Studies on carbon flux and carbon dioxide concentrations in a forested region in suburban Baltimore

John Hom[1], Sue Grimmond[2], Dan Golub[1], Brian Offerle[2] ,
David Nowak[1], Gordon Heisler[1], Rich Pouyat[1], and Wayne Zipperer[1]
[1]USDA Forest Service, Northeast Research Station,
[2]Indiana University, Bloomington, IN

Abstract: The purpose of this study is to characterize the carbon fluxes and carbon dioxide concentrations from a highly vegetated residential area of Baltimore. This will provide annual estimates of carbon sequestration in suburban ecosystems, areas traditionally called non-forest. The Cub Hill site is located 14 km from the Baltimore city center. It is the first permanent flux tower to measure carbon flux in an urban/suburban environment.

The ten level profile system for CO_2 and H_2O concentrations was initiated in February 2001. An eddy correlation system for carbon, water, and energy fluxes was started in late May 2001; however, data were not collected continuously until September 2001.

The average yearly carbon dioxide concentration in this Baltimore suburban environment is 385 ppm at the top of the 40 m Cub Hill tower, with peaks of more than 475 ppm. Additional CO_2 monitoring stations in the Baltimore city center were much higher - averaging 511 ppm. A weekly anthropogenic cycle was observed with lower CO_2 concentrations for the weekends than the weekdays during the winter, however this was less obvious during growing season. This residential region of Baltimore had high seasonal carbon uptake, similar to that of a natural deciduous forest due to the high 36% tree cover. Uptake showed two dominate vegetation responses: seasonal deciduous canopy with "grasslands" understory.

This suburban flux tower showed C dynamics with land use change, human patterns and energy cycles. Urban conditions of elevated carbon dioxide, ozone, nitrogen deposition and elevated heat island effects represent future scenarios which forests may face. This study give us a "window" into the future, so that we can estimate future long-term growth response to these multiple stresses.

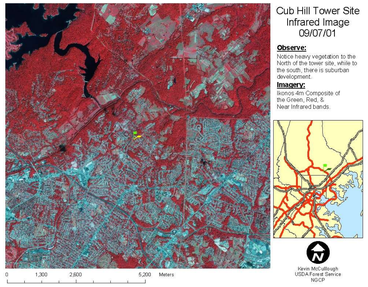

Fig. 1. Cub Hill tower site, vegetation

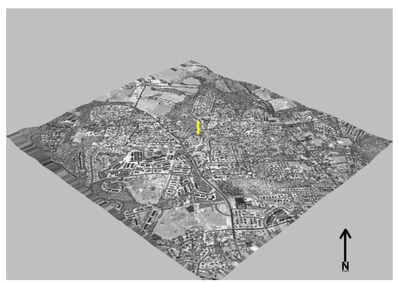

Fig. 2. Lidar image of tower site, 1 mi^2

Purpose & Objectives: The purpose of this study is to characterize the carbon fluxes and carbon dioxide concentrations from a highly vegetated residential area of Baltimore. This will provide annual estimates of carbon sequestration in suburban ecosystems. Land use is the most significant factor affecting forests. It is estimated that 80% of the U.S. population will live in urban areas by the year 2025, up from 74% in 1986. Urban areas account for less than 4% of the total US terrestrial life zones. With an average tree cover of 33.4%, metropolitan areas (urban counties) support 25% of the Nation's total tree canopy cover. However, estimates of suburban forest area and the amount of carbon stored in this land use classification are not as well known, as they fall between the inventories of rural and urban forests. The estimates of carbon stocks and flux for these non-forest suburban areas are the greatest source of uncertainty in the US Forest carbon budget.

By using wind direction and different land use "footprints" around the tower, it may be possible to characterize the air quality and meteorological fluxes that come from the urban city center, versus that originating from suburban residential and more vegetated regions.

