OBSERVATIONAL UNCERTAINTIES IN NET ECOSYSTEM CO_2 EXCHANGE

R. Monson[1,2], C. Yi[1], D. Anderson[3], J. Sun[4], B. Lamb[5], A. Turnipseed[6], S. Burns[1,4], B. Stephens[7], G. Allwine[5], A. Delany[4], and S. Oncley[4]

[1]*Department of Ecology and Evolutionary Biology, University of Colorado, Boulder, CO 80309*

[2]*Cooperative Institute for Research in Environmental Studies (CIRES), University of Colorado, Boulder, CO 80309*

[3]*Water Resources Division, US Geological Survey, Denver Federal Center, Lakewood, CO 80225*

[4]*Mesoscale and Microscale Meteorology Division, National Center for Atmospheric Research, Boulder, CO 80307*

[5]*Department of Civil and Environmental Engineering, Washington State University, Pullman, WA 99164*

[6]*Atmospheric Chemistry Division, National Center for Atmospheric Research, Boulder, CO 80305*

[7]*Atmospheric Technology Division, National Center for Atmospheric Research, Boulder, CO 80307*

ABSTRACT

Measurements of net ecosystem CO_2 exchange using continental tower flux networks provide a critical constraint in models of regional and global carbon budgets. Uncertainty exists in these measurements due to the effects of complex terrain and vegetation gradients. Using an array of seven towers distributed across a mountain landscape, we estimated that a significant error exists in the five-year record of measured net ecosystem CO_2 exchange. The error was due to the previously ignored influence of advective CO_2 fluxes. When this error was rectified by explicit consideration of the advective flux components, the forest was predicted to exhibit a 38% higher potential for carbon sequestration than previously thought.

INTRODUCTION

During the past decade tower flux networks have flourished for the purpose of quantifying surface-atmosphere CO_2 exchange. Expectations are high that these networks will provide the empirical constraint required for accurate regional and global carbon budget modeling. Fluxnet, the global articulation of tower flux networks on six continents, includes over 200 sites, each using the eddy covariance approach to measure net ecosystem CO_2 exchange (NEE) (http://daac.ornl.gov/FLUXNET/). The eddy covariance approach is most accurate when applied to ecosystems with flat topography and homogeneous vegetation cover. In cases where these criteria cannot be met, extensive characterization of the local wind and CO_2 fields must be conducted in order to satisfy the requirement for conservation of mass in the local carbon budget. Few of the Fluxnet sites currently in use meet the topographic and vegetation criteria required to permit accurate CO_2 budgeting. As a result, significant uncertainties surround reported estimates of NEE. As eddy flux networks become increasingly more utilized to provide the observational constraint on regional and global carbon models, it will be important to quantify and reduce these uncertainties. This will be especially important in regions, such as the continental U.S., where over half of the annual carbon sequestration occurs in ecosystems with hilly or mountainous terrain. We describe an experiment that utilized multiple flux towers at a single site with complex terrain in the Rocky Mountains of Colorado to measure components of the local CO_2 budget that often confound accurate measurements of NEE. Using a five-year record of continuous NEE measurements, we show that the magnitude of the uncertainty in the NEE measurement is high, and that the cause of the high uncertainty is nighttime drainage of cold air, which preferentially carries respired CO_2 to the lowest positions on the topographic relief.

In order to detect and quantify advective fluxes in the horizontal and vertical dimensions, we deployed a set of seven flux towers within a radius of approximately 300 m at the Niwot Ridge Ameriflux site in the Front Range of the Rocky Mountains. On each tower we mounted sonic anemometers to measure the vertical profile of the mean wind speed, and inlets for drawing air to infrared CO_2 analyzers to measure the vertical profile of the mean CO_2 concentration. Horizontal and vertical advective CO_2 fluxes during the summer growing season were inversely correlated with surface friction velocity (u*) below an upper limit, indicating that the advective fluxes were of the greatest magnitude and most frequent when the atmosphere was relatively stable as occurs during nighttime periods. Over a five-year record of eddy covariance measurements at our Niwot Ridge Ameriflux site, we found that 30% of the nighttime flux averaging periods required correction due to stable atmospheric conditions. When measured horizontal and vertical advective fluxes were used to correct this data record, the estimated five-year cumulative NEE reflected a 38% increase in net ecosystem CO_2 uptake. Because of the opposite directions of the CO_2 concentration gradient in the vertical and downslope horizontal coordinates, the respective advective fluxes were calculated with opposite mathematical signs; this caused the fluxes to mutually cancel part of their influence on the overall NEE correction. Very large errors in the estimated five-year NEE occurred if only one flux or the other was considered alone.

We released SF_6 tracer upslope from the primary measurement tower during two separate two-week campaigns (during the summers of 2001 and 2002). Measurements of SF_6 dispersion downslope from the tower during the evening hours revealed the presence of the drainage flows and informed us about their general structure. The air flow exhibited only slight upward mixing as it moved downslope. The plume vertical diffusion coefficients were relatively small and varied from 2 to 4 m at 50-m downwind and 3 to 6 m at 200-m downwind from the SF_6 source. These results reveal the nature of the drainage flows to be thin layers of air that move close to the ground as they carry respired CO_2 downslope, beneath the tower flux sensors.

Horizontal dispersion of the air flows appeared to be biased toward the lowest point on the local topography. We used data from vertical profiles of CO_2 concentration from the four main towers, and three additional towers, to reconstruct the spatial divergence in the mean CO_2 concentration across the flux footprint of the site. There are clear downslope gradients in mean CO_2 concentration, especially during the night, when soil-respired CO_2 flows differentially to the lowest points of the terrain. It is these CO_2 gradients that confound the assumptions of the eddy covariance approach and cause the large uncertainties in measured NEE. It is possible that water channels and dry channels formed by past hydrological erosion form a network of low relief that carries nighttime air drainage and its associated respired CO_2 downslope, and off areas of high topographic relief during stable nights.

Our results represent the first comprehensive assessment of observational uncertainties in net ecosystem CO_2 exchange due to the effects of complex terrain. Most of the 200 sites in the current global Fluxnet network are located on sites with non-ideal terrain; this must be expected as the eddy covariance approach is progressively more frequently applied to natural ecosystems, rather than the simpler agricultural ecosystems for which it was originally developed. Regional and global CO_2 budgets are inherently dependent on measurement networks of NEE to provide observational constraint on models and inventory procedures. The uncertainties in these observational constraints must be carried into the uncertainties of the carbon budgets themselves. Clearly, complex terrain can induce atmospheric flows and mean CO_2 concentration gradients that are not normally accounted for in regional budgets. Native forest ecosystems often occur in hilly or mountainous terrain and it these ecosystems that often reflect the principal carbon sinks in a region and those most in need of accurate accounting during the measurement of NEE.