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

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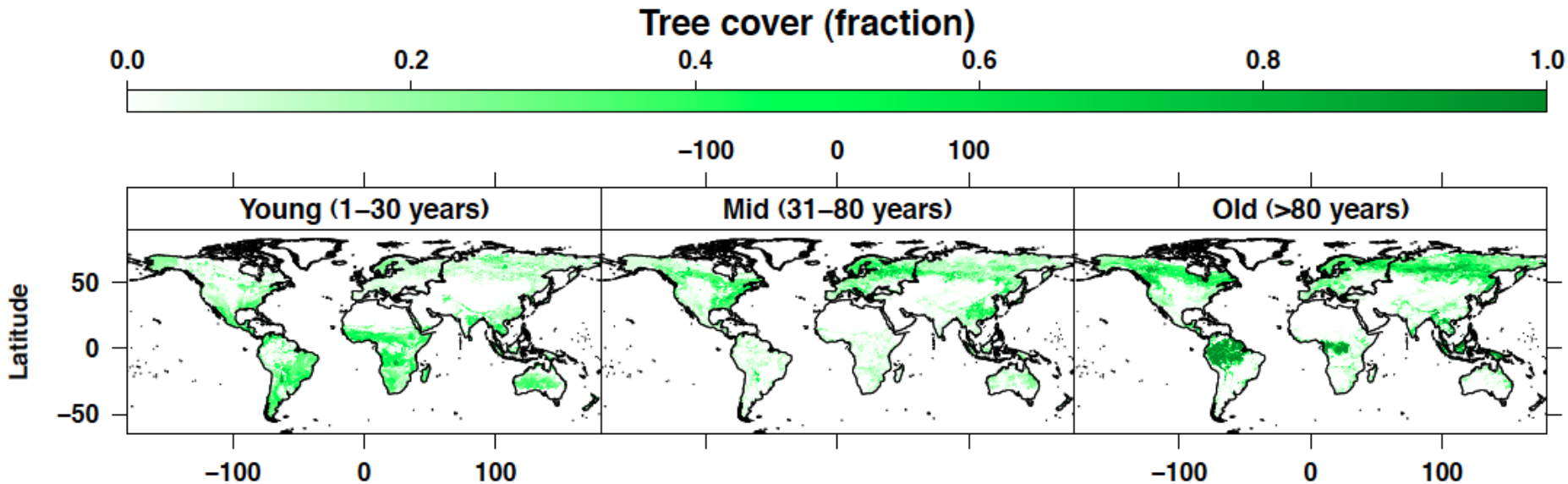
Representing disturbances in models requires…

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

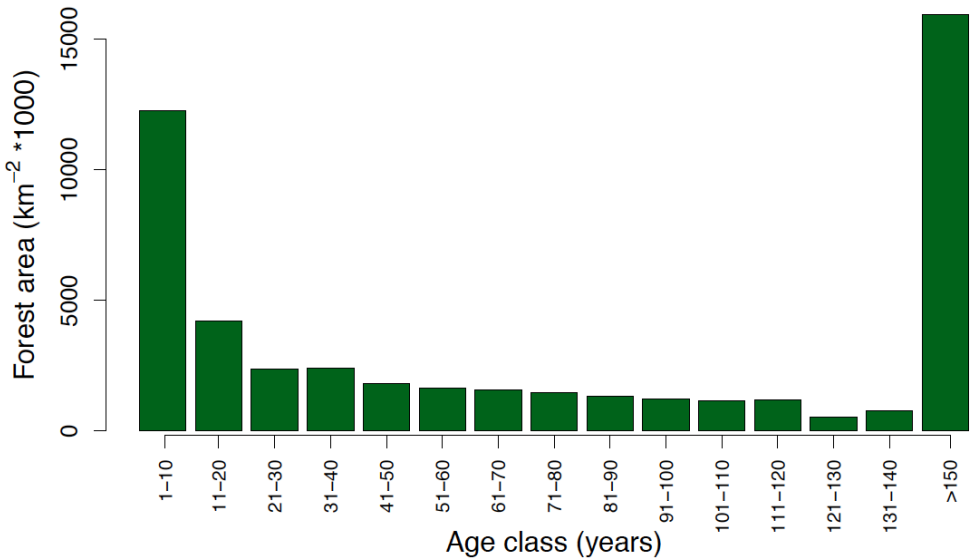
Representing post-disturbance recovery requires…

