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PICUS v1.6 – enhancing the water cycle within a hybrid ecosystem model to assess the provision of drinking water in a changing climate

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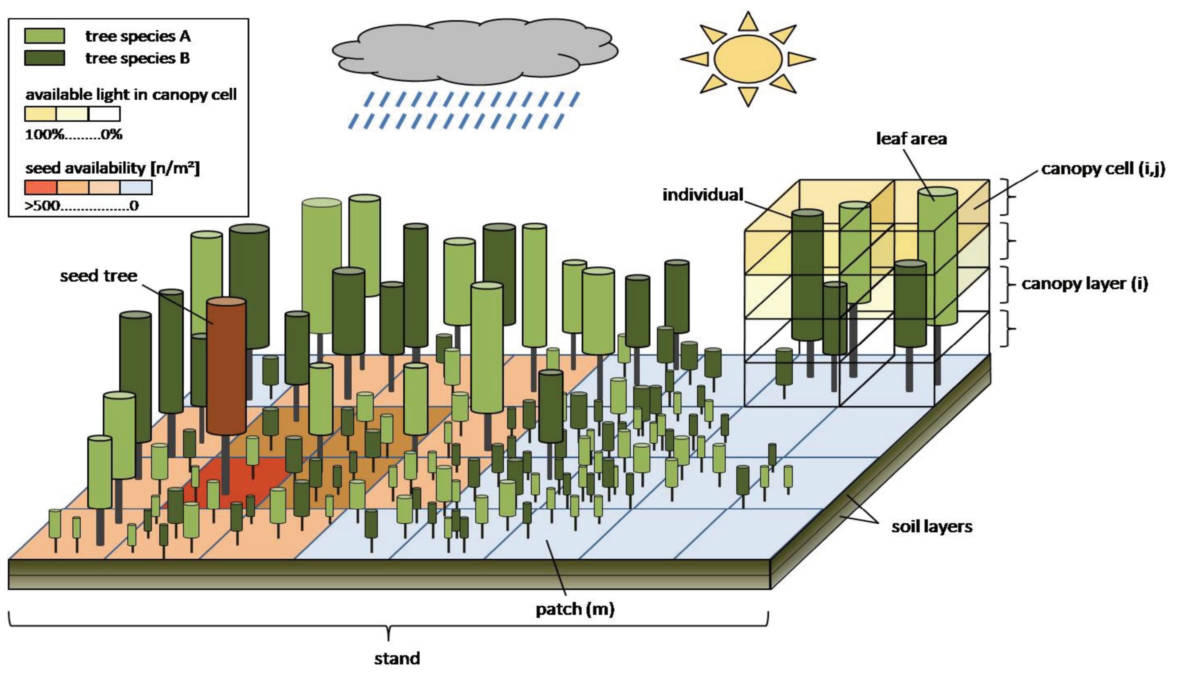
Introduction

The PICUS model is a hybrid ecosystem model which has proven in several applications the capacity to generate relevant forest related attributes to assess sustainable forest management under current and future climatic conditions. However, the relatively coarse monthly temporal resolution of the driving climate data as well as the process resolution of the major water relations within the simulated ecosystem hampered the inclusion of more detailed physiologically based assessments of drought conditions and water provisioning ecosystem services. In this contribution we present the improved model version PICUS v1.6 focusing on the newly implemented logic for the water cycle calculations. In enhancing the model overarching goal was to retain the large-scale applicability by keeping the input requirements to a minimum while improving the physiological foundation of water related ecosystem processes. The new model version is tested against empirical time series data.

The Ecosystem Model PICUS



PICUS is a hybrid forest gap model (Seidl et al. 2005) combining a 3D gap model approach (Lexer and Hönninger 2001) with a physiologically-based production approach (Landsberg and Waring 1997). The model simulates individual tree dynamics on 10×10m patches and was applied in this study on a generic one hectare basis. It accounts for spatially explicit interactions between patches via a 3D light module, simulates explicit seed dispersal as well as ecosystem carbon, nitrogen and water cycles. The model features includes a submodel of bark beetle disturbances in Norway spruce and a management module allowing any silvicultural treatment to be mimicked realistically. PICUS has been successfully evaluated in simulating equilibrium species composition as well as in reproducing longterm stand development in growth and yield experimental plots (Seidl et al. 2005). The model has recently been successfully applied to support climate change adaptation planning (e.g., Seidl et al. 2010).

