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Development of CO_2 inversion system based on the adjoint of the global coupled transport model

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We present the development of an inverse modeling system employing an adjoint of the global coupled transport model consisting of the National Institute for Environmental Studies (NIES) Eulerian transport model (TM) and the Lagrangian plume diffusion model (LPDM) FLEXPART.
NIES TM is a three-dimensional atmospheric transport model, which solves the continuity equation for a number of atmospheric tracers on a grid spanning the entire globe. Spatial discretization is based on a reduced latitude-longitude grid and a hybrid sigma-isentropic coordinate in the vertical. NIES TM uses a horizontal resolution of $2.5^\circ \times 2.5^\circ$. However, to resolve synoptic-scale tracer distributions and to have the ability to optimize fluxes at resolutions of 0.5° and higher we coupled NIES TM with the Lagrangian model FLEXPART. The Lagrangian component of the forward and adjoint models uses precalculated responses of the observed concentration to the surface fluxes and 3-D concentrations field simulated with the FLEXPART model. NIES TM and FLEXPART are driven by JRA-25/JCDAS reanalysis dataset.
Construction of the adjoint of the Lagrangian part is less complicated, as LPDMs calculate the sensitivity of measurements to the surrounding emissions field by tracking a large number of "particles" backwards in time.
Developing of the adjoint to Eulerian part was performed with automatic differentiation tool the Transformation of Algorithms in Fortran (TAF) software (http://www.FastOpt.com). This method leads to the discrete adjoint of NIES TM. The main advantage of the discrete adjoint is that the resulting gradients of the numerical cost function are exact, even for nonlinear algorithms.
The overall advantages of our method are that:
1. No code modification of Lagrangian model is required, making it applicable to combination of global NIES TM and any Lagrangian model;
2. Once run, the Lagrangian output can be applied to any chemically neutral gas;
3. High-resolution results can be obtained over limited regions close to the monitoring sites (using the LPDM part), and at coarse resolution for the rest of the globe (using the Eulerian part), minimizing aggregation errors and computation cost.
The adjoint of the coupled high-resolution Eulerian-Lagrangian model will be incorporated into the PYVAR CO_2 variational inverse system (Chevallier et al., 2005).

Chevallier, F., Fisher, M., Peylin, P., Serrar, S., Bousquet, P., Bréon, F.-M., Chédin, A., and Ciais, P.: Inferring CO_2 sources and sinks from satellite observations: method and application to TOVS data, J. Geophys. Res., 110, D24309, doi:10.1029/2005JD006390, 2005.