

## A MARKED PULSE IN ANNUAL GROSS ECOSYSTEM PRODUCTIVITY DETECTED BY E-C MEASUREMENTS IN INDIANA: IS IT REAL OR DUE TO A BUG?

Hans Peter Schmid\*, Danilo Dragoni, Craig Wayson, Reiko Toriumi, Sue Grimmond  
Indiana University

### 1. INTRODUCTION

We have collected eddy-covariance (E-C) based fluxes of CO<sub>2</sub> ( $F_C$ ), water vapor ( $F_{H_2O}$ ), and energy balance components at the AmeriFlux site in the Morgan-Monroe State Forest (MMSF) in Indiana (USA) since 1998. For compilations of annual estimates of net ecosystem production (NEP), and its components, gross ecosystem production (GEP) and ecosystem respiration (RE), we have used standard methods for quality control and gap-filling. In the years 1999-2003 we obtained values of NEP around 340 g C m<sup>-2</sup> ( $\pm 8\%$ ), contributed by GEP of 1260 g C m<sup>-2</sup> ( $\pm 3\%$ ) and RE of 910 g C m<sup>-2</sup> ( $\pm 5\%$ ). Small variations were mostly due to RE and can be linked to climatic controls. It thus initially came as a surprise that the NEP estimates for 2004 showed an increase of nearly 220 g C m<sup>-2</sup> (contributed by a large jump in GEP and a smaller reduction in RE) over the average of the preceding years.

Here, we report on our investigation of a series of hypotheses to explain the unusual data of 2004 (and, to a lesser extent, 2005): instrument uncertainty; change in instrumentation; variations in data processing and gap-filling procedures; environmental (climatic) interannual variations. We show that all of these explanations needed to be rejected. We then offer an interpretation that points to insect activity (i.e., a different kind of "bug") as the culprit for this unexpected behavior of the forest ecosystem.

### 2. MATERIALS AND METHODS

The experimental site is located in the Morgan-Monroe State Forest (MMSF) in Indiana (USA). The vegetation is secondary successional broadleaf forest with >29 identified species in the immediate vicinity of the tower,  $\frac{3}{4}$  of which are sugar maple (*Acer saccharum*), tulip poplar (*Liriodendron tulipifera*), sassafras (*Sassafras albidum*), white oak (*Quercus alba*) and black oak (*Quercus nigra*); the average height of the canopy is  $\approx 27$ m. The main eddy covariance system is located at the top of the 46m tall tower and consists of a three-dimensional sonic anemometer

(CSAT, Campbell Scientific Inc., Logan, UT) and a closed-path IRGA (Li-6262; Li-7000 as of winter 2003, LiCor, Lincoln, NE). Sampling rate is set to 10Hz, and eddy fluxes are calculated hourly. For details on the data acquisition and processing, see [Schmid, *et al.*, 2000]. In the course of this work, we re-analyzed all flux time series from 1999-2005, using the same objective data-rejection criteria to arrive at values of net ecosystem exchange (NEE), and procedures to partition NEE into its components, GEP and RE.

In June 1998, and again in June 2005, the roving AmeriFlux (AF) portable eddy-covariance system (<http://public.ornl.gov/ameriflux/sop.shtml>) was set up on the same level as our system for inter-comparison purposes. On both occasions, the two 7-day datasets showed good agreement. In 2005, the MMSF CO<sub>2</sub> flux magnitudes slightly underestimated those of the AF system ( $F_{C,MMSF} = 0.95 \times F_{C,AF} - 0.09$ ;  $R^2 = 0.95$ ), and slightly overestimated water vapor fluxes ( $F_{H_2O,MMSF} = 1.12 \times F_{H_2O,AF} - 3.86$ ;  $R^2 = 0.95$ ; Loescher, H., 2006, unpublished data). This good agreement is important, because we switched the IRGA model from LI-6262 to LI-7000 in the winter of 2003-04.

### 3. RESULTS

Annual net ecosystem exchange (NEE) for the years 1999 to 2003 ranged between -319 and 374 gC m<sup>-2</sup> year<sup>-1</sup>, annual GEP between 1210 and 1292 gC m<sup>-2</sup> year<sup>-1</sup>, and RE between 836 and 952 gC m<sup>-2</sup> year<sup>-1</sup> (Table 1).

Climatic conditions during 2004 and 2005 did not significantly differ from the average conditions recorded in the last 8 years (regarding: radiation, temperature, humidity, precipitation). However, annual NEE was estimated as -535 gC m<sup>-2</sup> year<sup>-1</sup> in 2004, about 60% higher than the average of the previous years. In 2005, NEE was still higher than any year in the period 1999-03 (45% higher than the 99-03 average), but lower than 2005 (Table 1). GEP was significantly higher than the period 99-03 for both years, while annual RE was not significantly different ( $p > 0.05$ ), although in the lower range of values for MMSF (Table 1).

