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U.S. DEPARTMENT OF ENERGY | Office of Science

FY 2015 Third Quarter Performance Metric: Demonstrate Higher Horizontal Resolution of a Regionally Refined Model Improves the Sub-Decadal Simulation of Precipitation in the United States

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1.0 Product Definition

The regionally refined capability in the Accelerated Climate Model for Energy (ACME) was used to show improvement of precipitation over mountainous regions in the United States at high-resolution without having to use a global high-resolution atmospheric model. The refined region was centered over the continental United States (CONUS). A regionally refined model can display the signatures of a global high-resolution model at a tenth of the computational cost of a global high-resolution simulation. A dry precipitation bias off the coast of the eastern United States in the global 1° low-resolution model was improved in the regionally refined simulation when compared to observations. This improvement in the regional refinement is also comparable to the global ¼° high-resolution simulation.

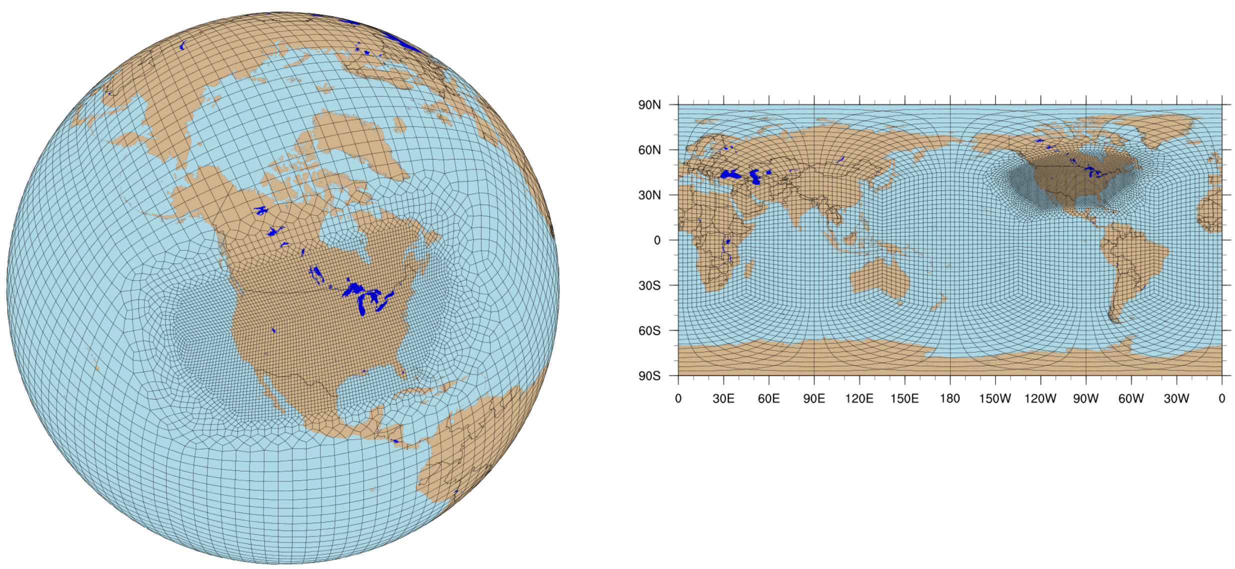
2.0 Product Documentation

To demonstrate the improvement of precipitation over the refined region, the climatologies of a regionally refined configuration, a global low-resolution 1° configuration, and a high-resolution ¼° configuration of the Community Atmospheric Model (CAM5.3), version 5.3, in the ACME model, version 0.1, are compared with a Tropical Rainfall Measuring Mission (TRMM) high-resolution ¼° precipitation dataset. Five-year pre-industrial simulations of the climatological year of 1850 of the CONUS grid, the 1° low-resolution grid, and the ¼° high-resolution grid were performed. The case for using regional refinement to reduce the computational costs is strong. The low-resolution 1° simulation has 5400 elements and can produce 3.31 Simulated Years per Day (SYPD) on an institutional cluster with 400 cores. The CONUS simulation has 9905 elements and can produce 0.90 SYPD on the same cluster. The reduction in speed is due to the smaller time step needed by the higher resolution region. For comparison, the number of elements in the globally uniform ¼° simulation is 86,400. This high-resolution simulation was not run on the institutional cluster because it would take months to produce a 5-year simulation, and therefore must be run on a Leadership Class Facility computer.

