Water partitioning and flux ages in temperate forest and grassland plots: assessment using the EcH2O-iso ecohydrological model

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Abstract

We used the process-based and tracer-aided ecohydrological model EcH2O-iso to assess the effects of vegetation cover on water balance partitioning and associated flux ages under temperate beech forest (F) and grassland (G) in Northern Germany. The model was tuned on the basis of a multi-criteria calibration against an unusually rich measured data set from a long-term monitoring site.. The calibration incorporates metrics of the energy balance, hydrological function and biomass accumulation. It resulted in good efficiency statistics for simulations of surface energy exchange, soil water content, transpiration and biomass production. The model simulations showed that the forest "used" more water than the grassland; from 620mm of average annual precipitation, losses were higher through interception (29% under F, 16% for G) and combined soil evaporation and transpiration (59% F, 47% G). As a result, groundwater recharge was greatly enhanced under grassland at 37% of precipitation compared with12% for forest. The model allowed us to track the ages of water in the different storage compartments and fluxes.In the shallow soil horizons, the average ages of soil water fluxes and evaporation were similar in both plots (1.5month), though transpiration and groundwater recharge were older under forest (6 months compared with 3months for transpiration and 12 months compared with 10 months for groundwater). Flux tracking with Cl tracers provided independent support for the modelling results, though also highlighted effects of uncertainties in forest partitioning of evaporation and transpiration. This underlines the potential for tracer aided ecohydrological models in land use change studies. By tracking storage – flux – age interactions under different land covers, the effects on water partitioning and age distributions can be quantified and the implications for climate change assessed.Better conceptualisation of soil water mixing processes, and improved calibration data on leaf area index and root distribution appear obvious respective modelling and data needs for improved model results.

WATER PARTITIONING AND FLUX AGES IN TEMPERATE FOREST AND GRASSLAND PLOTS: ASSESSMENT USING THE ECH2O-ISO ECOHYDROLOGICAL MODEL

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Background: It is established that forests "use" more water than grasslands, but accurately quantifying how different **land covers partition precipitation** into interception, evaporation, transpiration and groundwater recharge is rarely possible. **Ecohydrological models** that combine algorithms for (a) energy balance, (b) water balance and (c) biomass production can facilitate this, especially if applied at **well-instrumented sites** where **multi-criteria calibration** against diverse data set is possible. We applied **EcH2O-iso** to quantify the **role of forest and grassland** vegetation on the local water balance in terms of hydrological partitioning and the **ages** of water fluxes.

