Outlooks for vegetation and soil-biogeochemistry representations

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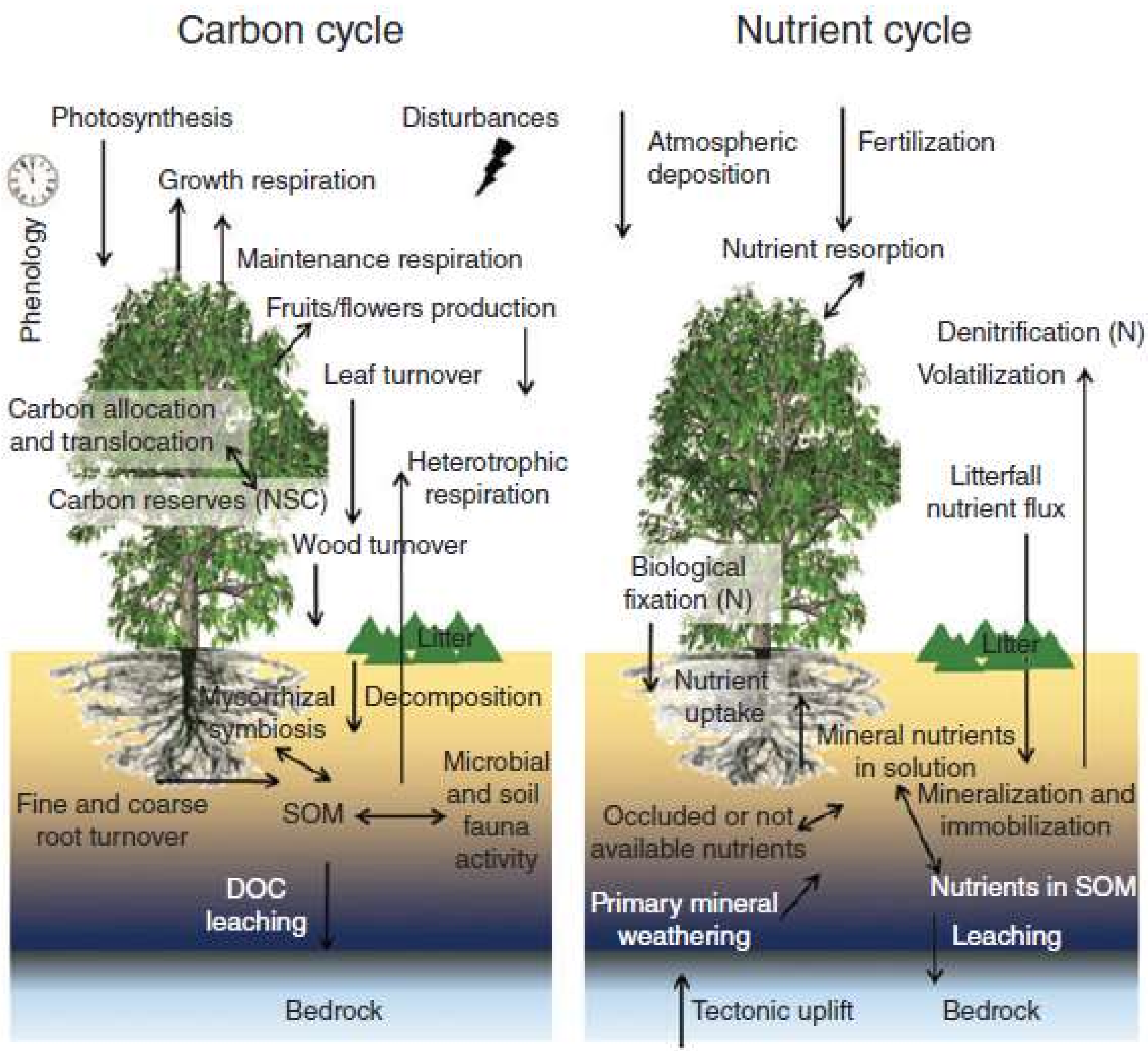
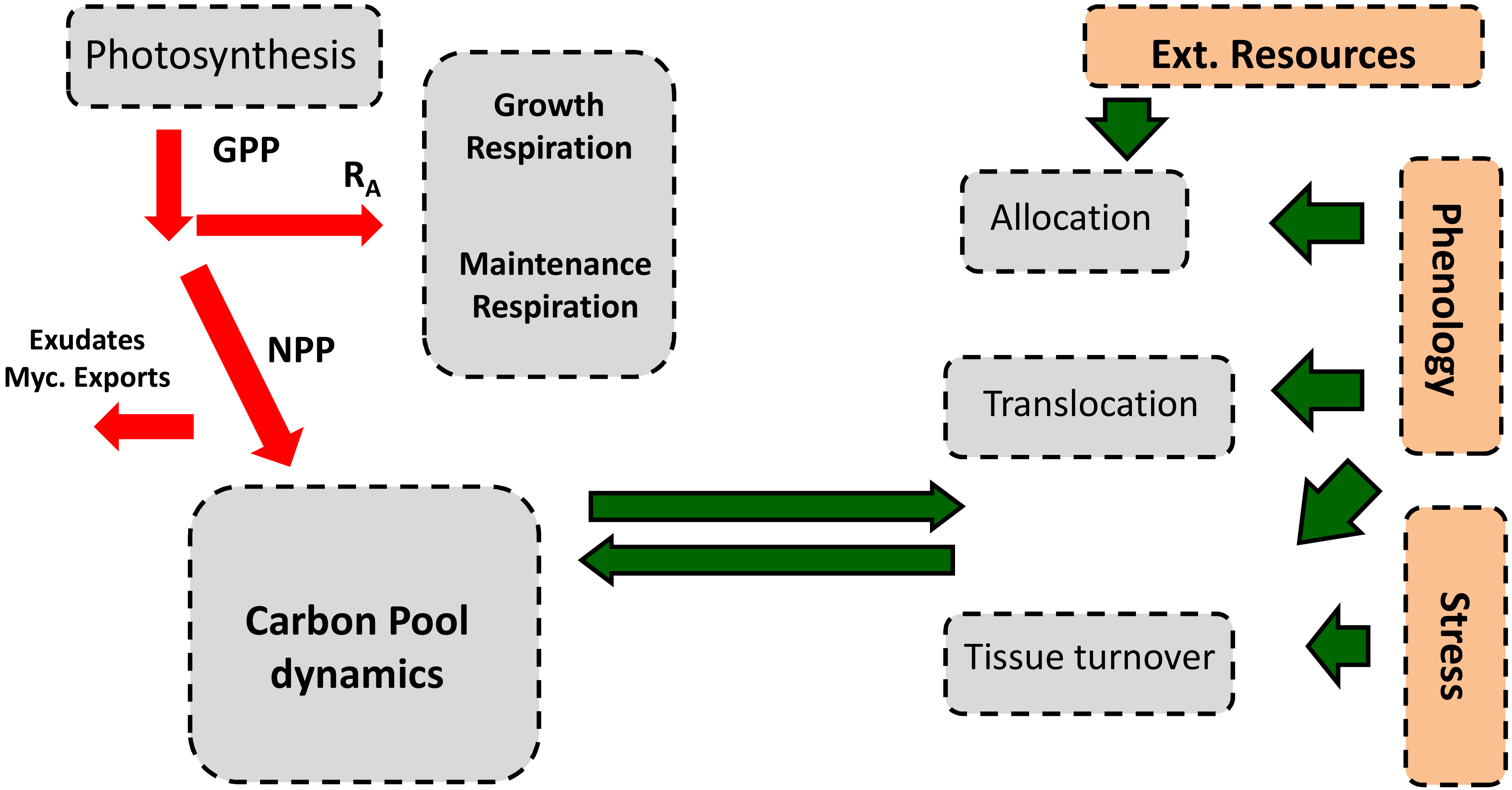
Including Carbon and Nutrient Cycle in Land-Surface Models



Fatichi et al. 2016 *Wires Water*

Carbon Pool - Concept



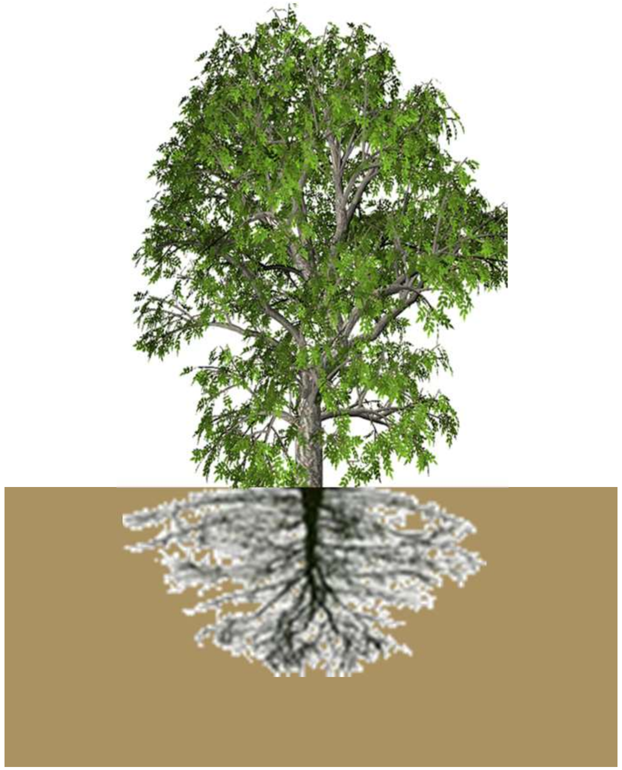
Plant structure and anatomy is conceptualized with a given number of carbon pools representing different functional compartments.

