10.6 OBSERVATIONS OF LOCAL-SCALE HEAT, WATER, MOMENTUM AND CO$_2$ FLUXES AT CUB HILL, BALTIMORE

C. S. B. Grimmond[1,*], B. D. Offerle[1], J. Hom[2], and D. Golub[2]
[1] Indiana University, Bloomington, IN [2] USDA Forest Service, PA

1. INTRODUCTION*

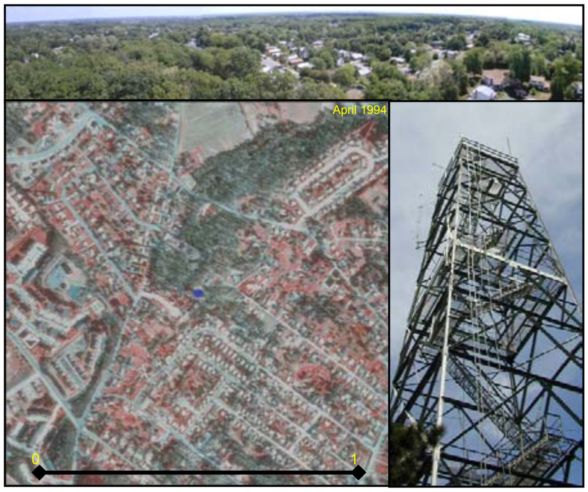
No long-term observations of CO$_2$ fluxes have been conducted in urban environments despite the fact that cities are major sources of CO$_2$ and sites where a large and ever increasing fraction of the world's population live (Grimmond et al. 2002). This paper presents details of research initiated in a residential neighborhood, Cub Hill, of Baltimore, MD, USA to continuously measure urban CO$_2$, heat, water and momentum fluxes. Details of the site, which is part of the Baltimore LTER project, and instrumentation are presented, along with a brief summary of the data collected to date.

2. METHODS

2.1 *Site*

Flux measurements are conducted from a tower located in the Cub Hill suburb (39.41°N 76.52°W), Baltimore, MD (Fig. 1). This neighborhood, which still retains extensive areas of trees, has experienced significant increases in building in recent years, predominately one storied single-family dwellings (Fig. 1). Further increases in housing density are likely. Trees within the vicinity of the tower are ~20-25 m tall and are more than 120 years old. The stand is a mix of yellow poplar and oak hickory.

Figure 1: Observation site. Top: View from tower in summer (leaf on). Left: Area surrounding tower. Right: Tower with instruments



2.2 *Instrumentation*

The base of the measurement tower is 146 m a.s.l. (USGS 1966). The turbulent flux instrumentation is mounted on a mast extending 2.13 m above the upper safety rail of a former fire observation tower (Fig. 1), at a height of 40.5 m a.g.l. This height is greater than twice the mean roughness element height. An RM Young (RMY) 81000 sonic anemometer is used with a Licor-7500 open path infra-red gas analyzer to calculate the turbulent fluxes of sensible heat (Q_H), momentum (τ), water (Q_E), and carbon dioxide (F_{CO2}) using the eddy covariance technique. The light sensitivity of the Li-7500 has not been determined at this time. Mounted on a second vertical boom at the same height is an RM Young wind sentry anemometer and vane.

The components of net all wave radiation are measured using a Kipp and Zonen CNR1 net radiometer, mounted on a boom that extends 2.7 m from the tower at a height of 38.2 m. At the same level, a Campbell Scientific (CSI) 500 temperature and relative humidity sensor is housed in an aspirated shield that is located 1.6 m from the tower face. Unshielded Omega T-type fine wire (36 AWG, 0.13 mm) thermocouples are installed at: 3.6, 7.8, 12.4, 17.0, 21.5, 26.1, 20.6, 35.2, and 40.5 m a.g.l. (in the sonic head volume) to measure heat exchanges in the urban canopy.

CO$_2$ and H$_2$O concentrations are measured using a Licor 6262 referenced against N$_2$ gas. Intakes located at 40, 35, 30, 25, 20, 5, 1, and 0.1 m a.g.l. are sequentially sampled continuously with a Scanivalve 12 port Sampivalve controlled by a PC, data acquisition board (Remote Measurement Systems ADC-1) and custom data acquisition program (Data Design Group). Air is continuously drawn through all lines with unsampled lines exhausted to decrease measurement lag (1.5 l/min). The selected sample line is drawn at 7 l/min using a separate pump (head on a two headed pump) for 2 min. IRGA measurements are averaged for the last 10 s.

Precipitation is measured using a Weathertronics 6011B tipping bucket raingauge mounted near the center of the tower at the level of the safety rail. Atmospheric pressure is measured with a Vaisala PTB101B sensor mounted at the top of the tower. Surface wetness sensors (CSI 237) are mounted on the net radiometer boom and at the ground level within the fenced compound of the tower. Additional equipment at ground level are two REBS HFT#1 soil heat flux plates at a depth of 0.055 m, with a CSI TCAV thermocouple system at 0.005 and 0.045 m below ground. Soil moisture is measured using CSI-615 time domain reflectometry 0.30 m probes that are installed between 0.06 and 0.18 m below the surface at an angle of 27°.

2.3 *Data Acquisition and Processing*

Data from the sonic are logged directly to a PC housed at the bottom of tower via a serial port using in-house software (Tower). The data are archived at 10 Hz. The other tower based instruments are sampled and logged with a CSI 23X datalogger mounted at the top of the tower, which is downloaded every 20 min to the PC

---

* *Corresponding author*: Sue Grimmond, Geography, IU, Bloomington, IN 47405; e-mail: grimmon@indiana.edu

via a serial connection using the CSI PC208 software. The fine wire thermocouples are wired to a CSI AM 16/32 multiplexer located at the midpoint of the tower to reduce thermocouple lead lengths. The remainder of the instrumentation is wired to a CSI Cr10 datalogger located in the shelter at ground level which is downloaded daily to the PC. Daily the datalogger clock is updated from the PC clock, which is adjusted to the correct local time on a weekly basis. The slow response data are sampled at 0.2 Hz and averaged (or totaled) in 15 min intervals.

