


# Carbon Accounting Issues and Challenges in the Circumpolar Boreal Forest

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The **International Model Forest Network (IMFN)** is a voluntary association of partners from around the world, using a shared approach to address the common goal of sustainable management of forested landscapes. The IMFN is based on an innovative approach that combines the social, cultural and economic needs of local communities with the long-term sustainability of forest landscapes.

## What is a Model Forest?

A model forest is both a geographic area and a specific partnership-based approach to sustainable forest management (SFM). Geographically, a model forest must encompass a land-base large enough to represent all of the forest's uses and values—it is a fully working landscape of forests and farms, protected areas, rivers, and towns.

A model forest is also a voluntary, partnership-based approach for moving collaboratively toward SFM. These partnerships fully represent the environmental, social and economic forces at play within the land-base. Three things are central to a model forest:

- A **landscape**: A large-scale geographic area representing the full range of its forest values—including environmental, social and economic values
- A fully inclusive **partnership** in which people who have an interest in their region's natural resources agree on a process for determining local sustainability priorities and goals, then work collaboratively—on the basis of transparency and consensus—to address them
- A shared effort to work toward **sustainability**: Focused on achieving SFM in tangible ways from the field level to the policy level, with stakeholders continually involved in developing, testing and sharing innovative approaches to SFM

## The IMFN Secretariat

The model forest approach was first brought to the world's attention at the 1992 United Nations Conference on Environment and Development (UNCED) where Canada promised to "internationalize" its national Model Forest Program. To support this effort, the International Model Forest Network Secretariat (IMFNS) was established in 1995. The role of the IMFNS is to facilitate the creation of a global network of model forests dedicated to managing the world's forest-based landscapes in a sustainable manner. The Secretariat provides the central day-to-day coordination of support and development services to the Network, works to strengthen and expand the Network and, at the site level where there is no regional network in place, supports new and existing model forests.

***The views contained within this document are those of the authors and do not necessarily represent the views of Natural Resources Canada–Canadian Forest Service, the International Model Forest Network, the International Model Forest Network Secretariat or the IMFN Circumboreal Initiative.***



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# Carbon Accounting Issues and Challenges in the Circumpolar Boreal Forest

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## 1. Introduction

There is global concern about the increasing effect of greenhouse gases on our climate and continuing scientific debate about the role of circumpolar boreal forests as a sink or source of atmospheric $CO_2$. The global Boreal forest is the second largest forest biome on Earth, occupying roughly 17% of the vegetated land surface. It circles the globe, just below the Arctic region and is found in Canada, Alaska, Russia, and Scandinavia. Forests in the boreal zone are an important part of the cultural and economic wealth of northern countries. As well, the Boreal forest plays an important role in the global carbon budget, The Boreal Forest stores 22 percent of the total carbon stored on the earth's land surface and almost twice as much carbon per unit area as tropical forests[1]. Its carbon budget is very dynamic in time and heterogeneous in space varying from a significant carbon source and sink over time ranging from annual to decadal to century scales.

The role of forests and forestry in the global carbon budget has become an important research and policy issue. The Kyoto Protocol[2] to the UN Framework on Climate Change Convention, agreed to in 1997 committed developed countries to limit their greenhouse gas (GHG) emissions in 2008–12 relative to their 1990 emissions. The Protocol recognizes the role of land use, land-use change and forestry (LULUCF) in contributing both sources and sinks to national greenhouse gas balances. It specifies that countries must identify those areas affected by afforestation, reforestation and deforestation since 1990, and then determine the carbon-stock changes (and non-$CO_2$ greenhouse gas emissions) on these areas during the first commitment period, from January 1, 2008 to December 31, 2012. For the first commitment period, Article 3.4 of the Protocol also provides countries with the option to include certain land-use and forestry activities in their national accounts of greenhouse gas sources and sinks. Countries choosing to include forest management in their greenhouse gas accounts for the first commitment period must identify areas subject to forest management and then account for carbon-stock changes (and non-$CO_2$ greenhouse gas emissions) on those areas during the commitment period.

Since, the inclusion of forest stocks and changes in stocks in the Kyoto Protocol boreal countries have directed considerable effort to develop the accounting and reporting infrastructure needed to comply with Kyoto reporting requirements and to provide the analytical capability to assess the consequences and opportunities arising from a decision to include or not include the managed forest in their national accounts. A number of issues and challenges have been faced in developing transparent and verifiable estimates of forest carbon stocks and changes in stocks. Although considerable progress has been made in developing the knowledge and technology needed a number of issues, challenges and opportunities remain.

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[1] R.T. Watson, I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verardo, and D.J. Dokken. 2000. Intergovernmental Panel on Climate Change Special Report. Summary for Policymakers: Land Use, Land-Use Change, and Forestry. IPCC Plenary XVI, Montreal, Canada. WMO & UNEP, Geneva.
[2] Kyoto Protocol website: http://unfccc.int/kyoto_protocol/items/2830.php

This paper briefly outlines the key issues affecting carbon accounting in the circumpolar boreal region, the key agencies involved in carbon accounting activities, and the major carbon accounting activities underway. This paper further identifies some major opportunities for addressing the challenges associated with developing transparent and verifiable estimates of forest carbon stocks and changes in stocks.

## 2. Strategic Questions

Several strategic questions and issues are related to the forest carbon cycle and its role in climate change. These include:

- What is the role of the circumpolar boreal forest in the global carbon cycle and climate change?
- What are the appropriate methods for the verifiable estimation of above- and below-ground forest sector C stocks and their changes over time, at a range of spatial scales
- What are the critical processes and factors (environmental, land use and land use change, disturbances) that contribute to changes in forest C stocks?
- How can forest management activities be adapted in a cost effective, environmentally sound, and socially acceptable manner, to increase carbon sequestration and stocks in forest?
- How will climate and global change affect the future circumpolar boreal forest carbon budget?

