

Status of MPAS-O

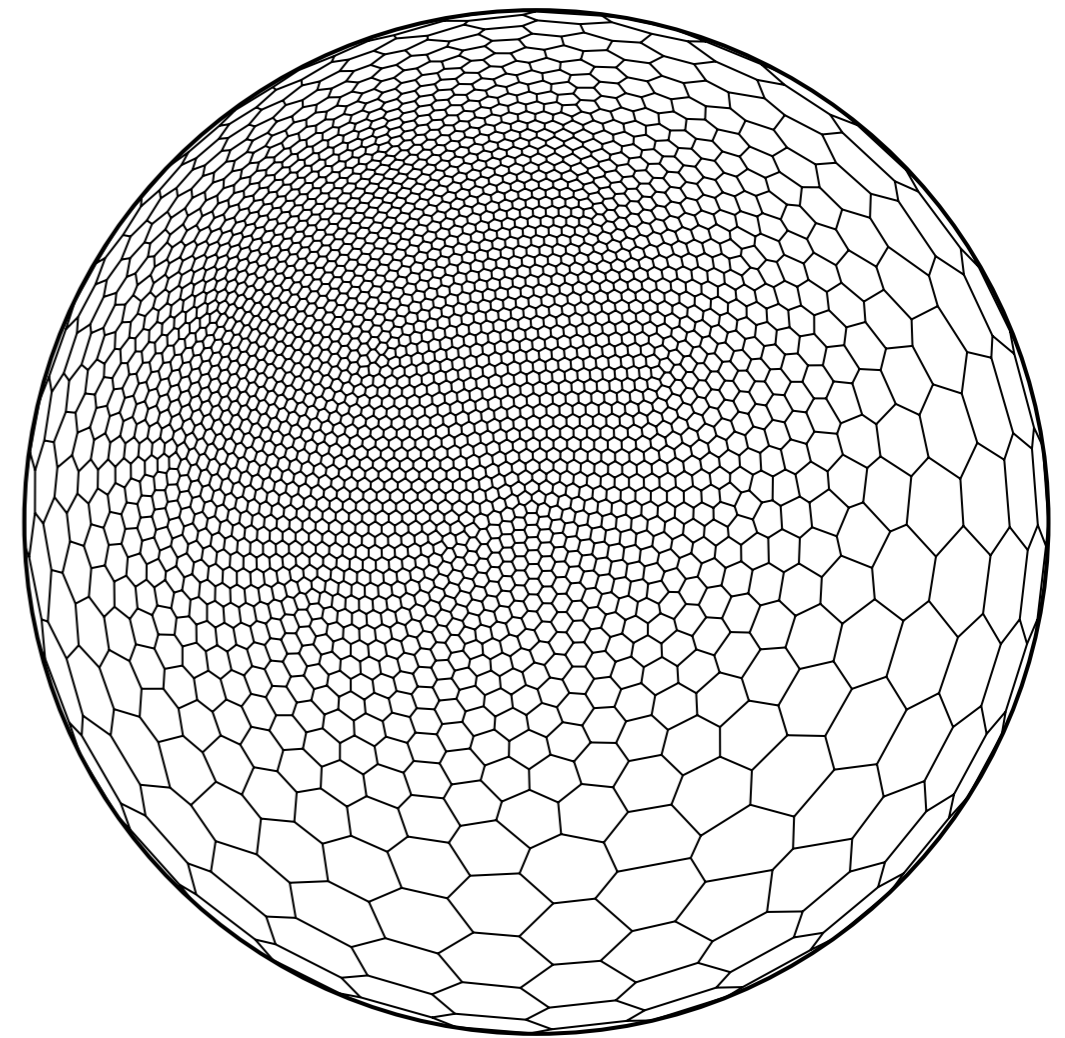
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Climate, Ocean and Sea-Ice Modeling Project
<http://public.lanl.gov/ringler/ringler.html>

What is MPAS?

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).



MPAS Component Development Teams

MPAS-Ocean Team:

Todd Ringler, Mark Petersen, Mat Maltrud, Chris Newman, Bob Higdon, Doug Jacobsen, Rob Lowrie, Jonathan Graham, Qingshan Chen

MPAS-Atmos Hydrostatic Team:

Bill Skamarock, Todd Ringler, Michael Duda, Sara Rauscher, Li Dong, Art Mirin, Chris Jeffery

MPAS-Atmos Non-Hydrostatic Team:

Bill Skamarock, Michael Duda, Laura Fowler and others in MMM

MPAS-Land Ice Team:

Bill Lipscomb, Steve Price, John Burkhart, Xylar Asay-Davis, Lili Ju, Max Gunzburger, Mauro Perego

All model components share a majority of their source code, are built from the same Makefile and will likely be used within the CESM.

A summary of the MPAS-O capabilities

Choice of isopycnal or z-level vertical coordinate at runtime.

Configurable with idealized or real-world boundary/forcing at runtime.

Can run on quad grids (i.e. POP meshes) or Voronoi tessellations.

Can run in quasi-uniform mode or with an arbitrary number of high-resolution regions.

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Can run on quad grids (i.e. POP meshes) or Voronoi tessellations.

Can run in quasi-uniform mode or with an arbitrary number of high-resolution regions.

High-order reconstruction for horizontal and **vertical transport**.

Laplacian and/or bi-harmonic mixing of velocity and tracers.

Nonlinear equation of state (Jackett and McDougall).

Pacanowski and Philander Richardson Number based vertical mixing.

Implicit solve for vertical mixing.

Two-time level, split-explicit time-stepping scheme (implemented and being tested).

Exact tracer conservation.

(**Items** discussed on following slides.)

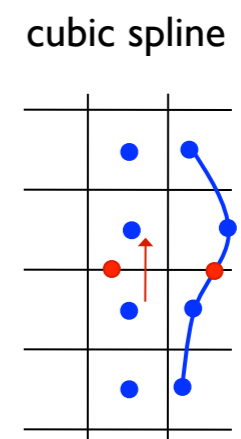
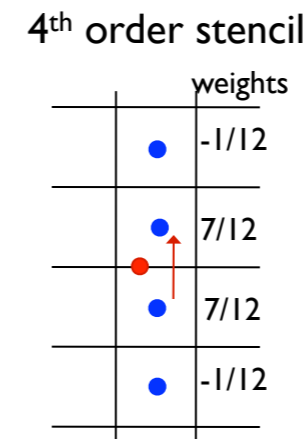
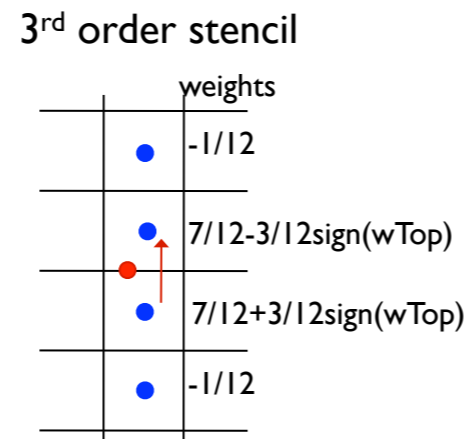
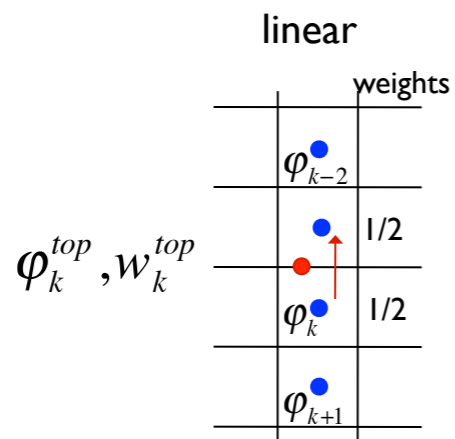
High-Order Vertical Tracer Advection

Vertical tracer advection, requires tracer values at vertical cell edge.

