



POTSDAM INSTITUTE FOR
CLIMATE IMPACT RESEARCH



4C: a cohort model for forest growth

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Overview

- Model overview
- Overview of core model processes:
 - Photosynthesis
 - Allocation
 - Soil processes
 - Phenology
 - Mortality
 - Forest management



**FORESEE -
FORESt
Ecosystems
in a Changing
Environment**

4C in short

- Physiological based forest growth model at stand scale
- Describes establishment, growth and mortality of tree cohorts
(Cohort: tree individuals with same age and dimension, and of same species)
- Competition for water, nitrogen and light between the cohorts
- Applicable for managed and non-managed stands
- Simulates C-, N- and water balance
- Sensitive to changing environmental conditions (climate, CO₂-concentration, nitrogen deposition)
- Currently parameterized for 12 tree species

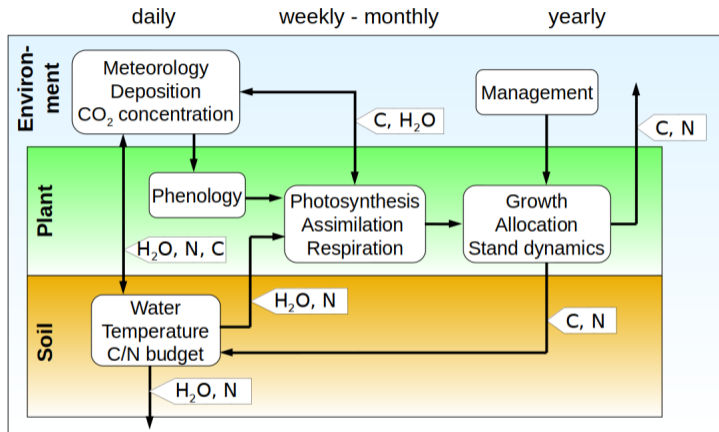
4C, a computer program

- Written in Fortran
- Developed over a timespan of 30 years
- Takes input data, produces output data
- Uses flags to easily switch processes on and off
- Around 22000 lines of code

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Model structure



Stand structure

- Cohorts represent groups of trees with equal size and architecture
- Tree dimensions:
 - Height
 - Bole height
 - Crown radius
 - Stem diameter
- Tree crowns are divided in layers (default: 0.5m), onto which leaf area is distributed
- Light transmission and absorption of cohorts calculated per canopy layer

Result: fraction of photosynthetically active photon flux (PPFD) absorbed by cohorts

Photosynthesis

- Farquhar-Model for average daily PPFD
- Leaf respiration proportional to photosynthetic capacity

Result: non water limited potential net photosynthesis

- Stand conductance passed to soil model
- Soil model calculates reduction of photosynthesis due to water supply limitations

Result: water limited photosynthesis

- Gross photosynthetic rate is scaled down with a nitrogen limitation factor
- This factor is determined with an empirical function in dependence of C/N-ratio of organic matter in soil or depending on the demand/supply ratio

Result: nitrogen limited photosynthesis

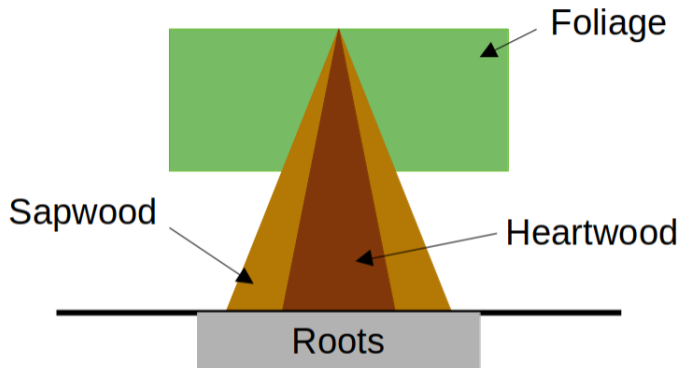
Net Primary Production (NPP)

NPP can be calculated in two ways:

- A constant fraction of the gross photosynthetic rate (50% of GPP)
- From respiration of fine roots and wood with organ specific, temperature dependent rates, where NPP is the difference between net photosynthesis and respiration

Result: Biomass production of a year, available for allocation

Allocation



Compartments for allocation:

- Fine roots (r)
- Foliage (f)
- Sapwood (s)

Basic laws for allocation

- "Functional balance" (Davidson 1969):
The assimilation of carbon and the uptake of nutrients should be balanced
Result: Fine root biomass is proportional to leaf biomass
- "Pipe model theory" (Shinozaki et al. 1964):
Relationship between foliage biomass and conducting vessels that supply water and nutrients
Result: Proportionality between cross sectional area at crown base and leaf biomass
- Mass conservation:
$$\lambda_r + \lambda_f + \lambda_s = 1$$

