U.S. DEPARTMENT OF ENERGY | Office of Science

DOE/SC-CM-12-002

FY 2012 Second Quarter Performance Metric: Demonstrate Coupled Climate Models at 30 km Resolution

March 2012

DISCLAIMER

This report was prepared as an account of work sponsored by the U.S. Government. Neither the United States nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

Contents

1.0 Product Definition 1
2.0 Product Documentation 1
2.1 Examples of Simulation Results 2
3.0 References 4

Figures

1. Annual distribution of simulated precipitation compared to corresponding CMAP satellite retrievals for the period 1979-1981 2
2. Snapshot of simulated column integrated water from ultra-high atmospheric simulation illustrating rich range of motion scales captured by a model of this class. 3
3. Response of the CAM4-SOM model to aerosol radiative forcing. 4

Demonstration of a high-resolution (30 km) atmosphere simulation with uniform representation

1.0 Product Definition

A global atmospheric general circulation model has been developed based on the CESM CAM4 using a 341 wavenumber triangularly truncated spectral dynamical core with an alias-free transform grid averaging less than 30 km. In such a framework, the horizontal representation of an arbitrary variable ψ consists of a truncated series of spherical harmonic functions,

$$\psi(\lambda, \mu) = \sum_{m=-M}^{M} \sum_{n=|m|}^{\mathcal{N}(m)} \psi_n^m P_n^m(\mu) e^{im\lambda},$$

where *m* denotes zonal wavenumber, n-m denotes a form of meridional wavenumber, and M and N are the spectral truncation limits. The advantage of the triangular truncation, as opposed to other forms of spectral truncation is that ***the solution is uniformly represented*** and invariant to any form of coordinate rotation. A three-dimensional monotonic shape-preserving semi-Lagrangian scheme is used for the accurate transport of water and trace constituents, such as cloud condensate. The high-resolution configuration was developed with parameter settings and datasets for an energetically-balanced ultra-high resolution T341 truncation.

A simulation of this high-resolution global atmospheric general circulation model was conducted in compliance with the Atmospheric Model Intercomparison Project (AMIP) protocol. The model employed a spectral representation for integrating equations forward in time using an alias-free transform grid of approximately 30 km. For purposes of the AMIP numerical integration, the high-resolution atmosphere is configured to couple to a fully interactive and sophisticated land-surface process model with a quarter degree finite volume discretization. This atmosphere and land model configuration can also be coupled to 1/10 degree resolution ocean and sea ice components or to a Slab Ocean Model (SOM) to allow simple exploratory investigations with an interactive ocean surface.

In addition to configuration work on the parameterized physics, a separate effort was made to optimize computational performance on massively parallel distributed-memory scientific computer systems. Current optimizations on the Oak Ridge National Laboratory (ORNL) Jaguar supercomputer yield 4.6 simulated years per day of computing using 6,144 cores. This allows a five-member 30-year AMIP simulation (150 years total) to be completed on 30,720 processor cores in less than one week.

2.0 Product Documentation

This atmospheric configuration has been prepared to be suitable for coupling to fully-interactive ocean and sea-ice components developed separately under the CESM project. It has been subjected to a variety of tests at a variety of resolutions to ensure the interactions with the other components are stable and well understood. To conduct the uncoupled AMIP simulation, the immediate product has employed

the specified sea-ice and ocean sea-surface temperature (SST) dataset of Hurrell et al. (2008). A unique element of the ORNL development work has been the generation of a more up-to-date higher resolution aerosol forcing dataset for the latter part of the 20th century, which includes observed inter-annual variability (e.g., due to biomass burning). Inter-annual variability of aerosol forcing induces statistically significant variability in the global climate system by direct and semi-direct effects of aerosols. A manuscript describing the creation of the new aerosol dataset and its impact on the climate system focusing on the tropical Atlantic and Africa has been submitted (Mahajan et al., 2012) to the *Journal of Geophysical Research*. Additional manuscripts documenting the detailed performance of this model configuration are in preparation. All work associated with configuring this high-resolution energetically balanced version of CAM4 is being released as part of a follow-on tag to the original CESM CAM4.

2.1 Examples of Simulation Results

Simulations for the AMIP period using this ultra-high resolution model are currently being analyzed against available observations. Standard analyses of seasonal mean simulation characteristics show good agreement with the corresponding observations. One example includes the simulated annual distribution of precipitation as compared with satellite retrievals as shown in Figure 1.

