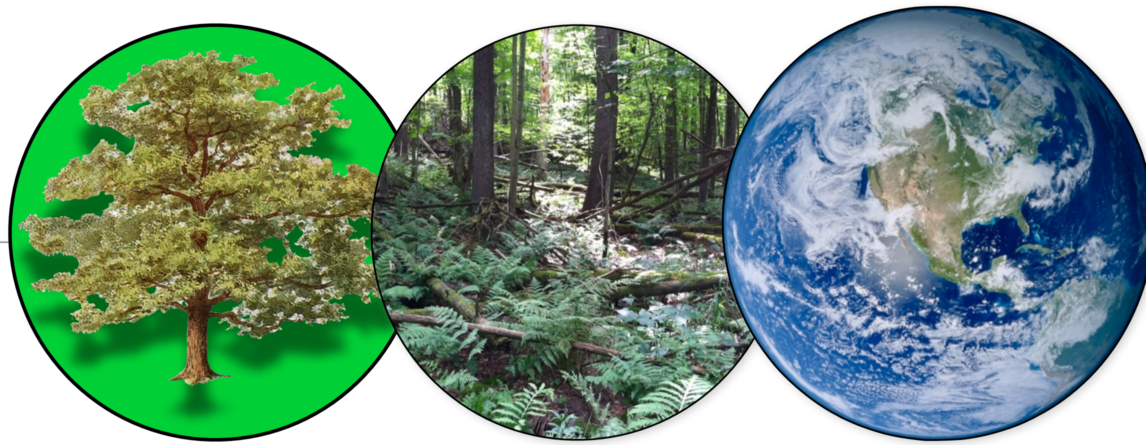
Vegetation carbon dynamics in the CLM



R. Quinn Thomas

Department of Forest Resources and Environmental Conservation

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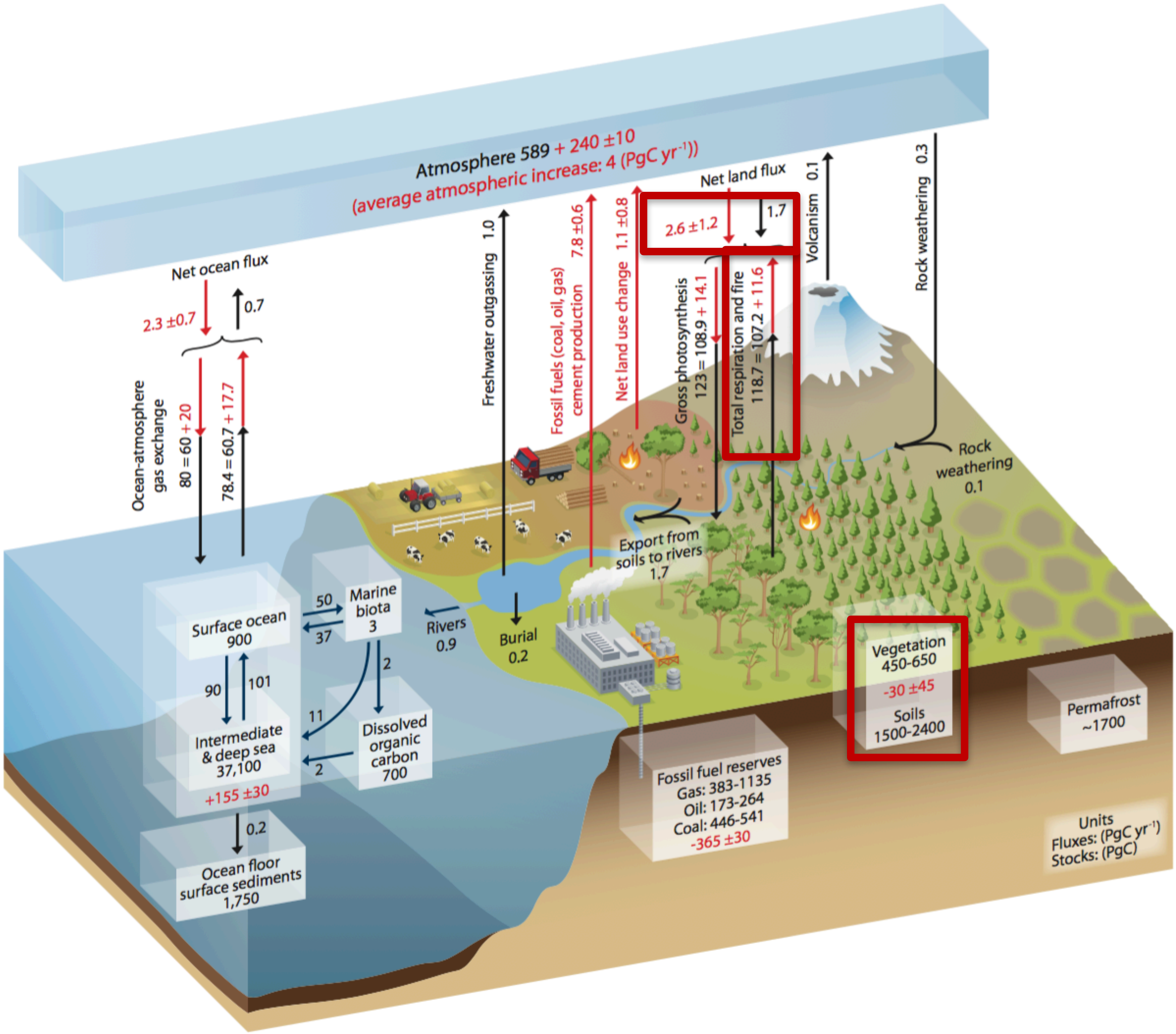
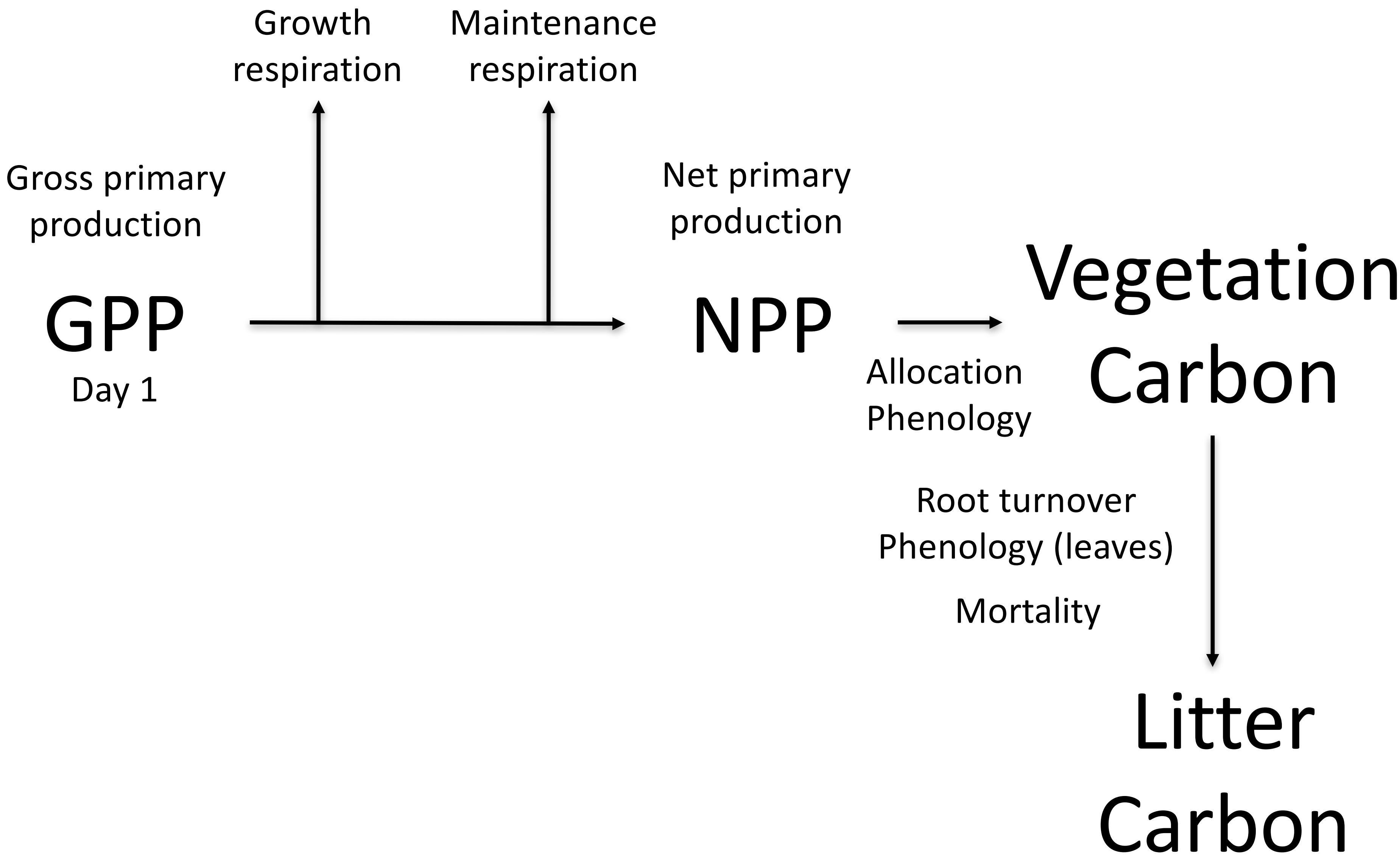
College of Natural Resources and Environment

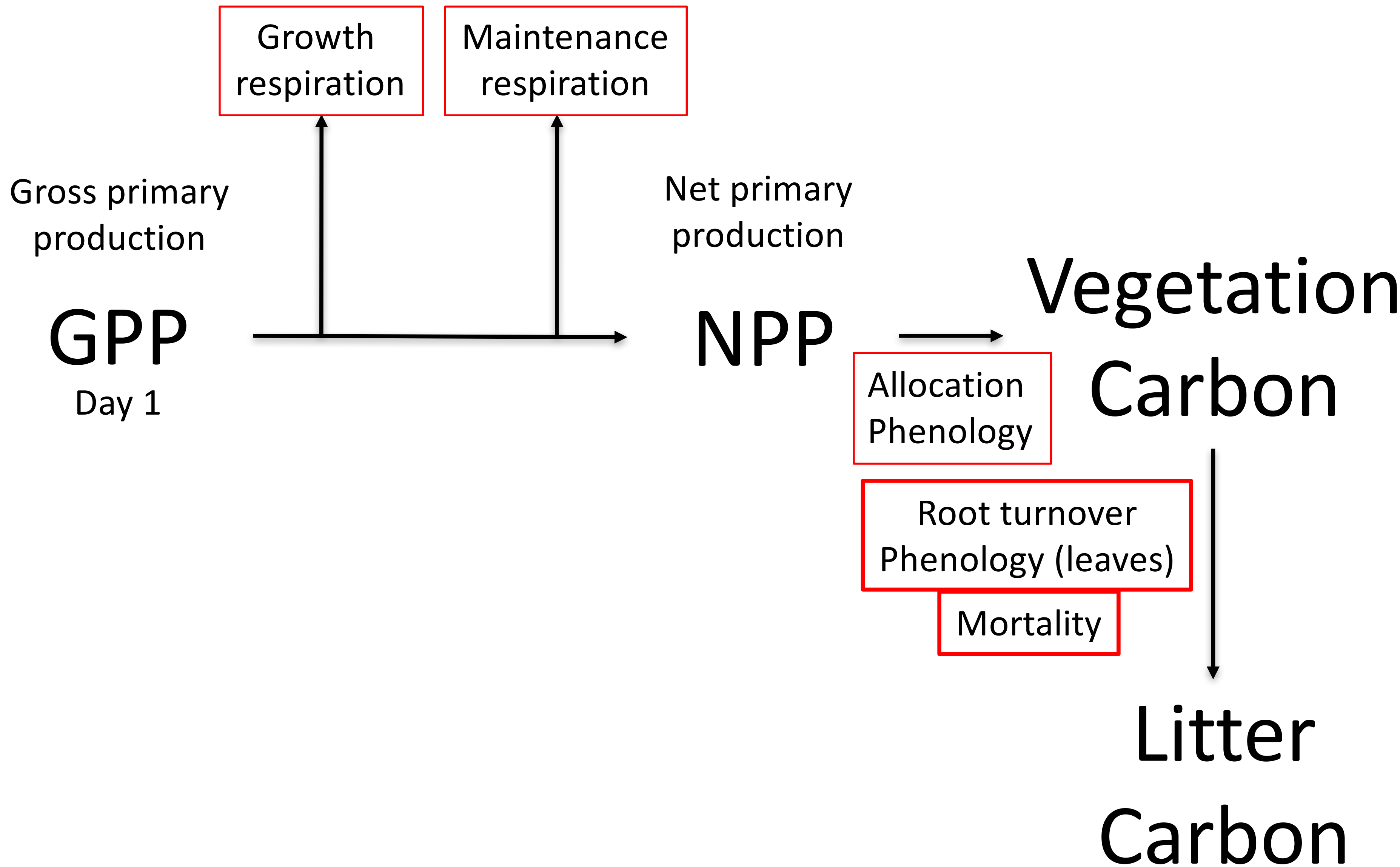


Atmosphere 589 + 240 ±10
(average atmospheric increase: 4 (PgC yr⁻¹))
Net ocean flux
2.3 ±0.7
0.7
Ocean-atmosphere gas exchange
80 = 60 + 20
78.4 = 60.7 + 17.7
Freshwater outgassing 1.0
Fossil fuels (coal, oil, gas) cement production 7.8 ±0.6
Net land use change 1.1 ±0.8
Net land flux
2.6 ±1.2
1.7
Gross photosynthesis 123 = 108.9 + 14.1
Total respiration and fire 118.7 = 107.2 + 11.6
Volcanism 0.1
Rock weathering 0.3
Rock weathering 0.1
Export from soils to rivers 1.7
Surface ocean 900
Marine biota 3
50
37
90
101
2
11
Intermediate & deep sea 37,100
+155 ±30
Dissolved organic carbon 700
2
Rivers 0.9
Burial 0.2
0.2
Ocean floor surface sediments 1,750
Fossil fuel reserves
Gas: 383-1135
Oil: 173-264
Coal: 446-541
-365 ±30
Vegetation 450-650
-30 ±45
Soils 1500-2400
Permafrost ~1700
Units
Fluxes: (PgC yr⁻¹)
Stocks: (PgC)

Overview


Growth respiration
Maintenance respiration
Gross primary production
GPP
Day 1
Net primary production
NPP
Allocation
Phenology
Vegetation Carbon
Root turnover
Phenology (leaves)
Mortality
Litter Carbon

Overview


Growth respiration
Maintenance respiration
Gross primary production
GPP
Day 1
Net primary production
NPP
Vegetation Carbon
Allocation Phenology
Root turnover Phenology (leaves)
Mortality
Litter Carbon

What are key feedbacks associated with allocation?

