Earth System Models and their Ecological Ambitions

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National Center for Atmospheric Research

Overview

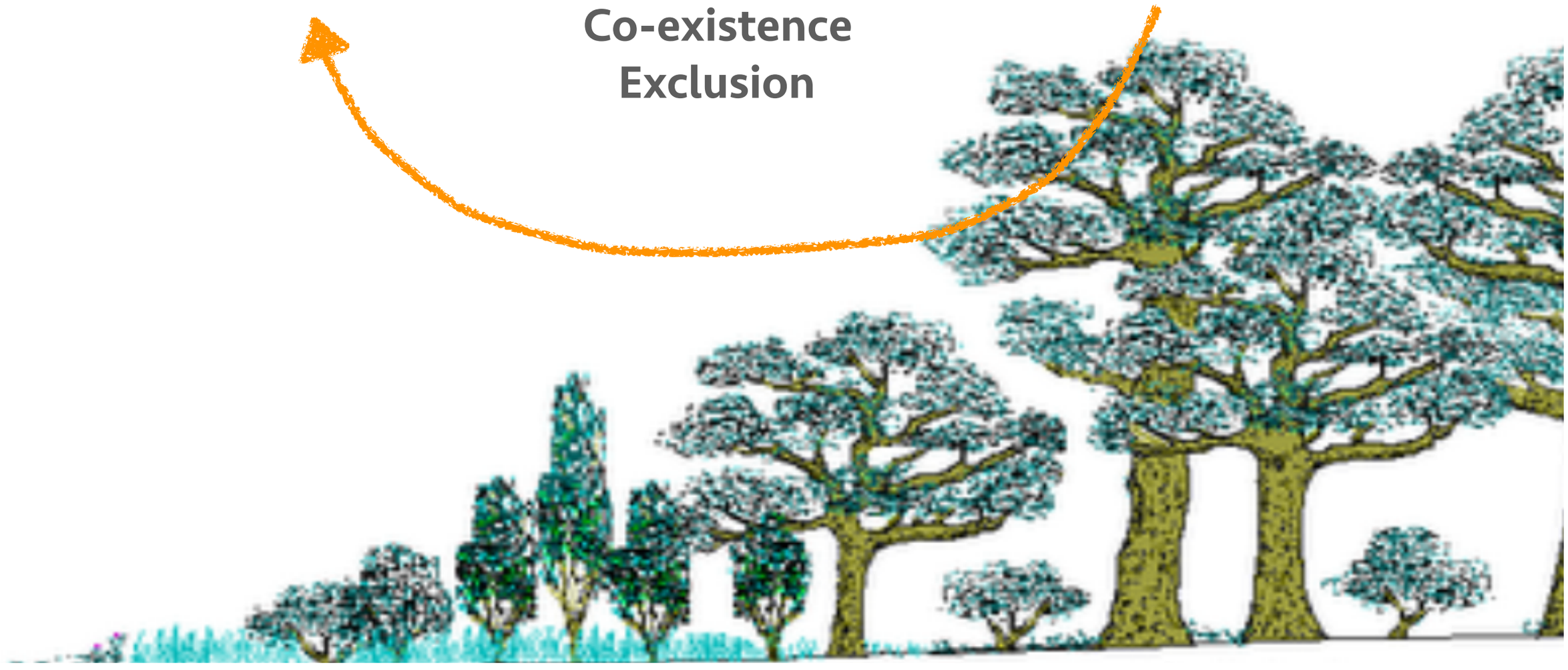
- What is Ecosystem Demography?
- Science Applications with ED
  - “Taking off the training wheels”
  - Drought trade-off study
- What is FATES? Future progress on ED

Fundamental ecological system

Recruitment

Growth
Competition
Co-existence
Exclusion

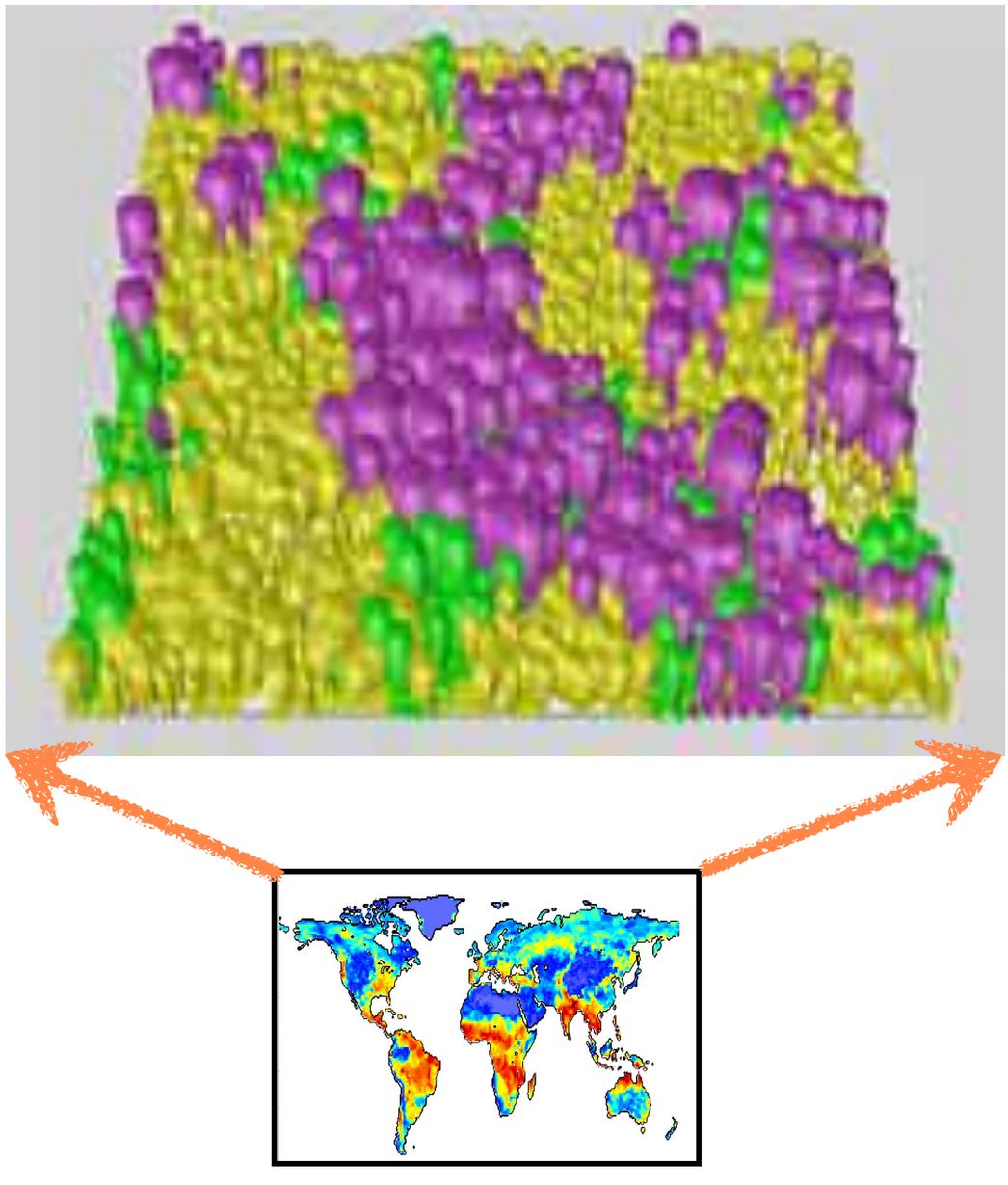
Mortality



‘Gap’ Models

(e.g. SORTIE, LPJ-GUESS, SEIB, aDGVM)

- **PROS**
- Individual Based
- 3D light environment
- Simulates: competition recruitment disturbance

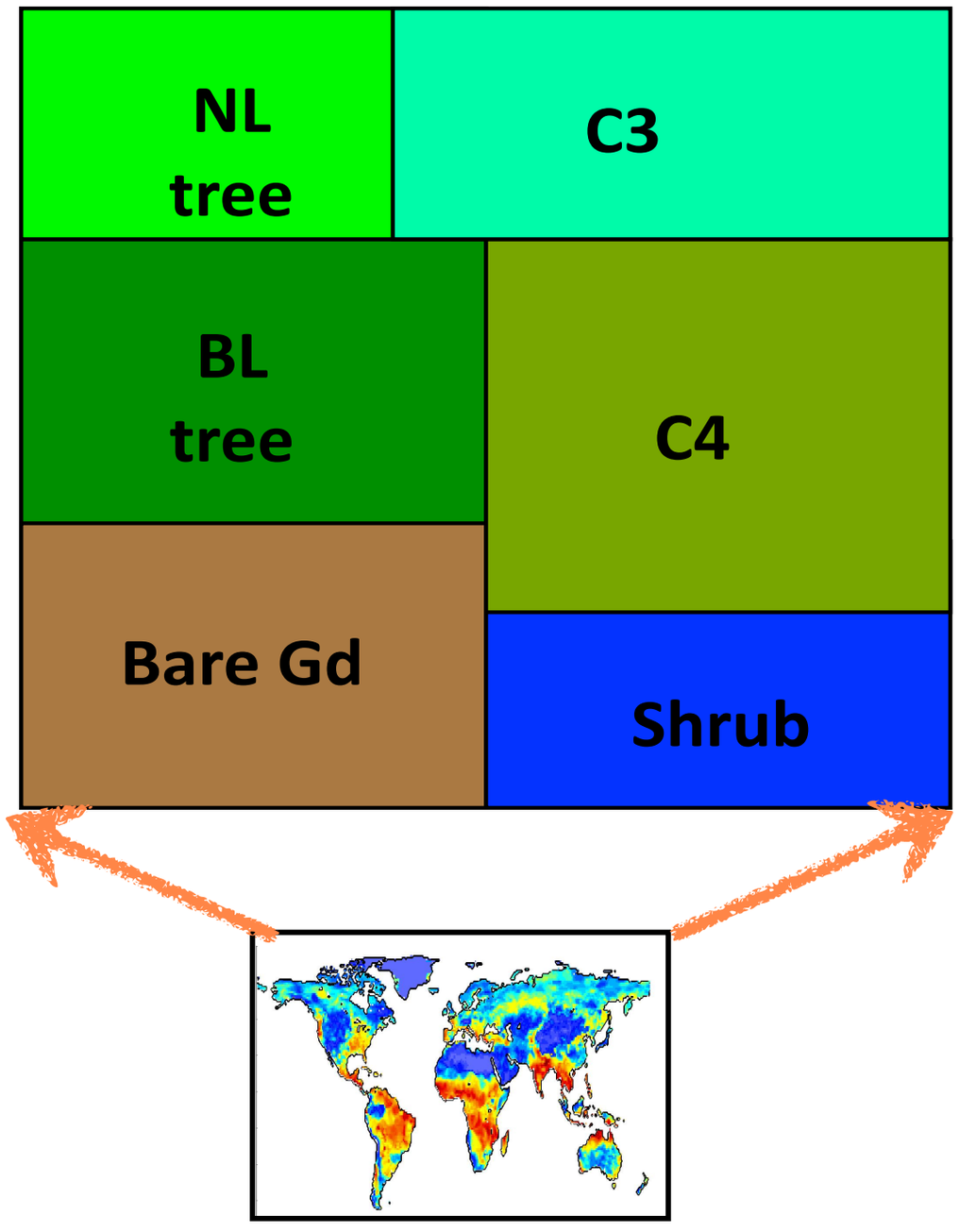


- **CONS**
- Stochastic processes…
- Computationally intensive
- Long timesteps
- Inappropriate for climate simulations?

‘Area-based’ Models

(e.g. CLM, TRIFFID, LPJ, IBIS - models used in IPCC assessments)

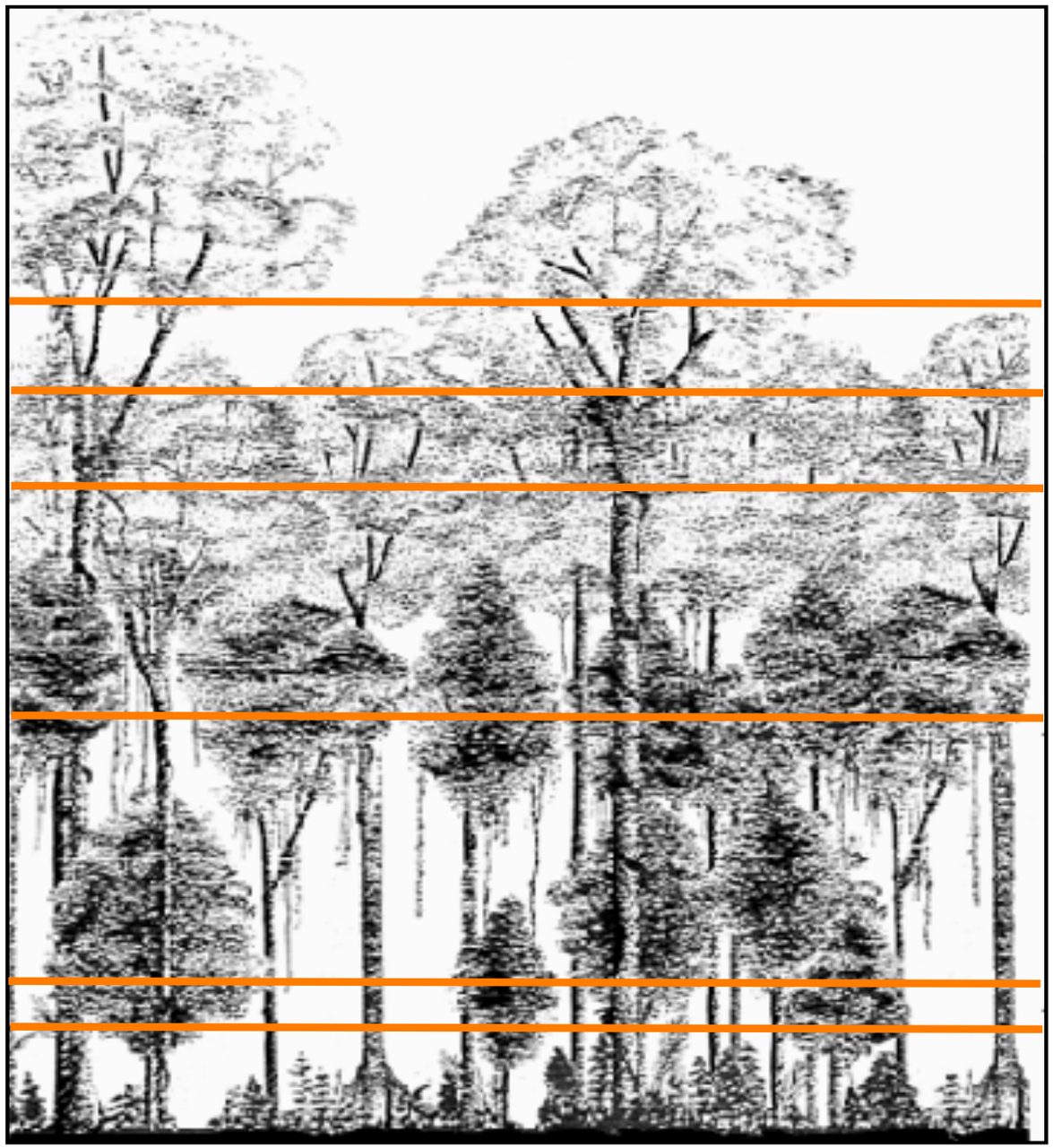
- **PROS**
- Deterministic
- Computationally efficient
- Default in ESM’s



- **CONS**
- 1 ‘average tree’ per plant type
- No height structure.
- No light competition

Ecosystem Demography Model (ED)

Moorcroft, Hurtt and Pacala. 2001



- ‘Cohorts’ of trees:, grouped according to:
  - Plant type
  - Height
  - Successional stage