Fluxes are computed using in-house (IUFlux) software. Lags were determined from the correlation of a thermocouple (~ 1 Hz response) within the sampling volume of the sonic and Ts. Covariances were rotated to streamwise coordinates, and flux corrections (Webb *et al.*, 1980) are applied.

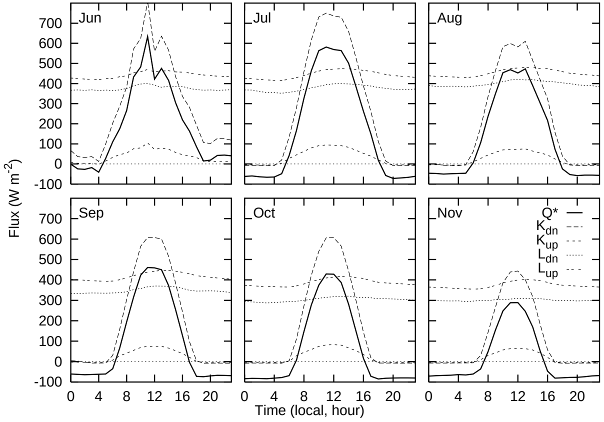
3. RESULTS

Observations began in May 2001. However, data were not collected continuously until September 2001. In the following figures, data coverage is not complete for June, July, and August .

3.1 *Radiation Balance*

Observations of the radiative components show the expected seasonal pattern, with a reduction in net all wave radiation in the wintertime, due to the reduction in the incoming shortwave radiation (Fig 2).

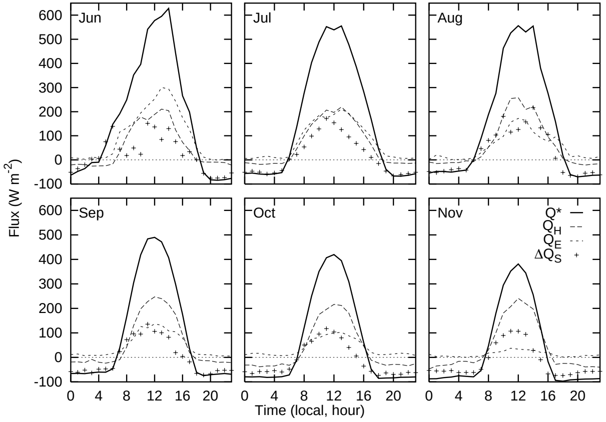
Figure 2: Ensemble diurnal pattern of radiation balance fluxes for six months (2001).



3.2 *Energy Balance*

The seasonal change in radiative energy (§ 3.1) limits the available energy that can be partitioned (Fig 3). The seasonal data allow us to see clearly how the importance of latent heat flux decreases as the leaves fall off the trees (cf November with summer months). In virtually all months, the turbulent sensible heat flux is the dominant mechanism to remove heat from the surface. The storage heat flux term (ΔQ_S) is determined as a residual in the surface energy balance (SEB). Inevitably this means it accumulates all the errors due to measurement and neglected terms (Grimmond and Oke 1999). It is a significant term at this site in the summertime, consistent with results at other suburban sites (Grimmond and Oke, 2002)

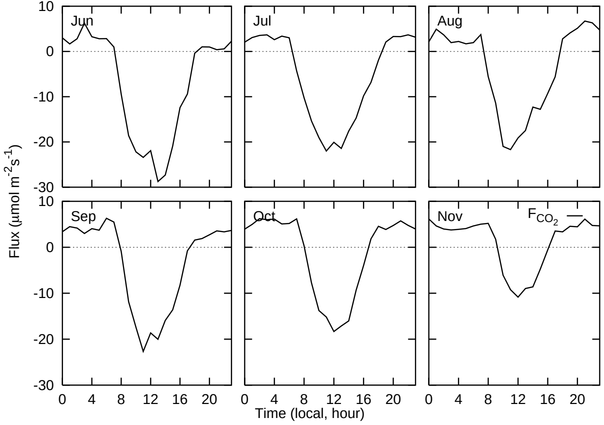
Figure 3: Mean diurnal pattern SEB fluxes for six months (2001).



3.3 *Carbon dioxide fluxes*

Though primarily a residential area, as noted above the area in the flux footprint of the Cub Hill site has patches of forest (their relative importance vary with wind direction). The impact of this is particularly evident in the F_{CO2} in Fig. 4. For all months when leaves are on the trees, the site functions as a net carbon sink. This is an interesting result, highlighting the potential significance of suburban ecosystems to offset the emissions of CO_2 known to occur in urban environments.

Figure 4: Mean diurnal pattern of F_{CO2} for six months (2001)



4. ACKNOWLEDGEMENTS: Funding provided by NSF 0095284 & USDA FS. We thank: F. Cropley, S. Scott, C. Souch; and the MD DNR, Communications, State Police and FS.

5. REFERENCES

Grimmond C.S.B. et al. 2002: Local-scale fluxes of carbon dioxide in urban environments: methodological challenges and results from Chicago. *Env. Poll.,* 116, S243-254.
-- & T.R. Oke 1999: Heat storage in urban areas: observations and evaluation of a simple model. *JAM*, 38, 922-940
--. & T.R. Oke 2002: Turbulent heat fluxes in urban areas: Observations & Local-scale Urban Meteorological Parameterization Scheme (LUMPS). *JAM (in press)*