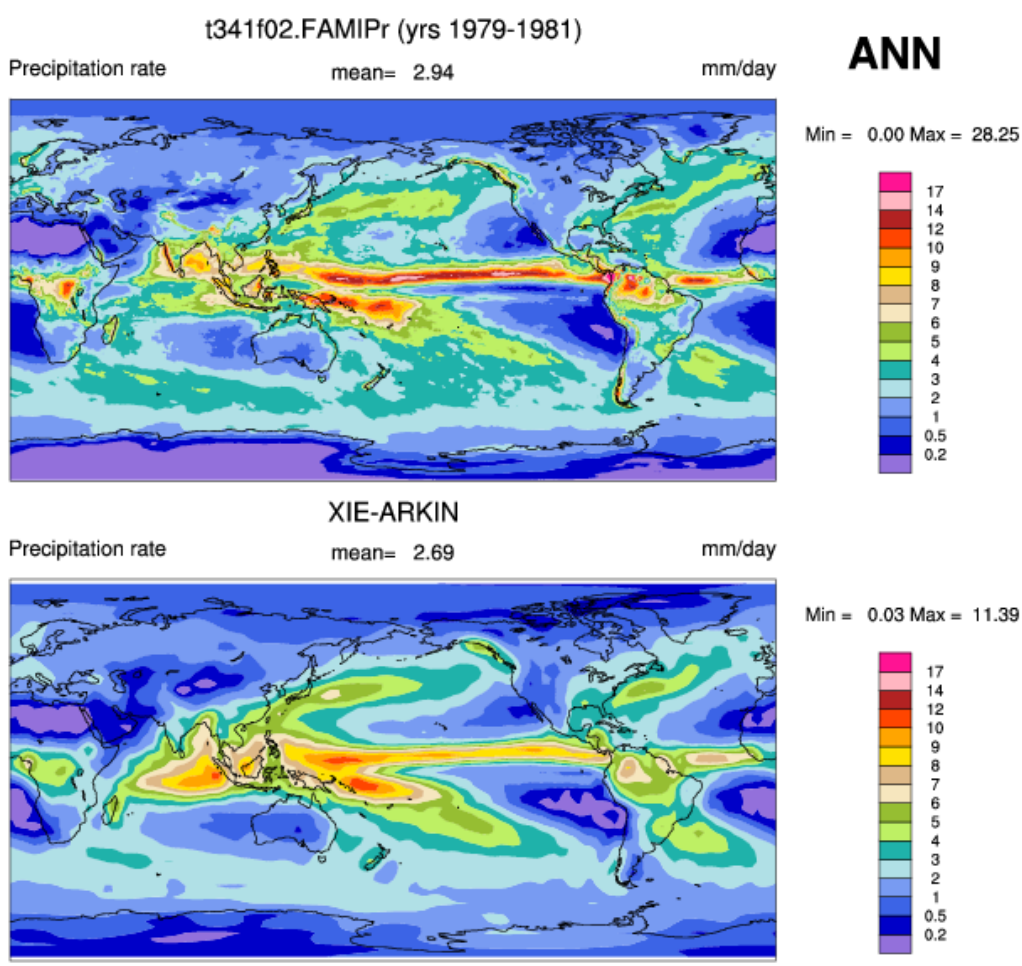

Figure 1. Annual distribution of simulated precipitation compared to corresponding CMAP satellite retrievals for the period 1979-1981.

Other analyses of these simulations involve examination of the higher order statistical characteristics of the simulation, the behavior of extreme hydrological events in particular. This high-resolution configuration admits new phenomenology such as the appearance of low-latitude tropical storms and other mesoscale phenomena as seen in the western Pacific (see Figure 2). The ability to realistically capture these motion scales provides a new opportunity to better represent the statistics of extreme events as well as to more realistically treat energy interactions with the underlying ocean, land, and cryosphere.

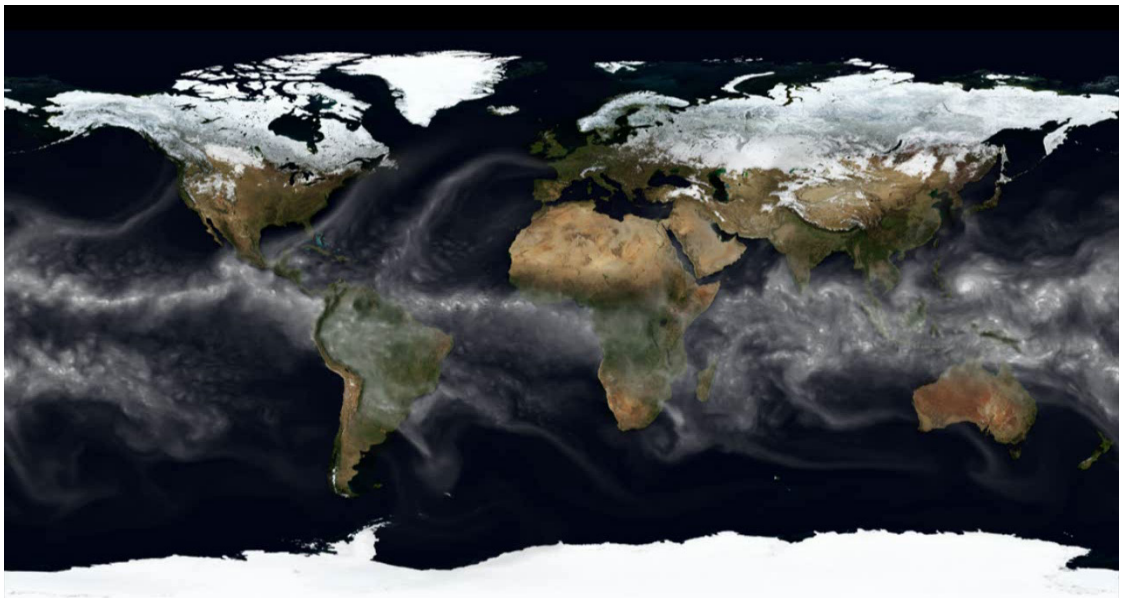

Figure 2. Snapshot of simulated column integrated water from ultra-high atmospheric simulation illustrating rich range of motion scales captured by a model of this class.

