Ocean Simulations using MPAS-Ocean

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MPAS
Model for Prediction Across Scales

Progress on MPAS-Ocean in 2010

- **MPAS-Ocean is a functioning ocean dynamical core that operates in isopycnal and z-level vertical coordinates.**
- **In January 2010 MPAS included the framework, a shallow-water core and hydrostatic atmosphere core.**
- **This year we created an ocean core (MPAS-Ocean) with:**
  - choice of isopycnal or z-level vertical grids as namelist option
  - global ocean with land boundaries and bathymetry
  - del2 and del4 horizontal diffusion
  - high-order horizontal advection for Voronoi tessellations
  - nonlinear equation of state (Jackett and McDougall)
- **MPAS-Ocean on quad meshes: Initial validation using POP**
- **MPAS-Ocean on Voronoi Tessellation meshes: both uniform and variable density meshes.**

MPAS Development: Benefits of Collaboration

- **MPAS is a collaborative development between MMM at NCAR, COSIM at LANL, and others (e.g. LLNL)**
- **All developers share the same repository.**
- **Atmosphere, ocean, and shallow water cores each have a time integration module and registry file.**
- **All cores share common framework modules, which include:**
  - i/o and restart modules
  - time managers
  - grid initialization
  - parallelization, boundary updates, and block decomposition
  - support for registry file that automates variable declaration and input namelists

MPAS Development: Benefits of Collaboration

- **Revisions to framework are reviewed before changing trunk**
  - Within the ocean model core, we have a formal branch review process.
  - Multiple developers with different uses has led to a well-vetted, resilient code base.
- **Improvements and bug-fixes from one core are transferred to other cores.**
- **Improvements to MPAS framework in 2010 include:**
  - Restructuring variables to include super-arrays, like tracers (NCAR)
  - Improved restart file format (NCAR)
  - Simplified interface of driver and subdrivers (NCAR)
  - Vector reconstruction from cell edges to centers using radial basis functions (LANL)
  - Graphics tools for NCL (NCAR)
  - Graphics tools for Paraview (LANL)
  - High-order horizontal advection, used in multiple cores (LANL)

Vertical Grid: choice of isopycnal or z-level

- **Isopycnal vertical grid:**
  - layer thickness *h* is prognostic variable for full 3D array
  - no vertical advection between layers (no remapping at this time)
  - density is fixed for each layer for all time
- **Z-Level vertical grid:**
  - top layer thickness *h* evolves freely to account for SSH changes
  - In lower layers, thickness equation used to compute *w*, and we set *dh/dt=0*
  - density computed from T & S at each timestep
  - use pressure rather than Montgomery Potential

thickness

$$\frac{\partial h}{\partial t} + \nabla \cdot (h\mathbf{u}) + \frac{\partial}{\partial z}(hw) = 0,$$

momentum

$$\frac{\partial \mathbf{u}}{\partial t} + q(h\mathbf{u}^{\perp}) + w\frac{\partial \mathbf{u}}{\partial z} = -\frac{1}{\rho_0}\nabla p - \nabla K + \nu_h(\nabla\delta + \mathbf{k}\times\nabla\eta) + \frac{\partial}{\partial z}\left(\nu_v \frac{\partial \mathbf{u}}{\partial z}\right),$$

tracer

$$\frac{\partial h\varphi}{\partial t} + \nabla \cdot (h\varphi\mathbf{u}) + \frac{\partial}{\partial z}(h\varphi w) = \nabla \cdot (h\kappa_h \nabla\varphi) + h\frac{\partial}{\partial z}\left(\kappa_v \frac{\partial \varphi}{\partial z}\right).$$

Topography in Z-Level mode

- grid.nc input file contains a maxLevelCell variable that specifies the deepest ocean cell, like KMT in POP.
- maxLevelEdge and maxLevelVertex variables are computed from maxLevelCell upon startup.
- No-slip boundary conditions on vertical walls.
- Code is "mesh-unaware". That is, code is identical for Voronoi Tessellation or quad meshes.
- Code is designed to accommodate flux boundary conditions in the future.

MPAS-Ocean z-level mode initial validation with POP

- MPAS-Ocean on quad grid and bathymetry identical to POP gx3v2, gx1v3, and 0.1 dipole grids.
- Levitus climatological mean initial temperature and salinity
- NCEP 1958-2000 annual mean wind stress
- No surface forcing or restoring of temperature and salinity
- Horizontal mixing: del2, constant coefficient viscosity (1.0e3 m^2/s) and diffusion (1.0e2 m^2/s).
- Vertical mixing: constant coefficient viscosity (2.5e-5 m^2/s) and diffusion (2.5e-5 m^2/s).
- Jacket & McDougall equation of state

How do POP and MPAS-Ocean differ in these tests?

