SYNTHESIS OF TOP-DOWN AND BOTTOM-UP SCALING OF REGIONAL TERRESTRIAL CARBON DIOXIDE FLUXES: IMPLICATIONS FOR GLOBAL TERRESTRIAL CO_2 FLUX

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ABSTRACT

Quantifying the regional scale (10-1000 km) exchange of carbon dioxide between terrestrial ecosystems and the atmosphere is vital for understanding the spatial and temporal variation in global CO_2 flux. Multiple investigations of top-down and bottom-up regional flux scaling are currently underway in the northern Great Lakes region, USA. Landscape and regional scale CO_2 fluxes from multiple line of evidence, including eddy covariance multi-tower aggregation, tall-tower flux footprint decomposition, ecosystem modeling, CO_2 mixing ratio boundary layer budgets and regional inversions reveal variations in CO_2 flux arising from variations in vegetation type, canopy structure and interannual climate variability. With careful calibration, encouraging consistency is seen from several independent regional flux estimates. Without parameter optimization and high resolution maps of land cover, global scale remote-sensing and ecosystem-model CO_2 flux estimates fail to accurately capture the local regional CO_2 flux. These results represent a first attempt to cross-compare multiple top-down and bottom-up regional flux estimates.

INTRODUCTION

Multiple independent investigations on regional flux scaling have been occurring as part of the Chequamegon Ecosystem-Atmosphere Study (http://cheas.psu.edu), located in the upper Midwest region of northern Wisconsin and Michigan, USA. The region is a highly productive area of dense forest and lowland wetlands. Eddy covariance flux measurements have been made at a regionally representative 447-m tall tower. Additionally, a cluster of seven multi-year and four short-term towers operated by several research groups has been assembled to sample various ecosystems that occur throughout the region including wetlands and forest stands of various age and type.

Independent regional multi-year bottom-up flux estimates have been performed with 1.) tall-tower flux footprint land-cover based decomposition [*W. Wang*, submitted, 2005], 2.) multi-tower land-cover based aggregation (A. Desai, submitted, 2005) and 3.) forest inventory and biometric based ecosystem modeling using the Biome-BGC and Ecosystem Demography (ED) models. These methods are entirely independent, though the all rely on common land-cover data. The first method relies entirely upon decomposition of the tall tower flux measurements, the second upon stand-level eddy covariance towers and the third upon biometric and chamber-flux measurements.

Independent estimates of regional flux from top-down methods using tall tower and airborne CO_2 data have been done with experimental ABL budget methods (Bakwin et al., 2004; Helliker et al., 2004) and more traditional ABL single-tower and aircraft based budget estimates [*W. Wang*, PhD dissertation, 2005]. A six-tower seasonal inversion and ABL budget are also in process to provide more robust top-down seasonal flux estimates than estimates derived from 1-D data only.

We hypothesized that simultaneous application of multiple top-down and bottom-up methods will converge upon statistically similar net CO_2 fluxes for the region on both seasonal and annual time scales.

MAJOR FINDINGS

A multi-year record of ecosystem-atmosphere CO_2 exchange at the tall tower shows that the surrounding forests and wetlands are a persistent annual source of CO_2 to the atmosphere [*Davis et al.*, 2003]. Interannual variability in fluxes is greater than the range of random error and therefore statistically significant. Multi-year carbon exchange measurements at the tall tower are clearly correlated with climate variability [*D. Ricciuto*, submitted, 2005].

Stand-level eddy covariance flux towers have observed significant spatial and temporal variability in net and gross carbon dioxide fluxes. Most of the spatial variations can be explained by stand age and species composition. Interannual variations of NEE, but not of GEP or ER, were generally coherent across all multi-year sites.

Scaling of stand-level towers shows that the tall tower is unique in its large respiratory fluxes. Aggregation scaling also suggests that although mature hardwood sites dominate the landscape, large respiratory sources from wetlands and recently disturbed sites cannot be neglected. However, none of the other towers in the cluster appear to capture the magnitude of the tall tower respiration. The flux footprint decomposition approach suggests that non-measured wetlands or recently disturbed stands around the tall tower are the likely source of this respiration. Further, biometric and chamber based measurements of mature hardwoods around the tall tower appear less productive than eddy covariance instrumented mature hardwood stands.

Bottom-up scaling methods generally converge to show moderate regional scale uptake, larger than observed at the tall tower and smaller than observed in mature forested stands. All bottom-up methods were sensitive to land cover spatial resolution, and ecosystem models generally required regionally-optimized parameters. Wetlands, clearcuts, and recent natural disturbances characteristically occur in small non-uniformly distributed patches, and are difficult to distinguish using coarse-resolution remote sensing. These types in aggregate form more than 30% of the landscape. Misclassification substantially biases landscape-level scaling via models.

The bottom-up methods are roughly consistent with top-down scaling methods. Top-down methods have been shown to be sensitive to boundary layer depth, free troposphere CO_2 entrainment and usage of reanalysis winds. While the scaling methods have yet to be carefully reconciled, some elements of the comparison are clear. All methods yield growing-season net uptake of carbon that is greater than that shown by the WLEF flux data when integrated directly, not weighted for regional vegetation cover distribution. The discrepancy among methods, however, is substantially larger than the desired level of consistency. More comprehensive up-scaling efforts are being conducted to reduce uncertainty.

IMPLICATIONS FOR REGIONAL AND GLOBAL SCALING

Until the large respiratory source in the WLEF region is identified, and the causes of large variability among similar ecosystem types, it appears that important drivers of regional carbon fluxes are not identified in our current vegetation classification scheme, which is already more complex than typical large-scale remote-sensing land classification schemes. We are in process of identifying the causes of these differences, collecting observations on poorly represented cover types, and obtaining information of forest structure, will bring us closer to the degree of landscape detail needed to observe and model regional carbon budgets in this complex landscape. This is a fundamental, enabling step required to achieve the aims of regional, continental and global scale carbon programs.

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