Final Report
U.S. Department of Energy Contract DE-FG02-03ER63682 A002
University of Minnesota Project 405-6451
Measuring and Modeling Component and Whole System Carbon – WLEF

Introduction

This report describes activities funded by the U.S. Department of Energy on a research project in northern Wisconsin. This project focuses on the WLEF Tall Tower, a globally-unique eddy covariance system and related measurement sites that measures ecosystem/atmospheric carbon (C) exchange over a complex landscape. We have amassed and over 10-year record of net C flux measurements at WLEF, with marked inter- and intra-annual variation in ecosystem-atmospheric carbon exchange. Flux tower and related measurements are the primary tools for collecting data on net carbon flows in ecosystems. These data are in turn the basis for our understanding of present and future earth system response to changing climates. This grant was a one-year study to continue measurements at the WLEF tower and related sites, from September 1 2005 through August 31 2006. This final report outlines activities and accomplishments during this period.

General Activities

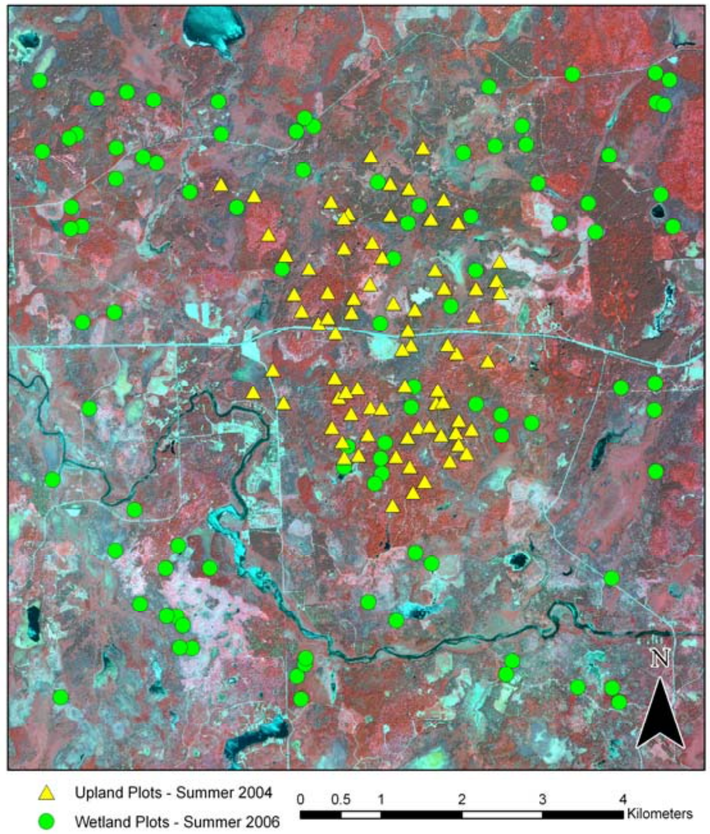
The study project involves a close collaboration between the University of Minnesota and Pennsylvania State University, Department of Meteorology. The research is funded separately to each institution directly from the Department of Energy, however the science plans and research work are tightly linked. The Penn State portion primarily involves flux tower data analysis and broad-scale atmospheric/biospheric interchange. The University of Minnesota portion focuses on plant and component fluxes, and ecosystem mechanisms and response to climatic forcings, and because of proximity and expertise, measurement system maintenance and upgrades.

University of Minnesota work on this grant supports two primary activities. The first is the maintenance and further development of the WLEF Tall Tower eddy flux system and related climate stations within the footprint of the WLEF tall tower. Flux tower maintenance include basic data stream and data file quality control, the detection and diagnosis of equipment malfunction and failure, troubleshooting, and equipment replacement and repair. It also includes routine maintenance such as calibration gas replacement, general equipment calibration, gasket, seal, tubing, and other replacement, and other general maintenance.

