Analysis of the MPAS hydrostatic dynamical core in aqua-planet mode

Todd Ringler

Theoretical Division
Los Alamos National Laboratory

Los Alamos NATIONAL LABORATORY EST. 1943

Climate, Ocean and Sea-Ice Modeling Project
http://public.lanl.gov/ringler/ringler.html

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Actually, I am going to cover a much broader scope.

A more appropriate title might be ....

Model for Prediction Across Scales: A Novel Approach for Global-to-Regional Climate Simulation

Contributors:

LANL: S. Rauscher, L. Dong, M. Petersen, M. Maltrud, P. Jones, D. Jacobsen, C. Newman, J. Graham

NCAR: W. Skamarock, M. Duda, J. Klemp

LLNL: A. Mirin

Florida State University: M. Gunzburger, Q. Chen

University of South Carolina: L. Ju

MPAS
Model for Prediction Across Scales

Global-to-regional climate simulation for atmosphere, ocean and ice systems.

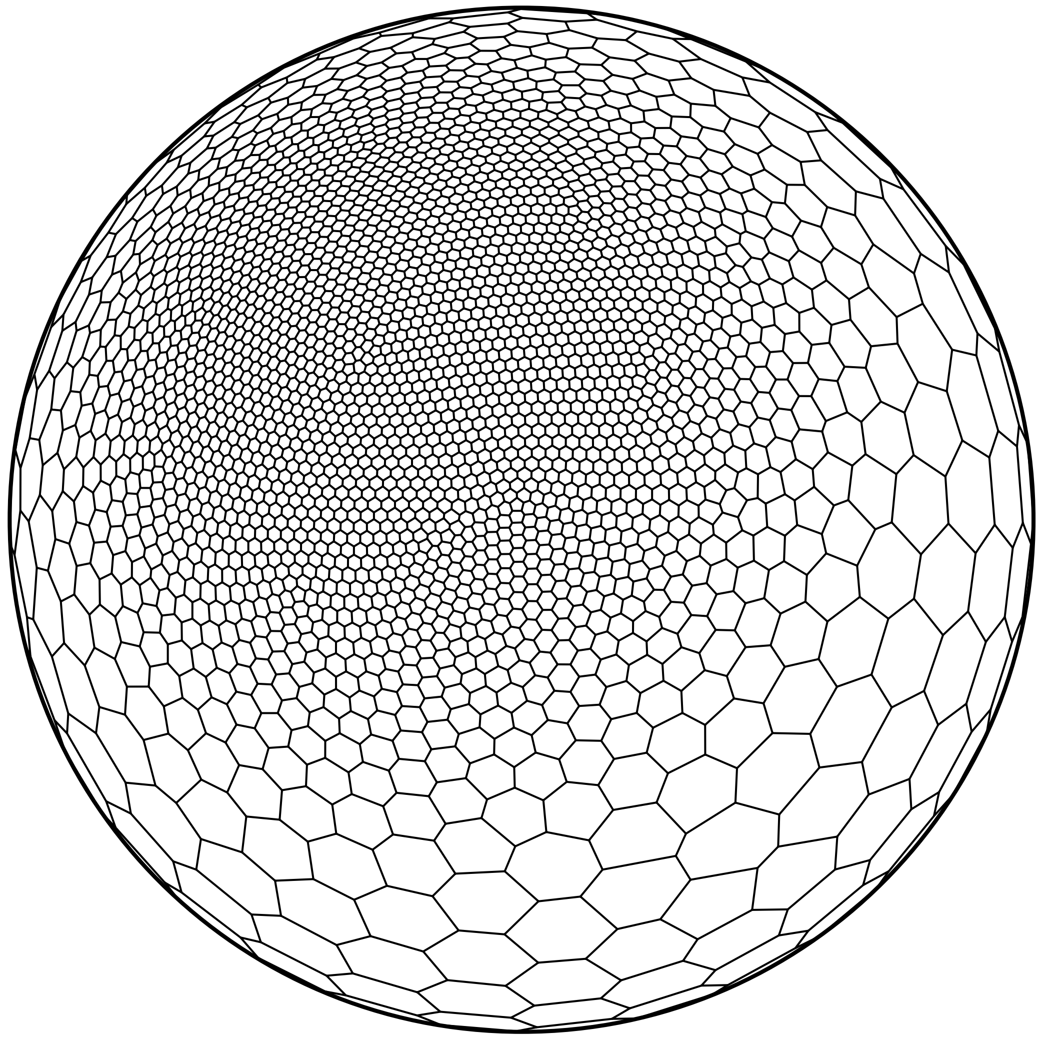
1. MPAS is an unstructured-grid approach to climate system modeling.

2. MPAS supports both quasi-uniform and variable resolution meshing of the sphere using quadrilaterals, triangles or Voronoi tessellations.

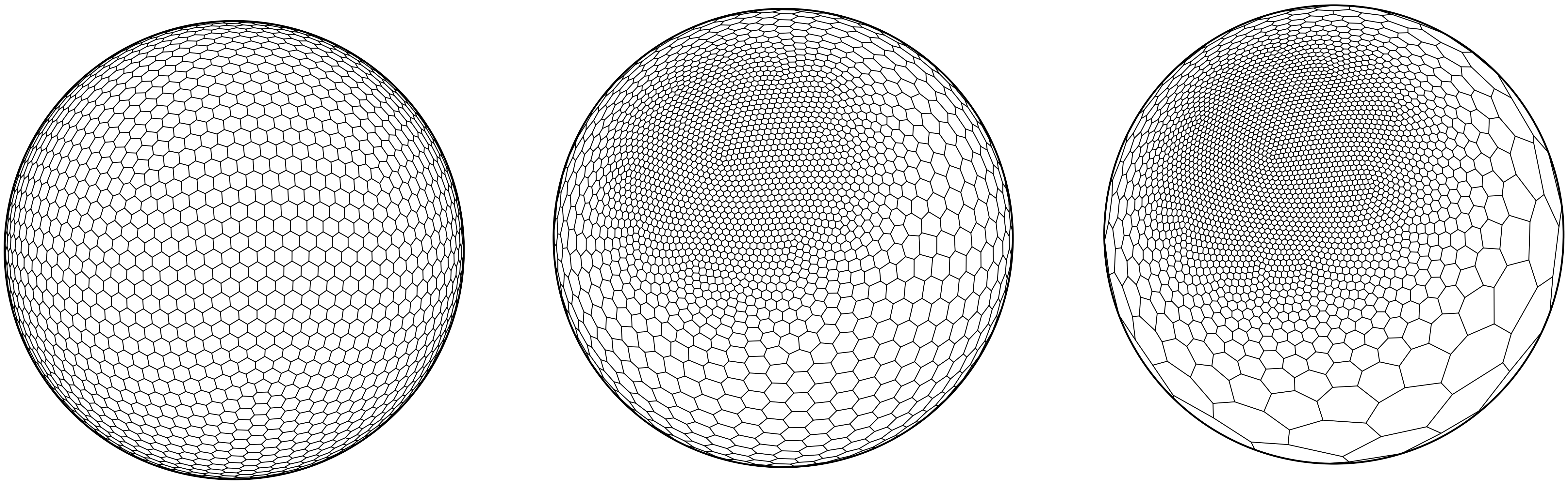
3. MPAS is a software framework for the rapid prototyping of single-components of climate system models (atmosphere, ocean, land ice, etc.).

