MPAS-Ocean Testing and Verification

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The importance of testing:

- E3SM is large and complex. Lines of active code: 463K in MPAS; 1.75M in E3SM*
- Numerous architectures, compilers, configurations. "If it is not tested, it's broken"

Goals for MPAS-Ocean verification:

- **Exact**: Term-by-term convergence tests against analytic solutions
- **Fast**: Run on simple domains, short simulations
- **Complete**: Goal is 100% code coverage.
- **Easy to run**: Automated within nightly regression suites
- **Easy to create**: Extensive front end in python is easy for newcomers to add and alter

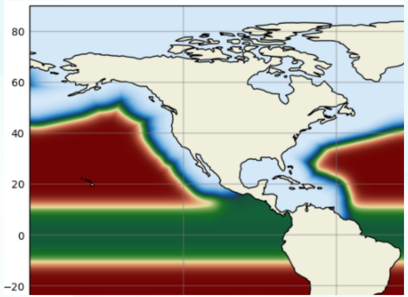

```
* git ls-files| xargs cat | sed '/^\s*#/d;/^\s*$/d;/^\s*$/d;' | wc -l
(no blanks or comment lines)
```

COMPASS: Configuration of MPAS Set-up

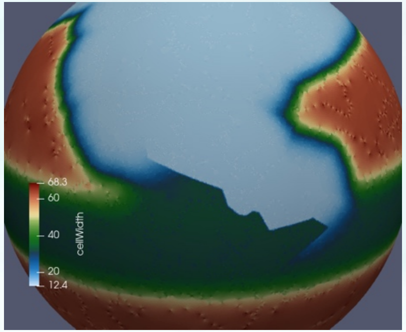
- Front end for mesh generation, ocean simulations, verification, and plots.
- See MPAS Mesh Generation Tutorial and COMPASS instructions
- COMPASS is available on github, and python environment available (e.g. on cori: source /global/project/projectdirs/e3sm/software/anaconda_envs/load_latest_compass.sh)

Steps in Mesh Generation for MPAS:

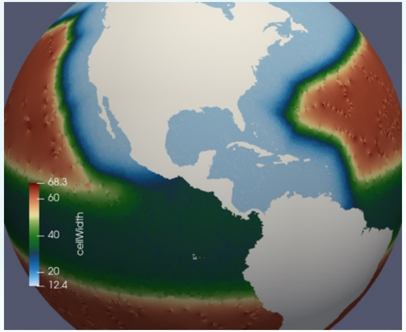
1. define base mesh
cell width as function of latitude, longitude



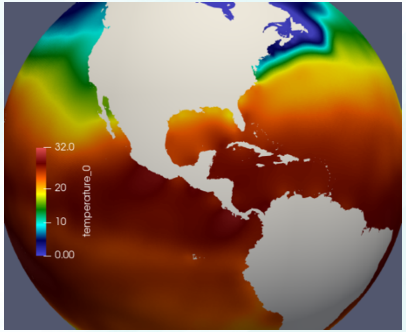
2. base mesh
jigsaw creates global spherical mesh



3. culled mesh
remove land cells from spherical mesh



4. initial state
add temperature, salinity, layers, bathymetry



Nightly Regression Suite in COMPASS

MPAS-Ocean regression testing packages together a number of tests

- pass/fail status on 18 tests, including:
  - Restart comparison, bit-for-bit
  - Domain partition comparison, bit-for-bit
  - Thread comparison, bit-for-bit
  - Analysis tests
  - Biogeochemistry tests
  - Idealized and realistic domains
  - Lagrangian particles
- bit-for-bit comparison on output of previous test with different executable
- performance comparison with previous tes
- These currently do not include convergence tests.
- COMPASS instructions for nightly regression suite

Verification of individual tendency terms

- Each term in the governing equations should have a convergence
- These are being added. For example, with tracer Redi mixing (PR #280).
- Does not involve time steps

momentum equation:

$$\frac{\partial \mathbf{u}}{\partial t} + \eta \mathbf{k} \times \mathbf{u} + w \frac{\partial \mathbf{u}}{\partial z} = -\frac{1}{\rho_0} \nabla p - \frac{\rho g}{\rho_0} \nabla z^{mid} - \nabla K + \mathbf{D}_h^u + \mathbf{D}_v^u + \mathcal{F}^u$$

thickness equation:

$$\frac{\partial h}{\partial t} + \nabla \cdot \left(h \overline{\mathbf{u}}^z \right) + w|_{z=s^{top}} - w|_{z=s^{bot}} = 0$$

