Progress report: Biomass energy: The climate-protective domain

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This is a three-year project initiated in 2008 and originally scheduled for completion at the end of February, 2011. Thanks to the availability of independent funds to support some of the project participants, we have been able to conserve some of the funds, which we are using to support a no-cost extension through February, 2012. During the project's third year, research focused on three main areas. These were (1) understanding the climate consequences of changes in land-surface properties related to biomass energy crops, (2) exploring the options for incorporating low-termperature pyrolysis into strategies for biomass energy utilization, and (3) mapping Brazilian land-use change as part of the strategy for understanding indirect deforestation. This was a successful year for the project. Several papers were published, including two in high profile journals. Georgescu et al. (Georgescu et al. 2011) was published in the Proceedings of the National Academy of Sciences, and Loarie et al. was published in Nature Climate Change. A PhD student working on the project (Lena Perkins, Mechanical Engineering) advanced to candidacy, and a new post doc (Sharon Gourdji) just agreed to join the project.

A brief summary of each of the main project areas follows.

1) understanding the climate consequences of changes in land-surface properties related to biomass energy crops

Loarie, S. R., D. B. Lobell, G. P. Asner, and C. B. Field. 2011. Land-Cover and Surface Water Change Drive Large Albedo Increases in South America*. Earth Interactions **15**:1-16.

Albedo is an important factor affecting global climate, but uncertainty in the sources and magnitudes of albedo change has led to very simplistic treatment of albedo in climate models. Here we examine nine years of historical 1-km MODIS albedo estimates across South America to advance understanding of the magnitude and sources of large scale albedo changes. We use the magnitude of albedo change from the Brazilian Amazon arc-of-deforestation (+2.8%) as a benchmark for comparison. Large albedo increases (>+2.8%) are 2.2 times more prevalent than similar decreases throughout South America. Changes in surface water drive most large albedo changes that are not caused by vegetative cover change. Decreased surface water in the Santa Fe and Buenos Aires regions of Argentina is responsible for albedo increases exceeding that of the arc-of-deforestation in magnitude and extent. The mechanism driving changes in surface water is a combination of natural flooding and human manipulations through dams and other agriculture infrastructure. This study demonstrates the substantial role that land cover and surface water change can play in continental-scale albedo trends.

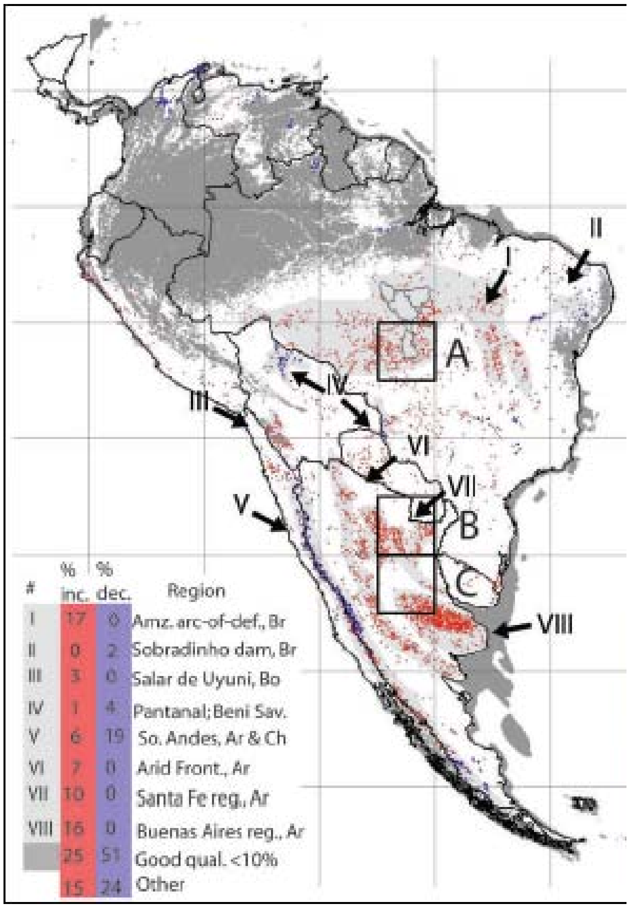

Figure 1. Large Increases (>+2.8%, red) and decreases (<-2.8%, blue) in albedo across South America. The legend shows the percentage of these large changes within regions of interest (light gray areas) labeled by roman numerals. Dark gray areas have scarce good quality data (<10%). Black outlines are country boundaries. Gray outlines indicate a sample of indigenous reserves in Brazil, including the Parque Nacional Indigena do Xingu. The gray grid shows 1200 x 1200 km MODIS tiles. A-C are quarter MODIS tiles that intersect three regions of interest.