To address these questions boreal countries have undertaken a number of research and monitoring activities to develop the knowledge and ability to quantify forest carbon stocks and changes in stocks. The following section outlines the major activities undertaken or currently underway in Canada, Russia, Scandinavia, and the US (Alaska) to develop and put in place the carbon accounting infrastructure to comply with Kyoto reporting requirements.

## 3. Major Circumpolar Boreal Carbon Accounting Players and Activities

### 3.1 Canada

In Canada the major player in carbon accounting research and development is the Canadian Forest Service - Natural Resources Canada (CFS). Supporting the CFS through a number of collaborative arrangements and partnerships include provincial governments, universities, model forests, other federal departments and industry. The carbon budget/dynamics and carbon accounting research undertaken by the CFS can be broken into six major elements: large scale/national modeling; field measurements of forest carbon dynamics; soil carbon dynamics; natural disturbances; fertilization; and climate change and variability impacts.

Canada to meet its forest reporting requirements for both the UN Framework Convention on Climate Change and the Kyoto Protocol has put in place the National Forest Carbon Monitoring, Accounting and Reporting System (NFCMARS). The first NFCMARS National Inventory report covering the period 1990 to 2004 (NIR 2006) was completed in 2005[3]. In November 2007, the NFCMARS system (along with all other aspects of Canada's GHG reporting system) completed an international review and audit by the Expert Review Team (ERT) of the UNFCCC Secretariat. While the formal report has not yet been received, the ERT in their closing presentation commended Canada for the scientific achievements in developing a national forest carbon accounting systems that fully implements and meets the requirements specified in the IPCC Good Practice Guidance and the IPCC Reporting Guidelines documents[4].

CFS is leading the development of the system and in cooperation with provincial/territorial government agencies is overseeing its implementation. Supporting the development of NFCMARS is the university led

[3] Caren C. Dymond, Thomas White and Werner A. Kurz, 2007. Overview of Canada's National Forest Carbon Monitoring, Accounting and Reporting System and the National Inventory Report 2006 on Land-use, Land-use change and Forestry (in preparation)

[4] W. Kurz – personal communication

Canadian Carbon Program (CCP) involving university and government from across Canada. The following briefly outlines the major activities linked to NFCMARS and CCP

*3.1.1 The National Forest Carbon Monitoring, Accounting, and Reporting System[5] (NFCMARS)*
The NFCMARS is designed to estimate past changes, e.g. from 1990 to the present (monitoring), and to predict, given various assumptions, carbon-stock changes in the next two to three decades (projection). Other uses planned for the NFCMARS include:

- Meeting reporting requirements for the UNFCCC, Kyoto, criterion and indicators reporting under the Montreal Protocol, reporting to the FAO, and others;
- Improve stakeholder understanding of the role of Canada's forests in the global carbon cycle, and
- Help forest resource managers consider carbon in their forest-management activities.

The System incorporates information - such as forest inventories, temporary and permanent sample plots, statistics on fires and insects, and systems quantifying forest growth and yield - into a modelling framework designed to bring together the best available information and scientific understanding of the ecological processes involved in forest carbon cycling.

Key components of the System include the:

- Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3)[6], and the
- New National Forest Inventory (NFI)[7].

*3.1.1.1 Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3)*
Since, 2002 the CBM-CFS model has undergone extensive revisions to enable analyses at four spatial scales (national, provincial, forest management unit and stand) and in annual time steps. CBM-CFS3 and its supporting databases can be used to track carbon stocks, transfers between pools, and emissions and removals of carbon dioxide ($CO_2$), methane ($CH_4$), and carbon monoxide (CO). It can be used to assess carbon-stock changes between 1990 and the present, and to predict future carbon-stock changes based on scenarios of future disturbance rates and management actions.

The CBM-CFS model was used to undertake a risk assessment of Canada's decision on the election of forest management under Article 3.4 of the Kyoto Protocol. Modeling results played a key role in Canada's decision in 2006 not to include forest management in Kyoto Protocol reporting. To date Canada is the only country in the world that has conducted a quantitative risk assessment of this type. As well, estimates from the CBM-CFS modelling work have also been used in preparing Canada's forest carbon budget information to both the CCFM[8] and Montreal Process Criteria and Indicators of Sustainable forest management reports and a number of the CFS State of the Forest reports[9].

An operational version of the CBM-CFS3, developed for forest managers, was made available in 2004[10]. This version was developed in co-operation with Canada's Model Forest Network[11], and its partners in the provinces and forest industry[12] to empower forest managers and analysts to assess and evaluate the impacts of alternative management strategies on carbon stocks and stock changes. Two model forests,

[5] National Forest Carbon Monitoring, Accounting, and Reporting System (NFCMARS) website: http://carbon.cfs.nrcan.gc.ca/

[6] Carbon Budget Model of the Canadian Forest Sector (CBM-CFS) website: http//carbon.cfs.nrcan.gc.ca/cbm/index_e.html

[7] National Forest Inventory website: http://www.pfc.cfs.nrcan.gc.ca/monitoring/inventory/index_e.html

[8] Criteria and Indicators of Sustainable Forest Management in Canada – Key Trends and Conditions 2005. Canadian Council of Forest Ministers, website http://www.ccmf.org/ci/index_e.php

[9] State of Canada's Forest – Annual Report 2007. Natural Resources Canada – Canadian Forest Service, Ottawa, Ontario. pp. 28. website: http://canadaforests.nrcan.gc.ca/rpt#focus

[10] Kull S., W. Kurz, G.Rampley, E. Banfield, T. Schvatcheva, M Apps, 2004. Operational Scale Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) Beta USERS GUIDE. Canadian Forest Service, Northern Forestry Centre, Edmonton. *Ca*300 pages

[11] Canada's Model Forest Website: http://www.modelforest.net/

[12] Kull S., W. Kurz, G.Rampley, E. Banfield, T. Schvatcheva, M Apps, 2004. Operational Scale Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) Beta USERS GUIDE. Canadian Forest Service, Northern Forestry Centre, Edmonton. *Ca*300 pages

the Lake Abitibi Model Forest [13] and the Western Newfoundland Model Forest [14] were used as pilot sites for development and testing of the model. As development proceeded, other model forests and their partners from across Canada contributed to model development through beta-version testing. Copies of the model and user guide are now available and can be downloaded from the CFS website.

