

**P2.14 ECOSYSTEM EVAPORATION, TRANSPIRATION AND SUB-CANOPY VAPOR FLUXES  
 AT THE MORGAN MONROE STATE FOREST, INDIANA**

**C.S.B. Grimmond<sup>1\*</sup>, P. J. Hanson<sup>2</sup>, H. P. Schmid<sup>1</sup>, S.D. Wullschlegler<sup>2</sup>,  
 F. Cropley<sup>1</sup>, H-B. Su<sup>1</sup>, B. Offerle<sup>1</sup>, and S. Scott<sup>1</sup>**

<sup>1</sup> Atmospheric Science Program, Indiana University, Bloomington, IN

<sup>2</sup> Environmental Sciences Division, Oak Ridge National Laboratory Oak Ridge, TN

**1 INTRODUCTION**

Daily, and annual fluxes of evapotranspiration (ET) and transpiration (T) at an AmeriFlux site in the Morgan-Monroe State Forest (MMSF), Indiana, USA, are presented for the growing seasons of 1998 and 1999. Turbulent flux measurements of ET are obtained using an eddy covariance system at 46 m (1.8 times the canopy height) and at 2 m. These rates of ET are compared with rates of T determined from measurements of sapflow using the Granier technique.

**2 METHOD**

Morgan Monroe State Forest (MMSF), located in South Central Indiana (39° 19' N 86° 25' W), is an extensive managed secondary successional broadleaf forest (in the maple-beech to oak-hickory transition zone), with a wide variety of tree species present (Von Kley *et al.*, 1994) (Table 1). The mean canopy height of the forest is approximately 26 m.

Micro-meteorological instruments are mounted on a 46 m tower (at 46, 34 and 2 m) and at a series of below-canopy sites in the vicinity of the tower. At each level on the tower, measurements of 3-d turbulent velocity fluctuations and eddy-covariance fluxes of momentum, sensible heat, water vapor, and CO<sub>2</sub> are collected using 3-d sonic anemometers (CSAT, Campbell Scientific Inc., 10 Hz sampling rate) and closed-path infrared gas analyzers (IRGAs, Li-6262 Li-Cor) (Schmid *et al.* 2000).

Individual tree thermal dissipation sapflow probes (Dynamax, Inc., Houston, TX) were installed on 9 indicator trees (Table 1). Measurements of sap velocity are made every minute, using two probes of 1.1 mm diameter, each of which are inserted 3 cm into the sapwood of the tree bole (Granier 1987). These data were averaged hourly and adjusted to account for radial gradients in sap velocity, and normalized to their sapwood cross sectional area to obtain sapflow rates for each of the key tree species for the plot. These data are appropriately weighted for the species' contribution to the plot area and then summed to yield daily T.

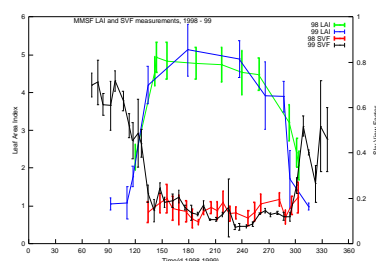
**3 RESULTS**

The winter of 97/98 was unusually mild (mostly attributed to a strong El Nino), consequently the onset of budding was visually observed to be about 2 weeks earlier than usual. Vegetation (leaf and bole) area index

VAI) for 1998 reached a maximum of  $4.7 \pm 0.5$ ; in 1999 the value was slightly higher,  $5.1 \pm 0.7$ .

Sapflow site composition				Ehman <i>et al.</i> 50 plots	
Species	Basal Area M <sup>2</sup> ha <sup>-1</sup>	(%)	Sapwood area m <sup>2</sup> ha <sup>-1</sup>	Basal Area %	
Elm	7.86	30.5	1.05	Sugar maple	27.09
Oak	5.94	23.1	1.26	Tulip poplar	19.17
Tulip poplar	4.27	16.6	3.07	Sassafras	9.45
Walnut	1.66	6.4	-	White oak	8.99
Locust	1.49	5.8	-	Black oak	8.54
Ash	1.23	4.8	0.94	White ash	5.33
Dogwood	1.09	4.2	0.13	American elm	3.52
Cherry	1.03	4.0	0.10	Red oak	2.46
Sassafras	0.64	2.5	-	Hackberry	1.72
Maple	0.38	1.5	0.50	American beech	1.58
Unknown	0.17	0.7	0.92	Slippery elm	1.56
				Black gum	1.53
				17 other species	9.05
<b>TOTAL</b>	<b>25.76</b>	<b>100</b>	<b>7.97</b>		<b>100.00</b>

**Table 1:** Species composition, basal area, and sapwood area for the trees surveyed in the stand around the sapflow site (0.16 ha) and for 50 plots around the tower (Ehman *et al.* 1999)



**Figure 1:** VAI and sky view factor for MMSF 1998 and 1999.

**3.1 Eddy covariance results**

ET is a significant flux at MMSF (Figure 2). In both years (1998 and 1999), cumulative ET (as measured at 46 m) was approximately 560 mm (growing season totals in both years exceed 500 mm). Between mid-May and mid-September, approximately 85% of the daytime available energy is consumed by ET, in contrast to only about 20-30% during the leaf-off period.

In both 1998 and 1999, ET rises rapidly in late April, driven by transpiration of the emerging forest foliage. Values peak in July and fall, due to increasing water stress, in August and September (more notable in 1999 than 1998; the latter part of 1999 had much less precipitation (Figure 2). In October, ET drops rapidly and sensible heat flux becomes more significant to the

\*Corresponding author address: Sue Grimmond, Dept Geography, Indiana University, Bloomington, IN, USA, 47405  
 Email: [grimmon@indiana.edu](mailto:grimmon@indiana.edu)

diurnal course of energy partitioning (see Schmid *et al.* 2000 for more details).

