Development of a dynamical core for the next-generation atmospheric meso-scale numerical model

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1. Introduction

Since terrain-following vertical coordinate (sigma) system (Phillips 1957; Gal－Chen and Somerville 1975) has been used extensively to accommodate orography in models for atmospheric flows, most of existing community meso-scale atmospheric numerical model in the word are using the terrain-following coordinate as the vertical coordinate. However, a problem that has received attention rather early in the development of sigma system primitive equation models is that of the noncancellation errors in the two terms of the gradient force in the momentum equation (Smagoringsky, et al. 1967). Mesinger and Janjic(1985), among others, have found that errors in computing the horizontal pressure gradient force in models using a sigma coordinate can be substantial in the vicinity of steep topography. To minimize this error, a step-mountain vertical coordinate, the so-called "eta coordinate", is implemented in the National Centers for Environmental prediction (NCEP) Meso Eta Model (Mesinger et al. 1988) in which the topography is represented as discrete steps (step mountain). Recently, representation of topography, i.e., the "shaved cell" approach, and the numerical scheme for the equations of geophysical flows, in which the height is used as vertical coordinate, have been proposed (Adcroft et al. 1997; Marshall et al. 1997; Bonaventura 2000). It is reasonable to expect that a goal of running a regional model at a horizontal resolution of O(100) m may be attainable in the near future, and the topography may then be more accurately represented. In such a situation, it seems natural to search for an alternative that will be better suited to handle the step topography and complex objects on the surface for the high-resolution models currently used as well as future next-generation models expected to run with a finer resolution.

2. Concept of the numerical framework

In this work, Finite Volume Method (FVM) in conjunction with the SIMPLER (Semi-Implicit Method for Pressure-Linked Equation Revised; Patankar 1980) algorithms is used for calculations of the unsteady, three-dimensional, compressible Navier-Stokes equations on a staggered grid. Abandoning the customary terrain-following normalization, the Cartesian coordinate, in which the height is used as the vertical one, is chose. A Cartesian-grid system approach, which consists of the variable regular cells and a special treatment of the boundary cells, is proposed for expression of the arbitrarily complex geometries. Blocking-off Method (Patankar 1980) is then introduced to handle the steep topography and complex objects above the Earth's sea-level surface, thus resulting in a robust and efficient numerical scheme which allows for applications to meso-scale flows over complex orography. The spatial discretization is obtained by a finite volume technique on the staggered grid, and higher-order upwind convection scheme is employed to relate the flux at each control volume face. For the temporal integration of the equation, the fully time implicit scheme is utilized. As the fully implicit temporal discretization is used, the time step can be determined only physical criteria and accuracy considerations.

3. Direct numerical simulation（DNS）on flow over a cube mounted on surface

As a preliminary test, the model has been run on flows over a cube mounted on surface (see Fig.). We found that no spurious flows are generated around the cube, and the simulations show a satisfying result. This inspires our confidence in the present numerical framework. Further work including three-dimensional computations on flow over/around a steep mountain is in progress.

4. Reference

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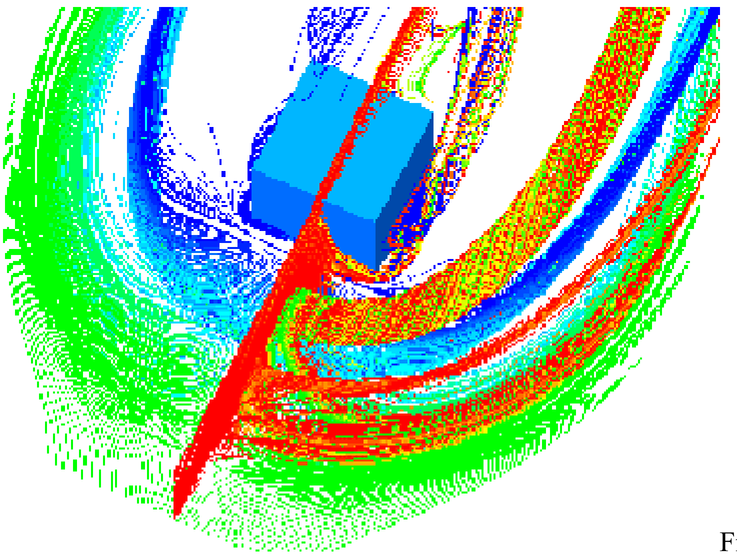

Fig. Flow over a cube mounted on surface (Re=800)