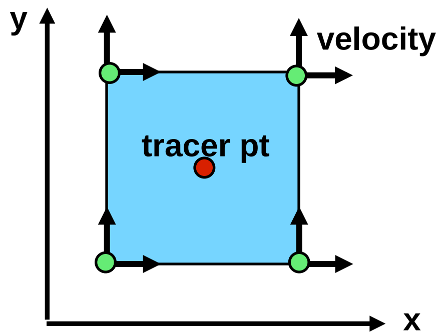
- **Time stepping and time splitting**
  - POP: Barotropic/Baroclinic implicit/explicit splitting, leap-frog timestep

    60 minute timestep for 1^{o} grid
  - MPAS-Ocean: no splitting, explicit 4th-order Runga-Kutta timestep

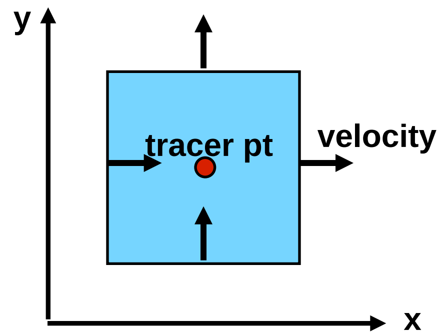
    1 minute timestep for 1^{o} grid

- **Grid:**

POP uses a B-grid: Velocities on corners

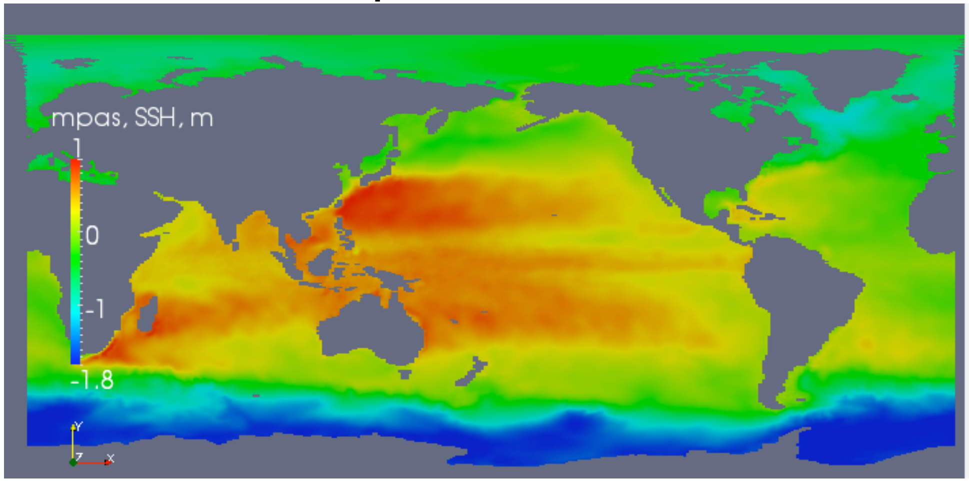


MPAS uses a C-grid: Velocities on edges

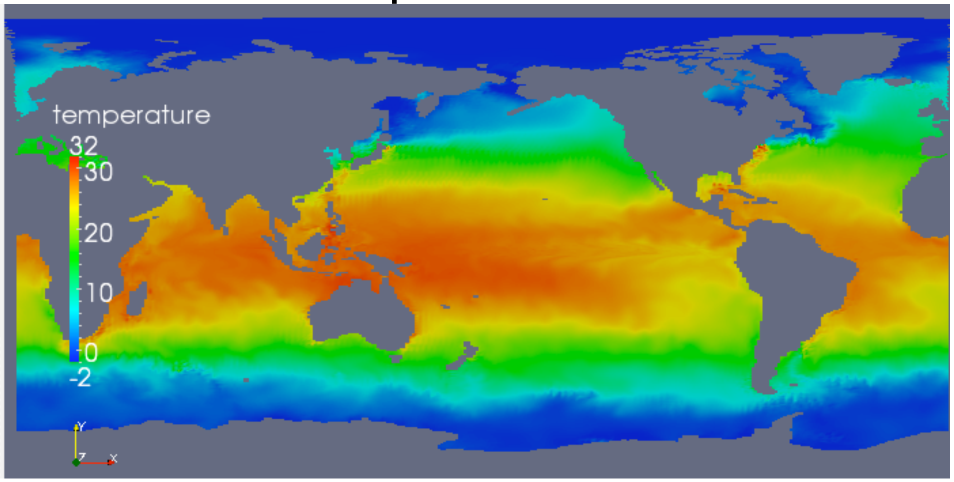


POP/MPAS-Ocean Comparison, 1º grid, 40 days

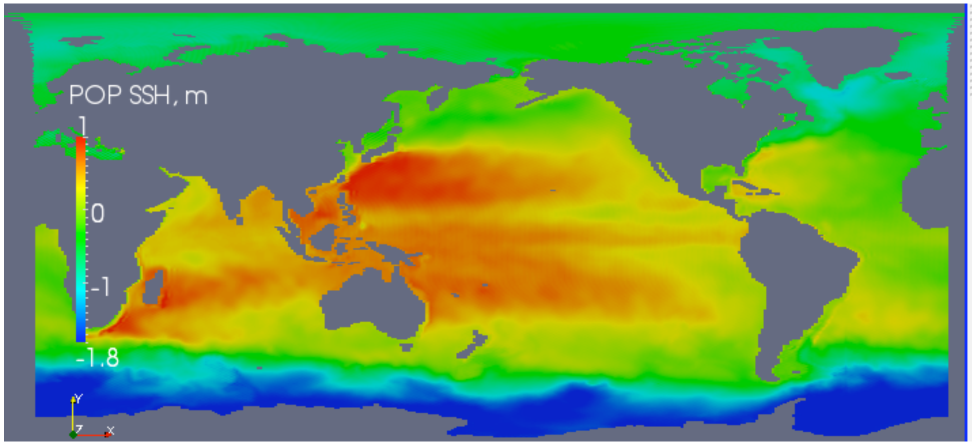
mpas SSH



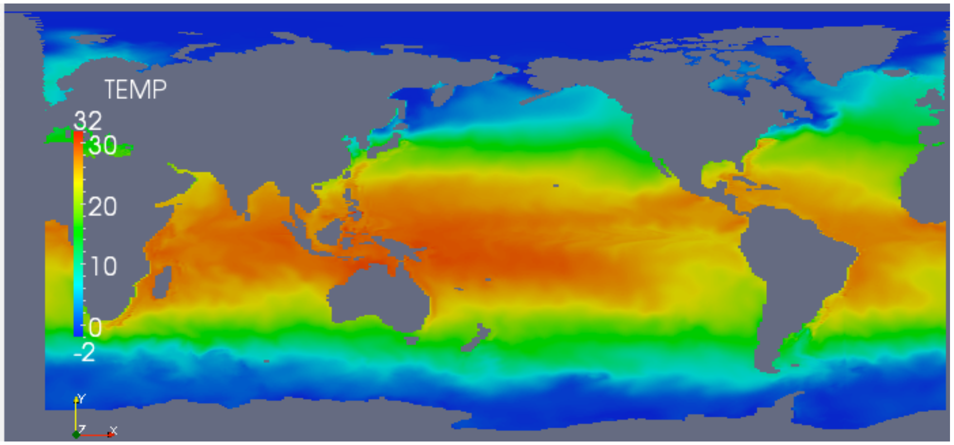
