Annual Report

Ecosystem-Atmosphere Exchange of Carbon, Water and Energy over a Mixed Deciduous Forest in the Midwest

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1. Abstract

During the project period we continued to conduct long-term (multi-year) measurements, analysis, and modeling of energy and mass exchange in and over a deciduous forest in the Midwestern United States, to enhance the understanding of soil-vegetation-atmosphere exchange of carbon. At the time when this report was prepared, results from nine years of measurements (1998 - 2006) of above canopy CO_2 and energy fluxes at the AmeriFlux site in the Morgan-Monroe State Forest, Indiana, USA (see Table 1), were available on the Fluxnet database, and the hourly CO_2 fluxes for 2007 are presented here (see Figure 1). The annual sequestration of atmospheric carbon by the forest is determined to be between 240 and 420 g C m^{-2} a^{-1} for the first ten years. These estimates are based on eddy covariance measurements above the forest, with a gap-filling scheme based on soil temperature and photosynthetically active radiation. Data gaps result from missing data or measurements that were

rejected in qua)lity control (e.g., during calm nights). Complementary measurements of ecological variables (i.e. inventory method), provided an alternative method to quantify net carbon uptake by the forest, partition carbon allocation in each ecosystem components, and reduce uncertainty on annual net ecosystem productivity (NEP). Biometric datasets are available on the Fluxnext database since 1998 (with the exclusion of 2006). Analysis for year 2007 is under completion.

2. Research activities

2.1. Objectives

Our main **long-term research questions** match the AmeriFlux science goals: (i) What is the magnitude of NEP at MMSF? Are there long-term trends of NEP and its components, gross ecosystem production (GEP) and ecosystem respiration (R_E)? (ii) How does the interannual variability of climate influence NEP at MMSF? (iii) How do local flows caused by small-scale topography affect vertical exchange measurements above the forest? **Specific questions** that we intend to answer are: (iv) What are the relative contributions of autotrophic and heterotrophic respiration to R_E? (v) How will C-assimilation, water-use efficiency and respiration be affected in future water-limited situations under climate change? (vi) How do the recently discovered methane emissions by foliage compare to the methanotrophic activity of soil bacteria (i.e., is an upland forest such as MMSF likely a net source or sink of this important greenhouse gas)?

2.2. Approach

The **principal approach** is to measure concentrations and fluxes of carbon dioxide (CO_2) and water/latent heat (H_2O/LE), sensible heat (H) and momentum (□) directly, using eddy covariance equipment mounted at multiple levels on a 46 m fixed tower in the Morgan-Monroe State Forest in Martinsville, Indiana. These observations are complemented by measurements of the radiation components and photosynthetically active radiation (PAR), soil heat flux, soil temperature and soil moisture, bole temperature and by standard meteorological measurements (precipitation, profiles of temperature and relative humidity, etc.). Currently, the full suite of eddy-covariance and radiation measurements is carried out at two levels above the canopy (at 1.8 and 1.3 times the canopy height) and at one level in the understory, at 2 m above ground. The rationale to maintain two levels of flux measurements above the canopy rests on the notion that they are separated far enough to result in different flux footprints. This approach thus facilitates estimates of spatial representativeness of fluxes within the naturally occurring heterogeneity of the deciduous forest ecosystem. Details about instrumentation, data acquisition and analysis are given in Schmid et al. (2000) and Dragoni et al. (2007).

An integral part of our research approach is our collaboration with our Forest Ecology partner project (led by J.C. Randolph, Indiana University), and with other AmeriFlux sites in the upper Midwest (particularly the UMBS~Flux site, PI: Peter Curtis, Ohio State University). These links serve as a source for comparison of net ecosystem exchange estimates by independent inventory methods (Ecology), and with a different site using very similar methods (UMBS~Flux).

3. Research highlights

Our work addresses unresolved issues around annual NEE estimates and the closure of energy balance from several angles. Much of this is work in progress, and has revealed more new questions than final answers. But such is the nature of this research and reflects its current status. Measurements

at MMSF~Flux have been ongoing since March 1998. Annotated data summaries (1998 – 2006) are available through the Fluxnet database (http://www.daac.ornl.gov/FLUXNET), 2007 flux data are currently being analyzed and 2008 flux currently collected. Our site and instrumentation are presented in Schmid et al. (2000), and an update to our methods of analysis, data quality control strategy and gap-filling (similar to UMBS~Flux) can be found in Schmid et al. (2003) and Dragoni et al. (2007). Highlights of our research results (both published and in progress) include:

- The annual sequestration of atmospheric carbon by the mixed deciduous forest is determined to be between 240 and 430 g C m^{-2} a^{-1} for the eight years (1998 - 2007) (Figure 2). These estimates are based on eddy-covariance measurements above the forest, with a correction scheme to fill data gaps and replace unreliable values during calm nights ($u_* < 0.3$ m s^{-1}). These results are found to be highly dependent on criteria of data rejection, gap-filling and on the complete coverage of auxiliary data (T_s and PPFD). To put the 1998 data on a calendar-year basis, the fluxes for January and February are estimates based on those from 1999.

