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T. J. Griffis[1], J. M. Baker[1, 2], and K. A. Billmark[1]

[1]Dept. of Soil, Water and Climate, University of Minnesota, St. Paul, MN, USA.
[2]United States Dept. of Agriculture- Agriculture Research Service

1 Research Site

Rosemount Research and Outreach Center (RROC), Upper Midwest, St. Paul, Minnesota, 4 Flux stations including a Tall Tower site located within a heavily managed landscape Funding Years: October 2007 to June 2009.

2 Final Report Summary

2.1 Research Objectives

The goal of this research is to provide a better scientific understanding of carbon cycle processes within an agricultural landscape characteristic of the Upper Midwest. This project recognizes the need to study processes at multiple spatial and temporal scales to reduce uncertainty in ecosystem and landscape-scale carbon budgets to provide a sound basis for shaping future policy related to carbon management. Specifically, this project has attempted to answer the following questions: 1. Would the use of cover crops result in a shift from carbon neutral to significant carbon gain in corn-soybean rotation ecosystems of the Upper Midwest? 2. Can stable carbon isotope analyses be used to partition ecosystem respiration into its autotrophic and heterotrophic components? 3. Can this partitioning be used to better understand the fate of crop residues to project changes in the soil carbon reservoir? 4. Are agricultural ecosystems of the Upper Midwest carbon neutral, sinks, or sources? Can the proposed measurement and modeling framework help address landscape-scale carbon budget uncertainties and help guide future carbon management policy?

2.2 Research and Education Activities

In this section we give a brief summary of work that is currently in progress that will form the basis of future manuscripts. Other results related to years 1 and 2 of this funding are available from previous DOE reports and the publications listed below.

With financial support from the United States Department of Energy (Grant # DE-FG02-06ER64316) we have established a near-continuous two-year record of isotopic CO_2 mixing ratios and EC isotopic fluxes from the University of Minnesota tall tower Trace Gas Observatory (TGO). Our original optical isotope and eddy covariance technique was published in the *Journal of Geophysical Research - Atmospheres* in April 2008. These first experiments and data have resulted in a number of other collaborative publications [*Griffis et al.*, 2008; *Lee et al.*, 2009; *Xiao et al.*, 2009]. Further, we have made significant progress in applying this new methodology to measuring isotopic water vapor exchange [*Griffis et al.*, 2009b].

Here we show a few recent results from a manuscript that was submitted to the journal, *Agricultural and Forest Meteorology* in September 2008. It is now being revised to address the concerns of the reviewers [*Griffis et al.*, 2009a].

Figure 9 shows the ratio of tall tower eddy covariance isotopic fluxes. This flux ratio method has proven to be very robust at the field scale. Here, we are using it to determine nighttime and daytime isotopic discrimination at the regional scale. The nighttime data in both 2007 and 2008 indicate that the isotopic composition of the regional respiration signal is relatively enriched (-16‰). In contrast, the daytime ecosystem discrimination is significantly more depleted (-21‰). These values indicate that the regional carbon budget is dominated (as much as 65%) by C4 agricultural systems (Figure 1).

These data are extremely rare and provide a first attempt of quantifying the regional isotopic disequilibrium (a key parameter used by the inverse modeling community). Based on isotopic mass balance calculations, we estimated an isotopic land use disequilibrium value of nearly 5‰. This is substantially larger than the current values used in inverse models for the Upper Midwest [*Scholze et al.*, 2008]. It appears, however, that our methodology may overestimate nighttime enrichment due to vertical advection (mass flow hypothesis) of CO_2 from a loft (Figure 2). When we account for mass flow, the isotopic disequilibrium value is reduced by approximately 2‰and is in much better agreement with model values currently prescribed for the region. We are continuing to investigate the seasonal and interannual variation in these key parameters.

