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Upscaling the Impact of Root System Architecture on Transpiration

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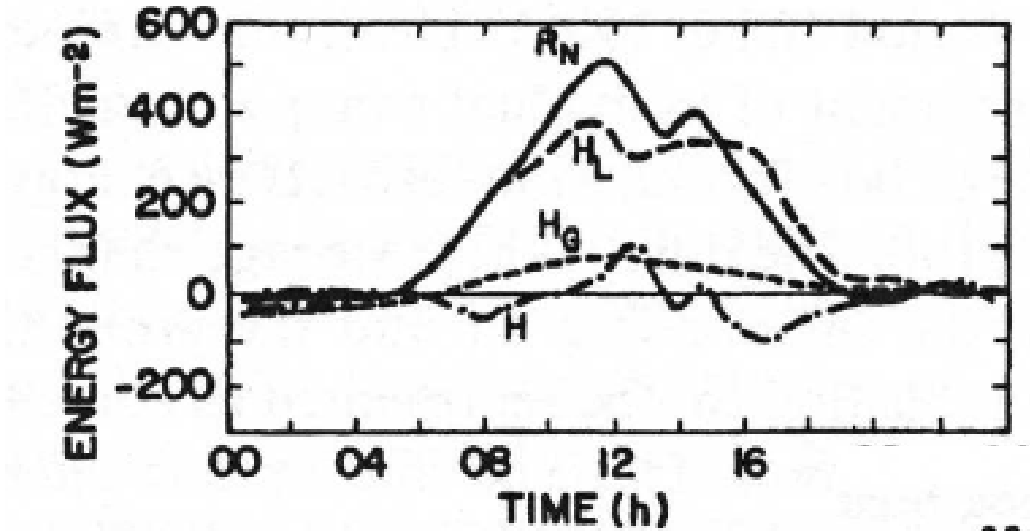
Outline

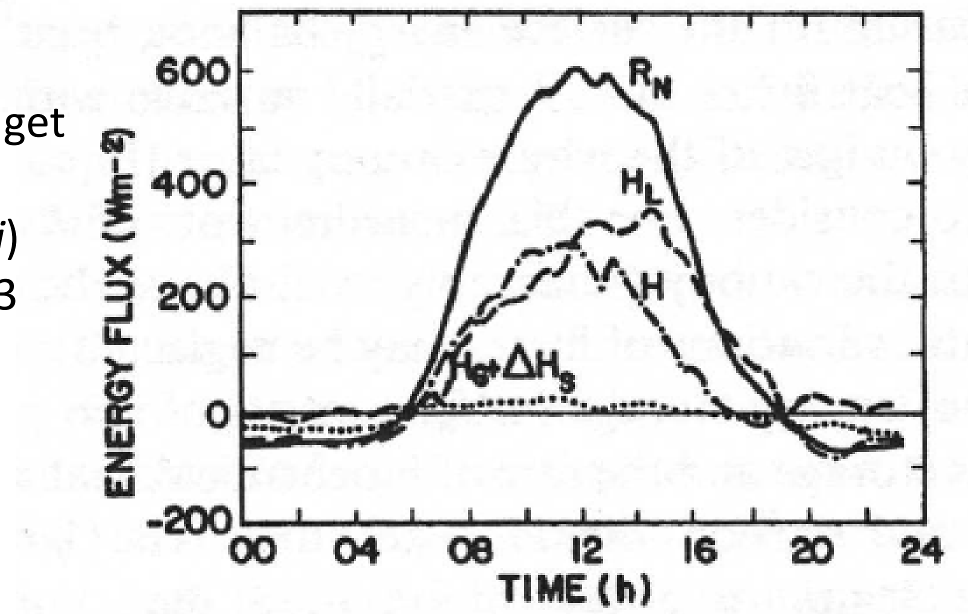
- Plant transpiration and classical DVM-LSM Modelling
- Root system architecture and transpiration
- Introduction to ED2.1 model
- Proposed changes

Latent heat flux



Left: Diurnal heat budget of barley field in England, July 23 1964

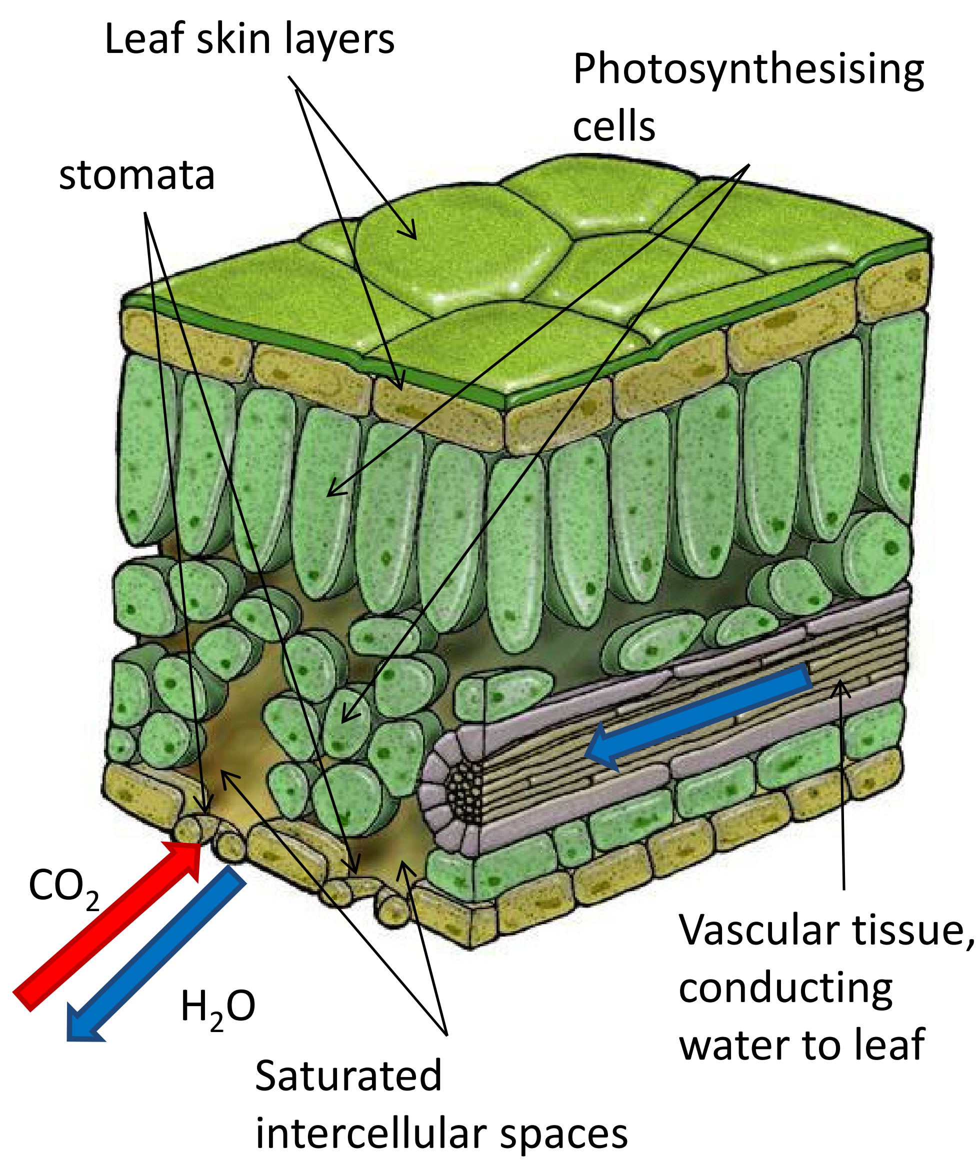
Right: Diurnal heat budget of Douglas fir (*Pseudotsuga menziesii*) stand in Canada, July 23 1970



