U.S. DEPARTMENT OF ENERGY | Office of Science

DEVELOPMENT OF FRAMEWORKS FOR ROBUST REGIONAL CLIMATE MODELING

Global climate models (GCMs) are the primary tools for predicting the evolution of the climate system. Through decades of development, GCMs have proven useful in simulating climates from continental to global scales. However, large uncertainties remain in projecting climate change at regional scales, which limit our ability to inform decisions on climate change adaptation and mitigation.

With advances in high performance computing, it is now feasible to run coupled atmosphere-ocean GCMs at horizontal resolutions that capture realistic regional climate forcings such as topography and land-sea contrast. Global models with local refinement using unstructured grids have also become available for modeling regional climate. While they offer opportunities to improve climate simulations, significant efforts are needed to systematically evaluate the sensitivity of climate simulations to dynamic approaches, model resolutions, and physics parameterizations.

Sponsored by the Department of Energy's Regional and Global Climate Program, the Development of Frameworks for Robust Regional Climate Modeling project represents a multi-laboratory, collaborative effort involving the Pacific Northwest National Laboratory (PI: L. Ruby Leung), Los Alamos National Laboratory (PI: Todd Ringler), Lawrence Berkeley National Laboratory (PI: Bill Collins), Sandia National Laboratory (PI: Mark Taylor), and Oak Ridge National Laboratory (PI: Moetasim Ashfaq). The project aims to evaluate three approaches including global high-resolution, global variable resolution, and nested regional climate modeling to test their veracity for regional-scale climate simulations.

APPROACH

This project adopts a hierarchical approach to evaluate regional climate simulations, progressing from simple to complex and from idealized to real world. The evaluation hierarchy has four stages:

1. Idealized, no physics test cases
2. Idealized, full physics test cases
3. Real world, single model component simulations
4. Real world, coupled system simulations.

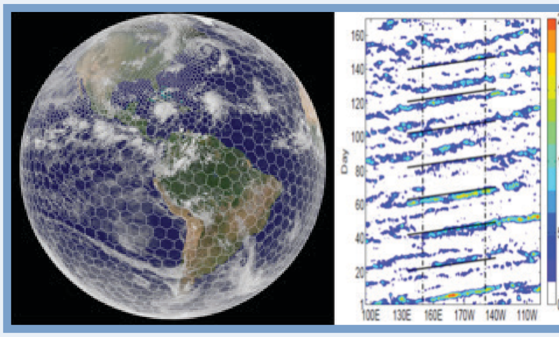
With this framework, deficiencies in each approach are more easily identified in simple and idealized simulations, which can then inform analyses and interpretations of biases in real-world simulations.

The Community Climate System Model (CCSM4, *http://cesm.ucar.edu*) and Weather Research and Forecasting model (WRF, *http://wrf-model.org*) were selected for comparison. Three dynamic cores of the Community Atmosphere Model (CAM4) including Spectral Eulerian, Spectral Element, and Model for Prediction Across Scales (MPAS-A) are used to perform global quasi-uniform resolution simulations at high and low resolutions. In addition, MPAS-A produces global variable resolution simulations