Since the models release the CFS in partnership with Canada's Model Forest Network has held 1 international and 6 national CBM-CFS3 Training Workshops across Canada, involving the forestry community; industry, academia, NGO's, First Nations, Model Forests, federal, provincial, state, and foreign government agencies, consulting firms, and research organizations[15]. Since its release the CBM-CFS3 software has been downloaded by 254 individuals: 80 in academic institutions, 28 in industrial forest companies, 10 in non-government organizations, 66 in forestry consulting companies, 11 in foreign governments, 40 in Canadian federal/provincial/First Nations agencies, 13 in research organizations, 3 in Model Forests, and 3 in the general public. Of those 254 downloaders, 49 attended the above noted training workshops[16]. The CBM-CFS modelling team is also working with scientists in the US (Alaska), Russia and Mexico who are using the model for analyses. Several publications and reports have been published by third parties on the results[17].

*3.1.1.2 National Forest Inventory*

The CFS compiles Canada's national forest inventory by collecting data from provincial, territorial and other forest management inventories. National inventories were compiled in 1981, 1986, 1991, and 2001. CanFI 2001 is the most recent inventory collected for Canada. Not all of the data in CanFI 2001 is up-to-date, and in some cases is more than 25 years old. About 20 per cent of the data submitted for CanFI 2001 was also used in CanFI 1991. Because of the differences between CanFI 1991 and CanFI 2001 the inventories cannot be compared in any meaningful way.

To enable tracking of changes over time a new design for Canada's NFI is being developed in cooperation with provincial and territorial governments. The new NFI will replace the current CanFI approach in 2009[18]

The new NFI allows for consistent reporting across the country on the extent and state of Canada's land base to establish a baseline of where the forest resources are and how they are changing over time. The core design elements include[19]:

- A network of ground and photo sampling points covering across Canada covering 1% of the land mass area. (The NFI sample protocol is based on a grid covering all of Canada's land area. Large plots (2 × 2 km) will be established at grid intersections (20 × 20 km) and their characteristics will be recorded from either aerial photographs or remote sensing);
- Stratification of the sampling points by terrestrial ecozone with varying sampling intensity among the strata so that each ecozone is adequately sampled for statistical reliability;
- Estimation of area and other attributes from remote-sensing sources (photo plots) for consistency, timeliness and to reduce cost;
- Integration of data from ground measurements, interpretation of aerial photography, and classification of satellite imagery;
- Estimation of species diversity, wood volumes, and other desired data from a ground-based sub sample for attributes not available from photo plots;
- Estimation of change from repeated measurements of sampling points—all plots are to be remeasured at regular intervals. Photo-plots will be re-inventoried at 5-year intervals while re-measurements of ground-plots are scheduled at 10-year intervals.

[13] Lake Abitibi Model Forest Website: http://www.lamf.net

[14] Western Newfoundland Model Forest website: http://www.wnmf.com

[15] S. Kull, CFS Pacific Forest Centre – personal communication.

[16] S. Kull, CFS Pacific Forest Centre – personal communication.

[17] S. Kull, CFS Pacific Forest Centre – personal communication.

[18] Canada's National Forest Inventory Business Report – Fiscal Year 2006-07, March 31, 2007. Canada's National Forest Inventory website: https://nfi.nfis.org/reporting/business/NFI_Business_Report_2006-07.pdf

[19] Canada's National Forest Inventory website: https://nfi.nfis.org/about_nfi/index_e.shtml

Remote sensing of forest area and its characteristics plays an important role in Canada's forest carbon accounting system. Major activities involving remote sensing include:

- Development of a high resolution(30 m pixels, Landsat 7) forest-cover map of Canada for the year 2000 ( this was done in collaboration between CFS and the Canadian Space Agency);
- Detection of forest changes (such as harvesting, wildfire and insect impacts) and land-use change. ( Developing and maintaining a database on land-use changes (afforestation, reforestation and deforestation) for Canada, as required under Article 3.3 of the Kyoto Protocol, is a major initiative involving close cooperation of Natural Resources Canada/Canadian Forest Service, Environment Canada, Agriculture and Agri-Food Canada, Statistics Canada and resource-management agencies in provinces and territories. Detection and estimating area disturbed by fire and insects is being undertaken in collaboration with provincial and territorial resource management agencies).

The new NFI ground plot guidelines have been adopted by other government and university research agencies. Fluxnet-Canada/Canadian Canada Program adopted the guidelines in 2003 as the standard protocol to measure C stocks and changes. The comparison of ground plot C stock changes against site level flux tower and model estimates of cumulative net ecosystem C exchange is a key objective of the Fluxnet-Canada/CCP research network. CFS and university scientist involved in the Fluxnet Canada/ Canadian Carbon Program (CCP) have collaborated in developing and testing a number of the NFI measurement and collection protocols.

