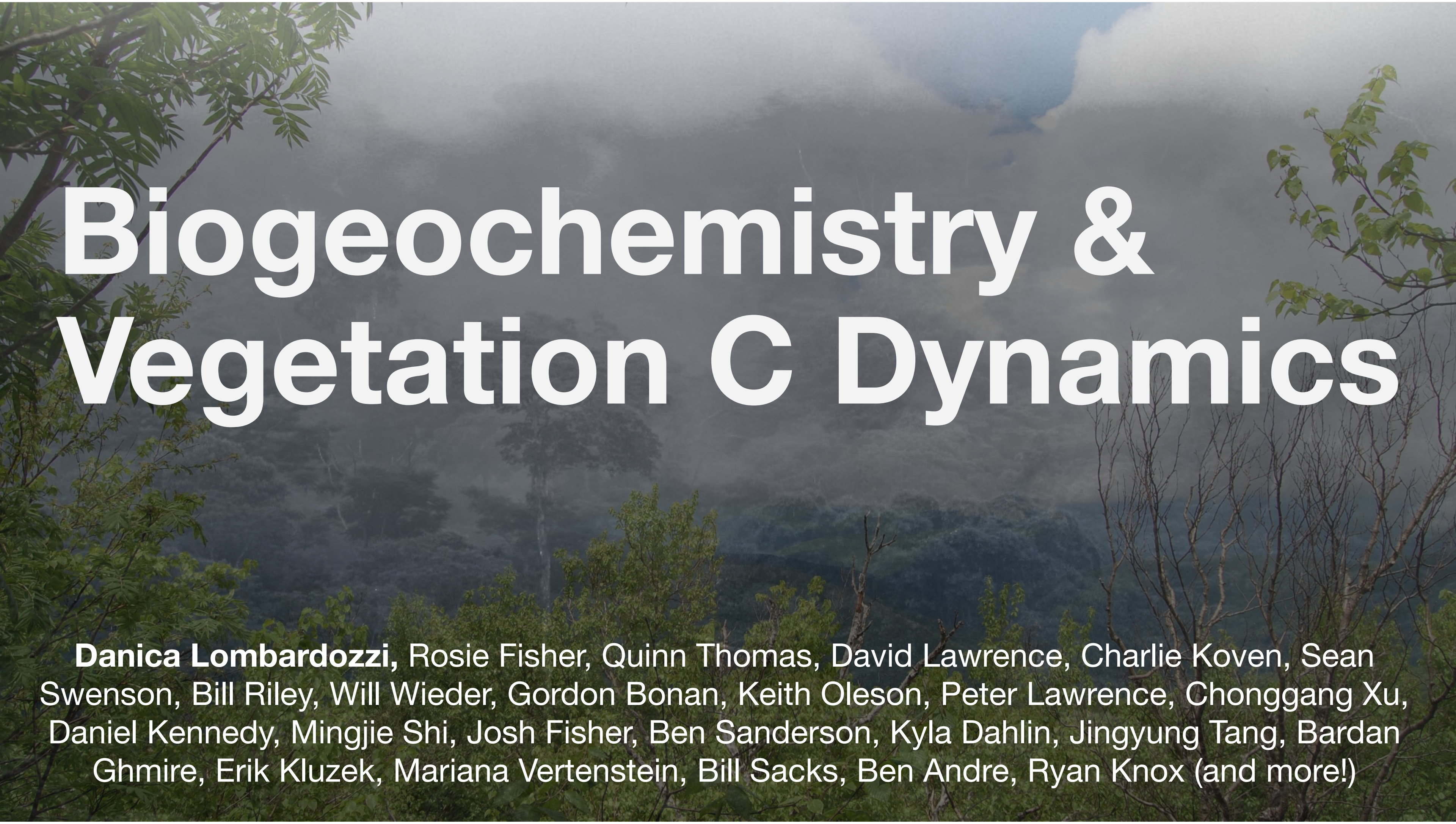
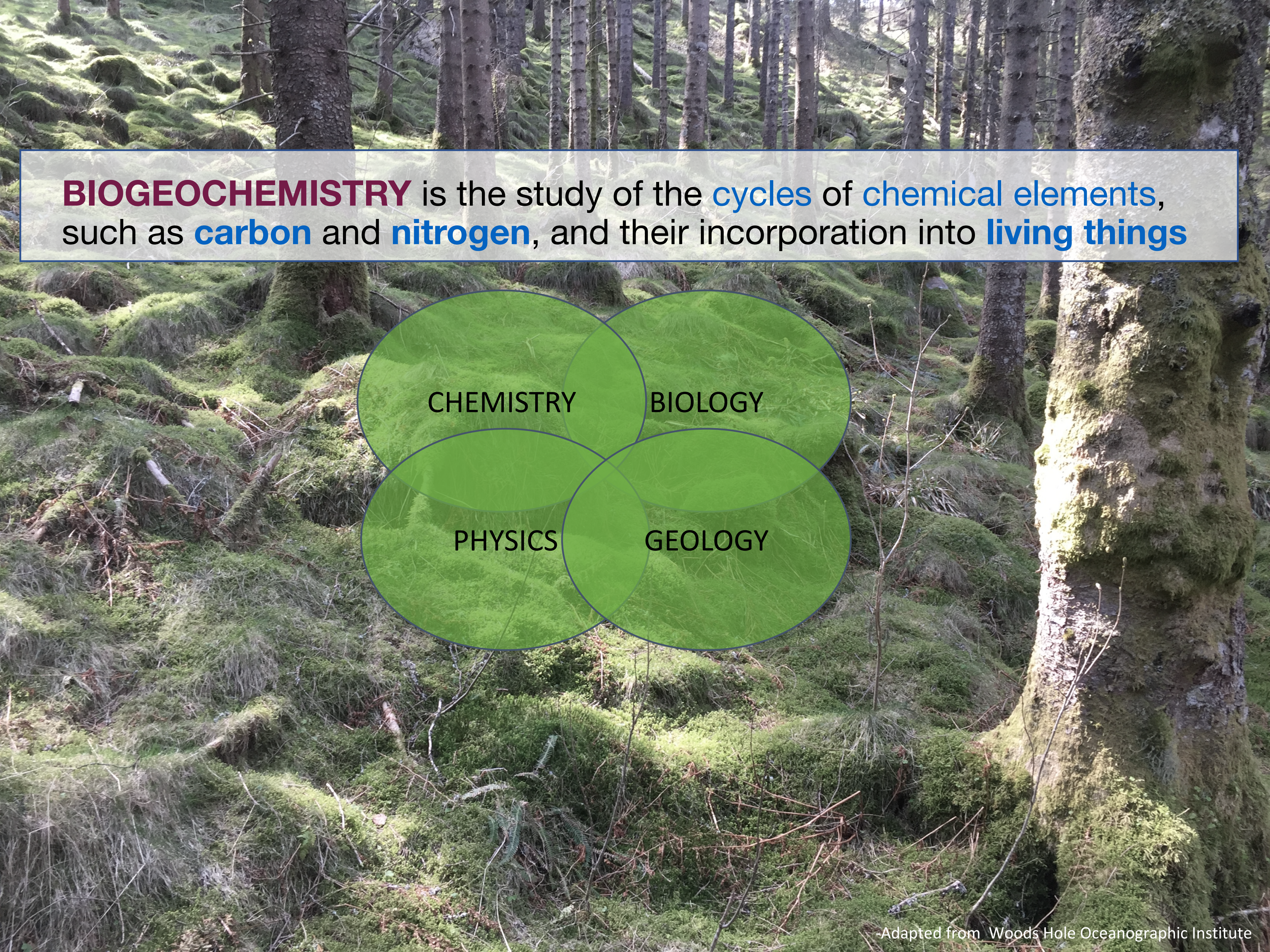


Biogeochemistry & Vegetation C Dynamics

Danica Lombardozzi, Rosie Fisher, Quinn Thomas, David Lawrence, Charlie Koven, Sean Swenson, Bill Riley, Will Wieder, Gordon Bonan, Keith Oleson, Peter Lawrence, Chonggang Xu, Daniel Kennedy, Mingjie Shi, Josh Fisher, Ben Sanderson, Kyla Dahlin, Jingyung Tang, Bardan Ghmire, Erik Kluzek, Mariana Vertenstein, Bill Sacks, Ben Andre, Ryan Knox (and more!)


What is biogeochemistry?

BIOGEOCHEMISTRY is the study of the cycles of chemical elements, such as **carbon** and **nitrogen**, and their incorporation into **living things**

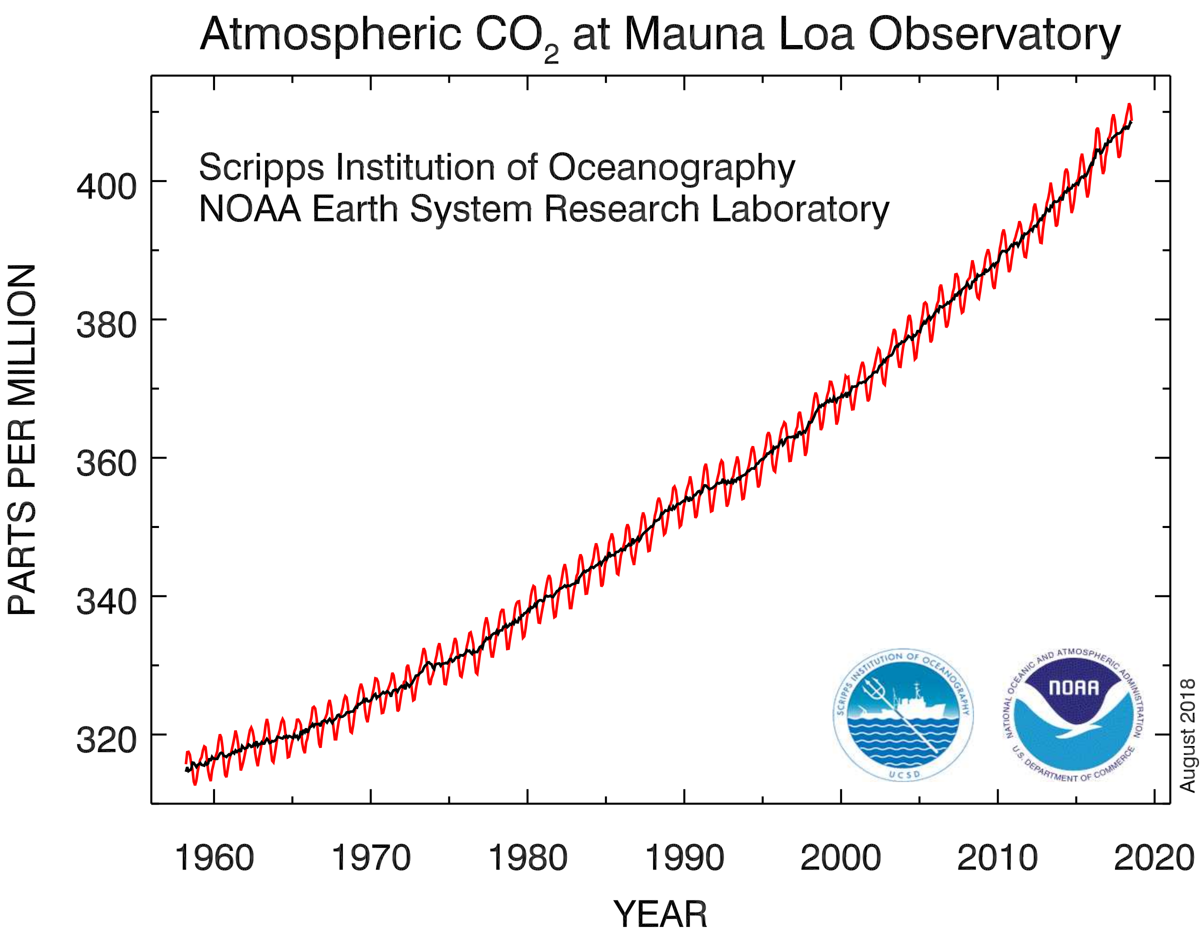


Today's Path

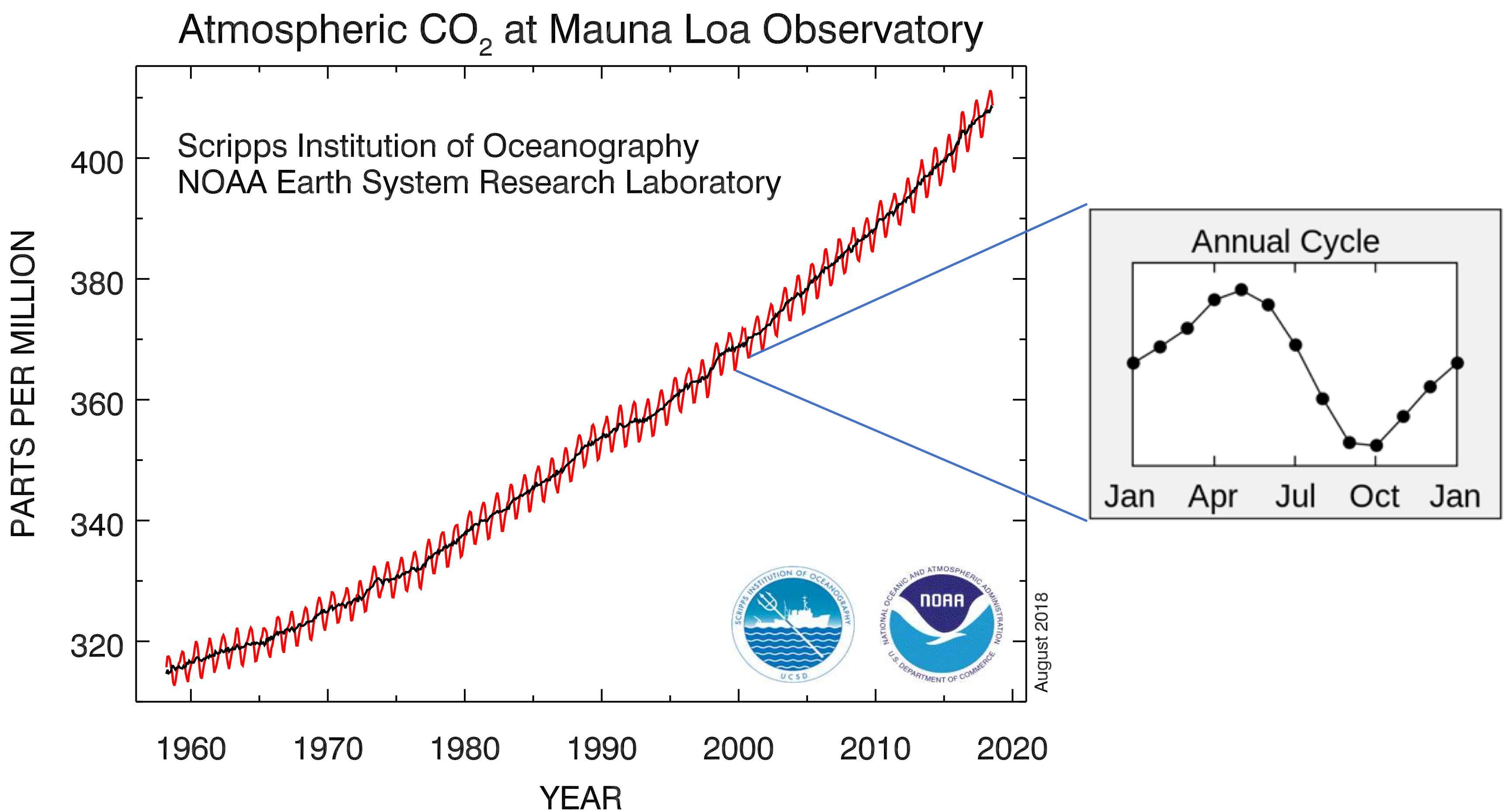
1) Why is biogeochemistry important

2) Vegetation C dynamics
   a) Allocation
   b) Respiration
   c) Phenology
   d) Mortality

1. Why is biogeochemistry important?



Atmospheric CO2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
PARTS PER MILLION
320
340
360
380
400
1960
1970
1980
1990
2000
2010
2020
YEAR
August 2018


Atmospheric CO_2 at Mauna Loa Observatory
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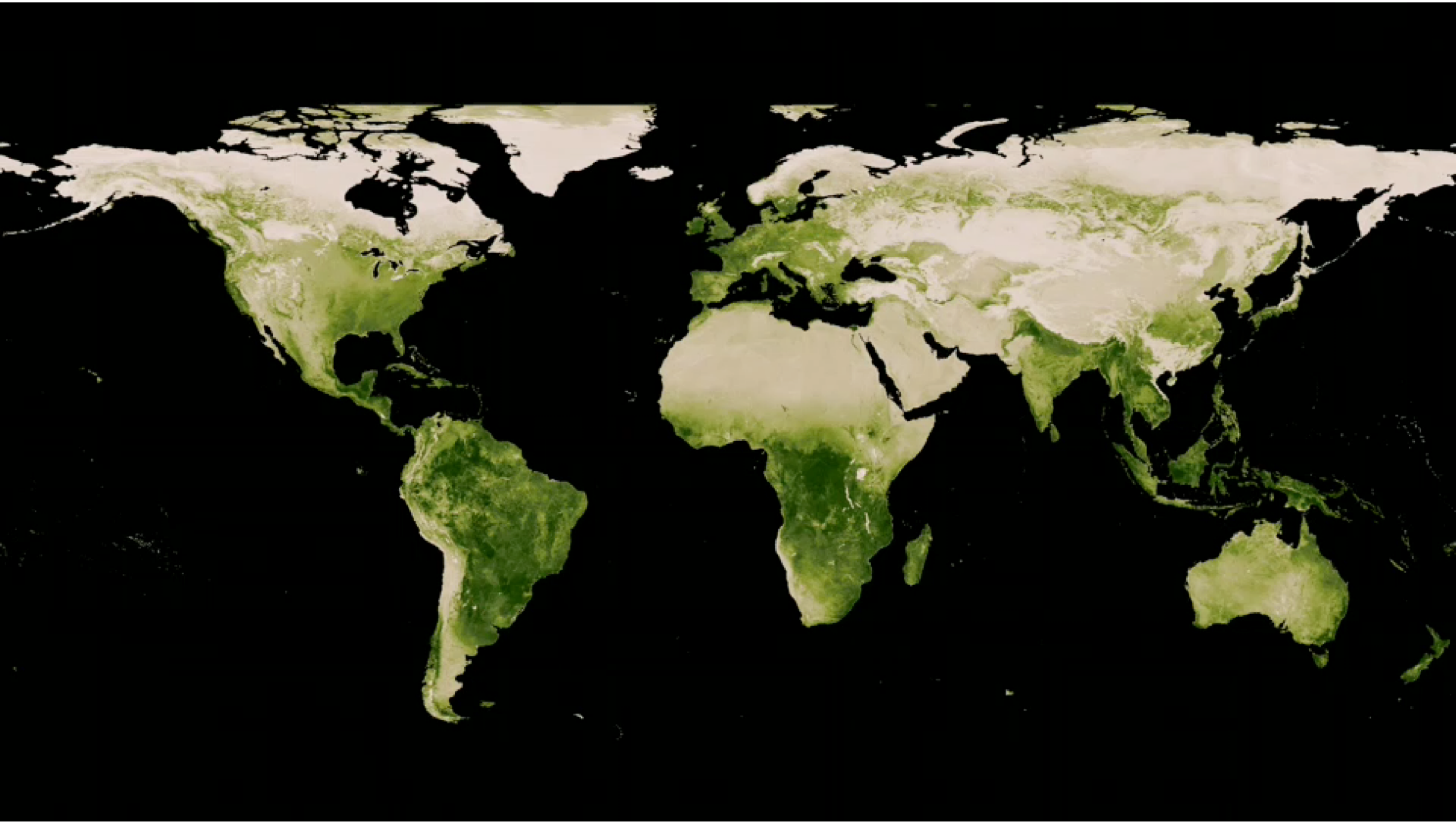
PARTS PER MILLION
400
380
360
340
320
1960
1970
1980
1990
2000
2010
2020
YEAR
August 2018
Annual Cycle
Jan
Apr
Jul
Oct
Jan