Figures from Arya, 2003

Transpiration

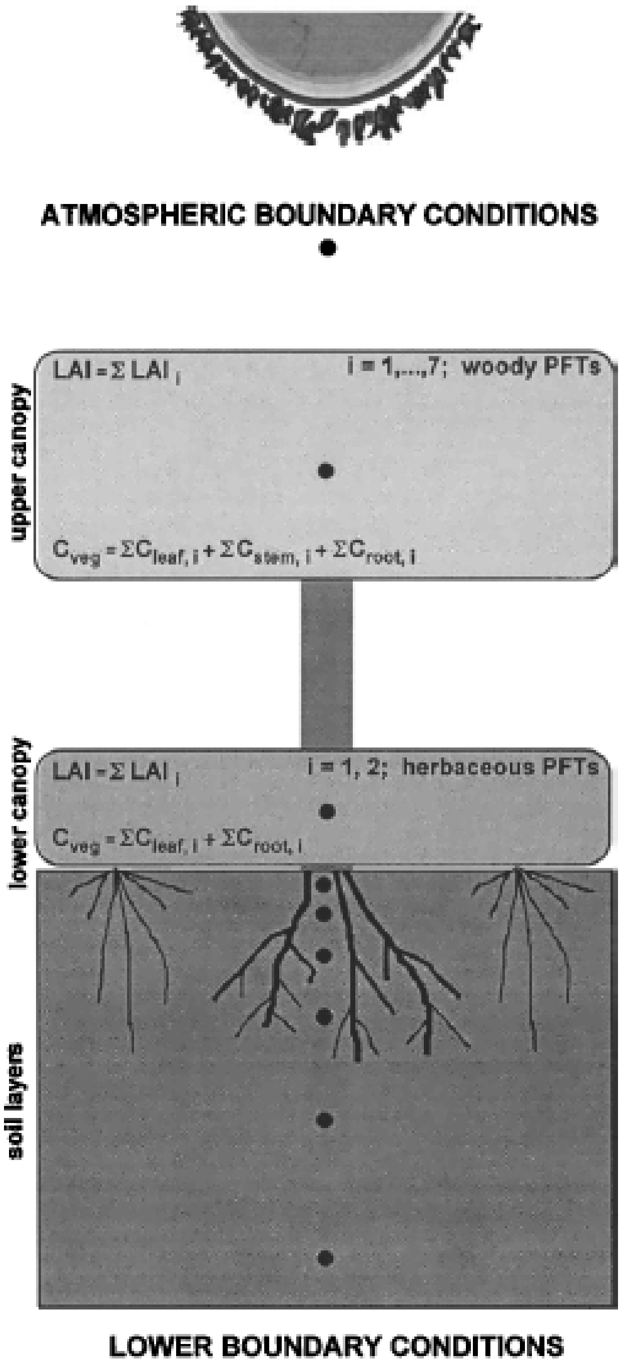
- Transpiration is simultaneous with Photosynthesis
- Continuous drying out, following stomatal opening for CO_2 uptake
- Transpirational demand satisfied by water uptake from soil at the roots and transport via vascular system

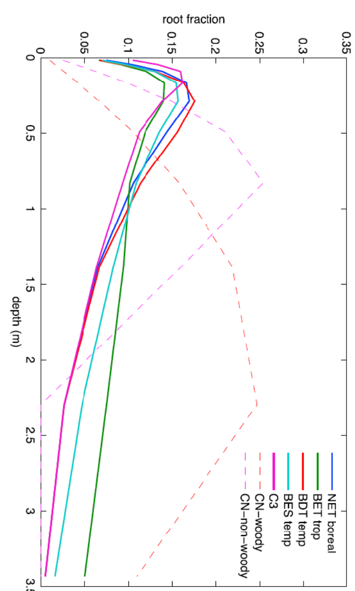


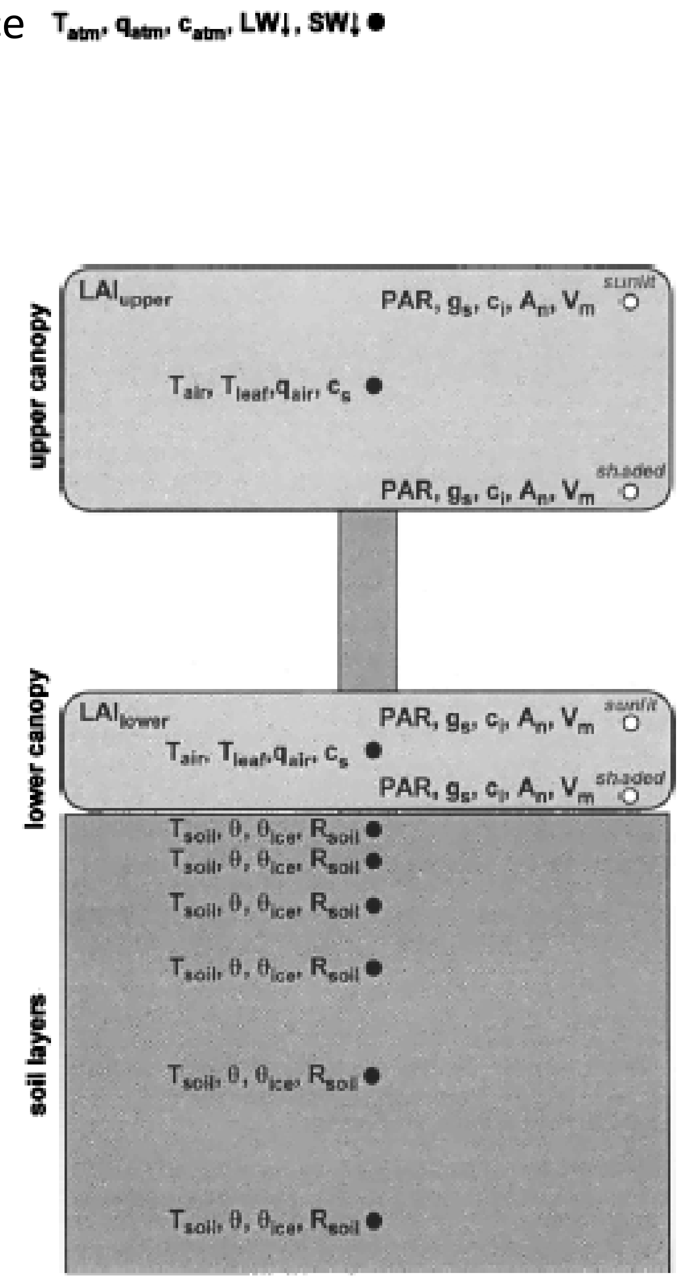
Coupling of Land Surface to atmospheric model

