R.E.D.

Robust Ecosystem Demography Model

A New DVGM

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NATURAL ENVIRONMENT RESEARCH COUNCIL

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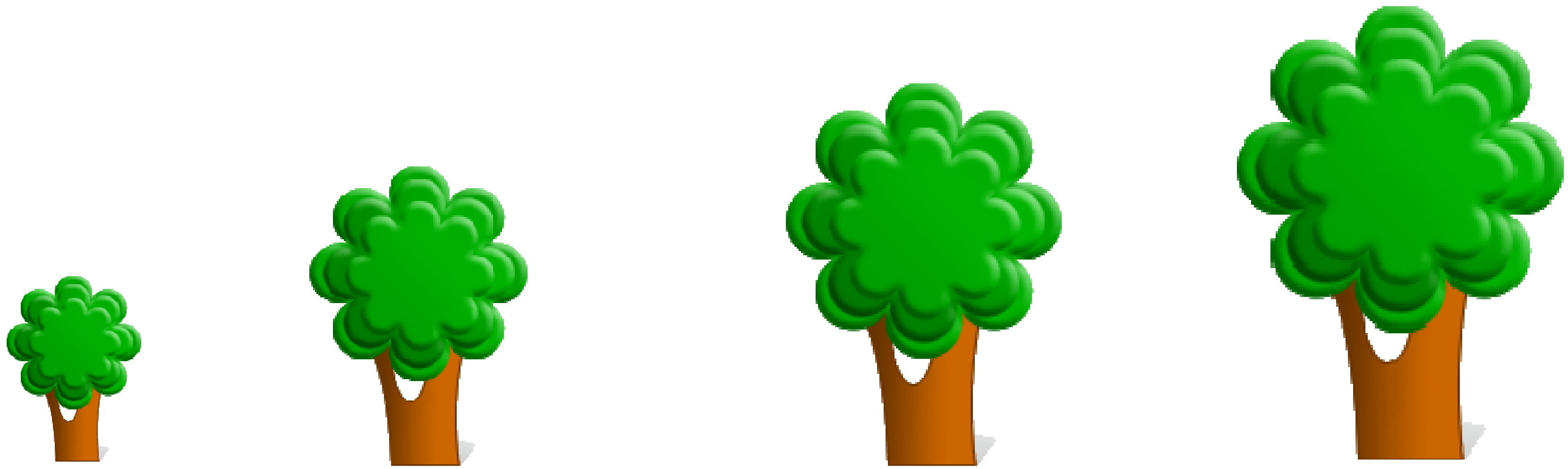
What is R.E.D.?

- Each plant functional type (PFT) type will have a fixed set of size classes.
- Size variable will be carbon mass. Will keep track of number trees per m^2 in each class.

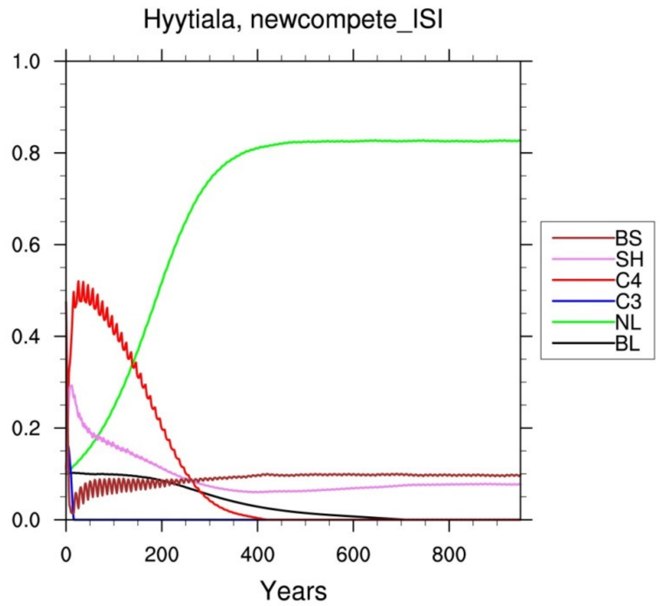


Why R.E.D.?

TRIFFID Problems

•Regrowth timescales (particularly tree P.F.T.s) are too long, so response to disturbance, land use, fire are less accurate.

•E.g. Hyytiala in Finland has regrowth of ~100 years, but TRIFFID simulates ~300 years.



JULES-ED Problems

•JULES-ED has a new cohort every time there is a disturbance -> number of cohorts grows indefinitely!

•Physiology is tied to dynamics, making it hard to modify or maintain the model.

Need a more robust model than JULES-ED but more advanced than JULES-TRIFFID.

R.E.D. Equation

- **Uses the continuity equation**

$$\frac{\partial n(m,t)}{\partial t} = -\frac{\partial}{\partial m}\left(\frac{\partial m(m,t)}{\partial t} n(m,t)\right) - \gamma n(m,t)$$

where n = plants per m^2, m = plant mass, γ = mortality rate

(In physics equation describes the transport of a conserved quantity)

- **Conserves the flow of trees (i.e. tree flux).**

Change in no. trees of size i = trees in from class i-1
– trees out to class i+1
– trees dying

