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Short communication

Bayesian calibration as a tool for initialising the carbon pools of dynamic soil models

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A B S T R A C T

The most widely applied soil carbon models partition the soil organic carbon into two or more kinetically defined conceptual pools. The initial distribution of soil organic matter between these pools influences the simulations. Like many other soil organic carbon models, the DAYCENT model is initialised by assuming equilibrium at the beginning of the simulation. However, as we show here, the initial distribution of soil organic matter between the different pools has an appreciable influence on simulations, and the appropriate distribution is dependent on the climate and management at the site before the onset of a simulated experiment. If the soil is not in equilibrium, the only way to initialise the model is to simulate the pre-experimental period of the site. Most often, the site history, in terms of land use and land management is often poorly defined at site level, and entirely unknown at regional level. Our objective was to identify a method that can be applied to initialise a model when the soil is not in equilibrium and historic data are not available, and which quantifies the uncertainty associated with initial soil carbon distribution. We demonstrate a method that uses Bayesian calibration by means of the Accept–Reject algorithm, and use this method to calibrate the initial distribution of soil organic carbon pools against observed soil respiration measurements. It was shown that, even in short-term simulations, model initialisation can have a major influence on the simulated results. The Bayesian calibration method quantified and reduced the uncertainties in initial carbon distribution.

Model initialisation can influence whether a model predicts soil at a given site to be a source or sink of CO_2 (Falloon and Smith, 2000). There are many ecosystem models in use today, designed to meet different objectives. Despite their diversity, most of the models share some basic assumptions which include the representation of soil organic matter (SOM) as multiple pools with differing inherent decomposition rates governed by first order rate constants modified by climatic and edaphic reduction factors (Smith, 2001). However, as these conceptual model pools often do not correspond to measurable fractions (Smith et al., 2002), the division introduces an initialisation problem (Falloon and Smith, 2000). Incorrect initialisation of soil carbon (C) pools can cause spurious trends in output. Flawed initial conditions may produce fallacious trends as the state variables drift back towards the modelled ideal, also potentially leading to inaccurate assessment of inter-annual variability. Some earlier literature on models of coupled C and nitrogen (N) cycles focused on descriptions of model mechanisms and dynamics, without explicitly addressing the problem of initialisation of pools (Bachelet et al., 1989; van Dam and van Breemen, 1995). In almost all models, these soil C pools are conceptual (Zimmermann et al., 2007), so it is often not possible to validate the dynamics of modelled SOM pools with measured pool changes; the only measurable quantity is total soil organic C. The initial distribution of C between the different pools is usually not known and the initial amount of C in the soil is dependent on the history of the simulated site. It is commonly assumed that the initial distribution between the pools is in equilibrium with the conditions before the onset of the experiment (Cole et al., 1989; Parton and Rasmussen, 1994; Romanya et al., 2000; Franko et al., 1996; Smith et al., 2005, 2006). However, observed soils can be far away from equilibrium because of long turnover times of some compounds and disturbances by fire, erosion, land use or land use change (Wutzler and Reichstein, 2007). The overall importance of

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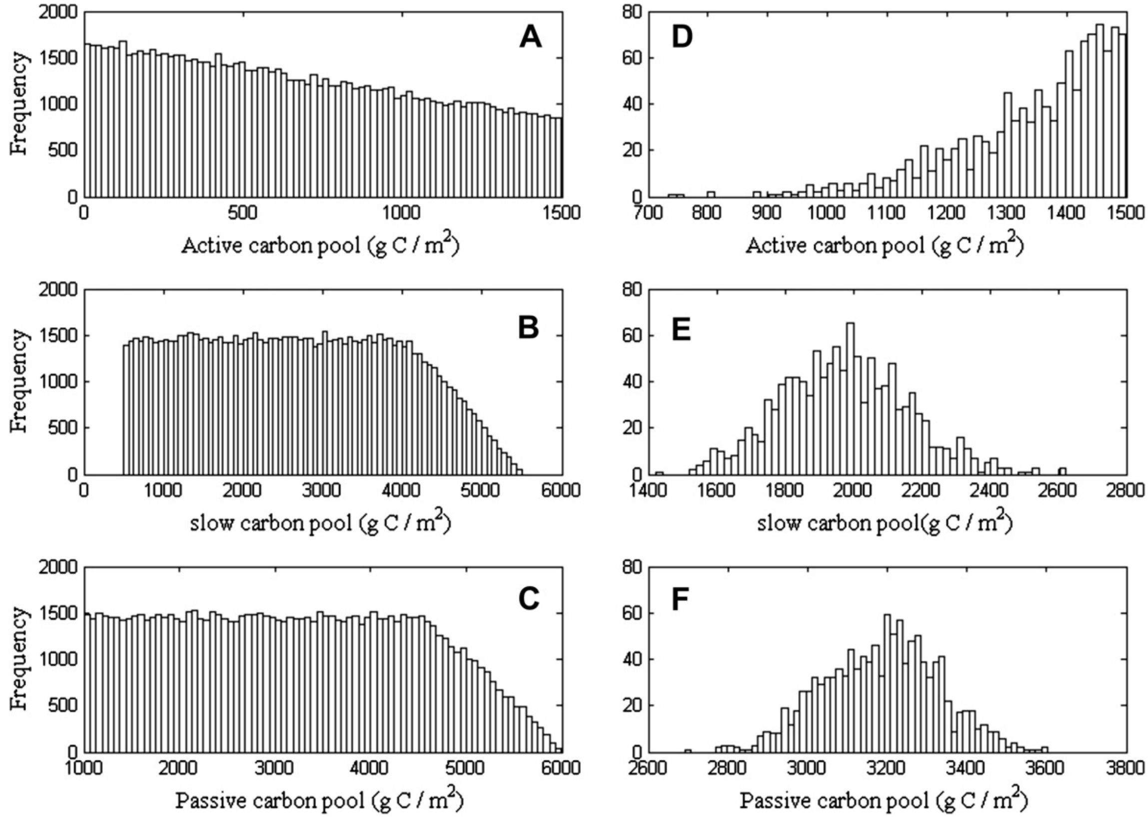