  References: Schmid et al. 2000, 2003.

- We developed a methodology to estimate the cumulative effect of random uncertainty on annual estimates of net ecosystem productivity of carbon (NEP). Our results (table 1) indicate that the overall uncertainty of annual NEP is dominated by the contribution of the gap-filling model, even at relatively small gap fractions of 20%. Also, our results show the random uncertainty of eddy-covariance based NEP is small compared to other potential sources of systematic bias, although very little is known about the long-tem cumulative covariate effects of systematic bias in the measured flux.

  Reference: Dragoni et al. 2007

- Recent observations made using sap flow techniques show that heterogeneity in transpiration of a sample of sugar maples (i.e., one of the dominant species in our forest) is partially driven by spatial and temporal variability is soil moisture caused by the topography of the area. This variability in transpiration is in general not detectable at eddy-covariance foot print scale. However, severe and prolonged droughts, like in the years 1999 and 2007, can result in temporarily reduction in net ecosystem exchange measured by the eddy-covariance system (Figure 1). During these periods, respiration (mostly from soil) and latent heat fluxes significantly decrease, while sensible heat fluxes increase. Despite these temporarily effects, annual NEP is similar (1999) or higher (2007) than the 10-year NEP average (Table 1). These findings have critical implications on how drought affects the carbon uptake at the MMSF. An on-going research activity is aiming to quantify more in detail spatial variability in drought response and further interpret past-year results.

  References: *K.K. Caylor. and DragoniD.,* Decoupling structural and environmental determinants of sap velocity: Part I – Methodological development. Agricultural and Forest Meteorology – accepted, subject to revision*;*
  D. Dragoni, K.K. Caylor, H.P. Schmid. Decoupling structural and environmental determinants of sap velocity: Part II – Observational application. Agricultural and Forest Meteorology, in review

- Comparison with complementary inventory methods shows that NEP estimates are well in agreement for most of the years between 1998 and 2005. Measurements from the inventory method are not available for the year 2006 and are under analysis for the year 2007. Our work at the MMSF confirms the importance of using both EC and inventory methods to reduce the overall

uncertainty of NEP estimates, increases the understanding of carbon partitioning among different compartments of the forest ecosystem, and helps to explain observed inter-annual variability This knowledge incorporated into larger-scale terrestrial carbon cycling models, will allow prediction of exchange processes more accurately.

*Reference: Wayson, C.A., D. Dragoni, J.C. Randolph, C.S.B. Grimmond, J.L. Ehman H.P Schmid. Top-down and bottom-up: integrated carbon flux analysis in a mid-latitude deciduous forest. S*ubmitted to Journal of Geophysical Research - Bioscience.

4. Research products

- Data set (nine years of hourly eddy-covariance flux data, 1998-2006 in Fluxnet database). Data from the year 2007 will be submitted soon.
- Data set (eight years of inventory-ecological data, 1998-2005, in Fluxnet database). Data from 2007 are under analysis and will be submitted soon.
- Meteorological and site data for the AmeriFlux carbon exchange model evaluation initiative (hourly data provided since January 1, 2000).
- Methodology to assess the random uncertainty on eddy-covariance measurements.
- Publications in scientific journals and conference proceedings.

5. Publications

Caylor K.K, D. Dragoni. Decoupling structural and environmental determinants of sap velocity: Part I – Methodological development. Agricultural and Forest Meteorology – accepted, subject to revision

Dragoni D., K.K. Caylor, H.P. Schmid. Decoupling structural and environmental determinants of sap velocity: Part II – Observational application. Agricultural and Forest Meteorology, in review

Dragoni D., Schmid H.P., Grimmond C.S.B., and H.W. Loescher: Uncertainty of annual net ecosystem productivity estimated using eddy-covariance flux measurements. Journal of Geophysical Research. Journal of Geophysical Research, 112, D17102, doi:10.1029/2006JD008149. 2007

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Kim, J., Q. Guo, D.D. Baldocchi, M. Y. Leclerc, L. Xu, and H.P. Schmid: 'Upscaling Fluxes from Tower to Landscape: Overlaying Flux Footprints on High Resolution (IKONOS) Images of Vegetation Cover'. Agricultural and Forest Meteorol. 134 (3-4): 132-146. 2006

Kljun, N., P. Calanca, M.W. Rotach, and H.P. Schmid: 2004. 'A Simple Parameterisation for Flux Footprint Predictions'. Boundary-Layer Meteorol. 112, 503-523.