‘Cohort-based’ Models as intermediate solutions

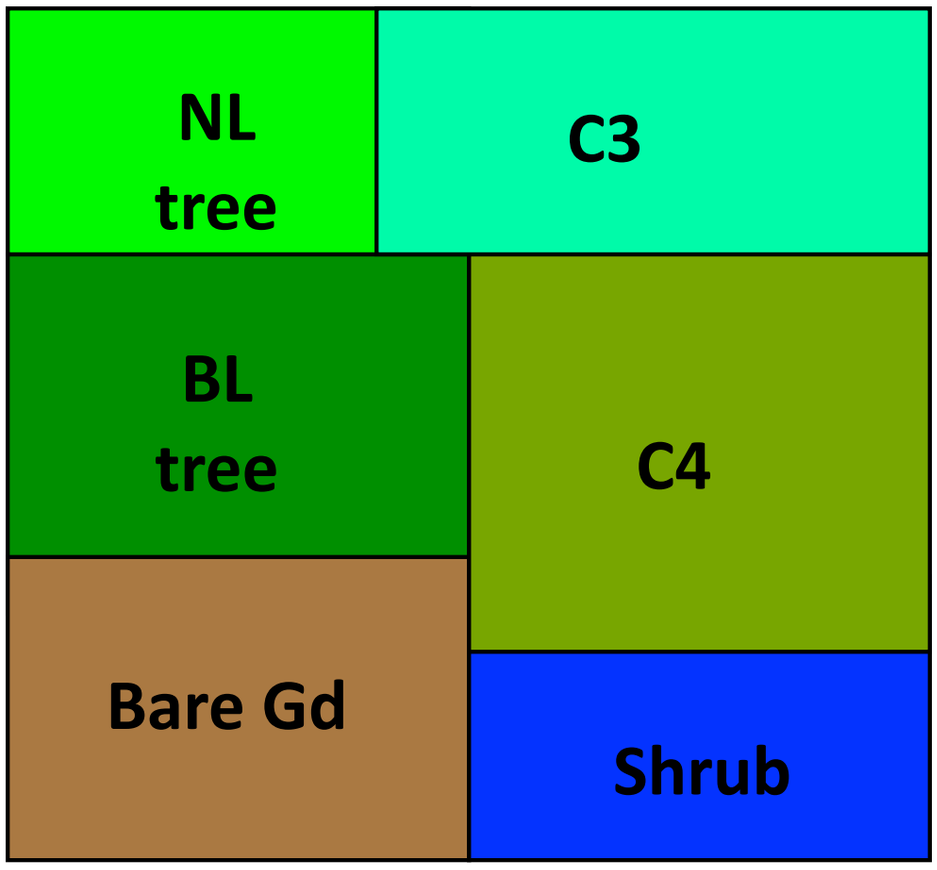
Big Leaf Model

Cohort model

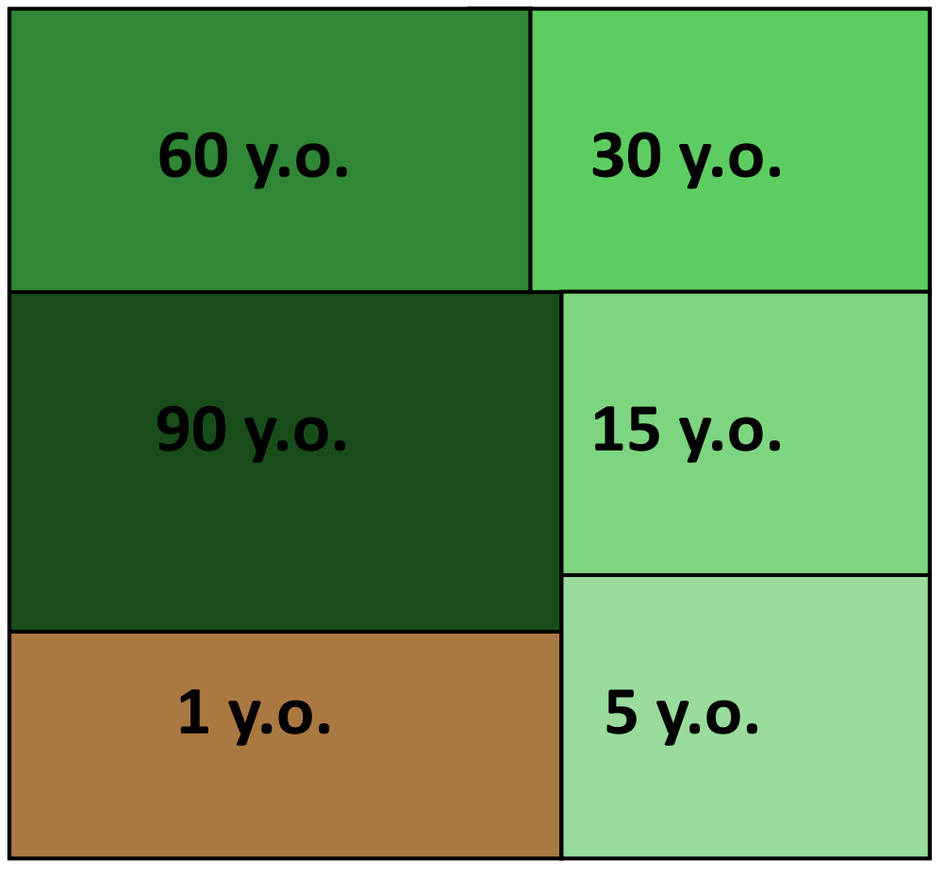
Stochastic Individual Model

Discretization of the land surface

Plant functional type based structure



‘Time since disturbance’ based structure



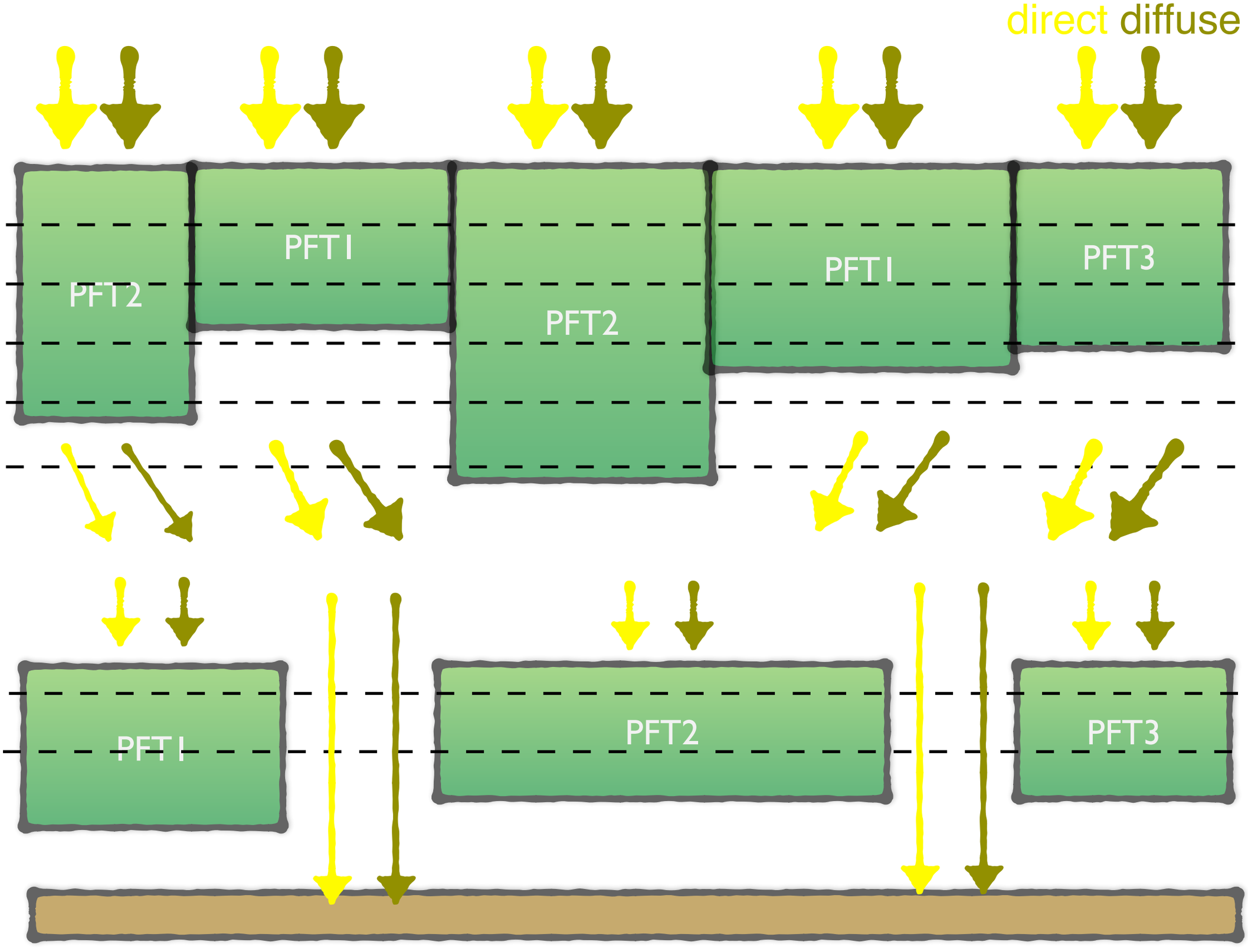
Resolves variation along successional axis

Merits of ED approach

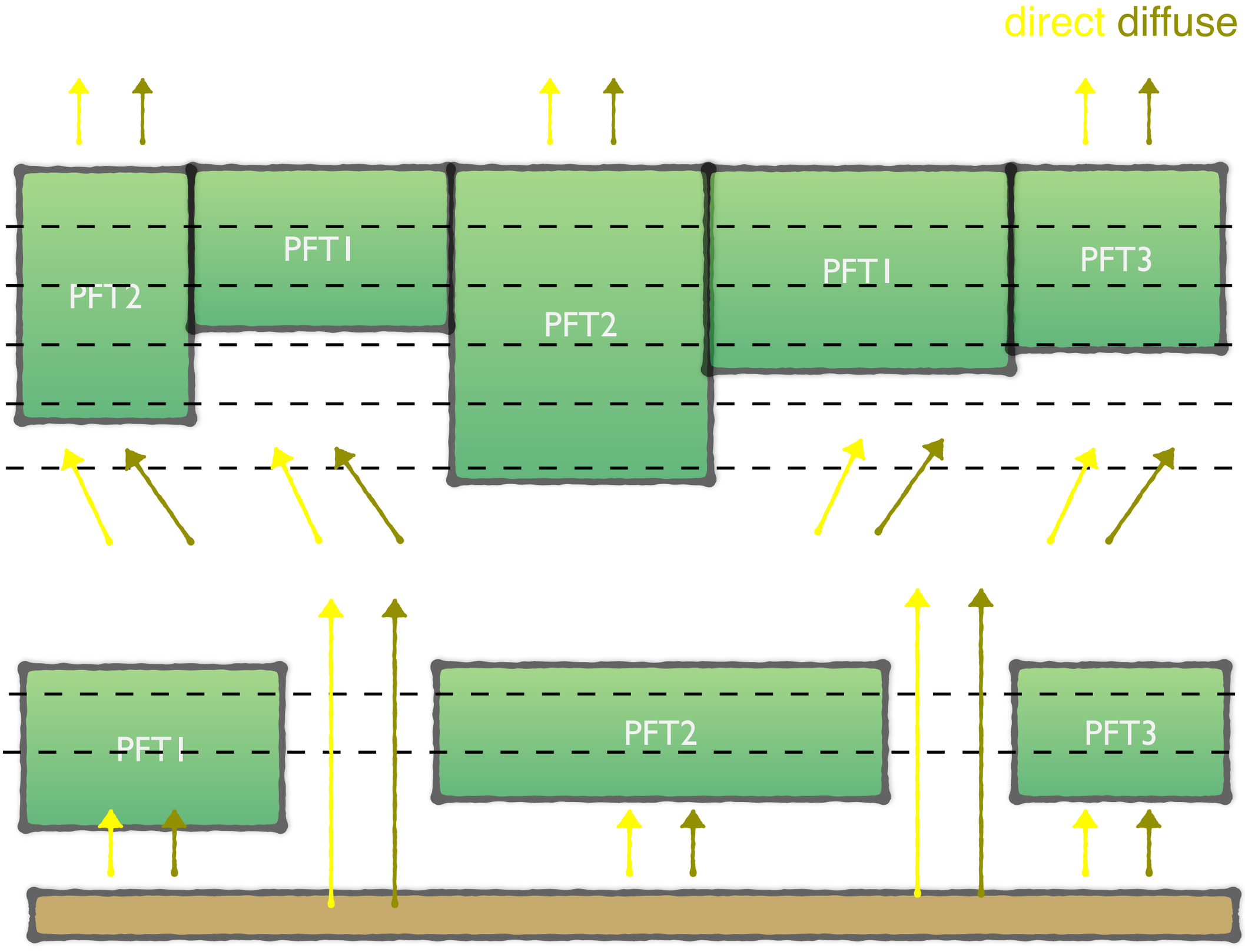
- Efficient simulations of ecological dynamics
- Spatial heterogeneity in light environment:
  - Possibility of co-existence along successional gradient
- Link to observations of forest demography
- Simulate impact of disturbance (fire, landuse, mortality).

How does this actually work?

Norman Radiation Scheme as applied to a mixed PFT canopy in CLM(ED)

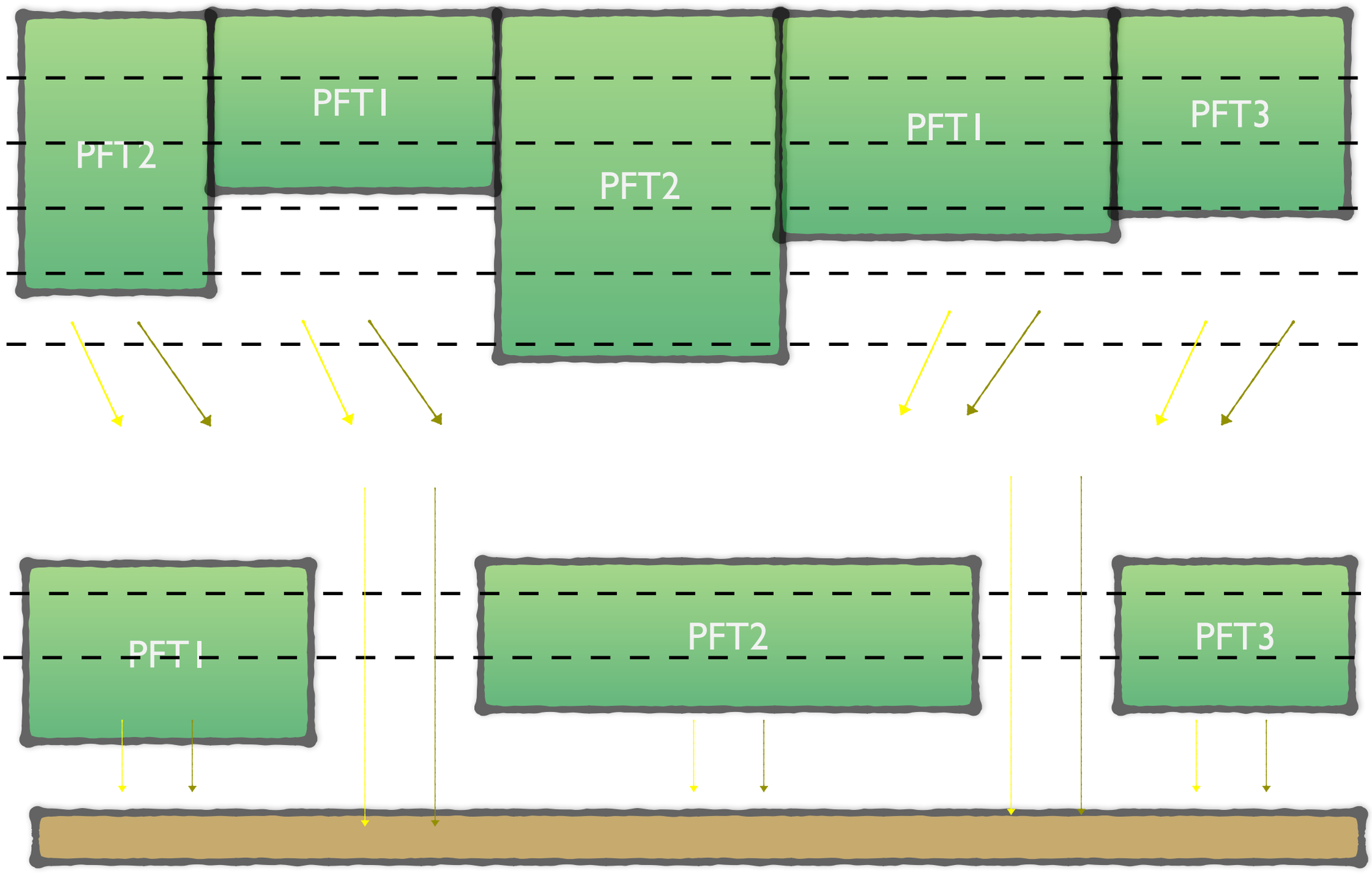


Norman Radiation Scheme as applied to a mixed PFT canopy in CLM(ED)

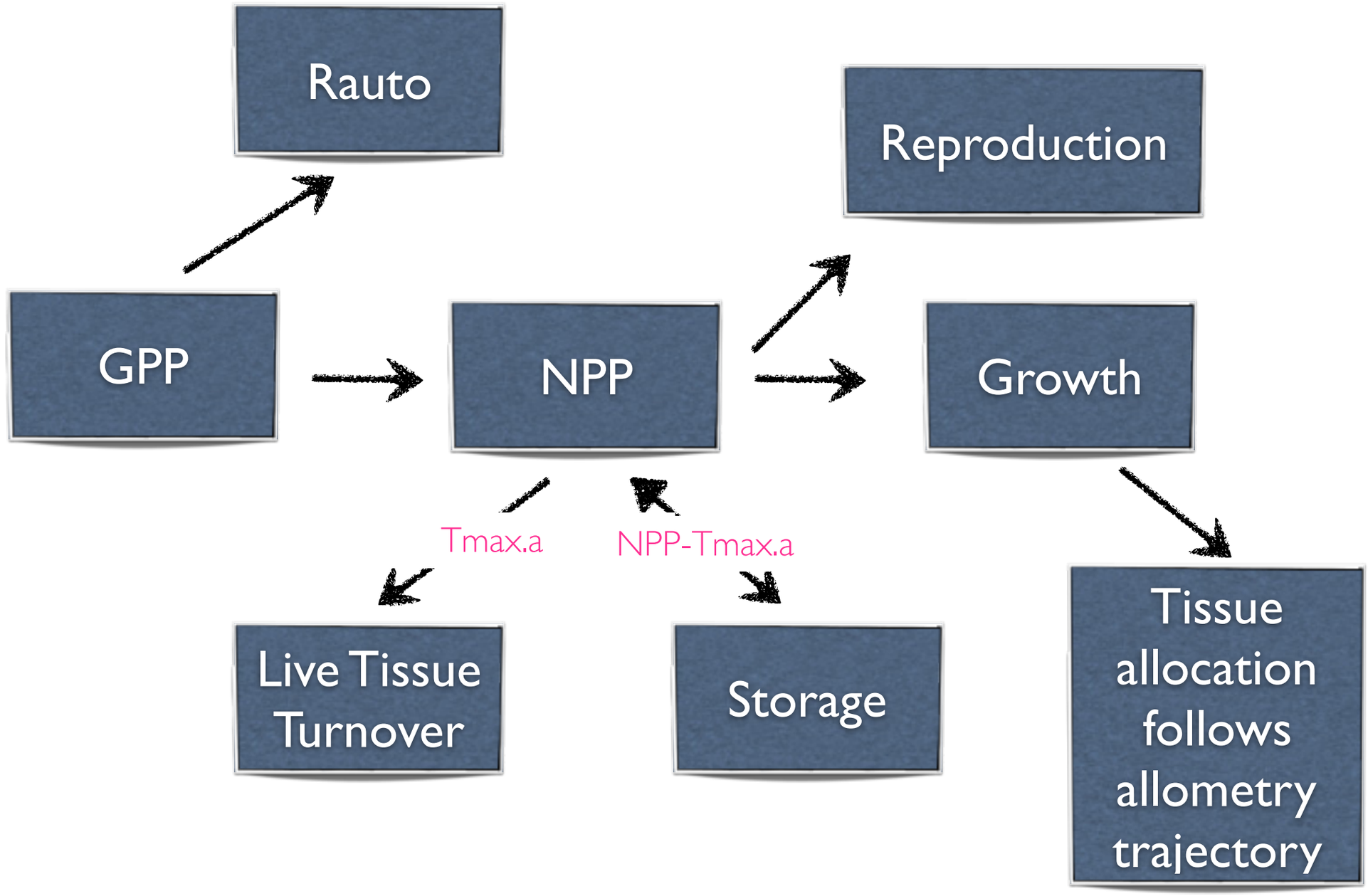


Norman Radiation Scheme as applied to a mixed PFT canopy in CLM(ED)

