A virtual tall tower network for understanding continental sources and sinks of CO2

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09/15/2003 – 09/14/2006

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Final Report for DE-FG02- 03ER63654

Introduction

Lack of continental mixing ratio data is a primary limit to our ability to infer continental sources and sinks of CO_2 via atmospheric inversions. The project examines the hypothesis that relatively low-cost, well-calibrated CO_2 mixing ratio measurements, deployed on existing flux towers, will substantially improve our ability to determine sources and sinks of CO_2 from North American terrestrial ecosystems. Both the accuracy of estimates of the net annual North American carbon balance and the spatial resolution of these estimates will be improved. These overarching hypotheses cannot be addressed by this project alone. This project, however, represents an essential contribution to these broader goals. In particular, this project aims to establish the network of well-calibrated CO_2 mixing ratio measurements utilizing a subset of the AmeriFlux towers. Further, we hypothesize that the value of the mixing ratio data will be enhanced by collocation with flux measurements, serving to regionalize the flux data and encourage the integration of flux measurements into continental-scale carbon budget analyses.

Approach

The overall approach of this project was to build, deploy, and maintain well-calibrated mixing ratio measurement systems at selected AmeriFlux sites, as well as to assist sites with independent funding in the installation of their own well-calibrated measurements. A micrometeorological correction will be applied to data to correct for the small offset between surface layer and mid-continental boundary layer mixing ratios. These sites will be used in concert with the NOAA-CMDL tall tower network, also under development, to determine the North American carbon balance via atmospheric inversions to much greater precision than is currently possible. The project did not support the atmospheric inversions, but did support the effort to establish and document an AmeriFlux CO_2 mixing ratio database of sufficient quality to be incorporated into Globalview CO_2.

Related results

Miles et al (in preparation) report on the development of low-cost, high accuracy and high precision CO_2 sensors needed to determine the carbon balance of terrestrial regions at higher spatial and temporal resolution than has been possible in the past. A short-term regional network of measurements was deployed in northern Wisconsin for several months in 2004 as a proof-of-concept. The regional measurements were successful, and shown to be accurate and precise to about +/- 0.3 ppm, sufficient to resolve regional gradients in CO_2 concentration caused by daily to seasonal ecosystem carbon exchange. Analyses of these data to infer the terrestrial carbon balance of this region is being conducted at Colorado State University. Final results are pending, but suggest that this approach will successfully measure the carbon balance of a large (roughly 200 x 200 km^2) region with unprecedented accuracy.

Results

The measurement system used in this experiment is based upon that deployed in Wisconsin in 2004, and was improved via collaboration with Britt Stephens at the National Center for Atmospheric Research. A schematic of the measurement system is shown in Figure 1. While accuracy and precison are very important to this study, fast time response of the CO_2 mixing ratio sensor is not required. The single-cell LI-820 sensor was chosen based on its relatively low cost compared to the two-cell LI-7000. Although peak-to-peak noise larger for the LI-820 than the LI-7000, the noise can be reduced sufficiently by averaging for 2–5 min because tests showed that the noise is random.

