WESS Water Earth System Science Competence Cluster

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# Impact of different degrees of detail in models of root water uptake on simulated seasonal patterns of evapotranspiration and soil moisture

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## Introduction

Plant water uptake is a crucial process linking water fluxes in the soil-plant-atmosphere continuum. Soil water extraction by roots affects the dynamic and distribution of soil moisture in the rooted zone. Water supply of plants controls transpiration, which is an important factor for the energy balance at the land surface. Effective algorithms for estimating root water uptake are therefore needed in land-surface models, which are designed to be coupled with climate models as well as in crop and forest stand models, which are designed to predict plant growth and yield at the field and stand scale. According to differences in the resolution of the variables calculated and due to the demands on the computational time the degree of detail how root processes are represented varies considerably between these models.

## Aim

Incorporation of more sophisticated root water uptake models into large scale vegetation models was recently identified as a promising strategy to improve regional climate models. The aim of the presented simulation study is to analyze the impact of different degrees of detail in models of root water uptake on simulated seasonal patterns of evapotranspiration and soil moisture in a **lysimeter study** with juvenile European beech (Fagus silvatica L.) and in a **field study** with winter wheat (Triticum aestivum L. cv. Cubus).

Three types of soil-plant models, differing in the degree of detail in calculating root water uptake, are used: the Community Land Model (**CLM 3.5**), the dynamic plant growth models **CERES 2.5** (for winter wheat) and **PLATHO** (for European beech), which use a similar root water uptake routine, and a newly developed finite element **1D-hydrodynamic xylem water flow model**. Simulation results are compared to observed daily evapotranspiration rates and soil moisture at different depth.

## The models

CLM 3.5 (Oleson et al. 2004)
- land surface model of the *Community Climate System Model* CCSM 4
- designed to be coupled with a climate model
- simulates energy and turbulent fluxes at the land surface;
- used in offline mode in this study (driven by measured climate data);
- Plants are represented as „Plant Functional Types": European beech = "broadleaf deciduous temperate", winter wheat = "crop"
- static vertical root distribution; monthly LAI-values are input;

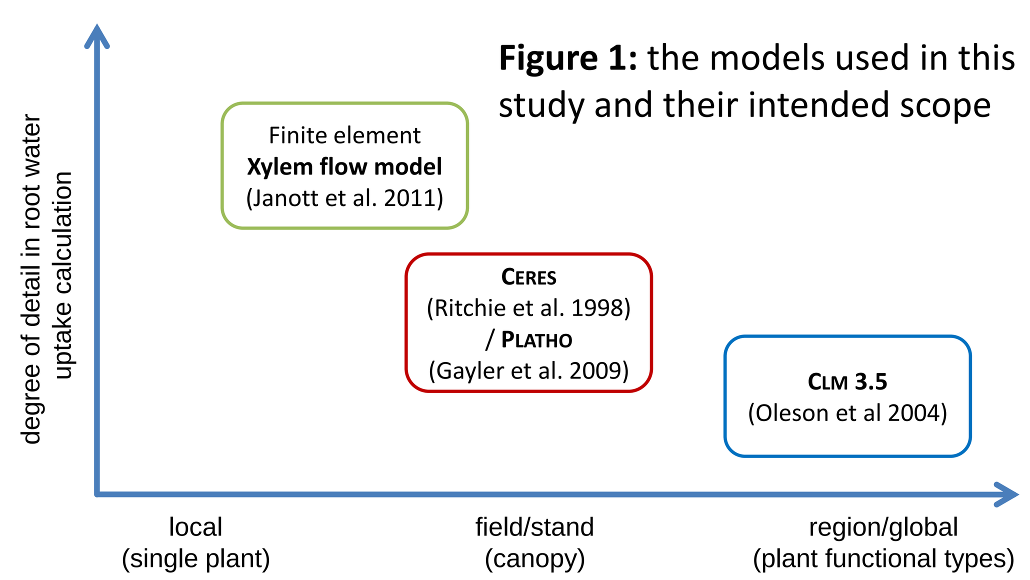



**Figure 1:** the models used in this study and their intended scope

CERES 2.5 (Ritchie et al. 1998) and PLATHO (Gayler et al. 2009)
- dynamical plant growth models
- designed to predict the impact of weather, soil characteristics and management on growth, development and yield
- species specific parameterizations and routines for winter wheat (CERES) and juvenile European beech (PLATHO)
- Dynamic simulation of LAI and vertical root distribution, depending on soil moisture und nutrient availability