Site description

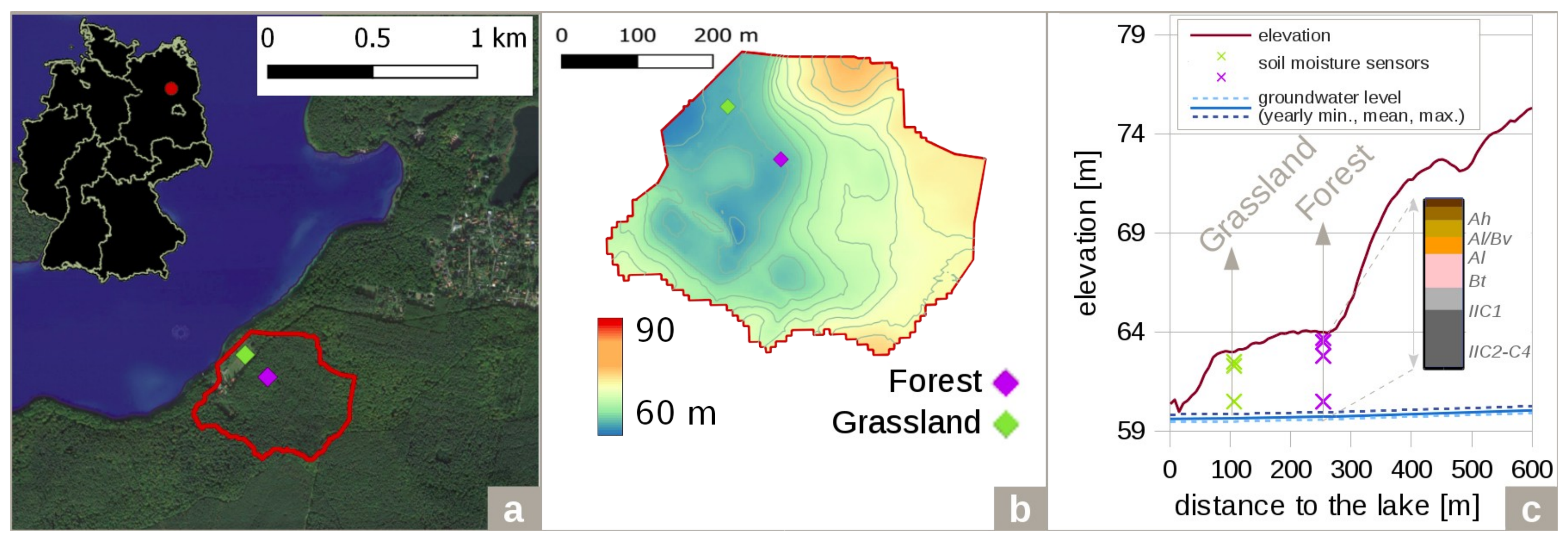

Fig 1. Study site location of the two monitoring plots in Northern Germany: aerial view of edge of Lake Stechlin (a), topography (b), schematic profile section of ground surface elevation, soil profile characteristics, water table depth and instrumentation depths.

Site: Forest and grass monitoring plots located in a lowland area in N Germany. **Climate:** temperate, continental climate with strong seasonality and inter-annual variability; precipitation ~ 620 [450 – 800] mm/yr; ETP ~ 645 [620 – 670] mm/yr during the 2000 – 2014 period. **Soil / geology:** weakly podzolised sandy soils (> 1 m) overlying sandy glacial outwash sediments (K ~ 10^{-4} ms $^{-1}$). The water table lies around 5 - 6m below the soil surface. **Vegetation:** forest plot: Fagus sylvatica (80 %), Pinus sylvestris (20 %); grassland plot: perennial semi-dry grassland dominated by Calamagrostis epigejos, Festuca ovina, and Koeleria glauca.

