Vegetation modelling

Syllabus

Written By

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Contents

Chapter 1

Introduction

1.1 Soil-plant-atmosphere continuum: the central role of vegetation in the earth system

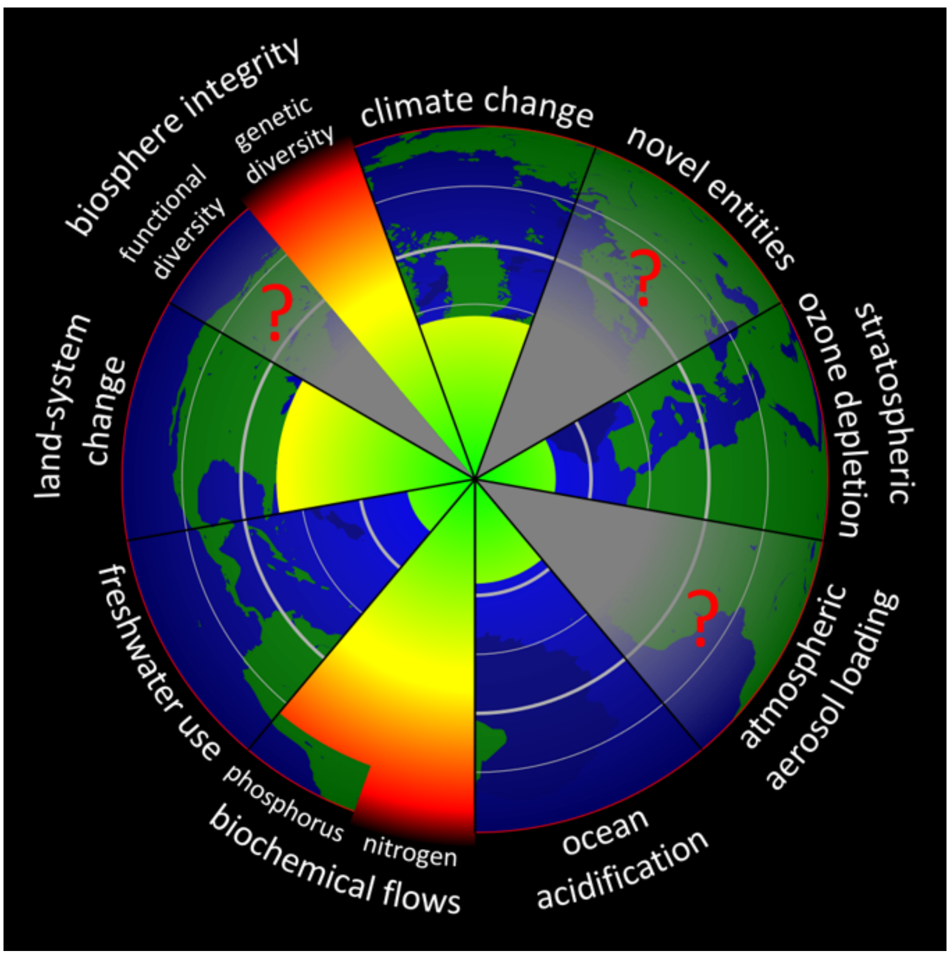


Figure 1.1: The planetary boundaries (www.stockholmresilience.org)

- Global change context
- Terrestrial ecosystems are central to solving the environmental and socioeconomic threats posed by changes in climate, atmospheric composition, and air quality; land use and land-cover change; habitat loss, species extinction, and invasive species; appropriation of freshwater, net primary

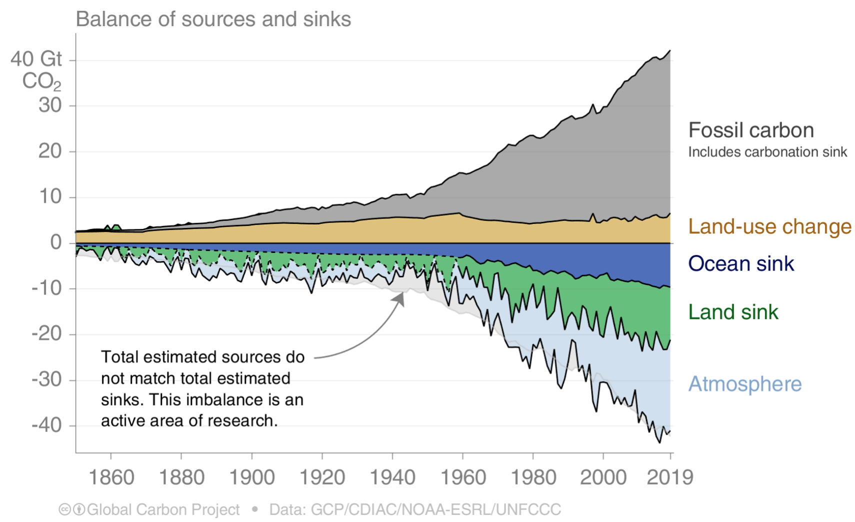


Figure 1.2: The global carbon budget (www.globalcarbonproject.org)

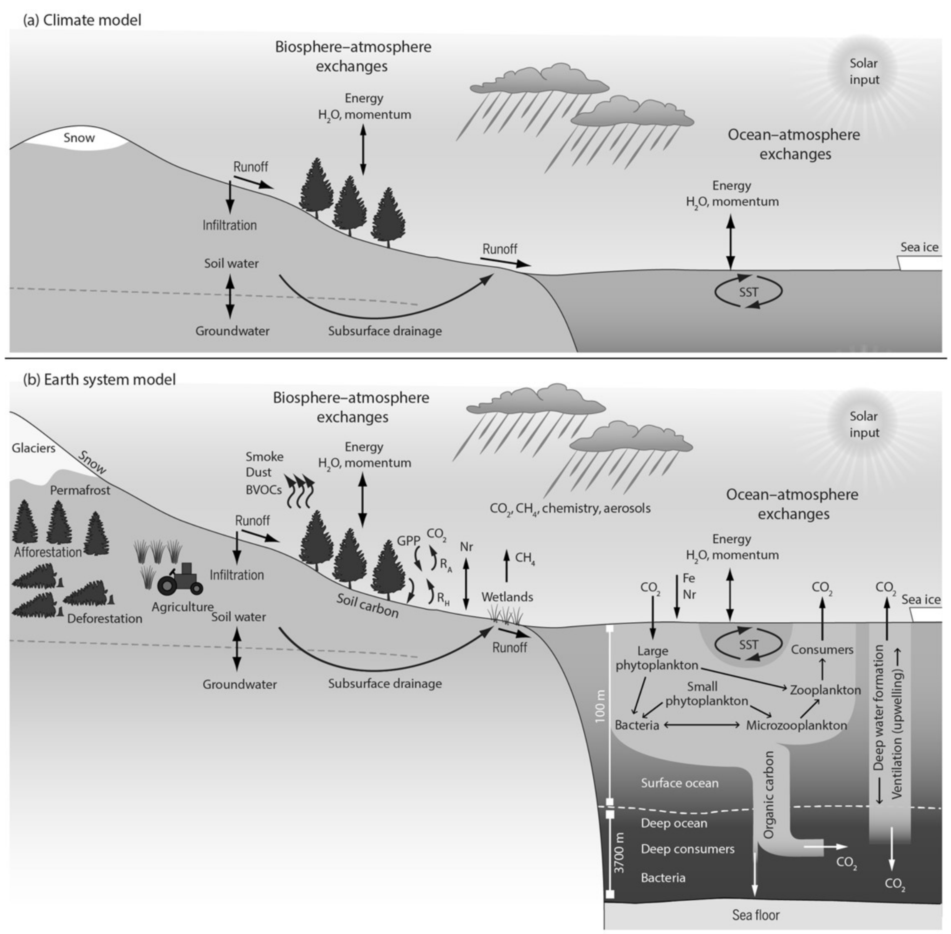


Figure 1.3: Scientific scope of (a) climate models and (b) earth system models. (Bonan 2019)

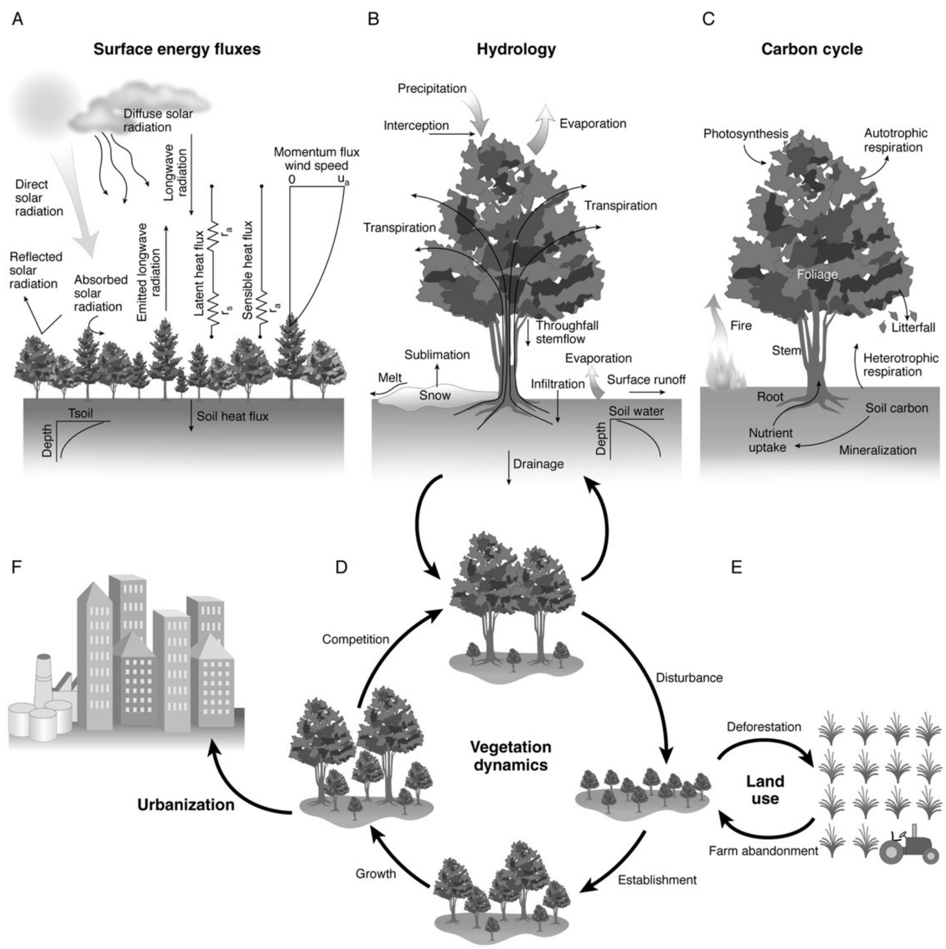


Figure 1.4: Scientific scope of terrestrial biosphere model. (Bonan 2019)

production, and other ecosystems goods and services for human uses; and anthropogenic addition of reactive nitrogen. (Bonan)

- Earth System Models and climate models (Fig 1.1 Bonan). In climate models vegetation is just representing physical fluxes, in ESM vegetation is representing biogeochemical cycles, biogeography, and dynamic vegetation – typically the realm of ecosystem models
- Land component continuum of terrestrial ecosystem models (vegetation models) (Fig 1.7)

1.2 Why do we need modelling?

- Devising suitable solutions to these global change challenges require not only strong empirically and experimentally based research at the local scale to understand how ecosystems are structured and how they function, but also sound theoretical foundations to generalize this understanding to regional, continental, and global scales and to make projections of the future. Computer models of terrestrial ecosystems are essential to this generalization. (Bonan)
- For prediction: study system behavior in conditions beyond which measurements can be made; to allow predictions of system behavior, especially in response to some imposed perturbation; and to inform management and policy decisions. These usages of models are particularly important in the context ofglobal change.
- For understanding: a formal organization of understanding; it originates from the knowledge of its developers about how the system operates. One purpose of modeling, then, is to identify the processes needed to adequately simulate the system. If a model replicates some observations, a scientist must ask why the model works correctly. If the model performs poorly, then the scientist must ask what is missing. It is testing hypotheses, just like you do with physical experiments.
- For data integration: to organize and link data in a structure way, as a research tool to guide data collection. What are the critical parameters that need to be measured? How precisely must these parameters be measured to reduce model uncertainty? What new observations are needed to test the model? In this context, models inform data collection and experimental design to both test the model and advance process understanding.

1.3 Model types

Type of model	Description	Example
Biogeochemical	Ecosystem model with emphasis on biogeochemical pools and fluxes	CASA, BIOME-BGC, CENTURY
Forest gap models	Individual trees, population dynamics, demography, community composition	JABOWA, SORTIE
Ecosystem demography	As gap models but cohort based	ED
Dynamic Global Vegetation Models (DGVM)	Biogeochemistry, community composition, global biogeography	LPJ, LPJ-guess, ORCHIDEE, JULES, ED2
Land Surface Models (LSM)	Global models of the land surface, as part of climate models with focus on biophysical coupling with the atmosphere. They now include biogeochemistry, and vegetation dynamics → they became a DGVM	ORCHIDEE, JSBACH, CLM, FATES, ED2, …
Plant canopy	Multilayer models with focus on coupling leaf physiology and canopy physics	CANOAK, FORUG
Canopy- chemistry	Plant canopy models that include chemical transport	CAFE
Ecohydrology	Similar to LSM, but spatially explicit with river routing, lateral flow	RHESSy

Figure 1.5: Continuum of terrestrial biosphere/ecosystem models. (Bonan 2019)

- continuum of terrestrial ecosystem models, from models with emphasis on biogeochemical pools and fluxes, dynamic vegetation models with focus on individual plants or size cohorts, canopy models with focus on coupling leaf physiological processes with canopy physics, and global models of the land surface for climate simulation. (Table 1.1, Bonan)
- Continuum of empirical to process-based models

	Process-based	Empirical
Relationship type	Causal	Correlative
Relative comprehensiveness	More comprehensive	Less comprehensive
Incorporation of mechanism	Explicit	Implicit
Primary source of error	Unknown parameters and processes	Extrapolation
Model uncertainty	Higher	Lower
Data requirements	Higher	Lower
Spatial scale for calibration	Smaller	Smaller to larger
Spatial scaling of prediction	Smaller to Larger	Best at scale of calibration

Figure 1.6: Continuum of process-based versus empirical models. (Adams et al. 2013)

- Types of vegetation models (depending on the purpose, questions, scales) (e.g. timber, yield, biogeochemistry, …) (ecologists, foresters, climatologist, atmospheric chemists, hydrologist all have different vegetation models…)
- Compare vegetation models to for example species distribution models…