Land is a critical sink of CO_2 emissions

CO_2 Sources

9.4±0.5 PgC yr^{-1} 88%

1.3±0.7 PgC yr^{-1} 12%

+

CO_2 Sinks

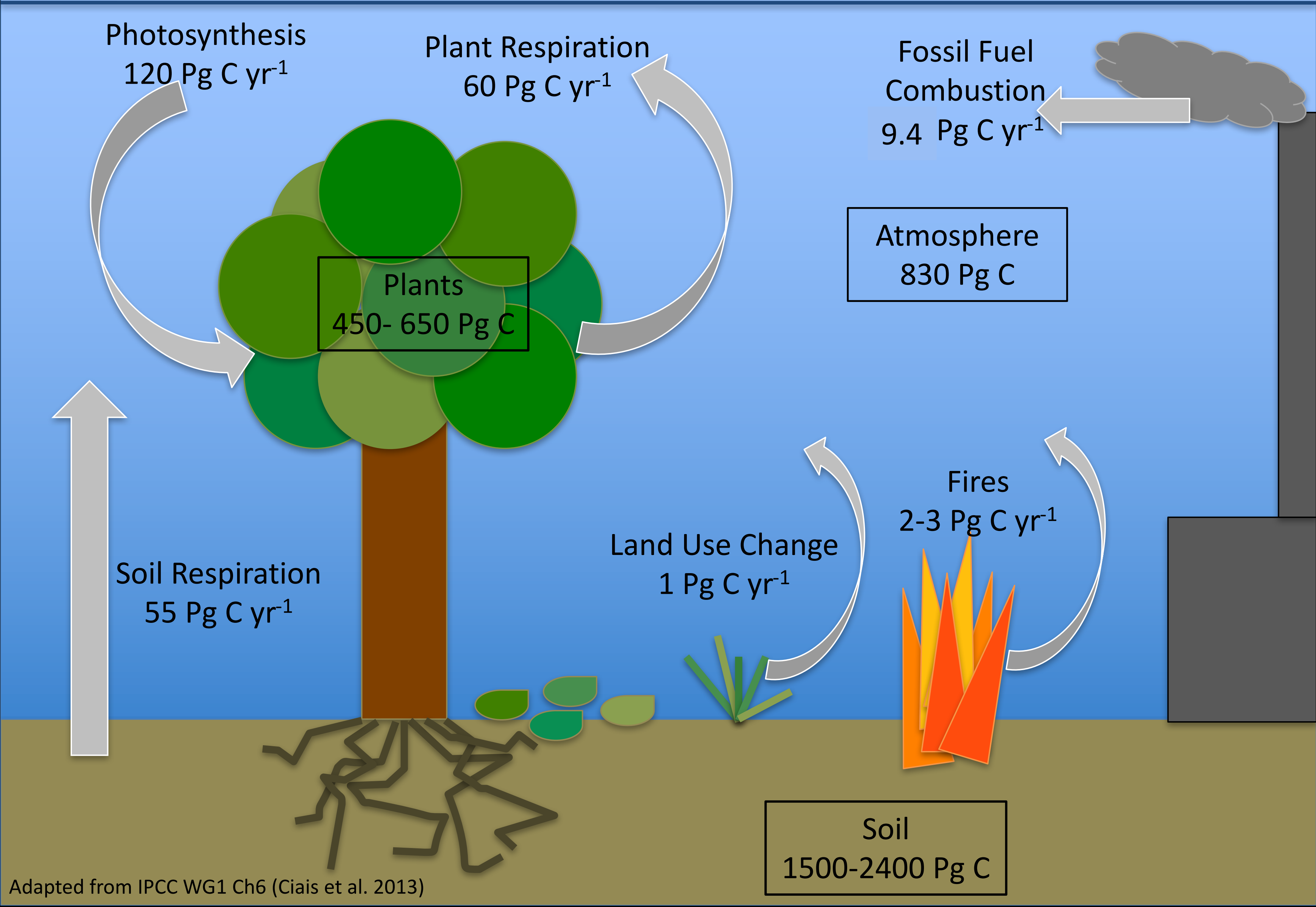
46%
4.7±0.2 PgC/yr

30%
3.0±0.8 PgC/yr

24%
2.4±0.5 PgC/yr

Notes: Values are averaged from 2007 – 2016; Budget Imbalance: 0.6 Pg C yr^{-1}; Source: Le Quéré et al. 2017

Terrestrial Carbon Cycle



Adapted from IPCC WG1 Ch6 (Ciais et al. 2013)

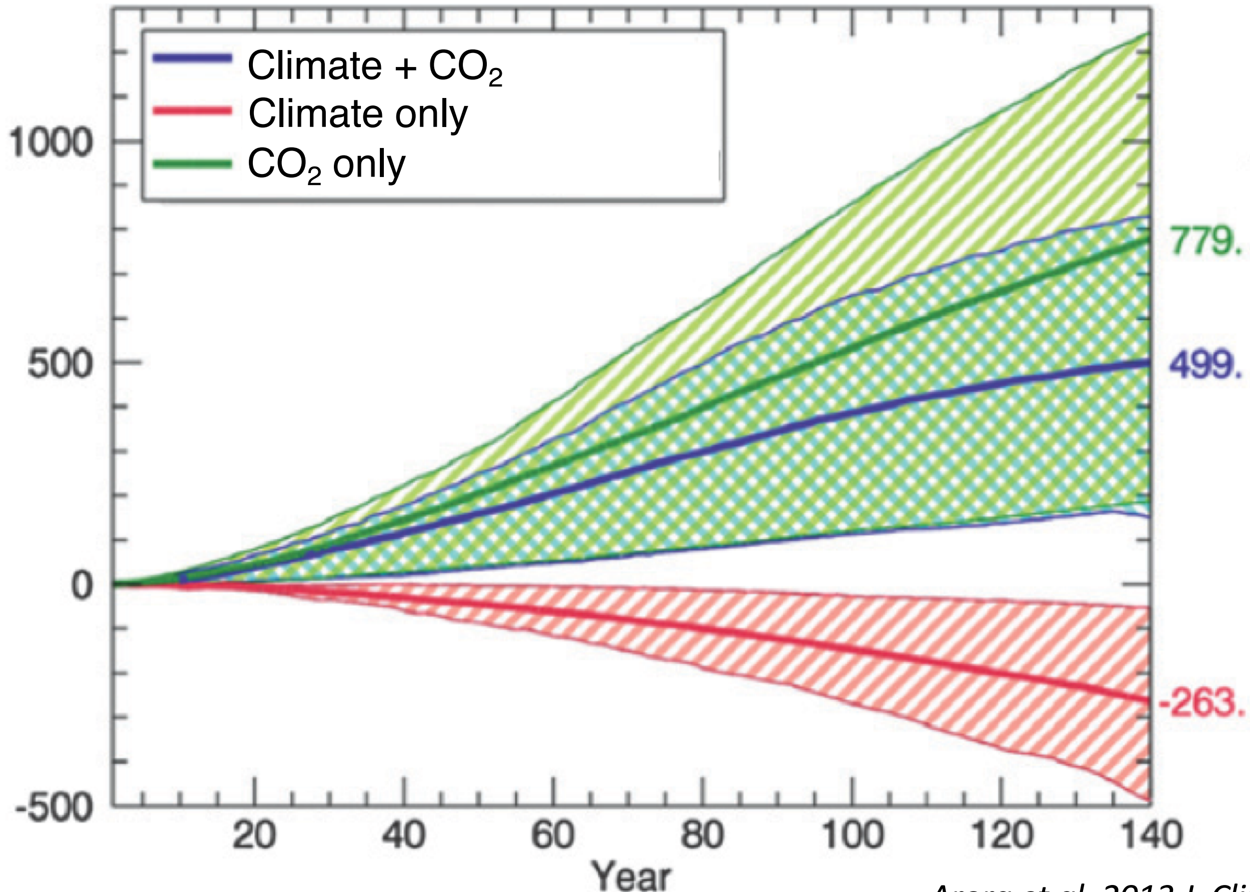
Terrestrial Carbon Cycle

The rate of these fluxes depend on other environmental variables, including:

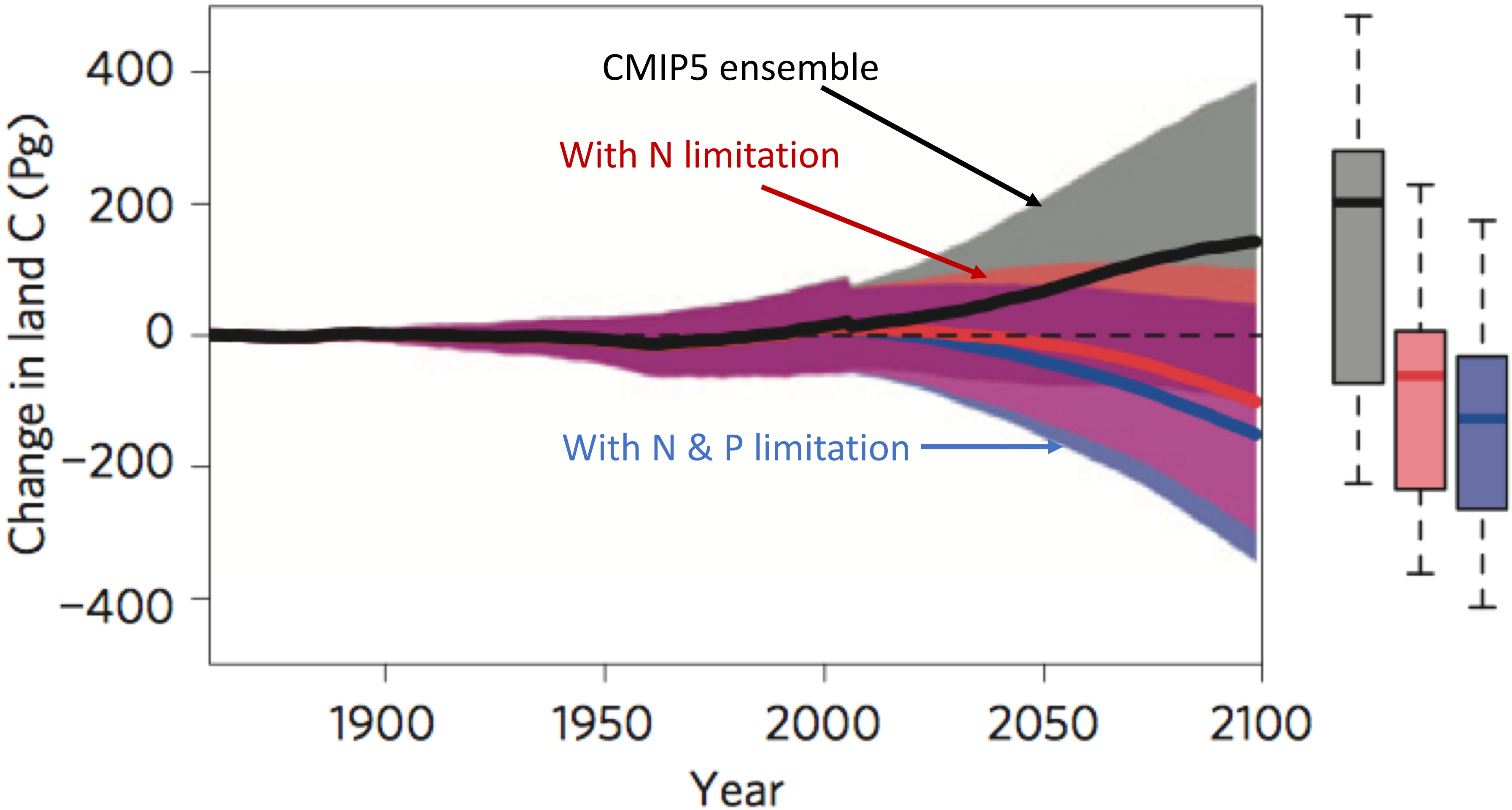
- Temperature
- Precipitation/Water availability
- Nutrient availability (especially nitrogen)

Adapted from IPCC WG1 Ch6 (Ciais et al. 2013)

Cumulative atmosphere-land CO_2 flux (Pg C)

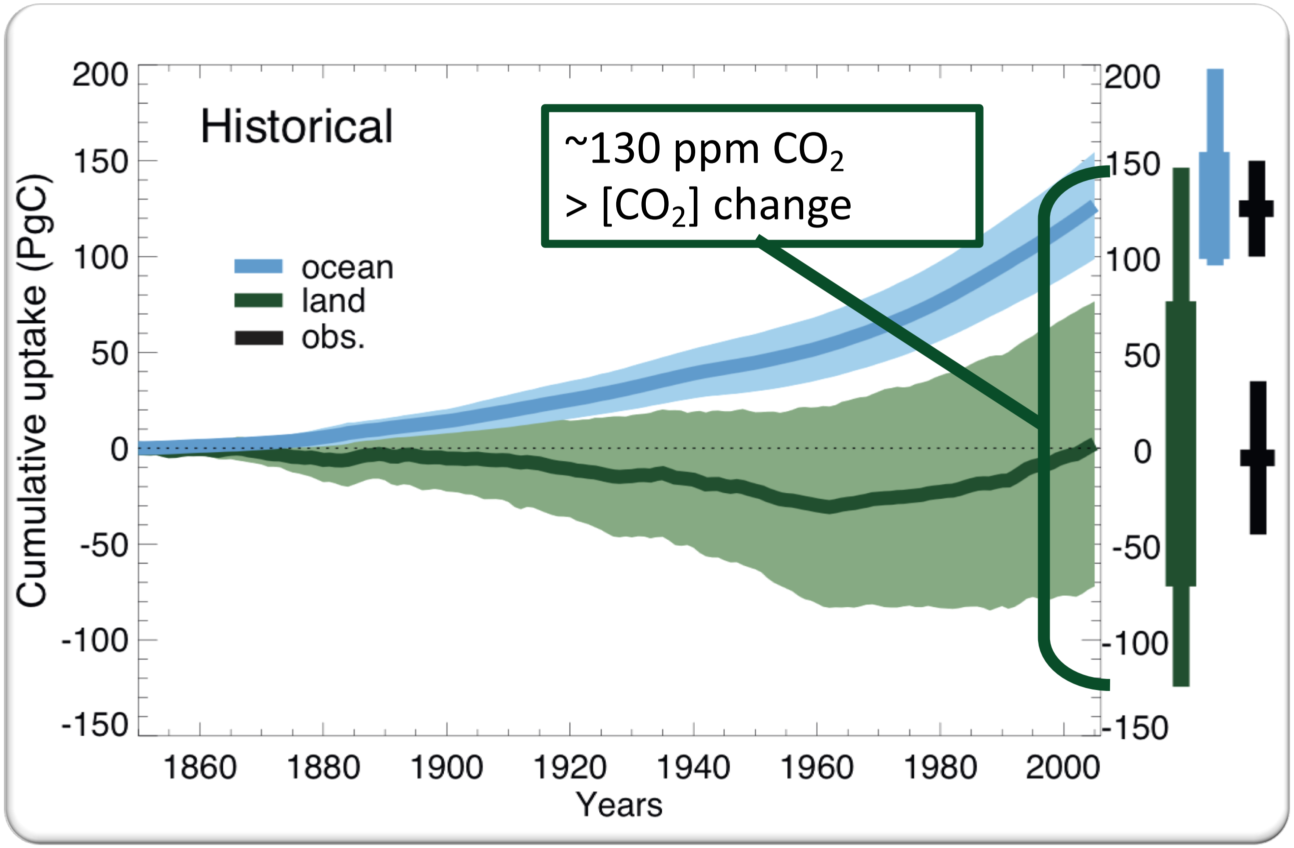


Arora et al. 2013 J. Climate

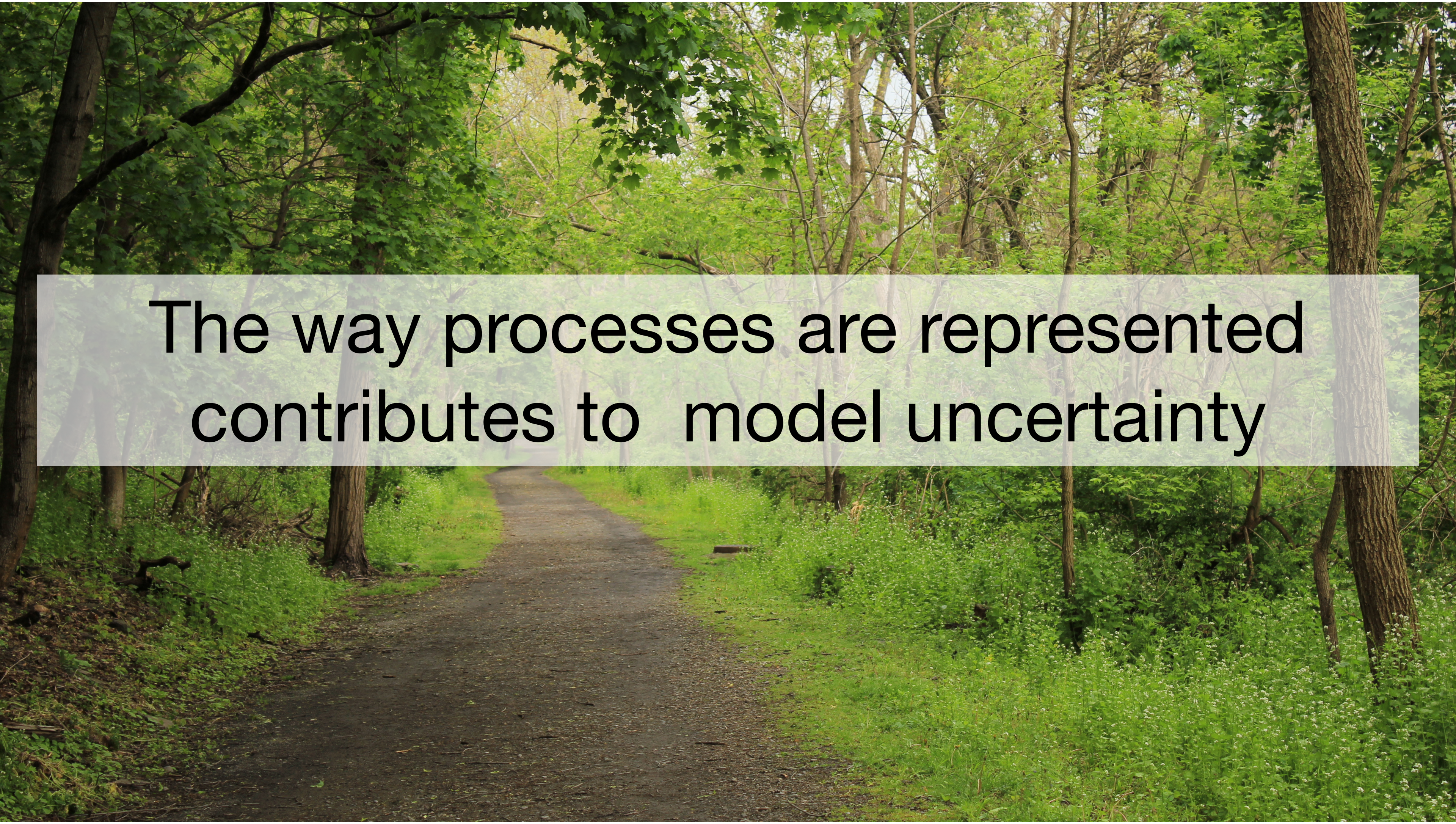


Wieder et al. 2015

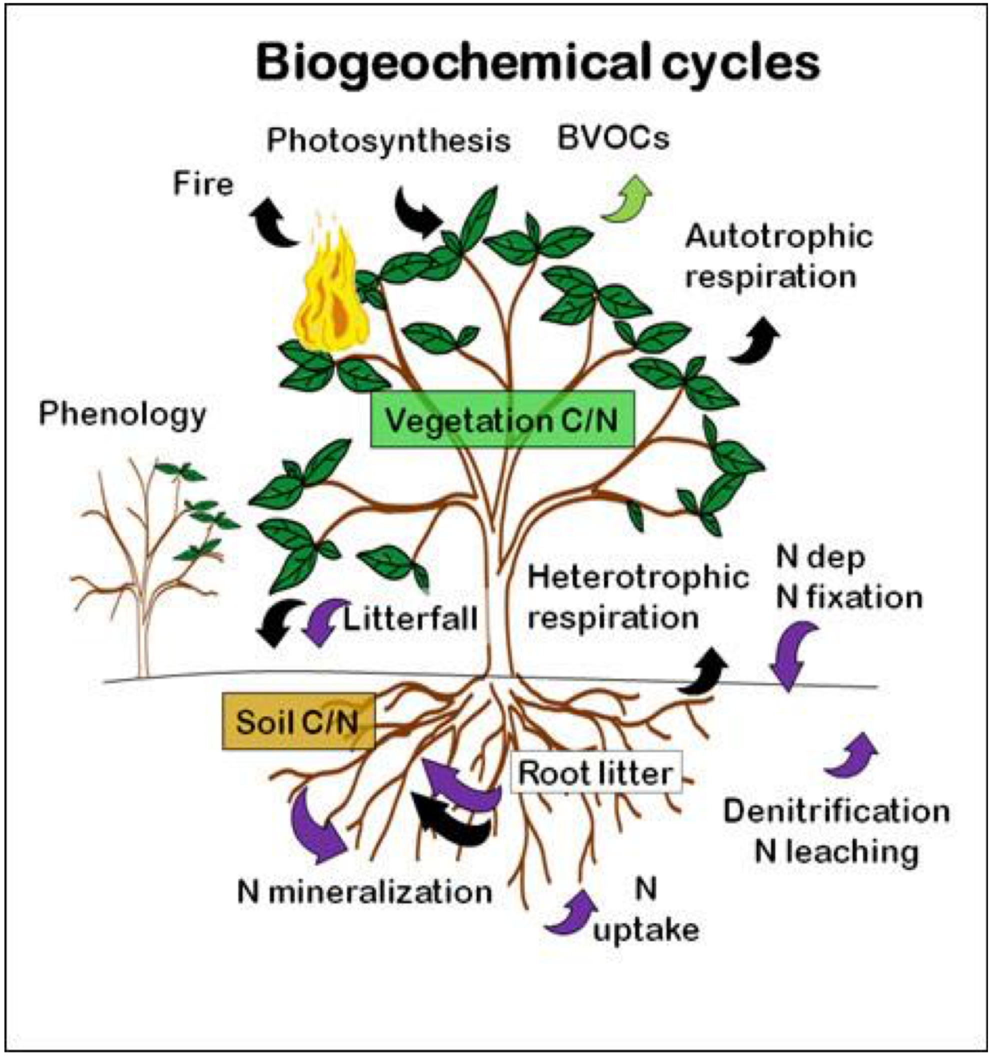
Multi-model carbon cycle uncertainty



IPCC WG1 Ch. 6 (Ciais et al 2013)

