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Climate-Weather Modeling Studies Using a Prototype Global Cloud-System Resolving Model

ALCF-2 Early Science Program Technical Report

Argonne Leadership Computing Facility

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prepared by
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Executive Summary:

Clouds remain the largest source of uncertainty in our understanding of global climate change. Different aspects of the planetary cloud field can provide positive and negative feedback to the Earth's energy balance, and clouds of course are directly implicated in changes to the planetary distribution of precipitation. A fundamental problem in our current understanding of the role of clouds in the dynamics of climate are that current resolutions do not resolve the fundamental length scales associated with clouds. We expect our understanding of the role of clouds in climate to undergo a qualitative change as the resolutions of global models begin to encompass clouds. At these resolutions (which roughly scale with the tropopause height of 10km) non-hydrostatic dynamics become significant and deep convective processes are resolved. We are poised at the threshold of being able to run global scale simulations that include direct, non-parameterized, simulations of deep convective clouds. The goal of this research is to use the Argonne Leadership Computing Facility to explore the frontier of weather prediction and climate modeling with the newly developed Geophysical Fluid Dynamics (GFDL) global cloud-resolving model. A single unified atmospheric modeling system with a cubed-sphere dynamical core and bulk cloud micro-physics running at 3.5km resolutions was run with the goal of capturing the climatology of clouds and severe storms in a warming world. The ability to reproduce historical tropical storm statistics will be used as a test of this ground-breaking model.

Project Summary:

We have completed several 3-months of experiments with the 3.5km resolution global hydrostatic atmospheric model. The figures below show the preliminary diagnostics from the experiment.

A significant amount of development has been undertaken to improve the computational and I/O performance of HiRAM. Work has also continued on improving the post-processing diagnostic packages for the high-resolution experiments.

Computational Infrastructure:

The GFDL weather and climate models are built on the Flexible Modeling System (FMS). Details of FMS can be found at: http://www.gfdl.noaa.gov/fms. FMS is written primarily in FORTRAN 90 with approximately 0.75M lines of executable code. The model also utilizes a high-level hybrid MPI/OpenMP model in all of the component models (atmosphere, land …). The parallel I/O layer allows for both single and multi-threaded I/O, as well as quilted I/O from a subset of MPI ranks. Output data uses the netCDF4 library, including its parallel I/O, chucking and deflation options.

Performance Studies:

Considerable progress has been made to improvements to the computational FMS infrastructure. These improvements have included:

- Enabling the performance scaling of the FMS infrastructure. The results of this work are shown for HiRAM and Held-Suarez in Figures 1 and 2
- Implementing a memory footprint that scales with increasing core counts
- Incorporating a high-level hybrid programming model in all component models
- Providing an I/O scheme that scales with increasing core counts

Understanding the performance characteristics of HiRAM is an important component of the study. Through development of diagnostics tools, in collaboration with IBM Watson Research, the results of the studies with the diagnostic tools show that HiRAM at 3.5km resolution has the following computational foot-print:

- HPM characteristics: 40% FPX-60% FXU. 10B/cycle (not bandwidth limited)
- Model timer counters: Atmosphere=75%, Physics=15%, land and coupler=10%. (70% compute and 30% communication)

We have also produced line and function-level timing data which we are using to direct optimizations. The have identified additional regions for OpenMP threading and elimination of data copies at statement-level and across subroutine boundaries.

Improving the post-processing performance of the FMS infrastructure is a critical component of the project. The model currently generates 250GB of history data per model day. These history files are currently downloaded and post-processed at GFDL. There are approximately 0.10M lines of post-processing scripts and eventually these will need to be moved to a system closer to BG/Q.

The development activity are being expanded based on the success of this work and this will enable the entire FMS software including the component ocean and ice models to execute efficiently on BG/Q. We have also begun studies to:

- Extend the scalability of HiRAM beyond the 250,000 hardware threads current used in production
- Improve single core performance of the code. The areas for study include the implementation of: prefetch, transactional memory, and vectorization in the code
- Exploit additional forms of higher-level parallelism in the codes including improvements to our OpenMP implementation
- Examine the trade-offs between process and thread based parallelism.
- Possible implementation of partitioned global address space (PGAS) in the codes
- Implement a parallel I/O scheme for the non-distributed arrays.