Why do allocation patterns matter?

- Allocation determines resource acquisition
  - Leaf C -> LAI -> photosynthesis (in CLM)
  - Wood C -> taller plant -> photosynthesis (in FATES)
  - Root C -> more surface area for nutrient and water update -> more resources to grow (in FUN)
  - Nutrient uptake respiration -> more N uptake -> more resources to grow (in FUN)

Why do allocation patterns matter?

- Allocation determines the residence time of C in vegetation
  - More wood -> lower turnover rates
- Allocation influences the plant demand for nitrogen
  - More wood -> less nitrogen demand per unit of carbon -> less N limitation -> increased C uptake

Why do allocation patterns matter?

- Allocation determines the wood products
  - More wood -> more carbon in the wood product pools -> less carbon in soil and atmosphere
- Allocation determines the fuel for fire
  - More aboveground carbon -> more fuel for fire
- Allocation determines albedo
  - More leaf C -> more LAI -> lower albedo
  - More stem C -> More SAI -> lower albedo (if wood albedo < soil/snow)

Why do allocation patterns matter?

- Allocation influences canopy conductance
  - More leaf C -> More LAI -> canopy conductance
- Allocation influences aerodynamic conductance
  - More stem C -> taller plants -> increased roughness length -> increased aerodynamic conductance

Why do allocation patterns matter?

- Others?

Area basis

g m^{-2} s^{-1}

CLM 5.0
BGC

Individual plant basis

g ind^{-1} s^{-1}

x

individuals

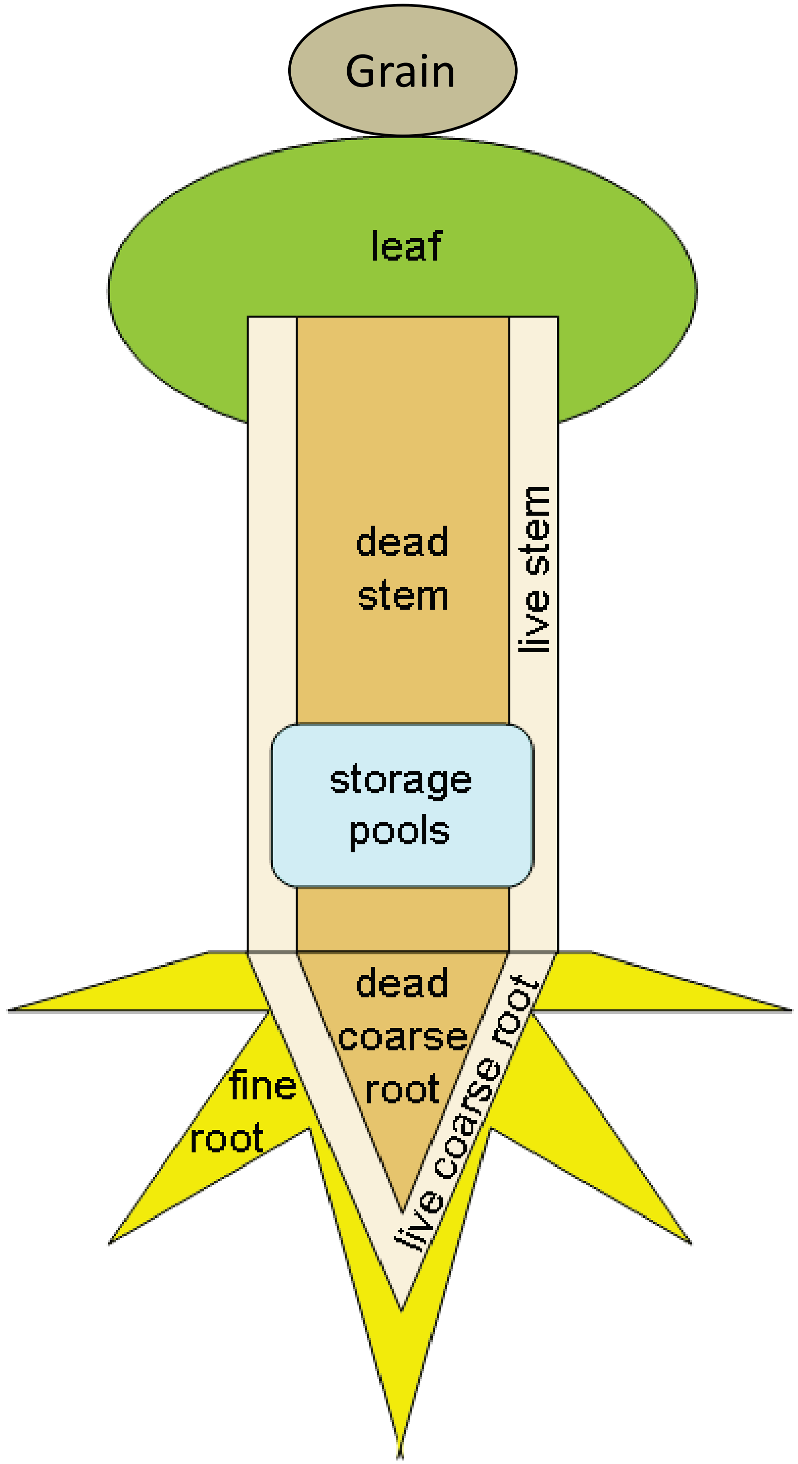
=

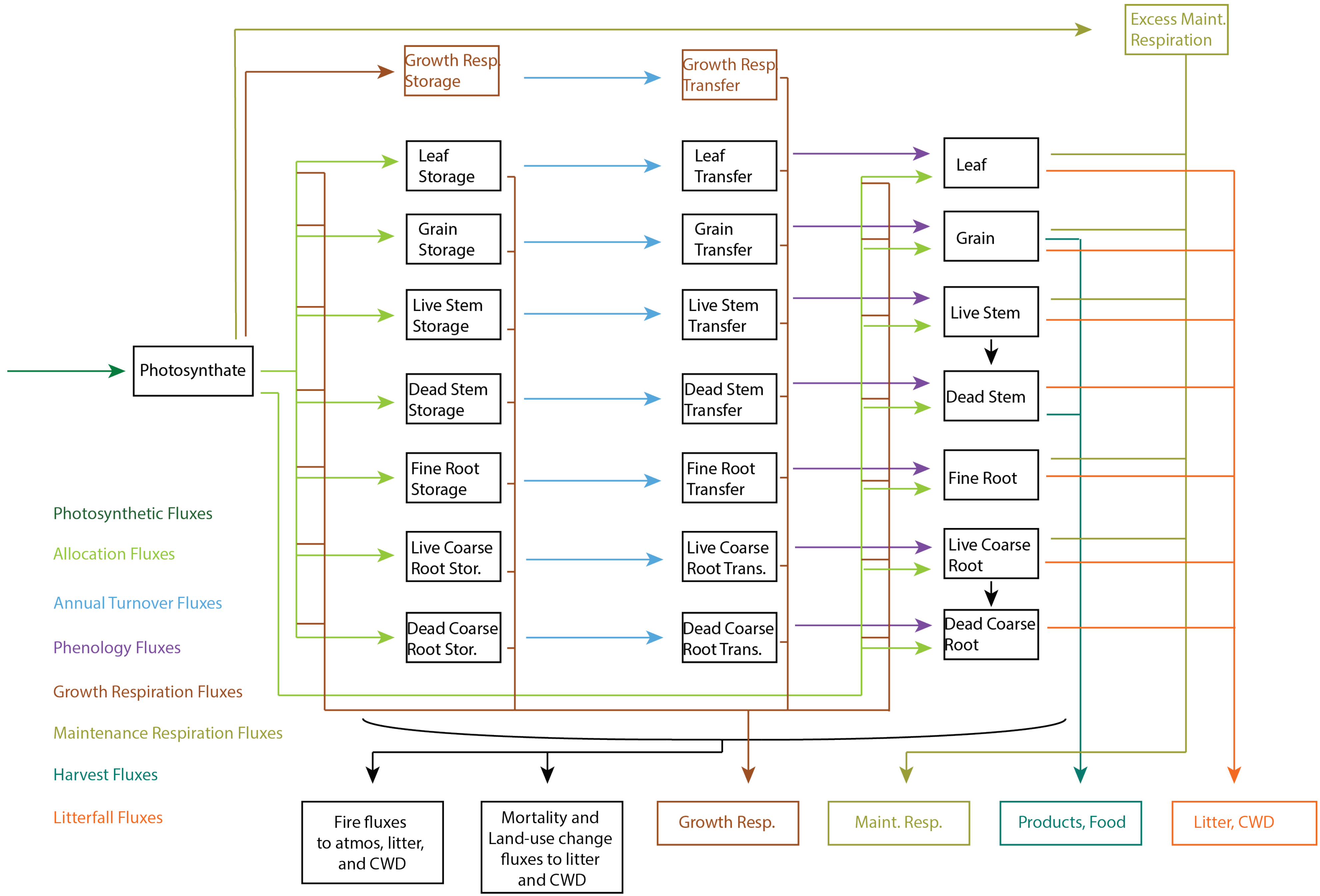
g m^{-2} s^{-1}

CLM 5.0
FATES

Allocation

NutrientCompetitionFlexibleCNMod.F90
NutrientCompetitionCLM45defaultMod.F90


Grain
leaf
dead
stem
live stem
storage
pools
dead
coarse
root
live coarse root
fine
root



Excess Maint. Respiration
Growth Resp. Storage
Growth Resp. Transfer
Leaf Storage
Leaf Transfer
Leaf
Grain Storage
Grain Transfer
Grain
Live Stem Storage
Live Stem Transfer
Live Stem
Photosynthate
Dead Stem Storage
Dead Stem Transfer
Dead Stem
Fine Root Storage
Fine Root Transfer
Fine Root
Live Coarse Root Stor.
Live Coarse Root Trans.
Live Coarse Root
Dead Coarse Root Stor.
Dead Coarse Root Trans.
Dead Coarse Root
Photosynthetic Fluxes
Allocation Fluxes
Annual Turnover Fluxes
Phenology Fluxes
Growth Respiration Fluxes
Maintenance Respiration Fluxes
Harvest Fluxes
Litterfall Fluxes
Fire fluxes to atmos, litter, and CWD
Mortality and Land-use change fluxes to litter and CWD
Growth Resp.
Maint. Resp.
Products, Food
Litter, CWD

Allocation Steps

Fraction of allocatable carbon to specific pool

Uses ratios

f1 = fine root: leaf
f2 = coarse root : stem
f3 = stem : leaf
f4 = live wood : total wood
f5 = grain : leaf
g1 = growth respiration: total allocation

total = leaf +		
	leaf*f1 +	(_________)
	leaf*f3*f4 +	(_________)
	leaf*f3*f2*f4 +	(_________)
	leaf*f3*(1-f4) +	(_________)
	leaf*f3*f2*(1-f4) +	(_________)
	leaf*f5	(_________)

growth respiration = total*g1

Allocation Steps

Fraction of allocatable carbon to specific pool

Uses ratios

f1 = fine root: leaf
f2 = coarse root : stem
f3 = stem : leaf
f4 = live wood : total wood
f5 = grain : leaf
g1 = growth respiration: total allocation

total = leaf +	
leaf*f1 +	(__fine roots_)
leaf*f3*f4 +	(__stem live wood_)
leaf*f3*f2*f4 +	(__coarse wood live wood_)
leaf*f3*(1-f4) +	(__stem dead wood_)
leaf*f3*f2*(1-f4) +	(__coarse wood dead wood_)
leaf*f5	(__grain_)

growth respiration = total*g1

How do you expect the following PFTs to differ in allocation?

Evergreen needleleaf tree
Deciduous tree
Shrub
C4 grass
C3 grass
Wheat
Corn

f1 = fine root: leaf
f2 = coarse root : stem
f3 = stem : leaf
f4 = live wood : total wood
f5 = grain : leaf
g1 = growth respiration: total allocation

Allocation parameters

Earth Interactions • Volume 4 (2000) • Paper No. 3 • Page 1

Parameterization and Sensitivity Analysis of the BIOME–BGC Terrestrial Ecosystem Model: Net Primary Production Controls

Michael A. White,* Peter E. Thornton, Steven W. Running, and Ramakrishna R. Nemani

Numerical Terradynamic Simulation Group, Missoula, Montana

Received 20 November 1999; accepted 21 June 2000.