DVM – LSM coupling:

carbon
water
heat

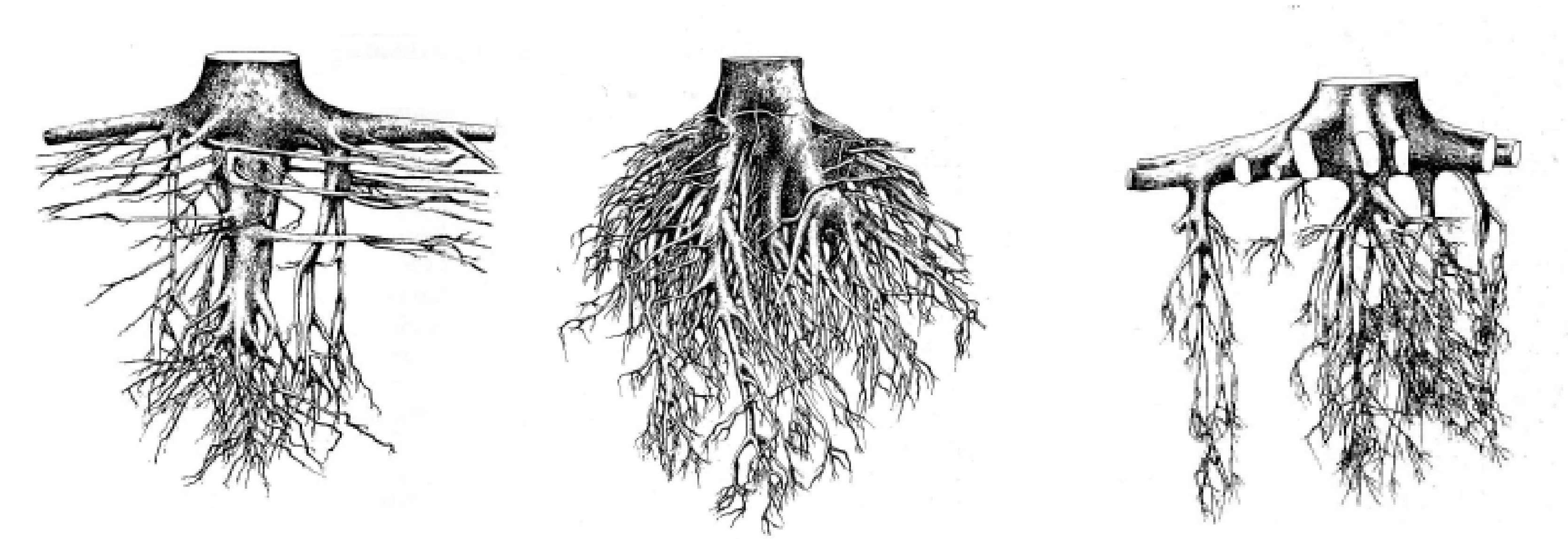






Figures from Foley et al. 1996, Sakaguchi et al. 2011

Root System Architecture

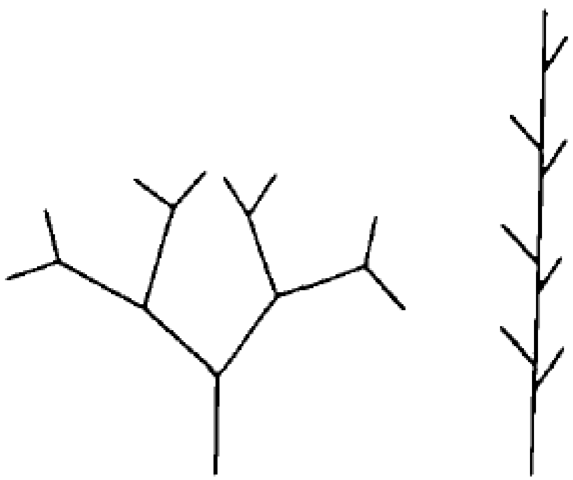


What is the impact of root system architecture on water extraction ability?

Figures from Köstler et al. (1968)

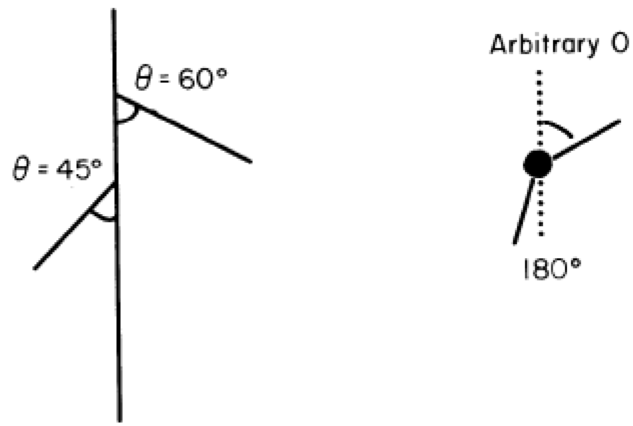
Architecture Fundamentals

Topology



- Magnitude
- Altitude

Geometry

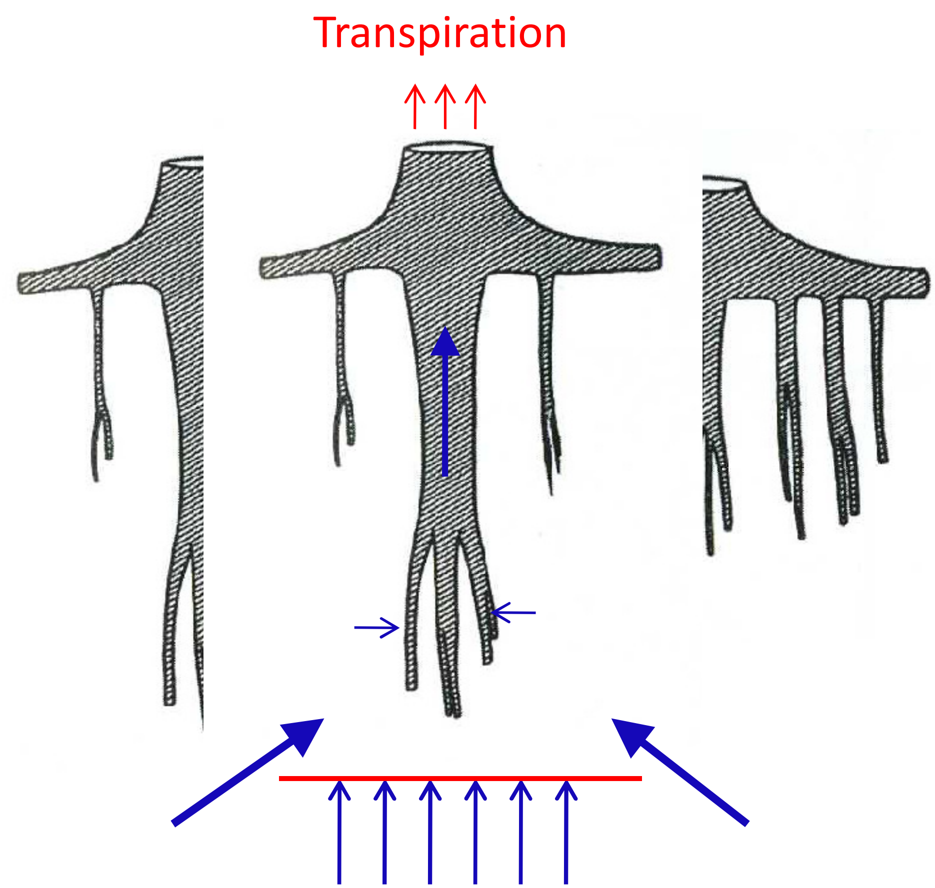


- Branching Angle
- Radial Angle
- Link Length

Figures from Fitter (1986, 1987)

