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PENNSTATE

Synthesis of Top-Down and Bottom-Up Scaling of Regional Terrestrial Carbon Dioxide Fluxes

Implications for Global Terrestrial CO_2 Flux

A.R. Desai*, W. Wang, D.M. Ricciuto, B.D. Cook, F.A. Heinsch, K.J. Davis, A. Noormets, J. Chen, P.V. Bolstad, S.J. Richardson, N. Miles, M. Uliasz, P.R. Moorcroft

*Corresponding author contact: The Pennsylvania State University, Dept. of Meteorology, University Park, PA 16802 USA 814-865-9617 adesai@psu.edu

MOTIVATION

- Quantifying regional scale (10-1000 km) land-atmosphere exchange of carbon dioxide is vital for understanding spatio-temporal variability in global CO_2 and the impact of global changes in climate, CO_2 and land use at the landscape scale
- Global ecosystem and tracer-transport inverse models perform poorly at characterizing regional-scale CO_2 exchange in complex landscapes, while low spatial-density intensive stand-level measurements cannot easily scale to the landscape
- Roles of disturbance, forest management and wetlands on carbon exchange remain poorly constrained
- Unique opportunity to construct verifiable, regional carbon balances as part of multi-investigator intensive sampling in complex, managed forested ecosystems of the upper Midwest (Chequamegon Ecosystem-Atmosphere Study: http://cheas.psu.edu)

APPROACH

- Region has globally unique 396-m tall tower and 12+ fixed and roving eddy covariance flux towers, which use high-frequency measurements of atmospheric turbulence and CO_2 concentrations to assess whole stand-scale carbon exchange (Fig. 1)
- Simultaneous application of top-down and bottom-up scaling can be used to converge on regional carbon fluxes
- Bottom-up scaling uses ecosystem models and remote sensing to aggregate stand-scale measurements to the regional scale
- Top-down scaling uses tall-tower and/or regional network of atmospheric measurements (Fig. 2) to infer regional carbon balance

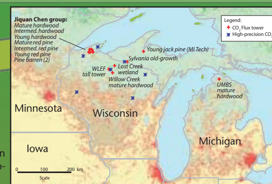

Figure 1. Map of region and existing eddy covariance flux towers

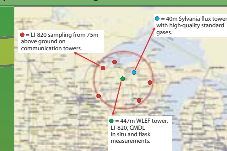
Figure 2. Map of region and network of high-precision CO_2 mixing ratio towers

Land cover variability

- Wetlands, clearcuts and natural disturbances occur in small non-uniformly distributed patches that aggregate to more than 30% of the landscape and are difficult to assess with coarse-resolution (> 250 m) remote sensing (Fig. 3)
- Biometric and chamber-based measurements of hardwoods around tall tower appear less productive than eddy covariance observations.
- Highest productivity in fully-stocked stands occurs at intermediate terrain positions – too much moisture shifts composition to sparser stands of less productive species and too little towards lower growth in primarily upland species
- Effect confounded in productive middle by disturbance-induced changes in species composition, age, and stocking

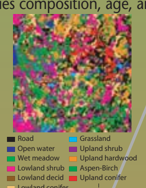

Figure 3. Land cover classification for 10x10 km around tall tower from 1-m resolution IKONOS. 1-km MODIS classifies entire area as mixed forest

Flux tower observations

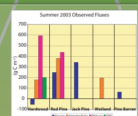
Figure 4. Observed net carbon exchange as function of stand type and age

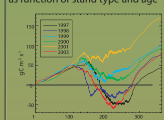
Figure 5. Six-year tall tower cumulative net ecosystem exchange of CO_2

- Stand-level eddy covariance flux towers have observed significant spatial variability in net and gross carbon dioxide fluxes, most of which can be explained by stand age and type (Fig. 4)
- Multi-year record of CO_2 exchange at the tall tower shows surrounding forests and wetlands are persistent source of CO_2 to the atmosphere (Fig. 5)
- Interannual variability in fluxes is general coherent among sites, statistically significant and clearly correlated with climate variability
- Model of climate variables parameterized with Bayes Monte-Carlo techniques explains seasonal variability in tall tower fluxes (Fig. 6)

