Vegetation demographics in Earth System Models: More progress, new priorities?

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With lots of help from the DBEN workshop team!

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RESEARCH REVIEW

WILEY Global Change Biology

Vegetation demographics in Earth System Models: A review of progress and priorities

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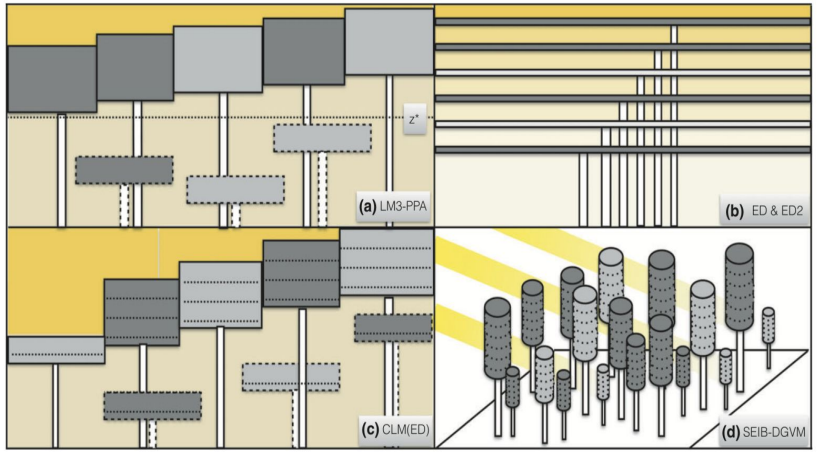
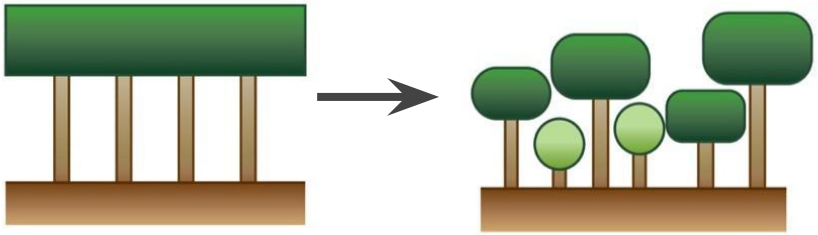


TABLE 1 Table of attributes of vegetation demographics models

Model acronym	Name	Vegetation representation
SEIB	Spatially Explicit Individual-Based model	Individual
LPJ-GUESS	Lund-Potsdam-Jena General Ecosystem Simulator	Individual or Cohort
LM3-PPA	Perfect Plasticity Approximation	Cohort
ED	Ecosystem Demography model	Cohort
ED2	Ecosystem Demography model v2	Cohort
CLM(ED)	Community Land Model with Ecosystem Demography	Cohort

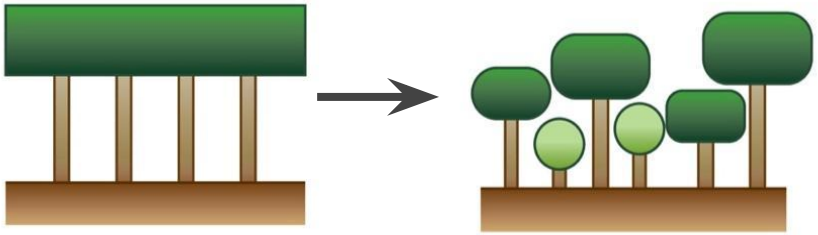
Why resolve demography?



“Big-Leaf” vegetation

Demographic Vegetation

Why resolve demography?



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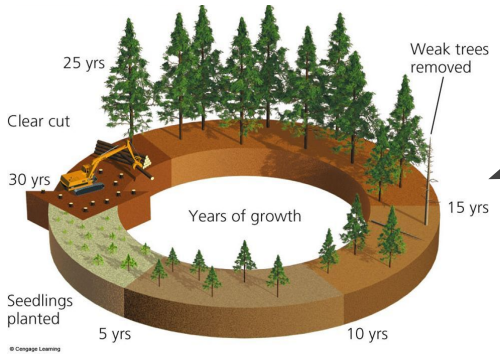


Tool for **predictive biogeography:** test hypotheses of how plant traits affect distribution in space and time

Climate - vegetation **timelags**

Regrowth after disturbance or land use change

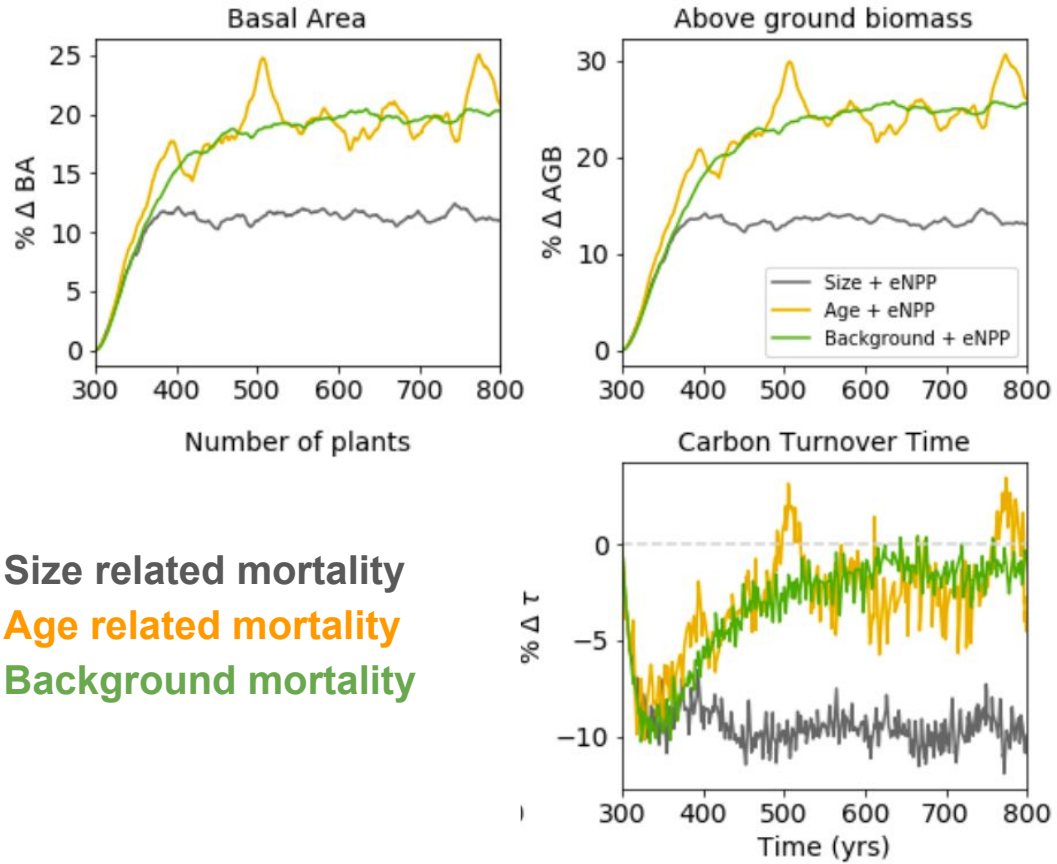
Better correspondence with **real world data.**

Some mechanisms are intrinsically demographic

If trees die as a function of age, eCO2 gives **twice as much biomass** as if they die as a function of size.

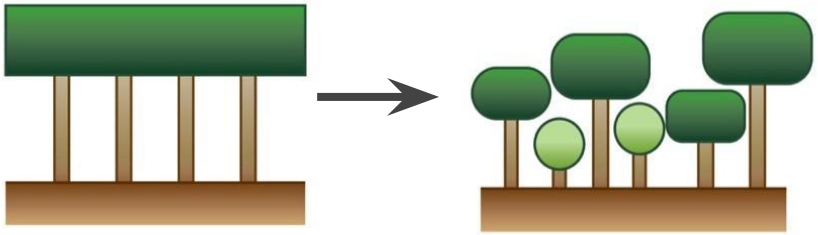
If you don't resolve demography, you can't do this.

Needham et al.
GCB, 2020



Size related mortality
Age related mortality
Background mortality

Why resolve demography?