ABSTRACT: Ecosystem simulation models use descriptive input parameters to establish the physiology, biochemistry, structure, and allocation patterns of vegetation functional types, or biomes. For single-stand simulations it is possible to measure required data, but as spatial resolution increases, so too does data unavailability. Generalized biome parameterizations are then required. Undocumented parameter selection and unknown model sensitivity to parameter variation for larger-resolution simulations are currently the major limitations to global and regional modeling. The authors present documented input parameters for a process-based ecosystem simulation model, BIOME–BGC, for major natural temperate biomes. Parameter groups include the following: turnover and mortality; allocation; carbon to nitrogen ratios (C:N); the percent of plant material in labile, cellulose, and lignin pools; leaf morphology; leaf conductance rates and limitations; canopy water interception and light extinction; and the percent of leaf nitrogen in Rubisco (ribulose bisphosphate-1,5-carboxylase/oxygenase) (PLNR). Using climatic and site de-

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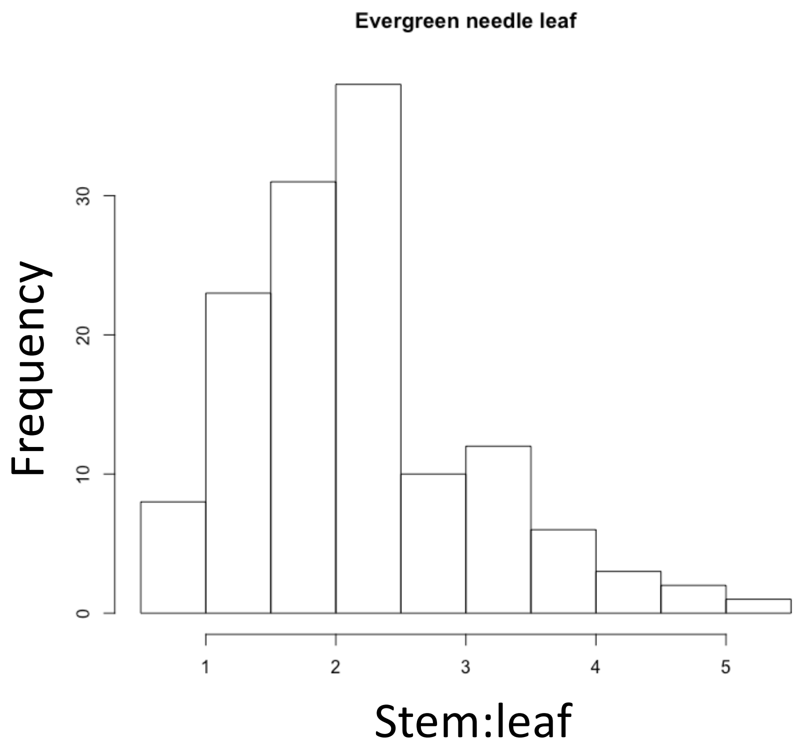
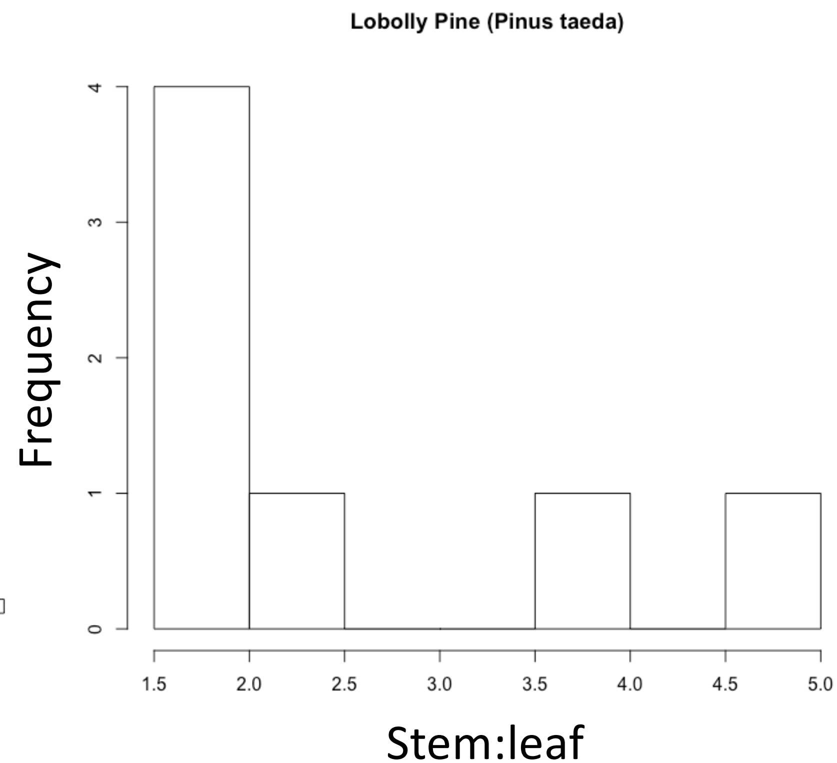
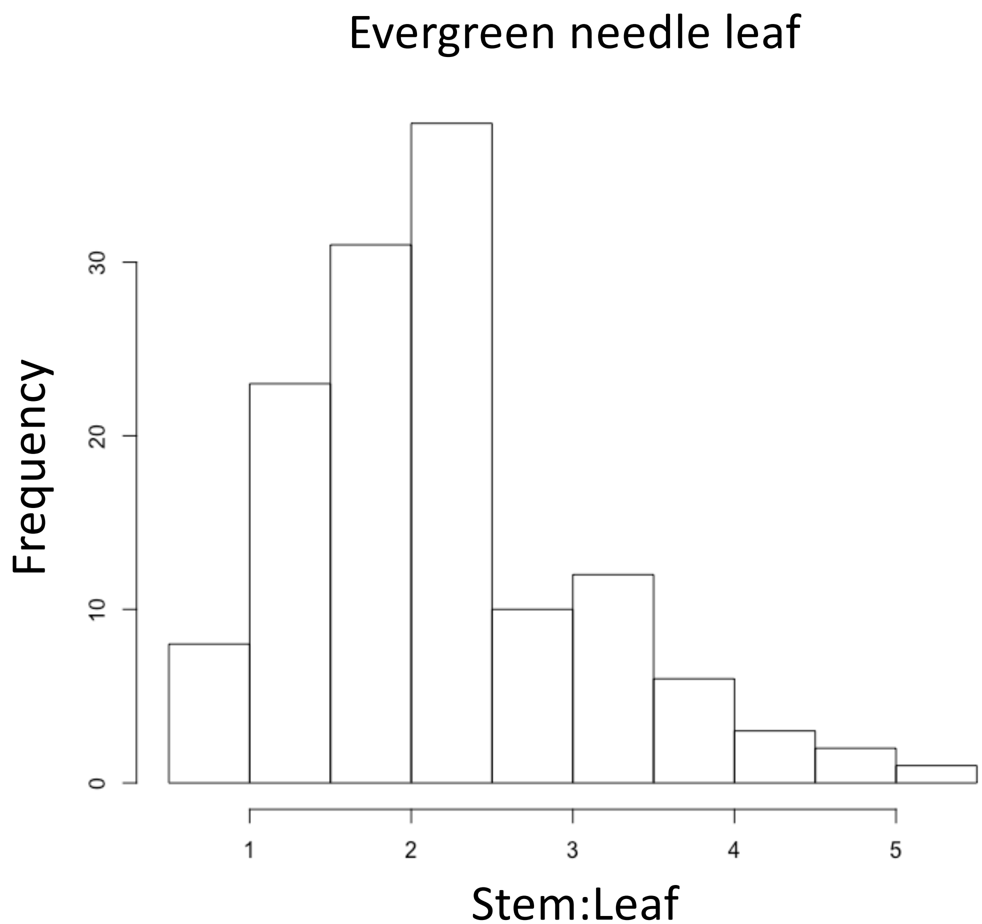
Stem : leaf





How is this data collected?

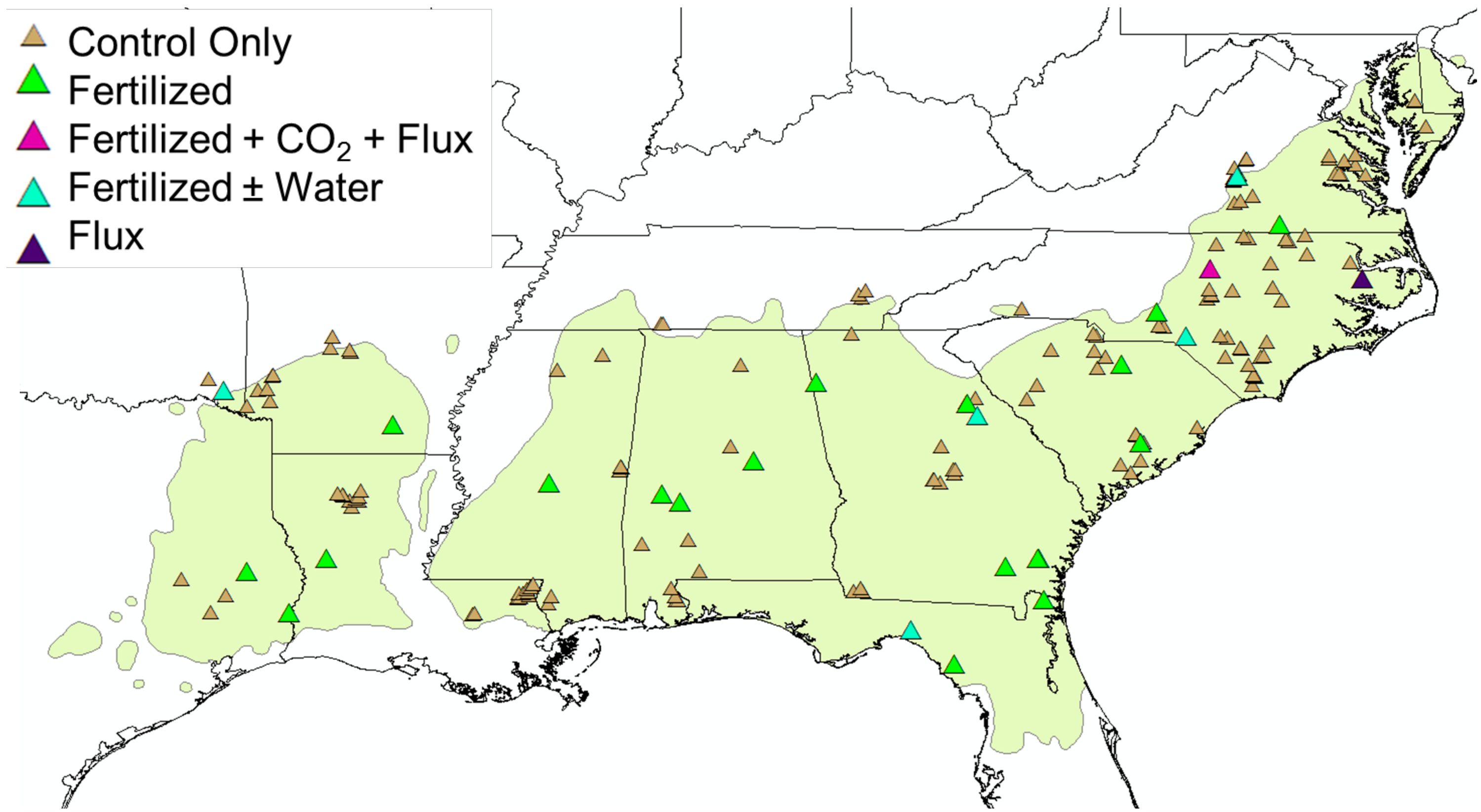
What might control this variation?



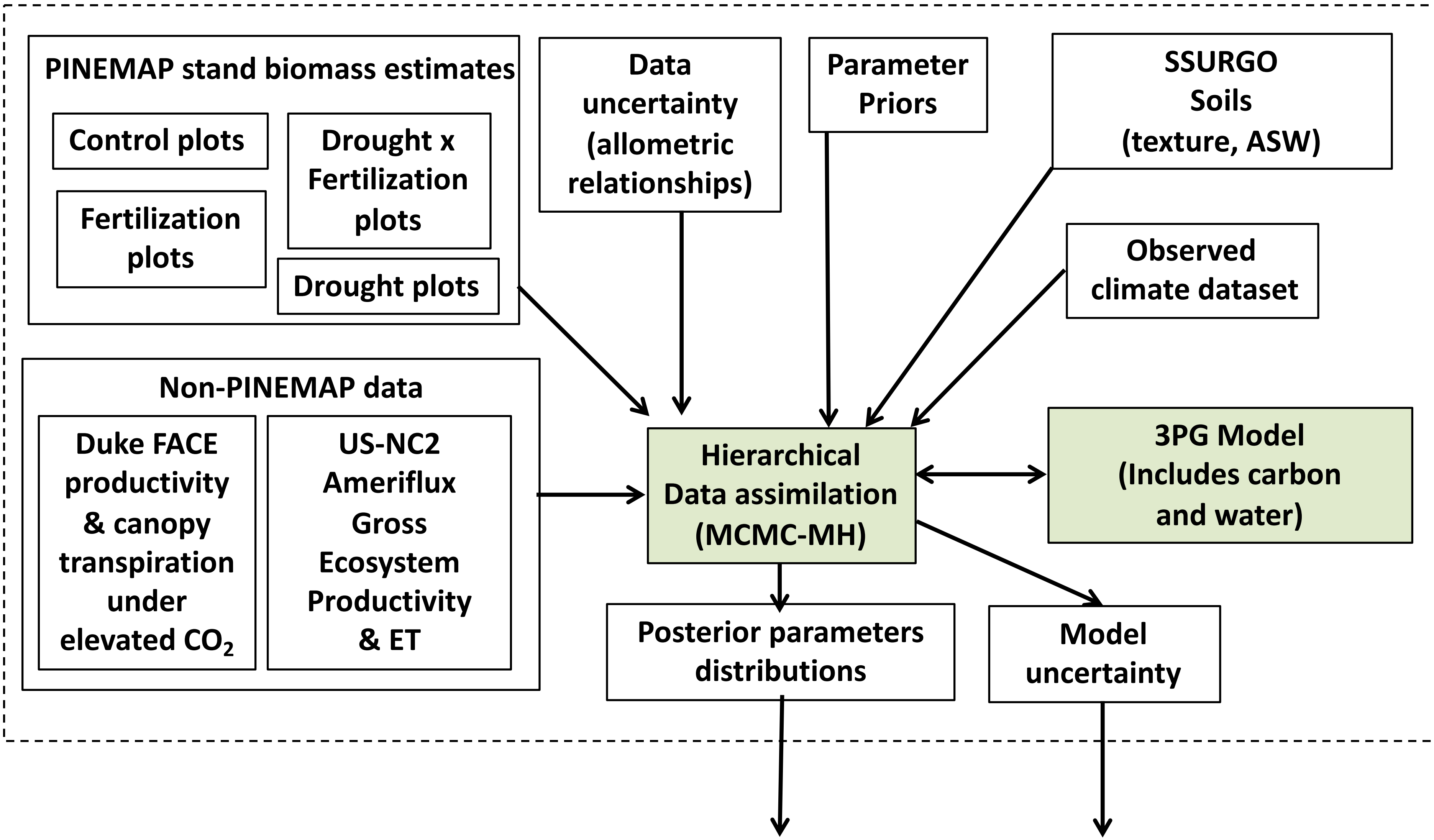
What might control this variation?

