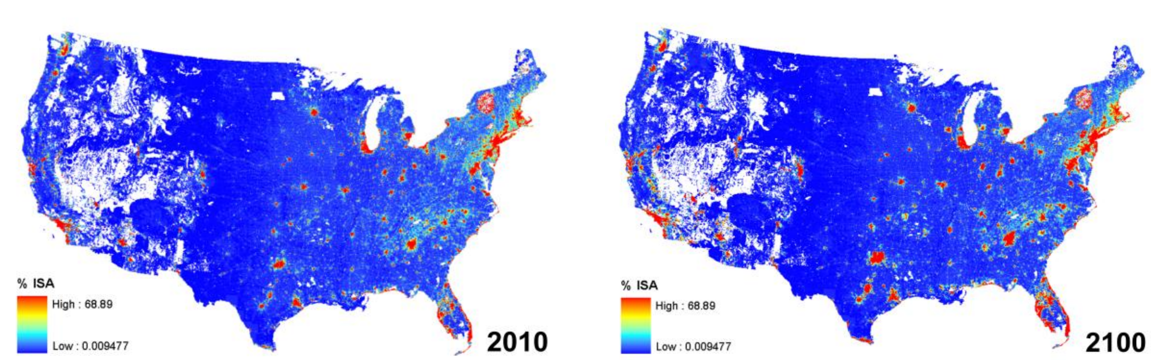

Figure 1. Predicted change in ISA across the U.S. from the year 2000 (left) to the year 2100 (right) based on predicted changes in population and associated housing growth (see Bierwagen et al. 2010). These results are used in the TOPS model simulations described below.

TOPS Predictions under Climate Change Scenarios

In the first year we utilized daily 250m resolution meteorological surfaces generated for the study region from January 2000 through December 2003 using the Surface Observation and Gridding System (SOGS; Jolly et al. 2004), a component of TOPS. SOGS automatically retrieves and stores observations from meteorological station networks and applies a library of interpolation algorithms to produce spatially continuous meteorological surfaces including surface air temperature (maximum, minimum, and average), precipitation, vapor pressure deficit, and shortwave radiation. For the grids for the Chesapeake region, we applied the SOGS gridding algorithms to produce the required meteorological inputs for TOPS for the land use change scenarios.

In the second year, we applied TOPS to generate 1km resolution surfaces for the eastern U.S. for baseline runs for the period from 2001-2010. In addition, we generated future climate scenarios for the eastern U.S. based on downscaled WCRP CMIP3 scenarios (Maurer et al., 2007). In our initial experiments for the eastern U.S., we are using three models (GFDL CM2.0, GISS-ER, CCSM3.0) and three scenarios for each model (A1B, A2, B1), for a total of nine climate scenarios (Figure 2). Since these scenarios only provide forecasts for temperature and precipitation, we also derived estimates of vapor pressure deficit and solar radiation following the methods described by Thornton et al. (1997, 1999). Since TOPS typically runs at a daily timestep, we also made a number of modifications to TOPS to facilitate use of the downscaled AR4 climate scenarios, which utilize a monthly time step. We explored use of a weather generator to derive daily scenarios from the monthly AR4 scenarios, but were limited by the additional computational demands of performing more than twenty modeling experiments at a daily time step for a 100-year time span. As such, we elected to modify components within TOPS to accept monthly inputs, which reduced the computational requirements and eliminated the need for use of a weather generator.

TOPS Predictions under Land Use Change Scenarios

In the first year of the project, we conducted a modeling experiment to evaluate the potential impact of land use change and increasing urbanization on watershed outflow and gross primary production (GPP), and to demonstrate the potential utility of TOPS for evaluating the combined impacts of climate and land use change at the regional scale. We conducted these simulations in the Chesapeake and Delaware watersheds, where we have done much previous work at more local scales. TOPS simulations to evaluate the impact of land use change on runoff and GPP were conducted using the BIOME-BGC model, which has been integrated with TOPS as a component model. In this modeling experiment, TOPS was used to estimate various water (evaporation, transpiration, stream flows, and soil water), carbon (net photosynthesis, plant growth) and nutrient flux (uptake and mineralization) processes. TOPS requires as inputs spatially continuous data layers to describe the land cover, soil texture and depth, daily meteorology, and elevation across the land surface. We used satellite-derived estimates of leaf area index (LAI) to parameterize equations for photosynthesis and plant growth.