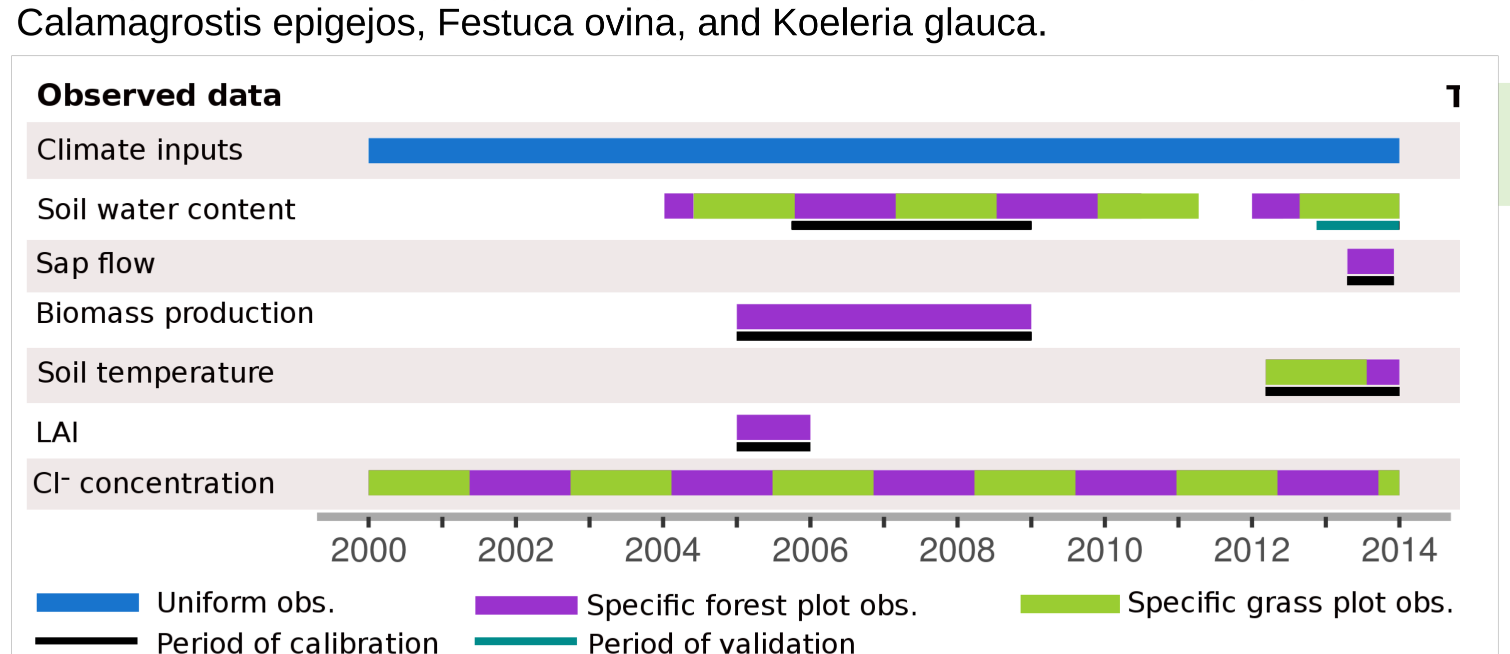

Fig 3. Temporal window covered by each data set in each plot: uniform observation (blue), specific forest plot (purple) or grass plot (green) observations, period used for model calibration (black).

Multi-objective calibration:

- The extensive monitoring (fig. 3) is used to **constrain the model** not only on the basis of the **water dynamic** simulations but also on the vegetation dynamic (**biomass production**) and the energy partitioning (**soil surface temperature**).
- Multi-objective criteria: additional combination of standardized local scores (i.e. related to each variable, fig.5). The local scores used are either based on time series errors or likelihood threshold depending of the confidence level of the obervations.
- Model results: selection of 15 best simulations after 30000 Monte Carlo runs.

Sensitivity analysis (fig.4):

- Preliminary analysis of the local scores constraints applied on the 26 (21) parameters in the forest (grass) plot.
- Main sensitive parameters:
  - → Both sites: Stomatal conductance (Gsmax), Soil saturated hydraulic conductivity (Kphi), leakance to the groundwater (Lg)
  - → Forest site specific senstivity: Sensitivity of the allocation to LAI (SaLAI), Maximum leaf turnover rate to cold stress (LtrmaxT), Root depth (Rd)
  - → Grass site specific sensitivity: soil depth where evaporation is possible (D1)

Eco-hydrological model : EcH2O-iso

EcH2O model [1]: Process-based, fully-distributed. Tightly couples two layers (canopy and surface) energy balance, hydrologic module for lateral (kinematic wave) and vertical transfers (Fig. 3), and transpiration-based plant phenology (trees and grasses [2]). Resolution: 20x20m , daily.

Cl⁻ tracking: The – **iso** – extension of the EcH2O model [3], used to track isotopic signature and ages of associated fluxes are adapted to simulate **passive tracers**.