- Changes in allocation through succession
- Differences in allocation among species
- Differences in allocation between soil environments (water and nutrient availability)
- Differences in allocation across broad climate space (boreal to tropics)

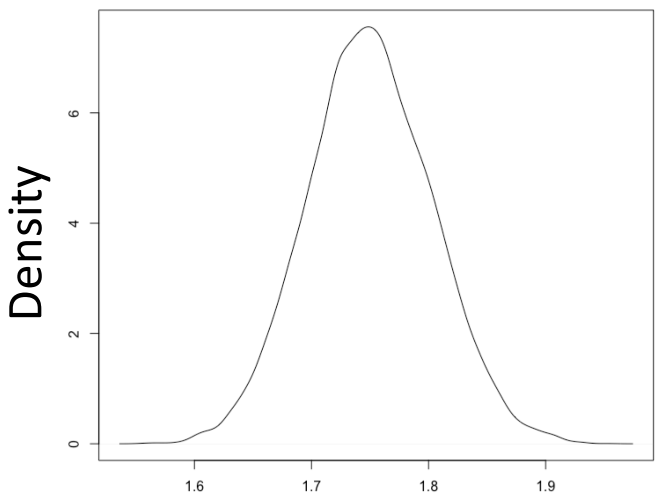
Parameterization example


Control Only
Fertilized
Fertilized + CO_2 + Flux
Fertilized ± Water
Flux

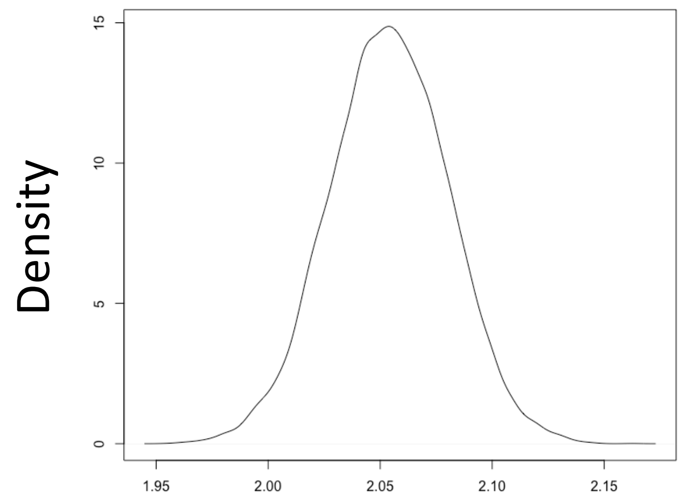
Data Assimilation of Pine Plantation Ecosystem Research (DAPPER) System



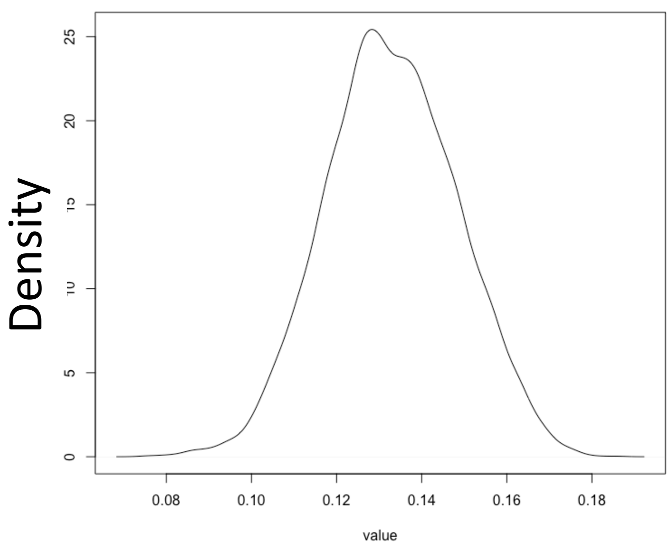
Parameterization example



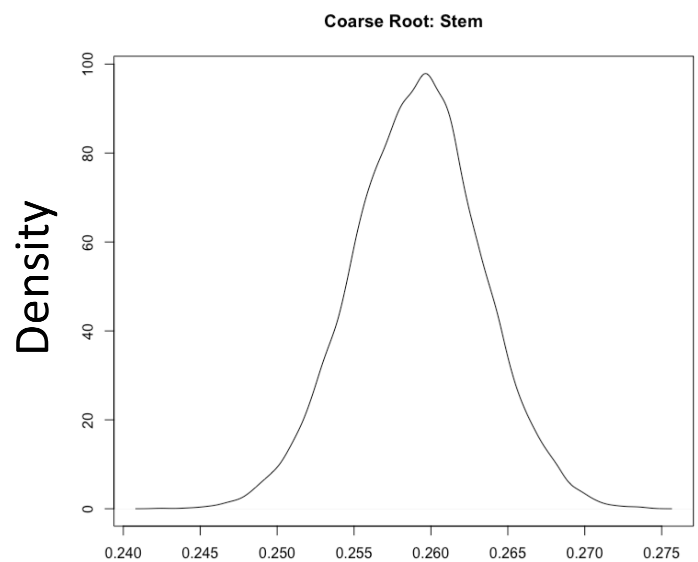
Stem:leaf (2 cm DBH)



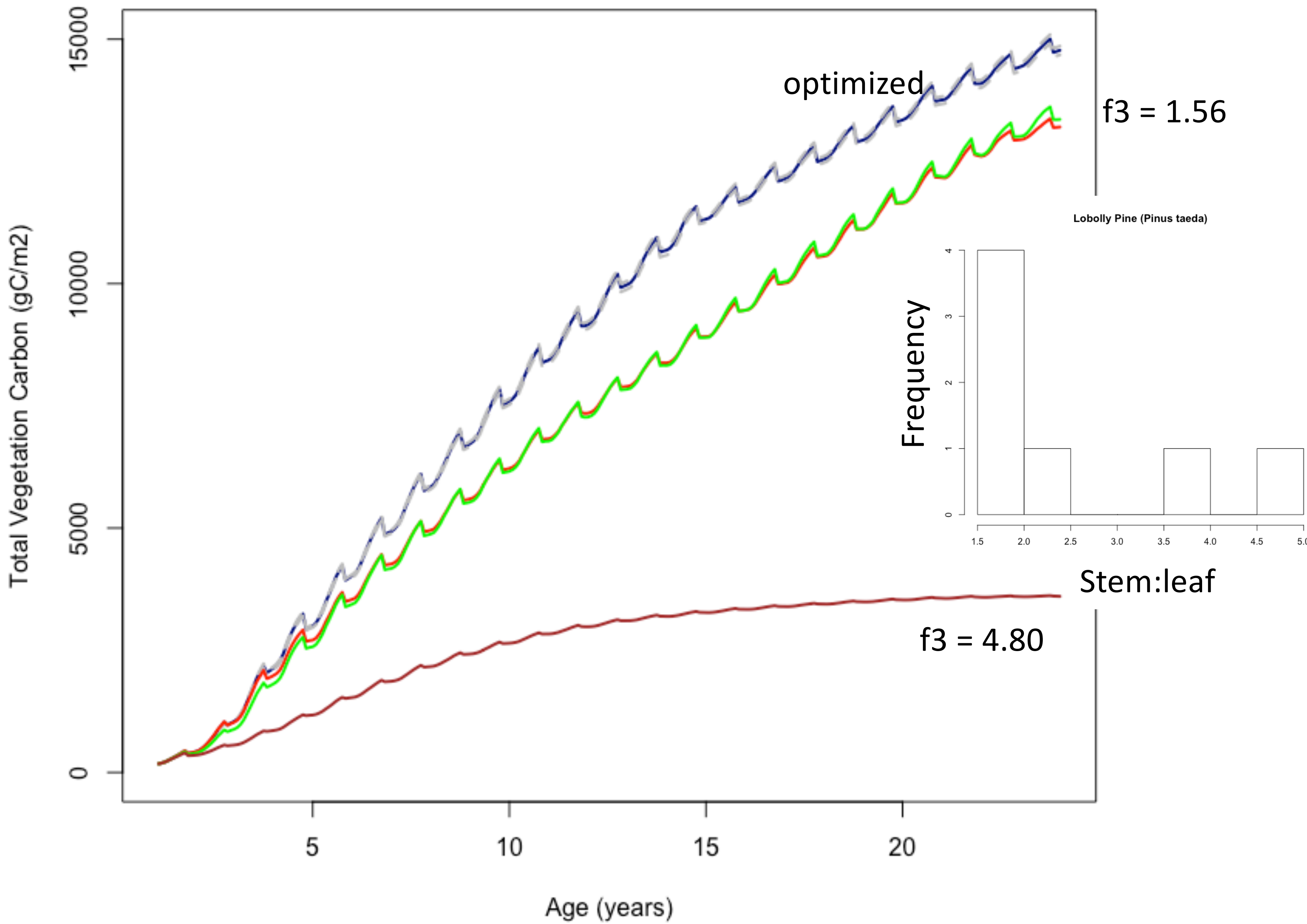
Stem:leaf (20 cm DBH)



Fine root: leaf



Coarse root: stem



Total Vegetation Carbon (gC/m2)
0
5000
10000
15000
5
10
15
20
Age (years)
optimized
f3 = 1.56
Lobolly Pine (Pinus taeda)
Frequency
0
1
2
3
4
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Stem:leaf
f3 = 4.80

Growth respiration

NutrientCompetitionFlexibleCNMod.F90
NutrientCompetitionCLM45defaultMod.F90

Growth respiration = grperc*(allocated carbon)

↑

Traditionally 0.25 – 0.30 but up for debate
Currently set to 0.12 in the CLM parameter file

Growth Respiration

Table 6.1 Concentration and carbon cost of major chemical constituents in a sedge leaf[a]

Component	Concentration (%)	Cost (mg C g^{-1} product)	Total cost[b] (mg C g^{-1} tissue)
Sugar	11.9	438	52
Nucleic acid	1.2	409	5
Polysaccharide	9.0	467	42
Cellulose	21.6	467	101
Hemicellulose	31.0	467	145
Amino acid	0.9	468	4
Protein	9.7	649	63
Tannin	4.8	767	37
Lignin	4.2	928	39
Lipid	5.7	1,212	69
Total cost			557

[a] Data from Chapin (1989)

[b] The four most expensive constituents account for 37% of the cost of synthesis but only 24% of the mass of the tissue. The total cost of production (557 mg C g^{-1} tissue) is equivalent to 1.23 g carbohydrate per gram of tissue, with 20% of this being respired and 80% incorporated into biomass

Chapin, Matson, and Vitousek 2011

Maintenance respiration

CNMRespMod.F90

br_mr (stem and grain respiration per gram nitrogen: g C s^{-1} gN^{-1})

Q10

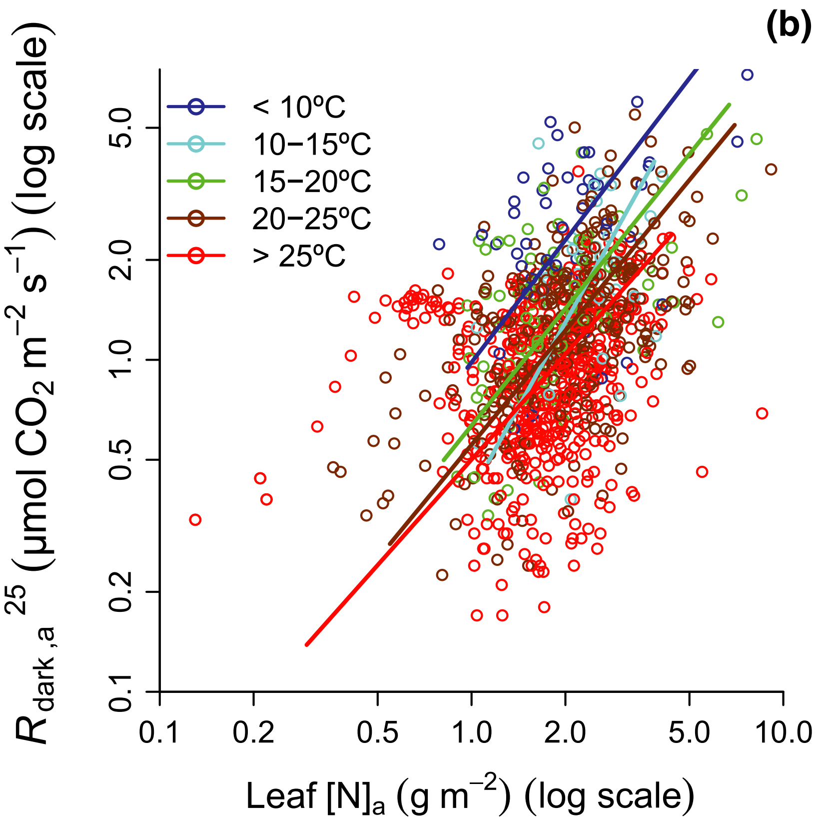
lmr_intercept_atkin

Respiration increases with nitrogen and temperature

Leaf respiration

Calculated in photosynthesis routine

Atkin et al. 2015



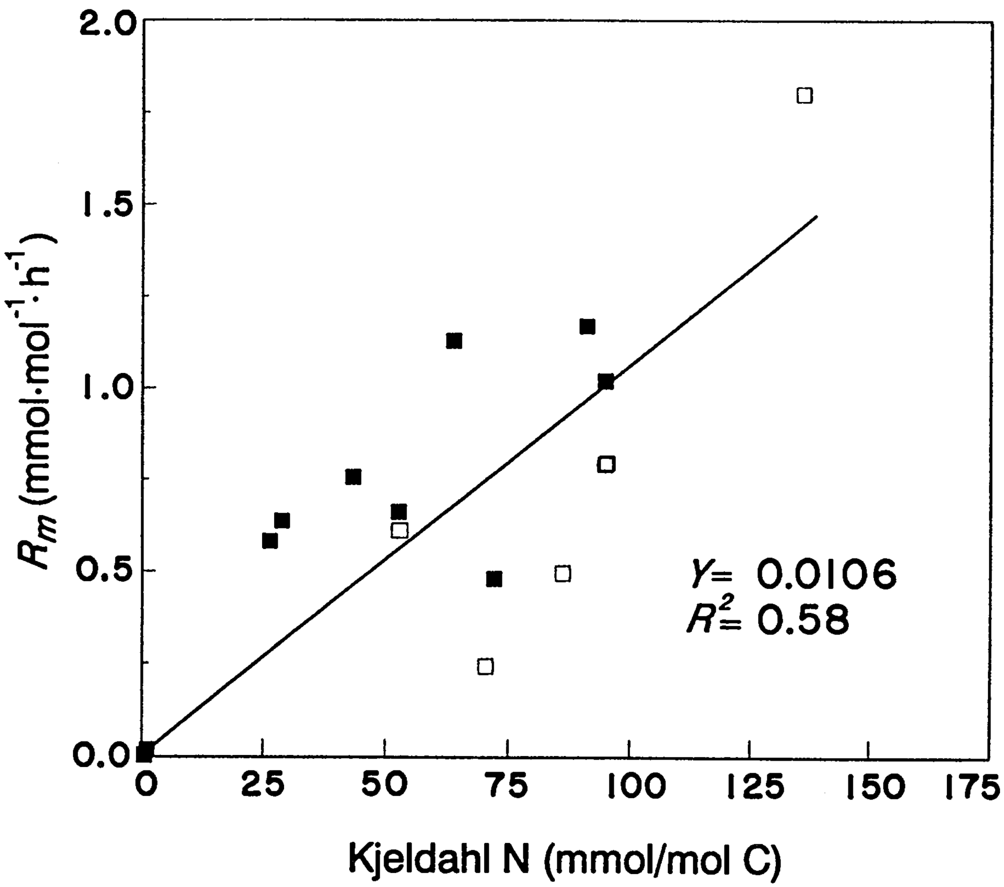
lmr_intercept_atkin + (N_a * 0.2061) - (0.0402 * t10)

