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A Nonhydrostatic Atmospheric Global Model for Prediction Across Scales (MPAS)

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We are developing a new global nonhydrostatic atmospheric model that will be well suited for both weather and climate applications on scales ranging from cloud to global, and that can run efficiently on massively parallel (petascale) computers. This development is part of a larger effort, in collaboration with the Los Alamos National Laboratory, that utilizes an unstructured-grid framework for ocean and sea-ice models in addition to the atmospheric model. These unstructured-grid models make use of spherical centroidal Voronoi tesselations (SCVT; nominally hexagonal grids) with C-grid staggering.

The nonhydrostatic atmospheric solver uses a hybrid terrain-following height vertical coordinate, a split-explicit third-order Runge Kutta time integration scheme, and a nominally third-order scalar transport scheme. The equations are cast in conservative form following Klemp et al (2007). The horizontal CVT grid used in the model is depicted in figure 1. Thermodynamic quantities (density ρ, coupled potential temperature $\rho\theta$), moisture and other scalars are defined at cell centers, and the normal horizontal velocity vectors are prognosed on the grid-cell faces in the C-grid discretization.

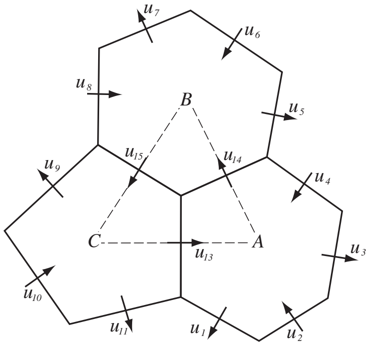

Figure 1: Schematic of the C-grid centroidal Voronoi tesselation used in horizontal discretization of MPAS. Normal velocities are defined and prognosed on the cell edge where the edge bisects the line connecting the cell centers.

C-grid discretizations had not been used for hexagonal-grid models because of a serious problem with nonstationary geostrophic modes (Ničković (2002)). A reconstruction of the tangential velocity that removes this problem is described in Thuburn et al (2009). Ringler et al (2010) present a potential-vorticity-conserving shallow-water equations solver based in part on the Thuburn et al reconstruction. We retain the shallow-water discretization in our horizontal discretization of the 3D nonhydrostatic system. Of particular note, we use a vector invariant form of the horizontal momentum equations as described in Ringler et al. Earlier prototypes for the atmospheric solver have demonstrated good accuracy, both in shallow-water solutions on the sphere and in nonhydrostatic cloud simulations on planar hexagonal grids.

At large scales on the globe using quasi-uniform grids, the nonhydrostatic solver produces solutions with accuracy similar to other global solvers at only slightly increased cost. To facilitate further testing and non-global applications, the MPAS grids and solver can also be configured to simulate flow in a doubly periodic Cartesian plane, and we can generate grids with variable resolution for the doubly periodic plane as well as the sphere. We are using this flexibility to test the MPAS solver using nonhydrostatic flows and variable resolution grids.

Figure 2 shows one of the variable resolution grids for a doubly-periodic Cartesian plane we using in convection-permitting simulations. The methods used to construct these grids are described in Ringler et al (2008). A central high-resolution region, with cell spacing (distance between cell centers) of approximately 1 km, is surrounded by a coarser-grid region where the cell spacing is approximately 3 km. The

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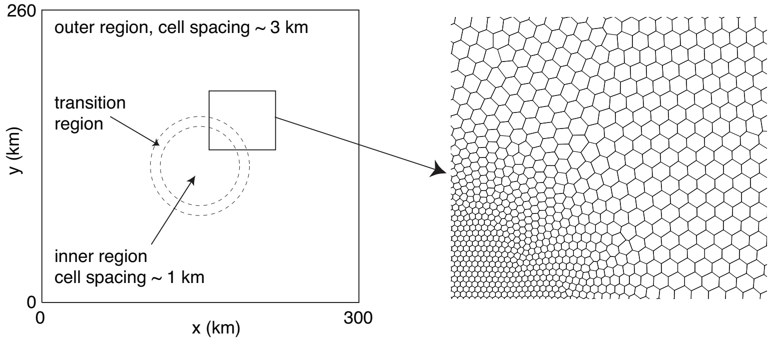

Figure 2: Variable resolution mesh used in the squall-line test simulations. The domain is periodic in both x and y, and 20 km deep with a 500 m vertical grid spacing.

grid transitions between these two regions over an approximately 15 km distance. The transition is relatively smooth, as can be seen in the portion of the grid depicted in figure 2.

Using this grid, we have performed 3D squall-line simulations similar to those described in Weisman et al (1997). Figure 3 shows the low-level vertical velocity associated with the line of convective cells as it propagates across the variable-resolution grid region. The squall line is transitioning to a significantly upshear-tilted system in this time period, with the convective cells weakening as the upshear tilt increases. The convective updrafts are better resolved in the high-resolution grid, but the overall structure of the line is similar in both the high and low resolution regions, and the results are similar to those produced on uniform grids using 1 km or 3 km cell spacing. There are no obvious flow anomalies in the vicinity of the grid transition. We have experimented with variable-resolution grids that possess more abrupt grid transitions, and we find that the abrupt transitions can create flow anomolies that are tied to the transition region. As expected, we find that the solutions are sensitive to filter formulations used in the model.

Model physics, including model filters, must work across a range of grid resolutions within a single grid. Convection simulations of the type presented here are our first efforts to evaluate model formulations and physics in multi-resolution simulations, and we will present these and additional results at the workshop.

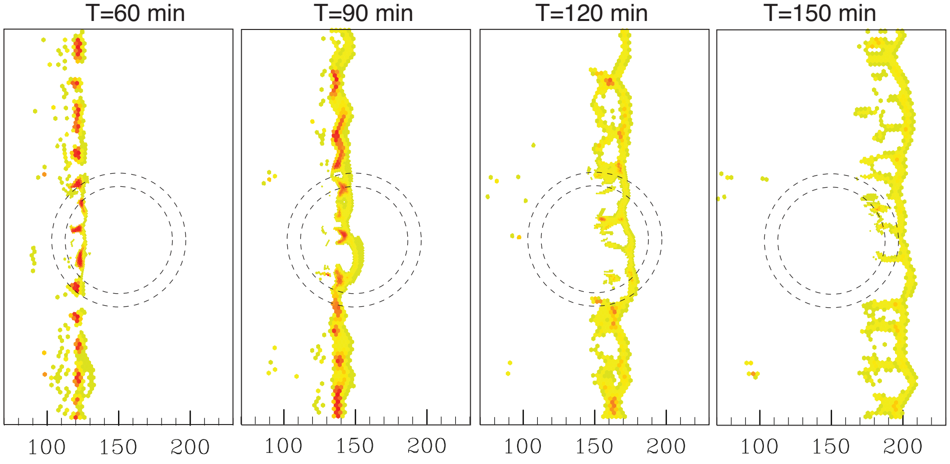

Figure 3: Vertical velocities at 2.5 km above the ground in the squall line simulation for moderate vertical wind shear. Only positive vertical velocities are shaded, with darker shading (red) indicating w > ~ 5 m/s.

References

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