Landuse Impacts on Belowground Carbon Turnover and Ecosystem CO2 Source Attribution Using Radiocarbon

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Project Description

Introduction

Forests represent a significant component of the terrestrial carbon pool of the United States and North America. Forest sequestration of carbon currently offsets in excess of 10% of US CO_2 emissions (Woodbury et al., 2007). How the net uptake of atmospheric CO_2 concentration by forests will respond to future changes in climate and land-use is not well understood. Thus the response of the terrestrial-biosphere and its feedback on atmospheric pCO_2 is a significant uncertainty in coupled carbon-climate models.

Soil respiration (R_S) is a significant flux of terrestrial CO_2 to the atmosphere and is a substantial component of total ecosystem respiration (R_E) (Raisch 2002; Cox 2000). Across deciduous broadleaf forests, variations in R_S explain much of the spatial and inter-annual variability in net ecosystem exchange (NEE) (Yuan et al., 2009). R_S is likely to be influenced by climate and land-use change, but prediction of future changes is challenged by difficulty in modeling fluxes over space and time.

The factors that are incorporated in modeling of R_S include temperature, moisture, and C substrate availability (Davidson et al 2006). The development of robust process-based models of R_S, to improve upon these empirical factor control models, has been difficult. One challenge is that R_S includes CO_2 released via autotrophic (root) respiration and heterotrophic (microbial) respiration, very different processes that respond to temperature and moisture differently, and are thus likely to respond differently to future changes in climate and ecosystem characteristics. In addition, changes in climate or land-use that favor microbial activity may change C sources used by microbes. For example, warmer temperatures or ecosystem disturbance may cause microbes to shift from labile soil C pools dominated by recent plant litter inputs towards a greater use of more stable soil C pools (through a process commonly referred to as priming) (Sulzman et al., 2005; Diochon and Kellman, 2008), carbon conventionally thought to be sequestered for multiple decades to centuries and millennia.

Project Plan

Our goal is to determine the short-term, interannual, effects of land-use/land management on R_E and R_S fluxes in a mature northern hardwood forest and to attribute changes in the regional biosphere signal of atmospheric $^{14}CO_2$ to this disturbance using ^{14}C as an isotopic tracer. Net ecosystem respiration integrates microbial (heterotrophic) and plant (autotrophic) respiration. Eddy covariance methods can be used to estimate bulk CO_2 fluxes but they cannot discriminate process nor C source of respired CO_2. It is these processes, which are parameterized in predictive models and may change with future climate and land-use change that our observations will directly address.

We will compare observations of ^{14}C in CO_2 fluxes and soil organic matter pools of varying turnover time made before and after selective harvest for a well studied region to determine which belowground carbon pools contribute to changes in overall ecosystem C storage and flux following management induced disturbance. We will then relate ecosystem-level respiration and $^{14}CO_2$ to regional patterns of $^{14}CO_2$. Our objectives and corresponding hypotheses are:

Objective 1: Partition C sources to CO_2 loss via R_E and R_S in northern hardwood forest before and after selective harvest.

Hypothesis 1): Disturbance will cause a shift C sources for ecosystem and soil respiration. More specifically, disturbance will cause a shift in C sources used by microbes from primarily labile pools toward increased use of stable soil C.

Objective 2: Determine the relationship between plot-level, ecosystem-level, and regional CO_2 fluxes

Hypothesis 2): Plot-level differences in respiration rates and C sources will be detected at ecosystem and regional scales.

Study Area

We propose to take advantage of a planned forest harvest scheduled for early 2012 in a well-studied and instrumented region of northern Wisconsin. The 160 km^2 study area is part of a multi-organizational effort to study biosphere/atmosphere interactions in northern mixed forest. The area is well instrumented for micrometerology and includes several eddy-covariance towers, which are or have been part of the Ameriflux network, and a NOAA ESRL/GMD tall tower (WLEF). The selection harvest will occur in an 8 km^2 area under the footprint of the Willow Creek eddy-covariance tower (AmeriFlux site US-WCr), which lies under the footprint of the WLEF tall tower.

