Preface

In the summer of 2003, a workshop was held in Portsmouth, NH, to discuss land measurement techniques for the North American Carbon Program. Over 40 scientists representing government agencies, academia and nonprofit research organizations located in Canada, the US and Mexico participated. During the course of the workshop a number of topics were discussed, with an emphasis on the following:

- The need for an intermediate tier of carbon measurements. This level of study would be more extensive than state-level inventories of the US Forest Service Forest Inventory and Analysis Program, but less detailed than intensive ecosystem studies sites such as those in Long Term Ecological Research network. This tier would ideally provide a basis to link and scale remote sensing measurements and inventory data, and supply data required to parameterize existing models (see Wofsy and Harriss 2002, Denning et al. 2005).
- The design criteria that such a network of sites should meet. The network and sampling design should be standardized, but flexible enough to be applied across North America. The design also needs to be efficient enough to be implemented without the need for large field crews, yet robust enough to provide useful information. Finally, the spatial scale must permit easy linkage to remotely sensed data.
- The key variables that should be measured at each site, and the frequency of measurement. Considerations include contribution of the process or property to quantifying and understanding carbon cycling at the site, usefulness as a model input, and practicality of implementation.

During the workshop, the participants developed a list of candidate variables for measurement at landscape-scale carbon monitoring sites, with recommended measurement intervals. The list was compiled and participants were asked to rate each variable as high, medium, or low priority. Numerical scores were assigned to each importance category and the list was compiled. The entire variable list, in order from highest score to lowest, is given in Table 1. General comments on the variable and suggested measurement frequencies (as discussed during the workshop) are also included. Through further discussion the list was refined. Some variables were included with others, for instance, geographic coordinates are part of the site description section. Some, such as nitrous oxide flux, were not included due to a

Table 1 Variables in order of numerical ranking, highest to lowest. Rows enclosed by brackets had tied rankings

Variable	Comments	Frequency
Aboveground biomass		Annually + mortality
Coarse woody debris	By size class	Every 5 years
Litterfall		Monthly or biweekly
Site history	Land use; disturbance	Once; annual update
Foliar nitrogen		Annual; seasonal
Forest floor mass		Varies with site age
Temperature		Continuous
Stand age (site age)	Mixed age stands?	Update every 5 years
Soil carbon dioxide (CO_2) flux		Monthly; biweekly
Precipitation		Continuous
{Coarse root biomass	Live and dead	Improve allometric equations
Photon flux density}	Paired – below canopy, clearing	Continuous
Vegetation height	LIDAR application	Every 5 years
Dead wood decomposition	From known event?	Annual
Leaf area index (LAI)	Coordinate with canopy height	Annual or monthly; seasonal
Soil moisture		Hourly or daily
{Woody shrubs	Mass/area of crown vs. height	Every 5 years
Soil carbon: nitrogen ratio		Once
Carbon 14 soil incubation}	Expensive	Repeat every 5–10 years
Soil carbon stocks	To what depth?	Every 10 years
Net radiation		Continuous
Soil temperature		Hourly; daily
Branchfall	Include in litterfall section?	Varies by season
Specific gravity by species	Dead wood	Once; subsampled
Fine root biomass	Not practical to measure turnover	
Vapor pressure		Continuous
Litter decomposition		Once
% Canopy cover		Annual
Wood utilization	Where harvests occur	
Methane (CH_4) fluxes	Appropriate in forested wetlands	Weekly in wetlands
Dissolved organic carbon	Important in some ecosystems	Monthly or weekly
Nitrous oxide (N_2O) flux	If forest fertilization is used	Daily
Suspended sediment	How to relate to sample plots?	Monthly
Geographic coordinates	Part of site description	
Labile carbon		
Root allometry		
Litter moisture		

decision to focus on carbon. Other measurements were omitted for reasons of high cost, low priority, or limited applicability. The end result was a slightly smaller list of variables thought to capture the properties and processes of carbon cycling aboveground and belowground that would also provide the data necessary to link to remotely sensed information as well as existing process models.

Once the list was refined, workshop participants indicated the areas in which they had expertise. One of the desired outcomes from the workshop was a field manual focused specifically on landscape-scale carbon inventory and monitoring. In view of this objective, the variables were grouped into subsets, and writing teams were self-selected from the list of individuals with expertise in each area. The writing teams each had responsibility for a chapter of the manual; chapters covered one or more of the variables in Table 1. Each chapter team discussed available methods and recommended one; where alternate approaches may be necessary or appropriate those are included as well. In addition, for some variables, several levels of measurements may be described. In these cases there is a fundamental level for required implementation followed by one or more additional levels of measurement that may be applied if budgets allow or if site investigators require more detail. For the most comprehensive dataset, it is recommended that data on all of the variables included in the manual be taken. It is worth noting that while the suite of variables was chosen with the needs of flux modeling in mind, a flux tower is not a necessary component of a landscape-scale carbon monitoring installation.

This manual is intended to serve as a reference for scientists wishing to implement landscape-scale carbon measurements. As such, the level of detail is intermediate in nature; descriptions of procedures are not exhaustive, but include many references to supporting material. Each chapter generally includes background information, recommended methods, equipment needs, required calculations, and practical considerations; chapters vary in length and content since these decisions were left to the writing teams. Each chapter team has extensive field experience in their measurement area.

A smaller team met in Durham, NH, to discuss plot layout and design for the proposed network. Design considerations included: compatibility with existing nationwide forest inventory protocols in North America, practicality of installation in a variety of landscape types, suitability for conducting a wide range of measurements, and integration with measurements taken at other tiers in the North American Carbon Plan hierarchy. Chapter One provides a complete description of the rationale behind the landscape scale measurement tier as well as the plot design that was chosen during the layout and design meeting.

The opening part of the manual continues with Chapter Two, which outlines the information required for an adequate site description, and Chapter Three, Meteorological Measurements. From that point, the recommended landscape-scale carbon measurements are organized into the following parts: Aboveground Carbon Pools, Aboveground Carbon Fluxes, Belowground Carbon Pools and Fluxes, and Supplemental Variables for Carbon Cycle Modeling. Finally, a concluding part includes chapters on integrating field measurements with remote sensing data and flux measurements, and lessons learned from implementing the measurements at pilot sites with very different characteristics.

While this manual provides specific guidance on the installation of landscape-scale forest carbon monitoring sites in the framework of the North American Carbon Plan, it can also be used as a reference for those interested in various aspects of forest carbon inventory and monitoring. We expect that instruments and methods will continue to improve, but the fundamental techniques outlined in this volume should serve investigators well into the future.

Coeli M. Hoover
US Forest Service
Northern Research Station
Durham, NH 03824

Literature Cited

Denning S, Oren R, McGuire D, et al. (2005) Science Implementation Strategy for the North American Carbon Program. Report of the NACP Implementation Strategy Group of the U.S. Carbon Cycle Interagency Working Group. Washington, DC: U.S. Carbon Cycle Science Program. http://www.carboncyclescience.gov/docs.php

Wofsy SC, Harriss RC (2002) The North American Carbon Program (NACP). Report of the NACP Committee of the U.S. Interagency Carbon Cycle Science Program. Washington, DC: US Global Change Research Program. http://www.carboncyclescience.gov/docs.php

Coeli M. Hoover
Editor

Field Measurements for Forest Carbon Monitoring

A Landscape-Scale Approach

Springer