Jennifer Corcoran (MS student) will graduate in spring 2009. Her work has focused on using remote sensing and GIS techniques to determine the spatial representativeness of our ecosystem scale data within a regional context. Her analysis has focused on land use and change and estimating NEP within the vicinity of the tall tower. A Landsat TM hybrid supervised/unsupervised land cover classification for 2007 determined that corn and soybean fields dominated the landscape, comprising more than 60% of the area within a typical daytime flux footprint of the tall tower. Leaf area index (LAI) of corn and soybean fields within the tall tower footprint was estimated using a field-scale relationship between LAI and the normalized difference vegetation index (NDVI) scaled-up with Landsat TM derived NDVI. Using a modified simple light response function, weighted by LAI, a simple scaling relationship was developed to estimate NEP of corn and soybean fields within the region. Figure 4 shows that measured NEP from our two fields appear to be representative of the greater region. This analysis is also supported by the typically flux patterns of CO_2

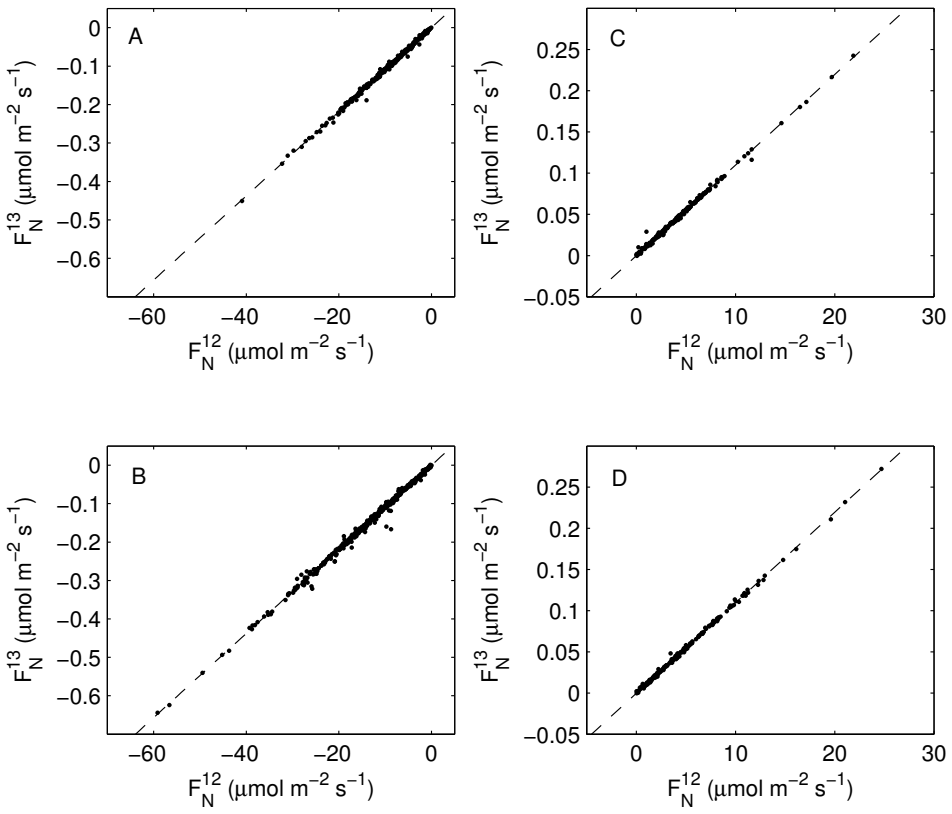

Figure 1: Estimating regional isotopic discrimination using the flux ratio analysis during growing season conditions A) daytime 2007; B) daytime 2008; C) nighttime 2007; D) nighttime 2008.