mpas SST



POP SSH

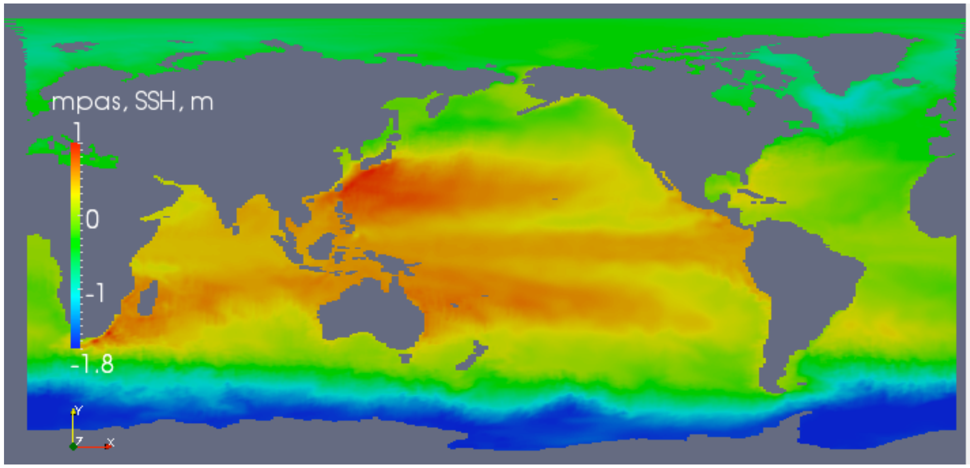


POP SST



POP/MPAS-Ocean Comparison, 1º grid, 165 days

mpas SSH



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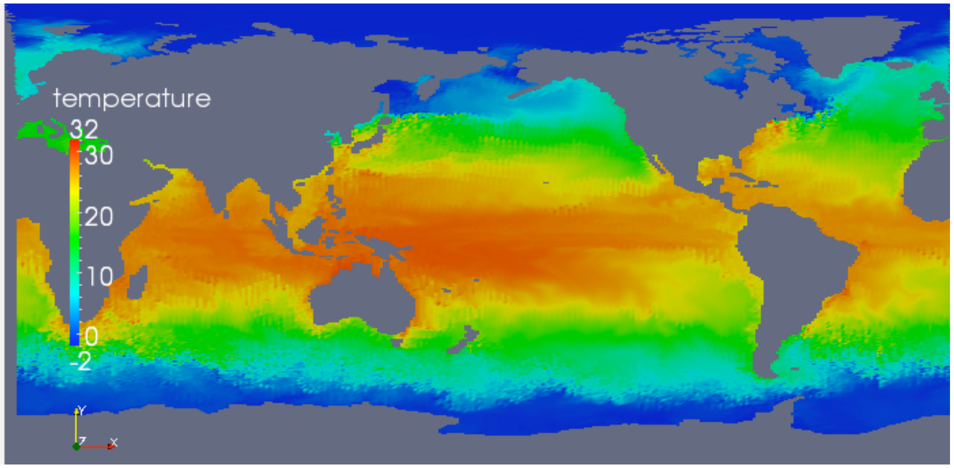
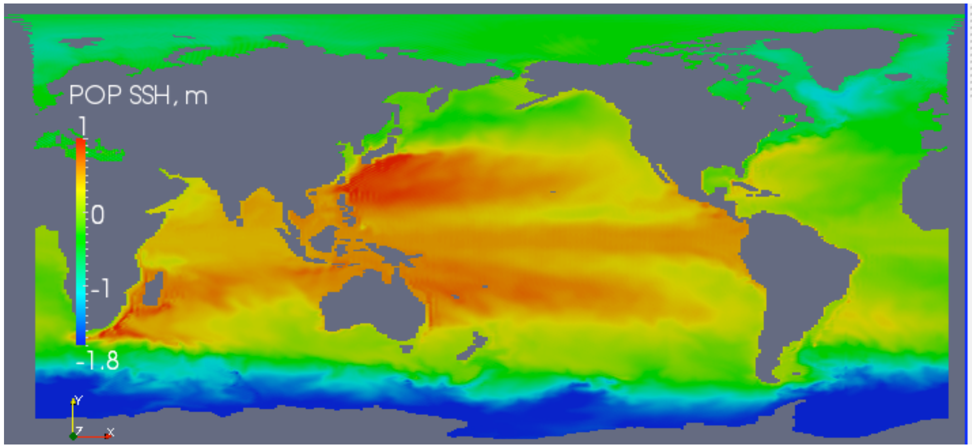
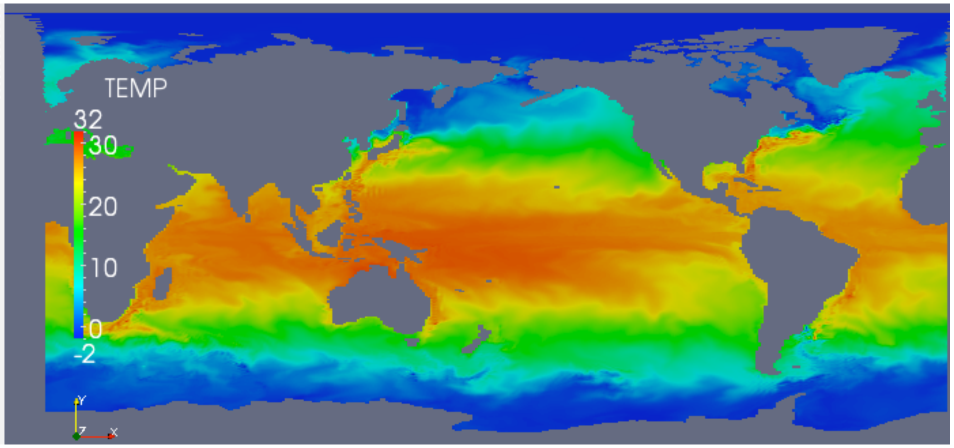