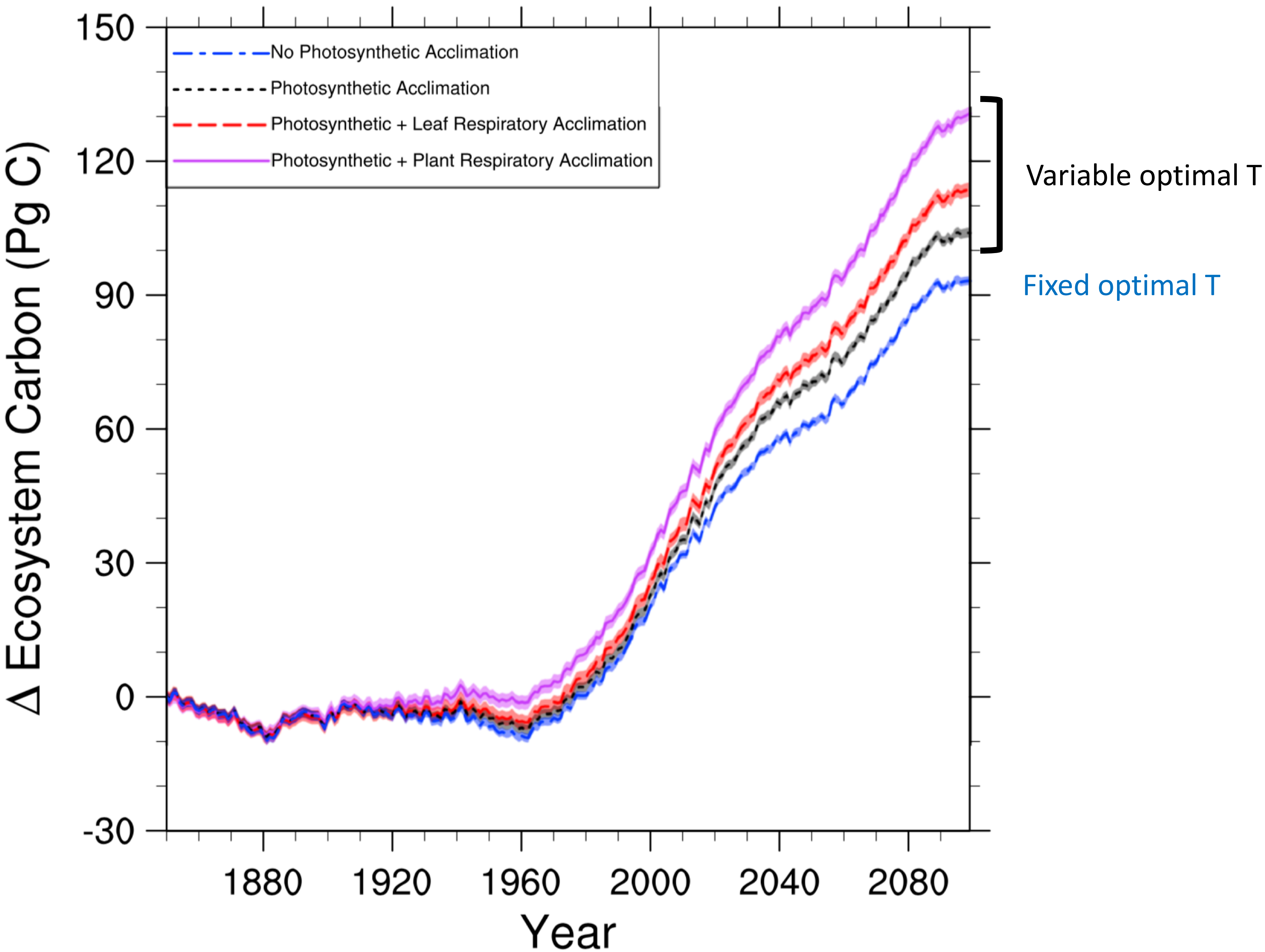

The way processes are represented
contributes to model uncertainty

Primary components of CLM's biogeochemistry model



http://www.cesm.ucar.edu/models/clm/biogeochemistry.html

Changing photosynthesis and respiration responses to temperature



Lombardozzi et al. 2015

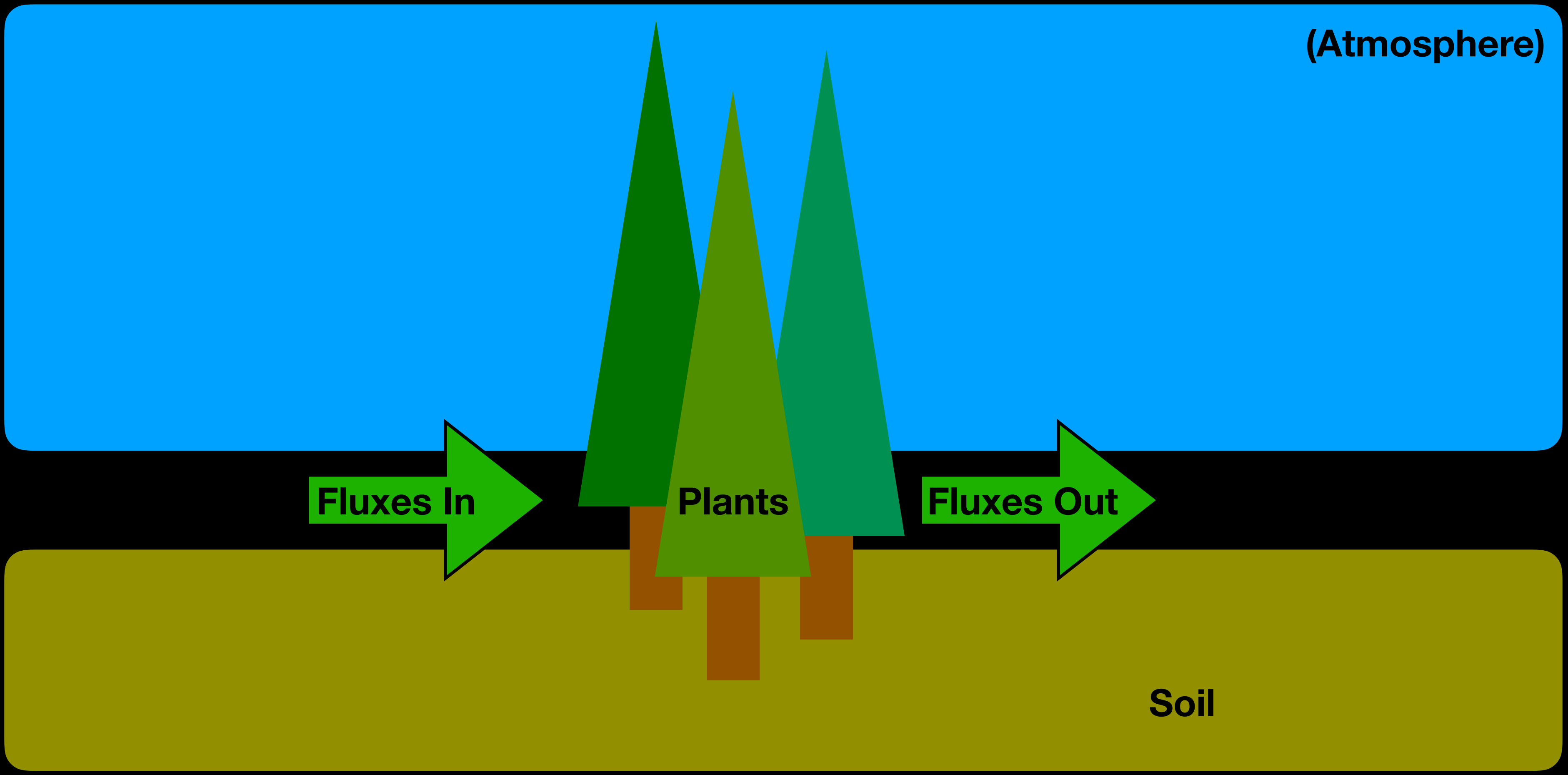
Stop what you are doing and become a biogeochemist

- "Allowable emissions" to get to 1.5, 2, 4 degrees of warming are all heavily contingent on carbon-cycle feedbacks.
- Terrestrial carbon-cycle feedbacks are among the largest uncertainties in ESMs
- Nutrients are an important constraint on C uptake, though parameterizations are uncertain and need to be evaluated

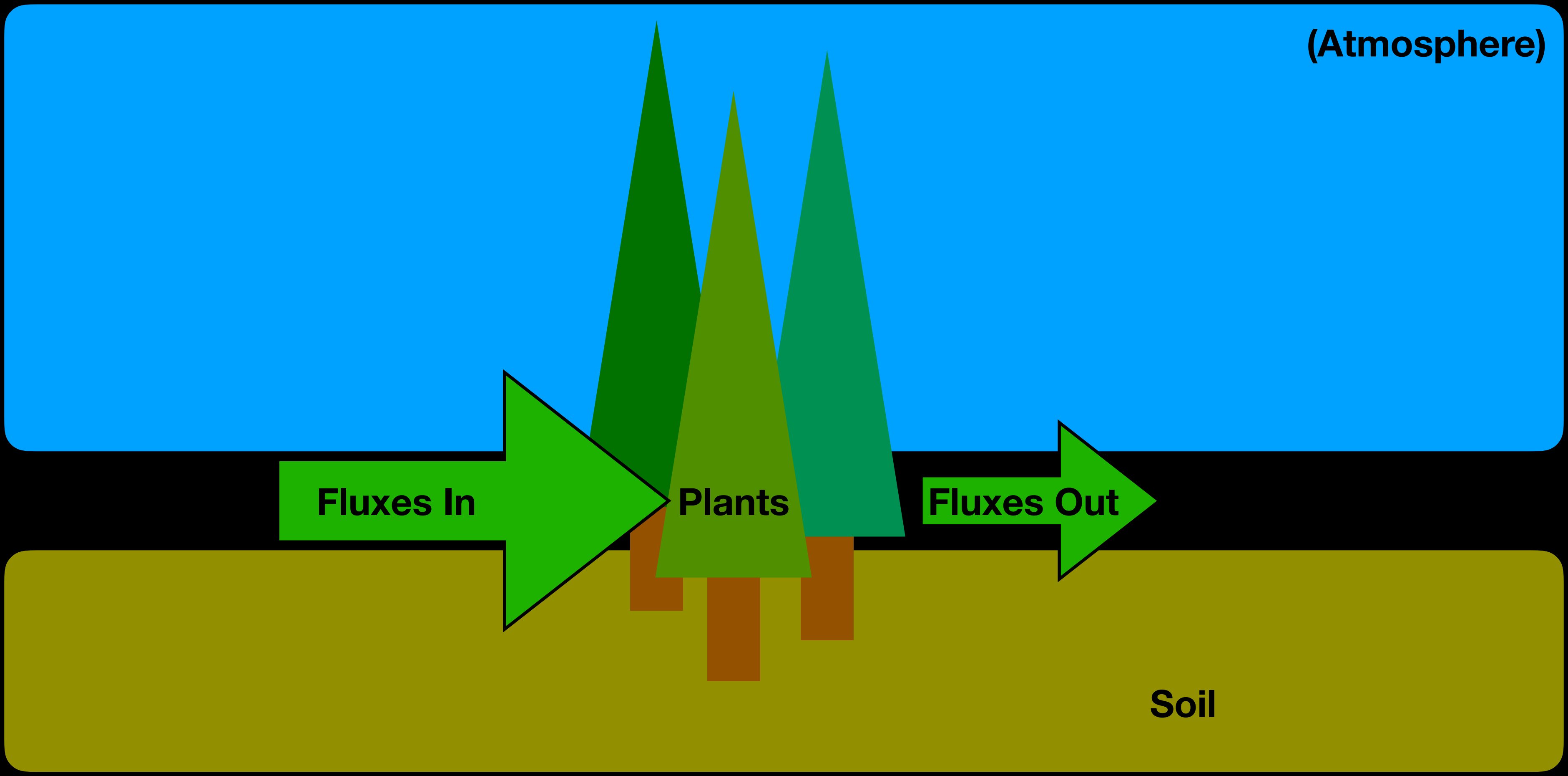
R. Fisher


2. Vegetation C Dynamics

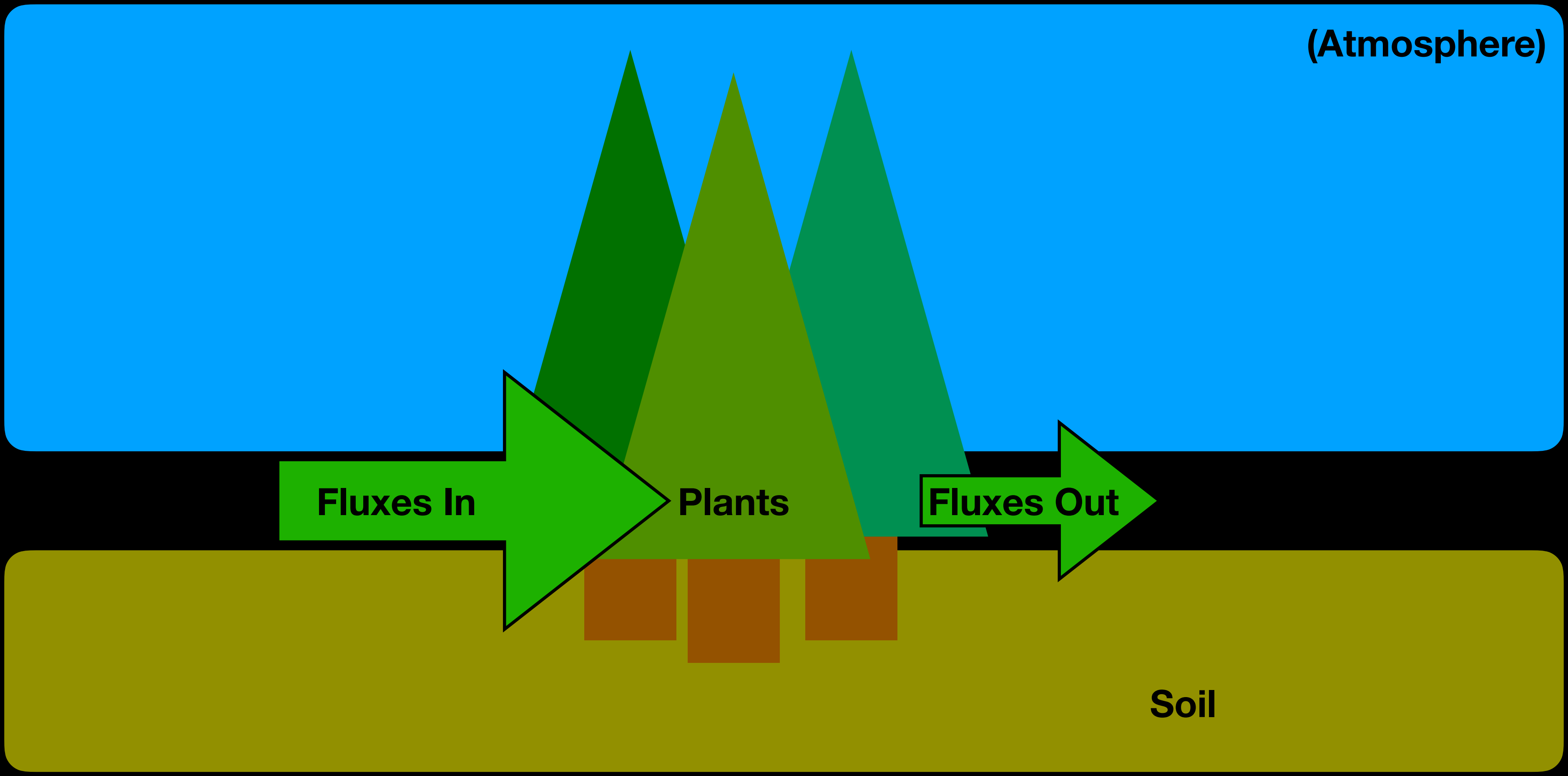
Terrestrial C and N Pools



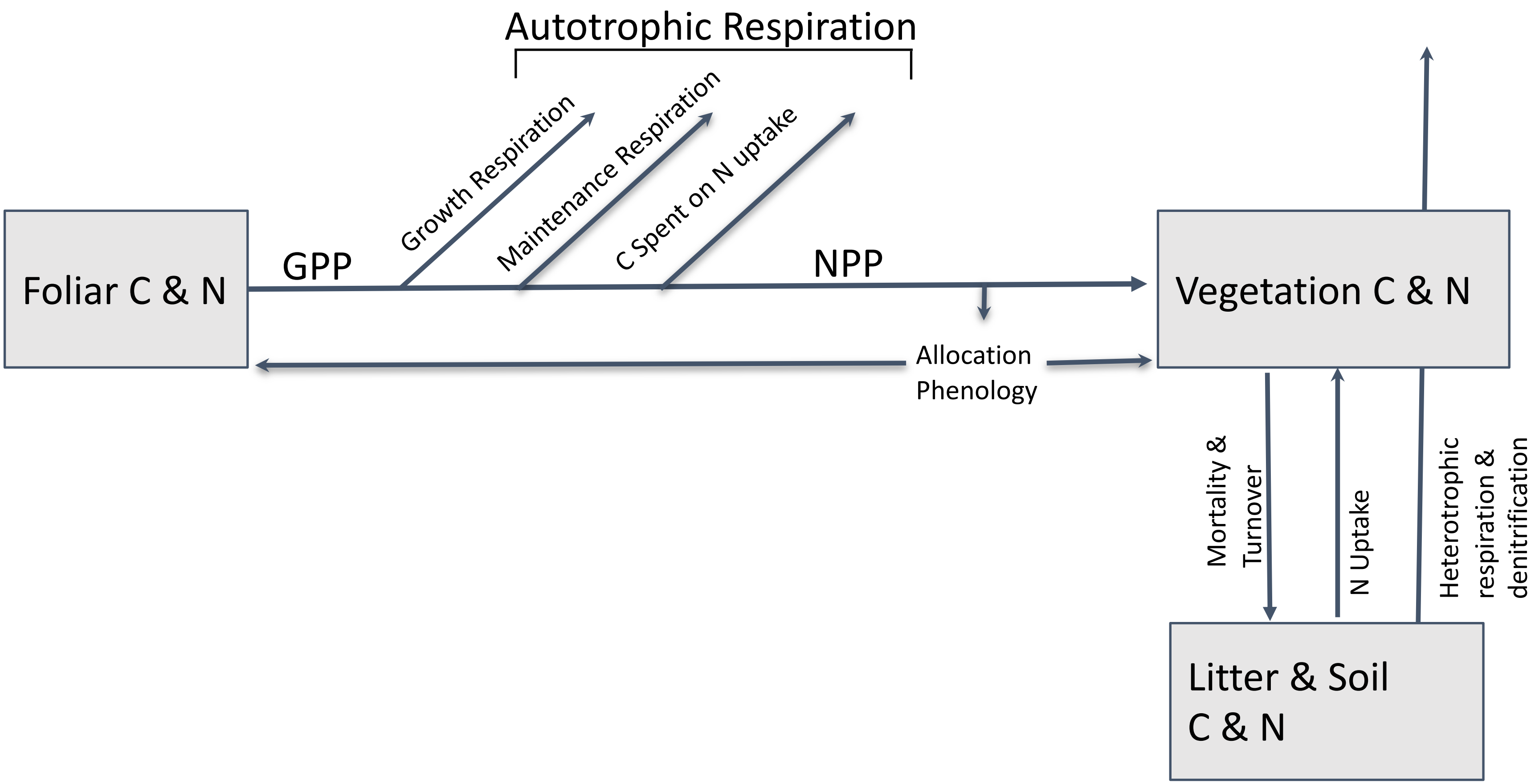
Terrestrial C and N Pools



Terrestrial C and N Pools

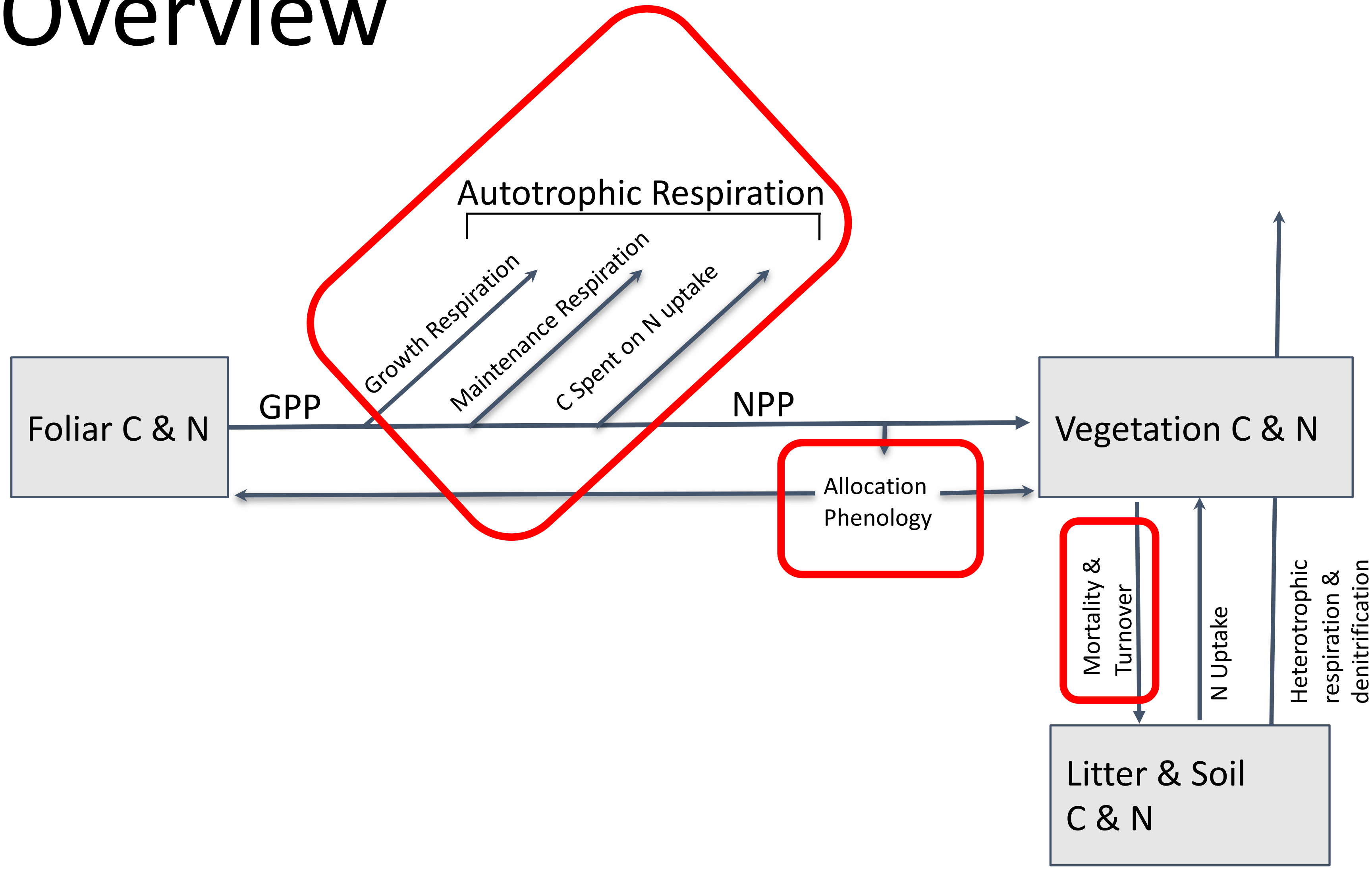


Overview



Autotrophic Respiration
Growth Respiration
Maintenance Respiration
C Spent on N uptake
Foliar C & N
GPP
NPP
Vegetation C & N
Allocation
Phenology
Mortality &
Turnover
N Uptake
Heterotrophic
respiration &
denitrification
Litter & Soil
C & N

