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Global CO_2 flux inversions from remote-sensing data with systematic errors using hierarchical statistical models

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The Orbiting Carbon Observatory-2 (OCO-2) satellite was launched on 2 July 2014, and it has been a source of atmospheric CO_2 data since September 2014. The OCO-2 dataset contains a number of variables, but the one of most interest for flux inversion has been the column-averaged dry-air mole fraction (in units of ppm). These global level-2 data offer the possibility of inferring CO_2 fluxes at Earth's surface and tracking those fluxes over time. However, as well as having a component of random error, the OCO-2 data have a component of systematic error that is dependent on the instrument's mode, namely land nadir, land glint, and ocean glint. Our statistical approach to CO_2-flux inversion starts with constructing a statistical model for the random and systematic errors with parameters that can be estimated from the OCO-2 data and possibly in situ sources from flasks, towers, and the Total Column Carbon Observing Network (TCCON). Dimension reduction of the flux field is achieved through the use of physical basis functions, while temporal evolution of the flux is captured by modelling the basis-function coefficients as a vector autoregressive process. For computational efficiency, flux inversion uses only three months of sensitivities of mole fraction to changes in flux, computed using MOZART; any residual variation is captured through the modelling of a stochastic process that varies smoothly as a function of latitude. The second stage of our statistical approach is to simulate from the posterior distribution of the basis-function coefficients and all unknown parameters given the data using a fully Bayesian Markov chain Monte Carlo (MCMC) algorithm. Estimates and posterior variances of the flux field can then be obtained straightforwardly from this distribution. Our statistical approach is different than others, as it simultaneously makes inference (and quantifies uncertainty) on both the error components' parameters and the CO_2 fluxes. We compare it to more classical approaches through an Observing System Simulation Experiment (OSSE) on a global scale. By changing the size of the random and systematic errors in the OSSE, we can determine the corresponding spatial and temporal resolutions at which useful flux signals could be detected from the OCO-2 data.