1.4 The history of vegetation models

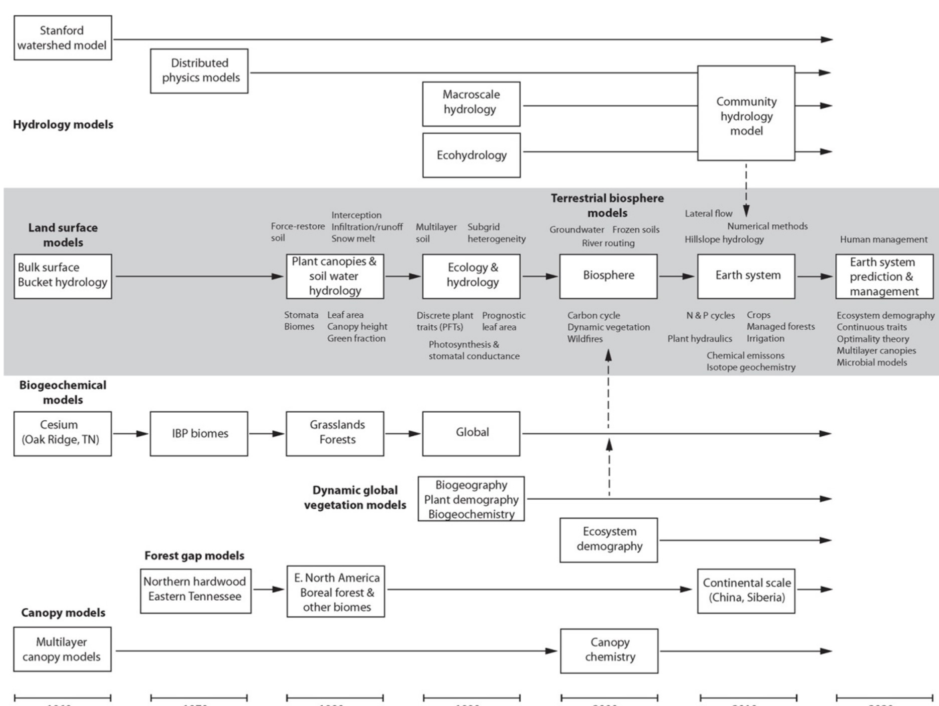


Figure 1.7: Timeline showing the parallel development of model types and the integration of model types into land surface models towards terrestrial biosphere models. (Bonan 2019)

- Conceptualisation of ecosystem to mass and energy flows among various compartments (refer to ecology course of Steppe in the Bio-ir Bachelors. 'box models in the 1960's and 1970's current global biogeochemical models are still box-type of models (Fig 1.4)
- In parallel individual based models of forest dynamics were developed, based on population dynamics, life cycle of species. They are also called "gap models" that simulate the demography in an area of 0.1 ha (size of a gap in the canopy) (Fig 1.5). Ecosystem properties such as carbon stocks are emerging from the demography simulation.

- More recently cohort based models
- DGVMs: These models also simulate changes in community composition, biomass, productivity, and nutrient cycling. Because the models are applied globally, they do not recognize individual species. Rather, they employ plant functional types, Table 1.2
- Fig 1.2 Bonan

1.5 Components of a model

Model component	Definition (syllabus)	Examples for a typical TBM
System boundary	What is in the system and what is out?	Lower atmosphere, deep soil
State variable	Time varying quantity	Carbon pools, soil water content
Model structure	The equations and connectivity	Photosynthesis equations
Parameters	Constants in process equations	Photosynthetic capacity, drought sensitivity parameter, …
Forcing inputs ('forcings')	Quantities needed to evolve the model state	Air temperature, radiation, …. (meteo), atm. CO_2 concentration
Initial conditions	State variables at model start-up	Carbon pools, soil water content
Model outputs	Quantities simulated by the model (state variables, fluxes,…)	Biogeochemical fluxes, dynamics of model states, …

Figure 1.8: Definition of key model components and examples for a typical TBM

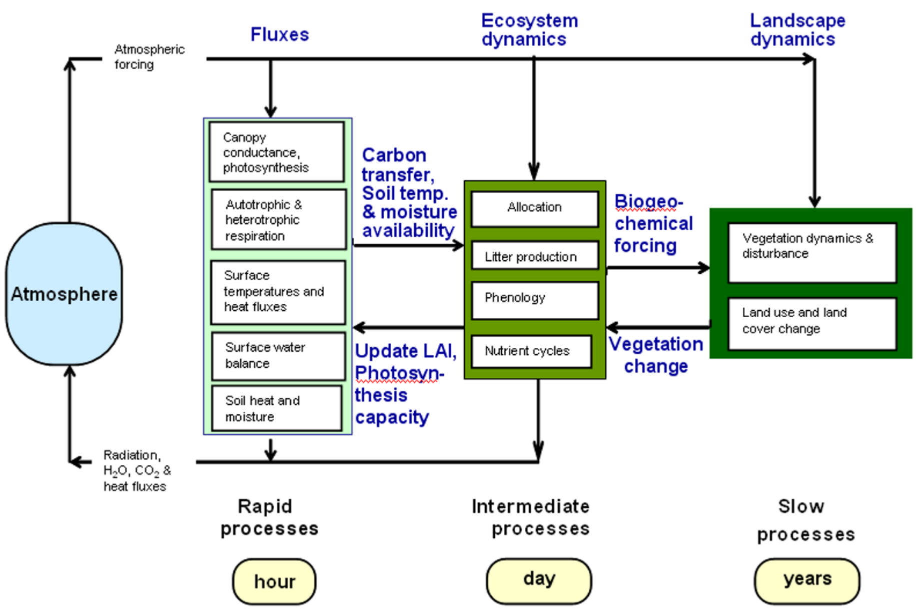


Figure 1.9: Structure of a vegattion model indicating the different time steps at which each process is simulated (Williams et al. 2009)

- Table 1.3 and Table 1.4
- Model structure (constraints: resolving of fluxes on short time scales, conservation of mass and energy,
- Parameters
- i/o variables, state variable
- time steps (fluxes must be resolved on a short time interval, diurnal cycles)
- spatial structure (Fig 1.11)
- Prognostic equations use time derivatives to describe the change in a state variable and are integrated forward in time from some initial condition. Prognostic variables must be numerically stepped forward from time n to n + 1 over the time interval deltat.

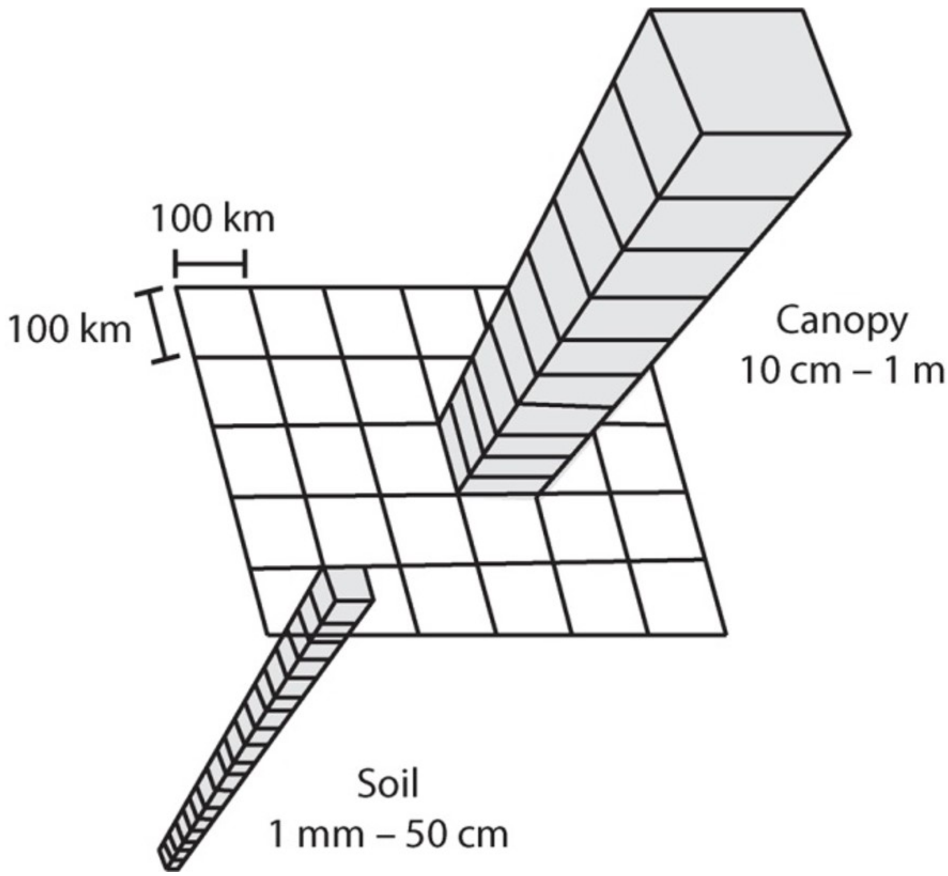


Figure 1.10: Three dimensional grid of a TBM structured in terms of longitude x latitude x level. The number of soil and canopy layers and the geographical resolution is model dependent, (Bonan 2019)

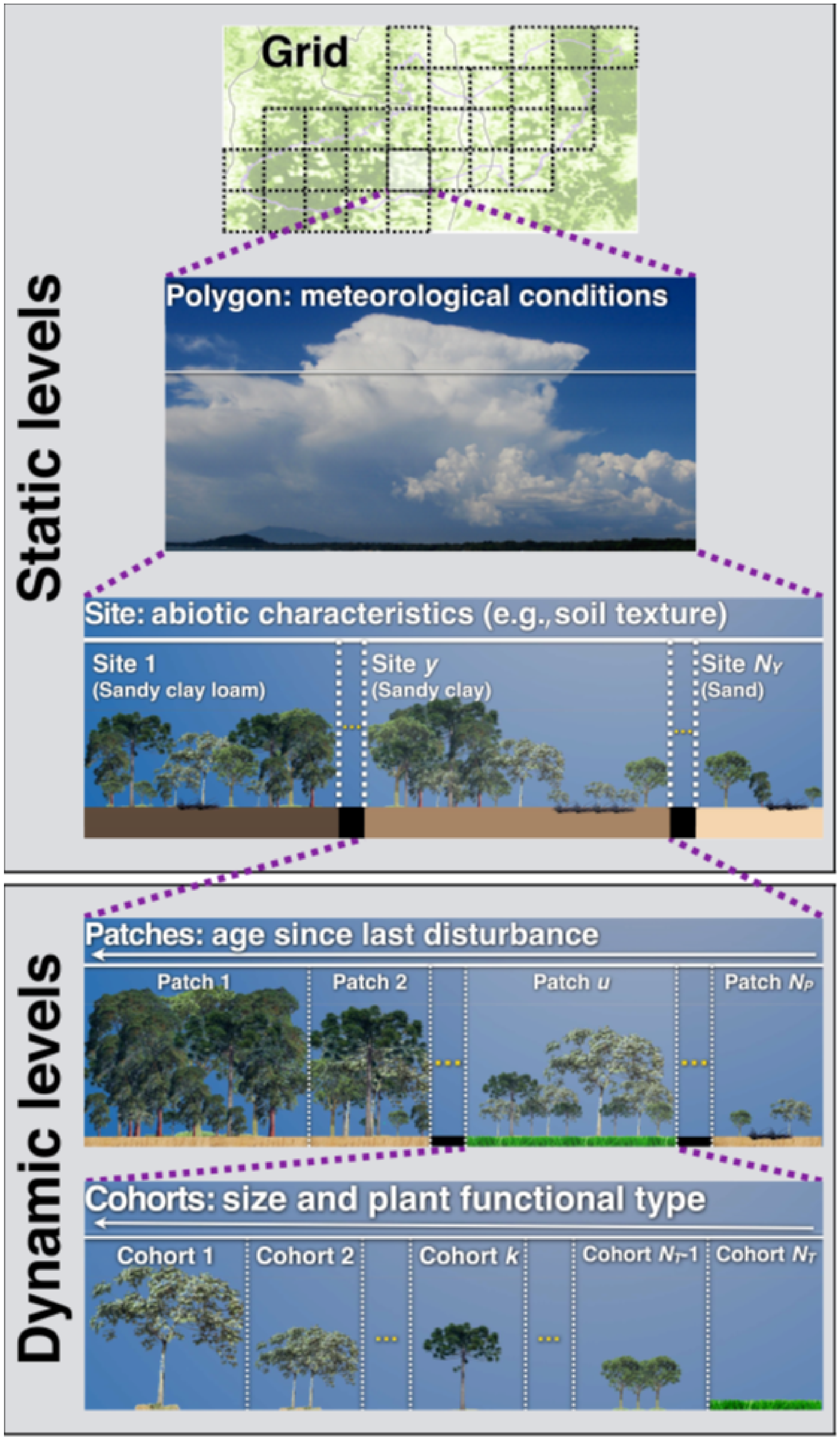


Figure 1.11: Example: the spatial multi-level grid structure of of the ED2 vegetation model (Longo et al. 2019)

- Conservation equations
- Diagnostic equations (e.g. ideal gas law) linking variables time-independent
- Initial conditions
- Model code, There is an enormous leap between seeing a mathematical equation in a research paper and actually using that equation in a model (Bonan Book).
- Model uncertainty and complexity (fig 1.12) (+ fig from Dietze book)

1.6 Modelling workflow and structure of the course

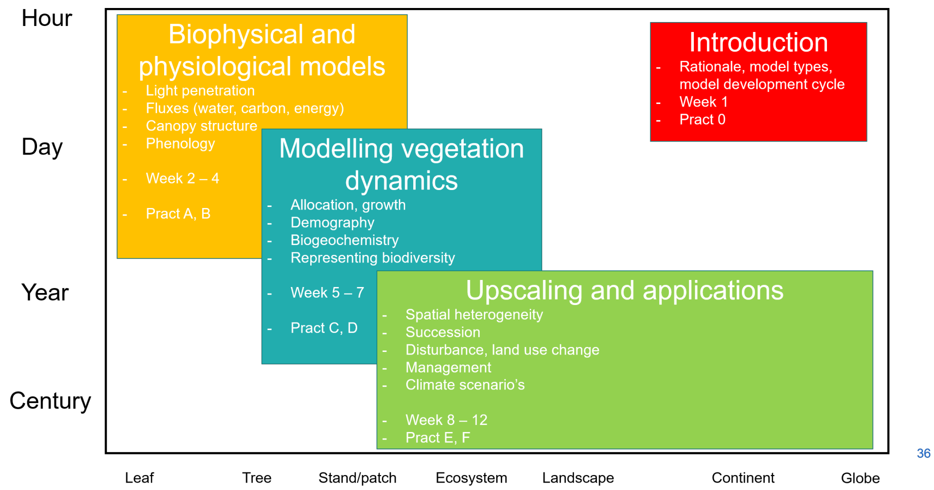


Figure 1.12: Progression through spatial and temporal scales throughout this course

