Title: MPAS-Ocean Response to CESM OMWG Request for Information
Key personnel: MPAS ocean and sea-ice model development team at LANL

Point-by-point response:

- Request: Advanced dynamical core technical capabilities, including flexible vertical coordinates and resolution, advanced tracer advection schemes, natural boundary conditions on freshwater and tracers, and support for non-Boussinesq configurations.

  Response: MPAS-Ocean contains state-of-the-art capabilities for the physical simulation of global ocean dynamics. These capabilities include multi-resolution capability [4, 6, 5], an arbitrary Lagrangian Eulerian vertical coordinate [2], a high-order tracer-conserving advection scheme [8] with flux-corrected transport [10]. The model is formulated to be mass conserving with native support for natural boundary conditions on freshwater and tracer fluxes. Supporting non-Boussinesq configurations is in our 2017 development plan. Our default global configurations use 100 vertical levels with 1 meter resolution at the surface. In the horizontal the global model spans resolutions from 5 km to 60 km in global configurations and sub- 1 km resolution in idealized configurations. Higher resolution regions, e.g. within the Southern Ocean, along coast lines and/or under ice shelves, within the global configurations are currently being explored in two NCAR SciDAC projects and in the DOE ACME system.

- Request: Model infrastructure and a development environment that provides strong support for collaborative model development with the university-based CESM community. This includes both structured programs such as Climate Process Teams and small group entrepreneurial projects.

  Response: MPAS-Ocean strives to practice and promote best-in-class software development, maintenance and validation practices. We consider the "model infrastructure" to include much more than the PDE solver. Rather, the model infrastructure is a coherent, end-to-end system, from grid generation to analyses, for the support of scientific study of ocean processes ranging from idealized process-based configurations to global coupled system configurations. Test cases, model configurations, PDE solver, continuous integration test harness and analysis tools are all maintained (and continuously tested) within the joint NCAR-LANL Model for Prediction Across Scales (MPAS) project git repository. Over the past five years, the MPAS project has developed a set of practices beyond software infrastructure that would naturally accommodate university- and CPT-driven development. These include weekly developer teleconferences, project design and testing documents and internal peer-review of project design, testing and software implementation. Our standard development strategy is for a single-PI or small team to implement new model features on a git branch. Once completed, the design, implementation and testing procedures are peer-reviewed and integrated into "master."

- Request: Strong support for both regional and climate modeling applications.

  Response: MPAS-Ocean seamlessly accommodates regional applications with a global modeling framework [5]. It does so while maintaining *all* of the important mimetic and conservation properties that exist in the global, uniform grid configurations.

- Question:Support for a wide range of resolutions and grids, and accompanying scale aware parameterizations.

  Response: A relative strength of MPAS-Ocean is the flexibility in the horizontal and vertical grids. The test cases (discussed below) are constructed to be as "grid-agnostic" as possible, so that a given test case specification is independent of the horizontal and vertical grids provided as input to the test case. Since the tracer transport is monotone, no ad hoc closure is required. The hyper-viscosity in the momentum equation scales naturally and seamlessly with grid resolution. By extending the analysis from [7], we are currently implementing a prognostic, mesoscale eddy closure that we expect will exhibit scale-aware properties.

- Request: Ability to configure and run simpler idealized configurations for process modeling and educational applications.

  Response: We currently have 41 test cases and configurations which are maintained with the MPAS-Ocean git project. Every test case configuration is fully automated and is immediately available to all developers. The configurations span the spectrum of single-column configurations, community-developed test cases [1], process-based configurations [9, 7, 3] to global, realistic configurations [5]. Every configuration is automatically included into the nightly regression testing where short-duration simulations are compared to baseline results. Maybe most importantly, the creation of new, user-developed test cases is completely *templated*. So additional test cases are easy to create, maintain and evolve. We strive to make sure that each test case includes a pre-configured, default analysis capability to allow users to view output immediately after simulation. All of the front-end configuration and back-end analysis are produced with Python code.