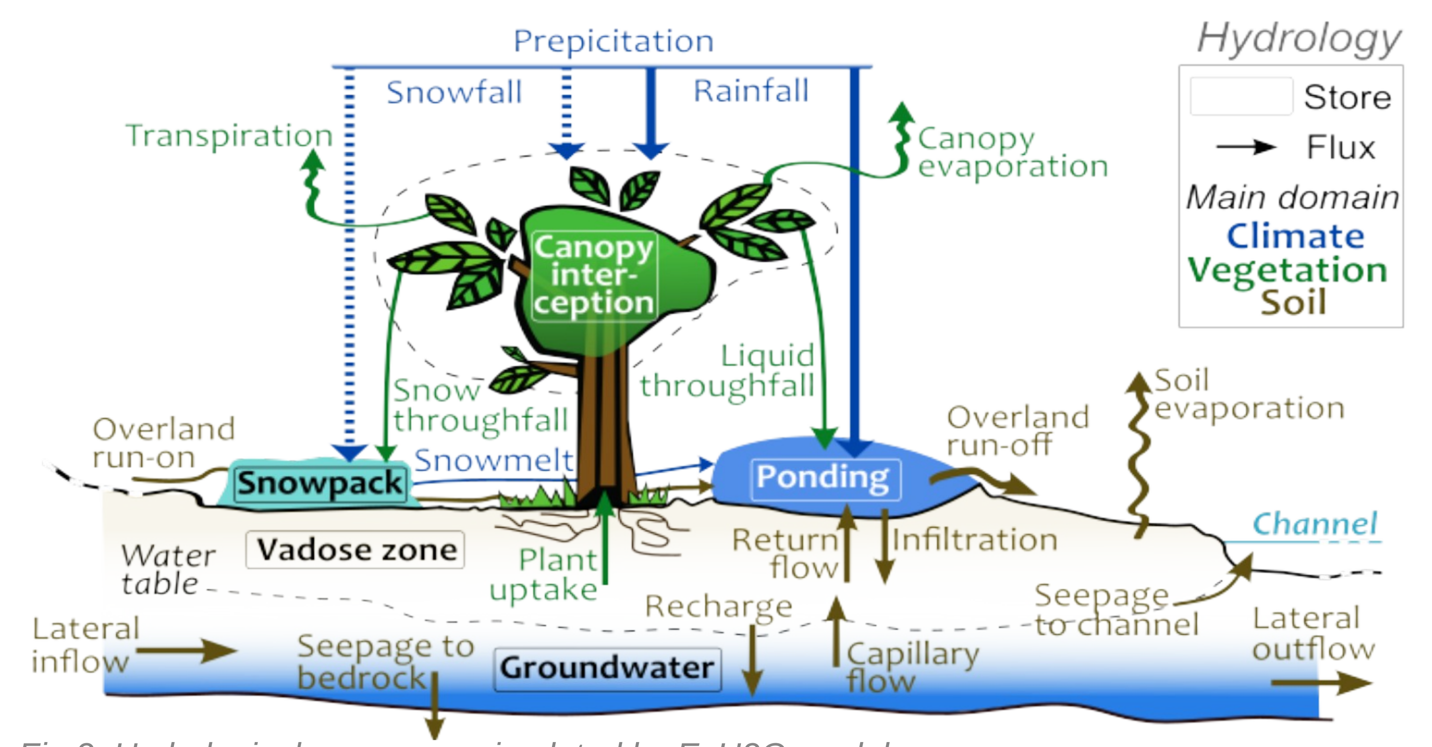

Fig 2. Hydrological processes simulated by EcH2O model

Multi-objective calibration

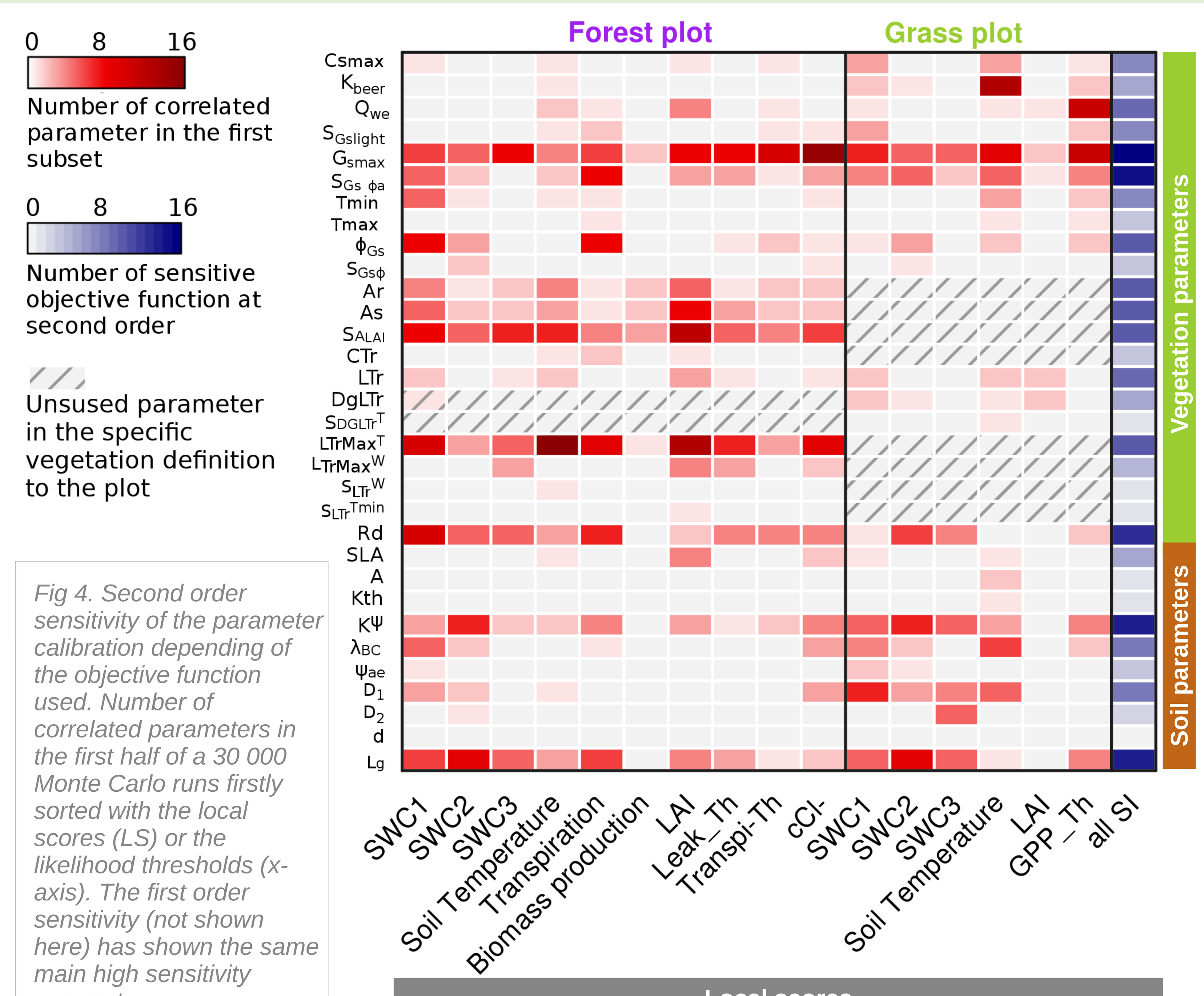

Fig 4. Second order sensitivity of the parameter calibration depending of the objective function used. Number of correlated parameters in the first half of a 30 000 Monte Carlo runs firstly sorted with the local scores (LS) or the likelihood