Annual Progress Report

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The Expansion of Rubber and its Implications for Water and Carbon Dynamics in Montane Mainland Southeast Asia

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Abstract
In the early 1950s, China decided that in order to secure its economic development it needed to produce its own natural rubber. The Chinese government subsequently invested heavily in research on growing rubber in marginal environments and eventually established state rubber plantations in Hainan and Yunnan provinces in areas that lie as far north as 22° north latitude. China's success in growing rubber in these 'non-traditional' environments greatly expanded the habitat in which rubber was perceived to be productive. Today entrepreneurs from China, Vietnam, Malaysia, and Thailand are investing heavily in rubber plantations in non-traditional rubber growing areas of Laos, Cambodia, and Myanmar, as well as in non-traditional rubber growing areas of their own countries—northwest Vietnam, and northeast Thailand. Under a previous grant from NASA we documented that soil moisture increases with depth for agriculture and secondary forest, and decreases for rubber plantation. Also, soil moisture oscillations at the surface are mimicked in deeper layers for secondary and agriculture vegetation but are dampened with depth under rubber (http://research.eastwestcenter.org/mmsea/).The overarching science question to be addressed by this proposal is: How will the expansion of rubber cultivation in non-traditional rubber growing areas of mainland Southeast Asia affect local and regional energy, water, and carbon fluxes, and what are the consequences of those changes for local and regional hydrology and carbon sequestration?

Research Questions:
The overarching science question to be addressed by this proposal is: **How does the conversion from existing land covers to rubber affect local energy, water, and carbon fluxes, how extensive will rubber become in non-traditional rubber growing areas of mainland Southeast Asia, and what are the consequences of those changes for regional hydrology and carbon sequestration?** Specific science questions are:

1. Where is rubber being planted in the region and what are current and predicted patterns of this expansion in relation to other land-cover types?
2. What are the ecophysiological characteristics of rubber and how do they differ from the vegetation that rubber is replacing?
3. What are the historical spatial and temporal patterns of carbon sources and sinks over mainland Southeast Asia? How will the expansion of rubber and related land-use change alter the region-wide storage of carbon?
4. How will climate change interact with rubber-related land-cover/land-use change (LCLUC) to alter the regional stocks and fluxes of carbon and water over the next 50 years?

Approach Adopted:
Multi-disciplinary, field and modeling approach in involving three teams: (1) LCLU Team; (2) Field Hydrology Team; and (3) Ecosystem Demography Modeling Team.

Goals and Accomplishments in Year 3:

1. LCLU team:
   Goal: Accurate rubber distribution mapping is critical to the study of its expansion and provides a better understanding of the consequences of land-cover and land-use change on carbon and water cycles.

Accomplishments:
We completed work on this goal and have had one paper published on methods, and another paper forthcoming on project results:
Paper on rubber distribution in the study region submitted for publication:

Li, Z. and J. Fox. Forthcoming. Rubber distribution mapping in northeastern Thailand using Landsat TM imagery, *Applied Geography*.

Paper on methods for mapping rubber distribution published:

Li, Z. and J. Fox. 2011 Integrating Mahalanobis typicalities with a neural network for rubber distribution mapping. Remote Sensing Letters 2(2): 157-166. First published on:13 October 2010. http://dx.doi.org/10.1080/01431161.2010.505589

2. Field Hydrology team:

Goal: Eddy-covariance measurements of water, carbon, and energy exchanges over rubber (for at least 2 full years), and early- and mid-successional vegetation, and grass/shrub PFTs (for at least two 6-mo periods each, covering portions of wet and dry seasons).

Accomplishments:

Prior Years: Two state-of-the-art eddy flux towers were installed within rubber plantations: Som Sanuk Tower, installed February 2009 in a private plantation with 17-yr-old rubber, located in Nong Khai Province, NE Thailand; CRRI Tower, installed September 2009 in the Cambodia Rubber Research Institute plantation with 6-yr-old rubber, located in Kampong Cham, Cambodia.

