REGIONAL ECOSYSTEM-ATMOSPHERE CARBON EXCHANGE OBSERVED SIMULTANEOUSLY VIA ATMOSPHERIC INVERSIONS AND FLUX-TOWER UPSCALING

K.J. Davis[1], A. Andrews[2], J.A. Berry[3], P.V. Bolstad[4], J. Chen[5], B.D. Cook[4], A.S. Denning[6], A.R. Desai[1], B.R. Helliker[7], N. Miles[1], A. Noormets[5], D.M. Ricciuto[1], S.J. Richardson[1], M. Uliasz[6], W. Wang[1]

[1]*Dept. of Meteorology, The Pennsylvania State University, University Park, PA 16802; kjd10@psu.edu*

[2]*Climate Monitoring and Diagnostics Laboratory, NOAA, Boulder, CO 80305*

[3]*Department of Global Ecology, Carnegie Institution of Washington, Stanford, CA 94305*

[4]*Dept. of Forest Resources, University of Minnesota, St. Paul, MN 55108*

[5]*Dept. of Earth, Ecological and Environmental Sciences, The University of Toledo, Toledo, OH 43606*

[6]*Dept. of Atmospheric Science, The Colorado State University, Fort Collins, CO 80523*

[7]*Department of Biology, University of Pennsylvania, Philadelphia, PA 19104*

ABSTRACT

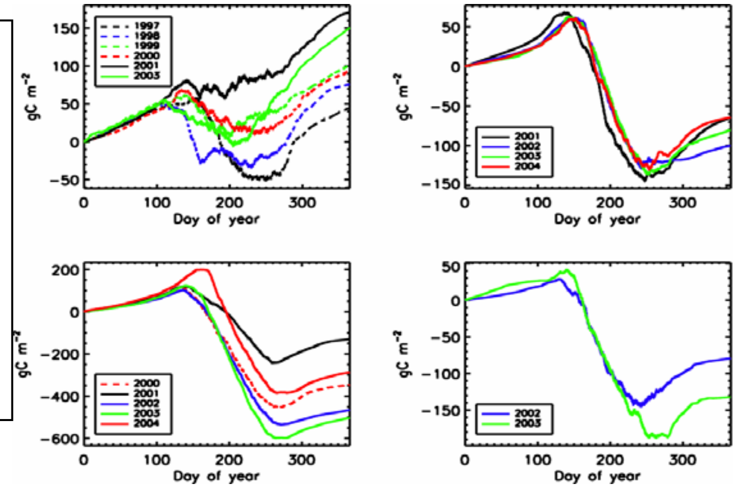
The overarching goal of a long-term, multi-investigator, regional study of ecosystem-atmosphere carbon cycling in a mixed forest ecosystem in the upper Midwest of the USA is to observe ecosystem-atmosphere exchange of carbon dioxide at scales of relevance to the global carbon balance, while simultaneously understanding the mechanisms governing this exchange. This study, the Chequamegon Ecosystem-Atmosphere Study (ChEAS), brings together multiple approaches to observing carbon fluxes, including chamber flux, sap flux and biometric measurements at the plot scale (~1 m^2), multiple stand-level (~1 km^2) eddy-covariance flux towers, landscape-scale (~10-100 km^2) eddy-covariance flux measurements from the WLEF tall tower, multiple regional (10^3-10^5 km^2) atmospheric boundary layer (ABL) budget approaches using tall tower mixing ratio measurements, and a regional (~10^5 km^2) ABL budget using a network of CO_2 mixing ratio measurements on communications towers. Flux measurements have been up-scaled to the region using a variety of approaches, and compared to the regional ABL budget methods. Top-down and bottom-up methods fall within a range of values for growing-season flux estimates that suggests a level of precision for regional flux estimates of approximately 0.5 gC m^{-2} d^{-1}. A multi-tower inverse study should increase the level of precision of the ABL budget flux estimates. Interpreting the mechanisms governing these fluxes requires plot- and stand-level data. These data show that variability in seasonal and annual fluxes among flux towers is large, refuting hypotheses that ecosystem-atmosphere exchange can be explained simply by climate, or that a sparse flux tower network can be used to map carbon fluxes over continental domains. Stand age and stand type (e.g. aspen, wetland, northern hardwood forest) explain a large fraction but not all of the observed variability among stands. More sophisticated land classification schemes may be needed to improve the precision of bottom-up methods. Multi-year records are used to examine interannual variability in the carbon balance of the region and show that interannual variability at WLEF is clearly correlated with climate variability. Limited multi-year records at the plot- and stand-level partly support the hypothesis that year-to-year variability in carbon fluxes are coherent across the region, and begin to describe the causes of the observed interannual variability. Further study is needed to evaluate the network design required to describe both the magnitude and mechanisms of interannual variability in the regional carbon balance.