4. MPAS offers the potential to explore regional-scale climate change within the context of global climate system modeling. Multiple high-resolution regions are permitted.

5. MPAS is currently structured as a partnership between NCAR MMM and LANL COSIM, where we intend to distribute our models through open-source, 3rd-party facilities (e.g. Sourceforge).



Pillar #1:Spherical Centroidal Voronoi Tessellations: Various ways to distribute 2562 nodes on the sphere.



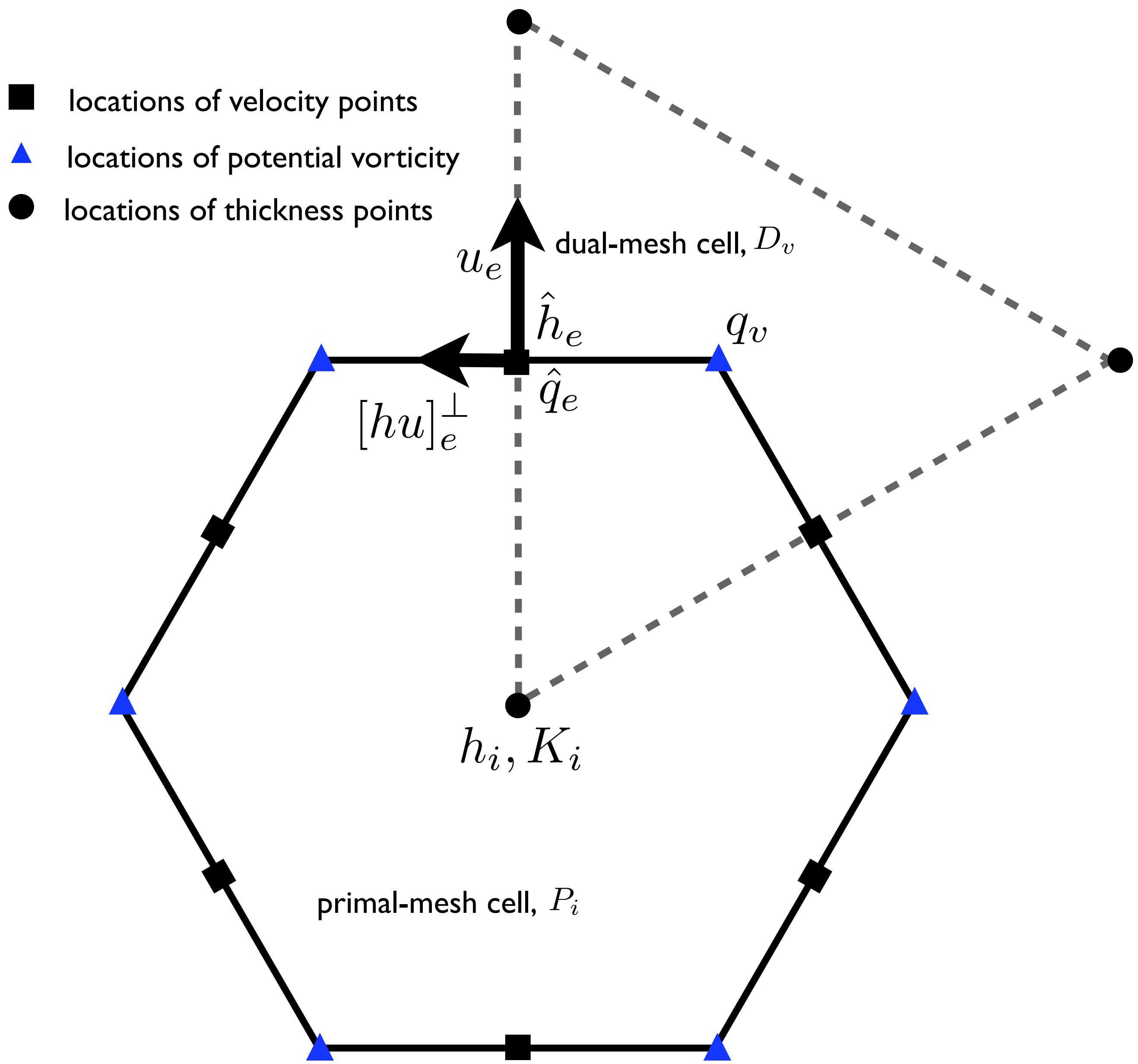
x1 x4 x16

1. The meshes are simple to produce.
2. The local resolution is controlled by a single, user-specified scalar function.
3. We have very precise control over the distribution of local grid resolution.
4. We have mathematical guarantees on the mesh quality.

• Ju, L., T. Ringler and M. Gunzburber, 2010, Voronoi Tessellations and their Application to Climate and Global Modeling, Numerical Techniques for Global Atmospheric Models, Lecture Notes in Computational Science. (pdf).

• Ringler, T., L. Ju and M. Gunzburger, 2008, A multiresolution method for climate system modeling: application of spherical centroidal Voronoi tessellations, Ocean Dynamics, 58 (5-6), 475-498. doi:10.1007/s10236-008-0157-2 (link)

Pillar #2: A Robust, Multi-Resolution Finite-Volume Solver



C-grid staggering applicable to any locally-orthogonal mesh.

Conserves mass, tracers and potential vorticity to round-off error.

Conserves total energy to within time-truncation error.

Dissipates potential energy using the anticipated potential vorticity method.

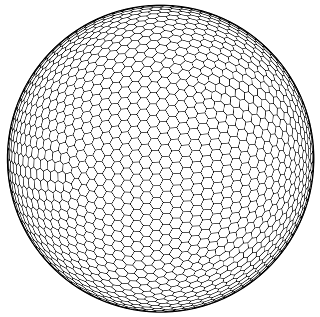
In summary, the finite-volume solvers has all of the properties that we expect in an atmosphere/ocean dynamical core.

• Thuburn, J., T. Ringler, J. Klemp and W. Skamarock, 2009: Numerical representation of geostrophic modes on arbitrarily structured C-grids, Journal of Computational Physics, 2009: 228 (22), 8321-8335. doi:10.1016/j.jcp.2009.08.006 (pdf)

• Ringler, T., J. Thuburn, J. Klemp and W. Skamarock, 2010: A unified approach to energy conservation and potential vorticity dynamics on arbitrarily structured C-grids, Journal of Computational Physics, doi:10.1016/j.jcp.2009.12.007 (pdf)

• Chen, Q., M. Gunzburger and T. Ringler, 2011: A scale-invariant formulation of the anticipated potential vorticity method, Monthly Weather Review, 39, 2614-2629. DOI: 10.1175/MWR-D-10-05004.1 (pdf)