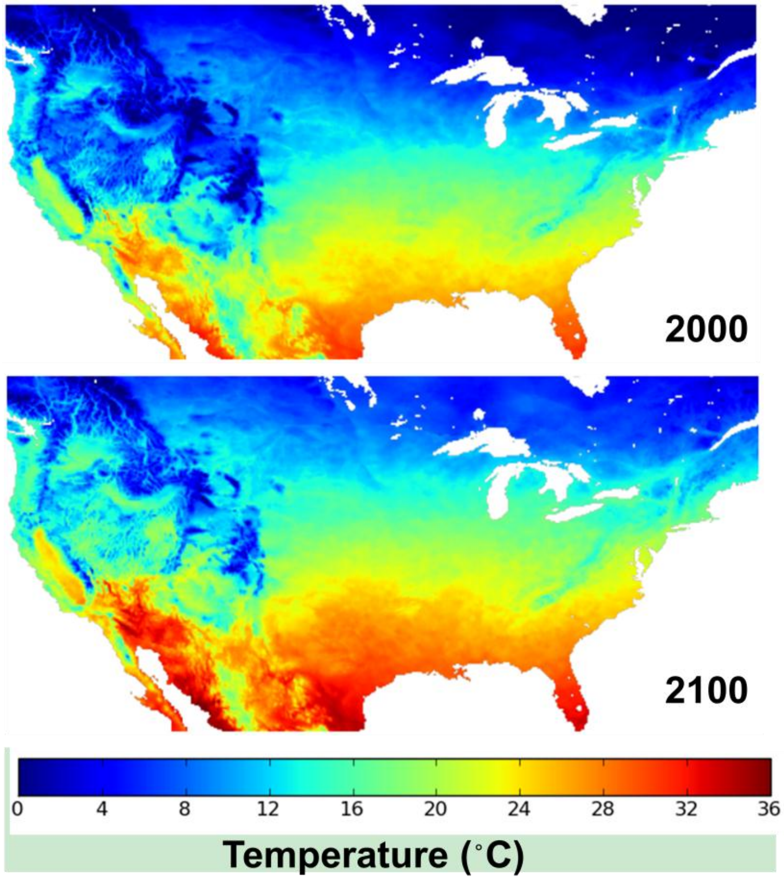

Figure 2. Sample climate forecasts from the GFDL CM2.0 A1B scenario showing changes from 2000 to 2100. These downscaled forecasts are being used to drive TOPS.

Results from the initial modeling experiment indicated the ability of TOPS to quantify the potential for significant impacts to occur as a result of land use change and increased impervious surface area. We are currently expanding this work to the entire eastern U.S. using the land use and climate scenarios described above. Using TOPS, we are currently conducting simulations to evaluate the independent and combined climate impacts of climate and land use change on runoff and ecosystem productivity. For each of the nine AR4 climate scenarios, we are conducting runs to evaluate the effects of climate change alone, as well as runs which utilize the corresponding SERGoM scenario (A1, A2, or B1) to evaluate the combined effects of climate and land use change. In addition, we are also using gridded meteorological surfaces for the period from 1950-2000 to represent the baseline climate, and using scenarios derived from these grids to evaluate the impacts of land use change alone. In total, we will perform 22 runs (including a baseline run for 2000-2010). Initial results from these runs will be presented at the LCLUC program meeting in March, and will be prepared for publication following completion of modeling experiments using all scenarios.

Project Related Publications to Date

Bierwagen, B.G., D.M. Theobald, C.R. Pyke, A. Choate, P. Groth, and P. Morefield. 2010. National housing and impervious surface scenarios for integrated climate impact assessments. *PNAS* 107(49):20887:20892.