Carbon Pools

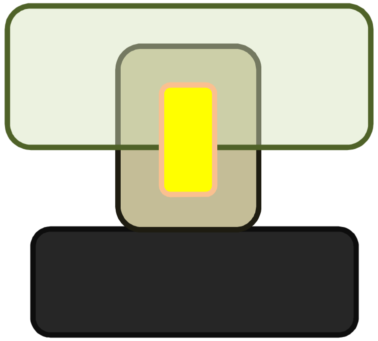
Tissue growth and turnover

- ❑ **Leaves**
- ❑ **Stem**
- ❑ **Fine roots**

- ❑ **Sapwood/heartwood**
- ❑ **Fine/Coarse Roots**
- ❑ **Carbohydrate Reserves (NSC)**
- ❑ **Reproductive Tissues**
- ❑ **Mycorrhiza**

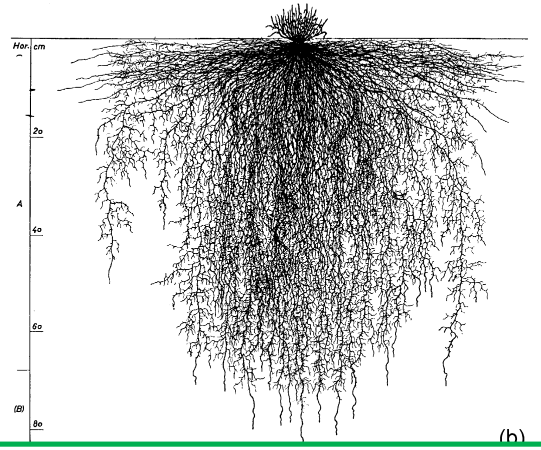


$$\begin{cases} \frac{dB_1}{dt} = f_1 NPP - t_1 B_1 \\ \frac{dB_2}{dt} = f_2 NPP - t_2 B_2 \\ \ldots \\ \frac{dB_n}{dt} = f_n NPP - t_n B_n \end{cases}$$

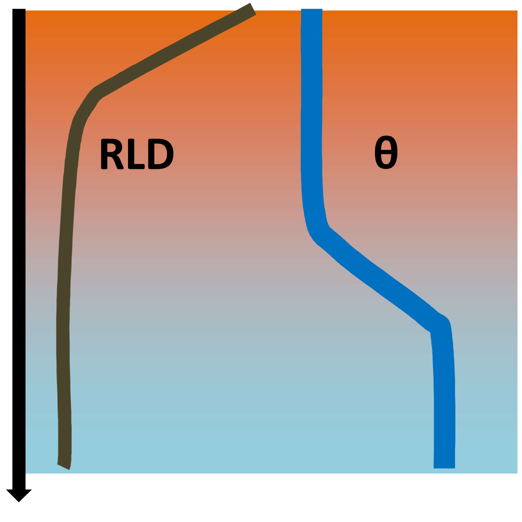


Mass-based representation with limited morphological details (LAI, SAI, H_c, RLD)

Root distribution



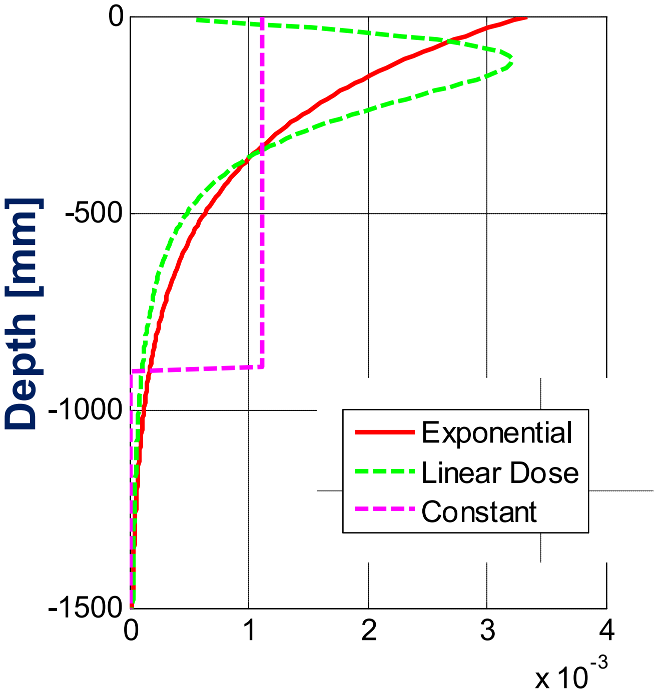
Pages et al 2004, *PLSO*



Sink capacity proportional to:
Root Biomass, RLD

RLI = RLD*Root_depth

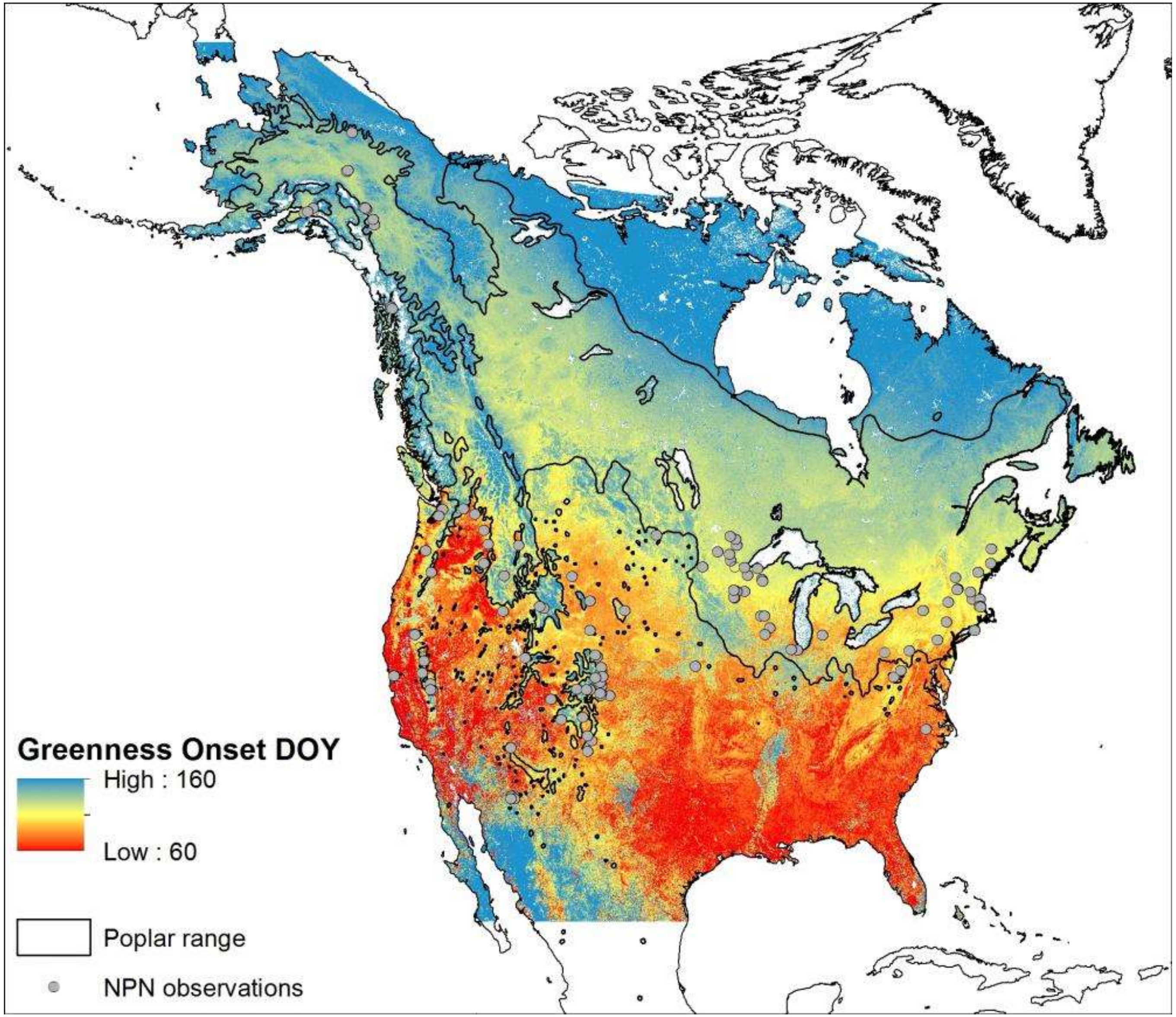
Root PDF



For each soil layer or for the bulk root system we can compute:

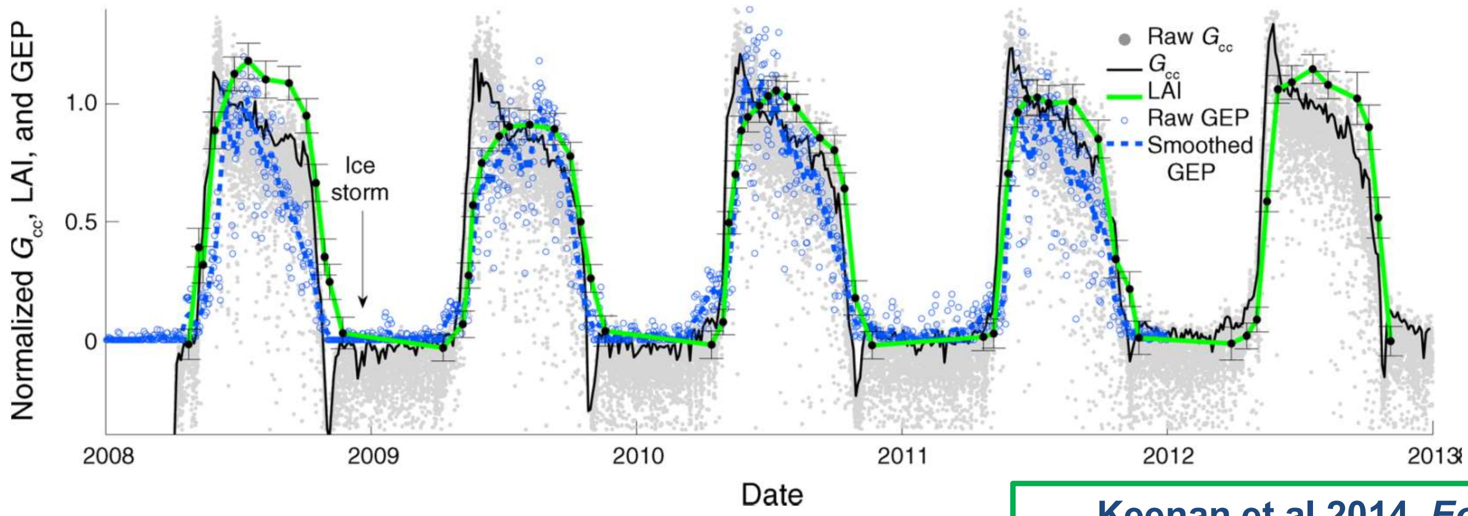
$$\theta_R, \psi_R, g_{sr}$$

Phenology



Source: https://www.usanpn.org/taxonomy/term/210

Phenology

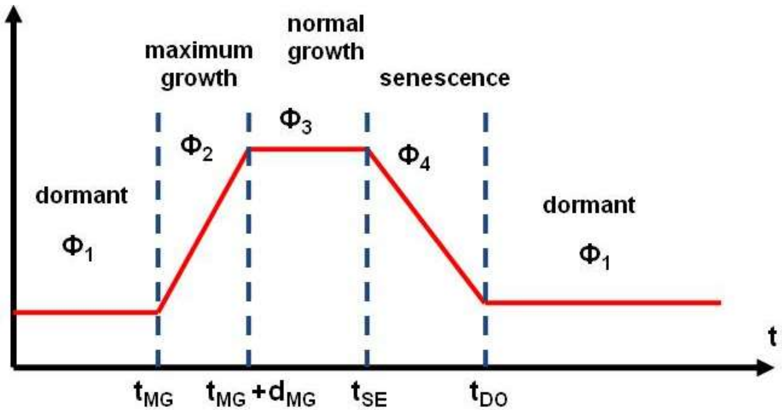


Keenan et al 2014, *Ecol. Appl.*

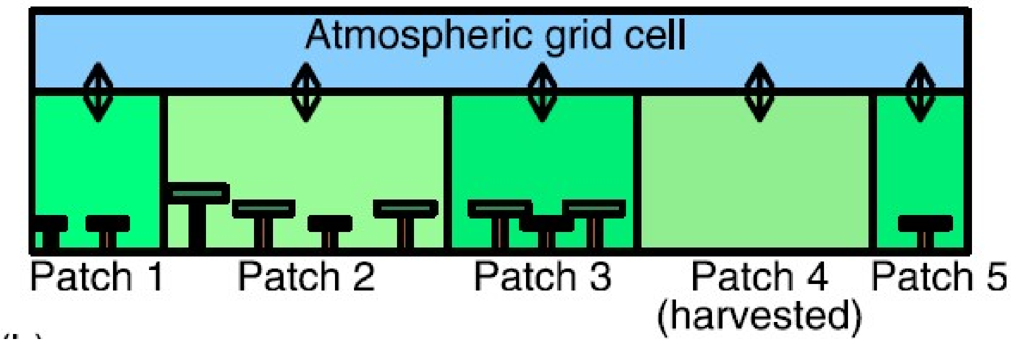
- ❑ Prescribed or Assimilated (Constant LAI, prescribed LAI annual cycle, derived from MODIS)
- ❑ Semi-prescribed (Annual shape prescribed but actual values are function of GPP)
- ❑ Prognostic (phenology is simulated dynamically in the model)