Year 3: Continued operation and maintenance of the two project towers. Developed and implemented software to analyze eddy covariance data from the two tower sites to provide time series of water, carbon, and energy exchanges over rubber plantations. Through collaboration with Dr. Kumagai of Kyushu University, Japan, we installed a carbon dioxide profile monitoring system at the CRRI tower site to enable better estimates of nighttime carbon exchange. We dug soil pits at both field sites to access soil samples at depths of up to 3 m, to facilitate gravimetric soil moisture measurements for calibrating continuously monitored soil moisture probes. At this time, we have not yet established comparative observations over non-rubber sites. However, we have established collaborations with other groups with observations over forest and other agricultural land covers.

Goal: Characterization of the important ecophysiological properties of rubber and other key PFTs in the MMSEA region.

Accomplishments:

Prior Years: We made detailed measurements of some ecophysiological properties of rubber at the two tower sites, including stem diameter, tree height, and LAI. We set up protocols to continue these measurements at regular intervals. Additional information on rubber and other land covers was gathered from plot studies done by our Japanese collaborators and others in the region.

Year 3: We continued our measurements of ecophysiological properties of rubber at the two tower sites, including stem diameter, tree height, and leaf area index. We installed under-canopy radiation sensors at both sites to allow continuous estimation of leaf area. In collaboration with Dr. Kumagai's laboratory (Kyushu University), we installed networks of sapflux sensors in stands of rubber trees of two different ages at the CRRI field site. These sensors are providing detailed information on transpiration and the response of rubber trees to varying environmental conditions. In collaboration with Dr. Miyazawa, also of Kyushu University, we made leaf-level measurements of processes and properties controlling photosynthesis and transpiration at both field sites. These measurements provide estimates of key properties needed for ecosystem modeling.

Goal: Biometric measurements of aboveground NPP for rubber, early- and mid-successional vegetation, and grass/shrub PFTs.

Accomplishments:

Prior Years: Biometric observations were initiated for both tower sites, including regular monitoring of stem diameter, tree height, leaf litter, coarse woody debris, and soil carbon stocks.

Year 3: We continued regular monitoring of biometric variables at both tower sites, including observations of stem diameter, tree height, leaf litter, coarse woody debris, latex production, and soil carbon stocks. Site specific allometric relationships were obtained through our collaboration with Dr. Mizoue of Kyushu University. Samples of leaves, flowers, seeds, litter, coarse woody debris, rubber latex, and soil were taken for laboratory analysis. In collaborated with Dr. David Beilman, Geography, UH Mānoa, these samples were analyzed for their nitrogen and carbon content. Soil respiration monitoring stations with 25 soil collars at each site were established and initial soil respiration measurements were taken.

3. Ecosystem Modeling team:

Goal: Modify the physiological and land use components of the model.

Accomplishments:

We seek to downscale the Ecosystem Demography Model (ED) from a global database to a database focused on upland areas (above 300 m) of Mainland Southeast Asia including parts of Laos, Thailand, Vietnam, Myanmar, Cambodia, and Xishuangbanna in southern Yunnan, China. We initially sought to build a vegetation map of the region before human disturbance by implementing the model for 300 years, a period sufficiently long for plant growth to achieve a natural forest balance with reasonable fluctuations. Our first simulations of this undisturbed landscape produced relatively high biomass density values in the northern portion of the region but low values in southern Thailand and Cambodia. The ED model contains several adjustable parameters, one set of which includes fire-related variables. We turned off the fire function module in Thailand and Cambodia to increase biomass in this region, but the simulated biomass density values in Thailand and Cambodia are still low compared to other data sources (e.g., the paper and Woods Hole Biomass Density Map): Our simulated values are in the order of 10 Mg/ha while other data sources are in the order of 100 Mg/ha in this region. A second category of adjustable parameters focuses on variables such as wood densities and leaf lifespan for each of the seven Plant Functional Types (PFTs) contained in ED. We are analyzing the responses of the PFTs' ecophysiological functions to environmental variables to see whether we should tune the PFT parameters so that vegetation of higher biomass density can dominate this region.

