U.S. DEPARTMENT OF ENERGY | Office of Science

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FY 2012 Third Quarter Performance Metric: Demonstrate Variable-Resolution Atmosphere Simulation, With Telescoping To Greater Than 20 km Resolution

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Demonstrate variable-resolution atmosphere simulation, with telescoping to greater than 20 km resolution

1.0 Product Definition

Driven by the need to improve the regional details represented in global climate models, much development in the Community Earth System Model (CESM) has been devoted to including more physical processes at higher resolutions and increased throughput. Resolution, in particular, is one of the key requirements for improving regional climate simulations, but it has a significant computational cost. As an example, doubling only the horizontal resolution while holding the vertical resolution fixed requires 8 times more computational resources. Furthermore, improving our high-resolution modeling capability requires hundreds of simulations to evaluate the strengths and weaknesses of the model, to calibrate the parameters of the model using observations, and to quantify the uncertainty in the model results.

Variable resolution can be used to make these simulations 10-100 times more efficient. In a variable resolution simulation, most of the Earth's atmosphere is simulated using a grid (for example) with a typical 110 km horizontal grid spacing over most of the globe, but also containing a small region of very high resolution, such as 13.5 km. Initially we do not expect these simulations to better model the climate in the high-resolution region, since increased resolution is just one of several improvements needed for better regional climate. Instead, variable resolution simulations provide an efficient testbed that can be used for evaluation, calibration and uncertainty quantification of the CESM at 13.5 km resolution in a particular region.

The Department of Energy (DOE) Climate Science for a Sustainable Energy Future (CSSEF) project is thus building an atmospheric testbed that will rely on variable resolution. The initial focus will be on improving the representation of the hydrological cycle in CAM (the Community Atmosphere Model in the CESM). The first step is to calibrate CAM at 13.5 km resolution in a continental size region. This region will be centered over the southern great plans ARM site where DOE has been collecting extensive atmospheric observations designed to validate and improve climate models. A strong case can be made that the improvements obtained through calibration in a small region of 13.5 km resolution will translate into improvements in CAM's global 13.5 km simulations. Establishing this is a key requirement for the success of CSSEF.

To support the CSSEF testbed, we have thus added a new variable resolution capability to CAM. Our initial simulations are being performed on the variable resolution grid shown in Figure 1. The figure shows a close-up of the high-resolution portion of the grid centered over the ARM site, with an average grid spacing of 13.5 km. There is a small transition region. The remaining grid, covering the rest of the globe, has an average grid spacing of 110 km.

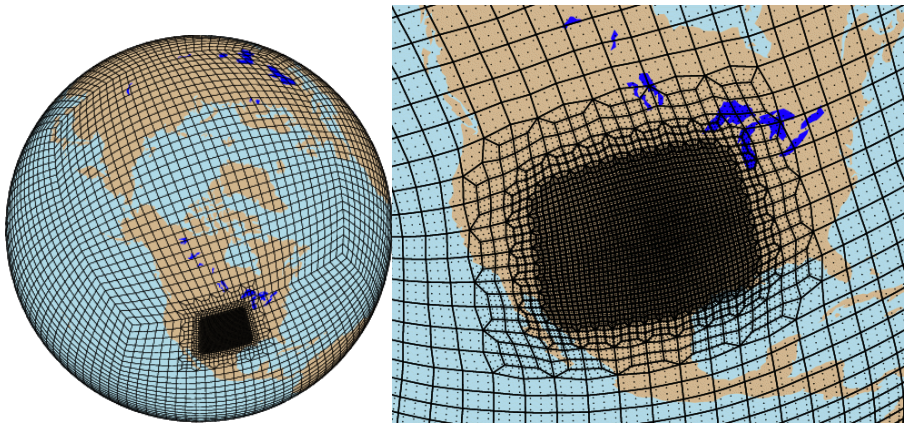

Figure 1. Spectral Element grid used for our variable resolution simulations (left) and a close-up view of the same grid (right), but with Winslow smoothing applied by the CUBIT grid generation program. Only the element outlines of the global grid are drawn on the left panel. The close-up view shows the 13.5 km region over the central U.S, as well as the 9 collocation points used within each element.