### 3.2 Comparison of ET and T

When  $ET_{46}$  rates are compared with those for T (Table 2, Figure 2), differences in the magnitude of the fluxes are evident. However, in terms of day-to-day variability the two fluxes seem to be responding to the same local/meso-scale environmental forcing.

At the beginning of the growing season T represents less than 10% of the  $ET_{46}$  data, rising up to a peak of just over 50% at the end of April. From then to the middle of July the ratio drops towards 30%, before rising back to 40% in August and September.

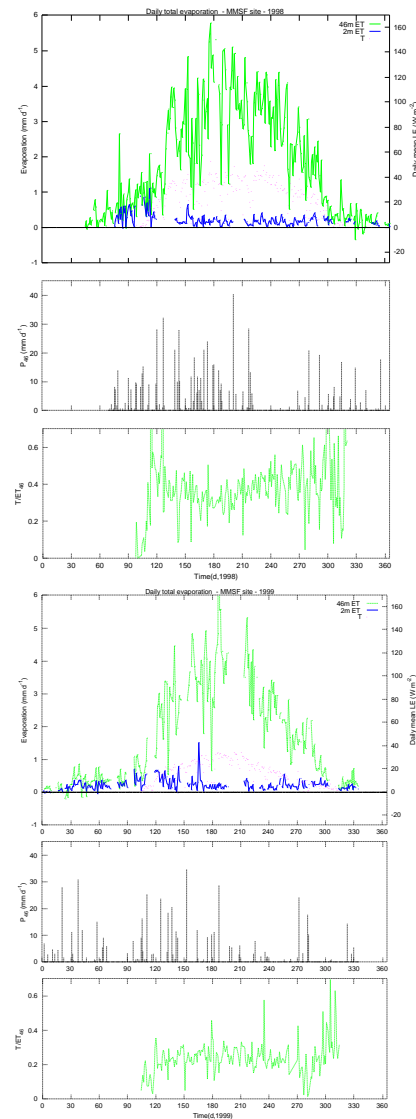
Comparative differences between ET and T have been documented previously (e.g., Wullschlegel *et al.* 1999). The magnitude to which ET exceeds T is dependent on the contribution of interception losses, soil evaporation, and transpiration to total E. Some of the differences observed here can be attributed to differences in the species composition of the sapflow sites, the overall composition of the forest (Table 1), and in the turbulent footprint of the tower. The individual trees studied by sapflow clearly are much more strongly influenced by very localized (small-scale) environmental conditions. The sapflow trees are located right on the crest of the ridge at MMSF, whereas the tower observations record a more integrated response of the upwind topographic variability. Landsat scenes show that ridges in this region commonly exhibit more signs of water stress than ravines in mid to late summer.

Despite considerable (but unknown) uncertainties associated with precipitation measurements on top of a 46 m tower and below canopy, such measurements serve to elucidate the differences in  $ET_{46}$  and sapflow T, at least in part (Table 2). During the growing season, approximately 60% (1998) and 50% (1999) of  $P_{46}$  was recorded at 2 m. Thus during the growing season, evaporation of intercepted water clearly is a significant component of the above canopy measurements of ET and a partial explanation for the  $ET_{46}$  and T differences.

(mm)		Growing Season	Full Leaf	Year
$ET_{46}$	1998	503	364	560
	1999	522	464	567
$ET_2$	1998	46	18	69
	1999	52	34	75
T	1998	191	118	na
	1999	118	105	na
$P_{46}$	1998	619	355	879
$P_2$	1998	384	202	582

**Table 2:** Preliminary estimates of cumulative  $ET_{46}$  and  $ET_2$ , T and P at the MMSF site, 1998 and 1999. Year 1998:98/76-99/75; Year 1999: 99/1-335. P for 1999 not final.

**ACKNOWLEDGEMENTS:** Work is funded by the U.S. Dept of Energy, NIGEC, Terrestrial Ecology Program, Earth Science Enterprise, NASA (Joint Program on Terrestrial Ecology and Global Change (TECO)). Site access: Indiana Dept. of Natural Resources, Div. of Forestry. All those who have helped in the field are gratefully acknowledged.



**Figure 2:** Comparison of ET (eddy covariance) and T (sapflow) results. Top: 1998; bottom: 1999. Subset top panel  $ET_{46}$ ,  $ET_2$ , and T; middle P and lower T: $ET_{46}$ .

### REFERENCES

- Ehman J., H.P. Schmid, C.S.B. Grimmond, P. Hanson, J.C. Randolph and F. Cropley 1999: Intercomparison of micro-meteorological and ecological estimates of carbon sequestration in a mid-latitude deciduous forest. Proc. Int. Cong. on Biomet., Sydney
- Granier, A. 1987. Evaluation of Y in a Douglas-fir stand by means of sap flow measurements. *Tree Physiol.* 3:309-320.
- Schmid H.P., C.S.B. Grimmond, F.D. Cropley, B. Offerle, & H-B Su. 2000. Measurements of CO<sub>2</sub> and energy fluxes over a mixed hardwood forest in the Midwestern United States. *Agric. For. Meteorol.*, **103**, 355 – 373.
- Wullschlegel, S.D., P.J. Hanson, and D.E. Todd. 1999. T from a multi-species deciduous forest as estimated by xylem sap flow techniques. *For. Ecol. Manag.* (In press).
- Von Kley, J.E., G.R. Parker, D.P. Franzmeier and J.C. Randolph: 1994, Field guide: Ecological classification of the Hoosier National Forest and Surrounding areas of Indiana, *USDA Forest Service*, 89 pp.