One particularly noteworthy equipment upgrade involves the replacement of older, proprietary tower data acquisition systems with standardized, more robust systems. Measurement and control systems are installed at each flux collection height (30m, 122m, and 396m), substantially increasing the reliability of these data streams with equal or incrementally improved data quality. Robust systems, built primarily on a combination of industry standard parts (e.g., Campbell Scientific) were constructed based on the measurement requirements and power constraints. These were deployed at three levels during the 2005-2006 study periods, yielding a much more robust, standardized, and easily maintained system. Systems have functioned superbly to date. This work has largely been conducted by Bruce Cook, a Ph.D. candidate and research associate working on this project.

The second primary activity funded on this project is component ecosystem pool sizes and fluxes, particularly developing and maintaining a network of biometric plots, and measuring soil and other component flux measurements.

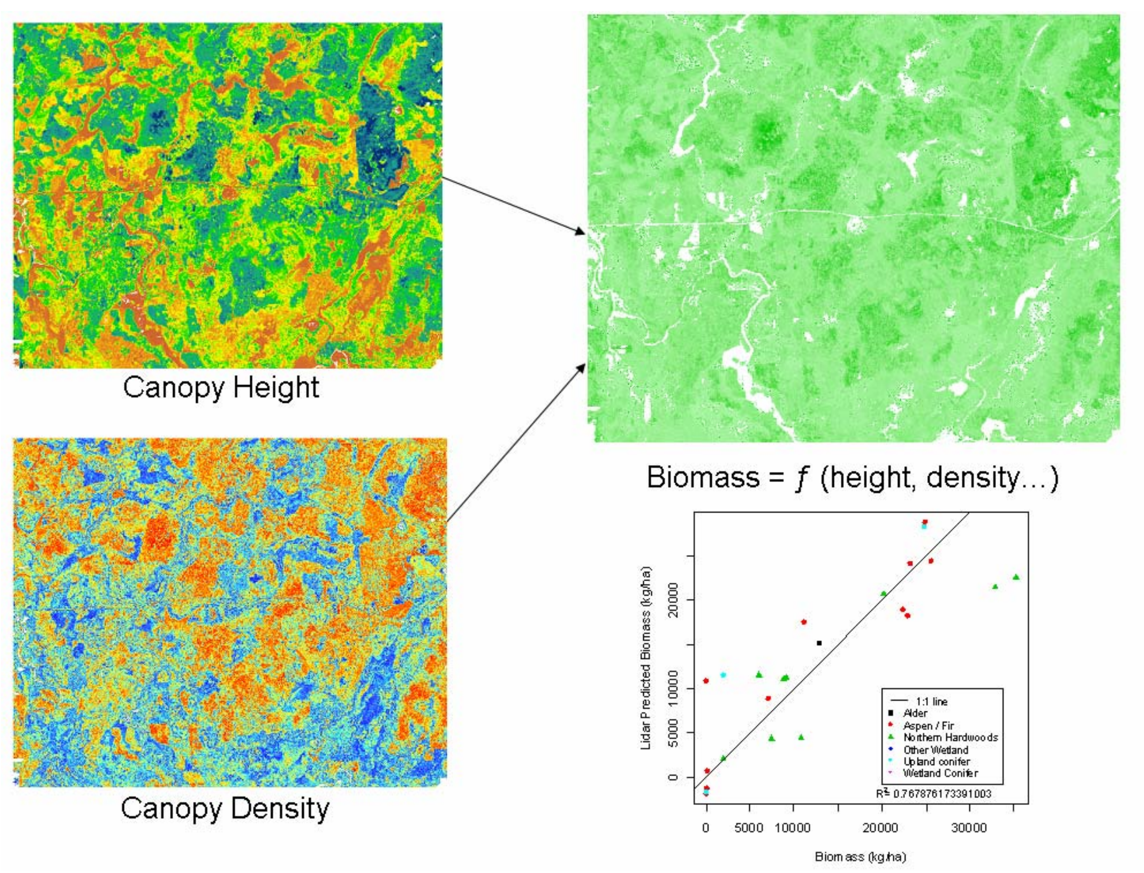
We had established a network of 88 biometric plots using the US Forest Service Forest Inventory and Analysis (FIA) plot design. Adopting this design aids in comparisons to the broader FIA data set, collected using a uniform national framework. We expanded our network with an additional 70 plots during the 2006 field season, focusing primarily on undersampled vegetation types (Figure, at right). These data were complemented by the collection and analysis of a Spring, leaf-off LiDAR data set. A graduate student, Ryan Anderson, funded on this project, led two field crews totaling eight undergraduate and graduate students, in plot selection, measurement, analysis, and quality control. Biometric plot measurements included increment cores of the central subplot of the FIA design, and the measurement of five-year and ten-year average woody growth increment. This allows us to calculate individual tree woody growth. These data may in turn be used to estimate areal woody growth on a plot basis, once adjusted for mortality.