Georgescu, M., D. B. Lobell, and C. B. Field. 2011. Direct climate effects of perennial bioenergy crops in the United States. Proceedings of the National Academy of Sciences:10.1073/pnas.1008779108.

Biomass-derived energy offers the potential to increase energy security while mitigating anthropogenic climate change, but a successful path toward increased production requires a thorough accounting of costs and benefits. Until recently, the efficacy of biomass-derived energy has focused primarily on biogeochemical consequences. In this paper, we showed that the biogeophysical effects that result from hypothetical conversion of annual to perennial bioenergy crops across the central U.S. impart a significant local to regional cooling with considerable implications for the reservoir of stored soil water (Figure 2). This cooling effect is related mainly to local increases in transpiration, but also to higher albedo. The reduction in radiative forcing (RF) from albedo alone is equivalent to a carbon emissions reduction of 78 t C ha^{-1}, which is six times larger than the annual biogechemical effects that arise from offsetting fossil fuel use. Thus, in the near-term, the biogeophysical effects are an important aspect of climate impacts of biofuels, even at the global scale. Locally, the simulated cooling is sufficiently large to partially offset projected warming due to increasing greenhouse gases over the next few decades. These results demonstrate that a thorough evaluation of costs and benefits of bioenergy-related land-use change must include potential impacts on the surface energy and water balance to comprehensively address important concerns for local, regional, and global climate change.

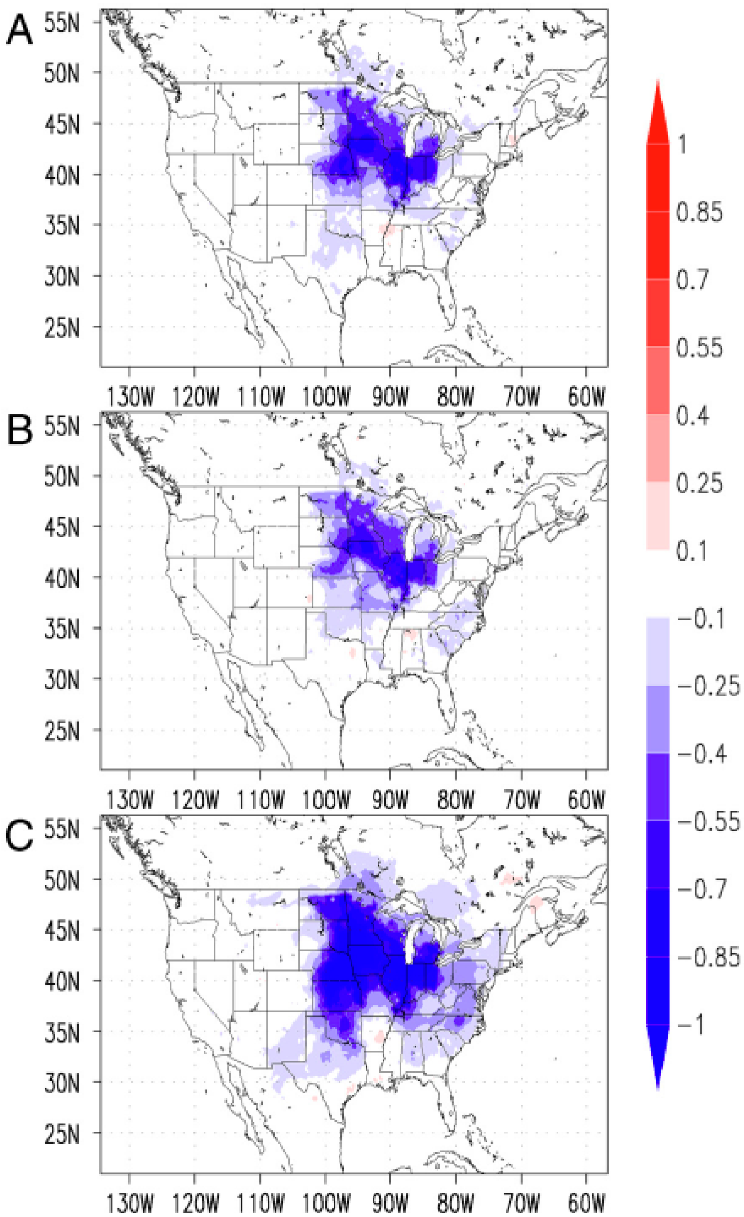

Figure 2. Simulated time mean (APR-OCT) difference in **(a)** 2 meter temperature [°C] (Perennials minus Annuals); **(b)** as (a) but perennial crop representation does not include albedo modification; **(c)** as (a) but perennial crop representation includes rooting depth of 2m.