- Age structure

Global mapping of forest age structure



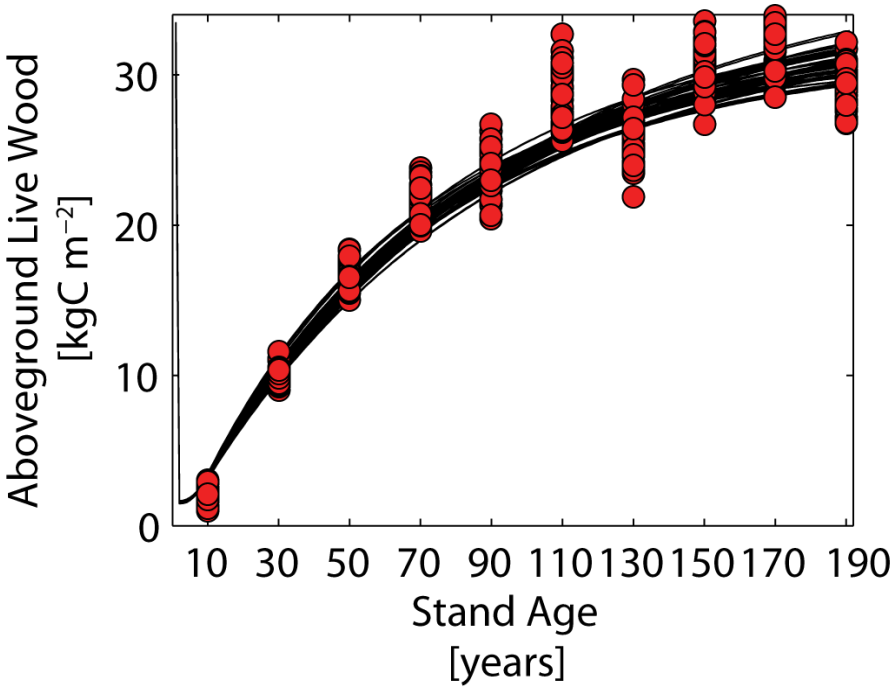
Global Forest Age



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

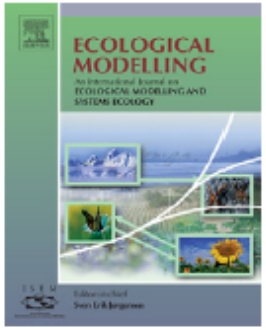
Carbon Budget Model of the Canadian Forest Sector