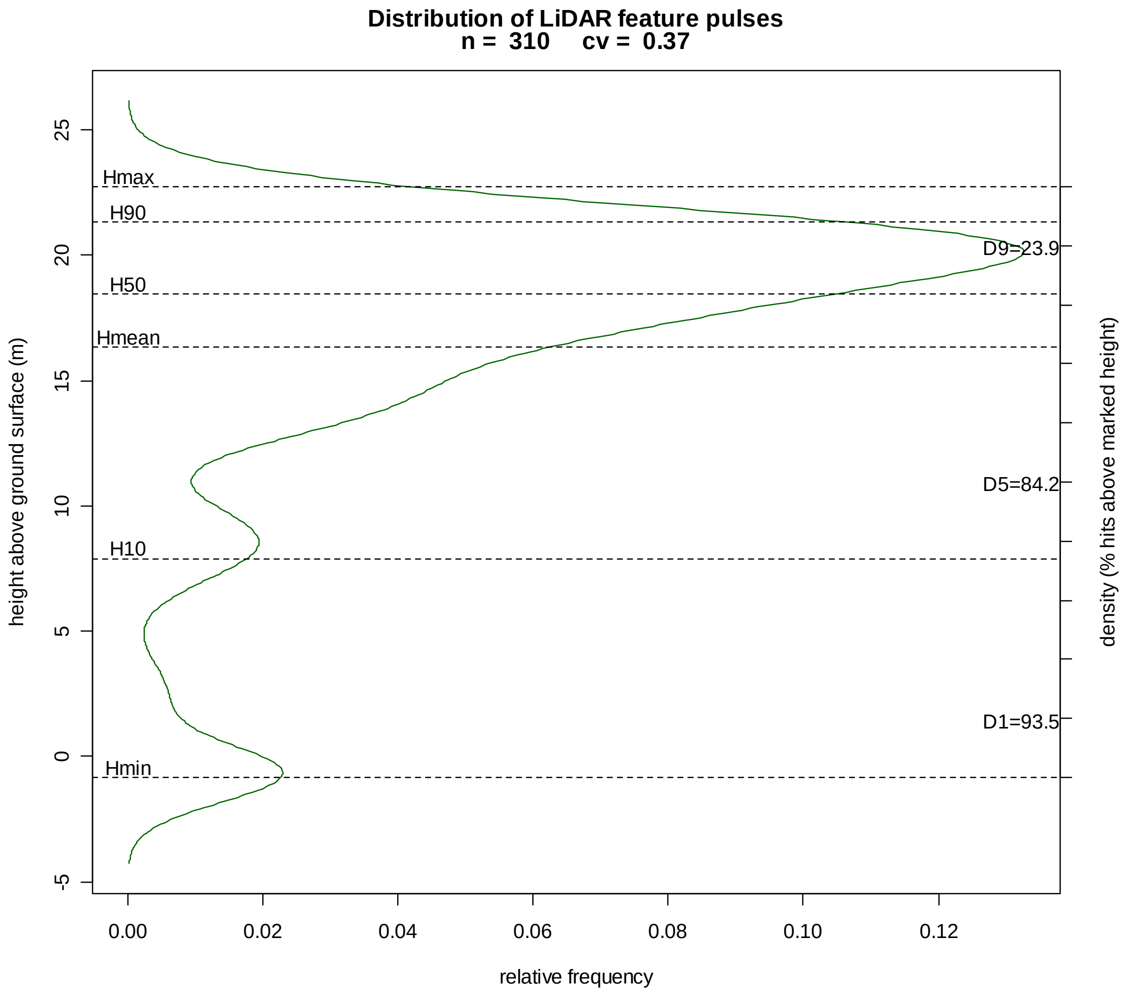
These biometric plots were supported by a number of other plot measurements. We remeasured 12 additional plots for various components, primarily tree mortality, detritral pools and changes, and soil and component (root and litter) respiration. Annual measurements at fixed plots will allow us to estimate individual stem mortality. These plots concentrate on a chronosequence of young to old aspen stands, and mixed hardwood stands, which are the prevalent upland types and the largest component of regional forest productivity. These data are crucial to estimating biometric carbon balance.

