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A framework for testing global nonhydrostatic models

N.P. Wedi (1), P.K. Smolarkiewicz (2)

(1) European Centre for Medium Range Weather Forecasts (ECMWF), Reading, UK (wedi@ecmwf.int), (2) National Center for Atmospheric Research, Boulder, Colorado, US

Historically, global-scale hydrostatic numerical weather prediction (NWP) models have been build up starting from a suitable set of shallow water equations on the sphere. However, more recently another approach is taken, where small- to mesoscale nonhydrostatic models — more typically applied in cloud resolving studies — are extended to the rotating sphere. In both cases the problem arises how to efficiently examine the robustness of the dynamical core for future global nonhydrostatic applications. We exploit a testing strategy — guided by the scale analysis of the governing equations — where the planetary radius is suitably reduced to capture nonhydrostatic phenomena without incurring the computational cost of actual simulations of weather and climate at nonhydrostatic resolution. The procedure is simple and allows to test various aspects of the discretised hydrostatic and nonhydrostatic equations in the same setting on the sphere and facilitates verification against analytic solutions and against LES benchmarks. We compare these solutions with the numerical results of two models with a distinctively different development path: the nonhydrostatic version of ECMWF's global-scale forecast model, and the multi-scale anelastic model EULAG. We illustrate the proposed framework with examples of inertia-gravity wave dynamics in linear and nonlinear regimes, including flows past idealised mountains, stratified shear flows, and critical layers. Furthermore, we test the thermodynamics with a rising-cumulus benchmark calculation and sea-breeze simulations. Finally, we investigate the dynamics of convective boundary layers on the sphere. This assesses the ability to adequately capture interactions of large-scale dynamics with locally turbulent structures, an important aspect of future weather and climate predictions.