R.E.D. Size Classes

n_i plants in class
of mass m_i

$$\frac{\frac{dm_{i-1}}{dt} n_{i-1}}{m_i - m_{i-1}}$$

Plants growing
from class below

$$\frac{\frac{dm_i}{dt} n_i}{m_{i+1} - m_i}$$

If +ve carbon balance,
member of class will
grow into next size

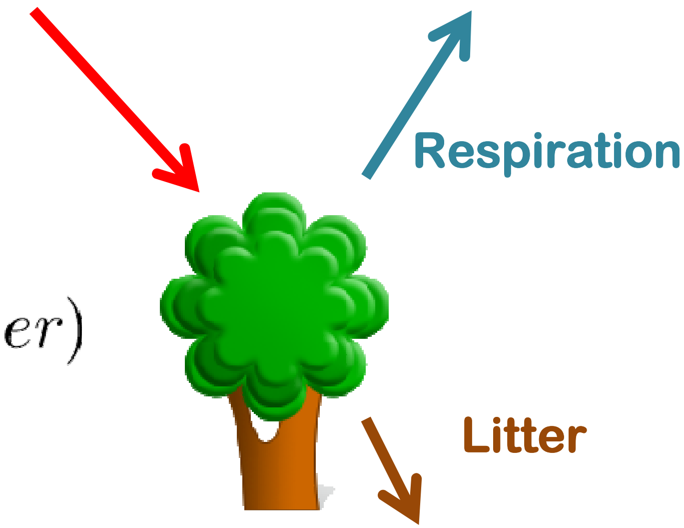
$\gamma\ n_i$

Losses from
mortality and –ve
carbon balance

R.E.D. Growth & Mortality

- **Growth is determined by GPP (photosynthesis), respiration and litter rates.**

$$\frac{dm(m)}{dt} = \frac{dm}{dC}(GPP - Resp - Litter)$$



- **Mortality rate is constant in R.E.D. Could be easily changed in future if needed.**

R.E.D. Carbon Balance

- If carbon balance ie growth of a class is negative then can either assume:-
  a) Trees shrink
  b) Trees die

- We feel trees dying is more realistic, so for negative growth rate we stop all growth to class above and increase mortality.

$$death_i = \begin{cases} -n_i\gamma & \text{For } \frac{\partial m_i}{\partial t} \geq 0 \\ -n_i\left[\gamma - \frac{1}{\Delta m}\left(\frac{\partial m_i}{\partial t}\right)\right] & \text{For } \frac{\partial m_i}{\partial t} < 0 \end{cases}$$

R.E.D. Allometry

- Allometry is the change in shape (e.g. height, diameter) with size and also affects the mass scaling.
- We use a simple power law allometry, which allows diagnosis of height, crown area, trunk diameter for each mass class.

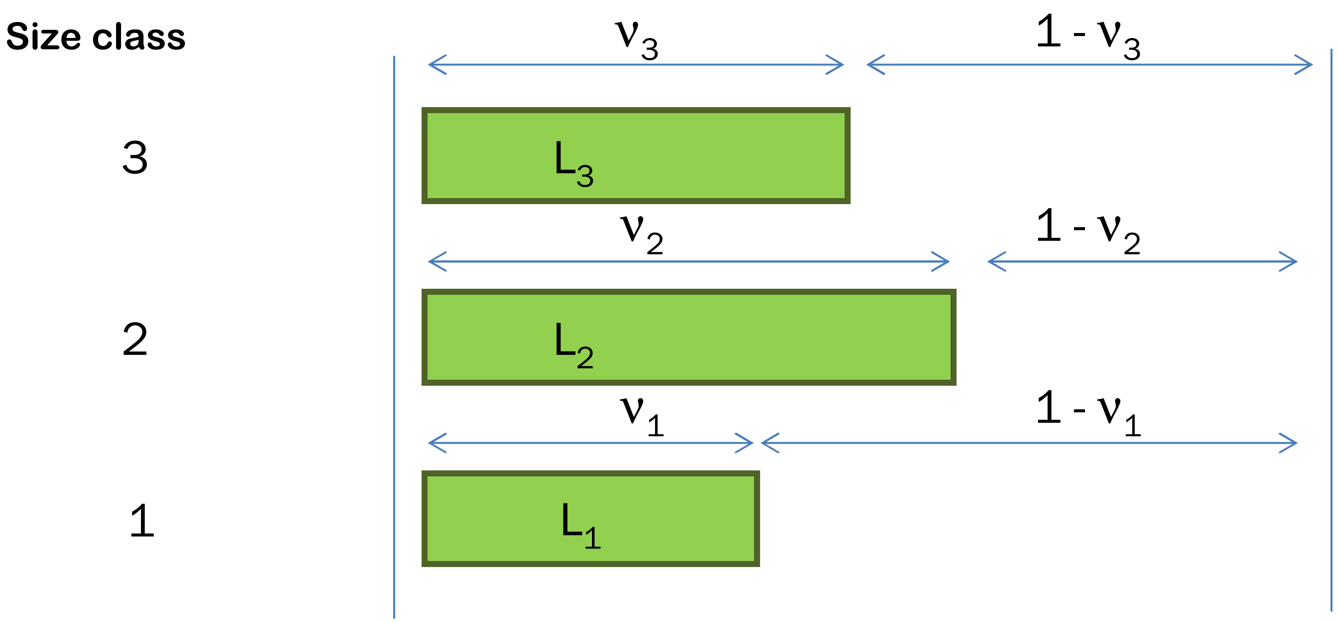
- Exponents currently chosen based on hydraulic scaling theory paper by Niklas & Spatz. PNAS, 101, 15661. 2004

$$S = aM^b$$

where S is size variable such as has height or trunk diameter and a and b are constants

R.E.D. Shading – Random Overlap

- **Light at a particular level is mean of shaded ν_i and unshaded fractional areas above.**