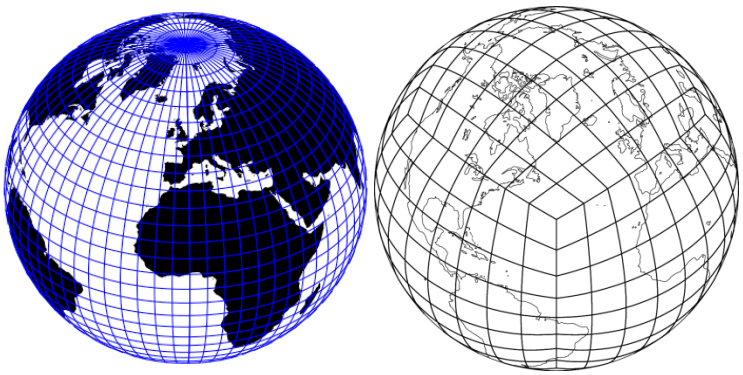

Figure 2. A structured latitude/longitude grid (left) and a quasi-uniform "cubed-sphere" spectral element grid (right). For uniform resolutions, the CAM with the spectral element dynamical core uses cubed-sphere grids so as to avoid clustering grid points at the poles.

2.0 Product Documentation

CAM has traditionally simulated the Earth's atmosphere with numerical methods that relied on structured latitude/longitude grids such as those shown in Figure 2 (left panel). Starting with the CAM version 4, we added the capability to use fully unstructured finite element grids, such as those shown in Figure 1 and Figure 2 (right panel). This capability was made possible due to DOE's investment in the development and integration of a spectral finite element method into CAM. Using CAM version 4, we focused on validating the model using uniform resolution grids such as Figure 1b, (Mishra et al., 2011a, 2011b, Dennis et al., 2012, Evans et al., 2012) and developing high-resolution global configurations (Dennis et al., 2012, Worley et al., 2011).

As CAM's spectral element method was designed from inception for unstructured variable resolution grids, only minor changes were needed to CAM in order to develop our initial variable resolution capability in CAM version 5. Much of our initial work focused on technical details required for new configurations: generating variable resolution grids using the CUBIT (http://cubit.sandia.gov) software package, generating the necessary boundary data sets and mapping files for the variable resolution grids and developing an efficient load balancing of processors across CESM model components. For the variable resolution simulation, there are still issues that can be improved, such as how to scale the horizontal mixing parameterization, generation of variable resolution topography and surface roughness data sets and determining the optimal grid resolution transition region.

For the results presented here, we used the 110 km/13.5 km variable resolution grid shown in Figure 1. This grid has 67 K grid points on the sphere, each representing a column made up of 30 levels in the vertical/radial direction. In comparison, our global 13.5 km uniform resolution (based on the cubed-sphere grid such as Figure 2 right) has 3.1 M grid points. The global 1/8° configuration is running efficiently on 64,000 cores of the Argonne National Laboratory Intrepid system at 0.25 simulated-years-per-days (SYPD), at a cost of 6M core-hours per year. The variable resolution configuration is more affordable, running at 0.65 SYPD on 512 cores of SNL's institutional Linux cluster. All simulations were performed with CAM version 5, including atmospheric chemistry and prognostic aerosols.

For the variable resolution simulation, we have completed a five-year simulation using the Atmospheric Model Intercomparison Project (AMIP) protocol. This involves running the CESM with active atmosphere, land and sea ice components, with prescribed sea ice extent and prescribed sea surface temperatures. The CESM coupler infrastructure was used to couple the atmosphere running on the variable resolution grid to the land model running on a ~110 km latitude/longitude grid and the sea ice and data ocean model running on a ~110 km displaced pole latitude/longitude grid. The model was driven by cyclic year 2000 ocean and ice conditions. For use as a benchmark, we have also completed a two year global high-resolution AMIP simulation. For that simulation, the atmosphere was running on a ~13.5 km cubed-sphere grid, the land model running on a ~27 km latitude/longitude grid and the sea ice and data ocean model running on a ~10 km tripole grid. It was forced with ocean and ice conditions from 2004-2005 observations.

An example of the simulation results is shown in Figure 3, where we plot the contours of sea level pressure (black lines), the column integrated atmospheric water content (precipitable water, grey shading) and the precipitation rate (color shading). Both simulations have captured strong convective storm systems. These types of systems are very poorly resolved at low resolution (~110 km), but when using the variable resolution grid, CAM can resolve these storms in the region of high-resolution. The CSSEF testbed will use this inexpensive variable-resolution CAM configuration to evaluate and improve CAM's ability to simulate these types of storms and other aspects of the Earth's hydrological cycle, ultimately leading to a high quality global 13.5 km resolution modeling capability with quantified uncertainties.