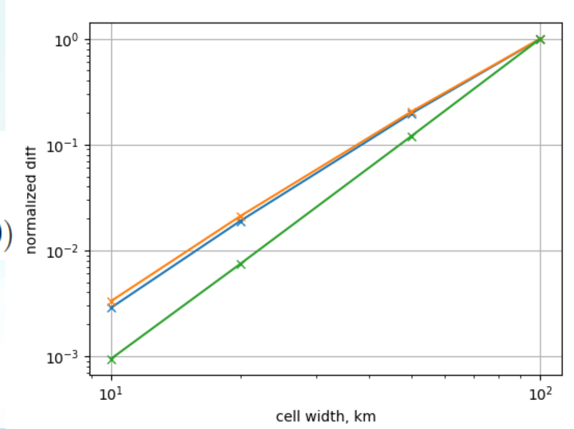
tracer equation:

$$\frac{\partial}{\partial t} h \overline{\varphi}^z + \nabla \cdot \left(h \overline{\varphi \mathbf{u}}^z \right) + \varphi w|_{z=s^{top}} - \varphi w|_{z=s^{bot}} = D_h^\varphi + D_v^\varphi + \mathcal{F}^\varphi$$

- Redi mixing was complicated enough that exact testing was required.

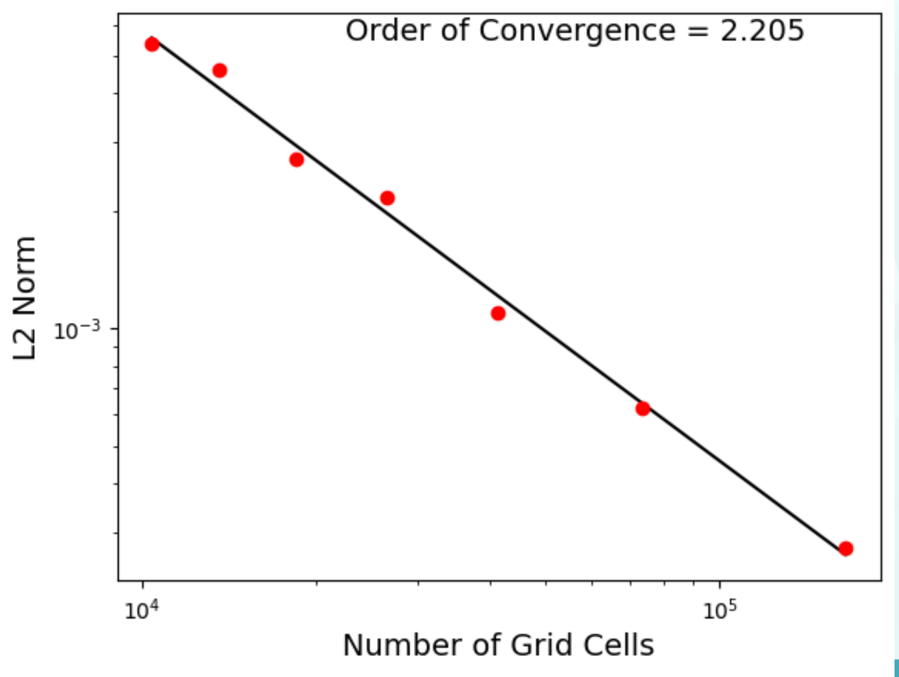
$$\nabla^r \cdot \left(h K^r \nabla^r \varphi \right) = \kappa_R \left[\nabla_r \cdot \left(h \nabla_r \varphi \right) + \nabla_r \cdot \left(h \widetilde{\mathbf{S}} \frac{\partial \varphi}{\partial z} \right) + \frac{\partial}{\partial z} \left(h \widetilde{\mathbf{S}} \cdot \nabla_r \varphi \right) + \frac{\partial}{\partial z} \left(h K_{33} \frac{\partial}{\partial z} \varphi \right) \right]. \quad (3.60)$$

- We created 9 analytic solutions with sympy to test the span of variations in these terms.