3.0 Results

The regionally refined grid was produced with the offline software tool, Spherical Quadrilateral Grid Generator (SQuadGen) [Ullrich, 2013]. The regionally refined area was centered over CONUS. The high-resolution area has an effective resolution of ¼°, or about 30 km. The low-resolution area occupying the remainder of the global has an effective resolution of 1°, or about 110 km. A transition region bridges the two resolutions.

Five-year pre-industrial simulations of the climatological year of 1850 of the CONUS grid (Figure 1), the 1° low-resolution grid, and the ¼° high-resolution grid were performed. Table 1 compares the number of elements and the computational performance of the simulations. The CAM5.3 atmospheric model uses the spectral element dynamical core on a cubed-sphere, which has been shown to scale-well in computational time as the number of elements and processors increases [Fournier et al., 2004]. For example, the low-resolution 1° simulation has 5400 elements and can produce 3.31 SYPD on an institutional cluster with 400 cores. The CONUS simulation has 9905 elements and can produce 0.90 SYPD on the same cluster. The reduction in speed is due to the smaller time step needed by the higher resolution region. For comparison, the number of elements in the globally uniform ¼° simulation is 86,400. This high-resolution simulation was not run on the institutional cluster because it would take months to produce a 5-year simulation. The high-resolution simulation was performed at a Leadership Computing Facility. The argument for using regionally refined grids strengthens as one realizes the computational expensive of global high-resolution simulations. The argument for using regionally refined grids becomes even stronger if the embedded high-resolution region has the same atmospheric signatures in the equivalent region as a global high-resolution model.



(a) (b)

Figure 1. The regionally refined grid over the CONUS in (a) an orthographic projection and (b) a cylindrical equidistant projection.

Table 1. Comparison of the number of elements in the global 1° low-resolution configuration and of the regionally refined CONUS configuration with resolutions of 1° to ¼°. Both configurations' computational speed is given in SYPD when 400 cores are used on an institutional cluster. The number of elements for a global high-resolution ¼° simulation is also given, although that simulation was not performed.

Resolution in Degrees	Number of Elements	SYPD (400 cores)
1°	5,400	3.31
¼°	86,400	n/a
CONUS, 1°→ ¼°	9,905	0.90

Improvements in modeled precipitation compared to observations as resolution increases have been previously documented over the CONUS region [Bacmeister et al., 2014; Wehner et al., 2014]. Although wet and dry biases formed in the CONUS region as model resolution increased, Bacmeister et al. (2014) showed wintertime precipitation in the southeastern United States to have a strong response to resolution.

The current theory behind precipitation's response to resolution is that at higher resolution, topography is better represented. This, in turn, will improve precipitation in areas affected by topography. Figure 2 shows the topography used in the CONUS, 1°, and ¼° simulations. Inside the CONUS region (Figure 2a), the topography is the same as the ¼° simulation (Figure 2c). Outside the CONUS region, the topography is the same as the 1° simulation. Thus, the CONUS topography has improved resolution over the 1° topography.