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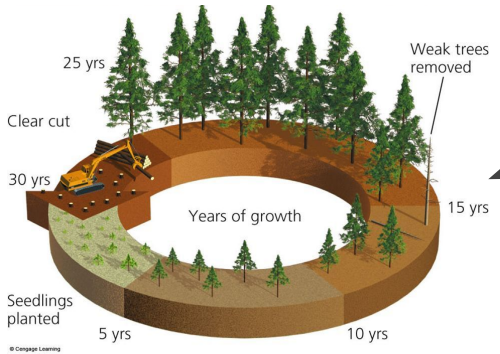

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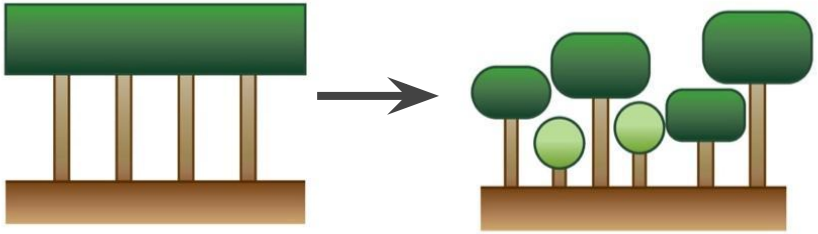
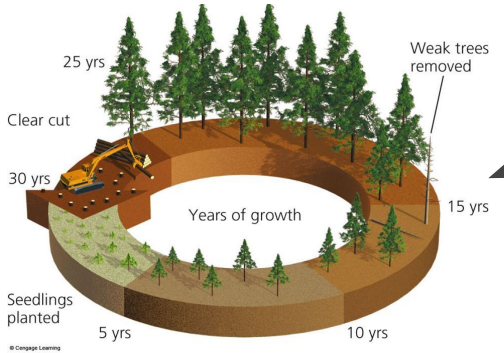


"Big-Leaf" vegetation

Demographic Vegetation



Regrowth after disturbance or land use change

Why resolve demography?

INDC/Net Zero scenarios
Carbon offsets schemes
REDD+

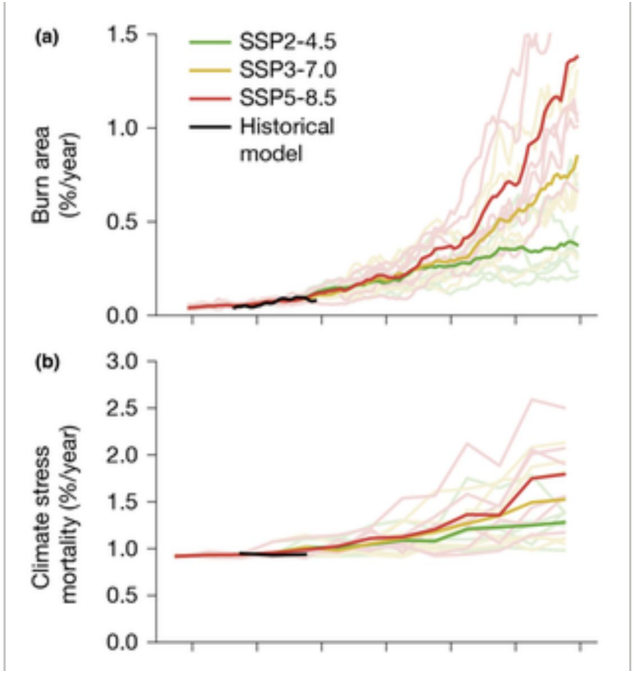
Desperate efforts, typically assume:
no climate driven risks (fire, drought)
no CO_2 fertilization
no climate feedbacks

Demographic land surface models are the only frameworks that have all this stitched together **and** can resolve forest management impacts…

So we have work to do!

Future climate risks from stress, insects and fire across US forests

William R. L. Anderegg ✉, Oriana S. Chegwidden, Grayson Badgley, Anna T. Trugman, Danny Cullenward, John T. Abatzoglou, Jeffrey A. Hicke, Jeremy Freeman, Joseph J. Hamman



A vertically discretised canopy description for ORCHIDEE (SVN r2290) and the modifications to the energy, water and carbon fluxes

K. Naudts[1,14], J. Ryder[1], M. J. McGrath[1], J. Otto[1,10], Y. Chen[1], A. Valade[1], V. Bellasen[2], G. Berhongaray[3], G. Bönisch[4], M. Campioli[3], J. Ghattas[1], T. De Groote[3,11], V. Haverd[5], J. Kattge[4], N. MacBean[1], F. Maignan[1], P. Merilä[6], J. Penuelas[7,12], P. Peylin[1], B. Pinty[8], H. Pretzsch[9], E. D. Schulze[4], D. Solyga[1,13], N. Vuichard[1], Y. Yan[3], and S. Luyssaert[1]

Accounting for forest age in the tile-based dynamic global vegetation model JSBACH4 (4.20p7; git feature/forests) – a land surface model for the ICON-ESM

Julia E. M. S. Nabel[1], Kim Naudts[1,a], and Julia Pongratz[1,b]

[1]Max Planck Institute for Meteorology, 20146 Hamburg, Germany
[a]now at: Department of Earth Sciences, VU University Amsterdam, Amsterdam, the Netherlands
[b]now at: Ludwig-Maximilians-Universität München, Munich, Germany

Robust Ecosystem Demography (RED version 1.0): a parsimonious approach to modelling vegetation dynamics in Earth system models

Arthur P. K. Argles[1], Jonathan R. Moore[1], Chris Huntingford[2], Andrew J. Wiltshire[3], Anna B. Harper[1], Chris D. Jones[3], and Peter M. Cox[1]

[1]College of Engineering, Mathematics, and Physical Sciences, University of Exeter, Exeter EX4 4QF, UK
[2]UK Centre for Ecology and Hydrology, Wallingford OX10 8BB, UK
[3]Met Office Hadley Centre, Fitzroy Road, Exeter EX1 3PB, UK

Modeling demographic-driven vegetation dynamics and ecosystem biogeochemical cycling in NASA GISS's Earth system model (ModelE-BiomeE v.1.0)

Ensheng Weng[1,2], Igor Aleinov[1,2], Ram Singh[1,2], Michael J. Puma[1,2], Sonali S. McDermid[3], Nancy Y. Kiang[2], Maxwell Kelley[2], Kevin Wilcox[4], Ray Dybzinski[5], Caroline E. Farrior[6], Stephen W. Pacala[7], Benjamin I. Cook[2]

A new version of the CABLE land surface model (Subversion revision r4601) incorporating land use and land cover change, woody vegetation demography, and a novel optimisation-based approach to plant coordination of photosynthesis

Vanessa Haverd[1], Benjamin Smith[1,2], Lars Nieradzik[3], Peter R. Briggs[1], William Woodgate[4], Cathy M. Trudinger[5], Josep G. Canadell[1], and Matthias Cuntz[6]

