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Modeling and uncertainty analysis of carbon and water fluxes in a broad-leaved Korean pine mixed forest based on model-data fusion

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Process-based ecosystem models are increasingly used to estimate the carbon and water exchanges between ecosystems and the atmosphere. These models inevitably suffer from deficiencies and uncertainties, which should be thoroughly examined to better understand the processes governing the ecosystem dynamics. In this paper, we systematically explored the uncertainties in model predictions of Changbaishan (CBS) broad-leaved Korean pine mixed forest using the SImplified PhotosyNthesis and Evapo-Transpiration (SIPNET) model and eddy flux and meteorological data from 2004 to 2009. We first screened out 21 key parameters from 42 model parameters using Morris global sensitivity analysis method, and then estimated their probability distributions through Markov Chain Monte Carlo technique. Two optimization set-ups, i.e. using observed net ecosystem exchange of CO_2 (NEE) only and using observed NEE and evapotranspiration (ET) simultaneously, were conducted to detect the different constraints of different observations on model parameters. Four parameters were well constrained using observed NEE only, including photosynthesis and respiration related parameters. While seven parameters were well constrained using measured NEE and ET simultaneously, four of which were water related parameters. Obviously, more information can be derived from the simultaneous optimization, since there was additional process information in water flux observation. The modeled ET of the NEE and ET optimization set-up had a much better fit to measured values than the NEE only optimization set-up (R2=0.70 vs. R2=0.30), although the modeled NEE from the two set-ups had a good fit to the observations (R2=0.85 vs. R2=0.83). This implied that assimilating carbon and water fluxes simultaneously can improve the parameterization and overall performance of the model. Then, we quantified the uncertainties in model predictions using Monte Carlo simulation, and trace them to specific parameter and parameter interactions through Sobol' variance decomposition method. The uncertainties of five outputs of interest in CBS site, NEE, gross primary productivity (GPP), ecosystem respiration (RE), ET and transpiration (T), were 50.82%, 22.35%, 21.25%, 9.98% and 19.54%, respectively. The uncertainty in predicted NEE was much larger since NEE is a small difference between two large fluxes, i.e. GPP and RE. The maximum net CO_2 assimilation rate (Amax) and carbon content of leaves (SLW) were classified as highly sensitive parameters for all outputs of interest in CBS site, contributing more than 70% of the uncertainties in all outputs except NEE. The importance of these two parameters holds for one subtropical evergreen coniferous plantation and one subtropical evergreen broad-leaved forest, too. Therefore, these two parameters and their underlying processes should be a focus of future model research, plant trait data collection and field measurement, at least for the sites in this study. This can help connect the model simulation research and field data collection, making them mutually informative.