Quantification of Transport Error Using a Coupled Meteorological and Constituent Transport Model Within an Ensemble Kalman Filter (EnKF)

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The uncertainty in the forecast estimate of a constituent is due to a combination of errors arising from uncertainties in wind fields, prescribed surface fluxes, and initial states of the constituent. The errors in wind fields are due to errors in initial states of winds and model formulation errors. Here we use the Environment and Climate Change Canada's (ECCC) weather forecast model adapted for GHG simulation (Polavarapu et al. 2016, ACP) to generate an ensemble of 64 forecasts of carbon monoxide (CO). Meteorological observations are assimilated every six hours. Over a period of a month, the various sources of errors are simulated in the ensemble. Flux errors use a spatial correlation length of 2000 km. The model formulation errors are simulated by every ensemble member using a different combination of parameterization (e.g. convective transport, boundary layer parameterizations, etc.). The initial state errors in CO are parameterized using a sample of 24-h differences in CO fields. Figure 1 shows that after 30 days of cycling, errors in CO are due in equal parts to those in fluxes, meteorology, and model formulation.

While it is difficult to account for all components of transport error in the context of a standard flux inversion, with a coupled state and flux estimation system within an Ensemble Kalman Filter (EnKF), this becomes feasible. Thus, ECCC's operational EnKF was extended for the estimation of CO_2, CH_4 and CO and their fluxes. This system is called the EC-CAS. Testing of this system was begun with CO state estimation. With simulated observations, the behaviour of the system was explored using a variety of observation networks [hypothetically dense, *in situ*, and Measurement of Pollution in the Troposphere (MOPITT)]. Figure 2 shows the benefit of assimilating MOPITT observations. The error reduction (benefit) due to the assimilation of MOPITT CO data is proportional to the root mean square error (RMSE) of CO when no data are assimilated. Thus, the benefit is greatest where flux errors are largest (central Africa and east Asia) and ranges from 5 to 40 ppb. Having demonstrated that the system is working, the next stage is to assess the ability to retrieve fluxes. The goal of this system is to provide estimates of GHGs and their fluxes along with their uncertainties on seasonal to annual timescales.

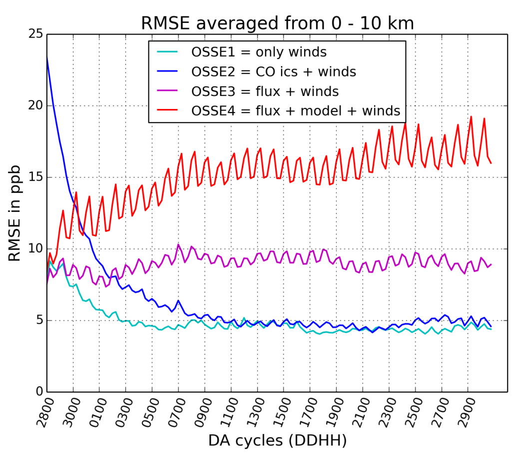

Figure 1. The RMSE is the difference between the ensemble mean and the truth in the model space. The cyan curve gives the lowest RMSE. This experiment uses only perturbed initial condition of winds. The blue curve uses perturbed CO initial conditions and perturbed winds. On a time scale of about 12 days the RMSE is similar to perturbing winds only. The red and magenta curves are for experiments using the perturbed flux field. The red curve additionally simulates model error.

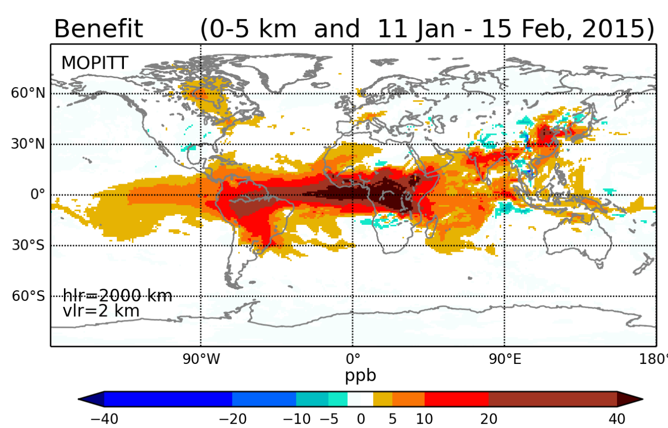

Figure 2. The benefit is the difference between the column averaged RMSE of the control and data assimilation (DA) experiment. The control experiment assimilates only meteorological observations (radiosonde, aircraft, surface, scatterometer and GPS radio occultation). The DA experiment assimilates both meteorological and MOPITT observations.