Goal: Simulate the regional carbon and water period of 1500-2011.

Accomplishments:

Based on the composition of the modeled natural forest (Goal 1), we implemented the ED model for another 500 year period to account for human disturbances; this region has a history of heavy human disturbances. The four major components of land use/cover in the region include natural forest, secondary forest, cropland and pasture. Natural forest experienced disturbance through conversion into other land use/cover types. Land use/cover type conversions also occurred among secondary forests, croplands, and pastures. A dateset of annual transition rates among these four land use/cover types was obtained from the George Hurtt's team at the University of Maryland. The chief land use/cover change occurring in the region is the expansion of cash crops, particularly rubber. Rubber was first planted in the region in Xishuangbanna in 1960 and continued to slowly spread into Northeast Thailand. Since the 1990s the rate of change has grown rapidly. We used the rubber distribution map generated by the LCLU team (see above). We aggregated the resolution of the map from the 250 m resolution produced from MODIS imagery into 1 by 1 degree grid cells. We can not reconstruct the expansion of rubber through time hence we assumed linear increments across the 1960 to 2011 period. We set up a hierarchy of land-use transitions into rubber. We also programmed the computer code such that the minimum land area of any land use type (in percent) must be larger than the smallest area found for that land use type in the historical land-use dataset.

Goal: Model validation at different simulation stages

Accomplishments:

We hope to be able to access two biomass density validation sources soon. One is the national level carbon stock dataset from the Woods Hole Research Center and the other is a recently completed study of carbon estimates in Laos. Simulations from the ED model can be validated at several stages. In the model initialization stage, parameters such as wood densities, leaf lifespans, allometric equations, and photosynthesis/respiration coefficients need to be tuned to represent the vegetation in this region, at least for rubber. We have collected data on these variables from rubber plantations near the two flux towers. These data are helpful for building an independent rubber simulation model. In the process of the model simulation, plant heights are one class of those annual outputs from the model. LIDAR is capable of scanning a large coverage in a continuous time series. The information from the LIDAR system offers a possible way of connecting remote sensor-derived data and modeled results. This is an under-going process. As reported above the project has built two eddy covariance towers in Thailand and Cambodia where we are recording energy and CO^2 fluxes. In the next step we will seek to compare measurements from these towers and the landscapes they cover with our simulated results from the two grid cells where the towers are located.

Most significant results

In Year 3 we accomplished the goals we set out to meet. Our most significant results were as follows:

- Finalized mapping of rubber in uplands of Mainland Southeast Asia and submitted results for publication.
- Acquired 2 years of water, carbon, and energy exchange data for one rubber site and 1.5 years of data for a second rubber site
- Continued ecophysiological observations and biometric monitoring of the rubber stands at the two tower sites.
- Revised the physiological and land use components of the model.
- Simulated the water and carbon fluxes for Laos (most of our study area, non-traditional rubber growing areas in mainland Southeast Asia) under natural disturbances.

Future steps

In Year 4 we will seek to meet the following goals:

- Continue to obtain field climate/hydrological data and soil, vegetation, and physical parameters for forcing, parameter setting, and calibration of models;
- Simulate water and carbon fluxes for with the revised model that include human disturbances (land use history).
- Perform intensive model validation with the flux data collected at the two tower sites.

Conclusions

We have accomplished the goals we set out to achieve in Years 1 through 3. We purposely managed our funding in order to enable us to continue monitoring beyond the original 04/09/11 project termination date. This was important for the outcome of the research because: (1) setting up of the two eddy covariance flux towers took longer than originally planned; (2) conditions at the two rubber plantation field sites are such that continued carbon dioxide profile monitoring and soil respiration measurements are needed to produce reliable estimates of ecosystem carbon exchange; our Japanese collaborators have recently installed a CO^2 profiling system at the CRRI site; and (3) our ED modeling efforts are progressing, but need more time to bear fruit.