Overview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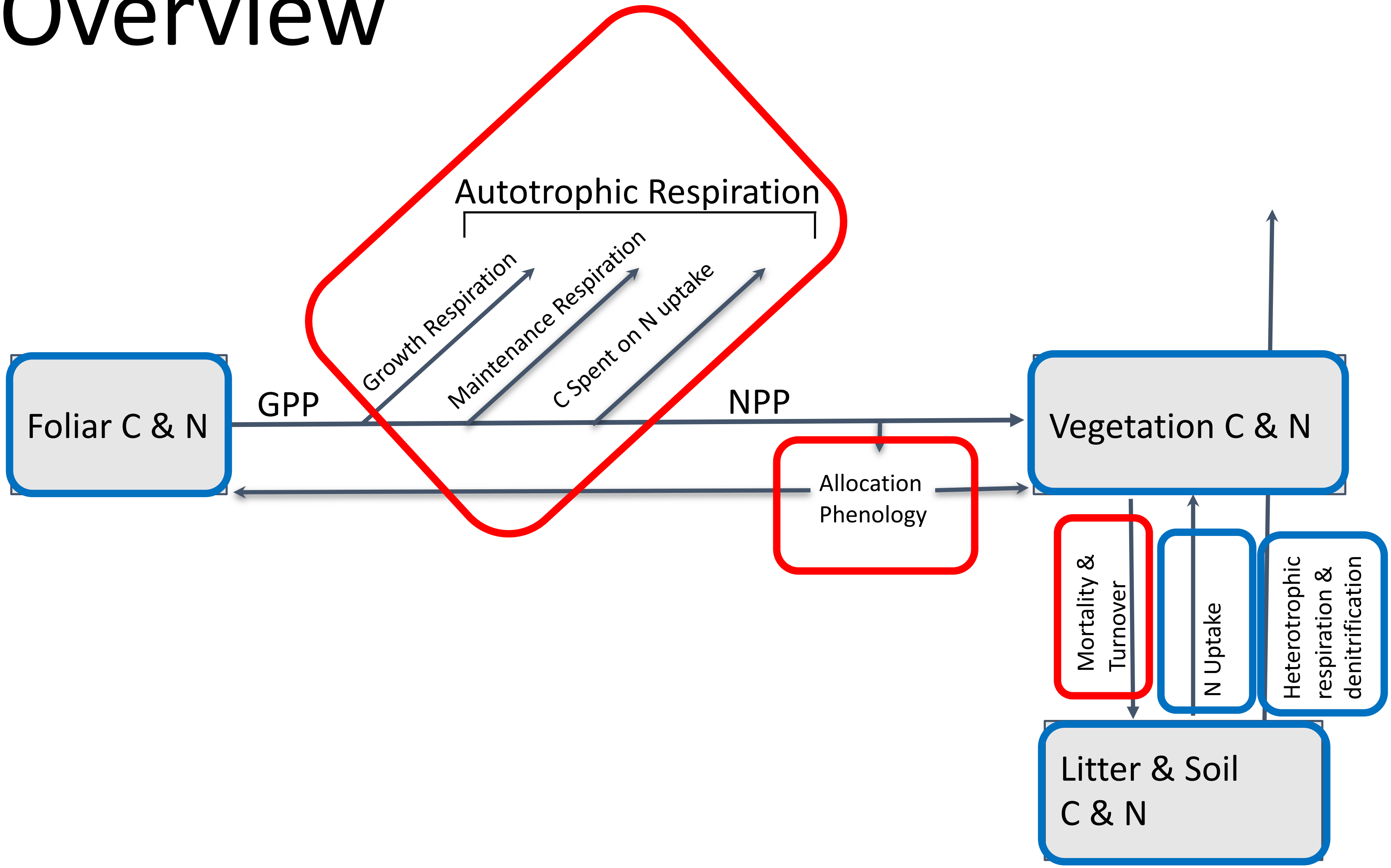
Overview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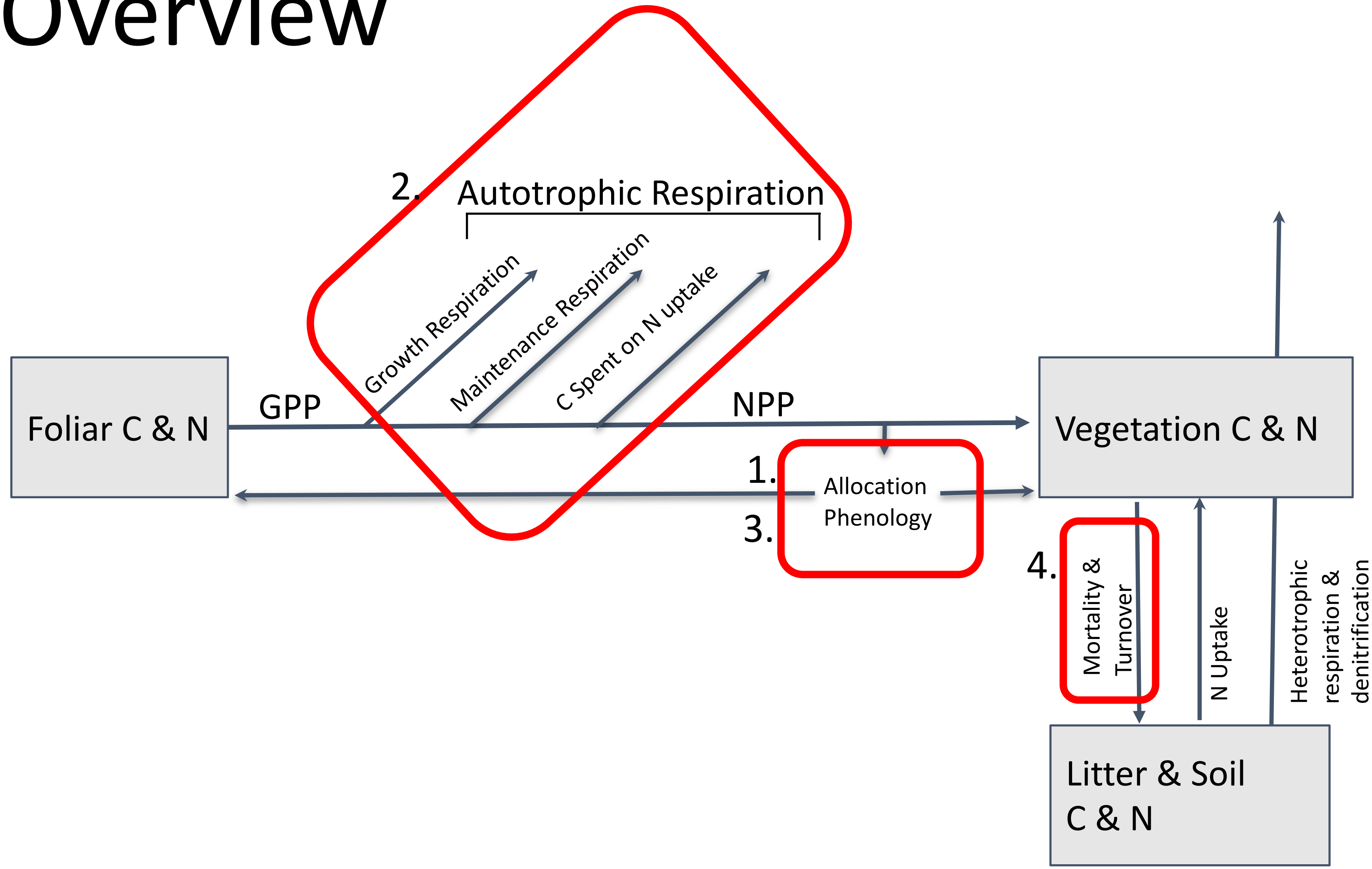
Overview



2.
Autotrophic Respiration
Growth Respiration
Maintenance Respiration
C Spent on N uptake
Foliar C & N
GPP
NPP
Vegetation C & N
1.
Allocation
Phenology
3.
4.
Mortality &
Turnover
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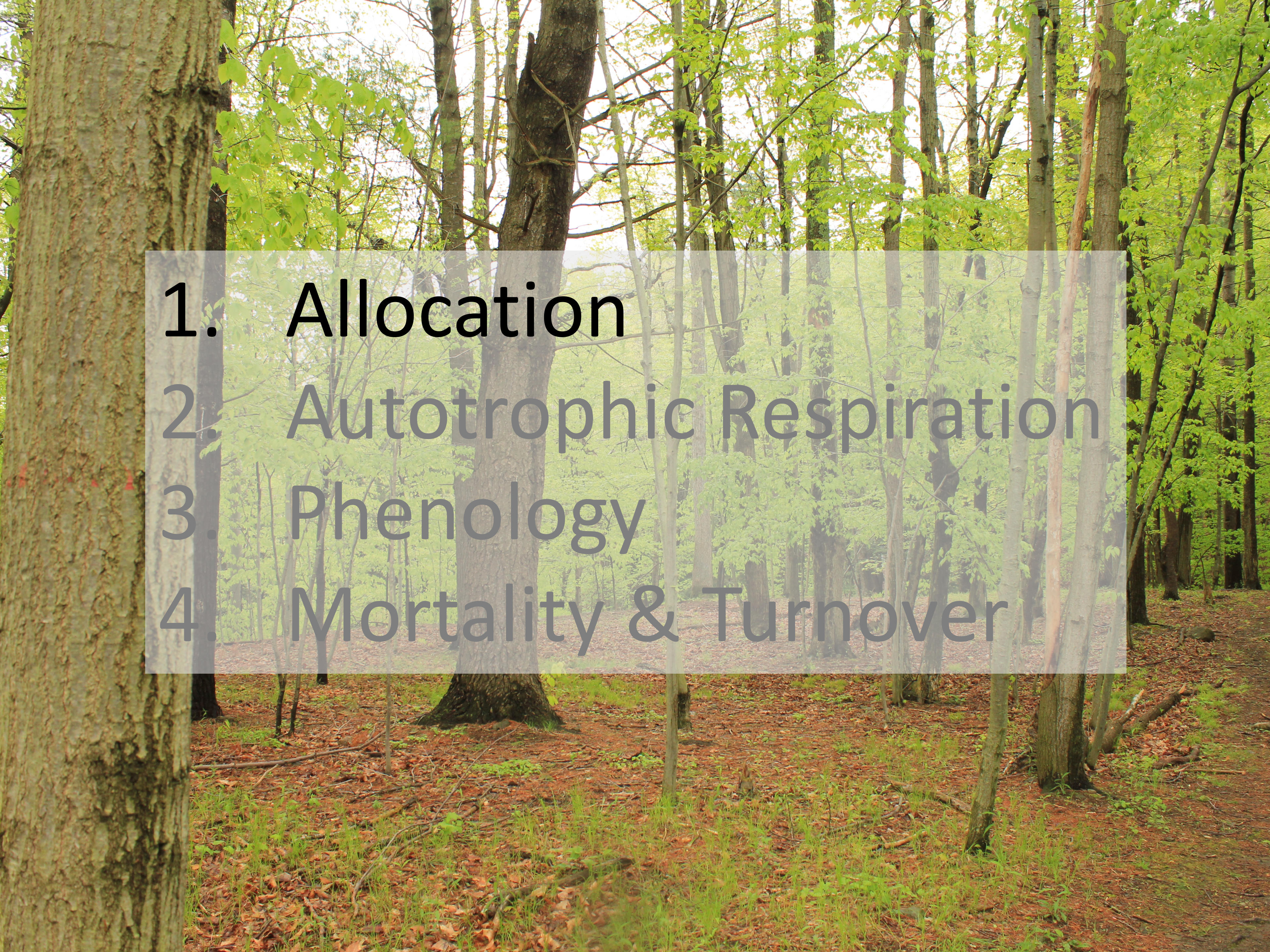

1. Allocation
2. Autotrophic Respiration
3. Phenology
4. Mortality & Turnover

Why does allocation 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 uptake -> more resources to grow (in FUN)
  - Nutrient uptake respiration -> more N uptake -> more resources to grow (in FUN)

RQ Thomas

Why does allocation matter?

- Allocation determines the **residence time of vegetation C**
  - 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 does allocation 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)

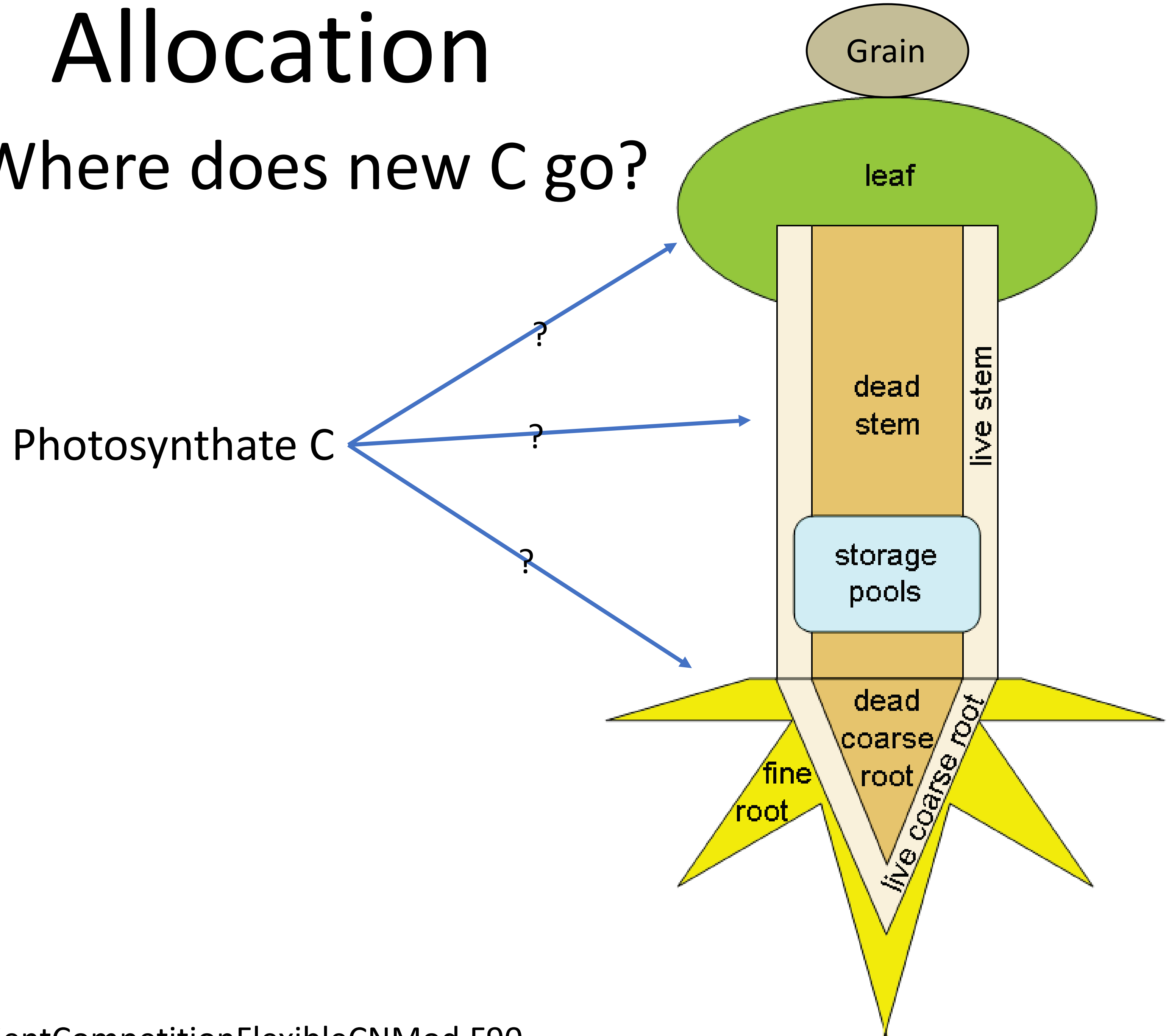
RQ Thomas

Why does allocation matter?

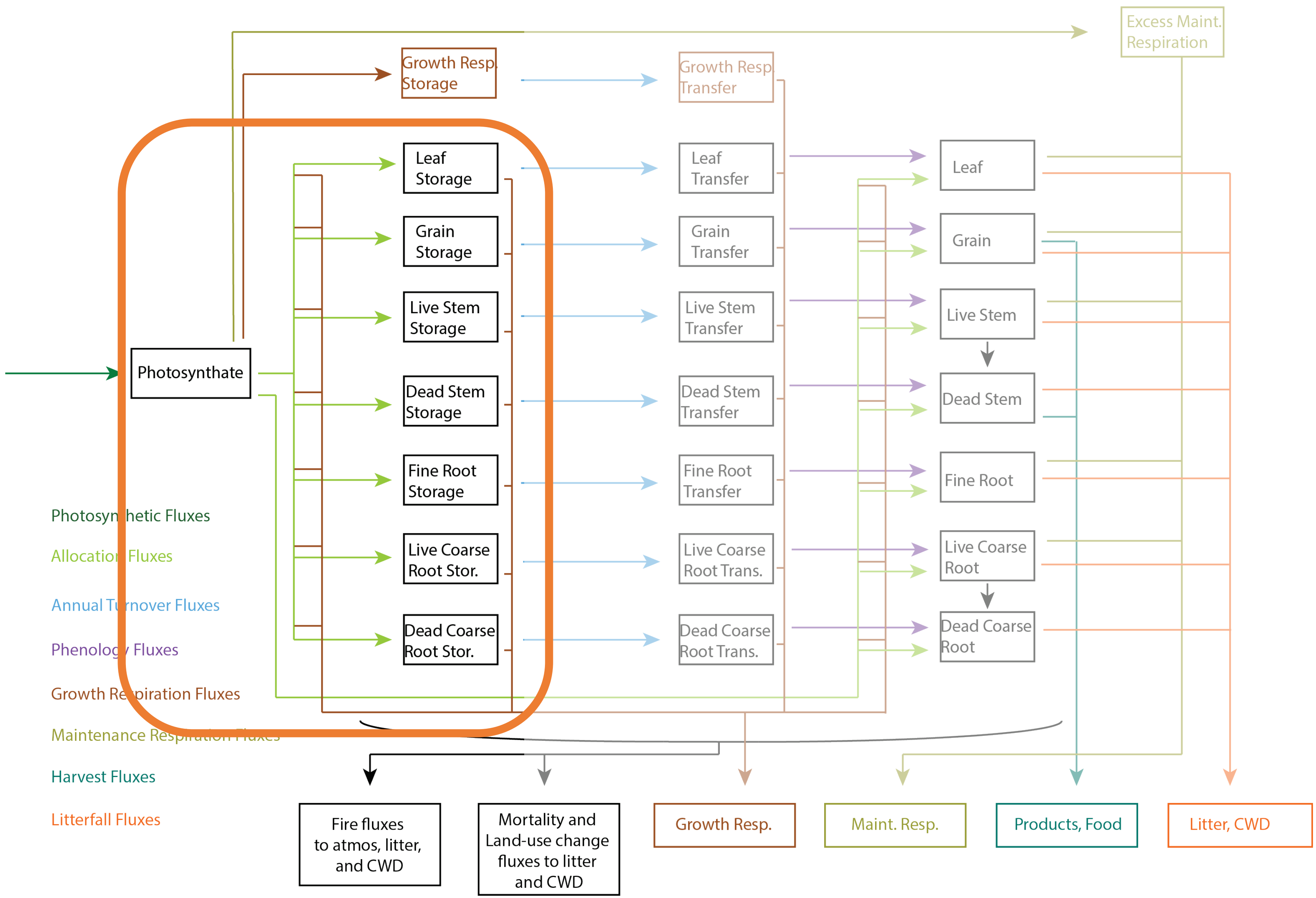
- Allocation influences **canopy conductance**
  - More leaf C -> More LAI -> canopy conductance
- Allocation influences **aerodynamic conductance**
  - More stem C -> taller plants -> increased roughness length -> increased aerodynamic conductance

Allocation

Where does new C go?



NutrientCompetitionFlexibleCNMod.F90


Excess Maint. Respiration
Growth Resp. Storage
Growth Resp. Transfer
Leaf Storage
Grain Storage
Live Stem Storage
Dead Stem Storage
Fine Root Storage
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Grain
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Photosynthate
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

Note that the values of these ratios vary by PFT and are defined in the parameter file

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

RQ Thomas

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

Note that the values of these ratios vary by PFT and are defined in the parameter file

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

RQ Thomas

How do you expect allocation to differ in these PFTs?