A Hierarchical Approach to Regional Climate Simulation: An Analysis of the Shallow-Water Equations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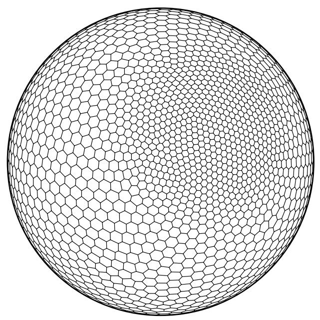
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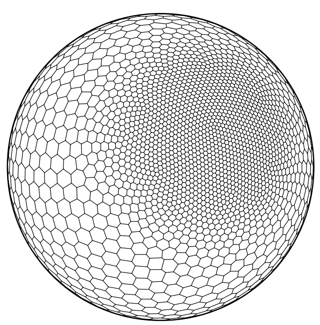
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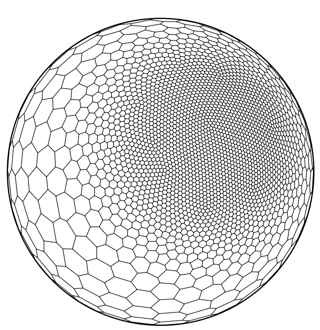
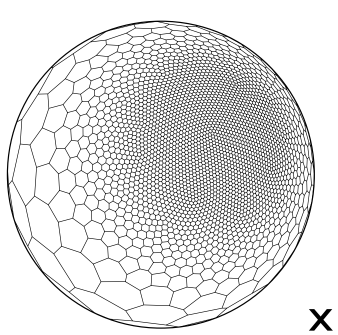

x8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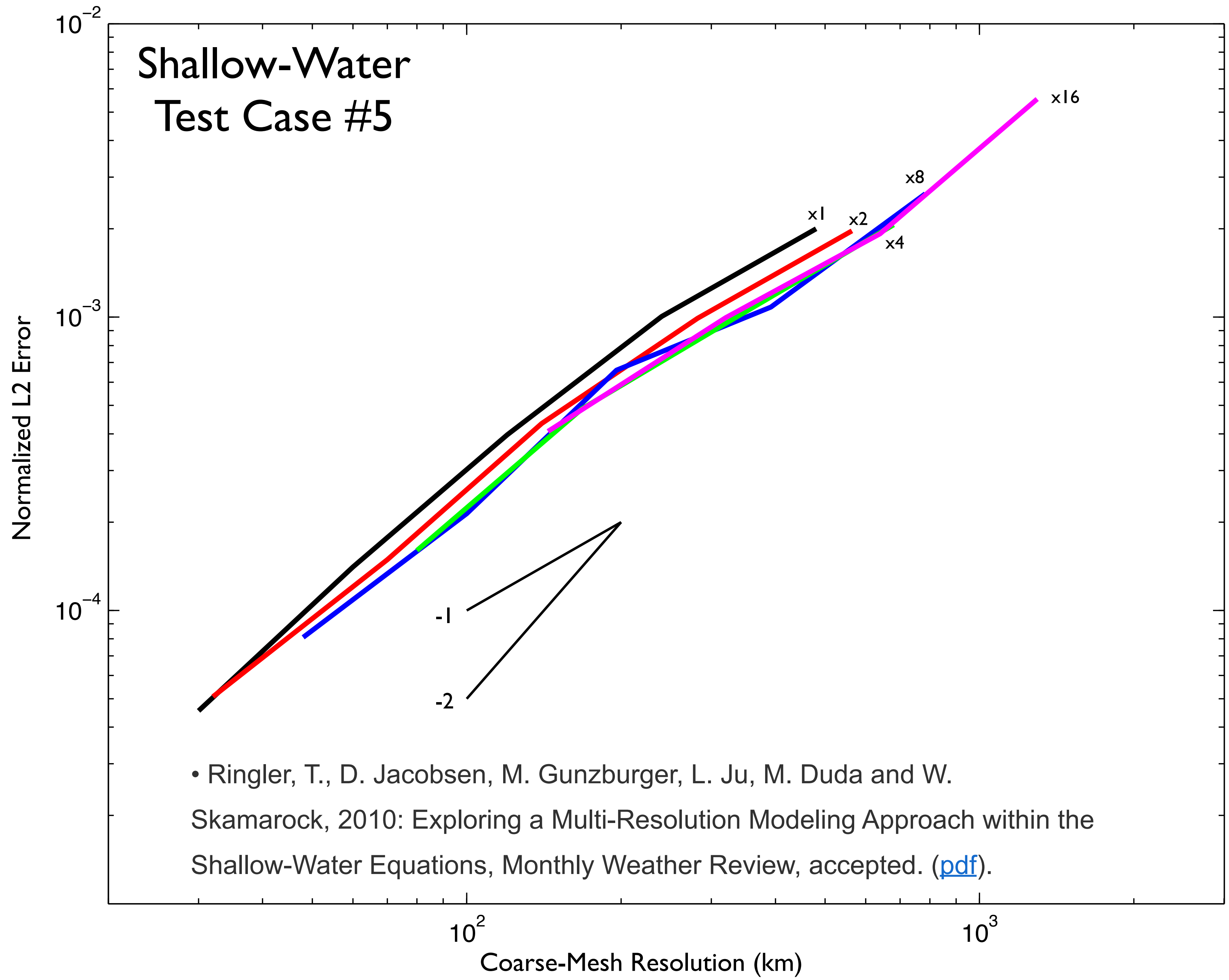
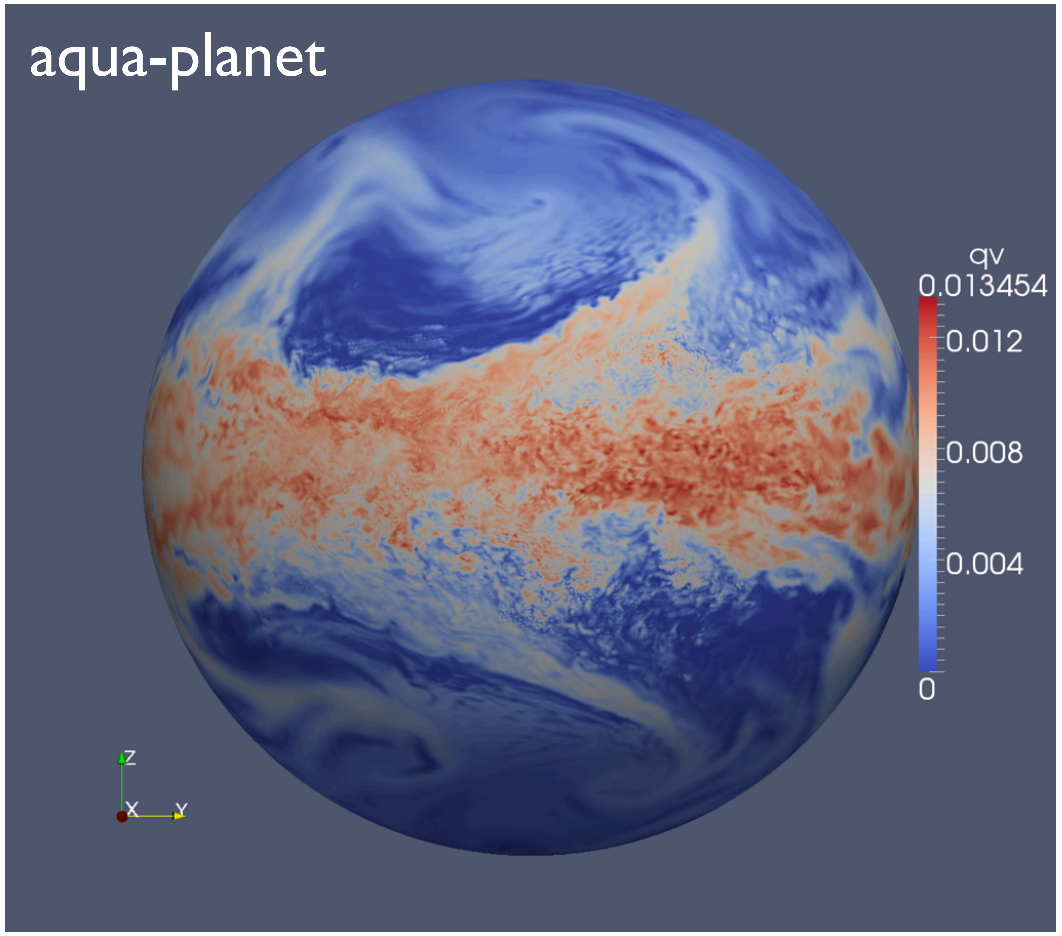


Conclusion: We can increase resolution locally in order to resolve regional features (i.e. clouds, ocean eddies, bathymetry, etc.) without increasing doing any harm to the global solution.