The harvest prescription and management goals are representative of management plans for the region. Trees will be selected for removal to accelerate forest transition from mid-successional even-aged mixed forest to uneven-aged northern hardwoods that mimic old-growth forest (a greater diversity of tree age and size and greater amounts of downed wood). This will include the removal of early successional tree species and creation of canopy gaps to provide better wildlife habitat, improve recreational activities, increase resilience to insect outbreaks, and promote diversity and stability. Harvest is scheduled for winter FY 2012, allowing for one year of pre-management measurements at Willow Creek. In addition, flux and micrometerological measurements are taken continuously at the nearby Park Falls (US-PFa) AmeriFlux site, making Park Falls an ideal control.

Ankur Desai and Erika Marin-Spiotta (University of Wisconsin-Madison) plan to measure ecosystem-level CO_2 fluxes at the Willow Creek tower and R_S before and after harvest (not supported by this project). We propose to add measurements of ^{14}C in R_E and R_S and in soil C pools that contribute to bulk R_S to be conducted at CAMS. These measurements will allow us to identify sources for C loss following disturbance and directly answer: Is it only 'young' labile pools that are actively respired following disturbance? Do other more recalcitrant pools of carbon become consumed? How much, if any, of the labile pool is transmuted into a longer-term storage pool? In addition, we propose to continue ^{14}C measurements of CO_2 collected at the WLEF NOAA tall tower nearby to allow for regional scaling.

Objective 1: Respiration Source Partitioning

Net ecosystem exchange of CO_2 is the balance between photosynthesis and R_E. R_E is a mixture of CO_2 respired by aboveground plant biomass and R_S (Figure 1). In turn, R_S is a mixture of root (autotrophic) respiration and microbial (heterotrophic) respiration.

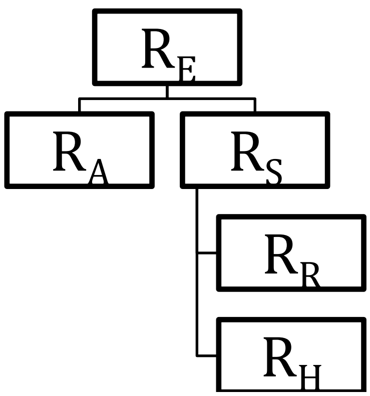

Figure 1. Schematic of Ecosystem and Soil Respiration component fluxes: R_E = ecosystem respiration, R_A = aboveground autotrophic respiration RS = soil respiration, R_R = root (autotrophic) respiration, R_H = heterotrophic (microbial) respiration

While respiration by plant roots and microbes combine to yield bulk R_S, the two component fluxes are driven by different processes. In order to better understand the mechanisms behind changes in R_S and consequent changes in R_E, it is necessary to separate CO_2 fluxes from roots and heterotrophic decomposition. Radiocarbon can be used to partition R_S fluxes into source components including separation of R_R from R_H (Carbone et al., 2008; Czimczik et al., 2006) and identification of C-sources for microbial decomposition (Czimczik and Trumbore, 2007). Source partitioning methods using natural abundance ^{14}C take advantage of the atmospheric $^{14}CO_2$ record, which includes a spike during the mid-20th century attributed to atmospheric nuclear weapons testing known as the bomb-curve and isotopic mixing models. Autotrophic respiration (R_A and R_R) has a $^{14}CO_2$ signature similar to the atmosphere as it is dominated by new photosynthate-C, while the ^{14}C signature of R_H reflects the C source(s) for microbial decomposition. Bulk R_S $\Delta^{14}C$ values result from the propotional mixing of R_R and $R_{H.}$

Canopy gap formation via selective harvest should increase soil temperature and moisture, changes that expected to increase R_H. However, these effects may be balanced by decreases in 1) R_A and R_R driven by decreased aboveground productivity or 2) R_H resulting from decreased plant C inputs. As a result of these interacting mechanisms, reported effects of selective harvest on R_S are inconsistent (e.g., Concilio *et al*., 2005; Peng and Thomas, 2006; Stoffel *et al*., 2010), but R_S is rarely separated into R_R and R_H in these studies and it is possible that in some cases heterotrophic responses were more or less important in determining overall flux than in others.

