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Algorithms for greenhouse gas flux inversions: pros and cons

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One method of estimating the flux of carbon into the atmosphere is through the use of inverse modelling combined with atmospheric measurements. With few observations and frequently few flux regions (for a well-posed problem), the standard method of Bayesian Synthesis inversion works well. However, it becomes prohibitively expensive when the number of unknown fluxes becomes large, as occurs when higher resolution flux estimates are needed. With the increasing availability of satellite observations (eg. from GOSAT, TES, AIRS, IASI, OCO-2), high spatial resolution is not only possible but necessary for geopolitical commitments to carbon monitoring and verification. Other algorithms which address the computational concerns include 4D-variational assimilation and Kalman smoothing and augmented state Kalman filtering and smoothing. In this work, we consider the pros and cons of each algorithm, illustrating results with the simplest possible model: a 1D passive tracer. We demonstrate the sensitivity of inversion to the initial CO2 state and argue that it is important to account for uncertainty in the initial condition. This is done in some 4D-Var algorithms and the Kalman Filter and Smoother, but not usually in Bayesian synthesis inversions. We note that quality of the inversion varies during the assimilation window with Bayesian results being less reliable at the end, Kalman filter results being poor at the beginning and 4D-Var results being best in the middle. Bayesian and 4D-var schemes handle poor temporal observation frequency better than the Kalman filter, but the latter is more effective with sparsely distributed observations. The presence of model error bias is problematic for all methods. Moreover, with multiple flux amplitudes, the results of repeated inversions for single fluxes are additive but this property is destroyed with a displacement error of just 1 source region. By comparing the properties and assumptions of the various algorithms we hope to identify avenues for improving flux estimates and their uncertainties.