Evergreen needleleaf tree

Deciduous tree

Shrub

C4 grass

C3 grass

Wheat

Corn

f1 = fine root: leaf

f2 = coarse root : stem

f3 = stem : leaf

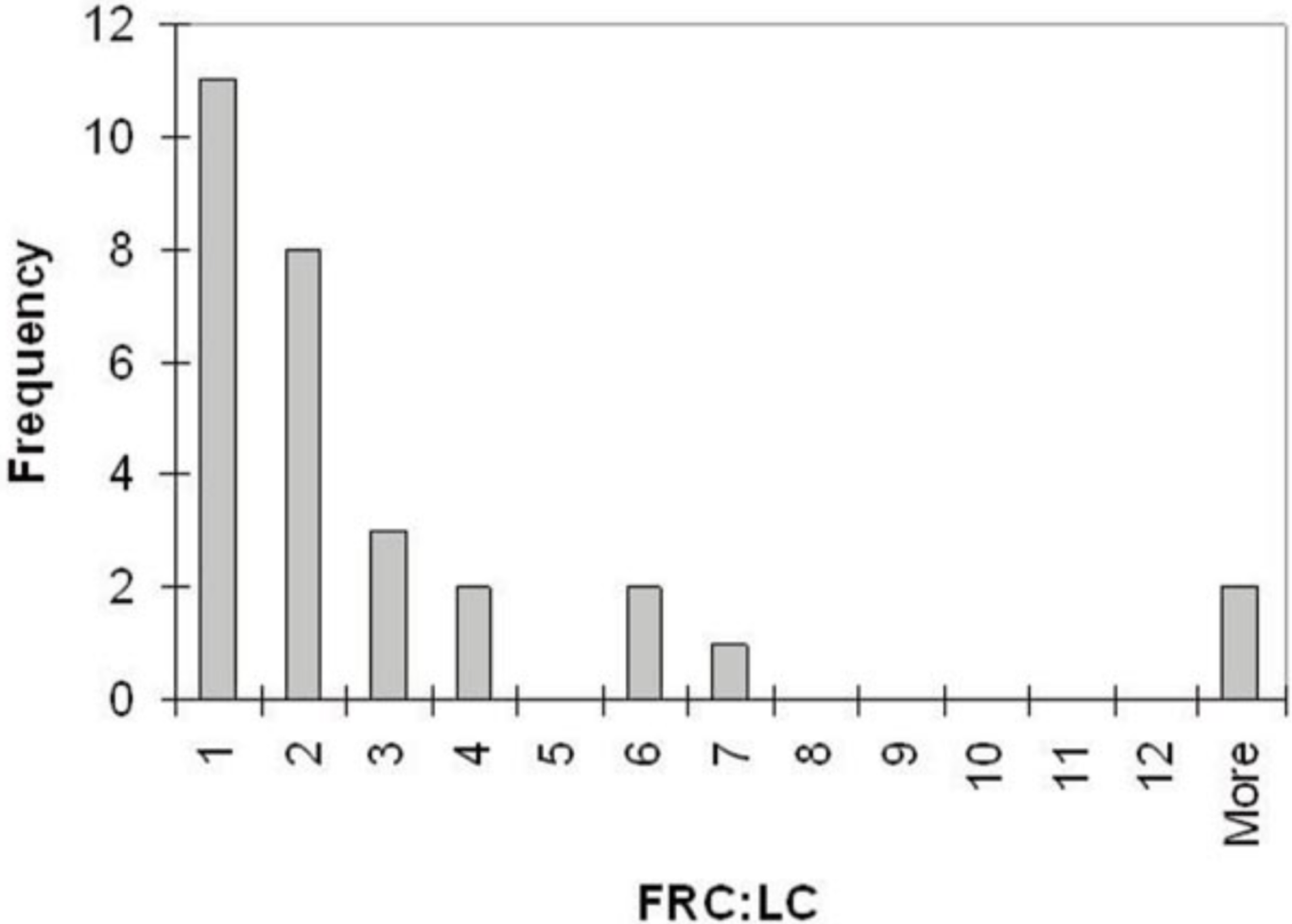
f4 = live wood : total wood

f5 = grain : leaf

g1 = growth respiration: total allocation

RQ Thomas

What might control this variation?

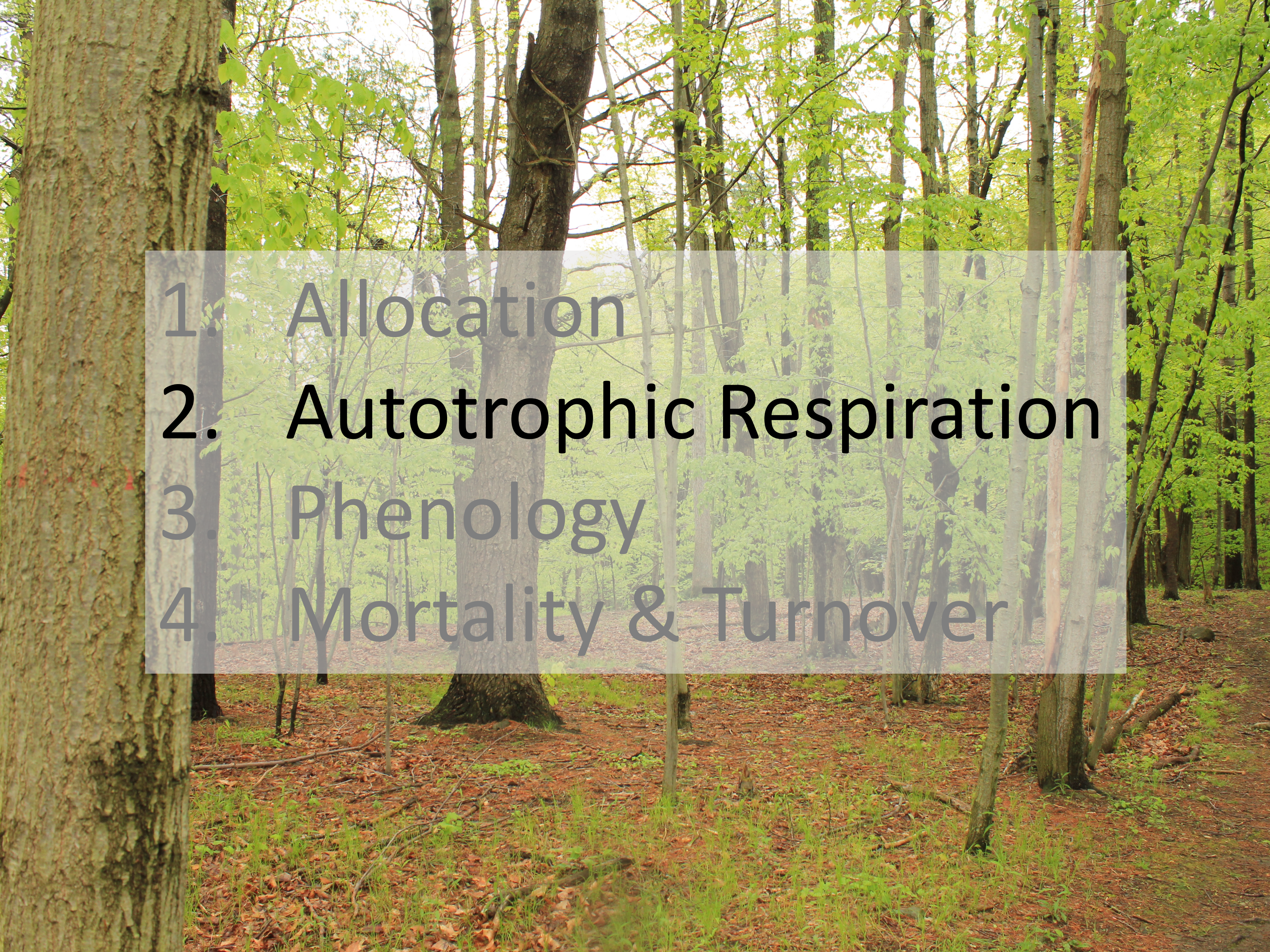


(fine root carbon : leaf carbon)

White et al. 2000

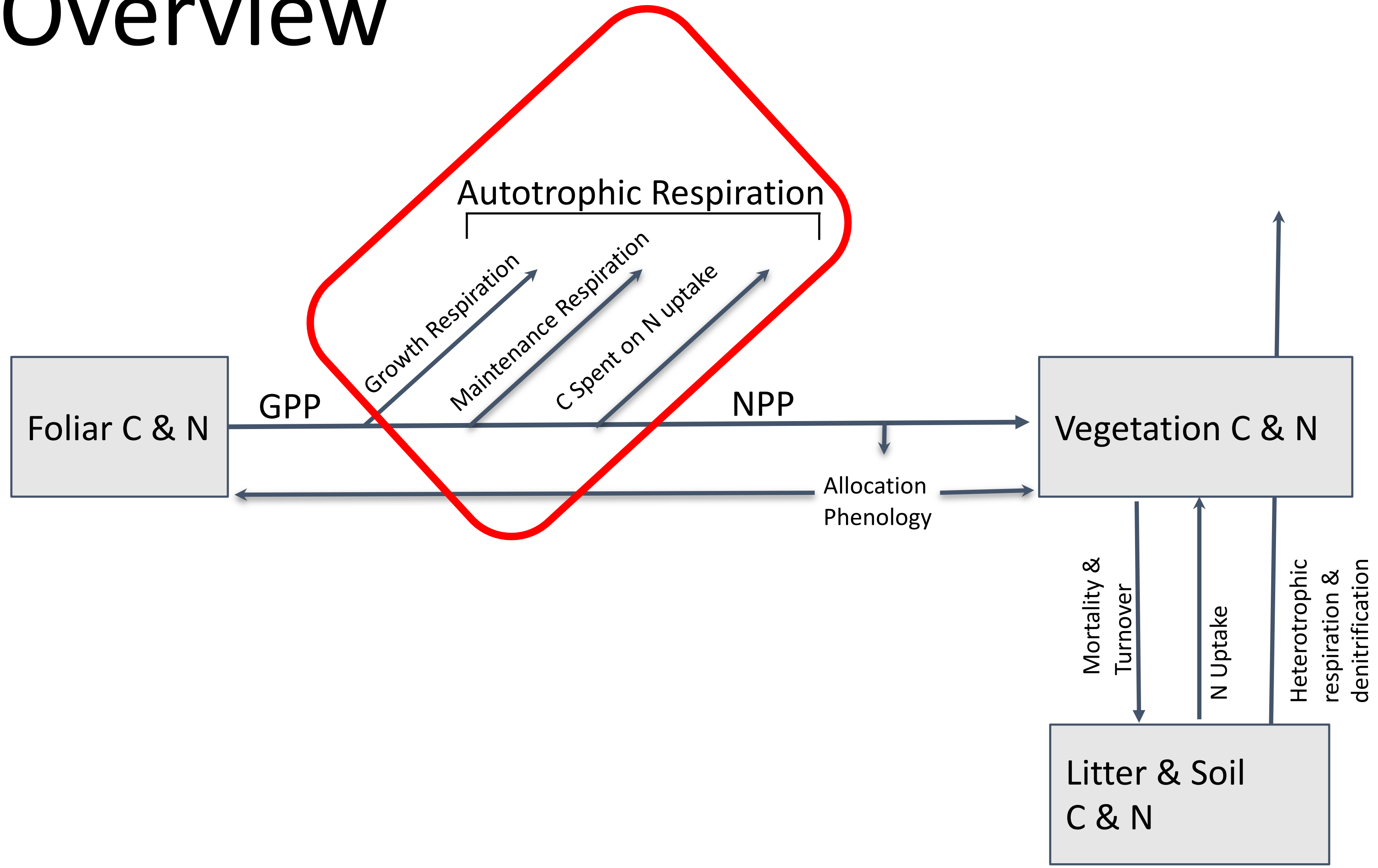
What might control this variation?

- 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)



1. Allocation
2. **Autotrophic Respiration**
3. Phenology
4. Mortality & Turnover

Overview



Autotrophic Respiration
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Maintenance Respiration
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Heterotrophic
respiration &
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Litter & Soil
C & N

Autotrophic Respiration (R_a)

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

Autotrophic Respiration (R_a)

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

Growth respiration

Additional C cost of the synthesis of new growth

R_{growth}^{*} = **grperc***(total C allocated to new growth)

↑

Currently set to 0.11 in the CLM parameter file, but value is uncertain

CNGresp.F90

Note: text in red denotes variable names found in the code

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

Autotrophic Respiration (R_a)

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

Maintenance respiration (tissue_mr)

Additional C cost to support metabolic activity of maintaining existing tissue

Total = leaf + fine root + live stem + live coarse root (+ grain)

(note that dead wood pools are not included)

↑ Only for crops

Respiration increases with nitrogen and temperature

CNMRespMod.F90

Maintenance respiration (tissue_mr)

Additional C cost to support metabolic activity of maintaining existing tissue

Total = leaf + fine root + live stem + live coarse root (+ grain)

$$MR_{tissue} = N_{tissue} * br\_mr * q10\_mr * ((T_{2m} - 20)/10)$$

N_{tissue}: gN/m^2 of the tissue

T_{2m}: 2-meter air temperature

br_mr (base rate for MR) = $2.525 * 10^{-6}$ gC gN^{-1} s^{-1}

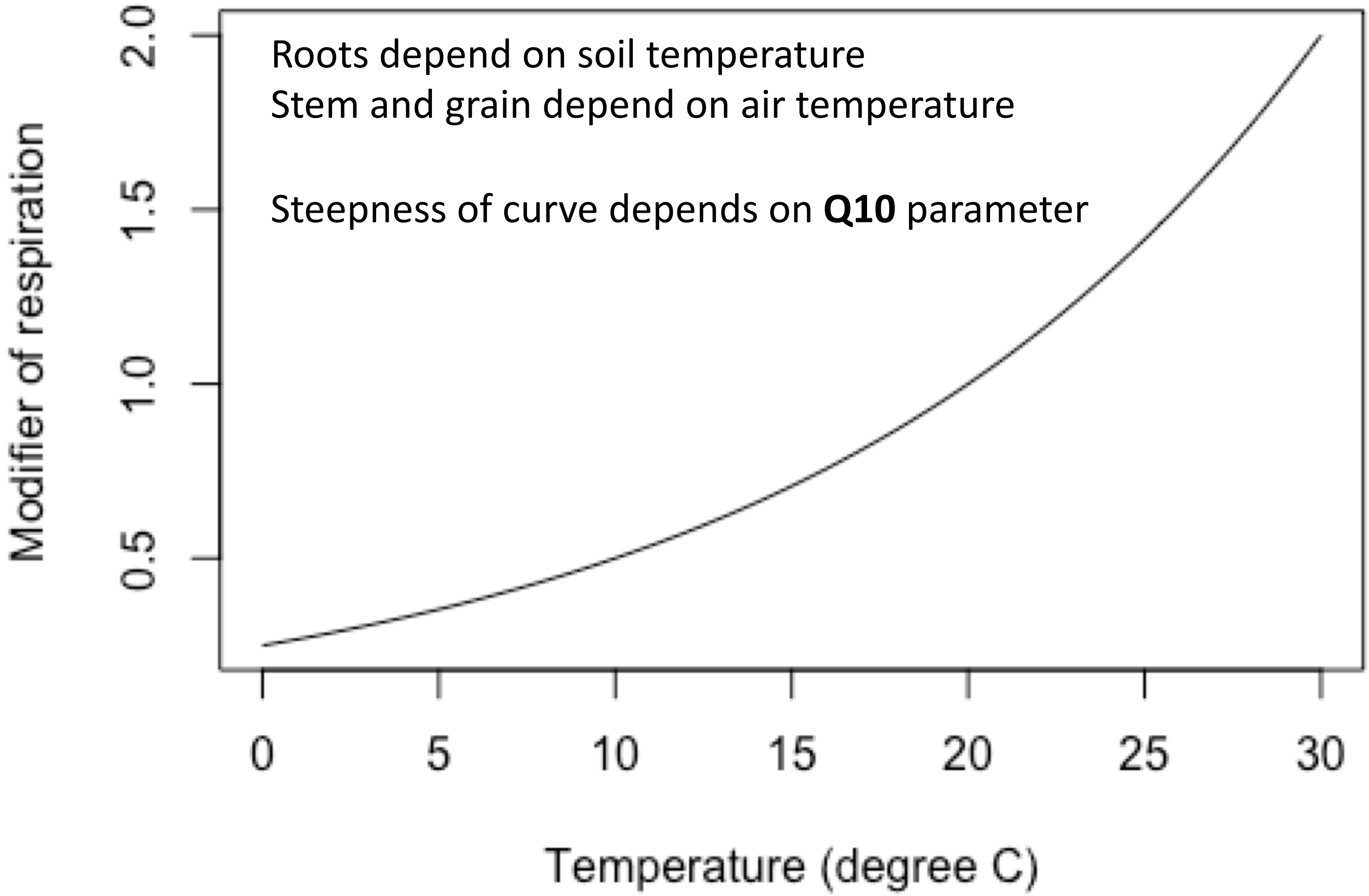
q10_mr (MR temperature dependence) = 1.5 (unitless)

Respiration increases with nitrogen and temperature

Note: text in red denotes variable names found in the code

CNMRespMod.F90

Climate sensitivity



Maintenance respiration (tissue_mr)

Additional C cost to support metabolic activity of maintaining existing tissue

Total = leaf + fine root + live stem + live coarse root (+ grain)

Respiration increases with nitrogen and temperature

Leaf maintenance respiration (lmr25top)

Note that after lmr25top is calculated, it is scaled for sunlit and shaded canopy fractions

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

PFT level parameter (lmr_intercept_atkin)

Leaf N per leaf area (lnc)

10 day running mean (Acclimation) (t10)

Also see *Lombardozzi et al. 2015* for additional details on acclimation

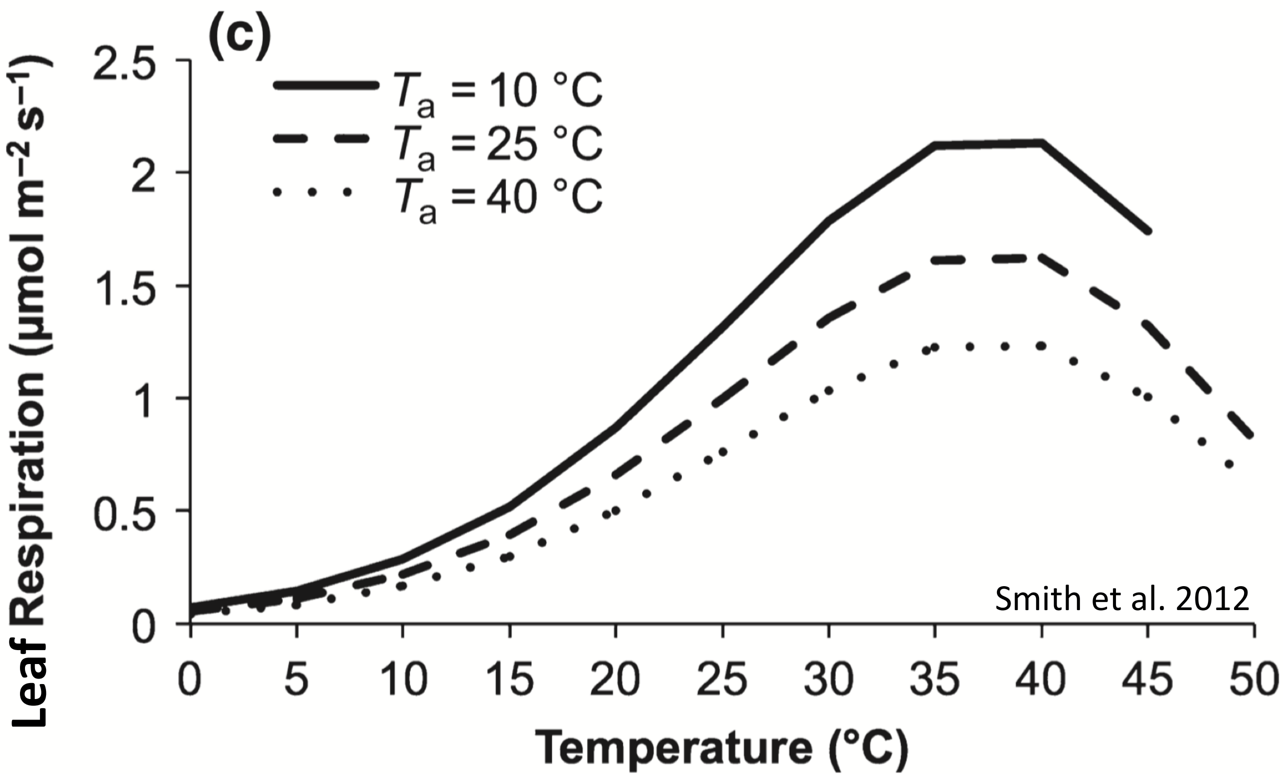
PhotosynthesisMod.F90

Leaf maintenance respiration (lmr25top)

Note that after lmr25top is calculated, it is scaled for sunlit and shaded canopy fractions

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

- lmr_intercept_atkin: PFT level parameter
- lnc: Leaf N per leaf area
- t10: 10 day running mean (Acclimation)



Also see *Lombardozzi et al. 2015* for additional details on acclimation

Autotrophic Respiration (R_a)