Ecosystem modeling

- The Ecosystem Demography (ED) model, which incorporates vegetation heterogeneity, canopy structure, stand age, disturbance and forest management, was parameterized with regional biometric data and meteorology, historical records of land management and high-resolution satellite land cover maps
- Preliminary runs, without forestry, show large variation in carbon exchange of potential vegetation with stand age since disturbance and significant respiration in young stands

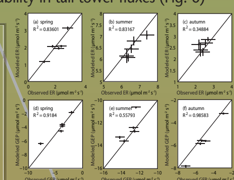
Figure 6. Correlation of five-year tall-tower observed to modeled seasonal gross ecosystem production (GEP) and ecosystem respiration (ER)

Multi-site synthesis aggregation

- Eddy covariance stand-level measurements were scaled using a combination of remote sensing, forest inventory stand age data and simple climate-driven models of carbon flux
- Mature hardwood sites dominate the landscape, but large respiratory sources from wetlands and recently disturbed sites cannot be neglected
- Scaled fluxes agree with footprint extended tall tower fluxes (Fig. 7), but also show tall tower is unique in its large respiratory fluxes (Fig. 8)

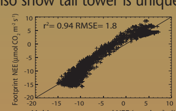
Figure 7. Correlation of synthesis aggregated growing season hourly net ecosystem exchange (NEE) to tall-tower extended footprint regional NEE

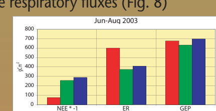
Figure 8. Net growing season carbon uptake of tall-tower (red), extended footprint (green) and synthesis aggregation (blue)

BOTTOM-UP SCALING

Footprint decomposition and extension

- Tall tower fluxes sample different patches or footprints of landscape as a function of wind direction, speed and atmospheric stability/conditions
- Remotely sensed landcover and footprint models can be used to decompose regional fluxes
- Results suggest that wetlands or recently disturbed stands around the tall tower are large unobserved sources ecosystem respiration (Fig. 9)
- Footprint extension, which rescales decomposed fluxes into regional estimates unbiased by footprint weighting, reveals growing-season net uptake of carbon that is greater than that shown by the tall tower when integrated directly, not weighted for regional vegetation cover distribution

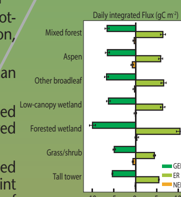
Figure 9. Tall-tower decomposed fluxes of gross ecosystem production (GEP - dark green), ecosystem respiration (ER - light green) and net ecosystem exchange (NEE - orange)

Tall tower boundary-layer budget

- Multiple vertical levels of atmospheric CO_2 concentration at the tall tower can be used to infer regional carbon balance at monthly timescales
- Method requires accurate measurement of boundary-layer height and entrainment rates
- Several complementary attempts show promising results when compared to directly-observed tall tower flux at 396 m (Fig. 10)

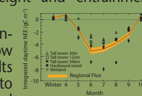
Figure 10. Daytime monthly average net regional carbon flux for budget method (orange) and towers

Multi-tower tracer-transport inversion and budget

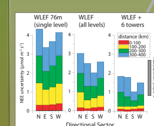
Figure 11. Uncertainty in net flux as functions of direction, distance and number of towers

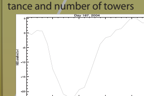
Figure 12. Preliminary hourly net carbon flux for one day using multi-tower budget method

