Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

ACG09-31 会場:301B 時間:5 月 28 日 15:45-16:00

On the optimal design for a global high-resolution surface CO_2 flux inversion model

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We devised an iterative inversion framework that is optimally designed for estimating surface CO_2 fluxes at a high spatial resolution using a Lagrangian-Eulerian coupled tracer transport model and atmospheric CO_2 data collected by the global reference in-situ network and satellite observations. In our inverse system, 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. Weekly corrections to given prior fluxes are calculated at a spatial resolution of the meteorology driver of FLEXPART (0.1 degrees) via iterative optimization. The hourly terrestrial biosphere fluxes are simulated with the VISIT model using the CFSR reanalysis. Ocean fluxes are calculated using a 4D-Var assimilation system based on the surface pCO_2 observations. Fossil fuel (ODIAC) and biomass burning (GFAS v1.1) 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 used in forward and adjoint runs of the coupled transport model. We apply Lanczos process to obtain truncated singular value decomposition of the scaled tracer transport operator. The square root of covariance matrix for surface fluxes is constructed by implementing two algorithms. The first algorithm uses a lookup table to store precalculated covariance matrix elements implemented as Gaussian function of a great circle distance between grid points. This algorithm appears to produce highly accurate results but it is becoming computationally expensive when implemented at a high spatial resolution. The second (faster) algorithm, which is based on an implicit diffusion operator with a directional splitting in latitude, longitude and time, was also tested. The covariance operator of the second algorithm approximates Matear function rather than Gaussian, the analysis of its singular value spectra and the singular vectors however shows that the resulting covariance matrix has very similar properties to Gaussian covariance matrix. In our method, the prior and posterior flux uncertainties are evaluated using singular vectors of scaled tracer transport operator. The weekly flux uncertainties at a resolution of 0.1 degree and flux uncertainty reduction due to assimilating single shot GOSAT X_{CO2} data were estimated for a period of one year. We demonstrated that our application of a coupled tracer transport model in adjoint-based assimilation system provides an efficient way to increase spatial resolution of the inverse model.

キーワード: remote sensing, carbon dioxide, data assimilation, inverse modeling
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