available at www.sciencedirect.com

Ecological Modelling (2009) 220: 480-504

ScienceDirect

journal homepage: www.elsevier.com/locate/ecolmodel



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

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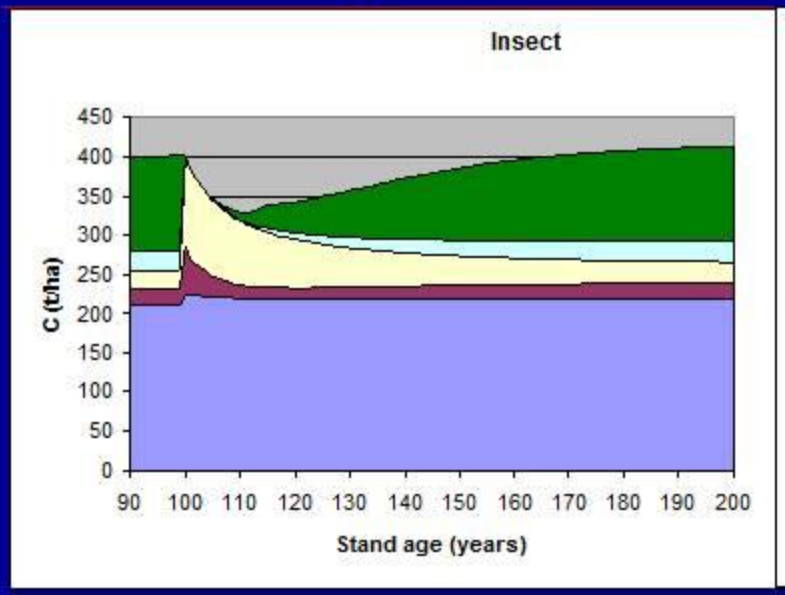
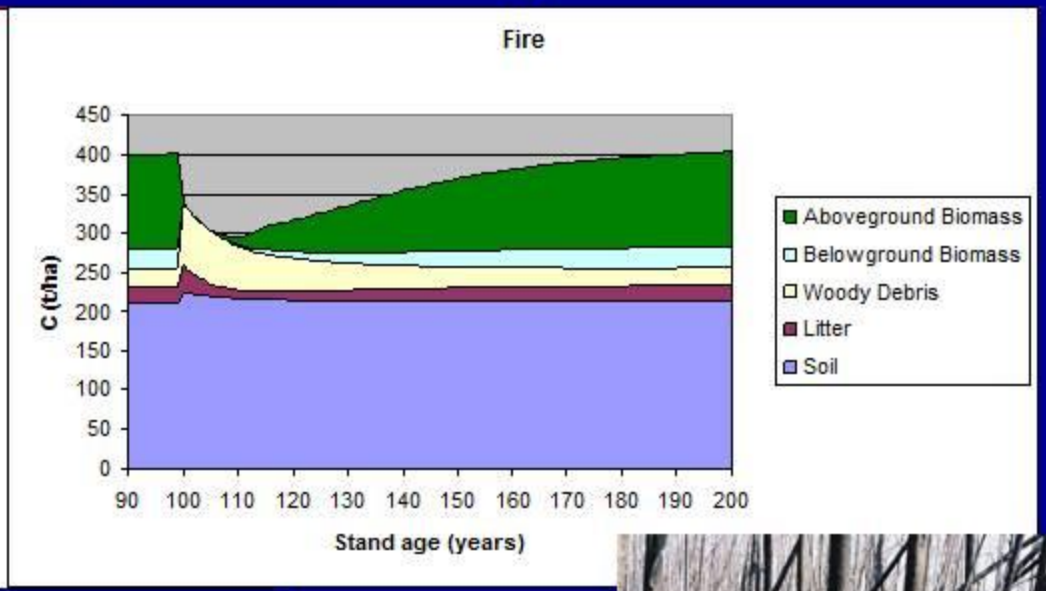
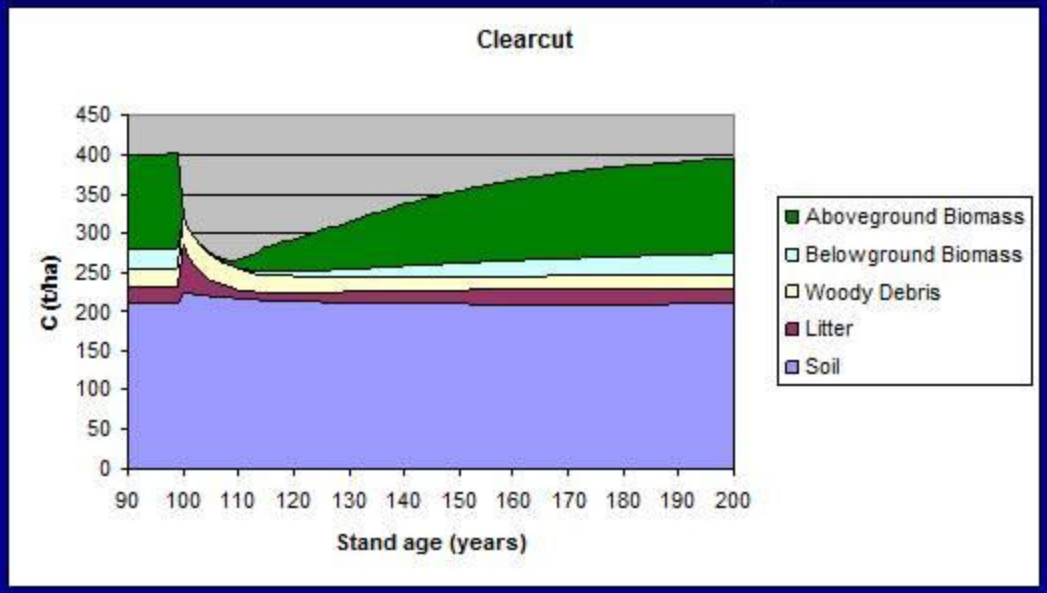
Disturbance type affects size and composition of post-disturbance forest C pools