Overview of Modelling Approach

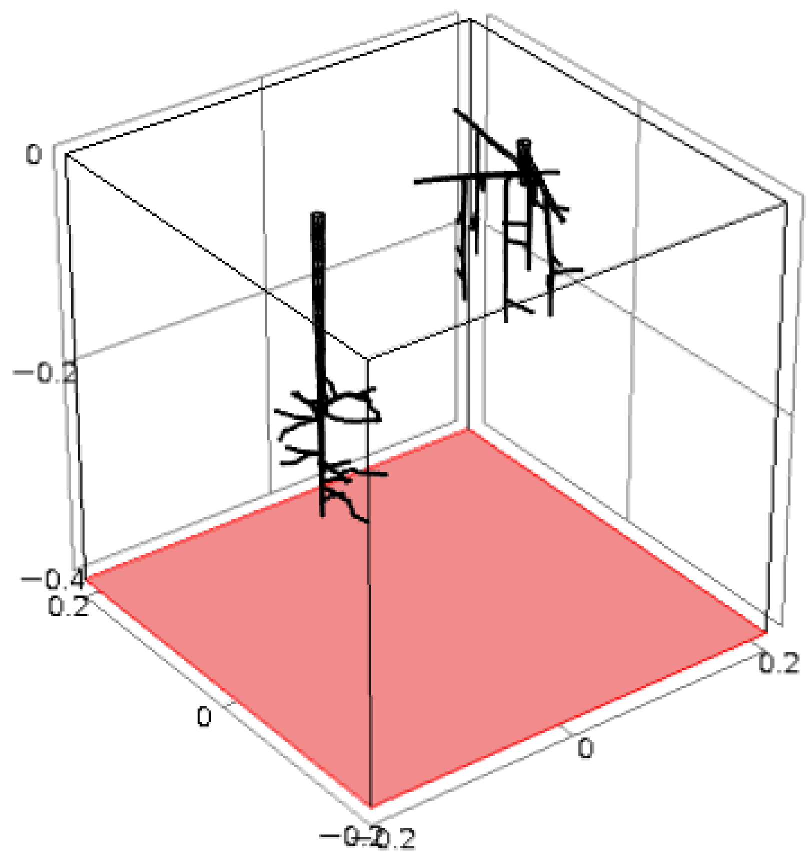
- Construction of Root Architecture
- Representation of Water Flow
- Varying Boundary Conditions



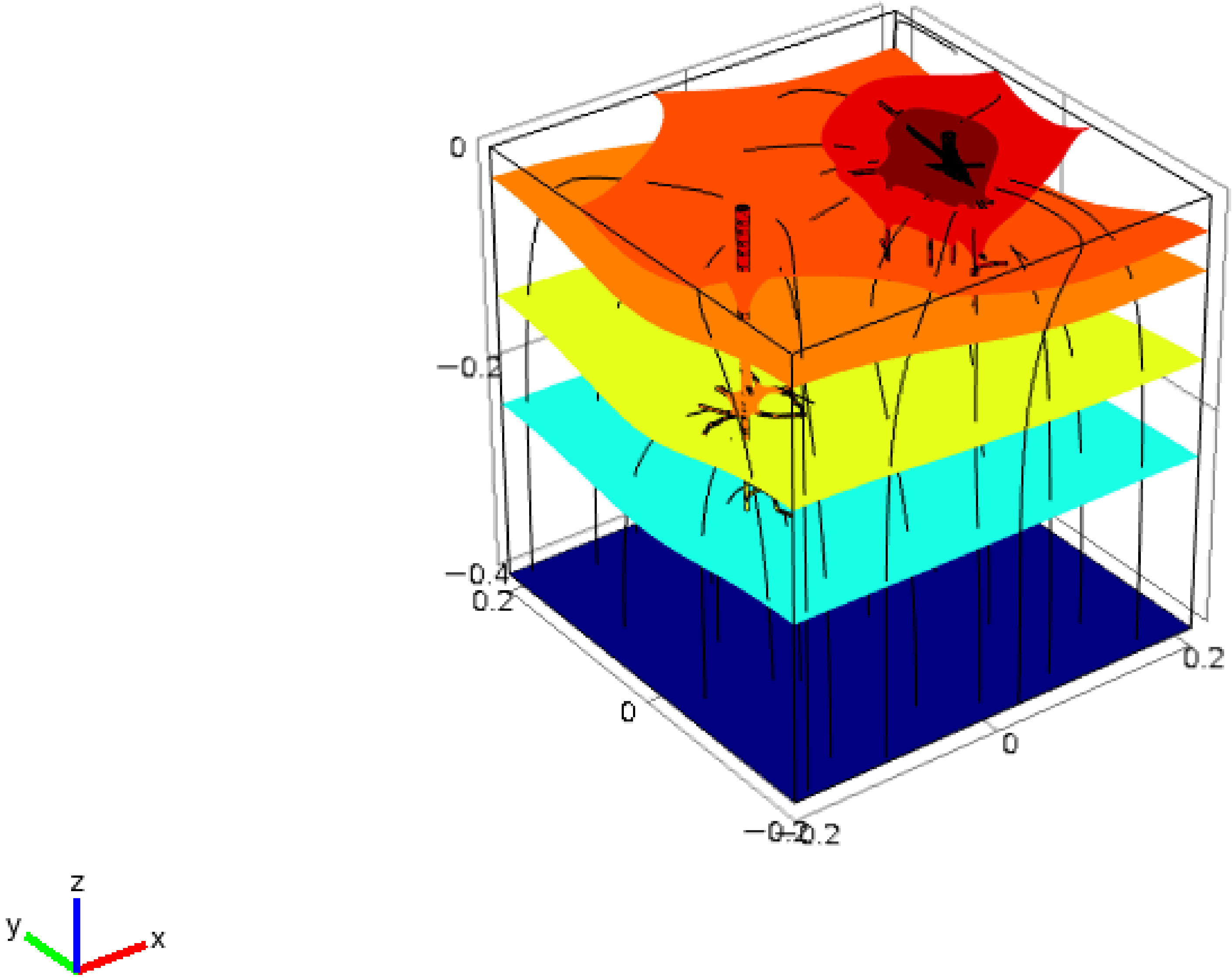
Figures from Köstler et al. (1968)

Example Study:

- 40x40x40 cm soil domain
- Boundary Conditions
  - Root collar: -0.6 MPa
  - Soil: -0.2 -> -0.4 MPa
- Roots calibrated to conifer conductivity/porosity
- Soil: very clayey!
- Solver: MUMPS
  - direct solver
  - finite element
  - COMSOL modelling platform