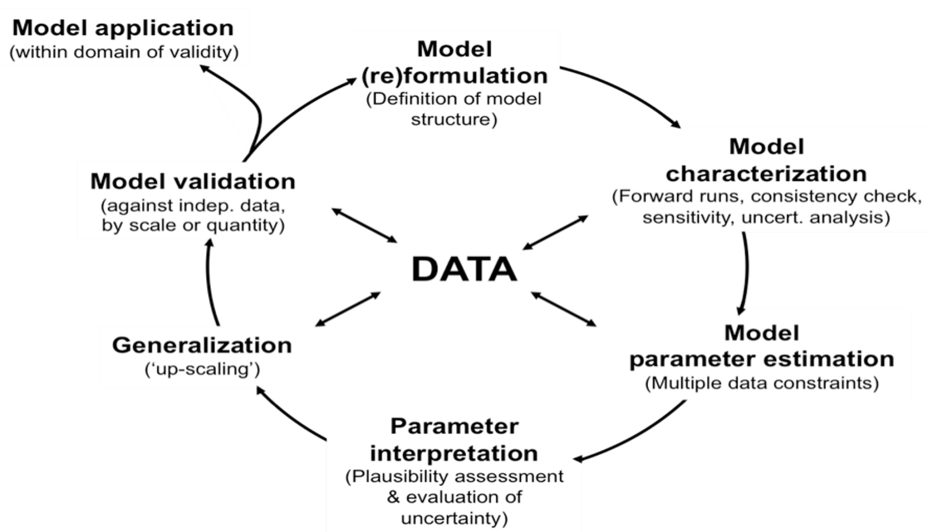


Figure 1.13: Model data fusion in every step of the model development cycle (Williams et al. 2009)

- a science that spans boundary layer meteorology, micrometeorology, atmospheric chemistry, plant physiology, ecosystem ecology, biogeochemistry, soil science, hydrology, and geochemistry … we will not discuss all the basics in this course, but we expect you to know from other courses (Ecology, plant physiology, forestry, hydrology, soil science …), but we will of course go into the processes, but focus on there mathematical formulation and translation into a workin model (code)
- progression through the course (space-time figure, with chapters)
- Model development cycle (structure for the methodological focus of each application/practical)

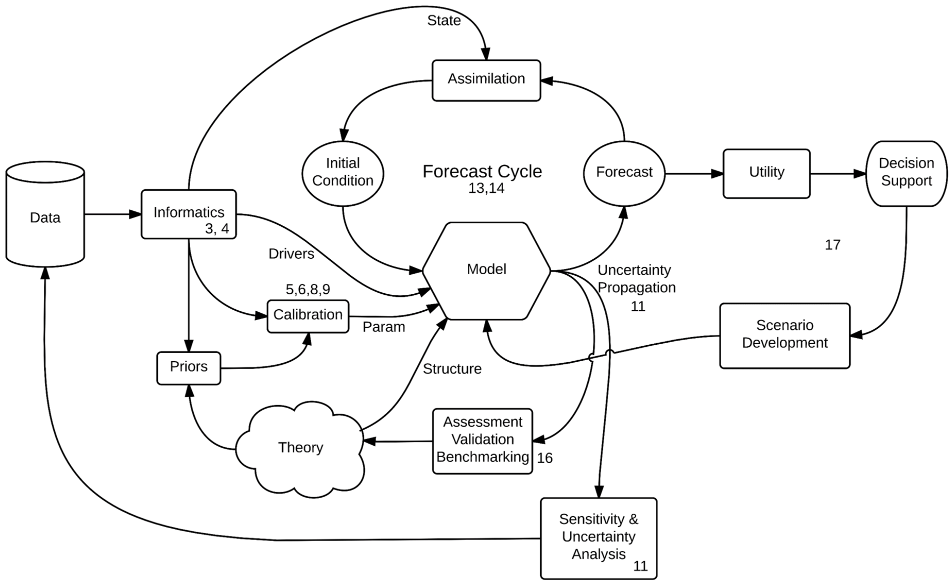


Figure 1.14: Methodological workflow of model data fusion (Dietze: Ecological Forecasting)

(Dietze figure)

to test: Idea of a conceptual figure that we will build block by block as we go deeper in the course. It represents the concept that vegetation modelling is to have an integrated representation of the plant functioning and all the underlying processes at different scales.

Part I

Biophysical and physiological models

Chapter 2

Modelling plant basic processes

For all processes, we provide an overview of existing models and approaches and we will detail only one of them for the practical course. This also apply for the other chapters, the idea of the course is to be more conceptual about how we model vegetation and the different applications and assumptions.

2.1 Photosynthesis models

2.1.1 Refreshing the basic knowledge

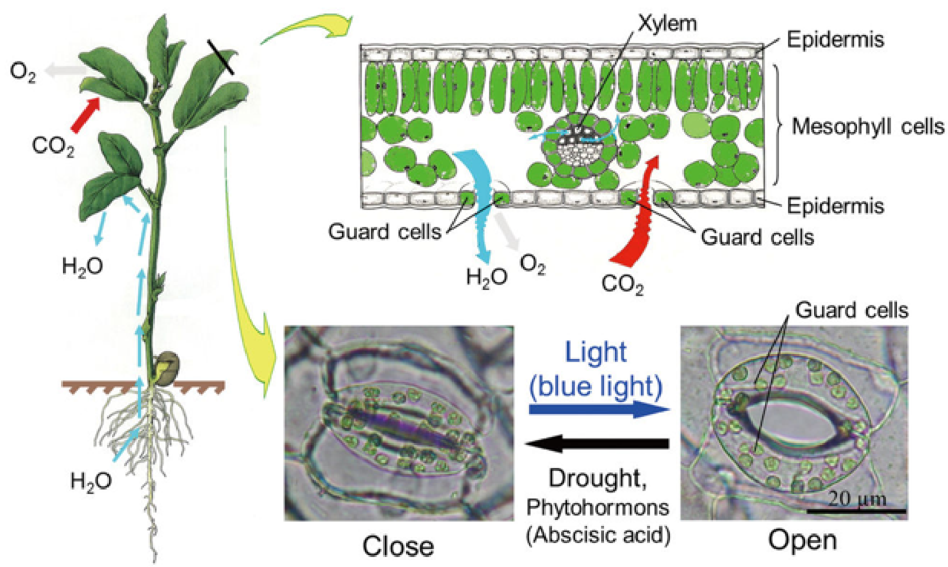


Figure 2.1: Leaf level processes transpiration and photosysnthesis are strongy interlinked and both regulated by stomatal conductance

2.1.2 C3 photosynthesis

2.1.2.1 Light response curve models

2.1.2.2 Light use efficiency models

2.1.2.3 The Farquahar model

- UCL 4.6.1

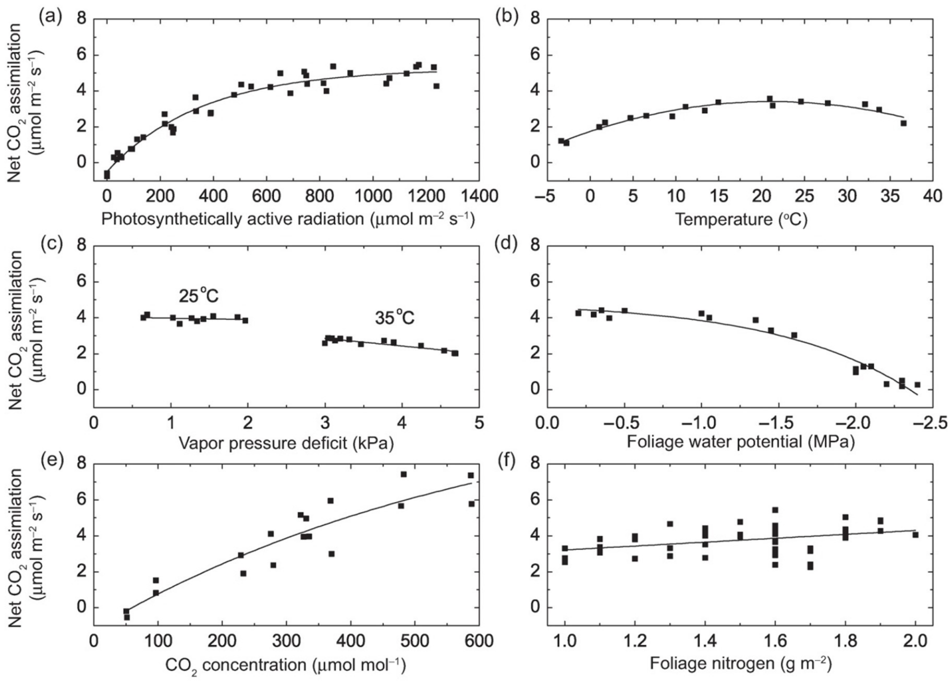


Figure 2.2: Photosynthesis in relation to (a) photosynthetically active radiation,(b) temperature, (c) vapor pressure deficit at 25°C and 35°C,(d) foliage water potential, (e) ambient CO2 concentration, and (f) foliage water potential for jack pine trees (Pinus banksiana). Bonan (2019)

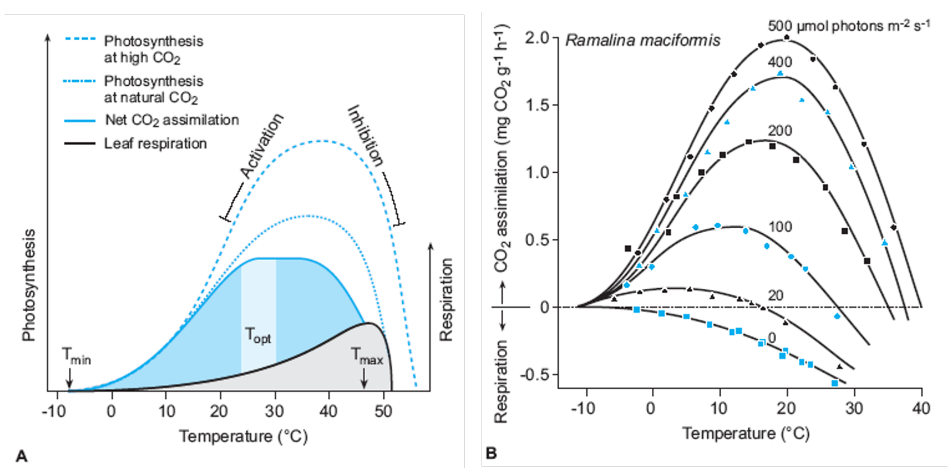


Figure 2.3: Temperature responses of photosynthesis, respiration and net CO2 exchange, interaction with CO2 concentration (A) and light (B) Schulze ()

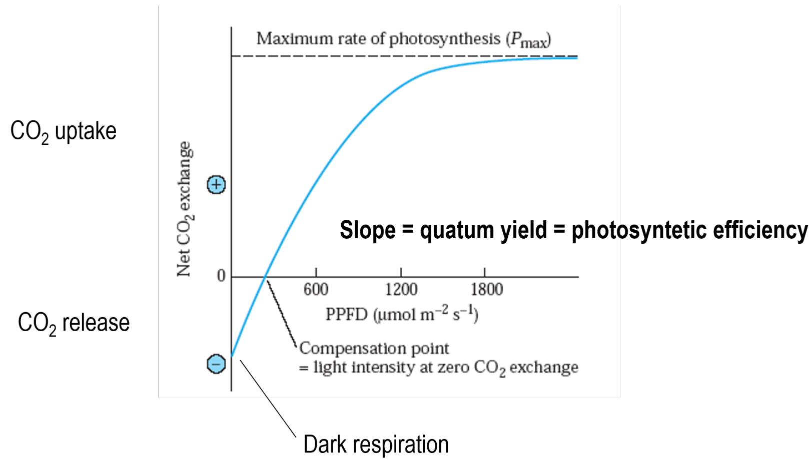


Figure 2.4: Conceptual figure of a leaf-level light reponse curve

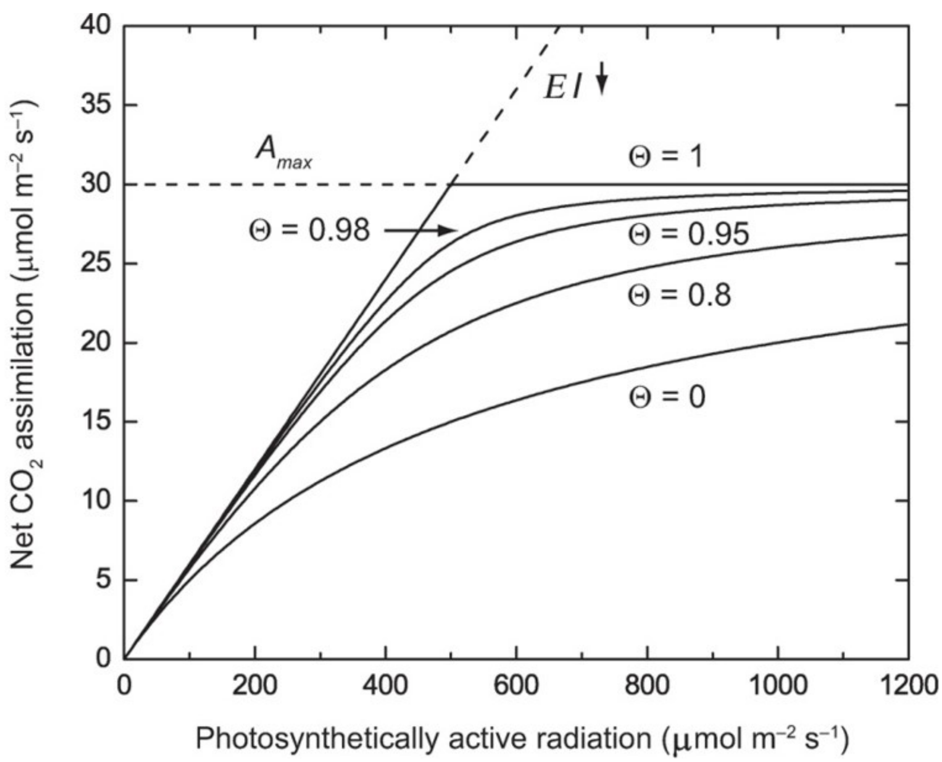


Figure 2.5: Co-limitation illustrated for photosynthetic response to light. The two dashed lines show the rates Amax adn EI The solid lines show the co-limited rate. (Bonan 2019)

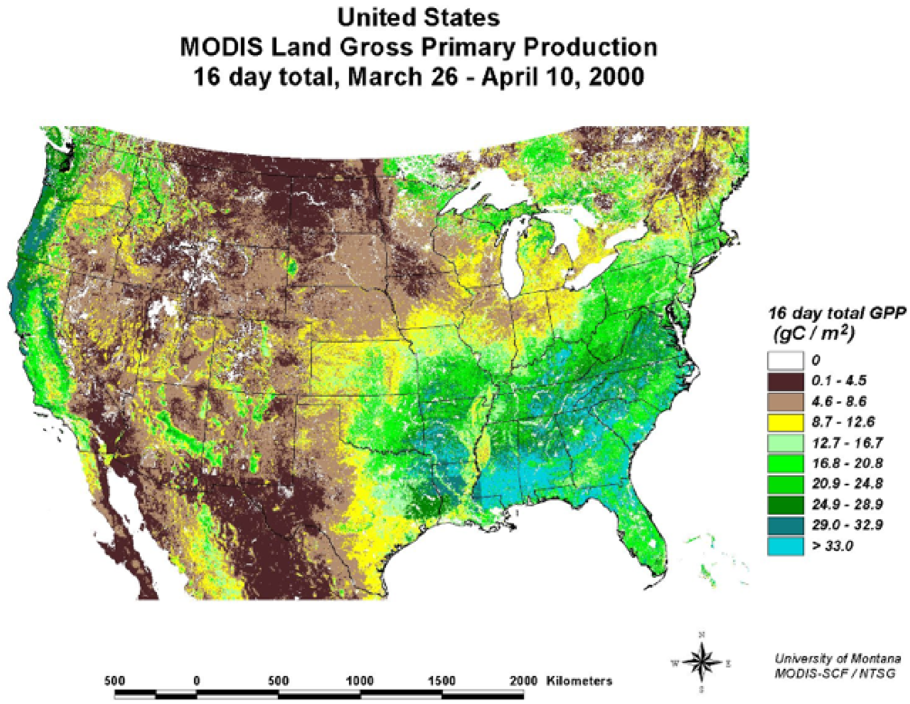


Figure 2.6: MODIS based GPP map of the US, based on a LUE model.