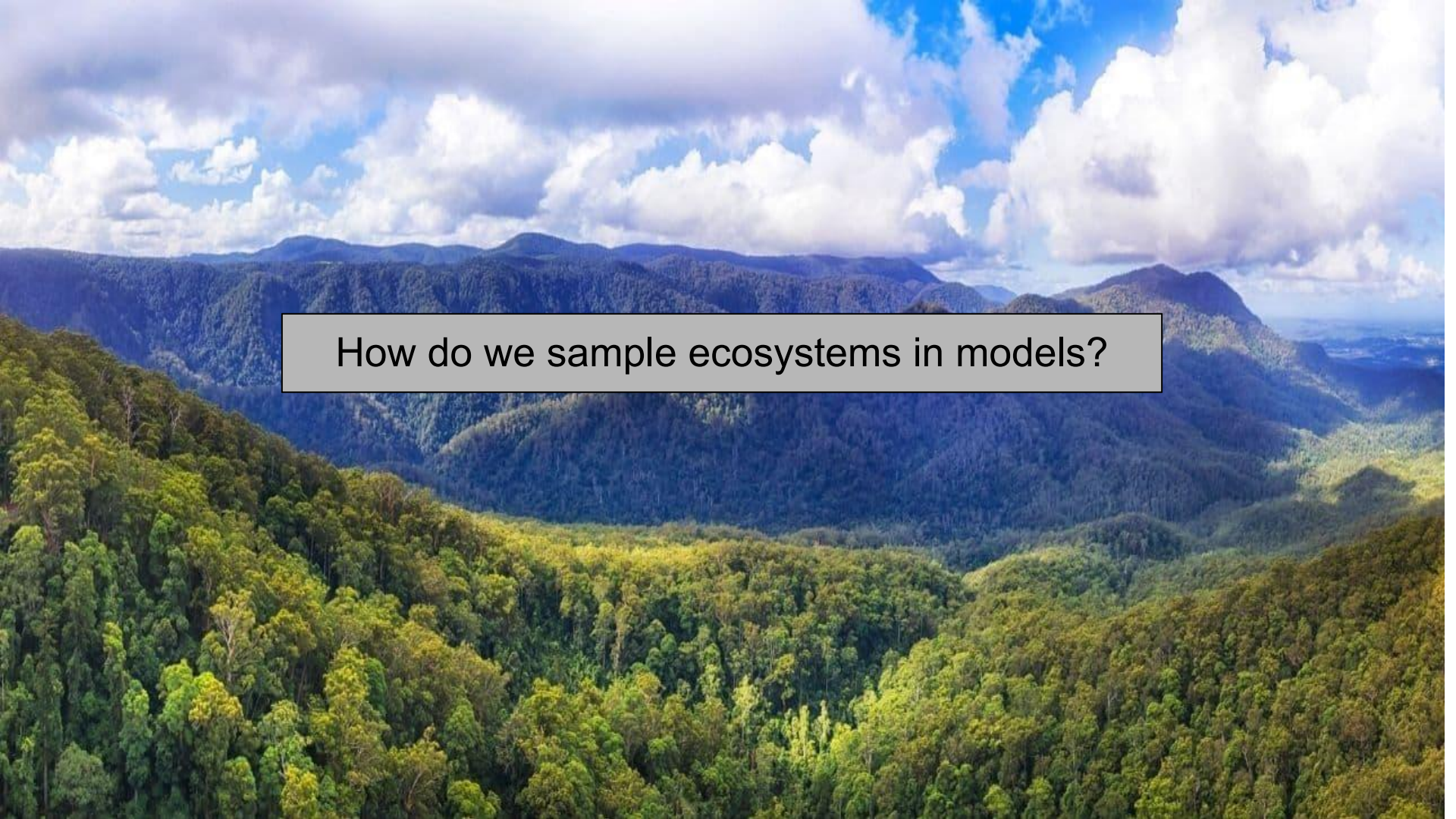
[1]CSIRO Oceans and Atmosphere, Canberra, 2601, Australia
[2]Dept. of Physical Geography and Ecosystem Science, Lund University, Sölvegatan 12, 22362 Lund, Sweden
[3]Centre for Environmental and Climate Research (CEC), Lund University Sölvegatan 37, 22362 Lund, Sweden
[4]CSIRO Land & Water, Canberra, 2601, Australia
[5]CSIRO Oceans and Atmosphere, Melbourne, 3195, Australia
[6]INRA, Université de Lorraine, AgroParisTech, UMR Silva, 54000 Nancy, France

Benchmarking and parameter sensitivity of physiological and vegetation dynamics using the Functionally Assembled Terrestrial Ecosystem Simulator (FATES) at Barro Colorado Island, Panama

Charles D. Koven[1], Ryan G. Knox[1], Rosie A. Fisher[2,3], Jeffrey Q. Chambers[1,4], Bradley O. Christoffersen[5], Stuart J. Davies[6], Matteo Detto[7,8], Michael C. Dietze[9], Boris Faybishenko[1], Jennifer Holm[1], Maoyi Huang[10], Marlies Kovenock[11], Lara M. Kueppers[1,12], Gregory Lemieux[1], Elias Massoud[13], Nathan G. McDowell[10], Helene C. Muller-Landau[6,7], Jessica F. Needham[1], Richard J. Norby[14], Thomas Powell[1], Alistair Rogers[15], Shawn P. Serbin[15], Jacquelyn K. Shuman[2], Abigail L. S. Swann[11,16], Charuleka Varadharajan[1], Anthony P. Walker[14], S. Joseph Wright[7], and Chonggang Xu[17]

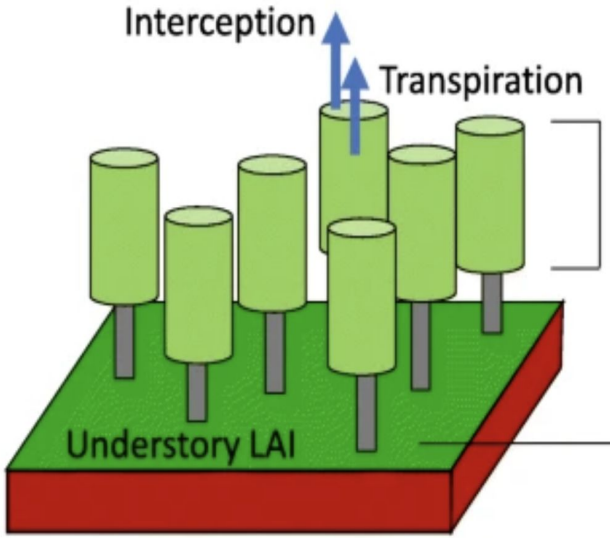
Demographic model BENchmarking meeting

(thanks to TAnnemarie Eckes-Shephard & Tom Pugh @Lund for organizing)

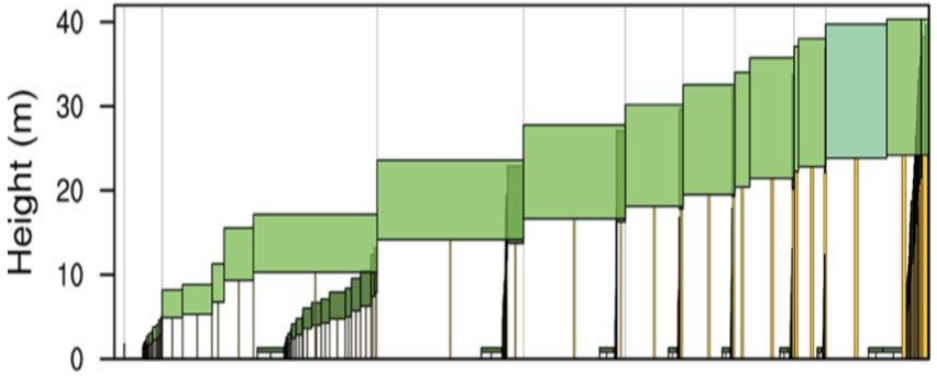

How do we sample ecosystems in models?

Cohorts or individuals?

SEIB-DGVM



Sato et al. 2015



FATES

LPJ-GUESS

ED2

CABLE-POP

LM3-PPA

ORCHIDEE

BiomeE

JSBACH4.0

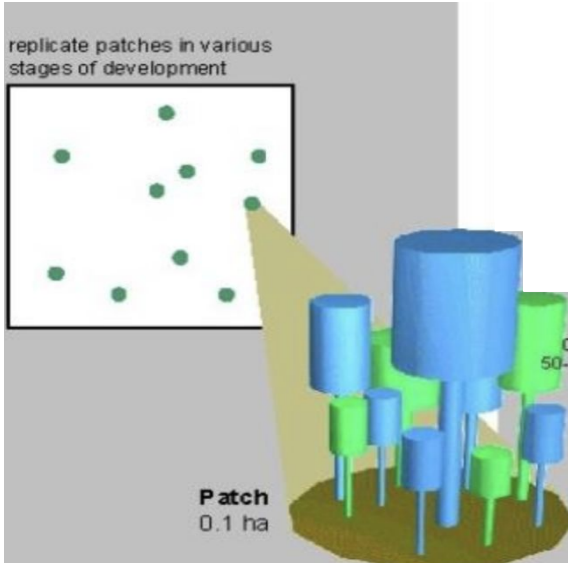
JULES-RED

Patch sampling or statistical approximation?