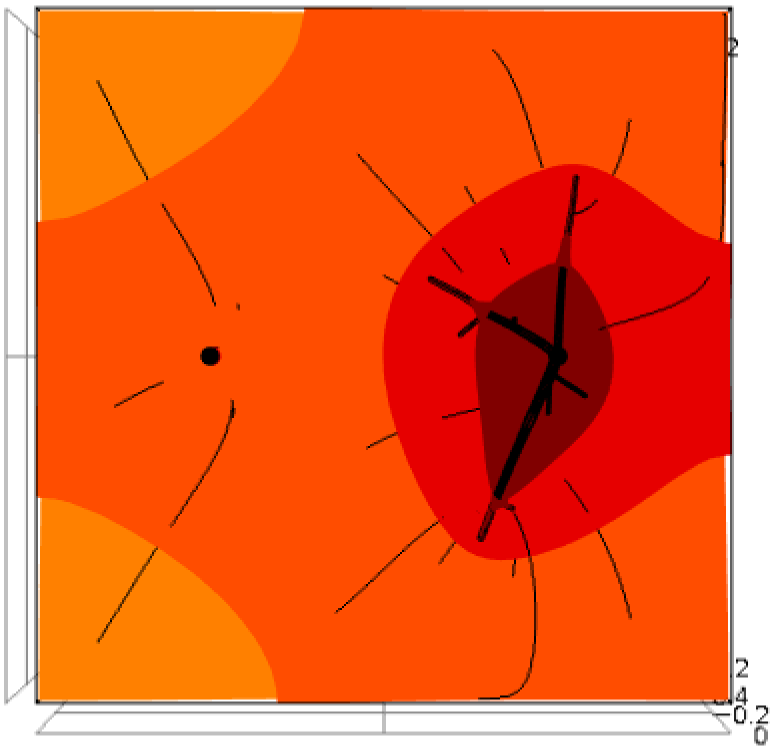


Solver reference: http://graal.ens-lyon.fr/MUMPS/

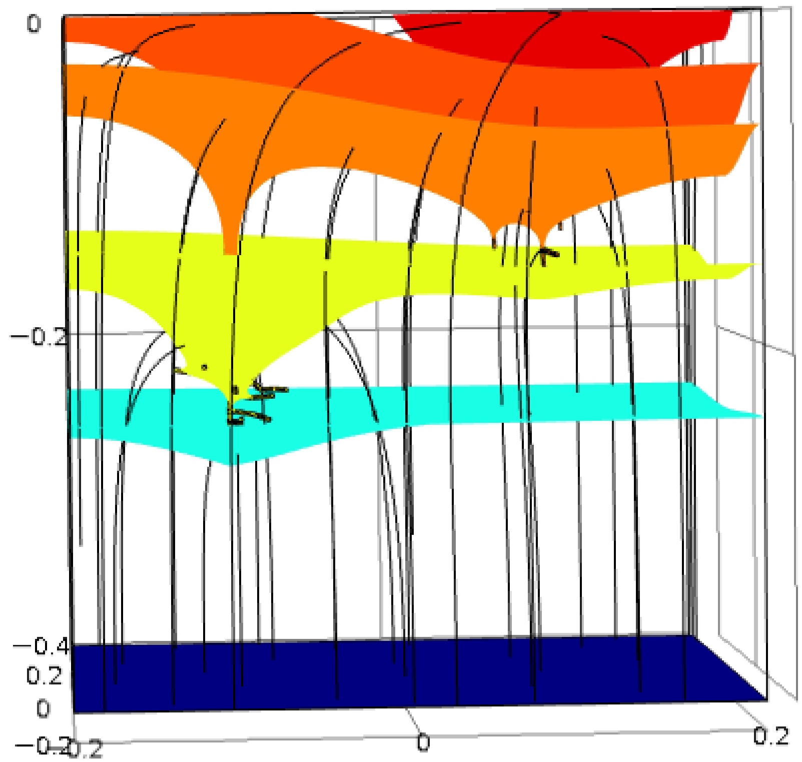


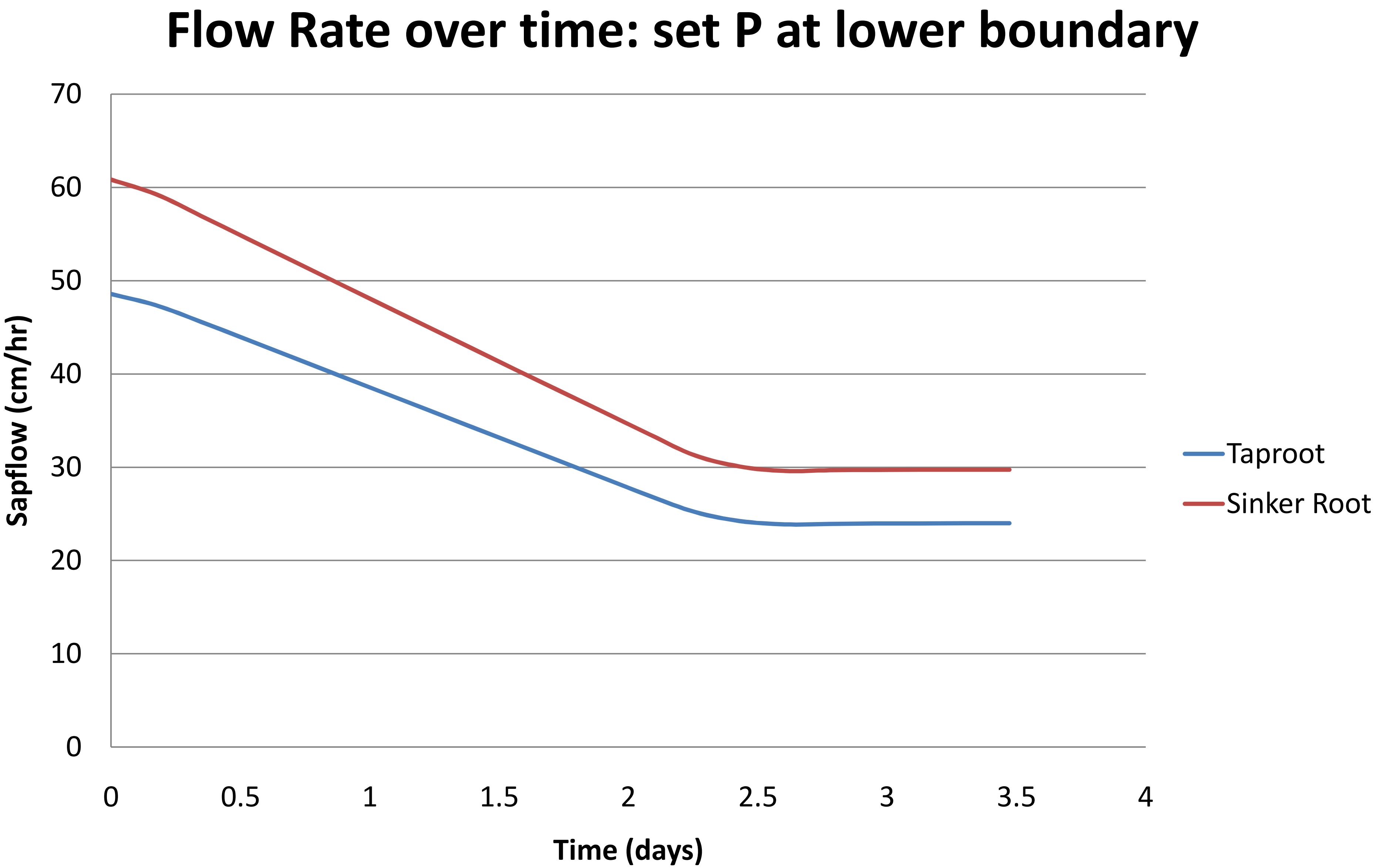
0
−0.2
−0.4
0.2
0
0.2
0
z
y
x

View down the z-axis