PFT level parameter

Leaf N per leaf area

10 day running mean
(Acclimation)

Nitrogen sensitivity



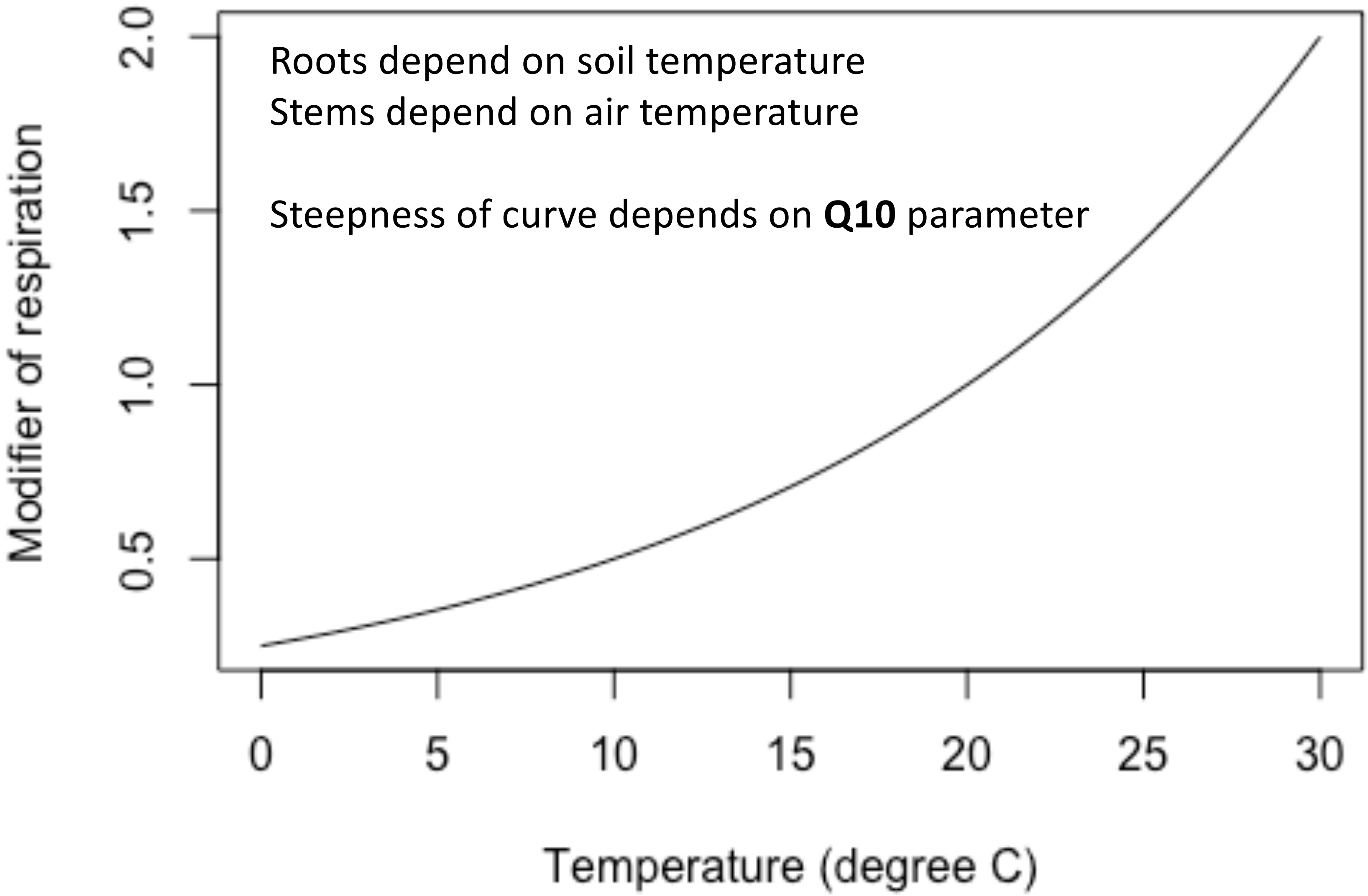
Slope = br_mr

Ecological Applications, 1(2), 1991, pp. 157–167

EFFECTS OF CLIMATE CHANGE ON PLANT RESPIRATION[1]

MICHAEL G. RYAN[2]
The Ecosystems Center, Marine Biological Laboratory, Woods Hole, Massachusetts 02543 USA

Climate sensitivity



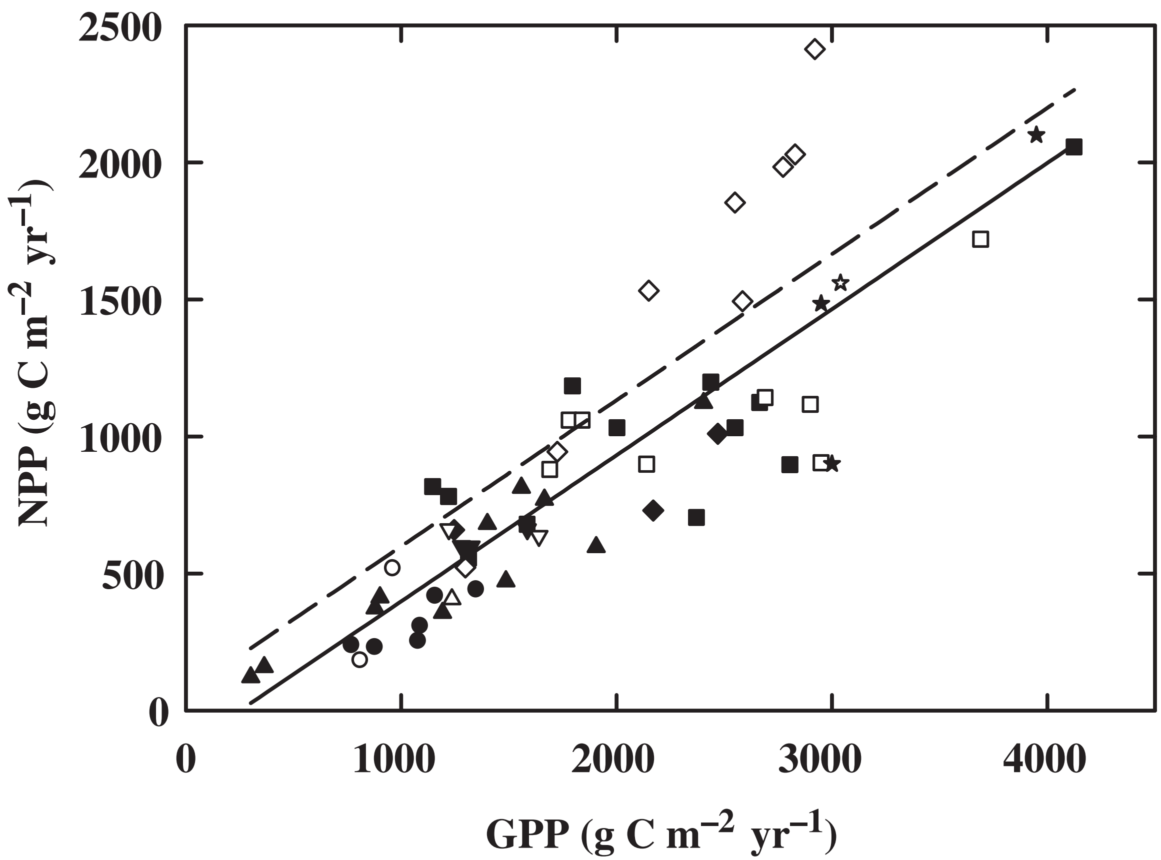
Nutrient acquisition respiration

In FUN, see Rosie Fisher's talk

No free lunch (if lunch is nitrogen)

$$R_a = R_{growth} + R_{maintenance} + R_{FUN}$$

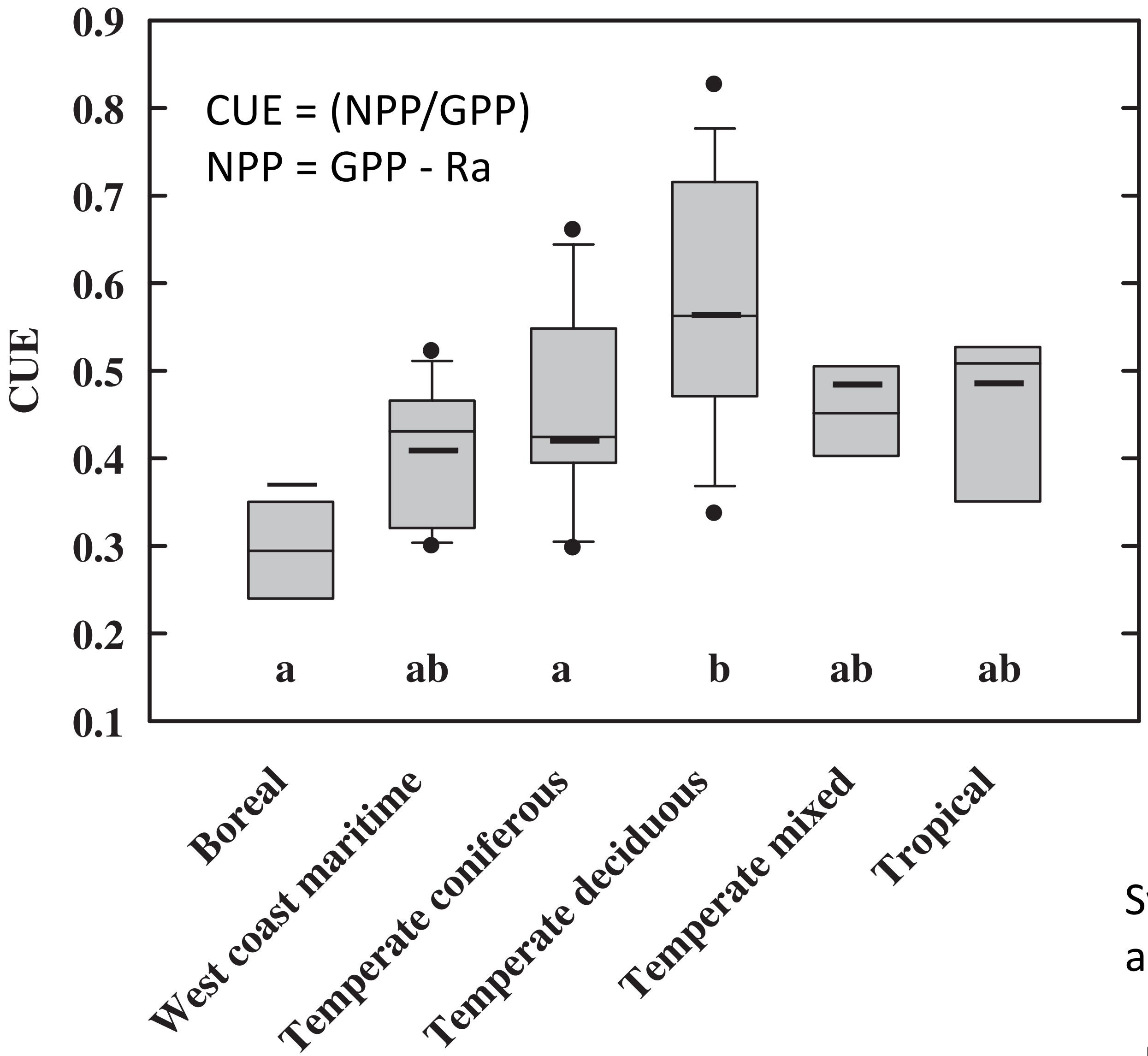
$$NPP = GPP - Ra$$



Synthesis of models and observations

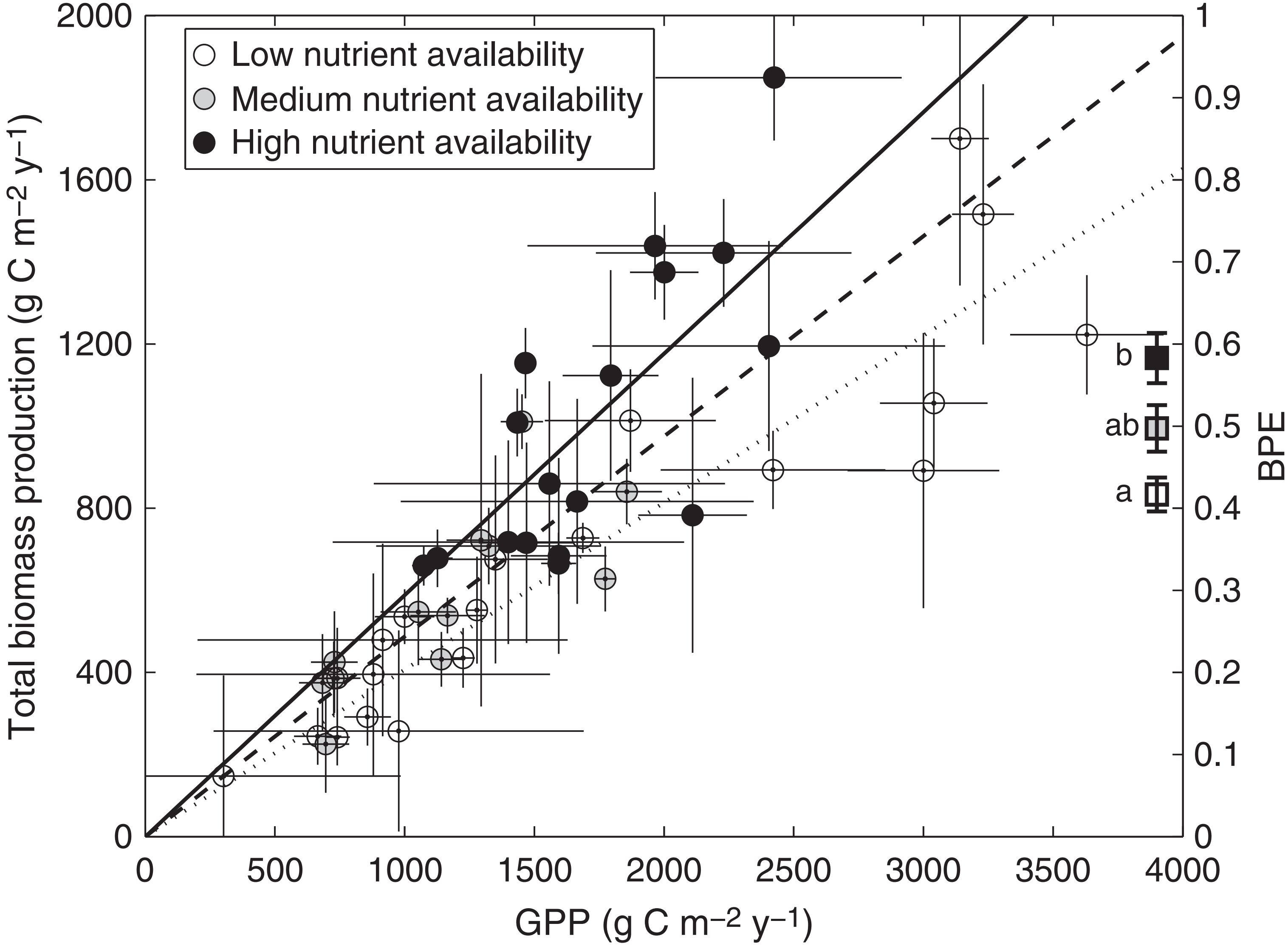
DeLucia et al. 2007

$$R_a = R_{growth} + R_{maintenance} + R_{FUN}$$



Synthesis of models and observations

DeLucia et al. 2007



Vicca et al 2009

What are key feedbacks associated with respiration?