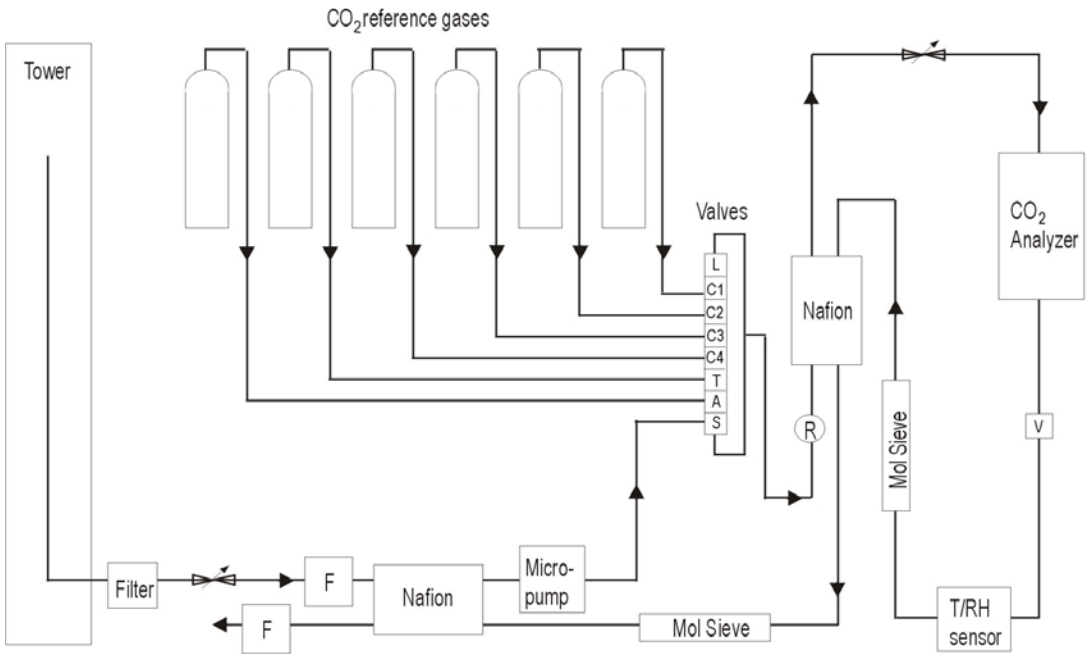

Figure 1. A schematic of the CO_2 mixing ratio measurement system.

Our group has deployed five of these measurement systems at AmeriFlux towers spread across the United States (Canaan Valley, WV; Chestnut Ridge, TN; Fort Peck, MT; Ozark, MO; Park Falls, WI). We have also supported the instrumentation of at least three additional AmeriFlux sites (University of Nebraska-Lincoln, Indiana University, Oregon State University) via technical advice to the site principal investigators, ranging from instrument construction to hosting visits from site technical staff. A map of well-calibrated CO_2 concentration measurements operational as of March 2007, as well as additional sites planned in conjunction with the North American Carbon Program MidContinent Intensive beginning spring 2007, is shown in Figure 2.

