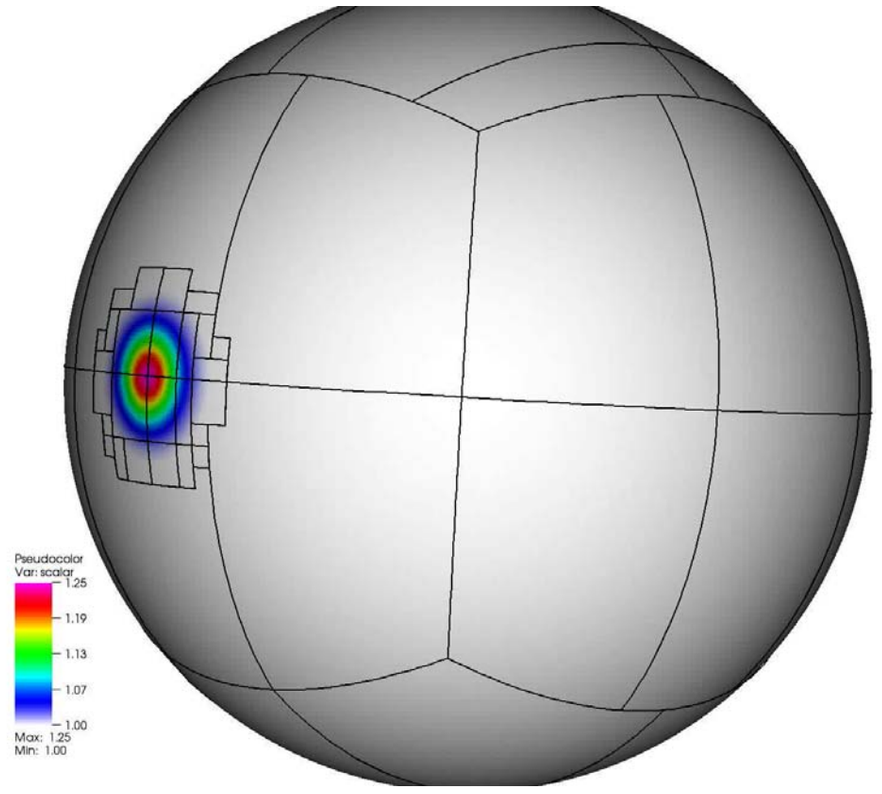
Developments in Global AMR Simulations with Chombo



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Outline

- Chombo-AMR and its place in the global climate model hierarchy
- "Chombo-AMR": Chombo dynamical core with adaptive mesh refinement
- Chombo-AMR strengths and weaknesses
- Preliminary test simulations
- Current status and future steps

