Representation of forest disturbance in carbon cycle models: Data limitations, process uncertainty, and theoretical considerations

- Jeremy Lichstein, University of Florida, jlichstein@ufl.edu
- Ben Poulter, Laboratoire des Sciences Climat l'Environnement, benjamin.poulter@lsce.ipsl.fr
- Elena Shevliakova, Princeton University, elena@princeton.edu
- Chris Williams, Clark University, CWilliams@clarku.edu
- Rich Birdsey, U.S. Forest Service, rbirdsey@fs.fed.us
Representing disturbances in models requires...

- Which disturbances? When? Where?
- What happened? (tree mortality rate, transfers between C pools)

Representing post-disturbance recovery requires...

- Age structure
Global mapping of forest age structure

Tree cover (fraction)

Global Forest Age

Slide courtesy of Ben Poulter
Testing/calibrating post-disturbance recovery in C-cycle models

Biomass regrows at an inventory-derived rate

Williams, Collatz et al. (2012) GBC

Slide courtesy of Chris Williams
CBM-CFS3: A model of carbon-dynamics in forestry and land-use change implementing IPCC standards

W.A. Kurz\textsuperscript{a,}\textsuperscript{*}, C.C. Dymond\textsuperscript{a}, T.M. White\textsuperscript{a}, G. Stinson\textsuperscript{a}, C.H. Shaw\textsuperscript{b}, G.J. Rampley\textsuperscript{a}, C. Smyth\textsuperscript{a}, B.N. Simpson\textsuperscript{b}, E.T. Neilson\textsuperscript{a}, J.A. Trofymow\textsuperscript{a}, J. Metsaranta\textsuperscript{a}, M.J. Apps\textsuperscript{a}
Disturbance type affects size and composition of post-disturbance forest C pools

Slide courtesy of Werner Kurz
Modifications to CLM (bark beetles in western U.S.)

- Stem C & N
- Coarse Root C & N
- Leaf C & N
- Fine Root C & N

Snag (m\textsuperscript{th} year)

Dead Foliage (n\textsuperscript{th} year)

CWD C & N

Litter C & N

Green Attack
Fading
Red Attack
Gray Attack
Snagfall
Recovery

*Edburg et al., JGR Biogeosciences, 2011*

Slide courtesy of Jeff Hicke
In development:
Prognostic bark beetle outbreak model for CLM-CN

Historical Effects
- ADS #trees killed
- C in killed trees

Future Effects
- drought (precip, T)
- year-round T
- winter T

- offline climate
- host availability
- outbreak initiation
- past & nearby populations
- building/continuing phases
- outbreak severity => C in killed trees
- collapse

Move carbon/nitrogen from live to dead pools; reset ages

CLM-CN

Slide courtesy of Jeff Hicke
Ecological Statistical Mechanics: The Ecosystem Demography (ED) model

\[ \frac{\partial}{\partial t} C_i(z, a, t) = -\frac{\partial}{\partial z} \left[ g_i(z, \bar{r}, t) C_i(z, a, t) \right] - \frac{\partial}{\partial a} C_i(z, a, t) \]

- Growth
- Aging
- Mortality

\[ \frac{\partial}{\partial t} p(a, t) = -\frac{\partial}{\partial a} p(a, t) - \lambda(a, t) p(a, t), \]

- Aging
- Disturbance

(Moorcroft et al. 2001)

Slide courtesy of Mike Dietze
Disturbance in the ED model

Slide courtesy of Mike Dietze
### Implementation of disturbance varies by ESM

<table>
<thead>
<tr>
<th>Model</th>
<th>Dynamic Veg</th>
<th>Harvest</th>
<th>Fire</th>
<th>Other mortality</th>
<th>Age structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCC-CSM1.1</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>?</td>
<td>N</td>
</tr>
<tr>
<td>CanESM2</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Bioclimatic limits</td>
<td>N</td>
</tr>
<tr>
<td>CESM1-BGC</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Includes heat stress, bioclimatic limits</td>
<td>N</td>
</tr>
<tr>
<td>GFDL-ESM2G</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Constant</td>
<td>Y</td>
</tr>
<tr>
<td>GFDL-ESM2M</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Constant</td>
<td>Y</td>
</tr>
<tr>
<td>HadGEM2-ES</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Constant</td>
<td>N</td>
</tr>
<tr>
<td>IPSL-CM5A-LR</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Includes heat stress, bioclimatic limits</td>
<td>N</td>
</tr>
<tr>
<td>MIROC-ESM</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Includes heat stress, bioclimatic limits</td>
<td>Y</td>
</tr>
<tr>
<td>MPI-ESM-LR</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Includes wind</td>
<td>N</td>
</tr>
<tr>
<td>NorESM-ME</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Includes heat stress, bioclimatic limits</td>
<td>N</td>
</tr>
</tbody>
</table>

Slide courtesy of Ben Sulman
Typical grid size 1 degree ≈ 100 km
Disturbances occur at much smaller scales
LM3 uses independent land tiles within each grid cell
- Primary forest, secondary forest, pasture, crops are separate tiles
- Multiple tiles represent secondary forest age structure
- New secondary tiles generated by wood harvesting and ag abandonment
- Each tile has independent vegetation, soil, hydrology and atmospheric fluxes
- Light competition and canopy changes are not explicitly simulated
Next generation of models

- Canopy dynamics
- Competition between individuals and species
- Effects of disturbance on forest structure

From Strigul et al. (2008)

Slide courtesy of Ben Sulman
Examples of Actions/Considerations

• Correlations suggest air pollution (e.g., ozone) are important source of mortality in eastern U.S. (Dietze & Moorcroft 2011, GCB)
• Re-sprouting: not all trees die in disturbance.
• Harmonize overlapping disturbance datasets to avoid double-counting disturbed area.
• Rh does not only depend on size and quality of soil and litter C pools. Need to explicitly model dynamics of microbial decomposers to accurately model Rh. How does disturbance affect microbial communities?
• Different disturbances result in different post-disturbance recovery dynamics. Need to organize existing empirical data by disturbance type to test models.
• Proposed DMIP: Model Intercomparison Project focused on C-cycle response to multiple disturbances. Possible test-beds include Canada and the western U.S.