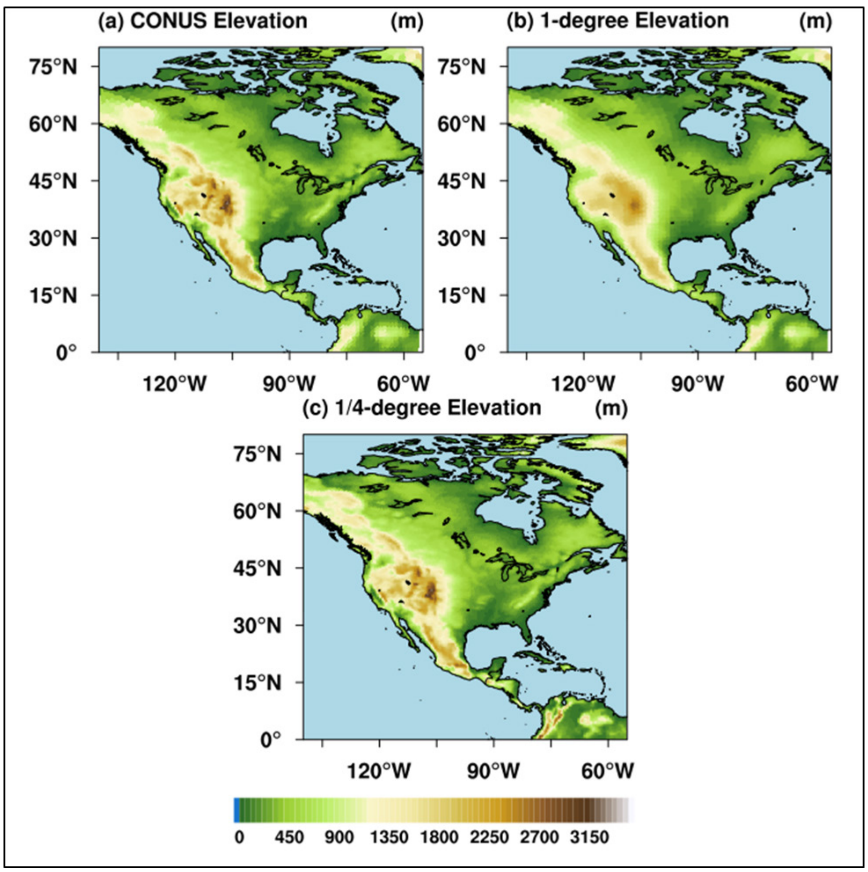


Figure 2. Topography used in (a) the regionally refined CONUS simulation, (b) the low-resolution 1° simulation, and (c) the high-resolution ¼° simulation. The simulations were compared with the TRMM 3B42 climatology [Huffman et al., 2007]. This daily data has a resolution of ¼°, covers the globe from 50 South to 50 North, and spans the time range of 1998-2013.

To remove transients and natural variability in both the observations and the simulations, the entire period was averaged by season so that the TRMM-3B42 observations could be more meaningfully compared with the simulations. The June, July, August (JJA) average of the 5-year simulations is compared with the TRMM-3B42 data from 1998-2013 in Figure 3. The most apparent improvement in the CONUS and ¼° simulations in comparison to the 1° simulation is the increase in maximum precipitation rate off of the eastern coast of the United States. Reasons behind this improvement are still an ongoing research effort. There appears to be little sensitivity to resolution over the Mountain West region during this season. Another area (albeit outside the U.S.) with improved agreement with the observations is in the Mexican Monsoon which shows a more narrow east-west extent of the north-south precipitation band with reduced precipitation in the interior of Mexico to the east.

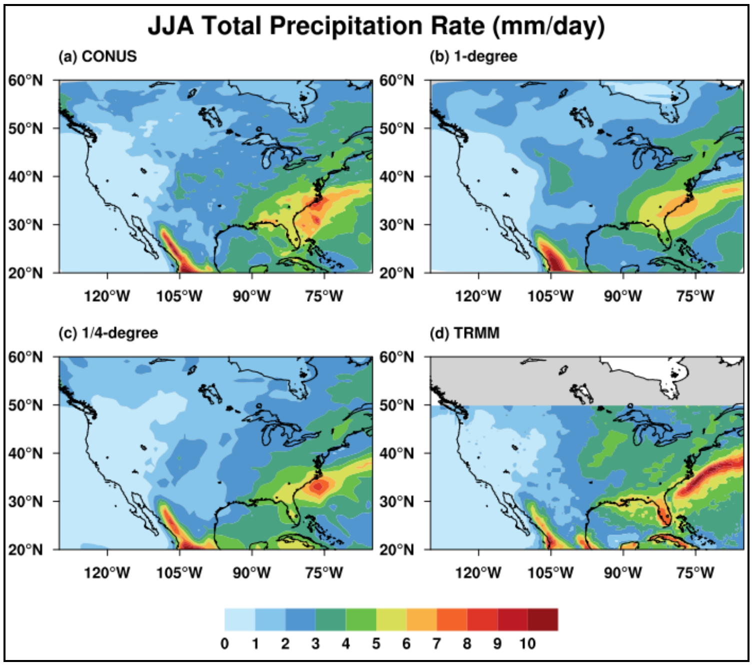


Figure 3. June, July, and August precipitation rate for the entire 5-year (a) CONUS simulation, (b) 1° simulation, and (c) ¼° simulation which are compared with the (d) the 1998-2013 TRMM data.