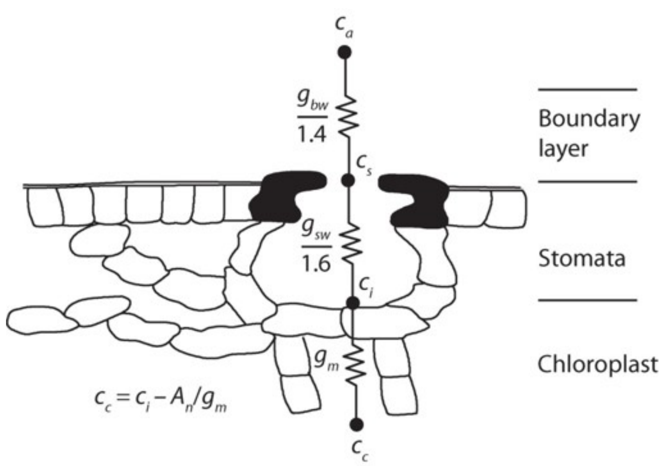


Figure 2.7: Diffusion of CO2 from free air across the leaf boundary layer and through stomata to the intercellular space. Diffusion to the chloroplast is additionally regulated by mesophyl conductance. (Bonan 2019)

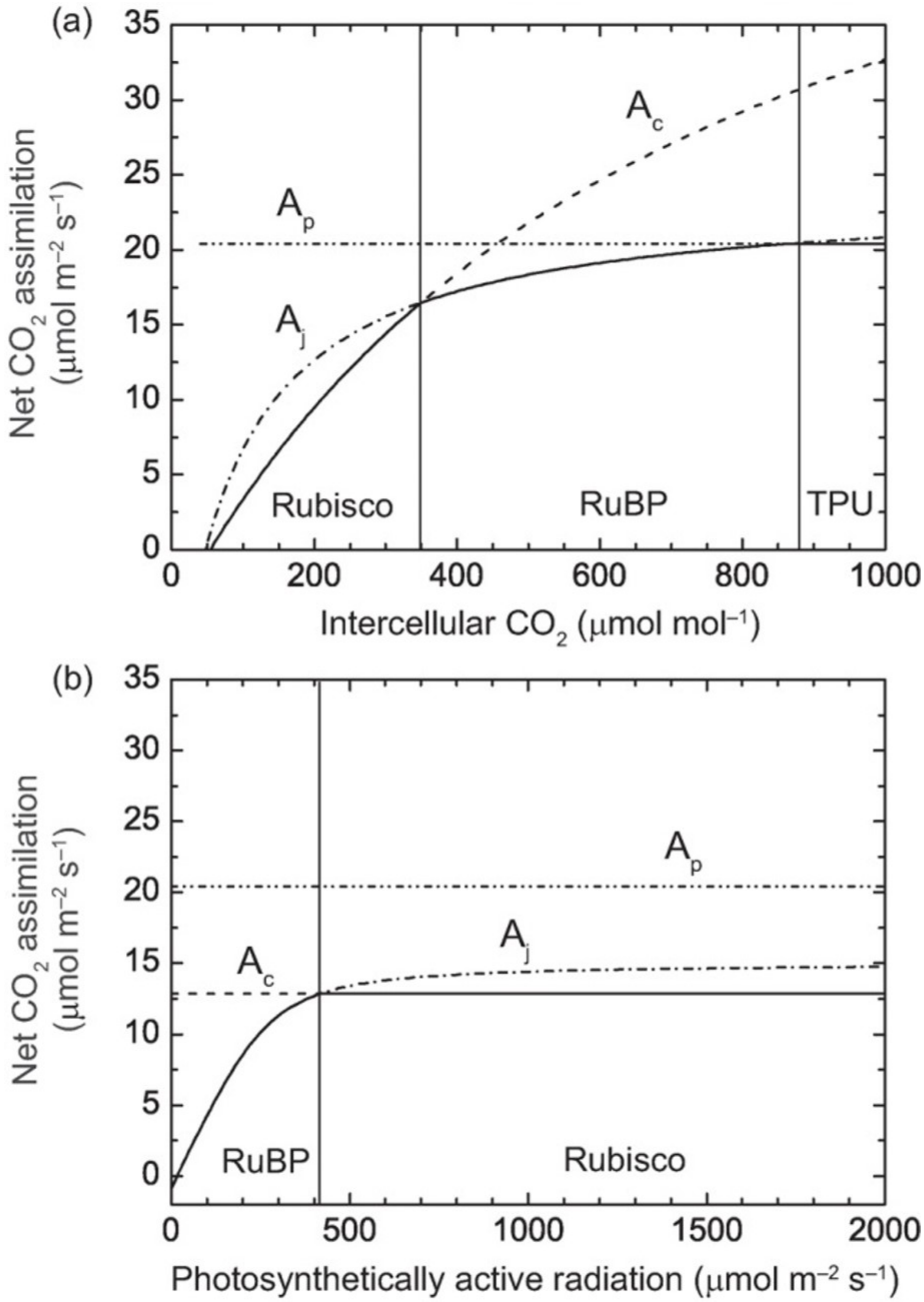


Figure 2.8: Simulated responses of C3 photosynthesis in relation to (a) intercellular CO2 (at I<U+2193> = 2000 µmol m–2 s–1) and (b) photosynthetically active radiation (at ci = 266 µmol mol–1). (Bonan 2019)

- Bonan, Chapter 11.1 The FvCB model Most equations between 11.1 and 11.31 Figure 11.2 a and b Table 11.1 for parameters values + a few simulations to illustrate Table 11.4

2.1.3 Parameter and temperature dependencies

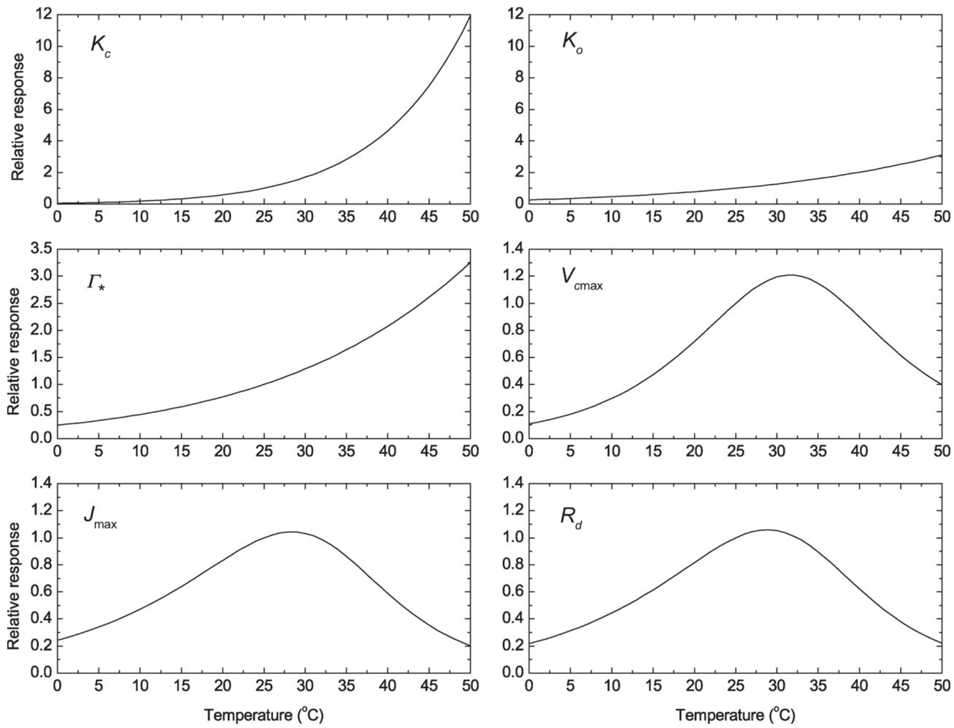


Figure 2.9: Relative temperature responses of the parameters of the Farquhar model (Bonan 2019)

- Bonan, Chapter 11.2 Equations 11.34-11.37 Table 11.2 Figure 11.3 for illustration

Summary with Table 11.5 and Figure 11.4

2.1.4 C4 photosynthesis

- Bonan, Chapter 11.7 PEP carboxylase Equations 11.69-11.74 Find an illustration

2.2 Stomatal models

2.2.1 Refreshing the basic knowledge

2.2.2 Empirical multiplicative models

- Bonan, Chapter 12.2

2.2.3 Semiempirical photosynthesis-based models

- Bonan, Chapter 12.3

2.2.4 WUE models and optimality theory

- Bonan, Chapter 12.4 + add optimality approach from Prentice et al.

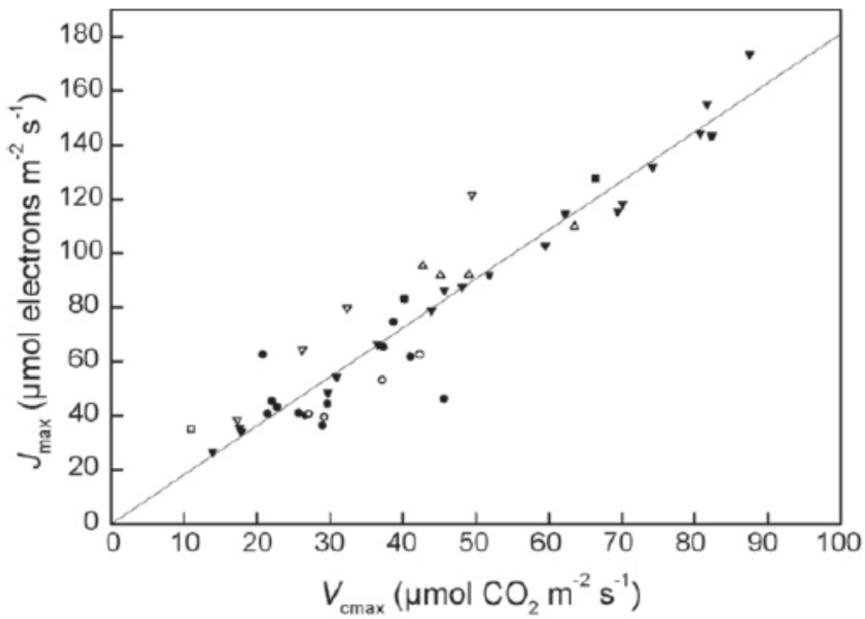


Figure 2.10: Linear relation between observed Vcmax and Jmax values for Beech (Verbeeck et al. 2008)

Definition	Equation
Rubisco-limited assimilation	$A_c = \frac{V_{cmax}\,(c_i - \Gamma_*)}{c_i + K_c\,(1 + o_i/K_o)}$
Light-limited assimilation	$A_j = \frac{J}{4}\left(\frac{c_i - \Gamma_*}{c_i + 2\Gamma_*}\right)$
Gross photosynthesis	$A = min(A_c, A_j)$ (no colomitation) $\Theta_A A^2 - (A_c + A_j)A + A_c A_j$ (colimitation)
Net photosynthesis	$A_n = min(A_c, A_j) - R_d$
Electron transport rate	$\Theta_j J^2 - (I_{PSII} + J_{max})J + I_{PSII} J_{max}$
PSII light utilization	$I_{PSII} = \frac{1}{2}\Phi_{PSII}\alpha_l I^{\downarrow}$
Maximum carboxylation rate	$V_{cmax} = V_{cmax25} \cdot f(T_l) \cdot f_H(T_l)$
Maximum electron transport rate	$J_{max} = J_{max25} \cdot f(T_l) \cdot f_H(T_l)$ $J_{max25} = 1.67 \cdot V_{cmax25}$
Leaf respiration	$R_d = R_{d25} \cdot f(T_l) \cdot f_H(T_l)$ $R_{d25} = 0.015 \cdot V_{cmax25}$
Michalis-Menten constant, CO_2	$K_c = K_{c25} \cdot f(T_l)$
Michalis-Menten constant, O_2	$K_o = K_{o25} \cdot f(T_l)$
CO_2 compensation point	$\Gamma_* = \Gamma_* \cdot f(T_l)$
Arrhenius function	$f(T_l) = exp\left[\frac{\Delta H_a}{298.15 \cdot R}\left(1 - \frac{298.15}{T_l}\right)\right]$
Hight temperature inhibition	$f_H(T_l) = \frac{1 + exp\left(\frac{298.15 \cdot \Delta S - \Delta H_d}{298.15 \cdot R}\right)}{1 + exp\left(\frac{T_l \cdot \Delta S - \Delta H_d}{T_l \cdot R}\right)}$

Figure 2.11: Equations of the full Farquhar model

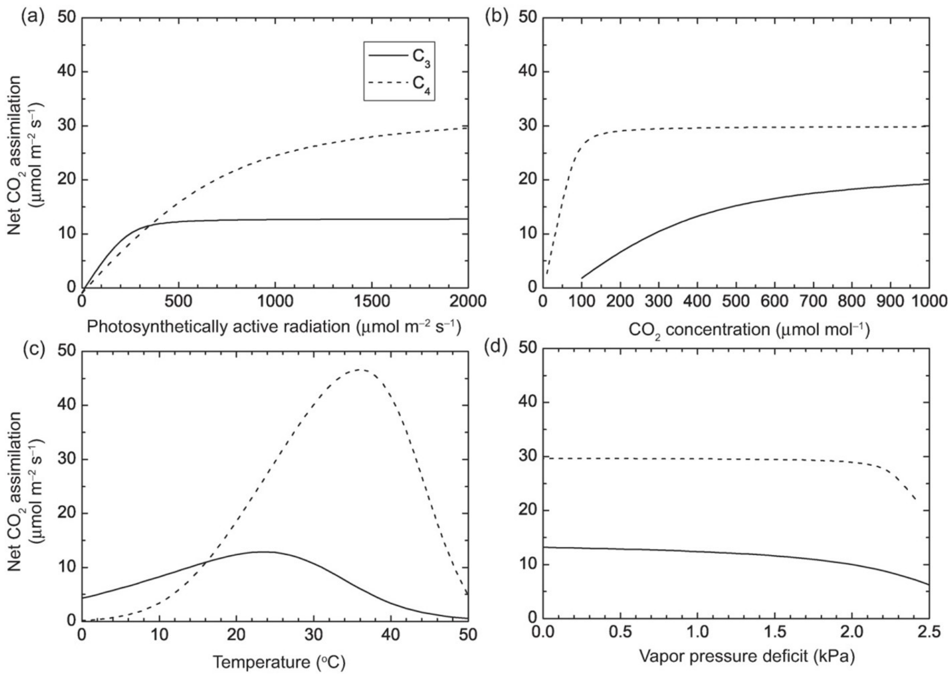


Figure 2.12: Comparison of C3 and C4 photosynthesis in response to (a) photosynthetically active radiation, (b) ambient CO2 concentration, (c) leaf temperature, and (d) vapor pressure deficit. In this figure, stomatal conductance is calculated using the Ball–Berry model and ci is obtained from the diffusion equation