Four methods are available to interpolate tracer values to cell interface:

$$\frac{\partial h\varphi}{\partial t} + \nabla \cdot (h\varphi\mathbf{u}) + \underbrace{\frac{\partial}{\partial z} (h\varphi w)}_{\text{vertical advection}} = \nabla \cdot (h\kappa_h \nabla \varphi) + h \frac{\partial}{\partial z} \left(\kappa_v \frac{\partial \varphi}{\partial z} \right)$$

$$\frac{\partial}{\partial z} (h\varphi w) = \varphi_k^{top} w_k^{top} - \varphi_{k+1}^{top} w_{k+1}^{top}$$



Richardson-Number based Vertical Mixing with an Implicit Solver

Pacanowski-Philander vertical mixing

Based on Richardson Number, so viscosity and tracer diffusion increase with vertical shear and weaker stratification.

Implicit vertical mixing

Allows mixing to occur stably at fast timescales without constraining the model time step.

Operator splitting used on explicit and implicit tendency terms in the momentum and tracer equations.

$$\frac{\partial h\varphi}{\partial t} + \underbrace{\nabla \cdot (h\varphi\mathbf{u}) + \frac{\partial}{\partial z} (h\varphi w)}_{\text{solve explicitly}} = \underbrace{\nabla \cdot (h\kappa_h \nabla \varphi) + h \frac{\partial}{\partial z} \left(\kappa_v \frac{\partial \varphi}{\partial z} \right)}_{\text{solve implicitly}}$$

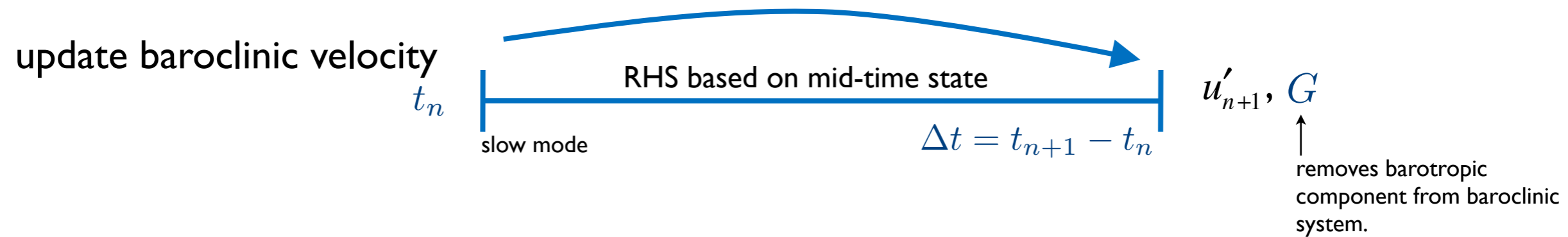
$$\left(1 - \Delta t \frac{\partial}{\partial z} \left(\kappa_v \frac{\partial}{\partial z} \right) \right) \varphi^{n+1} = \frac{\widetilde{(h\varphi)}^{n+1}}{h^{n+1}} \leftarrow \begin{array}{l} \text{new provisional value from} \\ \text{explicit solve} \end{array}$$

The modular computation of vertical mixing coefficients allows for an easy migration to KPP or other vertical turbulence closure scheme.

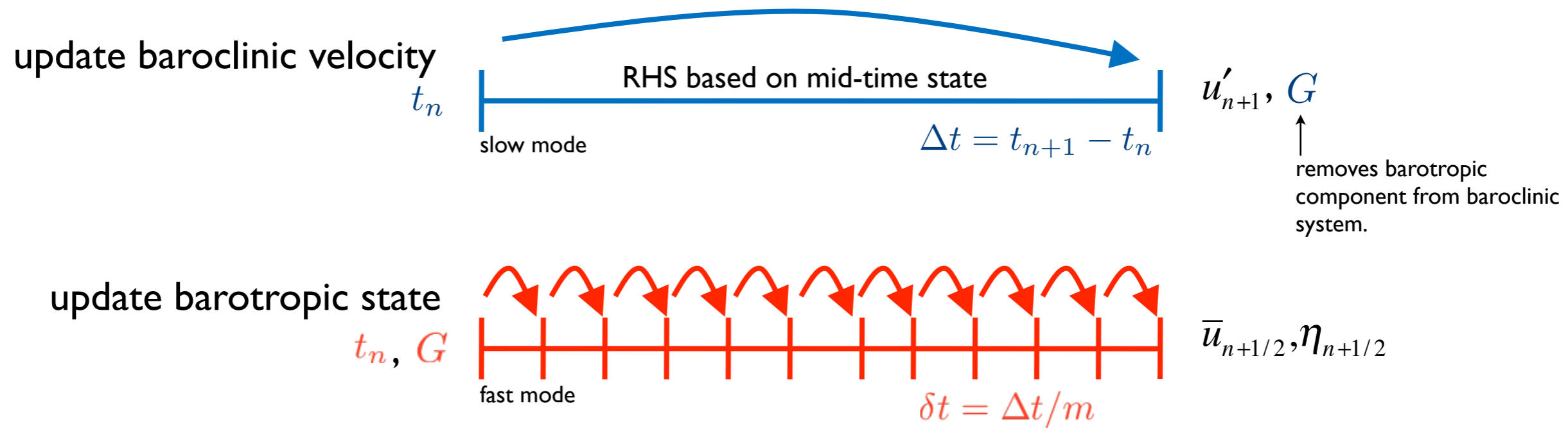
Design and Implementation of a two-time level, split-explicit scheme

removes barotropic
component from baroclinic
system.

Design and Implementation of a two-time level, split-explicit scheme

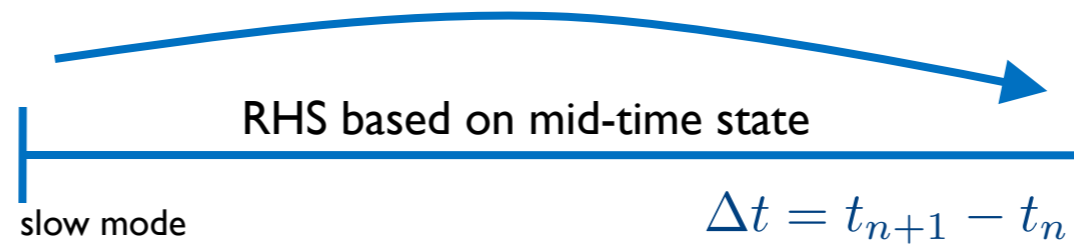


Design and Implementation of a two-time level, split-explicit scheme



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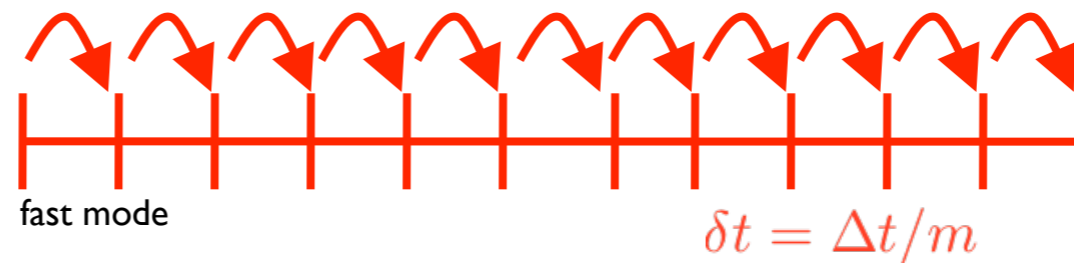
update baroclinic velocity
 t_n



u'_{n+1}, G

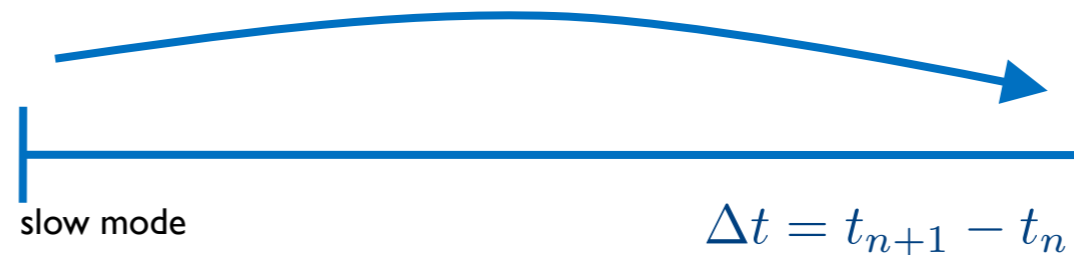
↑
removes barotropic
component from baroclinic
system.

