Potsdam Institute for Climate Impact Research

4C: a cohort model for forest growth

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August 2024

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

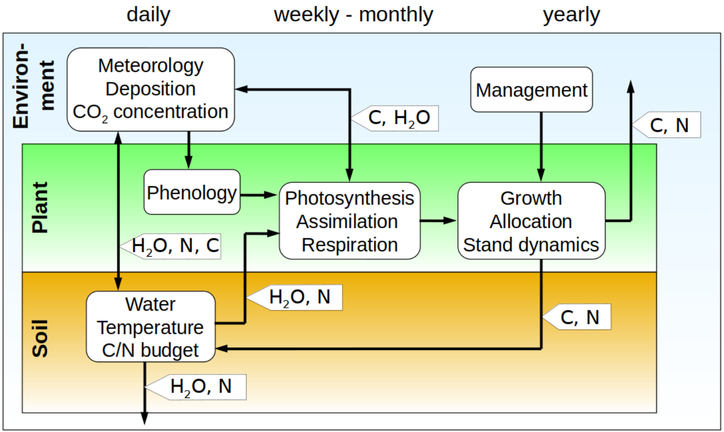
- Physiological based forest growth model at stand scale
- Describes establishment, growth and mortality of tree cohorts
  (Cohort: tree individuals with same age and dimension, and of same species)
- Competition for water, nitrogen and light between the cohorts
- Applicable for managed and non-managed 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

```
SUBROUTINE sim_control

use data_climate
use data_simul
use data_site
use data_out

implicit none

integer run_nr, ipp, ir1, ic1, i
character a
character(8) actdate
character(10) acttime, helpsim, text1, text2
real time1, time2, time3

unit_err=getunit()
if(flag_multi.eq.5) dirout = './'
open(unit_err,file=trim(dirout)//trim(site_name(1))//'_error.log',status='replace', position='append')
unit_trace=getunit()
open(unit_trace,file=trim(dirout)//trim(site_name(1))//'_trace.log',status='replace', position='append')
write (unit_trace, *) ' Trace of calls  -  subroutines of 4C '
write (unit_trace, *)
write (unit_trace, *) 'iday  time_cur    subroutine '
write (unit_trace, '(I4,I10,A)') iday, time_cur, ' sim_control'

! check daily output
if (year > 5 .and. flag_dayout .ge. 1) then
      write(*,*) '  Warning: Your choice of daily output is ON with a simulation time of'
      write(*,'(I6,A,I8,A)') year,'  years. This option will create ',365*year,' data records per file!'
      write(*,'(A)',advance='no') '  Do you really want do use daily output (y/n)? '
      read *,a
      IF (a .eq. 'n' .or. a .eq. 'N') then
         flag_dayout = 0
      ENDIF
ENDIF

! open file ycomp (yearly compressed output (multi run))
IF (time_out .ne. -2) call prep_out_comp

!call epsilon
    IF(flag_multi.eq.1) THEN
      run_nr = site_nr
    ELSE IF (flag_multi.eq.5) THEN
      run_nr = 1
    ELSE
      run_nr = repeat_number
    ENDIF

call date_and_time(actdate, acttime)
write (unit_err, *)
time3 = 0.

  if (.not.flag_mult910) then
    nrreal = 1
```

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

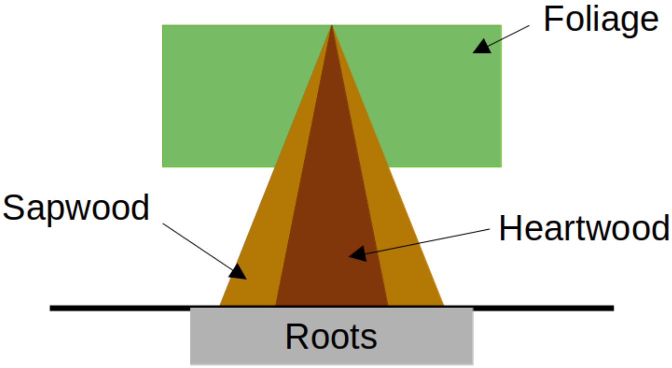
Net Primary Production (NPP)

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

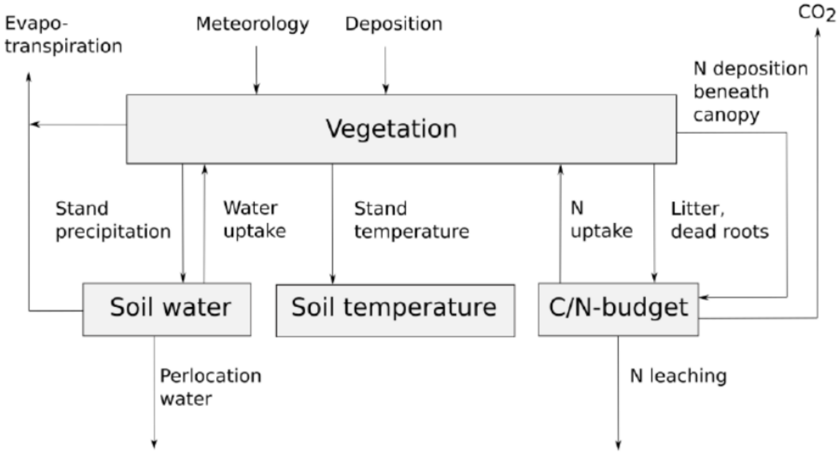
$$\frac{dM_i}{dt} = \lambda_i * NPP - s_i$$

M_i - Biomass of compartment i
λ_i - Fraction of NPP allocated to compartment i
s_i - Senescence rate of compartment i

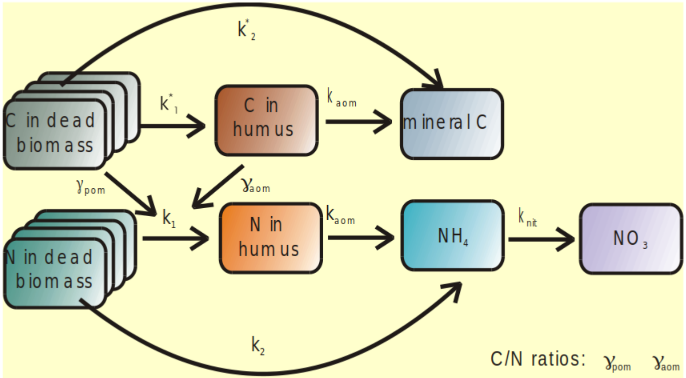
Soil processes

- 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



Reaction coefficients:

turnover of primary organic matter: $k_{pom} = k_1 + k_2 = k_1^* + k_2^*$

turnover of activ organic matter: k_{aom} nitrification: $\mathbf{k}_{nit}$

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

$t_0 = 1$ Nov.
$I(t_0) = 1$
$P(t_0) = 0$

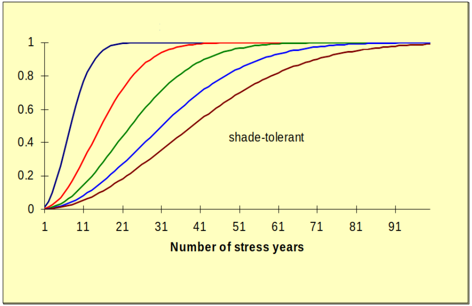
When $P = 1$ -> Bud burst

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