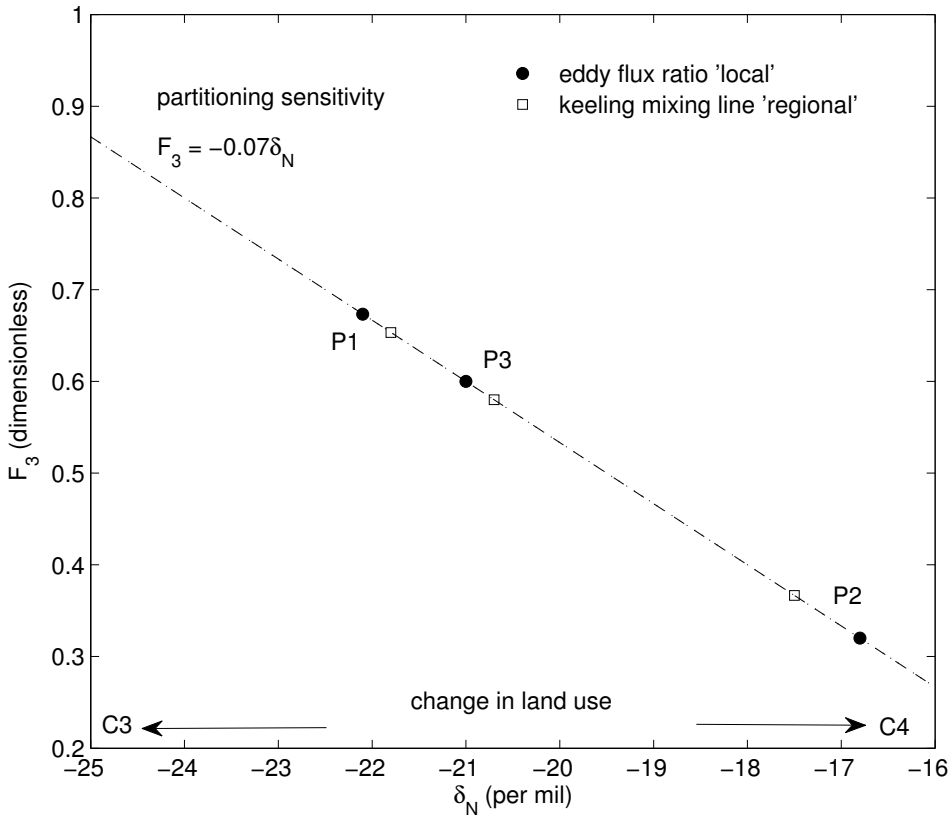

Figure 2: Seasonal variation in biosphere-atmosphere discrimination and net CO_2 flux partitioning determined for the three phenological periods using Keeling plots (regional signal) and eddy flux ratios (local signal).

