Estimation of Surface Fluxes with an Advanced Data Assimilation Methodology: Carbon, Heat and Moisture

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A simultaneous data assimilation of surface CO_2 fluxes and atmospheric CO_2 concentrations along with meteorological variables has been performed using the Local Ensemble Transform Kalman Filter (LETKF, Hunt et al., 2007) within an Observing System Simulation Experiments (OSSEs) framework. Surface CO_2 fluxes are not observed, but estimated as "parameters", augmenting the state vector of atmospheric CO_2 concentrations with the surface fluxes, and using the ensemble Kalman filter to estimate the multivariate error covariance. In our carbon cycle data assimilation system, we need a sophisticated method to represent reasonable background uncertainties among the state variables. When two variables in the multivariate error covariance matrix are not physically correlated, their error covariance is still estimated by the ensemble and, therefore, it is dominated by sampling errors. We introduce a "localization of variables" method, zeroing out such covariances between unrelated variables to the problem of assimilating carbon dioxide concentrations into a dynamical model. A range of covariance structures are explored for the LETKF, with emphasis on configurations allowing nonzero error covariance between carbon variables and the wind field, which affects transport of atmospheric CO_2, but not between CO_2 and the other meteorological variables. Such variable localization scheme zeroes out the background error covariance among prognostic variables that are not physically related, thus reducing sampling errors. Results from the identical twin experiments show that the performance in the estimation of surface carbon fluxes obtained using variable localization method is much better than that using a standard full covariance approach (Kang et al., 2011).

We also focus on the impact of advanced inflation methods and vertical localization of column CO_2 data on the analysis of CO_2 variables. With both additive inflation and adaptive multiplicative inflation, we are able to obtain encouraging multiseasonal analyses of surface CO_2 fluxes in addition to atmospheric CO_2 and meteorological analyses. By contrast, the analysis performed with a standard fixed multiplicative inflation results in a poor estimation of surface CO_2 fluxes which become "stuck" in time. In addition, we examine strategies for vertical localization in the assimilation of simulated CO_2 from GOSAT (or OCO-2) that have nearly uniform sensitivity from the surface to the upper troposphere. Since atmospheric CO_2 is forced by surface fluxes, its short-term variability should be largest near the surface layer. We take advantage of this by updating only the lower tropospheric CO_2, rather than the full column. This results in a more accurate analysis of CO_2 in terms of both RMS error and spatial patterns. We conclude that it is an effective strategy to emphasize the levels of a major variability within the column, the lower layers in this case, when we use the column observations whose sensitivity (averaging kernel) is fairly uniform in the vertical. Assimilating simulated CO_2 ground-based observations and CO_2 retrievals from GOSAT and AIRS with the enhanced LETKF, we obtain a rather accurate estimation of the evolving surface fluxes even in the absence

of any a priori information. We have also successfully tested this methodology for estimating surface fluxes of heat and moisture using simulated AIRS retrievals.

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