thresholds (x-axis). The first order sensitivity (not shown here) has shown the same main high sensitivity parameters.

Results: reproducing the observed discrepancies at the forest & grass plots

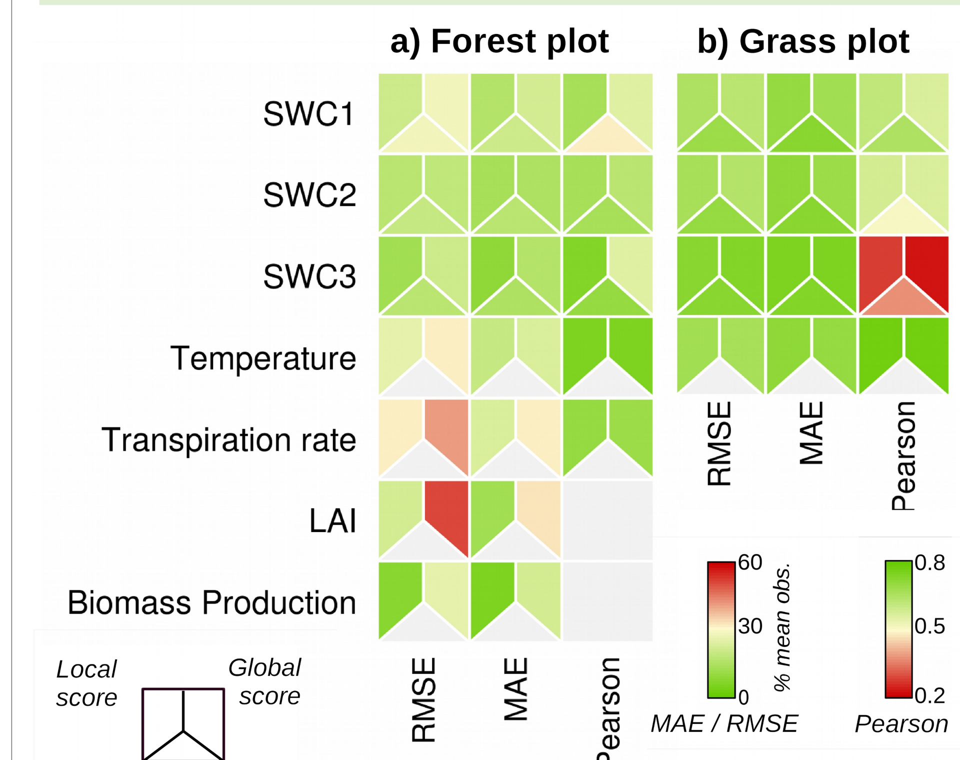

Fig 5. Overview of the performance metrics obtained after calibration of the modeling results in the forest and grass plot: 50th per. of the 15 best simulations.