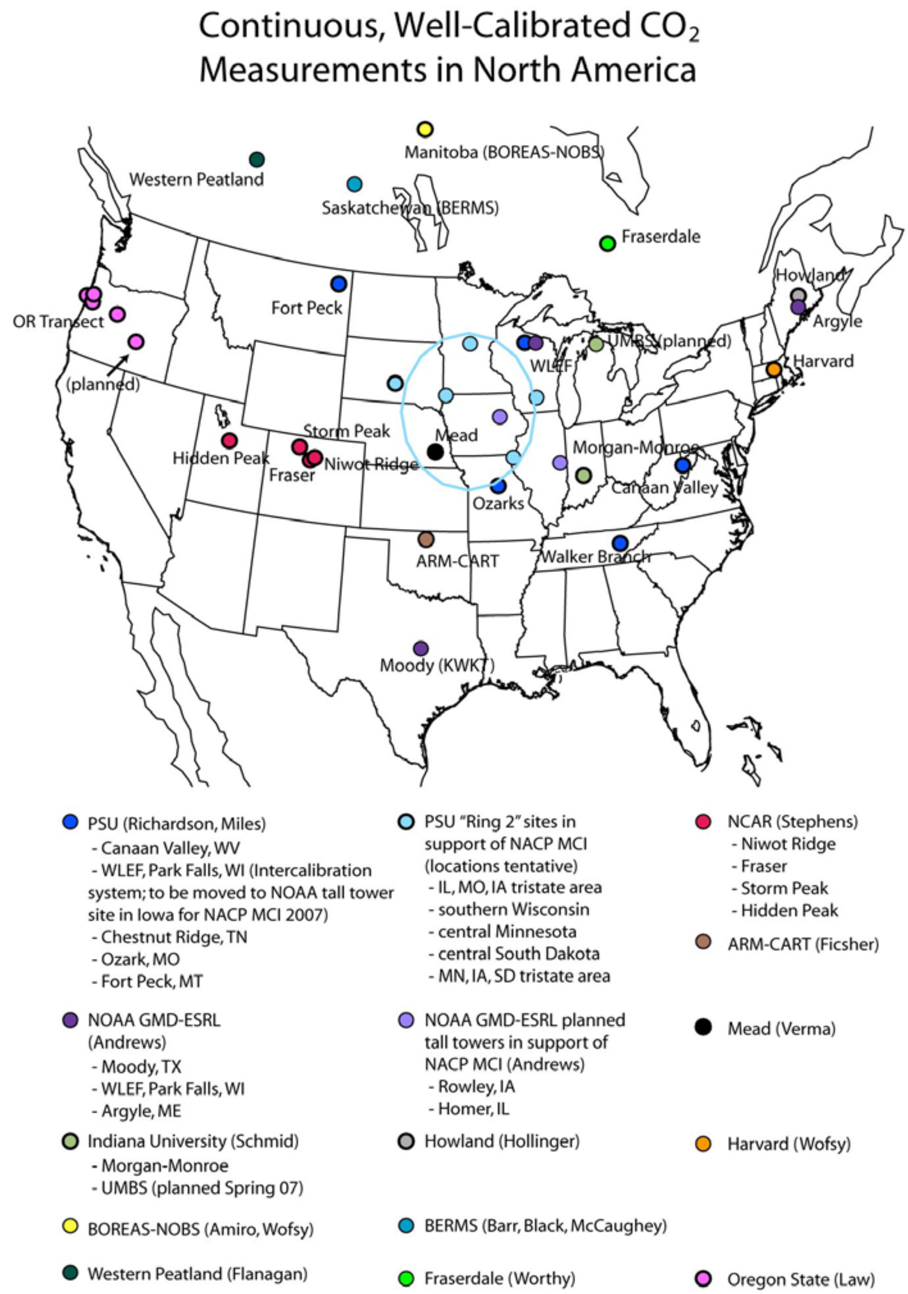

Figure 2. Map of well-calibrated CO_2 concentration measurements online as of March 2007, as well as additional sites planned in conjunction with the North American Carbon Program MidContinent Intensive beginning April 2007.

A website, www.amerifluxco2.psu.edu (Figure 3) was developed, describing the network of five high-precision, high-accuracy sites, including site details, examples of data quality, parts list, schematic, hints on construction, set-up, and maintenance, and intercalibration plans. Finally our group has begun to assemble a data base for these continuous observations of atmospheric CO_2 and VTT-adjusted values that will be made available to the scientific community.

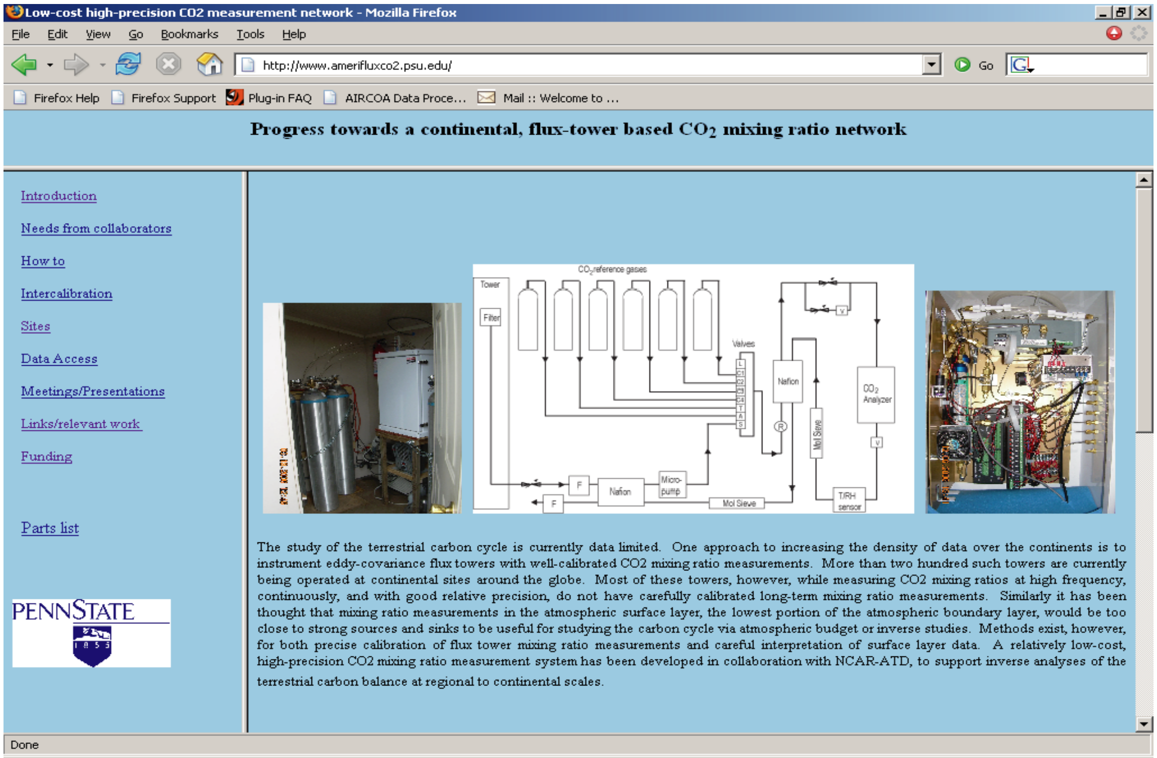

Figure 3. Front page of the website www.amerifluxco2.psu.edu which describes the network of five high-precision, high-accuracy sites, including site details, examples of data quality, parts list, schematic, hints on construction, set-up, and maintenance, and intercalibration plans.

