

The Functionally Assembled Terrestrial Ecosystem Simulator (FATES): A Community tool for vegetation demographics, physiology and hydrodynamics.

Rosie A. Fisher,

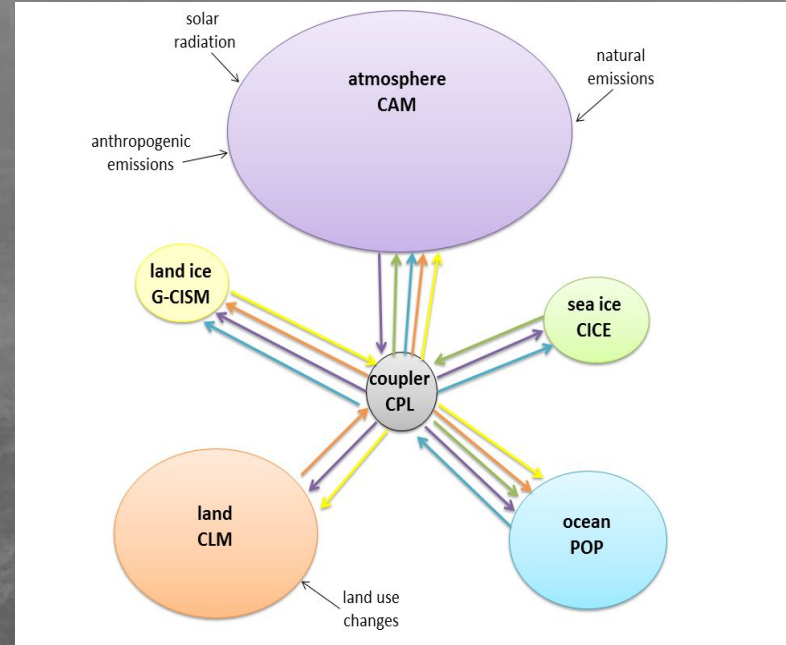
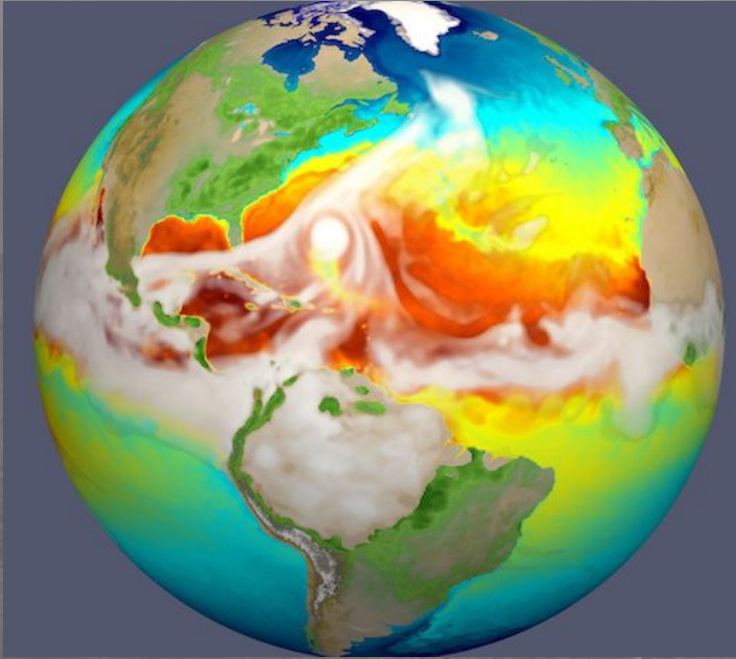
Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique, Toulouse.

National Center for Atmospheric Research, Boulder, CO

@CLM_science. <https://github.com/ngaet/fates>

Thanks to: **Charlie Koven, Ryan Knox, Dave Lawrence & the CLM and FATES development communities**

The Community Earth System Model (CESM)





The Community Land Model (CLM)

JAMES

**Journal of Advances in
Modeling Earth Systems**

Research Article |  Open Access |    

The Community Land Model version 5: Description of new features, benchmarking, and impact of forcing uncertainty

David M. Lawrence✉, Rosie A. Fisher, Charles D. Koven, Keith W. Oleson, Sean C. Swenson, Gordon Bonan, Nathan Collier, Bardan Ghimire, Leo van Kampenhout, Daniel Kennedy, Erik Kluzek, Peter J. Lawrence, Fang Li, Hongyi Li, Danica Lombardozzi, William J. Riley, William J. Sacks, Mingjie Shi, Mariana Vertenstein, William R. Wieder, Chonggang Xu,

&

Kennedy et al. (hydraulics),
Wieder et al. (fertilization responses)
Fisher et al. (parameter sensitivity)
Bonan et al. (forcing sensitivity)
Oleson et al. (urban model)
Cheng et al. (N cycle testing)

CLM is the land surface scheme of the CESM

Version 5 latest version.

Documented in AGU virtual issue,

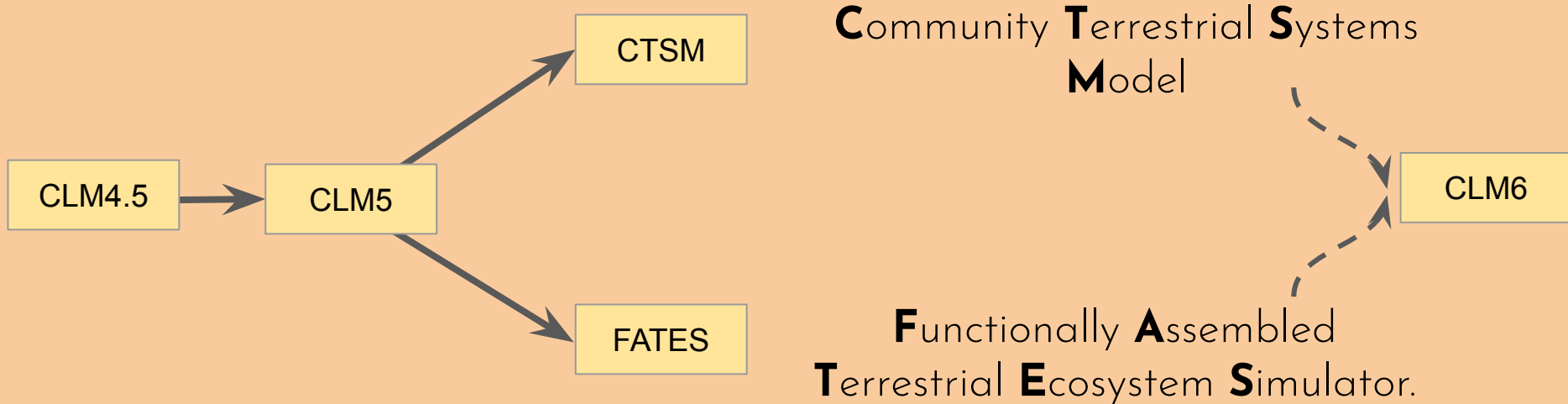
Ongoing public code development:

<https://github.com/ESCOMP/CTSM>

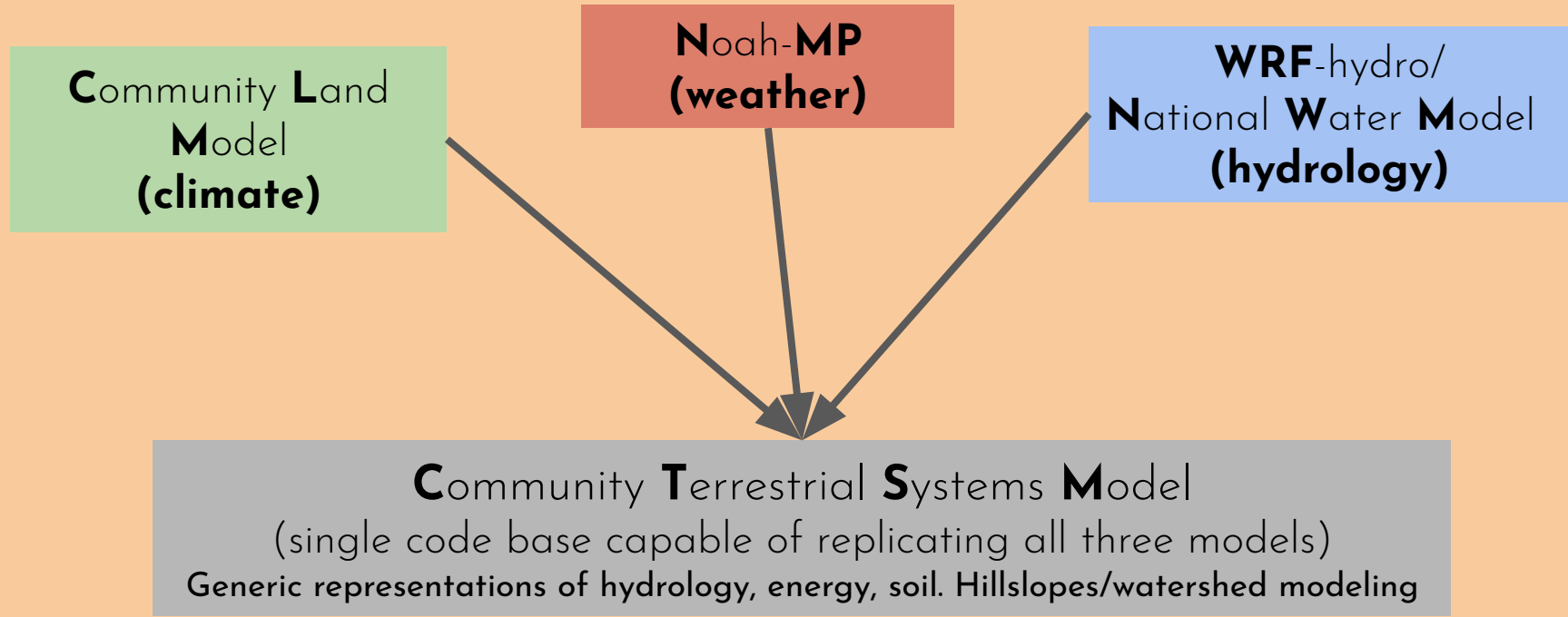
Technical note and user support:

www.cesm.ucar.edu/models/cesm2/land/

WHAT COMES NEXT?



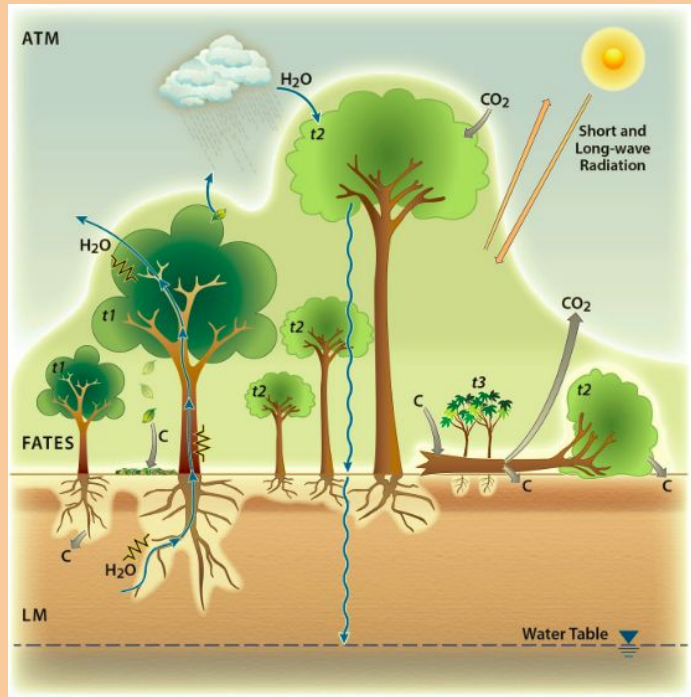
CTSM: CLIMATE&WEATHER LAND MODEL UNIFICATION



“...replacing a hard political problem with a hard software engineering problem...”

FATES:

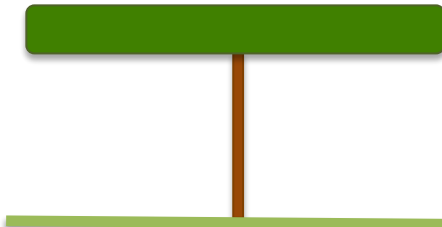
THE FUNCTIONALLY ASSEMBLED TERRESTRIAL ECOSYSTEM SIMULATOR



FATES
is an **open-source** module,
designed to run within a host
land surface model,
that simulates:
plant **physiology**,
competition processes,
ecosystem **assembly**
and
vegetation distribution