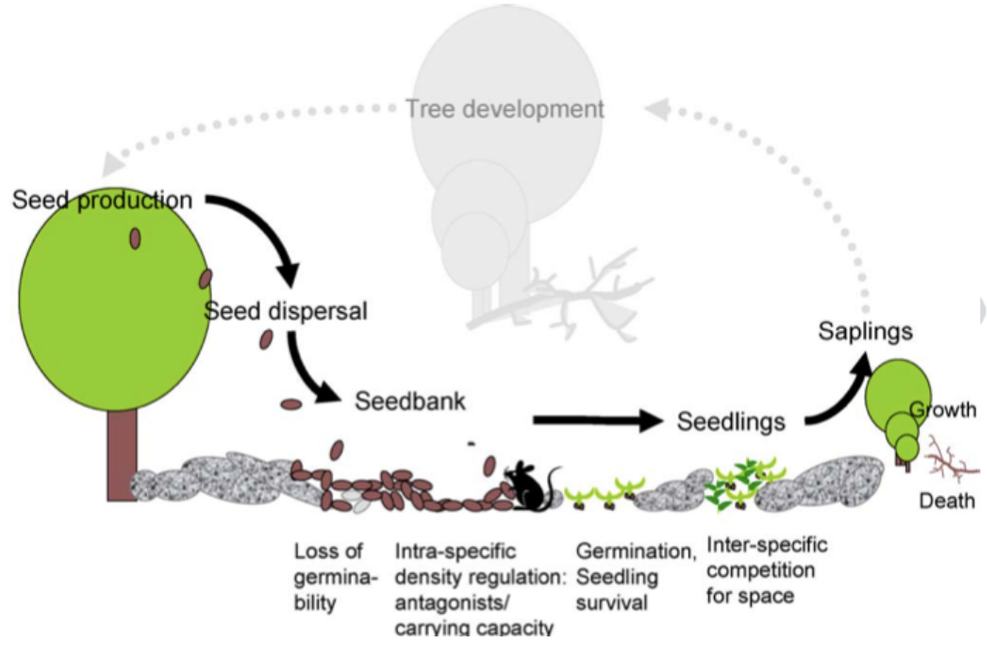
direct diffuse

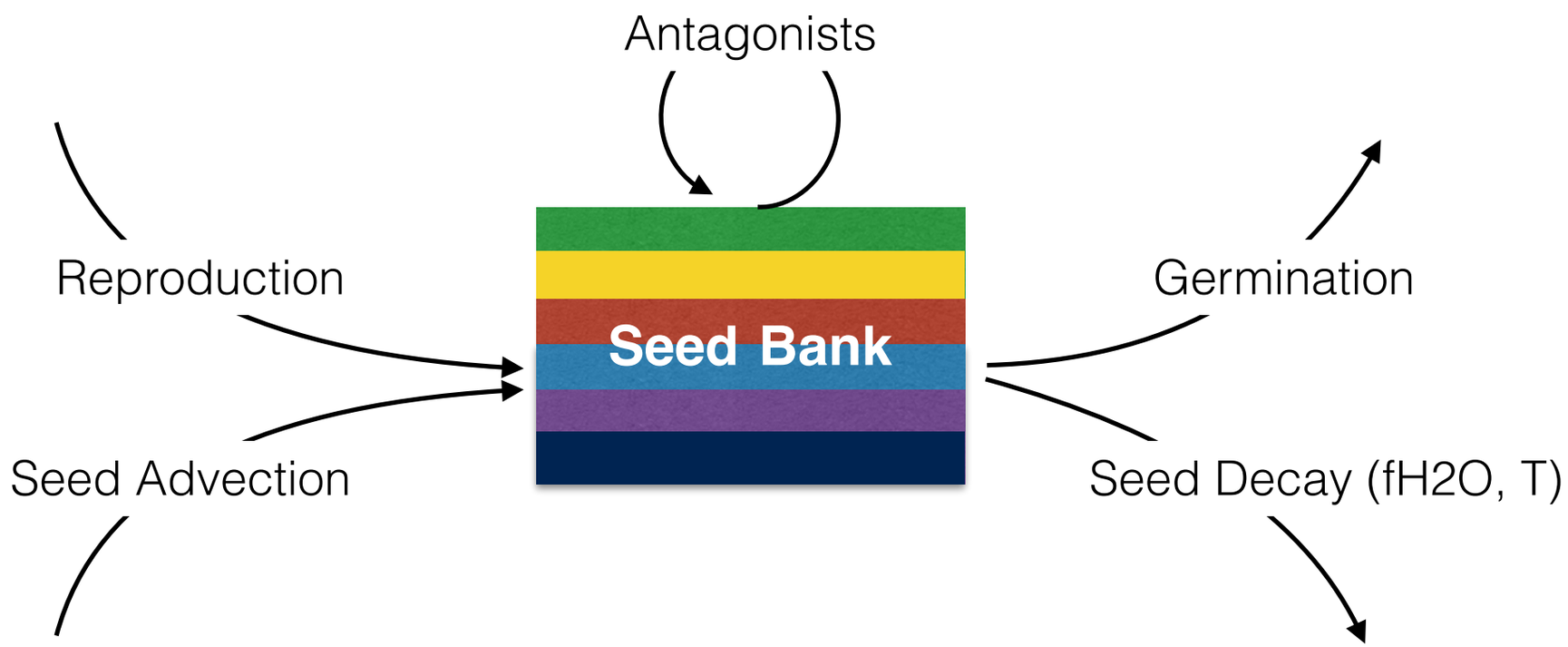


Leaf/Storage balance allocation scheme



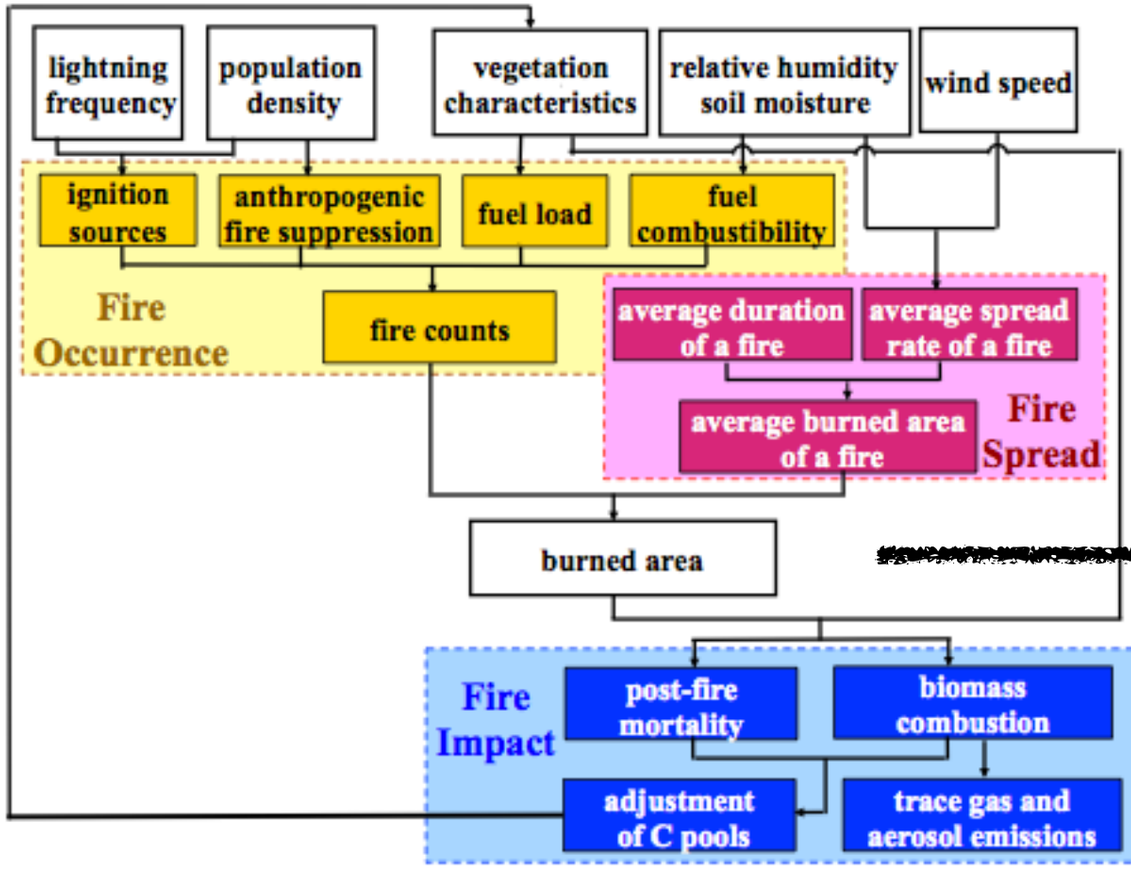
Seed Bank Model…

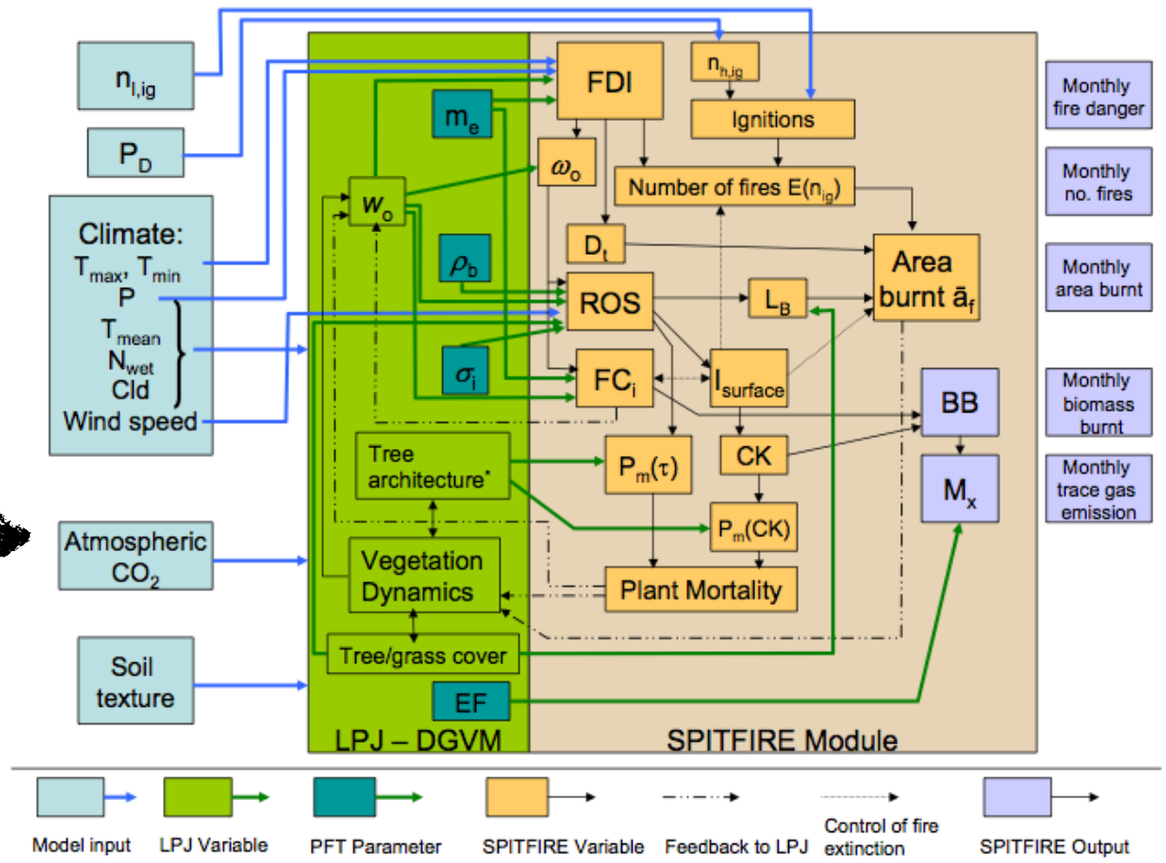




Seed Bank model based on TREEMIG: Lischke et al. 1998, 2006 etc. Collaboration with WSL Zurich

FIRE





CLM4.5 fire: Li et al. 2012

SPITFIRE: Thonicke et al. 2010

-Collaboration with Allan Spessa (Open Univ.) and Mathew Forest (Goethe Univ. Frankfurt)
-Agricultural, land use and peat fires and ignitions need to interface with the Li & Levis CLM4.5 fire model.
- Numerous modifications required to SPITFIRE implemented to allow size-structured fire impacts

Geosci. Model Dev. Discuss., 8, 3293–3357, 2015
www.geosci-model-dev-discuss.net/8/3293/2015/
doi:10.5194/gmdd-8-3293-2015

Geoscientific Model Development Discussions
Open Access

Taking off the training wheels: the properties of a dynamic vegetation model without climate envelopes

R. A. Fisher[1], S. Muszala[1], M. Verteinstein[1], P. Lawrence[1], C. Xu[2], N. G. McDowell[2], R. G. Knox[3], C. Koven[3], J. Holm[3], B. M. Rogers[4], D. Lawrence[1], and G. Bonan[1]

…WHAT TRAINING WHEELS?

Paradigm:

In Earth System Models, vegetation climate limits are a function of simple climate variables, defined from current distributions

Climate envelope parameterization
from Lund-Potsdam-Jena (LPJ) DGVM
(vegetation cannot survive outside limits)

Used in:
ORCHIDEE (IPSL), CTEM (CanESM)
SEIB (MIROC-ESM), CLM-DV (CESM)

Plant Functional Type	Temp coldest month (°C)	Temp hottest month (°C)	Growing Degree Days (°C)
Tropical broad-leaved evergreen	15.5	–	–
Tropical broad-leaved raingreen	15.5	–	–
Temperate needle-leaved evergreen	−2.0	22.0	900
Temperate broad-leaved evergreen	3.0	18.8	1200
Temperate broad-leaved summergreen	−17.0	15.5	1200
Boreal needle-leaved evergreen	−32.5	−2.0	600
Boreal needle-leaved summergreen	–	−2.0	350
Boreal broad-leaved summergreen	–	−2.0	350
Temperate herbaceous (TeH)	–	15.5	–
Tropical herbaceous (TrH)	15.5	–	–

Sitch et al. 2003

Problem of extrapolation

Vegetation climate limits might change as CO2 increases

Not clear what to do in no-analogue climates.

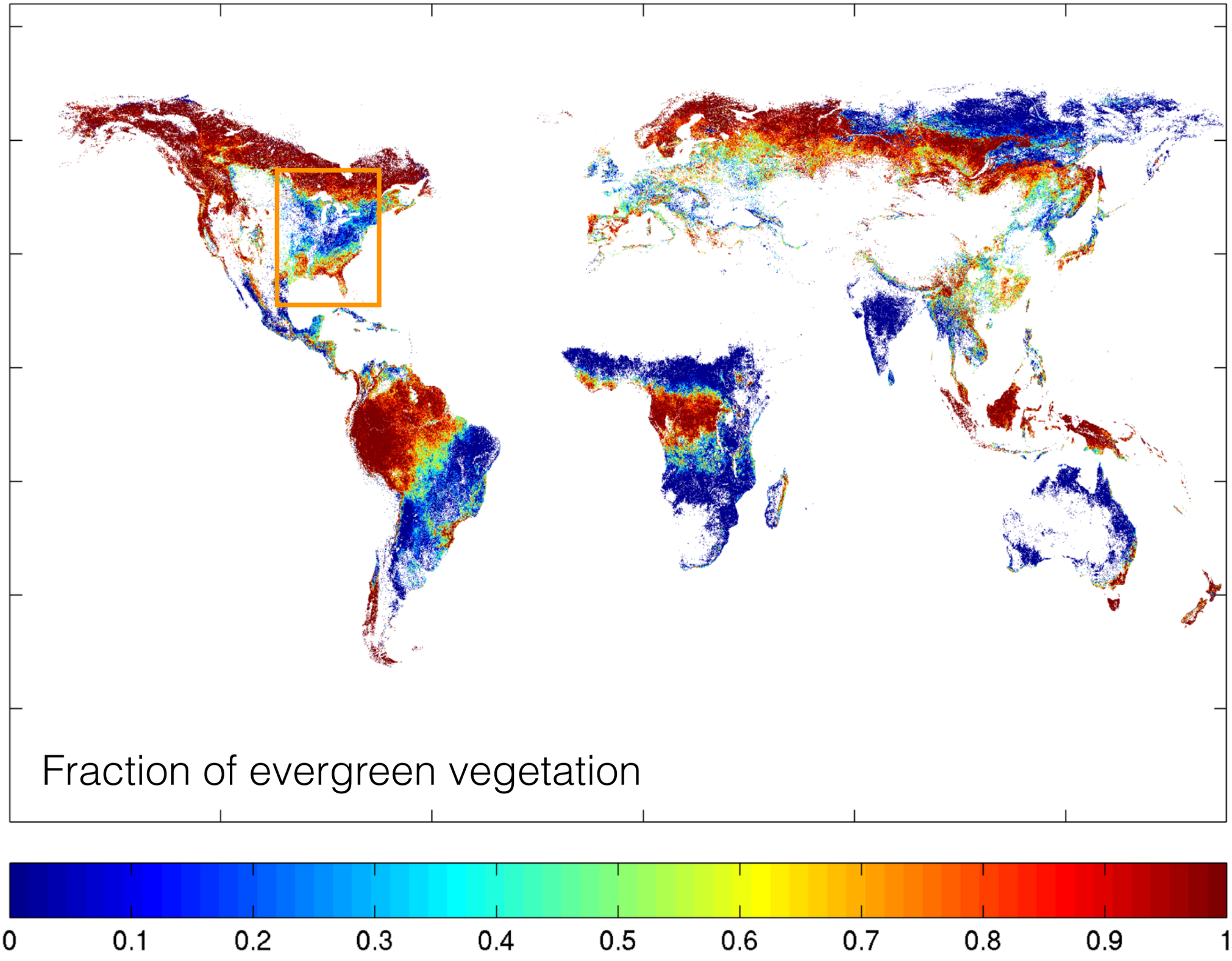
How to proceed?

The Ecosystem Demography model* we have integrated into the Community Land Model - CLM4.5(ED):

- Has no climatic envelopes
- Can be parameterized directly from plant trait data
- Predicts plant distribution as an outcome of performance
- We can in theory use CLM(ED) for testing hypotheses of vegetation distribution.