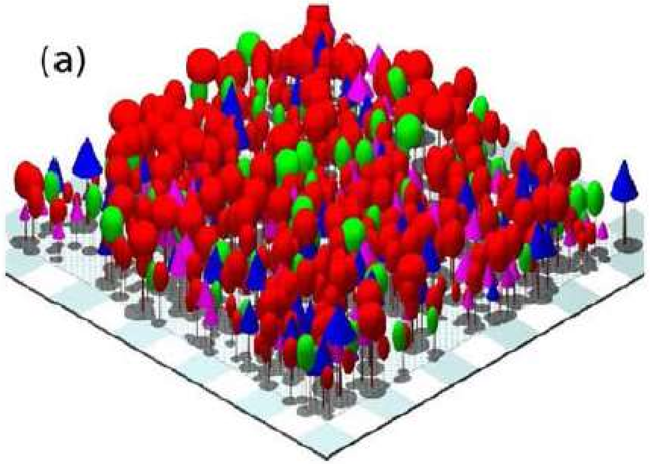
Temperature (T_{soil}, GDD, Spring T_a, Acc. Freezing)
Light (photoperiod)
Soil water content
Positive/Negative NPP

Arora and Boer, 2005, *GCB;*
Fatichi et al 2012, *JAMES*

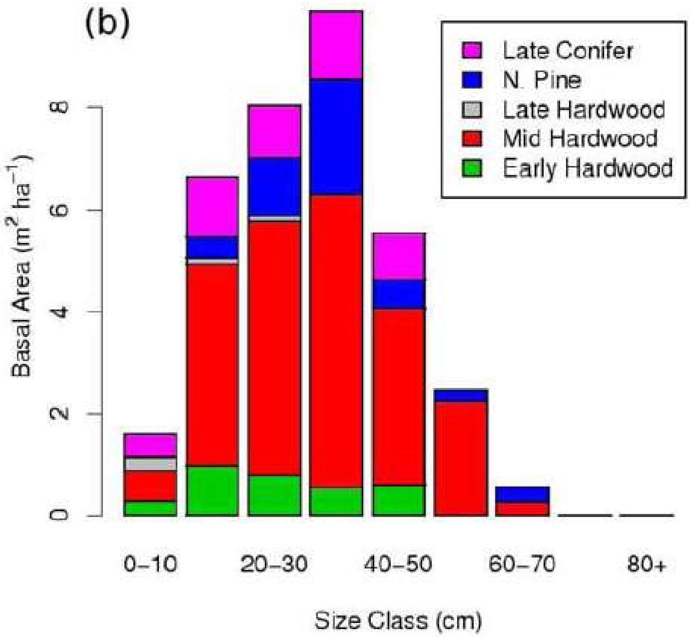


ED2 MODEL (linked to OLAM)





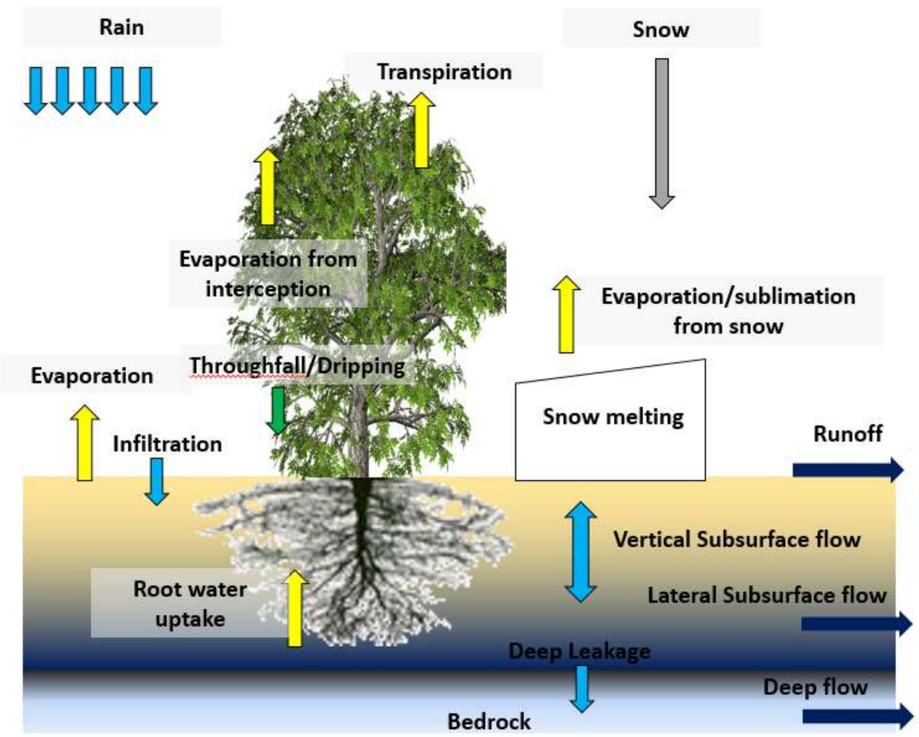
- Leaf physiology
- C-budget and allocation including C-storage
- Soil C decomposition
- Forest demography



ED2 model
Moorcroft et al 2001 *Ecol. Monog.*;
Medvigy et al 2009 *JGR*

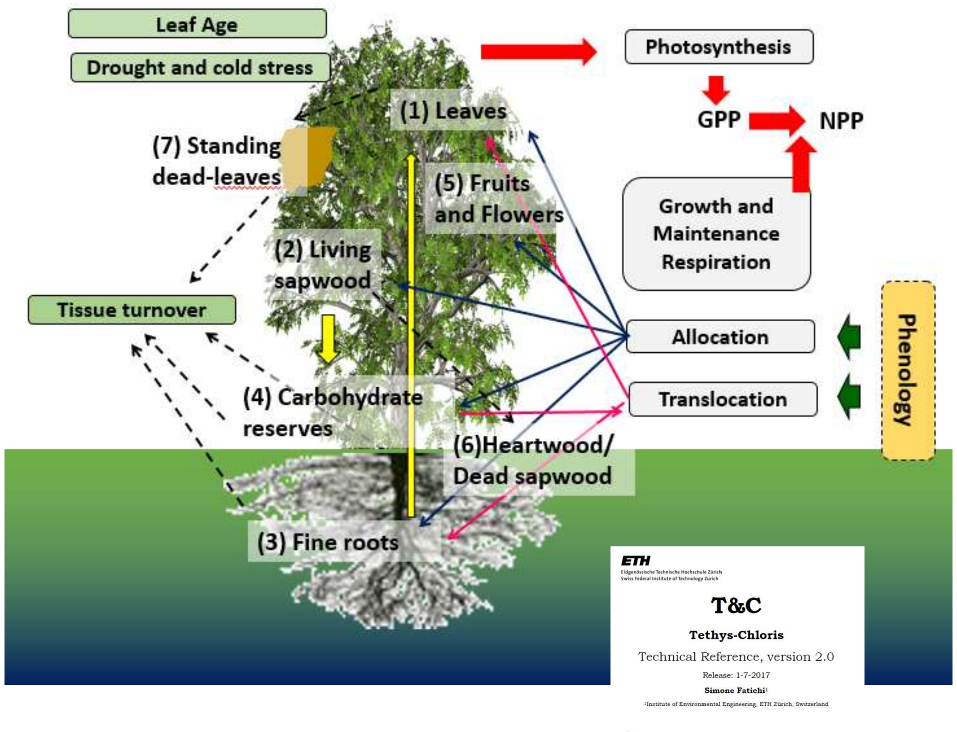
Tethys-Chloris (T&C) MODEL

Hydrological Part



Fatichi et al., 2012a,b, *J. Advances in Modeling Earth Systems*
Fatichi and Leuzinger 2013, *Agr. For. Met.*
Fatichi et al., 2014, *WRR;* Fatichi and Ivanov 2014, *WRR;* Fatichi et al 2016, *PNAS*
Pappas et al. 2016 *NP;* Paschalis et al. 2015 *JGR*
Fatichi and Pappas, 2017, *GRL*
Mastrotheodoros et al 2017, *JGR*

Vegetation Part



Technical Reference

Mechanistic Soil-Biogeochemistry

(i) Functional partitioning of soil organic carbon (SOC) pools
(ii) Representation of microbial biomass and diversity
(iii) Mechanistic coupling of carbon and nutrient cycles

Introducing microbial and extracellural enzyme explicit models

Soil-carbon response to warming dependent on microbial physiology

Allison et al 2010 *Nat. Geosc.*

Global soil carbon projections are improved by modelling microbial processes

Wieder et al 2013 *Nat. Clim. Change*

Representing life in the Earth system with soil microbial functional traits in the MIMICS model