*3.1.1.3 Ongoing NFCMARS Improvements:*
Over the period 2006-2009 research and development activities to improve the NFCMARS include:

**CBM-CFS3 improvements**:

- Assessing the sensitivity of the dead-organic matter sub-module of the operational scale version of the CBM-CFS3 to variation in model parameters. Work to improve our understanding of how uncertainty in data and model parameters interact is ongoing;
- Improved quantification of the area of managed forest and improved inventory data;
- Quantifying land-use change at 1 ha resolution over very large areas;
- Accounting for forest management impacts on dead organic matter and improving the response of DOM dynamics to climatic variables. (In 2004 and 2005, a network of sample plots on afforestation sites was installed in order to improve understanding of the carbon stock changes following the conversion of non-forest lands to forest lands. This information is also being used to improve predictions of carbon stock change in Dead Organic Matter (DOM) and Soil Organic Matter pools on lands converted to forest land in subsequent reports.);
- Improving emissions estimates from fire and insect disturbances (for example, the impacts of mountain pine beetle in the CBM-CFS3 are being changed between NIR 2007 & NIR 2008 based on reviews with local entomologists and validation against a mountain pine beetle population model.);
- Estimating C stock changes in forested wetlands;
- Incorporating between-year variability and long-term climate effects (To explore the impacts of inter-annual climate variability a new CFS/University of British Columbia collaborative research project, known as Process-model Simulation of Landscape-Level Carbon Dynamics, has been initiated between staff at the CFS Pacific Forest Centre and University of British Columbia's Department of Forest Resource Management. The project is assessing the effects of climate variation on annual net carbon fluxes by applying the process-based, physiological, forest-stand model (3-PG) to the prediction of carbon dynamics to a small research area in BC.
- Removing indirect and natural effects.

Current ongoing CBM-CFS3 related projects include[20]: uncertainty analysis, the Afforestation impacts projects, the Forest Ecosystem Carbon Database (FECD) comparison, the Canadian Wildland Fire

[20] Caren C. Dymond, Thomas White and Werner A. Kurz, 2007. Overview of Canada's National Forest Carbon Monitoring, Accounting and Reporting System and the National Inventory Report 2006 on Land-use, Land-use change and Forestry (in preparation)

Information Systems project, the Fluxnet comparison, the spatially explicit modeling study, and an assessment of the effects of interannual-variability in growth rates.

**NFI Improvements**:
As part of the ongoing improvement of the NFI a number of pilot projects are ongoing to:

- Evaluate various measurement protocols,
- Test the database and tools for data handling,
- Test the reporting tools; and
- Determine the cost for the ongoing measurement program.

*3.1.2 Canadian Carbon Program (CCP)* [21]
The Canadian Carbon Program, led by the Université Laval, is a national research network bringing scientists together across Canada from 17 universities, 2 federal and 2 provincial ministries and 1 national park. CCP is a follow-on program to BOREAS[22]/BERMS[23]/Fluxnet-Canada[24] that began in the early 1990s.

The CCP aims to improve the estimation of the carbon budget of Canada at monthly to multi-annual time scales through a coordinated program of measurements and modeling. There are four major components to the CCP network:

- High-Precision Atmospheric Greenhouse Gas Concentration and Related Isotope Measurements In collaboration with Environment Canada, measurements of atmospheric $CO_2$, carbon monoxide (CO) and methane ($CH_4$) are being taken over three different forests in Canada: Chibougamau (Québec) in eastern Canada, Prince Albert (Saskatchewan) in central Canada and Lac Labiche (Alberta) in Western Canada. These measurements will help reduce the uncertainly in the modelling of carbon budgets at regional, national and continental scales.
- Ecosystem Fluxes: Measurements of carbon, water and energy exchange in forest and peatland ecosystems in six different provinces are being undertaken at more than 20 sites, in order to cover several of Canada's major plant functional types. These measurements will lead a greater understanding of the effects of climate on carbon sources and sinks and the dynamics of carbon cycling in young and intermediate-aged forests as well as peat lands.
- Regional, National and Continental Scale Modeling of Carbon Sources and Sinks: A modeling framework is being developed that will serve as the scientific foundation for an integrated carbon monitoring and prediction system for Canada and North America.
- Process Modeling to Support Forest carbon Accounting and Carbon Management: Information on the impact of disturbance and climate on forest growth is being provided for integration into the CBM-CFS3 model, which forms the core module of Canada's National Forest Carbon Monitoring, Accounting and Reporting System (NFCMARS).

The CCP, like BOREAS/BERMS/Fluxnet-Canada before it is part of the International Fluxnet Project[25] a world wide network of over 140 flux tower sites in North, Central and South America, Europe, Scandinavia, Siberia, Asia, and Africa that use eddy covariance methods to measure the exchanges of carbon dioxide between terrestrial ecosystems and the atmosphere. The broader effort of the Fluxnet Project is to understand, monitor and model the global terrestrial carbon balance[26].

**3.2. Russia**
In Russia the major scientific program linked to carbon accounting is the on-going *State Program on Global Change of Climate and Environment* involving several Russian research institutions (many

[21] Canadian Carbon Program Website: http://www.fluxnet-canada.ca/home.php?page=home

[22] BOREAS website: http://daac.ornl.gov/BOREAS/bhs/Papers.html

[23] BERMS website: http://berms.ccrp.ec.gc.ca/Overview/e-overview-about.htm

[24] Fluxnet-Canada website: http://www.fluxnet-canada.ca/home.php?page=home

[25] International Fluxnet Project Website: http://www.fluxnet.ornl.gov/fluxnet/overview.cfm

[26] Canadian Carbon Program Website: http://www.fluxnet-canada.ca/home.php?page=home

belonging to the Russian Academy of Sciences). Key Russian research institutes involved in multi-year studies of terrestrial carbon include:

- Institute of Forest, Siberian Branch of the Russian Academy of Sciences, Krasnoyarsk (Dr. A. Onuchin, Director);
- Siberian Federal University, Krasnoyarsk, Acad. (E. Vaganov, Rector);
- Institute of Biological Problems of the Cryolitozone, Siberian Branch of the Russian Academy of Sciences, Yakutsk, (Dr. T. Maximov, Head of Department);
- Far Eastern Forestry Research Institute, Ministry of Natural Resources of the RF, Khabarovsk, (Dr. D. Efremov, Head of Department);
- Dokuchaev Soil Institute, Russian Academy of Agricultural Science, Moscow, (Prof. V. Rozhkov);
- Saint-Petersburg Forestry Research Institute, Saint Petersburg, (Dr. B. Romanjuk, Head of Department).

