Vegetation modelling

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Introduction

The central role of vegetation in the Earth system

Plants and vegetation play an essential role in the earth system. In Figure @ref(fig:f1), we have represented the planetary boundaries and the significant environmental challenges we are facing. For some of them, we are reaching the system's boundary, such as genetic diversity, biogeochemical cycling, and climate change. Plants and forest ecosystems are critical in multiple of these planetary problems. Therefore, it is crucial to understand how vegetation reacts to environmental problems (positive or negative feedback).

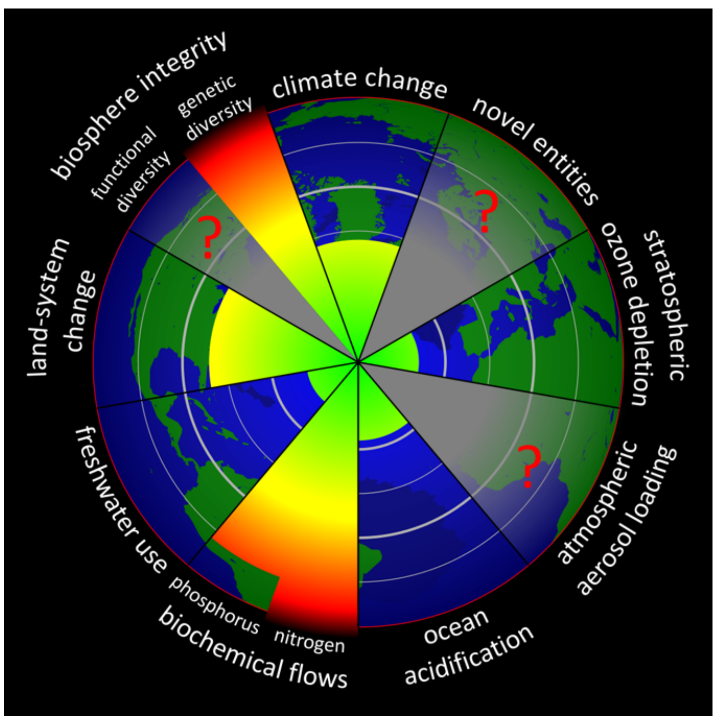


Figure 1: The planetary boundaries (www.stockholmresilience.org)

A more specific example is the global carbon budget. We are currently facing this significant change in biogeochemical cycling due to the rising fossil fuel emission over the last 150 years. Figure @ref(fig:f2) represents the balance between carbon sources (fossil carbon and land-use changes) and sinks (oceans, land, and atmosphere). The more we emit, the more the Earth system is capturing, as shown in Fig.2. This takes us to a question, frequently addressed by global vegetation models, about how long these sinks will continue or not capture our increasing carbon emissions. It is also important to highlight the high inter annual variability of the land component being the most challenging component to predict.

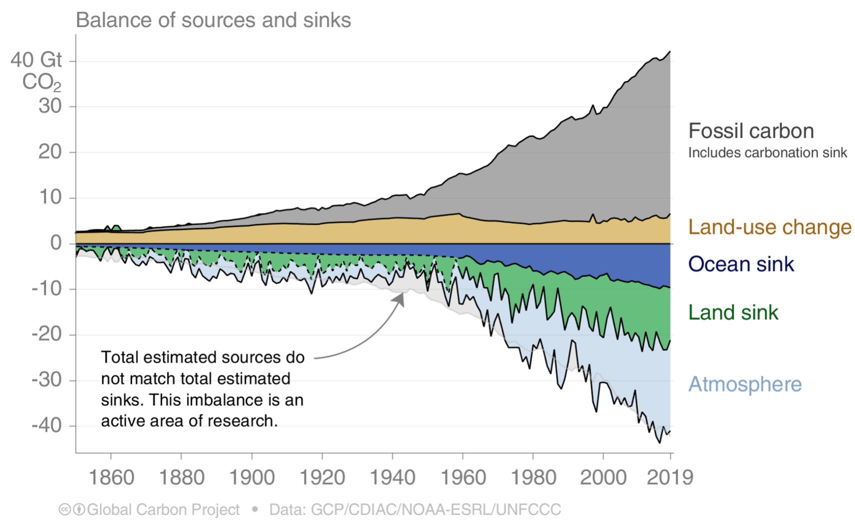


Figure 2: The global carbon budget (www.globalcarbonproject.org)

Climate Models predict how the long-term weather variation and average weather will evolve. These models include an atmosphere, land and ocean component (Fig.3, top). The original climate models focused on biophysics: energy and water balances, predicting precipitation, radiation and fluxes between the three components. More recently, climate models have evolved into **Earth System Models** (ESM). ESM have a more complex concept because they represents more processes (Fig.3, bottom). Why? If you want to predict the end of the century climate, we need to consider greenhouse gases and thus the full carbon cycle. ESM are more complex but also more realistic.

Vegetation models are often the land component of an earth system model. These 'terrestrial biosphere models'(TBM) or 'land surface models' (LSM)

- simulate **energy fluxes**: radiation, evapotranspiration and sensible heat fluxes between the land and the atmosphere. Depending on the vegetation type, the impacts are different.
- simulate the **hydrology** and the **carbon cycle**.
- simulate slower processes like **vegetation dynamics**: the succession of forest or **land use** and **urbanization**.

The biosphere acts as a coupler in earth system models. The coupler is a system that links different models. The vegetation provides the link between land and atmosphere component.

Why do we need modelling?

Modelling has proven to be a essential tool:

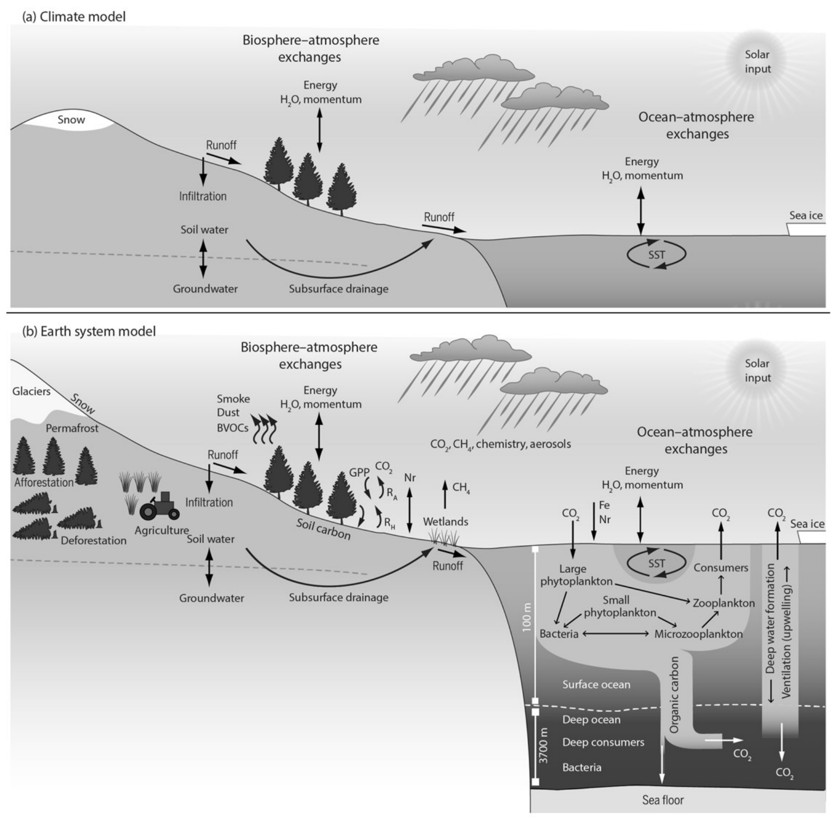


Figure 3: Scientific scope of (a) climate models and (b) earth system models. (Bonan 2019)

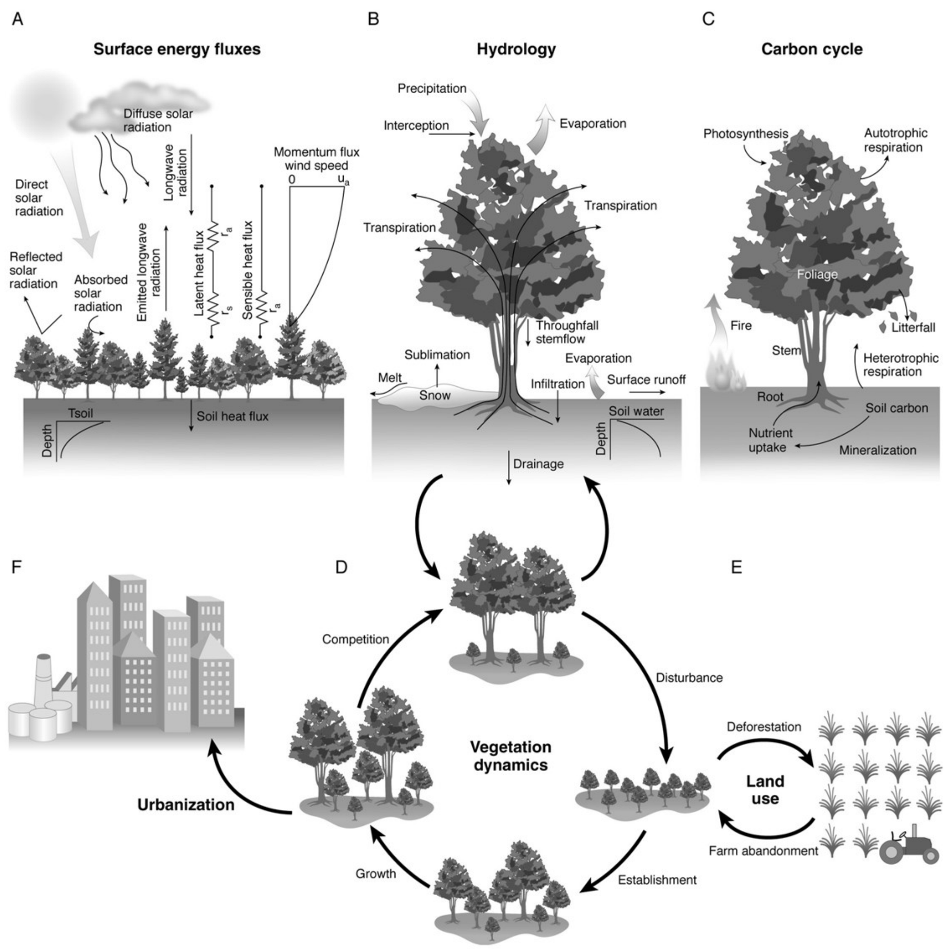


Figure 4: Scientific scope of terrestrial biosphere model. (Bonan 2019)

- For **understanding**: we need good theoretical foundations (understand processes) to generalize knowledge and observations in space and time (upscaling). Studying the inaccuraies in models leads to the formulation of new hypotheses.
- For **prediction**, how vegetation responds to expected changes (temperature or CO2) to develop management strategies and policies.
- For **data integration**: a framework to bring together multiple data sources and to guide future data collection.

Model types

How can we look at the different model types that exist (Table @ref(table:example))? We can divide model types into empirical models or process-based models. **Empirical models** are based on data and correlations, not describing precisely the biophysical processes — **process-based models** describing the biophysical processes and causal relations between the variables (Table @ref(table:empirical)). Most existing vegetation models are hybrid.

Table 1: Continuum of terrestrial biosphere/ecosystem models. (Bonan 2019)

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

Table 2: Continuum of process-based versus empirical models. (Adams et al. 2013)

	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

The model type depends on: - Purpose: will it be used for management support, policy support, research. - Question: different people will be interested in different questions (foresters, ecologists, policy makers…) - Scale: models that are to be applied for local use can be much more detailed than worldwide models because data gathering is much more straightforward on a small scale. Also the time-scale is of importance: will the model be used for research about the past, the present or the future?

The history of vegetation models

The first vegetation models have emerged in the 1960s and 1970s. There were some parallel evolutions during that time because of computers emerging, making it possible to study more complex systems.

One of the first models were the **box models** (1960); these models describe the flow of mass and energy through boxes. These models still exist in current biogeochemical models, where arrows represent the fluxes between the pools. In parallel, **gap models** had emerged. Gap models simulate the dynamics of the development of a gap in a forest and the growth of plants in this gap. Gaps can be created by fallen trees, by dead trees, … . This kind of models are individual-based and focused on population dynamics and the life cycle of species: growth, regeneration and mortality while taking environmental constraints in account. These models are the first models that were ever used for upscaling: from tree level, to plot-level, to landscape level. They were developed by forest scientists using forest inventories to derive growth, regeneration, and mortality in response to environmental variables. In 1973, the first model (MIAMI model) was developed to derive global net primary productivity (NPP), relating NPP in an empirical way to climate variables (temperature) with vegetation productivity. This was the first attempt to make a global upscaling of a vegetation process. In the 1980s surged the first **land surface models**. Land surface models are the models where the other models start to integrate into, and evolved as such into – **Terrestrial biosphere models** (see Figure @ref(fig:f7)), which are now the state-of-the-art land components of ESMs. Vegetation modelling therefore is a very interdisciplinary field because it involves knowledge of different scientific fields, making it difficult to find a common terminology. Global EMS are currently still not good to simulate realistic vegetation dynamics.

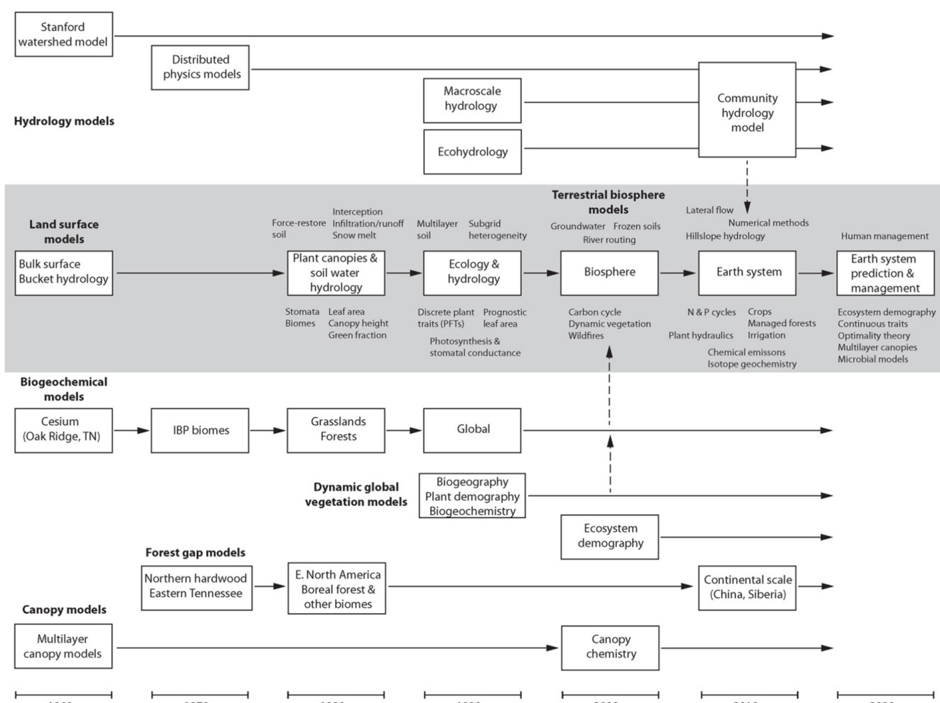


Figure 5: Timeline showing the parallel development of model types and the integration of model types into land surface models towards terrestrial biosphere models. (Bonan 2019)

Components of a model

What is a vegetation model? Two attempts for a definition:

- **Dynamic global vegetation models** (DGVMs) are powerful tools to project past, current and future vegetation patterns and associated biogeochemical cycles (Scheiter et al., 2013).
- A **Dynamic Global Vegetation Model** (DGVM) is a computer program that simulates shifts in potential vegetation and its associated biogeochemical and hydrological cycles as a response to shifts in climate. DGVMs use time series of climate data and, given constraints of latitude, topography, and soil characteristics, simulate monthly or daily dynamics of ecosystem processes. DGVMs are used most often to simulate the effects of future climate change on natural vegetation and its carbon and water cycles (Wikipedia 2021).

Table 3: Definition of key model components and examples for a typical TBM

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, …

Processes

They are a key component because we are focusing on process-based models in this course. There is a long list of processes (energy, water, turbulent transport, canopy scaling, carbon, nitrogen, trace gasses, demography,. . .) that the models integrate, especially the more complex ones. These processes will be discussed in detail in the following theory chapters and we will mainly focus on how to translate them into equations.

Equations

These are the mathematical representations of the processes. However, there are important constraints to insert equations into a vegetation model, such as the specific time scale at which a process operates. For example, it makes little sense to resolve the equation for forest composition (succession) on a daily calculation time step. This is a prolonged process with an extremely low variance between consecutive days. The solution for the equation for photosynthesis, on the other hand, varies significantly throughout the day and between consecutive days (cloudy day vs sunny day).

There are three types of equations within vegetation models: - **prognostic equations**: time derivatives of differential equations – they calculate the state's change over time -

conservation equations: equations describing the conservation of mass and energy - **diagnostic equations**: linking multiple variables independent from the time. Often there is no analytical solution of the equations describing on-linear processes in biological systems; therefore, we must use numerical methods to solve the equations.

Parameters

These are the constants in the model. Some parameters are highly uncertain because we can not measure them very well at the relevant scale. For example, we can make reliable measurements of the photosynthetic capacity of a single leaf. However, upscaling this parameter so that it is applicable for a forest or multiple PFTs (plant functional types) induces uncertainty. The more parameters a model uses, the more uncertainties that are to be taken into account.

Time Steps

Vegetation models run at multiple timescales (combining processes that are resolved at multiple timescales). Models present fast processes, which are calculated every hour (e.g. photosynthesis and energy balance), intermediate processes calculated daily (e.g. carbon allocation and growth) and slow processes in order of years (e.g. mortality) (Fig.6).

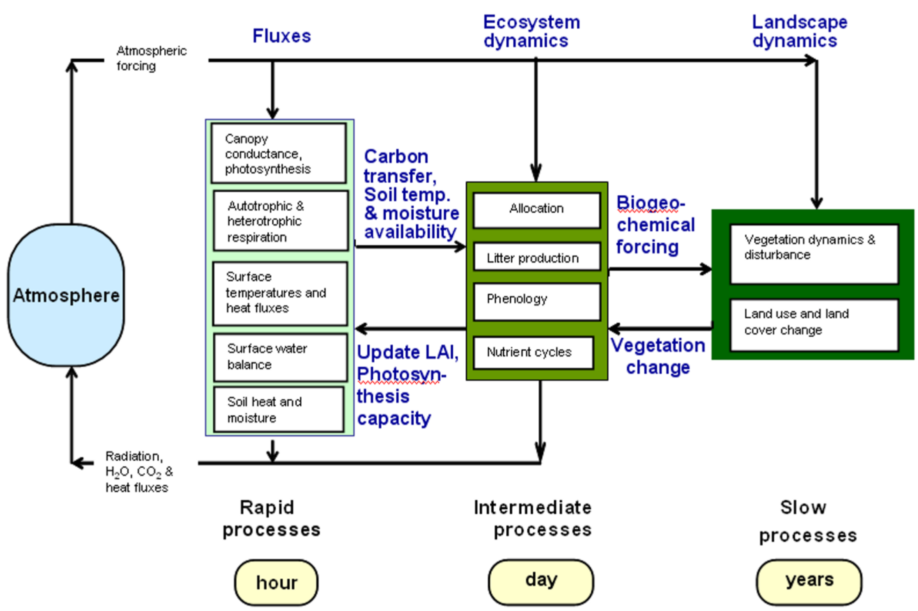


Figure 6: Structure of a vegatation model indicating the different time steps at which each process is simulated (Williams et al. 2009)

Spatial structure

The division of space in voxels, layers or grid cells and its resolution determines how many times we repeat our calculations in space. Global vegetation models have a typical spatial grid of 100km or even more and divide the landscape into patches.

In each patch, they simulate the vegetation (forest, savannas, grassland…). Models also have a horizontal grid or horizontal layering: some models consider multiple soil layers. The same is true for above ground layers, where some models divide the canopy into multiple layers (Figure @ref(fig:f10)). For example, the Ecosystem Demography Model (ED2.2) divides the forest into multiple grid cells where the same meteorological conditions apply within each grid cell. Then within each cell, this model has different sites with different soils. Each site is divided into multiple patches (forests with a similar disturbance history). For each patch, the model simulates multiple cohorts of trees (Figure @ref(fig:f11)).

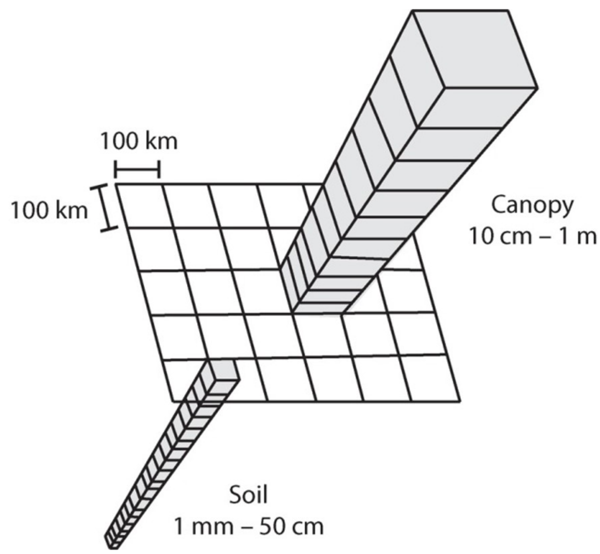


Figure 7: Three dimensional grid of a TBM structured in terms of longitude x latitude x level. The number of soil and canopy layers and the geographical resolution is model dependent, (Bonan 2019)

Model code, complexity and uncertainty

There is a gap between equations and how the are implemented in the actual model code. Also, a specific process can be implemented into an equation in various ways. Usually, large models also contain a "technical debt," which means over the years, multiple modelers have continued working on models and added code lines, but at some point, the code is so large that none of the developers still knows the entire code, resulting in persistent bugs or overlooked assumptions.

Models are always a simplification of the real world, but they tend to become overly complex

More complex models (adding more processes) become more realistic, but we also add more sources of uncertainty. Therefore, we should choose our model carefully based on the research question we want to adress.

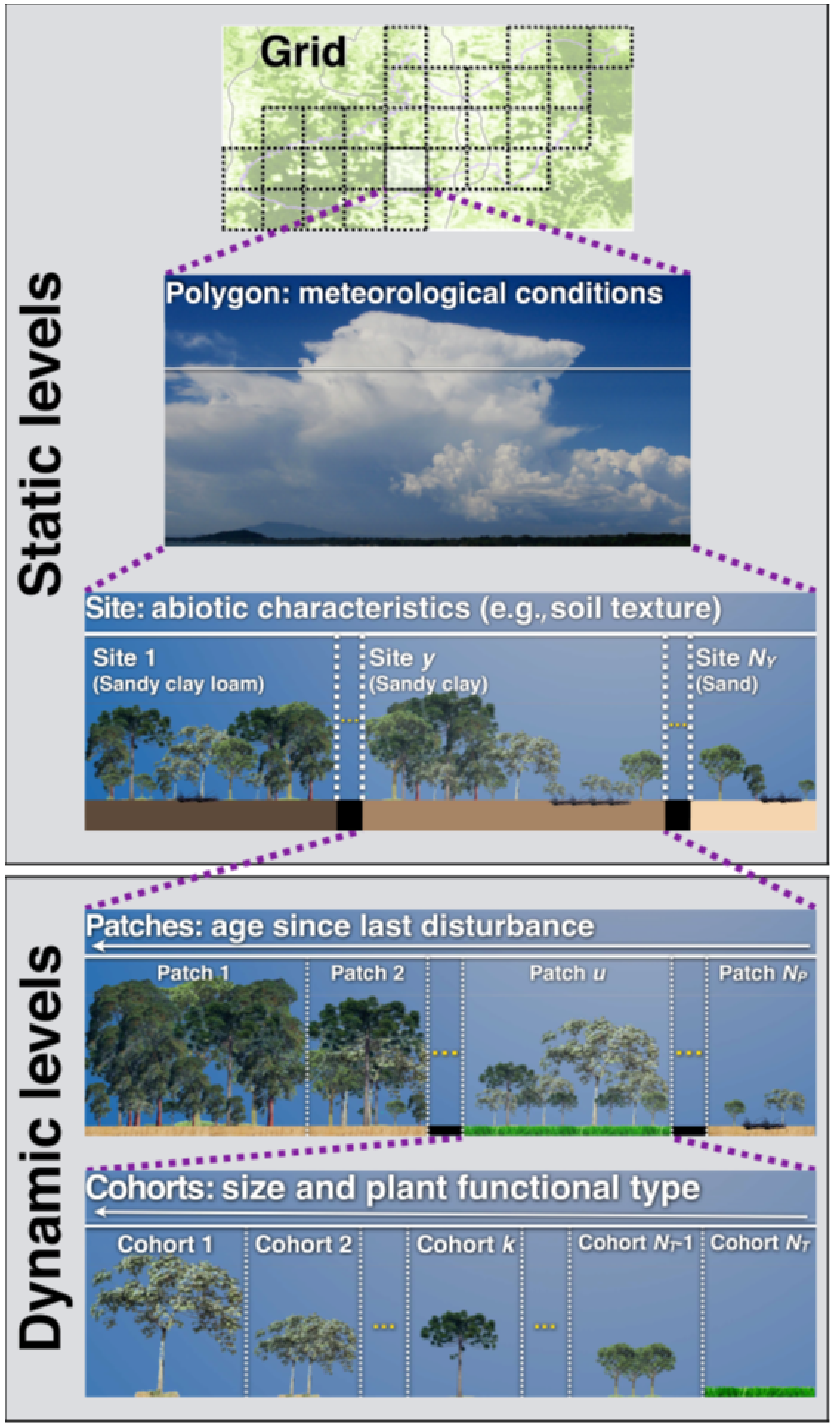


Figure 8: Example: the spatial multi-level grid structure of of the ED2 vegetation model (Longo et al. 2019)

Data

It is not possible to develop models without data. In general, the more data (multiple data sources), the better.