Global Climate Model Family Tree

Conventional GCMs

Fast, efficient, familiar

Coarse, uniform grid

Compartmentalized parameterizations

Numerous assumptions

ex: CAM5, AM3

Global CRM

Computationally demanding

Global ~3 km uniform grid

Simplified microphysics

Cloud system behavior explicitly resolved

ex: NICAM

MMF/ Superparameterization

Becoming faster

Coarse-grid GCM with embedded CRM

Identifiable deficiencies

Cloud system behavior explicitly resolved

ex: SPCAM

Variable-grid models

Balances speed, computing resources

Stretched or tiered grid

Scale-aware parameterization testbed

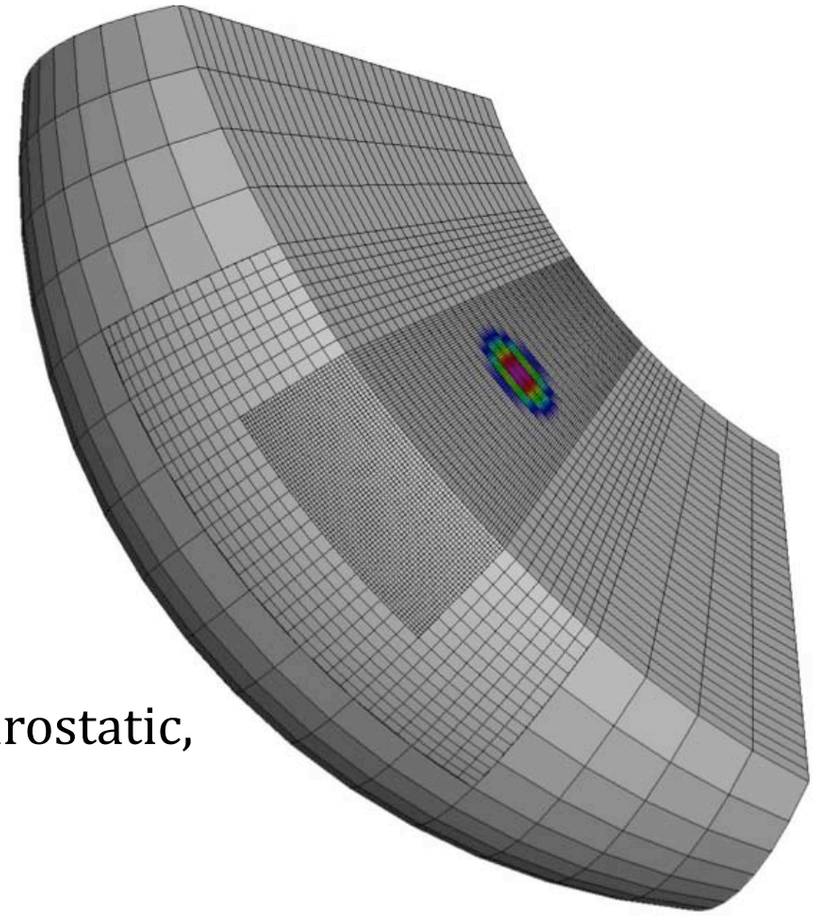
Cloud systems can be resolved

ex: CAM-SE, CAM-MPAS, Chombo-AMR

About Chombo-AMR

`chombo (Swahili): tool, vessel, container`

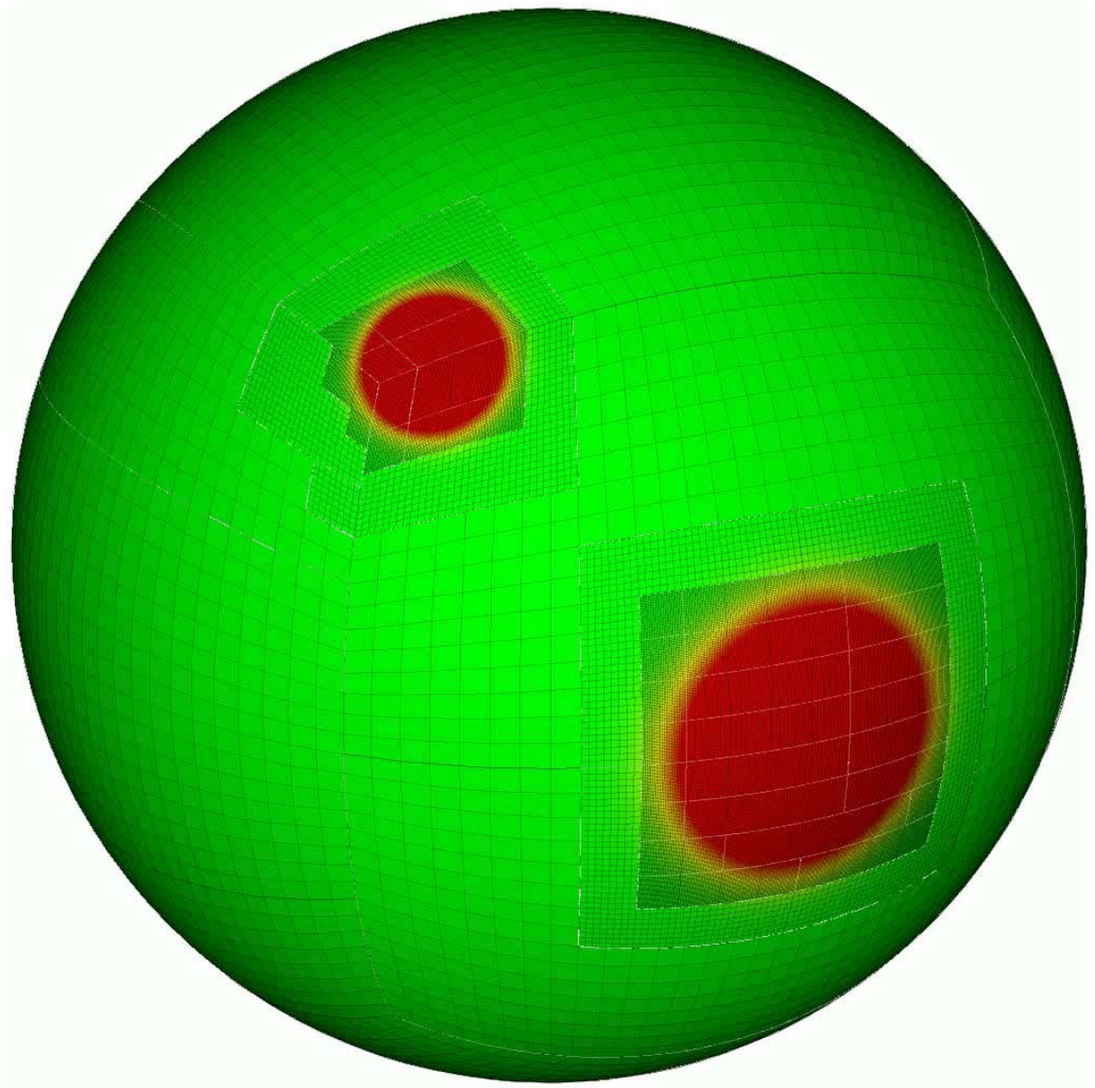
- Open-source toolset for implementing finite difference methods to solve PDEs on block-structured adaptively refined rectangular grids
- Successful implementation in fluid mechanics, geochemistry, plasmas, and ice sheet dynamics



