# Abstract

In this thesis the finite and spectral element methods (FEM and SEM, respectively) applied to problems in atmospheric simulations are explored through the common thread of Variational Multiscale Stabilization (VMS). This effort is justified by three main reasons. (i) the recognized need for new solvers that can efficiently execute on massively parallel architectures –a spreading framework in most fields of computational physics in which numerical weather prediction (NWP) occupies a prominent position. Element-based methods (e.g. FEM, SEM, discontinuous Galerkin) have important advantages in parallel code development; (ii) the inherent flexibility of these methods with respect to the geometry of the grid makes them a great candidate for dynamically adaptive atmospheric codes; and (iii) the localized diffusion provided by VMS represents an improvement in the accurate solution of multi-physics problems where artificial diffusion may fail. Its application to atmospheric simulations is a novel approach within a field of research that is still open. First, FEM and VMS are described and derived for the solution of stratified low Mach number flows in the context of dry atmospheric dynamics. The validity of the method to simulate stratified flows is assessed using standard two- and three-dimensional benchmarks accepted by NWP practitioners. The problems include thermal and gravity driven simulations. It will be shown that stability is retained in the regimes of interest and a numerical comparison against results from the the literature will be discussed. Second, the ability of VMS to stabilize the FEM solution of advection-dominated problems (i.e. Euler and transport equations) is taken further by the implementation of VMS as a stabilizing tool for high-order spectral elements with advection-diffusion problems. To the author's knowledge, this is an original contribution to the literature of high order spectral elements involved with transport in the atmosphere. The problem of monotonicity-preserving high order methods is addressed by combining VMS-stabilized SEM with a discontinuity capturing technique. This is an alternative to classical filters to treat the Gibbs oscillations that characterize high-order schemes. To conclude, a microphysics scheme is implemented within the finite element Euler solver, as a first step toward realistic atmospheric simulations. Kessler microphysics is used to simulate the formation of warm, precipitating clouds. This last part combines the solution of the Euler equations for stratified flows with the solution of a system of transport equations for three classes of water: water vapor, cloud water, and rain. The method is verified using idealized two- and three-dimensional storm simulations.