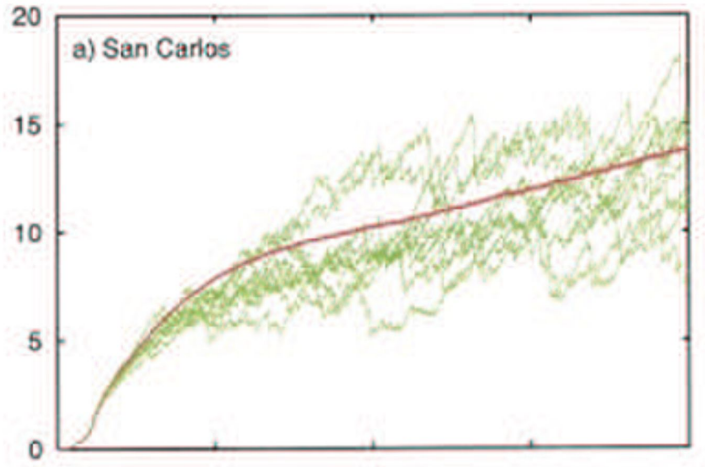
SEIB-DGVM

CABLE-POP

LPJ-GUESS



Haverd et al. 2015



FATES

ED2

LM3-PPA

ORCHIDEE

BiomeE

JSBACH4.0

JULES-RED

Multiple vs. single PFT canopies (light competition)

FATES

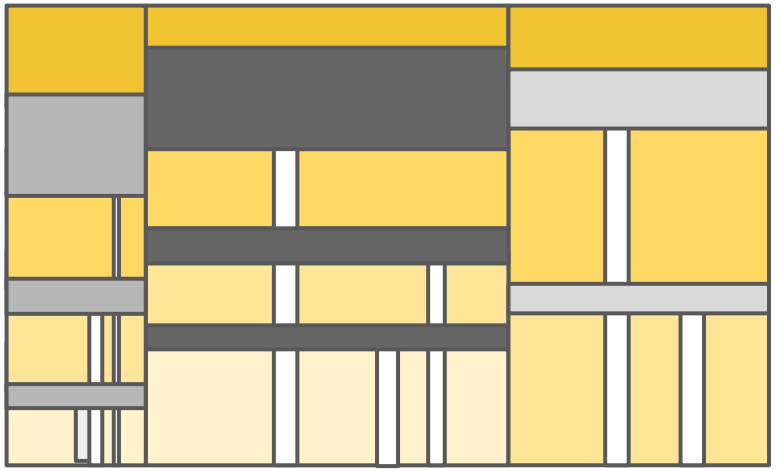
ED2

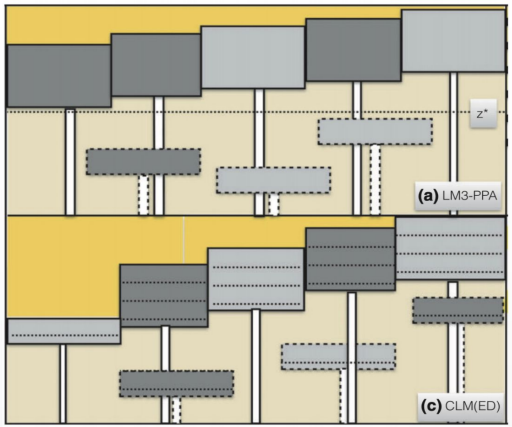
SEIB-DGVM

LM3-PPA

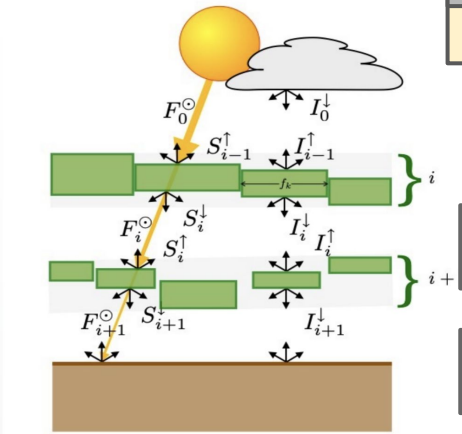
LPJ-GUESS

BiomeE





Fisher et al 2017



Shevliakova et al (in rev.)

JSBACH4.0

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Static vs. prognostic PFT composition (‘dynamic vegetation’)

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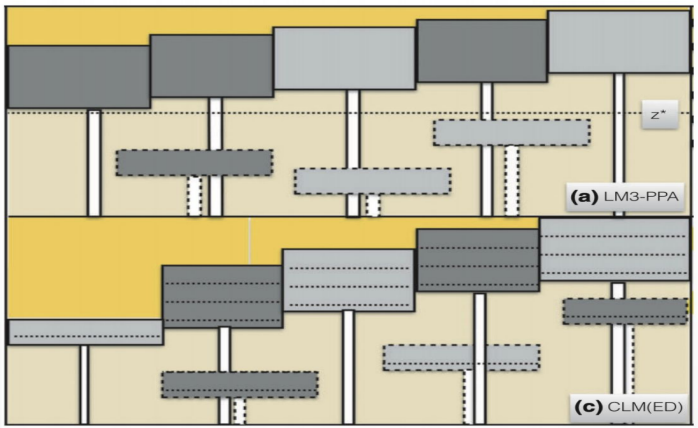
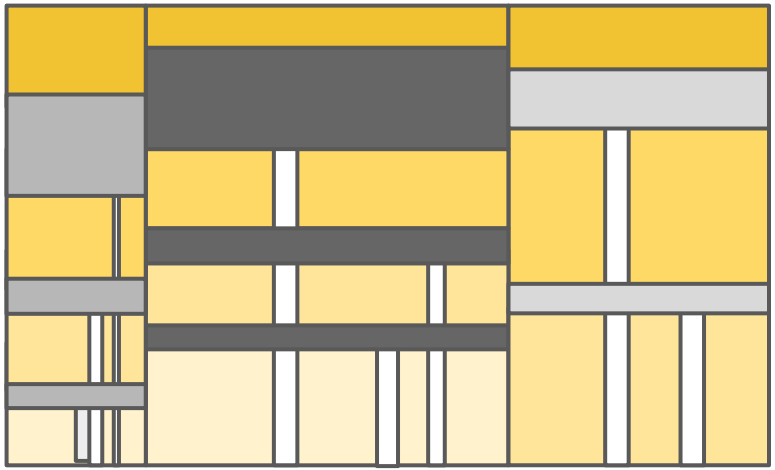


Fisher et al 2017



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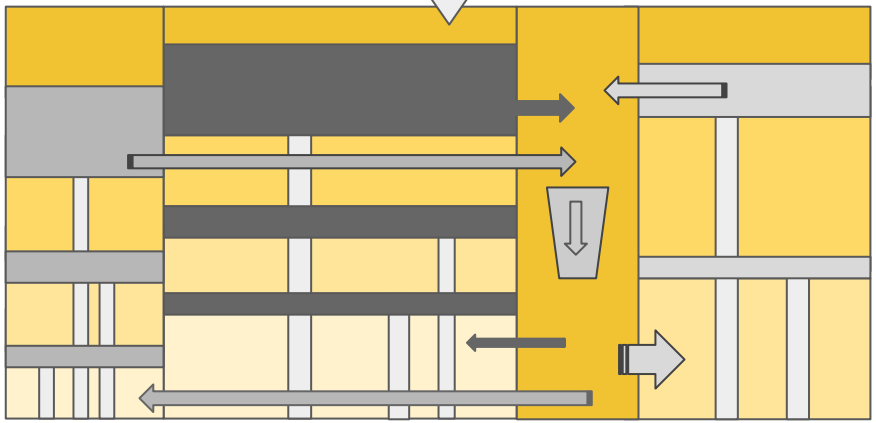
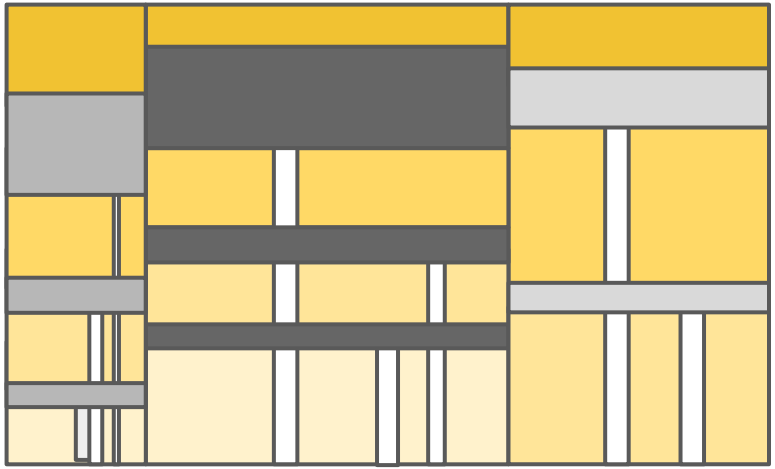




JSBACH4.0

ORCHIDEE

CABLE-POP

Disaggregated canopy vs cohort/individual physiology.