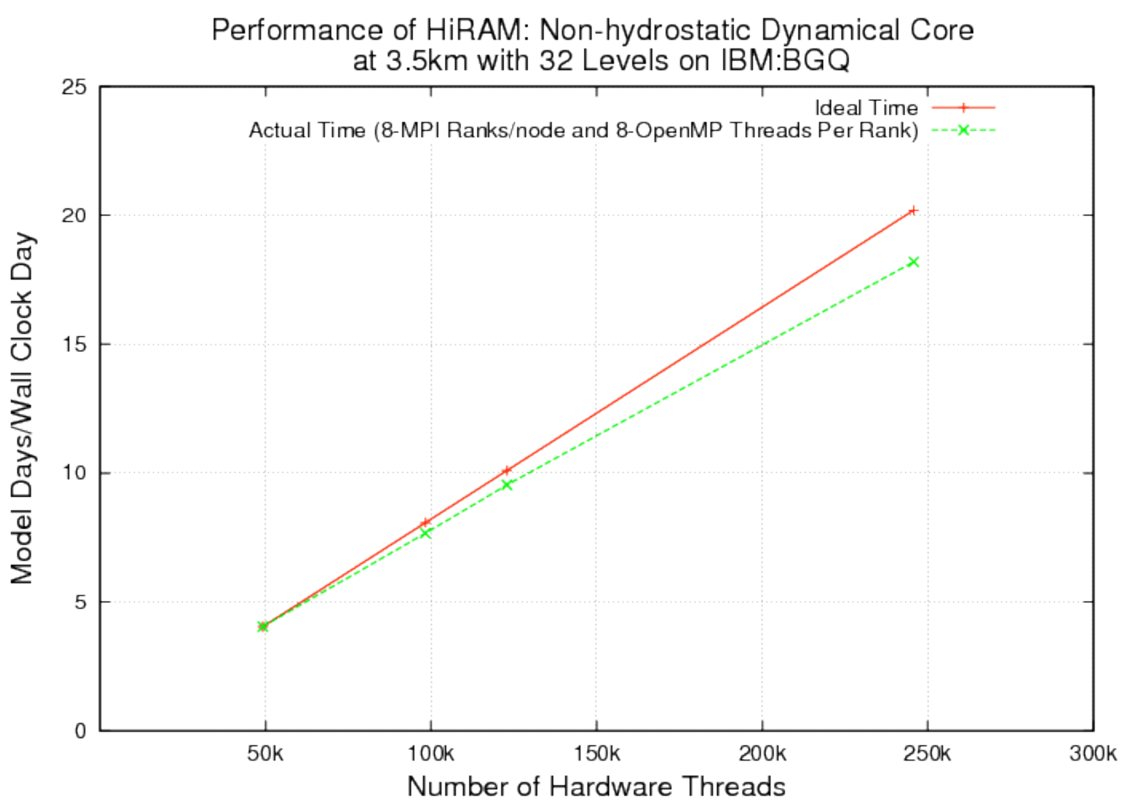

Figure 1: Shows the scaling of the global non-hydrostatic cloud-resolving model: HiRAM at 3.5km resolution. The model is configured to execute on 8-MPI Ranks/node and 8-OpenMP threads/rank. In production, HiRAM executes on either 15,360 or 30,720 MPI ranks with 8-MPI Ranks/node and 8-OpenMP threads/rank.

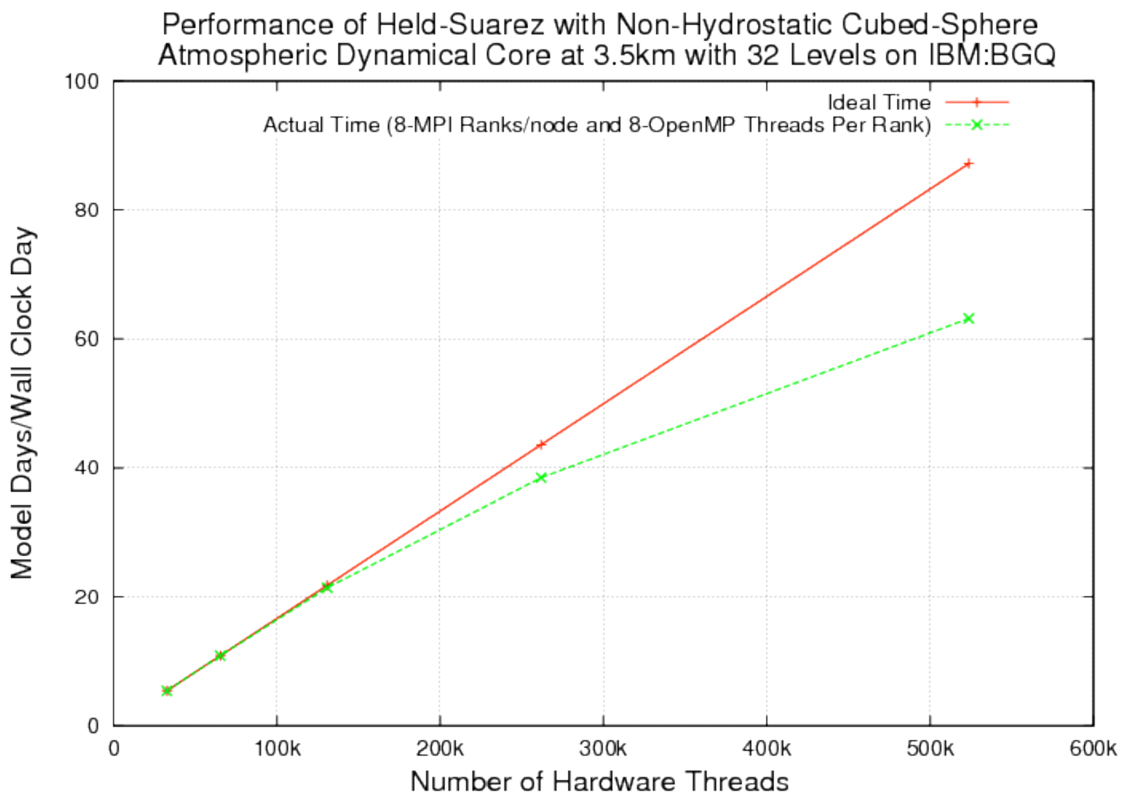

Figure 2: Shows the scaling of the Held-Suarez Test-Case with the Cubed-Sphere Dynamical Core at 3.5km resolution. The model is configured to execute on 8-MPI Ranks/node and 8-OpenMP threads/rank.

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