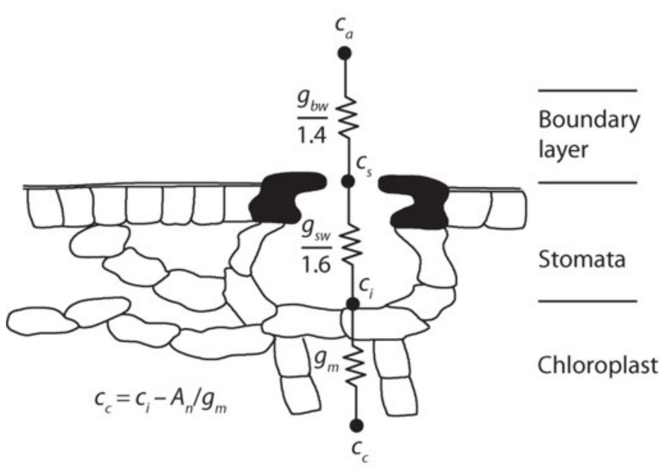


Figure 2.13: Diffusion of CO2 from free air across the leaf boundary layer and through stomata to the intercellular space. Diffusion to the chloroplast is additionally regulated by mesophyl conductance. (Bonan 2019)

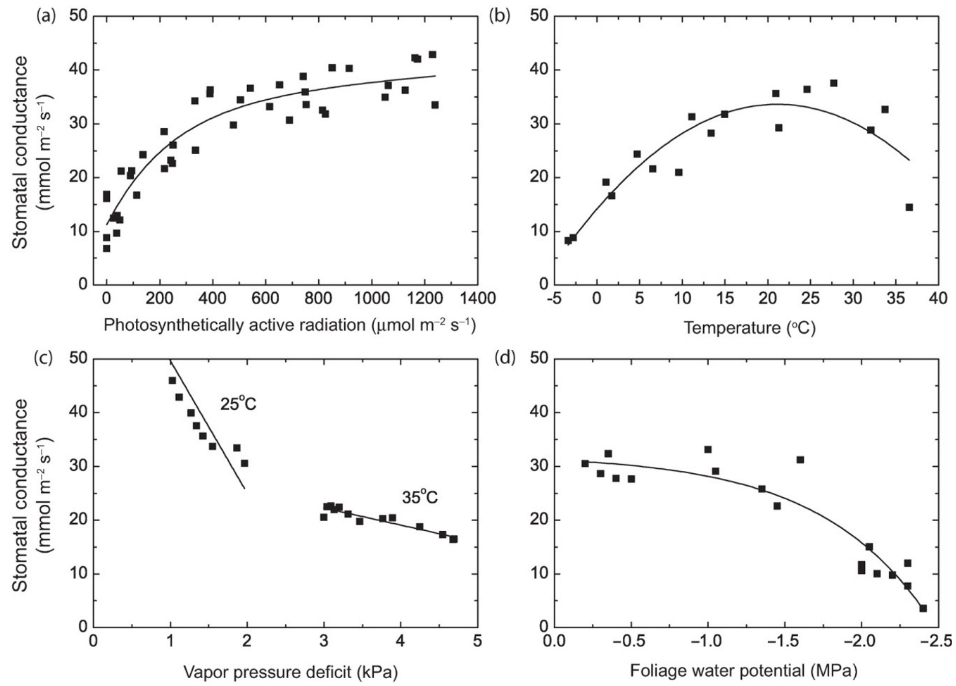


Figure 2.14: Observed responses of stomatal conductance for Pinus banksiana. (Bonan 2019)

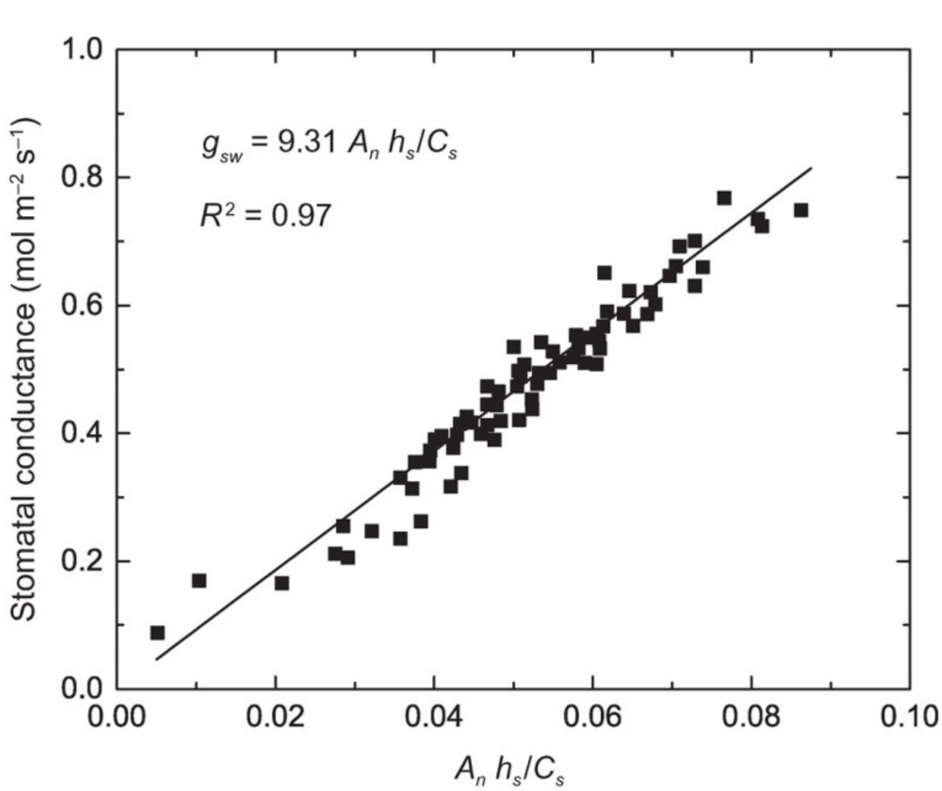


Figure 2.15: Relationship between stomatal conductance and Anhs/cs for soybean.(Bonan 2019)

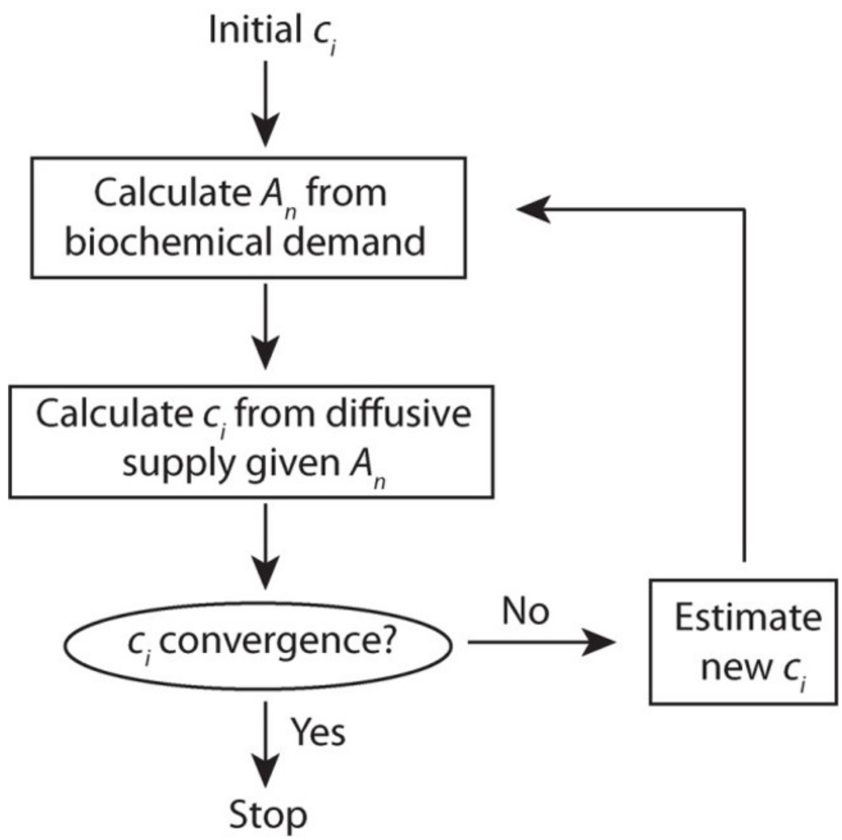


Figure 2.16: Flow diagram of the iterative procedure to numerically calculate ci.(Bonan 2019)

2.2.5 Soil drought stress

2.2.6 Hydraulic models

Figure 13.1 The soil-plant-atmosphere model Leaf water potential Plant water uptake Resistance analogy Multinode models

2.3 Upscaling from leaf to canopy

- Quickly introduce the problem of scaling in ecology (review paper of Jerome Chave) and refer to chapter 10 on upscalling
- Canopy integration: LAI layers, etc… Nice transition to chap 3 with the interception of light by the canopy

Leaf microclimate and boundary layer processes in relation to leaf dimension for sun and shade conditions.

2.4 Case studies

2.4.1 Case study 2.1 Ozone impact on global GPP

2.4.2 Case study 2.2 Drought impact on rainforest GPP

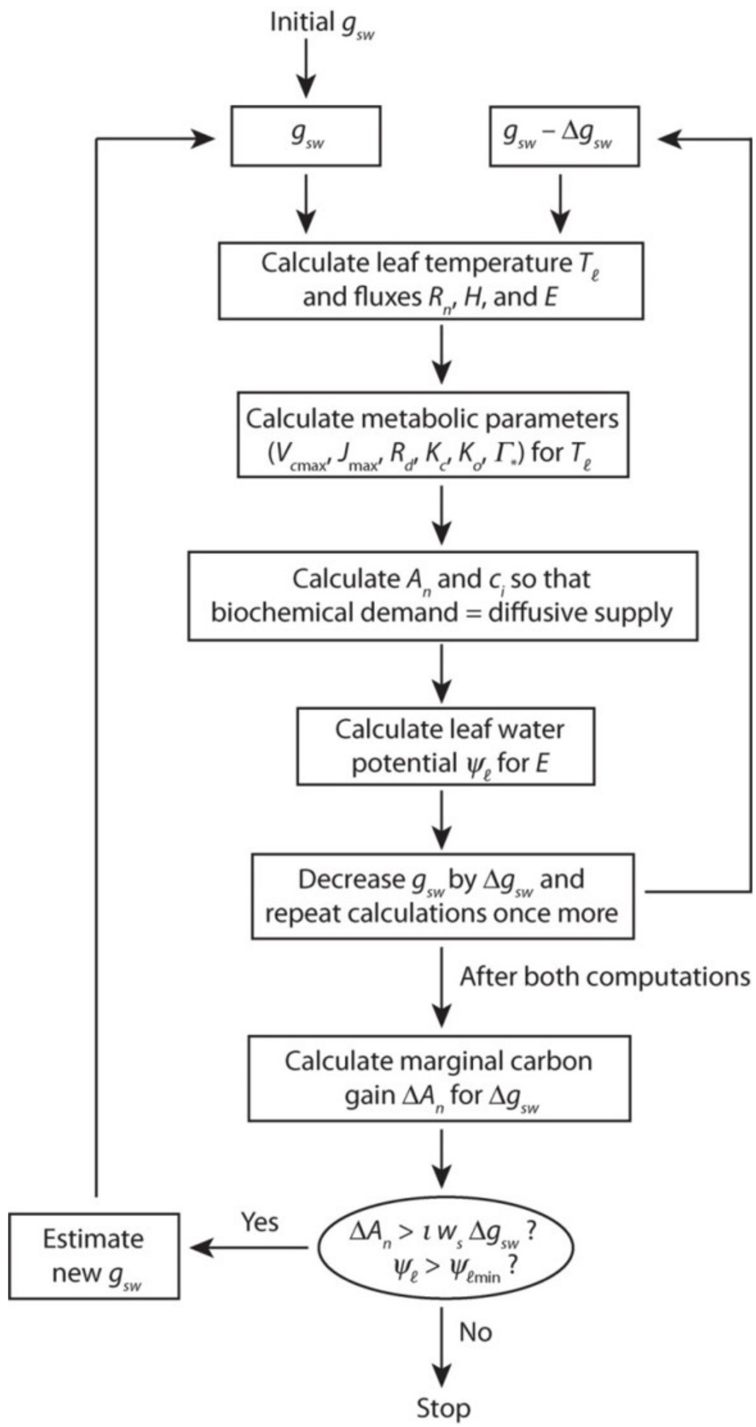


Figure 2.17: Flow diagram of leaf flux calculations to numerically solve for stomatal conductance that optimizes water-use efficiency.(Bonan 2019)

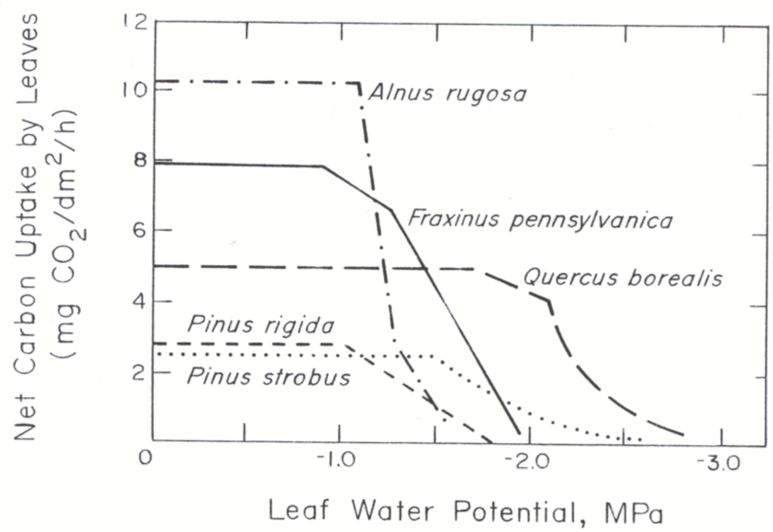


Figure 2.18: Leaf carbon uptake in response to leaf water potential for multiple tree species.

