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Constraining terrestrial carbon fluxes and uncertainties in ecological forecasting through model-data fusion

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Our ability to model terrestrial carbon fluxes, and forecast how those fluxes will respond to a changing climate, is not complete without a clear quantification of uncertainties in model predictions. Uncertainties can stem from either uncertain parameter values, or model structural error. As we move into a data rich era in ecology, more researchers are moving towards model-data fusion as a means to address this issue. Model-data fusion is a powerful framework by which to account for both parameter and model structural uncertainties through combining models with multiple data streams (including observations at different spatial or temporal scales). Its strength lies in the ability to propagate both model and measurement error throughout the analysis, thus giving an integrated view of our confidence with regard to modelled processes and states

Here we present results from a model-data fusion study using 17 years of flux data from the Harvard Forest in the north-eastern United States. We combine a forest carbon cycle model of intermediate complexity with 7 different data streams through markov-chain monte carlo. We developed novel techniques that account for systematic biases in ecological observations, and allow for the exploration of an infinite parameter space. Our multiple constraints approach constrained 25 of the 38 model parameters, with modelled uncertainty falling well within the error range of each data stream. The optimized model and the related uncertainties were then used to assess the potential for model-data fusion to quantify uncertainty in ecological forecasting, in particular under potential climate change scenarios. Our results show extreme sensitivity of the long term forest carbon cycle model predictions to initial conditions. Uncertainties in simulated fluxes and stocks were relatively stable until around 2050. After 2050, however, model states and fluxes became effectively unpredictable. This casts a shadow of doubt over the ability of current terrestrial carbon cycle models to make long term predictions, and highlights further data needs to better constrain current models.