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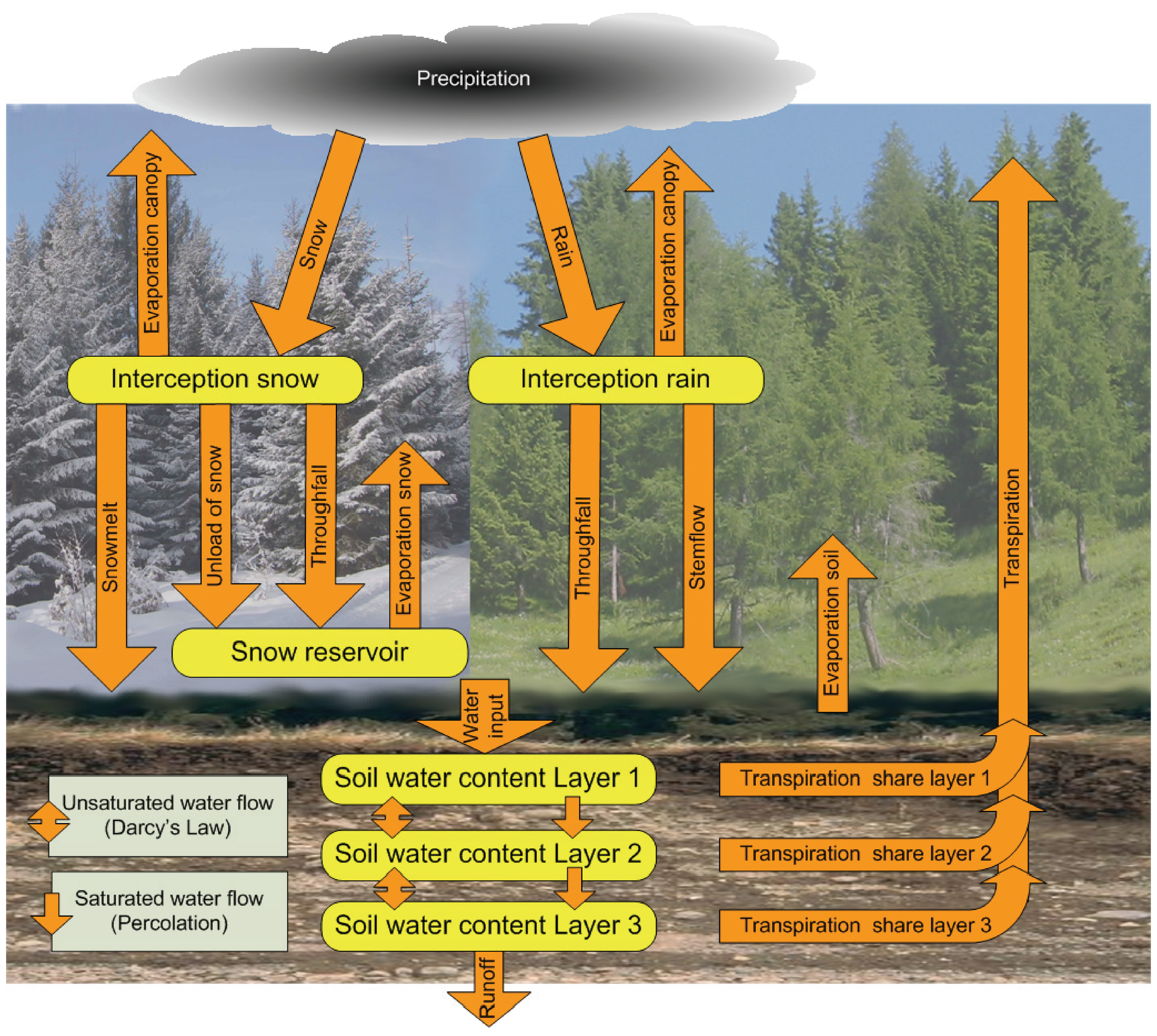
Watercycle Model