update barotropic state
 t_n, G



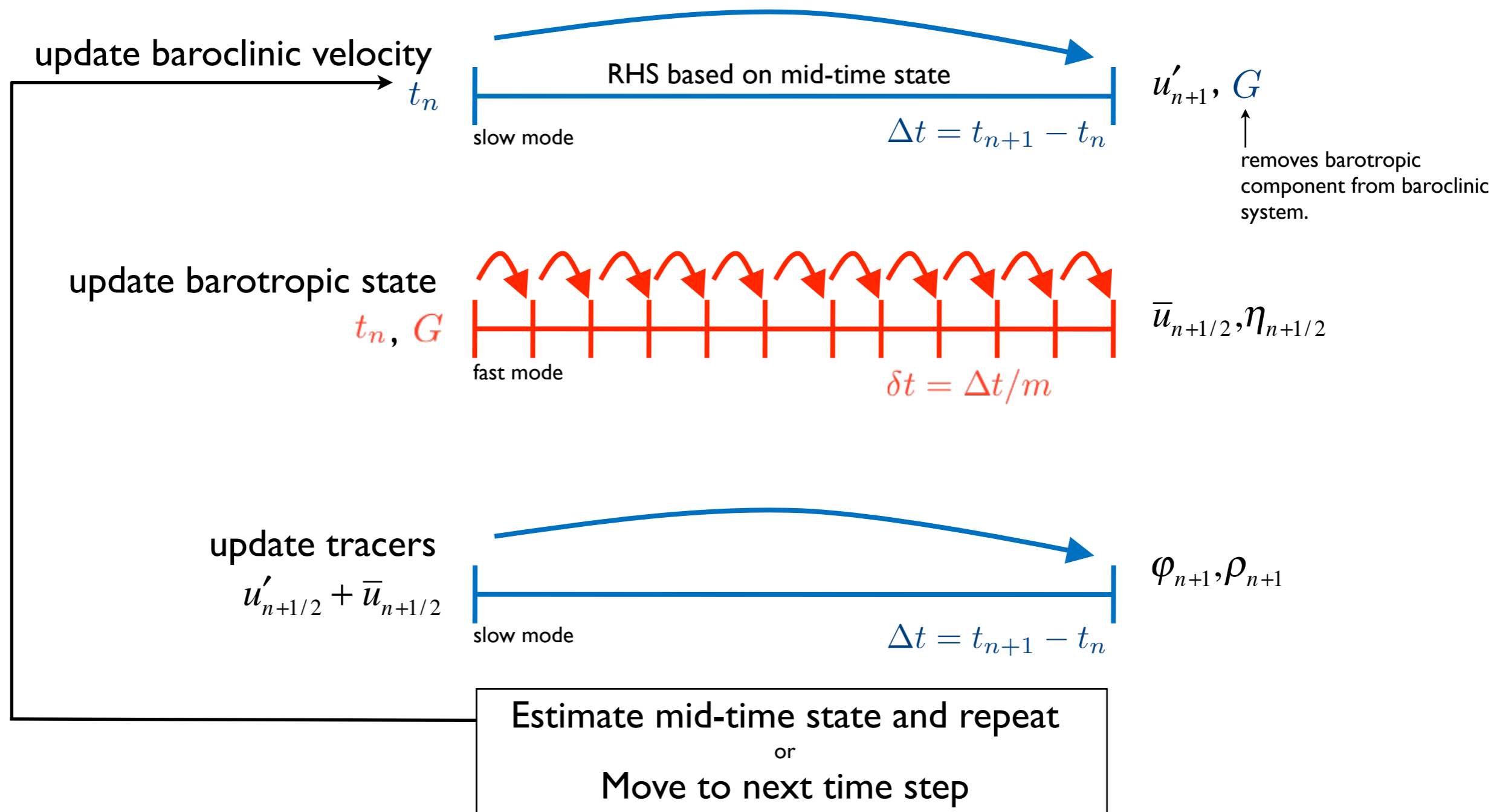
$\bar{u}_{n+1/2}, \eta_{n+1/2}$

update tracers
 $u'_{n+1/2} + \bar{u}_{n+1/2}$

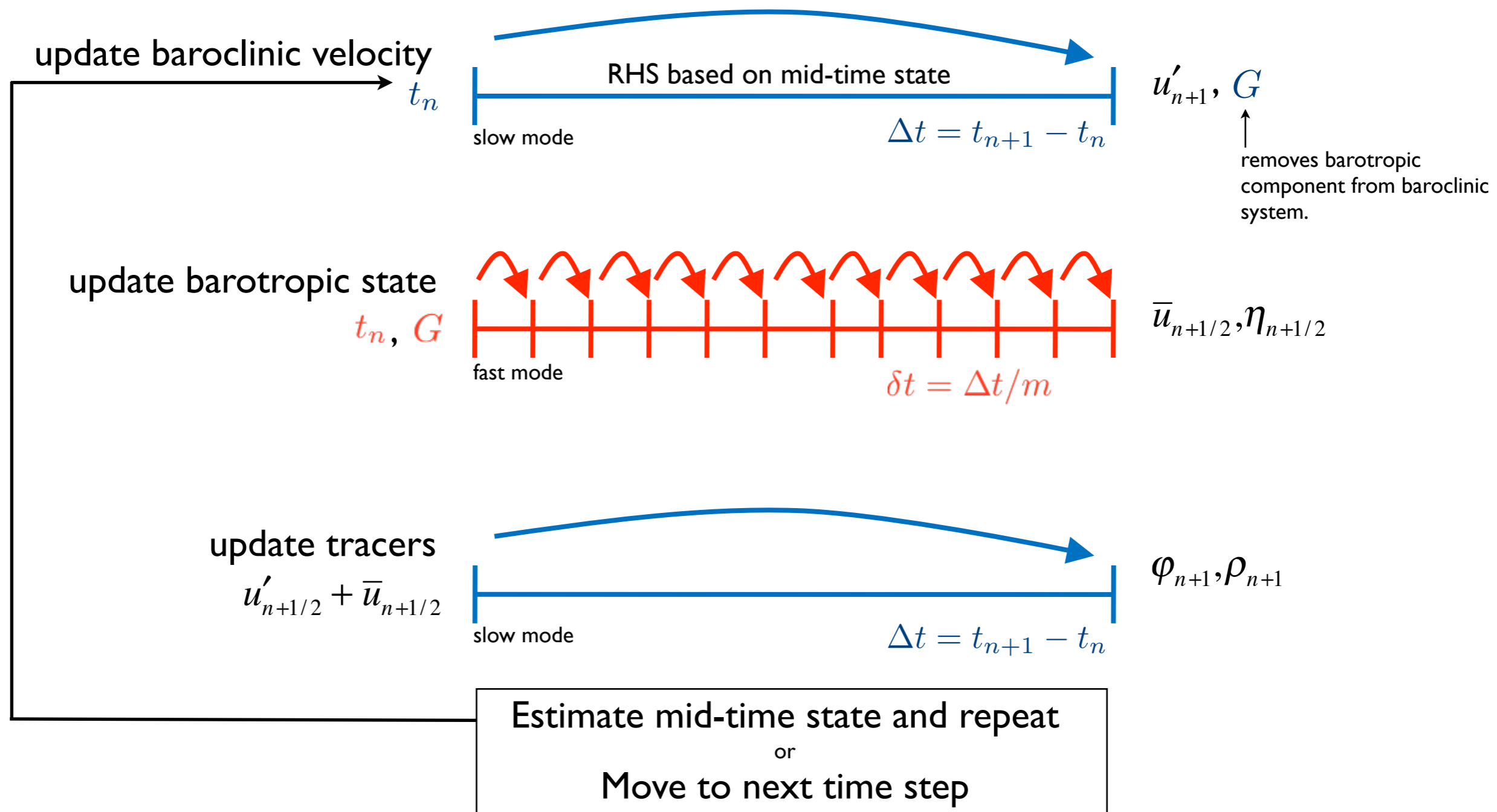


$\varphi_{n+1}, \rho_{n+1}$

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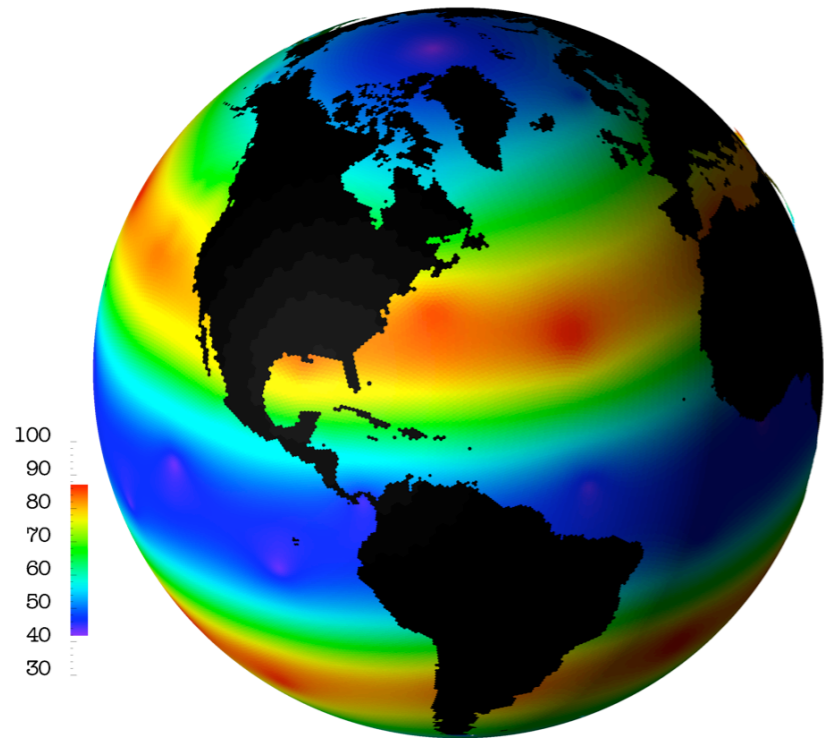