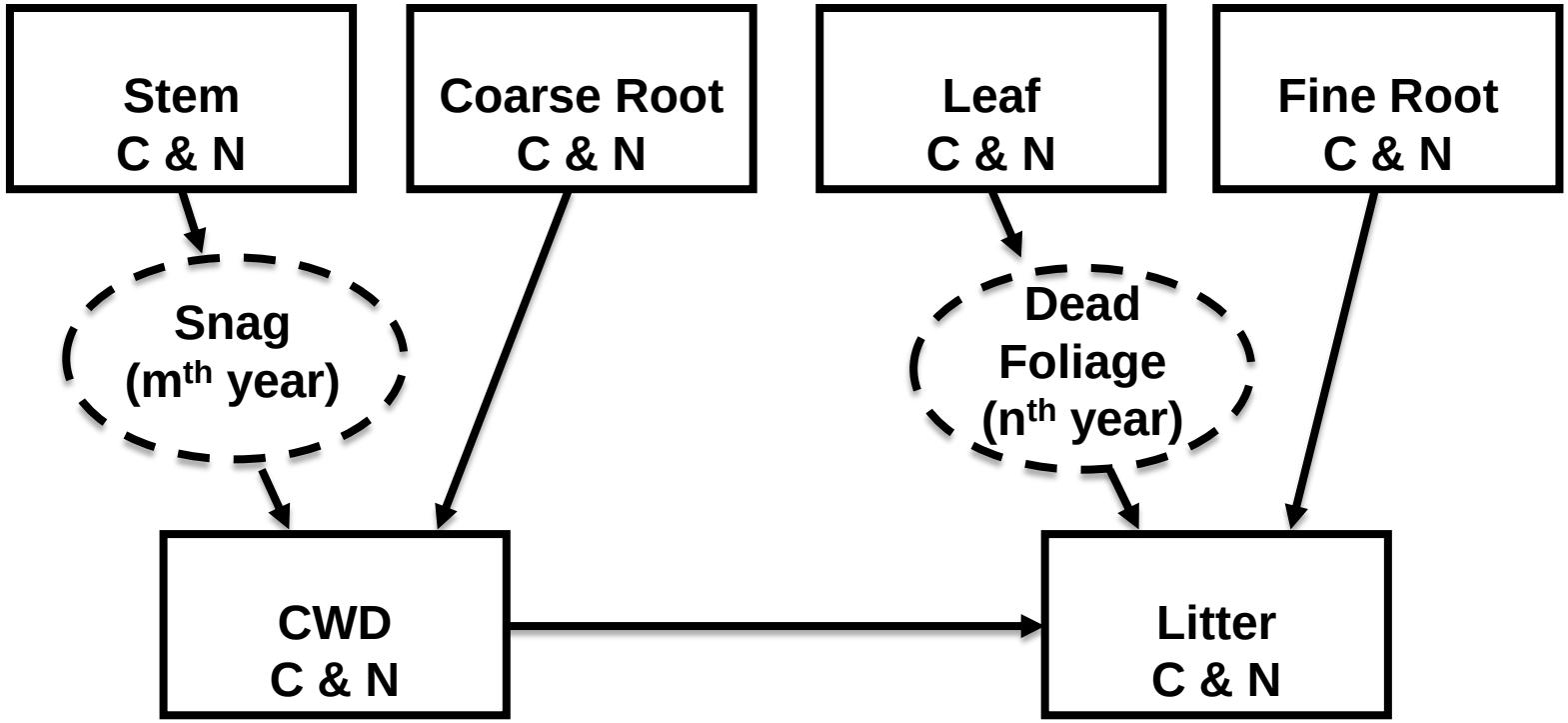


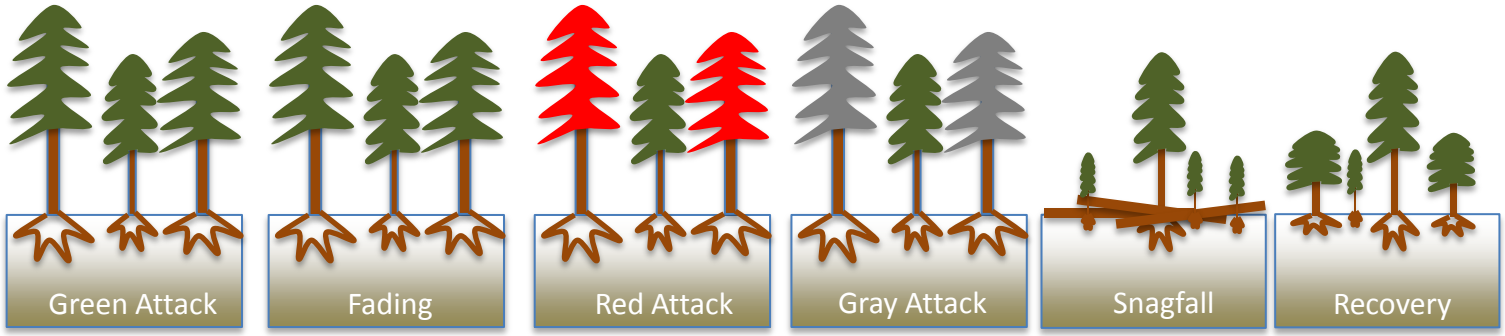




Slide courtesy of Werner Kurz

Modifications to CLM (bark beetles in western U.S.)