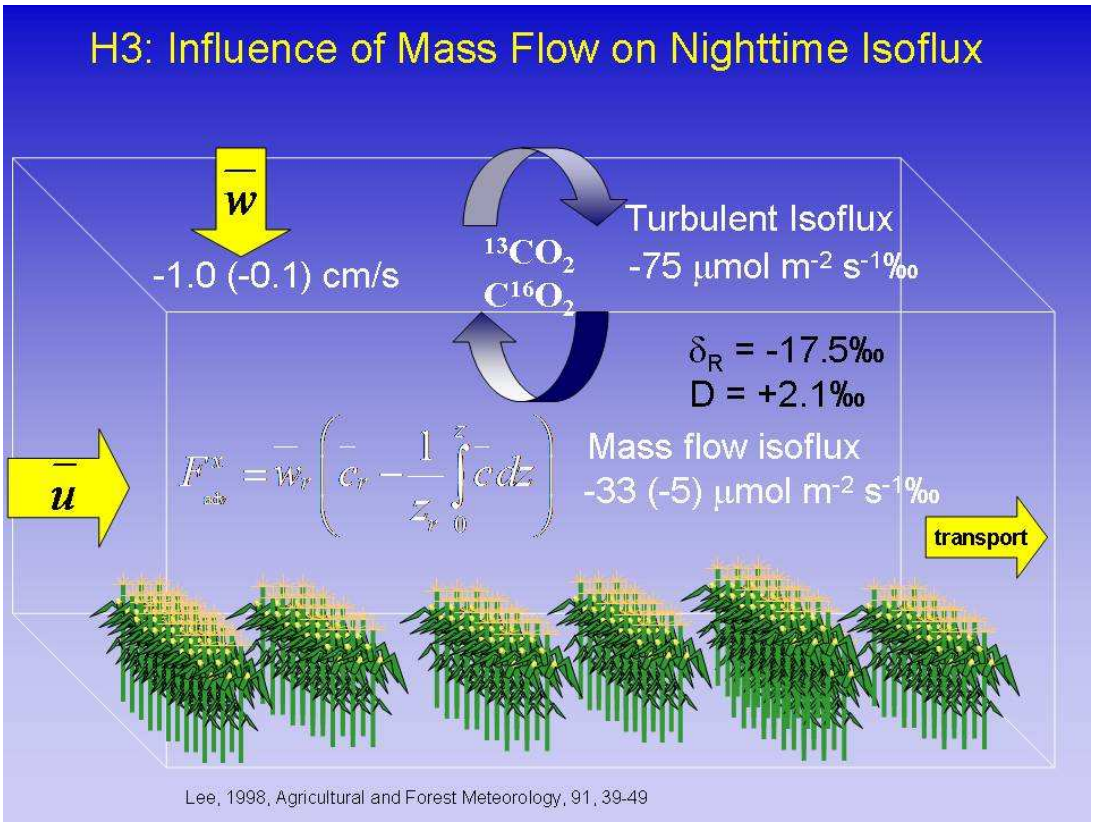

Figure 3: Potential impact of vertical advection on estimating regional isotopic discrimination.

and H_2O at the tall tower site. This land use classification will be highly valuable for our future modeling work.

Joel Fassbinder (MS student) has been examining the isotopic composition of ecosystem respiration. He will graduate in fall 2009. Joel's work involves the use of high frequency TDL measurement of $^{13}CO_2$ exchange using micrometeorological and automated chamber methods to better understand the factors that control shifts in respiratory sources on seasonal and diurnal time scales. Figure 5 (left panel) illustrates the seasonal shift in the isotopic composition of respiration (δ_R) caused by changes in the relative contributions of autotrophic and heterotrophic respiration in a managed agricultural ecosystem during the 2005 and 2007 C_4 growing seasons. Figure 5 (right panel) shows the diurnal variability of δ_R from mixed C_3/ C_4 soil columns sampled with an automated chamber system in a climate controlled greenhouse. The strong diurnal signal observed at the chamber scale illustrates a potential temperature-driven shift in sources for soil microbial communities that may help explain the relatively low contribution of late season, C_4-derived microbial respiration observed on the ecosystem scale even though significant C_4 substrate is available. This is a very significant result. In previous isotope partitioning studies, δ_R has been assumed to remain constant over the diurnal period.

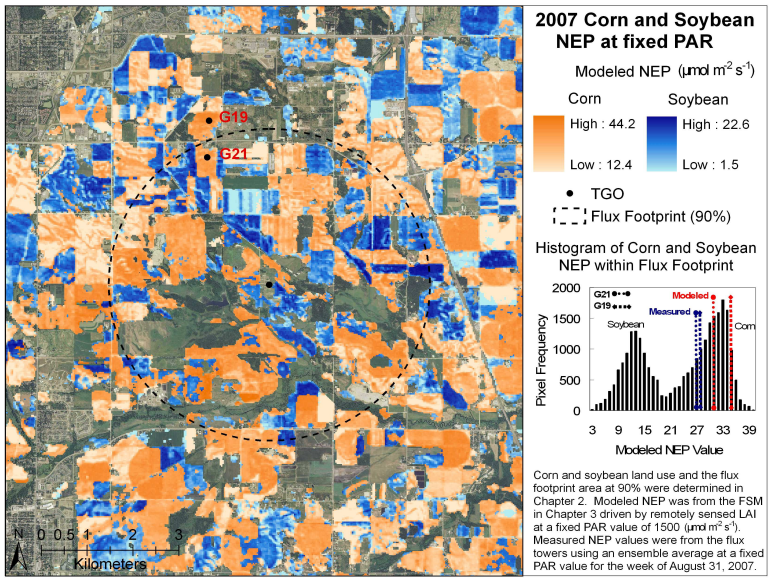

Figure 4: Evaluation of land use and spatial variation of NEP within the flux footprint of the tall tower