FATES

ED2

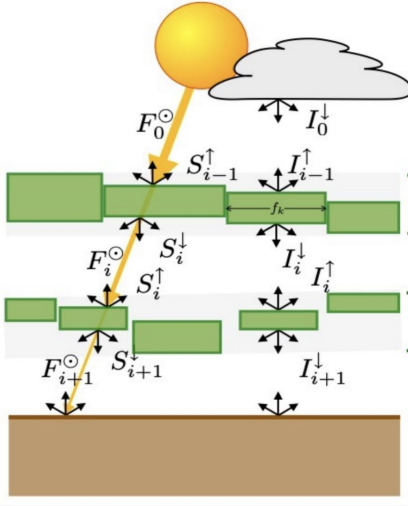
SEIB-DGVM

LM3-PPA

LPJ-GUESS

BiomeE

ORCHIDEE



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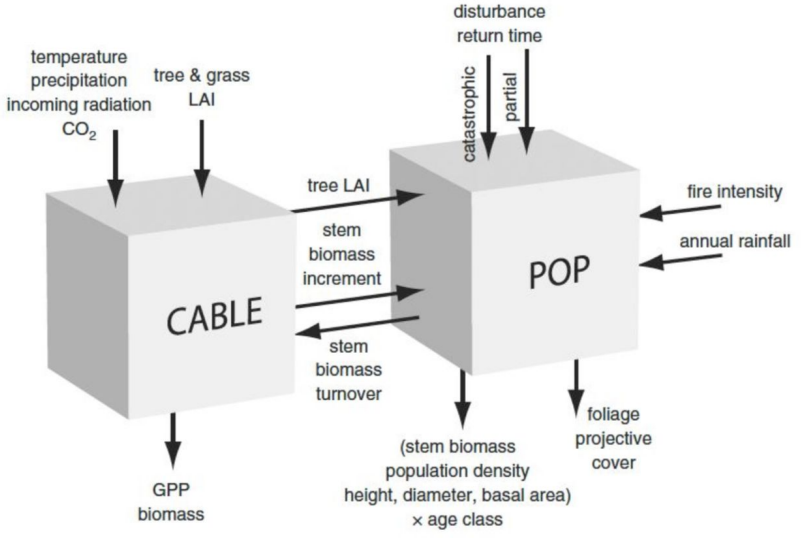


JSBACH4.0

CABLE-POP

JULES-RED

Eulerian (size class) vs. Lagrangian (cohorts)

FATES

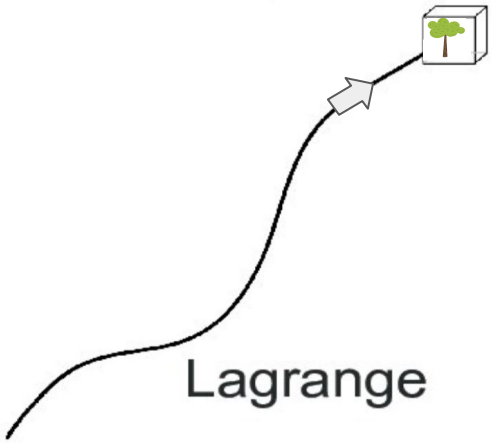
ED2

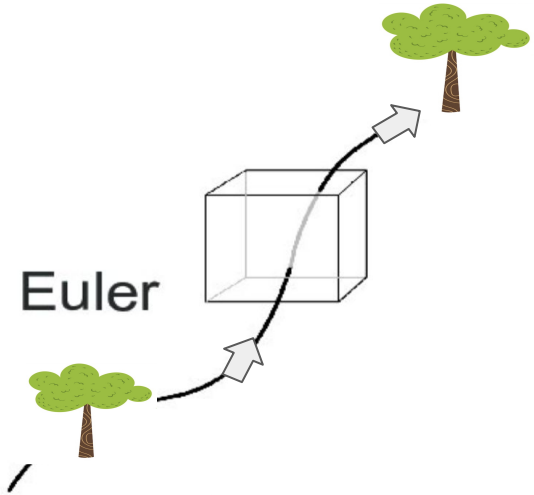
SEIB-DGVM

LM3-PPA

LPJ-GUESS

BiomeE





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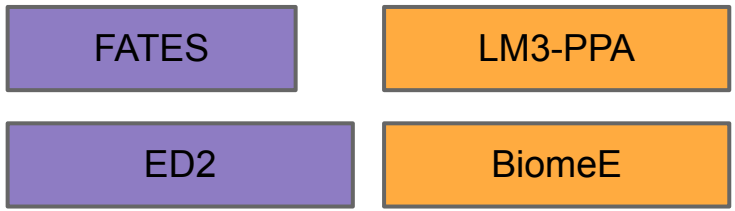
ED (ecosystem demography) vs. PPA (perfect plasticity approximation)



ED (ecosystem demography) vs. PPA (perfect plasticity approximation)

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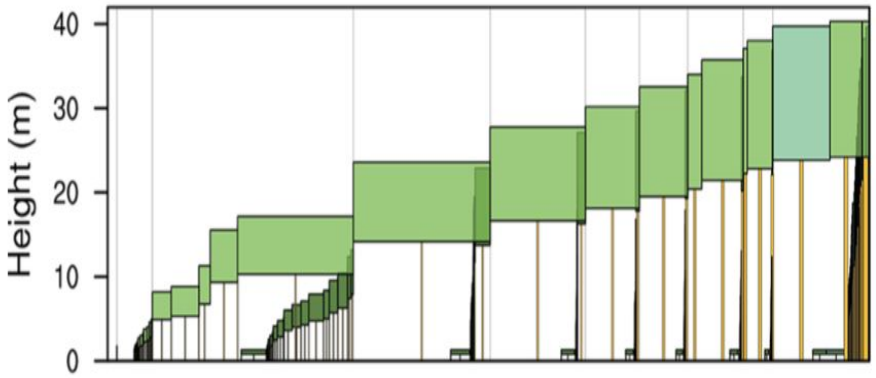
ED2

LM3-PPA

BiomeE

Size since disturbance tiling



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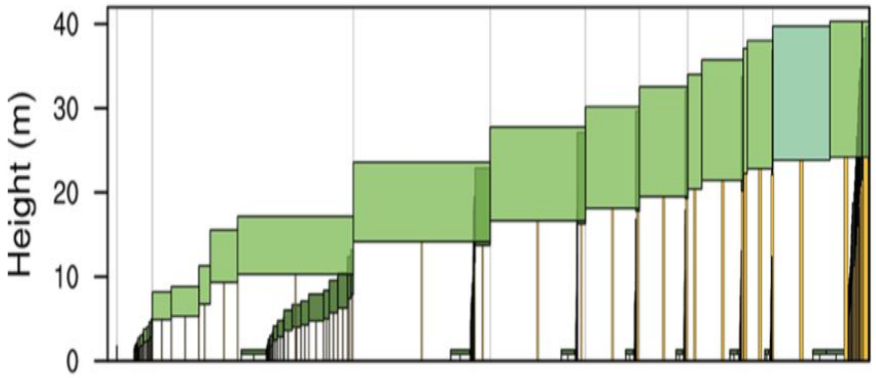

