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Multi-year model analysis of GPP in a temperate beech forest in France

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ABSTRACT

In this paper gross primary production (GPP) predicted by FORUG is compared with GPP calculated from eddy covariance measurements for a beech forest in France (Hesse). Two photosynthesis formulations at leaf level are compared: the biochemically supported approach described by Farquhar et al. [Farquhar, G.D., Von Caemmerer, S., Berry, J.A., 1980. A biochemical model of photosynthetic CO_2 assimilation in leaves of C3 species. Planta 12B, 549–587] (BCF) and an empirical light response curve (LRC). Five consecutive years (1996–2000) of measured GPP are compared with FORUG model predictions.

Results did not discriminate between both model formulations, but good agreement between modelled and measured GPP support the reliability of FORUG for both photosynthesis approaches. Although some discrepancies appeared, the parameterization combining literature and fitted parameters can be considered as a useful strategy.

Residuals were analysed to find explanations for discrepancies between model predictions and data. The increase in residuals over the years, indicate that interannual variability of GPP is not only determined by direct climatic effects. Due to interfering long-term effects, a combination of several climatic factors (drought, temperature), acclimation, environmental and management impacts account for the interannual variation in GPP. However, the long-term effect of drought appeared to be the most important driver of the interannual variability in GPP. Taking into account these long-term climate effects will be an essential step in development of better performing ecosystem models.

1. Introduction

The need for accurate assessments of CO_2 fluxes between forest ecosystems and atmosphere can be addressed by two efforts: observation of CO_2 fluxes in the field; and development and validation of models (Zhan et al., 2003). Amthor et al. (2001) stated that reliable measurements of carbon fluxes on ecosystem level are very difficult to obtain. Due to technical or meteorological reasons there will always be some gaps in experimental datasets. Moreover, for practical and finan-

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cial reasons carbon fluxes can only be measured on a limited number of places. Mathematical models are very useful to estimate carbon fluxes between vegetation and atmosphere. First, models make it possible to estimate the behaviour of complex terrestrial ecosystems which can not be derived from normal logic (Rykiel, 1996). Secondly, models can also be used to extrapolate results of short-term experiments to long-term predictions (Medlyn et al., 1999). Finally, models are useful to understand observed evidence and to situate knowledge of certain phenomena in a broader context (Amthor et al., 2001).

The question whether multilayer soil–vegetation–atmosphere transfer (SVAT) models could be good candidates for long-term simulations and global change scenario analysis is quite relevant (Kramer et al., 2002; Ogée et al., 2003). However, it seems to be very difficult to use multilayer SVAT models to predict carbon fixation of forests on the long-term and for large areas. One of the reasons is that phenomena involved in photosynthesis at leaf level are lost during upscaling in time and space (Song and Woodcock, 2003).

Reliable data are needed to calibrate and test models. Eddy covariance data are widely used for this. But only in the last few years, multi-year flux datasets have become available. These datasets can be used to understand seasonal and interannual variability of the carbon fluxes.

From a comparison study between several models and eddy covariance measurements of net ecosystem exchange (NEE), Kramer et al. (2002) concluded that models producing accurate results of NEE do not guarantee that they behave correctly at process level, which reduces reliability of models in predicting climatic change responses. In this study, we compare gross primary production (GPP) predictions with GPP estimates in order to come closer to the process level. GPP is a key parameter in any carbon cycle study, but GPP data cannot be provided by direct measurements (Larcher, 2003) and must be estimated from measured NEE (Falge et al., 2002; Reichstein et al., 2005).

Discrepancies between model predictions and measurements will always appear. However, these discrepancies are most interesting, because they can teach us more about the model and the forest ecosystem, and help us to find explanations for the seasonal and interannual variability of GPP.

In a model comparison to eddy covariance data, three problems are likely to be important (Finnigan et al., 2003; Medlyn et al., 2005). (1) The first is the problem of equifinality. Equifinality means that different model formulations or different parameter combinations can lead to the same (good) results. This makes it difficult to distinguish physical or biological effects on the model output. The equifinality problem plays a major role when comparing NEE predictions with measurements. Different combinations of GPP and total ecosystem respiration (TER) can lead to the same NEE. Part of the equifinality problem is solved in this paper by not comparing model predictions with NEE, but with GPP data. However, still several combinations of photosynthetic parameter values can lead to equal GPP rates. (2) Secondly, insensitivity of the model output for certain model inputs makes it difficult to identify factors that cause certain effects. (3) The third problem is the problem of uncertainty. The errors in a model test can have different sources that stem from uncertainties in the validation data, the model structure and the parameter values.

It seems scientifically most correct to parameterize a model without using validation data (flux measurements). For example Ogée et al. (2003) parameterized the *MuSICA* model without using flux measurements, in order to use them as proper validation test of the model. In contrast, several authors concluded that using published parameters to approximate the temperature response of a species can lead to significant errors in environmentally driven process-based models of canopy carbon uptake (Medlyn et al., 2002; Dungan et al., 2003). Moreover, Hollinger and Richardson (2005) found it desirable to use flux data to determine parameter values of a specified model. A problem of this approach is equifinality in the parameter sets, as mentioned before. The magnitude of this problem generally increases with model complexity. However, in this study we have chosen to use flux data to estimate several parameters.

Medlyn et al. (2005) stated that for testing model structure it is necessary to formulate different models and to observe whether data can be used to discriminate between different model formulations. Therefore, two photosynthesis process formulations at leaf level are compared in this paper. The first is a biochemically supported approach (BCF), described by Farquhar et al. (1980). The second approach is an empirical light response curve model (LRC) (e.g. Goudriaan, 1982; Boonen et al., 2002; Larcher, 2003). The FORUG model includes the two mentioned approaches. FORUG is a mechanistic vegetation model to simulate CO_2 and water vapour exchange between forest ecosystems and the atmosphere (Samson, 2001; Boonen et al., 2002; Verbeeck et al., 2006). We are not aware of models comparing the mentioned photosynthesis approaches at (forest) ecosystem level, and particularly not for several (consecutive) growing seasons.

The main objectives of this paper are: (1) to make a multi-year comparison (1996–2000) between measured and predicted GPP by the FORUG model for two photosynthesis approaches (BCF and LRC) for a beech forest in France (Hesse) and (2) to analyse the discrepancies between modelled and measured GPP in order to find explanations for the seasonal and interannual variability of GPP.

2. Materials and methods

2.1. *The FORUG model*

FORUG is a multi-layer process-based model that simulates CO_2 and H_2O exchange between vegetation stands and atmosphere (Samson, 2001; Boonen et al., 2002; Verbeeck et al., 2006). Main model outputs are NEE, TER, GPP and evapotranspiration. A conceptual diagram of the FORUG model is given in Fig. 1.

Integration of leaf fluxes to canopy scale requires the computation of controlling environmental variables as they vary with depth through the canopy and differ on sunlit and shaded leaf fraction (Baldocchi and Harley, 1995). Therefore, one understory and three upperstory canopy layers are considered. A radiation module calculates the available direct and diffuse photosynthetic active radiation (PAR) in each vegetation layer (Spitters, 1986; Spitters et al., 1986). To model the nonlinear response of photosynthesis to intercepted PAR,