Modelling workflow and structure of the course

Vegetation modelling is a multidisciplinary field. This course will mainly focus on the mathematical formulation of processes and translating these equations into a working model.

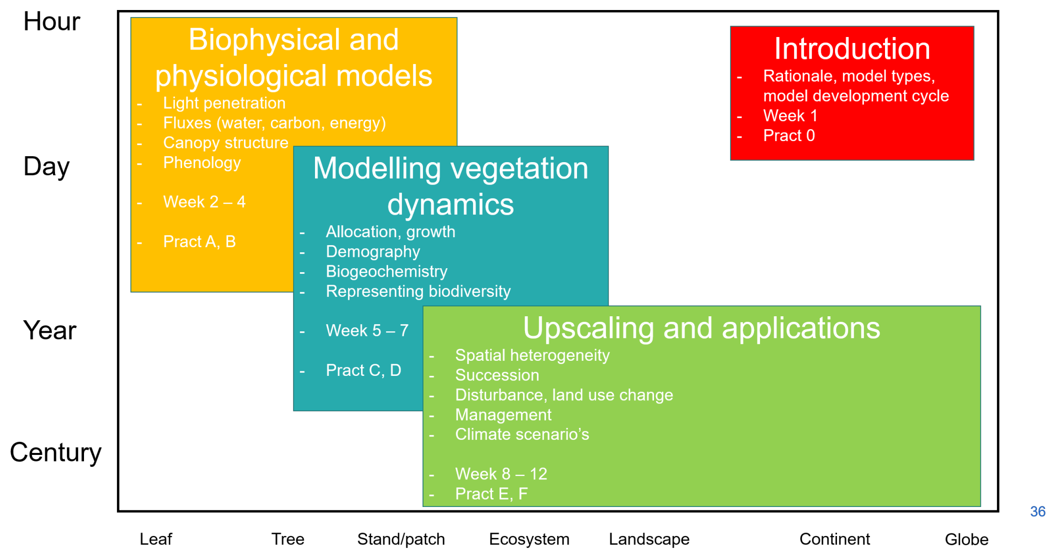


Figure 9: Progression through spatial and temporal scales throughout this course

The construction of a model is a continuous process – a model is never finished. As Figure 10 shows us, we start by describing our system in the form of equations, then running the computer program to characterize the model, perform parameter estimation and interpretation, and then apply it to other locations and validate against independent data.

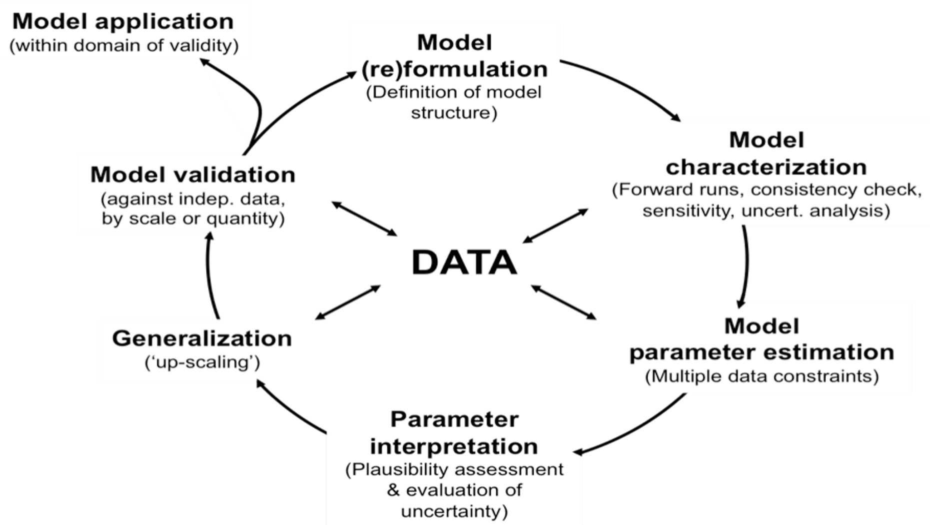


Figure 10: Model data fusion in every step of the model development cycle (Williams et al. 2009)

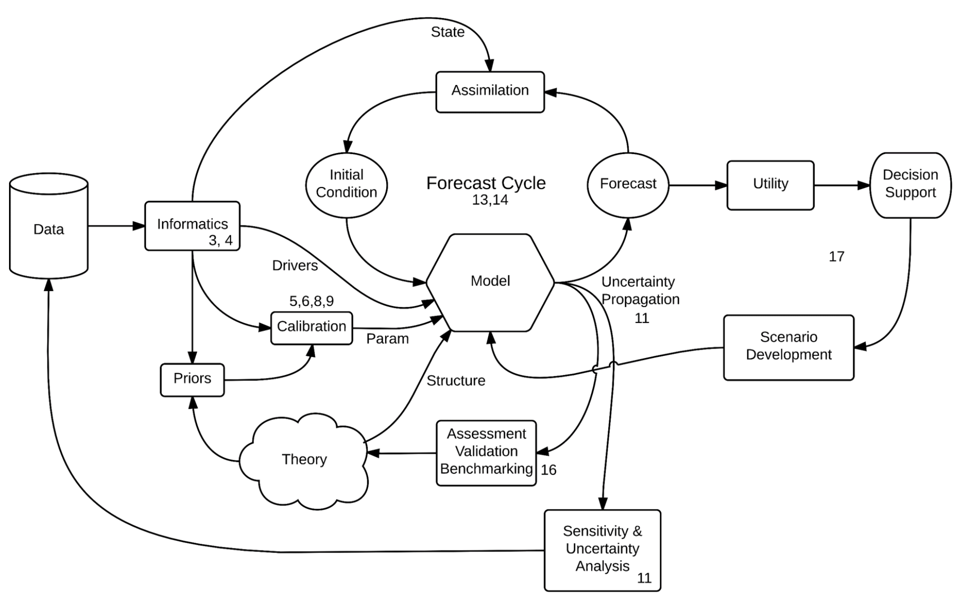


Figure 11: Methodological workflow of model data fusion (Dietze: Ecological Forecasting)

(PART) Biophysical and physiological models

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.

Photosynthesis models

Refreshing the basic knowledge

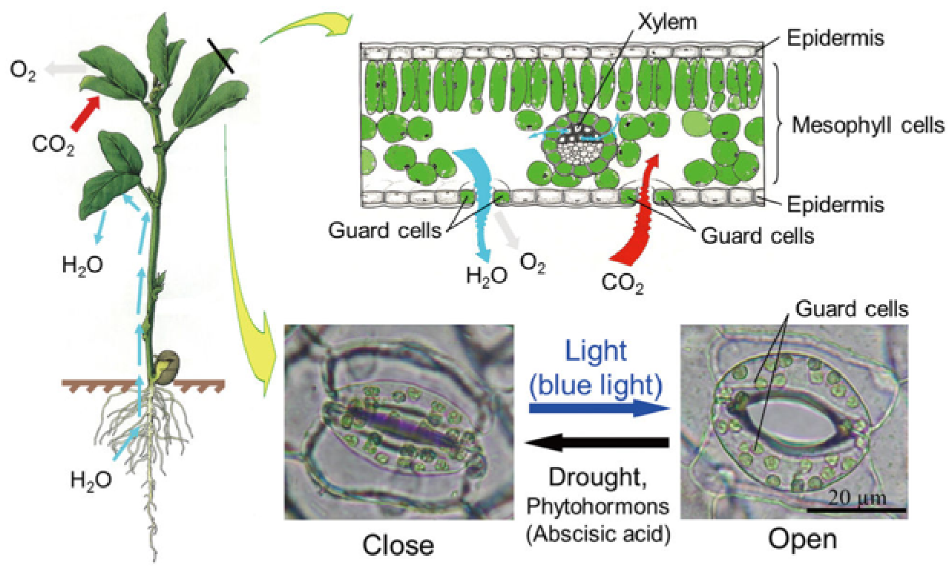


Figure 12: Leaf level processes transpiration and photosysnthesis are strongy interlinked and both regulated by stomatal conductance

C3 photosynthesis

Light response curve models

Light use efficiency models

The Farquahar model

- UCL 4.6.1

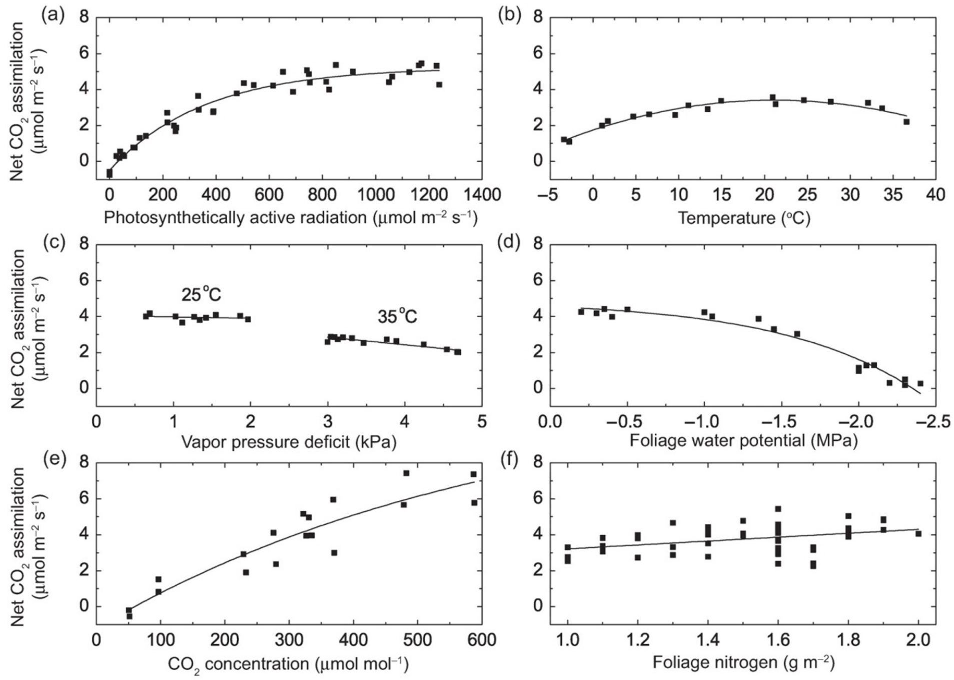


Figure 13: Photosynthesis in relation to (a) photosynthetically active radiation,(b) temperature, (c) vapor pressure deficit at 25°C and 35°C,(d) foliage water potential, (e) ambient CO2 concentration, and (f) foliage water potential for jack pine trees (Pinus banksiana). Bonan (2019)

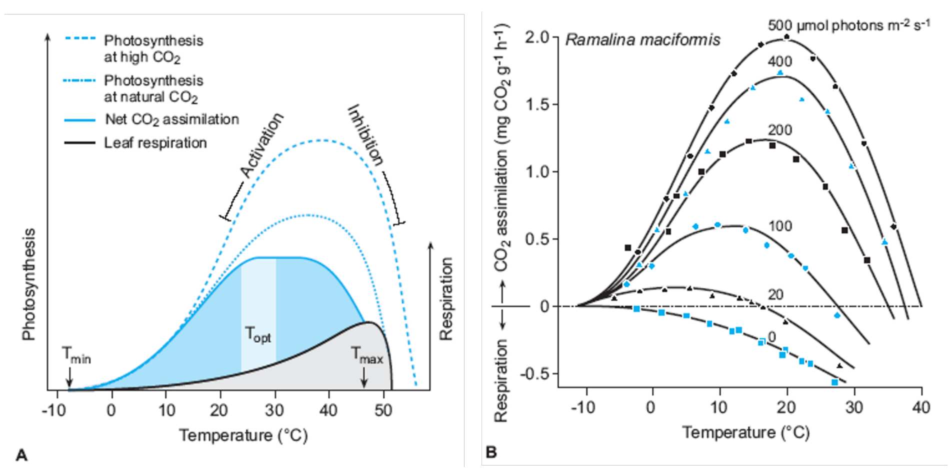


Figure 14: Temperature responses of photosynthesis, respiration and net CO2 exchange, interaction with CO2 concentration (A) and light (B) Schulze ()

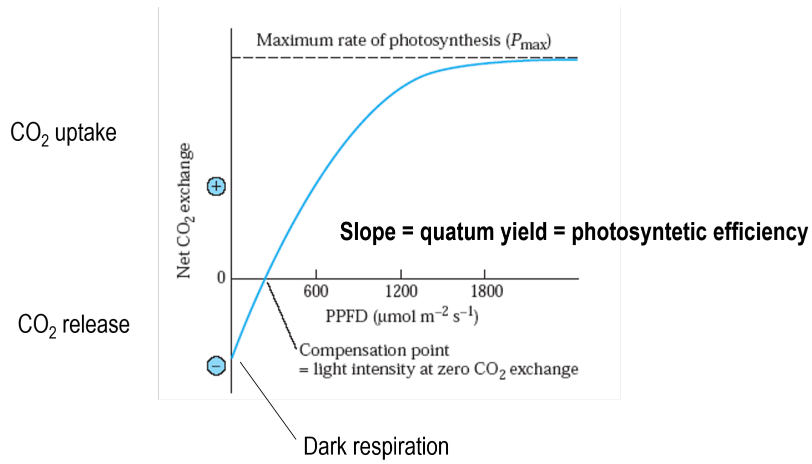


Figure 15: Conceptual figure of a leaf-level light reponse curve

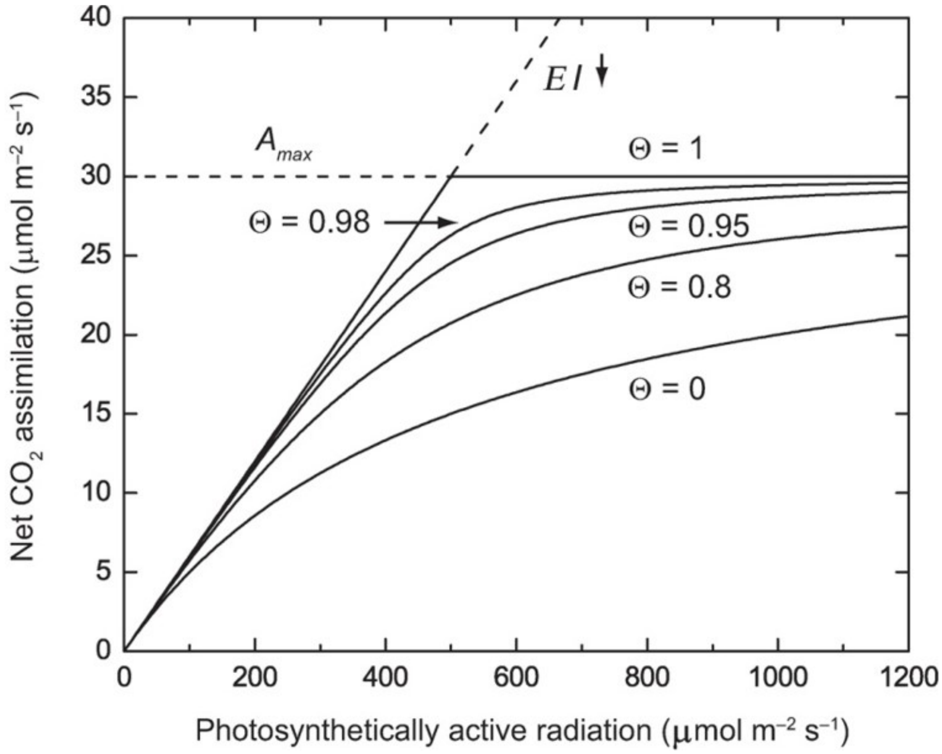


Figure 16: Co-limitation illustrated for photosynthetic response to light. The two dashed lines show the rates Amax adn EI The solid lines show the co-limited rate. (Bonan 2019)

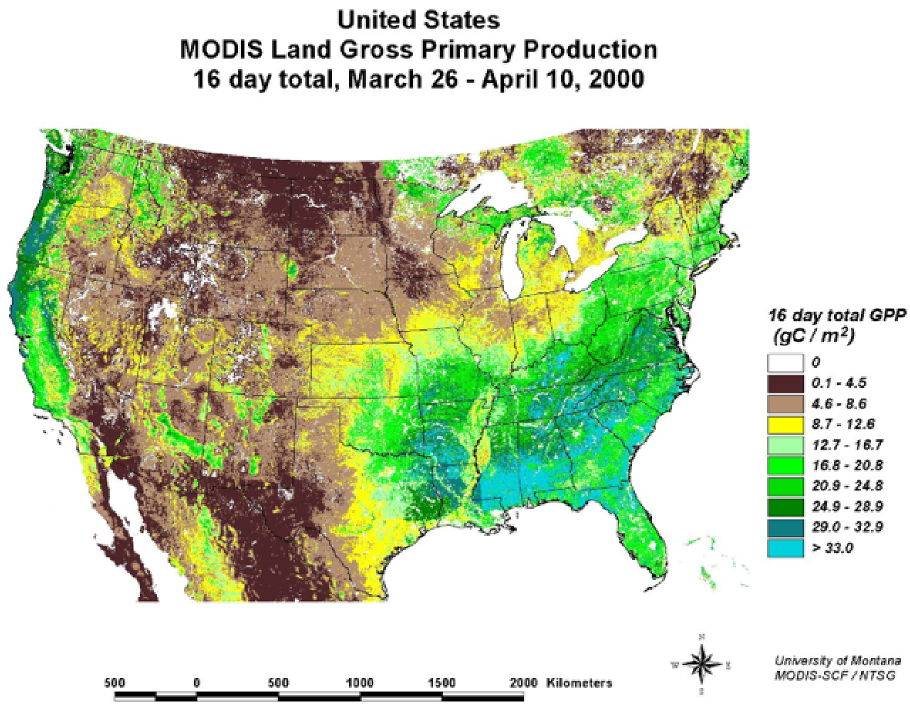


Figure 17: MODIS based GPP map of the US, based on a LUE model.

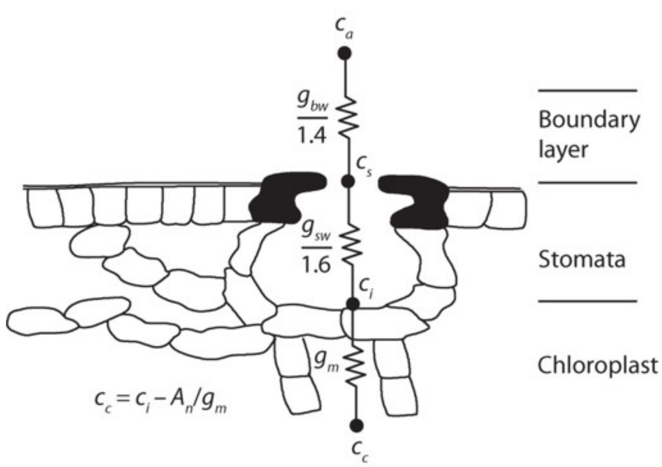


Figure 18: Diffusion of CO2 from free air across the leaf boundary layer and through stomata to the intercellular space. Diffusion to the chloroplast is additionally regulated by mesophyl conductance. (Bonan 2019)

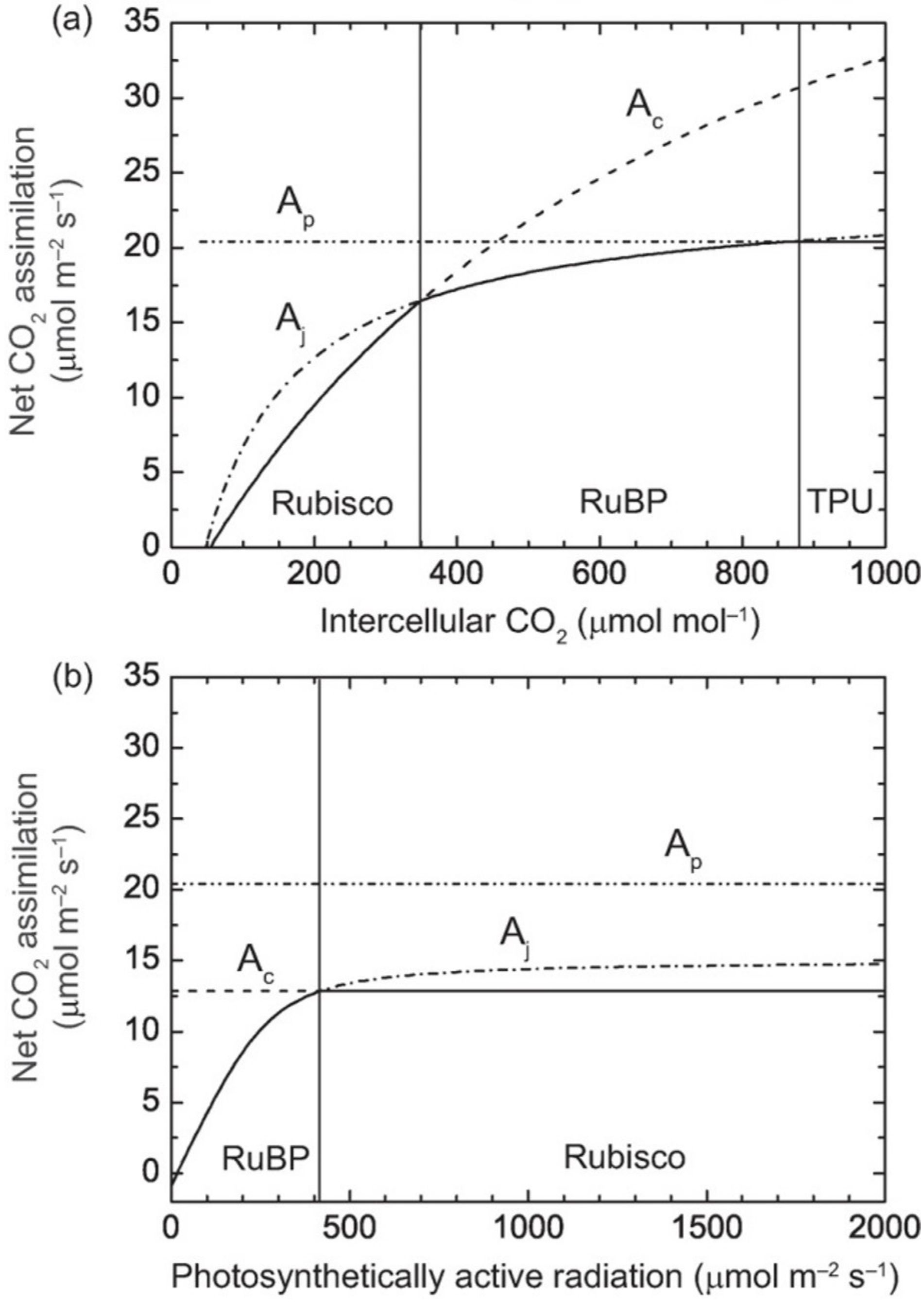


Figure 19: Simulated responses of C3 photosynthesis in relation to (a) intercellular CO2 (at I<U+2193> = 2000 µmol m–2 s–1) and (b) photosynthetically active radiation (at ci = 266 µmol mol–1). (Bonan 2019)

- 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

Parameter and temperature dependencies

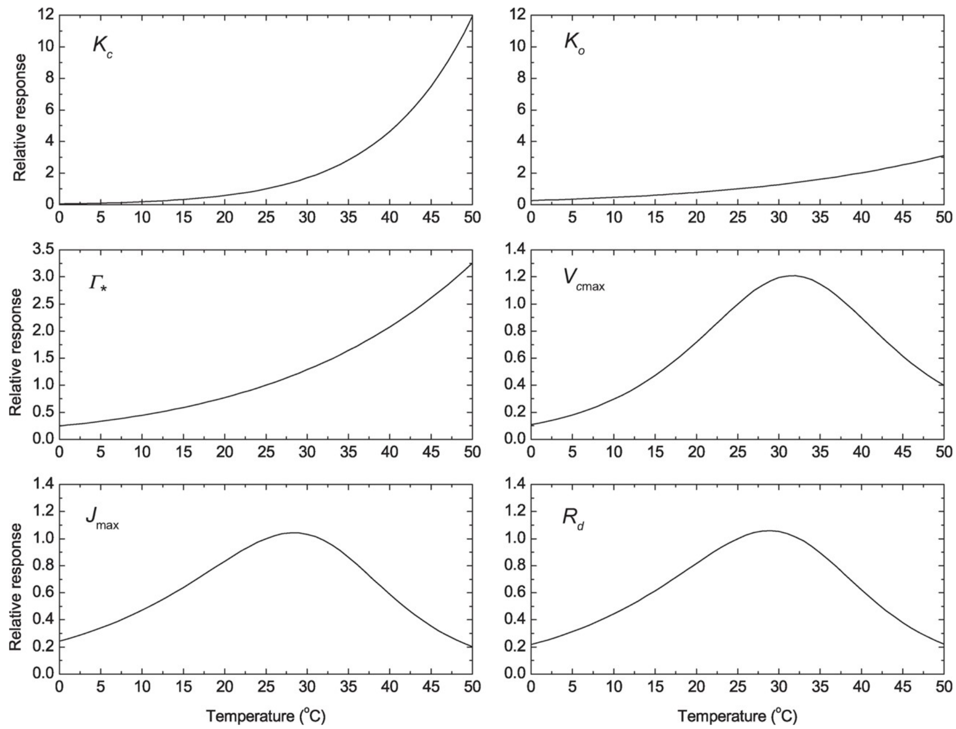


Figure 20: Relative temperature responses of the parameters of the Farquhar model (Bonan 2019)