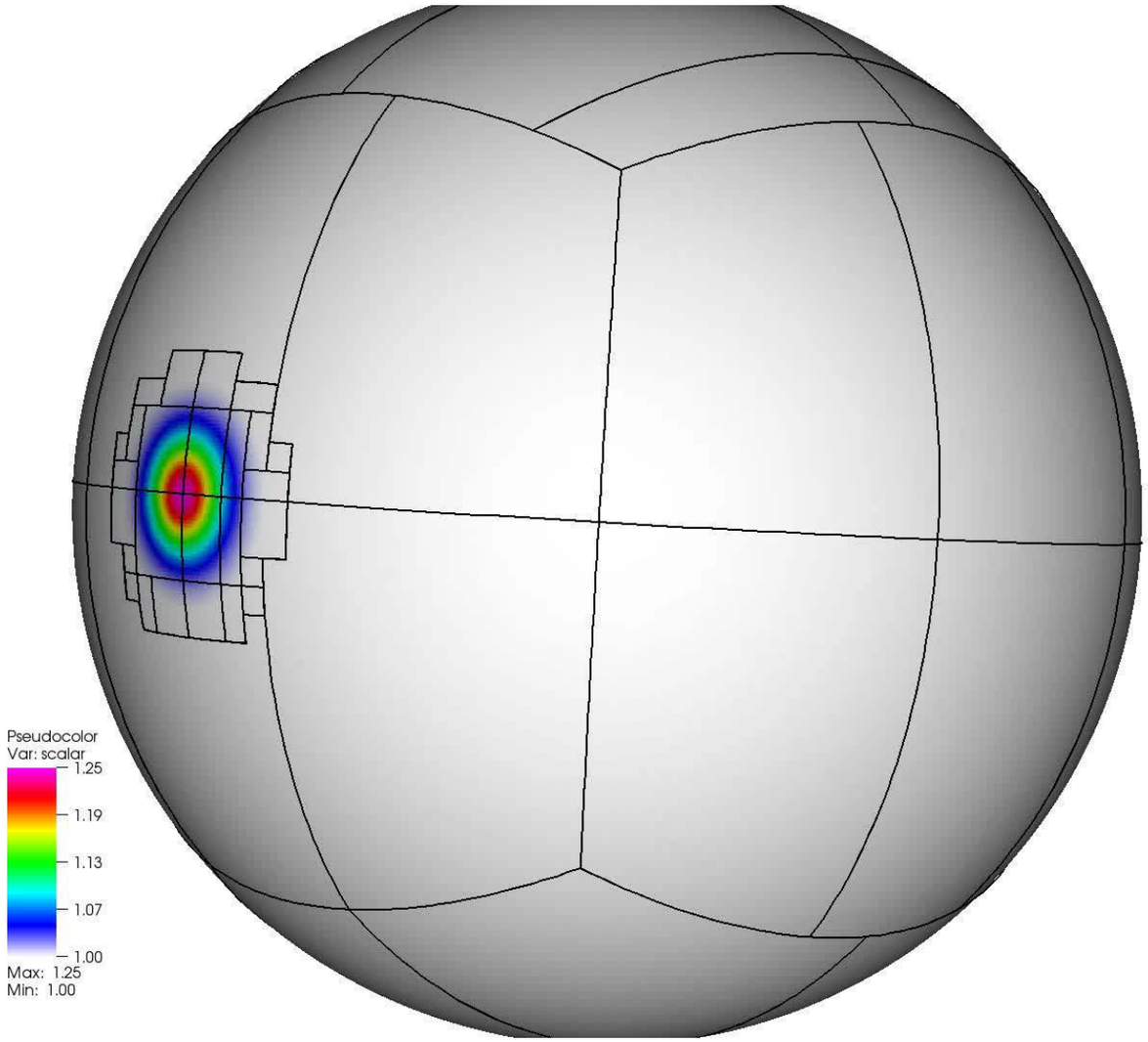
Application to climate simulations:

- Cubed sphere geometry
- Fourth-order accurate finite volume discretization to solve nonhydrostatic, fully compressible Euler equations
- Dynamic grid refinement in both space and time
- Additive implicit-explicit Runge-Kutta time stepping

Adaptive Mesh Refinement (AMR)



Linearized wave equation

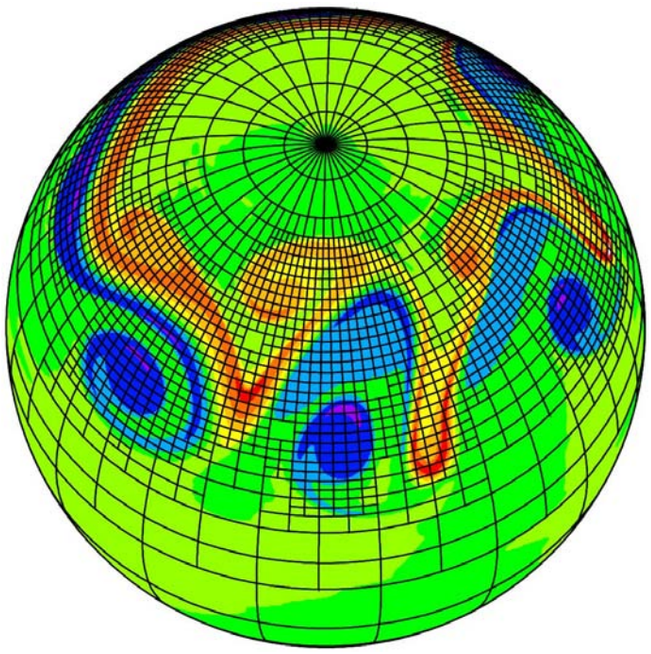


2D advection

Chombo-AMR Attributes

STRENGTHS

- Fourth-order space-time accuracy
- Dynamic scalability to the petascale
- Ideal testbed for “scale-aware” parameterizations and process integration (time coupling, operator splitting)
- AMR minimizes computational cost by targeting features of interest