Fig. 1. Samples from the prior ($n = 10^5$) and posterior ($n = 1179$) parameter probability distributions for the C1, C2 and C3 pools of the DAYCENT model. The figure illustrates prior marginal parameter distribution of A) active carbon pool B) slow carbon pool C) passive carbon pool and posterior parameter distribution of D) active carbon pool E) slow carbon pool F) passive carbon pools.

initialisation assumptions depends on the time frame of the study, the structure of the model, and the method of initialisation. Previously, the initialisation of each soil organic C pool required a spin-up simulation over a long-term to find a soil C equilibrium for undisturbed vegetation or to assume that the current land was in equilibrium. After the spin-up using undisturbed vegetation, the reconstructed disturbance history was then used to get a close estimate of the SOC pools. This two-step method requires informative historical data which are usually not available for a large area. Another significant uncertainty in spin-up runs is the initial estimate of inert or very slowly decomposing organic C (Falloon and Smith, 2000).

The overall objective of the present study was to (1) demonstrate the consequences of soil C pool initialisation for predicted short- and long-term changes in soil C and to (2) assess the potential of Bayesian calibration to initialise soil state variables and quantify and reduce the uncertainties in model initialisation. To demonstrate this, we applied the method to the DAYCENT model using data from a grassland site at Oensingen, Switzerland.

The DAYCENT biogeochemistry model (Parton et al., 2001; Del Grosso et al., 2001, 2006) is the daily time step version of the CENTURY model (Parton and Rasmussen, 1994). DAYCENT simulates the biogeochemical processes of C, N, phosphorus, and sulphur cycling associated with SOM dynamics for grasslands, agricultural lands, forests, and savannas. DAYCENT simulates decomposition, nutrient flows, soil water, and soil temperature. Required inputs used to drive the model include daily maximum/minimum temperature and precipitation, site-specific soil properties, current and historical land use, management practices such as grazing, cultivation, and organic matter or fertilizer additions.

The soil organic matter sub-model of DAYCENT contains three organic matter pools, which we refer to as C1, C2 and C3. The C1 pool (approximately 2–3 times the live microbial biomass) includes soil microbes and microbial products with short turnover times (1–3 months). The C2 pool (45–60% of total soil SOM) includes resistant plant material derived from structural plant material and stabilized soil microbial products that have turnover times ranging from 10 to 50 years depending on the climate. The passive C3 pool (45–50% of total SOM) includes physically and chemically stabilized SOM that is very resistant to decomposition (turnover times from 400 to 4000 years). The detailed structure of the SOM sub-model was described by Parton et al. (1987).

The grassland site at Oensingen, Switzerland, was selected from the site network of the NitroEurope project (Sutton et al., 2007). The climate, management information and soil parameters that are used in this analysis are described by other authors: Ammann et al. (2007), Calanca et al. (2007). The DAYCENT model was applied to the grassland at Oensingen with intensive management: high mineral fertilizer and manure application and more cutting events than in extensive management. For the calibration, we used data on system respiration flux rates at the Oensingen grassland site. System respiration, i.e. the sum of autotrophic and heterotrophic was monitored daily from 2004 to 2007 using a static chamber technique. We only used the winter season system respiration measurements, to ensure that the CO_2 flux rates were due almost entirely to SOC decomposition.

The prior predictive uncertainty is the uncertainty assumed for a given model parameter before the results of any model runs have been taken into account. Our method begins by quantifying the prior predictive uncertainty about the quantities of interest, i.e. the