A few nice properties of this approach:

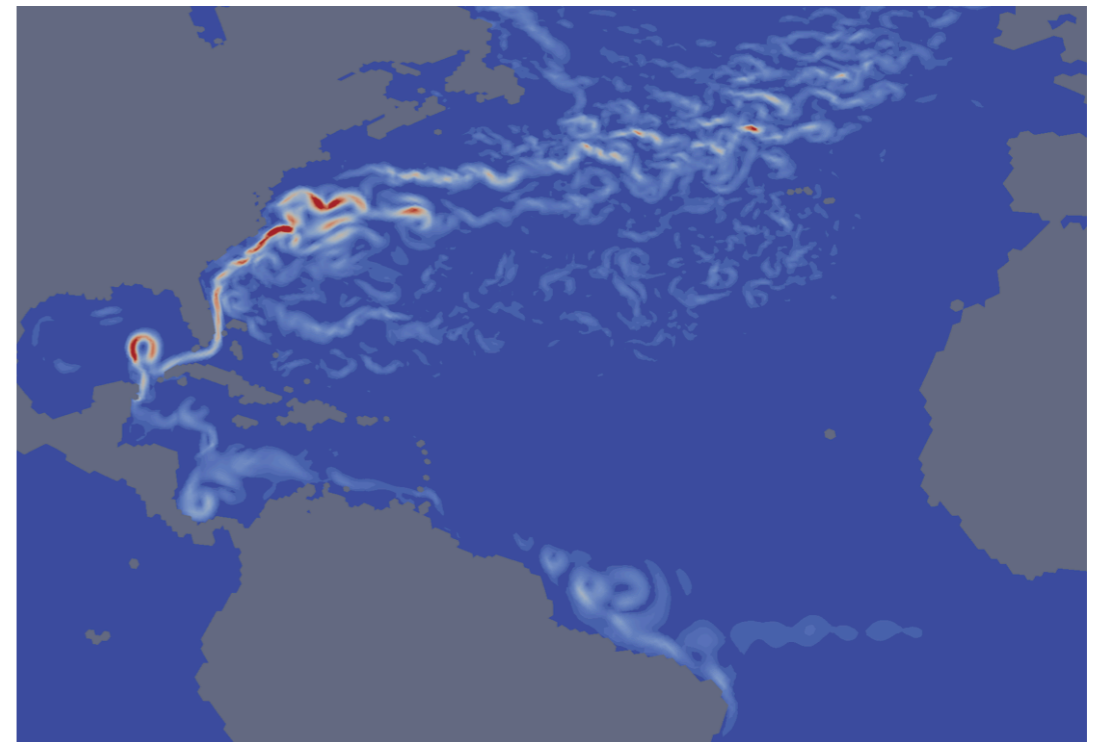
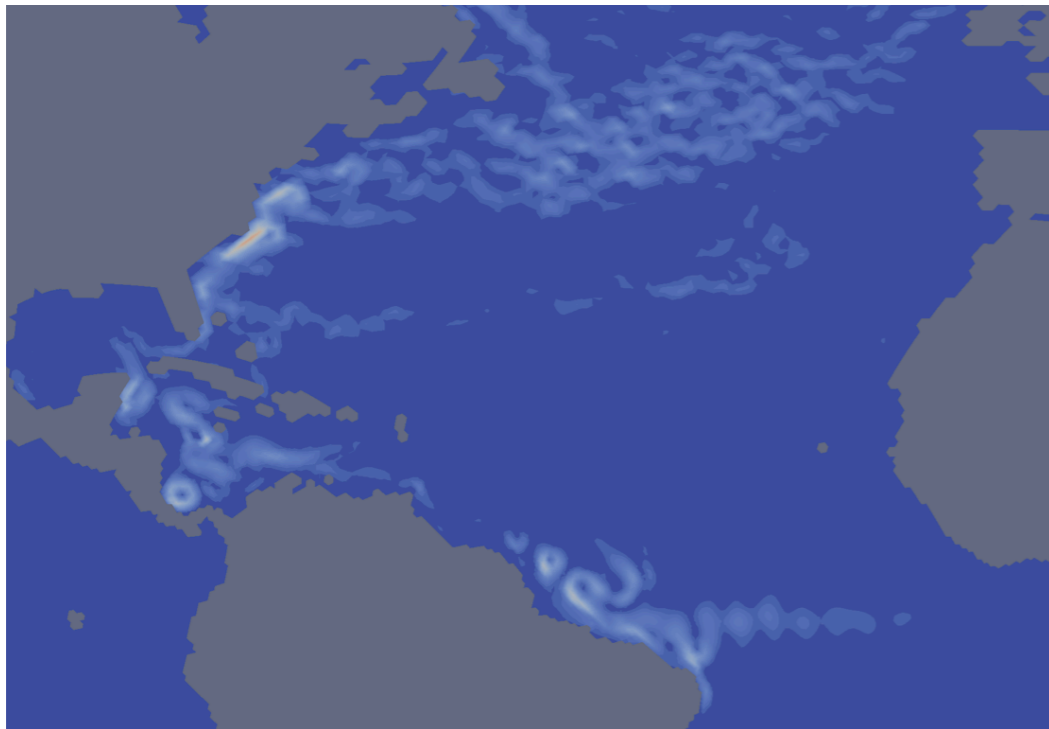
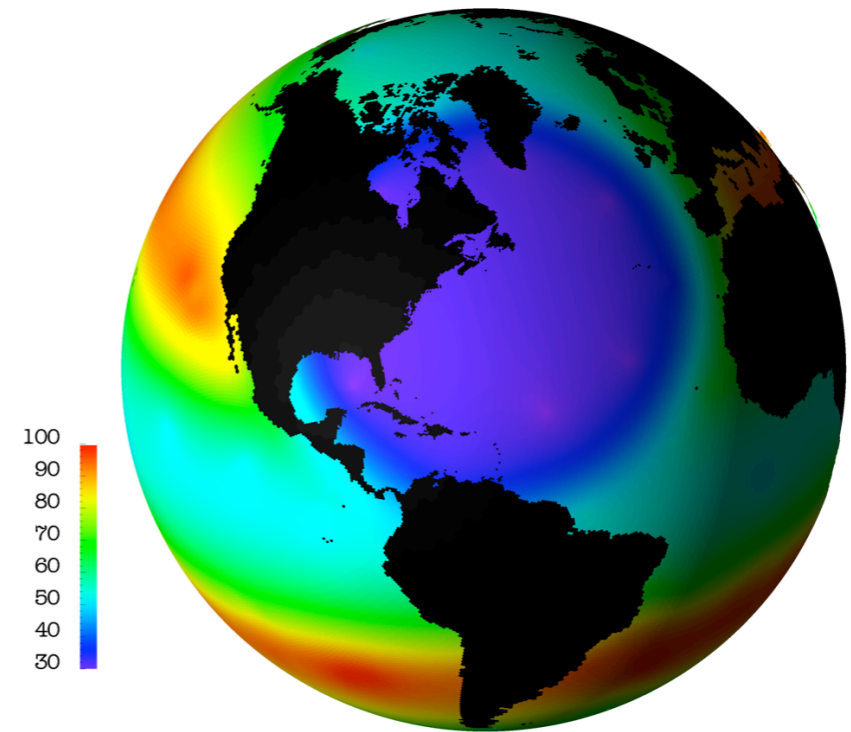
1. Only need time-level n information.
2. Can run with or without the splitting (runtime choice).
3. Maintain exact tracer conservation.
4. Splitting approach is same for z-level or layer model.