Ecological processes in earth surface models

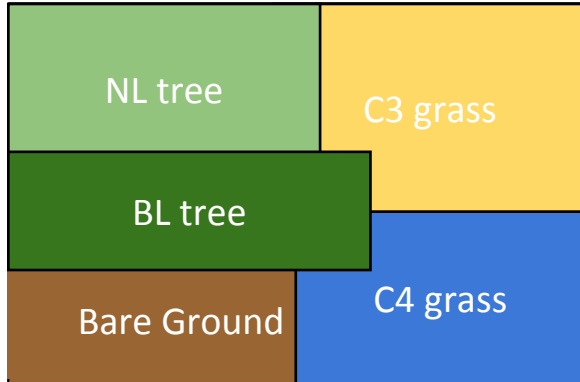
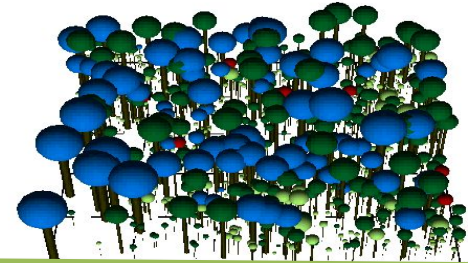
Big Leaf Model



Cohort model



Stochastic Individual Model

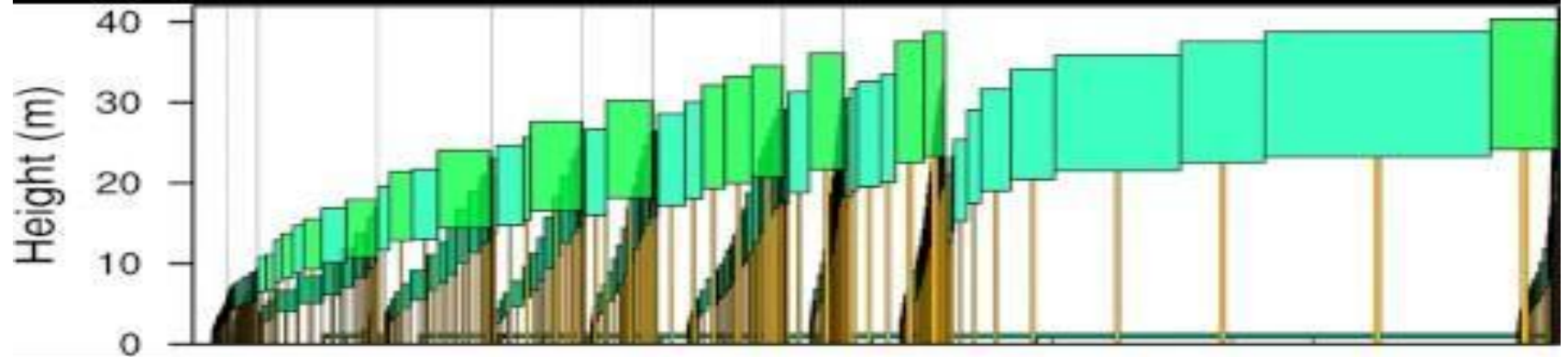


Recruitment

Growth
Competition
Co-existence
Exclusion

Mortality



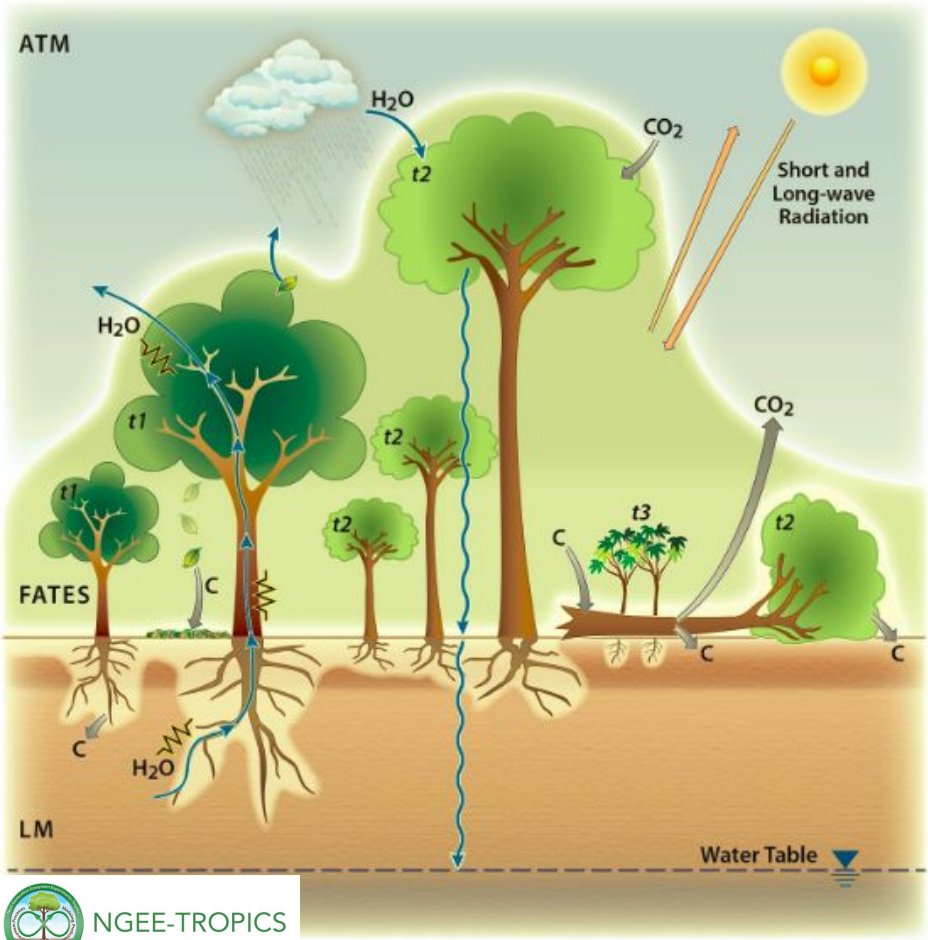


Short Tree Cohorts
Young Patches

Early Successional PFT
Late Successional PFT

Tall Tree Cohorts
Old Patches

How can demographic representation improve **ecological predictions**?