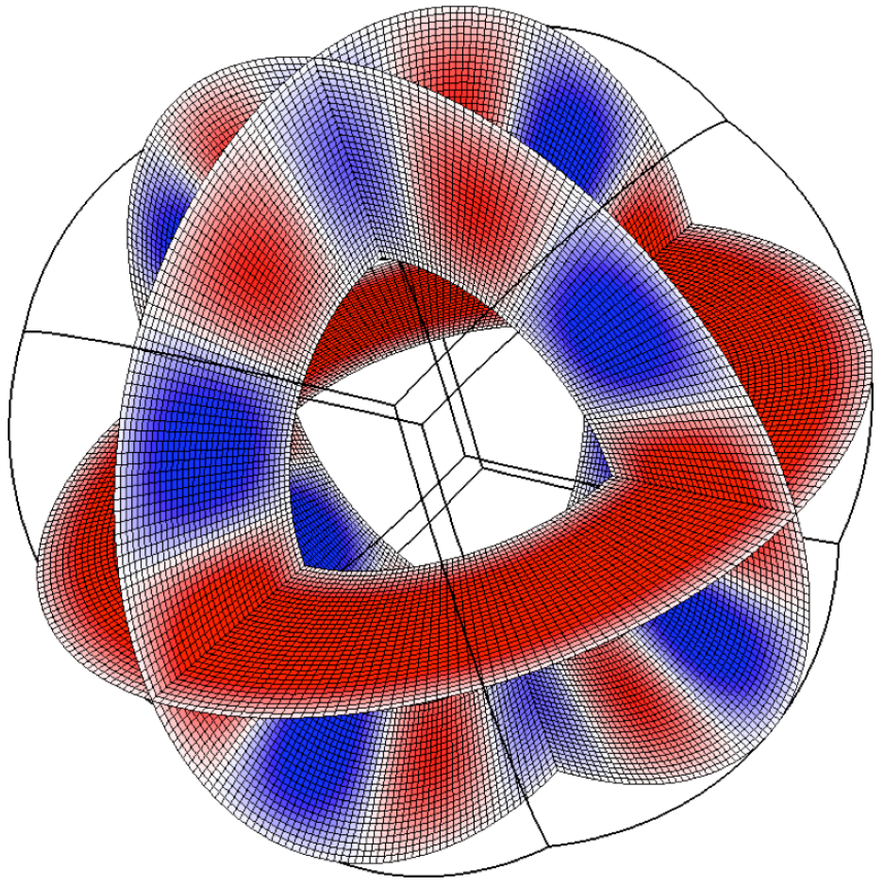
St-Cyr et al. 2008, MWR

WEAKNESSES

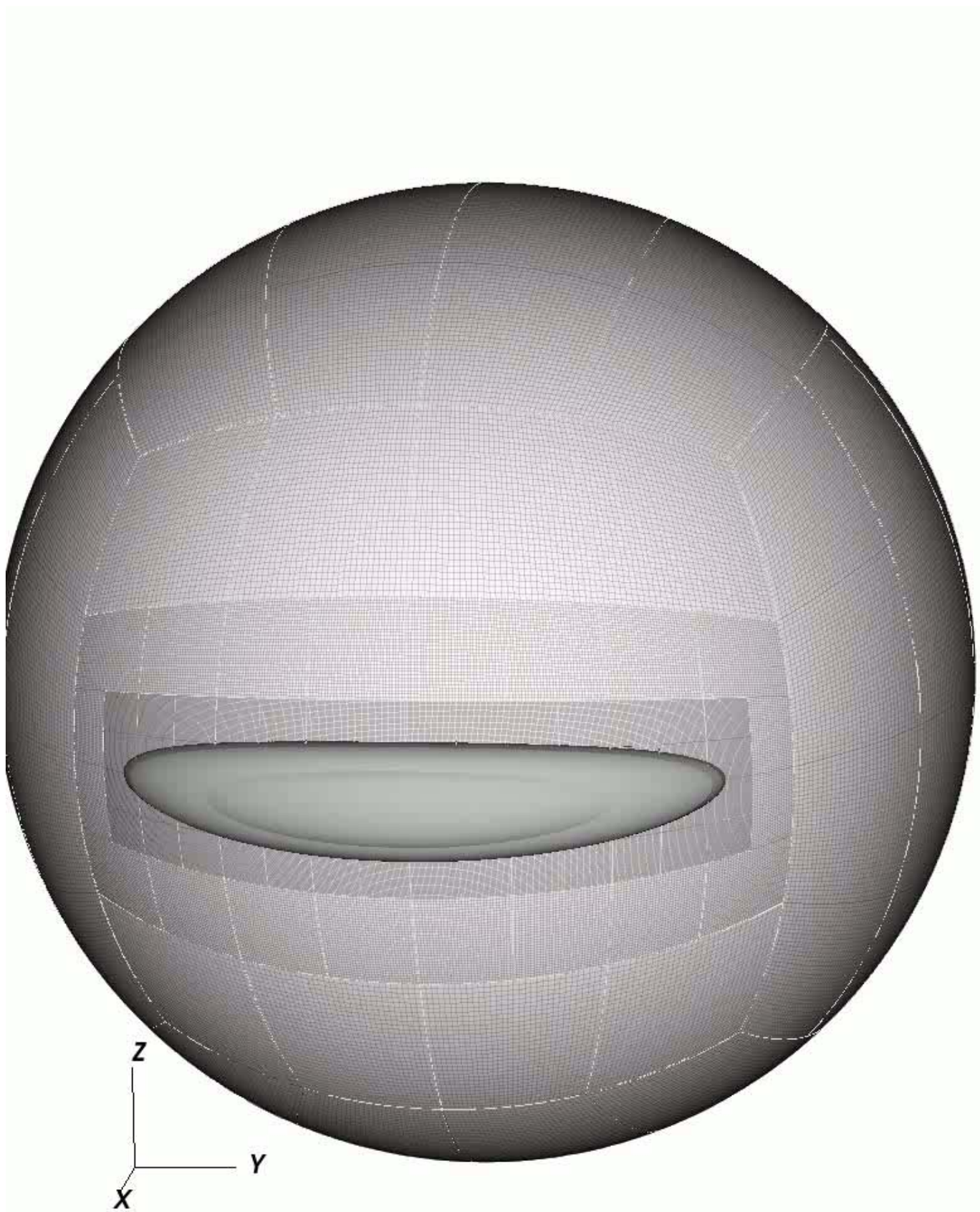
- Slower than conventional GCM
- Requires parameterizations to accommodate multiple scales
- Ongoing development, operational unknowns

