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A global inverse model for estimating surface CO_2 fluxes at a 0.1x0.1 degree resolution

Shamil Maksyutov (1), Tomohiro Oda (2), Rajesh Janardanan (1), Alexey Yaremchuk (3), Johannes W. Kaiser (4), Akihiko Ito (1), Dmitry Belikov (1,5), Ruslan Zhuravlev (6), Alexander Ganshin (6), and Vinu Valsala (7)

(1) CGER, NIES, Tsukuba, Japan (shamil@nies.go.jp), (2) USRA/GSFC, Greenbelt, MD, USA, (3) Acoustics Inst., Moscow, Russia, (4) MPI for Chemistry, Mainz, Germany, (5) NIPR, Tokyo, Japan, (6) CAO, Dolgoprudny, Russia, (7) IITM, Pune, India

We propose an iterative inversion method for estimating surface CO_2 fluxes at a high spatial resolution (0.1 degree) using atmospheric CO_2 data collected by the global in-situ network and GOSAT. The Lagrangian particle dispersion model FLEXPART was coupled to the Eulerian atmospheric tracer transport model (NIES-TM) and an adjoint of the coupled model was derived. The inverse model calculates weekly corrections to given prior fluxes at a spatial resolution of the surface flux footprints simulated by FLEXPART model (0.1 degrees). Prior fluxes are given at different spatial resolutions in low and high resolution mode implementations. The hourly terrestrial biosphere fluxes are simulated with VISIT model using CFSR reanalysis. Ocean fluxes are calculated using a 4D-Var assimilation system of the surface pCO_2 observations. Fossil fuel (ODIAC) and biomass burning (GFASv1.1) emissions are given at original model resolutions (0.1 degree), while terrestrial biosphere and ocean fluxes are interpolated from a coarser resolution. Flux response functions (footprints) for observations are first simulated with FLEXPART. The precalculated flux response functions are then used in forward and adjoint runs of the coupled transport model. We apply Lanczos process to obtain the truncated singular value decomposition (SVD) of the scaled tracer transport operator $A = R^{-1/2}HB^{1/2}$, where H - tracer transport operator, R and B - error covariance matrices for observations and fluxes, respectively. The square root of covariance matrix B is constructed by directional splitting in latitude, longitude and time, with exponential decay scales of 500 km on land, 1000 km over oceans and 2 weeks in time. Once singular vectors of AA^T are obtained, the prior and posterior flux uncertainties are evaluated. Numerical experiments of inverting surface CO_2 fluxes showed that the high-resolution (Lagrangian) part of the flux responses dominates the solution so that spatial patterns from the coarser resolution NIES TM (10x10 degree) are not visible in flux singular vectors and the optimized fluxes. The weekly flux uncertainties at a resolution of 0.1 degree and flux uncertainty reduction due to assimilating single shot GOSAT XCO_2 data were estimated for a period of one year in 2010. We demonstrated that our application of a coupled tracer transport model in adjoint-based assimilation provides an efficient way to increase spatial resolution of the inverse model.