- 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

C4 photosynthesis

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

Stomatal models

Refreshing the basic knowledge

Empirical multiplicative models

- Bonan, Chapter 12.2

Semiempirical photosynthesis-based models

- Bonan, Chapter 12.3

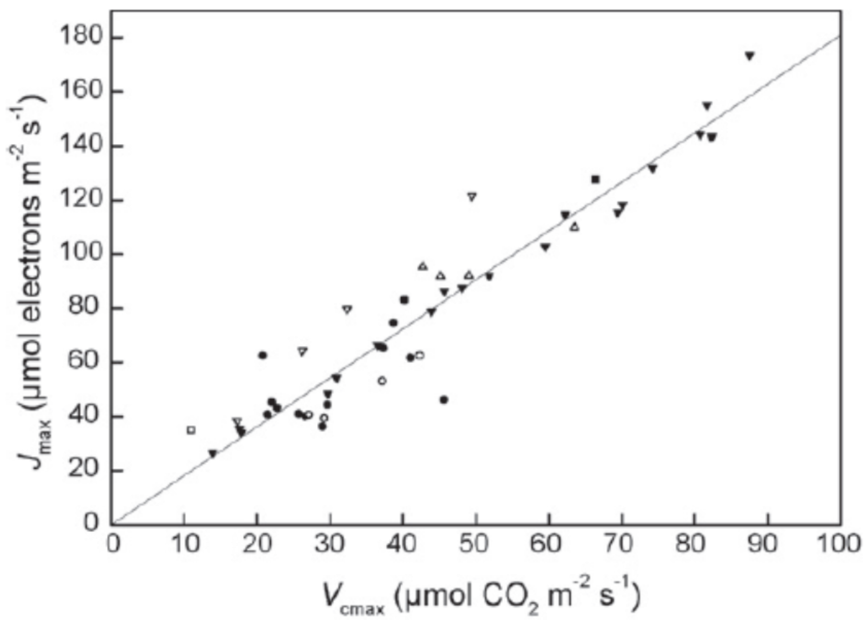


Figure 21: Linear relation between observed Vcmax and Jmax values for Beech (Verbeeck et al. 2008)

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 22: Equations of the full Farquhar model

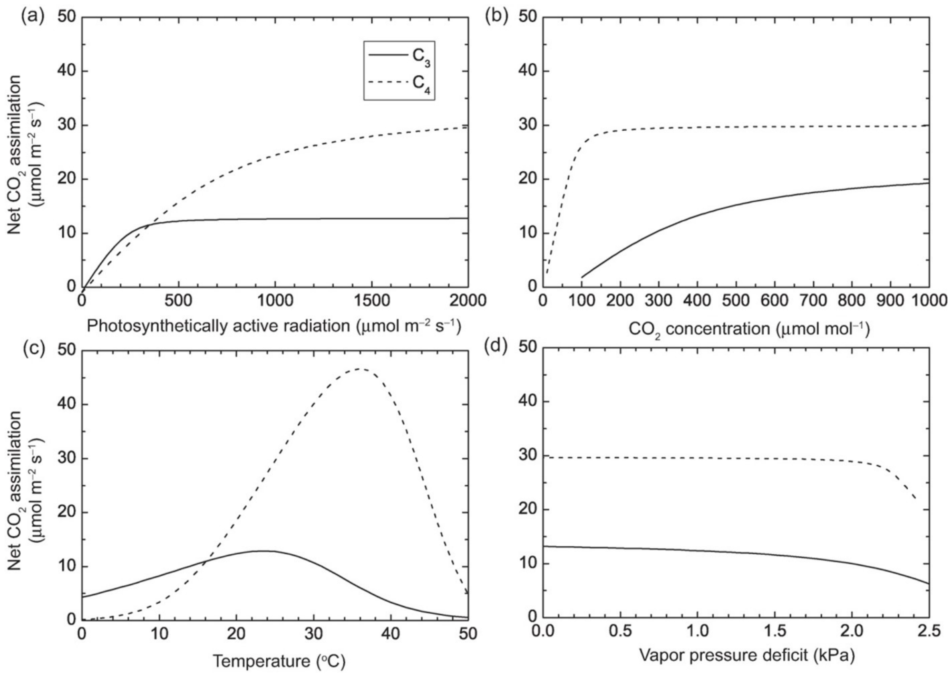


Figure 23: Comparison of C3 and C4 photosynthesis in response to (a) photosynthetically active radiation, (b) ambient CO2 concentration, (c) leaf temperature, and (d) vapor pressure deficit. In this figure, stomatal conductance is calculated using the Ball–Berry model and ci is obtained from the diffusion equation

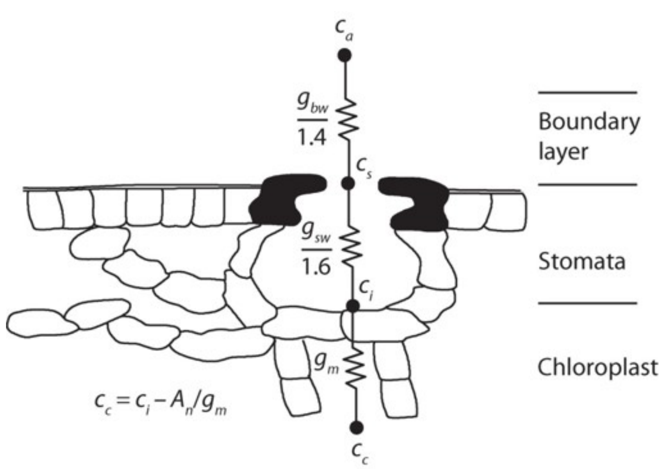


Figure 24: Diffusion of CO2 from free air across the leaf boundary layer and through stomata to the intercellular space. Diffusion to the chloroplast is additionally regulated by mesophyl conductance. (Bonan 2019)

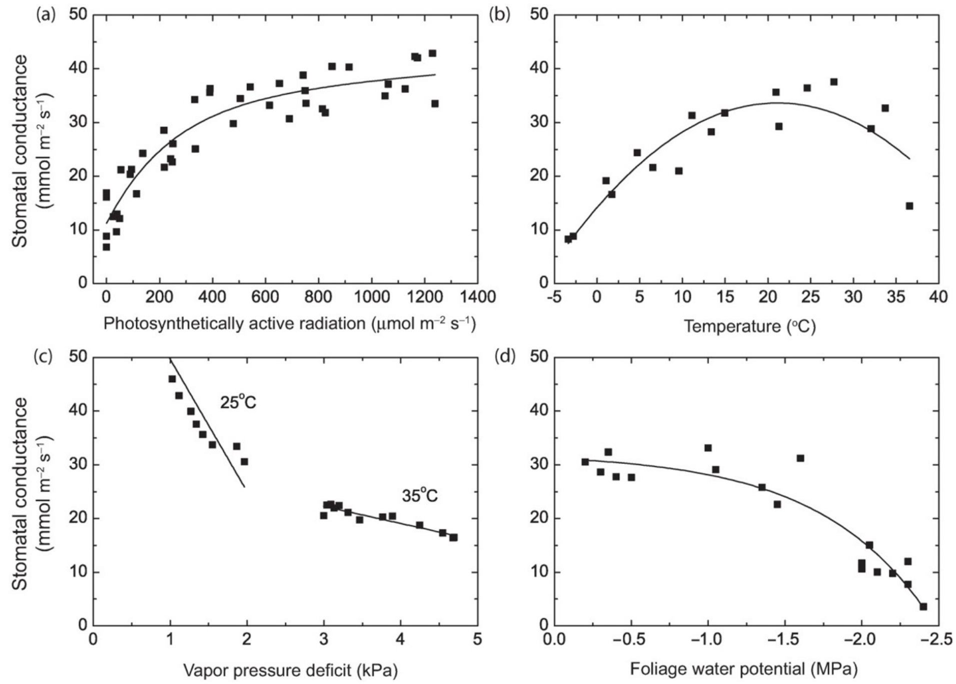


Figure 25: Observed responses of stomatal conductance for Pinus banksiana. (Bonan 2019)

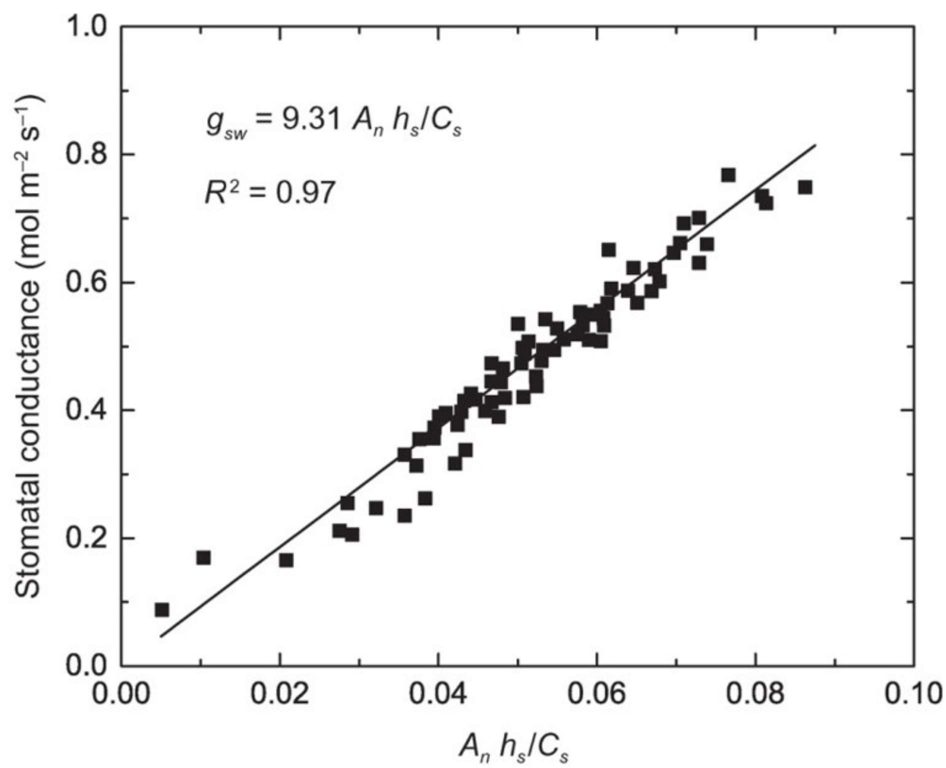


Figure 26: Relationship between stomatal conductance and Anhs/cs for soybean.(Bonan 2019)

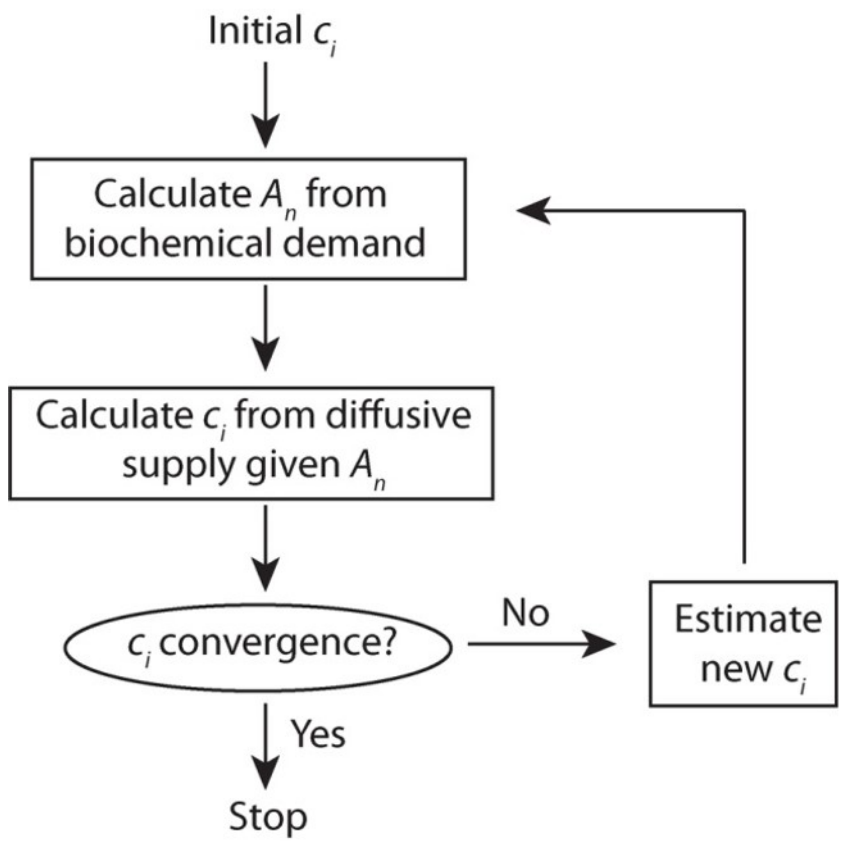


Figure 27: Flow diagram of the iterative procedure to numerically calculate ci.(Bonan 2019)

WUE models and optimality theory

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

Soil drought stress

Hydraulic models

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

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.

Case studies

Case study 2.1 Ozone impact on global GPP

Case study 2.2 Drought impact on rainforest GPP

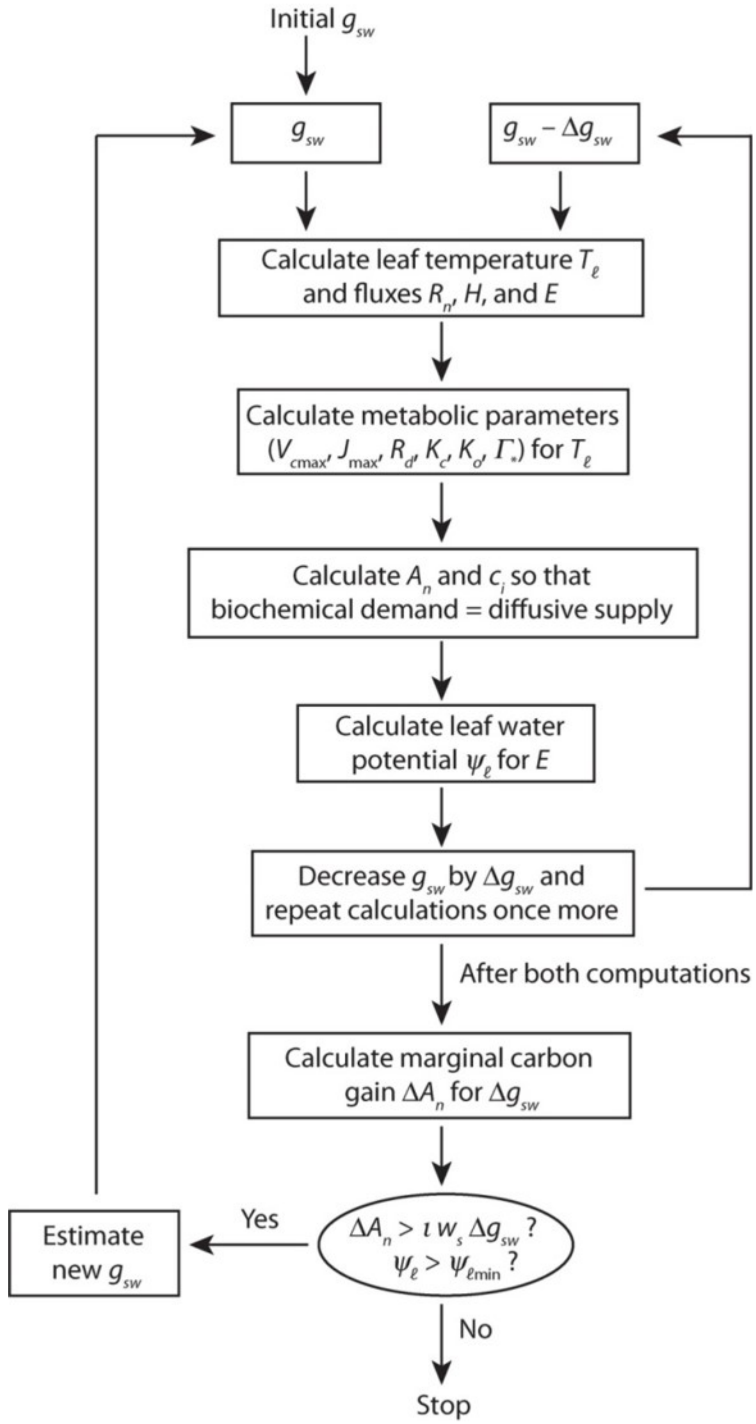


Figure 28: Flow diagram of leaf flux calculations to numerically solve for stomatal conductance that optimizes water-use efficiency.(Bonan 2019)

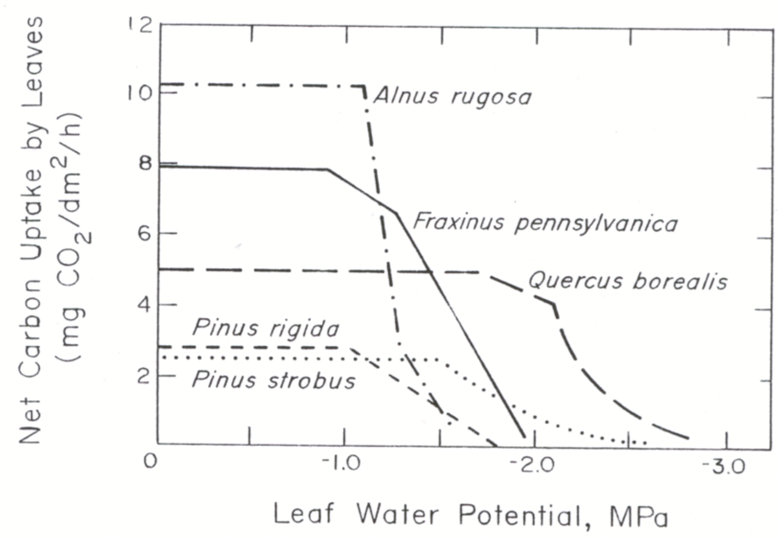


Figure 29: Leaf carbon uptake in response to leaf water potential for multiple tree species.

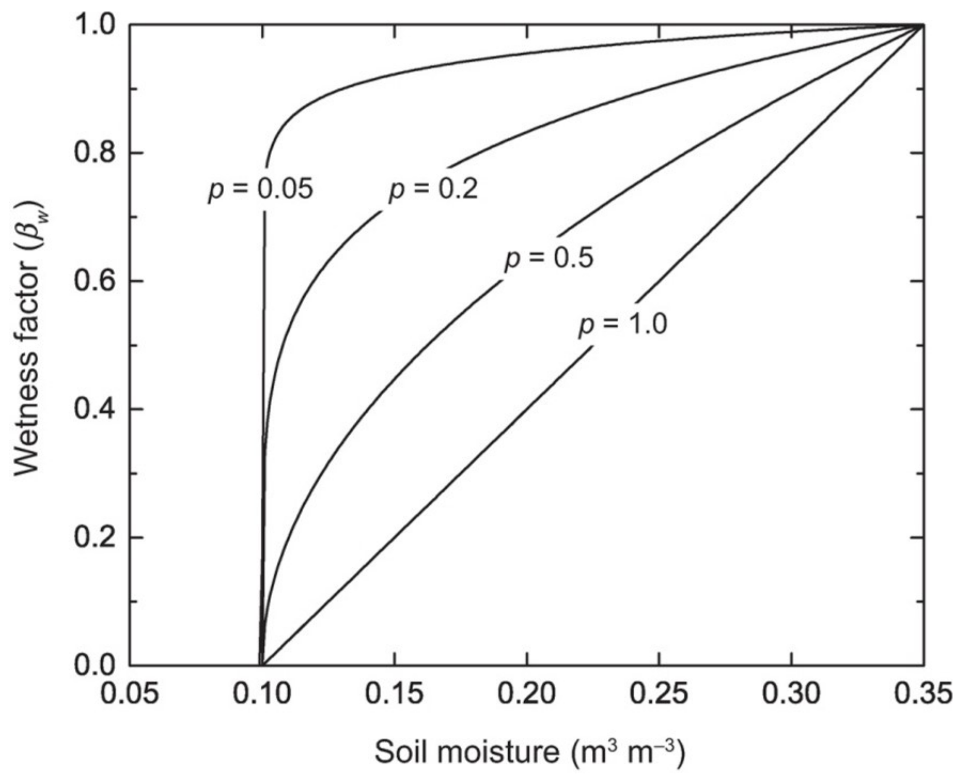


Figure 30: Soil moisture wetness factor in relation to volumetric water content. (Bonan 2019)

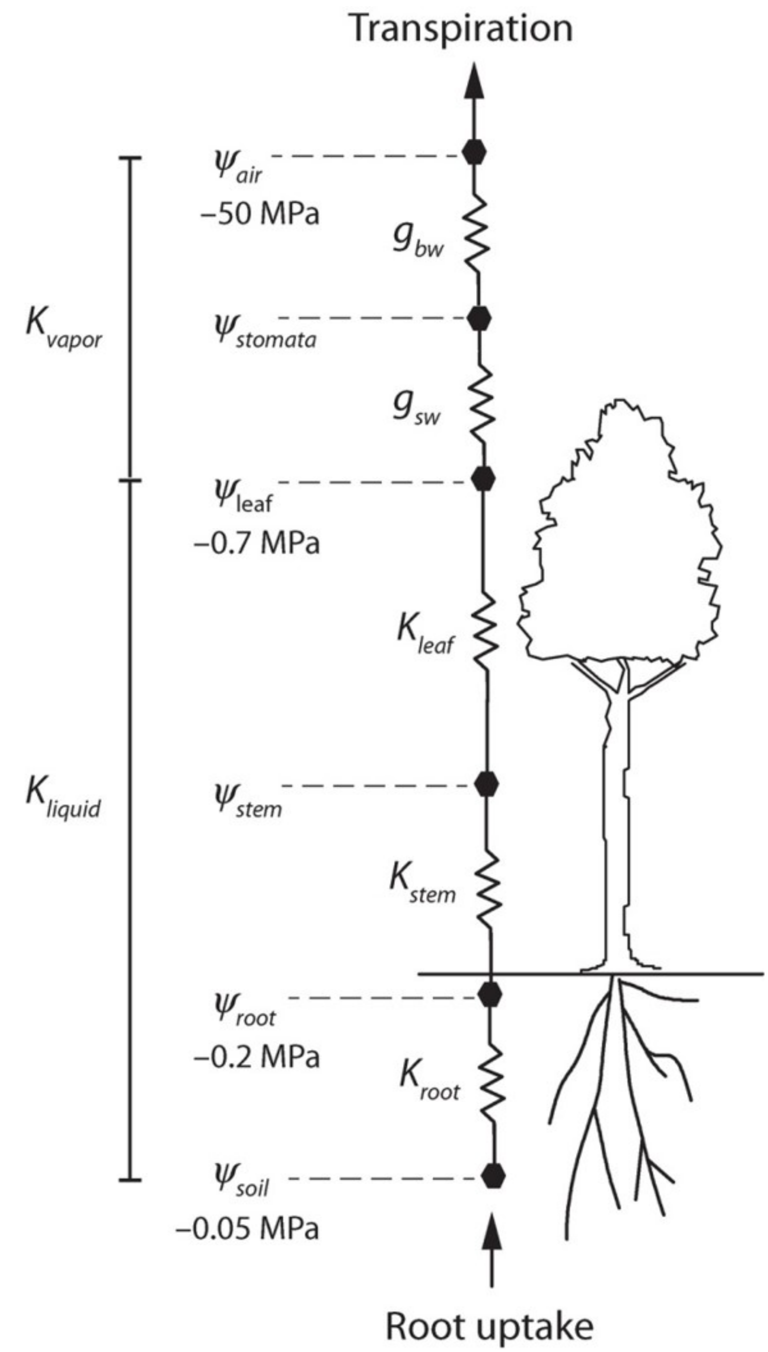


Figure 31: Flow of water and representative water potentials along the soil–plant–atmosphere continuum. Also shown are conductances along the hydraulic pathway.(Bonan 2019)

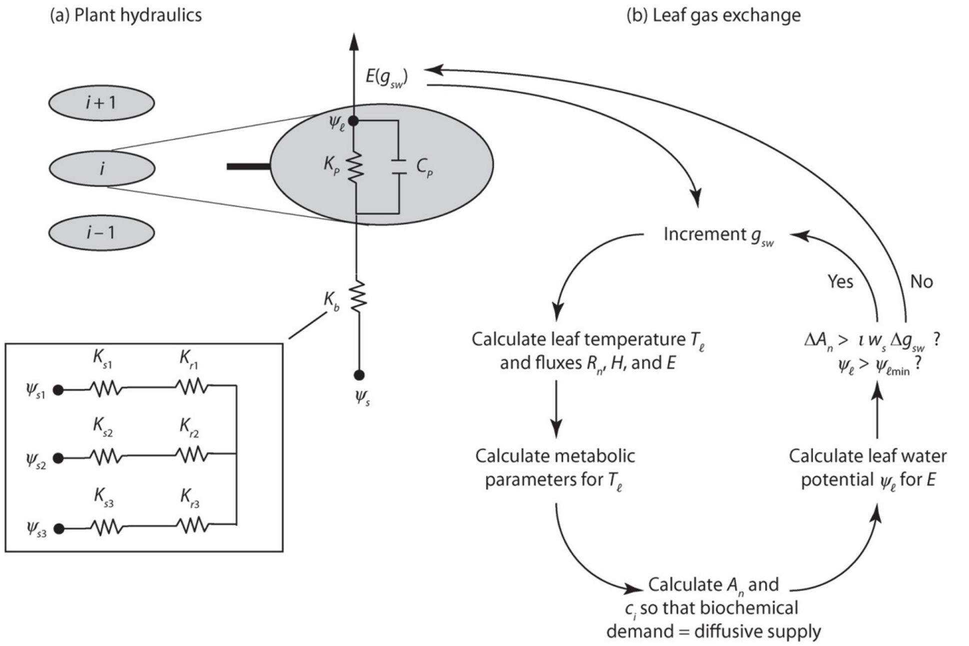


Figure 32: Depiction of (a) plant hydraulics and (b) leaf gas exchange in the Soil–Plant–Atmosphere (SPA) model. SPA is a multilayer canopy model.(Bonan 2019)