Light Intensity

$$I_{TOP} = I_3$$

$$I_2 = I_{TOP}(\nu_3 e^{-kL_3} + (1 - \nu_3))$$

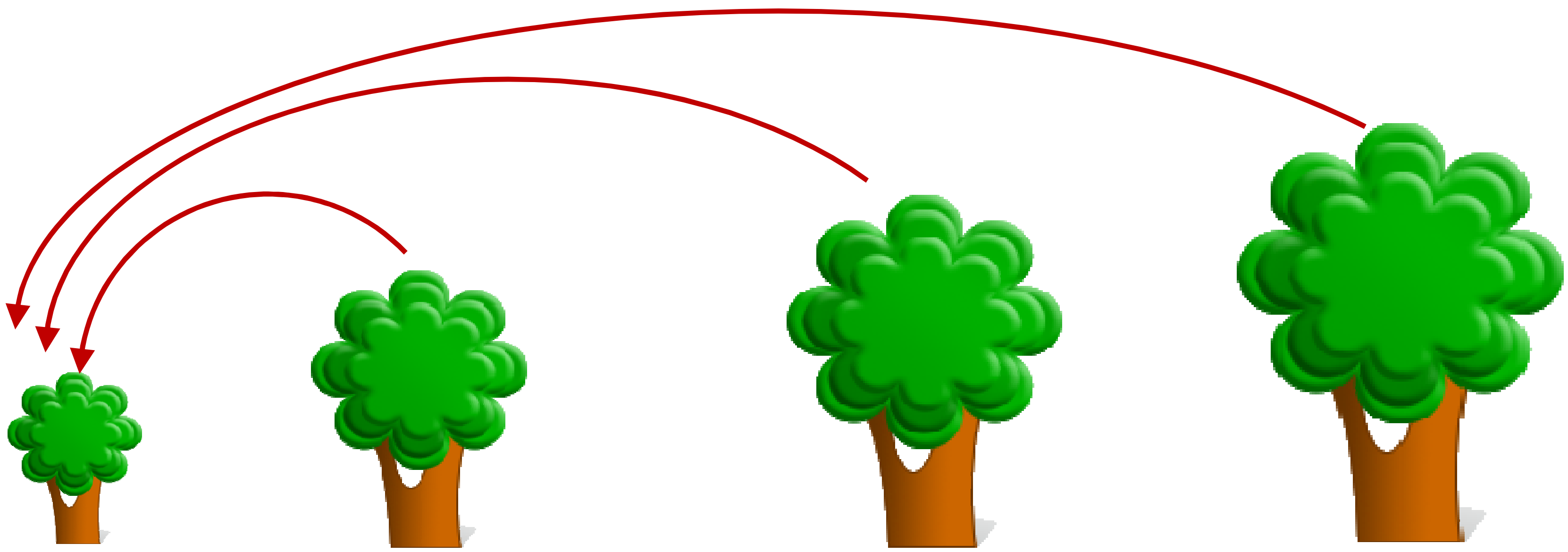
$$I_1 = I_2(\nu_2 e^{-kL_2} + (1 - \nu_2))$$

$$I_0 = I_1(\nu_1 e^{-kL_1} + (1 - \nu_1))$$

$$\text{Light fraction top of class i} = f_{li} = \frac{I_i}{I_{TOP}} = \prod_{j>i}^{n}(1 - f_{PARi}\,\nu_j) \quad f_{PARi} = 1 - e^{-kL_i}$$

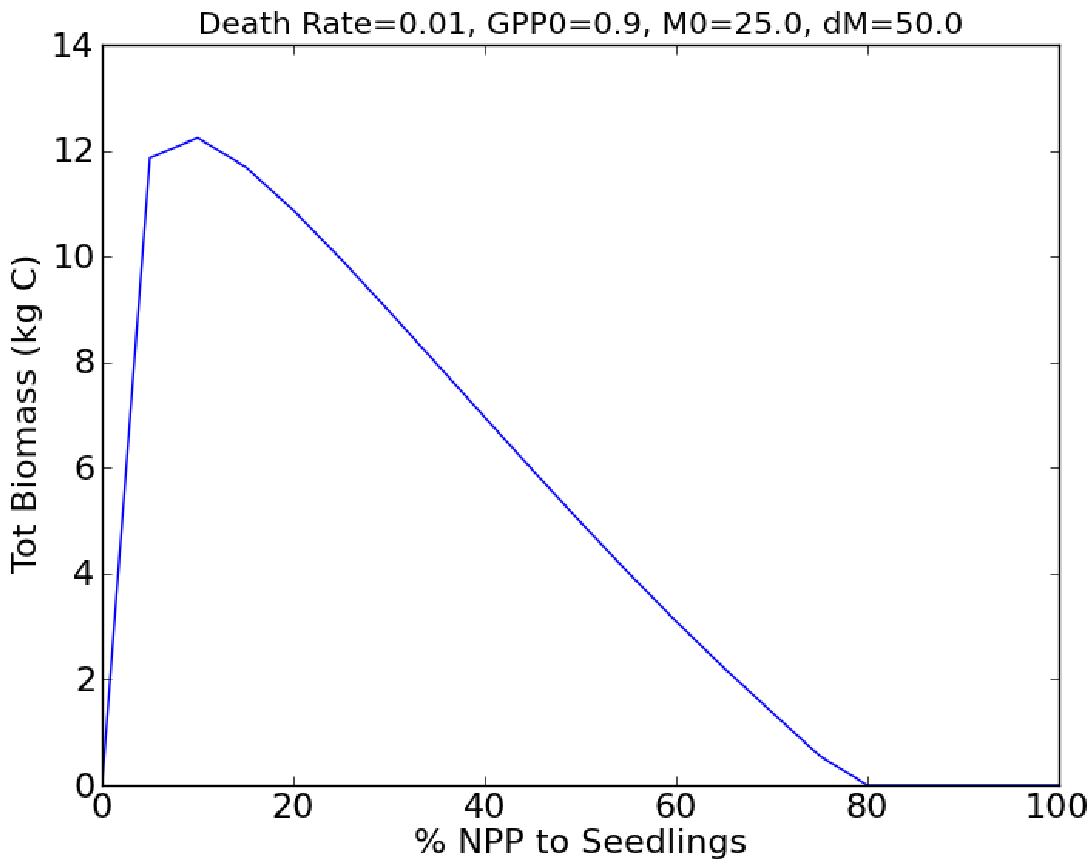
R.E.D. Seedling Recruitment

- Proportion of NPP (f_R) assumed to go into reproduction.
- Proportion of this (f_S) is assumed to go into seedlings, reduced further by space competition and shading.