Allocation of assimilated C in 4C

$$\frac{dM_i}{dt} = \lambda_i * NPP - s_i$$

M_i - Biomass of compartment i

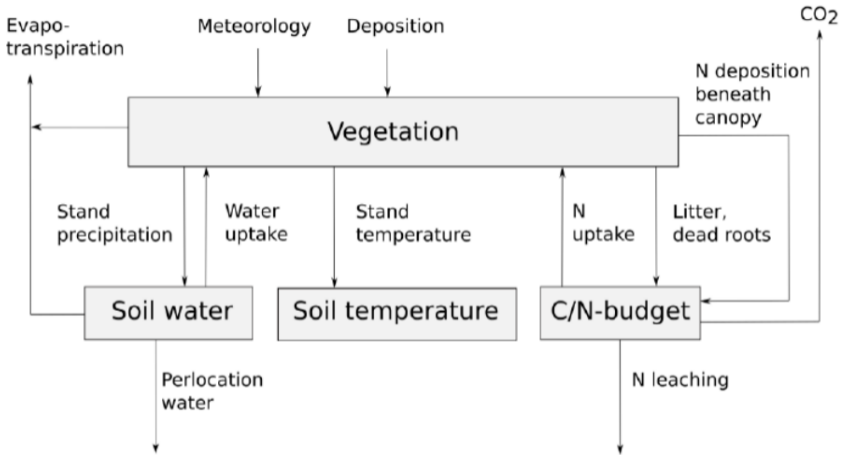
λ_i - Fraction of NPP allocated to compartment i

s_i - Senescence rate of compartment i

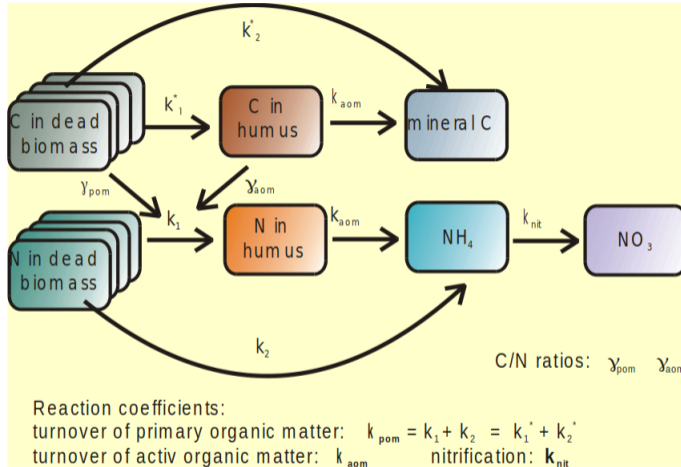
Soil processes

- Water balance
 - Bucket model (Koitzch/Glugla)
 - Link to vegetation is transpiration demand
 - Plant available soil water
 - Leaching water
- C/N-balance
 - C/N turnover is described by a reaction kinetic model
 - Nitrogen uptake of trees
 - N- and C-content of soils
 - Leaching
- Soil temperature model

Soil model overview



Turnover of organic matter



Phenology (bud burst)

Physiological approach:

- Interaction of growth-promoting (promoter) and growth-inhibiting (inhibitor) compounds
- Temperature and photoperiod control inhibitory processes I and promoting processes P

$t_0 = 1 \text{ Nov.}$

$I(t_0) = 1$

$P(t_0) = 0$

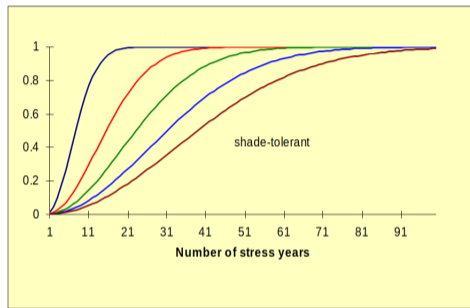
When $P = 1 \rightarrow$ Bud burst

Mortality

- Describes the mortality probability of trees in cohorts
- Applied annually
- Two types of mortality:
 - Intrinsic mortality, depending on maximum life span and the assumption that 1% of trees reach their maximum age
 - Stress-caused mortality
- Both mortality rates may be combined

Stress-caused mortality

- Idea: mortality of trees depends on their carbon balance
- Criteria: negative foliage mass increment at year t :
If $F(t) < F(t - 1)$: stress year
- Stress years are counted (so legacy effects are included)
- Mortality rate is calculated depending on number of stress years and shade tolerance of species using a Weibull distribution



Forest management

- Annual thinning, based on target nr of trees, biomass, basal area or rotation period
- Thinning from above or from below
- Thinning from overstorey or understorey
- Planting of seedlings

Try it for yourself

- Get all data
- Get the executable for your system:
 - Windows - FORESEE.exe
 - Linux - 4c_max
- Follow the instructions in the manual to start a simulation
- Familiarize yourself with the different output files that are generated (a good place to start may be *veg.out1)
- If you have time: try to run several scenarios and analyze the differences in the output using the provided R-script as an example