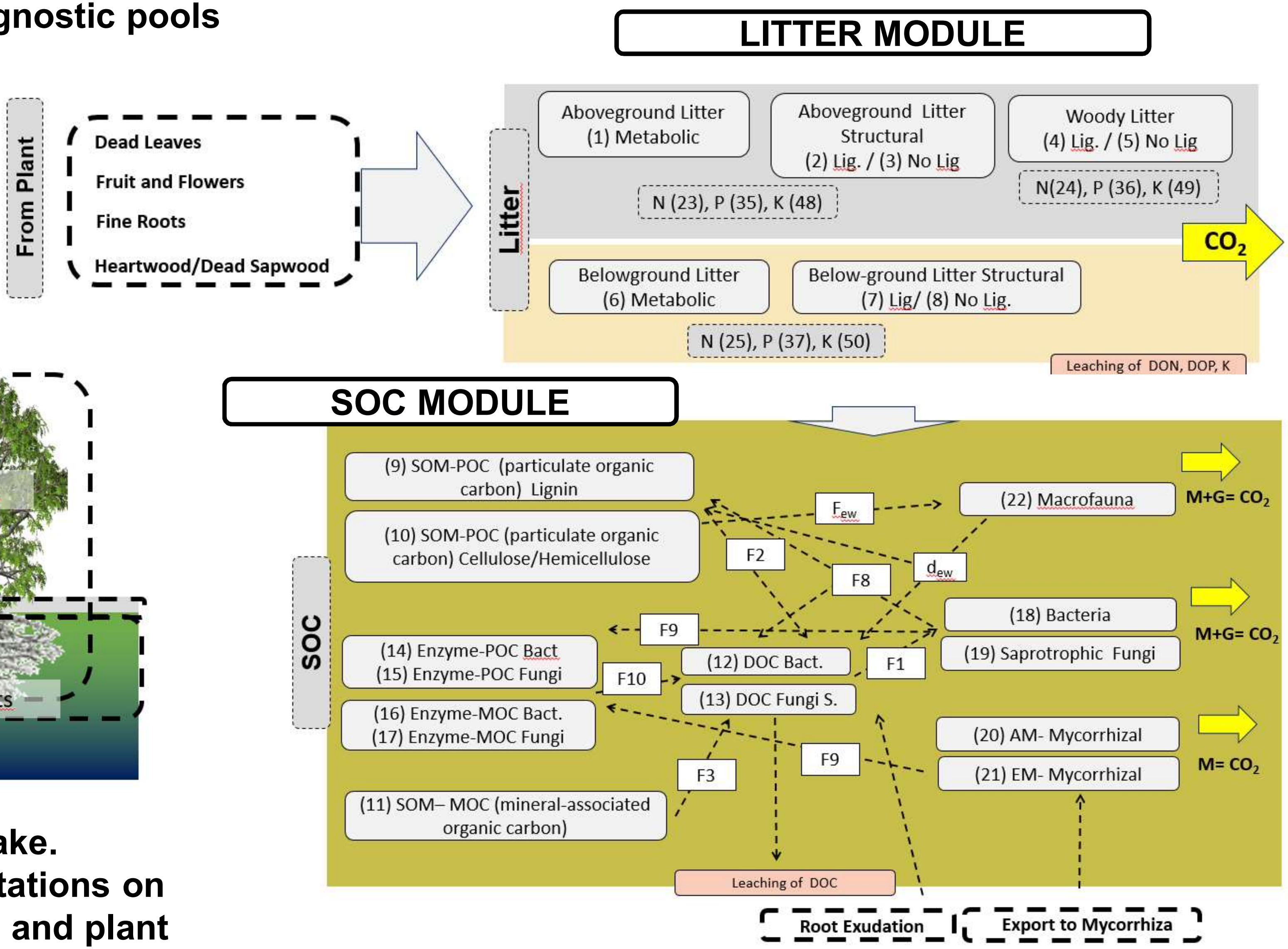
Wieder et al 2015 *GMD*

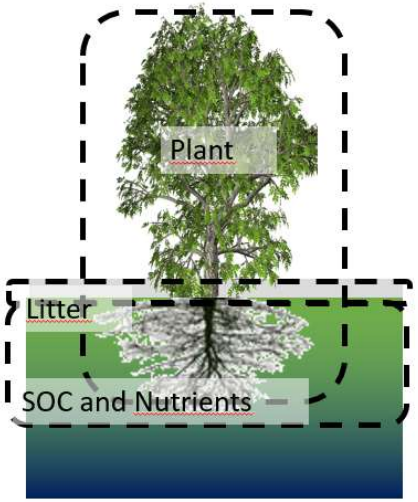
Explicitly representing soil microbial processes in Earth system models

Wieder et al 2015 *Glob. Biog. Cycles*

T&C-Soil Biogeochemistry Module

Many prognostic pools

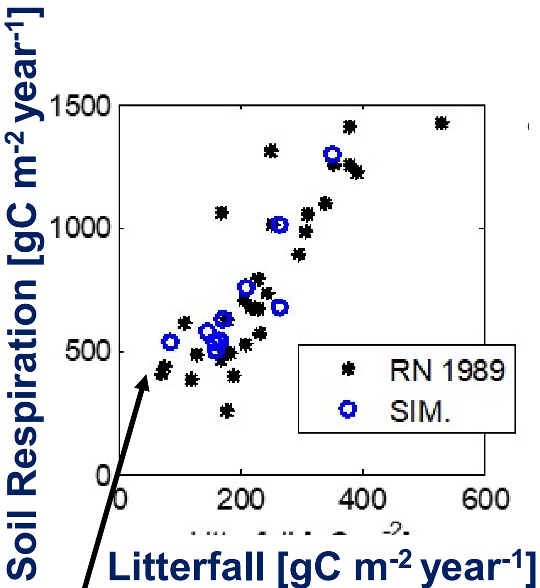


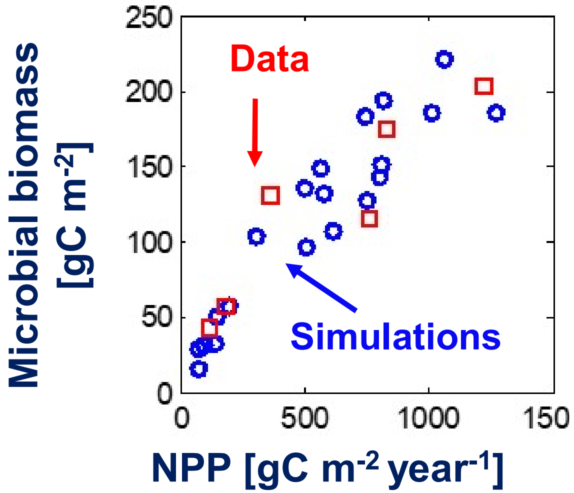


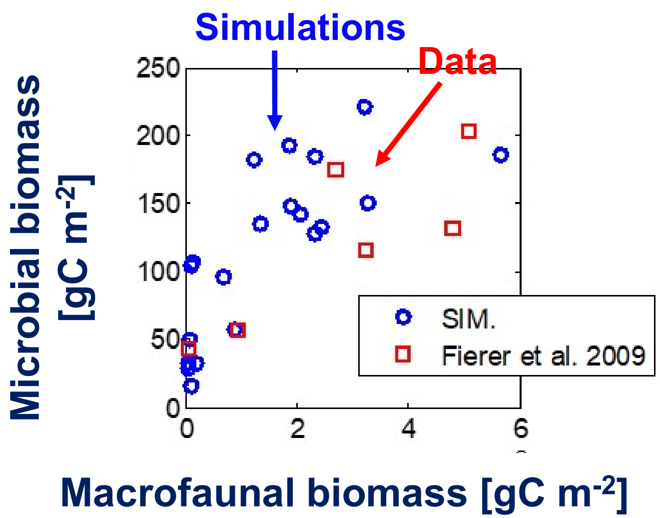
Nutrient uptake.
Nutrient limitations on plant growth and plant stoichiometric flexibility.

NUTRIENT MODULE: N, P, K cycles

Global patterns of belowground pools/fluxes



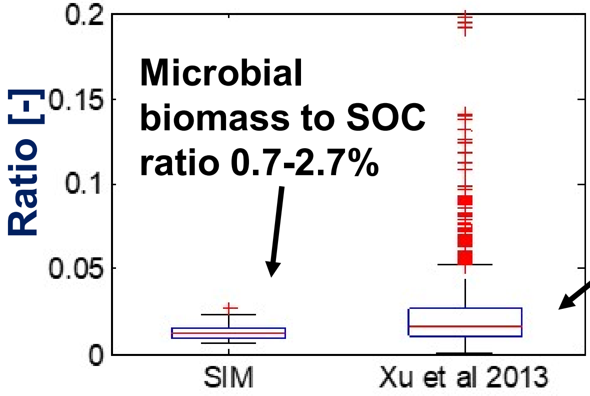




Data from Raich and Nadelhofer (1989), *Ecology*

Data from Fierer et al 2009 *Ecol Lett*

Microbial biomass/SOC



Data from Xu et al 2013 *GEB*

Simulations correspond to 20 case studies with different climate and biomes (no local tuning)

Biomes are quite different and heterogeneous

Amazonas (Brazil)

Kalahari Desert (Namibia)

Michigan (USA)

California (USA)

Different shapes and forms


Colorado (USA)


Sicily (IT)


Nevada (USA)


Inner Mongolia (CN)

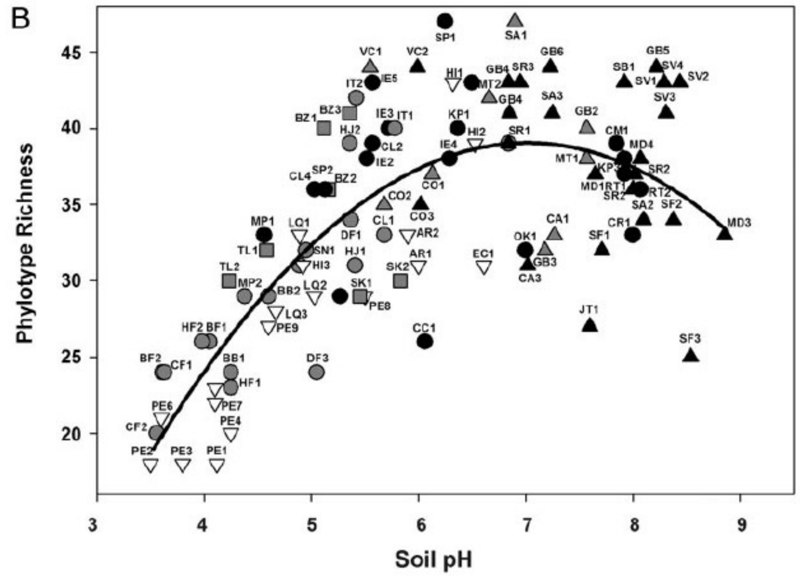

Valais (CH)

