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A Massive Parallel Variational Multiscale FEM Scheme Applied to Nonhydrostatic Atmospheric Dynamics

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The solution of the fully compressible Euler equations of stratified flows is approached from the point of view of Computational Fluid Dynamics techniques. Specifically, the main aim of this contribution is the introduction of a Variational Multiscale Finite Element (CVMS-FE) approach to solve dry atmospheric dynamics effectively on massive parallel architectures with more than 1000 processors. The conservation form of the equations of motion is discretized in all directions with a Galerkin scheme with stabilization given by the compressible counterpart of the variational multiscale technique of Hughes [1] and Houzeaux et al. [2]. The justification of this effort is twofold: the search of optimal parallelization characteristics and linear scalability trends on petascale machines is one. The development of a numerical algorithm whose local nature helps maintaining minimal the communication among the processors implies, in fact, a large leap towards efficient parallel computing. Second, the rising trend to global models and models of higher spatial resolution naturally suggests the use of adaptive grids to only resolve zones of larger gradients while keeping the computational mesh properly coarse elsewhere (thus keeping the computational cost low). With these two hypotheses in mind, the finite element scheme presented here is an open option to the development of the next generation Numerical Weather Prediction (NWP) codes.

This methodology is as new in Computational Fluid Dynamics for compressible flows at low Mach number as it is in Numerical Weather Prediction (NWP). We however mean to show its ability to maintain stability in the solution of thermal, gravity-driven flows in a stratified environment in the specific context of dry atmospheric dynamics. Standard two dimensional benchmarks are implemented and compared against the reference literature. In the context of thermal and gravity-driven flows in a neutral atmosphere, we present: (1) the density current evolution from a smooth initial cold disturbance as in Straka et al. [3]. (2) The warm raising anomaly of initial smooth distribution (i.e. Wicker and Skamarock [4]; Ahmad and Lindeman [5]) run on a structured grid of quadrilaterals first, and on a fully unstructured next; and (3) the interaction of a small cold anomaly falling and a raising warm bubble raising (Robert [6]). Problems in a stably stratified environment are also described and compared with (1) the hydrostatic and non-hydrostatic, linear and non linear mountain wave problems for flows over different sets of topographic features. The definitions and results of Smith [7], Bonaventura [8], Mayr and Gohm [9], and Schär [10] are taken as reference. The parallel performances of the algorithm were tested for the solution of the fully compressible Navier-Stokes equations in a three dimensional boundary layer problem. The scalability in the *strong* sense was measured for runs on 1, 1000, 2000, and 5000 processors, exploiting a combination of message passing interface (MPI) with automatic domain partition, and threads using OpenMP.

Keywords: Numerical Weather Prediction, Computational Fluid Dynamics, Low Mach, Compressible Flows, High Performance Computing

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