PARAMETER ESTIMATION FOR GRASSLAND CARBON CYCLE USING NONLINEAR INVERSION OF BIOME-BGC

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Introduction

One of today's most important environmental problems is global climate change. There are many uncertainties associated with the future of the global climate, but it has been proven that human activity influences the climate of the Earth by changing the chemical composition of the atmosphere (IPCC 2001).
The effect of fossil fuel emission, industry, agriculture and transportation manifest itself unequivocally, for example in the form of increased atmospheric concentration of greenhouse gases. Any change in the quantity of greenhouse gases can unbalance the energy budget of the Earth-atmosphere system and can cause global climate change.
The atmospheric abundance of CO_2, which is the most important anthropogenic greenhouse gas, is closely coupled with the terrestrial biosphere (Nagy et al. 2005). Since the carbon budget of the terrestrial ecosystems is influenced by many environmental factors (Balogh et al. 2005, Czóbel et al. 2005), it is essential to understand the basic drivers and the mechanism behind the processes. In order to accomplish this task, ecosystem scale carbon flux measurement data should be used to calibrate generalized numerical ecosystem models using mathematical description of the essential carbon cycle related processes.
The aim of this study was to use direct field measurement data measured in Hungary to calibrate the Biome-BGC ecosystem model using nonlinear inversion method.

Material and methods

Carbon dioxide and water vapor fluxes have been measured by the eddy-covariance technique in the western part of Hungary (Hegyhátsál, 46°57'N, 16°39'E, 248 m asl) over a managed, species-rich, semi-natural grass field (hay meadow), (Barcza et al. 2003). Based on the result of these measurements we simulate the carbon exchange of the grassland at Hegyhátsál, using a process-based biogeochemical model called Biome-BGC (Running et al. 1988)
Biome-BGC is a mechanistic ecosystem model that simulates the storage and fluxes of water, carbon, and nitrogen within the vegetation, litter, and soil components of the terrestrial ecosystems. Biome-BGC was developed from the Forest-BGC family of models (Running - Coughlan 1988, Running - Gower 1991, Running 1993). The Biome-BGC model is an extended version of Forest-BGC for use with different vegetation types. The latest version of the Biome-BGC used daily time step, and was driven by daily

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values for maximum and minimum temperatures, precipitation, solar radiation, and air humidity. The model requires the definition of several essential vegetation-, climate- and site characteristics to estimate fluxes of carbon, nitrogen, and water through the ecosystem.

Process based ecosystem models like Biome-BGC have many parameters and multiple outputs of interest so a calibration procedure is inevitably necessary, however it might be a challenging task. Bayesian approach offers a solution to the calibration problem. It is based on the Monte-Carlo technique where a large number of model simulations are performed with variable internal model parameters but constant input data (meteorological data). Bayesian calibration offers a method to accomplish global parameter optimization instead of the limited accuracy manual calibration. It provides not only a single best parameter set but also parameter estimates with measures of uncertainty and correlations amongst the parameters (Mosegaard - Tarantola 1995).

Results and discussions

Biome-BGC has 23 internal model parameters which are referred to the ecophysiological attributes of grass (with adjustable values). Eddy covariance data is used to calibrate Biome-BGC and to establish a cost function that is the measure of the misfit between the measured and the modeled data.

The first step of the Bayesian calibration is the estimation of the *a priori* distribution of model parameters. Since we do not have measurement data for the ecophysiological parameters, all 23 parameters were adjusted. We implemented a novel, two-step calibration method in order to find the most reliable parameters and to estimate their uncertainty.

As a first step, we estimated the *a priori* distribution of each parameter as a normal distribution using their observed minimum and the maximum value according to the literature (White et al. 2000). A likelihood function was then constructed for each 23 parameters in order to tighten the interval that is used in the second step of the calibration procedure.

Because all 23 parameters are changed in the same time, a huge number of iteration steps are necessary to accomplish the Monde Carlo simulation. In order to reduce the computation time we selected the five most sensitive parameters for the next step. The most sensitive parameters were determined based on our previous sensitivity analysis (Hidy 2006).

In the second step *a priori* parameter values and their uncertainties are set according to the results of the first step. This means that the parameters are varied in a much narrower interval, so their distribution is better defined.

These parameters, together with their definition, minimum and maximum value are represented in Table 1.

Table 1: Sensitive ecophysiological parameters of Biome-BGC model (C3 grass submodel)

abbrev.	definition
FRC:LC	Fraction of root carbon to leaf carbon. It establishes a relationship between different plant pools that control how photosynthetically produced carbon is allocated throughout the ecosystem
C:N(lv)	Carbon to nitrogen mass ratio in the leaves. It determines three important facto the nitrogen required to construct leaves, the amount of nitrogen available for investment in photosynthetic machinery and leaf respiration rates
CLEC	Canopy leaf extinction coefficient. It controls canopy photosynthetically active radiation absorption
SLA	Defines leaf area per unit mass: thin, light leaves, such as grass blades, have a higher SLA than dense conifer needles
MSC	Estimates the rate of stomatal conductance when environmental conditions are nonlimiting

The Monte Carlo method is then used to construct a new likelihood function based on the cost function also using the *a priori* intervals. We used 100,000 iteration steps to estimate the *a posteriori* distribution of the parameters. Optimal parameter values were finally determined with the convolution of the likelihood function and the (narrow) *a priori* intervals. The parameter values and the confidence intervals have changed as the result of the nonlinear inversion (Table 2). As the result of the calibration, the fit between the modeled and measured data is improved, the ecosystem scale processes became more realistic.

Table 2: The effect of the Bayesian calibration on the model parameter values and confidence intervals (which is determined by the minimum and the maximum value of the interval)

	a priori			a posteriori		
abbreviation	**value**	**min**	**max**	**value**	**min**	**max**
FRC:LC	1.23	0.26	2.2	1.45	1.12	1.76
C:N(lv)	37.5	15	60	35.1	27.3	43.6
CLEC	0.55	0.3	0.8	0.708	0.63	0.77
SLA	45	20	70	40.99	35.66	49.87
MSC	0.0014	0.0008	0.002	0.00109	0.00954	0.00126

Conclusions

Bayesian approach is used in this study to calibrate the highly non-linear ecosystem model Biome-BGC in order to simulate the carbon exchange processes of a grassland. We introduced a novel, two-step calibration method which uses the Monte Carlo approach to calculate optimal model parameters and their uncertainty also utilizing the eddy covariance data measured in the western part of Hungary, above grassland.

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Applying the optimized ecophysiological parameter set with Biome-BGC the correlation between the measured and the simulated flux data has dramatically increased. The uncertainty of the five most sensitive model parameters was decreased meanwhile. This means that the calibration procedure was successful, and the two-step approach is an appropriate tool that can be used to calibrate the Biome-BGC model against measurement data from other ecosystems.

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