We will measure $\Delta^{14}CO_2$ from R_E and R_R before (FY11/12) and after (FY12/13) selective harvest. $\Delta^{14}CO_2$ of R_E will be measured every three days from the Willow Creek eddy-covariance tower during the three years of this project. R_S fluxes and $\Delta^{14}CO_2$ of R_S will be measured at five plots under the Willow Creek tower weekly from May through October to capture the majority of R_S.

To partition respiration fluxes using ^{14}C at Willow Creek we will measure isotopic end-members monthly from May through October. Partitioning of soil respiration between, for example, root and heterotrophic sources using ^{14}C requires that $\Delta^{14}CO_2$ of R_R and R_H be known. Because they may change seasonally, $\Delta^{14}CO_2$ of R_R and R_H will be determined monthly. $\Delta^{14}CO_2$ for R_R will be determined by field incubation of freshly collected roots (rinsed free of soil), collection of respired CO_2, and ^{14}C analysis of collected CO_2. The $\Delta^{14}CO_2$ of R_H will be attained by sampling CO_2 respired during soil laboratory incubation without the presence of live roots. To ensure no R_R will contribute to CO_2 evolved during incubation, soil samples are collected and refrigerated for at least one week prior to incubation to ensure that any live roots severed during sampling have died. All incubations will occur in the dark to ensure no respiration by photosynthesizing tissues or organisms occurs. After bulk fluxes have been measured and the $\Delta^{14}C$ values of total, root, and heterotrophic organic and mineral soil respiration have been determined, respiration sources are partitioned using an isotopic mass balance approach.

The same methodology can then be used to partition R_H provided the ^{14}C of different microbial C sources are also determined. We will use physical fractionation of soil organic matter pools by density to isolate soil organic matter pools of varying stability. $\Delta^{14}CO_2$ values of these fractions will verify the differences in turnover times between these pools and provide end-members for source partitioning of R_H before and after harvest. Because the $\Delta^{14}C$ values of these soil pools do not change on a seasonal timescale they will be determined annually.

Objective 1: Respiration Source Partitioning

$\Delta^{14}CO_2$ measurements of air sampled at the WLEF tower will be made every 3 days during the course of this study, same as for the Willow Creek eddy-covariance tower. CO_2 concentrations and $\Delta^{14}CO_2$ measured at WLEF will be compared to CO_2 flux and $\Delta^{14}CO_2$ measurements made at the Willow Creek tower to determine the influence of changes in ecosystem respiration and respired $^{14}CO_2$ at Willow Creek following on $^{14}CO_2$ measured at WLEF.

Deliverables and Timeline

All ^{14}C measurements will be done at CAMS and be accompanied by ^{13}C measurements to correct for mass-dependent fractionation, allow for any additional interpretation provided by the stable isotope, and provide a more complete data set for modeling of C cycling in the study area.

Because ^{14}C measurements are expensive, most researchers using ^{14}C to partition respiration fluxes are limited in the number of measurements they can make. As a result, measurements are often made over small spatial scales and short timescales. We are in a unique position to make the number of ^{14}C measurements required to examine the effects of land management on respiration fluxes over multiple years and seasons and to relate $^{14}CO_2$ released by soil to ecosystem level respiration and to regional fluxes with temporal resolution. As a result, we will generate data useful for C cycle modelers operating at multiple scales,

Research tasks and deliverables outlined above will be completed as described in the timeline shown in Table 1. Field sampling will begin as soon as possible after funds are received in FY2011. Preparation of manuscripts to peer-reviewed journals will begin as soon as initial results have been produced. Results will also be presented at several professional meetings, including several domestic and one international conference. Data generated by this research will be available to the scientific community through AmeriFlux data archives.

Table 1. Timeline of proposed tasks in all fiscal years by season (fall, winter, spring, summer).

