Canadian Forest Carbon Budgets at Multi-Scales:

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OUTLINE

• Canada’s Forests and C Accounting System

• Canadian Forest Carbon Budgets
  - Modelling Approaches
  - Data sources
  - Model validation and comparison

• Future Challenges
Canada’s Forests

- 418 million ha of forest land – 75% in the boreal zone
- 245 million ha timber productive
- 148 million ha accessible

- 10% of global forests
- 25% of global boreal forests

Source: Lowe et al. 1996
LULUCF in the National GHG Inventory

Canada's National Greenhouse Gas Inventory (Environment Canada)

- Energy
- Industrial Processes
- Solvents
- Waste

Land-use Change and Forestry

Forest C Accounting System NRCan/CFS

Agriculture

Agriculture C and N\textsubscript{2}O Accounting AAFC

LUC - ARD
Key Components of Canada’s National Forest C Accounting System

- A landscape-level computer simulation model
- The new National Forest Inventory and other inventories
- Remote sensing programs for change detection and inventory updates
- Growth and yield information for biomass dynamics
- Simulation of dead organic matter dynamics as affected by management and natural disturbances
- Statistics on natural disturbances, forest management activities and land-use changes (ARD)
- A research program to address remaining data gaps and to help operationalise the system.
Development of C Accounting Tools at four Spatial Scales

• National Scale
  – Required to determine national net balance, and
  – Required in support of international reporting

• Regional Scale
  – Biome-level and provincial/territorial analyses
  – Can be building block for regional and national scale

• Operational / Management Unit Scale
  – Scale of forest management decisions
  – Can be building block for regional and national scale
  – Can use high resolution, spatially explicit approach

• Stand
  – Ground measurements and model validation
  – Scientific analyses
C Accounting at Four Spatial Scales

Ensures consistency across spatial scales
Uses best available data for each region

National

Regional or Provincial

Operational

Stand-level
Modelling Approach:

1. Forest Inventory Based Forest Carbon Accounting: CBM-CFS (Kurz and Apps, 1992, 1999)


3. Hybrid Model Simulation at Stand and Landscape Levels: TRIPLEX (Peng et al, 2002; Zhou et al. 2004)
CBM-CFS2: Carbon Budget Model of Canadian Forest Sector

- CBM-CFS
  - First national scale forest analysis

- Data Driven:
  - Forest Inventory (NFBI and CanFI)
  - Soil Data
  - Disturbances
    - Fire
    - Insects
    - Harvests

(Kurz, Apps, Webb, McNamee; 1992, Kurz and Apps, 1999)
The CBM-CFS2 accounts for all C pools

- Biomass
  - Aboveground
  - Belowground
- Dead Organic Matter
  - Litter
  - Dead Wood
  - Soil Organic Carbon

- Additional Forest Product Sector Model can track fate of carbon in harvested wood products using a variety of approaches
Forest C Stock Analyses

- Detailed Forest Inventory
- Volume to Biomass Conversion
- Volume / Age Curves
- Model parameters
  - Litterfall
  - Decomposition
- Harvesting
- Planting
- Disturbances
- Land-use change
- C Accounting Model
  - CBM-CFS2
- Results database
Carbon Budget Model of the Canadian Forest Sector (CBM-CFS2)

- Applied at
  - national scale (all forest, managed forest),

- Kurz et al. 1995
- Kurz and Apps 1999
Carbon Budget Model of the Canadian Forest Sector (CBM-CFS2)

- Applied at
  - national scale (all forest, managed forest),
  - regional scale (boreal, British Columbia, Ontario),

- Kurz and Apps 1996
- Kurz et al. 1996
- Peng et al. 2000
Carbon Budget Model of the Canadian Forest Sector (CBM-CFS2)

- Applied at
  - national scale (all forest, managed forest),
  - regional scale (boreal or provinces), and
  - forest management units.