*Moorcroft et al. 2001; Fisher et al. 2010; Fisher et al. GMDD 2015

What **can** we observe about vegetation distribution?



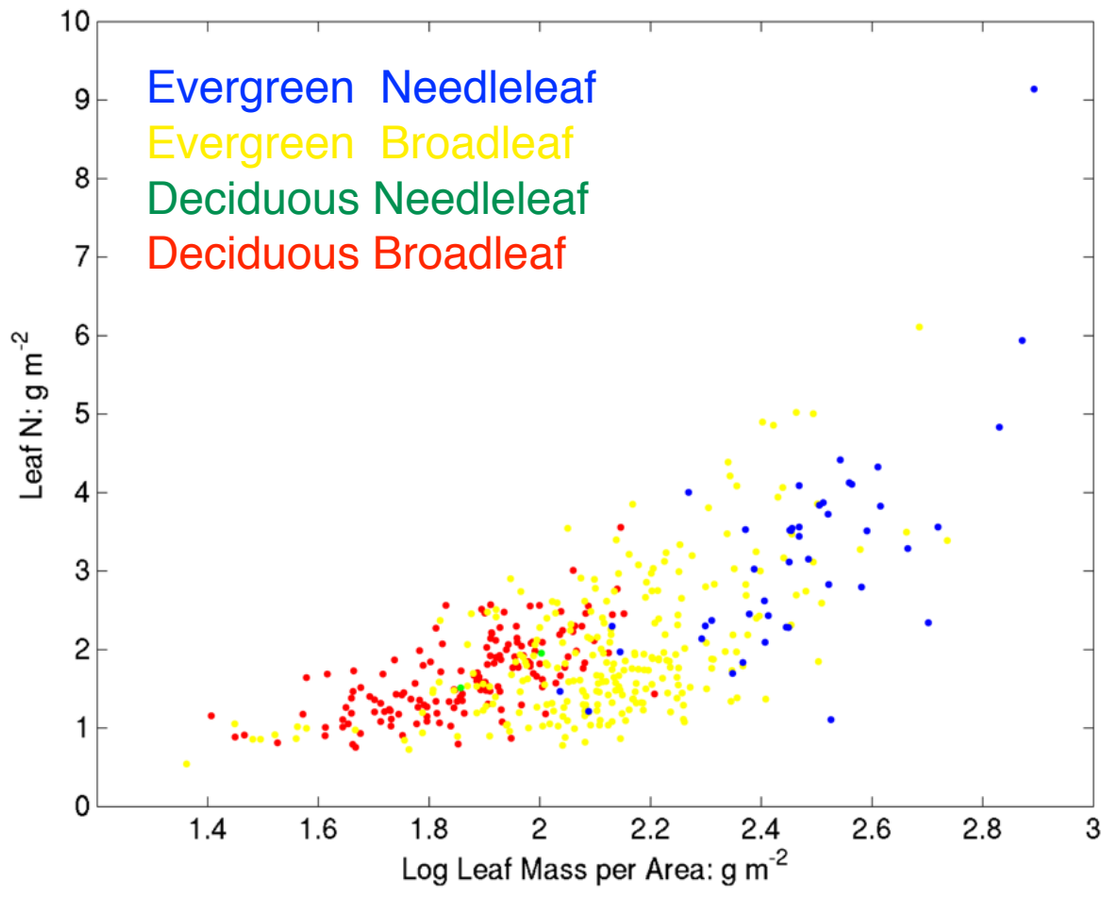
AVHRR Vegetation Continuous Fields. De Fries et al. 2000

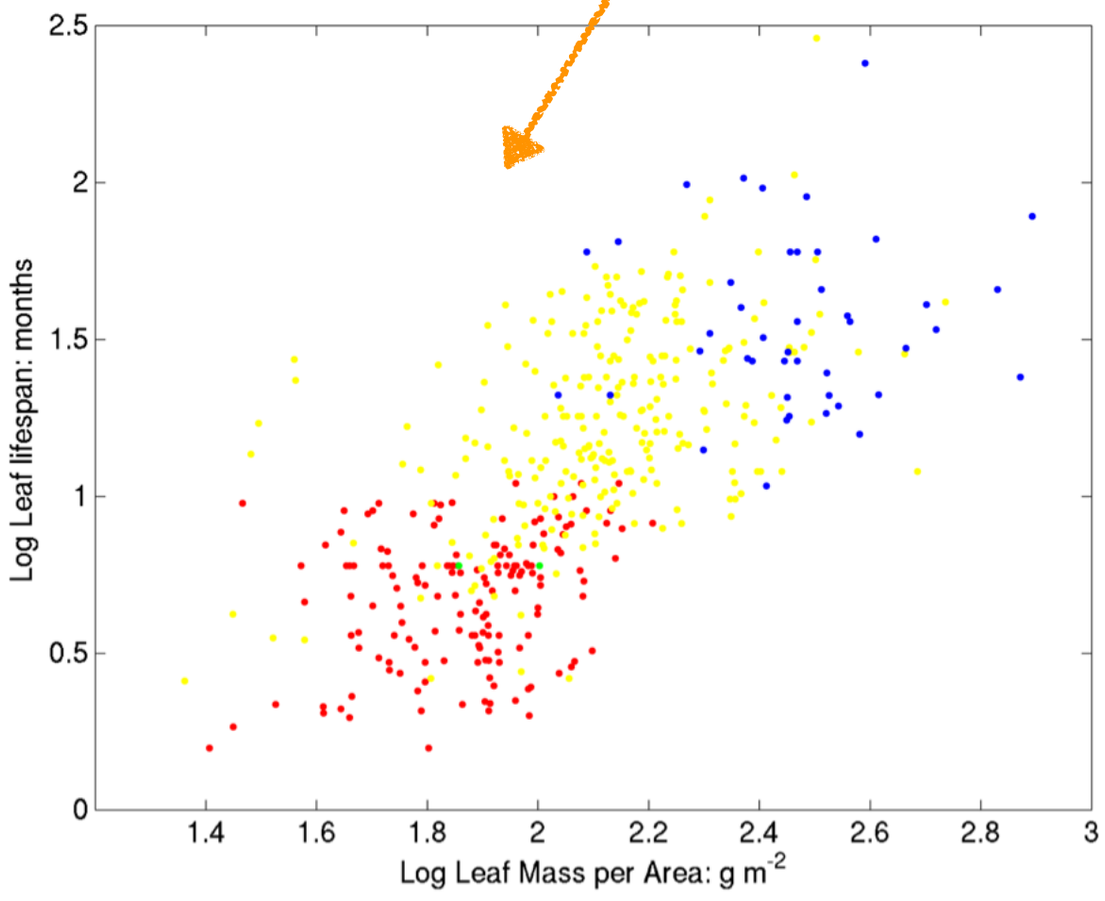
The worldwide leaf economics spectrum

Ian J. Wright[1], Peter B. Reich[2], Mark Westoby[1], David D. Ackerly[3], Zdravko Baruch[4], Frans Bongers[5], Jeannine Cavender-Bares[6], Terry Chapin[7], Johannes H. C. Cornelissen[8], Matthias Diemer[9], Jaume Flexas[10], Eric Garnier[11], Philip K. Groom[12], Javier Gulias[10], Kouki Hikosaka[13], Byron B. Lamont[12], Tali Lee[14], William Lee[15], Christopher Lusk[16], Jeremy J. Midgley[17], Marie-Laure Navas[11], Ülo Niinemets[18], Jacek Oleksyn[2,19], Noriyuki Osada[20], Hendrik Poorter[21], Pieter Poot[22], Lynda Prior[23], Vladimir I. Pyankov[24], Catherine Roumet[11], Sean C. Thomas[25], Mark G. Tjoelker[26], Erik J. Veneklaas[22] & Rafael Villar[27]

LEAF CONSTRUCTION HAS A 3-WAY TRADE OFF:

Leaf mass per area (**cost**)
vs.
Leaf Lifespan (**durability**)
vs.
Leaf Nitrogen per area (**performance**)





(One) Hypothesis: The relative carbon economy of deciduous vs. evergreen habits can predict biome boundaries

Next-generation dynamic global vegetation models: learning from community ecology

Simon Scheiter[1], Liam Langan[2] and Steven I. Higgins[2]

[1]Biodiversität und Klima Forschungszentrum (LOEWE BiK-F), Senckenberg Gesellschaft für Naturforschung, Senckenberganlage 25, D-60325, Frankfurt am Main, Germany; [2]Institut für Physische Geographie, Goethe-Universität Frankfurt am Main, Altenhöferallee 1, D-60438, Frankfurt am Main, Germany

"The major task for the developer of the kind of DGVM we are proposing is to conceptualize and parameterize life-history tradeoffs."

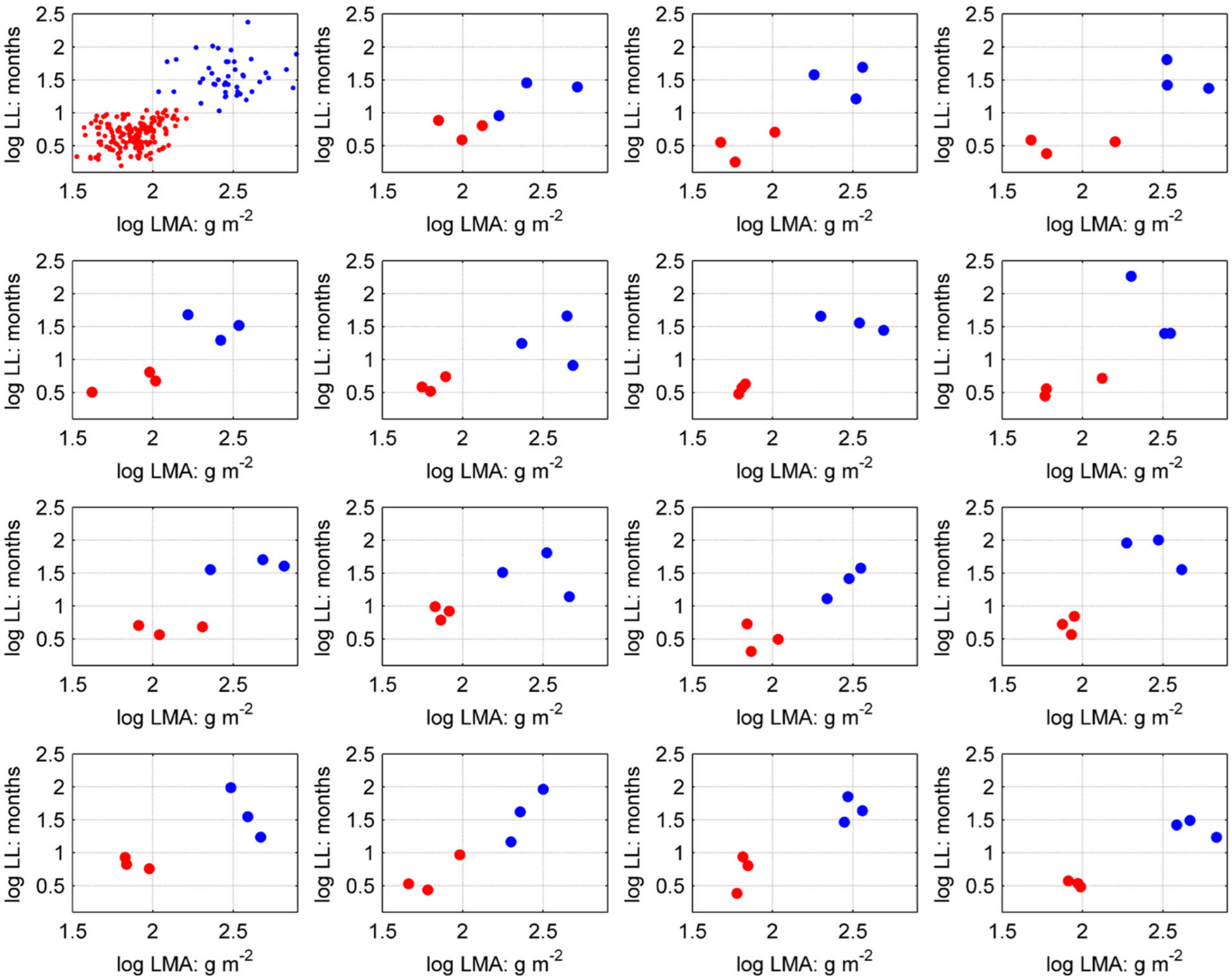
Evergreen Needleleaf
Deciduous Broadleaf

Question: Does how you sample the trait space matter?

Obs

Lifespan

Leaf

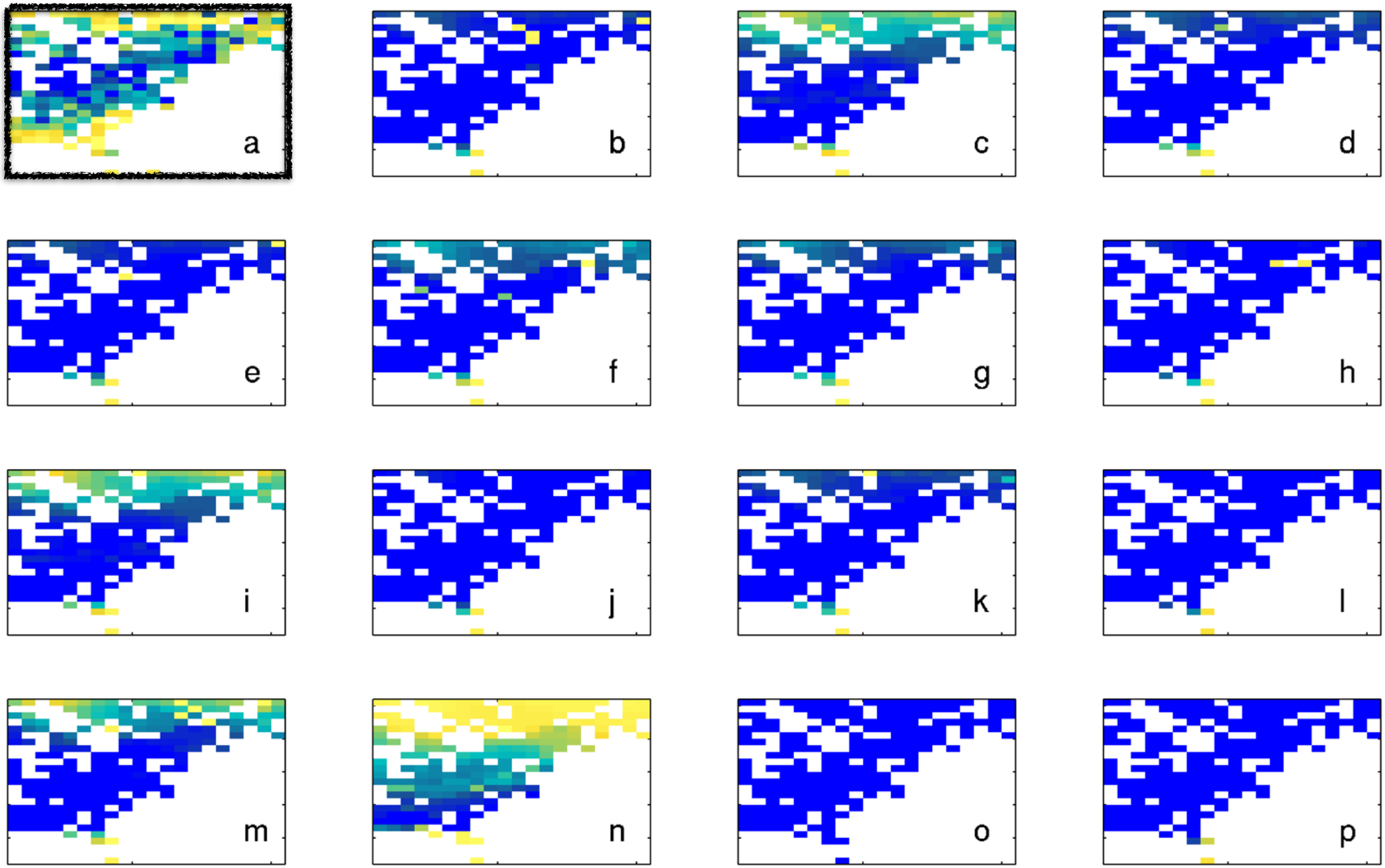


Leaf Cost

Obs

Answer: Yes!