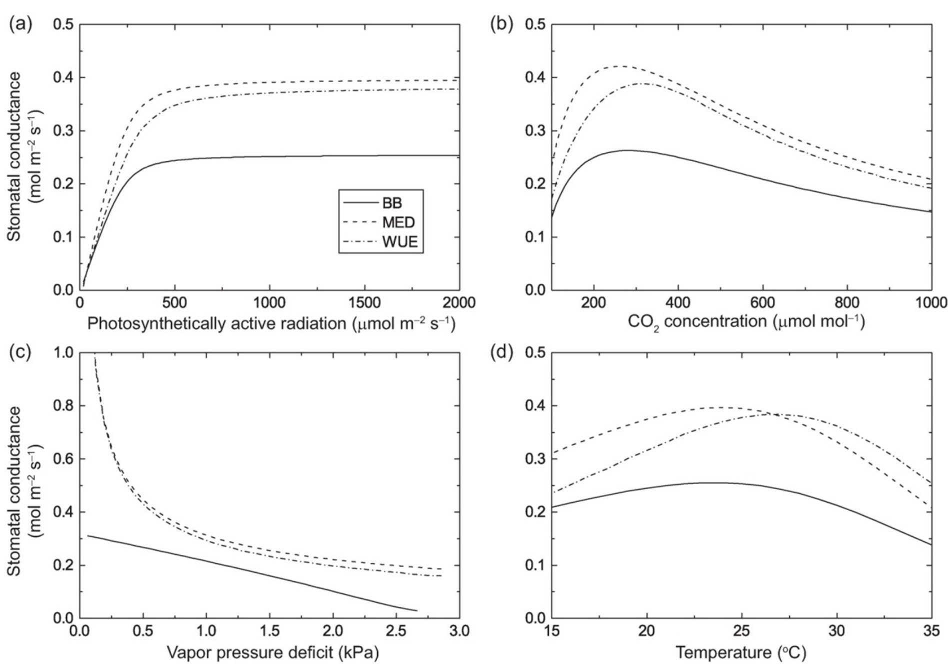


Figure 33: Simulated stomatal responses for various modelling approaches. (Bonan 2019)

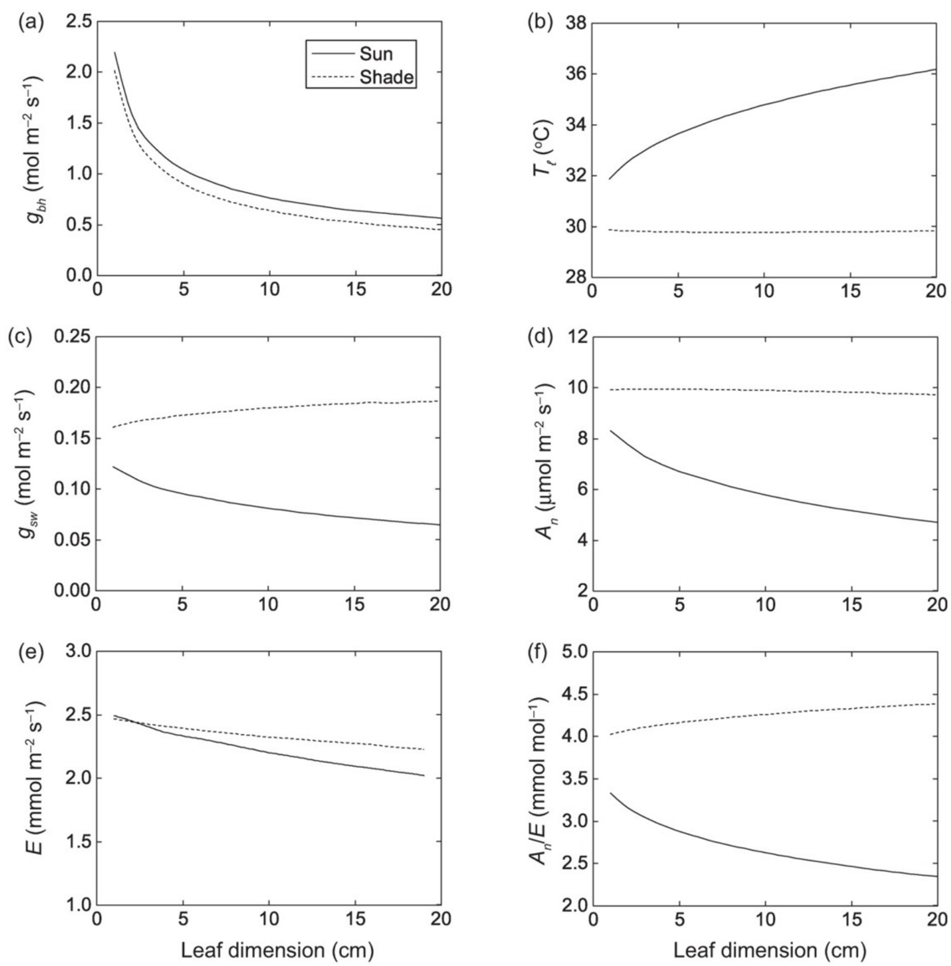


Figure 34: Leaf microclimate and boundary layer processes in relation to leaf dimension for sun and shade conditions.(Bonan 2019)

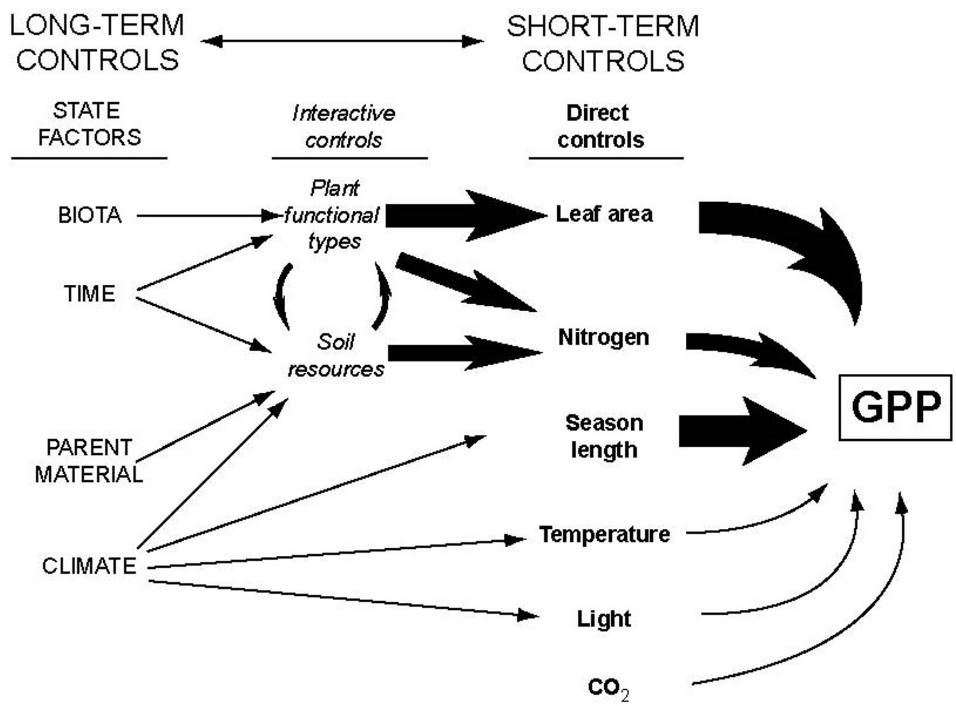


Figure 35: Controlling facors on ecosystem GPP. (Chapin)

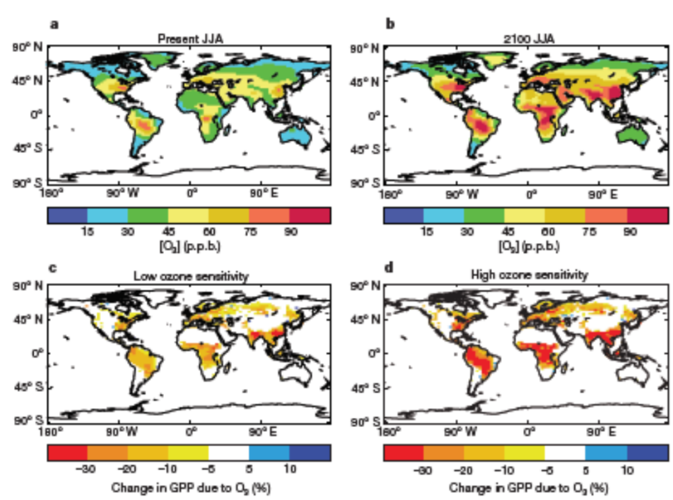


Figure 36: Simulated global GPP reduction in response to current and future atmospheric ozone concentrations

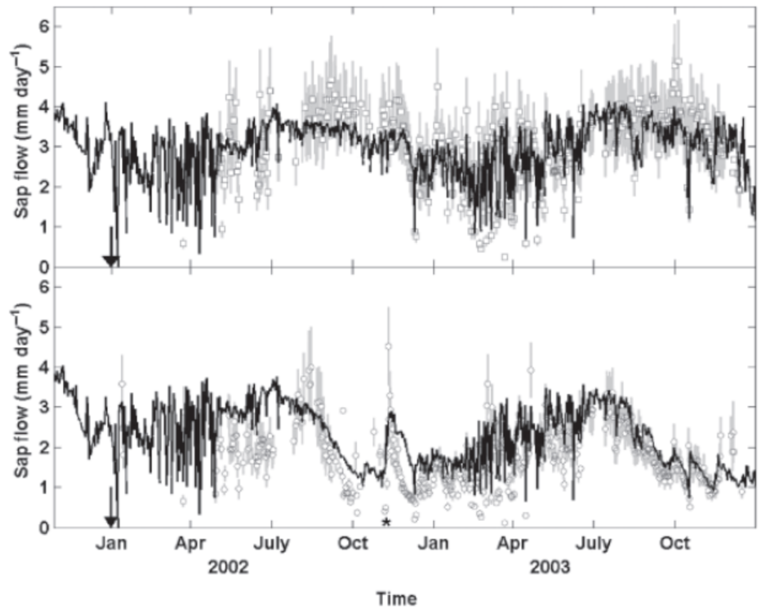


Figure 37: Simulated (SPA model) and observed sapflow for a drought experiment in the Amazon; Fisher et al. 2007

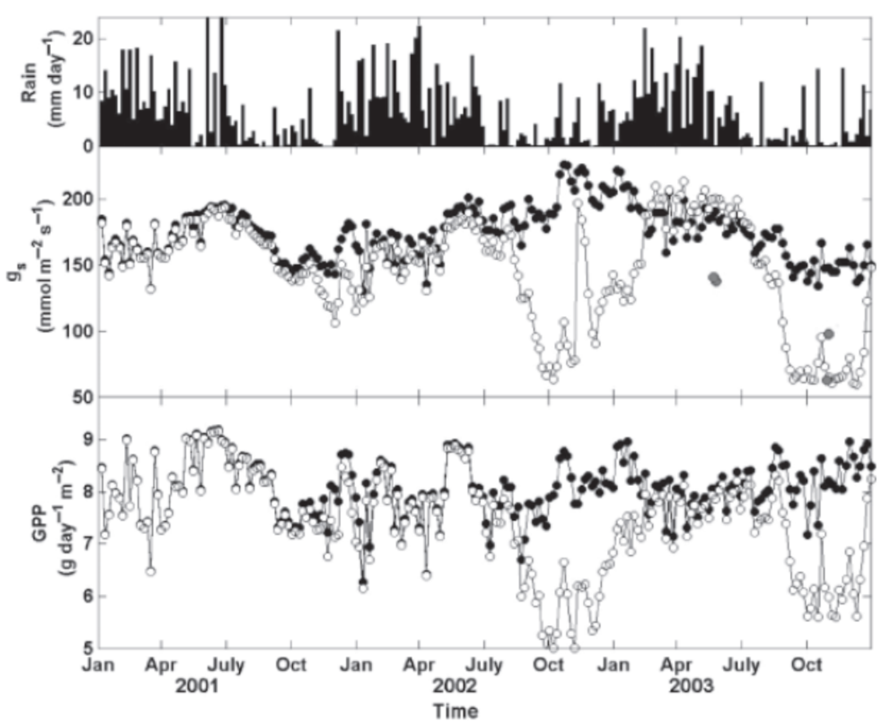


Figure 38: Simulated (SPA model) gs and GPP for a drought experiment in the Amazon. Fisher et al. 2007

Modelling radiation, vegetation canopies, and energy balance

Introduction

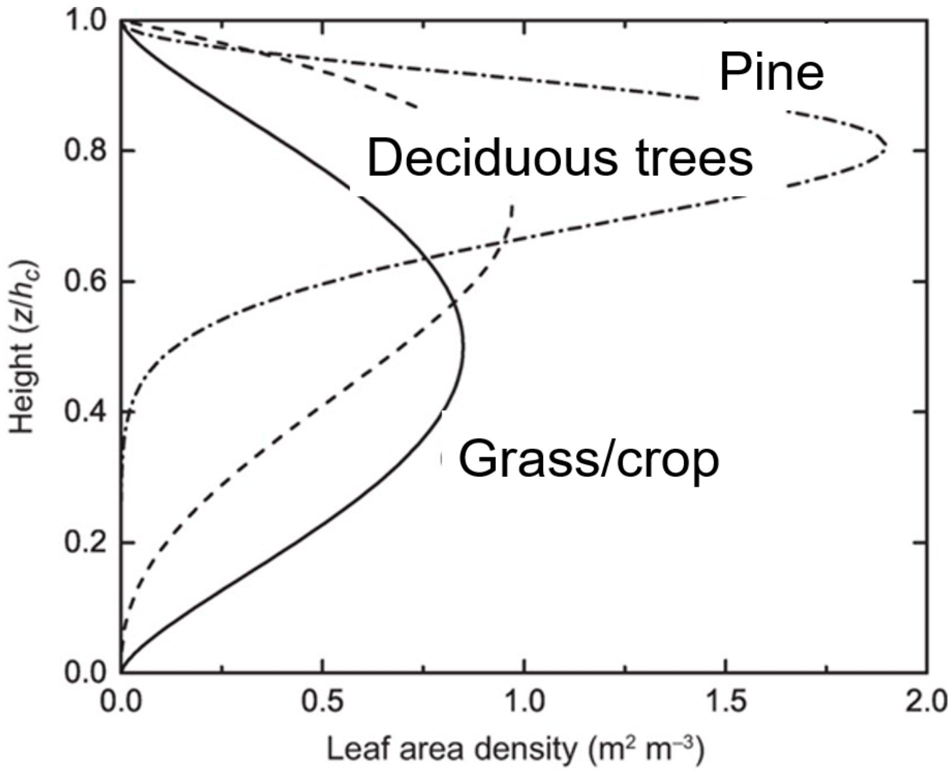


Figure 39: Generalized profiles of leaf area density in plant canopies. (Bonan)

Radiative transfer modelling

Leaf optical properties

Light transmission without scattering

Diffuse transmittance

The Norman Model(1979)

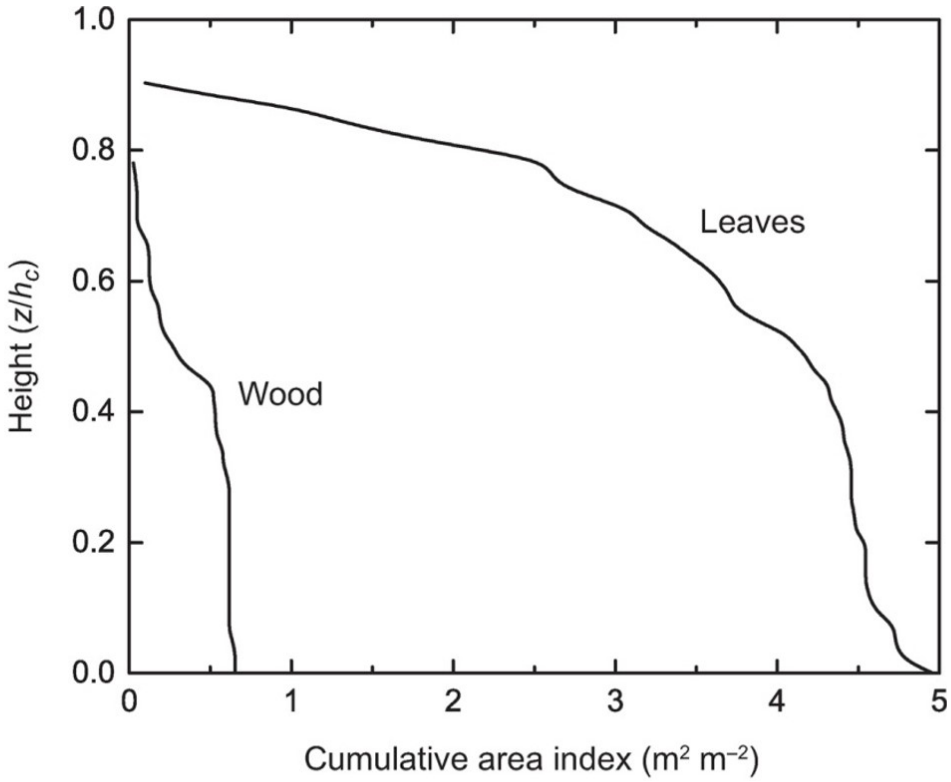


Figure 40: Cumulative LAI and WAI in a deciduous oak-hickory forest. (Bonan)

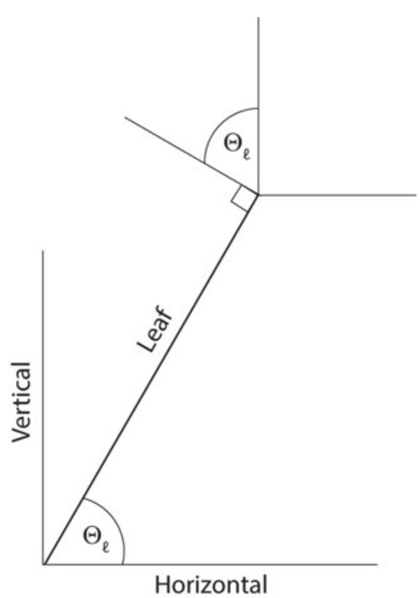


Figure 41: Illustration of a leaf (thick line) oriented at an angle Tl to horizontal. (Bonan)

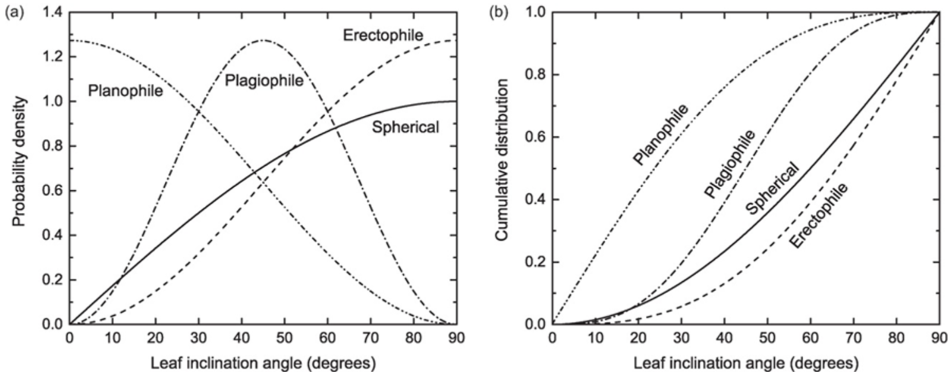


Figure 42: Planophile, erectophile, plagiophile, and spherical leaf angle distributions showing (a) the probability density function f(Tl) and (b) the cumulative distribution F(Tl). (Bonan)

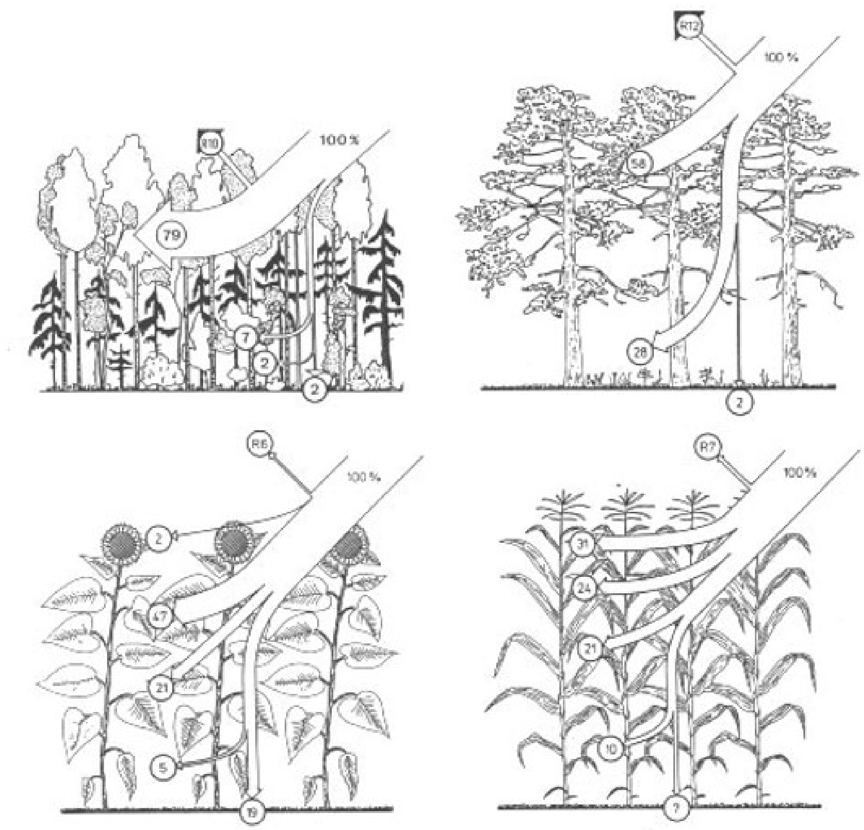


Figure 43: Illustration of leaf angle distributions and canopy architecture in general influences radiation attenuation in vegetation canopies.