At that last OMWVG, focus was on variable resolution capability of MPAS-O.

R60km: local grid resolution



R60kmNA: local grid resolution



See example of this same variable resolution approach in CAM at Sara Rauscher's poster.

The focus over the last development period has been on real-world, quasi-uniform simulations at 120 km, 60 km and 30 km resolutions.

nominal 120 km, 60 km and 30 km horizontal resolutions

z-level model, 40 levels (same as POP gx1v3)

topography taken from ETOPO, no smoothing, depth ≥ 2 levels

initial conditions for T and S from annual mean WOCE global climatology

time-invariant wind stress forcing from annual mean NCEP 1958-2000

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2nd-order, two-time level, predictor-corrector, unsplit time stepping

($\Delta t=200$ s, 100 s and 50 s for 120 km, 60 km and 30 km resolutions)

3rd-order reconstruction for horizontal transport

3rd-order reconstruction for vertical transport

Jackett and McDougall EOS

vertical diffusivity/viscosity based on Pacanowski and Philander with implicit solve.

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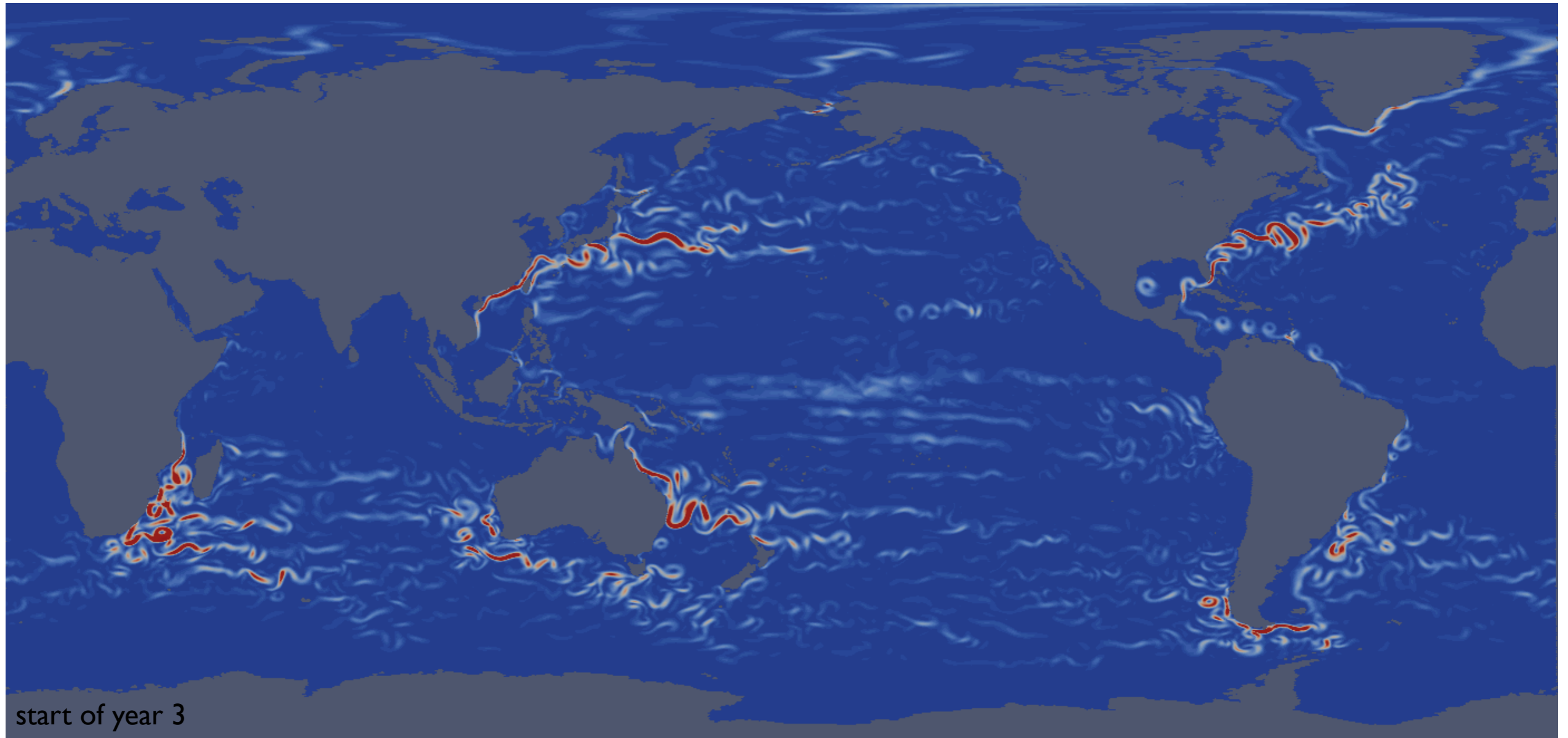
vertical diffusivity/viscosity based on Pacanowski and Philander with implicit solve.