CONTROL

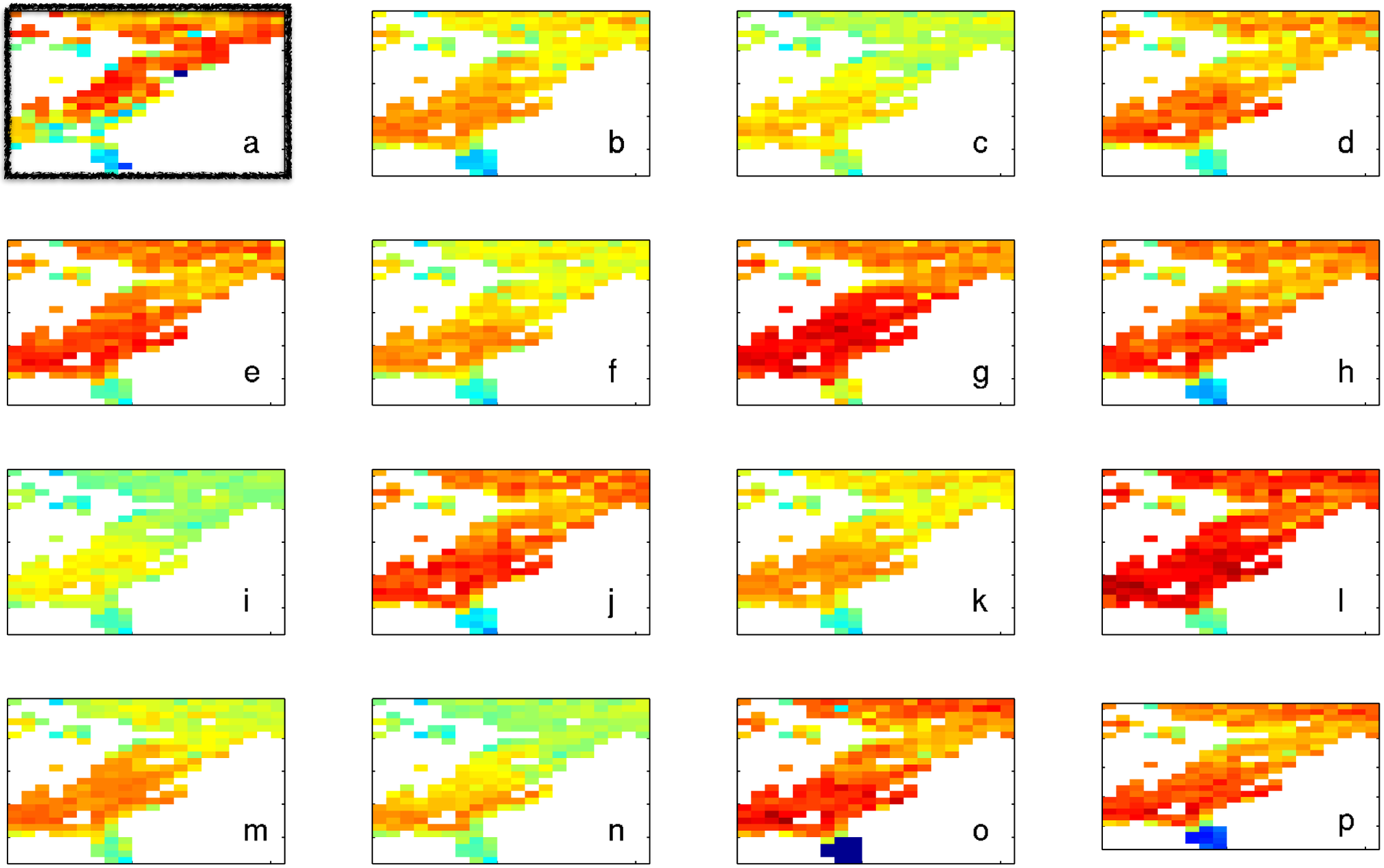


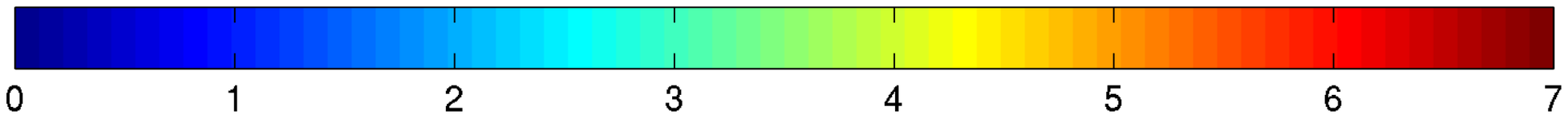
Fisher et al. GMDD 2015

Obs

CONTROL

+ ALLOC





Total Leaf Area Index

Leaf Maintenance Respiration

CLM4.5 (Ryan et al, 1991)

$$\mathrm{lmr}_{top,25} = N_{area} \cdot b_{resp}$$

=0.257 gC gN^{-1} s^{-1}

CLM4.5(ED) (Atkin et al. 2015)

for BDT

$$\log_{10}(\mathrm{lmr}_{top,25,BDT}) = \log_{10}(N_{area}) \cdot 1.134 - 0.300$$

~0.536 gC gN^{-1} s^{-1}

and for NET

$$\log_{10}(\mathrm{lmr}_{top,25,NET}) = \log_{10}(N_{area}) \cdot 1.005 - 0.346$$

~0.452 gC gN^{-1} s^{-1}

ATKIN ET AL. 2015

Obs

CONTROL

+ ATKIN RD

a b c d

e f g h

i j k l

m n o p

0 1 2 3 4 5 6 7

Total Leaf Area Index

RYAN ET AL, 1991

Obs

CONTROL

a b c d

e f g h

i j k l

m n o p

0 1 2 3 4 5 6 7

Total Leaf Area Index

Obs

CONTROL

a b c d

e f g h

i j k l

m n o p

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

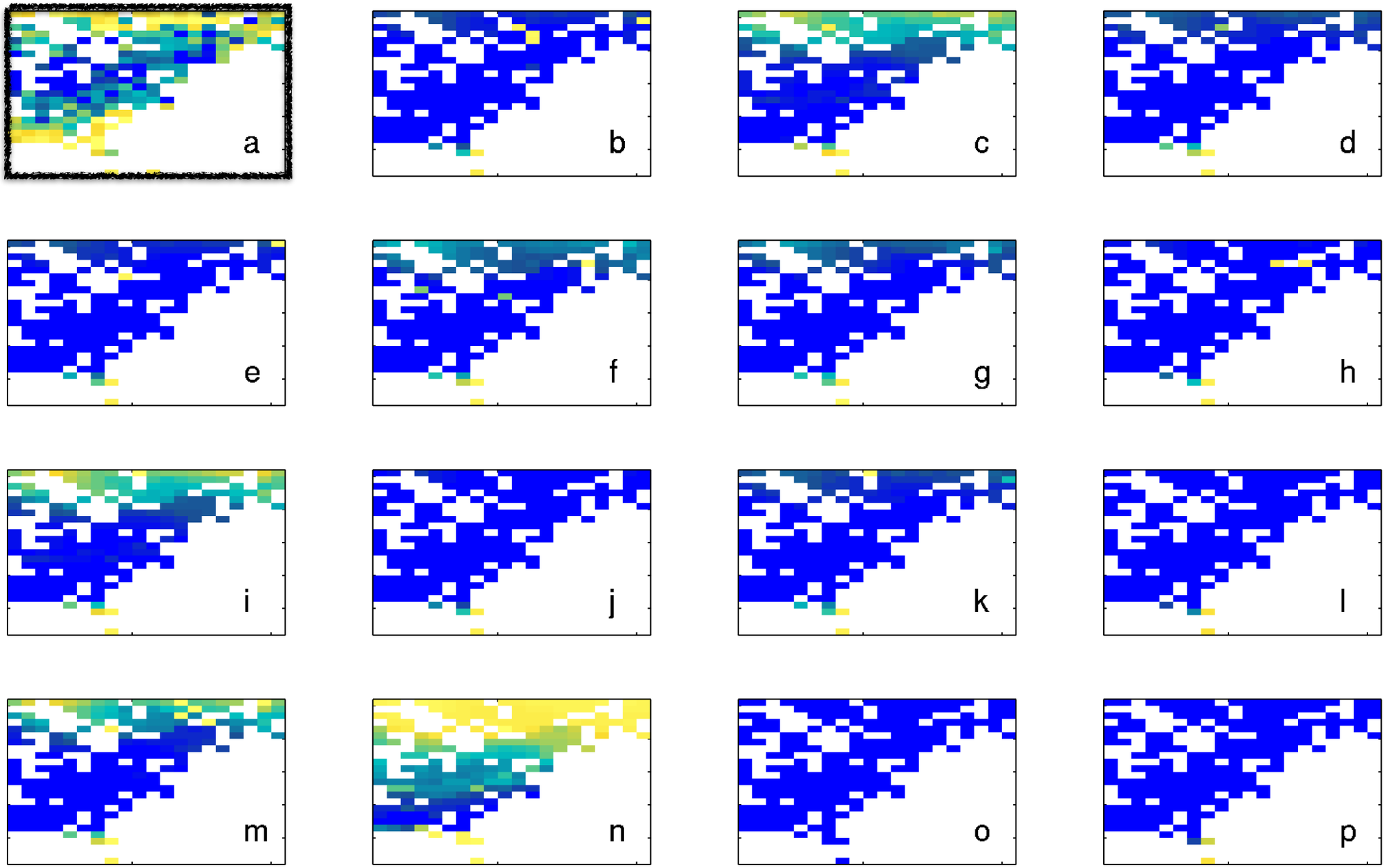
Fraction of evergreen vegetation

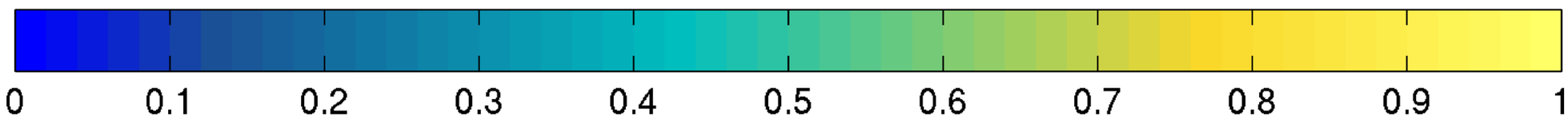
Fisher et al. GMDD 2015

Obs

CONTROL

+ATKIN R



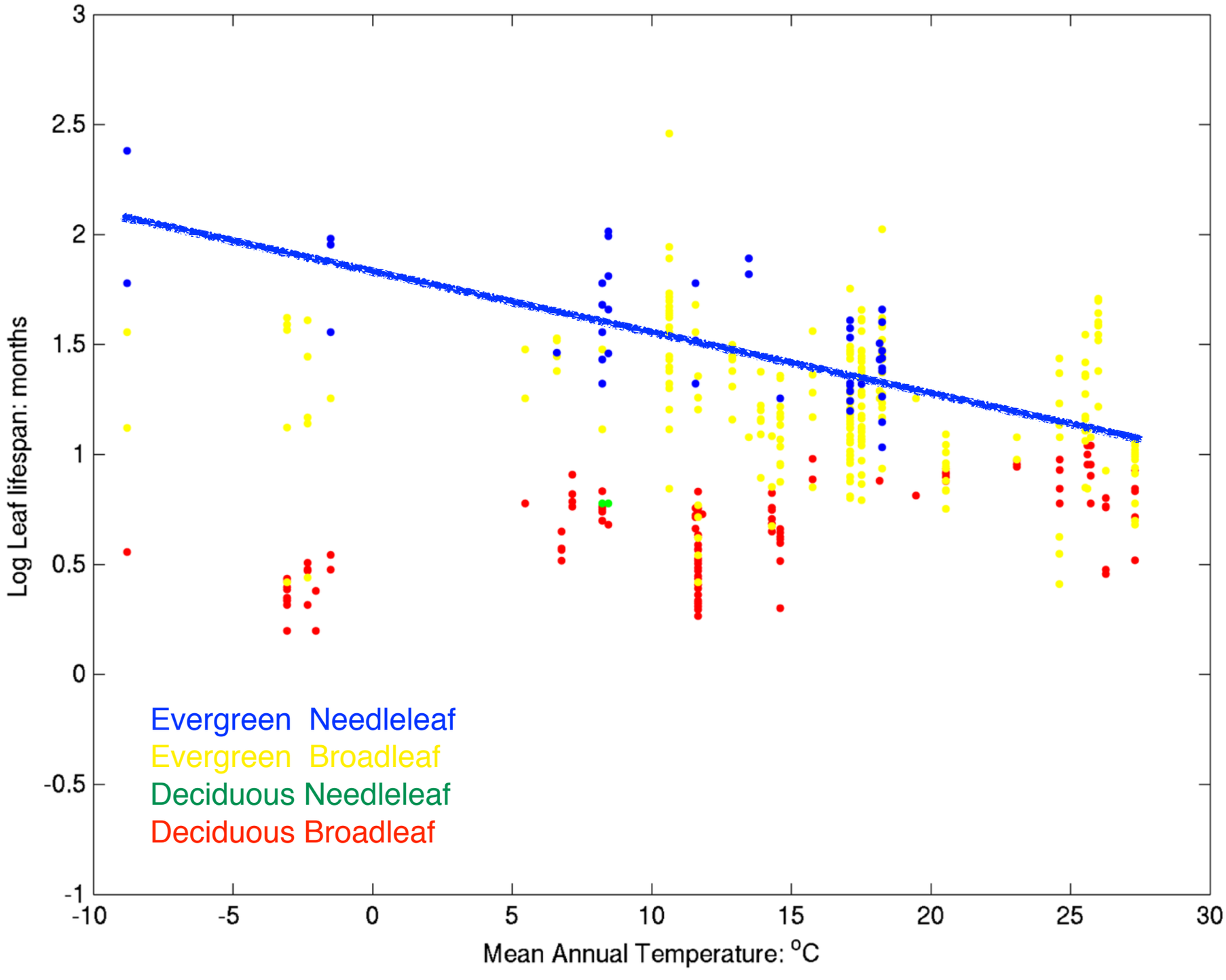


Fraction of evergreen vegetation

Fisher et al. GMDD 2015

Leaf Turnover vs. Temperature

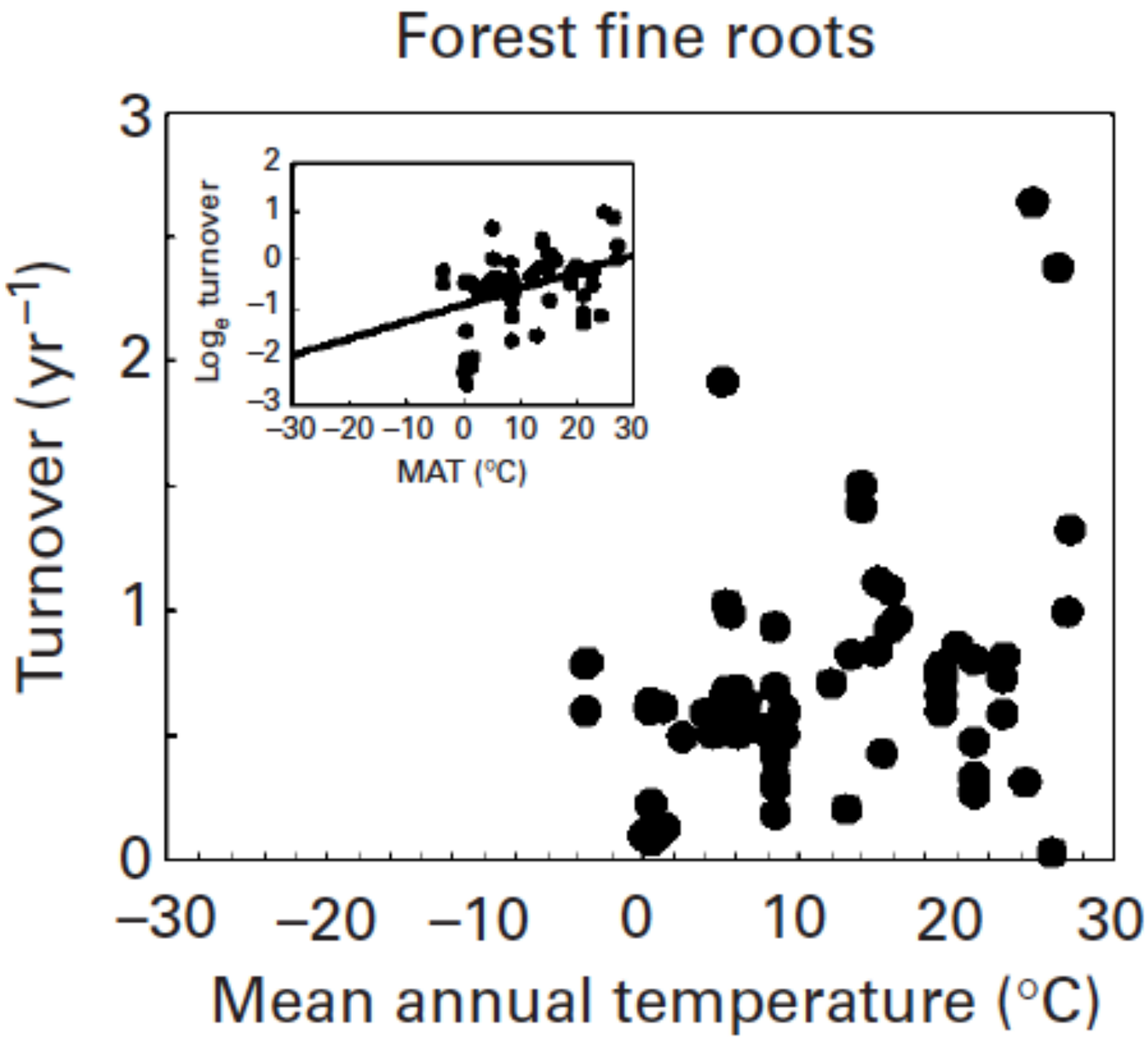
Is leaf lifespan dictated by construction cost, or the environment?