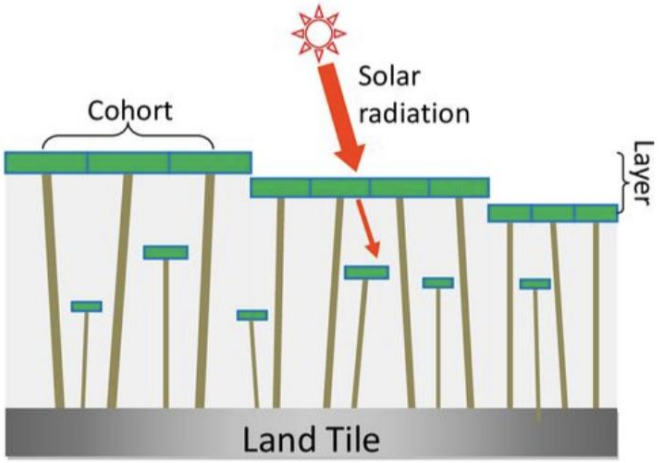

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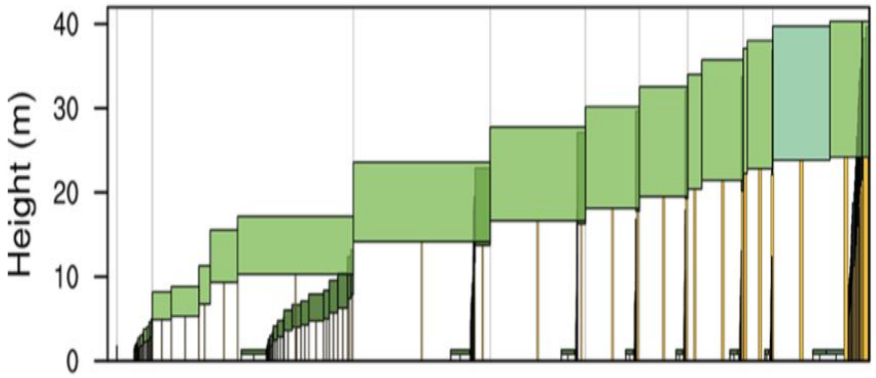
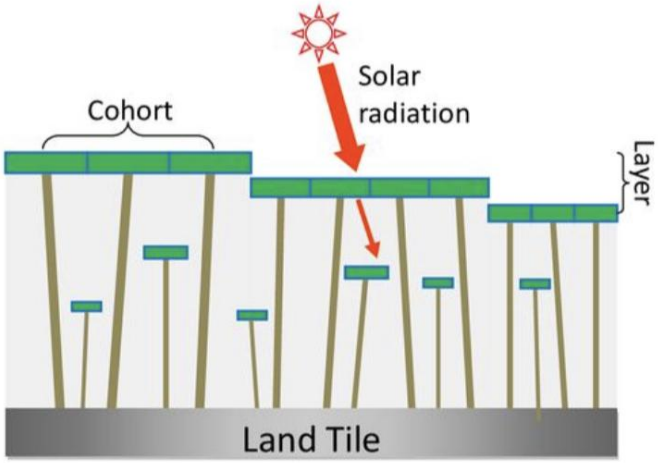


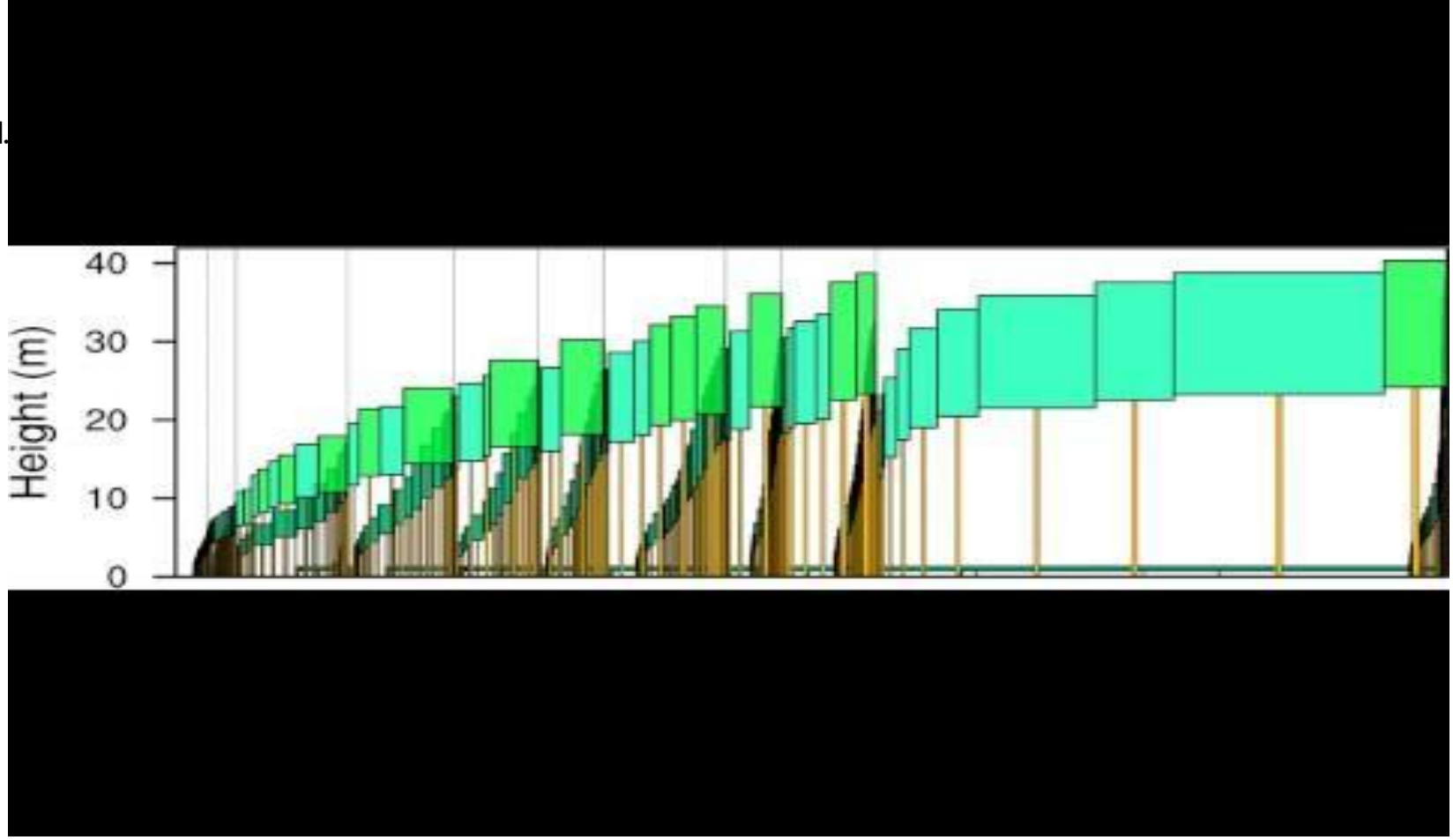


FATES model

Koven et al. 2019

CANOPY

UNDER STORY



Short Tree Cohorts
Young Patches

Early Successional PFT
Late Successional PFT

Tall Tree Cohorts
Old Patches

How do we aggregate ecosystems into demographic models?