The model system **EXPERT-N** (Priesack 2006) was applied to couple CERES, PLATHO and the plant hydrodynamics model to a HYDRUS-1D soil water flow model

Finite element **xylem flow model** (Janott et al. 2011)
- designed to simulated water flow through plants from individuals to filed scale
- based on the porous media equation
- originally developed for European beech and other trees species; in this study also parameterized for winter wheat
- considers explicitly the architecture of the root system and the tree crown (Fig. 2)
- LAI values and static architecture are model inputs.

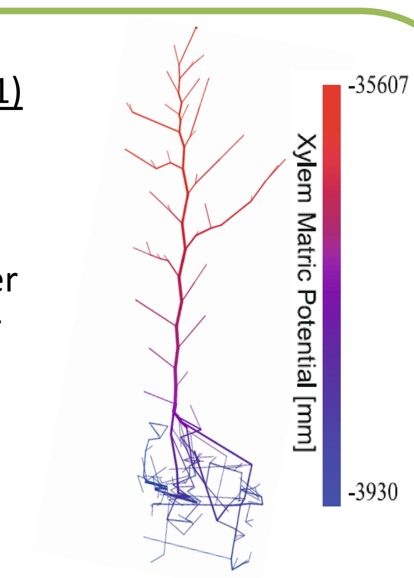



**Figure 2:** simulated water potential distribution in a Beech sapling

## Study sites:

### Lysimeter (European beech)

Saplings of European beech (4 plants m$^{-2}$) were grown from 2002-2006 at the lysimeter facility of the Helmholtz Zentrum München (48°13' N 11°36' E, 490m altitude). Daily evapotranspiration rates ET are obtained from measured amounts of precipitation P , percolation L and the change of lysimeter weight ΔW, which were automatically recorded every 1 to 6 times per hour:

$$ET = P - L - \Delta W$$

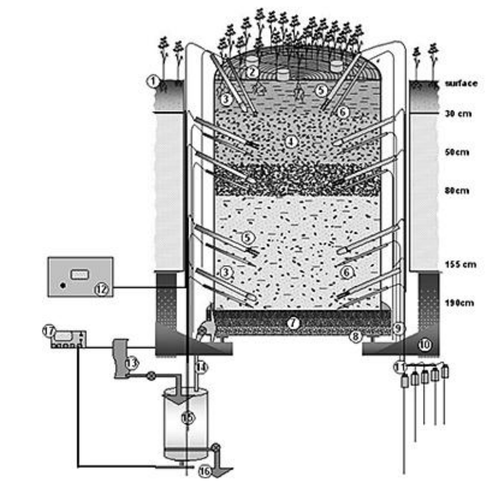


**Figure 3:** Scheme of a weighing lysimeter (from Reth et al. (2008) *Water Air Soil Pollut, Focus* 8:129–137)

### Winter wheat field site

Evapotranspiration rates and soil moisture dynamics were measured within the integrated research project PAK 346 "Structure and function of agricultural landscapes under global climate change" at the research site "Katharinentalerhof" (48.92°N, 8.70°, 385m altitude). Winter wheat was grown in 2009. Evapotranspiration rates were obtained from Eddy-covariance measurements (Ingwersen et al. 2011).

