Inferring atmospheric dynamics from tracer observations in 4D-Var: flow-dependent aspects

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In the operational NWP, the assimilation of ozone causes large wind and temperature analysis increments in the stratosphere to accommodate for the differences between background and observations. In such cases, unless the ozone feedback on dynamics is switched off, the strong-constraint 4D-Var internal dynamics without comprehensive bias correction makes spurious flow adjustments, especially in the regions with larger gradients in the tracer background field, and when there are insufficient constraints such as large background flow uncertainties and a lack of observations of dynamic variables. The wind-tracer feedback is also turned off for the aerosols and the trace gases. Thus, their useful information on the wind advection is not accounted for anywhere in the domain at any time instance. In this way, the tracer analysis quality is also deteriorated. Somewhat smarter, selective use of tracer information would be beneficial to alleviate unphysical analysis increments in certain regions and at the same time to retain the benefits of wind extraction in other areas.

Thus, we formulate the method for flow-dependent 4D-Var wind extraction, which switches the wind-tracer feedback on or off in the tracers’ tangent-linear model and wind adjoint model. The objective criterion for the selection is deduced from the ensemble of simulations and is based on the ratio of the tracer physical forcings' uncertainty and the mean tracer advection rate. The numerical tests with an intermediate-complexity incremental 4D-Var system MADDAM show promising results for both wind and tracer analyses. We also demonstrate that the aerosols have theoretically an even larger potential as the carriers of the advection information than humidity due to larger relative spatial gradients, which are crucial for successful wind extraction. The flow-dependent wind extraction method is compared with the weak-constraint 4D-Var, where the tracer model error obtained from the ensemble implicitly controls the amount of wind-tracer coupling.