Building a New Atmospheric Model: Testing a Nonhydrostatic Dynamical Core on Unstructured Variable Resolution Hexagonal C-Grids

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Introduction

Recent developments in numerical weather prediction have focused on the use of non-traditional grids to improve simulation accuracy and efficiency. One such development is the use of variable resolution spherical centroidal Voronoi tesselations (SCVTs). These types of grids, however, will require the development of new numerical methods. Additionally, increasing computing resources is allowing for finer resolutions and longer simulations. However, this makes traditional approximations such as the hydrostatic approximation invalid.

This research tests an approach to discretizing the nonhydrostatic equations developed by Klemp et al. (2006) and Ringler et al (2009) in SCVT meshes. The nonhydrostatic equation set is cast in flux form:

$$\partial_t \mathbf{V}_H = -(\nabla \cdot \mathbf{v}\mathbf{V}_H)_\zeta - \frac{\rho_d}{\rho_m}[\nabla_\zeta \tilde{p}' + \partial_\zeta(\zeta_H \tilde{p}')] + F_{V_H}$$

$$\partial_t W = -(\nabla \cdot \mathbf{v}W)_\zeta - \frac{\rho_d}{\rho_m}[\partial_\zeta(\zeta_z \tilde{p}') + g\tilde{\rho}'_m] + F_W$$

$$\partial_t \Theta_m = -(\nabla \cdot \mathbf{v}\Theta_m)_\zeta + F_{\Theta_m}$$

$$\partial_t \tilde{\rho}'_d = -(\nabla \cdot \mathbf{V})_\zeta$$

$$\partial_t Q_j = -(\nabla \cdot \mathbf{v}Q_j)_\zeta + F_{Q_j}$$

This approach conserves mass and other quantities important to weather prediction. The discretization of the nonhydrostatic equations employed by Klemp et al. (2006) is a split-explicit time integration method with a finite volume spatial discretization.

Effects of Diffusion

$$\partial_t \psi = \nu \partial_x^2 \psi$$

$$\psi_k^{n+1} - \psi_k^n = \frac{\nu \Delta t}{\Delta x^2}(\psi_{k+1}^n - 2\psi_k^n + \psi_{k-1}^n)$$

The diffusion equation (top) and its discretization (bottom)

Diffusion is a component of the nonhydrostatic equation. When discretizing the diffusion terms for use on a grid, the apparent diffusion coefficient is dependent on Δx^2 - the square of the distance between cell centers. Therefore, the physical diffusion varies on a variable resolution grid. Results produced scale υ linearly ($\upsilon*[\Delta x]$) and quadratically ($\upsilon*[\Delta x^2]$) with the distance between cell centers.

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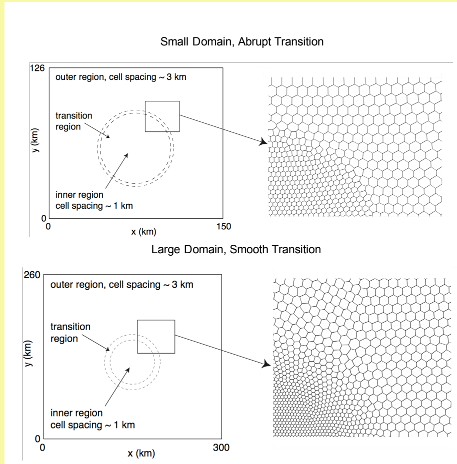
Methods and Test Cases

All test cases were performed on a planar grid. The initial tests were of a squall line performed on a planar, perfect hexagonal grid to test the dynamics of the scheme.