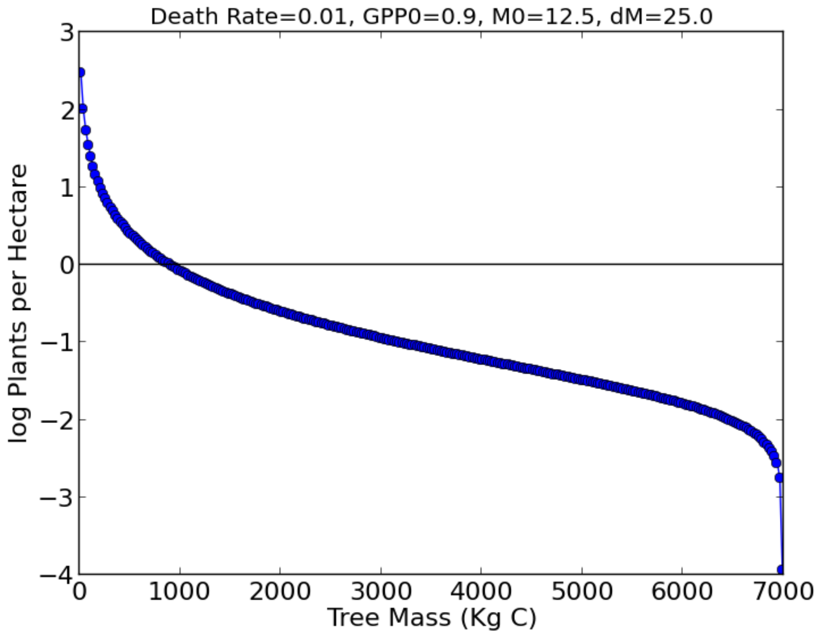
Optimum NPP to Reproduction

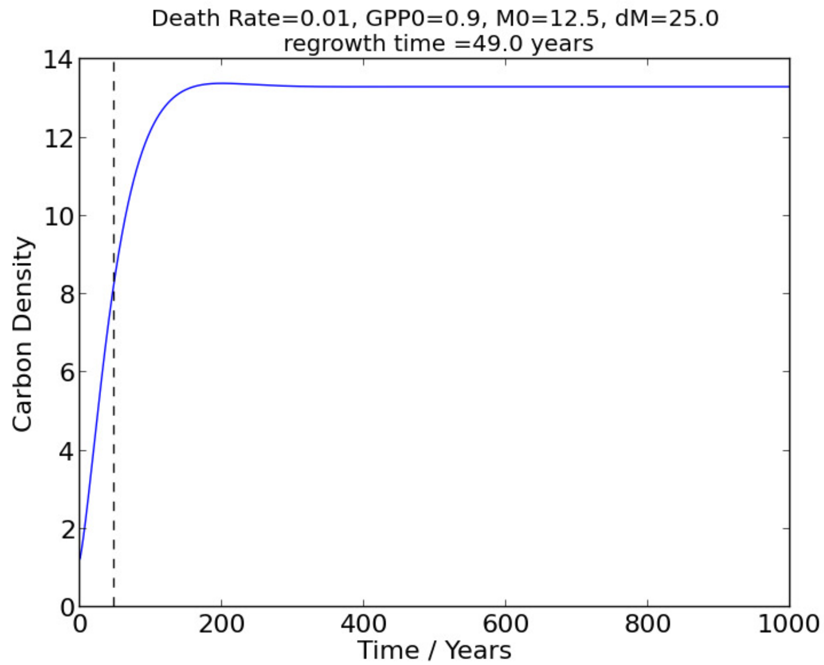
- **Appears that proportion NPP going to reproduction has an optimum around 10%**



R.E.D. Results

Typical results for Tropical Evergreen Tree





R.E.D. Future Work

Short Term Priorities

1. Kohyama has used similar model, and fitted to field data. Intend to validate RED, by fitting our model to his forest data.
2. Multiple PFTs. Will determine order of shading by height.
3. See if we can find an equilibrium solution to discretized model. Will avoid needing to spin up.
4. Early self-thinning tests suggest thinning more aggressive than standard self-thinning law. Need to investigate this.

Impacts of revised PFTs on JULES simulated carbon and moisture fluxes

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17 May, 2013

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PFT description

1. Expand TRIFFID to 9 PFTs:

Tropical broadleaf evergreen (BET-Tr)
Temperate broadleaf evergreen (BET-Te)
Deciduous broadleaf evergreen (BDT)
Needleleaf evergreen (NET)
Needleleaf deciduous (NDT)
C3 grass
C4 grass
Evergreen shrub (Esh)
Deciduous shrub (Dsh)