Our research has also examined the potential of cover crops for increasing carbon sequestration, food and biofuel. Recent regional (Upper Midwest) modeling analysis of cover cropping in corn/soybean systems suggests that rye biomass production of 1-8 Mg ha^{-1} is possible, with the lowest yields at the more northern sites, where both PAR and degree-days are limited in the interval between fall corn harvest and spring corn or soybean planting (Baker and Griffis, Agricultural and Forest Meteorology, In press). At all sites rye yields were substantially greater when the following crop was soybean rather than corn, since soybean is planted later. Soil water depletion was most likely in years and sites where rye biomass production was greatest. Consistent food and biomass production from corn/winter rye/soybean systems will, therefore, probably require irrigation in many areas, additional nitrogen fertilizer, and the use of either earlier-maturing corn varieties or aerial seeding of rye into standing corn in the northern portion of the corn belt. Our previous work has

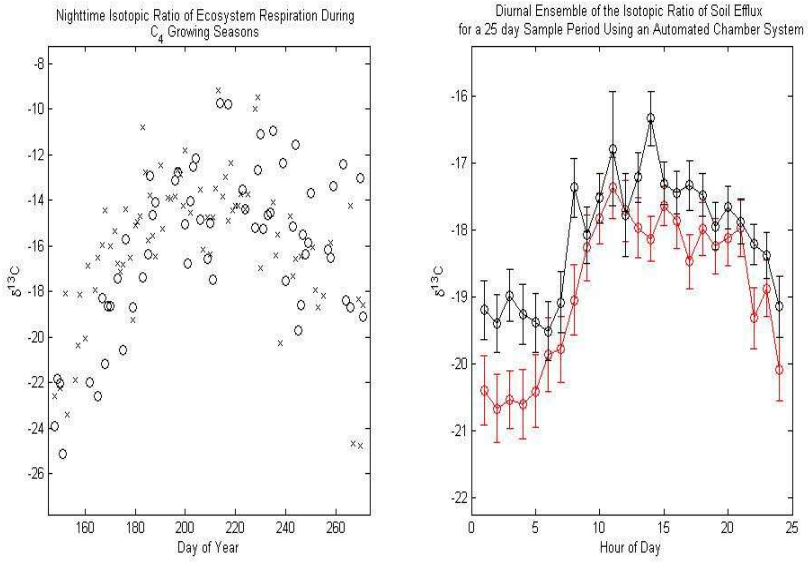

Figure 5: Seasonal and diurnal variation in the isotopic composition of ecosystem and soil respiration

also shown that cover cropping can cause a transient increase in carbon sequestration, but diminishes with time as ecosystem respiration increases (Baker and Griffis, In Prep).

Finally, over the past three years we have developed an Ecosystem-scale Isoflux Multilayer Model (ESIM) of $^{13}CO_2$ exchange. The description of this model and the results are presented in the PhD thesis of Dr. Jianmin Zhang [*Zhang*, 2007]. Unfortunately, Dr. Zhang left our group before completing the proposed regional analysis of isotopic CO_2 exchange and comparison with the tall tower data. However, this work is currently be advanced by Ming Chen (PhD student) and the overall approach has been modified to add key elements of ESIM into NCAR's Land Community Model version 3.5.

2.3 Presentations

This US-DOE grant has provided an opportunity to present results from our EC-TDL experiments at the following:

1. "Optical Isotopic Measurements of CO2 and H2O for Investigating Biosphere-Atmosphere Interactions: Recent Progress and Challenges, T.J. Griffis, December 15-19, 2008, Invited Speaker, American Geophysical Union (AGU), San Francisco, California, USA

2. "Tall tower observations of 13CO2 exchange within an agricultural landscape T.J. Griffis, AmeriFlux Workshop, October 15-17, 2008, Invited Speaker, Boulder Colorado, USA.

3. "Influence of land surface heterogeneity and boundary layer dynamics on atmospheric isotopic CO2 signals T.J. Griffis, Symposium on atmospheric boundary layers and land-

atmosphere interactions, Inaugural international conference of the American Society of Civil Engineers Engineering Mechanics Institute, May 18-21, 2008, Invited Speaker, Minneapolis, Minnesota, USA.