In 2004 the surplus in NEE and GEP was mostly accumulated during the vegetative season

\* Corresponding Author Address: Hans Peter Schmid,  
Indiana University, Geography Department, Bloomington,  
IN 47405, USA; email [hschmid@indiana.edu](mailto:hschmid@indiana.edu)

(Figure 1). The same pattern was observed in summer 2005, although less marked than the previous year (Figure 1).

Light use efficiency showed different patterns for the two years; in 2004 assimilation rates per unit of light ( $\sim 2.3\% \text{ mol mol}^{-1}$ , at  $\text{PPFD} = 1 \text{ mmol m}^{-2} \text{ s}^{-1}$ ) were significantly higher than those observed during 99-03 period ( $\sim 1.7\%$ ), while they were "normal" in 2005 (Figure 2).

Table 1: Total Net Ecosystem Exchange (NEE) and NEE uncertainty [Dragonì, et al., 2006, based on Monte Carlo simulation and the MMSF-AF intercomparison], gross ecosystem production (GEP), and respiration (RE) as estimated from the eddy covariance tower.

Year	NEE ( $\text{gC m}^{-2}$ )	GEP ( $\text{gC m}^{-2}$ )	RE ( $\text{gC m}^{-2}$ )
1999	$-374 \pm 8.9$	1210	836
2000	$-320 \pm 9.9$	1255	935
2001	$-332 \pm 8.6$	1284	952
2002	$-369 \pm 8.6$	1292	924
2003	$-319 \pm 10.2$	1233	914
2004	$-535 \pm 10.5$	1412	877
2005	$-495 \pm 9.3$	1352	857

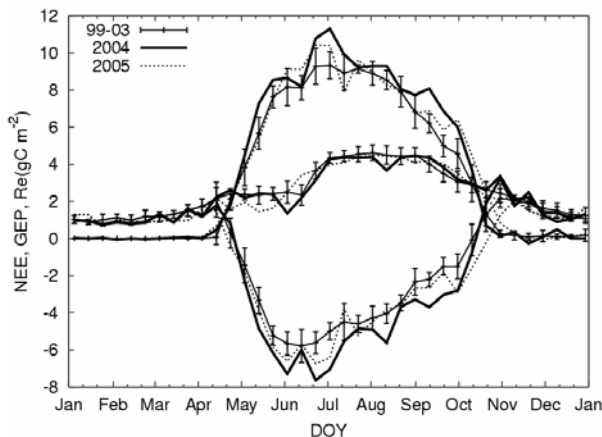


Figure 1: 10-day means of daily integrals of net ecosystem exchange (NEE), gross ecosystem production (GEP), and respiration (RE); the average for 1999 to 2003 is shown (thin solid line), with 95% confidence interval bars. Thick solid and dotted lines refer to 2004 and 2005, respectively.

Water use efficiency ( $\text{WUE} = \text{GEP}/F_{\text{H}_2\text{O}}$ , in  $\text{mmol mol}^{-1}$  here) during 2004 and 2005 summers was higher than the previous years, in particular for high values of GEP (Figure 3); for  $\text{GEP} > 1 \text{ gC m}^{-2} \text{ s}^{-1}$ , WUE averaged 4.0 from 1999 to 2003, and

5.5 during 2004, and 4.5 for 2005. Despite the differences in WUE, 2004 and 2005 vegetative seasons did not differ in total evapo-transpiration; for the year 99-03 the total net exchange of water vapor between the forest and the atmosphere (a process dominated by transpiration) ranged between 321 and 411  $\text{l m}^{-2}$ ; in 2004 and 2005 the total net exchange was 335 and 359  $\text{l m}^{-2}$ , respectively.

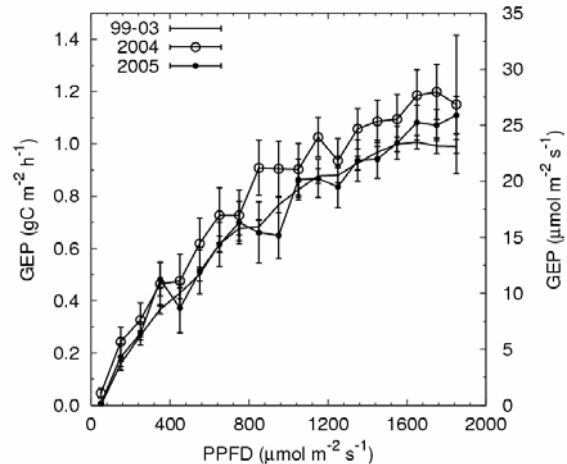


Figure 2: GEP vs. photosynthetic photon flux density (PPFD). Mean GEP and 95% confidence interval bars are shown in PPFD bins of  $100 \mu\text{mol m}^{-2} \text{ s}^{-1}$ . Empty and solid circles are for 2004 and 2005, respectively; the solid line is for 1999-2003.