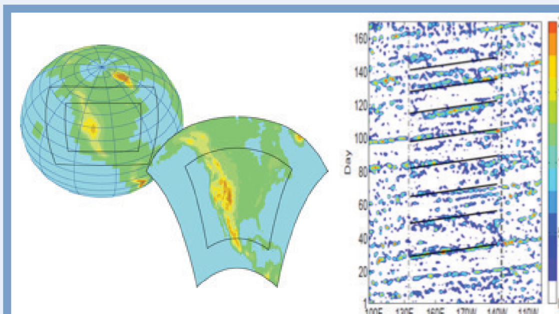
COMPARISON OF THREE APPROACHES TO REGIONAL CLIMATE SIMULATIONS

Global High Resolution Model

Global Variable Resolution Model

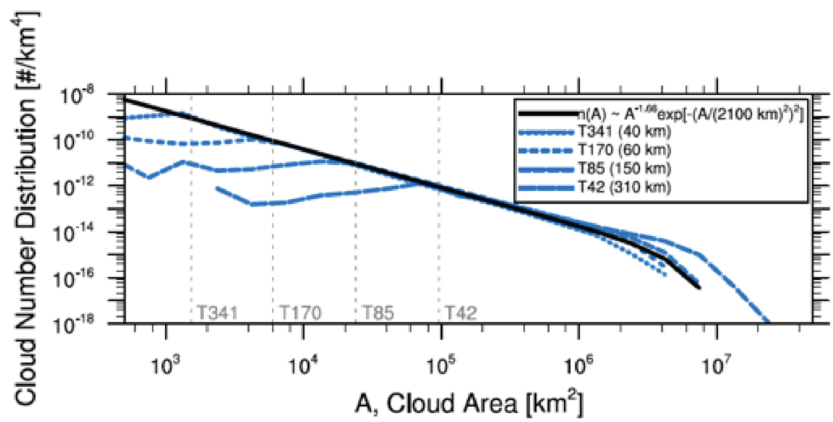


Nested Regional Climate Model



Three approaches to modeling regional climate are compared using a hierarchical evaluation framework that involves four stages of simulations from simple to complex and idealized to real world. Precipitation associated with tropical waves propagates smoothly from the low-resolution to high-resolution regions in MPAS-A and WRF (Source: Hagos S, LR Leung, S Rauscher, and T Ringler. 2013. "Errors characteristics of two grid refinement approaches in aqua-planet simulations." Monthly Weather Review. In press).

SCALING OF CLOUD SIZES IN CAM4 AT FOUR GRID RESOLUTIONS



Cloud area distributions from CAM4 aqua-planet simulations at resolutions ranging from about 40 km to 310 km. The distributions follow the power-law scaling over a wide range of cloud sizes similar to that found in observations up to a maximum cloud size that depends on model resolution (Source: O'Brien TA, F Li, WD Collins, SA Rauscher, TD Ringler, M Taylor, SM Hagos, and LR Leung. 2013. "Observed scaling in clouds and precipitation and scale incognizance in regional to global atmospheric models." Journal of Climate. In press).

with a high-resolution region embedded in a low-resolution global domain. Nested regional climate simulations are performed using WRF driven by CAM4 Spectral Eulerian low-resolution simulations. All models adopt the CAM4 physics parameterizations, so differences among simulations can be attributed primarily to model resolutions and dynamic frameworks.

ACCOMPLISHMENTS

A set of aqua-planet simulations have been completed using the three CAM dynamic cores at multiple resolutions. In addition, MPAS-A provided variable resolution simulations with an embedded high-resolution (0.25°) tropical region. Using a tropical channel domain at 100 km and 25 km resolutions, WRF simulations have been performed, including a nested configuration with a 25 km tropical region embedded one-way and two-way inside the 100 km resolution tropical channel. The high-resolution global and tropical channel simulations serve as the "reference" solutions for evaluation of the MPAS-A and WRF grid refinement approaches, respectively. Real-world atmospheric simulations with prescribed sea surface temperatures have also been performed similarly, but with the high-resolution regions over North and South America. Ocean simulations are being performed at horizontal resolutions between 4 km to 30 km using the MPAS ocean model (MPAS-O) and the Regional Ocean Modeling System (ROMS) for an idealized test case to evaluate the impacts of model resolution and dynamic framework on simulating ocean mesoscale activity. All model outputs have been archived at the National Energy Research Scientific Computing (NERSC) Center. Analysis that takes advantage of the hierarchical evaluation framework has provided significant insights on processes and feedback. The insights gained contribute to model dependence on dynamic frameworks and resolutions, leading to uncertainties in climate simulations at regional scales. In the past 2.5 years, 25 publications have resulted since the projects inception.

FUTURE WORK

To complete the implementation of the hierarchical evaluation framework, fully coupled atmosphere-ocean simulations will be performed using the CAM Spectral Eulerian and Spectral Element dynamic cores coupled with the Parallel Ocean Model (POP), and the MPAS-A coupled with the MPAS-O at low and high resolutions. Global variable resolution simulations will also be performed using MPAS-A coupled with MPAS-O with high-resolution regions over North and South America. Coupled WRF-ROMS simulations will be performed using boundary conditions from the low-resolution simulation of CAM Spectral Eulerian coupled with POP. Further analysis will be performed using the atmosphere-only and coupled simulations, with a focus on water cycle processes and hydroclimate over North and South America.

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Project Website

http://climatemodeling.science.energy.gov/projects/development-frameworks-robust-regional-climate-modeling