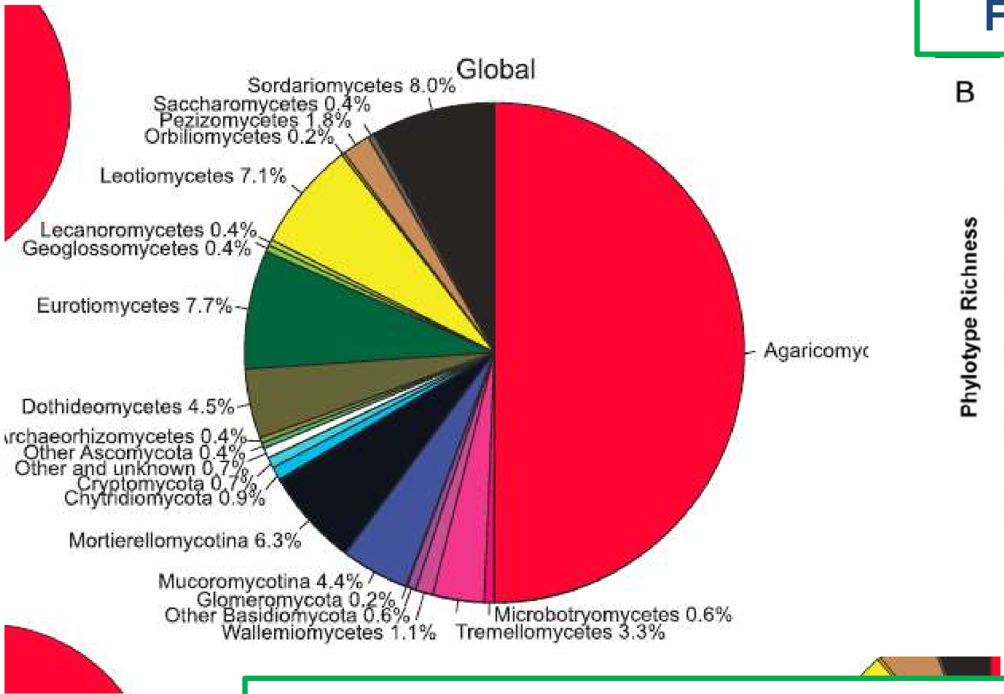

Hawaii (USA)


Kaui Forest (NZ)

Microbial traits are also varying

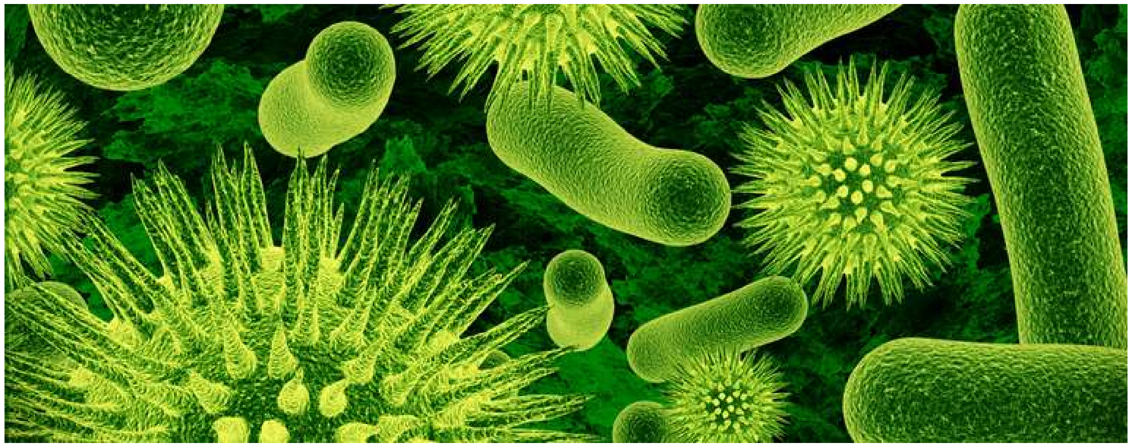
Fierer and Jackson 2006, *PNAS*



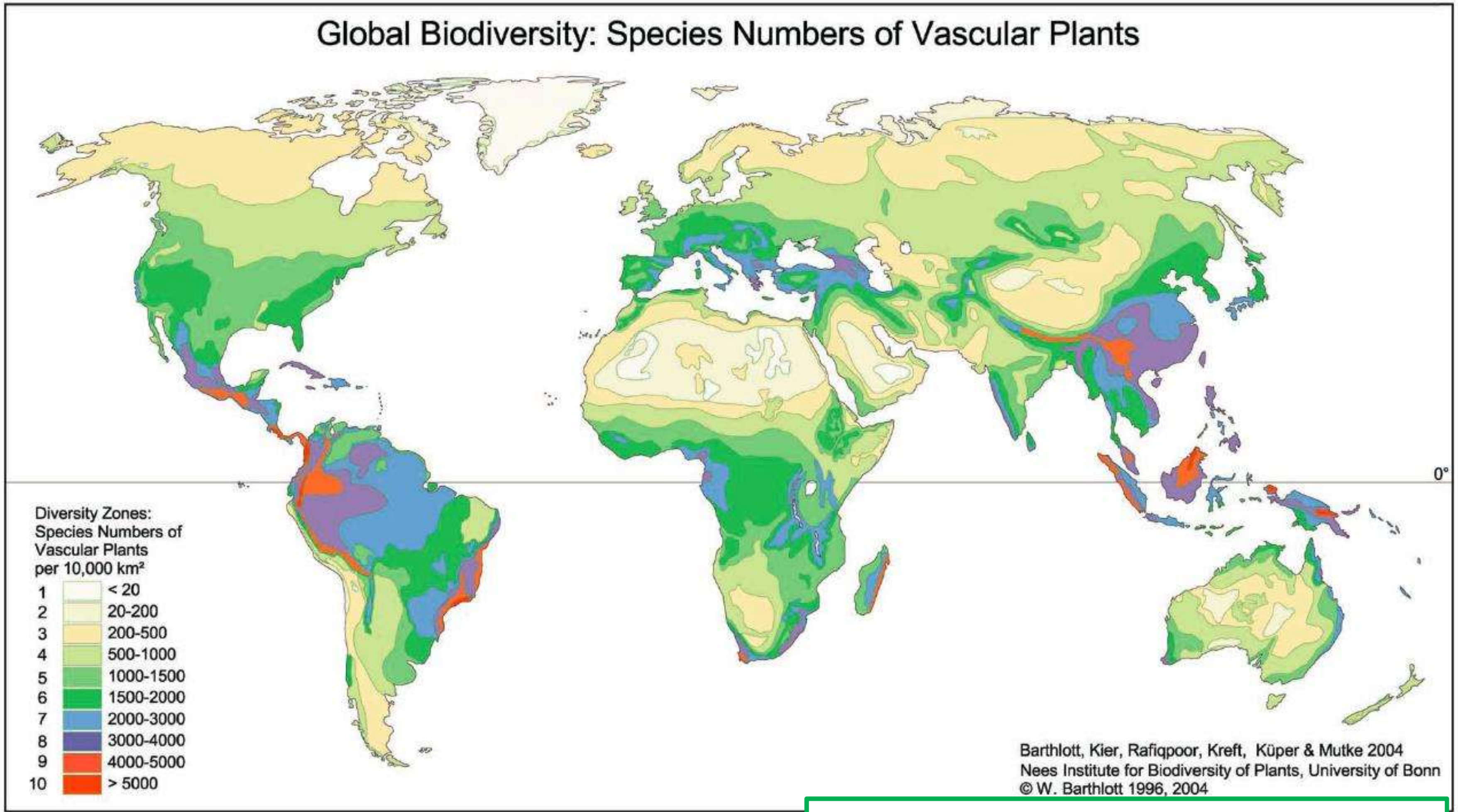


Tedersoo et al 2014, *Science*

Very limited characterization of microbial functional diversity



Global biodiversity

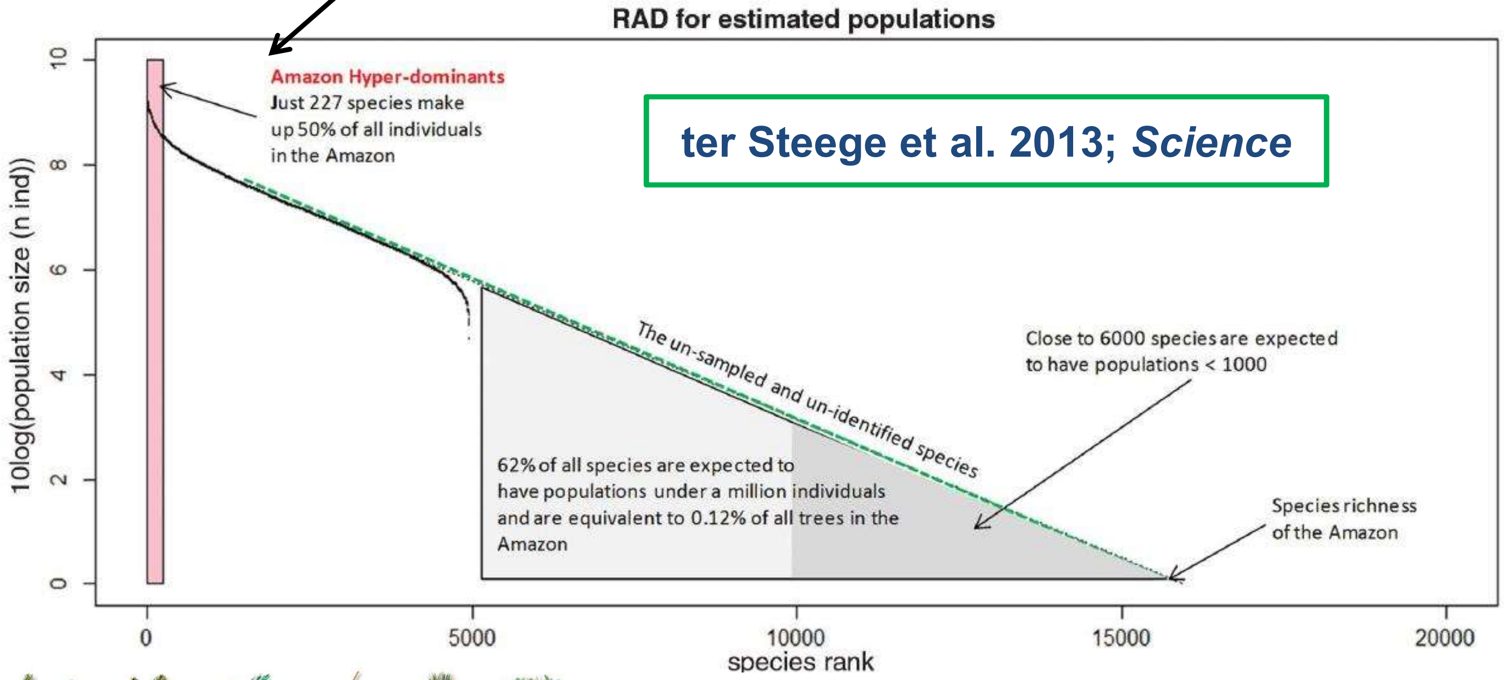


Muttke and Barthlott 2005 *Biol. Skr.*

How to summarize in models such an extent of "bio"-diversity?

