**Progress Report on McGuire Component of Taiga LTER Research Program**

**(Draft of 23 October 2002)**

My responsibilities in the Taiga LTER Program primarily involve the use of modeling as a tool in scaling and integration. Specifically, my research program in the LTER has focused on issues related to modeling carbon dynamics at large spatial and longer temporal scales. Over the last several years, my research program has made progress in (1) evaluating the use of stand-level data to model carbon dynamics, (2) representing soil thermal processes in modeling carbon dynamics, and (3) representing the role of fire in modeling carbon dynamics.

To evaluate the use of stand level data to model carbon dynamics, we parameterized version 4.1 of the Terrestrial Ecosystem Model (TEM, McGuire et al., 2000) for a mature black spruce ecosystem in interior Alaska based on data from the Taiga LTER Program. This parameterization has been used in several studies. One study involved the comparison of nine ecosystem process models that were used to estimate carbon and water exchanges by a 150-year-old black spruce forest in central Canada where these exchanges had been measured from 1994 through 1996 as part of the Boreal Ecosystem Atmosphere Study (BOREAS). The results of this study indicated that model time step and complexity played small roles in simulating monthly to annual exchanges of carbon and water (Amthor et al., 2001). While the nine models produced similar patterns of seasonal and annual exchanges of carbon and water, sensitivity studies with the models revealed that the models had similar sensitivities to changes in air temperature, surface irradiance, and decreased precipitation, but differed in sensitivities to changes in atmospheric carbon dioxide (Potter et al., 2001). The different sensitivities to changes in atmospheric carbon dioxide were attributed to differences among the models in the coupling of photosynthesis and decomposition to nitrogen dynamics. We followed up this study by evaluating the role of carbon-nitrogen dynamics on the historical and projected carbon balance of mature black spruce ecosystems across North America (Clein et al., 2002). This study revealed that the range of simulated decadal changes in carbon storage across North America black spruce ecosystems was substantially greater in simulations that did not consider the coupling of carbon and nitrogen dynamics. Analyses of the spatial variability in the decadal responses revealed that carbon fluxes simulated by coupled and uncoupled versions of the model have different sensitivities to climate and that the climate sensitivities of fluxes change over time. Thus, the issue of coupling between carbon and nitrogen dynamics in black spruce ecosystems has implications at large spatial and long temporal scales.

We conducted a study with three large scale ecosystem models (CASA, CENTURY, and TEM) in which the consideration of soil thermal dynamics in winter affected the release of carbon to the atmosphere in a way that improved the ability of all three models to simulate the seasonal concentrations of atmospheric carbon dioxide (McGuire et al., 2000). This led us to incorporate a permafrost model in TEM (Zhuang et al., 2001). Application of the new model to the range of black spruce ecosystems in

North America demonstrated that the model has the capability to operate over temporal and spatial domains that consider substantial variation in surface climate given that spatial variability in key structural characteristics and physical properties of the soil thermal regime are described. Based on this study, we highlighted the need data sets that describe important structural characteristics and physical properties of the soil thermal regime (Walsh et al., 2001). We parameterized this new version of TEM for global application based on soil thermal measurements at a number of LTER sites and applied the model to simulate 20$^{th}$ Century carbon dynamics of terrestrial ecosystems north of 30o N (Zhuang et al., in review). This study revealed that the representation of soil thermal dynamics improves the timing of the commencement of carbon uptake at the beginning of the growing season, which had been a general problem in large-scale models that use air temperature to define phenology (Dargaville et al., 2002).