The simulations use bi-harmonic dissipation on u and tracers

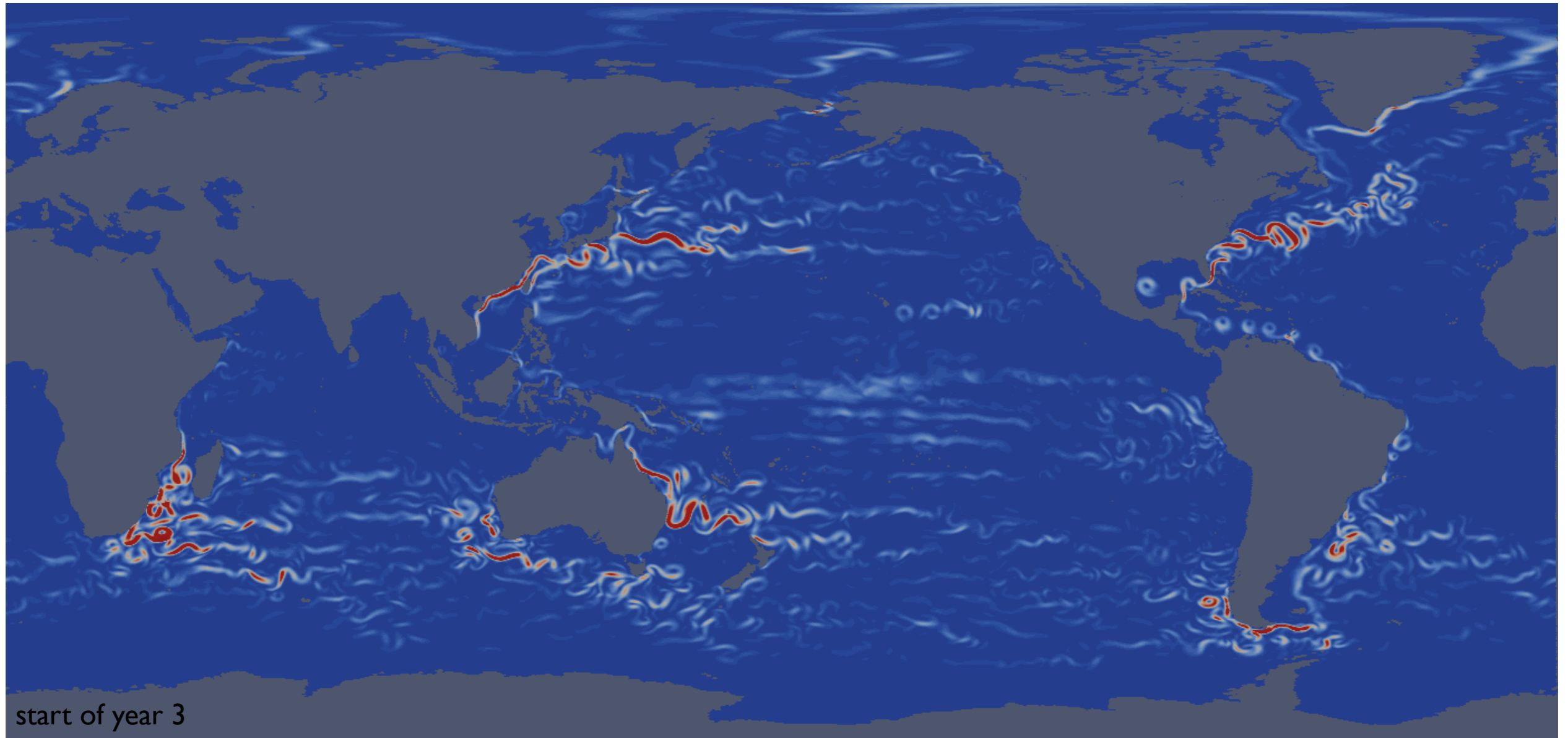
($\nu = 1.0 \times 10^{14}$ m⁴/s, 2.5×10^{13} m⁴/s and 5.0×10^{12} m⁴/s)

restoring to WOCE annual mean T and S with 45 day time scale

Global 30 km Simulation: Snap-Shot of Surface Kinetic Energy

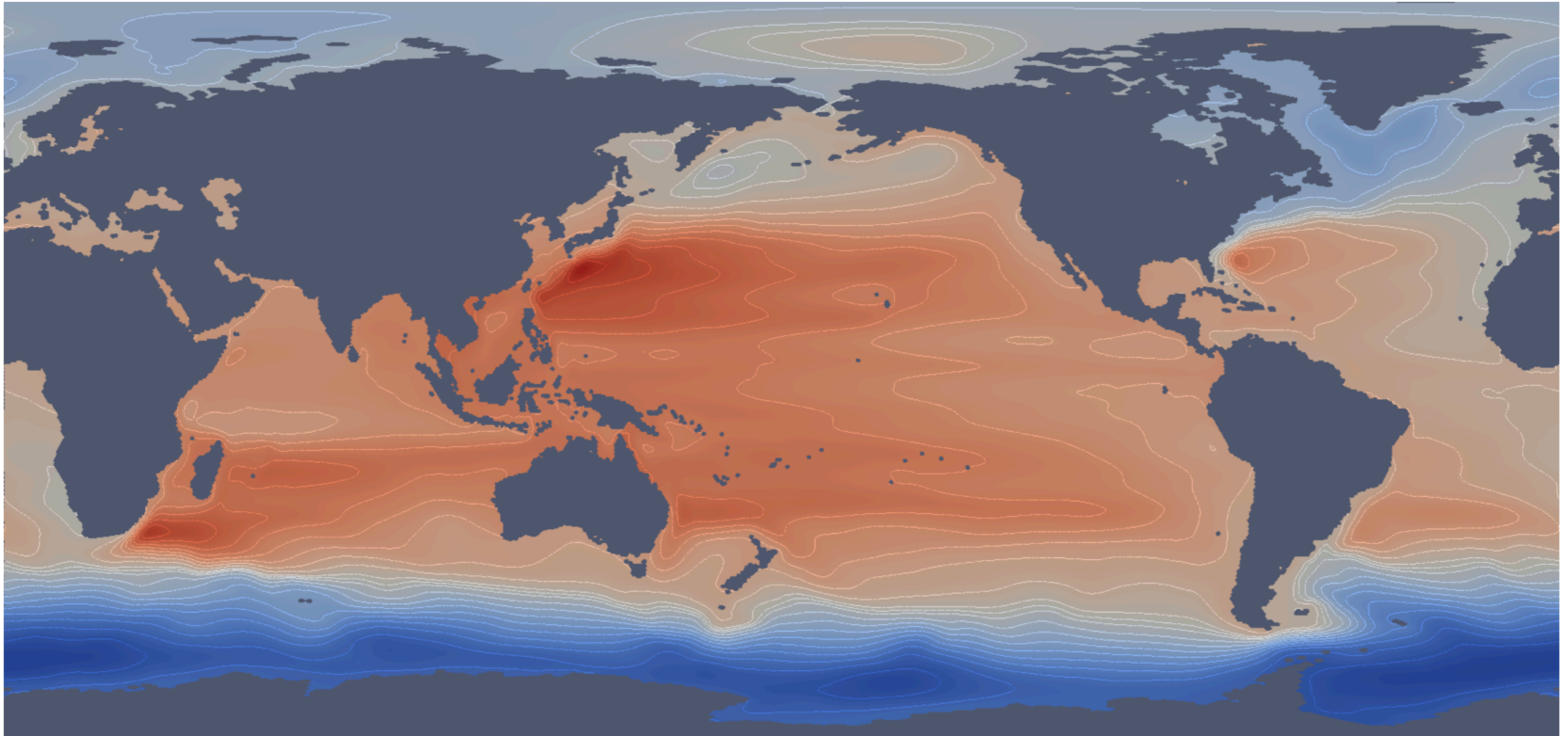


Global 30 km Simulation: Snap-Shot of Surface Kinetic Energy



There are many promising aspects of this simulation
all of which might disappear as we integrate the model longer.