Mortality

CNGapMortalityMod.F90

http://files.kristinsworld.com/uploaded_images/TreeWreckage-726318.jpg

Fixed percentage of biomass across globe (represents whole tree death)
Parameter: **am**

Multiplied by all vegetation pools

What are key feedbacks associated with mortality?

Phenology

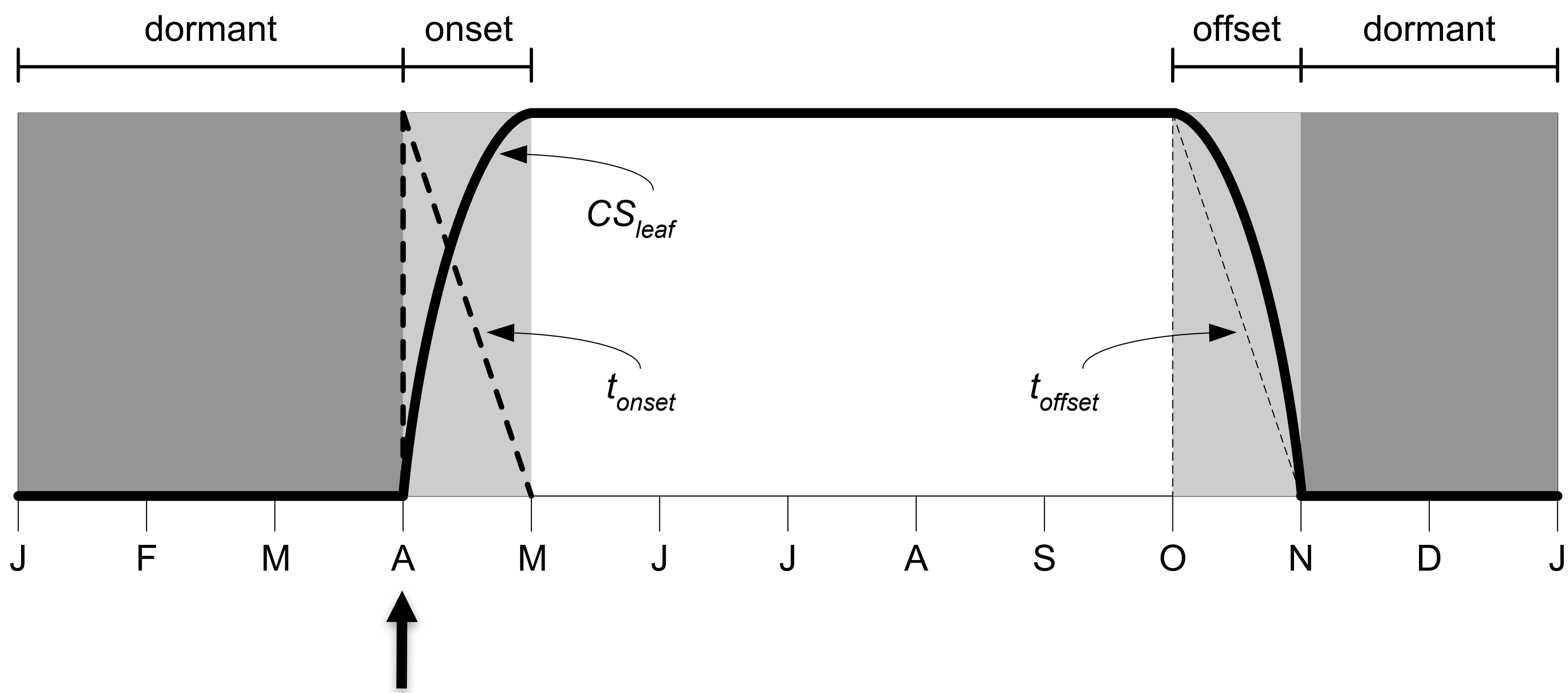
CNPhenologyMod.F90

Evergreen Phenology

Leaf allocation and turnover occurs throughout year
parameter: **leaf_long**

Seasonal Deciduous

Number of onset and offset days are parameters



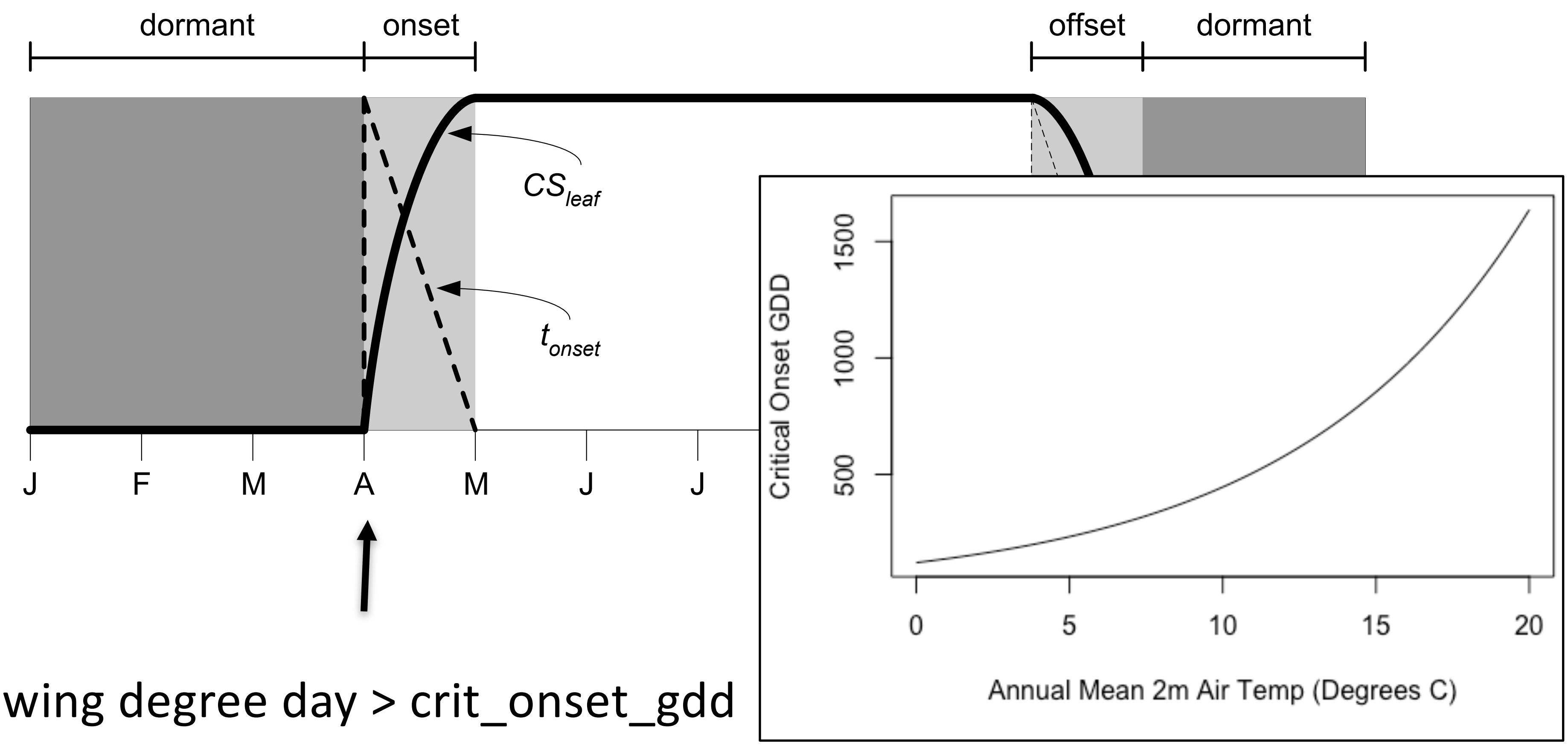
Temperature driven

Growing degree day > crit_onset_gdd

Growing degree = sum of daily soil temperatures greater than zero

Seasonal Deciduous