The watercycle in a forest stand can be separated in several processes: At first a part of the precipitation is intercepted by the canopy. This interception relates to the storage capacity of the canopy which depends on the leaf area index and the tree species. Precipitation which is not intercepted by the canopy as well as the water not evaporated from the canopy within one day passes to the forest ground as throughfall and stemflow respectively. The evaporation from the canopy is calculated using the Penman-Monteith formula (Landsberg et al. 1997). For the interception of snow (Hedstrom et al. 1998) the flows to the forest ground are slightly different. Beside the troughfall the unload of snow from the canopy must be considered and if temperature is more than 0°C also the melting of snow has to be included. The snow unloaded from the canopy and the throughfall of snow is added to a snow reservoir at the ground. This snow reservoir supplies the forest soil with water when temperature is above the freezing point and there is also evaporation of water from this snow layer. If there is no snow reservoir present the water evaporated from the forest ground is taken from the top soil layer (Soares et al. 2001). The incoming water in the forest soil results from throughfall and stemflow or from snowmelt. For the water balance the soil is split in several discrete soil layers. Between the soil layers two processes are modeled: saturated (percolation) and unsaturated water flow. The saturated water flow is dominant if the soil water content is above the field capacity and is driven by gravity (Arnold et al. 1998), while the unsaturated water flow is manly driven by differences of the soil water potential between two soil layers (Darcy's law; Ross 2003). Finally there is the process of transpiration which is determined using the Penman-Monteith formula with a species specific canopy conductance (Schwalm et al. 2004). This process depends on tree species, the climate, the stand (LAI) and the soil water demand. To determine the actual soil water supply the transpiration is distributed over the soil layers according to the fine root distribution in the root horizon.



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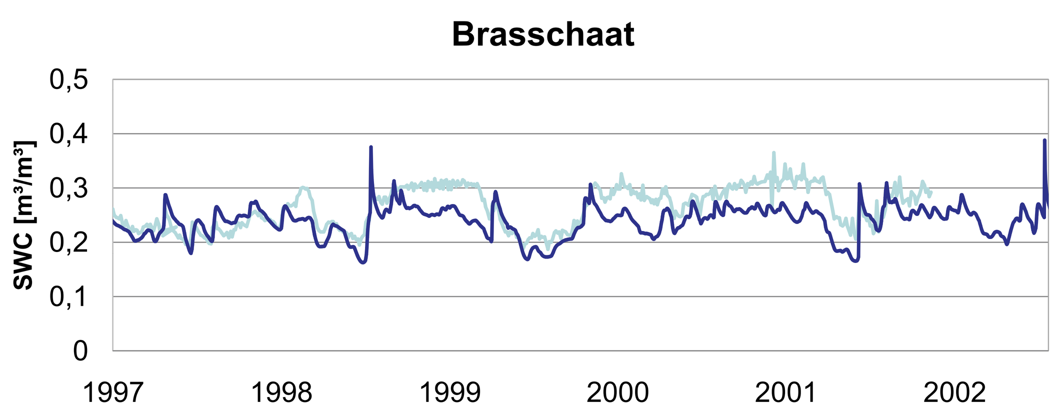
Summary

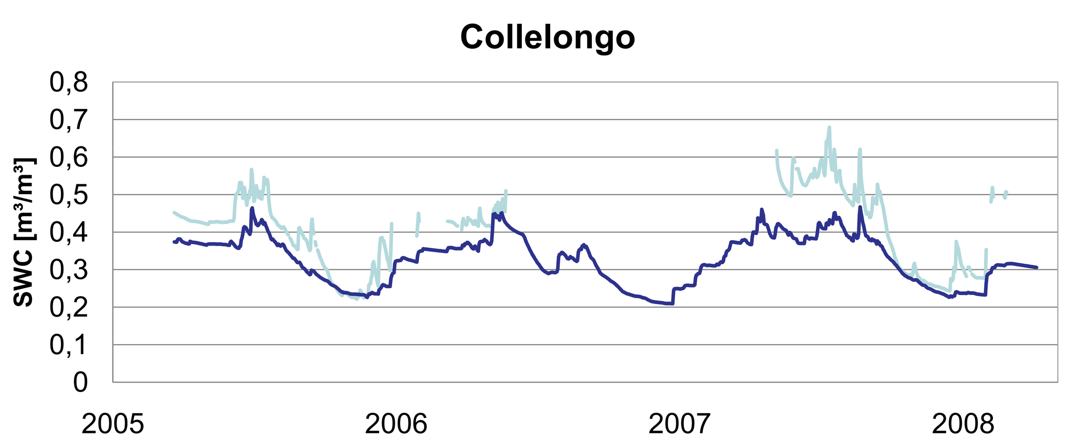
Advantages of PICUS v1.6:

- daily or monthly resolution for climate data depending on data availability
- detailed water cycle:
  - evaporation and transpiration is calculated with Penman-Monteith → species-specific daily evapo-transpiration
  - hydraulic characteristic of the soil for various soil layers and fine root distribution over soil layers → distinguish between shallow- and deep-rooting trees as well as younger and old trees
  - snow interception and evaporation from the snow layer
- growth response based on soil water potential - more realistic under dry conditions
- increased reliability of model predictions at dry ecotone transitions (e.g. beech-oak, forest-steppe)
- detailed watercycle provides more reliable results for provision of drinking water