RESULTS

Flux tower upscaling

Linking plot- and stand-level carbon flux measurements in terrestrial ecosystems to regional-scale fluxes and atmospheric CO_2 mixing ratio based ABL budget studies on seasonal to interannual time scales remains an important but elusive goal in carbon cycle science. An array of flux towers deployed in northern Wisconsin and Michigan, USA show substantial variability in carbon fluxes among towers (e.g. Figure 1), showing that measurements at any one stand does not capture regional fluxes, despite the fact that the towers are located within a few tens of kilometers of each other. Analyses using flux footprint decomposition at the WLEF tall tower [*Wang et al.*, submitted] and the full array of flux towers [*Desai et al.*, submitted] show that stand type (wetland, upland forest, aspen) and stand age explains some, but not all of the observed variability in carbon fluxes across stands. A companion paper by Desai et al attempts to reconcile flux-tower upscaling efforts in the region. More detailed land classification appears to be necessary to improve the precision of the regional upscaling.

Fig. 1. Cumulative NEE for multiple years at the WLEF, Lost Creek, Willow Creek and Sylvania flux towers. WLEF is a small region (~10^2 km^2) flux measurement, covering a mixture of wetland and upland forests. Willow Creek and Lost Creek represent mature upland deciduous and low-forest/shrub wetland sites, two of the dominant vegetation classes within the WLEF flux footprint. Sylvania is a mixed old-growth forest. All towers are within a few tens of km of each other.



Comparisons with ABL budgets

These flux tower upscaling efforts have been compared to several ABL budget methods of inferring fluxes in the region [*Wang*, 2005; Fig. 2]. The ABL budget regional flux estimates are in reasonably good agreement with the more sophisticated flux tower upscaling approaches. Growing season net carbon uptake appears to be between 1 and 2 gC m^{-2} d^{-1} in the region. A companion paper by Uliasz et al describes an attempt to reduce the uncertainty in the regional ABL budget carbon flux estimate using a ring of CO_2 mixing ratio measurements deployed on communications towers.

Interannual variability in the regional carbon budget

Ricciuto et al., [submitted] explain a large fraction of the seasonal-scale, interannual variability in WLEF CO_2 fluxes (e.g. Fig. 1) with a relatively simple ecosystem model that uses air temperature, photosynthetically active radiation, soil temperature and soil water content as inputs. Helliker et al., [submitted] have used an ABL budget approach over a similar time period, and find strong coherence between the WLEF cumulative annual fluxes and the budget estimates. Since climate across the entire region is very similar, this creates an excellent test bed for examining the mechanisms that govern regional interannual variability in carbon fluxes. It is evident from Figure 1 that some coherence exists in observed interannual variability across the flux towers, but that the same response is not found in either magnitude or sign at all sites. Further investigation will be required to create a mechanistic upscaling of interannual variability in the region's carbon balance.

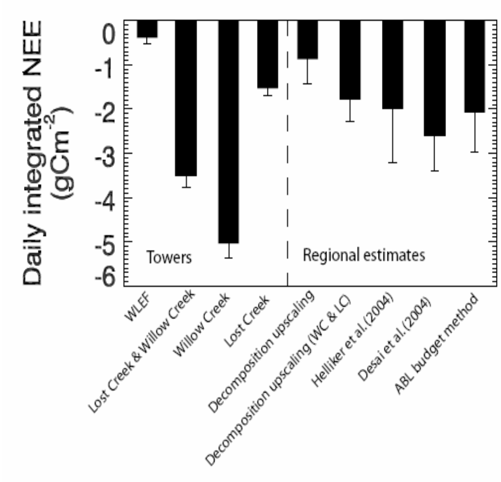


Fig. 2. Flux tower upscaling and ABL budget daily integrated growing season flux estimates for the ChEAS region, from Wang [2005], Helliker et al [2004] and Desai et al [submitted].

REFERENCES

Helliker, B.R., J.A. Berry, A.K. Betts, P.S. Bakwin, K.J. Davis, A.S. Denning, J.R. Ehleringer, J.B. Miller, M.P. Butler, and D.M. Ricciuto (2004), Estimates of net CO2 flux by application of equilibrium boundary layer concepts to CO2 and water vapor measurements from a tall tower, *J. Geophys. Res.*, 109(D20), D20106, doi:10.1029/2004JD004532.

Wang, W., (2005), Regional estimates of net ecosystem-atmosphere exchange of carbon dioxide over a heterogeneous ecosystem, Ph.D. thesis, 234 pp. The Pennsylvania State University, University Park, PA.