Root Turnover vs. Temperature

BDT $\log_{10}(\mathrm{lmr}_{\mathrm{top,25,BDT}}) = \log_{10}(N_{\mathrm{area}}) \cdot 1.134 - 0.300$

ENT $\log_{10}(\mathrm{lmr}_{\mathrm{top,25,NET}}) = \log_{10}(N_{\mathrm{area}}) \cdot 1.005 - 0.346$



(Data extracted from)
Gill & Jackson 2000

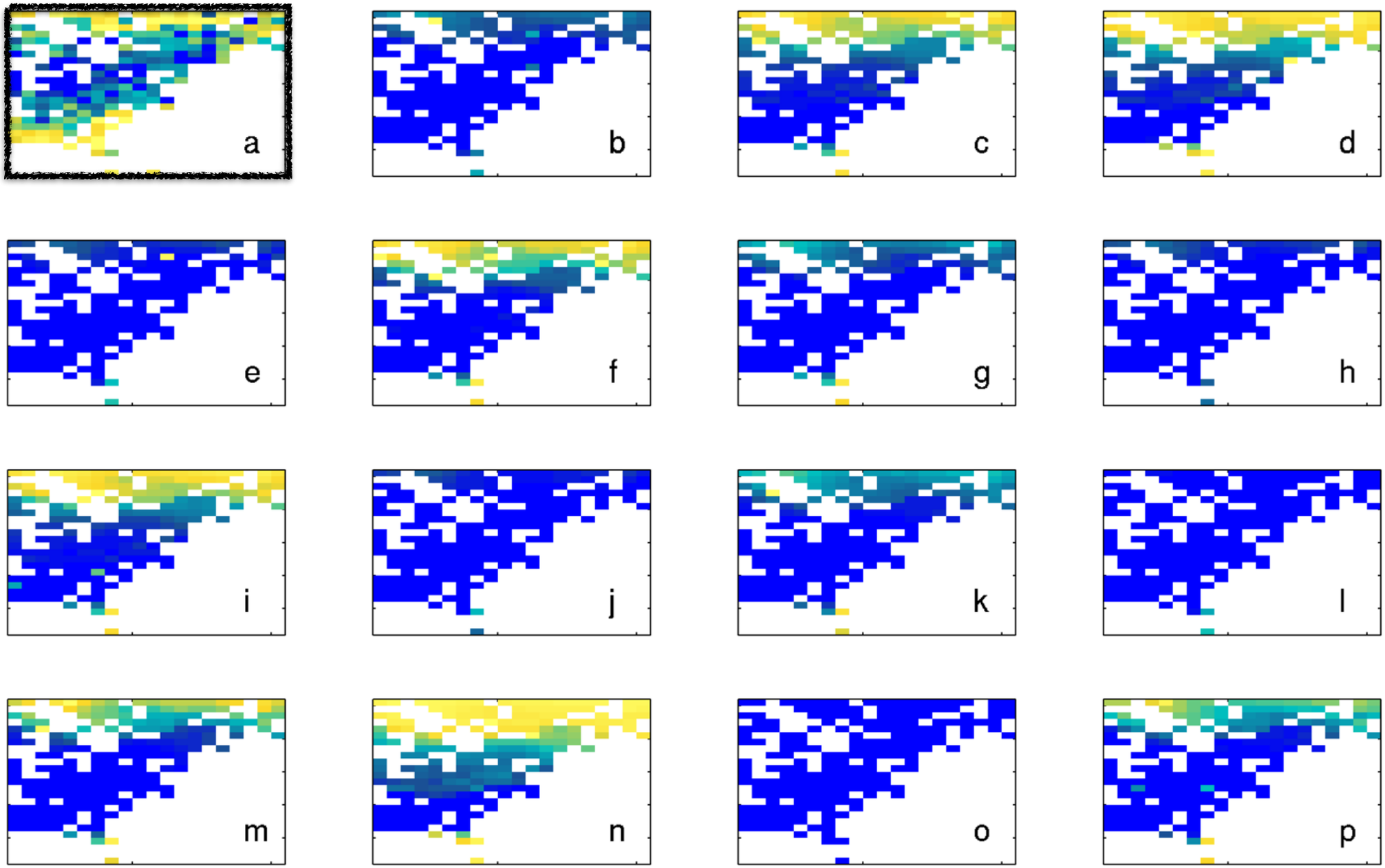
Obs

CONTROL

+ATKIN R

+L_LTEMP

+R_LTEMP

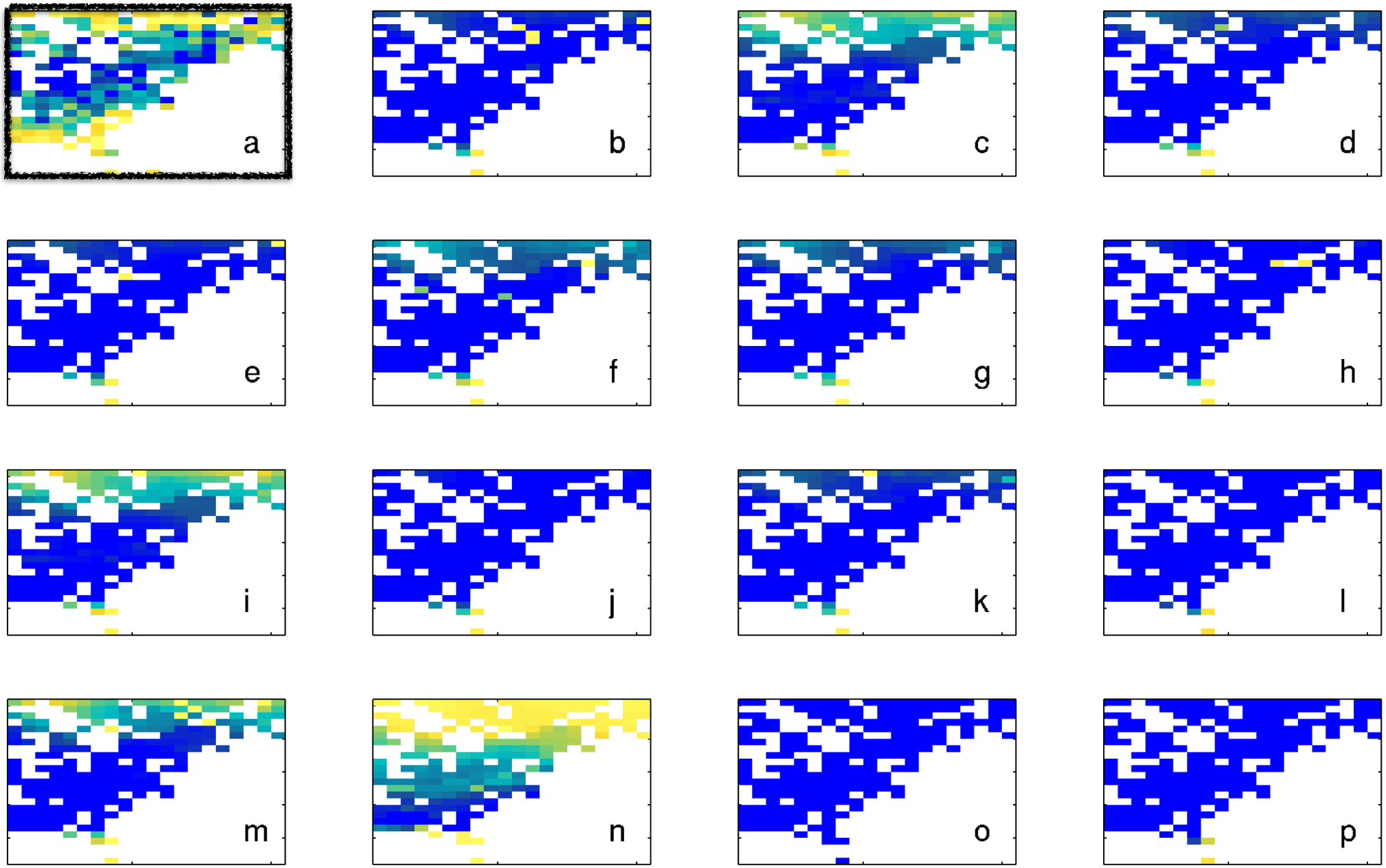


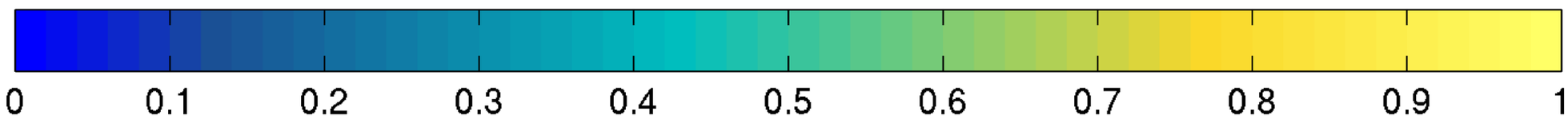
Fisher et al. GMDD 2015

Obs

CONTROL

+ATKIN R





Fraction of evergreen vegetation

Fisher et al. GMDD 2015

Conclusions #1

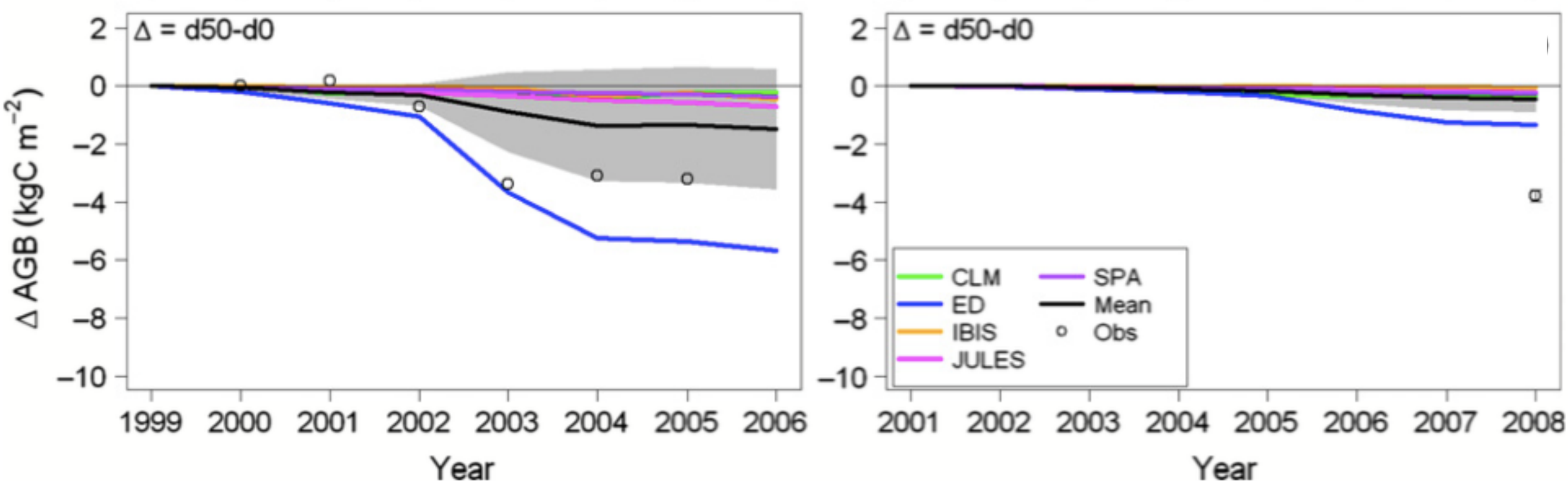
- Carbon economy of leaf habit can, **in some cases**, predict dec-evg biome boundaries

- **How we use** plant trait data matters for vegetation dynamics predictions.

- **Naïve use of plant trait databases does not necessarily lead to skillful prediction**

- Parametric and structural ensembles are **both** informative for understanding cause & effect in model predictions.

“Models are poorly skilled at simulating tropical drought experiments”



Is this because they don’t have a diversity of hydraulic function?

Powell et al. 2013

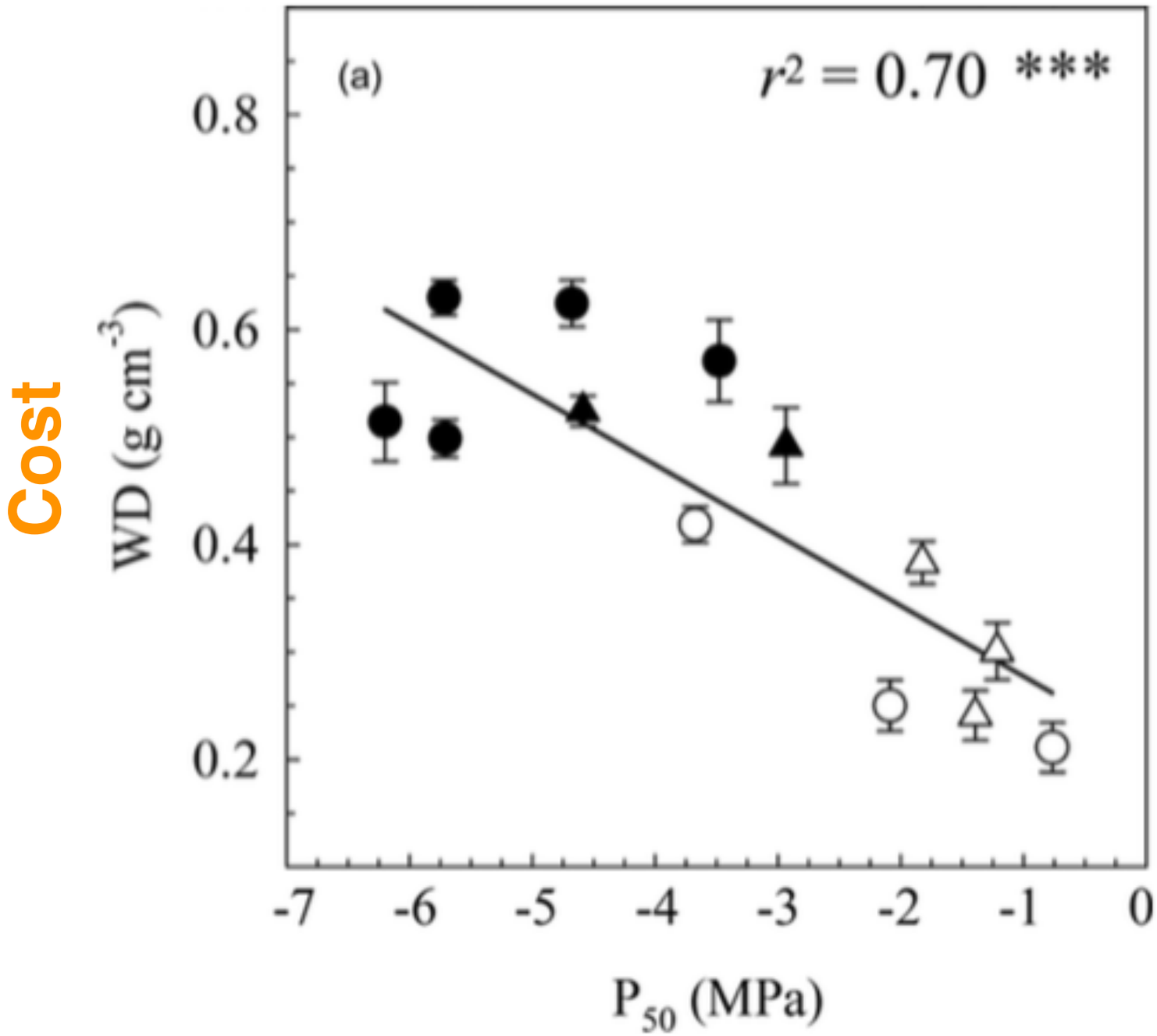
Next-generation dynamic global vegetation models: learning from community ecology

Simon Scheiter[1], Liam Langan[2] and Steven I. Higgins[2]

[1]Biodiversität und Klima Forschungszentrum (LOEWE BiK-F), Senckenberg Gesellschaft für Naturforschung, Senckenberganlage 25, D-60325, Frankfurt am Main, Germany; [2]Institut für Physische Geographie, Goethe-Universität Frankfurt am Main, Altenhöferallee 1, D-60438, Frankfurt am Main, Germany

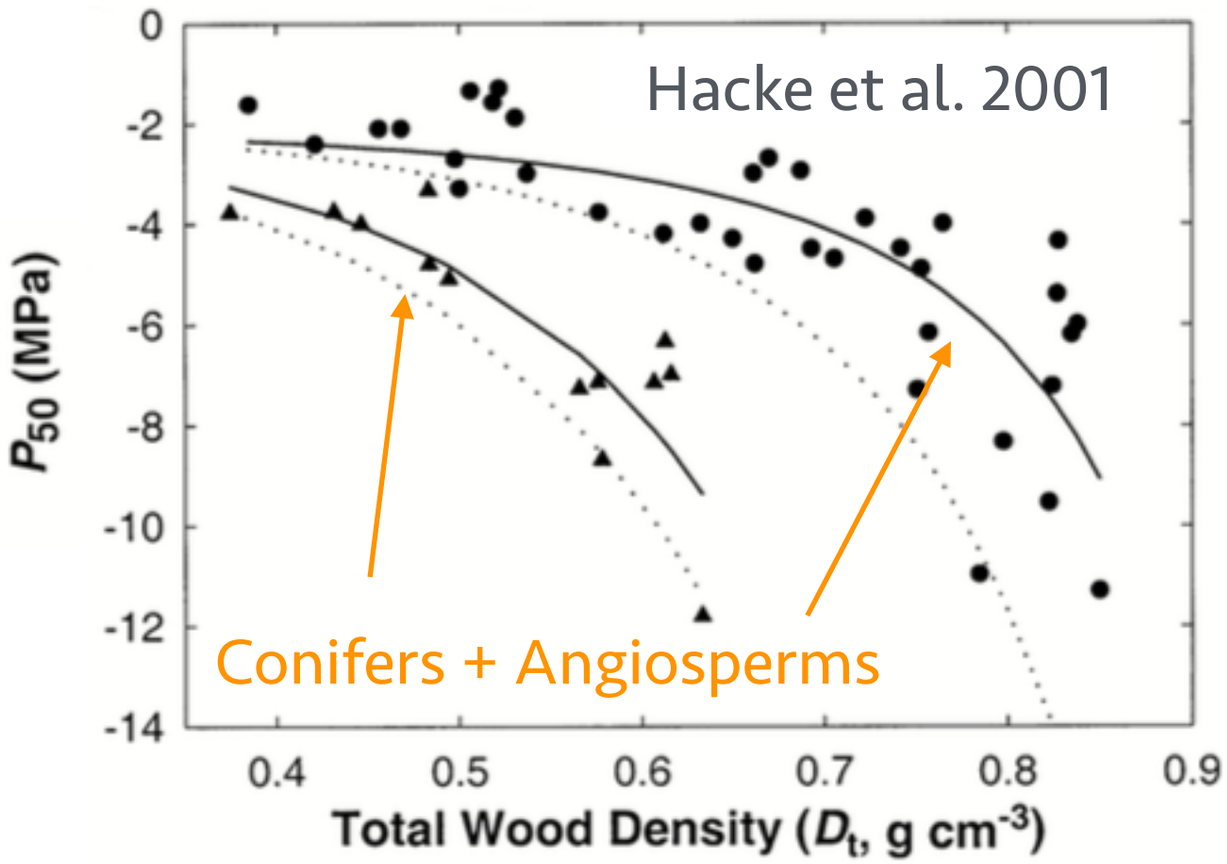
"The major task for the developer of the kind of DGVM we are proposing is to conceptualize and parameterize life-history tradeoffs."