Model result assessment (Fig. 5):

- Dynamics are well captured with local calibration.
- Overall expected but reasonable decrease in the model performance with multi-objective calibration: in general Δ_{RMSE} < 11 %, Δ_{MAE} < 8 %, $\Delta_{Pearson}$ < 0.15
- Most depreciation of the results of vegetation dynamic due to compromise between locals scores.

Energy balance: The model is able to reproduce the contrasts of the soil surface temperature between both plots (fig 6).

Soil water content dynamic and leakage: The simulations satisfactorily reproduce the seasonal variation of the soil water content at the forest plot and the quick event specific soil moisture increase at the grassland plot at depth. Similarly the simulated leakage dynamics show good agreements with the soil moisture measurements at depth (fig 7).

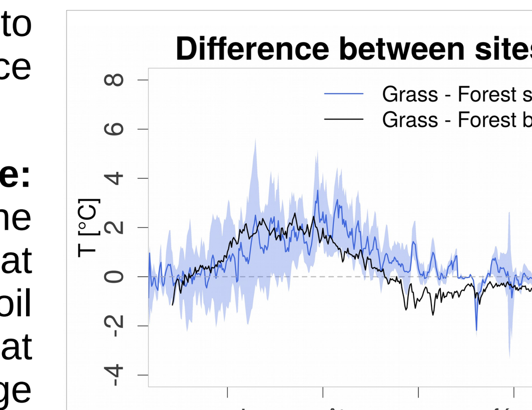

Fig 6. Soil surface temperature contrast between the plots

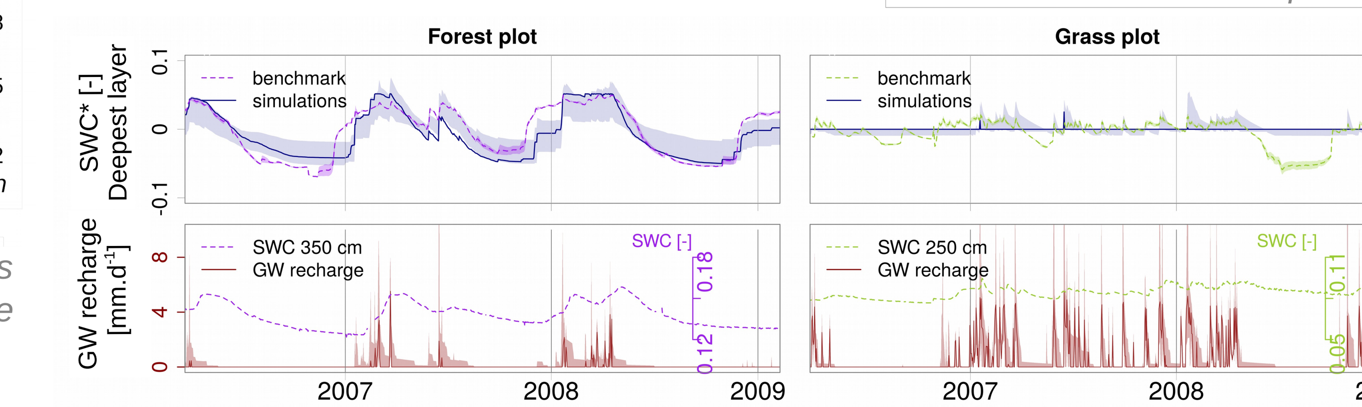

Fig 7. Simulation of the soil water content on the deepest layer at both sites. Best simulated and confidence interval of the 15 best simulated SWCi = SWCi – mean(SWCi), against the the observed SWCo* = SWCo – mean(SWCo) (dashed line). Simulated groundwater recharge compared with the SWC observation in deep layer.*

Vegetation dynamic: The LAI simulations showed limited skill in reproducing the exact timing of the leaf-out and senescence period, though general patterns were captured. In addition, the inter-annual biomass production related to climate variability is well simulated.