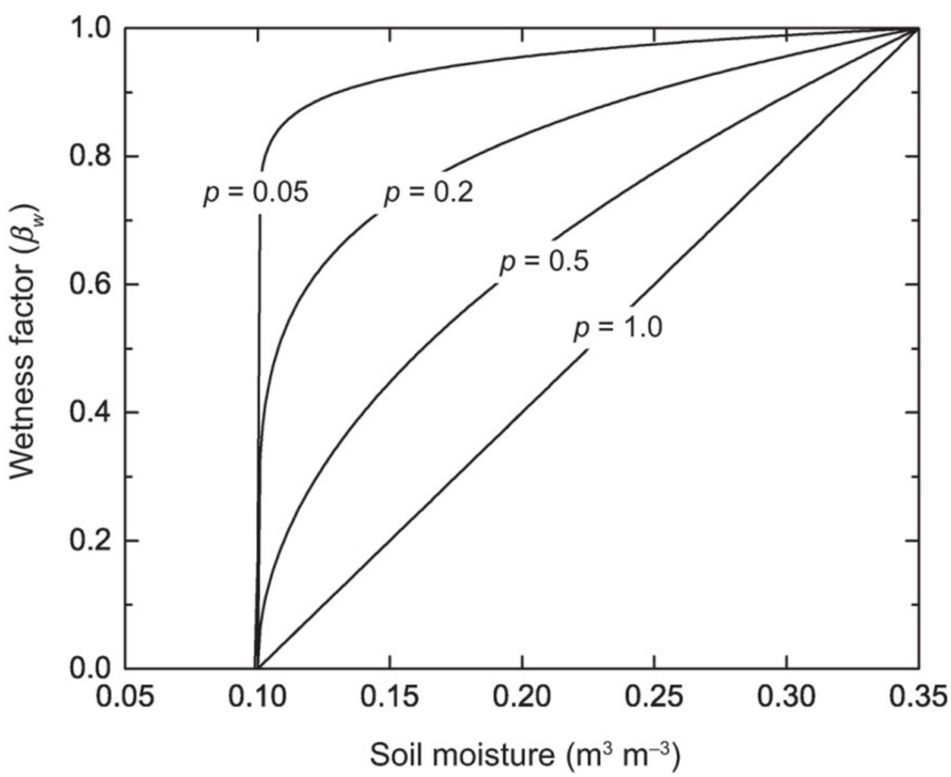


Figure 2.19: Soil moisture wetness factor in relation to volumetric water content. (Bonan 2019)

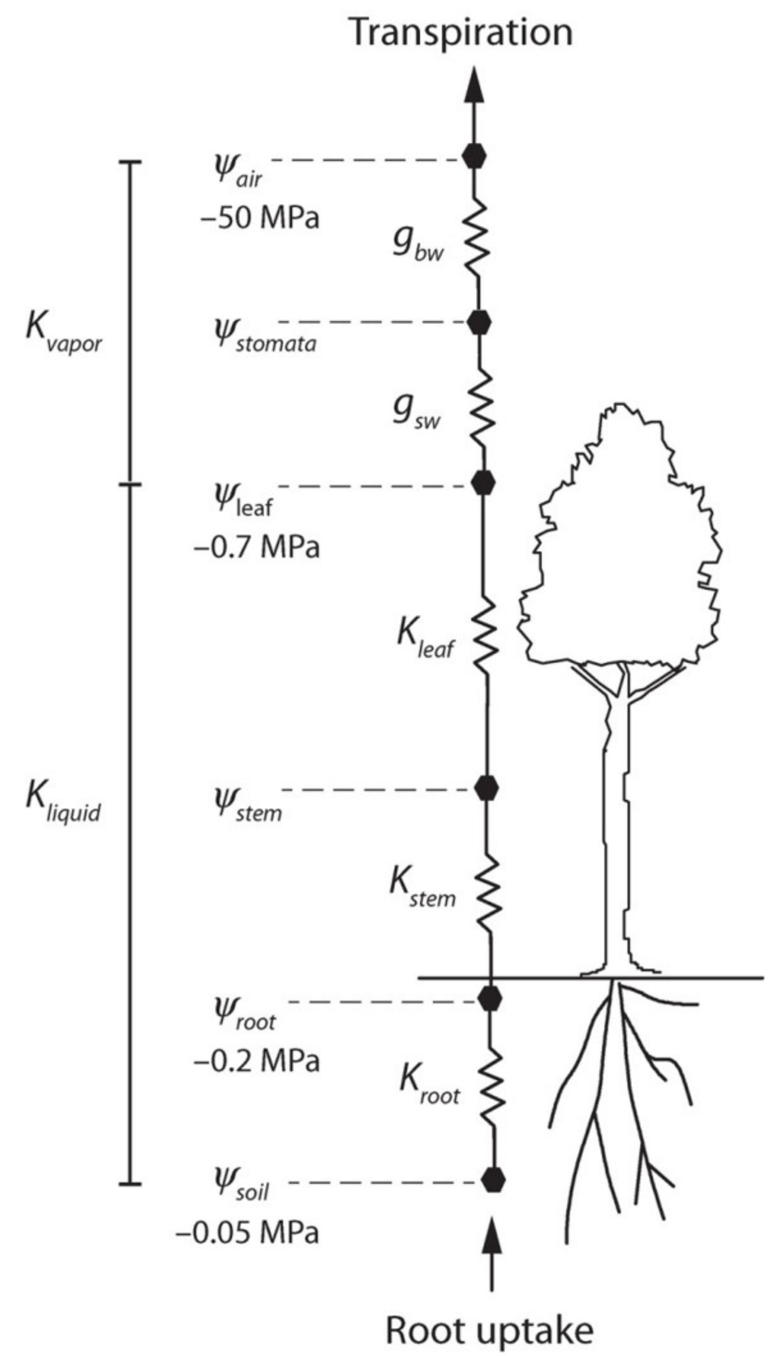


Figure 2.20: Flow of water and representative water potentials along the soil–plant–atmosphere continuum. Also shown are conductances along the hydraulic pathway.(Bonan 2019)

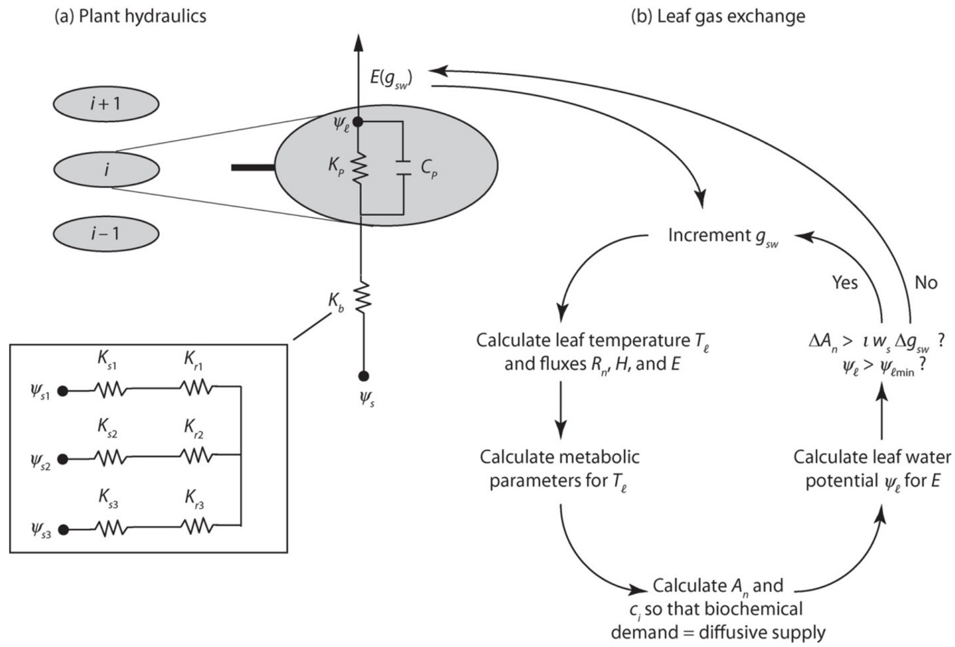


Figure 2.21: Depiction of (a) plant hydraulics and (b) leaf gas exchange in the Soil–Plant–Atmosphere (SPA) model. SPA is a multilayer canopy model.(Bonan 2019)

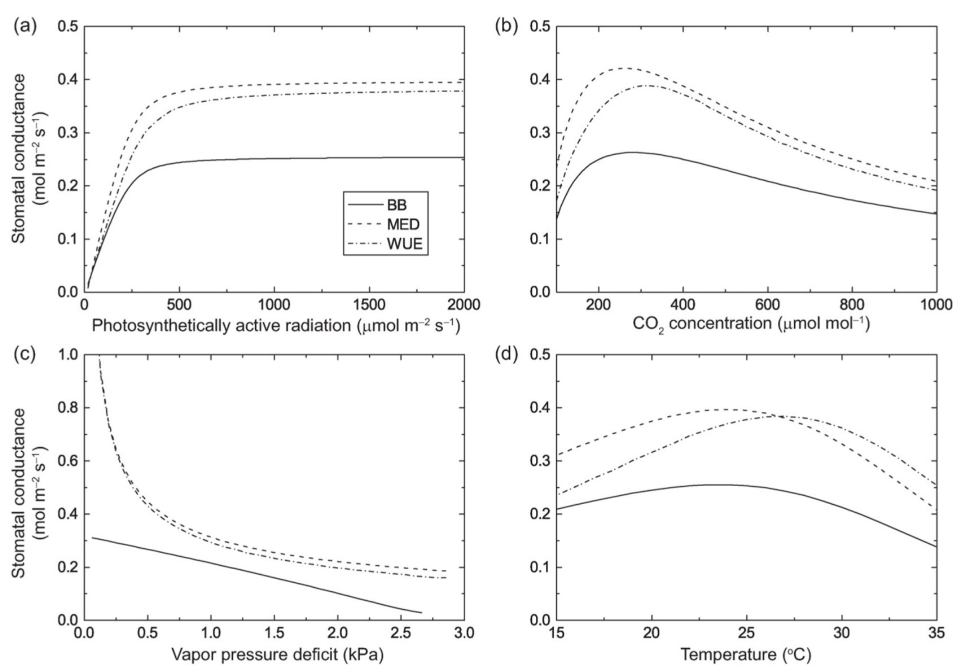


Figure 2.22: Simulated stomatal responses for various modelling approaches. (Bonan 2019)

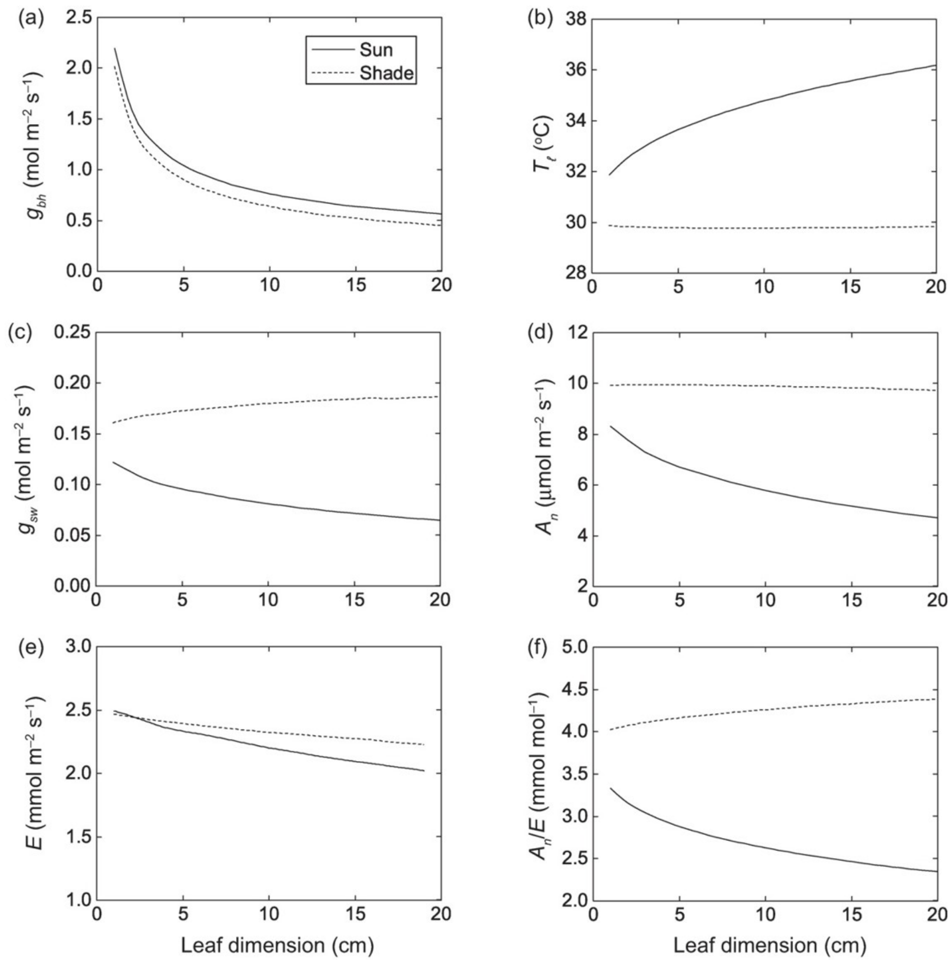


Figure 2.23: Leaf microclimate and boundary layer processes in relation to leaf dimension for sun and shade conditions.(Bonan 2019)

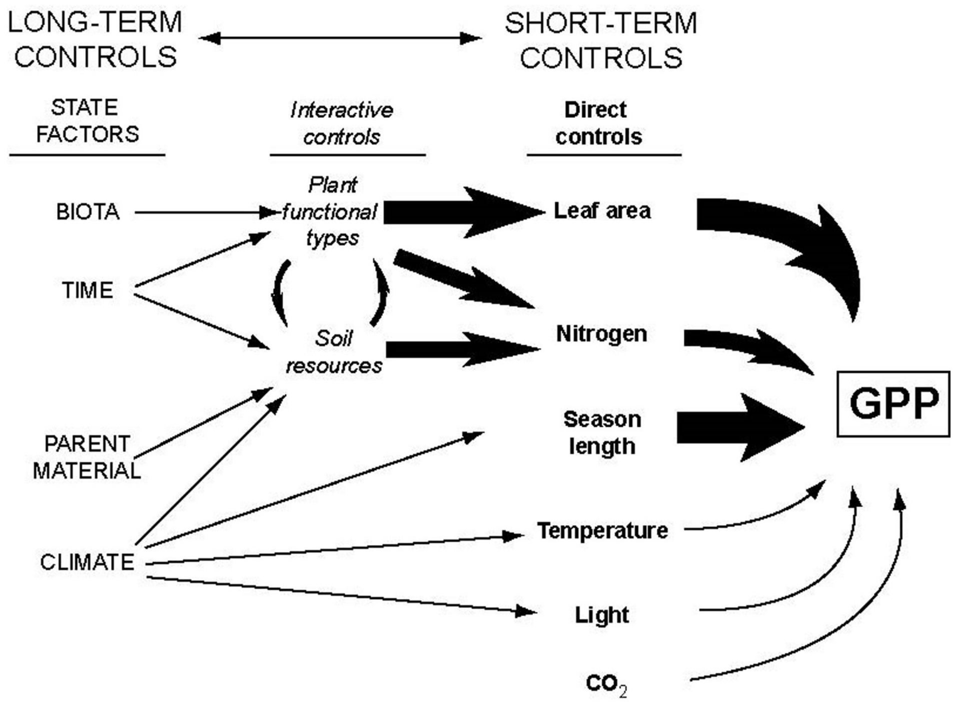


Figure 2.24: Controlling facors on ecosystem GPP. (Chapin)