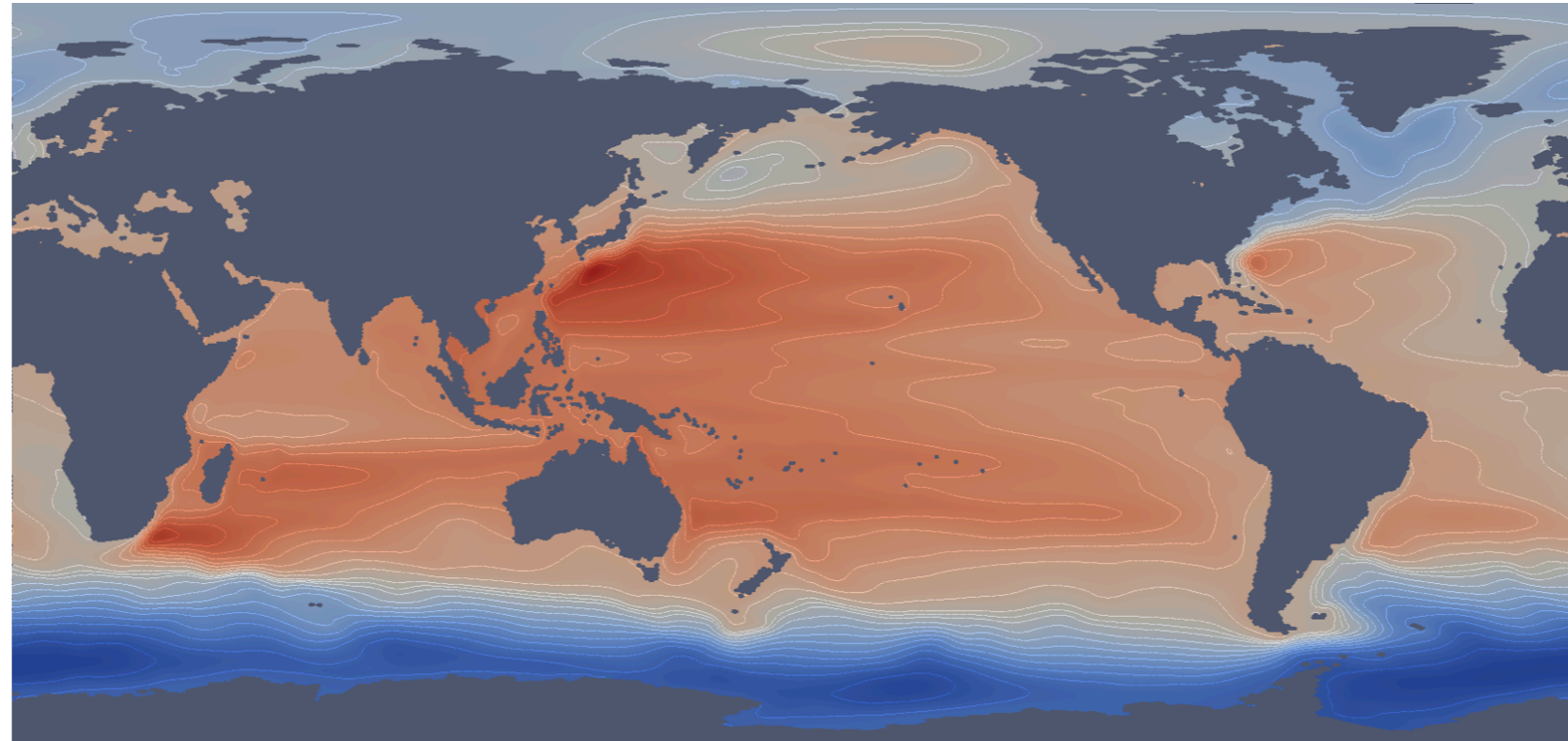
Global 60 km Simulation: Sea-Surface Height



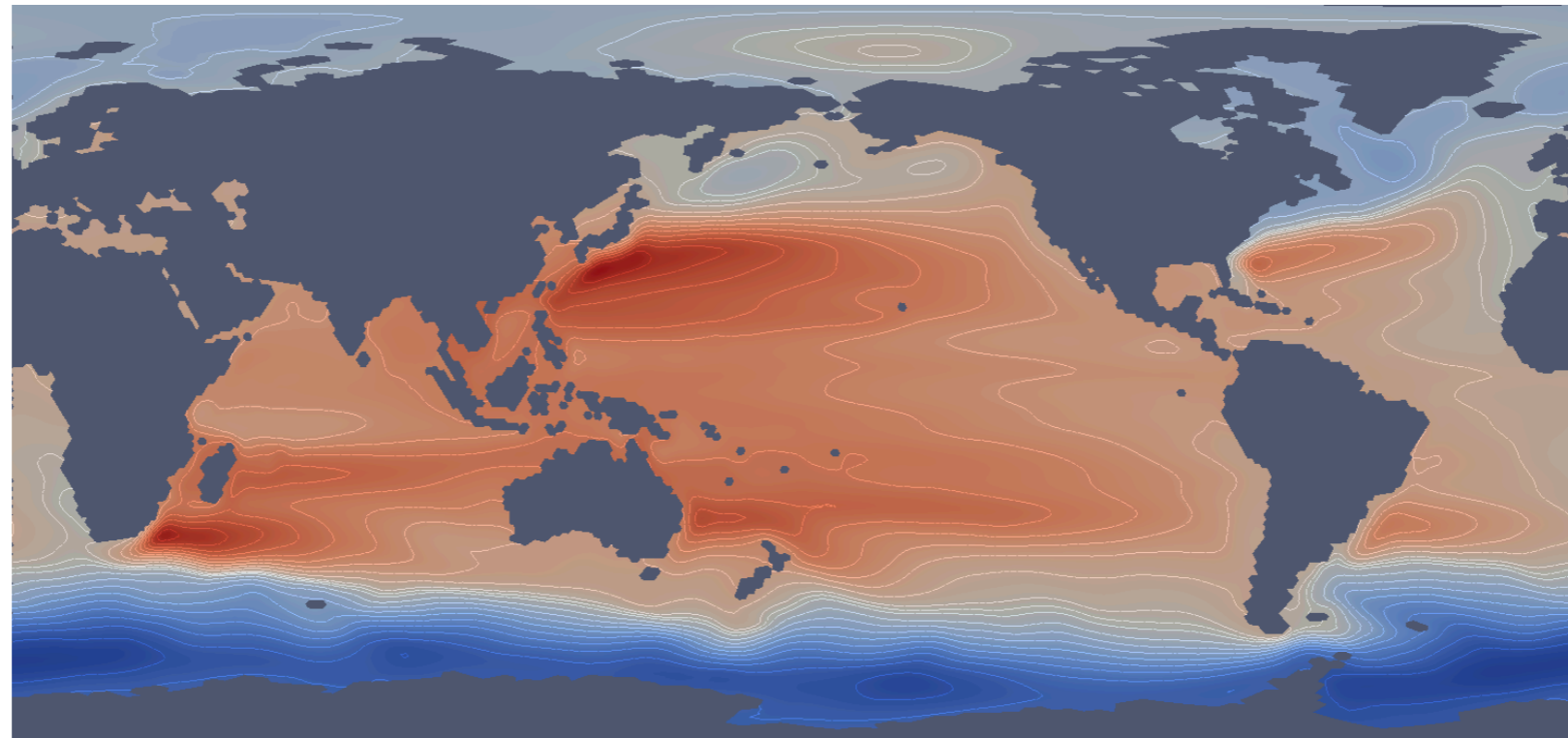
Time mean SSH, Year 3, contour interval = 0.15 m, peak-to-peak amplitude = 3.0 m.

Comparison of the 120 km and 60 km simulations.