4. "Tall tower observations of isotopic CO2 exchange within an agricultural landscape T.J. Griffis and J.M. Baker, April 28-May 2, 2008, 28th Conference on Agricultural and Forest Meteorology, American Meteorological Society, Orlando, Florida, USA.

5. "Observation and interpretation of atmospheric isotopic signals: New tools for global change research T. J. Griffis, April 17, 2008, Invited Speaker, School of Forestry and Environmental Sciences, Yale University, New Haven, Connecticut, USA.

6. "Measuring isotopic fluxes of carbon dioxide and water vapor using the eddy covariance technique T.J. Griffis, March 28, 2008, Invited Speaker, Atmospheric Research Seminar, Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia, USA.

7. "Observation and interpretation of isotopic CO2 signals in the biosphere: New tools for global change research T. J. Griffis, March 27, 2008, Invited Speaker, Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia, USA.

8. δ18O of evapotranspiration and the sites of leaf evaporation in a soybean canopy L. R. Welp, X. Lee, K. Kim, T. J. Griffis, K. Billmark, and J. Baker, American Geophysical Union (AGU) Fall Meeting, December, 2007. San Francisco, California, USA.

9. Simulating stable carbon isotope signatures and exchange of a C4 canopy: Comparison with a big leaf model J. Zhang, T.J. Griffis, and J.M. Baker, American Geophysical Union (AGU) Fall Meeting, December, 2007. San Francisco, California, USA.

10. Temporal dynamics and environmental controls on carbon isotope discrimination at the canopy scale K. Billmark, T.J. Griffis, X. Lee, L.R. Welp and J.M. Baker, American Geophysical Union (AGU) Fall Meeting, December, 2007. San Francisco, California, USA.

11. B07: Investigation of Carbon and Water Cycle Processes using Isotopes: New Techniques, Data, and Analyses Conveners: T.J. Griffis, X. Lee, K. Tu, American Geophysical Union (AGU) Fall Meeting, December, 2007. San Francisco, California, USA.

12. Isotopic CO2 and water vapor fluxes T.J. Griffis and X. Lee, December 9, 2007. Invited Speaker, BASIN Workshop on stable isotope techniques and laser spectroscopy, University of California-Berkeley, USA.

13. Observation and interpretation of isotopic CO2 signals in the biosphere: New tools for global change research T. J. Griffis, December 7, 2007, Invited Speaker, Water Resources Sciences, University of Minnesota, Minnesota, USA.

14. Regional observations of isotopic CO2 exchange T.J. Griffis, J.M. Baker, X. Lee, S. Sargent, M. Erickson, J. Corcoran, K. Billmark, AmeriFlux Workshop, October 16-18, 2007, Boulder Colorado, USA.

15. Investigation of carbon cycle processes within a managed landscape: Recent progress and future research T.J. Griffis and J.M. Baker, North American Carbon Program (NACP), January 22-26, 2007, Colorado Springs, Colorado, USA.

2.4 Manuscripts

This US-DOE grant has provided support for the following publications/manuscripts:

1. "Impacts of land management on the greenhouse gas budget of two alternatively managed ecosystems", T.K. Bavin, T.J. Griffis, J.M. Baker, K. Billmark, R. Venterea (Agriculture Ecosystems, and Environment, In review)

2. "Evaluating the potential use of winter cover crops in corn-soybean systems for sustainable co-production of food and fuel, J.M. Baker and T.J. Griffis (Agricultural and Forest Meteorology, In press)

3. "Using a simple isotopic land surface model (SiLSM) to investigate the controls and sensitivity of oxygen isotopic CO2 and H2O exchange, W. Xiao, X. Lee, T.J. Griffis, K. Kim, L. Welp and Q. Yu (Journal of Geophysical Research- Biogeosciences, In review)

4. "Influence of phenology and land management on biosphere-atmosphere isotopic CO2 exchange, K.A. Billmark and T.J. Griffis (Invited Book Chapter, In press)

