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A practical method to assess model sensitivity and parameter uncertainty in C cycle models

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The carbon cycle combines multiple spatial and temporal scales, from minutes to hours for the chemical processes occurring in plant cells to several hundred of years for the exchange between the atmosphere and the deep ocean and finally to millennia for the formation of fossil fuels. Together with our knowledge of the transformation processes involved in the carbon cycle, many Earth Observation systems are now available to help improving models and predictions using inverse modelling techniques. A generic inverse problem consists in finding a n-dimensional state vector x such that

$$h(x) = y,$$

for a given N-dimensional observation vector y, including random noise, and a given model h. The problem is well posed if the three following conditions hold: 1) there exists a solution, 2) the solution is unique and 3) the solution depends continuously on the input data. If at least one of these conditions is violated the problem is said ill-posed. The inverse problem is often ill-posed, a regularization method is required to replace the original problem with a well posed problem and then a solution strategy amounts to 1) constructing a solution x, 2) assessing the validity of the solution, 3) characterizing its uncertainty.

The data assimilation linked ecosystem carbon (DALEC) model is a simple box model simulating the carbon budget allocation for terrestrial ecosystems. Intercomparison experiments have demonstrated the relative merit of various inverse modelling strategies (MCMC, ENKF) to estimate model parameters and initial carbon stocks for DALEC using eddy covariance measurements of net ecosystem exchange of CO_2 and leaf area index observations. Most results agreed on the fact that parameters and initial stocks directly related to fast processes were best estimated with narrow confidence intervals, whereas those related to slow processes were poorly estimated with very large uncertainties. While other studies have tried to overcome this difficulty by adding complementary data streams or by considering longer observation windows no systematic analysis has been carried out so far to explain the large differences among results.

We consider adjoint based methods to investigate inverse problems using DALEC and various data streams. Using resolution matrices we study the nature of the inverse problems (solution existence, uniqueness and stability) and show how standard regularization techniques affect resolution and stability properties. Instead of using standard prior information as a penalty term in the cost function to regularize the problems we constraint the parameter space using ecological balance conditions and inequality constraints. The efficiency and rapidity of this approach allows us to compute ensembles of solutions to the inverse problems from which we can establish the robustness of the variational method and obtain non Gaussian posterior distributions for the model parameters and initial carbon stocks.