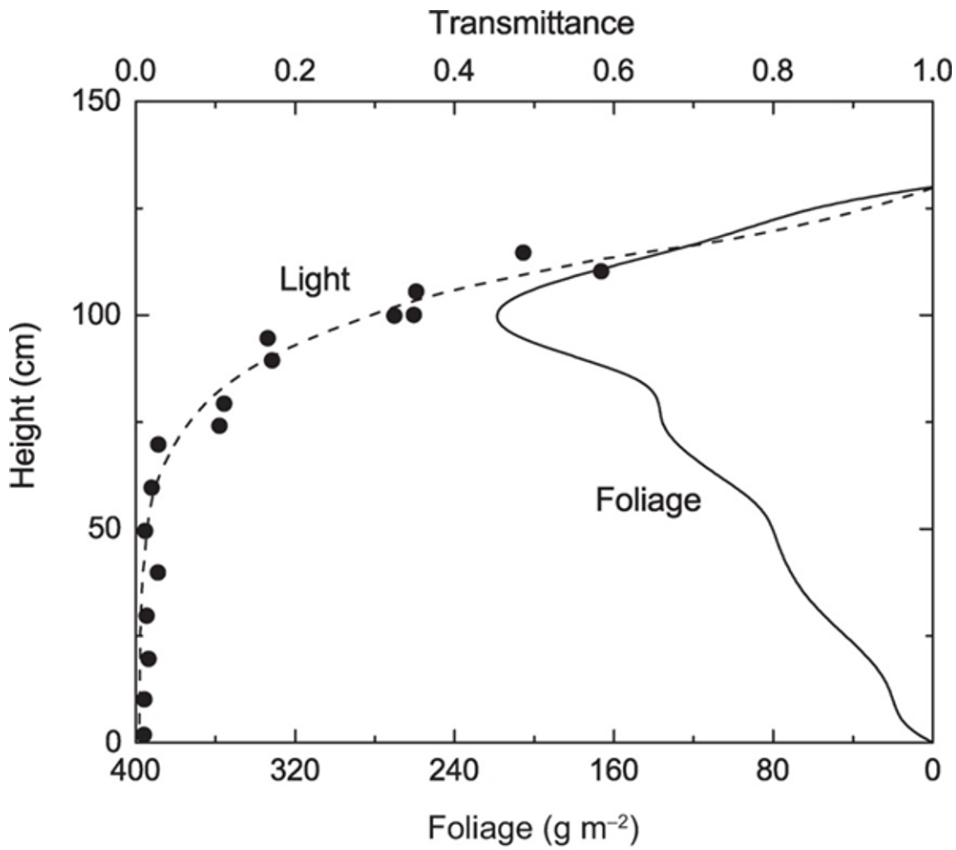


Figure 44: Profile of light and foliage in a stand of herbaceous plants approximately 130 cm tall. The horizontal axis shows transmittance as a fraction of incident radiation (top axis) and foliage mass (bottom axis) at various heights in the canopy. (Bonan)

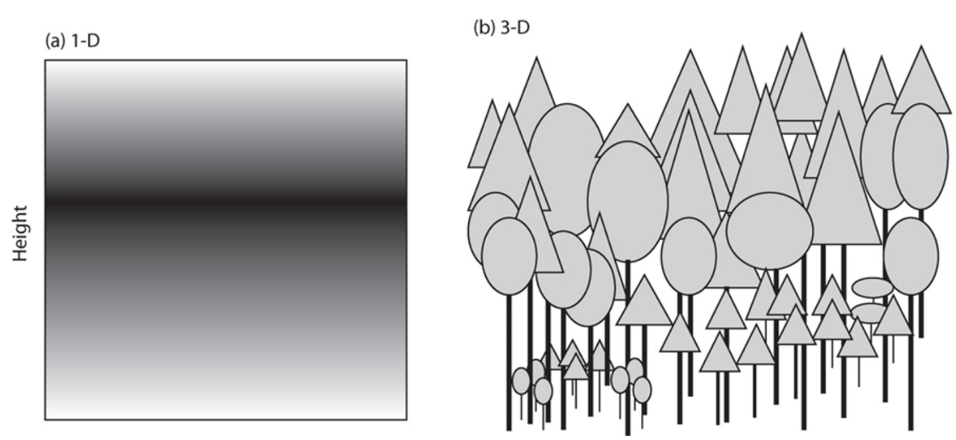


Figure 45: Representation of a canopy as (a) one-dimensional with a vertical profile of leaf area (shown by grayscale gradation in which darker shading denotes more leaves) that is horizontally homogenous and (b) threedimensional with vertical and spatial structure determined by crown geometry and spacing. (Bonan)

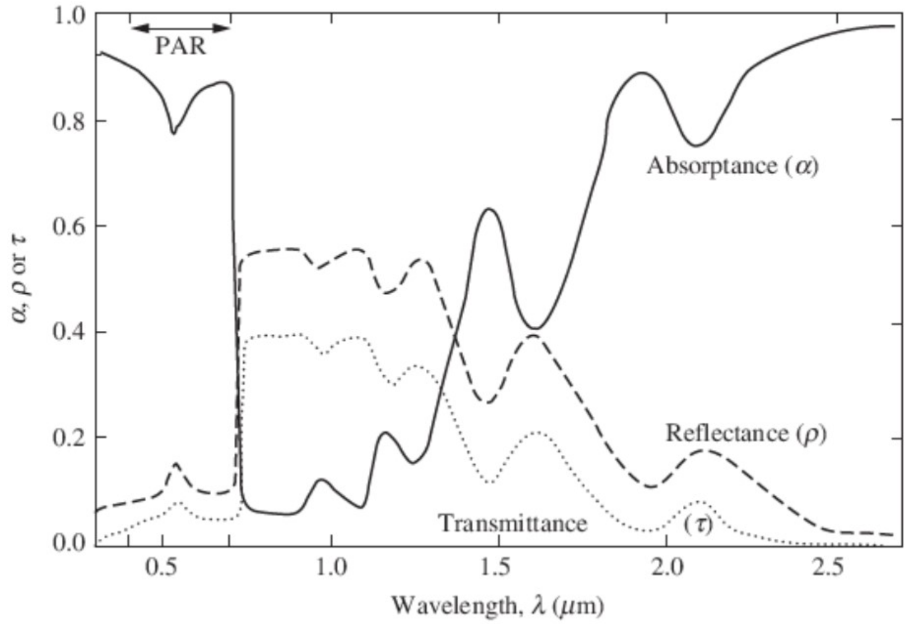


Figure 46: Spectrum of absorptance, reflectance and transmittance of a typical plant leaf (Jones, 2014)

	ρ_S (%)	α_S (%)
Single leaves		
Crop species	29–33	40–60
Deciduous broad leaves (low sun)	26–32	34–44
Deciduous broad leaves (high sun)	20–26	48–56
Artemisia sp. (white pubescent, high sun)	39	55
Verbascum sp. (white pubescent, high sun)	36	52
Conifers	12	88
Typical mean values for total shortwave (ρ_S, α_S)	~30	~50
Typical mean values for PAR (ρ_{PAR}, α_{PAR})	~9	~85
Vegetation		
Grass	24	
Crops	15–26	
Forests	12–18	
Typical mean values for total shortwave (ρ_S)	~20	
Typical mean values for PAR (ρ_{PAR})	~5	
Other surfaces		
Snow	75–95	
Wet soil	9 ± 4	
Dry soil	19 ± 6	
Water	5–>20	

Figure 47: Table showing typical reflectance and absorptance values for leaves and vegetation canopies of different Plant Functional Types (PFT).(Jones, 2014)

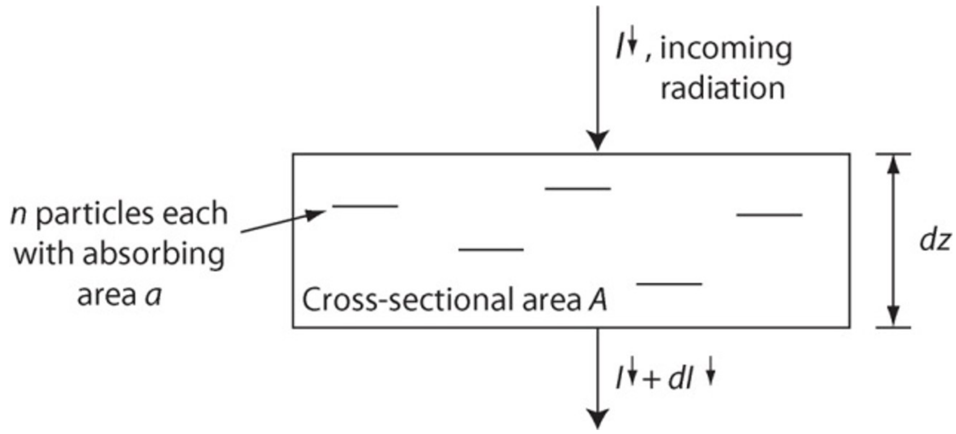


Figure 48: Transmission of solar radiation through a homogeneous medium in the absence of scattering. In this example, n non-overlapping opaque particles each with cross-sectional area a oriented perpendicular to the path of light are placed in a medium with cross-sectional area A and thickness dz. The radiation absorbed in the medium is dI.(Bonan)

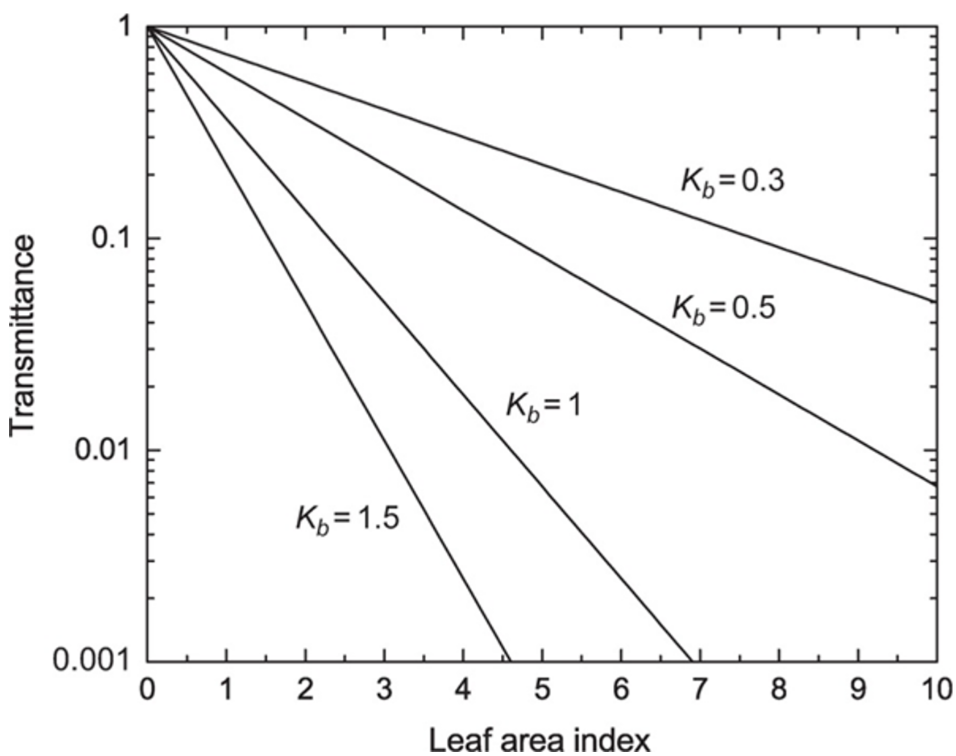


Figure 49: Transmission of direct beam radiation tb in relation to leaf area index for typical values of the extinction coefficient Kb. (Bonan)

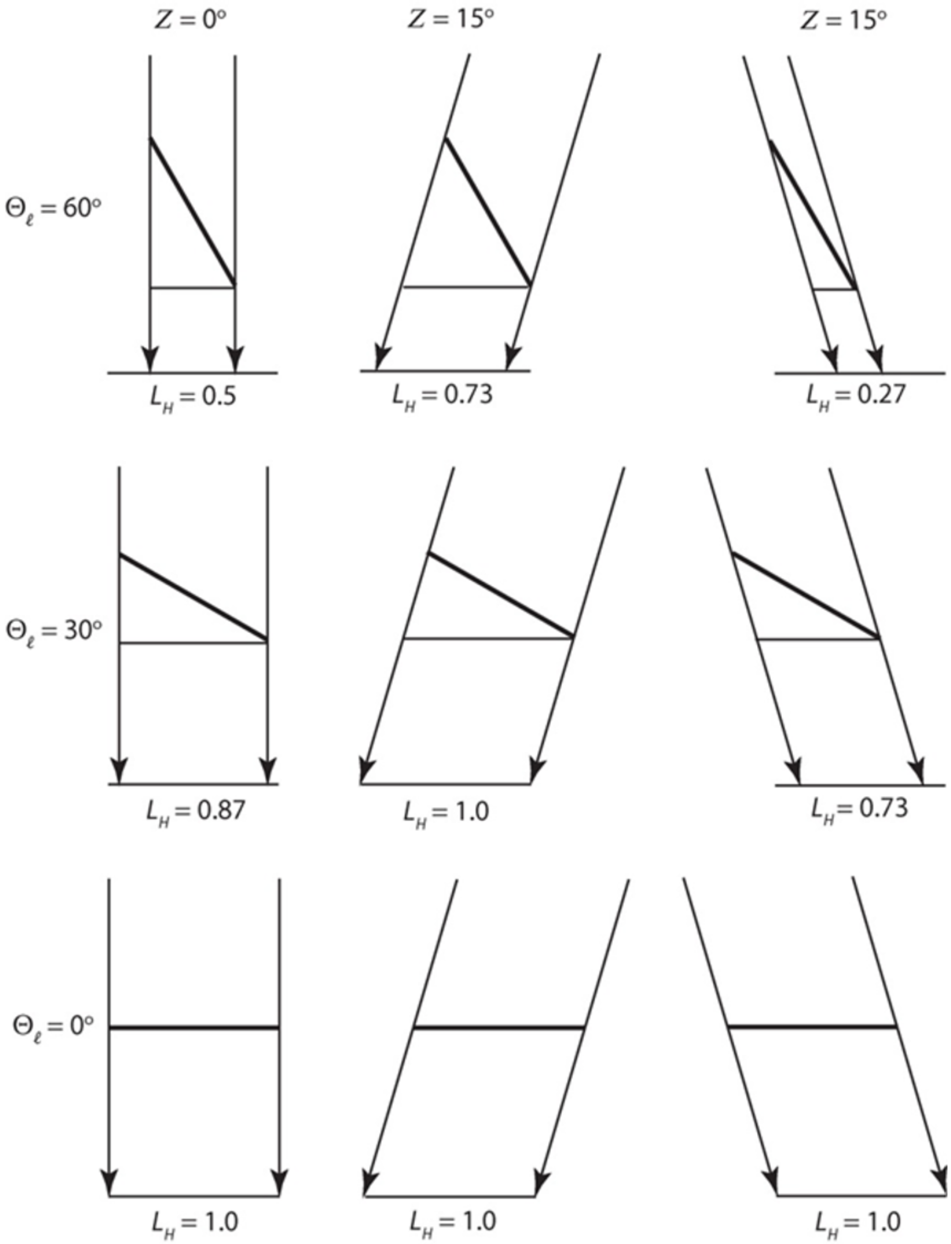


Figure 50: Extinction coefficient in relation to solar zenith angle <U+0396> and leaf inclination angle Tl. In each panel, a unit leaf area (L = 1), shown with a thick line, is projected onto a horizontal surface LH so that Kb = LH. The leaf inclination angle is 0° (bottom panels), 30° (middle panels), and 60° (top panels). In the left and middle columns, the leaf is oriented towards the Sun (<U+0391>l - <U+0391> = 0°) and the solar zenith angle is 0° (left column) and 15° (middle column). In the right column, <U+0396> = 15°, but the leaf is oriented away from the Sun (<U+0391>l - <U+0391> = 180°). In each panel, the arrows indicate the solar beam (Bonan)

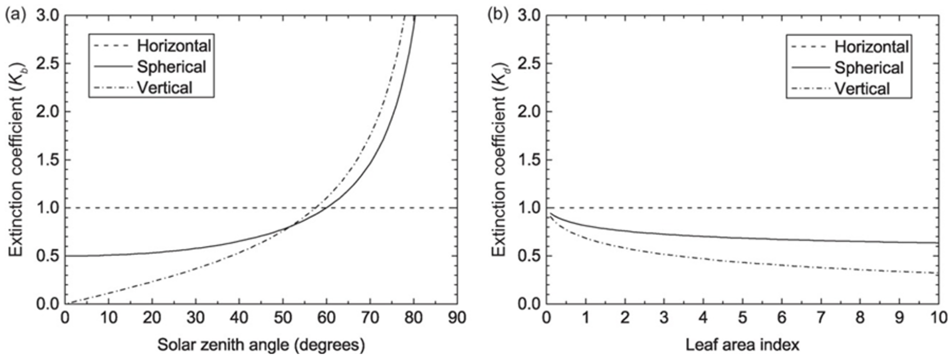


Figure 51: Extinction coefficients for horizontal, spherical, and vertical leaf angle distributions. (a) Direct beam radiation Kb in relation to solar zenith angle. (b) Diffuse radiation Kd in relation to leaf area index(Bonan)

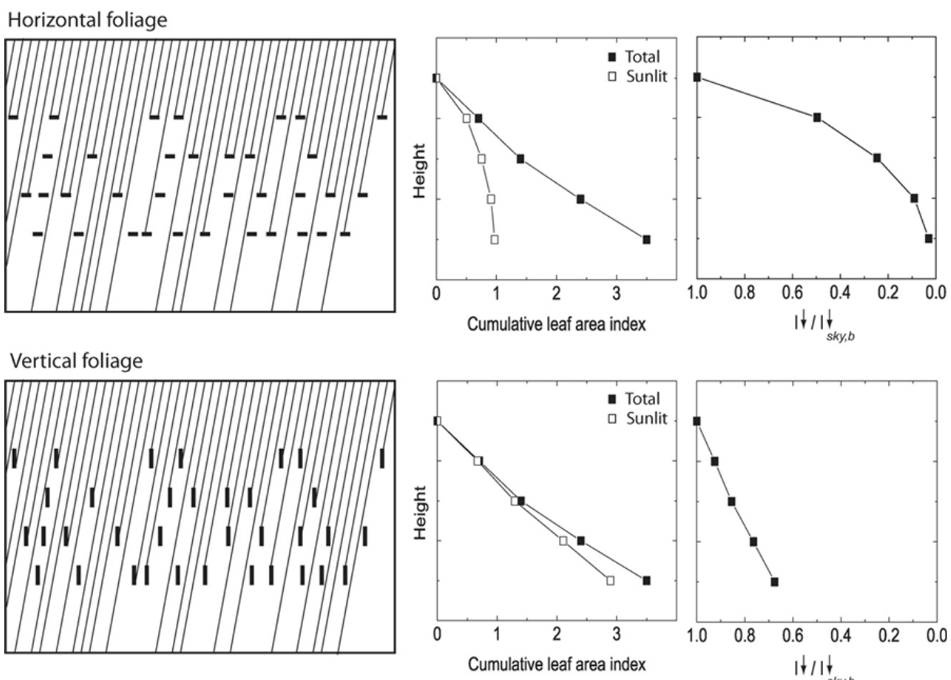


Figure 52: Radiative transfer and sunlit leaf area index for a canopy of horizontal leaves (top panels) with Kb = 1 and vertical leaves (bottom panels) with Kb = 0.112. The left-hand panels show a canopy consisting of four layers of leaves. Each thick black line represents a leaf area index of 0.1 m2 m–2. The thin lines depict interception or transmission of beam radiation with a zenith angle of 10°. The middle panels show cumulative leaf area index and sunlit leaf area index with depth in the canopy. The right-hand panels show direct beam transmittance with depth in the canopy. (Bonan)

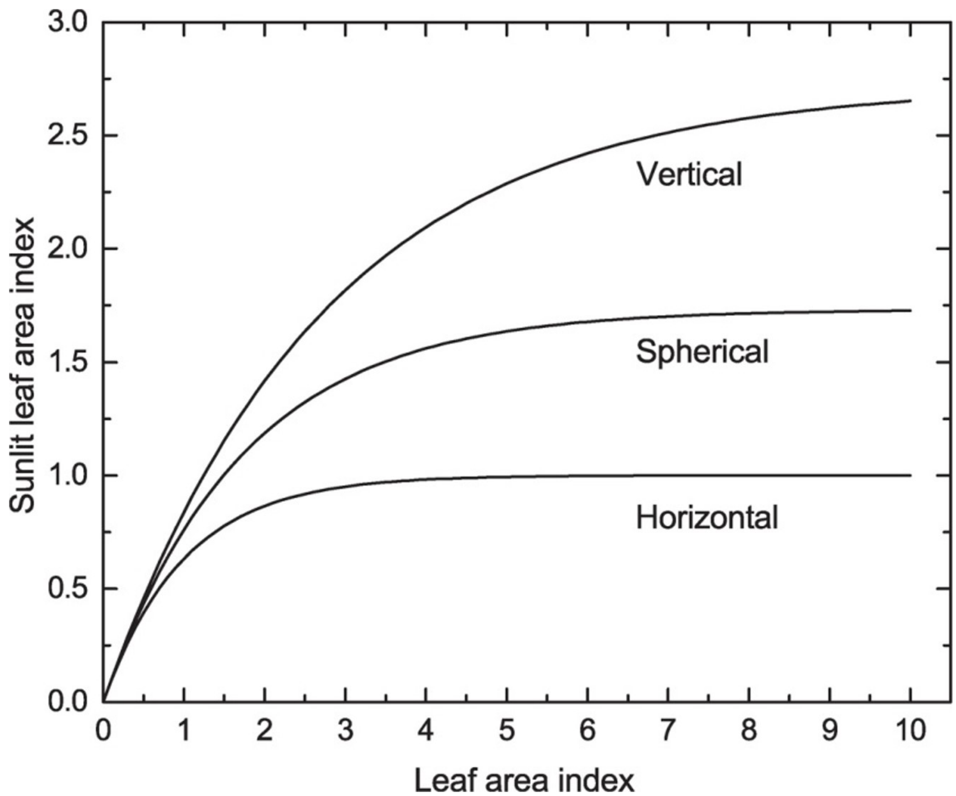


Figure 53: Sunlit leaf area index in relation to total leaf area index for horizontal, spherical, and vertical foliage orientations with solar zenith angle <U+0396> = 30°. Kb = 1, 0.577, and 0.368 for horizontal, spherical, and vertical foliage. (Bonan)

Figure 54: Images illustrating leaf/canopy clumping a various scales: leaf, crown, stand.

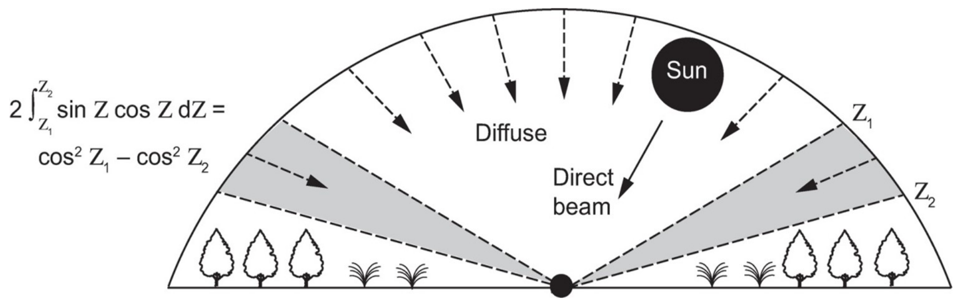


Figure 55: Illustration of direct beam and diffuse radiation. The sky forms a bowl, or inverted hemisphere, over a horizontal surface. Shown is a cross section of the sky hemisphere. Direct beam (solid line) originates from the direction of the Sun with zenith angle <U+0396>. Diffuse radiation (dashed lines) can be treated as independent beams of radiation each with an angle <U+0396>. The shaded region is the relative contribution between sky angles <U+0396>1 and <U+0396>2 to total sky irradiance.(Bonan)

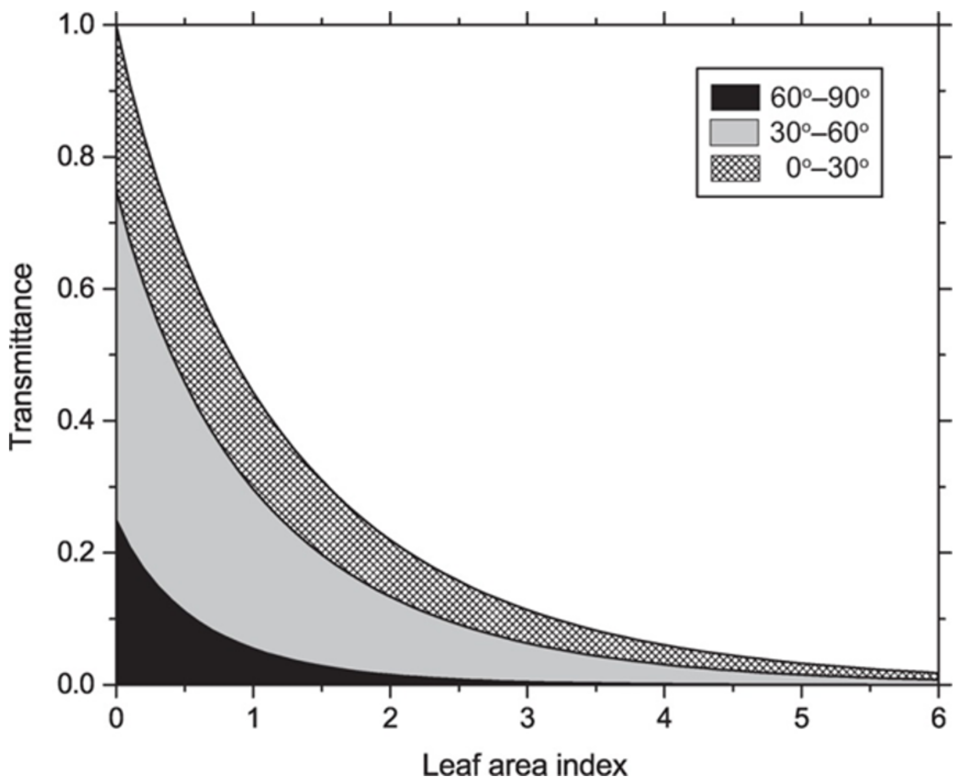


Figure 56: Transmittance of diffuse radiation td in relation to leaf area index for a spherical leaf distribution. Show are the transmittances for sky zones of 0°–30°, 30°–60°, and 60°–90° and also the total transmittance. Fill patterns show the contribution of each sky zone to total transmittance.(Bonan)

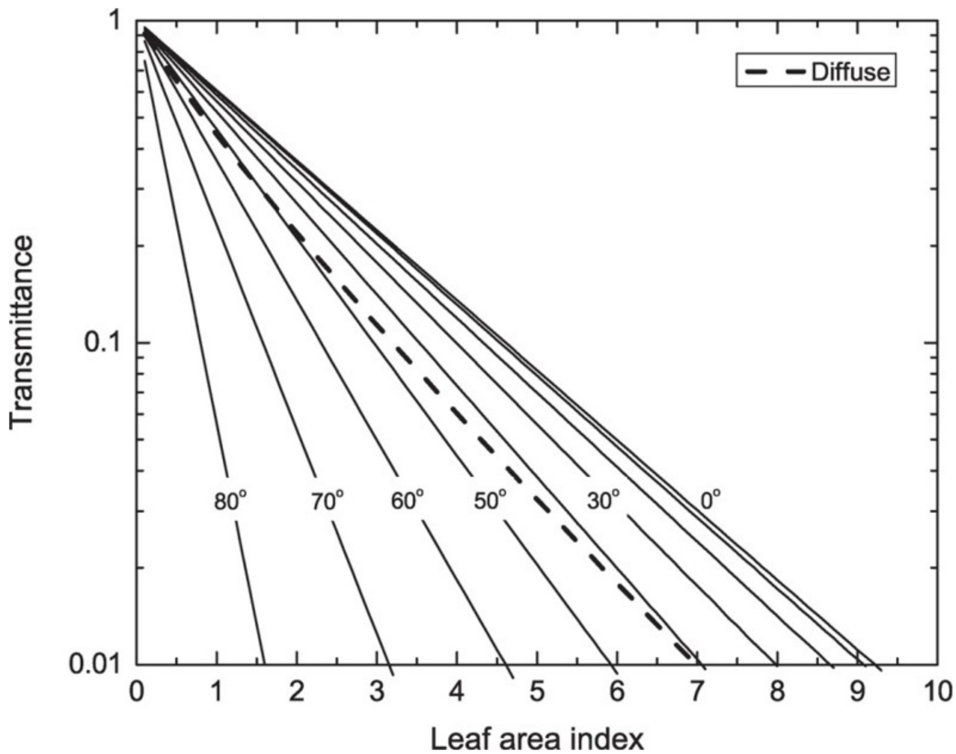


Figure 57: Transmission of solar radiation through a canopy with spherical leaf distribution in relation to leaf area index. The solid lines show direct beam transmittance tb for solar zenith angles of 0°–80° (in 10° increments).The dashed line shows the diffuse transmittance td. (Bonan)