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

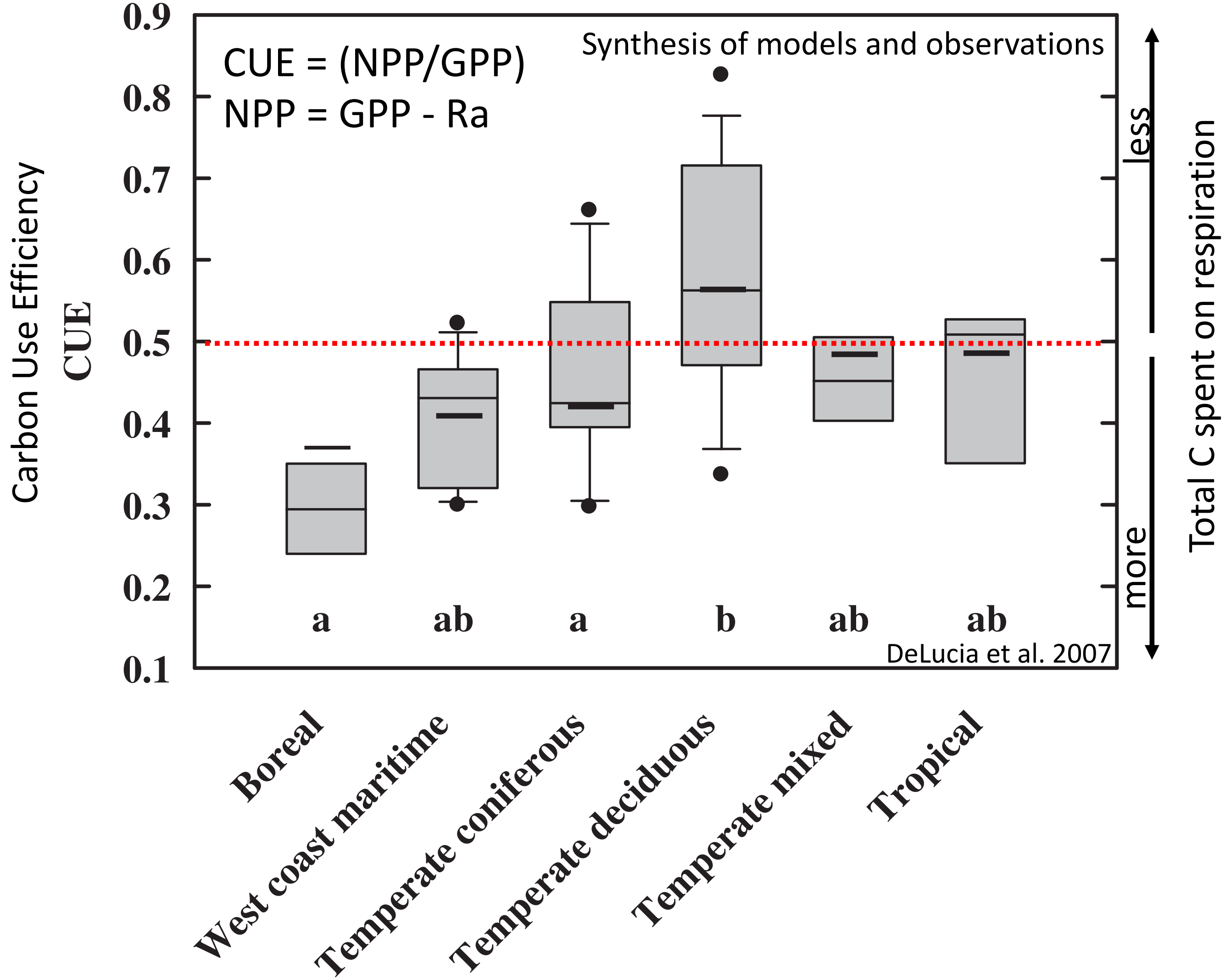
Respiration for nutrient acquisition
(Fixation and Uptake of Nitrogen)

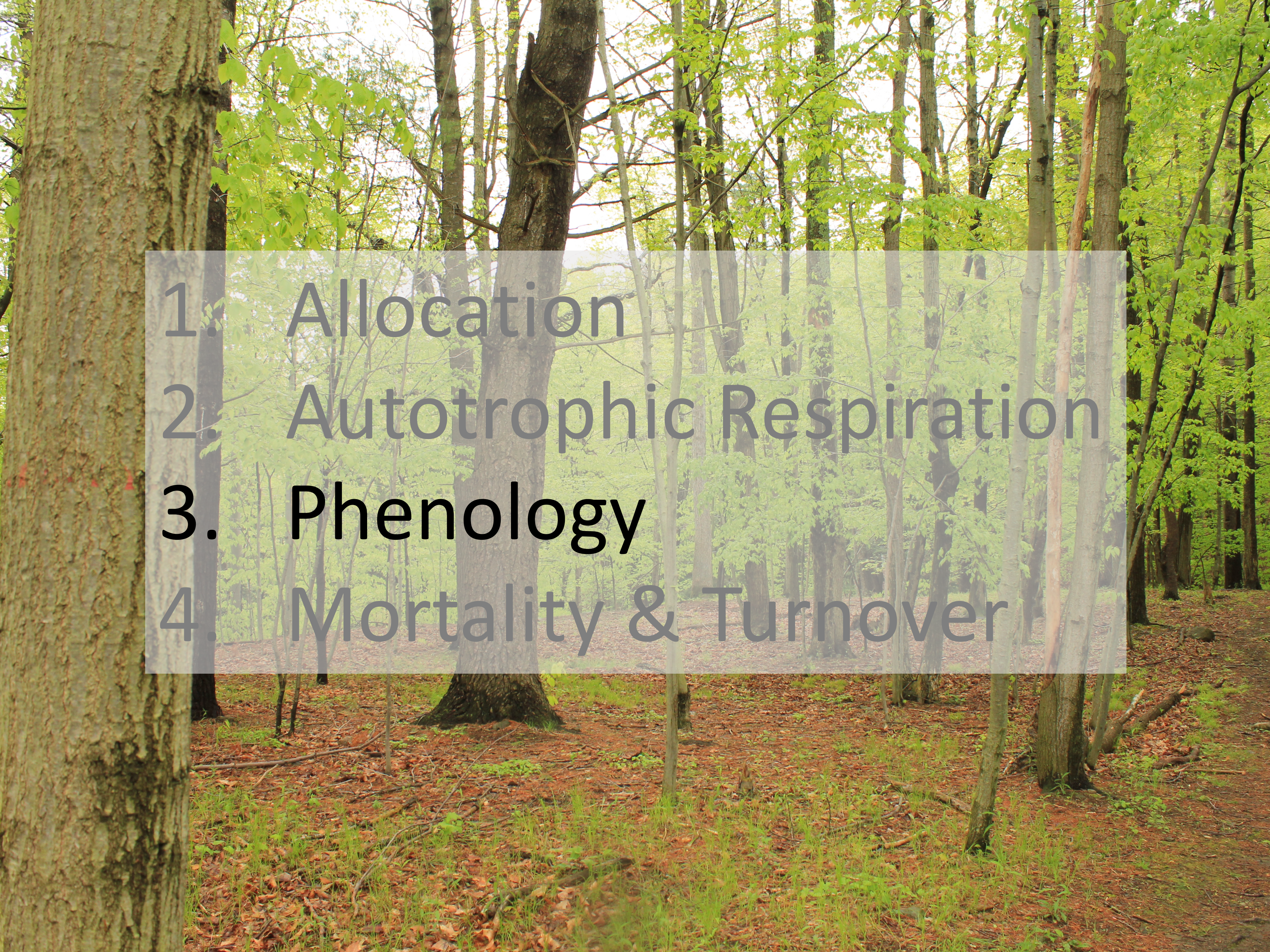
Respiration for Nutrient Acquisition

Calculated in
CNFUNMod.F90
(see Will's talk)

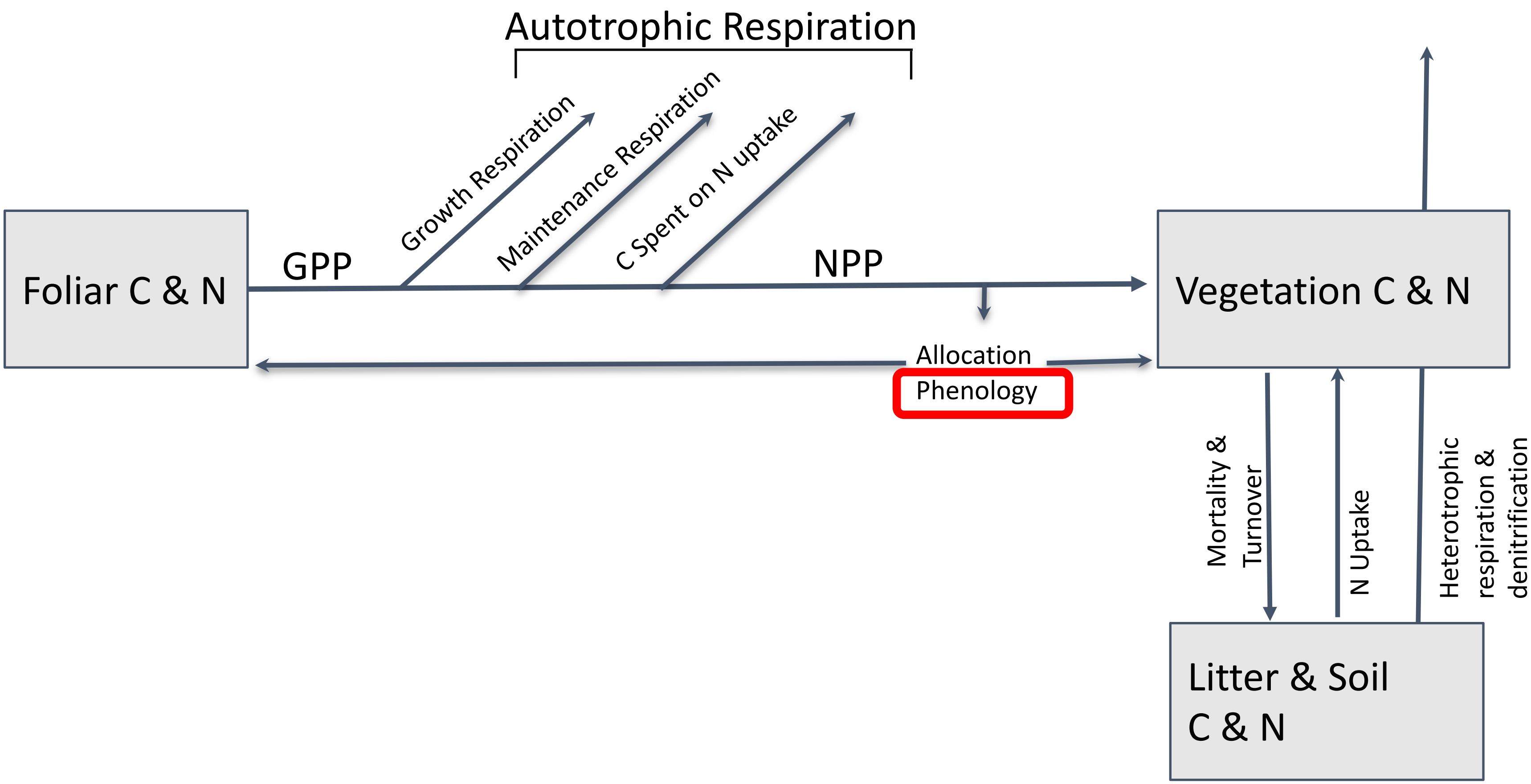
No free lunch
(if lunch is nitrogen)

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




1. Allocation
2. Autotrophic Respiration
3. Phenology
4. Mortality & Turnover

Overview


Autotrophic Respiration
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Phenology
Mortality & Turnover
N Uptake
Heterotrophic respiration & denitrification
Litter & Soil C & N

Phenology

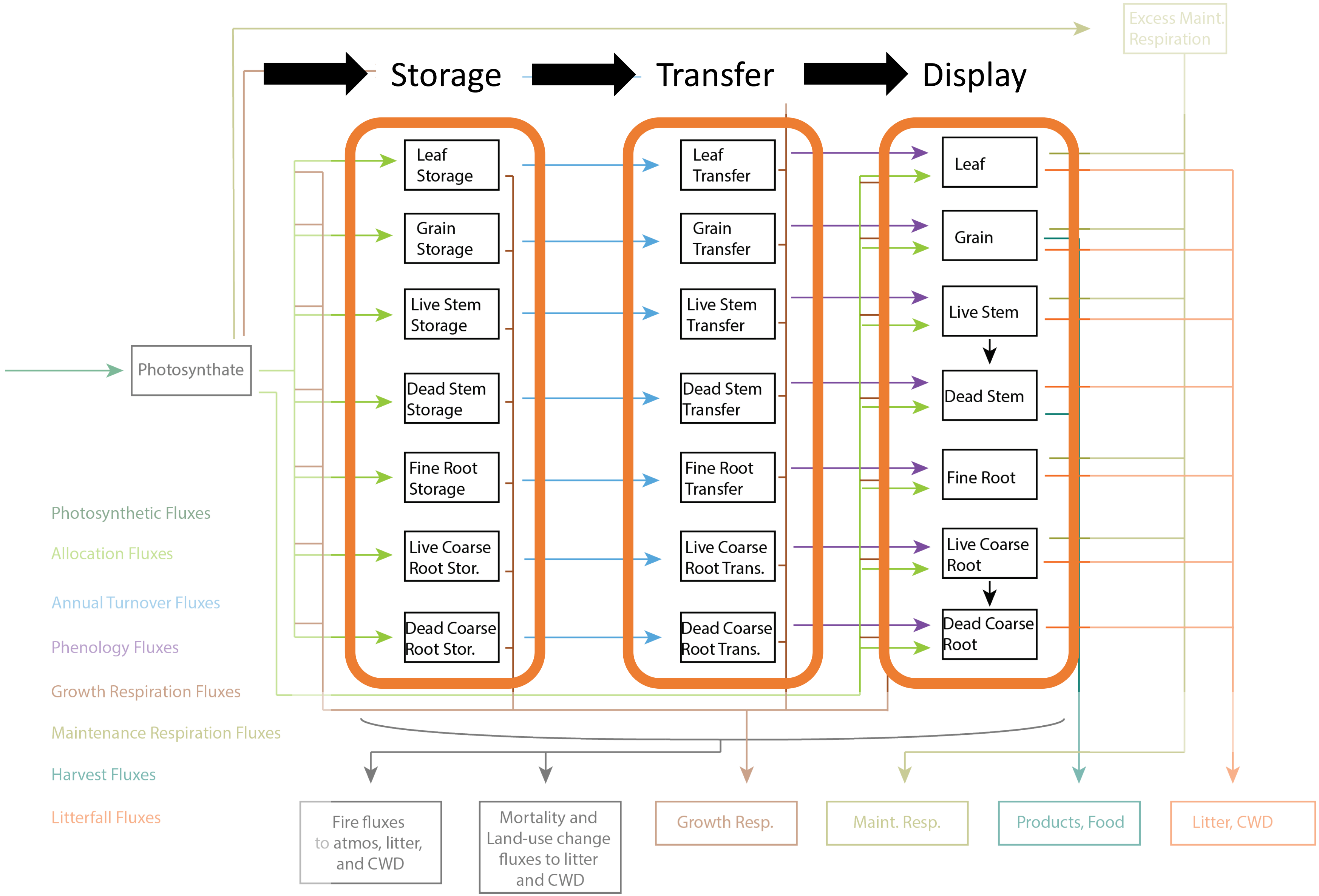
The cycling of seasonal biological events

Natural vegetation is separated into three phenological classes:

- Evergreen
- Seasonal deciduous
- Stress deciduous

In CLM, phenology is represented as the fluxes of C and N between storage pools and displayed pools, triggered by daylength, temperature, and/or soil moisture.

CNPhenologyMod.F90



Excess Maint. Respiration
Storage
Transfer
Display
Leaf Storage
Grain Storage
Live Stem Storage
Dead Stem Storage
Fine Root Storage
Live Coarse Root Stor.
Dead Coarse Root Stor.
Leaf Transfer
Grain Transfer
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Live Coarse Root Trans.
Dead Coarse Root Trans.
Leaf
Grain
Live Stem
Dead Stem
Fine Root
Live Coarse Root
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Photosynthate
Photosynthetic Fluxes
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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

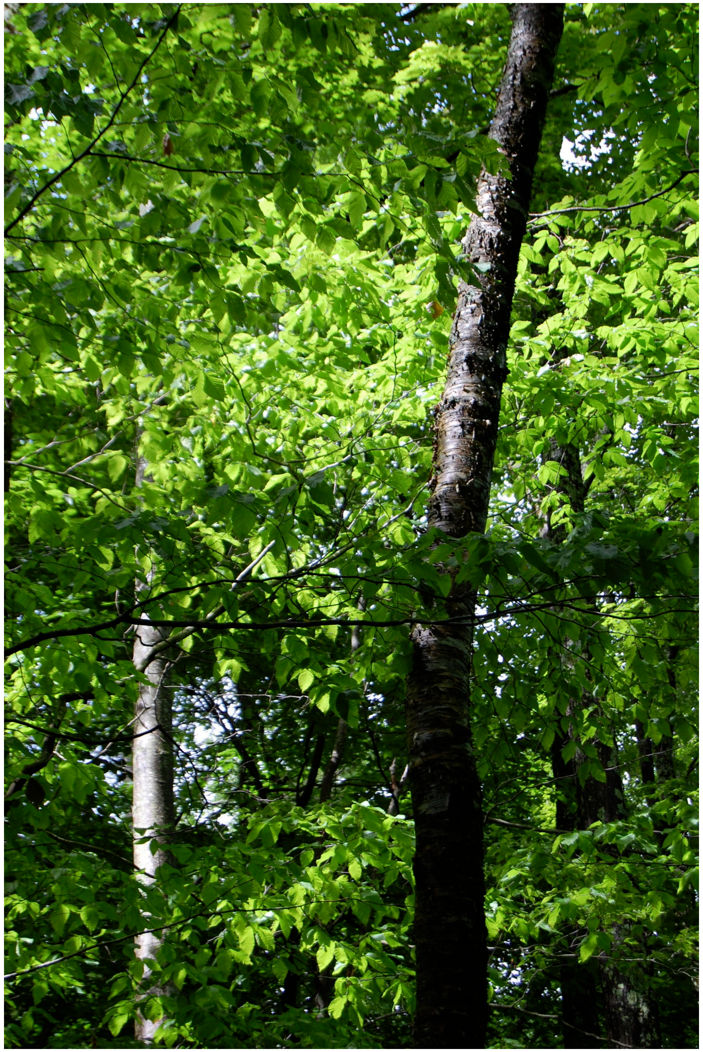
Evergreen Phenology

All C and N allocated for new growth goes immediately to the displayed growth pool

Leaf and fine root turnover occurs throughout year at background rates

PFT parameter **leaf_long** determines leaf turnover rates

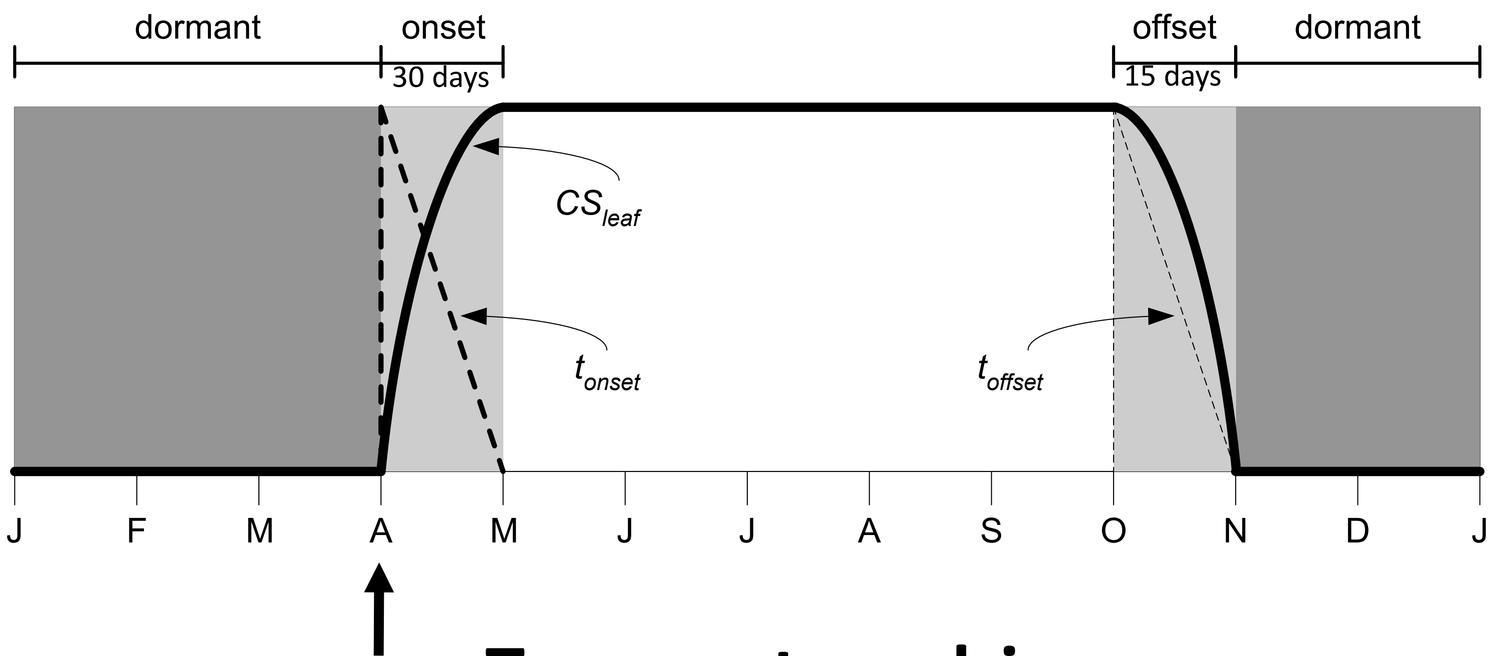
Seasonal Deciduous



Leaf onset and senescence are triggered by temperature and light

Seasonal Deciduous

Number of onset and offset days are parameters



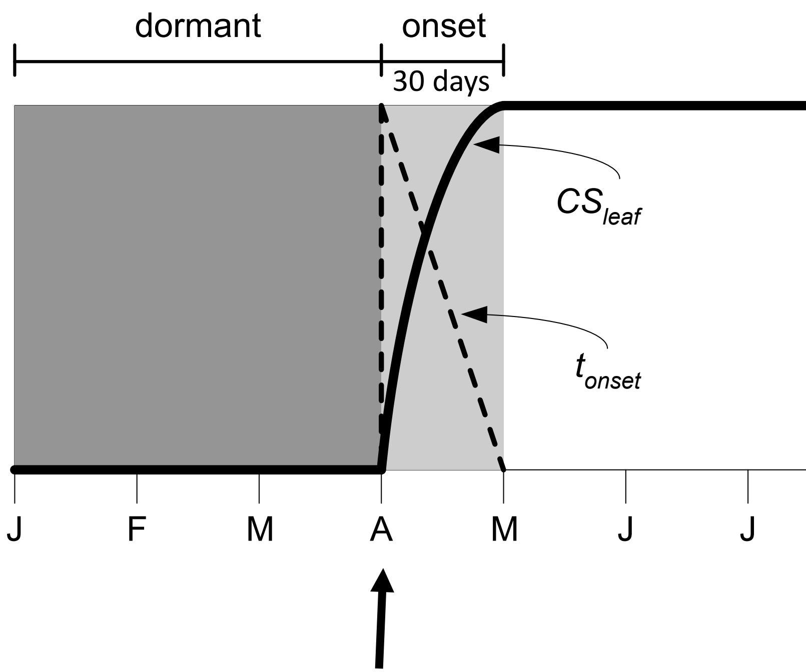
Temperature driven

Growing degree day > crit_onset_gdd

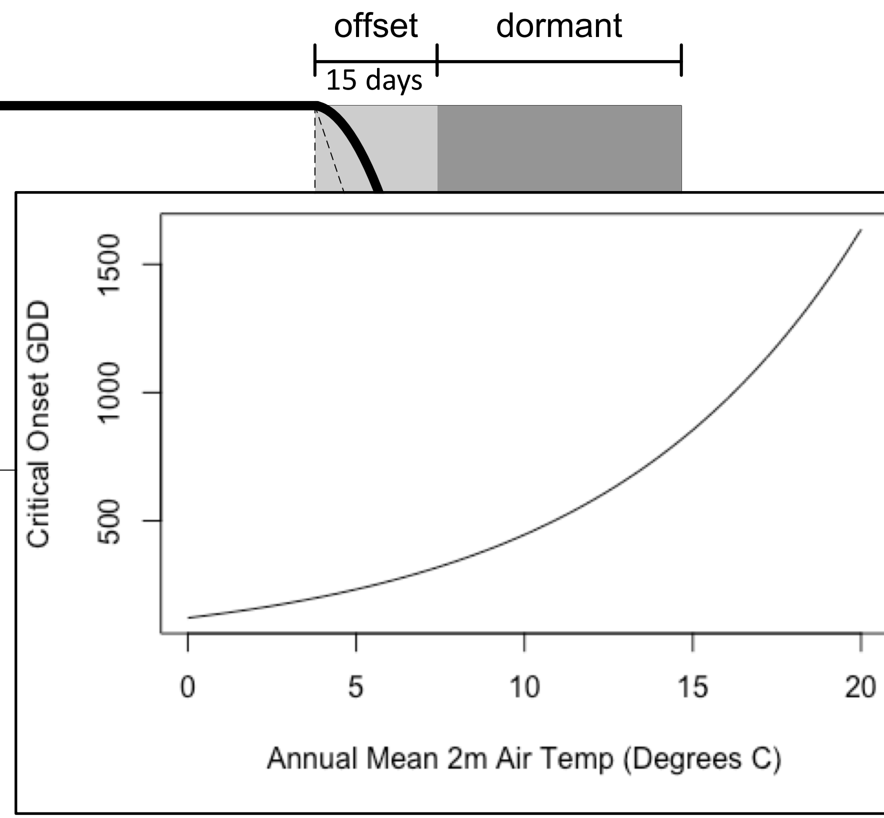
Growing degree = sum of daily soil temperatures greater than zero