60 km resolution

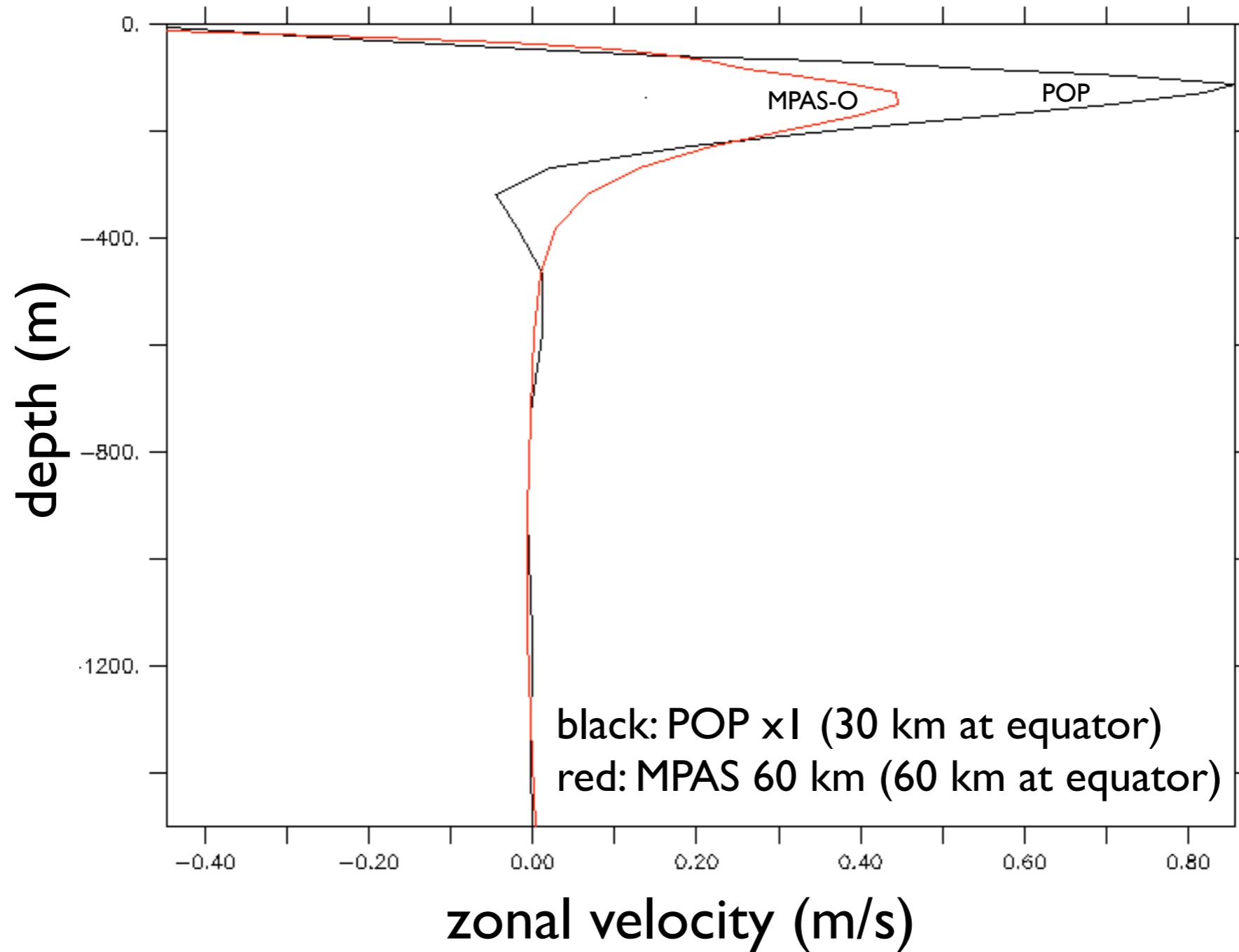


120 km resolution



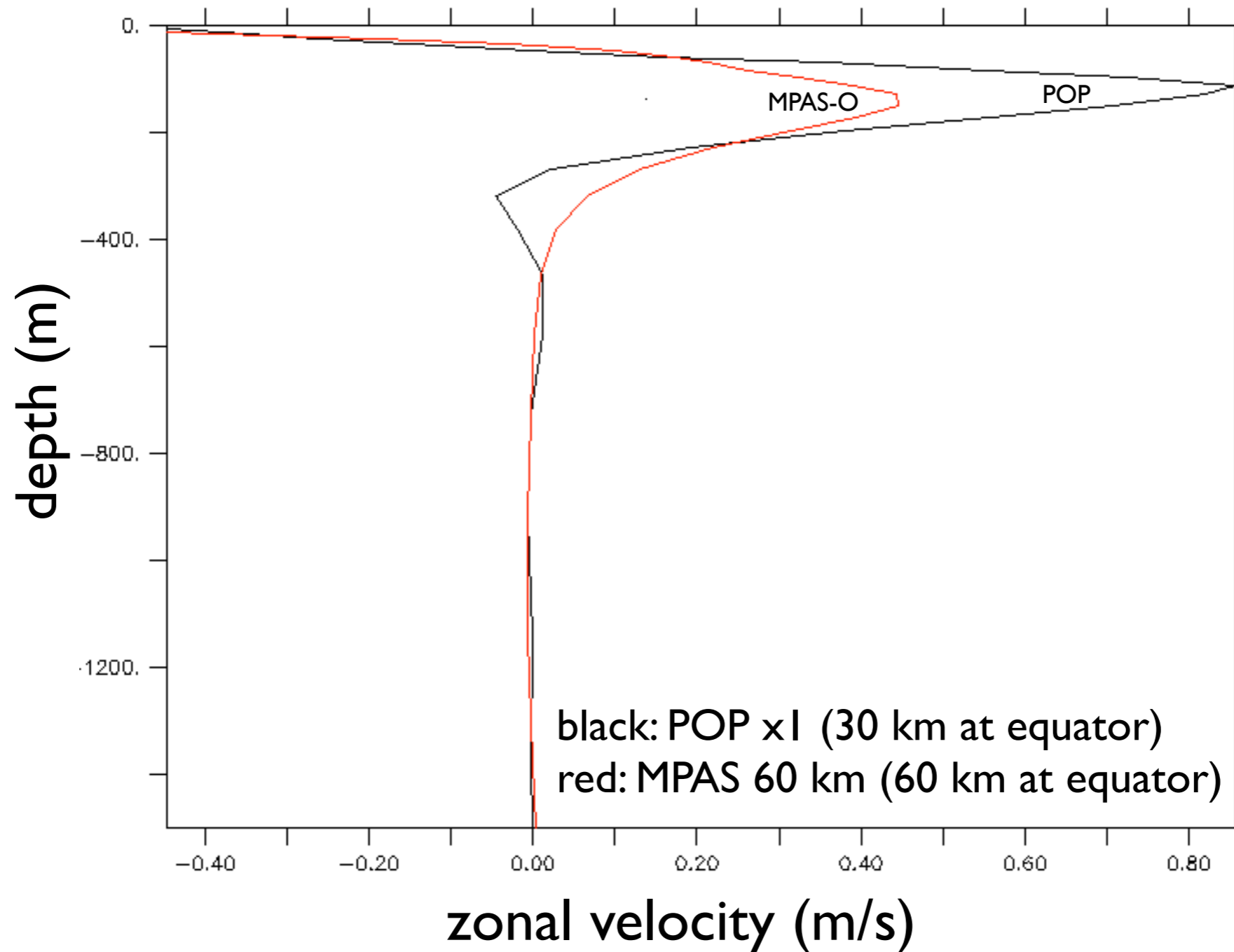
MPAS-POP comparison

Equatorial Undercurrent at 140W



MPAS-POP comparison

Equatorial Undercurrent at 140W



Overall, this figure does a great job of summarizing where we are at with MPAS-O. The raw features are present, sometimes with tantalizing hints of promise, but often without the fidelity a highly polished model.

MPAS-POP comparison

Computational Efficiency

For a given simulation, we want to minimize wall clock time. We can reduce wall clock time by increasing the scaling efficiency and by reducing the computational time per degree of freedom. We have shown previously that model scales well out to at least 1000 processors.

MPAS-POP comparison

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64 processors, MPAS @ 120 km, POP @ x1

| Model | Wall Clock per baroclinic time step |
|---------------|-------------------------------------|
| MPAS @ 120 km | 1.7 s |
| POP @ x1 | 0.3 s |

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MPAS is currently 6x slower than POP (caveats abound here). This is due to the following:

1. Have not invested any time in computational efficiency.
2. Use of derived data types and pointers (expect 2x improvement here).
3. Use of unstructured grids.

Our goal over the next six months is to bring MPAS on par with POP.

Plans for the next six-month cycle:

1. Finish testing and evaluation of two-time level, barotropic-baroclinic splitting scheme.
2. We plan to bring two manuscripts to the December meeting.
Manuscript #1: Exploring a Multi-Resolution Approach for Global Ocean Modeling
Manuscript #2: A Comparison of MPAS-O to POP
3. MPAS-wide optimization.
4. Facilitate/Coordinate/Participate in the design of general CESM/COM software interfaces to allow the use of unstructured-mesh dynamical core(s). (Note: This is already done on the CESM/CAM side.)
5. Finish implementation of Prather-like, method-of-moments, horizontal transport scheme. (This scheme will be available across the MPAS framework.)
6. Begin design of Gent-McWilliams mixing schemes.

MPPAS

Model for Prediction Across Scales

Thanks!