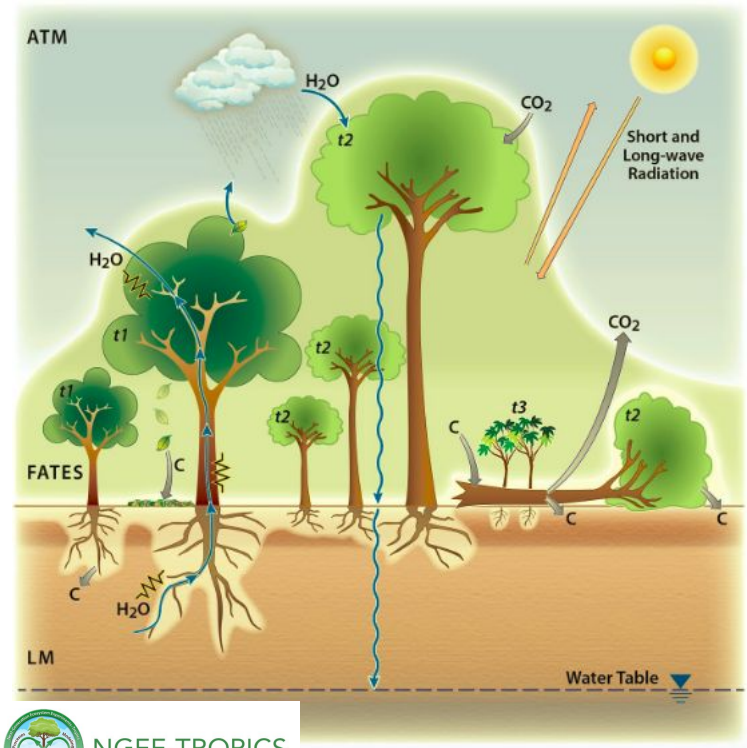


'Ecological' Motivations

- Representation of competition for light, succession, **regrowth after disturbance**.
- **Prognostic trait distribution** (why plants grow where they do).
- Demographic **lags** between climate and vegetation change



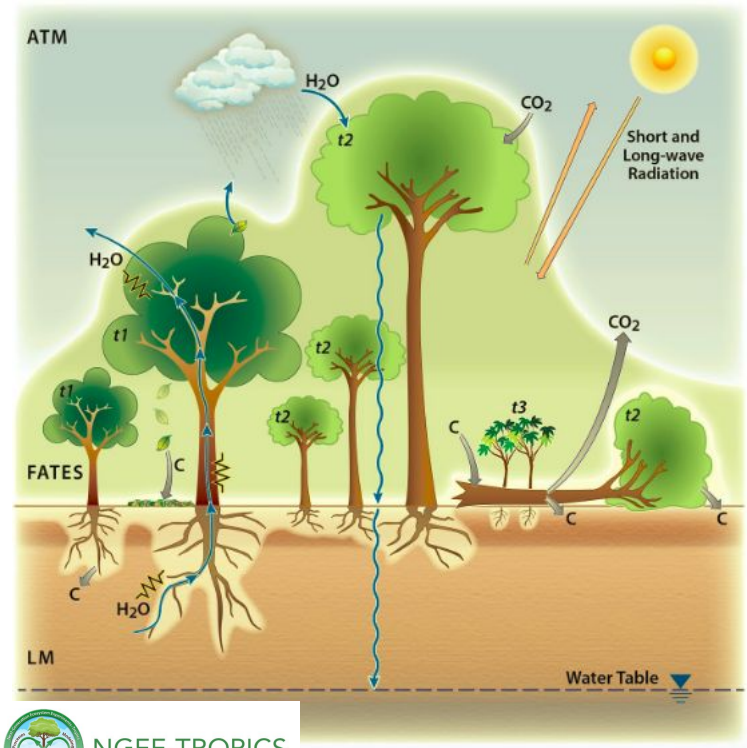
Demographic representation facilitates improved **physical process representation**.



NGEE-TROPICS

- Radiation Transfer
 - Vertically mixed PFTs, link to emerging EO products
- Plant Hydrodynamics
 - Rooting depth, path length, canopy position, mortality
- Nutrients
 - N fixation in gaps. Allometry impacts on C:N
- Fire
 - Interactions between fire and canopy structure
- Recruitment
 - Responsive to light, climate. Dispersal limitations.
- Snow
 - Size structure affects snow burial, frost hardening.
- Pests
 - Bark beetles preferentially attack larger trees
- Land Use
 - Selective logging, LUH2, pasture disturbance, regrowth
- Canopy turbulence
 - Wind mortality
- Hydrology and hillslopes
 - Root profile structure. Hillslopes/vegetation interaction

Demographic representation facilitates improved **physical process representation**.



NGEE-TROPICS

EXISTING MODEL
FEATURES
ONGOING DEV'T

- **Radiation Transfer** (Fisher, Knox, Koven)
 - Vertically mixed PFTs, link to emerging EO products
- **Plant Hydrodynamics** (Christoffersen, Xu, McDowell, Knox)
 - Rooting depth, path length, canopy position, mortality
- **Nutrients N&P** (Knox, Walker, Koven, Fisher)
 - N fixation in gaps. Allometry impacts on C:N
- **Fire** (Shuman, Fisher, Koven, Ding, Kueppers, Levis, Buotte)
 - Interactions between fire and canopy structure
- **Recruitment** (Kueppers/Eriksen/Hanbury-Brown)
 - Responsive to light, climate. Dispersal limitations.
- **Snow** (Lambert/Parmenter/Aas/Berntsen)
 - Size structure affects snow burial, frost hardening.
- **Pests** (Xu, Li)
 - Bark beetles preferentially attack larger trees
- **Land Use** (Huang, Keller, Longo, Rady, Thomas)
 - Selective logging, LUH2, pasture disturbance, regrowth
- **Canopy turbulence** (Bonan, Knox)
 - Wind mortality (Shuman, Negron Juarez, Chambers)
- **Hydrology and hillslopes** (Swenson, Shuman, Buotte, Lawrence)
 - Root profile structure. Hillslopes/vegetation interaction

FATES community development

2 tutorials

>100 participants

26+ institutions

±30 developers on bi-weekly calls.

3 Earth System Model devt teams
(CESM, E3SM, NorESM)

Rapid Development & Testing
Phase!

<https://github.com/ngmeet/FATES>

NGEET / fates

Unwatch 54 Unstar 40 Fork 31

Code Issues 142 Pull requests 6 Projects 4 Wiki Security Insights Settings

repository for the Functionally Assembled Terrestrial Ecosystem Simulator (FATES)