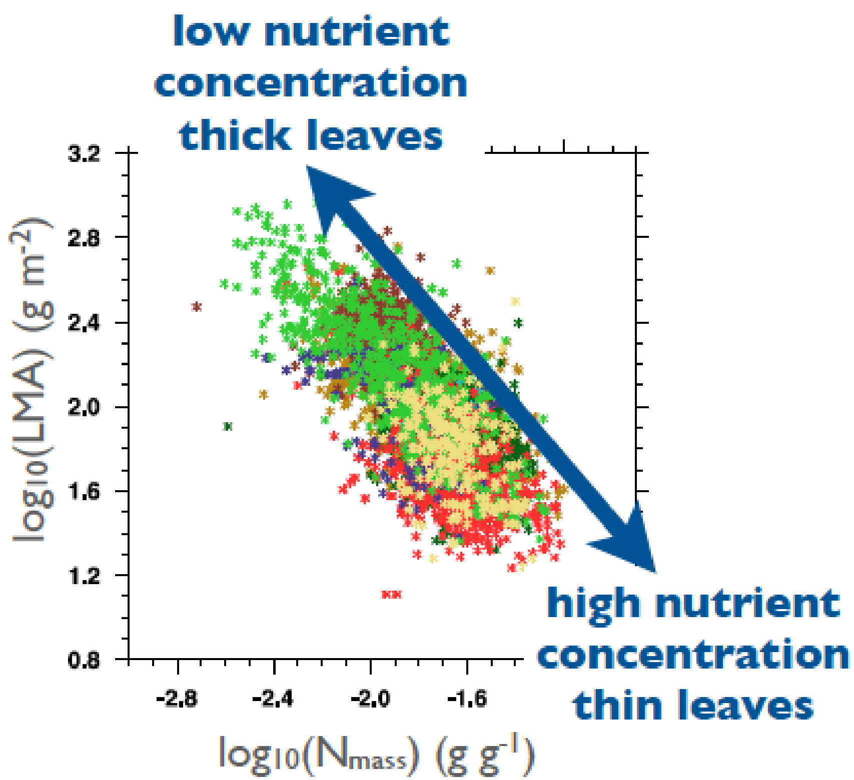
PFT descriptions

2. Observed leaf nitrogen and LMA and Vcmax relationships

3. Root depths from Zeng et al., 2001, PFT-dependent decay for N in the canopy

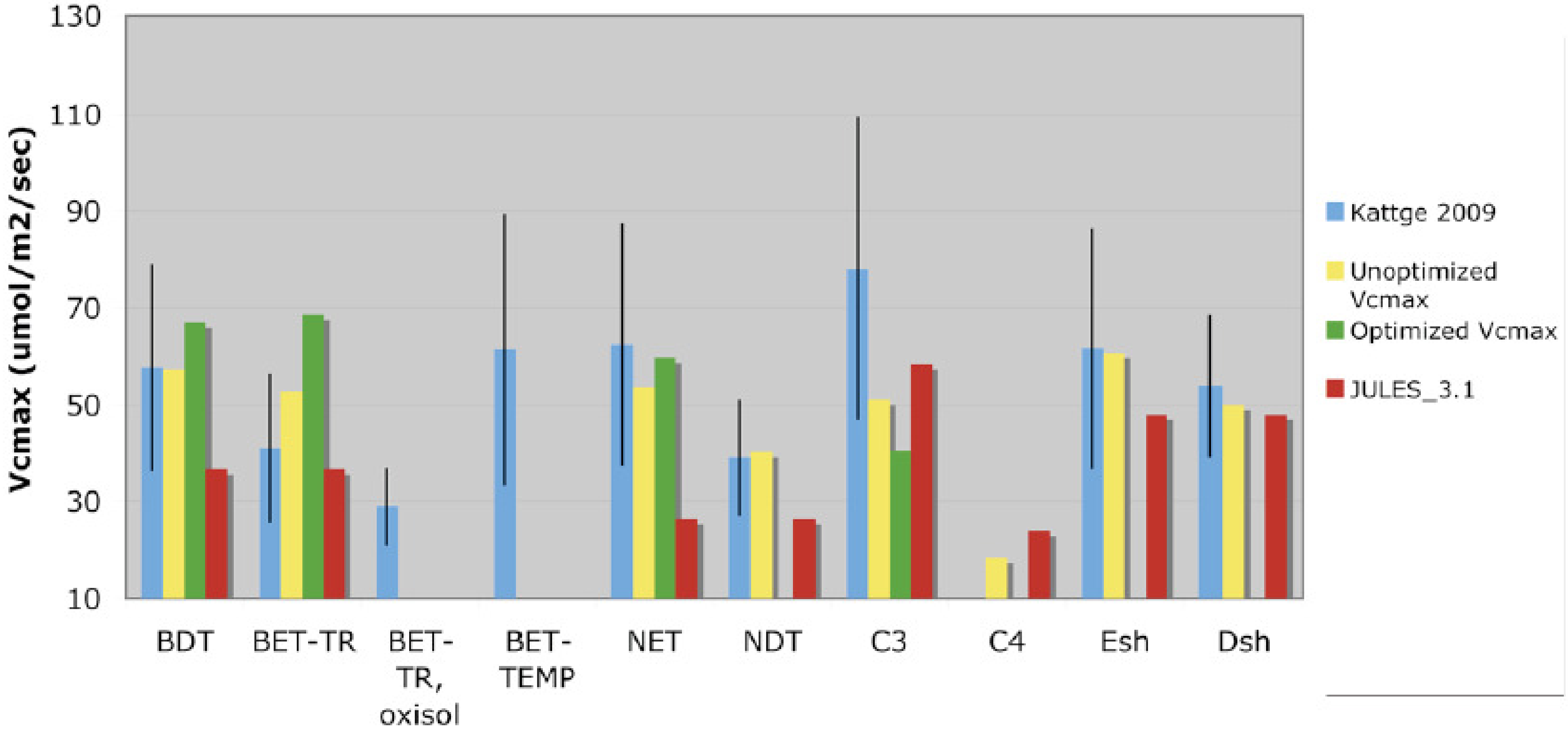
4. Parameter optimization with photosynthesis and stomatal conductance parameters. Optimize against observed timeseries of NEE and LEE (adJULES)

5. Updates to competition code to allow for canopy height-based competition between PFTs



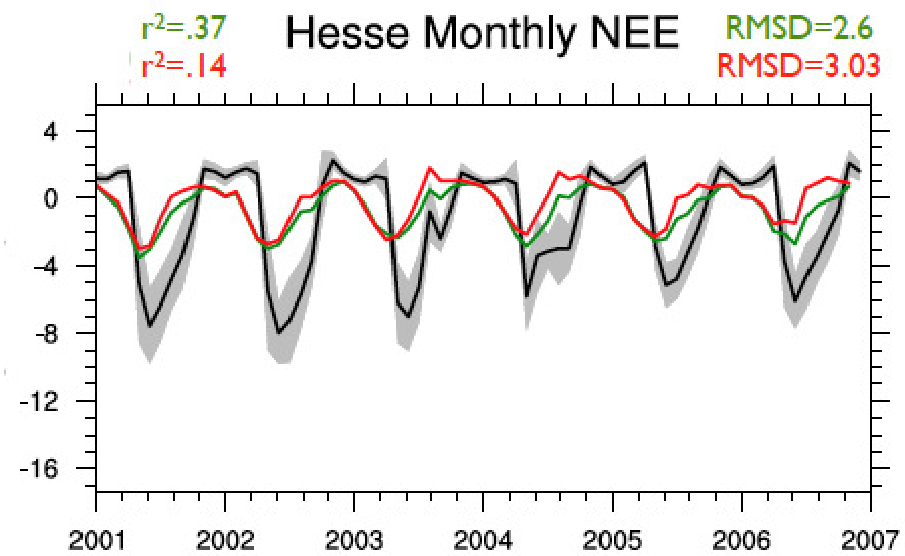
TRY database: Kattge et al. 2009; Wright et al. 2004