Task	Description	FY2011				FY2012				FY2013			
		F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su
Treatment													
	Pre-Harvest	X	X	X	X	X	X						
	Post-Harvest							X	X	X	X	X	X
^{14}C Measurements and Data Analysis													
	WLEF regional	X	X	X	X	X	X	X	X	X	X	X	X
	Willow Creek R_E	X	X	X	X	X	X	X	X	X	X	X	X
	Willow Creek R_S			X	X			X	X			X	X
	R_R, R_H			X	X			X	X			X	X
Deliverables													
	Soil fractions	X				X				X			
	Conferences		X			X	X			X	X		
	Data Archive	X	X	X	X	X	X	X	X	X	X	X	X
	Publications			X	X	X	X	X	X	X	X	X	X

Management Plan

^{14}C has yet to be incorporated into terrestrial C cycle studies that can be directly related to regional-scale fluxes of CO_2. One reason for this is that extensive ^{14}Cmeasurements, which CAMS is uniquely equipped to make, are necessary and systematic studies desired by large-scale modelers are in their infancy. Another reason is the level of ^{14}C experience required for data analysis and interpretation.

Karis McFarlane, the lead-PI, will be responsible for experimental design, sample collection, preparation for ^{14}C analysis, and data analysis. In addition, she will coordinate research efforts with collaborators working at the study site (Dr. Desai and Dr. Marín-Spiotta). McFarlane will present results at professional meetings, ensure that data are available to the scientific community, and prepare manuscripts generated from this work for publication in peer-reviewed journals.

Tom Guilderson will provide necessary expertise in sample collection and preparation for ^{14}C analysis at CAMS. These tasks include the implementation of sample collection from the Willow Creek eddy-covariance tower and the construction and testing of molecular sieves for trapping of CO_2 in the field.

Brian LaFrachi is involved in NOAA's tall tower measurements program and will provide additional expertise in scaling ecosystem to regional fluxes.

Additionally, we intend to use this project to engage a new post-doctoral researcher with a background primarily in field and remote sensing based ecosystem respiration and secondarily biogeochemistry modeling. The intent is for this postdoc to reside in the Natural Carbon Group at CAMS but they will be encouraged to interact with scientists in the Atmospheric Sciences Group, including but not exclusively, PCMDI.

Strategic Alignment

This work addresses LLNL's Mission Focus Area: Energy Security and Regional Climate Change Impacts. Specifically, this research will make valuable contributions to the improved ability to predict Regional Climate Change by improving our understanding of terrestrial processes effecting regional biosphere/atmosphere C exchange. In addition, this work will provide insights into terrestrial sources and patterns of atmospheric ^{14}C that will allow us to better quantify background terrestrial biosphere CO_2 fluxes and thus more accurately independently assess fossil fuel CO_2 emissions.

In addition, this work lies within two ST&E Pillars: Measurements and Experimental Science and Fundamental Research in the Disciplines. Eddy-covariance measurements of biosphere/atmosphere C exchange by forests have proven useful in identifying differences among ecosystems and regions, but do not allow for the partitioning of ecosystem C that is required for the development and testing of robust C models. Radiocarbon is an invaluable tool for partitioning fluxes into source components, but access to the number of ^{14}C measurements required to demonstrate the large-scale utility is limited for most of the scientific community. Most PI's consider the endeavor too high-risk to include in grant proposals because the potential for high-payoff is balanced by the high cost of the number of measurements required. At LLNL, we have access to a world-class AMS facility and the experience required to design, implement, and interpret a study demonstrating this technique. Our measurements will add to fundamental terrestrial C cycle science. In addition, this work will demonstrate the utility of ^{14}C as an isotope tracer in terrestrial biogeochemistry, reducing the perceived risk in using grant funds for measurements. This work will encourage the greater scientific community to use and support the use of ^{14}C in process-level research and modeling to advance C cycle and climate science.

Summary

We propose to take advantage of a planned forest harvest in a heavily studied and instrumented region to demonstrate the capability for ^{14}C to allow for the detection of shifts in C source for forest soil and ecosystem respiration. We propose to use ^{14}C to partition sources of C for soil respiration before and after selective harvest and to scale changes in ecosystem C fluxes to regional fluxes. This research will contribute significantly to our ability to predict regional changes in climate, particularly with regards to terrestrial biosphere feedbacks to land-use and climate change. In addition, this work will provide necessary data for the incorporation of ^{14}C into coupled climate-carbon models and for improved quantification of background terrestrial biosphere CO_2 fluxes for fossil fuel emission verification efforts. This study will also provide a demonstration of the utility of ^{14}C in process-based terrestrial C cycle science and will provide data to be used in future grant proposals to carbon programs at multiple agencies.

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