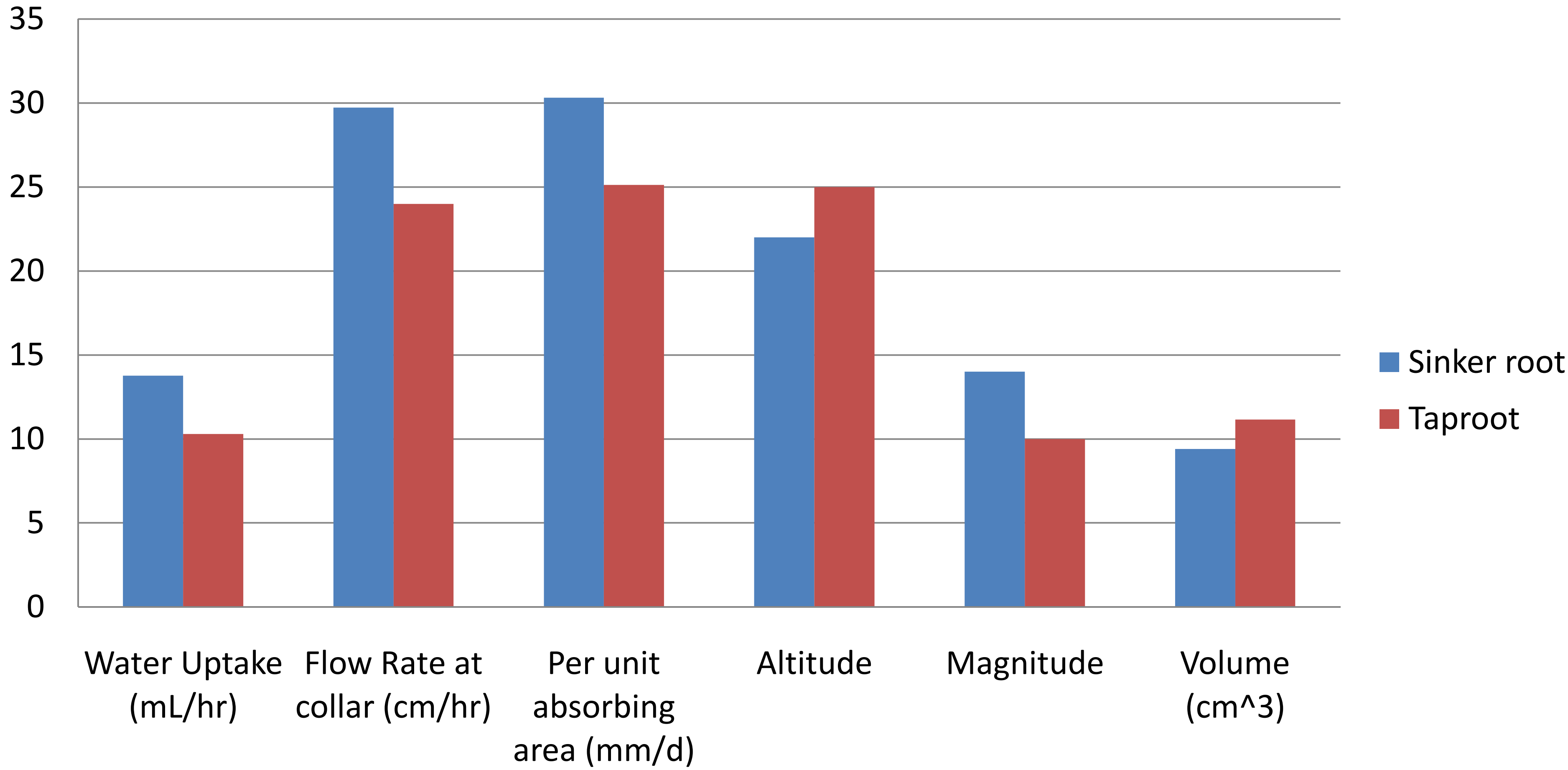


View down the y-axis

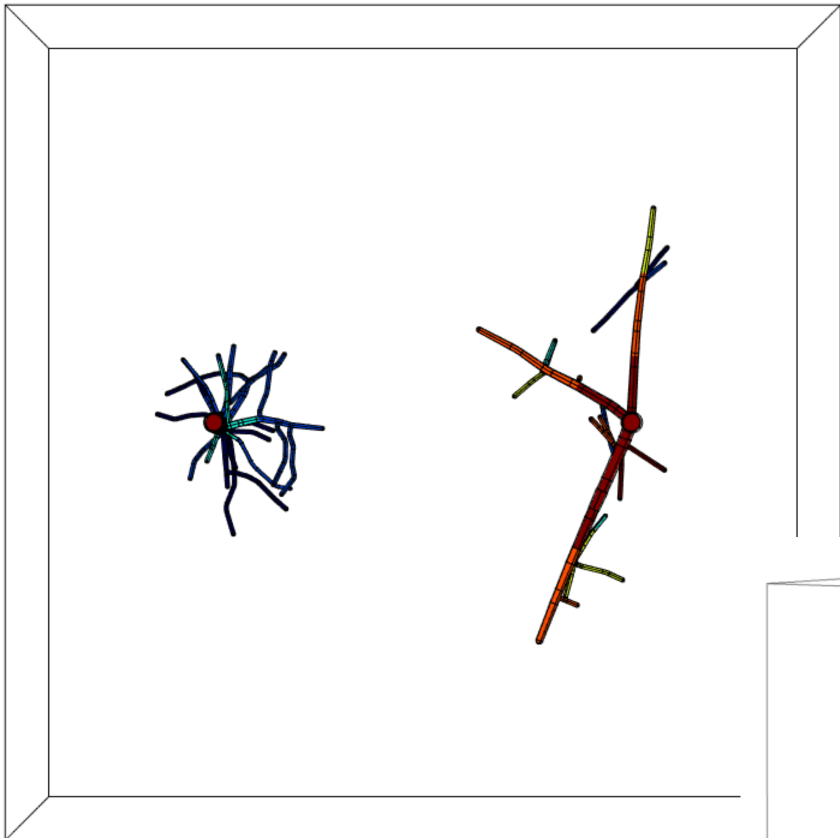



Flow Rate over time: set P at lower boundary
Sapflow (cm/hr)
70
60
50
40
30
20
10
0
0
0.5
1
1.5
2
2.5
3
3.5
4
Time (days)
Taproot
Sinker Root