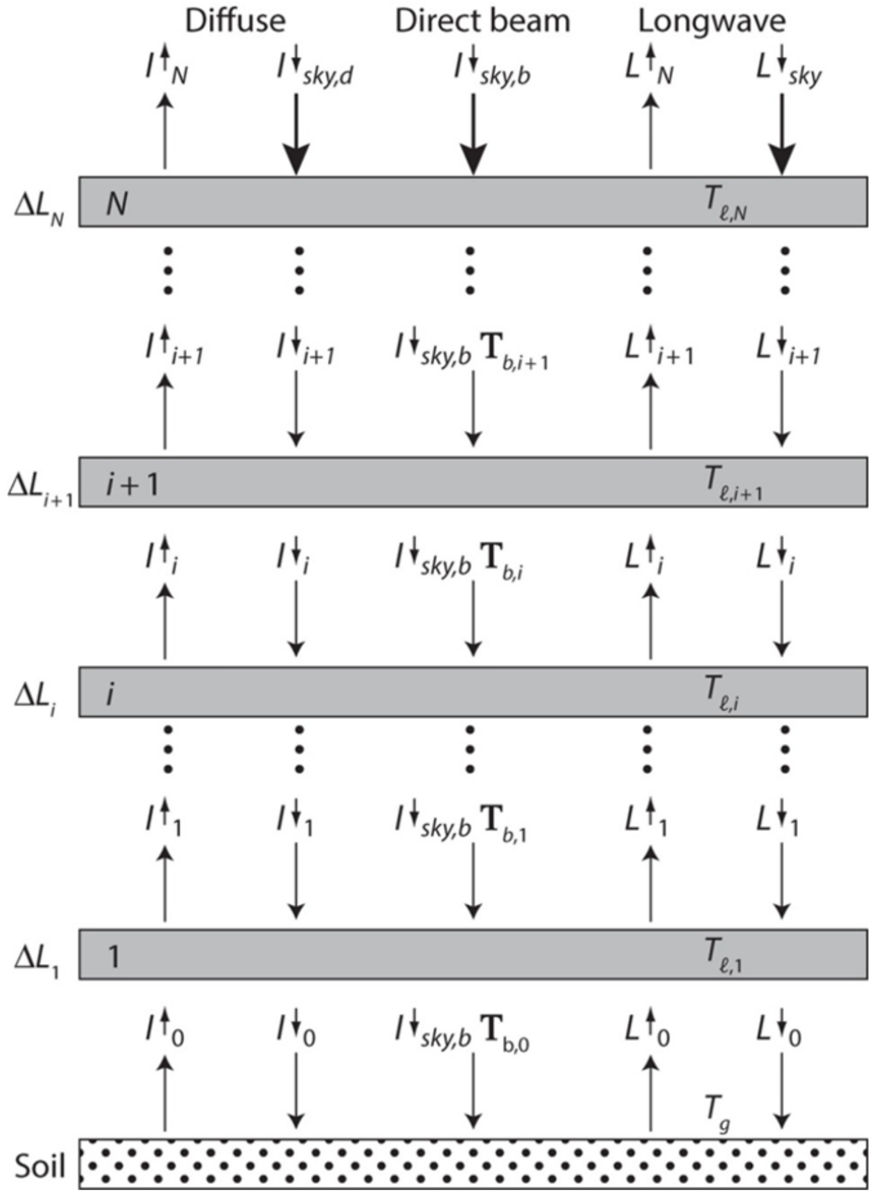


Figure 58: Radiative fluxes in a canopy of N leaf layers. The vertical profile is oriented with i = 1 the leaf layer at the bottom of the canopy, leaf layer i + 1 above layer i, and i = N the leaf layer at the top of the canopy. Each layer has a leaf area index <U+0394>L. is the downward diffuse shortwave flux onto layer i, is the upward diffuse shortwave flux above layer i, and is the unscattered direct beam flux onto layer i. and are the corresponding downward and upward fluxes of longwave radiation. These depend on leaf Tland ground Tg temperatures. Thick arrows denote boundary conditions of diffuse solar radiation , direct beam solar radiation, and atmospheric longwave radiation at the top of the canopy.(Bonan)

The Goudriaan and van Laar Model (1994)

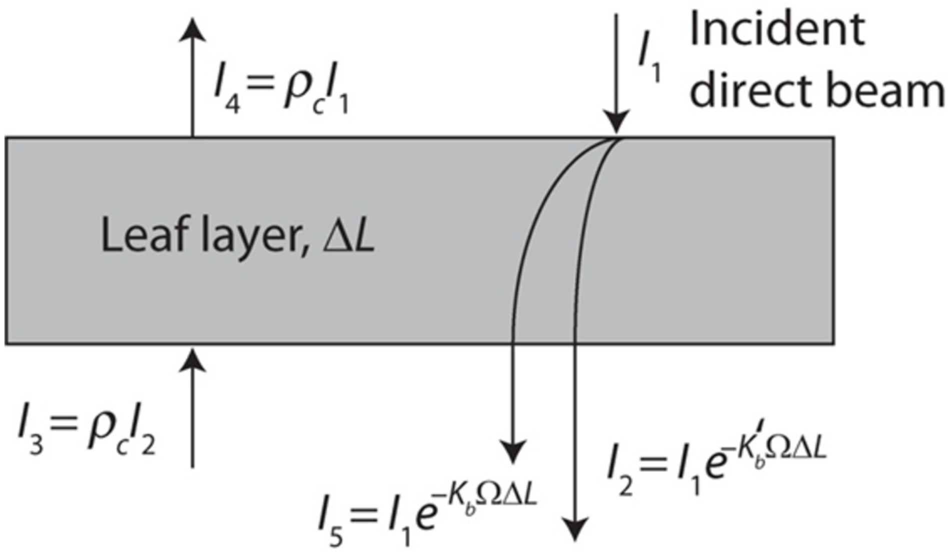


Figure 59: Derivation of absorbed direct beam solar radiation for a leaf layer with leaf area index <U+0394>L (Goudriaan 1982). <U+03C1>c is the reflectance of the leaf layer.(Bonan)

The Two-Stream approximation

Longwave radiation

Representing canopy structure in models

Big-leaf models

Multilayer models

3D ray tracing models

Ecosystem energy balance

Basic principles

Surface radiation balance

Bulk surface energy balance

Leaf energy balance

Case studies

Case study 3.1

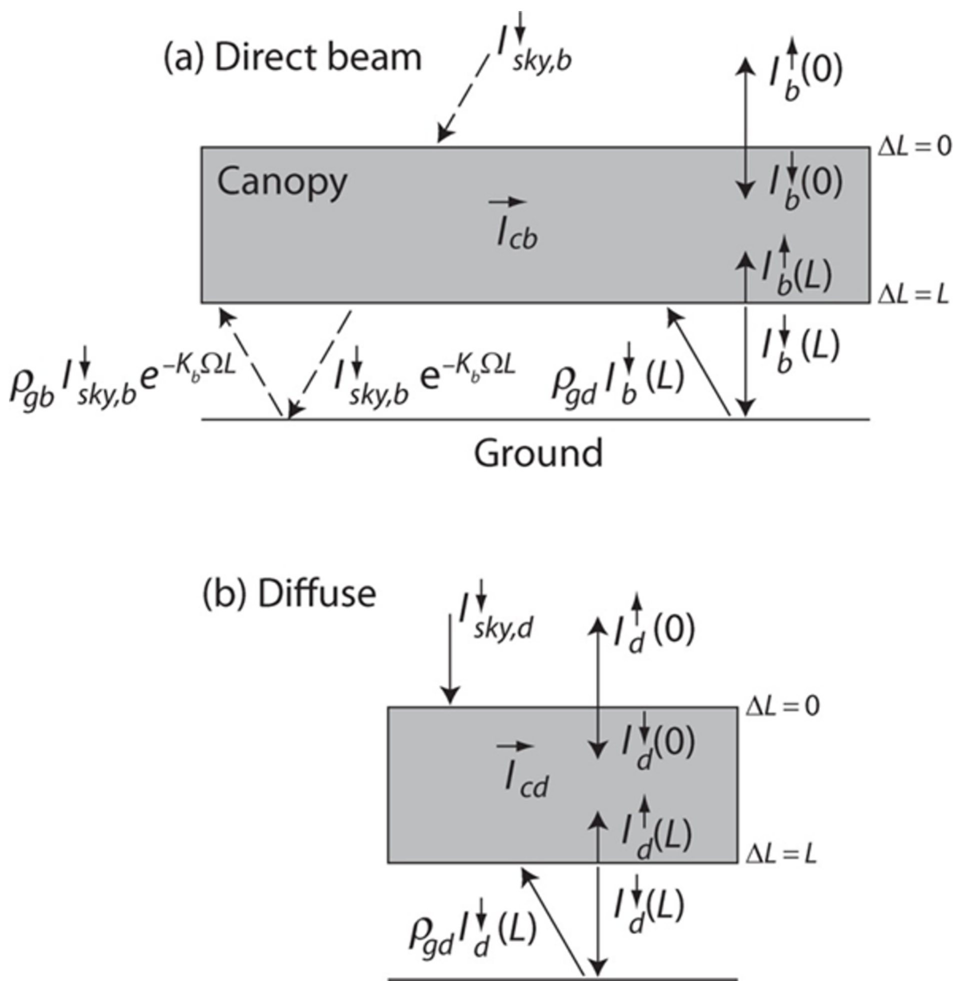


Figure 60: Fluxes for (a) direct beam and (b) diffuse radiation in the twostream approximation for a canopy with leaf area index L.(Bonan)

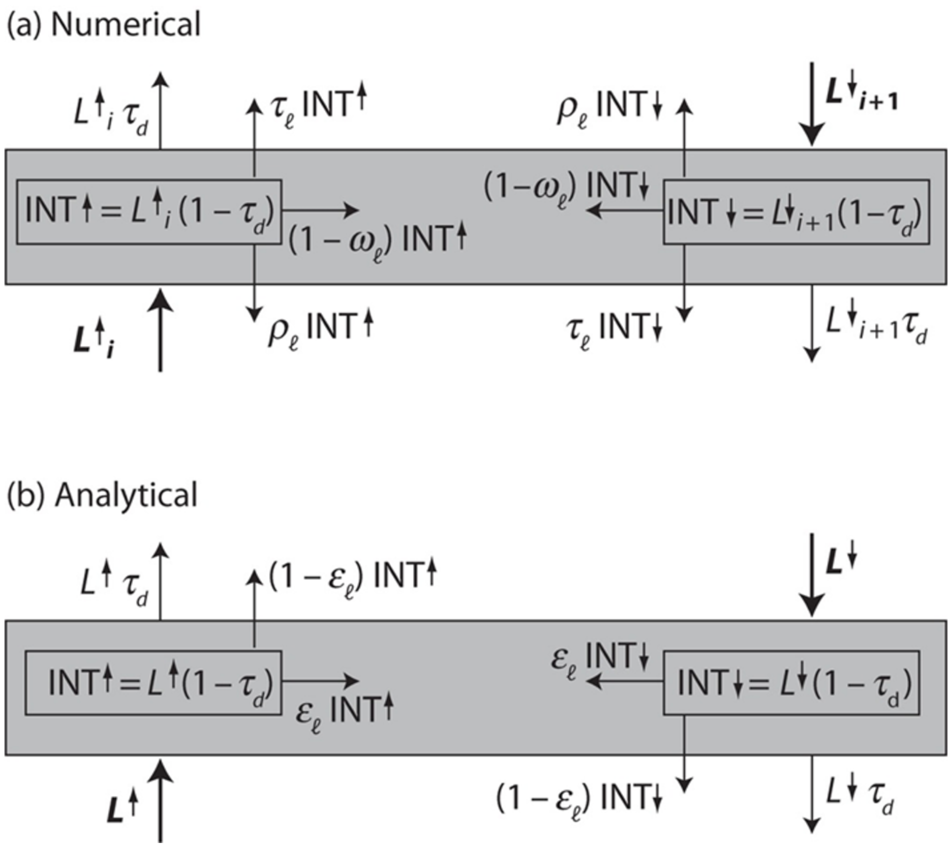


Figure 61: Longwave radiation fluxes represented for a single leaf layer.(a) Norman's (1979) numerical model. Shown is the radiative balance for leaf layer i + 1 located above leaf layer i. (b) A simplified model to allow only forward scattering (<U+03C1>l = 0 and tl = <U+03C9>l = 1 - el) and to permit an analytical solution integrated over a canopy. In both panels, emitted radiation is excluded. Thick lines denote fluxes incident onto the layer. (Bonan)

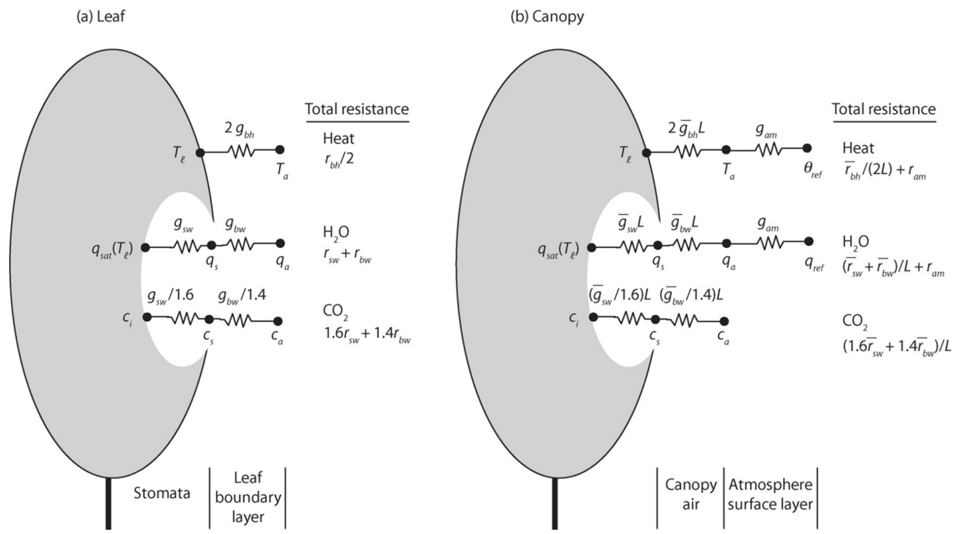


Figure 62: Scaling of leaf fluxes to the canopy using a big-leaf model. (a) Shown are leaf sensible heat, transpiration, and CO2 fluxes in relation to various conductances. Fluxes are exchanged between the leaf and air around the leaf. Also shown is the total resistance. (b) Shown are big-leaf canopy fluxes in which leaf fluxes are scaled by the average conductance and leaf area index and are further modified by turbulent transport in the atmospheric surface layer. Surface layer processes are commonly omitted for CO2 exchange. Only a single big leaf is shown, but separate sunlit and shaded big leaves can be similarly depicted. (Bonan)

Case study 3.2

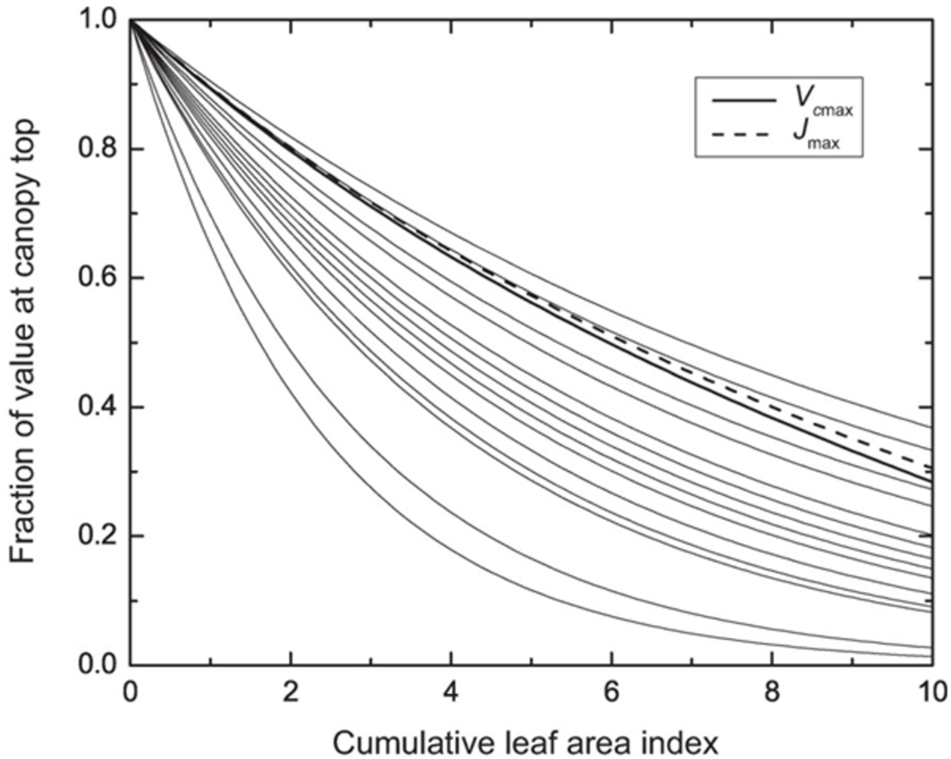


Figure 63: Canopy profiles of relative photosynthetic capacity in relation to cumulative leaf area index. Thin lines show exponential profiles using values of Kn for 16 temperate broadleaf forests and two tropical forests ranging from 0.10 to 0.43 (Lloyd et al. 2010). The two thick lines show observed profiles of Vcmax and Jmax from Niinemets and Tenhunen (1997) obtained for sugar maple (Acer saccharum). (Bonan)

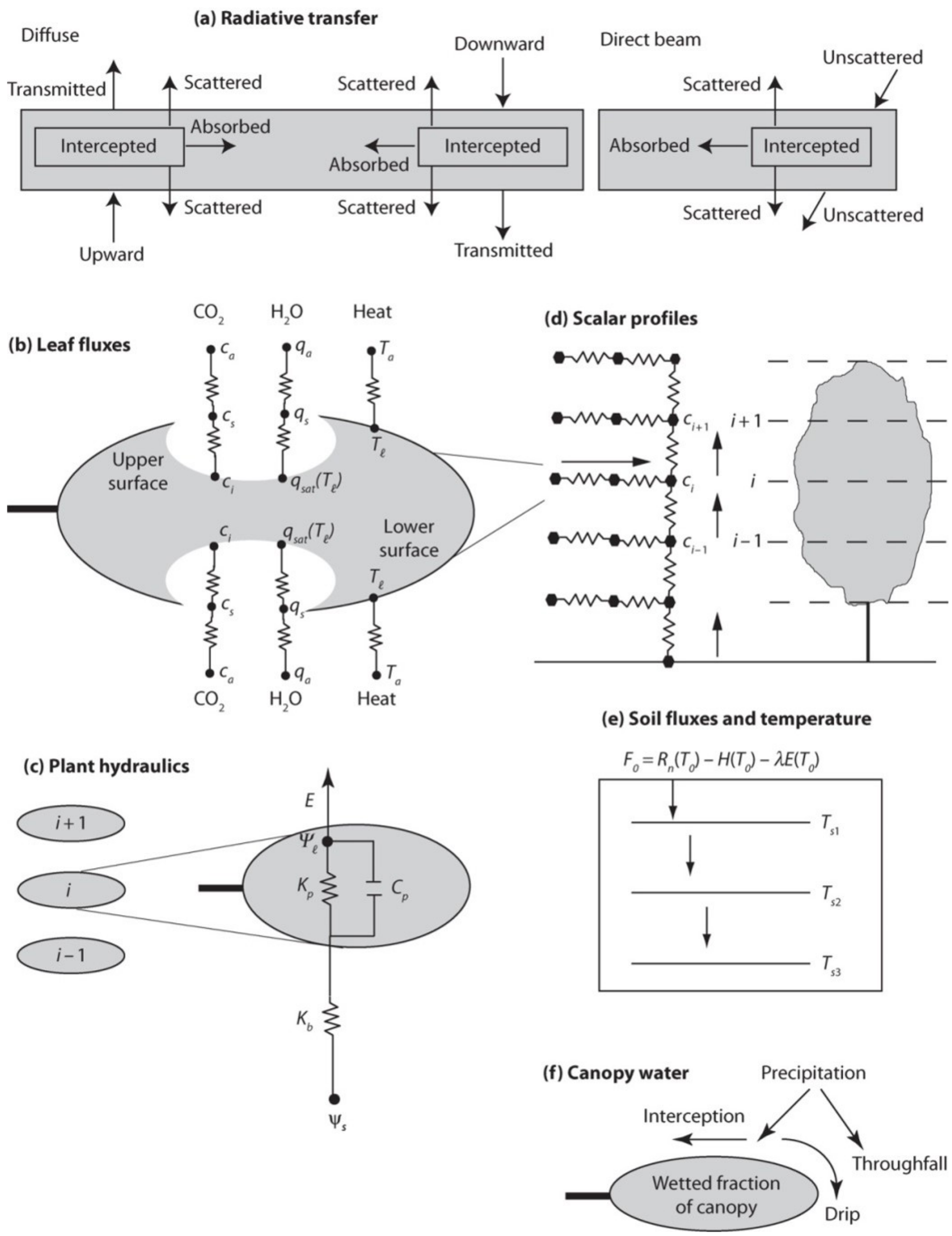


Figure 64: Overview of the main processes in a multilayer canopy model.The canopy is represented by N leaf layers with layer i + 1 above layer i. (a) Diffuse and direct beam solar radiation is transmitted or intercepted. The intercepted portion is absorbed or scattered in the forward and backward direction. Longwave radiation is similar to diffuse radiation. (b) Leaf sensible heat, transpiration, and CO2 fluxes depend on absorbed radiation and leaf boundary layer and stomatal conductances. Sensible heat is exchanged from both sides of the leaf. Water vapor and CO2 can be exchanged from one or both sides of the leaf depending on stomata. Leaf temperature is the temperature that balances the energy budget. (c) Stomatal conductance depends on leaf water potential. Plant water uptake for a canopy layer is in relation to belowground soil and root conductance and aboveground stem conductance acting in series and also a capacitance term. See Figure 13.4a for more details. (d) Scalar profiles are calculated from a conductance network. Leaf fluxes provide the source or sink of heat, water vapor, and CO2, along with soil fluxes. (e) Sensible heat, latent heat, and heat storage in soil depend on the ground temperature that balances the soil energy budget. (f) The wetted fraction of the canopy layer depends on the portion of precipitation that is intercepted. (Bonan)

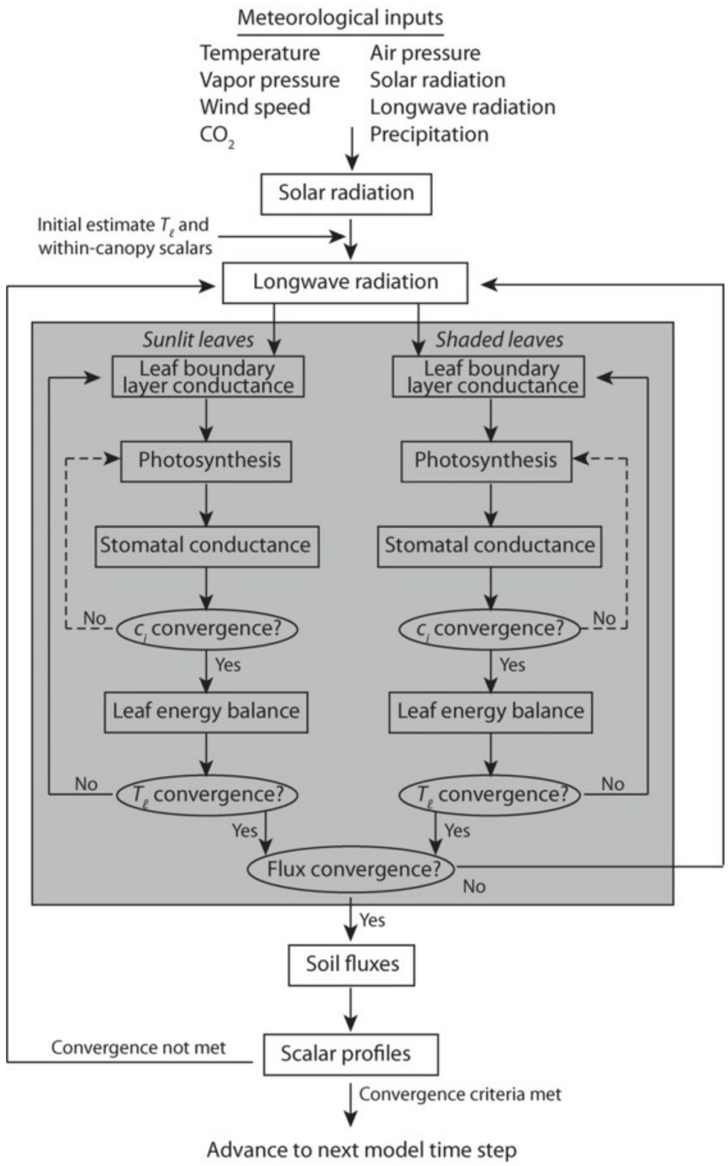


Figure 65: Flow diagram of processes in a multilayer canopy model. The shaded area denotes leaf processes resolved at each layer in the canopy. This is a generalized diagram of the required calculations for a dry leaf. Specific models differ in how the equation set is solved and the iterative calculations. Evaporation of intercepted water requires additional complexity.(Bonan)

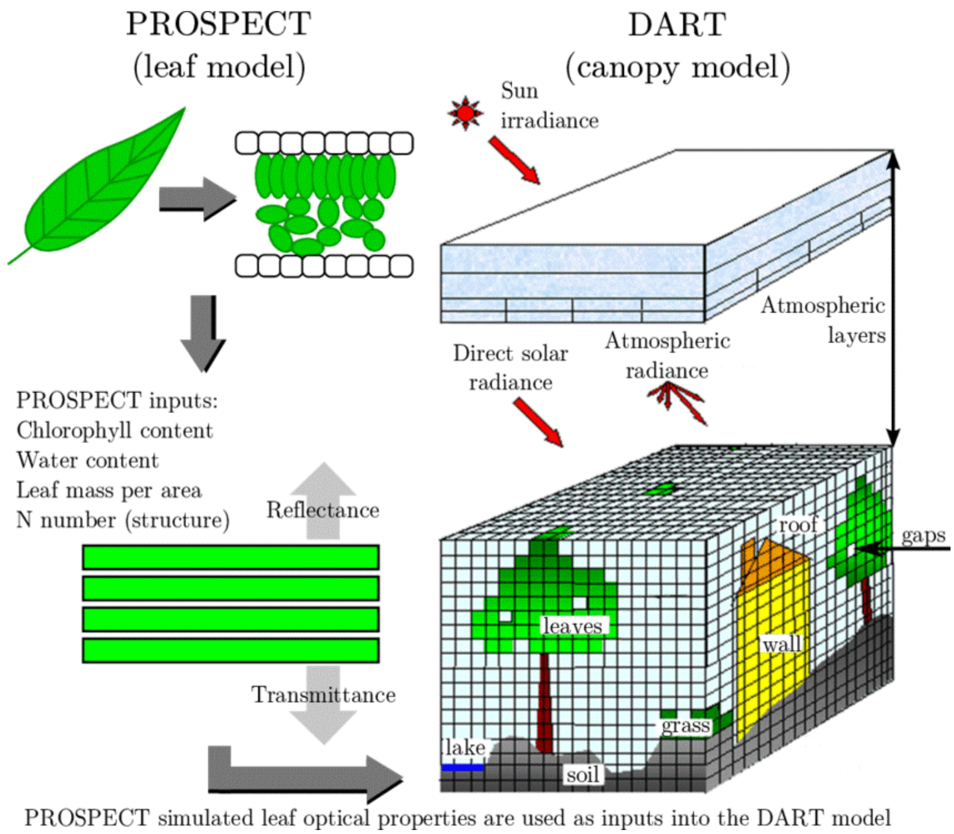


Figure 66: Example of the PROSPECT leaf optical model and the DART 3D ray tracing model.