Chombo-AMR Test Simulations

- Description: "Hadley cell advection"
- Horizontal grid: Adaptive space-time mesh refinement in 3 tiers (80km → 20km)
- Vertical grid: 32 levels
- Aquaplanet, idealized Equator-Pole SST gradient



- Dynamics: Prescribed Hadley cell flow, hydrostatic background state
- Physics: Large-scale condensation
- Moisture source: Time-periodic "MJO-like" perturbed surface moisture flux patch

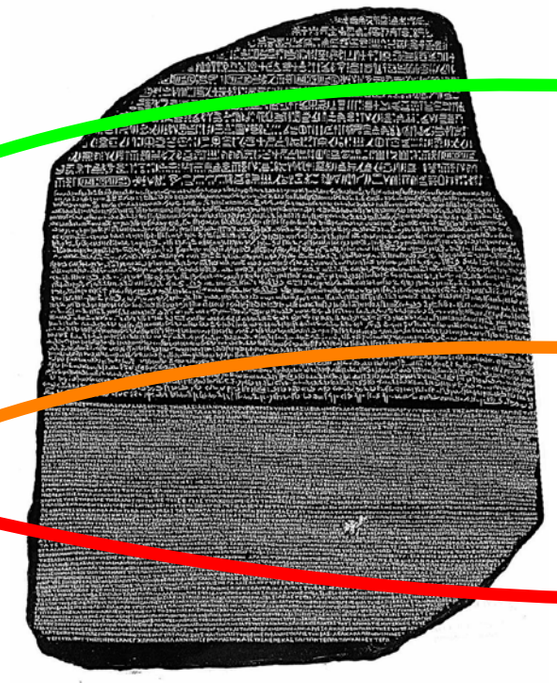


Chombo animation courtesy
of E. English, (CRD, LBL)

Dynamics-Physics Coupling Tests

Chombo driver program, dynamical core

Euler



"Intermediary"

CAM initialized using Chombo inputs

Chombo passes atmospheric state to CAM

CAM returns physics tendencies

CAM column physics

markosun.wordpress.com

Future Steps

Near-term:

- Complete and test “wiring” between Chombo and CAM physics
- Finish implementing nonhydrostatic dycore
- Complete DCMIP tests and additional AMR-relevant tests (e.g., vortex tracking)

Long-term:

- Use mesh refinement to examine multiscale nature of tropical convection
- Couple mixed-layer ocean (KPP) to Chombo
- Explore impact of refined air-sea coupling on tropical cyclones