- Price et al. 1997
- Kurz et al. 1998
Key steps in satellite-based estimation of carbon balance (NBP)

(J. Chen et al, 2003)
Additional datasets used

- Remotely sensed land cover and LAI maps (1 km resolution)
- Modeled and partially validated NPP map for 1994 (1 km resolution)
- Gridded climate data (1901-1998, U. East Anglia, 0.5°, monthly means)
- Soil Landscape of Canada (texture, total carbon, ~10k polygons)
- Nitrogen deposition data (1983-1998, 12 stations, CAPMoN)
- Tower flux data at 4 locations
Role of Disturbance

\[ \text{NBP} = \text{NEP} - \text{Fires} - \text{Harvest} - \text{Insect-induced Mortality} \]

NBP: Net Biome Productivity
The variation of NPP with age (Black Spruce in Ontario)

\[ NPP = 156 \times \left[1 + \left(2.0 \times \left(\frac{\text{age}}{25}\right)^{1.9} - 1\right)/\text{e}^{25}\right] \]

Role of Forest Age (Chen et al. 2002)
Ontario’s Forest Age-class Structure (1990)

- Boreal Region (BO)
  - 22.50
  - 11.49
  - 7.05
  - 11.50
  - 10.12

- Cool Temperate Region (CT)
  - 2.34
  - 1.50
  - 0.12

- Moderate Temperate Region (MT)
  - 0.39
  - 2.29
  - 4.76
  - 80.67
  - 77.14
  - 13.57
  - 21.30

- SA

CBM-CFS2

(Peng et al. 2000)
Ontario's Forest Age (1920-1990)

(Peng et al. 2000)
Model Validation and Comparison

Testing model simulations against:

- Forest Growth & Yield plots
- Forest Inventory
- Soil measurements
- Eddy Covariance Flux Towers
Comparison of Averaged Simulations and Observations - Aboveground Biomass (Hegyi, 1972)

TRIPLEX Simulations (Peng et al. 2002)
Comparison of modeled total aboveground biomass carbon with forest inventory

Average aboveground biomass carbon in different types of Canada's forests

y = 1.393x - 0.6304
R² = 0.8013

(J. Chen et al. 2003)
Comparison of modeled total soil organic carbon with polygon data from Soil Landscape of Canada

Average dead organic carbon in different types of Canada’s forests

\[ y = 1.0095x - 0.3114 \]

\[ R^2 = 0.8631 \]

(J. Chen et al. 2003)
Historical Variation in NEP

121-year old black spruce stand, Saskatchewan (53.890 °N, 105.114 °W)

Tower data source: Paul Jarvis of U Edinburgh and Andy Black of UBC

(J. Chen et al. 2003)
Comparison of simulated NPP with Remoted Sensing based estimation of NPP at Landscape Level (Lake Abitibi Model Forest)

(a) TRIPLEX Simulation (Zhou et al, 2004)

(b) Estimation based on Remote sensing (Liu et al. 2002)

Kappa Statistic:
K = 0.6
(Good agreement if 0.55 < K < 0.70)
Comparison of three sets of NBP results
All Canada's Forests, 1901 to 1998

Spatially Explicit Modeling (Chen et al., 2002b)
Spatially Aggregated Modeling (Chen et al., 2000b)
CBM-CFS (Kurz and Apps, 1999)

(J. Chen et al. 2003)
What do the changes in disturbances in Canada’s forests Affect Carbon Balance?

Note apparent increase after 1970
Challenges for Science

• **Weaknesses in Scientific Understanding:**
  
  – *Allocation of C in plant tissues*
  
  – *Nutrient feedback*
  
  – *CO₂ fertilization at ecosystem scale - is it real? important?*
  
  – Projecting *changes in disturbance regimes* *(fire, insect, harvesting, ice damage…)*
  
  – *Peatland carbon dynamics*
  
  – *etc….*
Scientific Challenges

• Quantifying land-use change at 1 ha resolution.
• Regional parameter databases and validation.
• Accounting for forest management impacts.
• Estimating C stock changes in forested wetlands.
• Estimating N\textsubscript{2}O and CH\textsubscript{4} emissions.
• Incorporating inter-annual variability and long-term climate effects.
• Identifying, quantifying and reducing uncertainty.
Forest Carbon Accounting
Comptabilisation du Carbone Forestier

Canadian Forest Service
Service canadien des forêts

http://carbon.cfs.nrcan.gc.ca

(Kurz and Apps, 2004)