Comparison of flow at steady state and topology

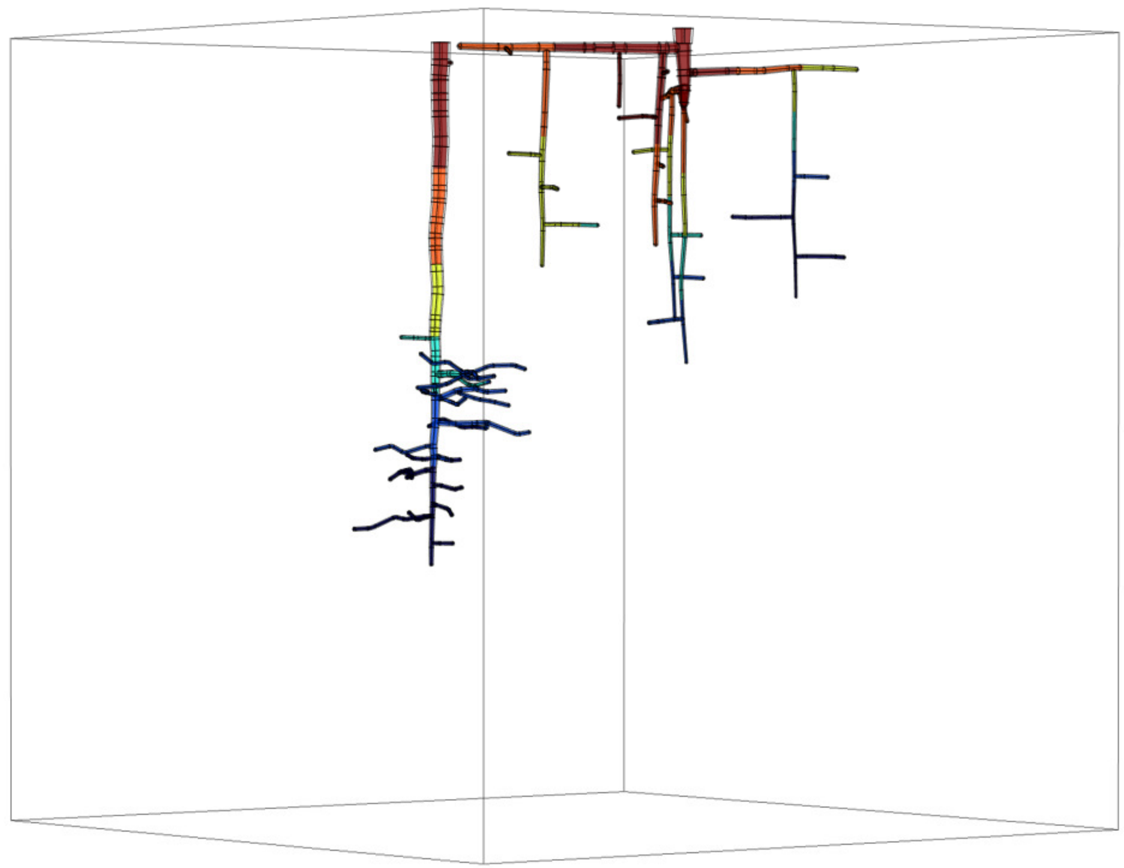


Ratio: 1.34 1.23 1.21 0.88 1.4 0.84



Root length density (RLD) alone does not explain water uptake

Pressure at root surface is lower (suction is greater) for the better-performing system, allowing it to withdraw more water per unit RLD/root surface area

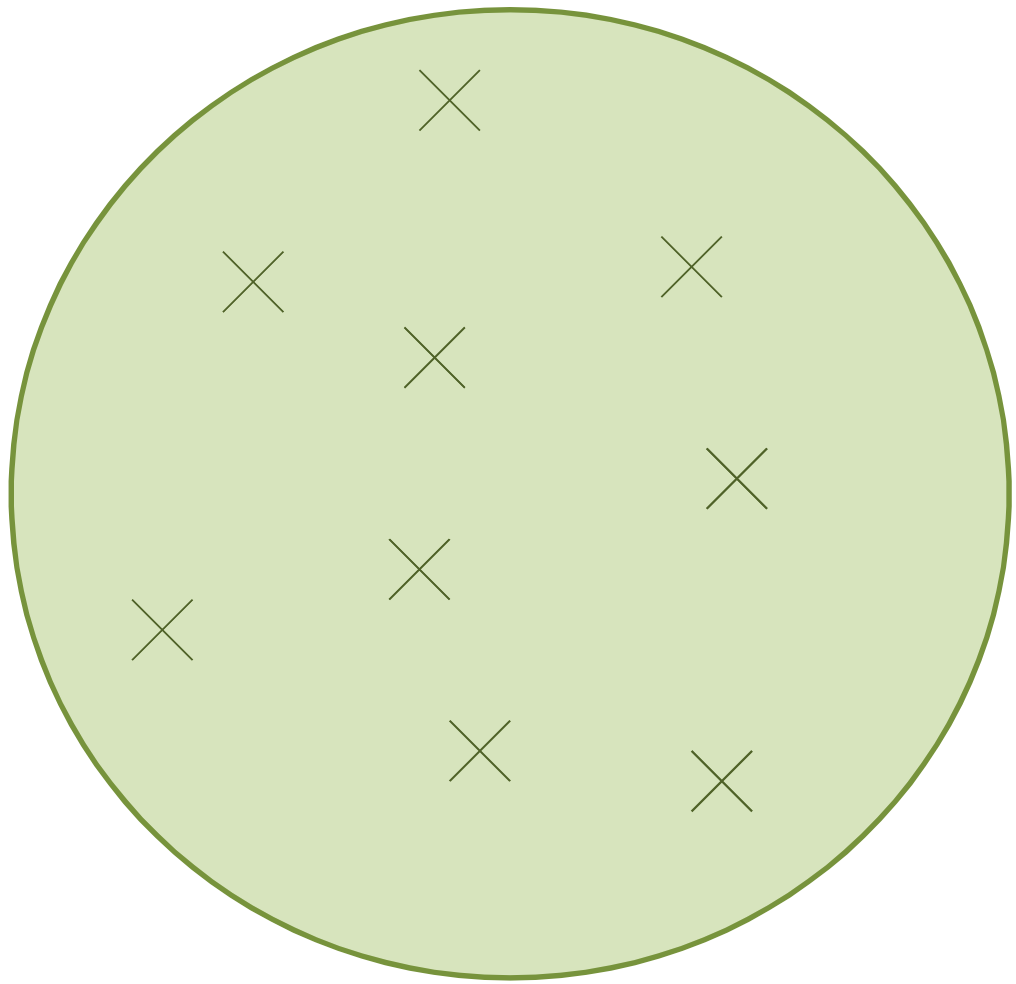


Note: with a coarser soil, the importance of this effect is lessened and the taproot gains more water.
Micro-scale anatomy may also impact the pressure distribution throughout the root system.

Upscaling

- LSM/DVM might be improved by taking architecture into account
- But is it significant?
  - To cycling of water, carbon, and heat?
  - To predicting vegetation?
- How to use conclusions from individual-scale modelling at the grid-cell scale?