Cohorts vs individuals

Patch sampling vs. Statistical aggregation

Dynamic vs. not dynamic vegetation

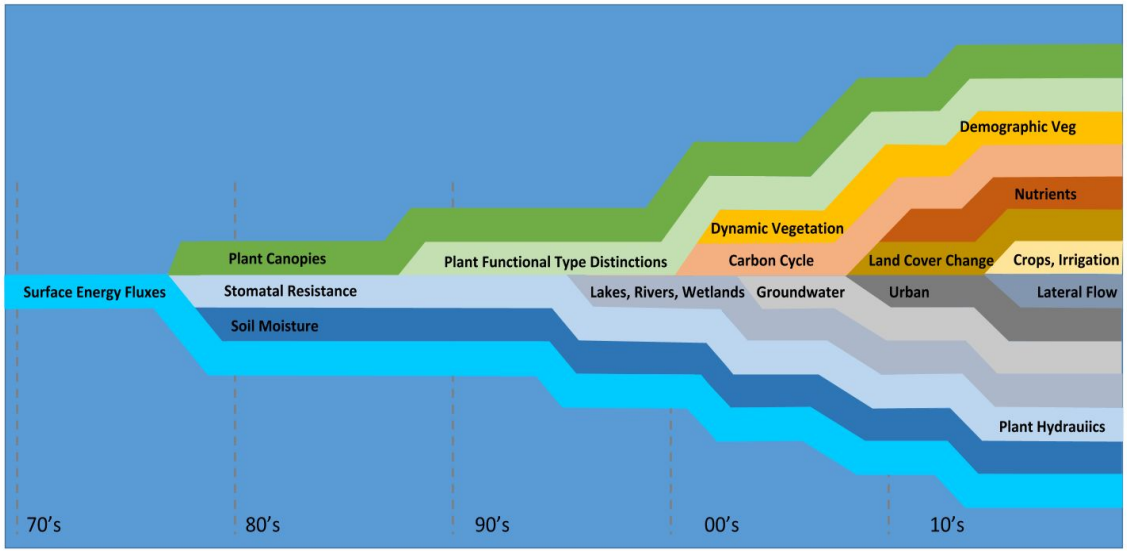
Multiple vs. single pft canopies

Canopy vs. cohort level fluxes

Eulerian vs. Lagrangian

Our existing ensemble turns out to be a quite good sampling of this space…

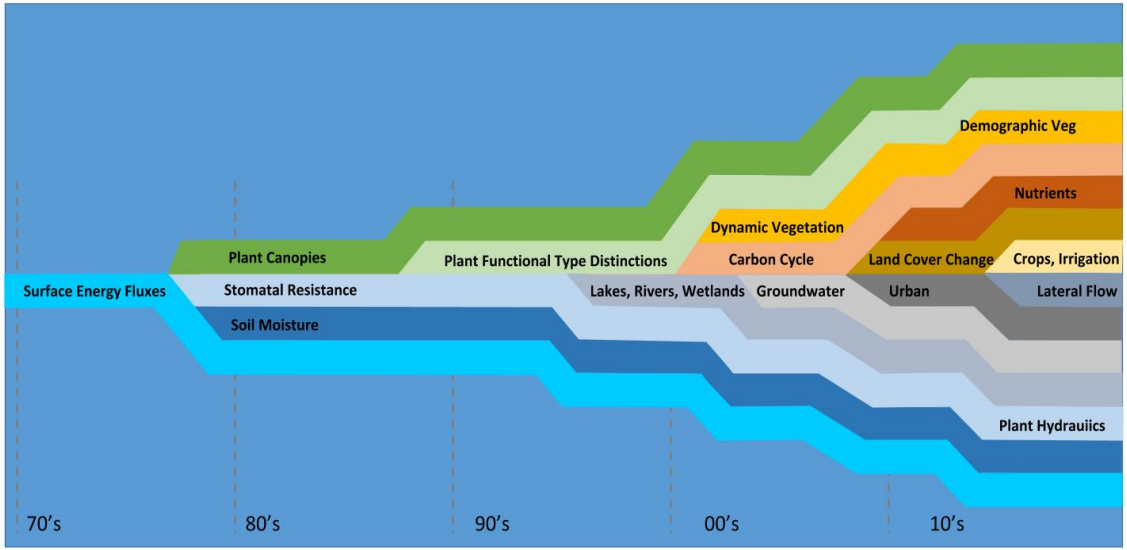
How connected up are demographic models?

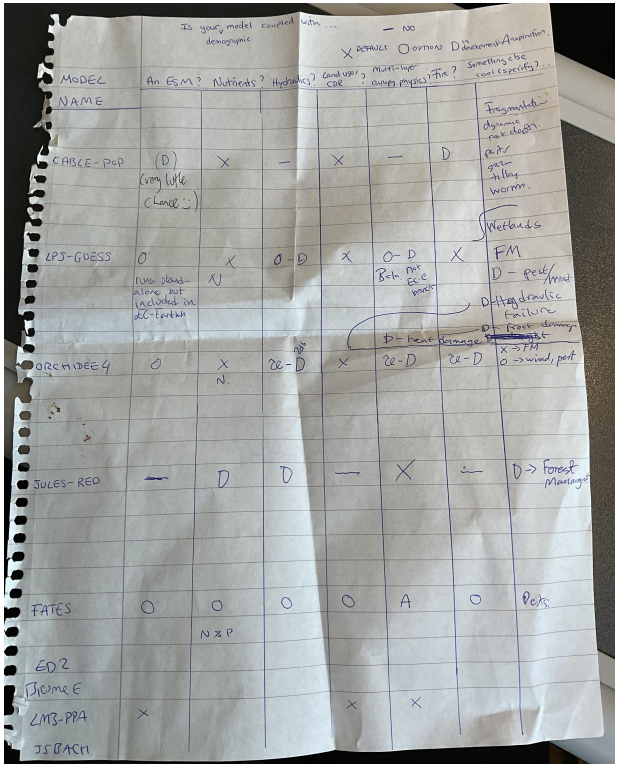


Fully integrated models or code branches?

Fisher and Koven 2020

How connected up are demographic models?





Are we nearly there yet?

	ESM	Nutrients	Hydraulics	Land Use change	Multi-layer physics	Fire
FATES	O	O (N&P)	O	O	A	O
JULES-RED	A	D	D	N	N	N
ORCHIDEE	O	X (N)	OreD	X	OreD	OreD
CABLE-POP	D	X (N)	N	X	N	D
SEIB-DGVM	O	N	N	N	N	X
LPJ-GUESS	O	X (N)	OreD	X	OreD	X
LM3-PPA	O	X (N)	X	X	X	X
JSBACH4	O	D	N	D	N	X
Key	X Default	O Option	OreD Option in redevelopment	D: In development	A: Aspiration	N: No

A variety of approaches to ‘ambient’ mortality

	Growth Efficiency	Carbon starvation	Self thinning	Age	Background	Episodic stand replacement
FATES		X			X	
JULES-RED					X	
ORCHIDEE			X			
CABLE-POP	X		X	X		X
JSBACH4.0						
LPJ-GUESS	X			X		X
LM3-PPA		X			X	
SEIB	X			X		

Heterogeneous implementation of forest hazards

	Hydraulic Failure	Fire	Freezing	Impact	Wind-throw	Bio-climate	Heat	Insects
FATES	X	X	X	X	D			D
JULES-RED								
ORCHIDEE	D	D	D					D
CABLE-POP								
JSBACH4.0								
LPJ-GUESS		X	D	X				
LM3-PPA				X				
SEIB		X				X	X	