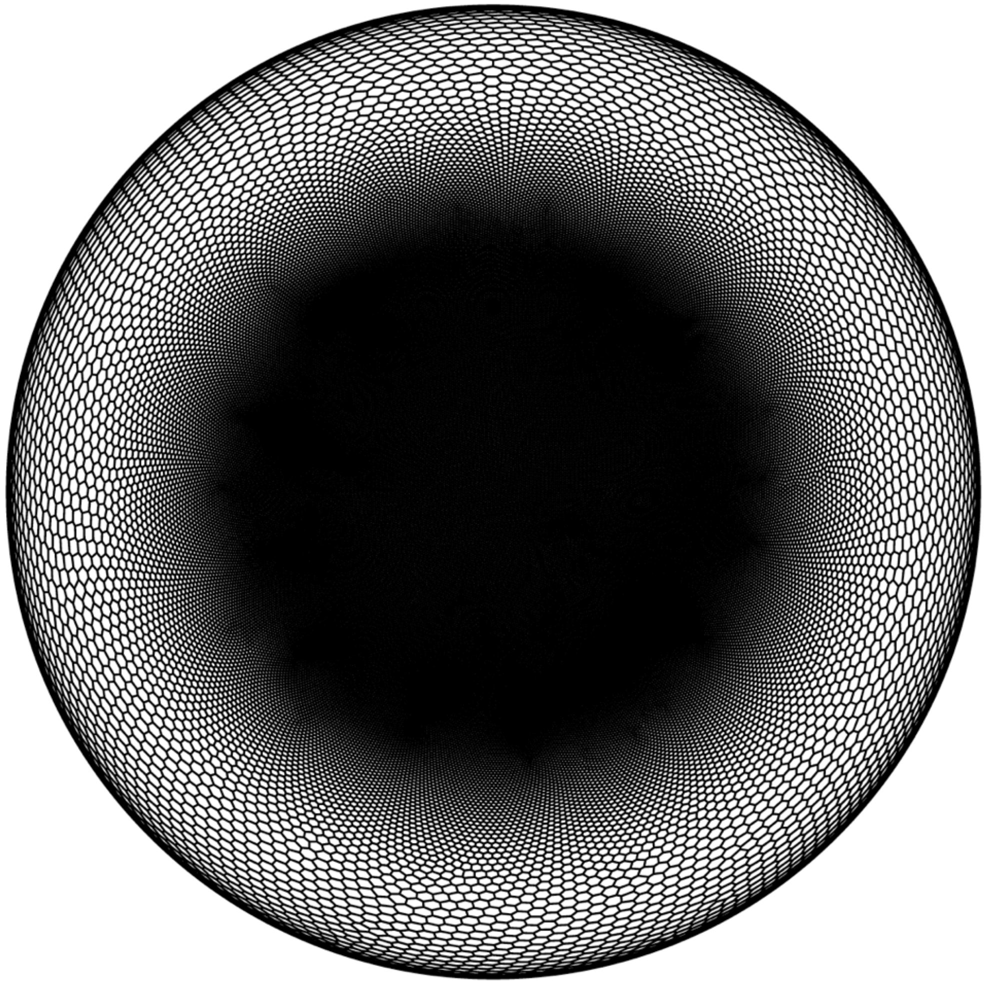
Evaluation of the MPAS-approach in Aqua-Planet Simulations.

The LANL/NCAR team is evaluating this approach in the context of the atmosphere hydrostatic system in aqua-planet mode using CAM4 physics.

The variable resolution mesh (right) has ~30 km grid spacing in the fine-mesh region and ~240 km in the coarse mesh region. It uses 1/10 the number of grid points as a global, quasi-uniform mesh of 30 km.



Snapshot of water vapor (kg/kg) at 450 hPa.
Figure centered on high resolution region.