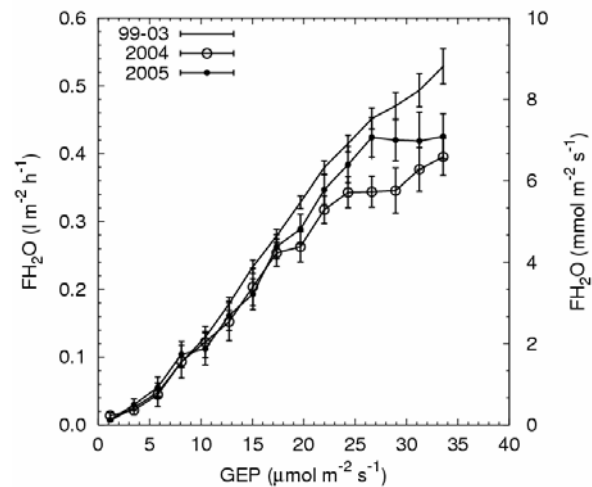


Figure 3: Water vapor flux ( $F_{\text{H}_2\text{O}}$ ) vs. GEP. Mean  $F_{\text{H}_2\text{O}}$  and 95% confidence interval bars are shown in GEP bins of  $0.1 \text{ gC m}^{-2} \text{ h}^{-1}$ . Empty and solid circles are for 2004 and 2005, respectively; the solid line is for 1999-2003.

#### 4. DISCUSSION

After re-analyzing all 1999-2005 data, the results of the AF roving system intercomparison,

and the results of uncertainty estimation (Section 2; Table 1), we are confident that the marked pulses of NEP and GEP in 2004 and 2005 over previous years cannot be explained by measurement error or uncertainty. Further, the dominant environmental (climatic) drivers of GEP did not exhibit any unusual behaviors in 2004 or 2005 at MMSF.

Thus, the questions remain: why did NEE and GEP show these marked pulses in 2004 and 2005? Why not also RE to the same extent? Why was evapotranspiration not affected? We do not have definitive answers. In contrast to previous years (Wayson et al., 2006), biometric measurements of the above-ground productivity made at our site showed a substantial disagreement with the E-C based estimates, and a continuity with the previous years in terms of net ecosystem productivity (J.C. Randolph, 2006; unpublished data). However, this apparent contradiction does not exclude the hypothesis that a large portion of the 2004 GEP pulse may have occurred underground, at root level.

The differences between 2004 and 2005, in particular the decrease of the NEE and GEP "pulse" and the return of light use efficiency and WUE to "normal" levels point to a transient phenomenon, starting in 2004, and partially extending to 2005.

In early summer 2004 southern Indiana, and thus our site, was in the center of a massive emergence of Brood-X of 17-year periodical cicadas (genus *Magicicada*, Figure 4, <http://www.indiana.edu/~preserve/cicada/cicada>). Brood-X, the largest such brood, emerged at end of May/beginning of June and after a period of intense mating and oviposition activity (but no herbivory), all its individuals died within two-three weeks. Over the 17 years since the last emergence, the cicada nymphs have remained below ground, as root-xylem feeders. The effect of cicadas on the carbon and water cycle of the ecosystem in which they live is still unclear; most research has concentrated on cicada biology [see for instance *Wheeler, et al.*, 1992; *Williams*, 1995]. However, it is likely that these root-xylem feeders have an impact on the nutrient and water cycles of trees, and the sudden release in the emergence has the classic features of a pulse in insect population dynamics.

The mechanisms, by which this insect population pulse could cause a pulse in GEP and NEP, are under investigation. In our ongoing research, we are considering several potential plant physiological, hydraulic, and soil physics processes to be affected by the cicada cycle.

Meanwhile, we suspect that the NEP data pulse of 2004 at MMSF was not caused by just one "bug", but by millions of them.



Figure 4: A mature Brood-X periodical cicada during oviposition into a young tree branch, June 2004. Length ~ 4 cm. Photo: H.P. Schmid.

**Acknowledgements:** This work is supported by the Biological and Environmental Research Program (BER), U.S. Department of Energy, through the Midwestern Regional Center of the National Institute for Global Environmental Change (NIGEC) under Cooperative Agreement No. DE-FC03-90ER61010. We are grateful for the AF comparison by Dr. Hank Loescher of Oregon State University; the technical support by Steve Scott, and the field assistance of numerous undergraduate and graduate students.

## 5. REFERENCES

- Dragoni, D., H. P. Schmid, and C. S. B. Grimmond (2006), Uncertainty on annual net ecosystem productivity estimated using eddy-covariance flux towers, *to be submitted to Geophysical Research Letters*.
- Schmid, H. P., C. S. B. Grimmond, F. Cropley, B. Offerle, and H. B. Su (2000), Measurements of CO<sub>2</sub> and energy fluxes over a mixed hardwood forest in the mid-western United States, *Agricultural and Forest Meteorology*, 103, 357-374.
- 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* (in press).
- Wheeler, G. L., K. S. Williams, and K. G. Smith (1992), Role of periodical cicadas (Homoptera: Cicadidae: *Magicicada*) in forest nutrient cycles, *For. Ecol. Manage.*, 51, 339-346.
- Williams, K. S. (1995), The Ecology, Behavior, and Evolution of Periodical Cicadas, *Annual Review of Entomology*, 40, 269-295.