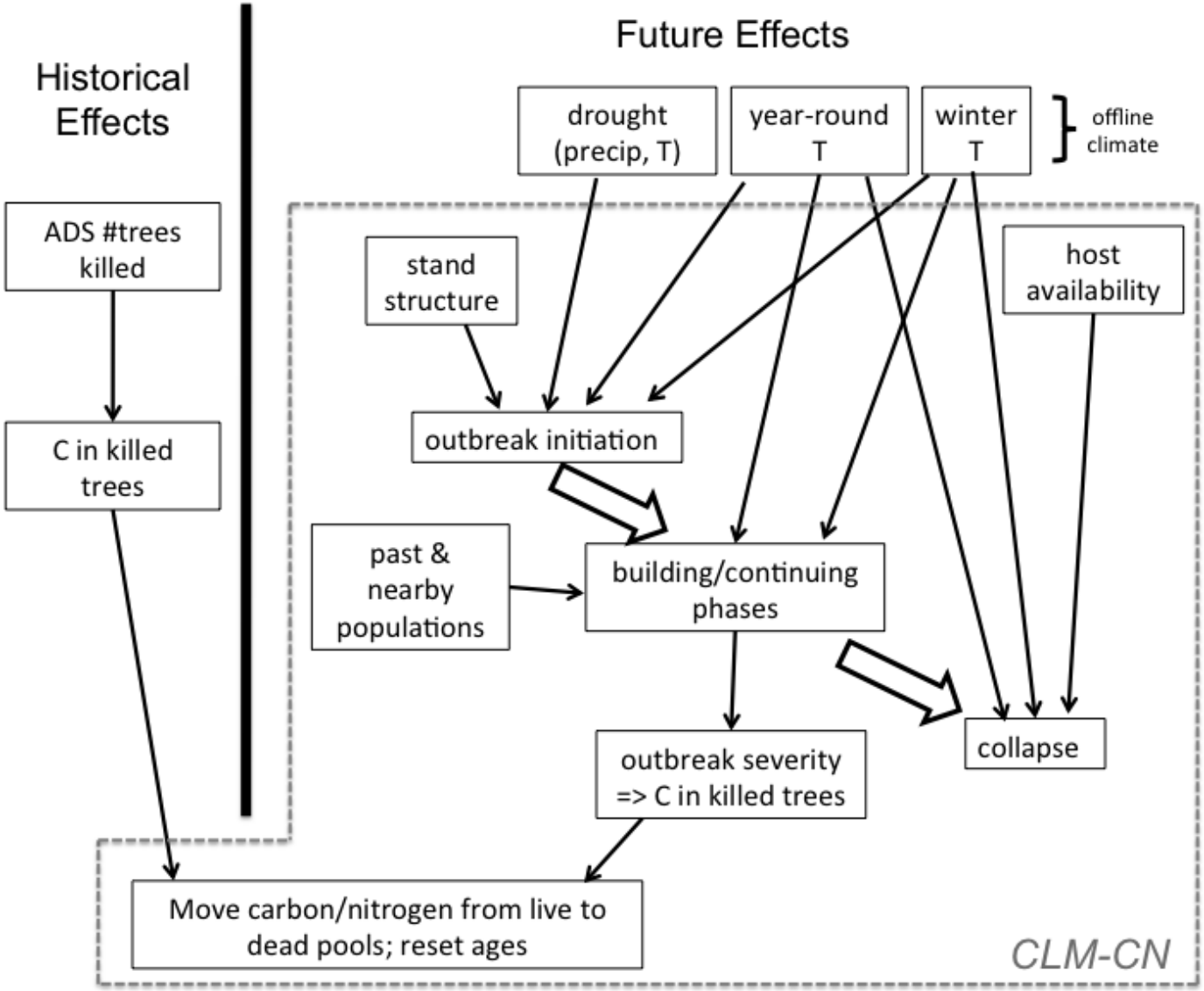




Edburg et al., JGR Biogeosciences, 2011

Slide courtesy of Jeff Hicke

In development:
Prognostic bark beetle outbreak model for CLM-CN



Slide courtesy of Jeff Hicke

Ecological Statistical Mechanics: The Ecosystem Demography (ED) model

$$\underbrace{\frac{\partial}{\partial t}C_i(z,a,t)}_{\text{ch. in biomass}} = -\frac{\partial}{\partial z}\underbrace{[g_i(z,\bar{r},t)C_i(z,a,t)]}_{\text{growth}} - \underbrace{\frac{\partial}{\partial a}C_i(z,a,t)}_{\text{aging}} - \underbrace{\mu_i(z,\bar{r},t)C_i(z,a,t).}_{\text{mortality}}$$

