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Advances in the U.S. Navy Non-hydrostatic Unified Model of the Atmosphere (NUMA): LES as a Stabilization Methodology for High-Order Spectral Elements in the Simulation of Deep Convection

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The prediction of extreme weather sufficiently ahead of its occurrence impacts society as a whole and coastal communities specifically (e.g. Hurricane Sandy that impacted the eastern seaboard of the U.S. in the fall of 2012). With the final goal of solving hurricanes at very high resolution and numerical accuracy, we have been developing the Non-hydrostatic Unified Model of the Atmosphere (NUMA) to solve the Euler and Navier-Stokes equations by arbitrary high-order element-based Galerkin methods on massively parallel computers. NUMA is a unified model with respect to the following criteria: (a) it is based on unified numerics in that element-based Galerkin methods allow the user to choose between continuous (spectral elements, CG) or discontinuous Galerkin (DG) methods and from a large spectrum of time integrators, (b) it is unified across scales in that it can solve flow in limited-area mode (flow in a box) or in global mode (flow on the sphere). NUMA is the dynamical core that powers the U.S. Naval Research Laboratory's next-generation global weather prediction system NEPTUNE (Navy's Environmental Prediction sysTem Utilizing the NUMA corE). Because the solution of the Euler equations by high order methods is prone to instabilities that must be damped in some way, we approach the problem of stabilization via an adaptive Large Eddy Simulation (LES) scheme meant to treat such instabilities by modeling the sub-grid scale features of the flow. The novelty of our effort lies in the extension to high order spectral elements for low Mach number stratified flows of a method that was originally designed for low order, adaptive finite elements in the high Mach number regime [1]. The Euler equations are regularized by means of a dynamically adaptive stress tensor that is proportional to the residual of the unperturbed equations. Its effect is close to none where the solution is sufficiently smooth, whereas it increases elsewhere, with a direct contribution to the stabilization of the otherwise oscillatory solution. As a first step toward the Large Eddy Simulation of a hurricane, we verify the model via a high-order and high resolution idealized simulation of deep convection on the sphere.

References

[1] M. Nazarov and J. Hoffman (2013) *Residual-based artificial viscosity for simulation of turbulent compressible flow using adaptive finite element methods* Int. J. Numer. Methods Fluids, 71:339-357