Bayesian calibration of the Pasture Simulation Model (PaSim) to simulate Swiss grasslands under climate extremes.

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The Pasture Simulation Model (PaSim) is a process-based biogeochemical model for grasslands consisting of sub-models for plants, animals, microclimate, soil biology, and soil physics. It simulates water, carbon and nitrogen cycles and is used to investigate the impacts of climate change on grasslands' services in Europe. It is a parameter-rich model (~150 parameters), which is difficult to calibrate. In practice, most of the parameters are assumed to be fixed and identical for all model realizations. Other parameters, which are suitable to be fitted to the experimental data across a range of conditions, are empirically calibrated, considering the sensitivity of the model to their variation.

This study documents the calibration of 17 vegetation and site-specific parameters of PaSim (as screened and ranked for their sensitivity) at two experimental Swiss grasslands, one located in a lowland river valley (Chamau, 47° 12′ 37″ North, 8° 24′ 38″ East, 393 m a.s.l.), and the other one situated on an undulating pre-alpine plateau (Früebüel, 47° 06′ 57″ North, 8° 32′ 16″ East, 982 m a.s.l.). Bayesian calibration was chosen because it applies to models of any type and combines model parameterization and uncertainty analysis. Prior parameter distribution (expression of current imprecise knowledge about parameter values) is updated to achieve a posterior distribution by incorporating the information contained in the measured data to reduce the uncertainty in parameters.

The Chamau grassland is intensively managed with six cuts per year, while the Früebüel grassland is moderately managed with typically one to two cuts per year and cattle grazing in autumn. At both sites, experimental manipulations of rainfall was carried out, including control plots (no manipulation) and treatment plots where precipitation was reduced using appropriately sized rain shelters. The following output variables, measured from 2006 to 2008, were used for the Bayesian calibration: leaf area index (m^2 m^{-2}), harvested yield (g m^{-2}), soil moisture (m^{-3} m^{-3}) and soil temperature (K) taken at three depths (0.05 m, 0.15 m and 0.30 m) and averaged at day time step.

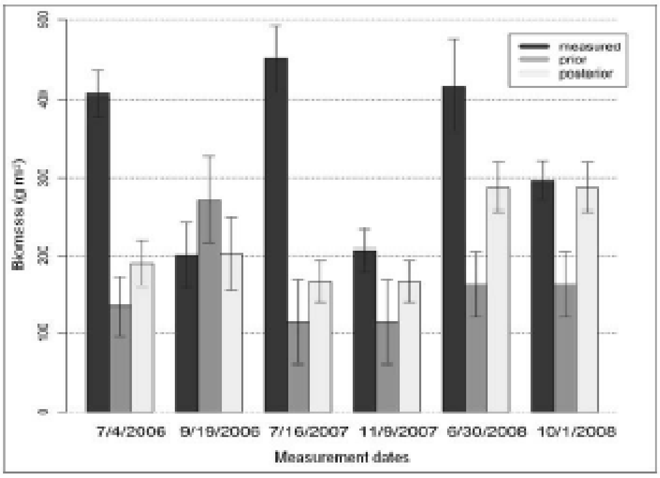

Figure 1. Uncertainty analysis for prior and posterior estimates of simulated biomass obtained at Früebüel for the treatment plots (vertical bars are standard deviations)

Table 1. Prior and posterior distributions for a sample of 13 parameters and the changes in CV values obtained at Früebüel (control plot)

Model parameter		Prior		Posterior		% in CV change
Symbol	Description	Mean	CV*	Mean	CV	
TypeA	Grassland functional type with high specific leaf area, high digestibility, short leaf lifespan and early reproductive growth	0.16	0.73	0.50	0.56	-24.01
TypeD	Grassland functional type with medium specific leaf area and high digestibility, long leaf lifespan and medium-to-late reproductive growth	0.08	1.92	0.52	0.54	-71.74
TypeC	Grassland functional type with low specific leaf area, medium digestibility, long leaf lifespan and medium-to-late reproductive growth	0.08	1.94	0.47	0.59	-70.02
zsb	Soil depth	1197	0.30	1162	0.17	-41.55
thetaszsb	Saturated volumetric soil water content	0.55	0.30	0.42	0.08	-73.30
thetasfc	Volumetric fraction of the saturated soil-water content for field capacity	0.51	0.31	0.65	0.15	-52.17
thetasfpwp	Volumetric fraction of the saturated soil-water content for permanent wilting point	0.36	0.32	0.36	0.22	-28.72
psieb	Air-entry water potential	-216	-0.40	-201	-0.53	30.80
wshtotcutinit	Shoot dry matter after cutting	0.14	0.34	0.18	0.26	-24.50
lcutinit	Leaf area index after cutting	0.37	0.66	1.03	0.39	-40.86
thetaslbspring	Water content of the soil boundary layer in spring	0.32	0.30	0.23	0.19	-35.99
thetaslbautumn	Water content of the soil boundary layer in autumn	0.32	0.30	0.29	0.18	-39.09
slaMax	Maximum specific leaf area	25.89	0.30	27.82	0.14	-52.59

*The coefficient of variation (CV) is the ratio of the standard deviation to the arithmetic mean. The sample size is 1000.

To explore the calibration results, we calculated prior and posterior means and coefficients of variation (CV) of the most influential parameters of PaSim. Here, we only show some illustrative results. At Früebüel, smaller CV values of most posterior parameter distributions showed that incorporation of more precise information reduced uncertainty on average by ~40% compared to the prior probability (Table 1). This improvement is reflected in the posterior estimates of output variables, which are closer to observations than using the prior distribution. For example, at Früebüel (Figure 1), the uncertainty associated with biomass estimates was reduced to ~30% of that of prior distribution. The root mean square error of soil moisture was reduced to 50% of its prior value for Chamau (for control) and to 25% of its prior estimate for Früebüel (for control and treatment). In general, we found that model improvement of prior to posterior distributions was stronger for Früebüel (of ~50%) than for Chamau. This may depend on differences in spatial site heterogeneity, management characteristics and climate.

In spite of differences between sites and treatments, the Bayesian framework was shown to be effective in improving the parameterization of PaSim under conditions of water stress. With few exceptions (e.g. air-entry water potential in Table 1), we observed an improvement of model performance and a reduction of uncertainty in the input parameters (negative values of CV changes), which is also reflected in the output variables. As a next step, we intend to update calibration with additional data until 2011, and extend the study to calibrate the model over long-term (≥ 6 years) observational studies at multiple European grasslands.

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