of plant type i

Cohort

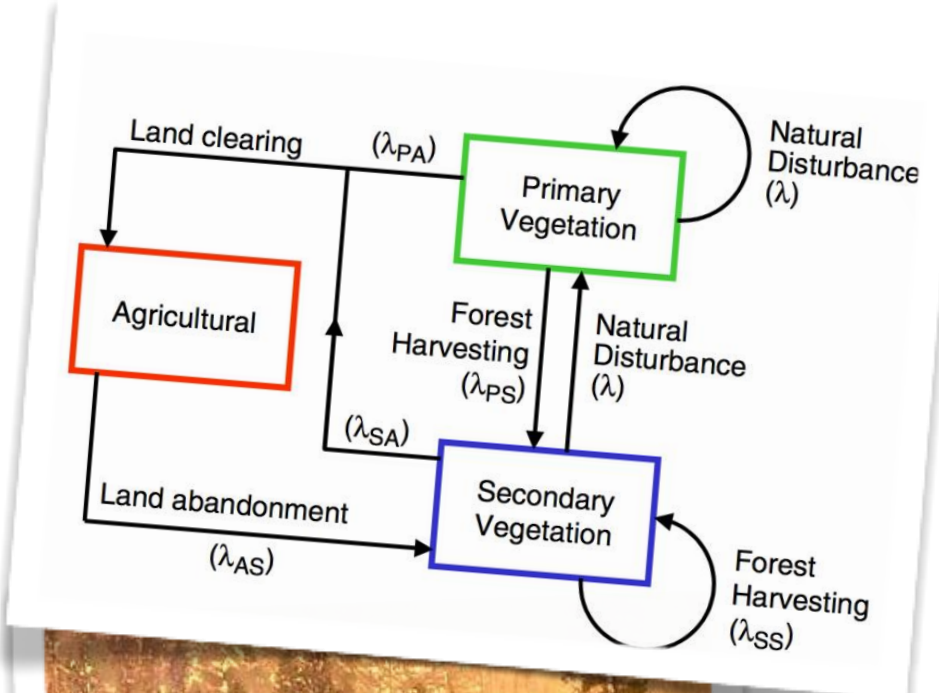
$$\underbrace{\frac{\partial}{\partial t}p(a,t)}_{\text{ch. in landscape age distribution}} = \underbrace{-\frac{\partial}{\partial a}p(a,t)}_{\text{aging}} - \underbrace{\lambda(a,t)p(a,t)}_{\text{disturbance}},$$

Patch

(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

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

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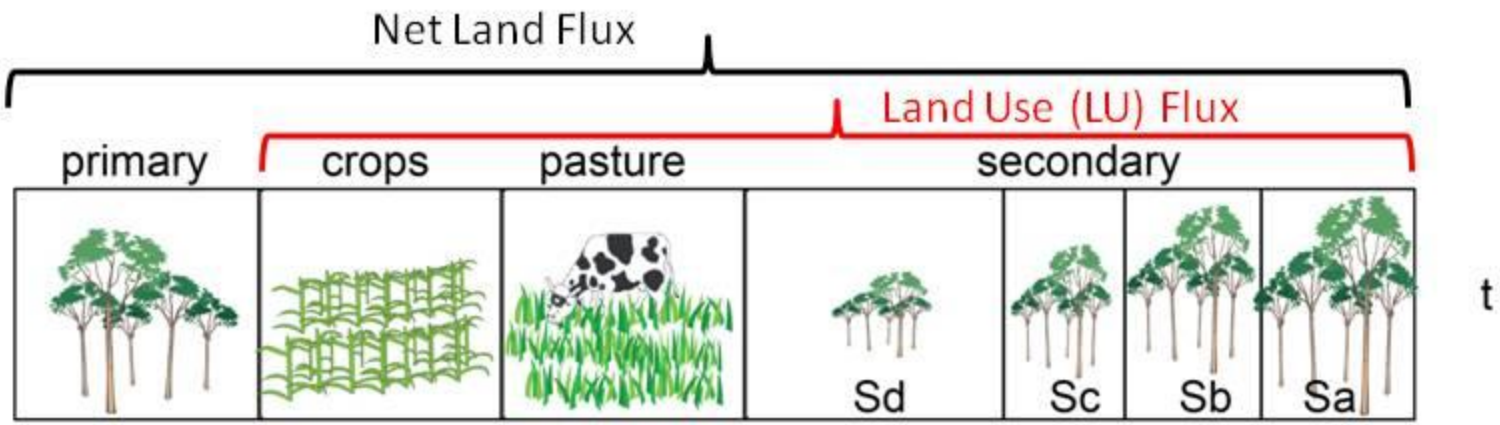
LM3 Sub-grid-cell heterogeneity and age structure