Photo credit: Ismail Saddik/Photobucket

Summary

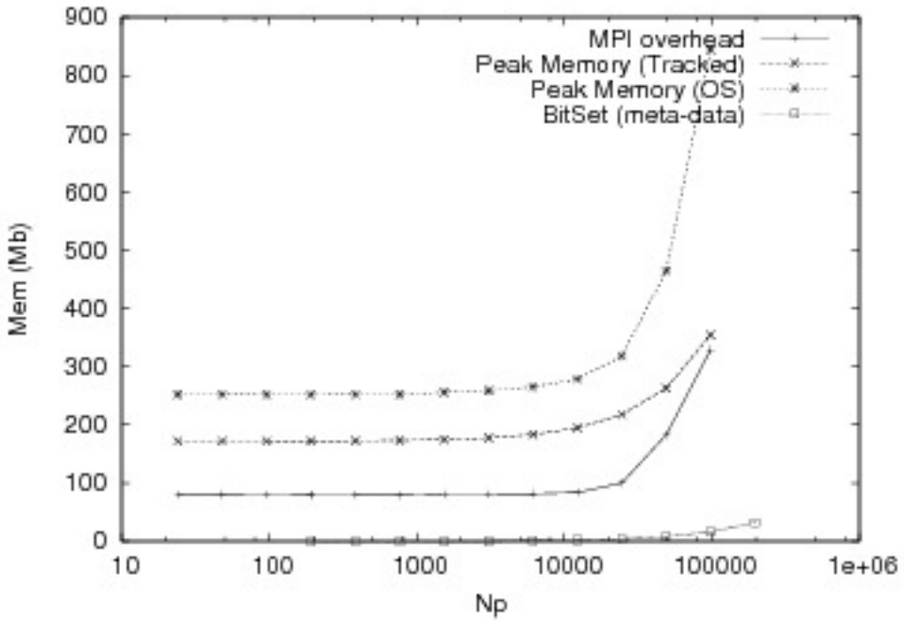
- Nonhydrostatic, high-order dycore with adaptive mesh refinement (Chombo-AMR) is being developed and tested
- Idealized Chombo-AMR test simulations are promising
- Wiring Chombo-AMR to CAM physics is ongoing...
- Long-term: Explore multiscale tropical convection

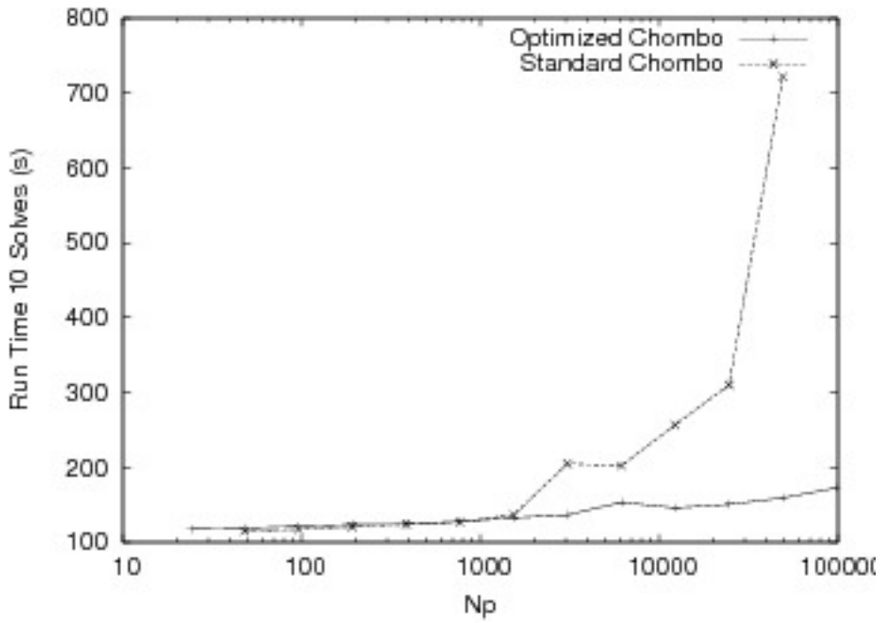
Funding source(s)

SciDAC (DOE) project “Multiscale Methods for Accurate, Efficient, and Scale-Aware Models of the Earth System”

(Supplementary)

Elliptic problem





Hyperbolic problem