Oliphant, A.J., C.S.B. Grimmond, H.N. Zutter, H.P. Schmid, H.-B. Su, S.L. Scott, B. Offerle, J.C. Randolph and J. Ehman. 2004. 'Observations of energy balance components in a temperate deciduous forest'. Agricultural and Forest Meteorol. 126, 185-201.

Oliphant, A., Susan, C., Grimmond, B., Schmid, H.P. and C.A. Wayson: Local-scale heterogeneity of photosynthetically active radiation (PAR), absorbed PAR and net radiation as a function of topography, sky conditions and leaf area index. Remote Sensing of Environment, 103(3): 324-337. 2006

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Wayson,C.A.; J.C. Randolph; P.J. Hanson; H. P. Schmid; and C.S.B. Grimmond. (2006) Comparison of soil respiration methods in a mid-latitude deciduous forest. Biogeochemistry, 80, 173-189.

7. Student degrees supported

Name	Degree	University	Home town	State	Date of Degree
Norma Froelich	Ph.D.	IU	London	Canada	PhD, expected 2009
Bin Deng	Ph.D.	IU	Nanning Guangx	China	PhD, expected 2009
Robert Wayne	M.S.	IU	Bloomington	IN	n/a
Sara Corbin	M.S.	IU	Bloomington	IN	n/a
Matt Trout	M.S.	IU	Bloomington	IN	n/a
Mark Lemon	M.S.	IU	Bloomington	IN	n/a
Elspeth Manwaring	M.S.	IU	Bloomington	IN	n/a
Henry Potter	B.S	IU	Bloomington	IN	n/a
Tyler Andrews	B.S.	IU	Bloomington	IN	n/a

Table 1: NEP estimate and random uncertainty at the MMSF site.

Year	NEP(gC m^{-2} $year^{-1}$)	Random uncertainty (gC m^{-2} $year^{-1}$)
1998	-249	21
1999	-314	11.8 (3%()
2000	-290	11.2 (4%)
2001	-293	10.4 (3%_
2002	-315	9.6 (3%)
2003	-284	9.9 (4%)
2004	-395	11.9 (3%)
2005	-383	9.7 (3%)
2006	-330	9.9 (3%)
2007	-429	Analysis under completion

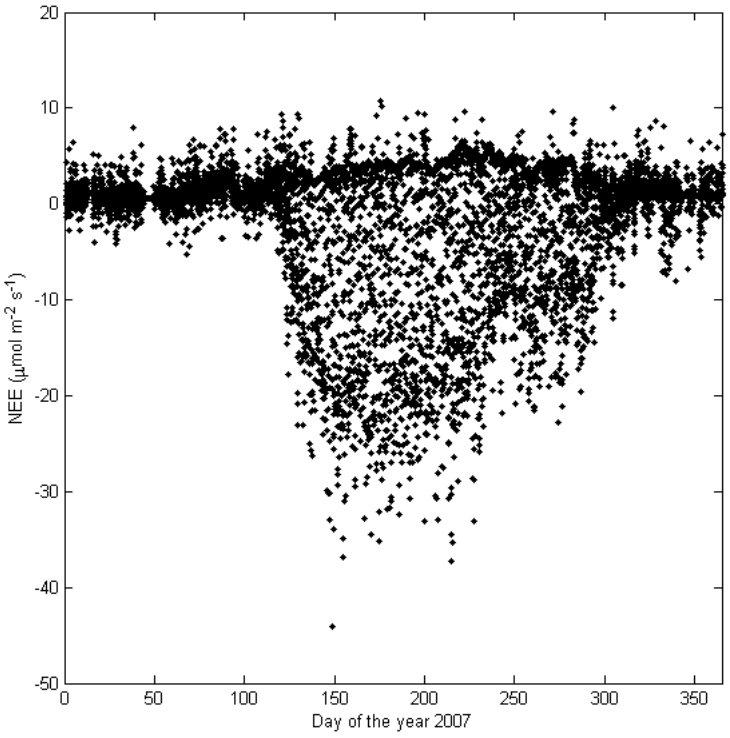

Figure 1: Preliminary estimated hourly values of NEE flux at the MMSF for the year 2007, as determined by eddy-covariance. The year 2007 was characterized by a severe and prolonged drought that reduced NEE flux for several days (around DOY 250). However, annual NEP was the largest since EC measurements started in 1998 (Table 1).