Figure 4 shows the September, October, November (SON) average of the 5-year simulations compared with the TRMM-3B42 data. An increase in precipitation is seen in the coastal mountains of the Pacific Northwest region in the CONUS simulation compared to the 1° simulation. However, it is difficult to determine how this compares with observations because the TRMM-3B42 data stops at 50°N. Ongoing research is exploring additional high-resolution precipitation datasets to compare with the Pacific Northwest region. As seen in both Figure 3 and Figure 4, the eastern off-coast ocean shows increases in precipitation. The band of high precipitation stretching from 80°W to 60°W in the TRMM measurements is missing from all simulations. In an isolated area directly north of the Great Salt Lake, an increase in precipitation occurs in the CONUS, ¼°, and TRMM data. That isolated area of higher precipitation is not resolved in the 1° simulation. This area shows how higher resolution topography can improve the sub-decadal simulation of precipitation in portions of the United States.

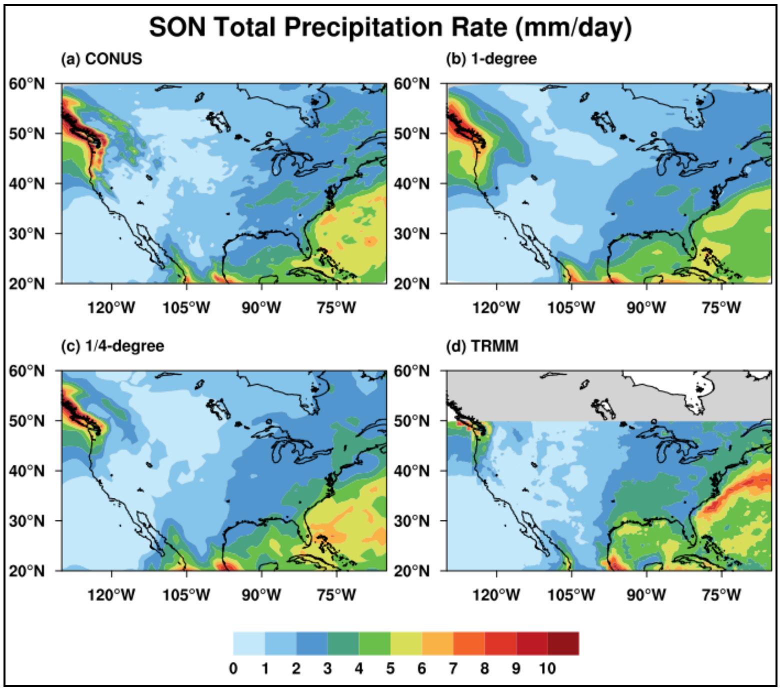


Figure 4. SON precipitation rate (mm/day) for the entire 5-year (a) CONUS simulation, (b) 1° simulation, and (c) ¼° simulation which are compared with the (d) the 1998-2013 TRMM data.

A regionally refined model can display the signatures of a global high-resolution model at a tenth of the computational cost of a global high-resolution simulation. The regionally refined tool was configured to be used over the continental United States to show that improvements in precipitation, as documented previously in global high-resolution simulations, could be reproduced. The dry precipitation bias off the coast of the eastern United States in the global 1° low-resolution model was improved in the regionally refined simulation when compared to TRMM-3B42 observations. This improvement in the regional refinement is also comparable to the global ¼° high-resolution simulation. Future work includes comparisons of observations and simulations in sub-regions in the United States, such as the Pacific Northwest.

4.0 References

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