Loarie, S. R., D. B. Lobell, G. P. Asner, Q. Mu, and C. B. Field. 2011. Direct impacts on local climate of sugar-cane expansion in Brazil. Nature Clim. Change **1**:105-109.

The increasing global demand for biofuels will require conversion of conventional agricultural or natural ecosystems. Expanding biofuel production into areas currently used for agriculture reduces the need to clear natural ecosystems, leading to indirect climate benefits through reduced greenhouse gas emissions and faster payback of carbon debt. Biofuel expansion may also cause direct, local climate changes by altering surface albedo and evapotranspiration, but these effects have been poorly documented. This study quantifies the direct climate effects of sugarcane expansion in the Brazilian cerrado, based on maps of recent sugarcane expansion and natural vegetation clearance combined with remotely sensed temperature, albedo, and evapotranspiration over a 1.9 million km^2 area. On a regional basis and clear sky day time conditions, conversion of natural vegetation to a crop/pasture mosaic warms the cerrado by an average of 1.55 (1.45 – 1.65) °C, but subsequent conversion of that mosaic to sugarcane cools the region by an average 0.93 (0.78 – 1.07) °C resulting in a mean net increase of 0.6 °C (Table 1). Our results suggest that expanding sugarcane into existing crop and pasture land has a direct local cooling effect that reinforces the indirect climate benefits of this land-use option.

MODIS variable	Land-use transition	Slope	s.e.	p.val	c.i.	Int.	N	R^2
Temp (°C)	from nat. veg. to crop/past.	1.55	0.05	<0.001	1.45 - 1.65	0.03	8507	0.11
Temp (°C)	from crop/past. to sugarcane	-0.93	0.07	<0.001	-1.07 - -0.78	-0.67	2376	0.06
ET (mm/day)	from nat. veg. to crop/past.	-0.60	0.02	<0.001	-0.67 – -0.53	0.08	8495	0.08
ET (mm/day)	from crop/past. to sugarcane	0.43	0.04	<0.001	0.30 – 0.56	0.01	2354	0.05
Albedo (%)	from nat. veg. to crop/past.	1.73	0.04	<0.001	1.65 - 1.80	0.48	8507	0.19
Albedo (%)	from crop/past. to sugarcane	0.20	0.05	<0.001	0.09 - 0.31	0.43	2376	<0.01

Table 1: Results of linear regressions fit through scatter plots of fractional change in land-use against change in MODIS variables. A subset of pixels separated by at least 5 km was used to minimize spatial autocorrelation. For each row, fractional change in landcover represents the abscissa and the MOIDS variables represent the ordinate. n refers to the number of 1 km^2 pixels in each regression and reflects the restricted subset of pixels >=5 km apart. Standard error of the slope parameter is referred to as s.e., the p-value of the slope parameter is p.val., and c.i. is the 95% confidence interval for the slope estimate. R^2 is the fit of the regression. All regressions were significant with p-values < 0.001.

2) exploring the options for incorporating low-termperature pyrolysis into strategies for biomass energy utilization

PhD student Lena Perkins (Mechanical Engineering) is making good progress modeling fast pyrolysis and carbonization in the context of utilizing them in the capture of biomass energy. The critical challenge with pyrolysis is that processing intended to leave a lot of carbon for sequestration (e.g. as biochar) releases little energy, and processing intended to yield energy rich products leads to limited options for sequestration. Still, several lines of evidence suggest that some form of pyrolysis could be important in biomass energy, underscoring the importance of a clear understanding of the process. The primary objective of Lena's modeling work is developing a model that supports comparisons among fast pyrolysis, slow pyrolysis, carbonization/torrefaction, and hydropyrolysis. While the modeling activities are not yet complete, they are advanced enough do demonstrating the interacting roles of time and temperature in controlling the mass remaining in carbonization (Figure 3).