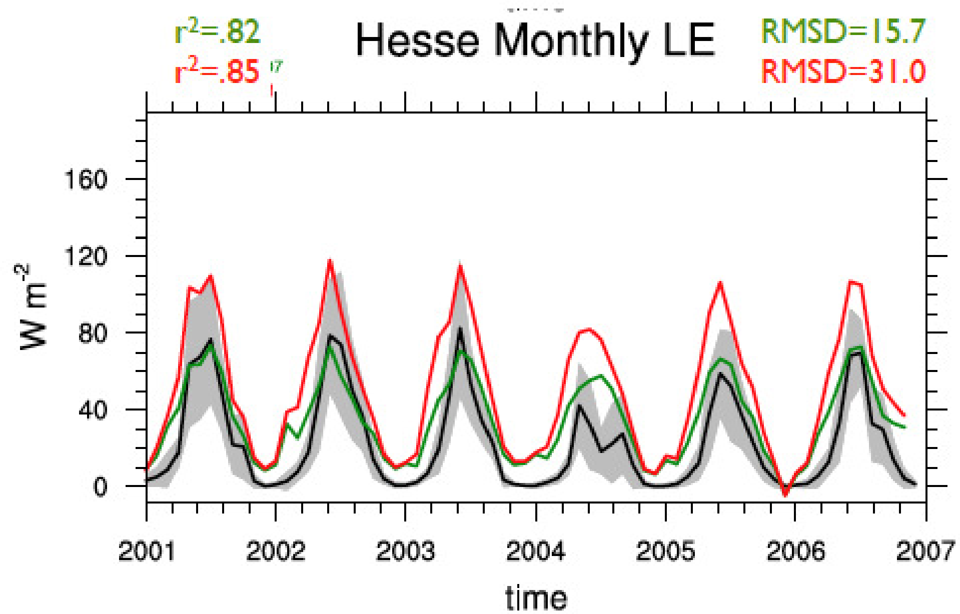
Trait-based parameters



- V_{cmax} = maximum rate of carboxylation of Rubisco, related to Rubisco and export limited rates of photosynthesis in JULES

Broadleaf deciduous trees





New PFT parameters (Broadleaf Deciduous tree)
Old PFT parameters (Broadleaf tree)

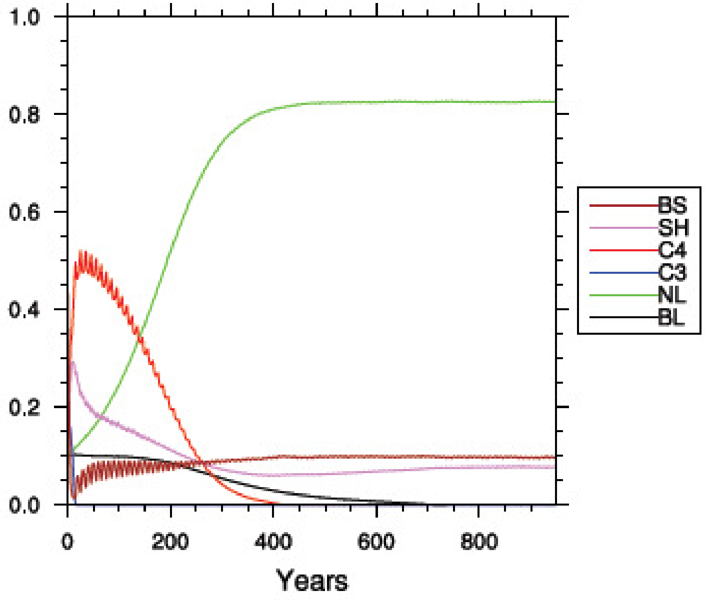
Are optimized parameters applicable at other sites?

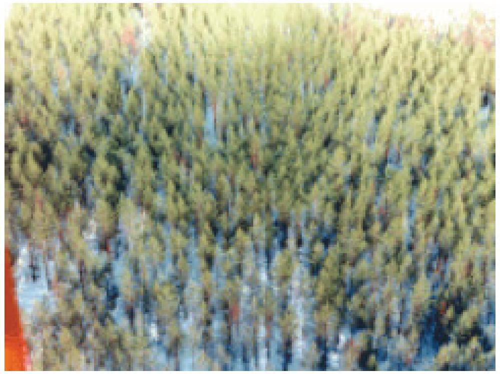
Yes, parameters from Harvard are applicable at Hesse.

Need to re-evaluate with appropriate soil carbon.