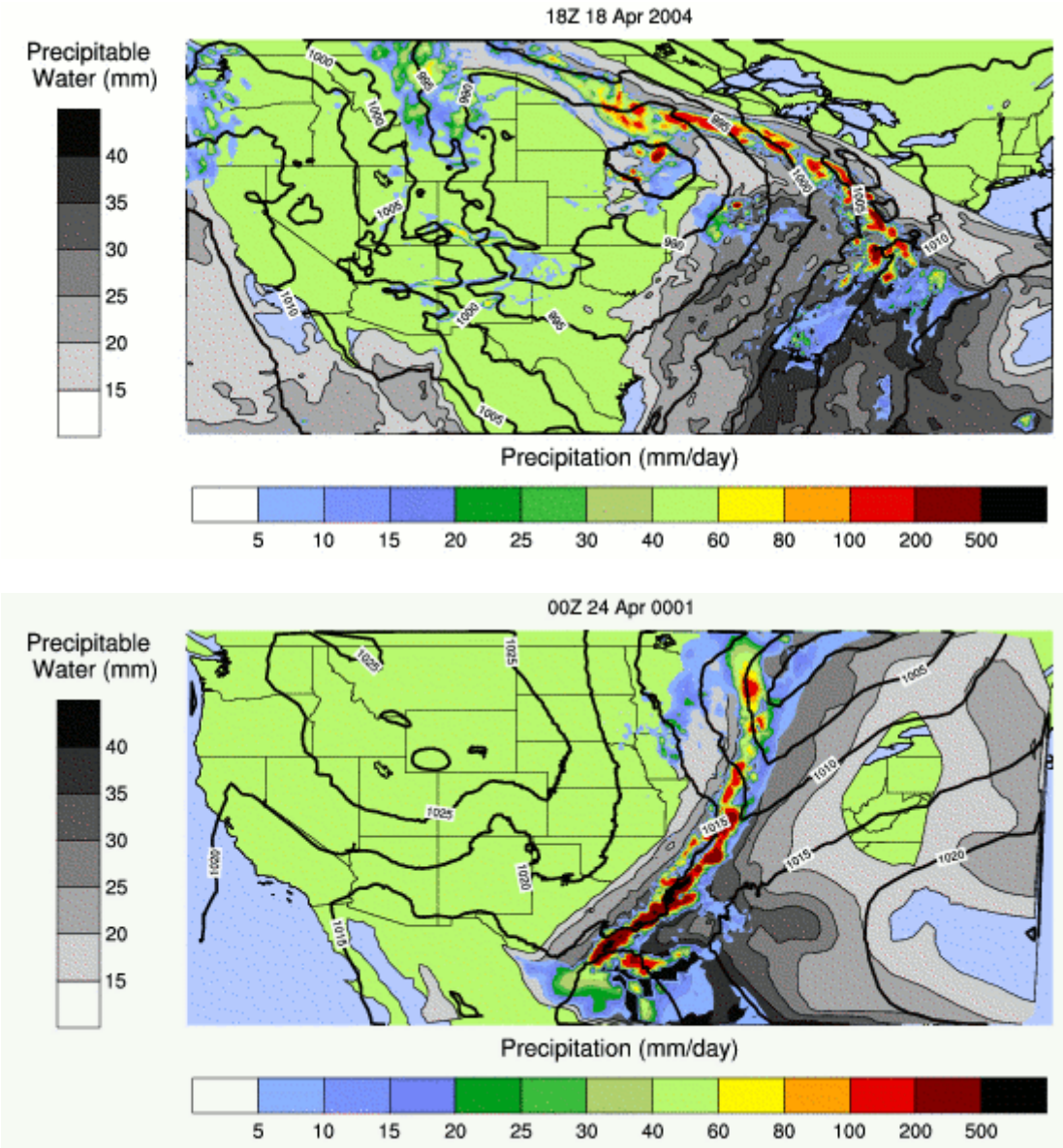

Figure 3. Examples of convective storms captured by CAM at global 13.5 km resolution (top) and on the variable resolution grid with 13.5 km resolution over much of the U.S. (bottom). Such detail is typical of 13.5 km simulations and cannot be captured in lower-resolution simulations. These are free-running climate simulations, so the results are not the simulation of a particular storm, but instead show the types of storms that the model will generate.

3.0 References

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