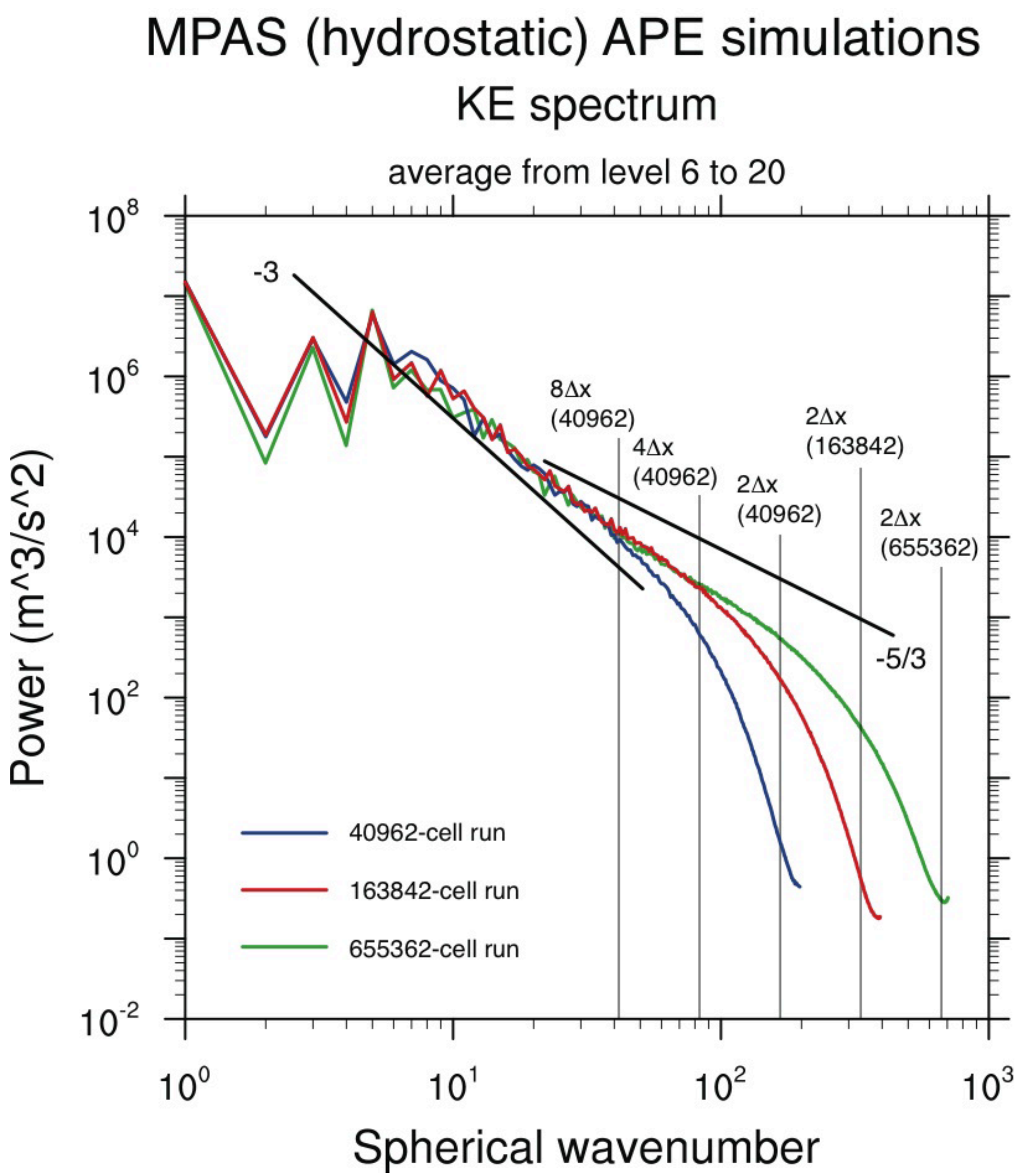


30 to 240 km mesh

Model for Prediction Across Scales
Evaluation of Aqua-Planet Simulations

Description of Simulations

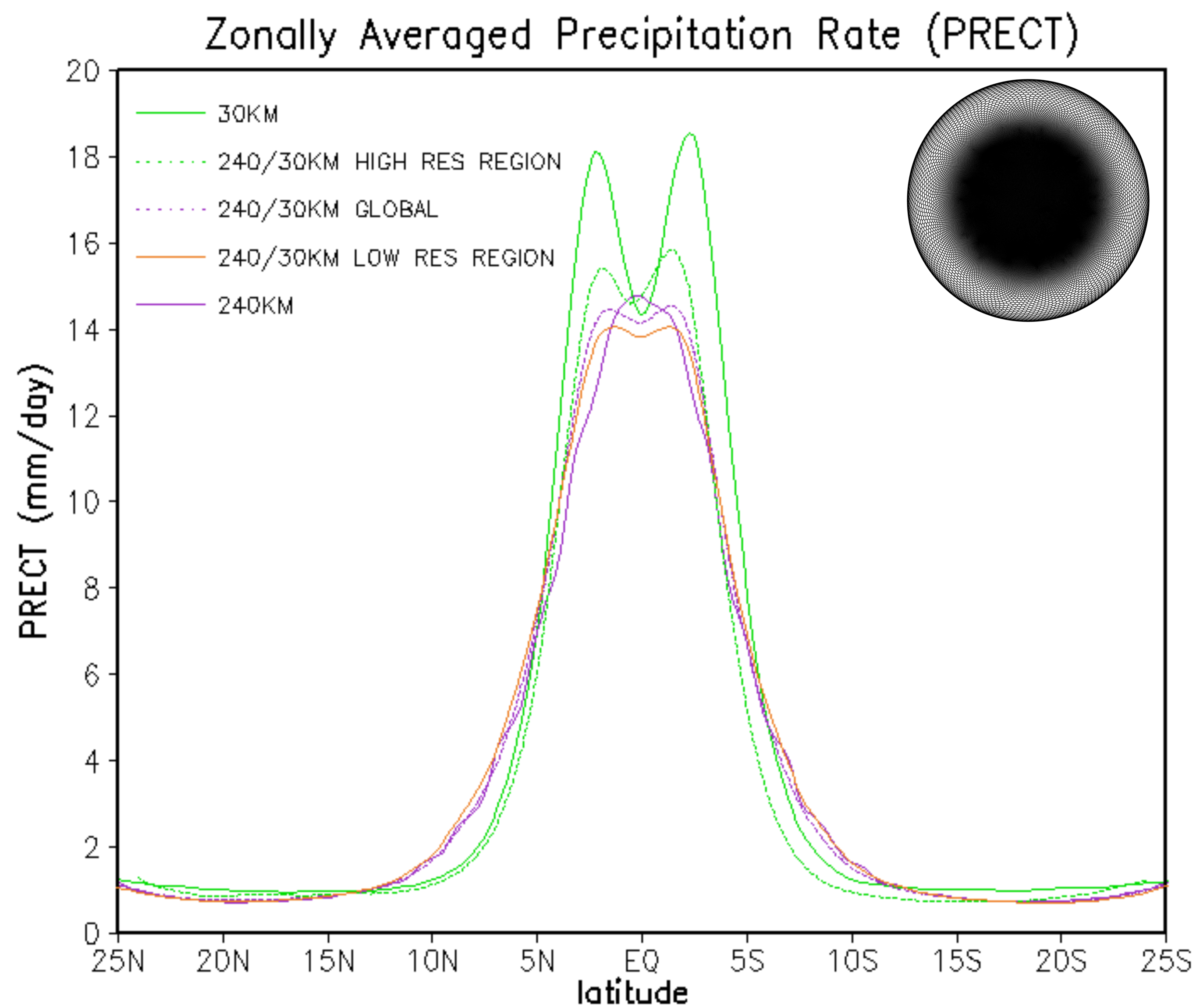
Resolution	Hyperdiffusion	Physics time step	Dynamics time step	Simulation length (will eventually be 4 years for each) All sims but 30km have 0.5 years spinup
10242 (~240km)	5e15	600 seconds	100 seconds	2 years
40962 (~120km)	5e14	600 seconds	100 seconds	2 years
163842 (~60km)	5e13	600 seconds	100 seconds	2 years
655362 (~30km)	5e12	600 seconds	100 seconds	4 months (1 month spinup)
65538 (~240km->30km)	Scaled by mesh density from 5e15 to 5e12	600 seconds	100 seconds	2 years



Consistent with Nastrom and Gage (1985) we see a transition from -3 to -5/3 slope at a horizontal scale of approximately 400 km. (Note, 480 km is about 4 dx on the 40962 mesh.

Model for Prediction Across Scales: Understanding multi-resolution aqua-planet simulations

resolution (km)	global precip (mm/day)	high-res precip (mm/day)
30	3.18	5.20
240	2.93	4.53
30-240	2.97	4.37



Strong interaction between the low- and high-resolution regions of 30-240 km run is apparent.

The double ITCZ found in the global 30 km run is found in the high-res region of the 30-240 km run, but not with the same amplitude.