POP SSH



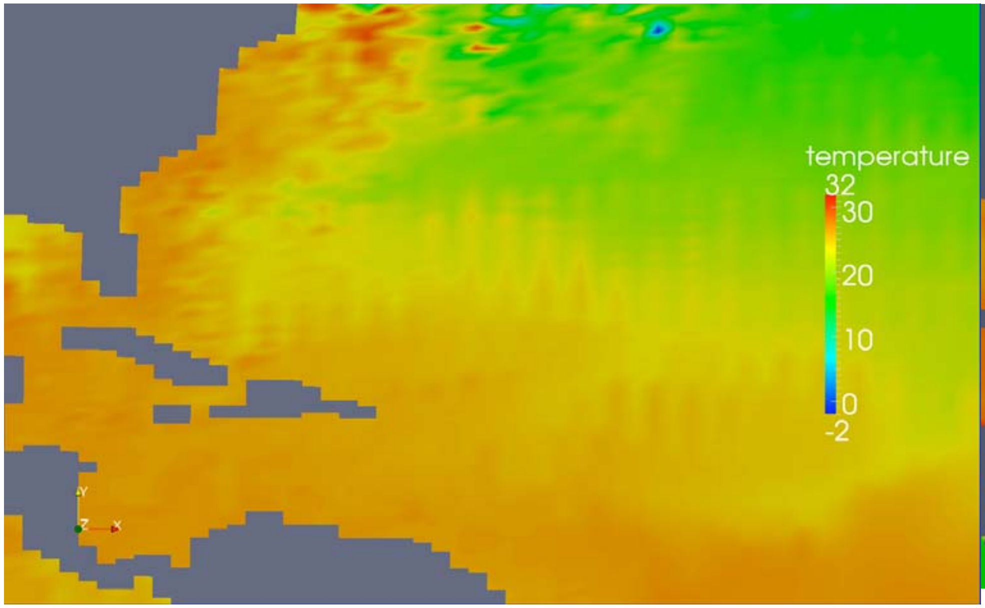
POP SST



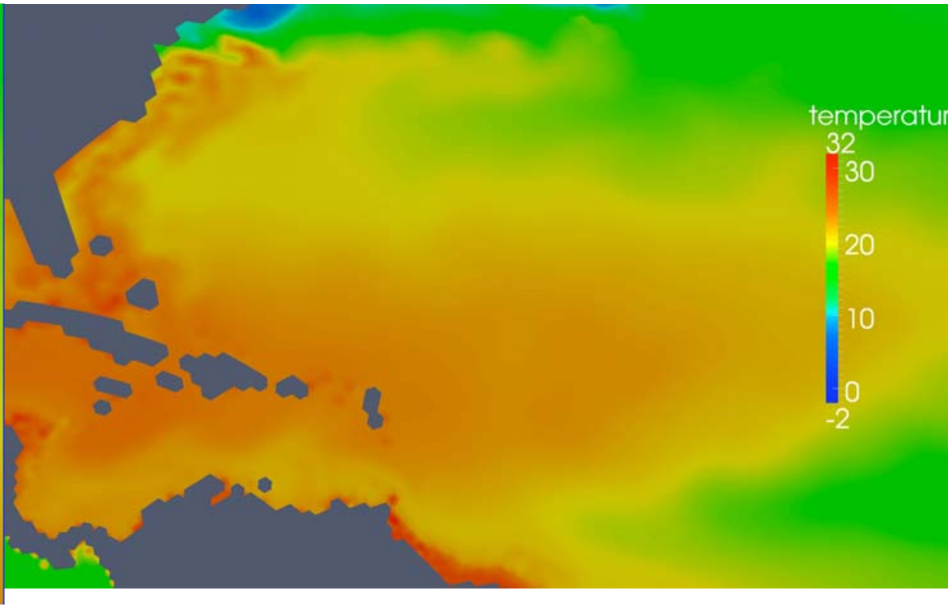
POP/MPAS-Ocean Comparison, 1º grid, 165 days