Jantz, C. A., S. J. Goetz, D. Donato, and P. Claggett. 2010. Designing and implementing a regional urban modeling system using the SLEUTH cellular urban model. *Computers, Environment and Urban Systems* 34:1-16.

Theobald, D. M., S. J. Goetz, J. Norman, and P. Jantz. 2009. Watersheds at risk to increased impervious surface cover in the coterminous United States. *Journal of Hydrologic Engineering* 14:362-368.

Wang, W., J. Dungan, H. Hashimoto, A. Michaelis, C. Milesi, K. Ichii, and R. Nemani, 2010: Diagnosing and assessing uncertainties of terrestrial ecosystem models in a multi-model ensemble experiment: 1. primary production, *Global Change Biology* 17(3):1350-1366.

Wang, W., J. Dungan, H. Hashimoto, A. Michaelis, C. Milesi, K. Ichii, and R. Nemani, 2010: Diagnosing and assessing uncertainties of terrestiral ecosystem models in a multi-model ensemble experiment: 2. carbon balance, *Global Change Biology* 17(3):1367-1378.

Wang, W., K. Ichii, H. Hashimoto, P. Thornton, and R. Nemani. 2009. A hierarchical analysis of the terrestrial ecosystem model BIOME-BGC: model calibration and equilibrium analysis. *Ecological Modeling* 220(17):2009-2023.

Project Related Presentations to Date

February 2011. S.J. Goetz, B. Bond-Lamberty, B. Law, J. Hicke, R. A. Houghton, S. McNulty, A. J. H. Meddens, E. M. Pfeifer, C. Huang, D. Mildrexler, M. Sun, T. O'Halloran, E. Kasischke *Observations and assessment of forest recovery following disturbance in North America.* North American Carbon Program annual meeting (poster). New Orleans, LA

December 2010. F.S. Melton; S.J. Goetz; W. Wang; C. Milesi; D.M. Theobald; R.R. Nemani. *Modeling Coupled Climate and Urban Land Use Change in the Eastern United States*. American Geophysical Union annual meeting. San Francisco CA 2010.

December 2010. S.J. Goetz, R.Dubayah. *Introduction to the Application of Remote Sensing in Terrestrial Carbon Monitoring, Modeling and Management*. American Geophysical Union annual meeting. San Francisco CA 2010.

June 2009. S. Goetz, F. Melton, W. Wang, D. Theobald, C. Milesi. World Bank 5th Urban Research Symposium on Cities and Climate Change: Responding to an Urgent Agenda. Our contribution, entitled *Modeling Strategies for Adaptation to Coupled Climate and Land Use Change in the United States*, was selected as one of just a few to be included in the proceedings. Marseilles France.

October 2009. F. Melton, W. Wang, S. Goetz, C. Milesi, R. Nemani, H. Hashimoto, A. Michaelis, P. Votava. California Air Resources Board Forest Inventory Symposium. Invited presentation to the California Air Resources Board, *Assessing Impacts of Climate and Land Use Change on Carbon Fluxes with the NASA Terrestrial Observation and Prediction System*. Sacramento, CA.

Project Components and Schedule

SCHEDULE	**Year 1**		**Year 2**		**Year 3**	
Task	**Q1-Q2**	**Q3-Q4**	**Q1-Q2**	**Q3-Q4**	**Q1-Q2**	**Q3-Q4**
Land Use Change						
Model parameterization	■	■				
Scenario development		■	■	■		
Impervious conversions			■	■		
BMP development				■	■	■
TOPS						
Compilation of TOPS core data layers for region	■					
Selection of CMIP3 scenarios & validation of TOPS implementation using hindcasts & observed GPP & streamflow		■	■			
Regional climate scenarios and impacts w/ ensemble forecasts			■	■	■	
Incorporate land use scenarios and BMP parameterization			■	■	■	
Combined climate / land use change scenarios; ensemble forecasts for wshed simulations					■	■
Regional simulations					■	■
Analysis of forecast results						■