Manage topics

2,018 commits 3 branches 53 releases 13 contributors View license

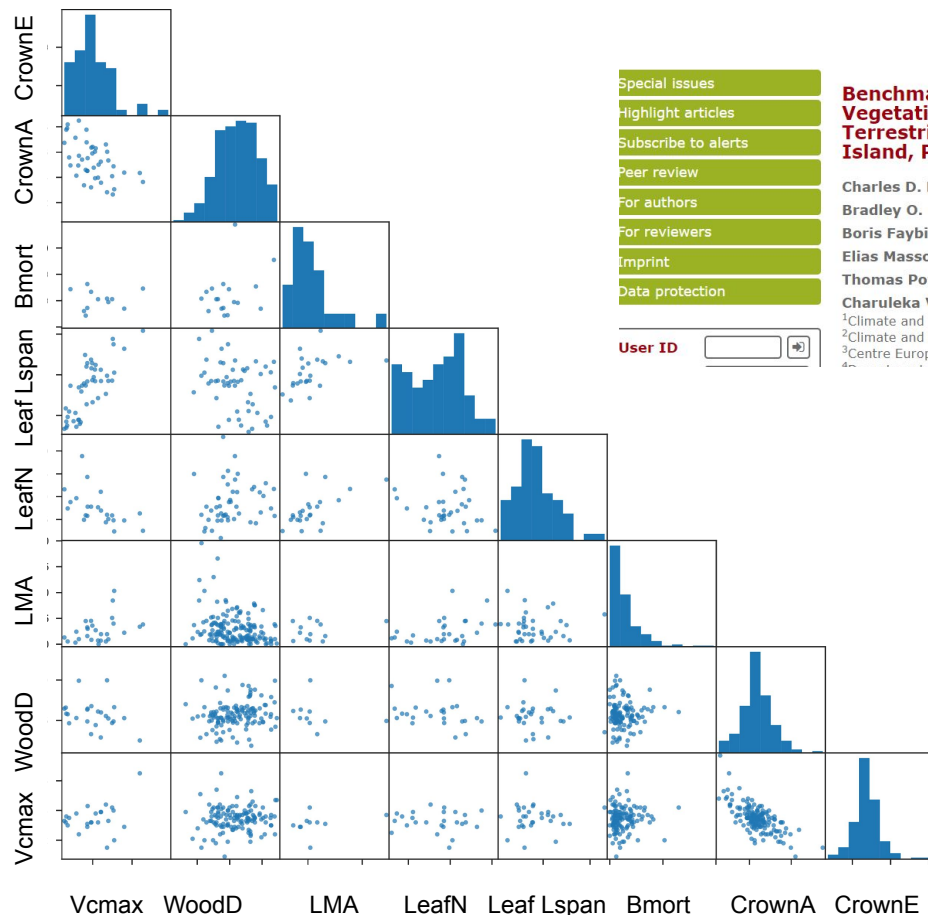
Branch: master New pull request

Create new file Upload files Find file Clone or download

glemieux Merge pull request #579 from rgknnox/fix-leafstatus	Latest commit 87ce240 13 days ago
<code>.github</code>	update PR template, README and CONTRIBUTING last year
<code>biogeochem</code>	Update biogeochem/EDPhysiologyMod.F90 26 days ago
<code>biogeophys</code>	Merge pull request #524 from rgknnox/parteh-acnp-merged 2 months ago
<code>fire</code>	Merge pull request #561 from jkshuman/ignition-fixes 2 months ago
<code>functional_unit_testing</code>	Merge branch 'master' into parteh-acnp-merged 3 months ago
<code>main</code>	changing loop entry into nearzero comparison last month
<code>parameter_files</code>	made phen_mindayson 90 instead of 30 last month
<code>parteh</code>	Update parteh/PRTAllometricCarbonMod.F90 26 days ago
<code>tools</code>	UPdated pft swapper tool to use doubles 4 months ago



FATES status & analysis across 8-dimensional trait space



- Special issues
- Highlight articles
- Subscribe to alerts
- Peer review
- For authors
- For reviewers
- Imprint
- Data protection

User ID

Benchmarking and Parameter Sensitivity of Physiological and Vegetation Dynamics using the Functionally Assembled Terrestrial Ecosystem Simulator (FATES) at Barro Colorado Island, Panama

Charles D. Koven¹, Ryan G. Knox¹, Rosie A. Fisher^{2,3}, Jeffrey Chambers^{1,4}, Bradley O. Christoffersen¹, Stuart J. Davies⁶, Matteo Detto^{7,8}, Michael C. Dietze¹, Boris Faybishenko¹, Jennifer Holm¹, Maoyi Huang¹⁰, Marlies Kovenock¹¹, Lara M. Kueppers^{1,12}, Gregory Lemieux¹, Elias Massoud¹³, Nathan G. McDowell¹⁰, Helene C. Muller-Landau^{10,6,7}, Jessica F. Needham¹, Richard J. Norby¹⁴, Thomas Powell¹, Alistair Rogers¹⁵, Shawn P. Serbin¹⁵, Jacquelyn K. Shuman², Abigail L. S. Swann^{11,16}, Charuleka Varadharajan¹, Anthony P. Walker¹⁴, S. Joseph Wright^{10,7}, and Chonggang Xu¹⁷

¹Climate and Ecosystem Sciences Division, Lawrence Berkeley National Lab, Berkeley, CA, USA

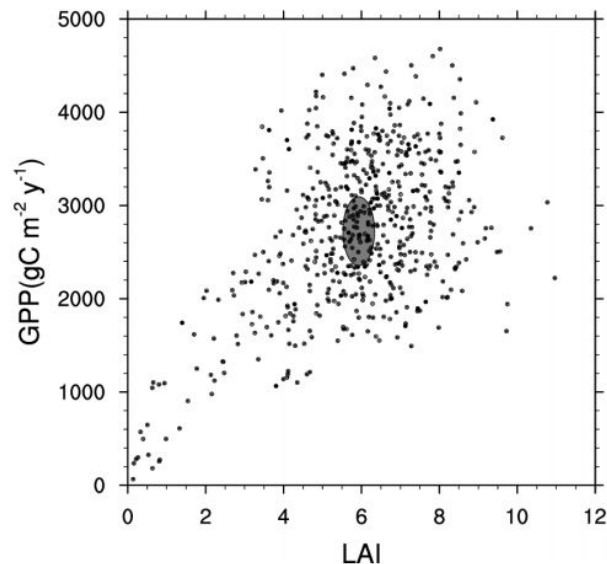
²Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, CO, USA

³Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique, Toulouse, France

⁴Centre National de la Recherche Scientifique, Paris, France

Review status

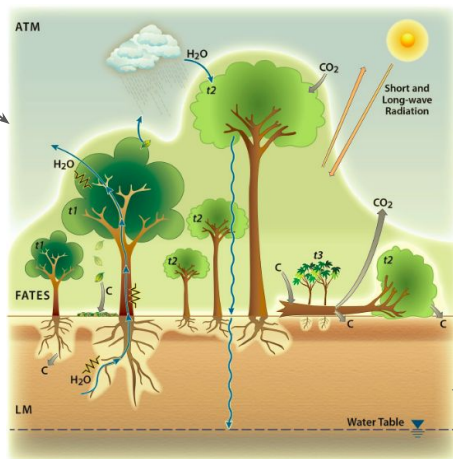
This discussion paper is a preprint. It is a manuscript under review for the journal Biogeosciences (BG).