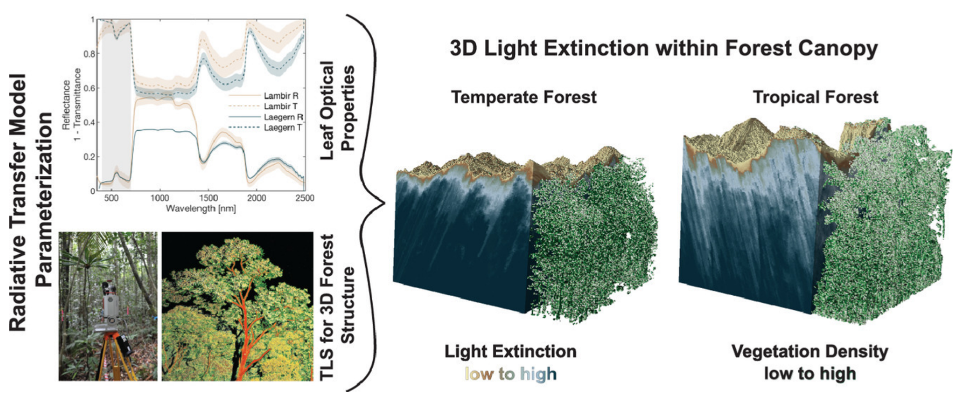


Figure 67: Example of a study that uses terrestrial laser scanning (TLS) to construct a full 3D model of a forest as input for a 3D ray tracing model (Kükenbrink et al. 2020)

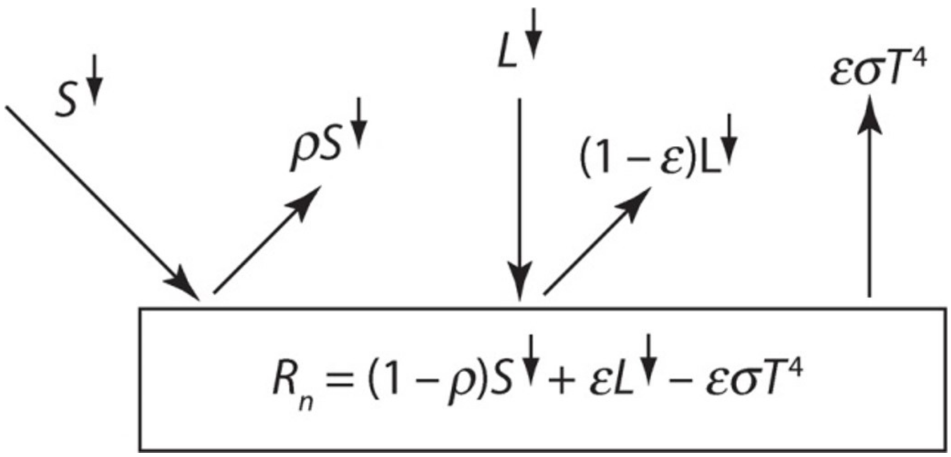


Figure 68: Radiative balance of an opaque gray body receiving downwelling solar S<U+2193> and longwave L<U+2193> radiation.(Bonan)

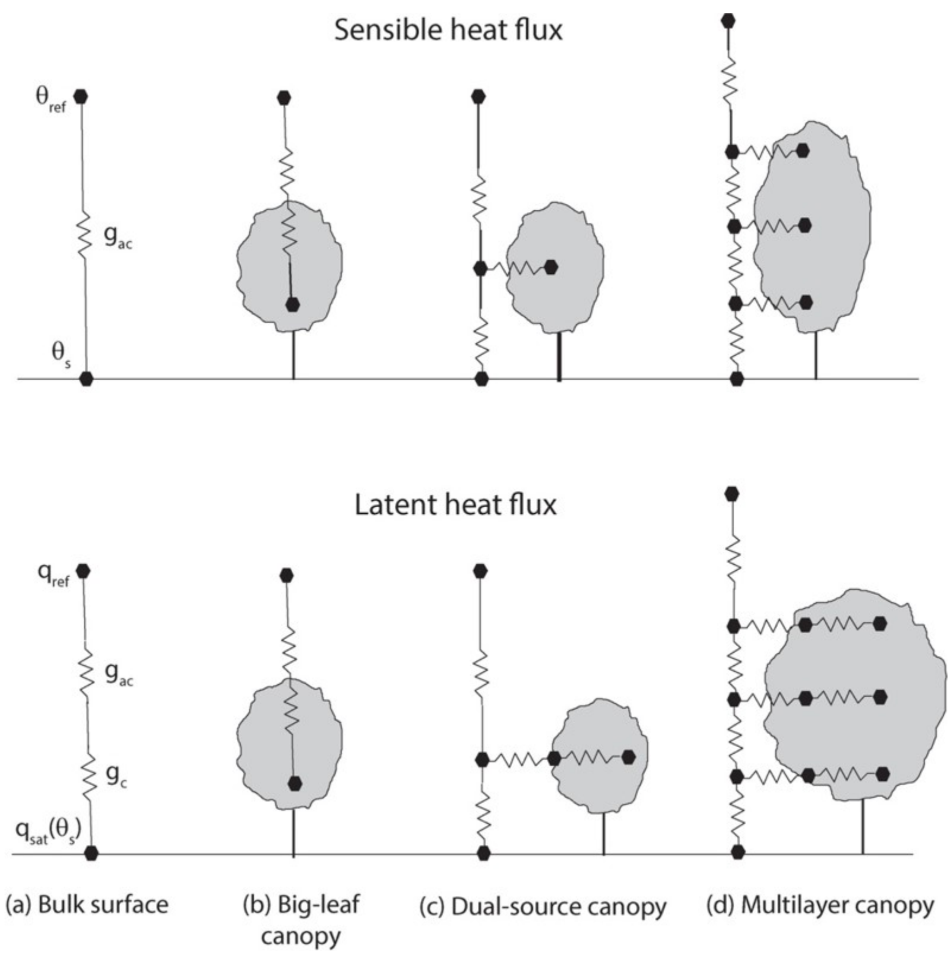


Figure 69: Conductance networks for sensible heat flux (top) and latent heat flux (bottom) for various depictions of the land surface. This chapter describes the bulk surface and big-leaf canopies. (Bonan)

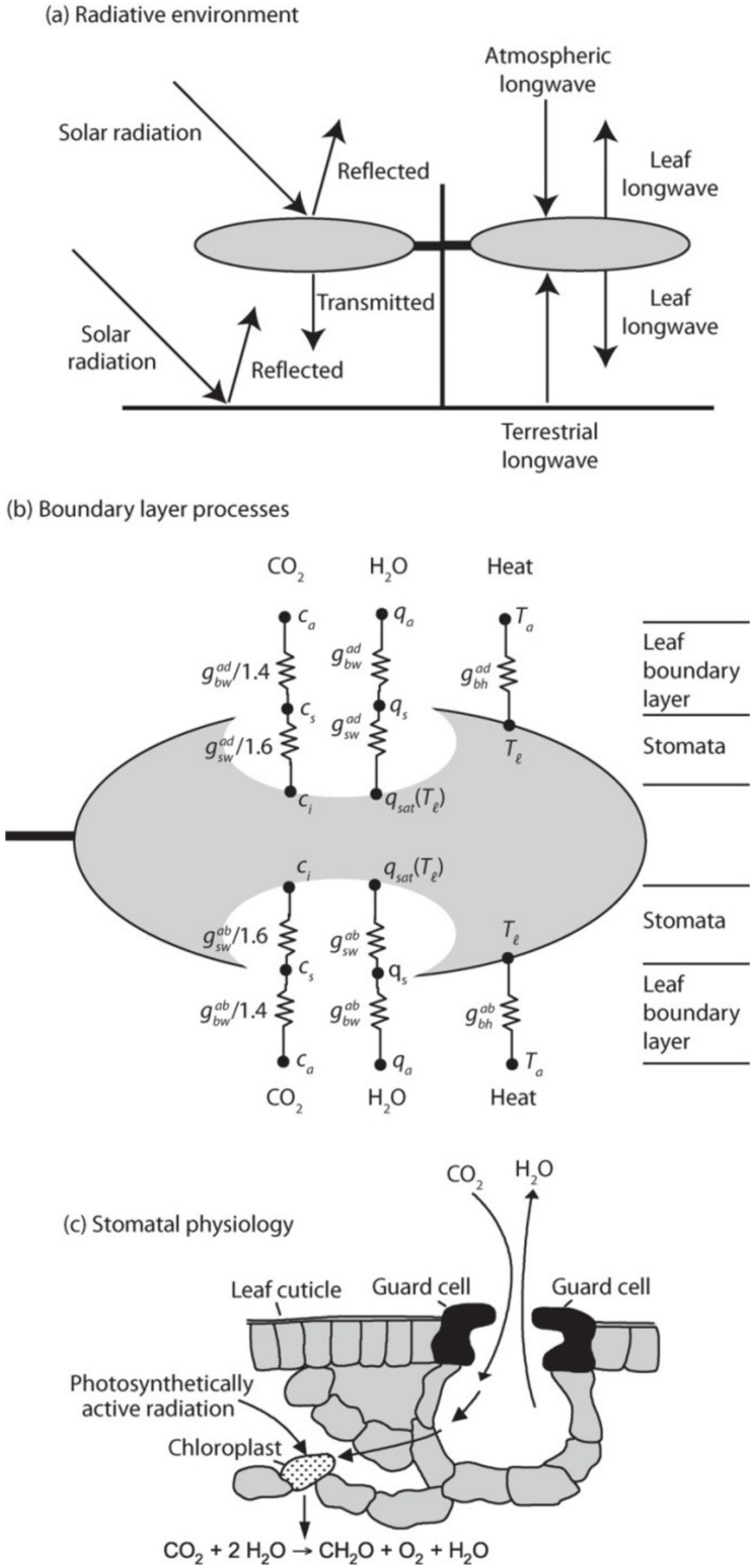


Figure 70: Biophysics and biochemistry of leaves. (a) The radiative environment consists of solar radiation (left) and longwave radiation (right). (b) Leaf fluxes include CO2, H2O, and heat through the boundary layer. These fluxes are shown as a network of

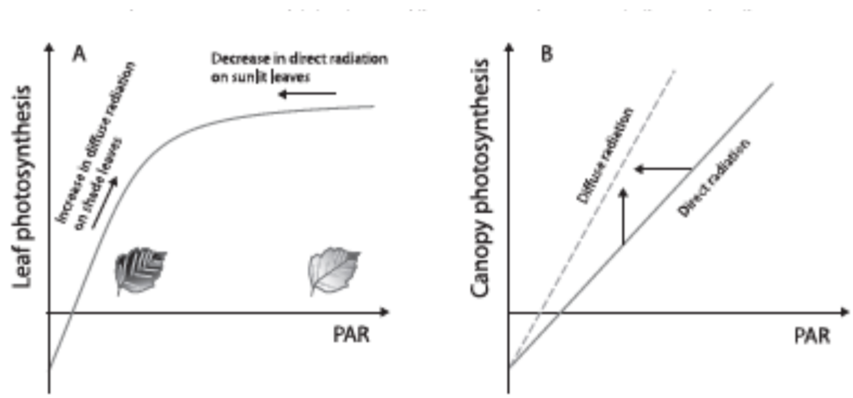


Figure 71: Principle of the effect of increased diffuse raditaion on leaf/canopy photosynthesis. (Knohl et al. 2008)

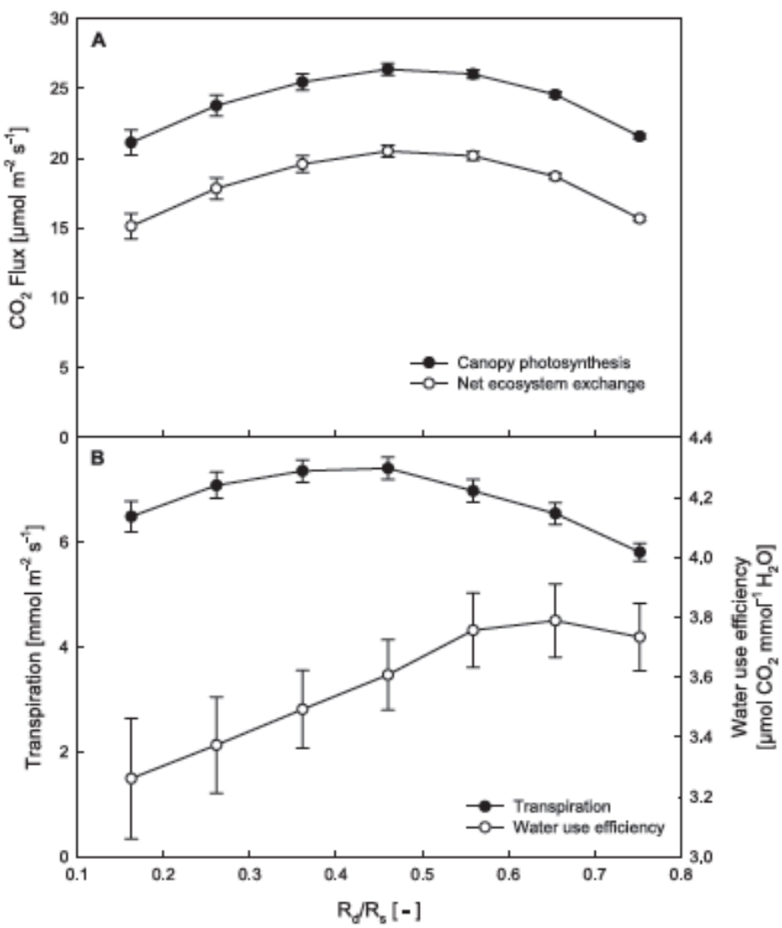


Figure 72: Resulting impact of changing diffuse fraction on carbon and water fluxes and WUE (Knohl et al. 2008)

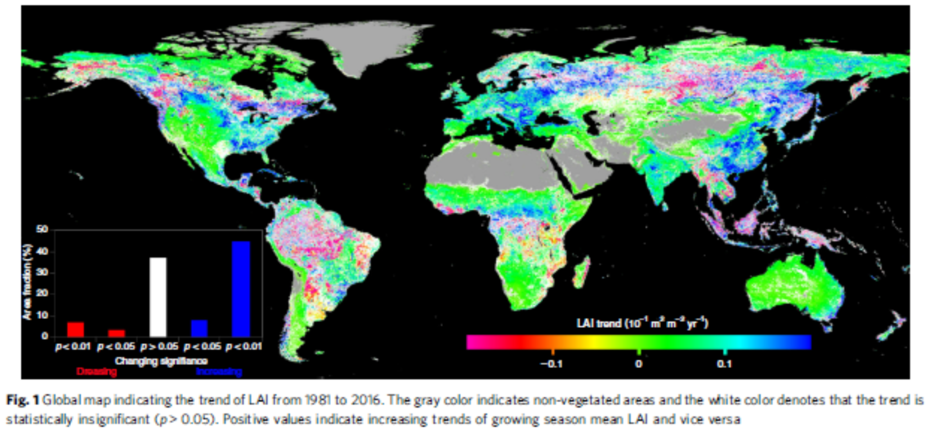


Figure 73: Global map of LAI trend between 1981 and 2016 based on remote sensing (Chen et al. 2021).

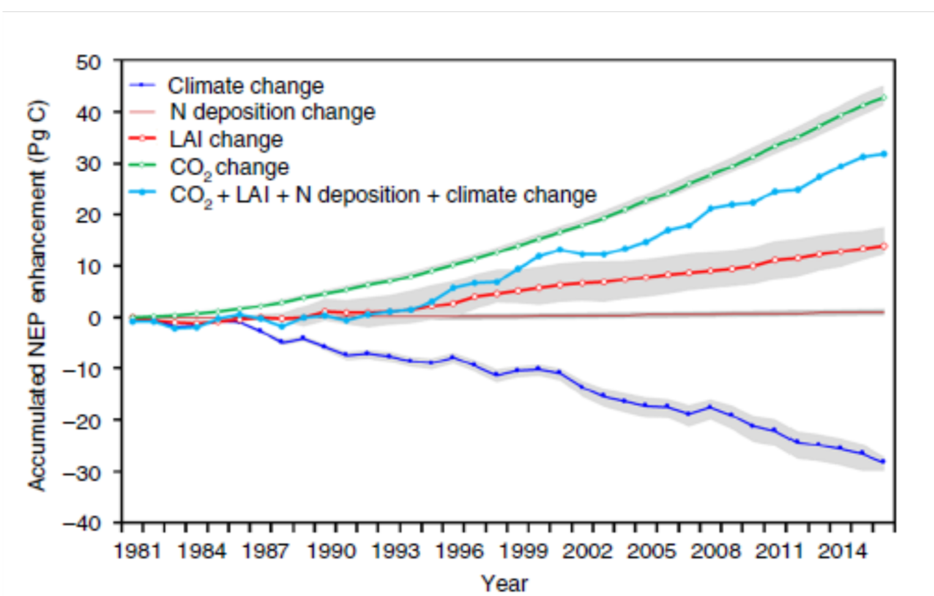


Figure 74: Simulated impact of different factors contributing to the increased global land C sink since 1981 (Chen et al. 2021)

Modelling temporal and seasonal dynamics

Introduction on temporal dynamics

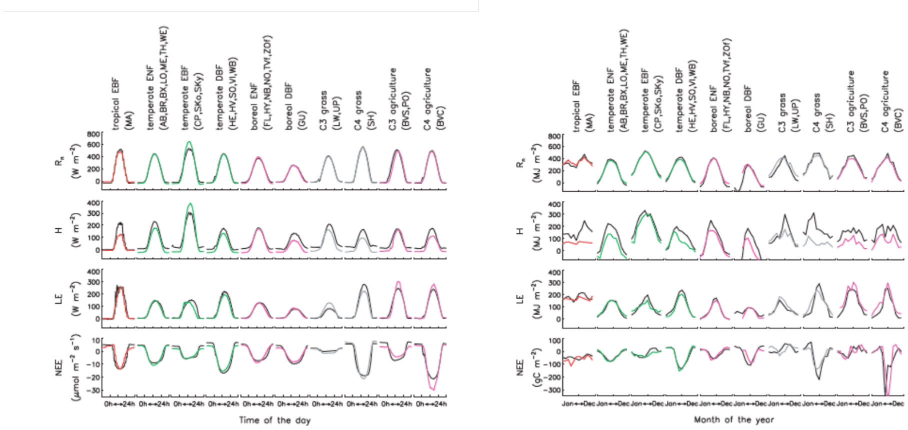


Figure 75: Evaluation of the temporal dynamics of fluxes (Rn: Net Radiation, H: sensible heat, LE: latent heat, NEE: net ecosystem exchanges of CO2) simulated by the global model ORCHIDEE. LEFT: measured (color) and modelled "summer" diurnal cycle for each flux and each PFT. RIGHT: measured (color) and modelled seasonal cycle for each flux and each PFT. (Krinner et al. 2005)

Phenology: the background

Leaf phenology models

Prescribed phenology

Budburst models

Snescence models

Leaf age

Phenology in DGVMs

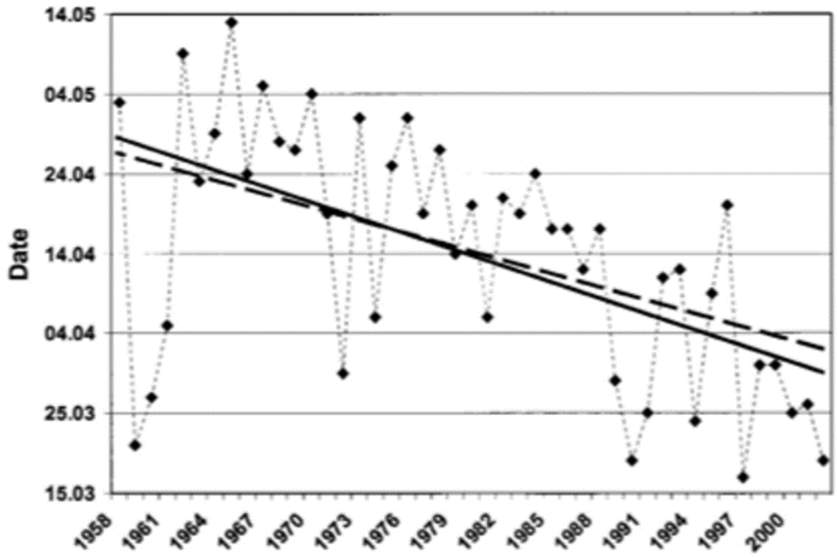


Figure 76: Larch needle appearance in Sargans 1958-2002. Dashed line is trend 1958-1999, solid line is trend 1958-2002. (Defilia and Clot 2005)

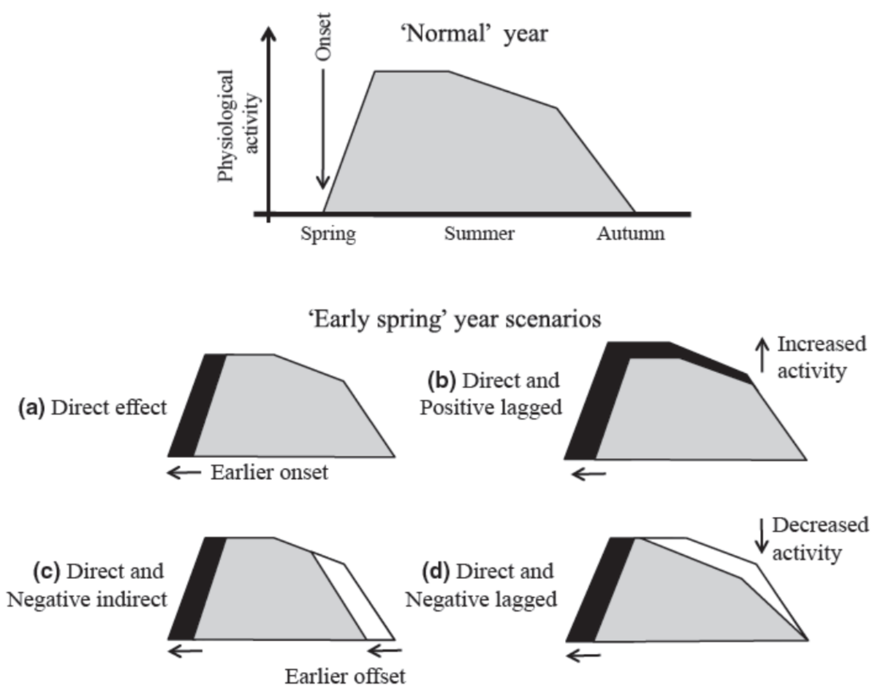


Figure 77: Concept of various effect that changing phenology can have on ecosystem processes (e.g. productivity or transpiration). (Polgar and Primack 2011)