The Far Eastern and Saint Petersburg Institutes are heavily involved in activities of two model forests (in Pskov *oblast'* and Khabarovsk *kray*).

As well, carbon accounting research in Russia is being undertaken by several international agencies including: the International Institute for Applied Systems Analysis (IIASA) (Austria)[27], the Max Plank Institute for Biogeochemistry (Germany), the National Institute for Environment Studies, (Japan), and the Woods Hole Research Centre[28] (WHRC) -Oregon State University (OSU)-NASA (US).

The Forestry Program (FOR) of the International Institute for Applied Systems Analysis together with a number of Russian and Western institutions for many years has been providing research on development of a Terrestrial Biota Full Carbon (and Full Greenhouse Gas) Account (FGGA) for Russian forests. The first report was published in 2000[29]. The FOR program has developed a wide network of Russian collaborators on the topic. A new FGGA for Russia using new methodologies and advanced information is currently being worked on.

The Max Plank Institute for Biogeochemistry (Jena, Germany) as part of the CarboEurope project in collaboration with the Institute of Forest (Krasnoyrask) has installed a super tall tower for measurements of carbon fluxes (Prof. D. Schulze, Prof M. Heimann). This team provides diverse ecological measurements.

The National Institute for Environment Studies, Tsukuba, Japan (Dr. S. Maxyutov, Dr. Y. Yamagata) together with the Institute of Atmospheric Optics SD RAS is providing measurements of atmospheric composition of carbon contained gases and aerosols.

The Woods Hole Research Centre (R. Houghton**,** *David Butman, Tom Stone and Peter Schlesinger*), Oregon State University (O. Krankina) in collaboration with NASA and Russian colleagues, maintain a land use and land cover database for Russian land management**.** WHRC and OSU are currently involved with the Land Cover and Land Use Change program at NASA trying to quantify and develop carbon accounting models for these forests. As well, R. Birdsey, US-Forest Service is a co-operator with Vladislav Alexeev of the Saint-Petersburg Forest Ecological Center and the Sukachev Institute of the Russian Academy of Sciences in a project to estimate the Russian carbon budget.

In terms of ongoing multinational collaborative activities in Russia there are two large field measurement and modeling programs underway looking at the carbon budget of Russian forest ecosystems: SIBERIA-II and TCOS SIBERIA:

[27] IIASA Forestry Program website: http://www.iiasa.ac.at/Research/FOR/index.html?sb=1

[28] Woods Hole Reseach Centre website: http://www.whrc.org/russia/index.htm

[29] Nilsson, S., Shvidenko, A., Stolbovoi, V., Gluck, M., Jonas, M., and Obersteiner, M. 2000. Full Carbon Account for Russia. Laxenburg: IIASA, Interim Report IR-00-021, 180 p.

*3.2.1 SIBERIA II*[30]

SIBERIA-II is a large multinational project investigating the greenhouse gas budget and its interactions with climate change in the Eurosiberian region. The project led by Friedrich-Schiller-University Jena Institute of Geography Department of Geoinformatics, Jena, Germany, involves a consortium of 14 agencies from 7 European countries The overall objective of SIBERIA II is to demonstrate the viability of full carbon accounting (including Greenhouse Gases (GHG's): CO2, CO, CH4, N2O, $NO_x$) on a regional basis. The 3.28 million km² project study area covers the steppe and tundra biomes between 52-72 degrees North latitude and 88-110 degrees East longitude The project uses data collected from remote sensing and detailed data bases of local information dynamic vegetation models to account for carbon fluxes between the land and atmosphere. The overall objective is to develop a combined monitoring system to provide estimates of carbon sources, sinks and pools at multiple spatial and temporal scales. Russian agencies involved in the project include: the Sukachev Institute of Forestry, Siberian Branch of the Russian Academy of Sciences, the Irkutsk Regional Forest Management Service, and the Dokuchaev Soil Institute.

*3.2.2 Terrestrial Carbon Observation System Siberia (TCOS SIBERIA)*[31]

**TCOS SIBERIA** project which has been completed was part of the much larger CarboEurope project[32]. TCOS SIBERIA led by Martin Heimann, Max Planc Institute for Biogeochemistry (Germany) involved 11 agencies from 7 European countries. Russian agencies involved included: the Severtzov's Institute of Evolution and Ecology Problem (Russian Academy of Sciences), the Sukaschev's Laboratory of Biogeocenology (Moscow); the V.N. Sukachev Institute of Forestry (Siberian Branch of Russian Academy of Sciences, Krasnoyarsk); the Institute of Biological Problems of Cryolithozone (Siberian Branch of Russian Academy of Sciences, Yakutsk); and the Pacific Institute of Geography (Russian Academy of Science, Yakutsk). The principle objective of TCOS SIBERIA was the implementation of the first components of a continental scale observing system to help determine the net carbon balance of Siberia and its variation from year-to-year. The project involved continuous surface flux measurements at 4 locations (three long-term surface $CO_2$ flux-measuring stations in a west-east transect (Fedorovskoje, Zotino, Yakutsk) along 60N, complemented by a station in the southern Siberian grasslands (Ubsu Nur near Kyzil).and vertical profile measurements from aircraft in the lower troposphere at 6 locations. The surface and atmospheric observations were combined to provide the basis of a continental scale meteorological and biogeochemical-modeling framework.