Collaboration en France!

natural enemies
environmental variation
stabilizing mechanisms
jansen-connell
storage effect
stable v. unstable persistence
lottery model
density-dependence
niche differentiation
competition-colonization
assymmetric competition
dispersal
resource partitioning
source-sink dynamics
relative nonlinearity
heteromyopia
neutrality
fitness-density covariance
invasibility
equalizing mechanisms
local v regional tradeoffs
assymmetric competition

Leverage community ecology
community to improve
representation of
high-dimensional coexistence

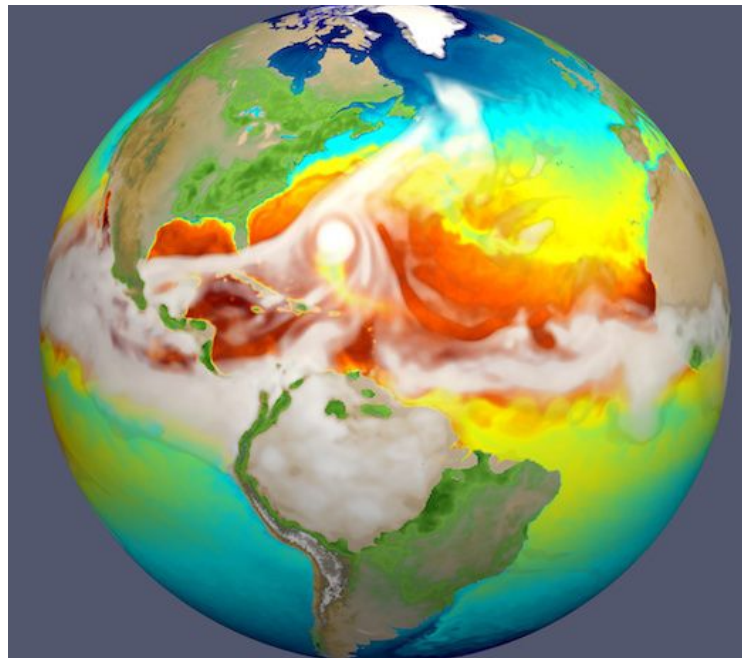
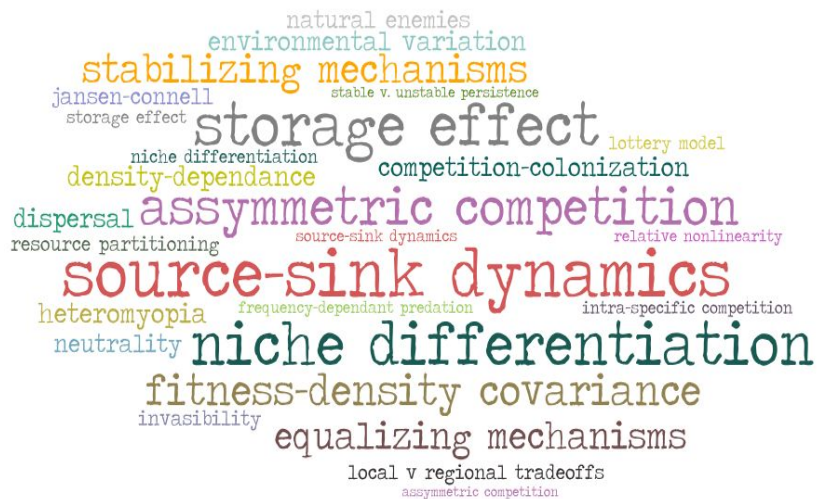


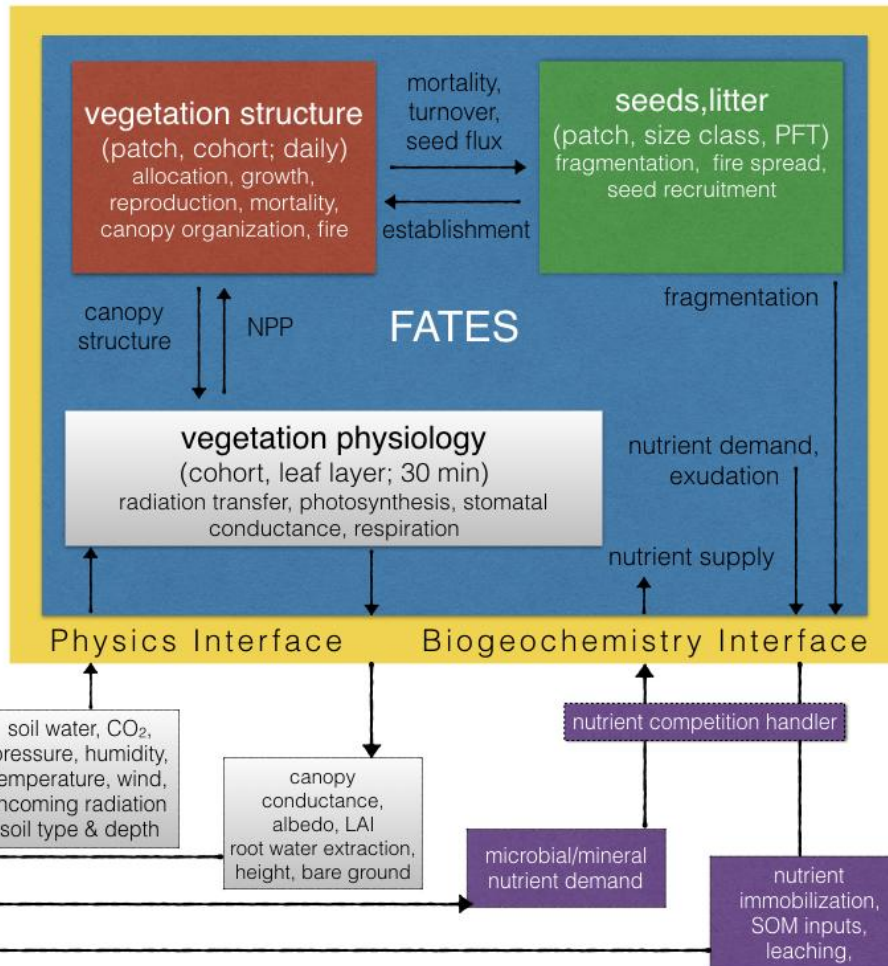
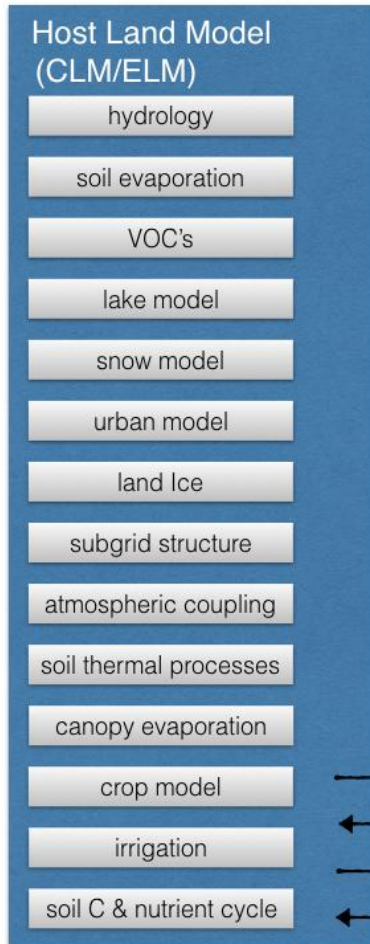
Coordinate developments
across FATES community,
facilitate new collaborations

Find new ways of comparing
vegetation demographic models
(in general) against data
-remote sensing
Plant hydraulics
demography

Fin...