Interesting interactions between hardening, hydraulics and drought mortality

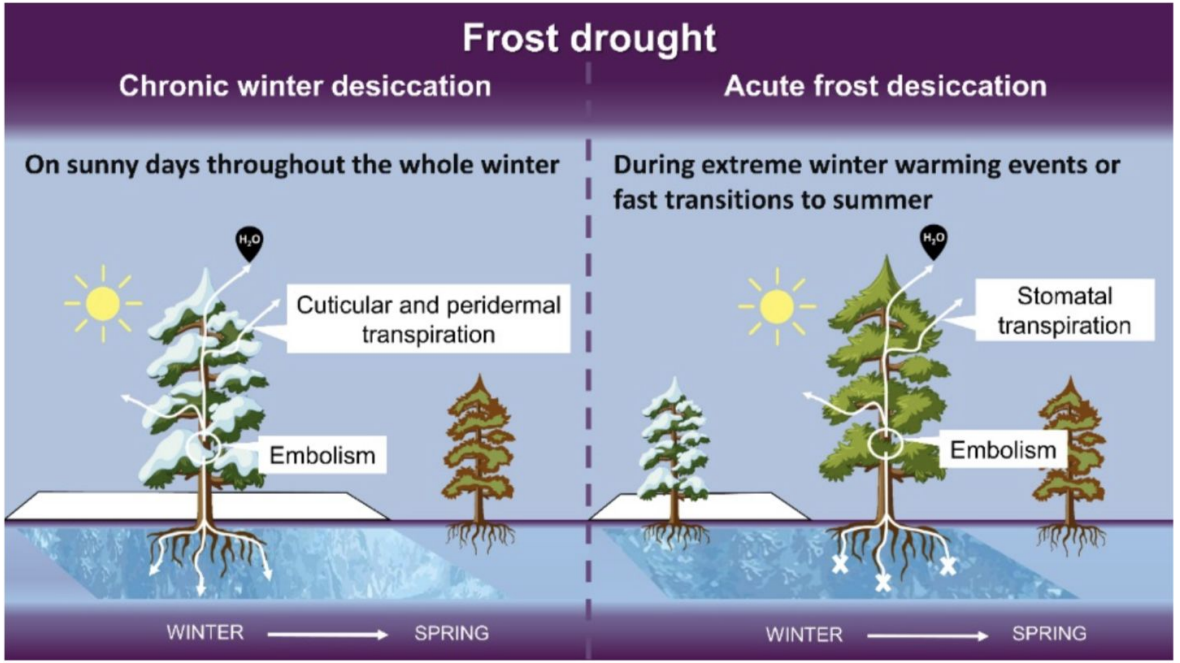


Figure 3: *Types of frost drought: left) Chronic winter desiccation resulting from root water exudation and winter transpiration, right) Acute frost desiccation from fast transition to summer and lack of available liquid soil water.*

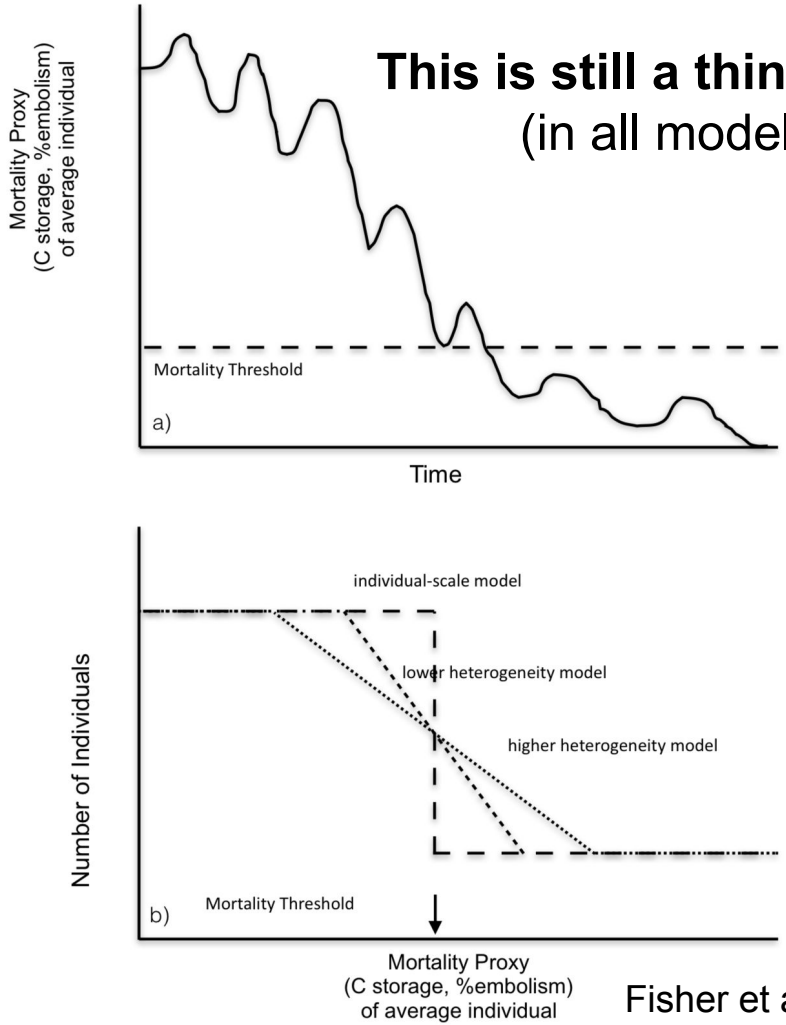
Lambert et al, in review (GMD), poster by Kjetil Aas

Trees do not die all at the same time!

We must scale from **average individual stress** to **cohort level mortality** rate

This slope requires empirical parameterization.

This reflects the **heterogeneity of stress across the landscape.**



Fisher et al 2018

Conclusions

The world desperately needs operational systems that predict the size of and risks to terrestrial carbon sinks.

In the absence of much greater investment in land carbon science, society risks making huge errors in its emerging attempts to mitigate climate change.

Demographic models provide the only framework that connects age related forest C uptake with climate risks and feedbacks.

Most LSMs now have vegetarian demographics.

The era of (collaborative) calibration and benchmarking has arrived…
(see Daniel Kennedy &Charlie Koven's talks tomorrow)

https://github.com/NGEET/fates

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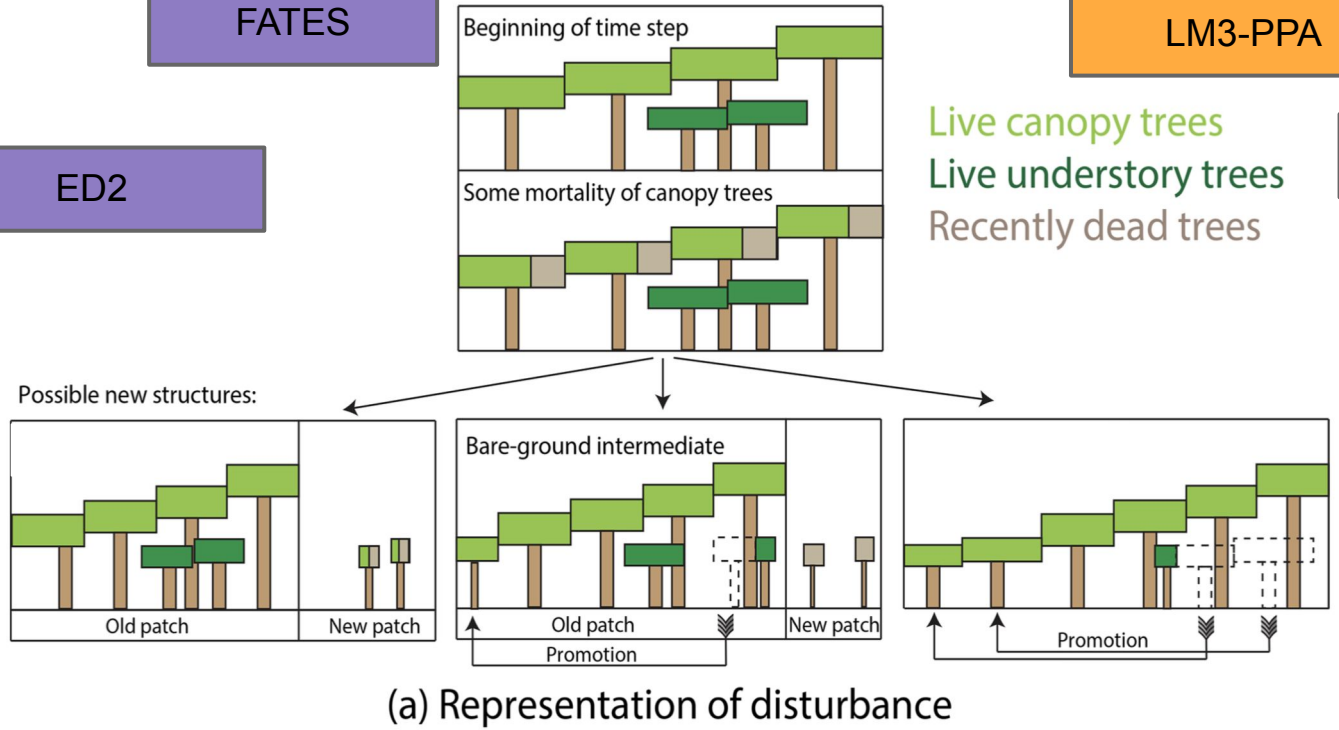
ED (ecosystem demography) vs. PPA (perfect plasticity approximation)

FATES

ED2

LM3-PPA

BiomeE



(a) Representation of disturbance

Koven et al. 2020