**3.3. Scandinavia**

In Scandinavia the key players involved in carbon accounting research includes: the Finnish Forest Research Institute (METLA), the University of Helsinki, the European Forestry Institute and the Swedish University of Agricultural Sciences (SLU).

Major carbon accounting activities currently underway for each of the above agencies is summarized as follows:

**Finnish Forest Research Institute (METLA)** [33]

i) Greenhouse gas inventory of forests
ii) MIL research program (Functioning of forest ecosystems and use of forest resources in changing climate)
iii) Peatland emission research

**University of Helsinki**[34]

i) Eddy covariance measurements and soil carbon processes modeling at Hyytiälä and Sodankylä forest field stations (SMEAR stations[35]). These sites are linked into the International Fluxnet program and the CarboEurope program.

[30] SiberiaII website: http://www.siberia2.uni-jena.de/index.php

[31] Terrestrial Carbon Observation System- Siberia website - http://www.bgc.mpg.de/public/carboeur/web_TCOS/

[32] CarboEurope website: http://www.carboeurope.org/

[33] Finnish Forest Research Institute (METLA) website: http//www.metla.fi

[34] University of Helsinki website: http://www.mm.helsinki.fi

**European Forest Institute**[36]:

i) Uncertainty assessment of forest carbon balance[37], This is a joint research project of scientists at the Finnish Forest Research Institute (METLA), the European Forest Institute (EFI) and VTT Technical Research Centre of Finland (VTT). The objectives are to: develop a calculation system for the carbon sink and source inventories of LULUCF sector according to the new IPCC methodology; identify and quantify the sources of uncertainty in these inventories; develop a model on these uncertainties; and estimate the overall uncertainty in the carbon sink and source inventories of LULUCF sector and determine the key classes of LULUCF in relation to inventories of all other sectors.

ii) CASFOR-II soil carbon model development. The objectives of this project are to develop a general model for estimating carbon balance and carbon sequestration capacity in forested landscapes or regions, and disseminate the developed CO2FIX model amongst the user-community via the Internet

iii) CarboInvent project[38]—a joint International Project now completed that identified, developed and tested methods for the assessment of carbon (C) stock changes in forests at national/EU levels in Europe. Involved - Dr. Risto Sievanen and Dr. Raisa Mäkipää - Finnish Forest Research Institute; Dr. Mats Olsson Swedish University of Agricultural Sciences; and Dr. Marcus Lindner European Forest Institute

**Swedish University of Agricultural Sciences (SLU)**[39]**:**

i) Forest inventory,

ii) Soil carbon modeling,

iii) Land use strategies for reducing GHG emissions (Heureka Research Programme)

### 3.4 US–Alaska

Alaska is the least monitored area of the U.S. because of its remoteness and low population density. Because of remoteness and lack of historical data, improving carbon monitoring and accounting in Alaska is a significant challenge. Approaches that emphasize remote sensing and modeling with a minimum dependence on in-situ observations are considered to be the most practical means for estimating forest carbon stocks and changes in stocks.

According to the forestry chapter of the recent "State of the Carbon Cycle Report" for North America[40], decisions concerning carbon storage in North American forests and their management as carbon sources and sinks will be significantly improved by: filling existing gaps in inventories of carbon pools and fluxes; improving our understanding of how management practices affect carbon in forests; and improving estimates of potential changes in forest carbon under climate change and other factors. Of particular importance in Alaska are the effects of natural disturbances related to fire and insects on forest carbon stocks and changes in stocks[41]

Key players and major activities underway in carbon accounting in Alaska include:

[35] SMEAR website: http://www.atm.helsinki.fi/SMEAR

[36] EFI website: http://www.efi.int/

[37] EFI website: http://www.efi.int/projects/uncertainty:

[38] EFI CarboInvent project website: http://www.joanneum.ac.at/CarbonInvent/:

[39] The Swedish University of Agricultural Sciences, The Faculty of Forest Science – Climate Change and Boreal forests. http://www.rtcc.org/2008/html/res-con-1.html

[40] Birdsey, R.A., J.C. Jenkins, M. Johnston, E. Huber-Sannwald, B. Amero, B. de Jong, J.D.E. Barra, N. French, F. Garcia-Oliva, M. Harmon, L.S. Heath, V.J. Jaramillo, K. Johnsen, B.E. Law, E. Marín-Spiotta, O. Masera, R. Neilson, Y. Pan, and K.S. Pregitzer, 2007: North American Forests. In: *The First State of the Carbon Cycle Report (SOCCR): The North American Carbon Budget and Implications for the Global Carbon Cycle*. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [King, A.W., L. Dilling, G.P. Zimmerman, D.M. Fairman, R.A. Houghton, G. Marland, A.Z. Rose, and T.J. Wilbanks (eds.)]. National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC, USA, pp. 117-126.

[41] Kasischke, E.S., and M.R. Turetsky. 2006 Recent changes in the fire regime across the North American boreal region- spatial and temporal patterns of burning across Canada and Alaska, Geophys. Res. Lett., 33, L09703, doi:10.1029/2006GL025677.