Dealing with biodiversity

227 species makes 50% of the Amazon Individuals



ter Steege et al. 2013; *Science*

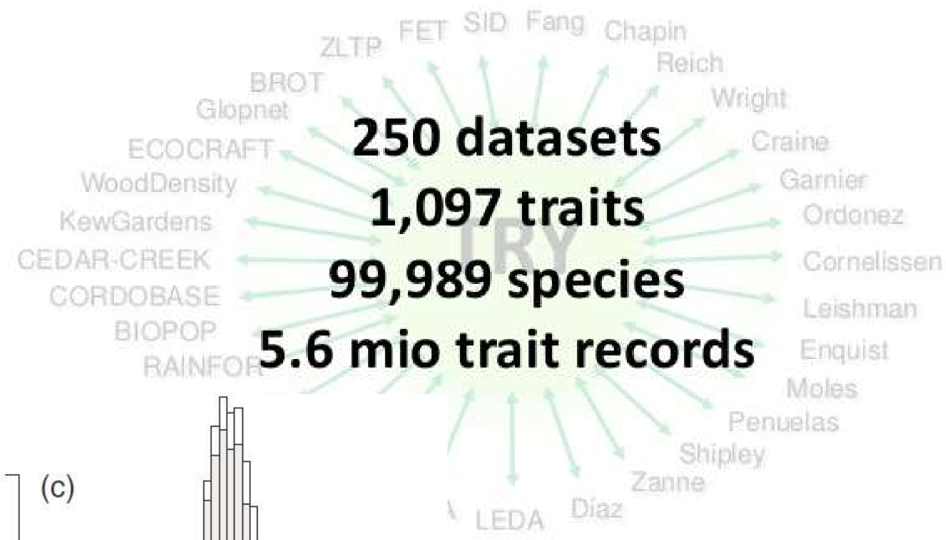
30 species cover a very large fraction of forest diversity in Switzerland

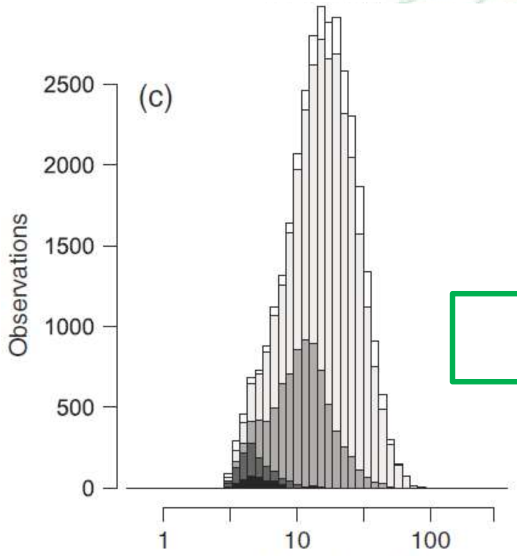
Swiss National Forest Inventory
https://www.lfi.ch/resultate/baumarten.php?lang=de

Trait Distributions

TRY – a global database of plant traits

Second generation of data pooling

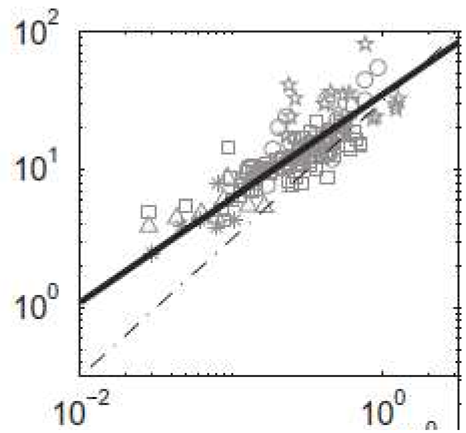




Specific Leaf Area
[mm^2 mg^{-1}]

Kattge et al. 2011; *GCB*

Max Photosynthetic Capacity
[μmolC m^{-2} s^{-1}]

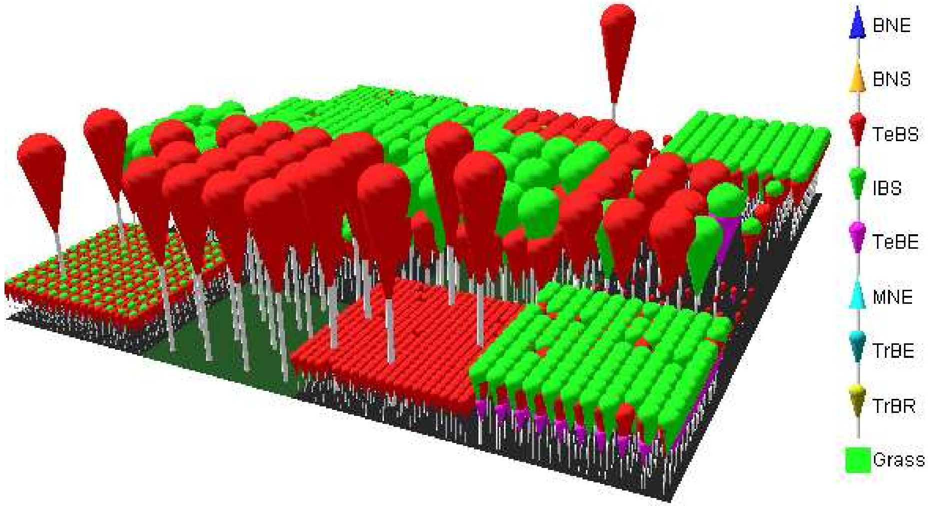


Max Stomatal Conductance
[mol m^{-2} s^{-1}]

Manzoni et al 2013; *AWR*

How plants are represented in numerical models?

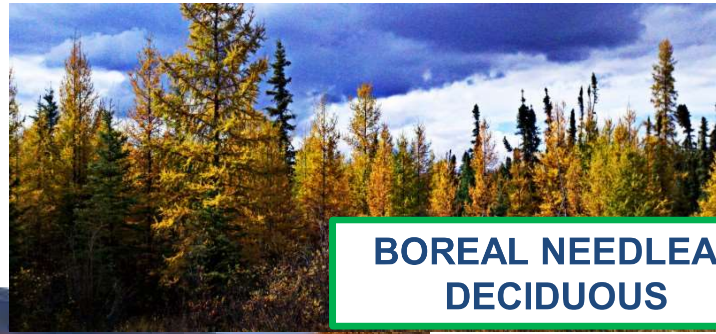
Plant Functional Types



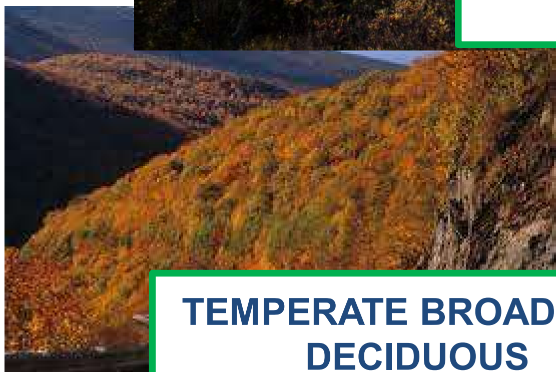
Source: LPJ-GUESS user manual

Axes of stratification:

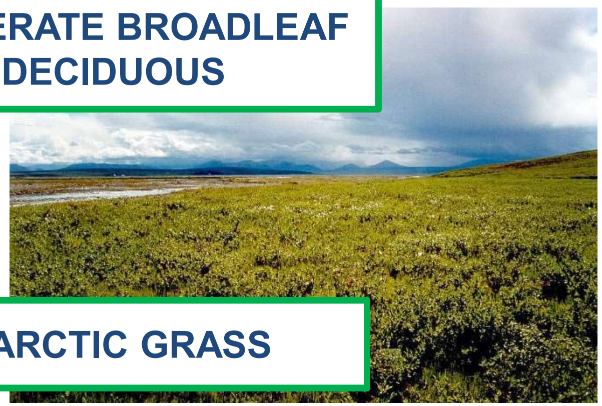
Broad Bioclimatic Limits
Leaf morphology
Phenology
(Successional stage)



