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Comparison of the tangent linear properties of tracer transport schemes applied to geophysical problems

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Data assimilation is one of the most common inverse problems encountered in geophysical models. One of the leading techniques used for data assimilation in numerical weather prediction is four dimensional variational data assimilation (4DVAR). In 4DVAR the tangent linear and adjoint versions of the nonlinear model are used to perform a minimization with time dependent observations. In order for the minimization to perform well requires a certain degree of linearity in both the underlying equations and numerical methods used to solve them.

Advection is central to the underlying equations used for numerical weather prediction, as well as many other geophysical models. From the advection of momentum, temperature and moisture to passive tracers such as smoke from wildfires, accurate transport is paramount. Over recent decades much effort has been directed toward the development of positive definite, non-oscillatory, mass conserving advection schemes. These schemes are capable of giving excellent representation of transport, but by definition introduce nonlinearity into equations that are otherwise quite linear. One such example is the flux limited piecewise parabolic method (PPM) used in NASA's Goddard Earth Observing System version 5 (GEOS-5), which can perform very poorly when linearized.

With a view to an optimal representation of transport in the linear versions of atmospheric models and 4DVAR we analyse the performance of a number of different linear and nonlinear advection schemes. The schemes are analysed using a one dimensional case study, a passive tracer in GEOS-5 experiment and using the full linearized version of GEOS-5. Using the three studies it is shown that higher order linear schemes provide the best representation of the transport of perturbations and sensitivities. In certain situations the nonlinear schemes give the best performance but are subject to issues. It is also shown that many of the desirable properties of the nonlinear schemes are redundant or lost when considered in the context of linearisation.