Applications

One way to utilize the continental atmospheric CO_2 observational network data is through the Virtual Tall Tower (VTT) approach. Careful interpretation of surface layer data via this method allows cost-effective surface layer tower measurements to be used in atmospheric inversions that have low resolution in the surface layer. We sub-sample for midday, well-mixed conditions, and use mixed layer similarity theory to estimate the tall tower (396 m) CO_2 mixing ratio given the mixing ratio at a typical flux tower height (30m). The adjustment algorithm requires input data readily available at flux towers: displacement height and tower top CO_2 mixing ratio, CO_2 flux, sensible heat flux, and temperature. We calculate for 3-6 mid-day hours depending on the time of year, and screen for minimum sensible heat flux, boundary layer depth, and convective velocity scale. The magnitude of the VTT adjustment from a surface layer measurement to a tall tower (396 m) value depends on season, as shown in the below table for 6 years of data at WLEF. The bias, or the difference between the VTT-adjusted value and the actual measured value, is relatively small for spring, summer, and fall. For comparison, the average estimated uncertainty for 76-m NOAA-ESRL [CO_2] during May-August 2004 was 0.29 ppm (Andrews, personal communication).

	Spring	Summer	Fall	Winter
Adjustment (ppm)	0.13	0.98	0.38	-0.05
Bias (ppm)	-0.03	-0.16	0.04	0.43

Table 1. Seasonal values of the adjustment between the CO_2 concentration at 30 m and that at 396 m, and the difference between the 396-m concentration estimated from the 30-m concentration and the concentration actually measured at 396 m.

Plans for NACP's Mid Continent Intensive Regional Experiment

A second regional network of CO_2 concentration measurements will be deployed in the upper Midwest, more focused on the corn belt, for a period of approximately 18 months in support of the NACP's Midcontinent Intensive regional experiment. This deployment is expected to begin in the spring of 2007, and analyses will be conducted both at Penn State and Colorado State University. Data will be made open to the scientific community. This regional network will be used to test how well the planned long-term observing network (NOAA tall towers and well-calibrated CO_2 concentration measurements at a subset of AmeriFlux towers) is able to determine the carbon balance of this region, or if additional observations will be needed.

Summary

Our understanding of the North American terrestrial carbon cycle is limited by both a lack of continental atmospheric CO2 data, and by a need for methods to interpret these and other continental data with confidence. In response to this challenge a rapid expansion of the N. American carbon cycle observational network is underway. This expansion includes a network of continuous, continental CO2 mixing ratio observations being collected at a subset of AmeriFlux towers. Progress in developing this resource includes instrument development, site installation, calibration and intercalibration efforts, and initiation of a uniform data product. Progess in applying these data include proposed methods for interpreting surface layer measurements in atmospheric inversions (the virtual tall towers approach), examination of coherence patterns in continental mixing ratios in response to weather and climate, and application of these mixing ratio measurements in formal atmospheric inversions. Future work will merge these methods with interpretation of flux towers observations of terrestrial carbon fluxes in an effort to create a single coherent diagnosis of North American terrestrial carbon fluxes over a multi-year period.

Publications

A manuscript describing results from the Wisconsin 2004 regional network, "Demonstration of a high-precision, high-accuracy CO_2 concentration measurement network for regional atmospheric inversions" (Miles, N.L., Richardson, S.J., Davis, K.J., Desai, A.R., Uliasz, M., and Denning, A.S.), is in preparation and will be submitted to the Journal of Atmospheric and Oceanic Technology. A poster, "Well-calibrated CO2 observations on AmeriFlux towers to constrain the North American CO2 budget: A contribution to the continental atmospheric CO2 observational network" was presented at the U.S. North American Carbon Program investigators meeting (2007 in Colorado Springs, CO).