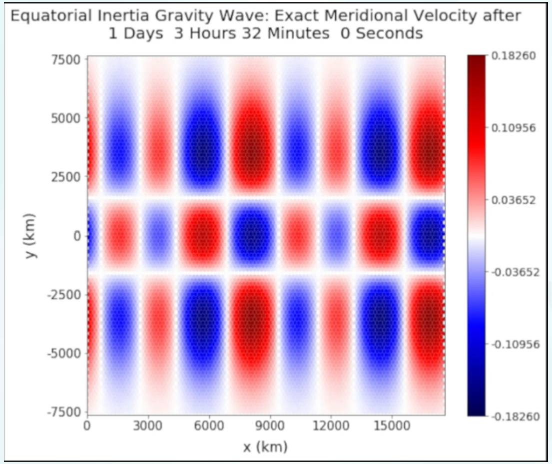
Advection scheme verification

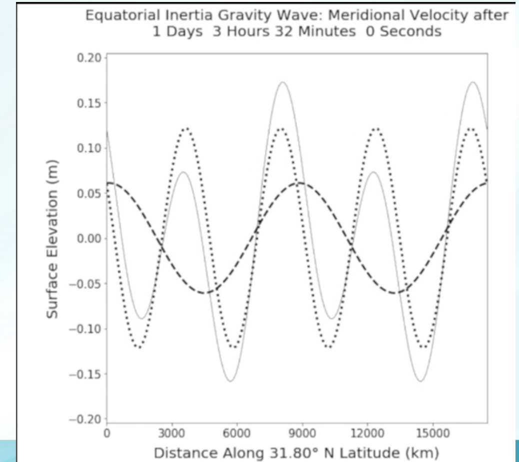
- Some tests step forward in time with a limited number of terms, where the exact solution is known.
- We added an advection test in [PR #583](PR #583) (with Luke Van Roekel)
- Cosine bell advected around sphere
- This test revealed bugs: two sign typos on high order advection terms
- Takes 12 minutes on 4 nodes to run 7 resolutions and show convergence
- Set up with a single COMPASS command
- produces plot and order of convergence



Barotropic Test Suite, with Sid Bishnu

- Barotropic/baroclinic time step splitting is a complex part of MPAS-Ocean
- Sid has designed a suite of 12 geophysical test cases for the barotropic mode
- All tests have analytic solutions
- Increasingly complex tests add Coriolis term, variable bathymetry, boundaries
- Sid wrote an extensive python code for comparison with MPAS output.
- Test suite will be used to compare barotropic time-stepping algorithms for accuracy and performance.



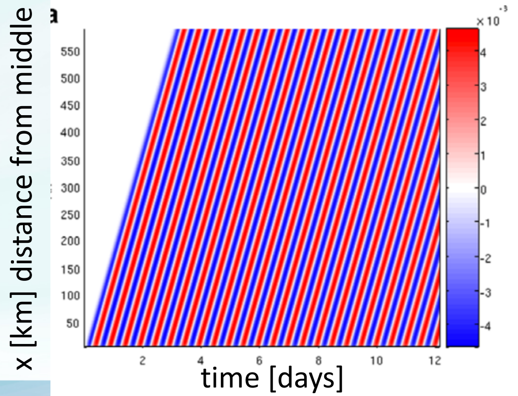


Internal gravity wave test case (with Hyun Kang)

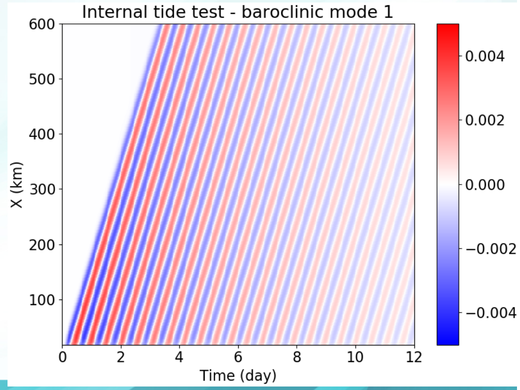
- Tests in the literature provide benchmarks for comparison
- From Marsaleix et al (2008) and Demange et al (2019)
- Flow over deep sea ridge driven by sea surface gradient
- Produces multiple internal gravity wave modes
- Used to measure energy dissipation of barotropic/baroclinic time stepping
- Test created for new semi-implicit time stepping (PR #422)

Images show magnitude of first baroclinic mode, which have a 12 hour period and propagate out from the center. This case helps us minimize the energy dissipation within the stability limit of the time stepping scheme.

ROMS, Marsaleix et al (2008)



MPAS-Ocean



The Plan for MPAS-Ocean Verification Tests

- MPAS-Ocean nightly regression suite has excellent code coverage, but these are not convergence tests against exact solutions.
- We are adding tests ‘as we go’ when we add new functionality.
- New test cases are great projects for students, post-docs, and staff who are new to MPAS-Ocean.
- COMPASS will become a stand-alone repo this month, so MPAS and E3SM pull requests are no longer needed for COMPASS development.
- COMPASS cases for idealized domains previously used MPAS init mode, which is in Fortran and compiled into MPAS. We have transitioned to python scripts that are much easier for newcomers.