We also measured soil and component forest floor respiration at an overlapping set of plots. Root exclusion collars were placed at four plots, to depths of 30, 60, and 100 cm, paired with standard 6 cm collars. Soil respiration was measured periodically at 8-12 collars in each plot. Soil respiration was measured continuously for 5 day periods on a rotating schedule at these plots. These data may be combined with leaf litterfall data collected at these plots to estimate net soil carbon balance, and hence total carbon balance when combined with biometric measurements.

LiDAR data were also collected and analyzed to complement the biometric data. First and last-return lidar measurements at an approximate density of 2 pulses per square meter were collected. These were combined with high-resolution GPS measurements of biometry plot centers to co-register these data sets, and identify statistical relationships between LiDAR returns and canopy metrics. Because LiDAR measures the density, height, and vertical volume of the forest canopy, and because these metrics are related to forest growth (e.g., leaf area is strongly related to productive capacity, which in turn drives net production), many previous studies show substantially improved growth estimates when using LiDAR. Our results also show strong, statistically significant relationships between LiDAR metrics and biomass, and more variable but significant relationships with annual production. These data may be combined to estimate biomass and growth at a very fine scale, and with improved accuracy, across large areas (Figure, below).



The LiDAR data also provide substantial detailed data on a stand basis that may be used for mechanistic models. We have been analyzing LiDAR vertical profiles for delineated stands. These profiles combine LiDAR returns for a forest stand delineated manually from recent aerial photographs or high-resolution satellite data (Quickbird 2.4 meter data collected Spring 2006). These profiles (see Figure below) provide the vertical distribution of leaf area. A number of studies have shown that variation in light interception is the primary control on variability in predictions. Increased accuracy in vertical leaf distributions will improve modeling of forest growth. Measures of vertical LAI may be used to test productivity models that yield vertical distributions as emergent properties (e.g., PnET), or may use vertical distributions as input or constraints (e.g., ED, SiB).



Collaborations, Wider Data Use

We wish to highlight the easy access provided for our data, and the broad use. The flux and/or biometric data have been used by at least 30 additional research labs and projects and have contributed to four major synthesis activities and papers. These data are freely distributed over a website (cheas.psu.edu), and contributed to the ORNL DACC. These data have been accessed by the atmospheric modeling and measurement community, biometeorologists, and ecosystems modelers at a number of labs and from at least three continents. The biometric data are in the process of quality control and analysis, and will be added to the DACC and website within the next 9 months.

This work also explicitly contributes to the NACP Mid-continent intensive program. We designed our data measurement system and are sharing these data with NASA and NASA-affiliated personnel. For example, NASA scientists have visited a large number of our biometry plots to measured below-canopy light interception, leaf area, and canopy architecture. These data will be combined with satellite-based measurements. Similar collaborative measurements have been made with research groups at four other universities, NOAA-NCAR labs, and international collaborators as part of the NACP mid-continental intensive campaign.

