Multi-factor analysis of the forces driving carbon dynamics in the North American Boreal Forest

Daniel Hayes
Environmental Sciences Division &
Climate Change Science Institute,
Oak Ridge National Laboratory
Oak Ridge, Tenn. USA

International Boreal Forest Research Association (IBFRA) Conference 2013
Co-authors

D.J. Hayes – ORNL
G. Chen – ORNL
G. Stinson – CFS
W.A. Kurz – CFS
A.D. McGuire – UAF

International Boreal Forest Research Association (IBFRA) Conference 2013
Sensitivity of the Pan-Boreal Carbon Cycle

- Large and potentially vulnerable C stocks
- Uncertain C fluxes: sensitive to climate warming, drought & disturbance
Sensitivity of the Pan-Boreal Carbon Cycle

Carbon Sink of Circum-Boreal Region

Figure 2. Estimated cumulative net uptake of atmospheric CO$_2$ (NEE) by boreal land regions since the latter half of the 20th century, according to the simulation experiment with all factors included (Sim7).
Sensitivity of the Pan-Boreal Carbon Cycle

Canada’s Managed Forest (Stinson et al., 2011)
Scaling Methodology

Regional Carbon Dynamics: Diagnosis & Attribution

Fig. 5 Mean area-weighted average annual NEE (g C m^{-2} yr^{-1}), 2000-2006 for the Forest Lands, Crop Lands and Other Lands sectors.
## Scaling Methodology

### Inventory & Modeling Approaches: Pros & Cons

<table>
<thead>
<tr>
<th></th>
<th>Inventory-based</th>
<th>Atmospheric inversion models (AIMs)</th>
<th>Terrestrial biosphere models (TBMs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strengths</strong></td>
<td>1) Employ a large number of repeated biomass measurements</td>
<td>1) Assimilates measurements of atmospheric CO₂ concentration</td>
<td>1) Processes are represented so attribution is possible</td>
</tr>
<tr>
<td></td>
<td>2) Allows estimation of product-related C sources</td>
<td>2) Employs atmospheric mass balance</td>
<td>2) Sensitive to interannual variation in climate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3) Many opportunities for validation</td>
</tr>
<tr>
<td><strong>Weaknesses</strong></td>
<td>1) Not all C pools are measured</td>
<td>1) Transport model uncertainty</td>
<td>1) Many inputs, each with their own uncertainty</td>
</tr>
<tr>
<td></td>
<td>2) Possible undersampling</td>
<td>2) Limited number of CO₂ measurements</td>
<td>2) Many parameters, each with their own uncertainty</td>
</tr>
<tr>
<td></td>
<td>3) Limited attribution ability</td>
<td>3) Low spatial resolution</td>
<td>3) Spatial resolution may not resolve management scale disturbances</td>
</tr>
<tr>
<td></td>
<td>4) Missing NEE of unmanaged ecosystems</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5) Poorly resolved temporally</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5: A comparison of the strengths and weaknesses of alternative NEE scaling approaches (inventory-based, AIMs and TBMs)
Integrated Scaling Methodology

Net Ecosystem Exchange (NEE), State of Oregon, USA, 2000 to 2005: -8.6 Tg C yr⁻¹

Atmospheric Inverse Modeling Region

DC export = -2.6
HWP Import – Export = -4.9
HWP = 6.4
ΔHWP = -0.5
Crop
ΔLive = 0.0
Forest
ΔLive = -9.7
HWP Decay = 0.6
Fire Emissions = 0.8
CH₄ / CO
HWP Humans = +0.2
HWP Livestock = +2.9
River Evasion = +2.2
Statewide -NEP = -17.1
Terrestrial Biosphere Modeling Grid

Inventory Sectors: Crop Land, Forest Land, Other Land

Flux Legend: Biogenic, Product, Pyrogenic, Aquatic, Non-CO₂, Lateral
Integrated Scaling Methodology

(a) BOOK-KEEPING FRAMEWORK

Organizing Framework for Data Synthesis

(b) DATA SYNTHESIS

Ecosystem C Fluxes (kgC m$^{-2}$ yr$^{-1}$)

Define Rates of Transition

Define Land Unit Areas

Prescribe Transitions

Prescribe Disturbance

Prescribe PFTs

(c) REMOTE SENSING

(d) PROCESS MODELING
Dynamic Cohort Approach

Each 0.25° climate grid cell can have any number of individual, non-spatial “cohorts” of unique vegetation type and disturbance history, which is tracked through time according to disturbance and land use.
for year in YEARS:
  for disturb_type in DISTURB_TYPES:
    for spu in SPUS:
      Annual Disturbance Data Sets
      Get SPU cells & target disturb area
      GIS Look-up
      Current Year Cohorts
      Get cohorts in SPU
      sort cohort list
      Disturbance - specific sorting rules
      Next cohort: split
      ‘parent cohort’ area = parent area – disturbed area
      ‘child cohort’ area = disturbed area
      Disturb parameters (C transfers)
      Target area = 0?
      NO
      YES
      Continue to next SPU, disturbance type or year
Annual Disturbance Area: “BCNorth”
(TEM Cohort Model Results)
Annual Disturbance Area & Resulting Forest Stand Age Distributions

Kurz and Apps, 1999 (CANADA)

Forest Stand Age Distributions

Fig. 7: The distribution of Canadian forest area in 20-yr age classes in 1920, 1970, and 1990 (adapted from Kurz et al. [1995]).
**Attribution**

**North American Boreal Forest**

<table>
<thead>
<tr>
<th>Decade</th>
<th>Effect on NEE (Tg C decade$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960s</td>
<td></td>
</tr>
<tr>
<td>1970s</td>
<td></td>
</tr>
<tr>
<td>1980s</td>
<td></td>
</tr>
<tr>
<td>1990s</td>
<td></td>
</tr>
<tr>
<td>2000s</td>
<td></td>
</tr>
</tbody>
</table>

- **Source**
  - CO2
  - O3
  - Ndep
  - Climate
  - Fire
  - Harvest
  - Agric
  - Total

- **Sink**

**Strengthening source:** Fire > CO$_2$ fertilization effect
Attribution: Fire Effects

Figure 5. The spatial pattern of the (a) total fraction of grid cell area burned and (b) average annual effect (gC m⁻² yr⁻¹) of all controlling factors on NEE across the boreal land regions over the 1997 to 2006 time period.
Attribution: Climate Effects

Effect of $\Delta$ALT on IAV and trends in $f$GHG
Discussion: Going forward

Synthesis and Integration

- Understanding the current (and projecting the future) role of Boreal Forests in the global carbon cycle requires analysis of multiple “top-down” and “bottom-up” constraints

- Understand what each of these scaling approaches measure, model and include in their methods

- Integrated methods for full diagnostic, attribution and predictive capabilities
Discussion: Going forward

Inventory-Process Model Integration

- Incorporate full suite of key disturbance mechanisms in the process-based, biogeochemical modeling framework
- Drive the “cohort-level” process modeling with datasets to capture disturbance history: impacts and legacies
Thank You!

More Info:  hayesdj@ornl.gov