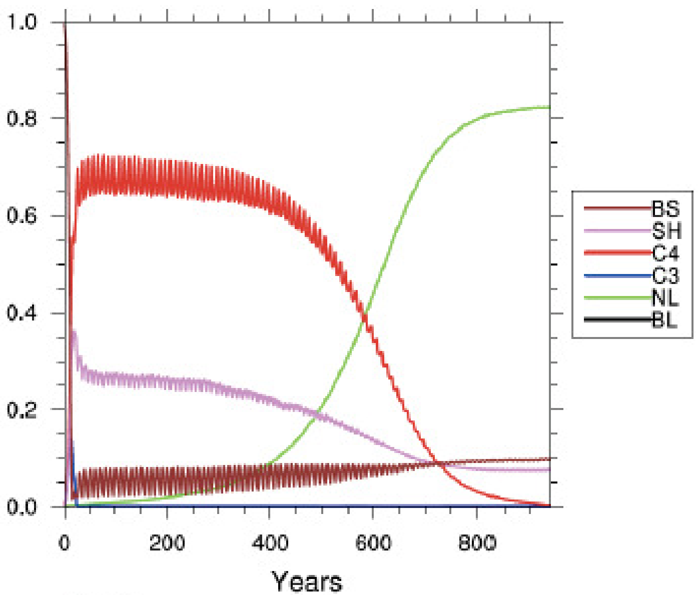
Hyytiala

New Competition, new PFT, optimized

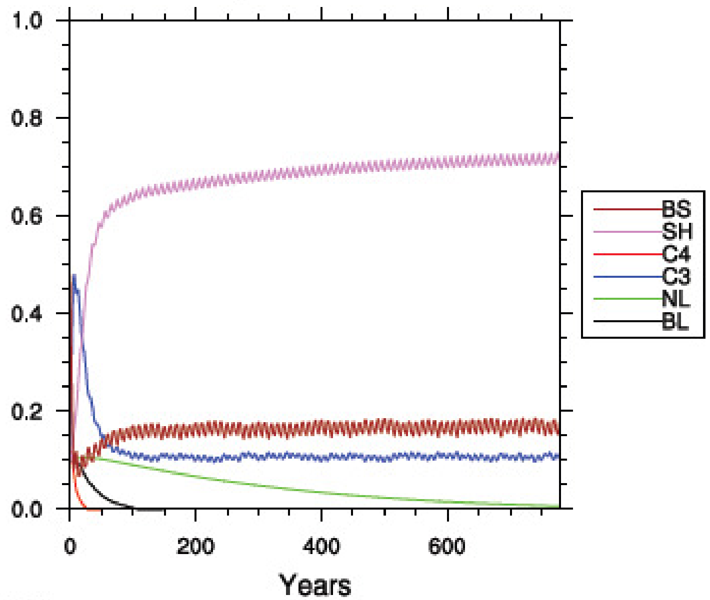




New Competition, new PFT, optimized. from bare soil

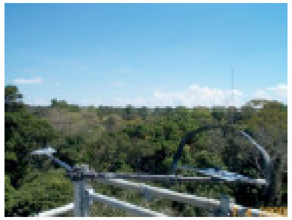


Old Competition, old PFT



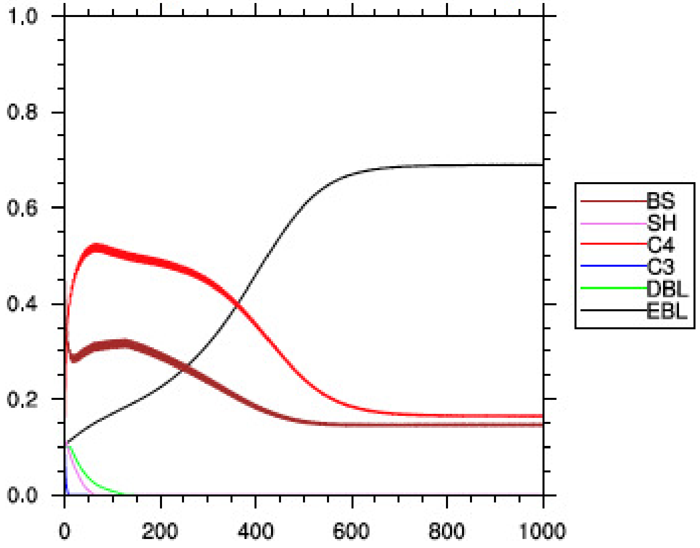
A. Harper

JULES PFTs

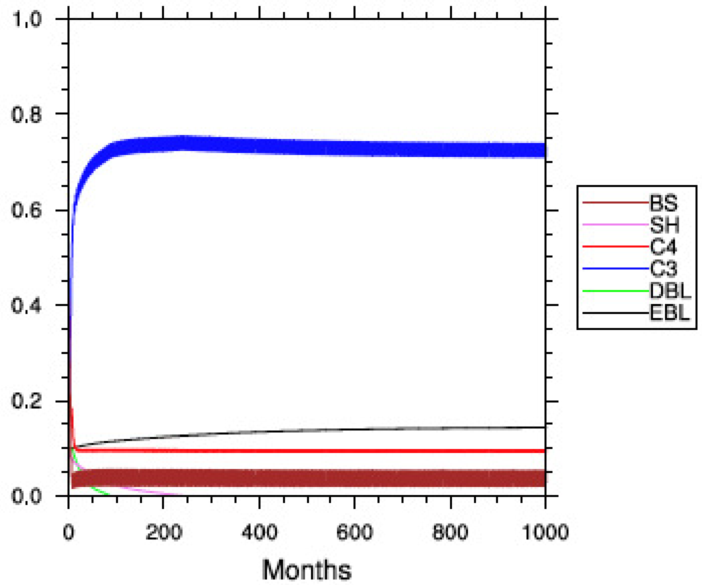


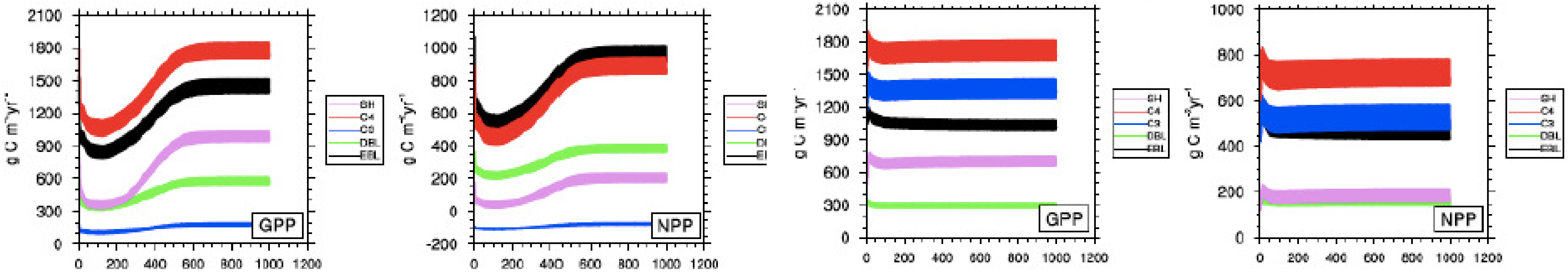
Tapajos

New Competition, new PFT, optimized



Old Competition, old PFT





The End!