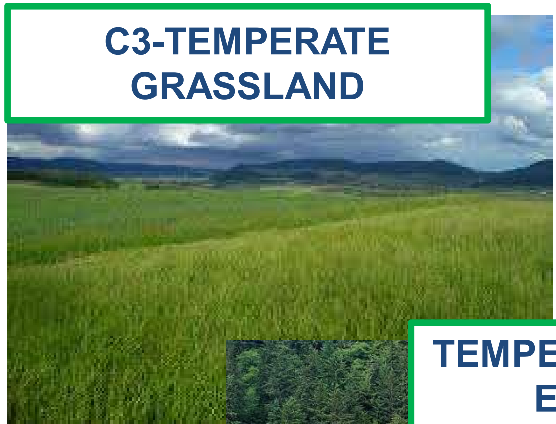
BOREAL NEEDLEAF DECIDUOUS



TEMPERATE BROADLEAF DECIDUOUS



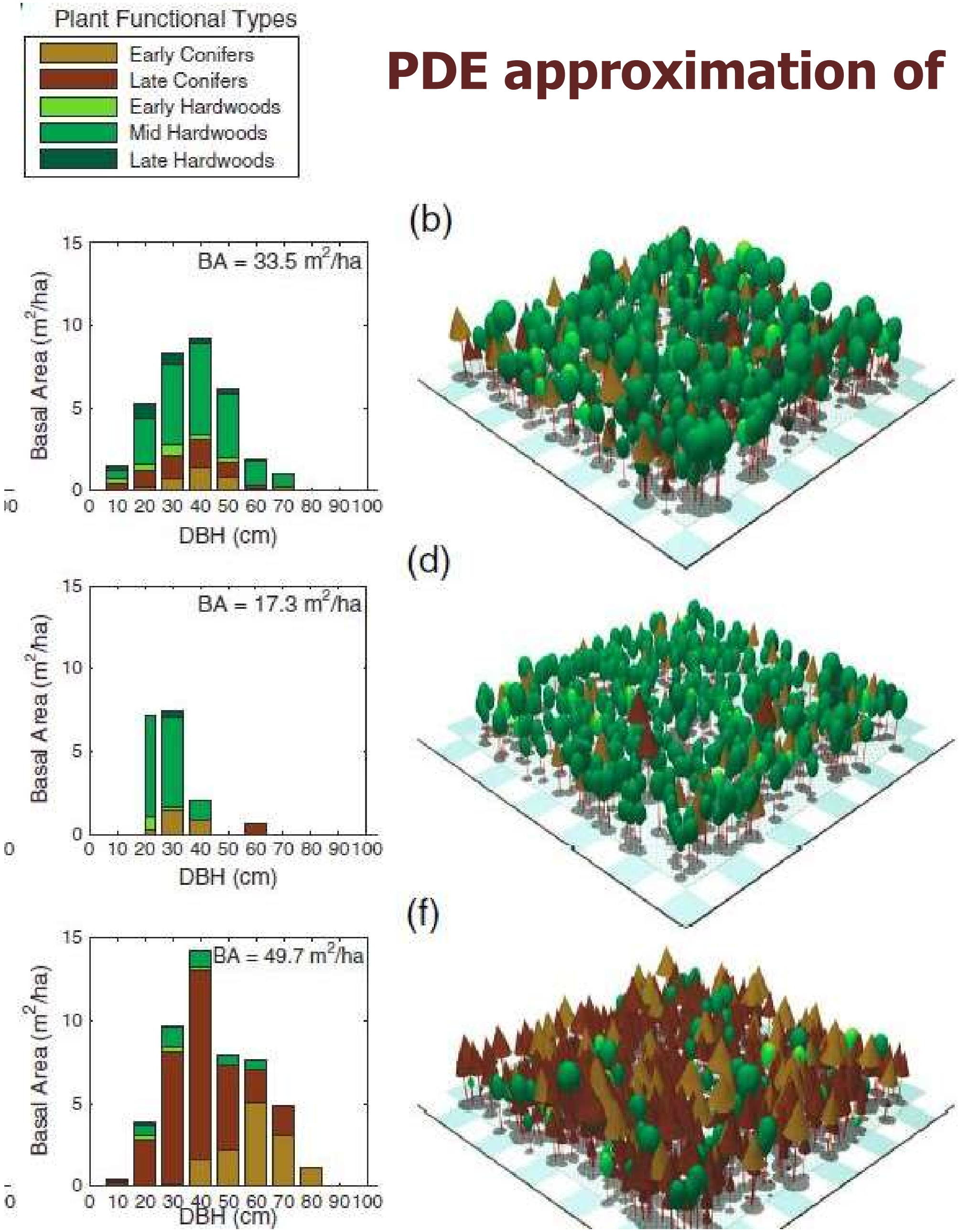
C3 ARCTIC GRASS



C3-TEMPERATE GRASSLAND

TEMPERATE NEEDLEAF EVERGREEN

PDE approximation of individual based models



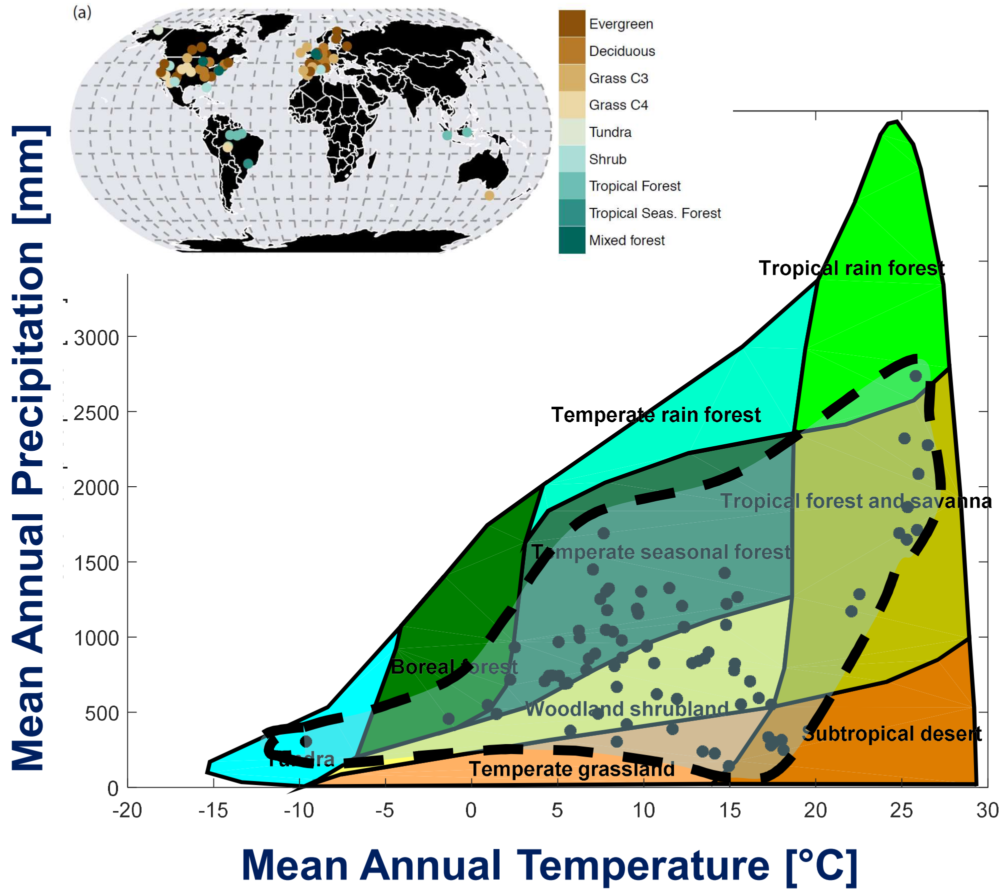
Subgrid scale biotic heterogeneity arising from disturbance events is captured using a system of plant type, size- and age-structured partial differential equations (PDEs) that closely approximate the ensemble mean behavior of a corresponding individual-based stochastic gap model.

ED2 model
Moorcroft et al 2001 *Ecol. Monog.*; Medvigy et al 2009 *JGR*

Antonarakis et al. 2014 *GRL*

A POTENTIAL ALTERNATIVE APPROACH

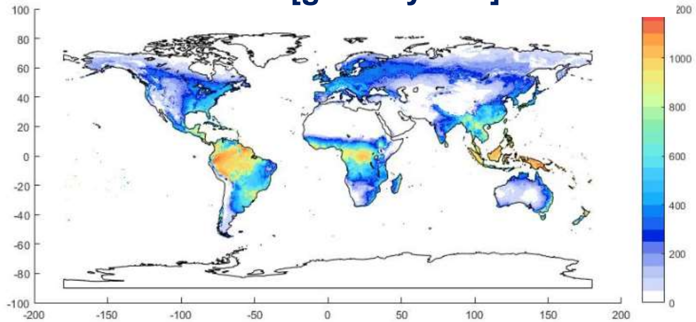
Multiple locations where we can constrain the model simulations and have a reasonable estimate of parameters



Machine learning techniques

Distributed Parameters

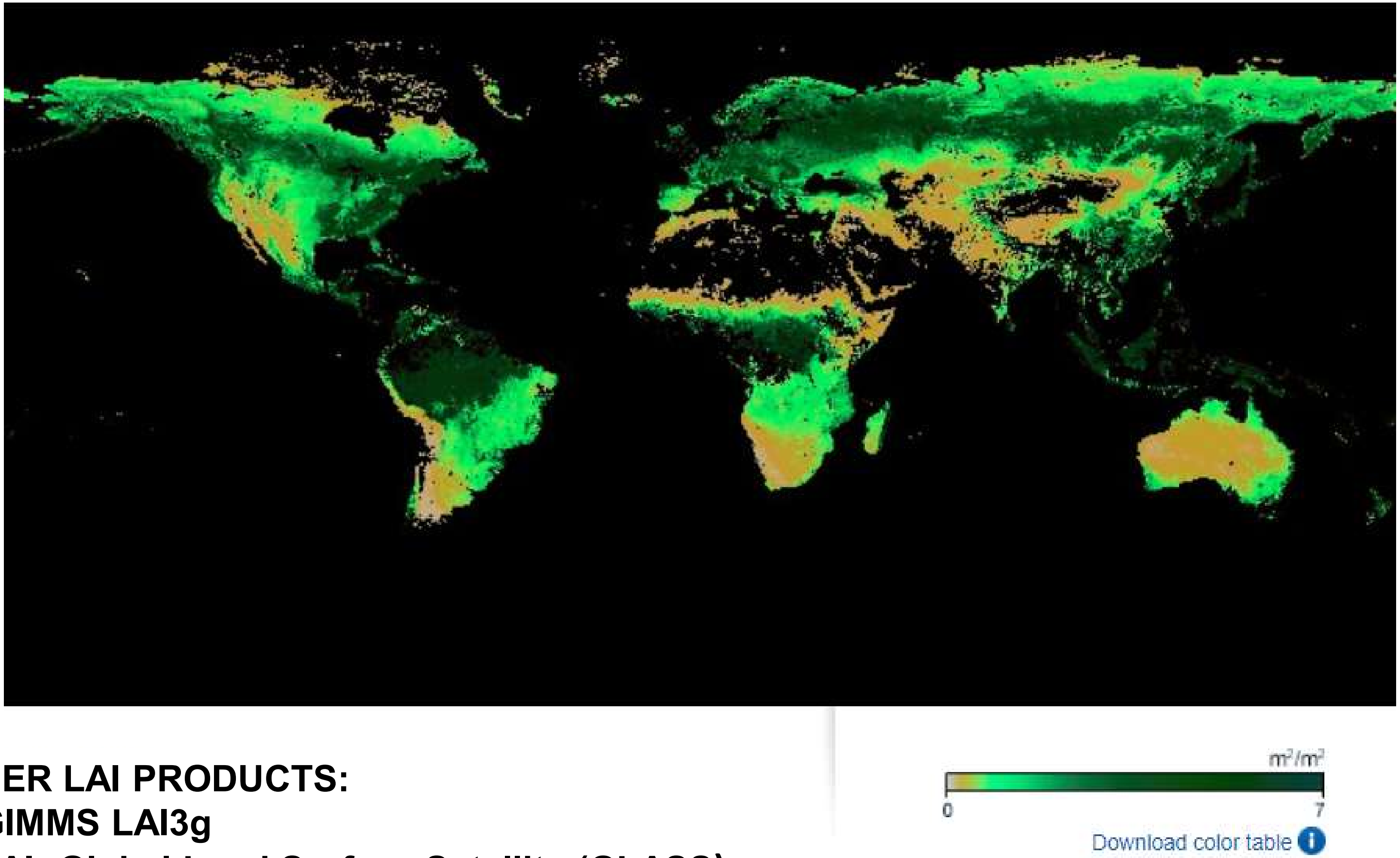
NPP [gC m^{-2} year^{-1}]



REMOTE SENSING PRODUCTS

MODIS – PRODUCTS: e.g., LAI, GPP, NPP, Albedo, Surface temperature

LEAF AREA INDEX (1 MONTH - TERRA/MODIS)



OTHER LAI PRODUCTS:

- **GIMMS LAI3g**
- **LAI- Global Land Surface Satellite (GLASS)**

REMOTE SENSING PRODUCTS

Chlorophyll Fluorescence (GOSAT, GOME-2, new FLEX-ESA mission)