We are working on a number of papers and talks, in addition to those published and in press, listed below.

Outputs Based Wholly or in Part on this Project Funding
Peer-reviewed Publications
Accepted, in press

Desai, A., Noormets, A., Bolstad, P.V., Chen, J., Cook, B.D., Davis, K.J., Euskirchen, E.S., Gough, C., Martin, J.M., Ricciuto, D.M., Schmid, H.P., Tang, J. and Wang, W., 200x. Influence of vegetation type, stand age and climate on carbon dioxide fluxes across the Upper Midwest, USA: Implications for regional scaling of carbon flux, in press, *Agricultural and Forest Meteorology*.

Noormets A., A.Desai, D. Ricciuto, B. Cook, K. Davis., P. Bolstad, H. Schmid, P. Curtis, E. Carey, H. Su, J. Chen, 200x. Moisture sensitivity of ecosystem respiration: comparison of 14 forest ecosystems in northern Wisconsin, USA, in press, *Agricultural and Forest Meteorology*.

Ricciuto, D.M., Butler, M.P., Davis, K.J., Cook, B.D., Bakwin, P.S., Andrews, A.E. and Teclaw, R.M., 200x Causes of interannual variability in ecosystem-atmosphere CO_2 exchange in a northern Wisconsin forest using a Bayesian synthesis inversion, in press, *Agricultural and Forest Meteorology*.

2006

Heinsch, F.A., M. Zhao, S.W. Running, J.S. Kimball, R.R. Nemani, K.J. Davis, P.V. Bolstad, B.D. Cook, A.R. Desai, D.M. Ricciuto, B.E. Law, W.C. Oechel, H. Kwon, H. Luo, S.C. Wofsy, A.L. Dunn, J.W. Munger, D.D. Baldocchi, L. Xu, D.Y. Hollinger, A.D. Richardson, P.C. Stoy, M.B.S. Siqeira, R.K. Monson, S. Burns, and L.B. Flanagan, 2006. Evaluation of remote sensing based terrestrial producitivity from MODIS using regional tower eddy flux network observations, *IEEE Transactions on Geosciences and Remote Sensing*, 44:1908-1925.

Richardson, A.D., Hollinger, D.Y., Burba, G.G., Davis, K.J., Flanagan, L.B., Katul, G.G., Munger, J.W., Ricciuto, D.M., Stoy, P.C., Suyker, A.E., Verma, S.B. and Wofsy, S.C., 2006. A multi-site analysis of random error in tower-based measurements of carbon and energy fluxes. *Agricultural and Forest Meteorology*, 136, 1-18.

Tang, J., P.V. Bolstad, B.E. Ewers, A.R. Desai, K.J. Davis, E.V. Carey, 2006. Sap-flux- upscaled canopy transpiration, stomatal conductance and water use efficiency in an old-growth forest in the Great Lakes region of United States. Journal of Geophysical Research – Biogeosciences, 111, G02009

Wang, W., K.J. Davis, B.D. Cook, D.M. Ricciuto, and M.P. Butler, 2006. Decomposing CO2 fluxes measured over a mixed ecosystem at a tall tower and extending to a region: A case study, *Journal of Geophysical Research - Biogeosciences*, **111** (G02005), doi:10.1029/2005JG000093

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Desai, A.R., P. Bolstad, B.D. Cook, K.J. Davis, and E.V. Carey, 2005. Comparing net ecosystem exchange of carbon dioxide between an old-growth and mature forest in the upper Midwest, USA, *Agricultural and Forest Meteorology*, **128** (1-2), 33-55

Martin, J. G., and P.V. Bolstad, 2005. Soil respiration in temperate forests: influence of soil moisture and site biological, chemical and physical characteristics, *Biogeochemistry*, 73:149-182.