- **Grid-scale oscillations appears on MPAS-Ocean quad mesh, but not on Voronoi Tessellation mesh.**

mpas quad mesh



mpas Voronoi Tessellation mesh

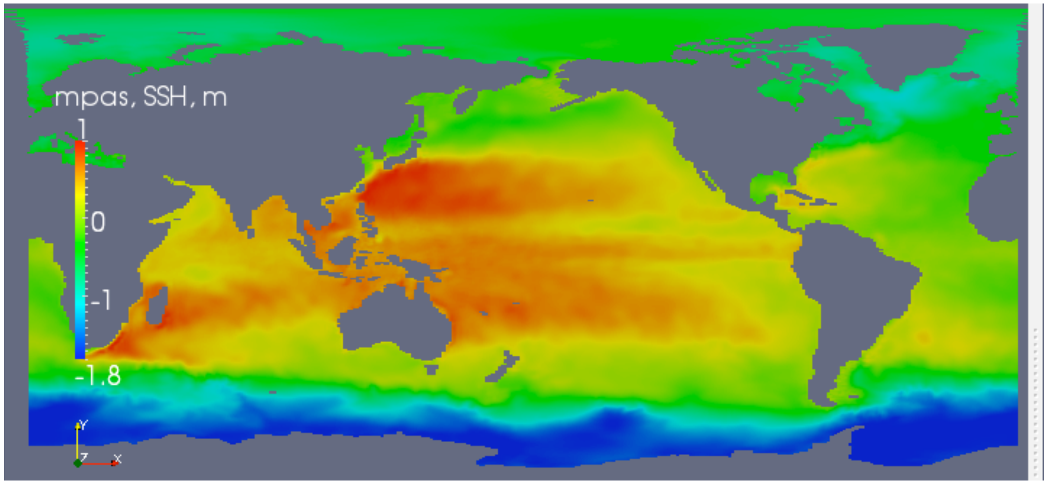


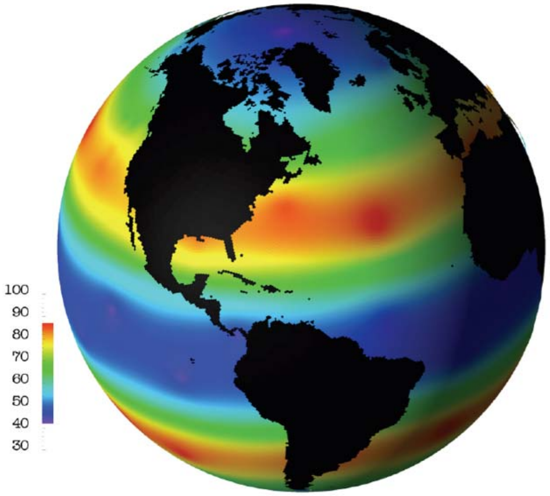
Efficiency

- **Array structure**
  - POP: TRACER(i, j, k, tracer_index, time_index, iblock) *hor. neighbors in cache*
  - MPAS: tracers(tracer_index, k, iCell, time_index) *tracers & column in cache*
  - Indirect array references for neighbors in MPAS.
  - MPAS includes no land cells.
  - In MPAS, adding tracers and vertical levels will not add much computational time.
- **We have done no profiling on MPAS-Ocean yet, so large gains may be possible.**
- **Major task is to include timesplitting to lengthen baroclinic steps**
- **Assuming longer timestep in split mode, MPAS-Ocean is currently 5-10 times slower than POP.**

Visualization Tools for Unstructured Grids

- **POP's structured horizontal grid makes for easy plotting in Ferret and Matlab.**
- **MPAS unstructured grids required additional tools to convert NetCDF output files to plotable formats**
- **At LANL, we made conversion tools for Paraview .vtk format in:**
  - spherical projection
  - latitude-longitude projection
  - combined POP/MPAS output for direct comparison
- **NCAR staff is creating unstructured visualization tools for NCL.**





Conclusions

- **MPAS-Ocean is a functioning ocean dynamical core that operates in isopycnal and z-level vertical coordinates.**
- **MPAS-Ocean quad grid simulations compare well with a POP simulations, although grid-scale noise is visible after 160 days.**
- **MPAS-Ocean work for 2011:**
  - Higdon baroclinic/barotropic time splitting
  - high-order vertical advection
  - GM horizontal mixing
  - implicit vertical mixing, KPP
  - time-varying surface forcing
  - analysis of POP versus MPAS using 0.1^{o} grid
  - variable del2 and del4 horizontal mixing coefficients for variable density meshes
  - peer-reviewed publications introducing MPAS-ocean
  - reference manual
  - profile performance, scaling, and efficiency improvements