Can Earth system modeling and community ecology find common ground?





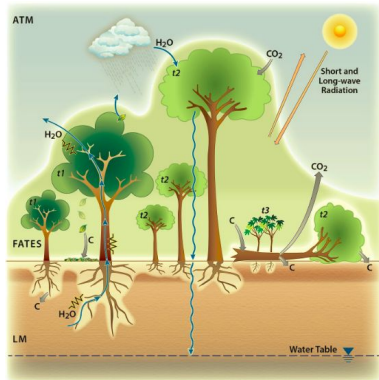
FATES module

Currently runs inside:
CESM,
E3SM,
NorESM
and (in principle)
CMCC.

FATES planned activities

- E3SM development team
 - Radiation transfer upgrades
 - **Land-use** (LUH2)
 - Global PFT calibrations

- Californian studies
 - Western US forests
 - Wildfire benchmarking
 - FATES x CLM **hillslope** model
 - Regeneration parameterization



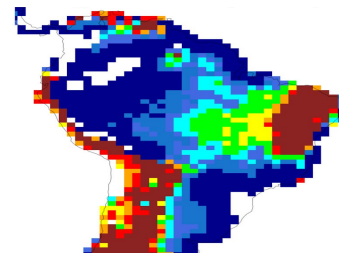
- Los Alamos
 - **Insect** dynamics
 - Fire-atmosphere interactions
 - **FATES-Hydro** testing & calibration

- NGEE-tropics Phase II
 - **Software Support**
 - **Nutrient cycling (N&P)**
 - Fire, Gas Exchange, Physiology testbeds
 - Community assembly
 - Tropical trait space
 - Tropical phenology, windthrow mortality
 - Acceleration
- NorESM devt team
 - High latitude PFTs
 - Thermal tolerance
 - **Snow burial**
 - Dispersal
 - Mosses/shrubs/lichens

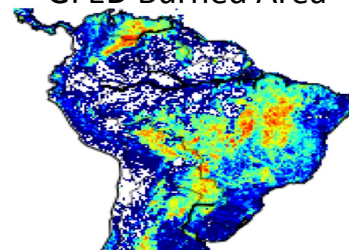
New questions we can ask with FATES

- How does the differential effect of drought across trees of different sizes scale to impact Earth system feedbacks?
- How does variation in plant hydraulic traits across climate gradients feed back on atmospheric circulation?
- How does changing tree growth under changing climate and elevated CO₂ lead to changes in light competition and vegetation carbon residence time?
- How do changing disturbance regimes interact with community trait distributions and ecosystem function?

FATES Burned Area



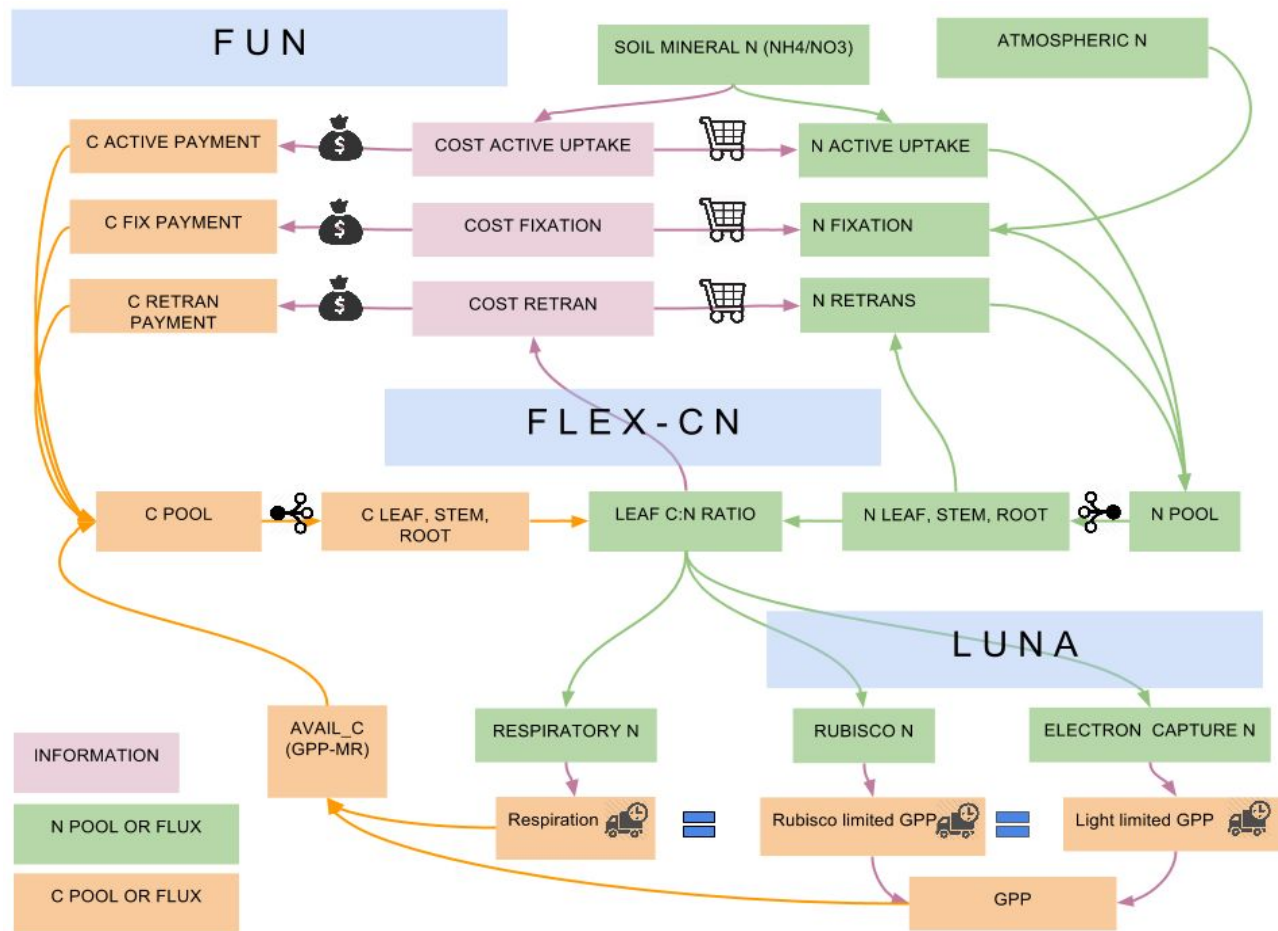
GFED Burned Area



Annual Burned Fraction (% year⁻¹)



Shuman, Fisher, et al. in prep



The CLM5 Nitrogen cycle


FUN (Fixation and Uptake of Nitrogen) : Marketplace for N.