Wang, W., Davis, K.J., Cook, B.D., Bakwin, P.S., Yi, C., Butler, M.P. and Ricciuto, D.M., 2005. Surface layer CO2 budget and advective contributions to measurements of net ecosystem-atmosphere exchange of CO2. Agricultural and Forest Meteorology, 135(1-4): 202-214.

Talks and Posters

2006

Anderson, R., P. Bolstad, B. Cook. Chequamegon Ecosystem-Atmosphere Study IX, Workshop Presentation, LiDAR Based Upscaling of Forest Biomass, Woodruff, WI, Jun. 6, 2006.

Tang, J., P.V. Bolstad, J.G. Martin. Decline in soil respiration with age in a chronosequence study of deciduous forests. Poster presented in the 1st Integrated Land Ecosystem-Atmosphere Processes (iLEAPS) Science Conference, Boulder, CO, Jan. 21-26, 2006.

Tang, J., P.V. Bolstad. Simulating soil carbon dynamics in northern hardwood forests using the Century Model. Presented in a Workshop on Soil Carbon Dynamics in Northern U.S. Forests, sponsored by U.S. Forest Service Northern Global Change Research Program. Minneapolis, MN, Jan. 17-18, 2006.

Tang, J., P.V. Bolstad, J.G. Martin. Soil respiration in a chronosequence of deciduous forests in the Great Lakes region of the United States. Presented in the American Geophysical Union (AGU) Fall Meeting in San Francisco, CA, Dec. 5-9, 2005.

2005

Bolstad PV, Desai A, Cook B, Davis KJ. 2005. Bias and Variability in Biometric Estimates of Forest Woody Carbon Gain at Landscape Scales: An Empirical Test in North Central Wisconsin. Eos Trans. AGU, 86(52), Fall Meet. Suppl., Abstract B44B-08.

Davis KJ, et al. 2005. Top-down mixing ratio data fusion. AmeriFlux Annual Science Team Meeting, Boulder, CO (18-20 October 2005).

Davis, K. J., A. Andrews, J. A. Berry, P. V. Bolstad, J. Chen, B. D. Cook, A. S. Denning, A. R. Desai, B. R. Helliker, N. Miles, A. Noormets, D. M. Ricciuto, S. J. Richardson, M. Uliasz, and W. Wang. 2005. Regional ecosystem-atmosphere carbon exchange observed simultaneously via atmospheric inversions and flux-tower upscaling. 7th International Carbon Dioxide Conference, 25-30 September 2005, Boulder, CO.

Desai, A. R., W. Wang, D. M. Ricciuto, B. D. Cook, F. A. Heinsch, K. J. Davis, A. Noormets, J. Chen, P. V. Bolstad, S. J. Richardson, N. Miles, M. Uliasz, and P. R. Moorcroft. 2005. Synthesis of top-down and bottom-up scaling of regional terrestrial carbon dioxide fluxes: Implications for global terrestrial CO2 flux. 7th International Carbon Dioxide Conference, 25-30 September 2005, Boulder, CO.

Davis K, Andrews A, Berry J, Bolstad P, Chen J, Cook B, Denning AS, Desai A, Heinsch F, Helliker B, Miles N, Noormets A, Ricciuto D, Richardson S, Uliasz M, Wang W. 2005. Regional Forest-Atmosphere Carbon Exchange via Atmospheric Inversions and Flux-Tower Upscaling. Eos Trans. AGU, 86(52), Fall Meet. Suppl., Abstract B44B-06.

Richardson, A.D., David Y. Hollinger, George C. Burba, Kenneth J. Davis, Lawrence B. Flanagan, Gabriel G. Katul, J. William Munger, Daniel M. Ricciuto, Paul C. Stoy, Andrew E. Suyker, Shashi B. Verma, and Steven C. Wofsy. 2005. Uncertainty In Tower-Based Measurements of Carbon and Energy Fluxes: A Multisite Analysis. AmeriFlux Annual Science Team Meeting, Boulder, CO (18-20 October 2005).