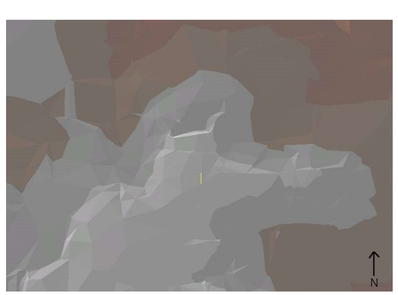

Fig. 3. Topography of site using lidar

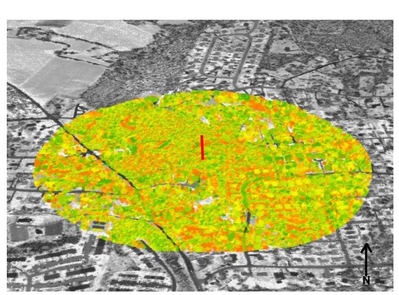

Fig. 4. Vegetation and structure around tower, 300 m.

Produced by Kevin McCullough, USDA FS Northern Global Change Program

Site Description and Methods: The Cub Hill site is located 14 km from the Baltimore city center (Fig. 1, 2). It is the first permanent urban carbon flux tower in an urban/suburban environment. The site is a yellow poplar-oak-hickory stand with a canopy height of 65-80 feet. The residential area is south, and large areas of forest and vegetation are to the north and west (Fig 2, 3). Measurements include net CO_2 exchange, input and partitioning of radiation (net, solar, PAR, IR, UV), 3-D wind speed and direction, precipitation, relative humidity and air temperature.

The ten level profile system for CO_2 and H_2O concentration was initiated in February 2001 on an existing fire lookout tower (Fig. 5). An eddy correlation system for carbon, water, and energy fluxes was started in late May 2001 (Fig. 6); however, data were not collected continuously until September 2001.

Fig. 5. Cub Hill Tower

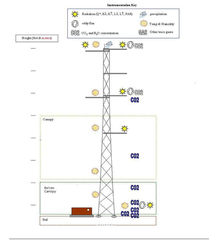

Fig. 6. Instrumentation and equipment trailer

Fig. 7. CO_2 Profile System

Science questions and goals: The urban/suburban flux site will address these science questions:

- What are the elevated levels of CO_2, temperature, and nitrogen deposition in urban sites.
- How do human temporal cycles affect the CO_2 concentration, ozone concentration, N deposition, and i.e. diurnal traffic/rush hour, workweek vs. weekends?
- How much carbon does the suburban ecosystem sequester, and how does it compare with rural forested systems?

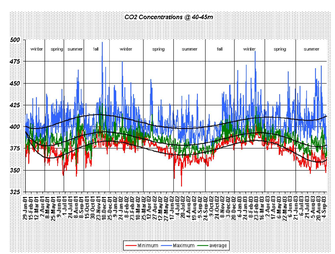

Fig. 8. Cycling of CO_2 concentration at 40m, showing seasonality

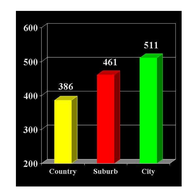

Fig. 9. CO_2 concentration gradient from Baltimore city center to western suburbs

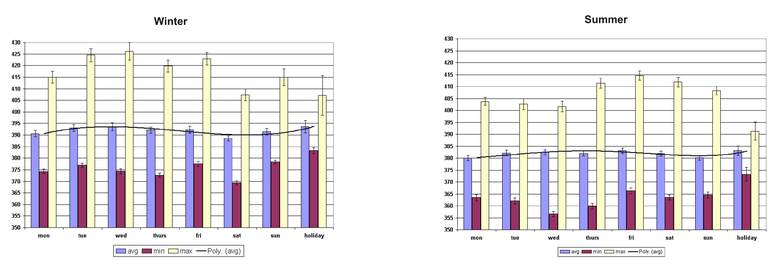

Fig. 10. Weekly cycle of CO_2 concentration at 40m, anthropogenic influence of work week.