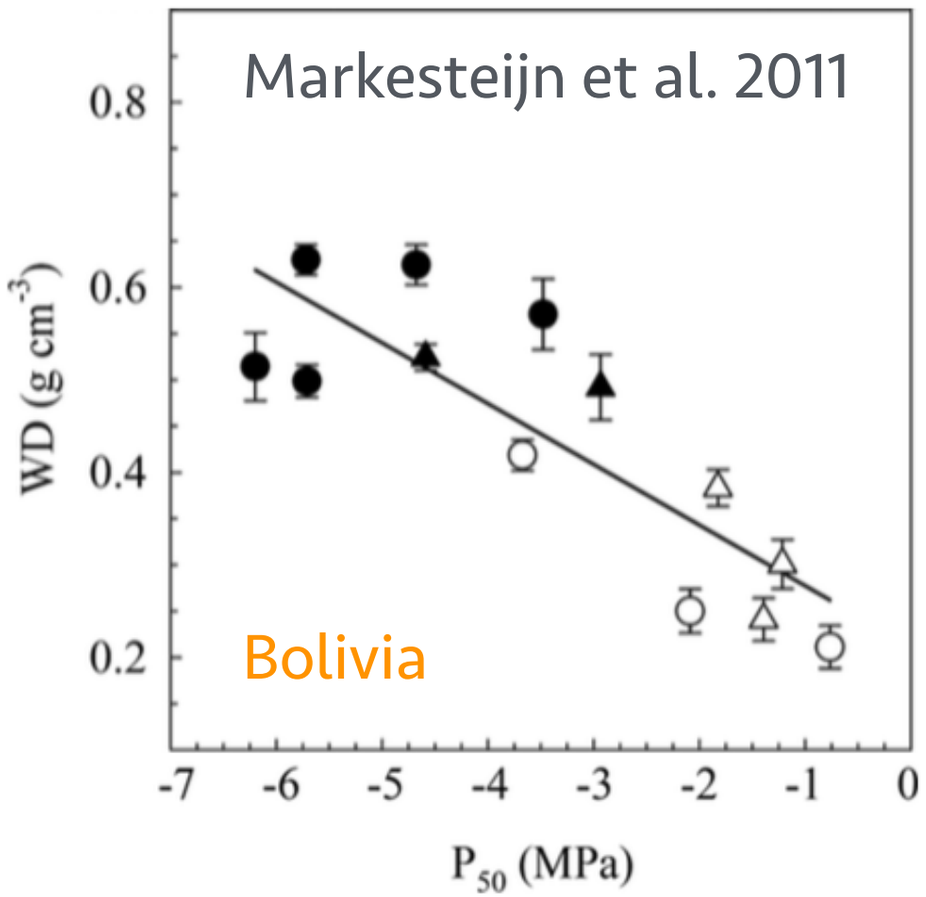
Can we observe diversity in hydraulic function?

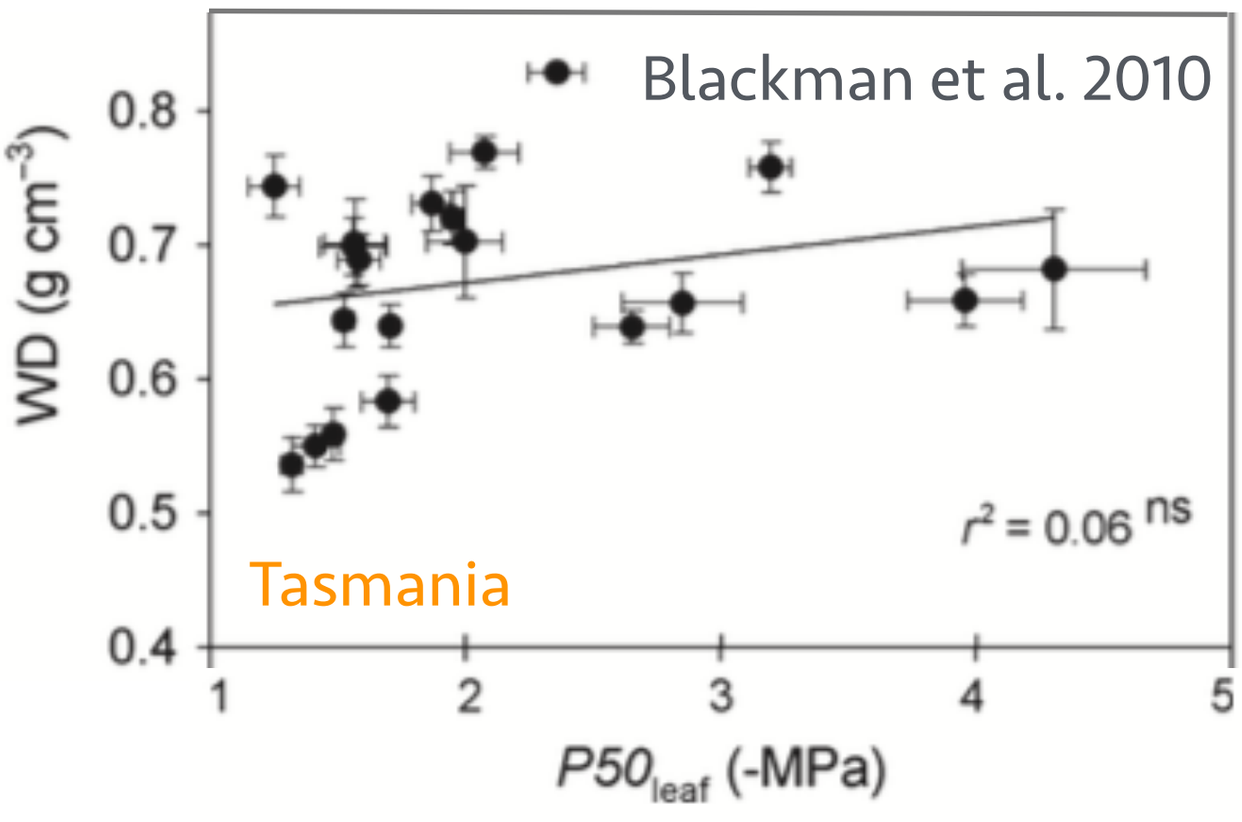


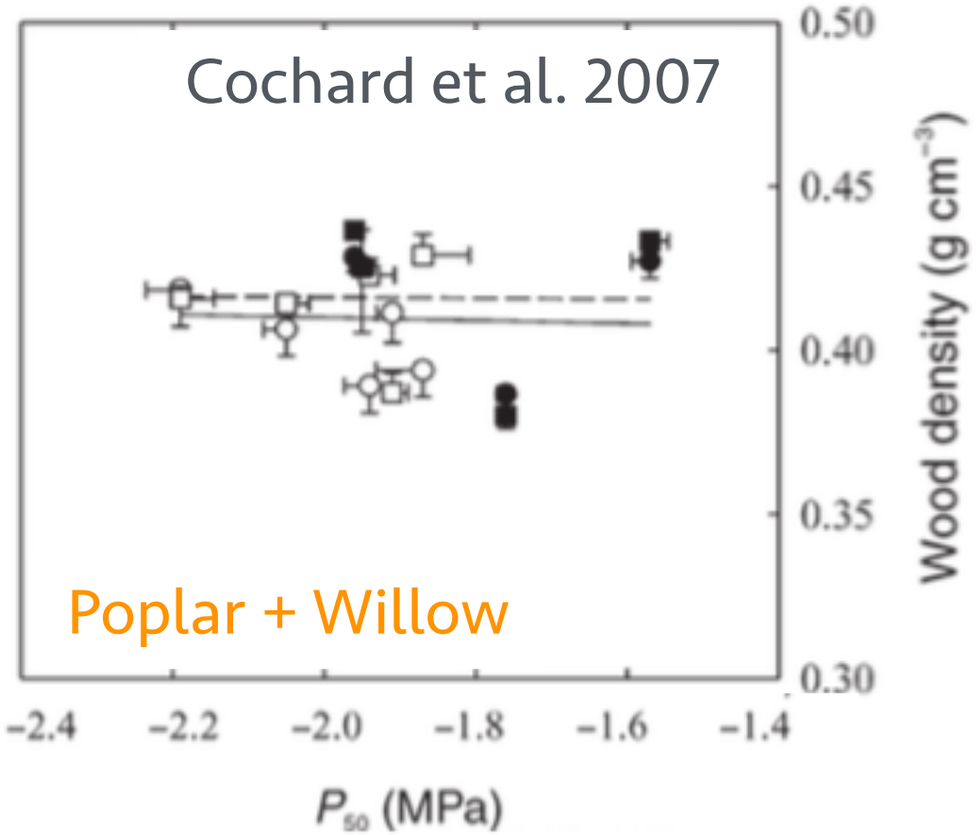
Example from Bolivia

Markesteijn et al. 2011

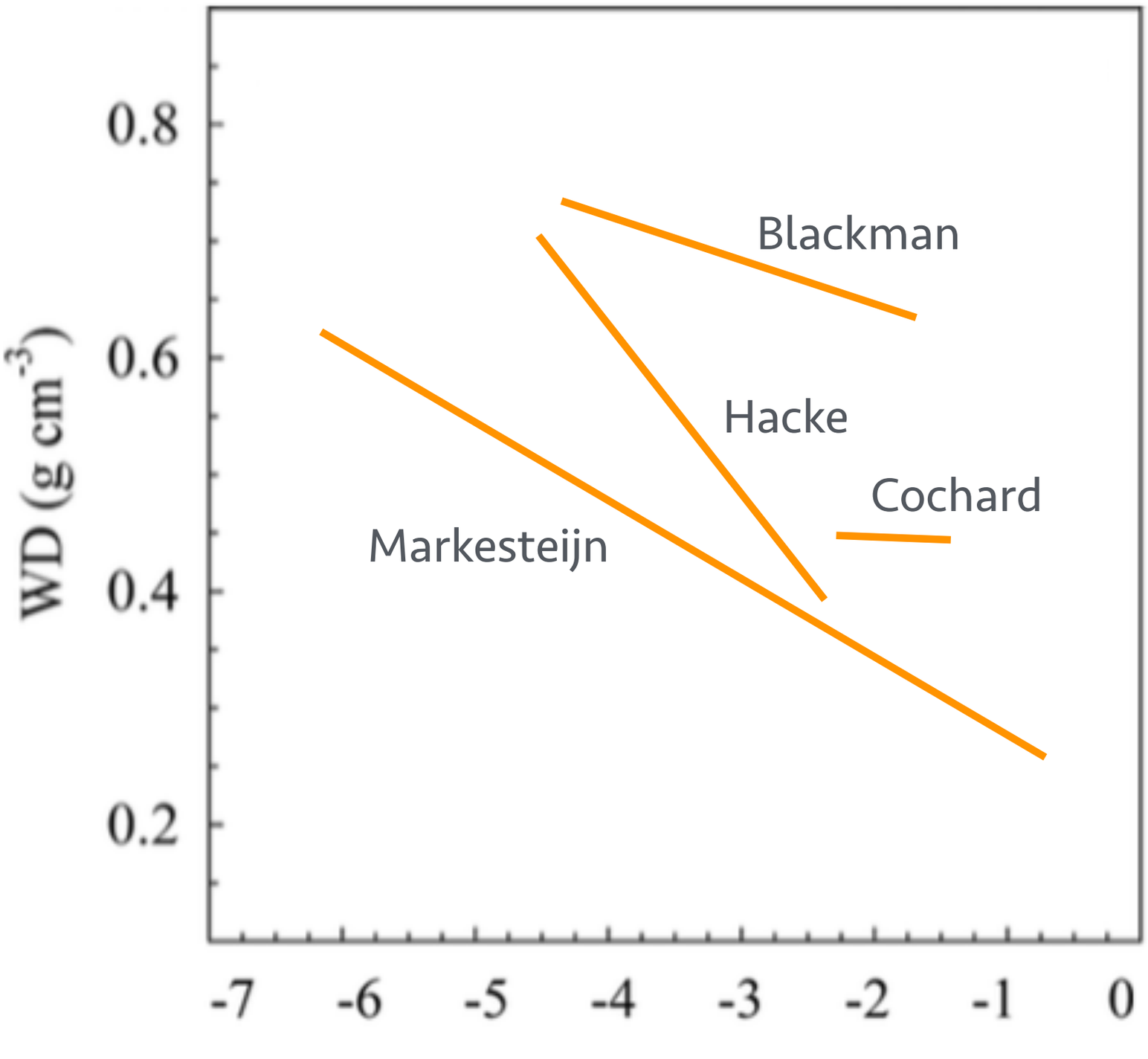

Hacke et al. 2001
Conifers + Angiosperms
P_{50} (MPa)
Total Wood Density (D_t, g cm^{-3})


Markesteijn et al. 2011
Bolivia
WD (g cm^{-3})
P_{50} (MPa)


Blackman et al. 2010
Tasmania
r^2 = 0.06 ns
WD (g cm^{-3})
$P50_{leaf}$ (-MPa)


Cochard et al. 2007
Poplar + Willow
Wood density (g cm^{-3})
P_{50} (MPa)

What is the cost of drought tolerance?



Powell et al. 2013

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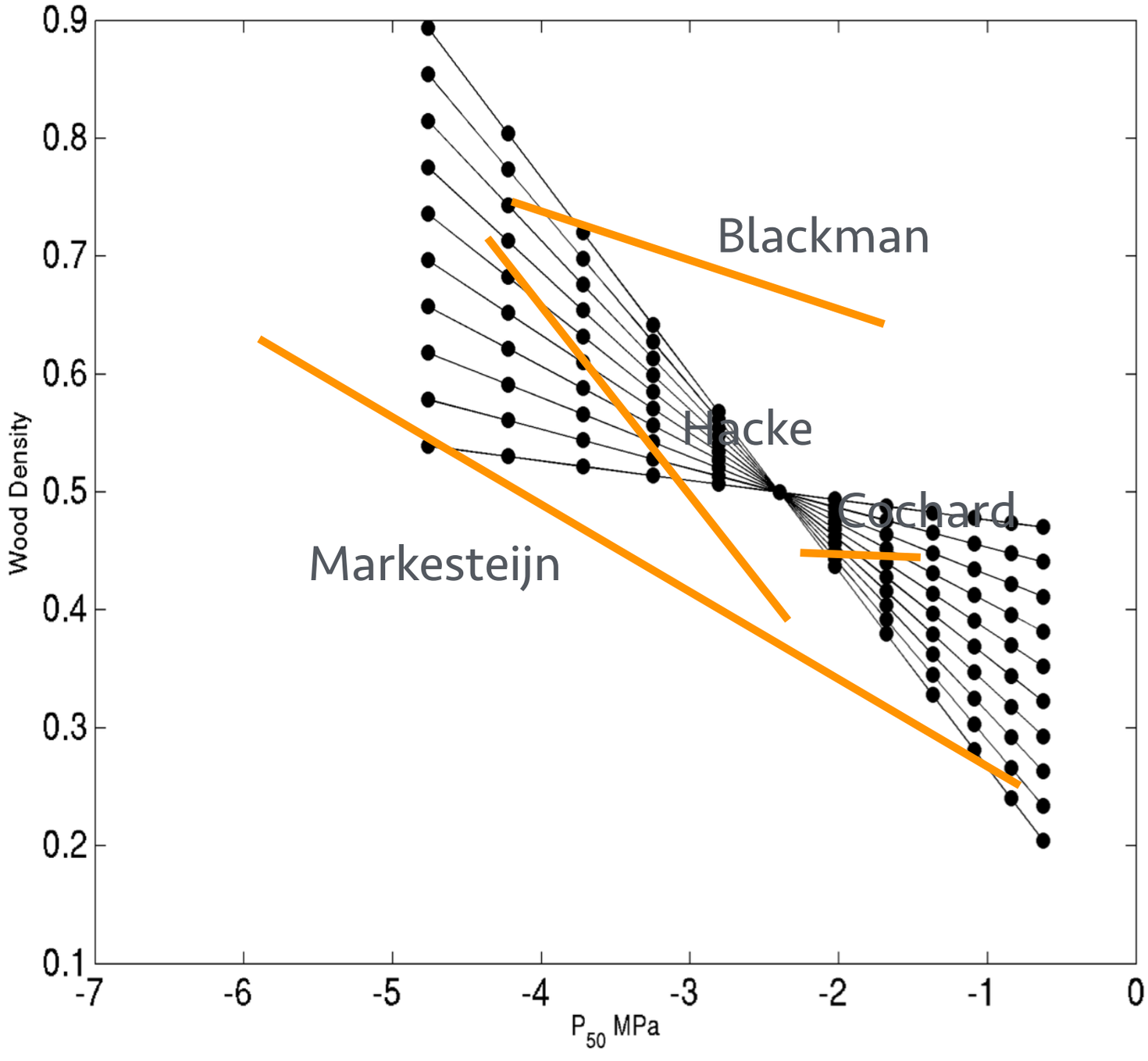