One final example is new insight emerging from the more realistic specification of atmospheric aerosol, which includes monthly variability of global wildfire emissions. A manuscript describing the creation of the new aerosol dataset and its impact on the climate system focusing on the tropical Atlantic and Africa has been submitted publication examining a lower resolution version of this modeling framework (see Figure 3, Mahajan et al., 2012) where a parallel examination of aerosol effects in the high resolution configuration is underway including an examination of how wildfire emissions over the Indian monsoon region induce significant inter-annual variability of the simulated Indian monsoon.

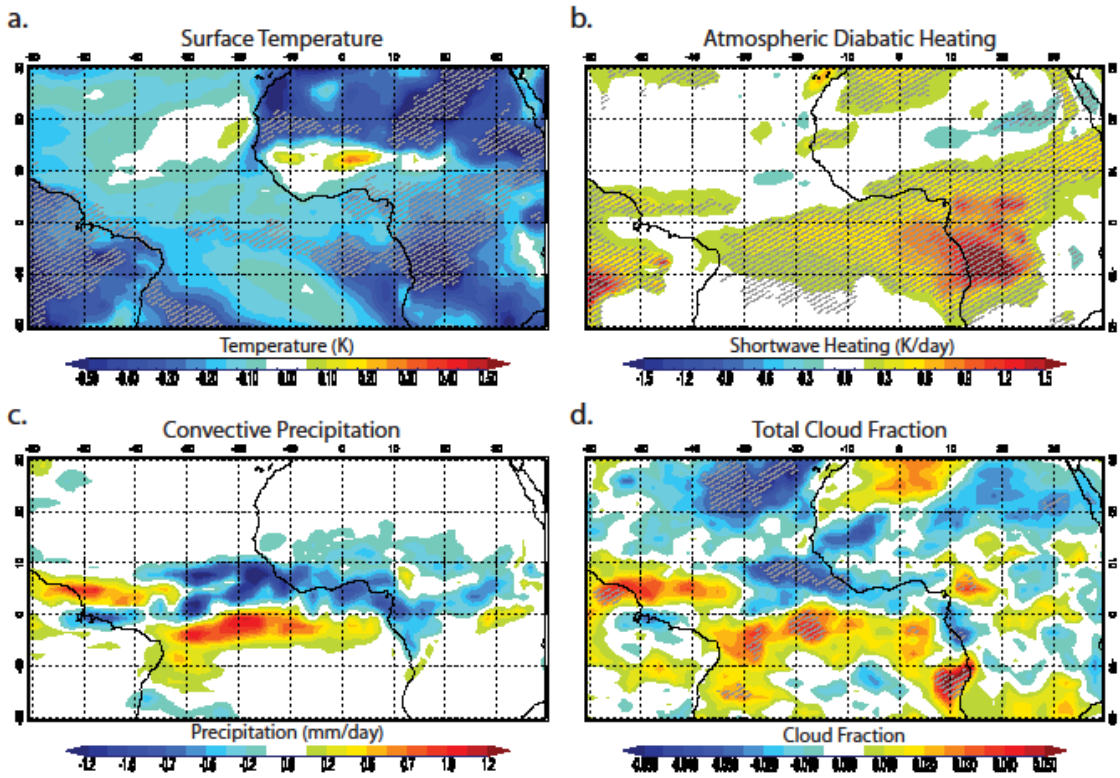

Figure 3. Response of the CAM4-SOM model to aerosol radiative forcing. Differences in the mean (a) surface temperature, (b) convective precipitation, (c) total cloud fraction and (d) vertically integrated atmospheric shortwave heating in the boreal summer season averaged over 30 years.

3.0 References

Hurrell JW, JJ Hack, D Shea, J M Caron, and J Rosinski. 2008. "A New Sea Surface Temperature and Sea Ice Boundary Dataset for the Community Atmosphere Model." *Journal of Climate* 21(19): 5145-5153. DOI: 10.1175/2008JCLI2292.1

Mahajan S, KJ Evans, JE Truesdale, JJ Hack, and J-F Lamarque. 2012. "Inter-annual Tropospheric Aerosol Variability in Late Twentieth Century and its Impact on Tropical Atlantic and West African Climate by Direct and Semi-direct Effects." Submitted to the *Journal of Geophysical Research*. In review.

U.S. DEPARTMENT OF
ENERGY

Office of Science