## Simulation results

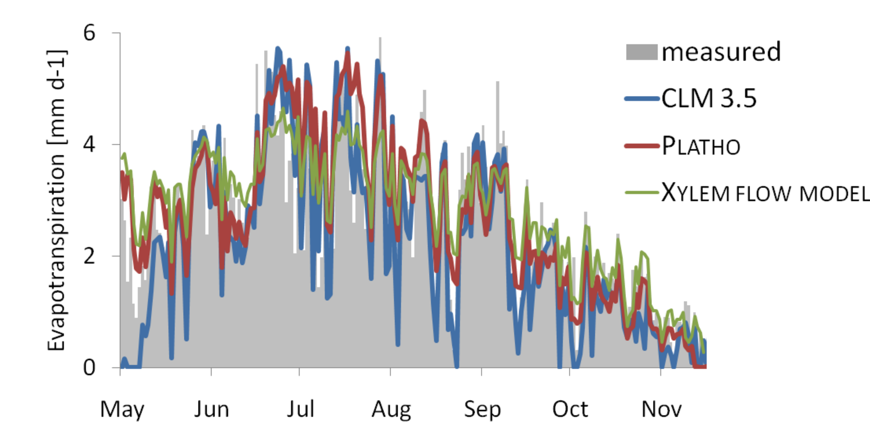
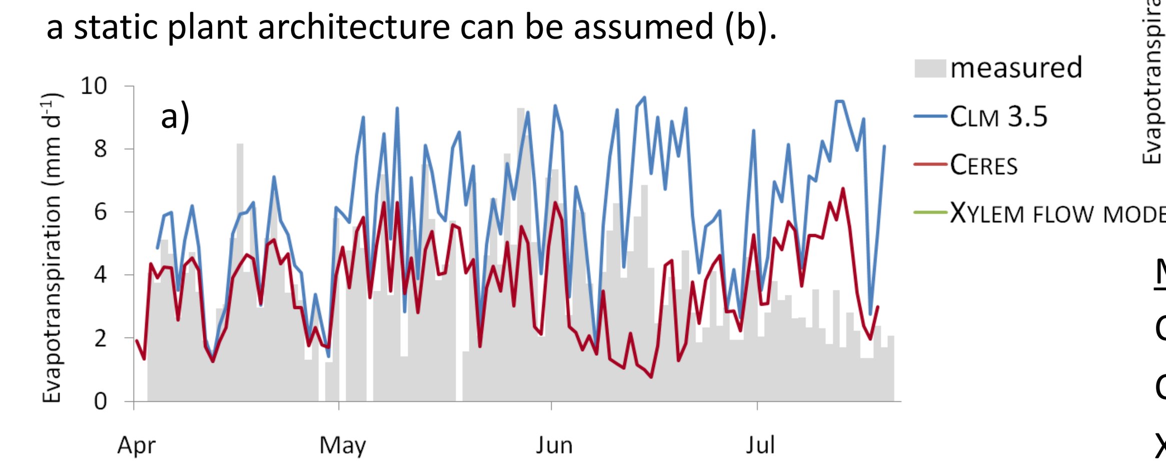


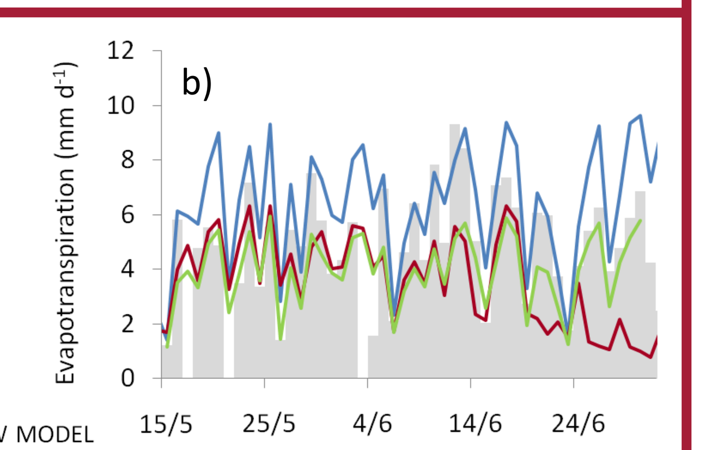

**Figure 4:** simulated daily evapotranspiration rates compared to measured ET of the European beech-lysimeter stand during the growing season 2005 (ΣP = 609mm from May-October).

Modelling efficiencies (Nash-Sutcliff):

| | |
|---|---|
| CLM 3.5 | 0.46 |
| PLATHO | 0.68 |
| XYLEM FLOW MODEL | 0.69 |

**Figure 5:** simulated daily evapotranspiration rates compared to Eddy-covariance measurements at the winter wheat field site during the growing season 2009 (a). The hydrodynamic xylem model was applied only during a shorter period when a static plant architecture can be assumed (b).