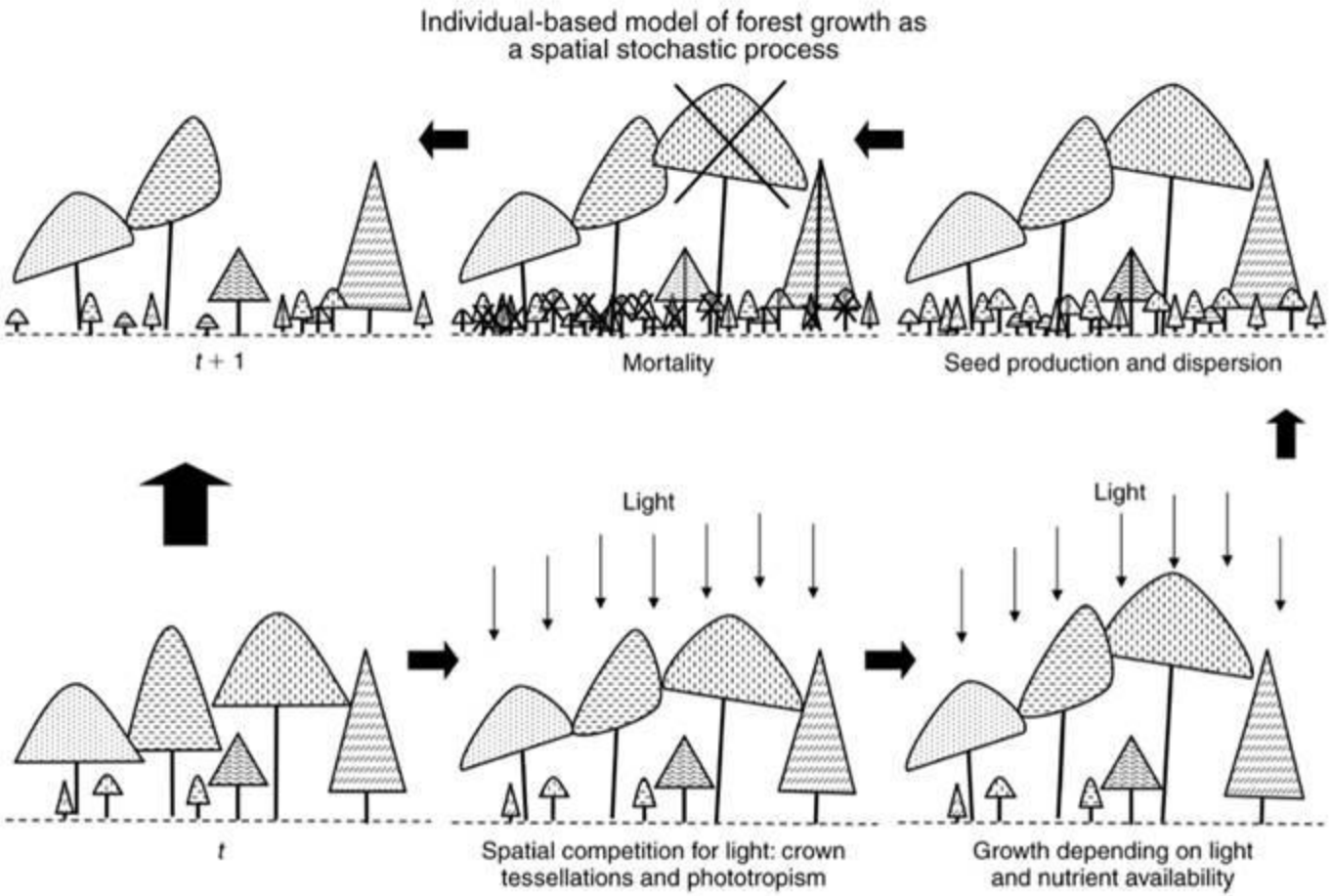


- Typical grid size 1 degree ≈ 100 km
- Disturbances occur at much smaller scales
- LM3 uses independent land tiles within each grid cell
  - Primary forest, secondary forest, pasture, crops are separate tiles
  - Multiple tiles represent secondary forest age structure
  - New secondary tiles generated 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

Slide courtesy of Ben Sulman

Next generation of models

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



Slide courtesy of Ben Sulman

From Strigul *et al.* (2008)

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.