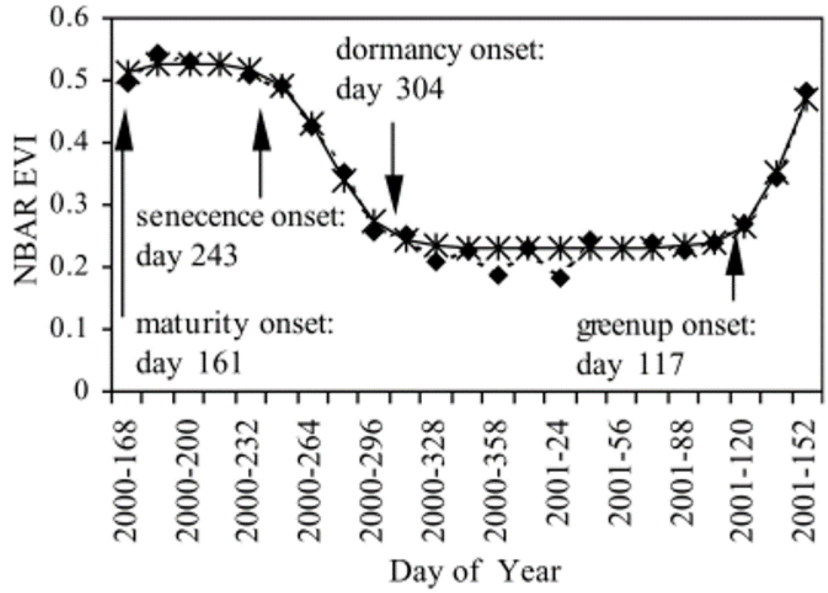


Figure 78: Sample time series of MODIS EVI data and estimate phenological transition dates for a mixed forest pixel in New England. Diamonds: EVI data, solid line with stars: fitted logistic model. (Zhang et al. 2003)

Phenology in the tropics

\begin{figure}

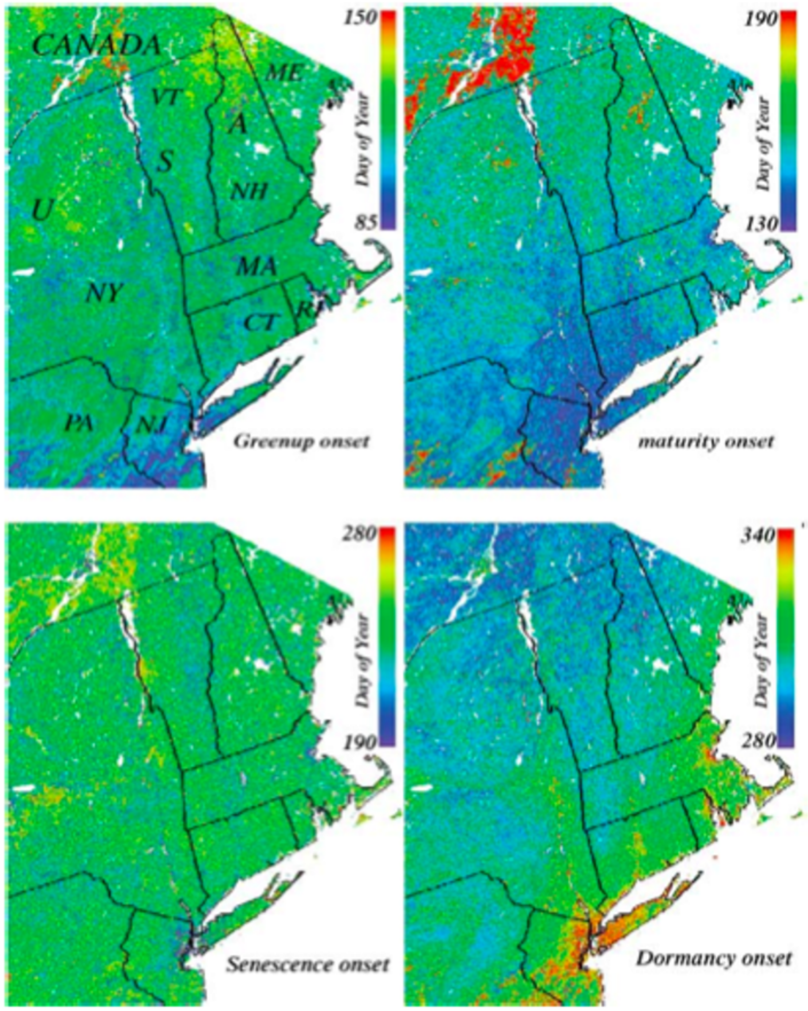


Figure 79: Maps of phenological transition dates for New England. (Zhang et al. 2003)

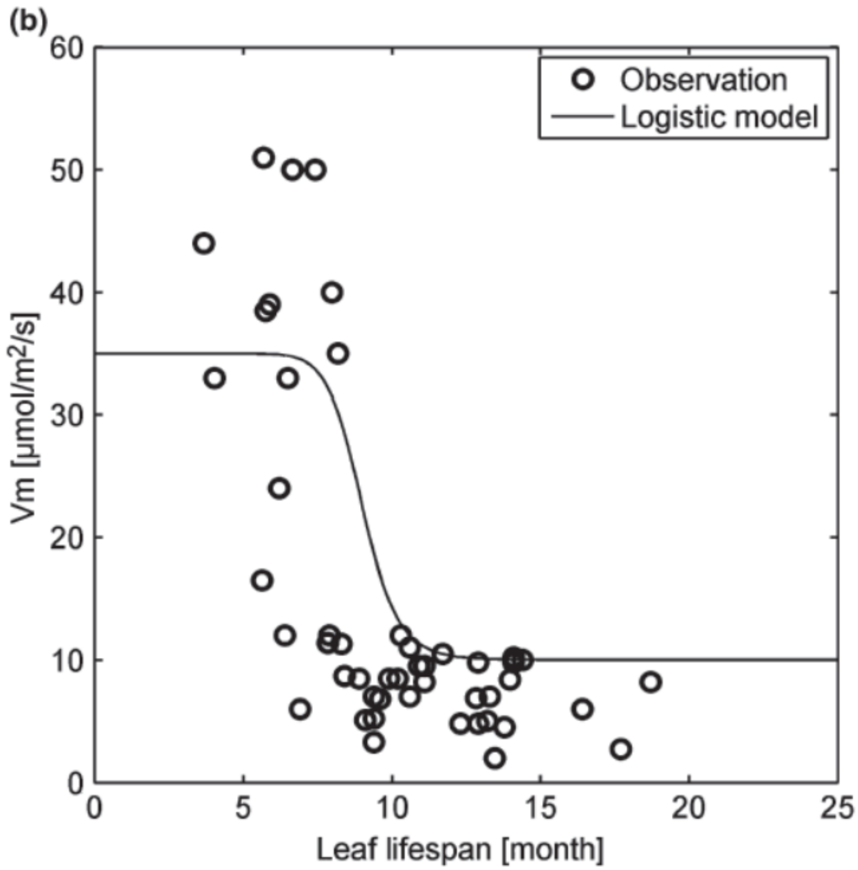


Figure 80: Relation between Vcmax and leaf age in the ED2 vegetation model. (Kim et al. 2011)

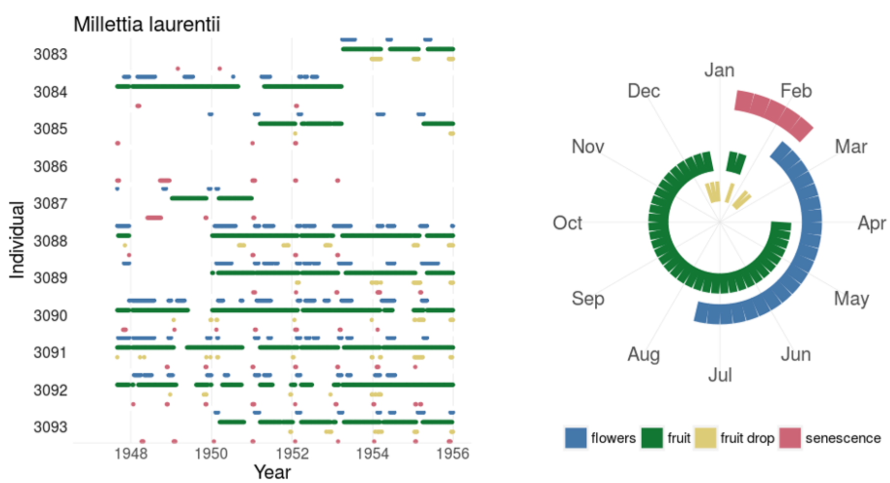
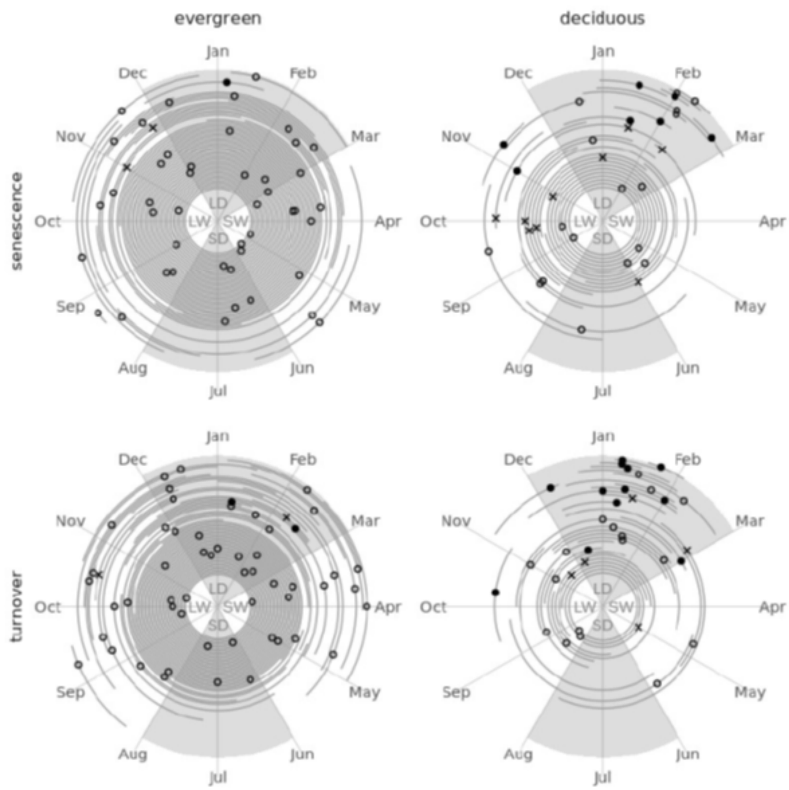


Figure 81: Example of how manual historical phenology observations in Yangambi (DR Congo) are trasnlated in a visual phenology pattern for a single tree species. (junglerythms.org))



{

}

\caption{Overview of species-specific timing of onset of leaf phenophases for evergreen and deciduous species in tropical forest in Yangambi (DR Congo). The median timing of the onset of leaf senescence and turnover is indicated for each species. Species-specific bootstrapped 95%-confidence intervals are indicated with a line segment. Species are arranged according to the variability in the timing of the phenophase, with species with the lowest uncertainty at the outer edge and continuing towards the center. Species with an annual (full circles) or sub-annual (crosses) fourier-based seasonality are indicated. Grey shaded areas represent the average timing of the long and short dry seasons (LD and SD; monthly precipitation < 150 mm), separated by the long and short wet seasons (LW and SW). (Kearsley et al. 2021))} \end{figure}

Case studies

Case study 4.1

Case study 4.2

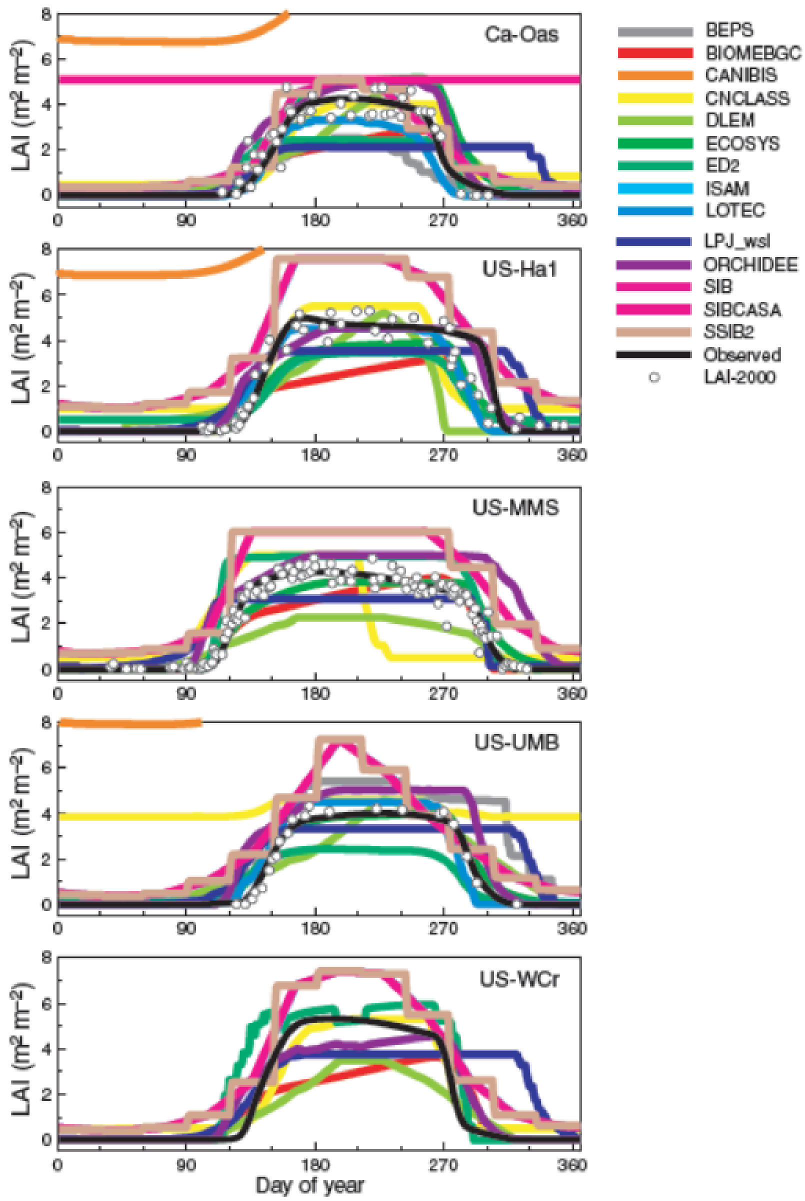


Figure 82: Simulated and observed LAI for 5 deciduous forest sites and 14 vegetation models participating to the NACP model intercomparison project. (Richardson et al. 2012)

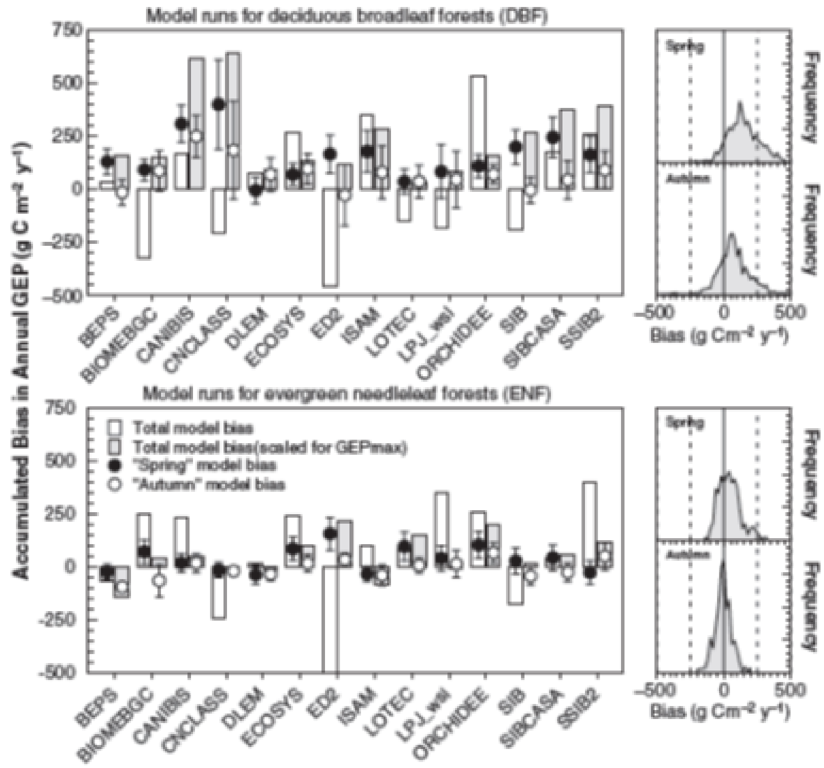


Figure 83: Bias in modeled gross ecosystem photosynthesis (GEP=GPP) for deciduous broadleaf (top) and evergreen needleleaf (bottom) forests. Left panels show bias, by model. Right panels show the frequency distribution of these spring and autumn biases in re-scaled model GEP, across all models, sites, and years of data, for each forest type. The sign convention is that positive bias means that modeled GEP > tower GEP. (Richardson et al. 2012)

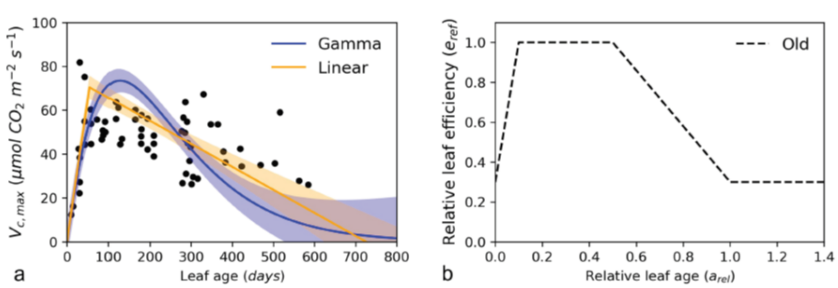


Figure 84: Observed and assumed relation between Vcmax and leaf age in the ORCHIDEE global model, for the tropical evergreen PFT. (Chen et al. 2018)

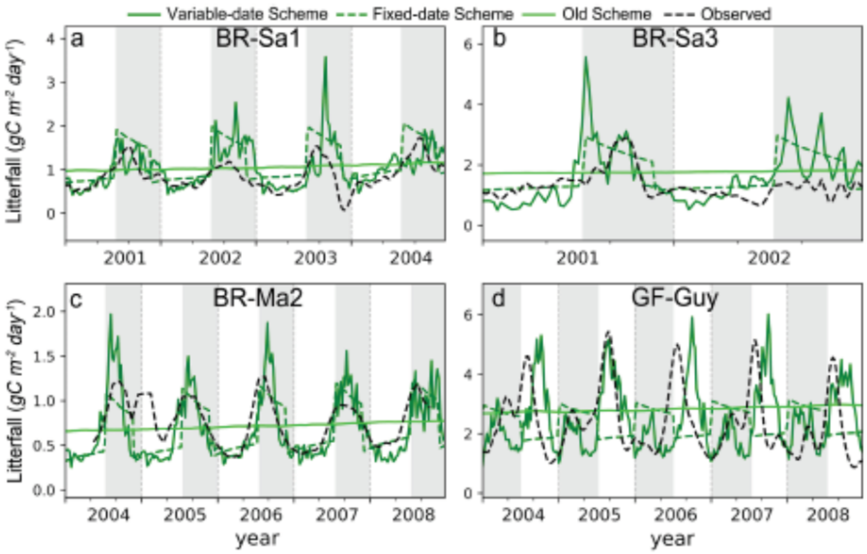


Figure 85: Comparison of litterfall data with two new and the old leaf turnover schemes in the ORCHIDEE model for 4 sites in the Amazon. (Chen et al. 2018)

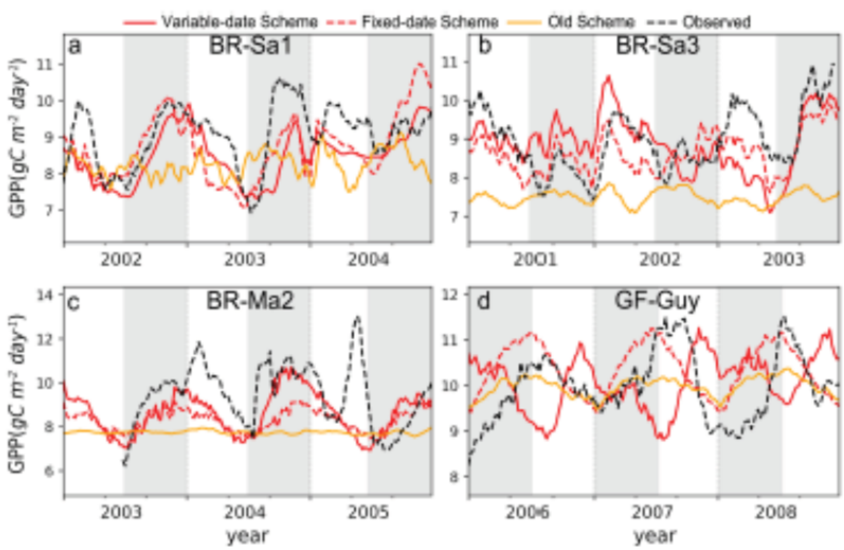


Figure 86: Comparison of GPP fluxtower data with two new and the old leaf turnover schemes in the ORCHIDEE model for 4 sites in the Amazon. (Chen et al. 2018)

(PART) Modelling vegetation dynamics

Modelling plant growth and biogeochemical cycles in vegetation models

- UCL 4.2.2

based on Bonan Chapter 17

Process-based growth modelling

C-allocation models

- C pools: Allocation to leaf, wood, fruit

Applications of growth modelling in forestry and agriculture

- short, link with inventory course

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

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

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

Nutrient cycle models: soil biogeochemical models

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?

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

Other nutrients

- K and Mg in Eucalyptus and other tropical plantations

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

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

Representing biodiversity in vegetation models

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.

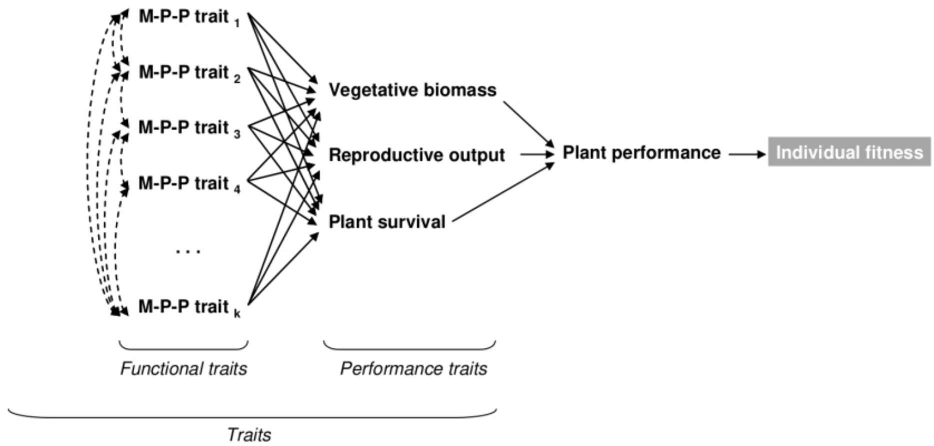
Functional diversity

- 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

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)

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.

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

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.

Eco-evolutive optimality approaches

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

Competition models

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

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

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..

Representation of trait distributions

- Trade-offs

Communities

- Successions and impact on cycles, species composition etc.

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

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

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

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

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

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

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) Upscaling and applications

Spatial heterogeneity, landscape scale, metapopulations

Patch dynamics

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

Spatial heterogeneity: Definitions

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

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

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

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

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

Land-use changes

- Land use is linked to spatial heterogeneity and patch dynamics

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

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

Monitoring land-use

- remote sensing, rapid link to other courses

How Land-use is represented in vegetation models?

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

Natural and Anthropogenic disturbances

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

Wind and extrem events

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

Herbivory

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

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

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.

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

Upscaling from the leaf to the globe

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

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

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

DVGMs as a part of Earth System Models

- Partially in UCL 4.3.3

One Biosphere

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

Atmosphere, Ocean, lakes and urban areas

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

Coupling of processes with different time steps and regional scale

Simulating feedbacks

- Nice transition to chap 11 with future scenarii

Model projections and scenario analysis

Climate scenarios

Representative Concentration Pathway (RCP scenarios)

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

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…

Use of RCP in vegetation modelling

- ENSEMBLE simulations
- IPCC
- Example of applications

How can we evaluate future scenarios?

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

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

Land-use scenarios

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?

How can we evaluate land use scenarios?

- Based on historical data
- Remote sensing

Management scenarios

Construction of Land-use scenarios

How can we evaluate management scenarios?

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) 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) 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