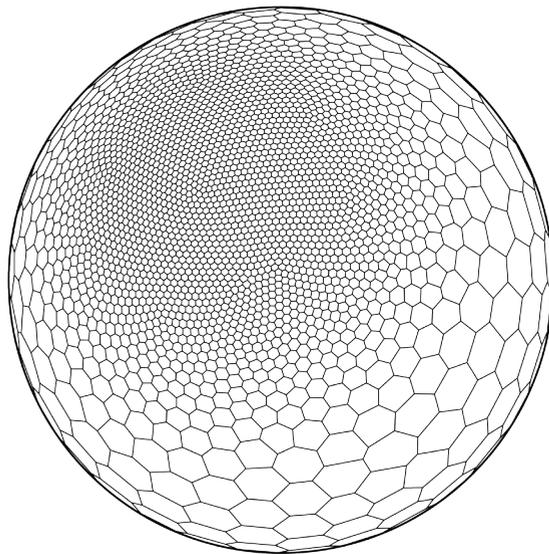


MPAS-Ocean: A New Ocean Dynamical Core for Climate Simulations

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With the release of the 2007 Intergovernmental Panel on Climate Change report on climate change [1], most policy makers have shifted their discussions from the general threat of climate change to assessing impacts of a changing climate on their local area of interest in the coming decades. This has led to an accompanying change in scientific inquiry with a high priority placed on regional and decadal climate prediction. Numerical simulations of the earth system are a useful tool for investigating climate change impacts, such as changes in oceanic circulation, melting of glaciers, and increases in droughts, floods, and hurricanes. There is currently a strong need for numerical models that can resolve physical processes in particular regions, for example melting in Greenland or droughts in the southwestern US. These simulations need to include realistic global patterns of atmospheric and oceanic circulation, but not pay the computational cost of a global uniformly high-resolution grid.

Fig. 1. The MPAS framework supports the use of unstructured, variable-density grids for ocean, atmosphere, and land ice component models, making MPAS a powerful tool for studying the regional effects of climate change.



Investigation of regional climate impacts is the motivation for the new Model for Prediction Across Scales (MPAS), a collaborative effort between scientists at LANL and the National Center for Atmospheric Research (NCAR). MPAS is a model framework that supports unstructured grids, so that high-resolution grids may be placed in regional areas of interest, while lower-resolution grids are used for the remainder of the earth (Fig. 1). Current methods of regional modeling typically use one-way nesting of grids, where there is a sharp transition

between grids, and data is only communicated into the nested high-resolution region. MPAS grids have smooth transitions, and all gridcells are integrated in the same way, so that fluid properties are advected smoothly over changing gridscales.

Development of the MPAS-Ocean model began in early 2010 by the LANL scientists in the Climate, Ocean, and Sea Ice Modeling team (COSIM) in CCS-2 and T-3. The MPAS effort includes dynamical cores of the atmosphere, ocean, shallow water equations, and sea ice. Each of these models share common tools available in the MPAS framework, including grid initialization, time management utilities, input/output and restart modules, and automated variable declaration. An intense collaboration between LANL and NCAR to create shared resources among dynamical cores has led

to rapid development and testing of these new models. Each dynamical core differs in its governing equations and physical parameterizations, but they share a common finite volume numerical scheme. This scheme discretizes the vector-invariant form of the momentum equation, and uses the relationship between the nonlinear Coriolis force and the potential vorticity flux to guarantee that mass, velocity, and potential vorticity evolve in a consistent and compatible manner [2,3].

A primary issue in ocean modeling is treatment of the vertical coordinate: isopycnal coordinates model the ocean as stacked layers of constant density, while z-level models utilize layers at fixed depths. There are advantages to each. Z-level models possess favorable stability properties and vertical resolution can be easily specified. Isopycnal models are less diffusive, but vertical resolution and deflated layers are difficult to control. MPAS-Ocean is able to run with either isopycnal or z-level coordinates using the same executable by only changing a setting in the input file. Simulations in isopycnal mode have already been used to investigate eddy closure parameterizations (Fig. 2) [4]. The z-level mode supports topography, so that global simulations may be run with land boundaries and ocean basins. Other additions completed in 2010 to make MPAS-Ocean a working ocean dynamical core include high-order horizontal advection, horizontal diffusion terms, and a nonlinear equation of state.

