DEVELOPMENTS IN MULTISCALE CLIMATE MODELING WITH ADAPTIVE MESH REFINEMNT

EARTH SCIENCES DIVISION

BERKELEY LAB

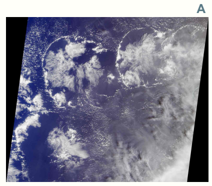
MULTISCALE METHODS FOR ACCURATE, EFFICIENT, AND SCALE-AWARE MODELS OF THE EARTH SYSTEM

James J. Benedict, W. D. Collins, J. N. Johnson (LBNL ESD) E. English, H. Johansen, P. McCorquodale (LBNL CRD / FASTMath)

SCIENCE DRIVERS

Motivation

The Climate and Environmental Sciences Division urges continued development of Earth system models to strengthen understanding and predictive skill of weather and climate. We know that:



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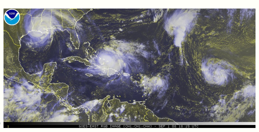
- Progress toward accurate climate simulations is impeded by known model biases linked to parameterized processes.
- Climate simulations improve when model grid resolutions approach characteristic scales of key phenomena like clouds.
- Simulations with globally uniform resolution at these scales require extreme computational resources.
- Models with variable-resolution global grids mitigate this problem by balancing the benefits of fine-scale resolution in targeted areas with increased computational burden.

Background

As part of the "SciDAC Multiscale" project, variable-resolution climate models are used to:

- Develop and implement "scale-aware" parameterizations & advanced numerical methods
- Prepare these models for future computing architectures allowing finer resolution.

We review recent progress in our effort to advance a variable-resolution climate model with dynamic adaptive mesh refinement (AMR) capabilities, called the "AMR dycore". The AMR dycore has an advanced design that accurately and efficiently tracks refined-grid patches that migrate with evolving features of interest rather than requiring enhanced resolution over the entire globe. A comprehensive physics parameterization package [1] is now being added to the AMR dycore to more accurately account for unresolved physical processes such as cumulus cloud behavior.



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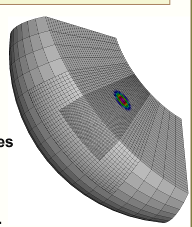
MODEL FEATURES

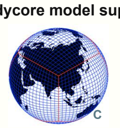
Global Grid: Cubed Sphere

- Stretched vertical grid ~ refined boundary layer resolution
- "Thin atmosphere" approximation (simplifies metrics)
- Gnomonic (great circle) horizontal coordinates on six panels
- 4th-order accurate least squares interpolation of conserved variables between cubed sphere faces



Mesh Refinement

- AMR dycore model supports various horizontal grid configurations:



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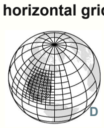
Uniform global grid ~ grid cells are approximately the same size



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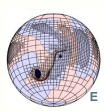
Static mesh refinement ~ grid cells differ in size but remain fixed in time



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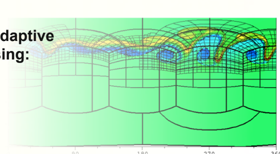
AMR ~ grid cell sizes evolve in time; high-res "patches" track migrating features (e.g., cyclones)

- Sub-integration in time limits computational expense to areas of highest resolution

Flow Equations and Integration

Using LBL's Chombo software package [2] to compute adaptive solutions of partial differential equations, we proceed using:

- Fully compressible Euler equations
- 4th-order accurate finite volume grid discretization
- Refinement in both space & time using "subcycling"



[3]

Treatment of Unresolved Processes

G

Climate models must continue to parameterize certain key processes. For the AMR dycore:

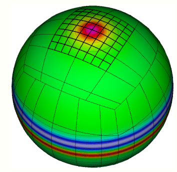
- Currently, only grid-scale condensation is supported
- We are now integrating the CAM5 physics parameterization package into AMR dycore to handle moist convection, radiation, and other physical processes

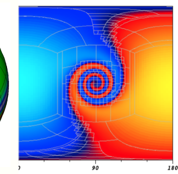
DEMONSTRATION OF METHODS

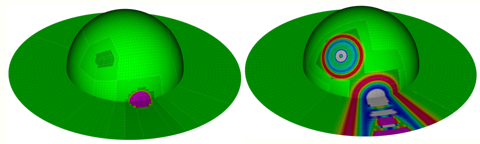
Tests in a Simplified Dynamical Framework

(Near R) Two-level AMR for shallow water equations: 4th-order accurate with a Gaussian initial condition.

(Far R) A tracer is transported around moving vortices with little numerical diffusion in a successful AMR 2D advection test. From [3].

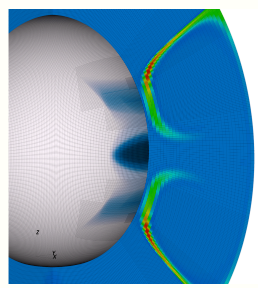






(L) Success of implicit-explicit 3D linearized wave equation test. Coarse vertical resolution requires the algorithm to be stable at 1000:1 aspect ratio.

Tests of Tracer Transport with Idealized Physics in a Prescribed Flow



Goal: Explore AMR dycore's ability to transport a tracer on a sphere with an evolving mesh at fine resolution

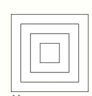
- AMR with 3 tiers (80km→20km horiz. resolution)
- 32 vertical levels
- Scenario: A simple surface flux of water vapor is advected in a Hadley cell flow field, and precipitates out as rain due a vertical temperature gradient.

(L) Simulation snapshot shows the tracer (water vapor in green/red shading) as it enters its second Hadley cell circuit. Rain (dark blue) has accumulated on the Earth surface. Fine-resolution areas track regions of large water vapor, indicating AMR is functioning correctly.

SCIENCE IMPACT

Applications

The AMR dycore is a powerful tool with which to explore several computational and scientific issues related to multiscale climate modeling:



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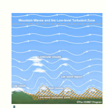
Tests "scale-awareness" of parameterizations



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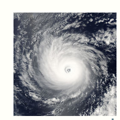
Well-suited to accurately simulate orographic flows



J

Well-suited to simulate non-stationary, intermittent, multiscale weather phenomena such as tropical cyclones, atmospheric rivers, and the MJO

Long-term Vision

The techniques used to construct the AMR dycore will benefit the climate modeling community for years to come. Parameterization of certain physical processes continues to be unavoidable. Even as model resolutions become finer and computational resources more powerful, multiscale grids will continue to act as an efficient intermediate step between feasible globally uniform grid resolutions and those just beyond our capabilities.

REFERENCES AND ACKNOWLDGEMENTS

[1] Neale, R. B., and Coauthors, 2012: Description of the NCAR Communicty Atmosphere Model (CAM 5.0). NCAR Technical Note TN-486, available: http://www.cesm.ucar.edu/models/cesm1.0/cam/docs/description/cam5_desc.pdf

[2] Information on the Chombo software package is available at: http://chombo.lbl.gov/

[3] Ferguson, J., and C. Jablonowksi, 2014: Assessments of the Chombo AMR Model in Shallow Water Mode. Workshop on Partial Differential Equations on the Sphere (PDES), Boulder, CO. April 2014.

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