Modelling efficiencies (Nash-Sutcliff):

| | |
|---|---|
| CLM 3.5 | 0.24 |
| CERES | -0.19 |
| XYLEM FLOW MODEL | 0.32 |

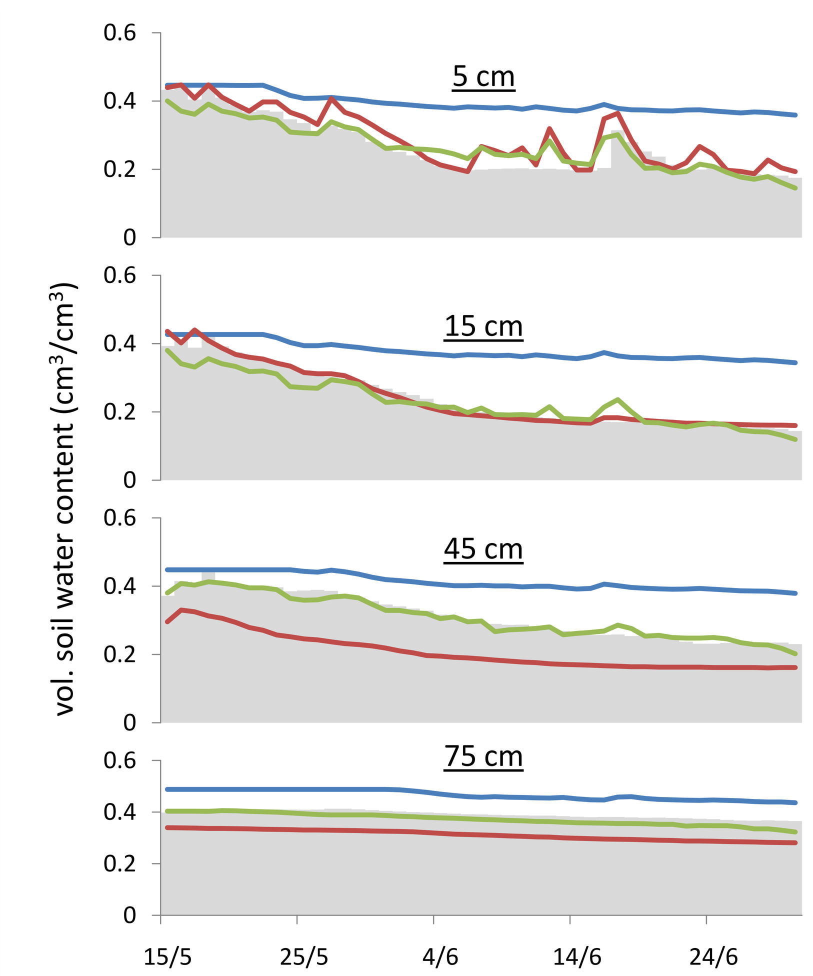



**Figure 6:** simulated and observed soil moisture dynamics at different depths from May 15 to July 1 at the winter wheat field site

## Conclusions

- All models were able to simulate adequately ET of the European beech stand during the very wet growing season 2005 when actual ET equals potential ET
- For winter wheat, best results of simulated evapotranspiration over a whole season could be achieved using a model with a detailed representation of plant growth dynamics (CERES)
- Over short periods, where the root system can be approximated by a constant structure, simulation results of the model with explicit plant architecture are closest to measured data
- In case of CLM 3.5, discrepancies between simulated and measured evapotranspiration are mainly due to a weak simulation of soil moisture dynamics
- None of the models represents adequately senescence effects on root and stomatal conductivity
- Integration of more specific plant processes into landsurface models (e.g. CLM) can help to achieve more realistic water flux simulations at the lower boundary in coupled land-surface/climate models

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**Gayler et al. (2009)** *Plant and Soil* 323:125–141; **Ingwersen et al. (2011)** *Agricultural and Forest Meteorology* 151: 345–355; **Janott et al. (2011)** *Plant and Soil* 341:233–256; **Oleson et al. (2008)** *Journal of Geophysical Research* 113(G1):G01021; **Priesack (2006)** *FAM Bericht* 60, Hieronymus, München; **Ritchie J.T. (1998)** in: Suji et al. (eds.), *Understanding options for agricultural production*. Kluwer, The Netherlands pp. 79-97