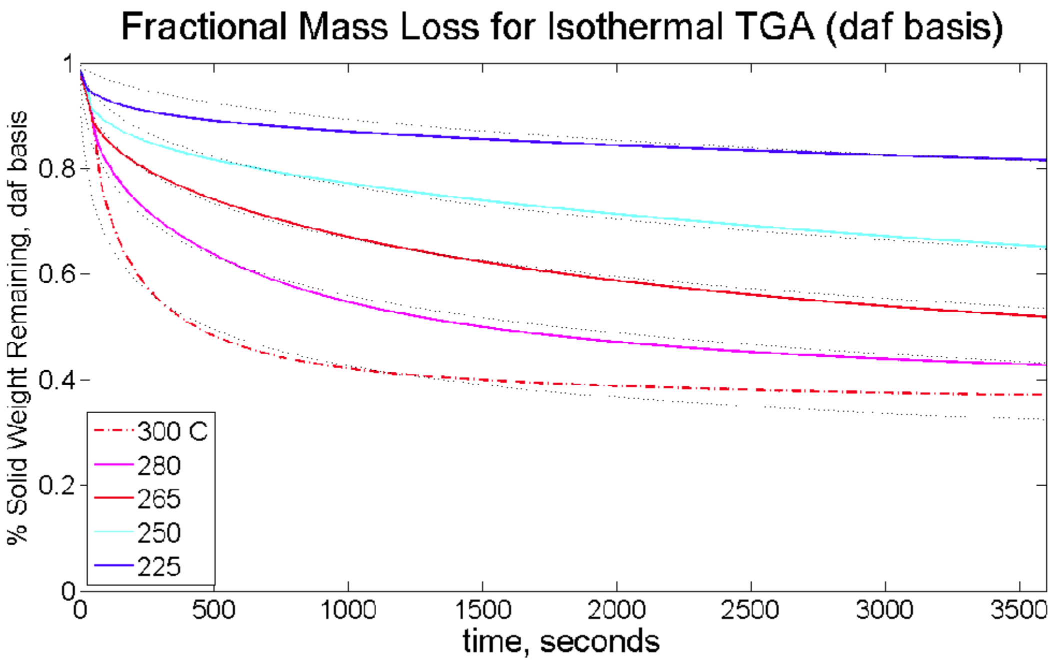

Figure 1. Gaussian Distributed Activation Energy Model applied to Isothermal TGA traces.

3) mapping Brazilian land-use change as part of the strategy for understanding indirect deforestation

One of the goals of this GCEP project is developing additional clarity on the topic of indirect deforestation, defined as clearing for crops in response to conversions elsewhere of lands from agriculture for food production to agriculture for fuel production. Indirect deforestation is incredibly difficult to quantify, because it is in fact indirect. The putative mechanism is that reduction in the supply of food lead to increases in price, and that increases in food prices increase the attractiveness of clearing forest lands in order to use them for food production. The situation is even more complicated in Brazil, where deforestation results from a combination of factors potentially involving a chain of interlinked processes. The hypothesis is that expansion of sugarcane displaces soy, and the displaced soy expands in areas that had been used for cattle ranching. This pushes the cattle into areas that had been cleared for subsistence agriculture, potentially pushing the small-scale farmers to expand forest gaps related to selective logging. All of these steps are influenced by a wide range of market and policy practices. They also occur over huge spatial scales.

To contribute to the assessment of indirect deforestation, we have been carefully mapping pastures and the changes. The pasture mapping effort is being managed as a collaboration. GCEP is covering the costs, with Brazilian scientists, including students, in the field. The Brazilian side of the mapping is being led by Prof. Dr. Claudio Rodrigues Leles from the Federal University of Goiás, Brazil. We anticipate that 2 papers from this project will be submitted in 2011.

(Loarie et al. 2011a, Loarie et al. 2011b) (Asner et al. 2010)

GCEP-supported publications over the last year.

Asner, G. P., S. R. Loarie, and U. Heyder. 2010. Combined effects of climate and land-use change on the future of humid tropical forests. Conservation Letters **3**:395-403.

Georgescu, M., D. B. Lobell, and C. B. Field. 2011. Direct climate effects of perennial bioenergy crops in the United States. Proceedings of the National Academy of Sciences:10.1073/pnas.1008779108.

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