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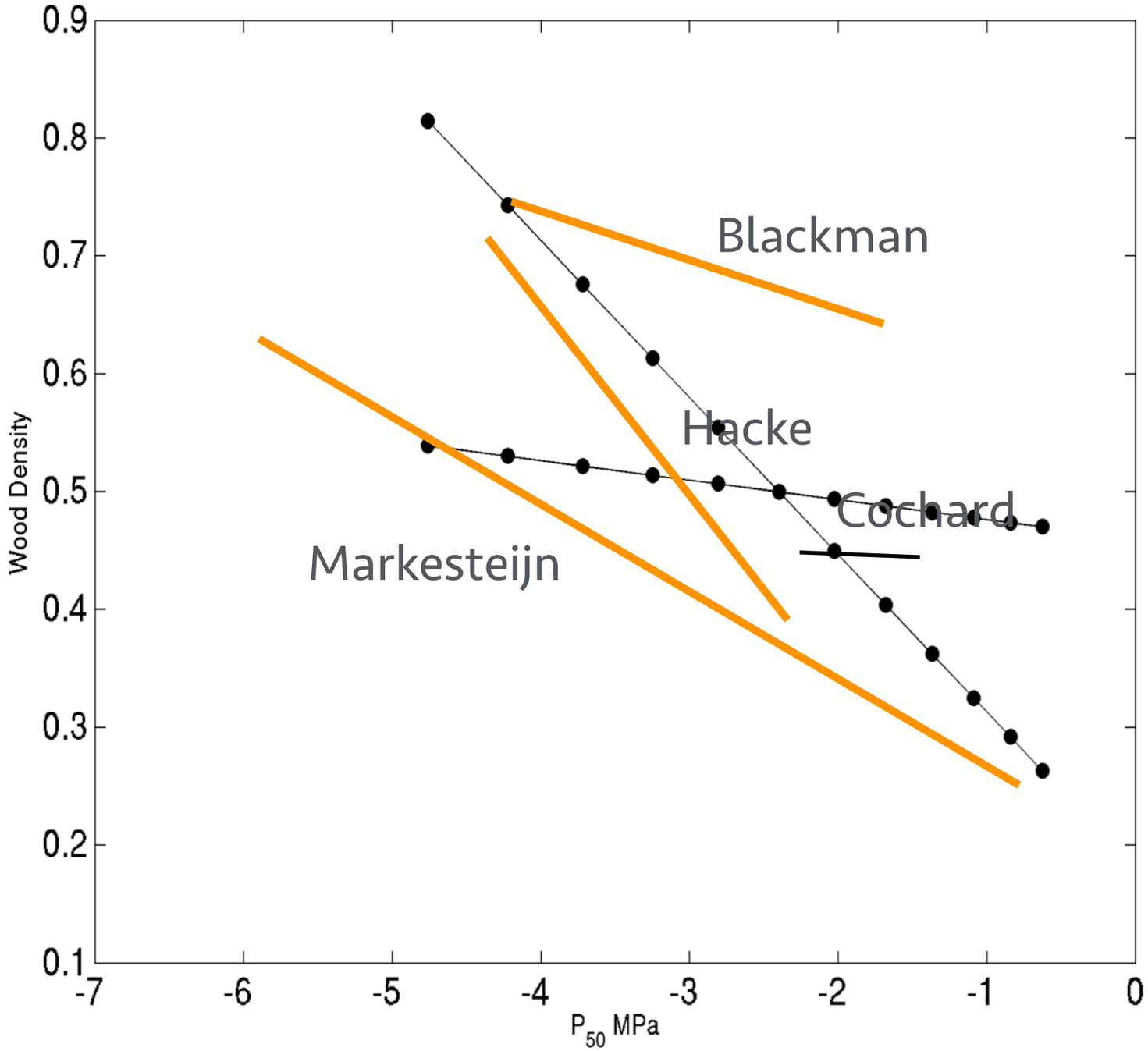
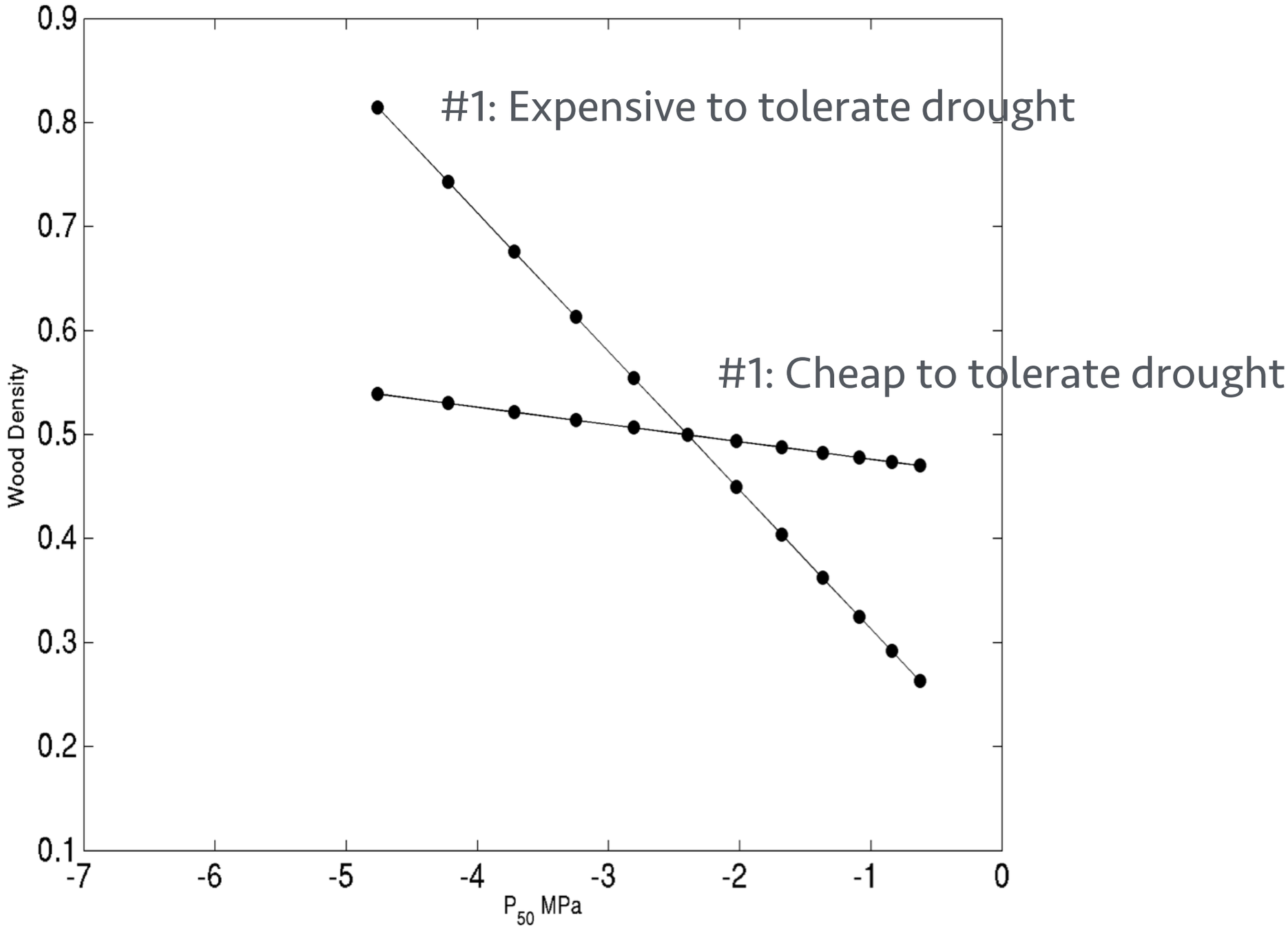
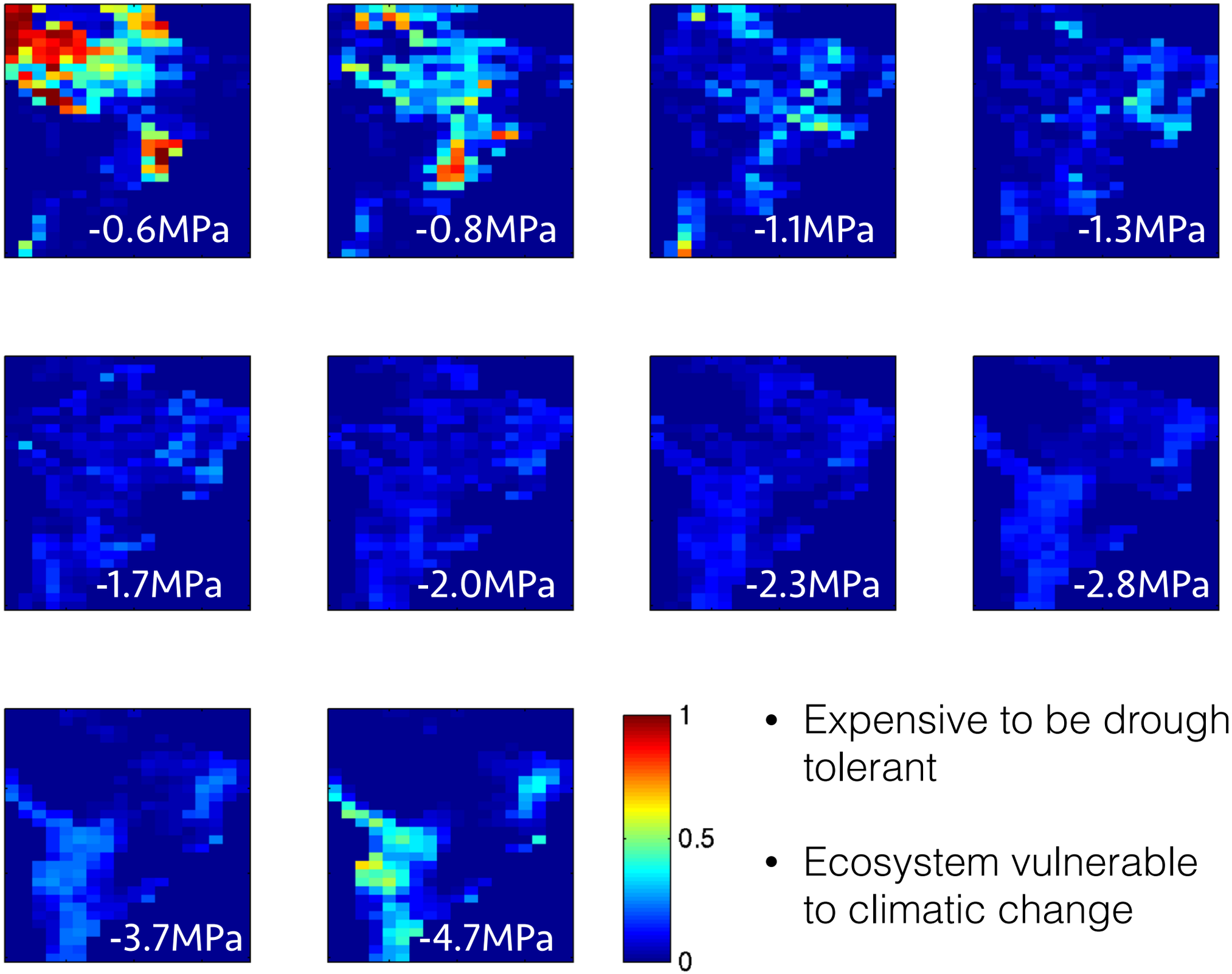


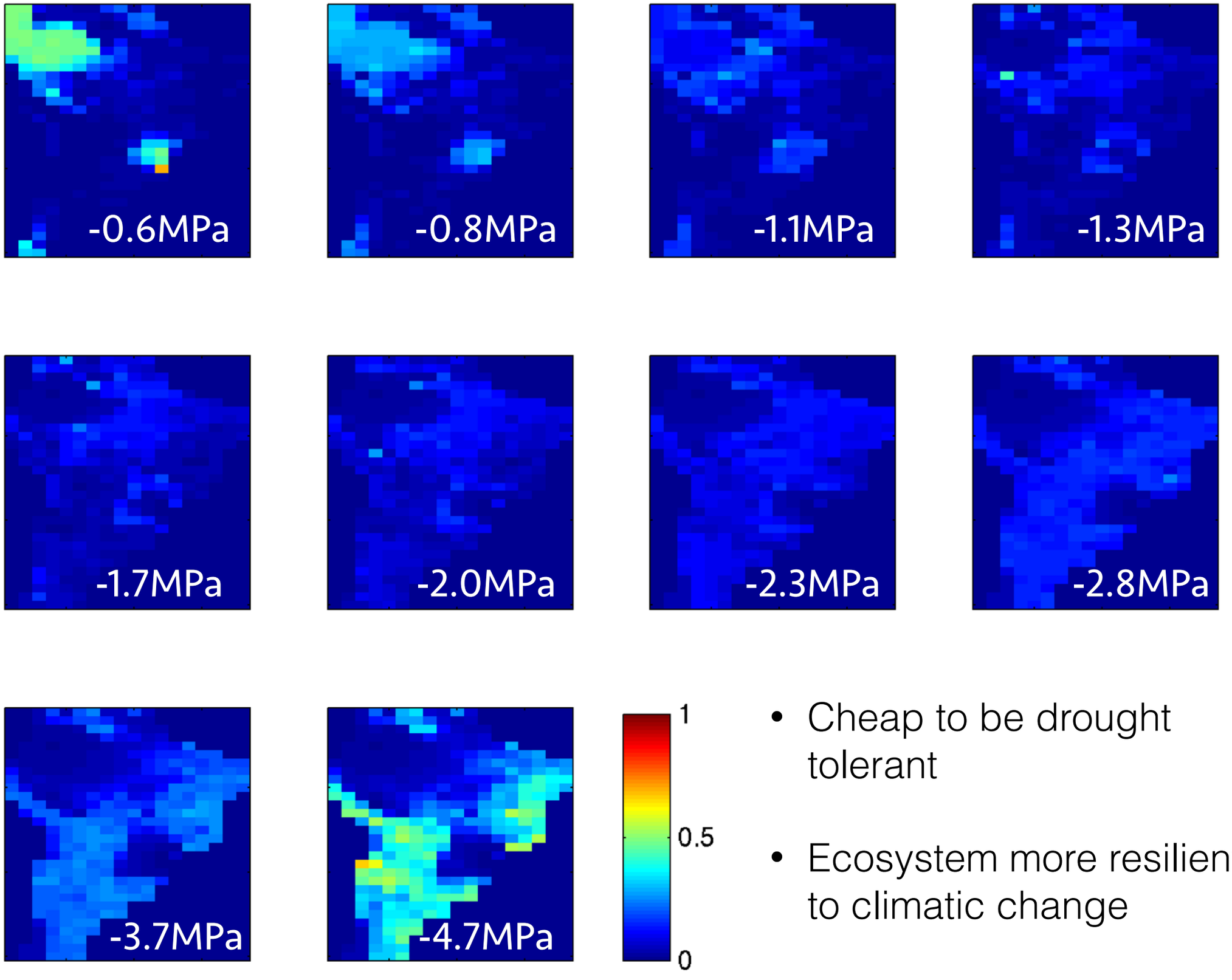
What is the cost of drought tolerance?





- Expensive to be drought tolerant
- Ecosystem vulnerable to climatic change

#1:Fraction of biomass in each plant type. Numbers correspond to soil water potential at stomatal closure



- Cheap to be drought tolerant
- Ecosystem more resilient to climatic change

#2:Fraction of biomass in each plant type. Numbers correspond to soil water potential at stomatal closure

Conclusions II

- Earth System Models are moving towards ‘trait filtering’ schemes.

- Cost-benefit trade-offs are the ‘raw material’ of trait filtering models, but are typically poorly quantified.

- This development presents a huge opportunity for quantitative hypothesis testing of biome boundaries.

- Understanding the quantitative costs and benefits of alternative life history strategies is important!

NGEE TROPICS

NEXT GENERATION ECOSYSTEM EXPERIMENT - TROPICS

$100M 10 year project

U.S. DEPARTMENT OF ENERGY | Office of Science

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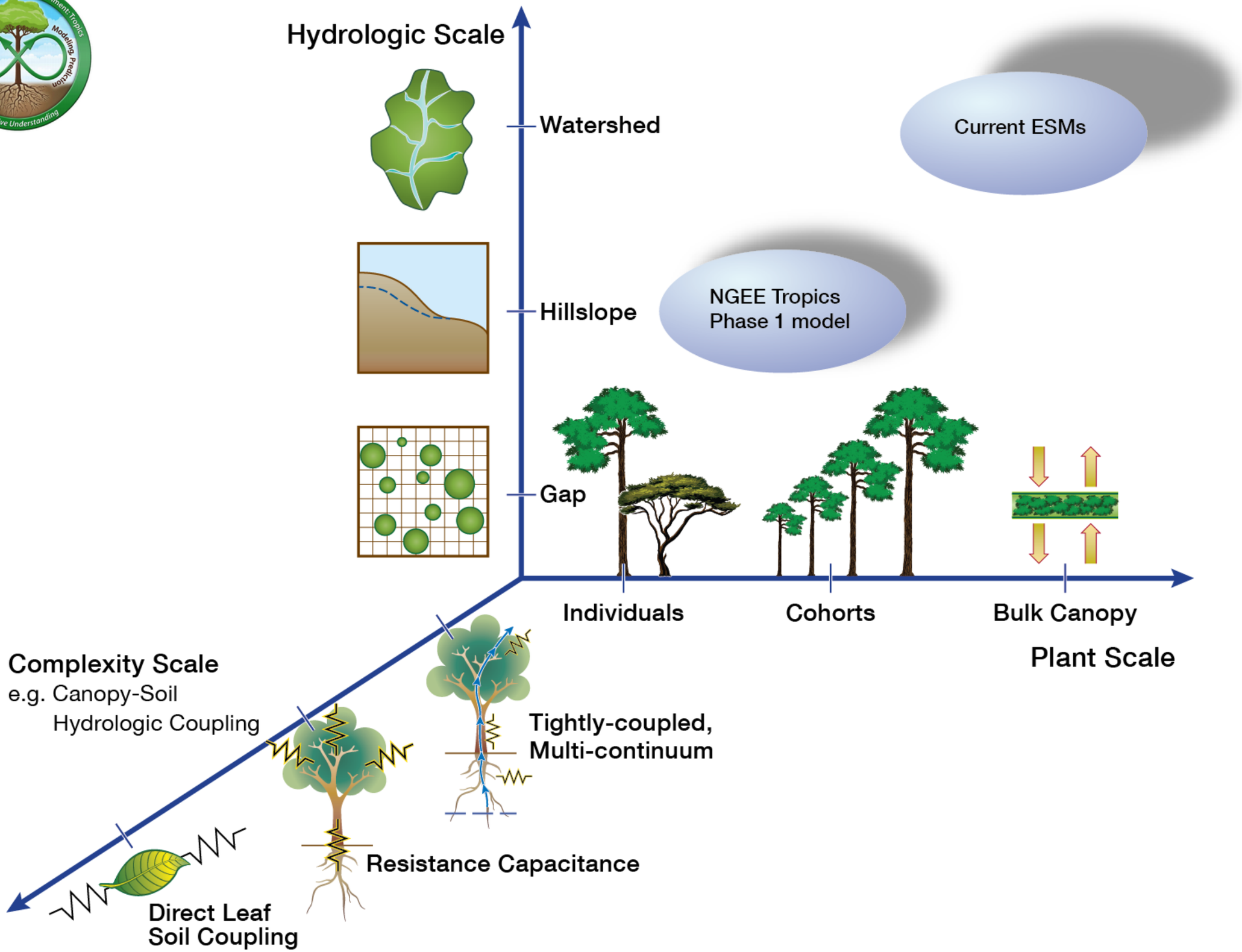

NGEE-tropics mode scaling plan

Land Surface Model (CLM, ALM)

- Hydrology
- Soil evaporation
- VOC's
- Lake model
- Snow model
- Urban model
- Land Ice
- Subgrid structure
- Atmospheric Coupling
- Soil Thermal Processes
- Crop model
- Irrigation

Vegetation structure
(patch, cohort)
Allocation, growth, reproduction, mortality, canopy organization, fire

mortality, turnover, seed flux →

← establishment

Seeds,Litter
(patch, size class, PFT)
Fragmentation, fire spread, seed recruitment

canopy structure ↓↑ NPP

ED module

fragmentation ↓

Vegetation physiology
(cohort, leaf layer)
Radiation transfer, photosynthesis, evapotranspiration, respiration, interception

nutrient supply →

← nutrient demand, exudation

Soil Biochemistry
(depth, chemistry)
Nitrogen fixation, denitrification, SOM decay, vertical transport, nutrient competition

Interface Layer

Soil water + temperature [CO2], P, humidity, wind, temperature, incoming radiation intercepted water, land use, soil type & depth →

← LH, SH, albedo Root water extraction, LAI, height, bare ground frac, GPP, $R_{auto,}$

Nutrient inputs, dust, drydep →

← Nutrient Leaching, Gaseous N loss, R_{het}

Plan for FATES in CLM5

FATES will be a ‘dynamically linked’ library, so that updates to FATES can be made independent of releases of CLM

The INTERFACE code will likely remain constant.

If you plan on using FATES, please contact me (rfisher@ucar.edu) or Charlie (cdkoven@lbl.gov) to check in on the latest science updates.