- Request: Compatibility with the CESM sea-ice model.

  Response: MPAS-Ocean is compatible with MPAS-Seaice that can be considered the unstructured-grid counterpart to the CESM CICE model. LANL is spearheading and DOE is financially supporting the creation of a community-driven sea-ice model consortium to develop, test and maintain physical parameterizations of sea-ice processes that are not directly tied to the model's horizontal discretization. One purpose of this consortium is to aid the community's transition from CICE to MPAS-Seaice. Somewhat related, LANL has embarked on a project to develop a computationally efficient discrete element method sea-ice model that is valid at horizontal scales typical of high-resolution global simulations. If successful we expect that this model will significantly enhance the accuracy of sea-ice dynamics at high resolutions and eventually replace the MPAS-Seaice model in ACME.

- Request: Ability to interface with CESM coupled data assimilation system.

  Response: Coupling between MPAS-Atmosphere and DART and between MPAS-Ocean and DART have been completed under previous projects. The MPAS-Ocean / DART interfaces will have to be revisited and updated, but that capability should be easy to revive and move forward.

- Request: Familiar post-processing and analysis capabilities (akin to CESM workflow tools.

  Response: The MPAS-Ocean output is in (nearly) COADS-compliant netCDF format. Data on the native grid can, in principle, be ingested into and viewed with NCL analysis products. Alternatively, NCO now supports command-line regridding of MPAS grids to more familiar grids, such as latitude-longitude grids. A near term workflow that "maps" MPAS grids to POP grids that can then be fed into OMWG diagnostic packages is certainly a path forward. Within the ACME project, we are building an extensive, HPC-capable analysis framework built around Python. For example, Lagrangian particle statistics from MPAS-Ocean (called LIGHT [9]), are routinely processed in parallel using many hundreds of computing cores.

Current state of model development within the MPAS ecosystem: From its inception, the entire MPAS activity has been jointly led by LANL and NCAR. The MPAS framework presently supports five different physical models: MPAS-Ocean [5], MPAS-Atmosphere [8], MPAS-Landice, MPAS-Seaice and MPAS-ShallowWater [6]. The development of MPAS-Atmosphere is led by NCAR scientists within the MMM Division. Each model is a stakeholder in the maintenance and development of the MPAS modeling infrastructure. Each of these models is developed using a shared modeling infrastructure that greatly reduces the burden of developing and maintaining machine-portable, production-ready models. The MPAS activity strives to identify common needs across the suite of MPAS models and we work jointly in developing model functionality that can be leveraged across the modeling system. We continuously evaluate our software and development work flows in an attempt to foster a set of best practices. These practices include revision control, code review, design documents, continuous integration, end-to-end provenance and automated regression across a large test case suite. If an additional model is supported within the MPAS framework, that model would be considered as an additional stakeholder within the MPAS community with equal authority and responsibility.

Configuration of MPAS-Ocean - CESM Collaboration on Ocean Model Development: We propose to create an Ocean Model Development Consortium, with NCAR and LANL as the primary stakeholders. The goal of the Consortium is to work jointly to improve MPAS-Ocean along a coherent development trajectory, while also allowing for mission-driven differences to be accommodated. The consortium would identify, manage and integrate shared development projects. The consortium will develop a set of guidelines to help manage developments in a way that is mutually beneficial to both groups. The consortium would also track the relationship between the agency-specified level of support for each joint development project and progress of that project.

We expect that DOE resources will be directed toward ACME's science goals and joint development projects. In turn, NSF resources will be directed toward NCAR's science goals and joint development projects.

Status: This document puts forward a possible working relationship at the scientist/model level. A fleshing out of how, or if, such a relationship is workable will necessarily have to include a larger and more diverse stakeholder group that includes ACME, CESM SSC, NCAR MMM, DOE CESD and NSF.

References

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