Ecosystem Demography Model: Stochastic gap modelling



Ecosystem Demography Model: Individual-based

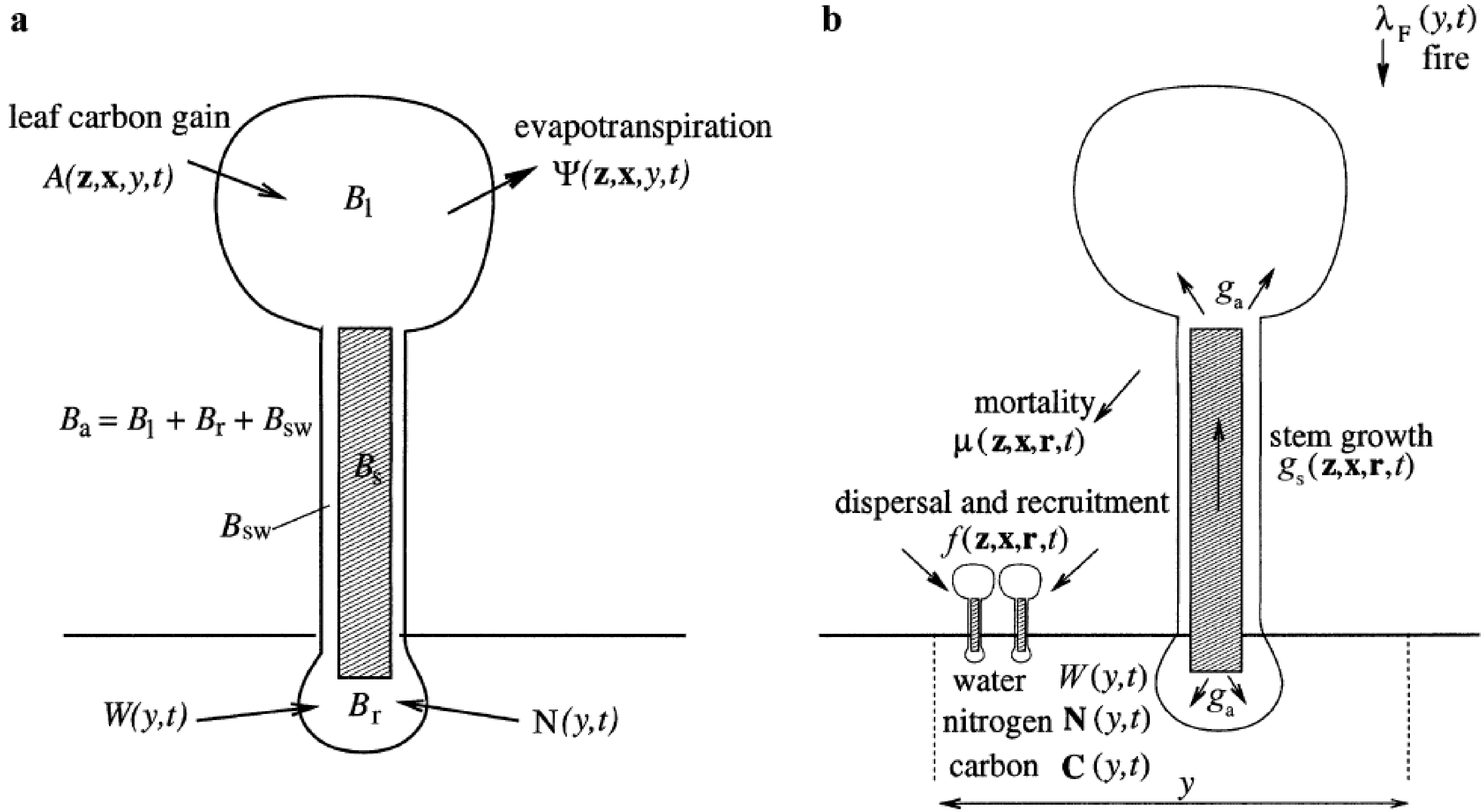
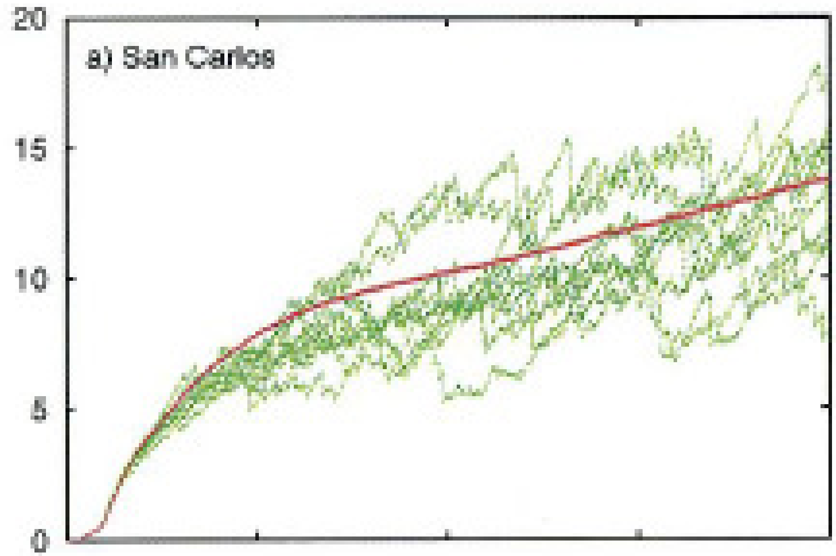


Figure from Moorcroft et al., 2001

Ecosystem Demography Model: The Innovation

- Instead of averaging individual runs, derived PDE's for the average run based on prob. density functions

- These are solved at the level of cohorts, not individuals:
  - Cohorts are defined by position in 3D space:
    - a: gap age
    - z_a: plant size
    - z_s: plant size
  - PDE's solved for
    - n: plant density
    - p: age structure
- Nevertheless, thery are made up of individual-based expressions



Aboveground biomass kg C m^{-2}

Ecosystem Demography Model: A critique

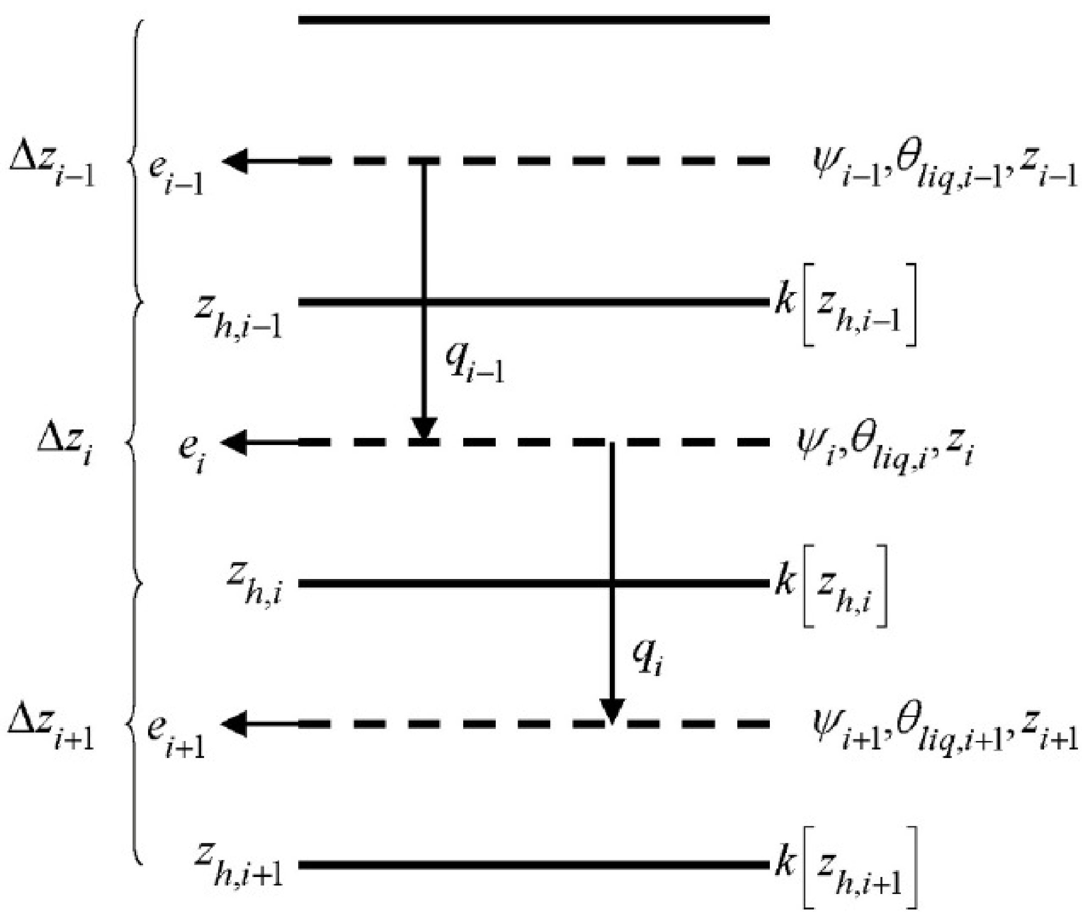
(a) Density-dependent mortality affected by coefficient calibrated by making the understory composition look "reasonable."

(b) Model strives for 1:1 shoot-root ratio

(c) Simulating the average gap seems like it might invalidate the individual-level competition approach.

Adjusting ED2 to account for root system architecture

- Add root architectural information to PFT allometry description
- At each growth time-step, distribute root biomass among soil layers
  - Fine roots (active biomass) re-allocated on faster time-step than structural roots (structural biomass)
- At each water/CO_2 uptake time-step:
  - Living biomass in each layer increases individual's ability to withdraw water there
  - Structural biomass affects ability to use living biomass (multiplying coefficient, representing the ability to extract via these roots)



$$e_i = \frac{W_i f_1(B_{ri}) f_2(B_{sr})}{\sum_i W_i f_1(B_{ri})\, f_2(B_{sr})}$$

f_1 : converts mass into surface area

f_2 : expresses mean pressure at surface of fine roots in this layer