After determining from these initial tests that the core produced realistic results, more robust simulations were performed. Further squall line simulations were run on variable resolution grids:



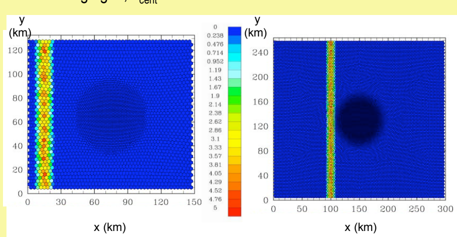
The variable resolution grids used in this research. Note that the transition region on the small grid (top) is much more abrupt than on the large grid (bottom)

To test the behavior of the method over the variable resolution region, the squall line tests were initialized by introducing a warm bubble perturbation.

$$T = \bar{T} + T'(1 + 0.2 \times M)cos(\frac{\pi * r}{2})$$

$$r = \sqrt{(x - x_{cent})/x_r + (z - z_{cent})/z_r}$$

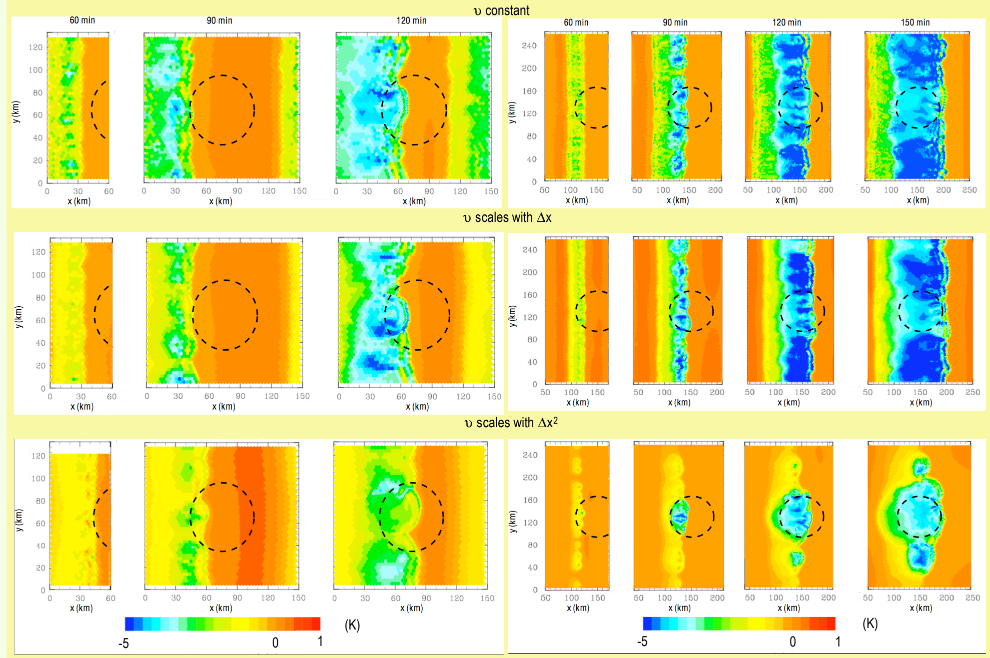
Here, x_r = 10 km, z_r = 1.5 km, z_{cent} = 1.5 km, T_0 is the environmental temperature, T' = 3 K, and M is a random number that varies between -1 and 1. For the small grid, x_{cent} = 15 km, and for the large grid, x_{cent} = 100 km.



The intial temperature profile at the 3rd model level (z = 1.5 km) for the small grid (left) and the large grid (right).

Small Domain Results

Large Domain Results



Temperature perturbation for the first model level (z = 250 m). The dashed line indicates the area of fine resolution.

Discussion

•Storms will be better resolved over the fine resolution region. Ideally, the system should scale the same way over both the fine and coarse resolution region.

•These results are plausible. Similar tests with grid nesting (the predecessor to variable resolution grids) would yield extremely unrealistic results.

•The transition region of the grid has an extremely important effect on the development of storms on a variable resolution grid.

- •The runs on the small domain are unrealistic with any diffusion.
- •The runs on the large domain are realistic with constant and linearly-scaling diffusion.

•The definition of the diffusion coefficient must also be considered for variable resolution grids.

•The results shown here are very promising - the most realistic runs look similar to constant resolution runs.

Future Work

Further research into grid generation and model filter formulation is needed. Turbulence models of the atmosphere scale diffusion with the cell area, not the distance between cell centers. Examples can be seen in Smagorinsky (1963) and Lilly (1962).

This research is part of a larger effort for the Nonhydrostatic Atmospheric Global Model for Prediction Across Scales (MPAS). Other test cases, such as baroclinic waves and mountain waves are being run. Efforts are also underway to incorporate robust microphysics suites.

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