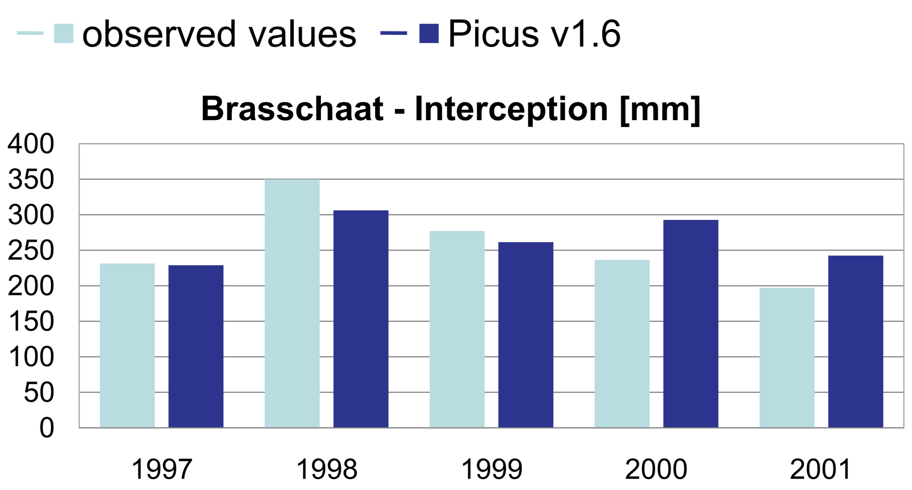
Evaluation of the Watercycle Model

Validation with observed data





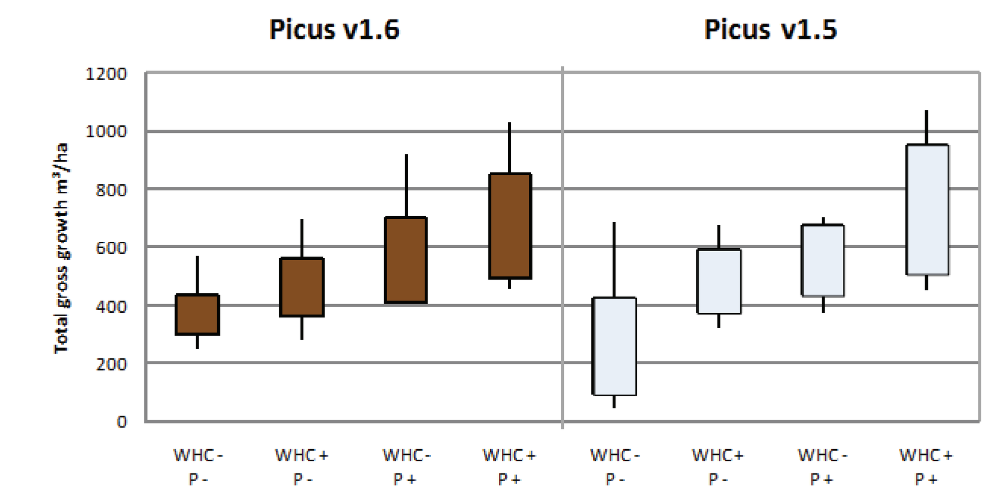
Comparison of observed and simulated soil water content (SWC) at two locations (Brasschaat in Belgium; Pinus sylvestris and Collelongo in Italy; Fagus sylvatica) over several years in selected soil layers. Validation of the yearly amount of intercepted precipitation is shown at the test site Brasschaat.



Data References:
Part of the FLUXNET-Network (http://fluxnet.ornl.gov)
Reinhart Ceulemans University of Antwerpen, Department of Biology,Wilrijk, Belgium
Riccardo Valentini, University of Tuscia, Dept. of Forest Science and Resources (DISAFRI), Viterbo, Italy

Model Comparison

Sensitivity analysis was conducted at different precipitation levels and water holding capacities of the soil.
The diagram compares the total gross growth of 30 different stands over 100 years calculated with Picus v1.6 with the new water module and with without (previous version Picus v1.5). Especially at low water holding capacities and low precipitation the new version differs from the old one an provides more sensitive and reasonable values.



P - ……….precipitation < 900 mm/year
WHC - …..water holding capacity <100 mm
P + ……….precipitation > 900 mm/year
WHC +…...water holding capacity > 200 mm