**University of Alaska Fairbanks and the U.S. Geological Survey (A. David McGuire)**

- Scientific synthesis and assessment of the arctic c-cycle which is an activity of the Arctic Monitoring and Assessment Program (AMAP) on behalf of the eight countries of the Arctic

**Alaska Fire/Climate Interactions Research sponsored by NSF/USFS (LTER), JFSP, and NASA (Eric Kasischke, Jennifer Harden, Merritt Turetsky, A.D. McGuire, J. Johnstone, T. Chapin)**

- Implications for atmospheric trace gas emissions and long-term soil carbon storage of wildfire consumption of ground-layer organic matter in North American boreal forests and peatlands; iii) soil climate and its control on wetland carbon balance in interior boreal Alaska

**University of Maryland (Eric Kasischke)**

- Developing approaches to integrate field and satellite observations to assess changes in effects of fire on terrestrial carbon cycling in the boreal region

**U.S. Geological Survey (Peter Murdoch)**

- the Yukon River Basin Project to study the effects of climate change on carbon, water, and energy

**US Forest Service**

- L. Heath—Updating the national-level forest carbon budget model FORCARB and contributing to the development of an interactive web-based geographic system to produce carbon estimates from annualized USDA Forest Service, Forest Inventory & Analysis data;
- R. Birdsey—development of methods to estimate national carbon budgets for forest lands from forest inventory data,
- Y. Pan—in collaboration with Jing Chen (University of Toronto) is investigating impacts of disturbance and climate on North American forests.

## 4. Strategic Opportunity

The Kyoto Protocol specifies that forest carbon stocks and changes in stocks must be reported on by signatory countries in a transparent and verifiable fashion. To accomplish this research is needed to develop a scientifically credible C accounting framework that:

- Complies with international guidelines;
- Standardizes the methods used for C accounting;
- Facilitates transparency and verification of estimates; and.
- Supports ongoing efforts by the forest management and policy communities to assess progress on reducing C sources and enhancing C sinks.

Development of a transparent and verifiable C accounting frameworks for circumboreal countries depends on:

- Developing spatially-explicit national database of existing and newly acquired information on the extent and composition of (and future changes in) circumboreal forests;
- Undertaking of field and modeling studies to refine stand-level ecosystem carbon processes and dynamics (growth, mortality, decomposition, etc.) and test and validate regional and national models;
- Assessing impacts of short and long-term fluctuations in climate and other environmental factors on processes at the stand (growth, decomposition) and landscape (insects, fire, forest boundary shifts) levels;
- The integration of information obtained from various sources and spatial scales for the calculation of regional and national C stocks estimates.

Key challenges in the development of transparent and verifiable accounting frameworks include:

- Quantifying the managed forest area;
- Quantifying and improving our understanding of soil carbon;
- Quantifying and improving our understanding of fire and insect disturbances;

- Quantifying land-use change at 1 ha resolution over very large areas;
- Accounting for forest management impacts on dead organic matter.
- Estimating C stock changes in forested peatlands and wetlands.
- Incorporating between-year variability and long-term climate effects.
- Separating indirect and natural effects from human induced changes; and
- Improving our estimates and understanding of how uncertainty in data and model parameters interact.

To undertake research to address these challenges strategic opportunities exist for the International Model Forest Network to position itself as the network that:

- Carries out scientific investigation of the forest C cycle at all spatial scales;
- Leads the synthesis and integration of existing and emerging scientific knowledge on the forest C cycle (aimed at identifying priority research questions) for the circumpolar boreal region;
- Facilitates and assists in the compilation of regional and national data sets required to estimate and report forest C stocks and stock changes;
- Co-operates with government agencies, industry and universities to develop estimates of C stocks;
- Develops, maintains and supports C accounting tools;
- Contributes to national and international policy analysis of C stock change scenarios, as affected by climate change, forest management actions, and natural disturbance regimes;
- Contributes to national and national policy analysis in support of international negotiations;
- Trains and supports experts that can participate on international audit teams as part of the international verification process; and
- Is an active participant in regional, national and international C cycle science and policy activities.

The International Model Forests are well positioned in the circumpolar boreal region to act on these opportunities through monitoring, undertaking of field studies and the provision of data and scientific expertise in many aspects of forest ecosystem carbon dynamics and modeling. Model forest sites provide "platforms" for conducting carbon cycle monitoring and research, and for testing responses to changing conditions in boreal forests in close cooperation with practical land use and management. The network itself, through its regional and international structures, provides a mechanism for collaboration and information sharing amongst researchers, practitioners and policy makers. Finally the International Model Forest Network is well situated to play an important role in promoting the development of a universal carbon budget model that could be easily used with commonly available information by any forest manager.

The Carbon Canada Program (Canada), TCOS Siberia (Russia) , Siberia-II (Russia), SMEAR program (Finland) and CarboEurope Program (Russia, Sweden, Finland, Norway) are examples of successful multi-government agency, university partnerships and collaborative efforts that could be strengthened and expanded with International Model Forest Network involvement. Such programs are means by which the IMF network could stretch its limited funding and acquire essential data, expertise and other resources to help address circumpolar boreal forest carbon accounting issues. Currently, the circumpolar boreal initiative is in initial planning stages. Under this joint initiative involving Canada, Russia, Sweden and potentially, the US, Finland and Norway a partnership could be created to measure and improve our understanding of the role of the circumpolar boreal forest in the global carbon cycle and for the development of carbon accounting procedures and techniques that comply with Kyoto reporting requirements. Through the Circumpolar Initiative the opportunity exists for the International Model Forest to become a partner and major contributor to resolving forest carbon accounting issues and challenges.