Main Findings : water partitioning and flux ages assessment

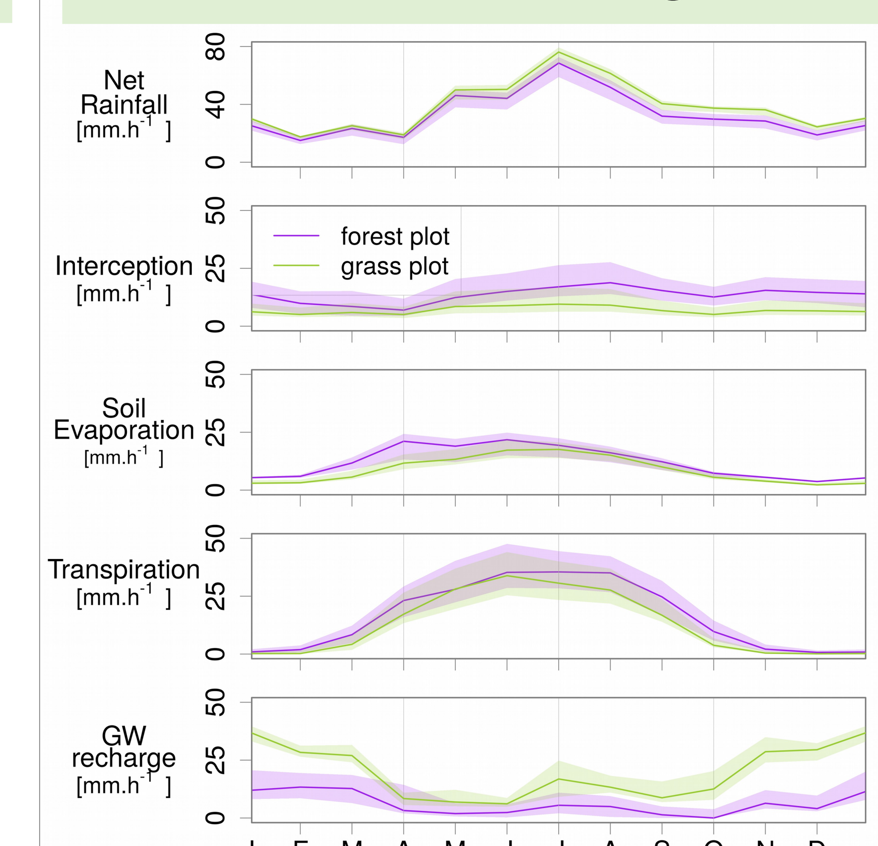

Fig 8. Seasonal variation of the water fluxes with the uncertainty of the assessment

Water fluxes assessment

- **Balance:** the forest "used" more water than the grassland; from 620 mm of average annual precipitation, losses were higher through interception (29% under F, 16% for G) and combined soil evaporation and transpiration (59% F, 47% G). As a result, groundwater recharge was greatly enhanced under grassland at 37% of precipitation compared with 12% for forest.
- **Inter-annual variability:** the **GW recharge at the grassland plot** exhibits the greatest inter annual variability (+105 mm), with low variation of the other fluxes. In contrast in forest plot, the climate variability similarly affects **transpiration** (+55 mm) and **GW fluxes** (+67 mm).

Water fluxes ages

- In the shallow soil horizons, the average ages of soil water fluxes and evaporation were similar in both plots, though transpiration and groundwater recharge were older under forest.
- There is higher uncertainty in the 3rd layer at forest plot due to root distribution uncertainty.

Table 1. Water ages in fluxes over the 2004-2014 period: mean and standard variation.

[day]	Evaporation	Transpiration	Top layer	2nd layer	3rd layer
Forest	45 ± 8	176 ± 35	48 ± 7	147 ± 29	358 ± 66
Grass	44 ± 7	87 ± 10	47 ± 7	150 ± 25	295 ± 29

Conlusions

- Multi-criteria calibration help to simulate the "right results for the right reasons".
- Sensitivity analysis highlight the key importance of accurate measurements of root depth distribution, water uptake functioning, and LAI dynamic.
- The LAI dynamic is a significant driver of the energy partitioning and the resulting blue and green water fluxes.
- Calibration on water tracers is a further step to reduce the uncertainty when assessing the water fluxes.

References:

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