Number of onset and offset days are parameters

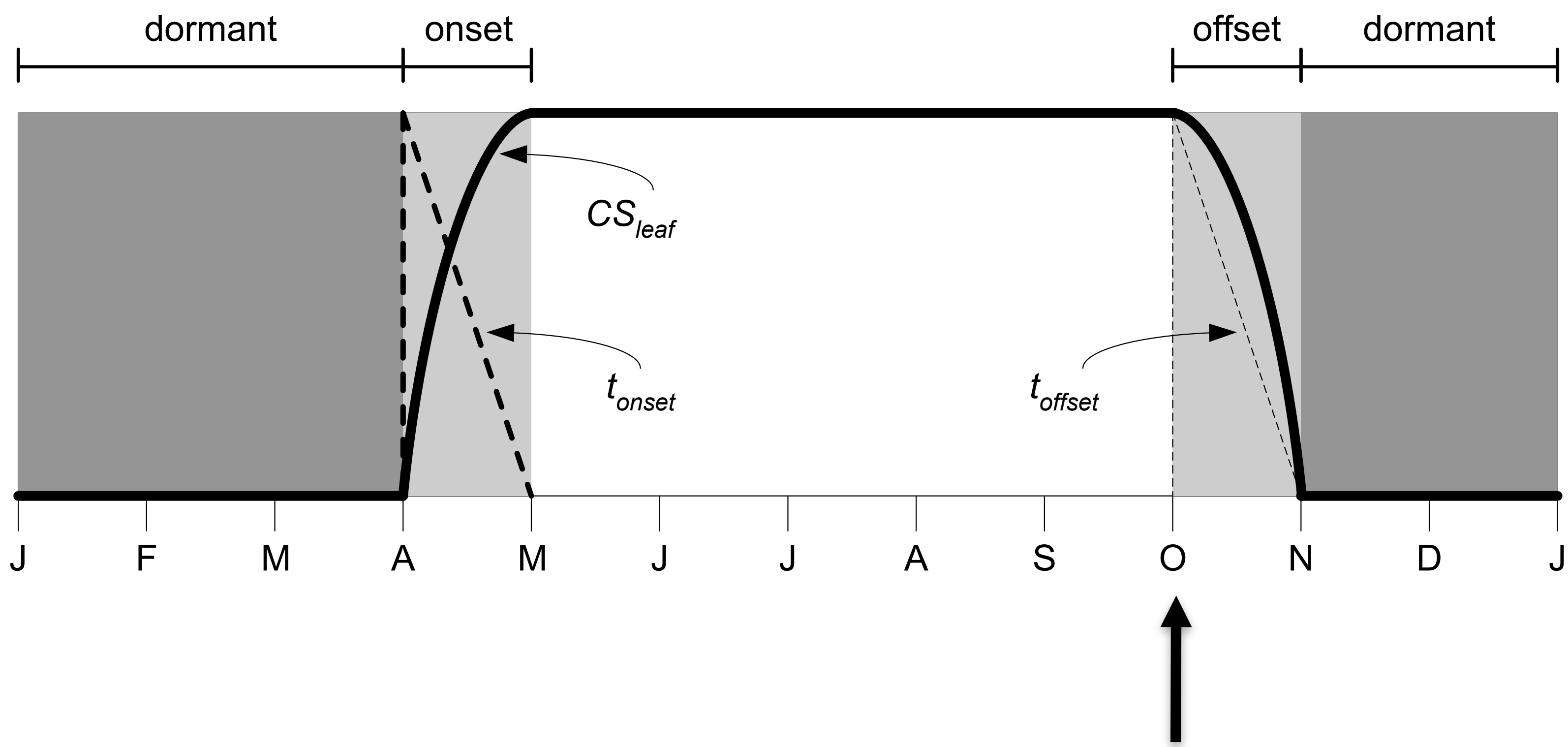


Growing degree day > crit_onset_gdd

Warmer locations require more GDD to start growing leaves

Seasonal Deciduous

Number of onset and offset days are parameters

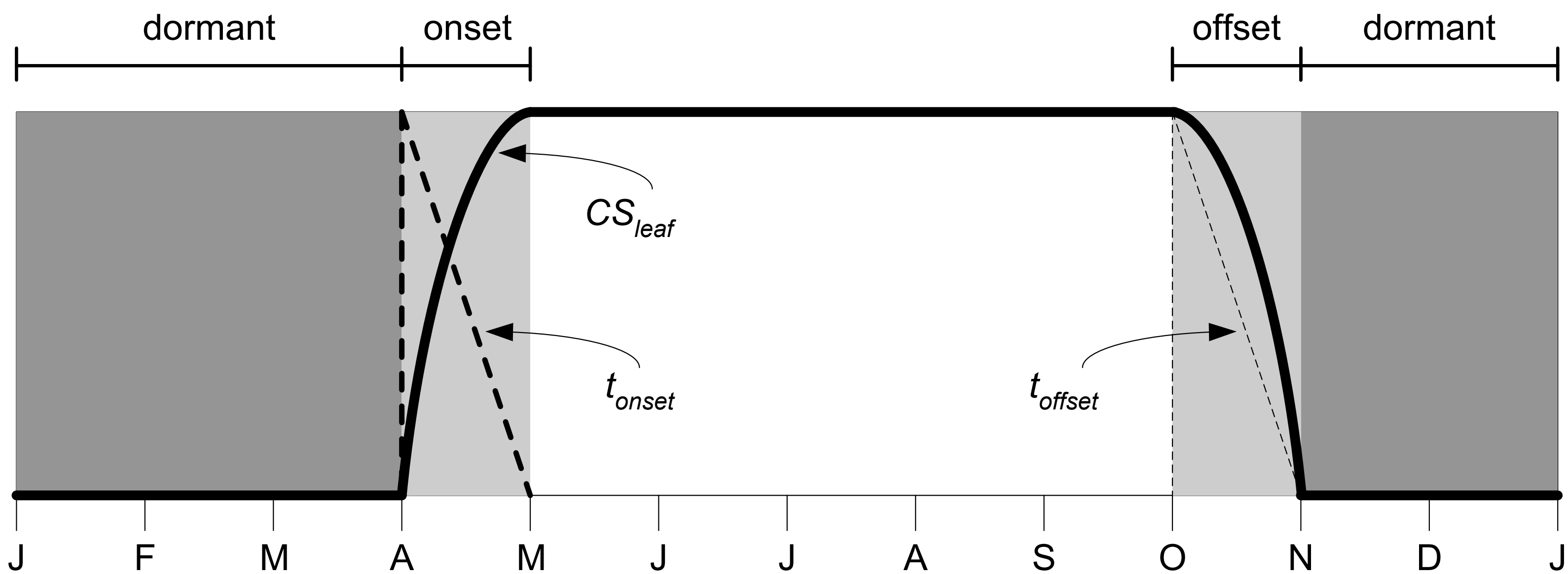


Day length driven

Day length < crit_dayl

crit_dayl a parameter shared across PFTs

Stress Deciduous



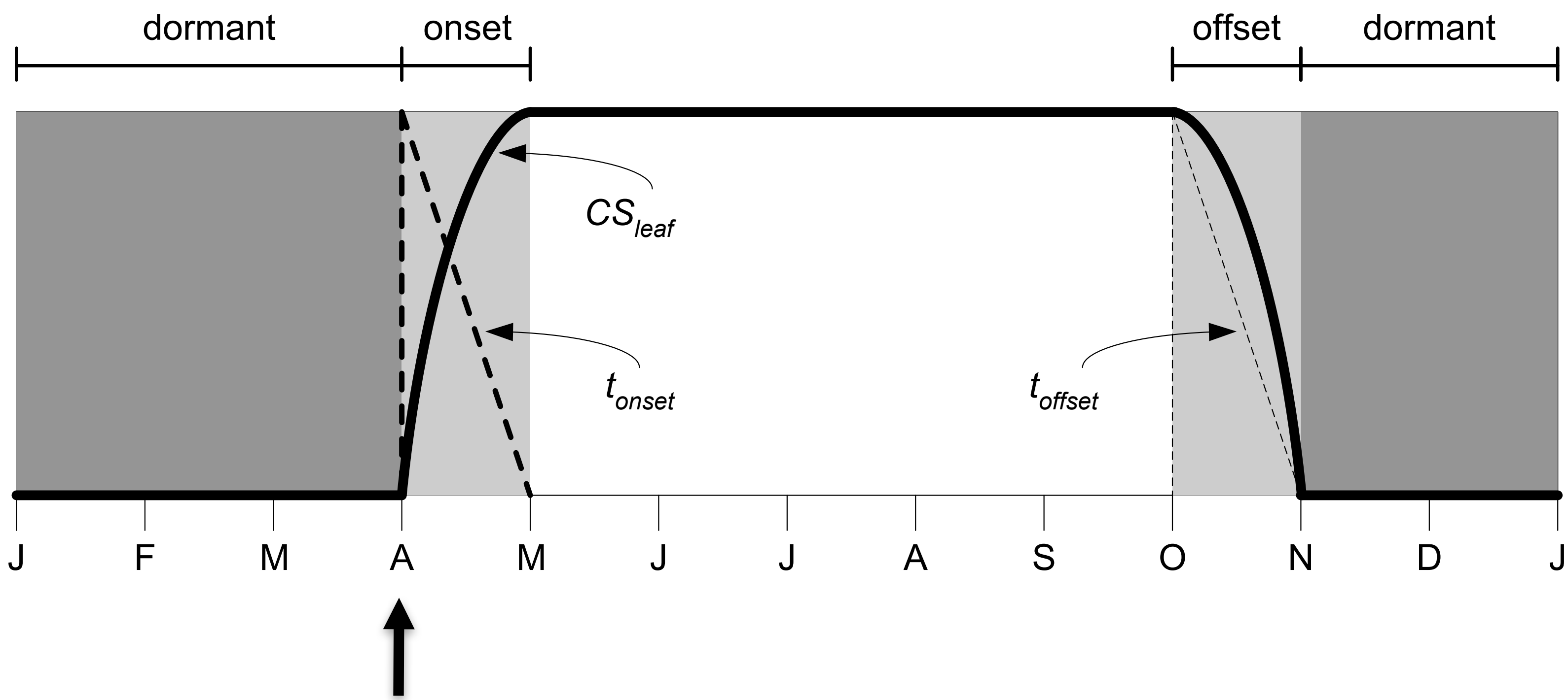
Wet to dry soil water

Cold to warm (cold requirement)

Low rain to rainy

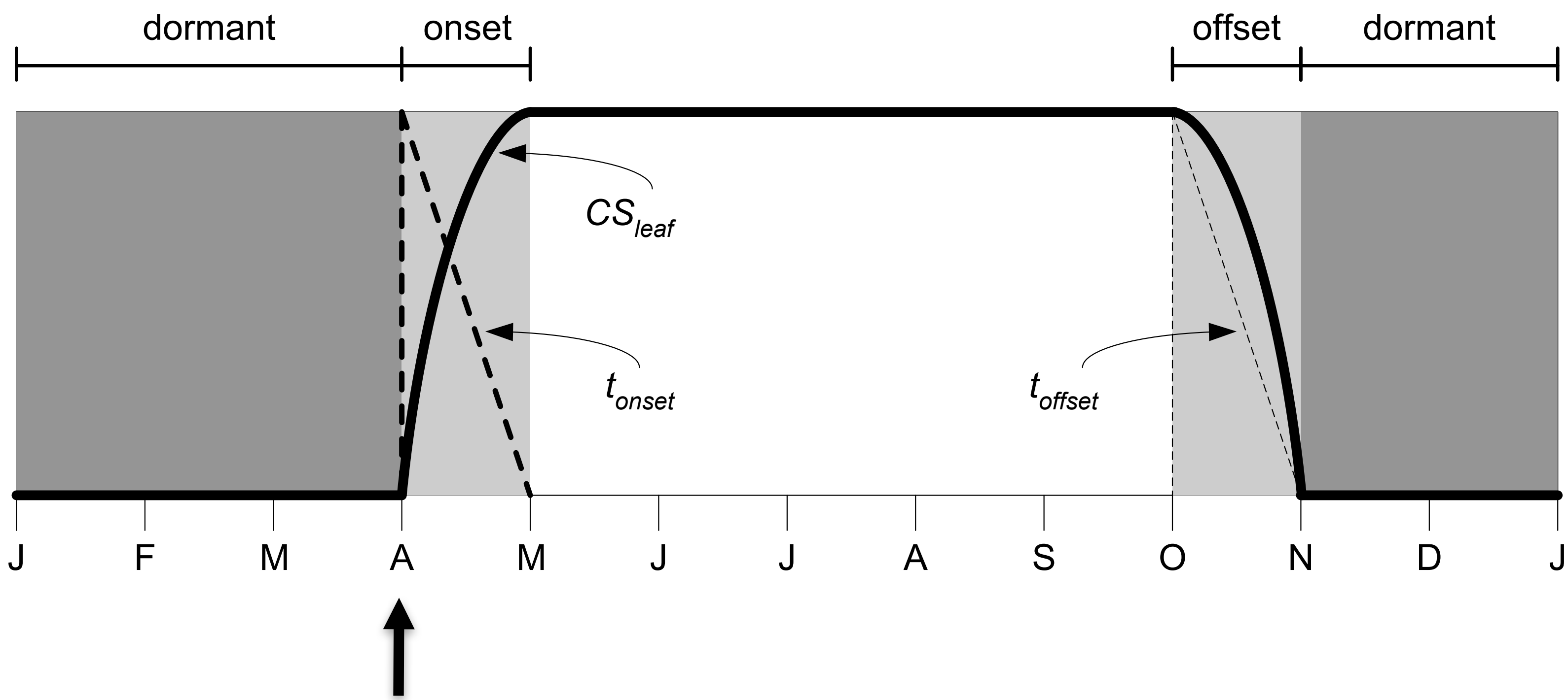
Day length

Stress Deciduous



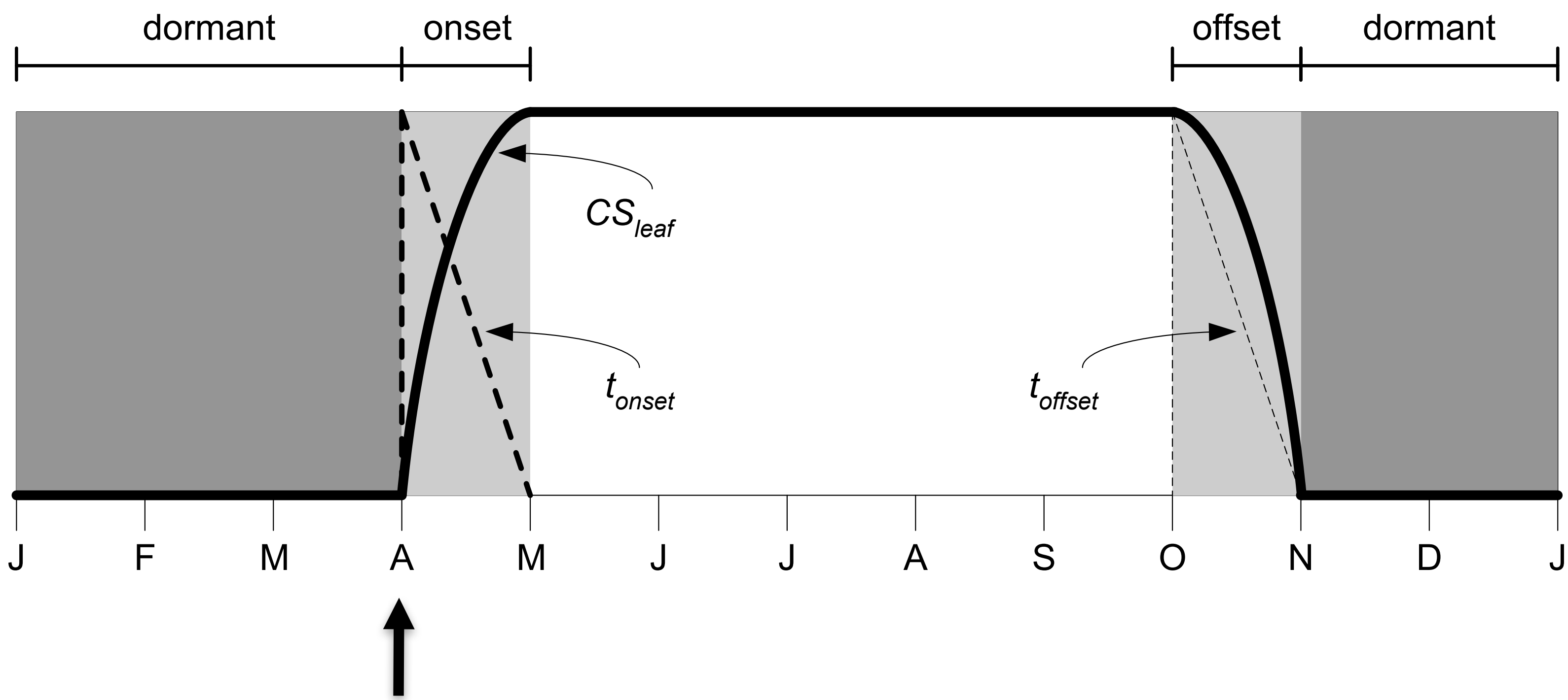
# of days with soil water potential above a specified value (**soilpsi_on**) > **crit_onset_swi**