In addition to the explicit fourth order Runge-Kutta scheme for time integration, methods based on barotropic-baroclinic splitting are under development for MPAS-Ocean. These methods decompose the fast and

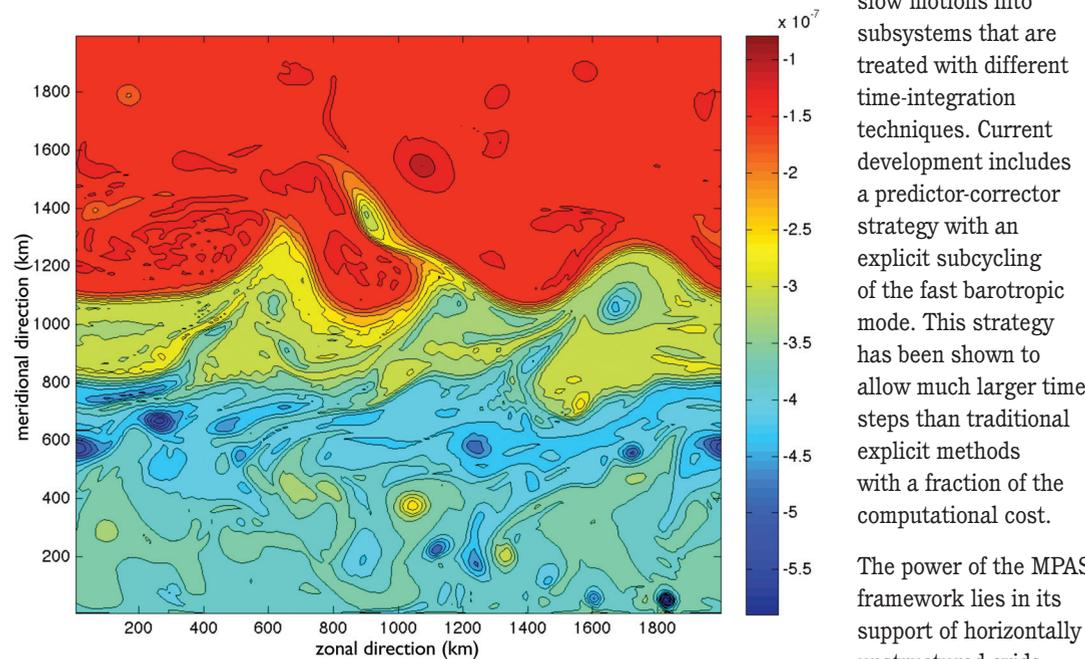


Fig. 2. Potential vorticity from an MPAS-Ocean simulation, run in isopycnal mode, used to study turbulence closure models [4]. The configuration is a zonally periodic wind-driven channel that captures the relevant features of the southern ocean: a meandering zonal jet, vorticity filaments, and westward-propagating eddies.

simulations. However, MPAS also supports uniform grids that can be useful for backwards compatibility and comparisons with other models. A series of validation simulations of MPAS-Ocean and the POP ocean model have shown that MPAS-Ocean produces realistic circulation features (Fig. 2). The COSIM POP model is well known and trusted by the ocean modeling community, so these verifications are essential for MPAS-Ocean to be accepted as a functional dynamical core.

The creation of a new ocean model requires the committed effort of a focused team of developers. The LANL COSIM team has made great strides this year, but much work remains, including additional mixing parameterizations, advanced time-stepping schemes, documentation, and performance improvements. Additionally, new challenges of variable density grids, such as scale-aware parameterizations, will be addressed in the coming year.

slow motions into subsystems that are treated with different time-integration techniques. Current development includes a predictor-corrector strategy with an explicit subcycling of the fast barotropic mode. This strategy has been shown to allow much larger time steps than traditional explicit methods with a fraction of the computational cost.

The power of the MPAS framework lies in its support of horizontally unstructured grids to conduct regional

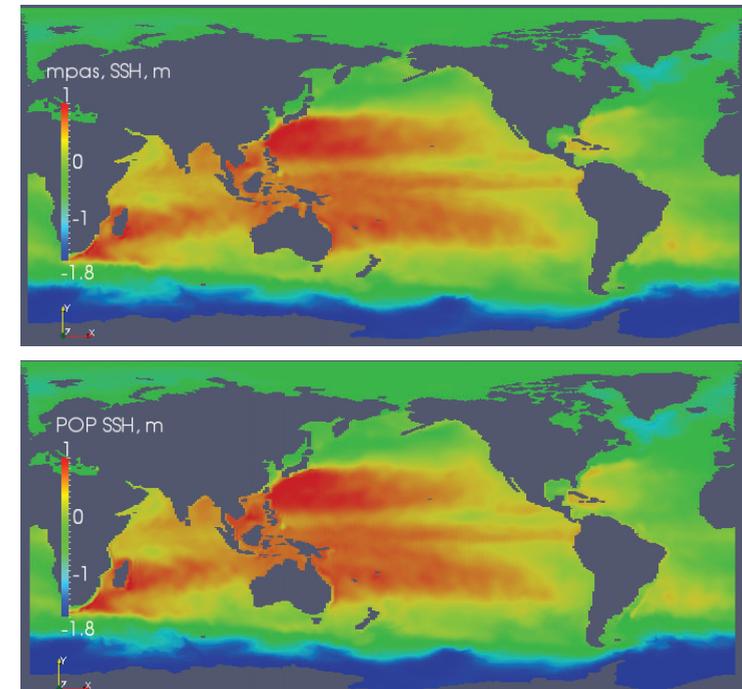


Fig. 3. Comparison of the sea surface height from an MPAS-Ocean simulation (top) and a POP ocean model simulation (bottom). Validation of a new ocean dynamical core such as MPAS-Ocean is a critical step towards being accepted by the ocean modeling community.

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