5. "Canopy-scale kinetic fractionation of atmospheric carbon dioxide and water vapor isotopes X. Lee, T.J. Griffis, J.M. Baker, K.A. Billmark, K. Kim, L.R. Welp (Global Biogeochemical Cycles, 2009, 23, GB1002, doi:10.1029/2008GB003331)

6. "d18O of evapotranspiration and the sites of leaf evaporation in a soybean canopy, L.R. Welp, X. Lee, K. Kim, T.J. Griffis, K. Billmark, and J.M. Baker (Plant Cell and Environment, 2008, 31, 1214-1228, doi:10.1111/j.1365-3040.2008.01826.x)

7. "Direct measurement of biosphere-atmosphere isotopic CO2 exchange using the eddy covariance technique, T.J. Griffis, S.D. Sargent, J.M. Baker, X. Lee, B.D. Tanner, J. Greene, E. Swiatek, and K. Billmark (Journal of Geophysical Research- Atmospheres, 2008, 113, D08304, doi: 10.1029/2007JD009297).

8. "Tall tower observations of 13CO2 Exchange within an agricultural landscape, T.J. Griffis, J.M. Baker, S.D. Sargent, B.D. Tanner, M. Erickson, and J. Corcoran (Agricultural and Forest Meteorology, In Revision)

2.5 Data and Tools

We continue to develop and improve our Matlab Biomet Database Tool and laser software. It is a tremendous teaching and research resource. It is available for download from the following website: http://www.biometeorology.umn.edu

We continue to share our data in real-time with our close collaborators (Dr. Xuhui Lee at Yale University, Dr. Lisa Welp at Scripps, Dr. Xiao Wei at the Chinese Academy of Sciences). Our data is posted on our own web site, which is mirrored by CDIAC. Flux data (2007 and 2008) from the Tall Tower will be posted pending the revision of our manuscript that was submitted to *Agricultural and Forest Meteorology*. Isotope data from our earlier experiments have been posted to the AmeriFlux network.

Analysis of our Biometeorology Website statistics indicate that numerous resources are down loaded. Analysis of unique IP addresses (unique downloads) indicates that our datasets have been down loaded 35 times (independent of CDIAC) and that images, matlab tools, and manuscripts have been down loaded more than 1500 times since August 2008.

2.6 Student Training, Research and Development

This DOE grant has helped support 2 undergraduate, 5 graduate, and 2 postdoctoral students. Each student has participated in field and lab work and has gained valuable practical experience working with micrometeorological equipment, and state-of-the-art TDL systems and mass spectrometers. Each student has gained new technical skills related to computer programming and data analyses. Our most recent undergraduate trainee (Natalie Schultz) has played a major role with leaf and soil water extractions and isotope ratio analysis of water. We are hoping that she will join our group as a PhD student in September 2009.

Travis Bavin (MS Student) graduated in spring 2008 and accepted a research scientist position with the Minnesota Department of Natural Resources. Dr. Jianmin Zhang graduated and left my lab during spring 2008 for a postdoctoral position at San Diego State. Her work is being advanced by Ming Chen (a new Phd Student that arrived in my lab in August 2008). Ming has a strong climate modeling background from the Chinese Academy of Sciences. She is currently running NCARs Community Land Model (CLM3.5) on our computing cluster to simulate isotopic fluxes within the Upper Midwest for comparison with our tall tower observations.

2.7 Synthesis Activities and Data Sharing

Over the past few years our eddy covariance, carbon isotope, water isotope, phenological camera/biomass data have been made available on our web site (www.biometeorology.umn.edu) and has been mirrored by CDIAC. In addition, we have made our data available to our collaborators including: Xuhui Lee; Lisa Welp, Xiao Wei; Xin Zhang; Andrew Richardson; Ken Davis; Tagir Gilmanov; Shashi Verma; Kevin Tu (BASIN) and others. We are currently providing data to Mid Continent Intensive synthesis activities. In particular we have communicated/or shared data with Stephen Ogle, Ken Davis, and Shashi Verma.

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Zhang, J., Using stable isotope techniques to investigate carbon cycle dynamics of an agricultural ecosystem, Ph.D. thesis, University of Minnesota-Twin Cities, 2007.