Thank You

R.E.D. Allometry

Niklas Hydraulic Allometry

Source: Niklas & Spatz. PNAS, 101, 15661. 2004

Leaf Mass	$\frac{dm}{dt} = k_0 M_L = k_1 M^{3/4}$ $M_L = k_2 D^2$	**Trunk Diameter**	$D = \left(\frac{k_1}{k_0 k_2}\right)^{1/2} M^{3/8}$
Aboveground wood mass	$M_S = k_4 D^2 H \propto M$	**Crown Area**	$A = k_7 H^2 \propto M^{1/2}$
Belowground root mass	$M_R = k_3 M_S \propto M$	**Leaf Area Index**	$L = \frac{M_L}{\sigma_l A} \propto M^{1/4}$
Height	$H = k_5 D^{2/3} \propto M^{1/4}$	**Carbon density**	$C = \frac{M}{A} \propto M^{1/2}$
$k_5 = \left(\frac{k_0 k_2}{k_1}\right)^{4/3} \frac{1}{(1+k_3)k_4}$		**Basal Area**	$B = \frac{\pi D^2}{4} \propto M^{3/4}$

R.E.D. on a Page!

- **Mass classes**
- **Main equation**

$$m_i = \frac{\Delta m}{2} + i\Delta m$$

$$\frac{\partial n_i}{dt} = -\frac{1}{\Delta m}\left(n_i \frac{\partial m_i}{dt} - n_{i-1}\frac{\partial m_{i-1}}{dt}\right) - \gamma n_i$$

$$\frac{\partial n_i}{dt} = growout_i + growin_i + death_i$$

$$growout_i = \begin{cases} \frac{-1}{\Delta m} n_i \frac{\partial m_i}{\partial t} & \text{For } \frac{\partial m_i}{\partial t} \geq 0 \\ 0 & \text{For } \frac{\partial m_i}{\partial t} < 0 \end{cases}$$

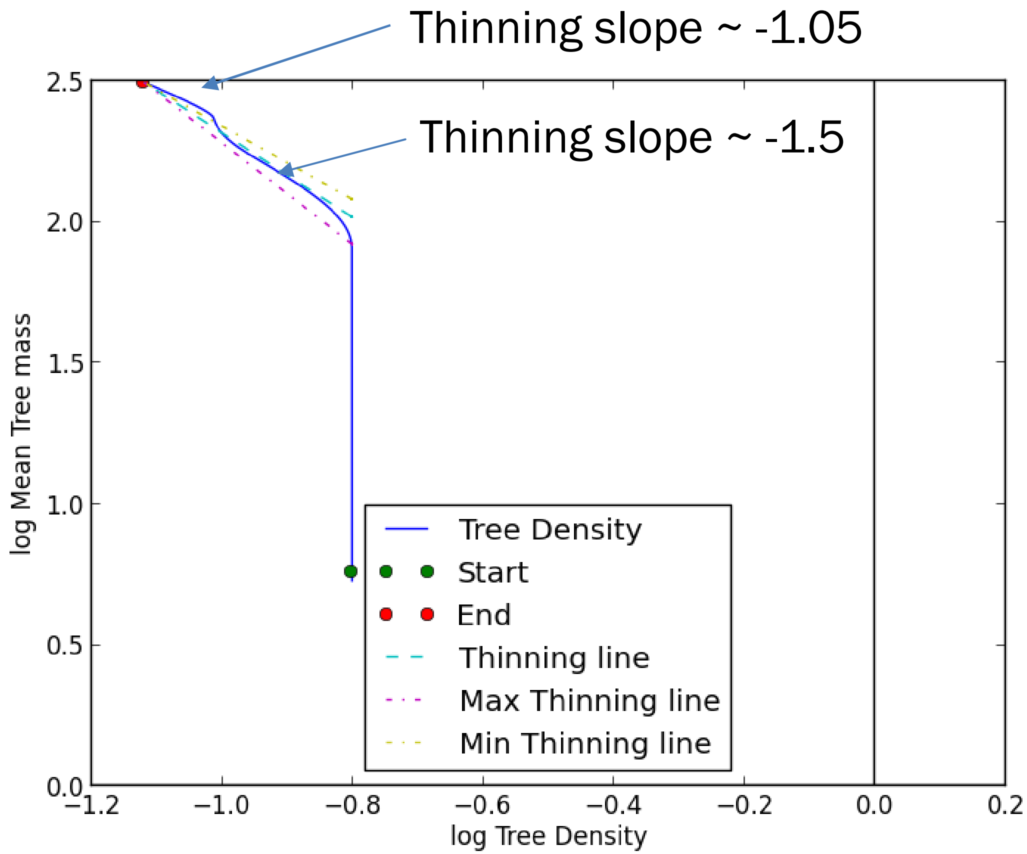
$$death_i = \begin{cases} -n_i \gamma & \text{For } \frac{\partial m_i}{\partial t} \geq 0 \\ -n_i \left[\gamma - \frac{1}{\Delta m}\left(\frac{\partial m_i}{\partial t}\right)\right] & \text{For } \frac{\partial m_i}{\partial t} < 0 \end{cases}$$

$$growin_i = \begin{cases} \frac{Seed_{TOT}}{m_0} + Seed_{ext} & i = 0 \\ -growout_{i-1} & \text{For } i > 0 \end{cases}$$

$$Seed_{Tot} = f_{l0}(1 - \nu_0) f_R f_s \sum_i \Pi_i$$

R.E.D. Self - Thinning

- **Model appears to self-thin, if no NPP seeding or mortality**



Max thinning line slope -1.8
Min thinning line slope -1.3
Ideal thinning line -1.5