- High-precision atmospheric boundary layer CO_2 mixing ratio measurements can be used with meteorological transport fields to infer regional fluxes
- Mesoscale network of six high-precision CO_2 concentration systems installed at 75 m in 2003 and 2004 growing seasons (Fix. 2)
- Virtual tall tower method can be applied to scale surface layer (0-100 m) measurements to boundary layer average (0-200 m)
- Regional flux uncertainty expected to be significantly smaller compared to single-tower budget method (Fig. 11)
- Concentration network and tropospheric aircraft or remotely sensed column CO_2 can also be used with simpler boundary-layer budget methods to infer daytime flux in convective conditions
- Preliminary budget results show encouraging ability to assess regional carbon exchange (Fig. 12)
- More information on top-down inversions at Davis et al. poster

TOP-DOWN SCALING

IMPLICATIONS

- Encouraging consistency is seen in top-down and bottom-up methods, but the discrepancies are substantially larger than desired level of consistency (Fig. 13)
- Current results support hypothesis that regional carbon balances limited to sampling dominant stands and coarse-resolution biogeochemical models limited to biome-scale parameterization neither accurately capture the observed variability of carbon fluxes nor match the inferred regional carbon flux in complex regions
- Work in underway in collecting observations on poorly represented cover types, and obtaining information of forest structure so as to improve the degree of detail needed to observe and model regional carbon budgets in this complex landscape, which is a fundamental, enabling step required to achieve the aims of regional, continental and global scale carbon cycle analyses

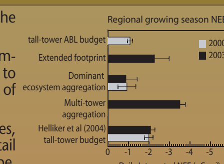

Figure 13. Regional growing season net ecosystem exchange of CO_2 for several different top-down and bottom-up methods

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Ankur R Desai

Research Assistant / Ph.D. Candidate
The Pennsylvania State University
Department of Meteorology

503 Walker Building
University Park, PA 16802 USA
Phone: (814) 865-9617
Mobile: (814) 441-0505
Fax: (814) 865-3663
Office: Walker 416
Email: adesai@psu.edu
Web: http://met.psu.edu/~adesai

I am a Ph.D. candidate working with Dr. Kenneth J Davis. My research examines the impact of land cover variability, forest management and disturbance on regional exchanges of carbon dioxide and water vapor between ecosystems and the atmosphere. My research relies on a high-density network of eddy covariance flux towers, high-precision atmospheric boundary layer trace gas measurements, airborne CO_2 profiling, satellite remote sensing and ecosystem models used as part of the Chequamegon-Ecosystem Atmosphere Study in the upper Midwest, USA. I am currently looking for post-doctoral, entry-level faculty or other research positions beginning August 2006. Please feel free to visit my website or contact me if you have any questions.

Education

Pennsylvania State University, University Park, PA, Ph.D. Meteorology, expected May 2006
University of Minnesota, Minneapolis, MN, M.A. Geography, 2000
Oberlin College, Oberlin, OH, B.A. Environmental Studies & Computer Science, 1997

Selected Publications

Desai, A.R., Bolstad, P.V., Cook, B.D., Davis, K.J., Carey, E.V., 2005. Comparing net ecosystem exchange of carbon dioxide between an old-growth and mature forest in the upper Midwest, USA. *Agricultural and Forest Meteorology* 128(1-2): 33-55, doi:10.1016/j.agformet.2004.09.005.

Desai, A.R., Davis, K.J., Senff, C., Ismail, S., Browell, E.V., Stauffer, D.R. and Reen, B.P., 2005. A case study on the effects of heterogeneous soil moisture on mesoscale boundary layer structure in the southern Great Plains, USA. Part I: Simple prognostic model, *Boundary Layer Meteorology*, in press, doi:10.1007/s10546-005-9024-6.

Desai, A.R., Noormets, A.N., Bolstad, P.V., Chen, J., Cook, B.D., Davis, K.J., Euskirchen, E.S., Gough, C.M., Martin, J.G., Ricciuto, D.M., Schmid, H.P., Tang, J.W. and Wang, W., 2005. Influence of vegetation and surface forcing on carbon dioxide fluxes across the Upper Midwest, USA: Implications for regional scaling, *Agricultural and Forest Meteorology*, in review