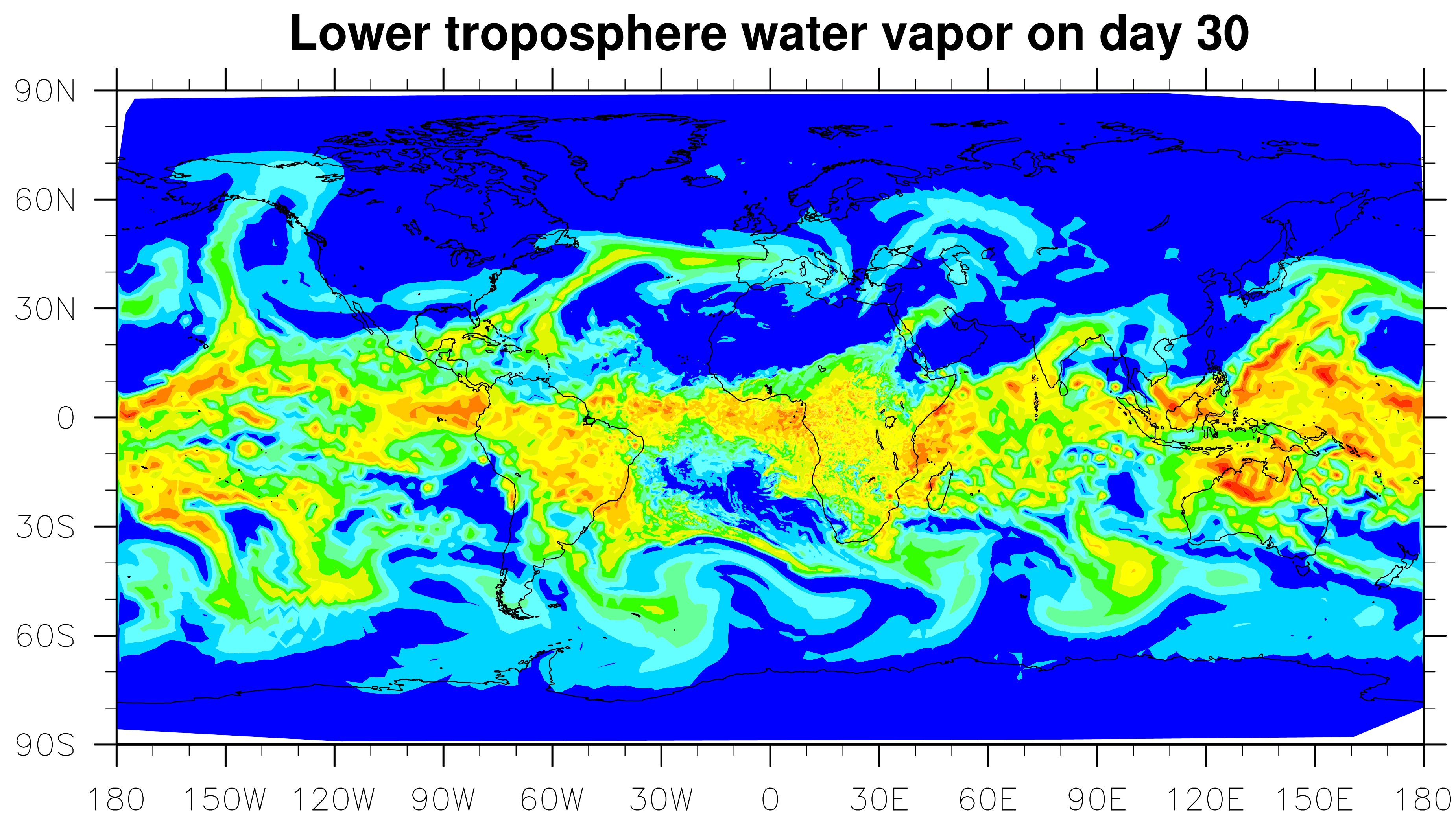
Hints of a double ITCZ are found in the low-resolution region of the 30-240 km run, even though the global 240 km run shows only a single ITCZ.

see Petersen talk in Global Ocean breakout
see Ringler talk in High Resolution breakout

We have configured the MPAS atmosphere model in an AMIP-style, real-world configuration.

Several years of simulation at 120 km completed. The analysis is ongoing.

Issues with negative weights in remapping files have precluded multi-year simulations with the 30-to-240 km mesh.

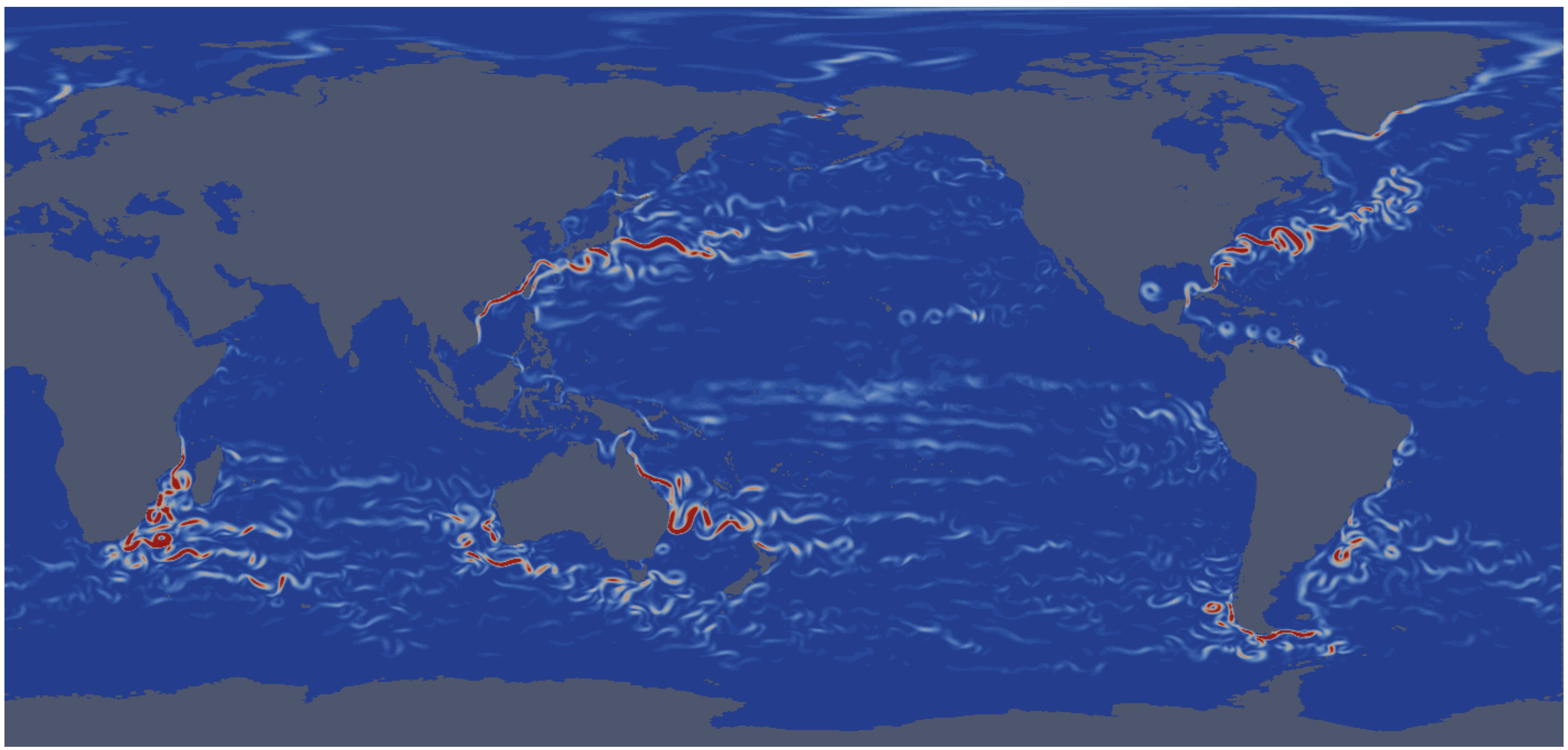


Snap-shot of water vapor from lower troposphere at day 30 in 30-240 km simulation. High-resolution region is centered in figure.