We have conducted three studies relevant to representing the role of fire in modeling carbon dynamics of boreal forest ecosystems. In the first study, we applied the version of TEM with permafrost to simulate soil thermal and carbon dynamics of a post-fire chronosequence in interior Alaska (Zhuang et al., in press). The comparison between simulated and observed measurements revealed that the model is capable of accurately simulating soil temperature and soil respiration in the growing season for both control and burned stands of the chronosequence, which is an indicated that the model is capable of representing decadal- and century-scale soil thermal and carbon dynamics. Sensitivity analyses with the model indicate that along with differences in fire and climate history, a number of other factors influence the response of carbon dynamics to fire disturbance. These factors include nitrogen fixation, the growth of moss, changes in the depth of the organic layer, soil drainage, an fire severity. A second study we conducted was to estimate large-scale fluxes in high latitudes from terrestrial biosphere models and an inversion of atmospheric carbon dioxide measurements (Dargaville et al., 2002). This study revealed that there are larger uncertainties in the estimates from the inversion over Europe and Boreal Asia than over Boreal North America. We have conducted preliminary simulations with the permafrost version of TEM over Boreal North America, and these simulations have similar inter-annual variability in carbon exchange in comparison to the inversion only when fire is considered in addition to climate variability and increases in atmospheric carbon dioxide. Finally, we have conducted a study to compare carbon dynamics and aspects of the fire regime among the high latitude transects of the International Geosphere Biosphere Programme (McGuire et al., 2002). These studies reveal that vegetation carbon in boreal forest ecosystems of Boreal Asia turns over slower than in Boreal North America even though fire frequency is higher in Boreal Asia. Differences in how fire is carried across the landscape has been identified as the factor responsible for this seemingly non-intuitive relationship between vegetation turn over and fire frequency, as Scots pine forests of Boreal Asia are primary affected by ground fires that allow trees to survive while black spruce forests of North America are primarily affected by stand-replacing fires that kill trees. Thus, the applications of models to represent the role of fires across the boreal forest biome must consider how fires affect tree survival.

**Publications**


Zhuang, Q., A.D. McGuire, J.M. Melillo, J.S. Clein, R.J. Dargaville, D.W. Kicklighter, R.B. Myneni, J. Dong, V.E. Romanovsky, J. Harden, and J.E. Hobbie. Carbon cycling in extratropical ecosystems of the Northern Hemisphere during the 20th Century: A modeling analysis of the influences of soil thermal dynamics. Submitted to *Tellus*.

Zhuang, Q., A.D. McGuire, J. Harden, K.P. O'Neill, V.E. Romanovsky, and J. Yarie. In press. Modeling soil thermal and carbon dynamics of a fire chronosequence in interior Alaska. *Journal of Geophysical Research - Atmospheres*. In press.

McGuire, A.D., C. Wirth, M. Apps, J. Beringer, J. Clein, H. Epstein, D.W. Kicklighter, J. Bhatti, F.S. Chapin III, B. de Groot, D. Efremov, W. Eugster, M. Fukuda, T. Gower, L. Hinzman, B. Huntley, G.J. Jia, E. Kasischke, J. Melillo, V. Romanovsky, A. Shvidenko, E. Vaganov, and D. Walker. 2002. Environmental variation, vegetation distribution, carbon dynamics, and water/energy exchange in high latitudes. *Journal of Vegetation Science* 13:301-314.

Dargaville, R., A.D. McGuire, and P. Rayner. 2002. Estimates of large-scale fluxes in high latitudes from terrestrial biosphere models and an inversion of atmospheric $CO_2$ measurements. *Climatic Change* 55:273-285.

Clein, J.S., A.D. McGuire, X. Zhuang, D.W. Kicklighter, J.M. Melillo, S.C. Wofsy, P.G. Jarvis, and J. M. Massheder. 2002. Historical and projected carbon balances of mature black spruce ecosystems across North America: The role of carbon-nitrogen interactions. *Plant and Soil* 242:15-32.

Walsh, J.E., J. Curry, M. Fahnestock, M.C. Kennicutt II, A.D. McGuire, W.B. Rossow, M. Steele, C.J. Vorosmarty, and R. Wharton. 2001. Enhancing NASA's Contribution to Polar Science: A Review of Polar Geophysical Data Sets. National Academy Press. Washington, D.C. 124 pages.

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Potter, C., S. Wang, N.T. Nikolov, A.D. McGuire, J. Liu, A.W. King, J.S. Kimball, R.F. Grant, S.E. Frolking, J.S. Clein, J.M. Chen, and J.S. Amthor. 2001. Comparison of boreal ecosystem model sensitivity to variability in climate and forest site parameters. *Journal of Geophysical Research - Atmospheres*. 106:33,671-33,688.

McGuire, A.D., J.M. Melillo, J. T. Randerson, W.J. Parton, M. Heimann, R.A. Meier, J.S. Clein, D.W. Kicklighter, and W. Sauf. 2000. Modeling the effects of snowpack on heterotrophic respiration across northern temperate and high latitude regions: Comparison with measurements of atmospheric carbon dioxide in high latitudes. *Biogeochemistry* 48:91-114.

**Graduate Student Theses**

Qianlai Zhuang (December 2001): Modeling the influences of climate change, permafrost dynamics, and fire disturbance on carbon balance of high latitude ecosystems.

Xinxian Zhang (May 2001): Modeling stand-level canopy maintenance respiration of black spruce ecosystems in Alaska: Implications for spatial and temporal scaling.