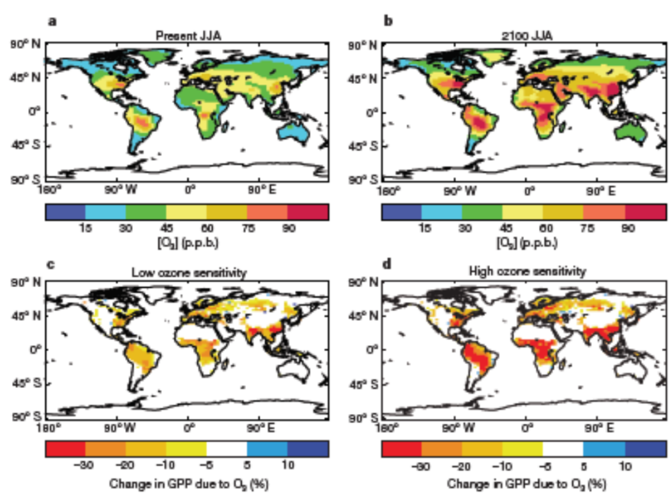


Figure 2.25: Simulated global GPP reduction in response to current and future atmospheric ozone concentrations

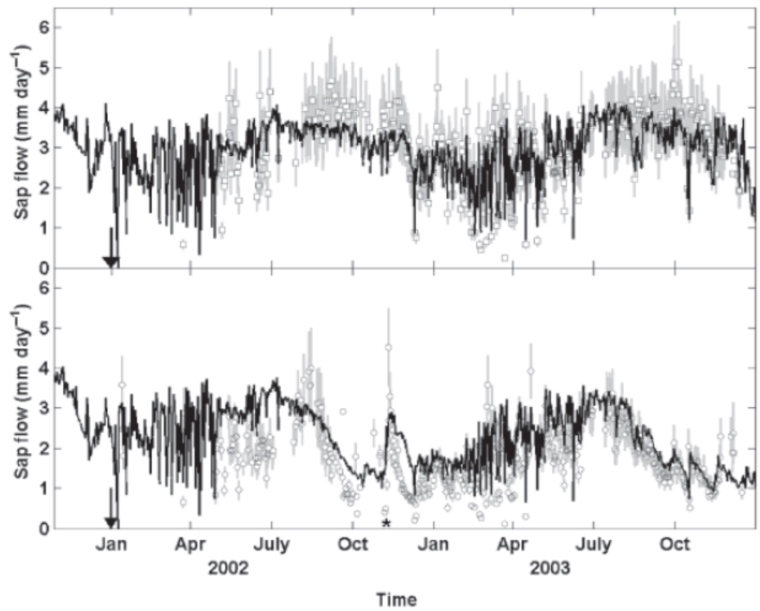


Figure 2.26: Simulated (SPA model) and observed sapflow for a drought experiment in the Amazon; Fisher et al. 2007

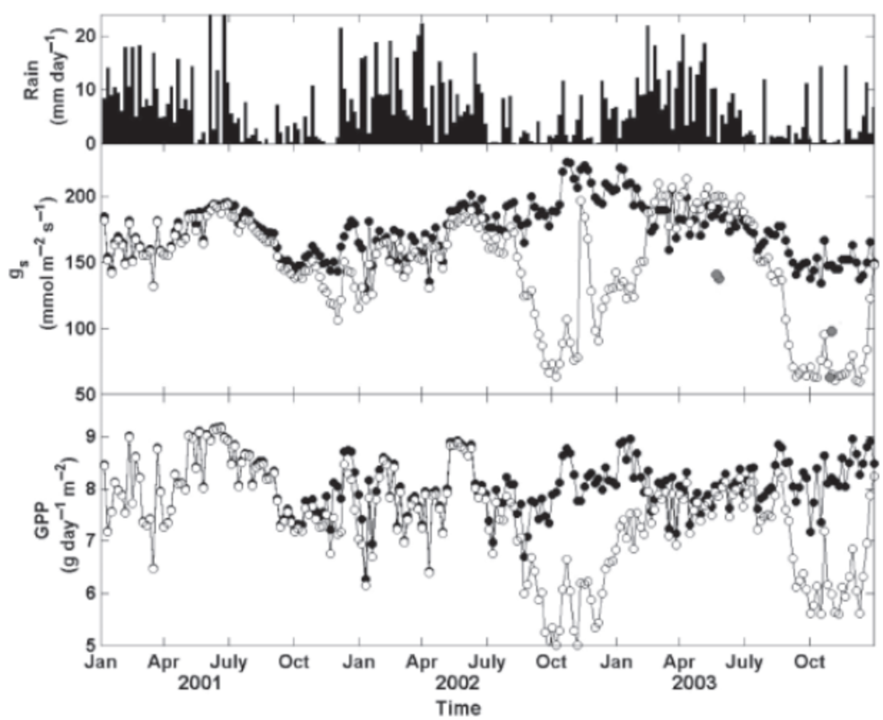


Figure 2.27: Simulated (SPA model) gs and GPP for a drought experiment in the Amazon. Fisher et al. 2007

Chapter 3

Modelling light penetration, vegetation canopy representation, and energy balance

- Mainly Chapter 14 from Bonan

3.1 Introduction

- Bonan, Chapter 14.1 Figure 14.1 Figure 14.2

3.2 Radiative transfer modelling

3.2.1 Leaf optical properties

- Bonan, Chapter 14.2 Example of leaf spectrum Prospect model Example of parameters 14.2 + simulations/analysis of sensitivity

3.2.2 Light transmission without scattering

- The Beer-Bouguer-Lambert law
- Bonan, Chapter 14.3 Most of quations 14.2-14.17 for model description Figure 14.4 and Figure 14.5

3.2.3 Direct beam extinction coefficient

- Could be skipped
- Bonan, Chapter 14.4

3.2.4 Diffuse transmittance

- Bonan, Chapter 14.5 Figure 14.12

3.2.5 The Norman Model

- Bonan, Chapter 14.6
- Numerical Figure 14.15

3.2.6 The Goudriaan and van Laar Model

- Bonan, Chapter 14.7
- Analytical Figure 14.16 + 14.15 and 14.17 for comparison with the Norman model

3.2.7 The Two-Stream approximation

- Bonan, Chapter 14.8 Figure 14.19 + simulations

3.2.8 Surface Albedo

- Bonan, Chapter 14.9 Figure 14.20 and Figure 14.21

3.2.9 Longwave radiation

- Bonan, Chapter 14.10

3.3 Representing canopy structure in models

3.3.1 Big-leaf models

- Bonan, Chapter 15.2

3.3.2 Multilayer models

- Bonan, Chapter 15.4

3.4 Ecosystem energy balance

- UCL 2.3 and 4.2
- Bonan, Chapter 7

3.4.1 Basic principles

- UCL 2.3.1 and 4.2.1

3.4.2 Atmospheric absoprtion

- UCL 2.3.2

3.4.3 Radiative forcing

- UCL 2.3.3

3.4.4 Land surface schemes

- UCL 4.2.3
- First, second and third generation models

Chapter 4

Temporal and seasonal dynamics

4.1 Phenology

- UCL 4.5.2 The study of life-cycle events. Here refers to the temporal dynamics of vegetation. Broader sense of phenology. Applies to most plant. Circadian to seasonal cycles Tissue turnover and senescence

4.1.1 The example of crop phenology

- UCL 4.5.1 Definition +Simple example of phenology (wheat for example: germination + spread + full coverage + allocation to storage organs + ripening)

4.2 Mechanisms of phenology and evidence of changes

- UCL 4.5.3

4.2.1 Overview of controls at different levels

- temperature
- light
- water
- Nutrients
- Drivers of seasonality and phenology

4.2.2 Vegeation index and changes over time

- This is also why phenology is a "metrics" of climate change

4.2.3 Seasonality feedbacks

- Phenology affects phenology (phenophases are linked, one perturbation will affect the next phenophase in the cycle)
- The control of phenology on climate: example, early spring leaf unfolding excacerbates drought in summer

4.3 Models of phenology

- UCL 4.5.4

4.3.1 budburst models

4.3.2 senescence models

4.3.3 Phenology in DGVMs

- Figures from Zhang et al. 2003

Part II

Modelling vegetation dynamics

Chapter 5

Modelling plant growth and biogeochemical cycles in vegetation models

- UCL 4.2.2

based on Bonan Chapter 17

5.1 Process-based growth modelling

5.1.1 C-allocation models

- C pools: Allocation to leaf, wood, fruit

5.1.2 Applications of growth modelling in forestry and agriculture

- short, link with inventory course

5.2 Carbon cycle models: stocks and fluxes

This chapter will develop the ecological foundation and mathematics to describe ecosystem carbon dynamics using biogeochemical models. Biogeochemical models abstract an ecosystem as pools of carbon and the flows of carbon among these pools.

Use specific model as an example to illustrate? In Bonan: CASA-CNP model

5.2.1 Model structure

Biogeochemical models simulate processes of allocation of photosynthetic carbon gain to plant parts (e.g., foliage, fine root, wood), turnover of plant biomass as litterfall, transformation of litter to soil organic matter, and carbon loss during respiration.

Principles: - net carbon input is equal to gross primary production minus autotrophic respiration; - carbon flows from donor to receiver pools at a rate that depends on the donor pool size and its chemical quality as modified by the environment; - mass balance is maintained as carbon flows through the system of interconnected pools; - decay of litter and soil organic matter releases CO 2 as heterotrophic respiration.

Models: a system of first-order, linear differential equations to describe carbon pools and fluxes (typically time step of one day)

Pools and fluxes to be included: - Carbon gain from gross primary production minus autotrophic respiration - Allocation of carbon to growth of leaves, wood, and roots pools (partitioning varies with light availability, soil temperature, soil moisture, and nutrients + temporal for leaves (ref to phenology) - Carbon turnover (comprising litterfall, background mortality, and disturbances) + turnover rates depending on the plant material - litter pools: metabolic litter, structural litter, coarse woody debris (vary in chemical quality and turnover rate; base turnover rates are modified for soil temperature and soil moisture (environmental scaling factors)) - decomposition to soil organic matter pools: fast SOM, slow SOM, passive SOM (vary in chemical quality and turnover time) - portion of the decomposition flow lost as heterotrophic respiration

Bonan - Figure 17.2: structure of a typical biogeochemical model - equations 17.1 − 17.10

Additional details? - maintenance respiration and growth respiration - storage pool of nonstructural carbohydrates - some models separate wood into live stems (sapwood) and dead stems, roots into fine roots and coarse roots, and coarse roots into live pools and dead pools to account for the different physiological functioning of these biomass components

5.2.2 Allocation and turnover parameterization

- types of allocation models (see Campioli et al 2013 and work of Fatichi et al.)
- allocation parameters
- fixed allocation and dynamic allocation (specified by biome or based on environmental conditions)
- Optimality models: plants optimally allocate resources to balance light acquisition (foliage), structural support and water transport (stems), and water and nutrient uptake (roots).
- allocation based on scaling relationships among plant components (specified ratios of foliage, root, and wood biomass)
- Turnover rates vary depending on plant material and are specified as a fraction of biomass.
- Turnover rates are commonly estimated as the inverse of residence time or longevity
- biogeochemical models can be applied to any type of ecosystem such as grassland, savanna, forest, shrubland, and tundra

5.3 Nutrient cycle models: soil biogeochemical models

5.3.1 Nitrogen cycle

- Bonan Chapter 17.6 Nitrogen Cycle
- Bonan Figure 17.8: Depiction of the nitrogen cycle
- only ~recently added in most biogeochemical models
- closely coupled to carbon cycle
- important role to limit plant productivity
- similar to carbon with an associated nitrogen pool and transfer.
- cycling of nitrogen can be represented by a system of linear differential equations similar to that for carbon.
- allocation of plant nitrogen uptake up to plant pools
- loss of nitrogen in litterfall + portion is reabsorbed
- soil nitrogen cycle is more complex (various forms)
- decomposition of litter and soil organic matter, (mineralization and immobilization)
- nitrification, denitrification, leaching, ammonia volatilization

- additional inputs from biological nitrogen fixation, atmospheric deposition, and fertilizer
- some examples of models? CLM?
- All models simulate a decrease in plant growth when soil mineral nitrogen is insufficient to meet demand, but they differ in the manner in which this is implemented.
- maybe also more soil oriented model (CENTURY , ...)
- discuss different approaches?

5.3.2 Phosphorus cycle

Not in Bonan - Some models additionally include phosphorus (Wang et al. 2010; Yang et al. 2014; Goll et al. 2017) - ORCHIDEE, CLM-CNP

5.3.3 Other nutrients

- K and Mg in Eucalyptus and other tropical plantations

5.4 Water balance

- focus on the surface energy balance and vertical water movement in the soil–plant atmosphere system (e.g., soil moisture control of evapotranspiration)
- Specific components in terrestrial biosphere models:
  Interception, throughfall, stemflow, infiltration, surface runoff, soil water redistribution, subsurface runoff, snow melt, evaporation, transpiration, plant water uptake, stomatal conductance

5.4.1 A bucket model hydrologic cycle

- refer to hydrology courses in the program
- change in soil water is the difference between precipitation and evapotranspiration, excess runs off
- based on maximum water-holding capacity

Chapter 6

Representing biodiversity in vegetation models

6.1 Why and how representing biodiversity in vegetation models?

We can start with the applications? I think it is more interesting than finishing with the applications. Application: Conservation, ecosystem resilience, vegetation-atmosphere feedbacks

Biodiversity refers here to functional diversity.

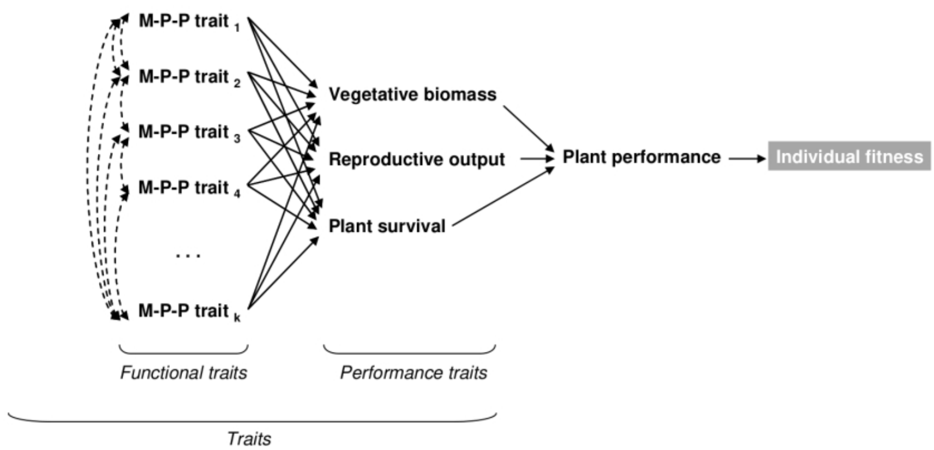
6.2 Functional diversity

- check the book " Terrestrial Ecosystems in a changing world" from P. Canadell (2007)
- Part C: Landscapes under changing disturbance regimes:
  - PFT
  - Fire and disturbances
  - upscalling
  - construction, evaluation and examples of DGVM applications

6.2.1 Definition of funcional diversity and plant functional traits

Any morphological, physiological or phenological feature measurable at the individual level, from the cell to the whole-organism level, without reference to the environment or any other level of organization. It is functional if it affects fitness indirectly via its effects on growth, reproduction and survival.