Evaluation of the MPAS-approach in Ocean Simulations.

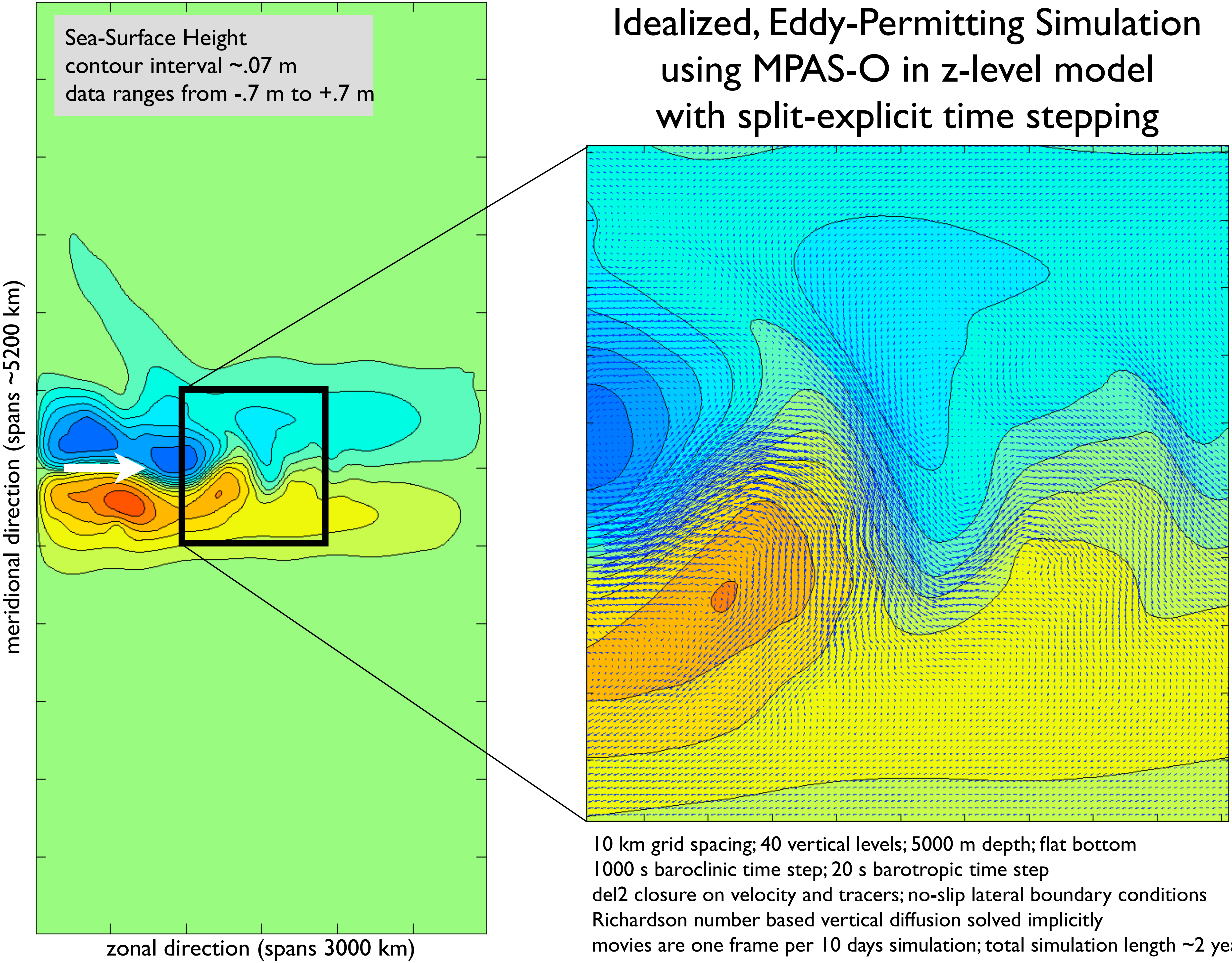
The LANL team is evaluating this approach in the context of ocean hydrostatic system using idealized and real-world configurations.

MPAS-O is our next-generation prototype global ocean model, i.e. MPAS-O is the model that we hope/expect will replace POP as our community distributed ocean model.



Snap-shot of surface kinetic energy from a global 30km MPAS-O simulation.

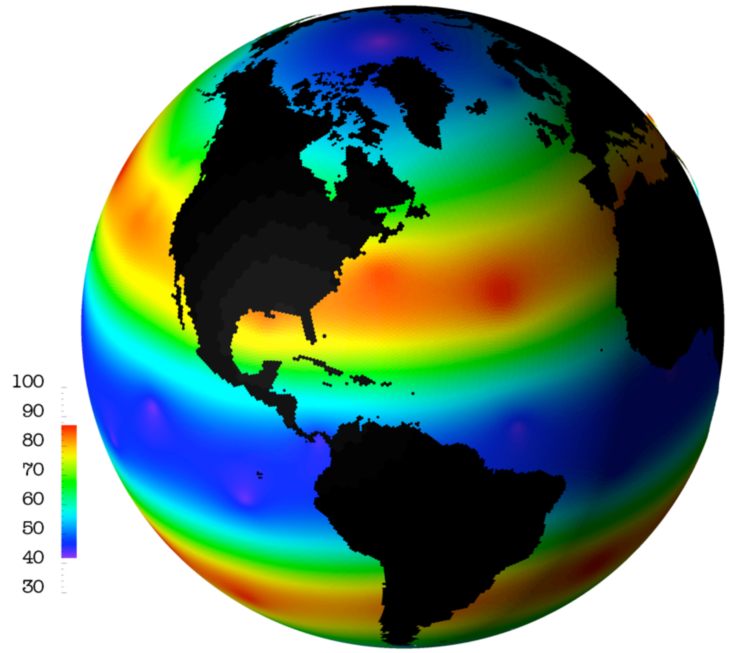
Idealized, Eddy-Permitting Simulation using MPAS-O in z-level model with split-explicit time stepping



10 km grid spacing; 40 vertical levels; 5000 m depth; flat bottom
1000 s baroclinic time step; 20 s barotropic time step
del2 closure on velocity and tracers; no-slip lateral boundary conditions
Richardson number based vertical diffusion solved implicitly
movies are one frame per 10 days simulation; total simulation length ~2 years

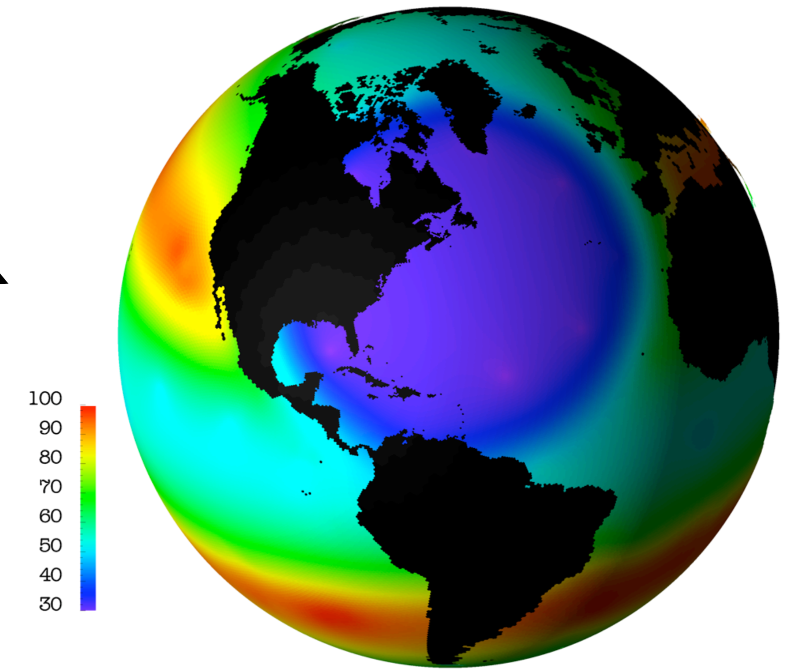
2. Exploring a multi-resolution approach to global ocean modeling: Demonstrating the value of a multi-resolution approach.

