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MPDATA: Third-order accuracy for variable flows

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We extend the structured-grid multidimensional positive definite advection transport algorithm (MPDATA) [1] to third-order accuracy for temporally and spatially varying flows. This is accomplished by identifying the leading truncation error of the standard second-order MPDATA, performing the Cauchy-Kowalevski procedure to express it in a spatial form and compensating its discrete representation—much in the same way as the standard MPDATA corrects the first-order accurate upwind scheme. The procedure of deriving the spatial form of the truncation error was automated using a computer algebra system, enabling various options in MPDATA to be included straightforwardly in the third-order scheme. Following the spirit of MPDATA, the error is compensated using the upwind scheme resulting in a sign-preserving algorithm, and the entire scheme can be formulated using only two upwind passes. Established MPDATA enhancements, such as formulation in generalised curvilinear coordinates, the nonoscillatory option or the infinite-gauge variant, carry over to the fully third-order accurate scheme.

Global tracer-transport benchmarks demonstrate benefits for chemistry-transport models fundamental to air quality monitoring, forecasting and control. A series of explicitly-inviscid implicit large-eddy simulations of a convective boundary layer [2] and explicitly-viscid simulations of a double shear layer [3] illustrate advantages of the fully third-order-accurate MPDATA for fluid dynamics applications.

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