## Author Biographies

**Dr. Robert B. Stewart**
Robert B. Stewart retired from Natural Resources Canada-Canadian Forest Service with 31 years service in October 2006. As a civil servant I worked in 3 federal departments: Environment Canada - Meteorological Services of Canada, Agriculture and Agri-food Canada, and Natural Resources Canada - Canadian Forest Service as a climate change research scientist, coordinator/ science advisor and science manager. As the climate change research coordinator and science advisor for the Canadian Forest Service for the last 15 years of his career he was responsible for coordinating, at the national and international level, all climate change research involving personnel at 5 CFS research centres across Canada. Robert also was involved in the development and management of Government of Canada climate change research funding Programs including the Energy Research and Development (PERD), the Climate Change Action Fund (CCAF) and the Action Plan 2000 Program (AP2000 providing scientific advice and guidance he led and coordinated the development of forest components linked to these programs. In terms of major science field programs he was involved in the development, implementation and management of major carbon cycling research efforts involved in the Boreal Ecosystem and Atmospheric Science (BOREAS) program, the Boreal Ecosystem Research and Monitoring Sites (BERMS) and Fluxnet-Canada programs. Over his career he has published a number of papers on the implications of climate change for forestry in Canada. Robert participated in the 1996 Second Assessment Report of the Intergovernmental Panel on Climate Change - as a lead contributing author to the IPCC Working Group II - Socioeconomic Impacts of Climate Change on Forestry chapter.

**Dr. Richard A. Birdsey**
Richard A. Birdsey, is the program manager for global change research at the USDA Forest Service Northeastern and North Central Forest Experiment Stations, where he has been for more than ten years. Previously he worked for 13 years as a scientist and manager with the Forest Inventory and Analysis Program of the USDA Forest Service. Dr. Birdsey is a specialist in quantitative methods for large-scale forest inventories and was a pioneer in the development of methods to estimate national carbon budgets for forestlands from forest inventory data. He has helped compile and publish estimates of historical and prospective U.S. forest carbon sources and sinks, and he has analyzed options for increasing the role of U.S. forests as carbon sinks. This work comprises the official estimates for the forestry sector reported by EPA and other agencies as part of the inventory of U.S. greenhouse-gas emissions. He has also worked with colleagues in Russia and China to develop methods to inventory and monitor forest carbon in those countries. Currently serving as program manager, Dr. Birdsey is coordinating a national effort to improve the inventory and monitoring of forest carbon to identify forest-management strategies to increase carbon sequestration, to understand and quantify the prospective impacts of climate change on U.S. forests and forest products, and to develop adaptation strategies.

**Dr. Sten Nilsson**
Dr. Sten Nilsson, has been the Deputy Director of IIASA since 2002. He joined IIASA's Biosphere Project in January 1986 and became Leader of the Forestry Program in 1990. Before joining IIASA, Professor Nilsson was Leader of the Institute of Forest Industry Market Studies and Professor in Economic Planning at the Swedish University of Agricultural Sciences. He is an expert on boreal forests and global forest sector analysis, he is frequently asked to address international meetings on different issues dealing with the forest sector. He has held a number of consultancies in organizations such as The World Bank, FAO, OECD, EC and SIDA. He has served as an expert in different international organizations such as the World Commission on Forests and Sustainable Development (WCFSD), the International Boreal Forest Research Association (IBFRA), the International Union of Forest Research Organizations (IUFRO), WWF and Forest Trends. He leads an IUFRO Task Force on Information Technology and the Forest Sector and most recently was appointed as a lead author of the upcoming IPCC 4th Assessment Report. Professor Nilsson has authored and coauthored over 300 scientific publications. Most recently he has produced a "Governmental Bill" entitled *Shared Responsibility on development policies for the Swedish forest sector*. The "Bill" is based on (and copies) the principles and concepts presented in a real Bill by the Swedish Government dealing with Sweden's Policy for Global Development (Governmental Bill 2002/03:122). The new "Governmental Bill" on Swedish Forest Sector

Development is to be regarded as a contribution to the debate on the development of the Swedish forest sector.

**Dr. Anatoly Shvidenko**
Dr. Anatoly Shvidenko has been with the Forestry Program at the IIASA as a senior scientist since October 1992. Before joining IIASA, he was the Director of the All-Russian Scientific Research and Information Center for Forest Resources in Moscow. Since joining IIASA he has been principal investigator in a number of projects on the forest sector of Northern Eurasia including projects financed by the European Commission, European Space Agency and other international organizations (Siberia, Siberia-II, GSE-FM, IRIS, Enviro-RISK ).

Professor Shvidenko's main fields of interest are forest inventory, monitoring, mathematical modeling, global change, and boreal forests. He has authored and coauthored over 300 scientific publications, including 12 books. He served as lead author and coordinating lead author in the Third Millennium Ecosystem Assessment, and in the 2nd, 3rd and 4th IPCC Assessments. He took part in a number of important international global change activities and initiatives as member of steering committees and councils (Global Terrestrial Observing System, Terrestrial Carbon Observation Panel, FAO Forest Resource Assessment, International Boreal Forest Research Association, Scientific Council of the World Commission on Forestry and Sustainable Development, Siberian National Committee on IGBP etc.). He is a member of editorial boards of three international scientific journals.

**Dr. Aleksi Lehtonen**
Dr. Lehtonen is a forest ecologist who has been at the Finish Forest Research Institute (METLA) as a post-doctorate researcher since January, 2006. He obtained his Doctorate from the University of Helsinki, Forest Ecology, Carbon stocks and flows in forest ecosystems based on forest inventory data. Prior to obtaining his Doctorate Aleksi was a Researcher at the Finnish Forest Research Institute from 2001 to 2005 and was funded by the Academy of Finland and worked on integrated method to estimate carbon budgets of forests (SUNARE). He also received funding from the EU FP5 CarboInvent Project. His main fields of interest are in biomass estimation and carbon flows in forest ecosystems. Currently, Aleksi is involved in two projects: one is responsible for the greenhouse gas reporting and its development in the sector of Land Use Land Use Change and Forestry (LULUCF) including Kyoto Protocol reporting for Finland; the other is investigating the interlinkage between forest biodiversity and carbon sequestration. Since joining METLA he has published a number of papers on the results of his carbon accounting and biomass estimation work.

Landscapes










Partnerships





Sustainability




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