Stress Deciduous



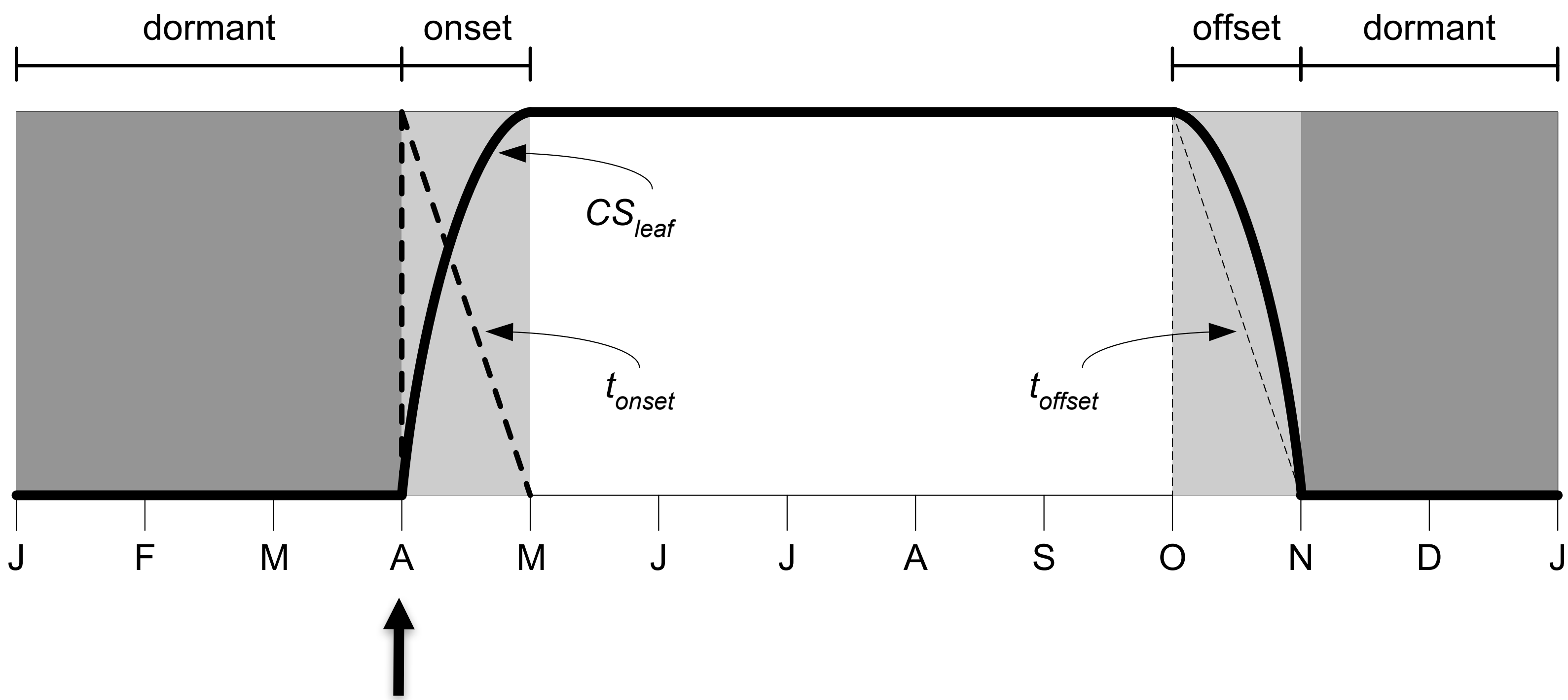
# of freezing days > **crit_onset_fdd**
(a requirement for cold dominancy in cold climates)
Growing degree day after dominancy requirement passed> crit_onset_gdd

Stress Deciduous



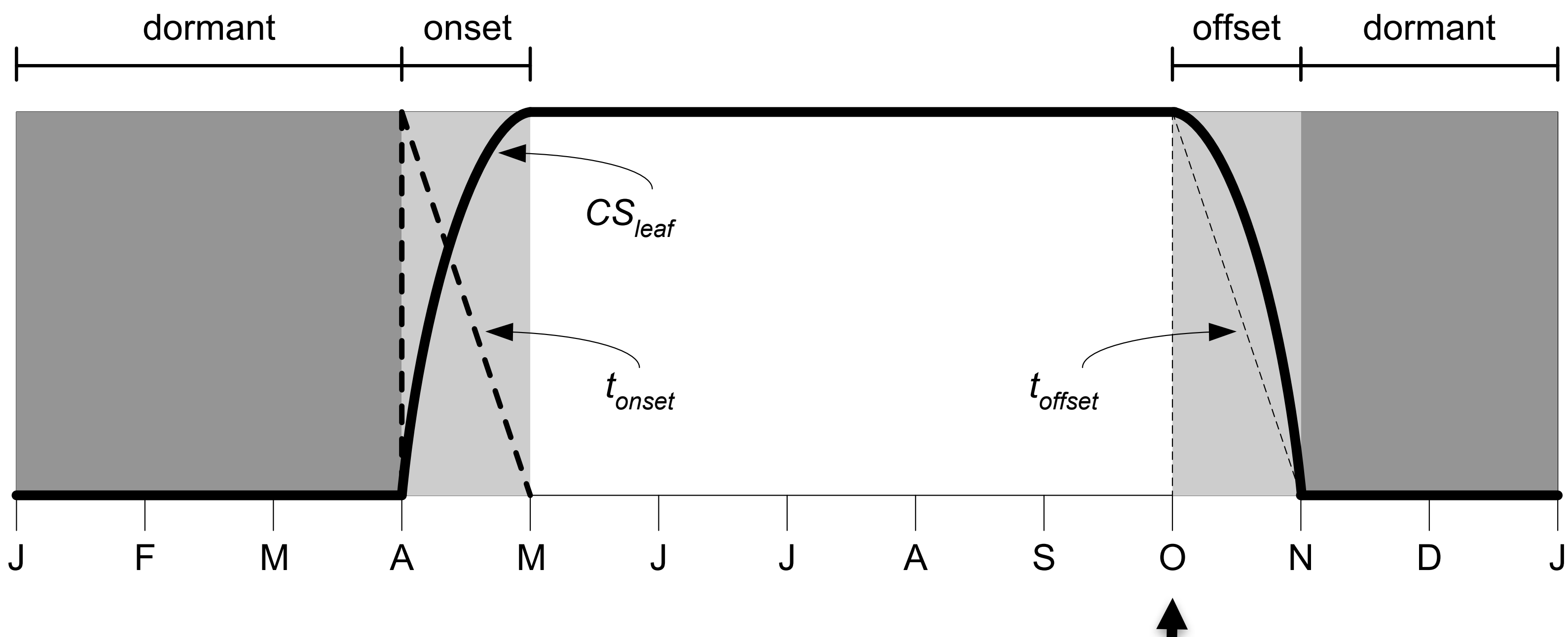
Day length > 6 hrs.

Stress Deciduous



10 day precipitation > rain_threshold
(in code as 20 mm)

Stress Deciduous

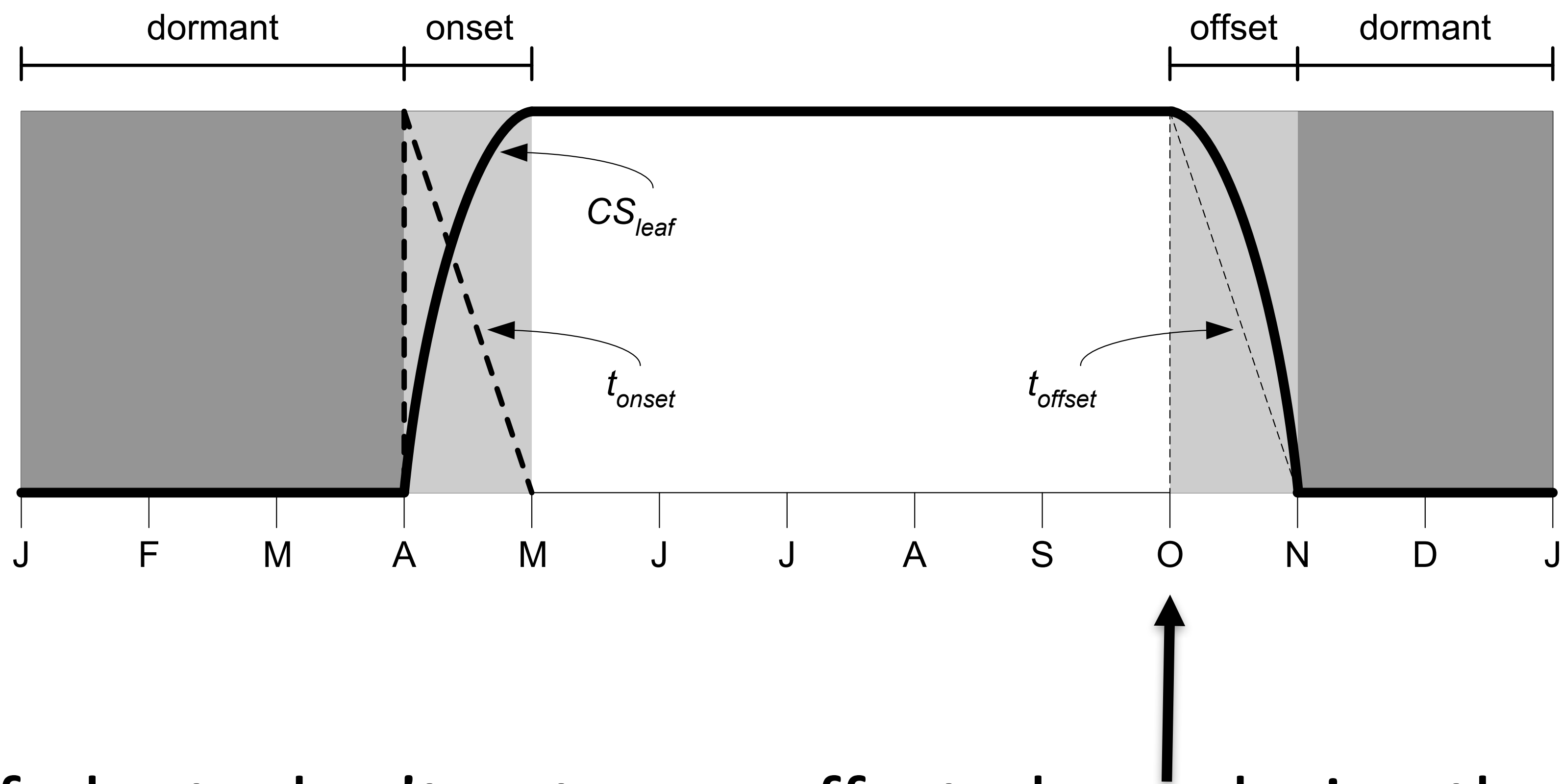


Low soil water

# of freezing days

Daylength (if < 6 hrs then drop leaves)

Stress Deciduous

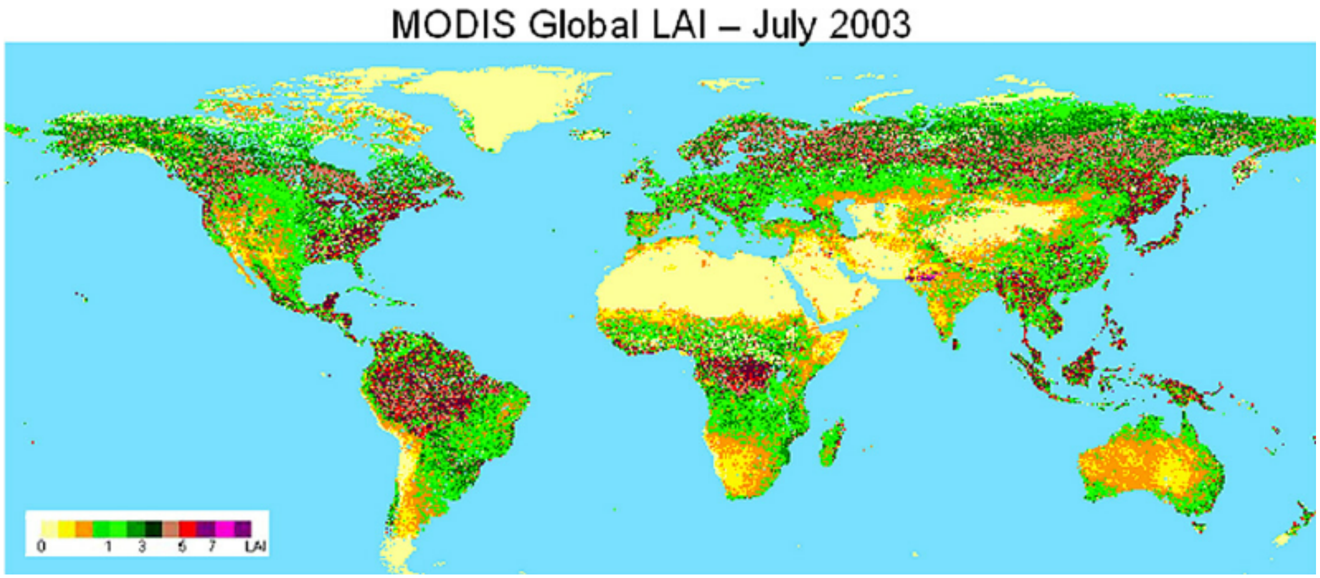


If plants don't enter an offset phase during the year, they become an evergreen plant with temporary evergreen phenology

Crop Phenology

See Crop model talk

Satellite Phenology

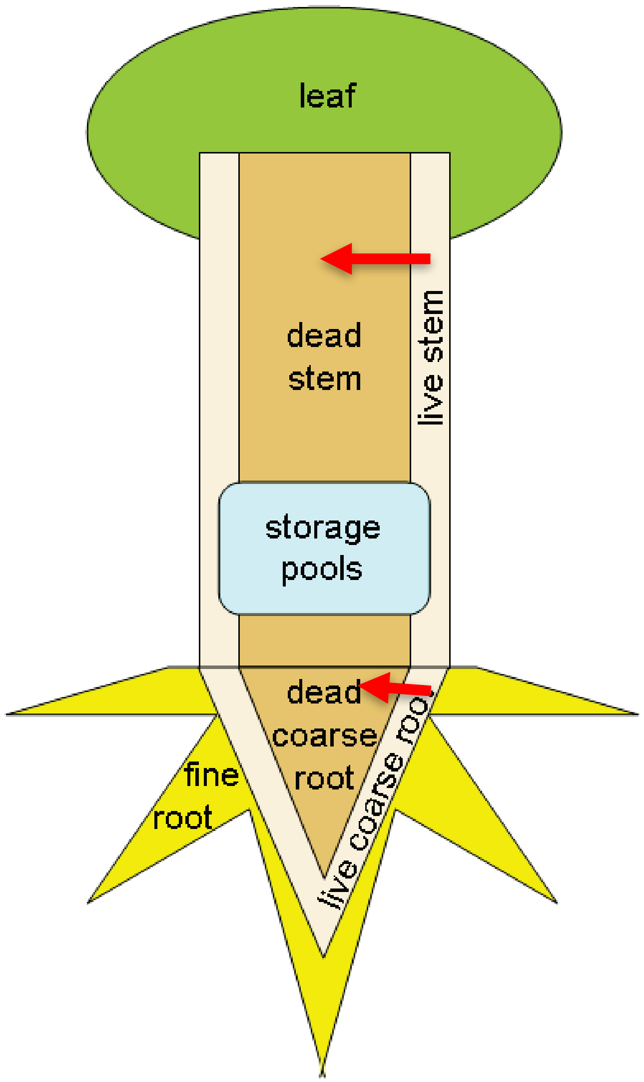


Average year of MODIS LAI used to specify LAI

Dynamic phenology not used and carbon cycle turned off (other than photosynthesis

Map from Pisek and Chen 2007

Live wood to dead wood



Occurs throughout year based on specified rate

Parameter: **lwtop**

Associated with retranslocation of N because live wood has more N than dead wood

What are key feedbacks associated with Phenology?