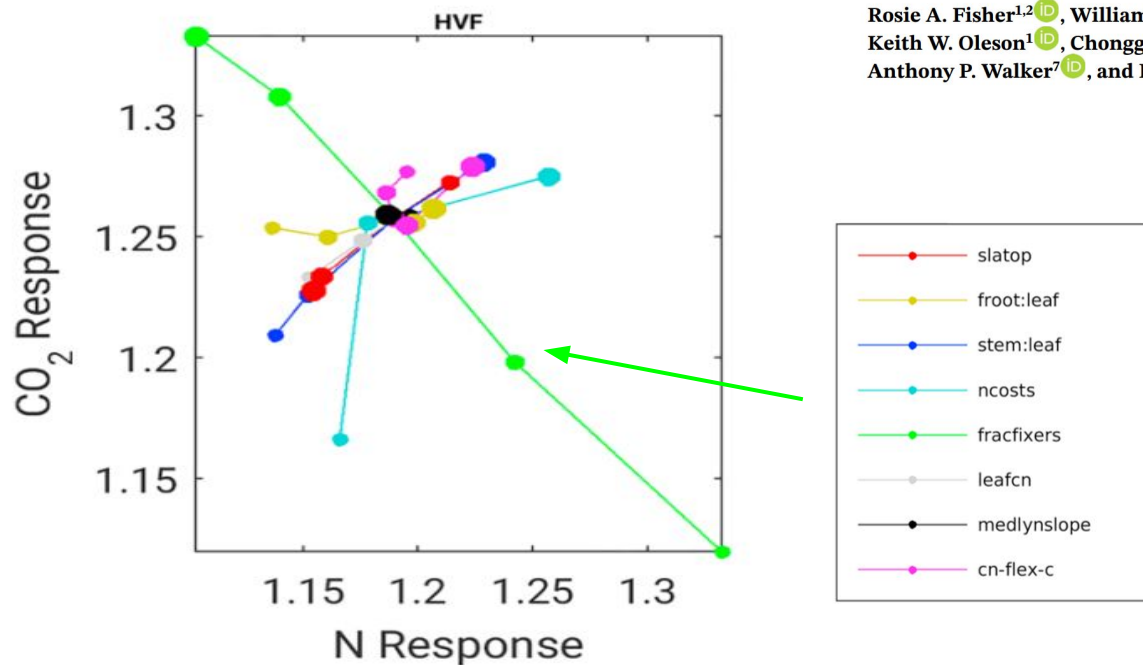
FlexCN: Flexible tissue C:N ratios

LUNA: Optimal allocation of N across leaf gas exchange processes

The degree of allowed N fixation is dominant over CO₂ responses

Parametric Controls on Vegetation Responses to Biogeochemical Forcing in the CLM5

Rosie A. Fisher^{1,2} , William R. Wieder^{1,3} , Benjamin M. Sanderson² , Charles D. Koven⁴ ,
Keith W. Oleson¹ , Chonggang Xu⁵ , Joshua B. Fisher⁶ , Mingjie Shi⁶ ,
Anthony P. Walker⁷ , and David M. Lawrence¹ 



The fraction of N fixing plants is a **static** feature of the ecosystem...

... prediction from dynamic principles would be better...

*convenient 'segway' into talking about demographic models :)

A variety of vegetation demographic approaches are currently in development in ESMs globally.

Received: 11 April 2017 | Revised: 12 August 2017 | Accepted: 17 August 2017
DOI: 10.1111/gcb.13910

RESEARCH REVIEW

WILEY Global Change Biology

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

Rosie A. Fisher¹ | Charles D. Koven² | William R. L. Anderegg³ | Bradley O. Christoffersen⁴ | Michael C. Dietze⁵ | Caroline E. Farrior⁶ | Jennifer A. Holm² | George C. Hurtt⁷ | Ryan G. Knox⁸ | Peter J. Lawrence¹ | Jeremy W. Lichstein⁸ | Marcos Longo⁹ | Ashley M. Matheny¹⁰ | David Medvigy¹¹ | Helene C. Muller-Landau¹² | Thomas L. Powell¹³ | Shawn P. Serbin¹³ | Hisashi Sato¹⁴ | Jacquelyn K. Shuman¹ | Benjamin Smith¹⁵ | Anna T. Trugman¹⁶ | Toni Viskari¹² | Hans Verbeeck¹⁷ | Ensheng Weng¹⁸ | Chonggang Xu⁴ | Xiangtao Xu¹⁹ | Tao Zhang⁸ | Paul R. Moorcroft²⁰

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¹³Environmental and Climate Sciences Department, Brookhaven National Laboratory, Upton, NY, USA

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¹⁸Center for Climate Systems Research, Columbia University, New York, NY, USA

¹⁹Department of Geosciences, Princeton University, Princeton, NJ, USA

²⁰Department of Organismic and Evolutionary Biology, Harvard University, Cambridge, MA, USA

TABLE 1 Table of attributes of vegetation demographics models discussed in this paper

Model acronym	Name	Vegetation representation	Coupled to ESM?	Stochastic?	Canopy structure	Disturbance history patches?
SEIB	Spatially Explicit Individual-Based model	Individual	MIROC-ESM	Yes	Individuals	No
LPJ-GUESS	Lund-Potsdam-Jena General Ecosystem Simulator	Individual or Cohort	EC-Earth, RCA-GUESS	Yes (optional for some processes)	Flat-top	Yes
LM3-PPA	Perfect Plasticity Approximation	Cohort	GFDL-ESM	No	PPA	No
ED	Ecosystem Demography model	Cohort	RAMS	No	Flat-top	Yes
ED2	Ecosystem Demography model v2	Cohort	RAMS	No	Flat-top	Yes
CLM(ED)	Community Land Model with Ecosystem Demography	Cohort	CESM	No	PPA	Yes