Results and Accomplishments (part. 1): The average concentration in this Baltimore suburban environment is 386 ppm at the top of the Cub Hill tower, with peaks of more than 475 ppm., slightly higher than the average global carbon dioxide of 370 ppm (Fig. 7). The weekly CO_2 cycle (Fig. 9), shows lower overall CO_2 emissions for the weekends than that of the weekdays during the winter, possibly due to higher energy use for the workweek. However this was less obvious in the spring and summer with the influence of the deciduous vegetation. Yearly seasonal cycles show the influence of the deciduous tree cover (Fig. 8). Monitoring stations at the city center is much higher - averaging 511 ppm (Fig. 10).

- Results of our CO2 profile system showed a diurnal cycle associated with energy use and the workweek
- Lack of vegetation response from the dormant tree cover during the winter.
- Mean concentration at 40m is 386 ppm,
- Lower CO2 concentrations for the weekend than that of the weekdays during the winter, however this was less

Results and Accomplishments (part 2): The patches of forests and vegetation cover at Cub Hill have a substantial impact on the amount of carbon dioxide sequestered in the residential area using the eddy correlation method (Fig. 11,12). For all months when leaves are on the trees (Fig. 13), the site acts as a "carbon sink When trees shed their leaves, there is still uptake from lawns and evergreens, but at reduced levels (Figs 14, 15). Uptake showed two dominate vegetation responses: seasonal deciduous canopy with "grasslands" understory (Fig. 15).

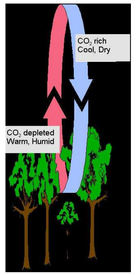

Fig. 11. Eddy correlation methodology

Fig. 12. CO_2 and H_2O Flux Instrumentation

Fig. 13.. Seasonal tree cover in residential area

Results and Accomplishments (part 3):

- Net uptake of carbon is similar to that of a natural temperate deciduous forest ecosystem, i.e. compared to Morgan Monroe State Forest, Indiana
- Uptake shows two dominate vegetation responses: seasonal deciduous canopy and grass/ maintained/ evergreen cover which has a longer growing season.
- Contributes to carbon sequestration from "non-forest" definition regions
- Interaction with anthropogenic factors

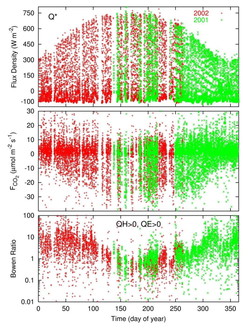

Fig. 14. Fluxes: Light, CO_2 and H_2O

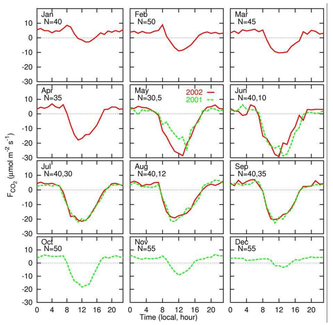

Fig. 15. Monthly CO_2 flux, FCO_2

New Studies: Land use change and associated carbon dynamics are occurring within the footprint of this suburban site. A 5 acre housing development (Fig. 16,17,18) cleared a heavily wooded area within 300 m of the tower and we are using wind direction from different land use "footprints" around the tower to estimate carbon changes.

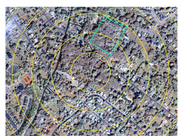

Fig. 16. Land use change within tower footprint

Fig. 17. Vegetation plots

Fig. 18. 5 acre housing development, before/after

Conclusions:

- From this suburban tower, we were able to show seasonal and workweek cycles of CO2 concentration that are influenced by anthropogenic activity and the maintained vegetation.
- Slightly elevated levels of CO2 were monitored at the site, averaging 386 ppm at 40 m, in contrast to 511 ppm in the city center.
- Carbon uptake rates were similar to a natural deciduous forest due to the high tree cover in the residential areas 36%.
- Two dominant vegetation responses in carbon exchange: seasonal deciduous canopy and "grasslands" and maintained vegetation.
- The suburban flux tower is able to measure C dynamics land use change, human patterns, and energy cycles.

Acknowledgments: This research is supported by the USFS Northern Global Change Program, Urban Forestry Research, Forest Inventory and Analysis, NSF Baltimore Ecosystem Study LTER, and Indiana University.