- Seminal papers from the plant functional trait community Violle 2007, Lavorel, garnier, Shipley, etc...



- Mention here the interesting summer school: http://www.cef-cfr.ca/index.php?n=MEmbres.AlisonMunsonPlantTraits?userlang=en - List of reference papers in the link above - 3 types of traits: dynamic, response & constant, that are linked to the processes we studied in the previous chapter (slow/fast processes)

6.2.2 Representing 400 000 plant species in a single model: the Plant Functional Type approach

Short description in UCL 4.3.2
No description in Bonan

- Lack of observations for every species
- Computing resources problem (refers to the history of DGVMs from the introduction)
- A simplification based on biome description and plant functionning at the ecosystem level
- Different definitions of PFT: statistical classification, etc.
- Table of classical PFTs used in models here.
- PFT mapping: multi-obs approach based on remote sensing.
- First use of PFTs managed to reproduce well the gradients at the global scale, but now it is unsuficcient.

6.2.3 Limits of the PFT representation in the context of global change

- Including acclimation and adaptation processes
- Dynamic vegetation: Accounting for non-random species turnover
- Quantifying vegetation-environment feedbacks
- Quantifying impacts of biodiversity on ecosytem functioning and climate

6.2.4 From model parameters to plant traits

- Reconciliating modelling with functional ecology.
- Existing databases (TRY)
- Empirical approach: More PFTs with traits instead of model-specific parameters, trait-trait, trait-environment relationships
- Trade-offs: modeling plant strategies –> LES, PES, RES, all the ES :D
- Role of data assimilation in regions without data and to assess spatial variability of vegetation properties

- But: requires lots of observations in space and time.

6.2.5 Eco-evolutive optimality approaches

- New generation of models
- PPA, coordination, ect…
- Paper from Oskar.

6.3 Competition models

Not in Bonan nor UCL
In Bonan Chapter 19 on demography, gap models, etc… which is a part of competition.

6.3.1 Representation of PFTs in vegetation models

- Parameterization and calibration of PFTs–> data assimilation, traits, model-specific parameters
- representation by pixels
- shared processes, different processes
- interaction between PFTs
- Depend on the model: individual/cohort/big leaf

6.3.2 Competition for ressources / Plant strategy?

- In fact we can extend the trait based approach and plant strategy (PES, etc) in the competition and community section?
- Mortality, turnover, etc..

6.3.3 Representation of trait distributions

- Trade-offs

6.4 Communities

- Successions and impact on cycles, species composition etc.

6.5 What about crops?

- Not our focus but we don't forget it. A few words to say that specific crop models exists
- Diversity is not a problem anymore
- Plant functional traits are still central to crop modelling, but competition and diversity are no more an issue.
- Other problematics specific to agriculture, such as agro-ecosystems where we have multi layers of vegetation (Trees over crops) –> Very interesting modelling problem and application especially in arid/semi-arid and tropical regions

Chapter 7

Modelling vegetation dynamics and demography

Bonan Chapter 19.2 Another class of models, known as individual plant or ecosystem demography models, retains the complexity of individual plants or cohorts of similar plants. In these models, ecosystem properties such as carbon storage are the outcome of demographic processes.

- plant populations
- community composition
- ecosystem structure
- driven by demographic processes of recruitment, establishment, growth, and mortality

7.1 Gap models, individual and cohort based models

- small scale models; landscape represented as a mosaic of hundreds of independent forest patches, each of which can differ in species composition and stage of development in response to disturbance that creates an opening in the canopy
- models track the establishment, growth, and death of individual trees in an area of land.
- Each tree is characterized by its species, stem diameter, height, and age.
- trees compete for light, soil moisture, and nutrients.
- patch undergoes temporal changes in the density, size, and composition of trees with the formation of a gap in the canopy
- Community composition, biomass, productivity, and biogeochemical cycles are emergent outcomes of individual trees interacting among themselves and with the environment to acquire the resources necessary for growth and survival
- cohort-based models define patches based on age since disturbance and simulate the dynamics of cohorts of similar plant functional types rather than tracking every individual.
- Common to each model is the representation of vegetation demography, with age- and size-dependent growth and mortality and in which growth is constrained by allometric relationships of stem diameter with height, sapwood area, leaf area, and biomass. cohort models –> modelling size distributions

7.2 Allometric relationships

- link with growth modelling of previuous chapter
- allometric relationships are a critical driver of individual tree growth.

- Height is important for its effect on stem diameter increment, both directly through tree volume growth and indirectly through shading.
- Biomass allocation: empirical equations that constrain foliage, stem, and root mass for a given size tree
- relationship between stem diameter and leaf area drives light extinction in the canopy
- annual growth of a tree is calculated from its diameter and height as modified by light, climate, and site conditions. Growth curves figure 19.5

7.3 Competition for light

- critical driver of forest dynamics
- shading of smaller individuals by taller trees
- vertical profile of leaf area in the patch (vertical structure in which trees are arranged into canopy layers)
- height of a tree determines its location in the cumulative leaf area profile
- light extinction coefficient
- figure 19.6: representation of plant canopies

7.4 Seed dispersal and recruitment

- regeneration: stochastic process
- seeds of species are assumed to be present on-site
- available light at the forest floor, climate tolerances, and other site conditions determine which species become established.
- sprouting based on size
- Species are characterized by life history characteristics + maybe add example of herb layer models of FORNALAB

7.5 Mortality

- stochastic process
- Trees die with a constant probability each year
- The probability of mortality increases when tree growth is less than some minimum
- disturbance related mortality : Wildfire and insect outbreaks can be included
- The occurrence of fire is treated stochastically with an annual probability of burning. An individual patch may, for example, have a 1% change of burning in any given year.

Part III

Upscaling and applications

Chapter 8

Spatial heterogeneity, landscape scale, metapopulations

8.1 Patch dynamics

Some references: - Book: The ecology of natual disturance and patch dynamics, Pickett & White, 2013

8.1.1 Spatial heterogeneity: Definitions

- Definition of Patch Dynamics, Perturbation, Disturbance:
- Spatial heterogeneity
- Resilience and shifts

8.1.2 Impact of heterogeneity on ecosystem fonctionning and environmental feedbacks

- Show examples here of the impact of heterogeneity
- Application in the design of nature reserves for example

8.1.3 Heterogeneity is a matter of resolution

- Imbricated levels of heterogeneity depending on spatial and temporal resolution
- Heterogeneity is also a matter of the studied question: important in term of modelling since it will govern how processes are implemented

8.1.4 Representation in Vegetation models: what are the drivers of spatial heterogeneity?

- List here the different drivers
- Heterogeneity is a patchwork of homogeneity in most models
- But we can still represent dynamics in heterogeneity –> mortality, growth and shifts in species composition

8.1.5 Disturbances and Patch dynamics

- We listed the different drivers above, we will now discuss in detail the most important aspects affecting patch dynamics
- Link to land-use and disturbance

8.2 Land-use changes

- Land use is linked to spatial heterogeneity and patch dynamics

8.2.1 Role of Land-use in global emissions and biogeochemicel cycles

- impact C stocks and fluxes
- impact on nutrients (depletion over rotations, etc…)
- important impact on respiration
- vegetation cover and biophysical impact: albedo, etc…
- Specific case of deforestation, one of the most important imapct (make a paragraph on that?)
- How are fluxes attributed to land use in gas emission assessments? –> central role of vegetation modeling

8.2.2 The important role of land use in the water cycle

- Affects regional precipitations
- Affects water routing –> Compared to the local impact on vegetation, here we touch something that will have an impact for the surrounding regions

8.2.3 Monitoring land-use

- remote sensing, rapid link to other courses

8.2.4 How Land-use is represented in vegetation models?

- Compared to vegetation dynamic which is process-based, here land use is imposed.
- management
- urban areas

8.3 Natural and Anthropogenic disturbances

- We provide an overview of disturbances but we will detail only one of each: Fires and Management

8.3.1 Wind and extrem events

- Modelling storms
- Modelling heat and cold waves, frost impact

8.3.2 Herbivory

- Yes herbivory is represented in vegetation models :D
- Palability traits/ fixed fraction/ insects

8.3.3 Modelling fires

- In UCL Practical chap. 6
- For estimating the impact on ecosystems
- To be able to predict fires
- Observation of fires and quantifications of fluxes
- Fires and deposition
- Aerosols
- Modelling "fire" traits, drought and temperature stress in models to simulate fires

8.3.4 Human activity: Management and urban areas

- Forest management: existing models, representation of forestry and use of models
- Fertilization and irrigation in vegetation models
- Urban areas in vegetation models
- Concrete application: Paper of Luyssaert: forest management in Europe did not help in mitigating climate change.

8.3.5 The specific case of CO2 and temperature increase

- conclude the chapter here by refering to climate change, one of the biggest "Continuous" distrubance compared to previous "discrete" disturbances
- Simulating acclimation and adaptation
- refers to chapter 2 for acclimation of processes
- refers to chapter 11 for scenarios

Chapter 9

Upscaling from the leaf to the globe

Some references: - Scalling processes and problems, Jarvis 1995 - upscalling in global change research, Harvey 2000

9.1 Spatial and temporal non-linearities: Cascading effect in the Earth system

- spatial upscalling
- temporal upscalling
- classification of upscalling problems:
  - Spatial variability + process nonlinearity
  - Minimim scale to observe the process
  - Different processes dominate at different scales
  - Feedbacks between scales
  - Development of emergent properties
  - Edge effects
  - Temporal lag dependent on spatial scale change
  - Collective response with differential effects
- Solutions to upscaling problems:
  - Ignore (easy solution)
  - Increase model resolution (now more and more possible thanks to computing ressources, and data assimilation)
  - etc… ** Nice review in Harvey 2000 **

–> Solution depends on the application, show some examples here

9.2 Land surface models

- Dependence to other disciplines (Biology, ecology, physics, chemistry (VOC, etc), hydrology, pedology, datascience and mathematics, etc…)
- Figure 1.7 from Bonan
- UCL 4.2: Land surface schemes
- Focus on the coupling of different models and what it implies, not the technical aspects ### Soil-Vegetation-Atmosphere-Transer models
- Description of SVAT models, regroups what we studied in Chap1-9

9.3 DVGMs as a part of Earth System Models

- Partially in UCL 4.3.3

9.3.1 One Biosphere

- Chapter 1 of Bonan, specifically 1.5
- Coupling to other components

9.3.2 Atmosphere, Ocean, lakes and urban areas

- Rapid desciption of other models
- Reference here to previous chapter on heterogeneity

9.3.3 Coupling of processes with different time steps and regional scale

9.3.4 Simulating feedbacks

- Nice transition to chap 11 with future scenarii

Chapter 10

Model projections and scenario analysis

10.1 Climate scenarios

10.1.1 Representative Concentration Pathway (RCP scenarios)

- How scenarios are defined
- How current emissions are measured and attributed to different factors?

10.1.2 Different models, different RCP

- The central role of ESM: coupling to Atmosphere and Ocean and feedbacks
- Here refers to preivous Chapter 10
- list some examples and differences: IPSL, HadGEM, etc…

10.1.3 Use of RCP in vegetation modelling

- ENSEMBLE simulations
- IPCC
- Example of applications

10.1.4 How can we evaluate future scenarios?

- FACE
- Rainfall exclusion experiments
- Natural gradient (Iceland and soil temperature based on volcano and geothermy)

10.1.5 The central role of Paleo studies and historical datasets.

- Good performance for past and current conditions is mandatory to evaluate future scenarios
- Here remind the central role of experiments and monitoring

10.2 Land-use scenarios

10.2.1 Construction of Land-use scenarios

- Hyde for historical land-use, https://themasites.pbl.nl/tridion/en/themasites/hyde/
- Scenario for future land-use

–> We can follow the same structure as for RCP?

10.2.2 How can we evaluate land use scenarios?

- Based on historical data
- Remote sensing

10.3 Management scenarios

10.3.1 Construction of Land-use scenarios

10.3.2 How can we evaluate management scenarios?

10.4 Some concrete applications of vegetation models

- As a conclusion of the whole course I see a nice diagram that we constructed throughout the course with small boxes added to each others and we link that to all the possible application

Part IV

Appendix

Contributing to this document

First steps

First, visit the course webpage on https://github.com/femeunier/VegMod_course, and fork it to your own github account. Open a RStudio session and (if it is your first time with git) introduce yourself:

```
git config --global user.name "FULLNAME"
git config --global user.email you@yourdomain.example.com
```

Note that you can do every single step below using the terminal and the git tabs in RStudio. Clone the newly forked folder to your local machine:

```
git clone https://github.com/femeunier/VegMod_course.git
```

or using SSH (to set up it first, see for instance https://help.github.com/en/github/authenticating-to-github/connecting-to-github-with-ssh)

```
git clone git@github.com:femeunier/VegMod_course.git
```

Define upstream

```
cd VegMod_course
git remote add upstream git@github.com:femeunier/VegMod_course.git
```

New pull request

Get the latest code from the main repository

```
git pull upstream master
```

Create a new branch (here new_branch is the new branch's name)

```
git checkout -b new_branch
```

Do some coding, add files and commit them

```
git add filepath
git commit -m "Message"
```

Push your changes to your github (when a feature is working, a set of bugs are fixed, or you need to share progress with others).

```
git push origin new_branch
```

Before submitting code back to the main repository, make sure that book compiles (buikd book). Open the PR online by visiting your github repository. To ease those previous steps you can take advantage of the git GUI in RStudio. To do so, create a new project from an existing directory.

Supporting material

Crash course, basic programming (R), theory about model evaluation etc.

Part V

Practicals

Practical A

PC-room, supervised exercise

Simple model on diurnal variation in solar angle, radiation extinction and photosynthesis in vegetation types with different and canopy structure and LAI: grassland, broadleaved forest, coniferous forest

Scale: aggregated stand level (big leaf model)

Methodological focus: model formulation: translating a few equations into code

Methodological focus: compiling code, running model, reading input-output

Practical B

Group work, report, PC room

Modelling diurnal cycle of carbon and water fluxes for flux tower sites (Savanna's Sahel)

Scale: aggregated stand level

Methodological focus: model-data comparison (goodness-of-fit), simple parameter optimisation

Practical C

PC-room, supervised exercise

Modelling the size structure of a temperate forest (stand diameter distribution)

Scale: forest stand

Methodological focus: initial conditions

Practical D

Group work, report, PC room

Modelling carbon stocks (above and belowground) and fluxes

Scale: ecosystem

Methodological focus: Spinup and sensitivity analysis (testing which climate variables have strongest impact on stocks)

Practical E

PC-room, supervised exercise

Simulating forest succession, meta-analysis of trait dataset to prescribe vegetation functional composition (using PEcAn-framework)

Scale: landscape

Methodological focus: parameter meta-analysis (PFT construction), data assimilation

Practical F

PC-room, group work, microteaching

Climate/land use/management scenario analysis

Scale: site/globe? (Pecan framework) each group choses a question and a model

Methodological focus: sensitivity and uncertainty analysis