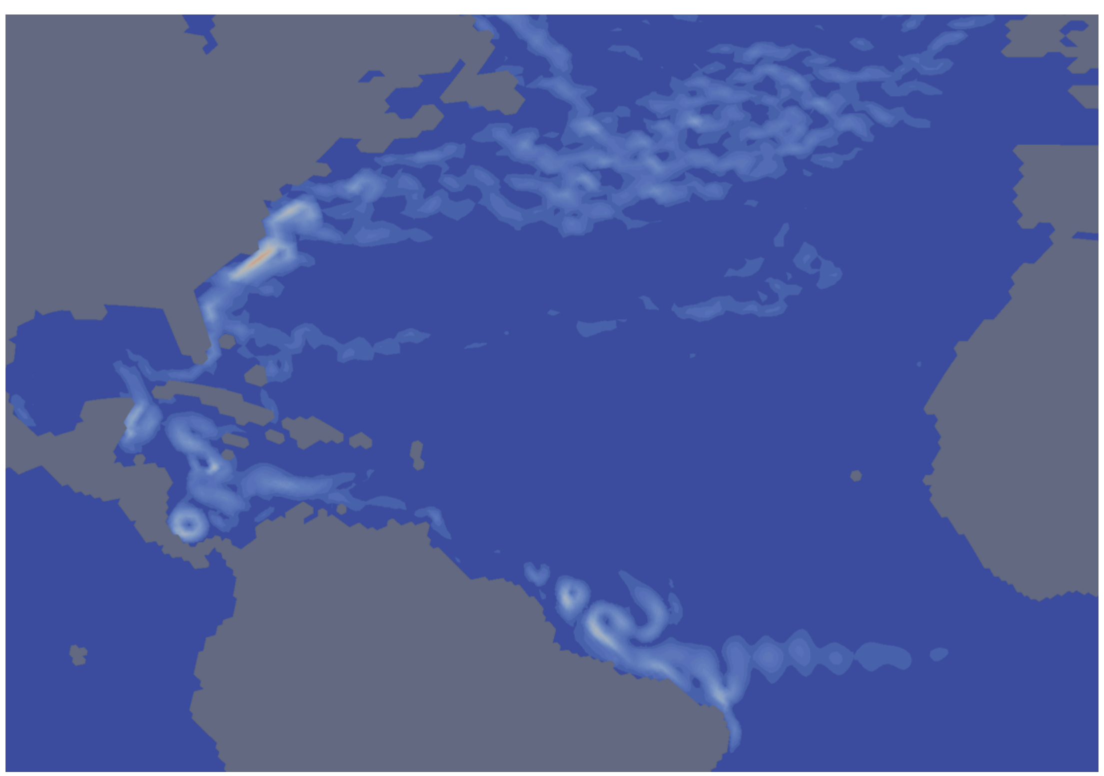
R60km: local grid resolution



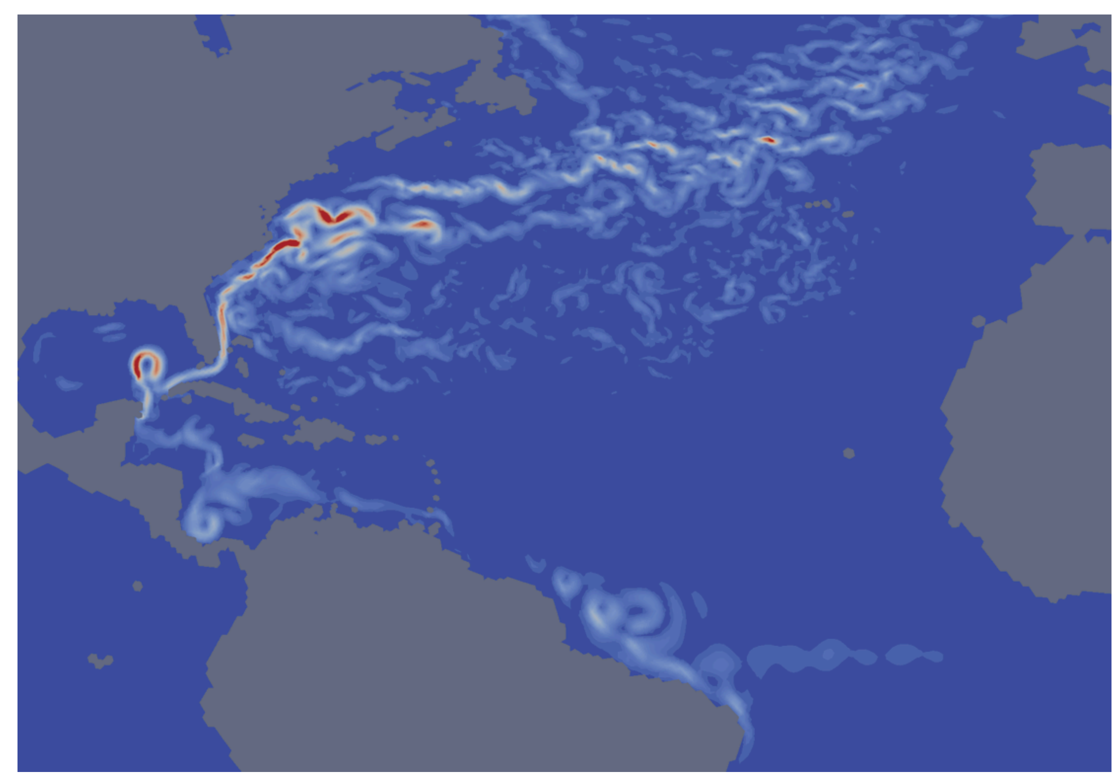
same number of grid cells

R60kmNA: local grid resolution





surface kinetic energy



surface kinetic energy

Model development goals for the next 12 months.

Atmosphere:

Publish multi-resolution aqua-planet simulations. (Rauscher, Skamarock et al.)
Multi-decadal AMIP-style simulations with ~20 km resolution over NA (Dong et al.)
Conduct coupled-climate simulations using high-res POP ocean (Dong et al.)

Ocean:

Design coupling interface to allow use of MPAS-O with the CESM (w/ NCAR CGD)
Write Paper #1 introducing MPAS-O to community (Ringler et al.)
Write Paper #2 comparing MPAS-O to POP (Petersen et al.)
Optimize algorithms (Jacobsen, Jones, et al.)
Develop LES closures for multi-resolution meshs (Graham et al.)
Test multi-resolution formulations of Gent-McWilliams (Chen, Gent, et al.)

MPAS

Model for Prediction Across Scales

Thanks!