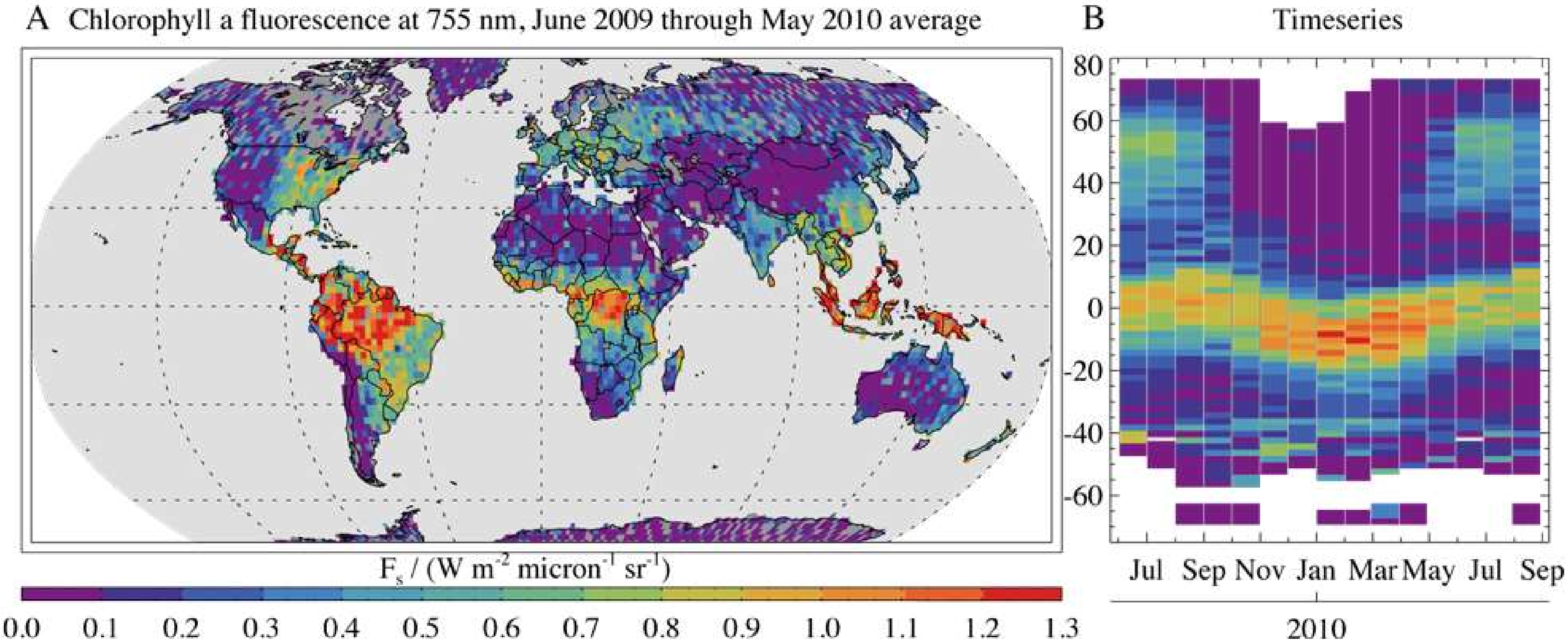
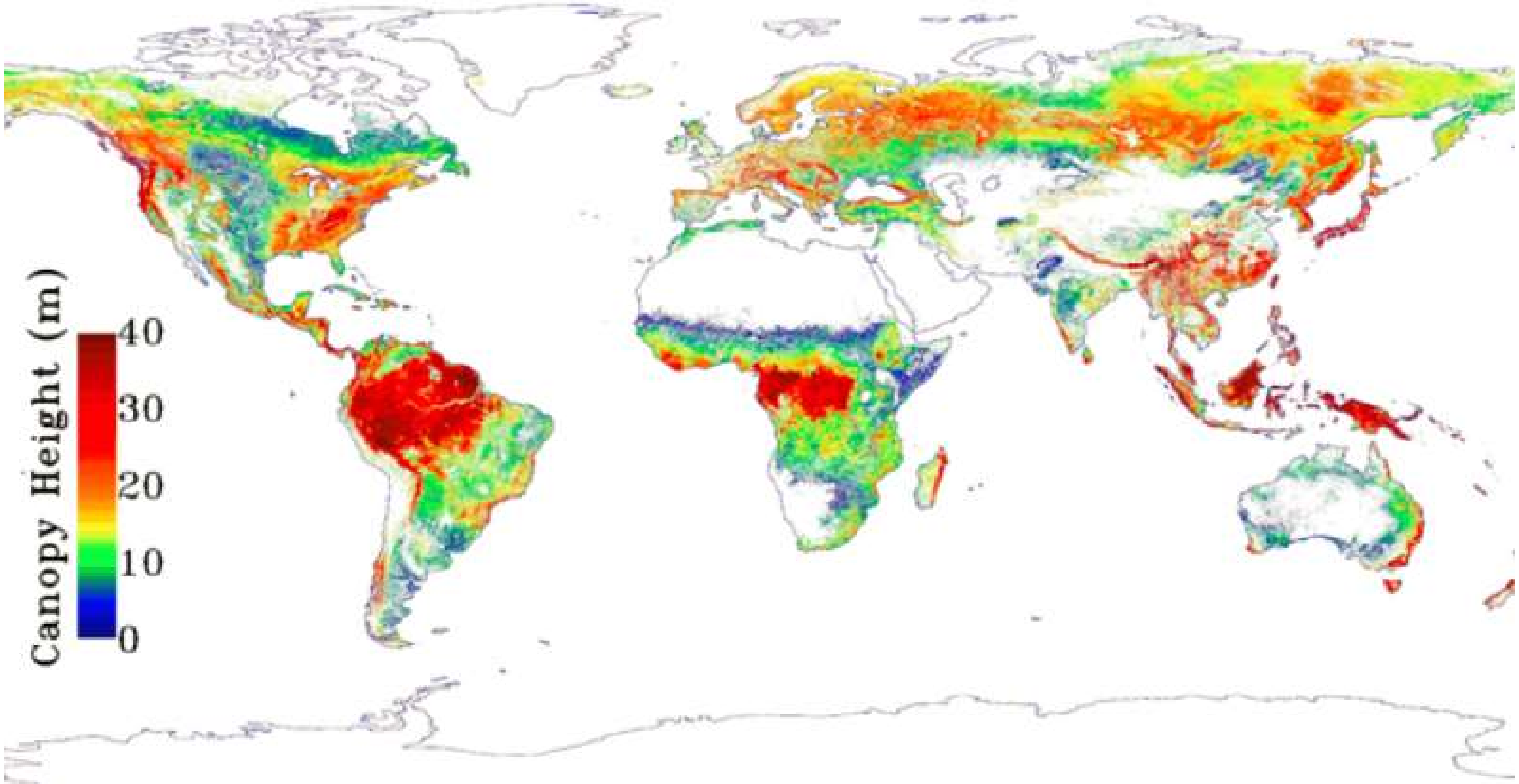


Image Source: https://climate.nasa.gov/news/693/watching-the-planet-breathe/

Frankenberg et al 2011 *GRL*; Joiner et al 2011 *Biogeo*; Zhang et al 2016, *Rem Sens. Env*.

REMOTE SENSING PRODUCTS

Global forest canopy height

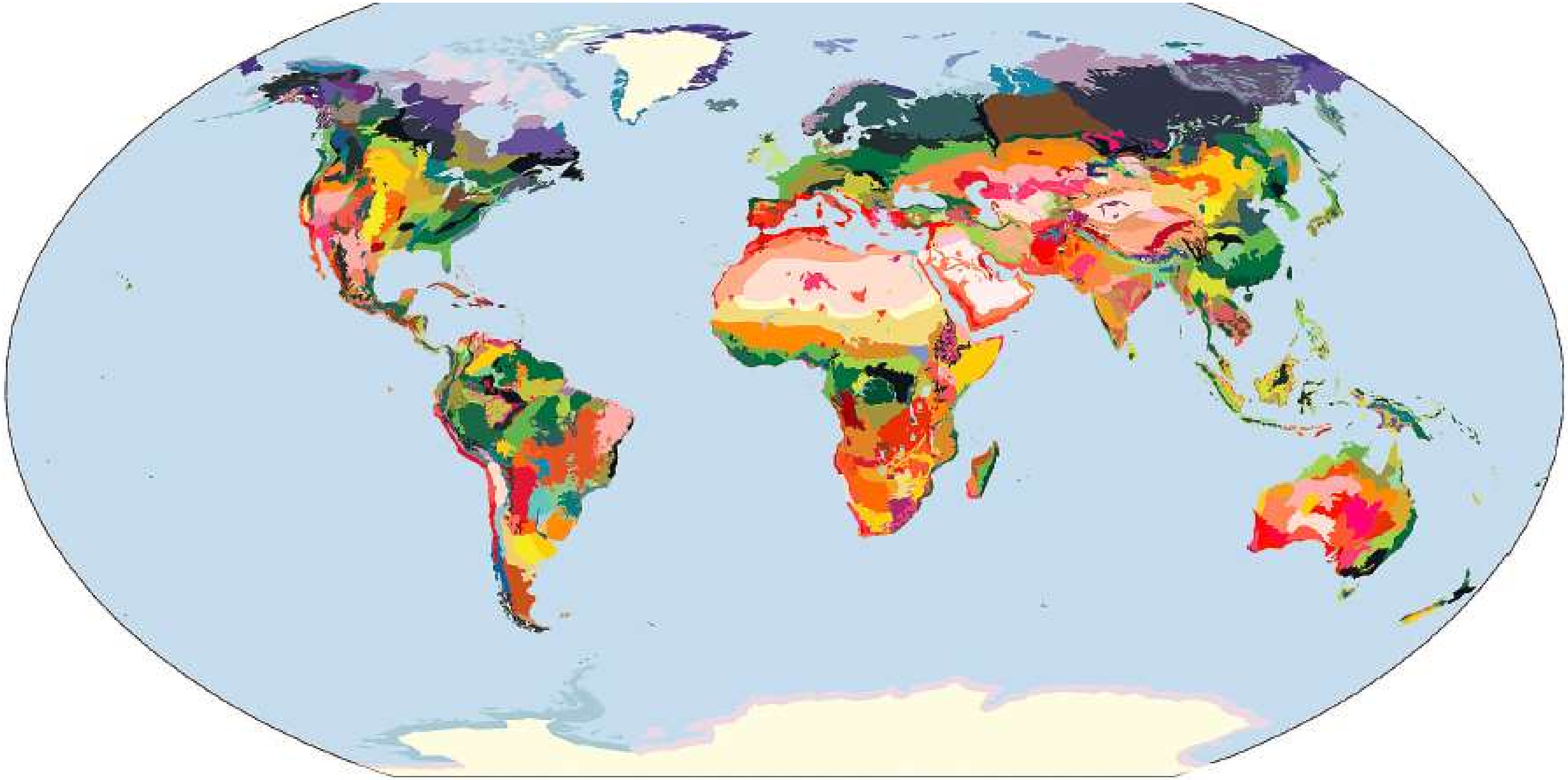


Lefsky 2010, *GRL*; Simard et al 2011 *JGR*

- **LIDAR estimates of carbon stocks**

OTHER PRODUCTS

Terrestrial Ecoregions of the World



867 Distinct Units

Olson et al. 2001 *Bioscience*


Thanks for your attention !