FVM: A nonhydrostatic finite-volume dynamical core for the IFS

Christian Kühnlein and Piotr K. Smolarkiewicz
European Centre for Medium-Range Weather Forecasts, Reading, UK

We present a nonhydrostatic finite-volume global atmospheric model formulation for numerical weather prediction with the Integrated Forecasting System (IFS) at ECMWF, and compare it to the established operational spectral-transform formulation. The novel Finite-Volume Module of the IFS (henceforth IFS-FVM) integrates the fully compressible equations using semi-implicit time stepping and non-oscillatory forward-in-time (NFT) Eulerian advection, whereas the spectral-transform IFS solves the hydrostatic primitive equations (optionally the fully compressible equations) using a semi-implicit semi-Lagrangian scheme. The IFS-FVM complements the spectral-transform counterpart by means of the finite-volume discretisation with a local low-volume communication footprint, fully conservative and monotone advective transport, all-scale deep-atmosphere fully compressible equations cast in a generalised height-based vertical coordinate and flexible horizontal meshing. Nevertheless, both the finite-volume and spectral-transform formulations can share the same quasi-uniform horizontal grid with co-located arrangement of variables, geospherical longitude-latitude coordinates, and physics parametrisations, thereby facilitating their comparison, coexistence and combination in the IFS.

Following Kühnlein et al. 2018, we highlight the advanced semi-implicit NFT finite-volume integration of the fully compressible equations in IFS-FVM considering comprehensive moist-precipitating dynamics with coupling to the IFS cloud parametrisation by means of a generic interface. These developments, which also include a new horizontal-vertical split NFT MPDATA advective transport scheme, variable time stepping, effective preconditioning of the elliptic Helmholtz solver in the semi-implicit scheme, and a revised computationally-efficient node-based implementation of the median-dual finite-volume approach, provide a basis for the efficacy of IFS-FVM and its application in global numerical weather prediction. Here, numerical experiments focus on relevant dry and moist-precipitating baroclinic instability at various resolutions. We show that the presented semi-implicit NFT finite-volume integration scheme on co-located meshes of IFS-FVM can provide highly competitive solution quality and computational performance to the proven semi-implicit semi-Lagrangian integration scheme of the spectral-transform IFS.

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