Seasonal Deciduous

Number of onset and offset days are parameters



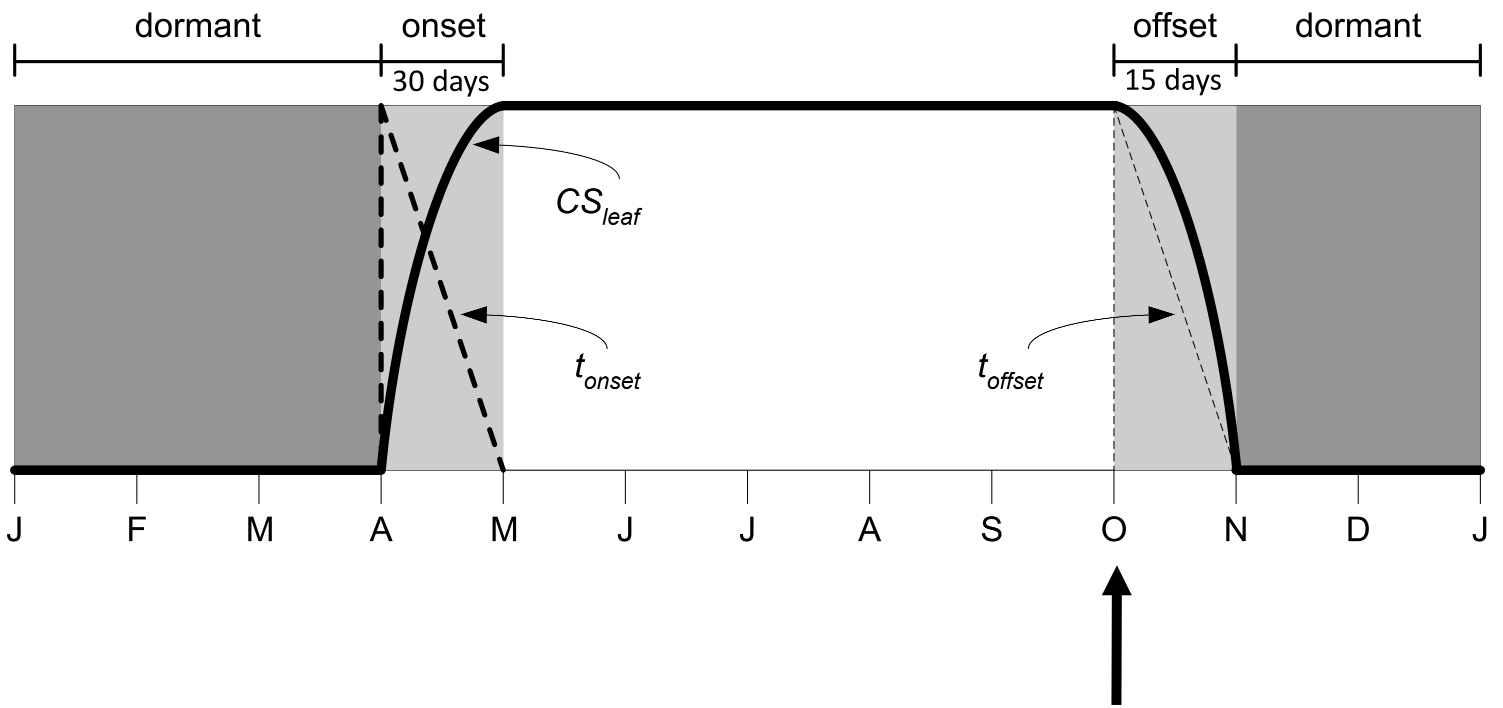
Growing degree day > crit_onset_gdd



Warmer locations require more GDD to start growing leaves

Seasonal Deciduous

Number of onset and offset days are parameters



Day length driven

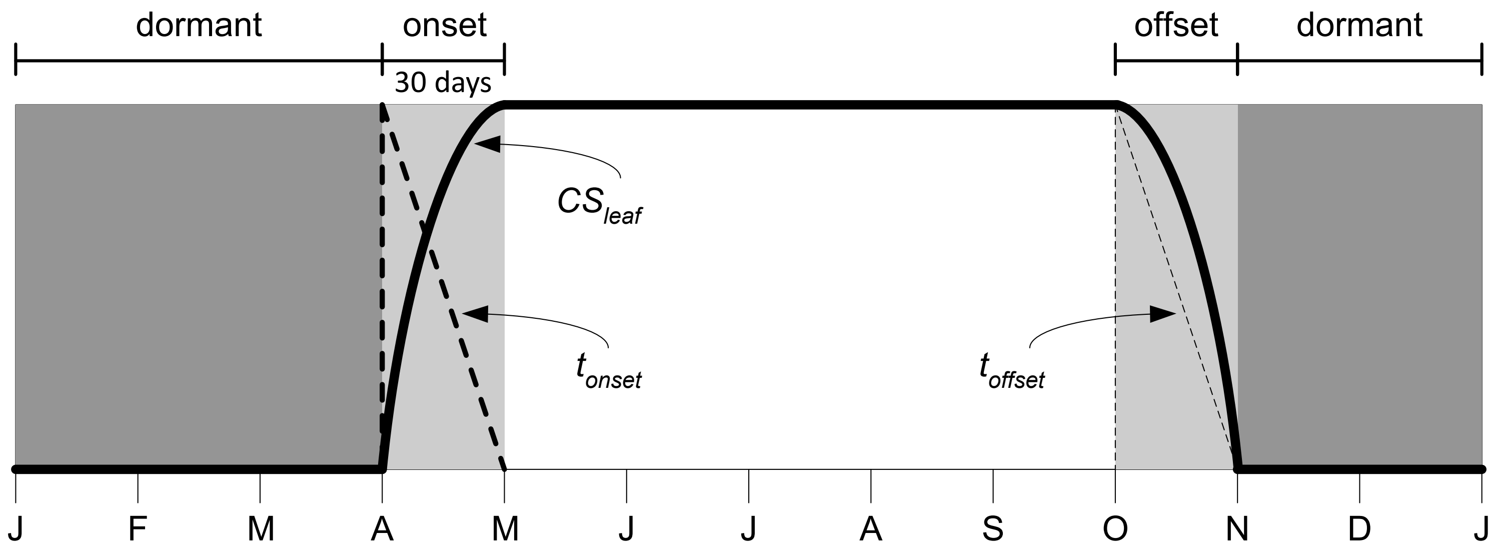
Day length < crit_dayl

crit_dayl a parameter shared across PFTs

Stress Deciduous

Temperature and drought stress can cause multiple growing seasons per year

Stress Deciduous



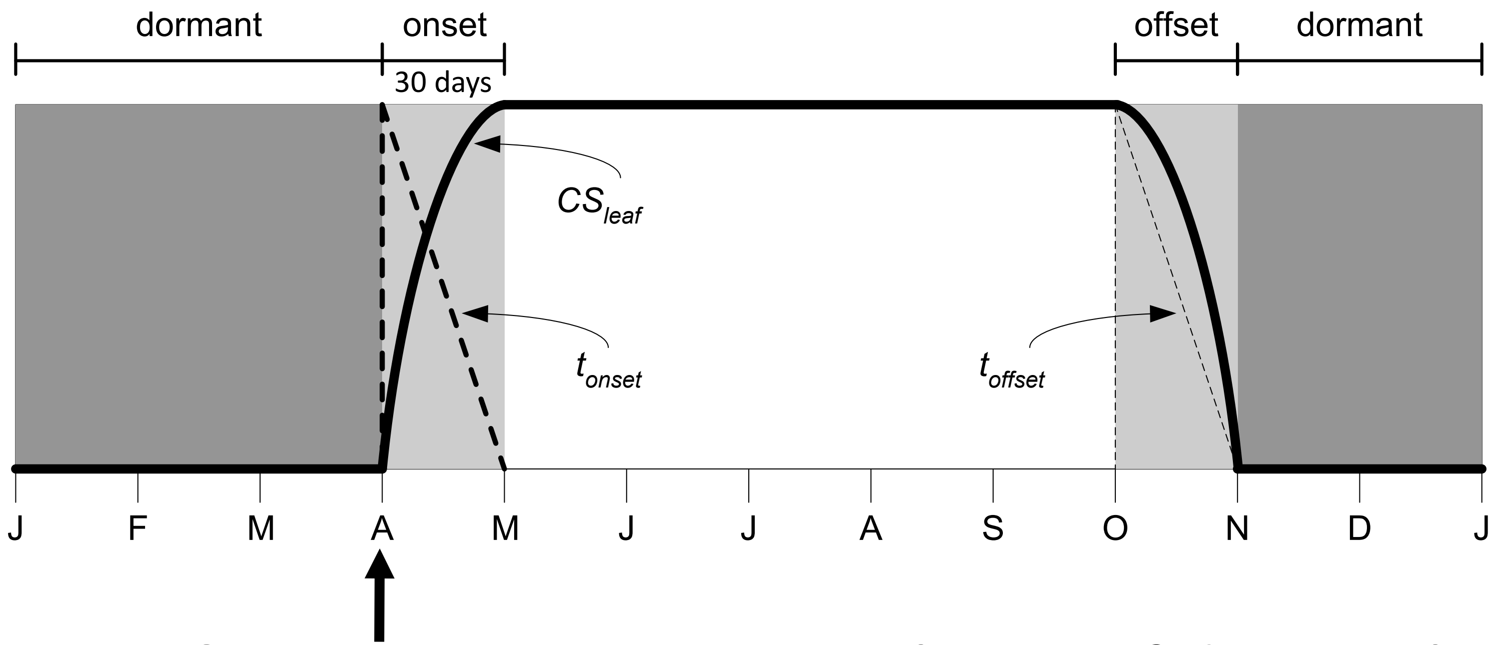
Soil water availability

Temperature

Precipitation

Day length

Stress Deciduous



In warm climates, onset occurs when # of days with soil water potential is above a specified value:

soilpsi_on > crit_onset_swi

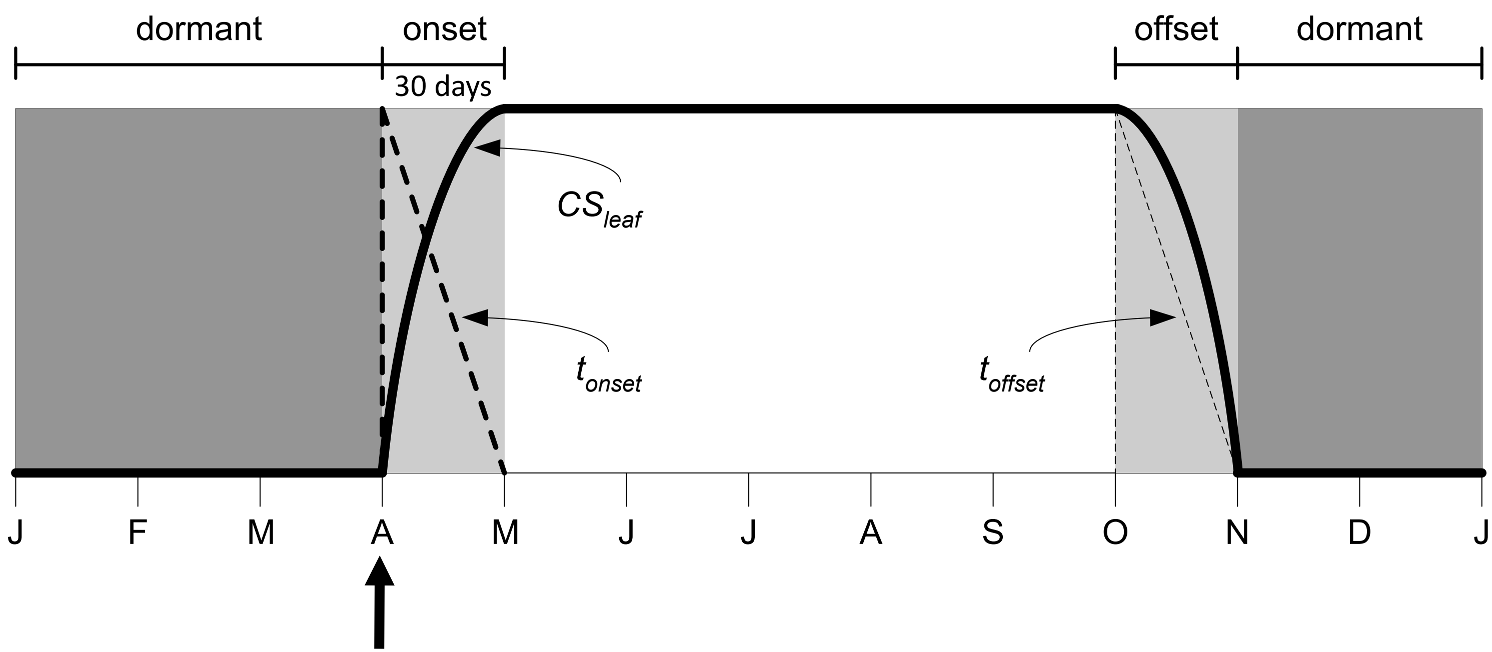
Other requirements that must be met:

Precipitation: 10 day precipitation > rain_threshold (20 mm)

Daylength: daylight > 6h

Dahlin et al. 2015

Stress Deciduous



In climates with a cold season, onset occurs when:

# of freezing days > crit_onset_fdd (requirement for cold dominancy)

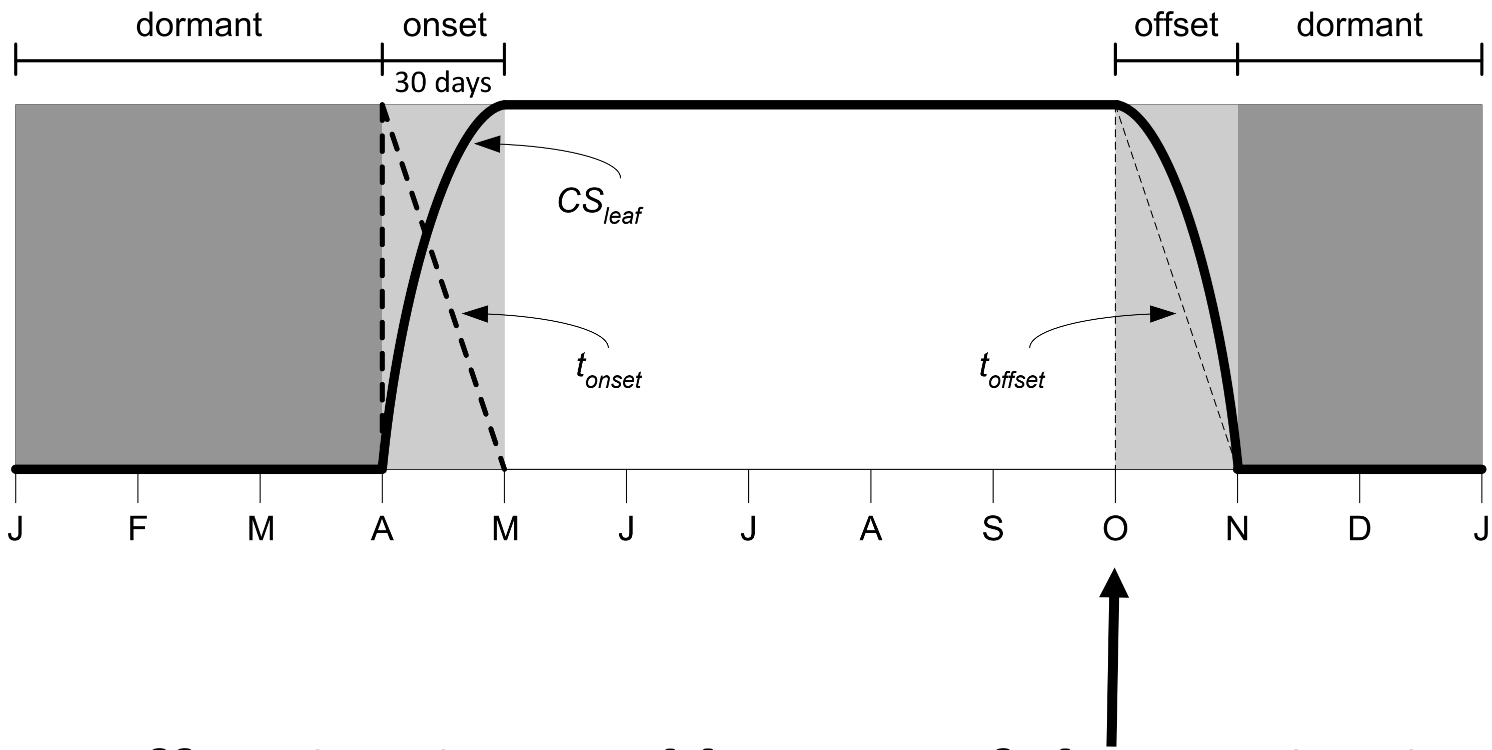
Other requirements that must be met:

