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Adjoint of the coupled Eulerian-Lagrangian 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. 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. 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 required significant manual code modification owing to the structure and complexity of the NIES model.

The overall advantages of our method are follows:

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 results are verified using a series of test experiments. These tests demonstrate the high accuracy of the NIES-FLEXPART adjoint when compared with direct forward sensitivity calculations. Adjoint of coupled NIES-FLEXPART model therefore combines the flux conservation and stability of an Eulerian finite difference of adjoint formulation with the flexibility, accuracy and high-resolution of a Lagrangian backward trajectory formulation.

The accuracy of the adjoint model is extensively verified by comparing adjoint to finite difference sensitivities. We show acceptable tolerance of agreement obtained. The potential for inverse modeling using the adjoint of NIES- FLEXPART coupled model is assessed in a data assimilation framework using simulated observations, demonstrating the feasibility of exploiting CO_2 measurements for optimizing CO_2 emission inventories.

Keywords: carbon cycle, atmospheric transport, adjoint model, inverse modeling