Temperature: growing degree day > crit_onset_gdd

Water: soilpsi_on > crit_onset_swi

Daylength: daylength > 6 hours

Stress Deciduous



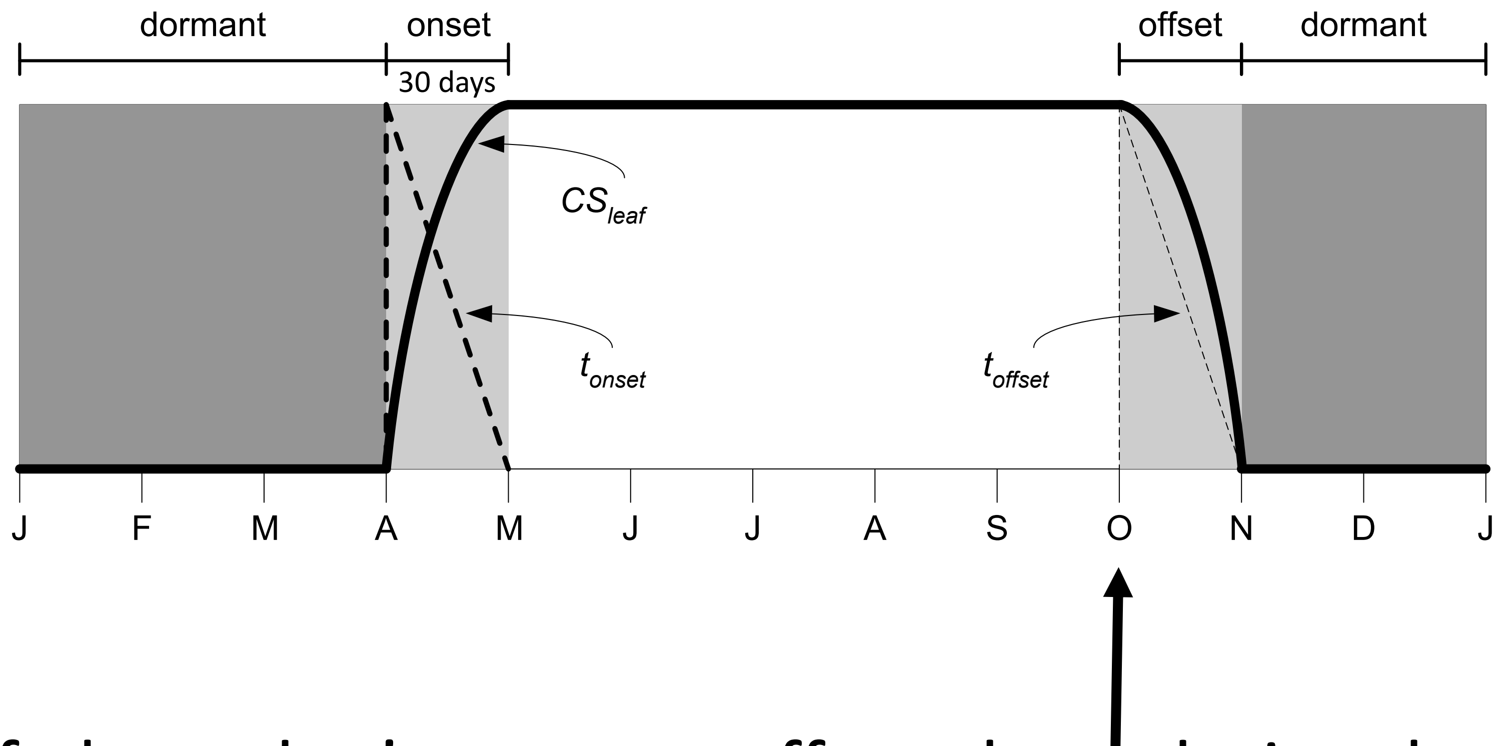
Offset is triggered by one of three criteria:

soilpsi_off < crit_offset_swi

# of freezing days < crit_offset_fdd

Daylength < 6 hrs

Stress Deciduous



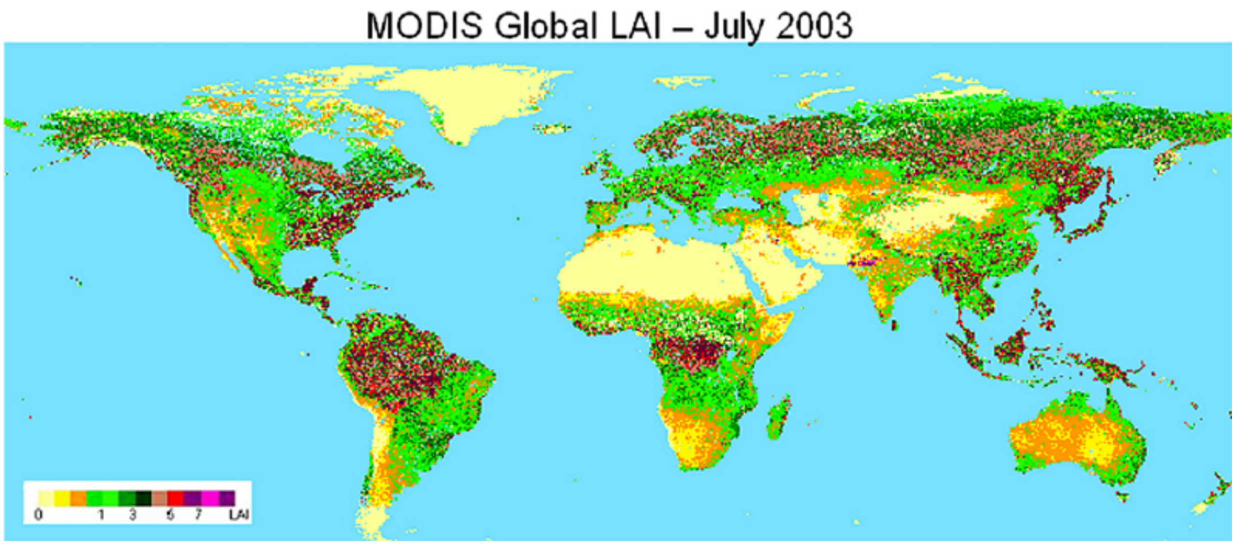
If plants don't enter an offset phase during the year, they switch to background litterfall rates until offset is triggered.

Crop Phenology

Is different from natural vegetation phenology

See crop model talk tomorrow

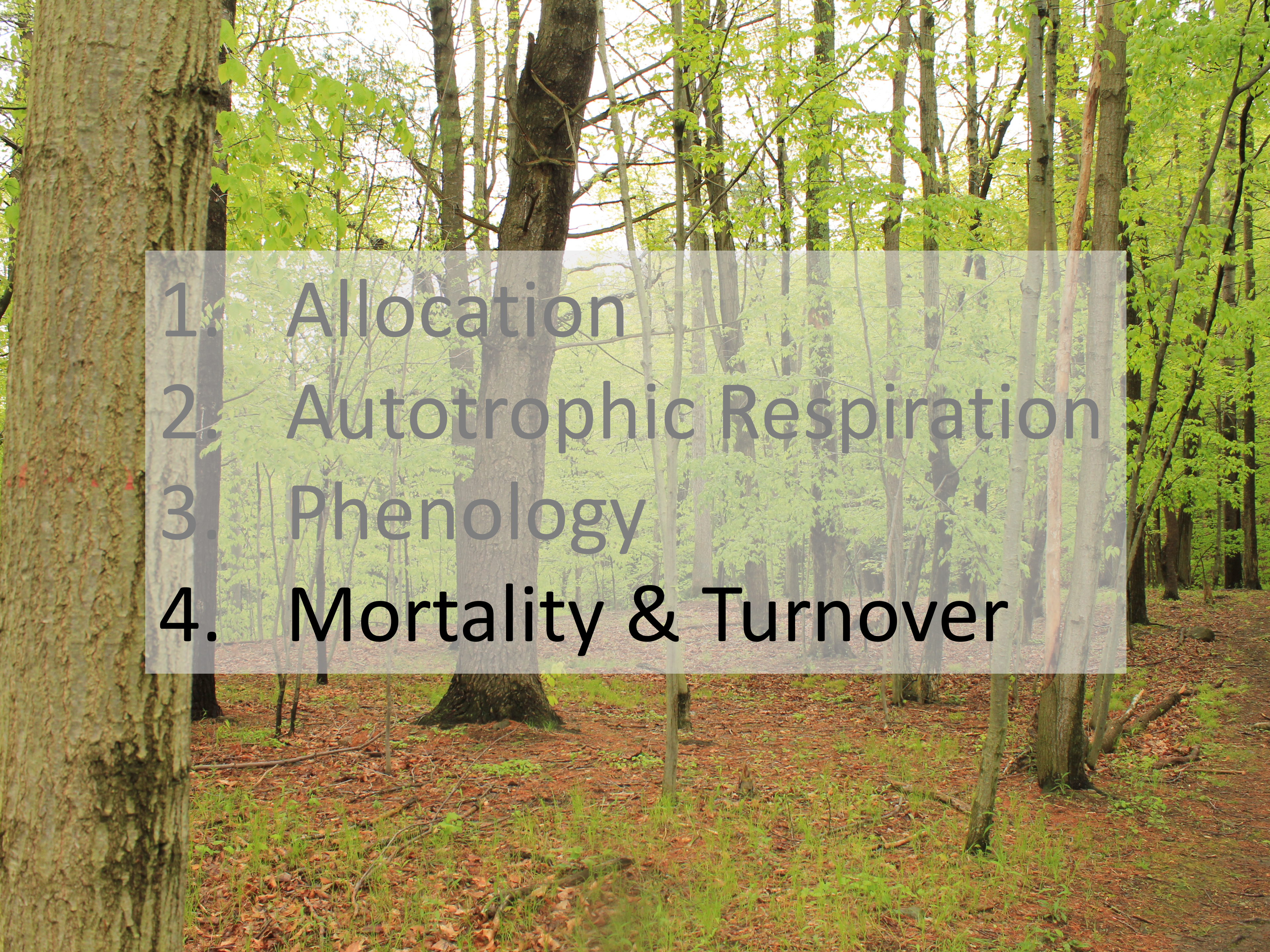
Satellite Phenology (SP)



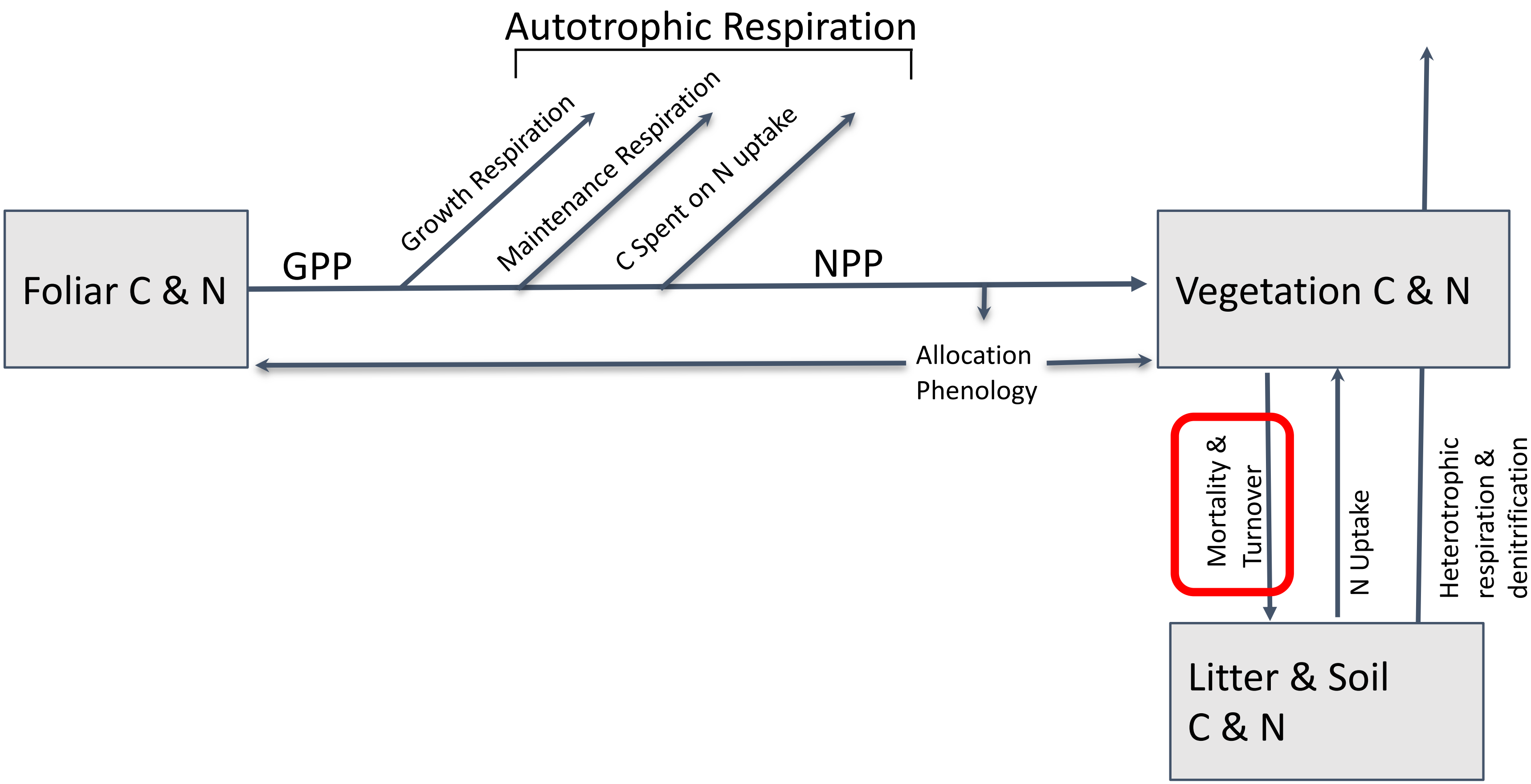
Uses climatological average of MODIS LAI (monthly values)

Dynamic phenology not used and biogeochemistry turned off

Map from Pisek and Chen 2007


1. Allocation
2. Autotrophic Respiration
3. Phenology
4. Mortality & Turnover

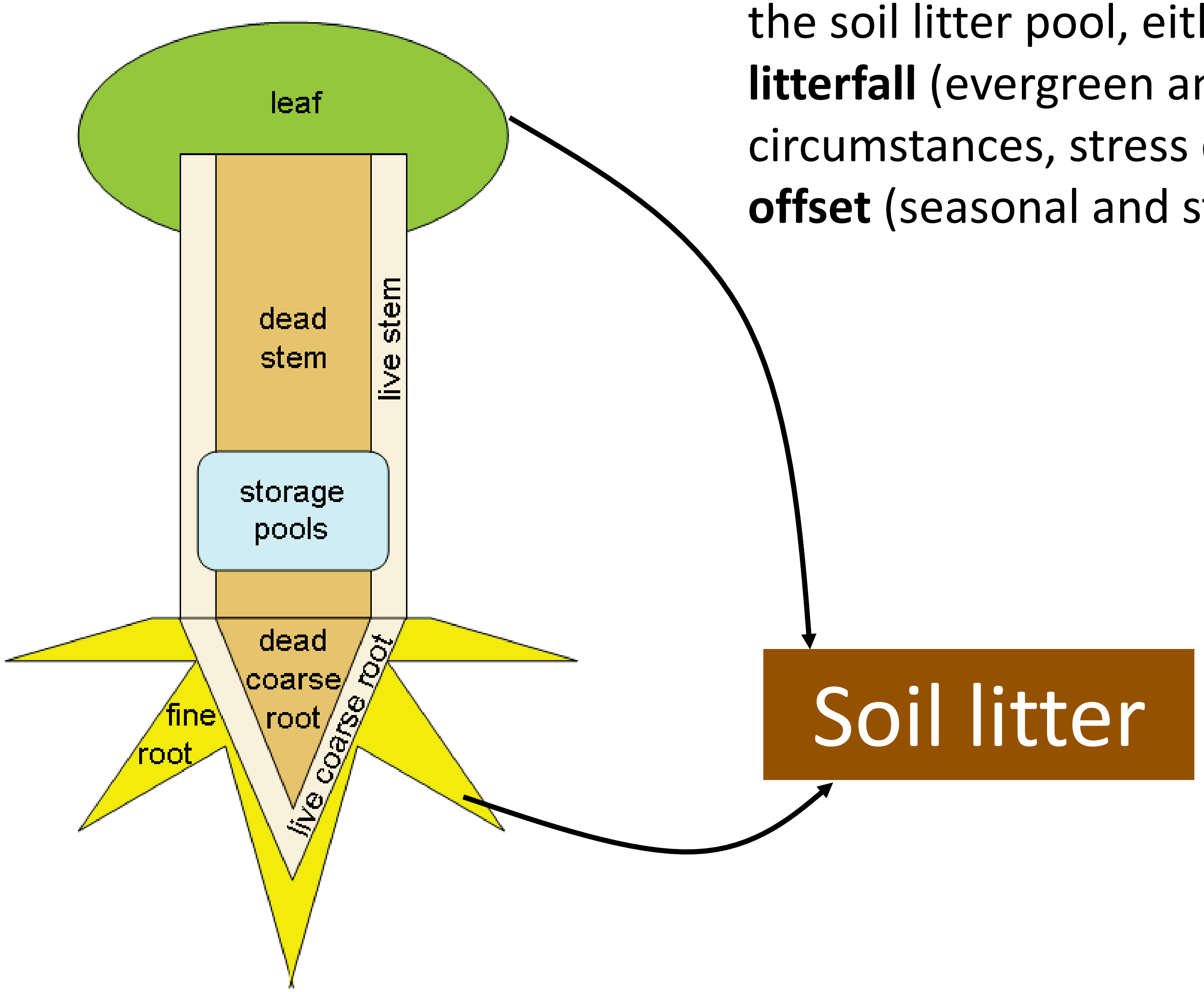
Overview



Autotrophic Respiration
Growth Respiration
Maintenance Respiration
C Spent on N uptake
Foliar C & N
GPP
NPP
Vegetation C & N
Allocation
Phenology
Mortality & Turnover
N Uptake
Heterotrophic respiration & denitrification
Litter & Soil C & N

Litterfall

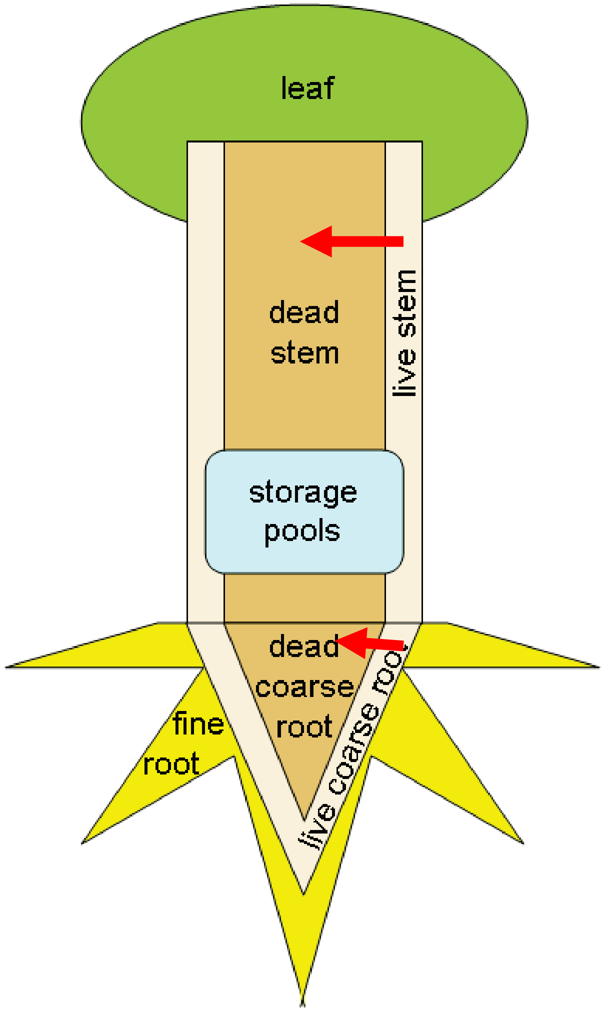
Leaf and fine root C and N are transferred to the soil litter pool, either through **background litterfall** (evergreen and under some circumstances, stress deciduous) or during **offset** (seasonal and stress deciduous)



CNPhenologyMod.F90

Live wood to dead wood

Includes stem and root pools



Occurs throughout year based on specified rate

Parameter: **lwtop_ann** = 0.7

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

CNPhenologyMod.F90

Mortality

Gap-phase mortality is intended to represent perennial plant death due to wind throw, insect attack, disease, extreme temperatures or drought, and age-related decline in vigor (aggregated)

Fixed percentage of biomass across globe
Parameter: **am** = 0.02

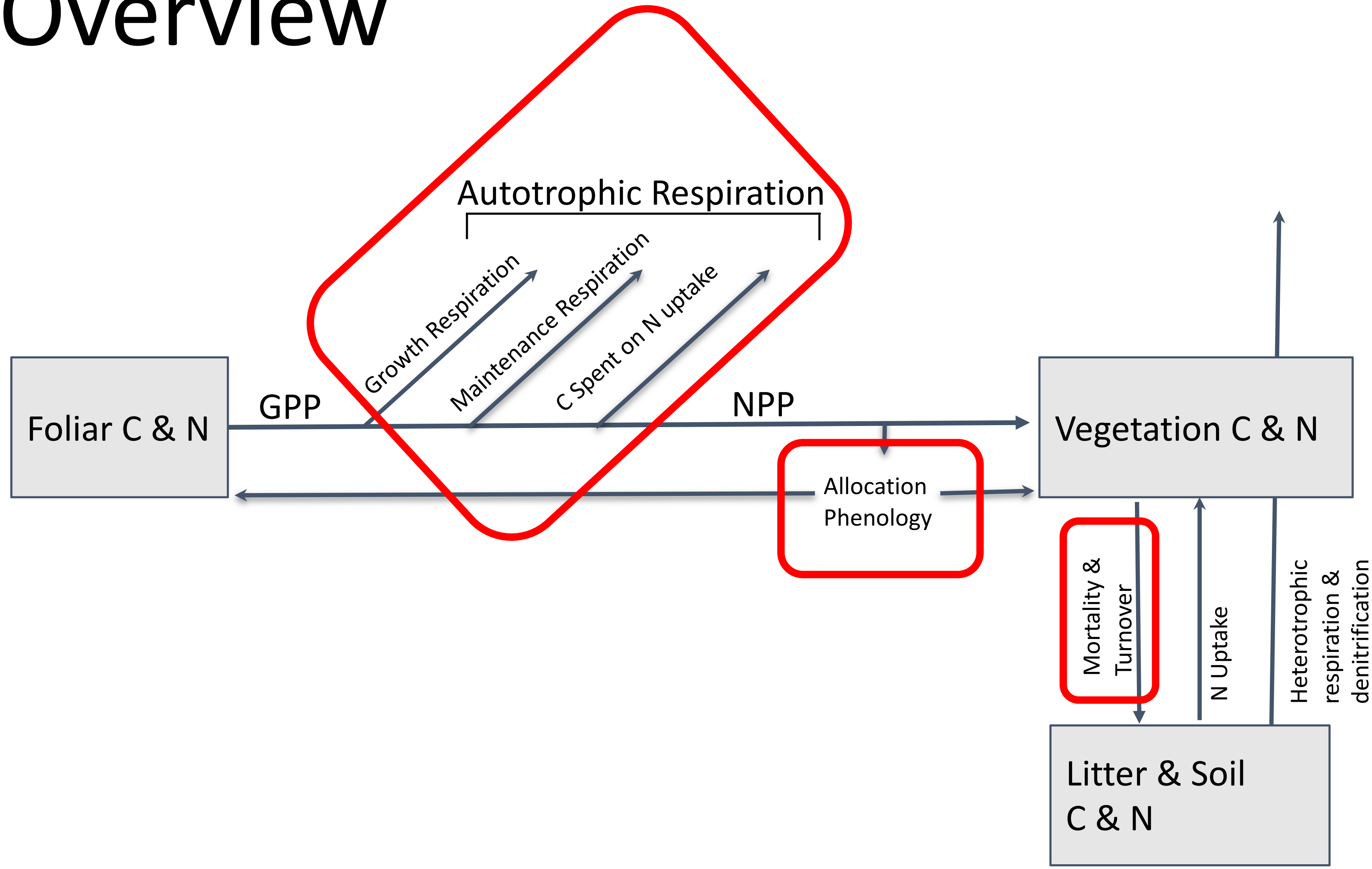
Multiplied by all pools (represents whole tree death)

Leaf and fine roots transferred to litter; wood and coarse roots to coarse woody debris

Note: Mortality related to fire and land use change is treated separately

CNGapMortalityMod.F90

Overview



Autotrophic Respiration
Growth Respiration
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respiration &
denitrification
Litter & Soil
C & N