Science Requirements for CESM2 Ocean Component Model

Requirement: Natural boundary condition on freshwater and tracers
Priority: High
Background: Virtual salt fluxes (and associated treatment for other tracers like carbon), in addition to being unphysical, can introduce biases in the tracer distributions due to spurious forcing at high and low concentrations. Advancements of other aspects of the model, e.g., coastal freshwater exchange and ice sheet interactions, are being held back by this issue.
Development required: Moving the flux boundary condition from the tracer equations to the (volume or mass) continuity equation is relatively straightforward, and is currently implemented in POP2, but has implications for stability in the case of small upper layer thickness. It will also be necessary to distinguish between freshwater fluxes from the atmosphere or land (which change the mass in a column) and from floating ice (which do not).

Requirement: Mass conservation
Priority: Medium
Background: Under the Boussinesq approximation, the model conserves volume, not mass. Therefore, it cannot simulate steric sea level rise explicitly. A posteriori corrections are available to recover this component of sea level, but there are some suggestions in the literature that aspects of the dynamics and surface boundary conditions are better represented in a mass-based rather than volume-based formulation.
Development required: The most straightforward approach could be to adopt a pressure based vertical coordinate. Other methods for relaxing the Boussinesq approximation have been suggested (Greatbatch et al.) and implemented in early versions of POP.

Requirement: Small vertical scale structures in upper-ocean
Priority: High
Background: The current implementation of mode splitting and the free surface formulation require surface layer thickness of at least O(10 m). Even this becomes problematic when trying to implement natural boundary conditions for ice covered areas. There are physical phenomena of interest, e.g., diurnal layers, coupling to wind waves, equatorial Small Velocity Scale (SVS) features where O(1 m) vertical resolution would be desirable.
Development required: A reformulation in a vertical coordinate that maintains a uniform (or nearly so) upper layer thickness, rather than a variable thickness with a constant depth lower interface, would circumvent this problem.

Requirement: High frequency forcing
Priority: High

Background: It has become computationally and physically necessary to begin representing surface exchanges at a frequency that resolves diurnal and inertial periods.
Development required: The current centered time differencing with periodic averaging steps, combined with the requirement for exact conservation over coupling intervals, requires adjustment of the frequency of mixing steps as a function of coupling interval, rather than as dictated by numerical stability. The introduction of high-frequency motions also has implications for advection and vertical coordinate choices.

Requirement: Less dispersive/ more accurate scalar advection
Priority: Medium
Background: A monotone advection option (LW-lim) has been available, but has been found to be too diffusive in some applications. As we become more explicit and precise in our treatment of physical mixing processes, we need to revisit the question of numerical sources of dispersion and mixing.
Development required: There is a lot of activity in this area outside of CESM, as well as within other component models. We may need to develop some more appropriate testing and evaluation frameworks to guide our choices in this area.

Requirement: Closures for mesoscale resolving models
Priority: Low-Medium
Background: There has not been much progress on specifying sub-grid scale closures for our eddy-resolving simulations since the late 1990's. Recent work on sub-mesoscale processes provide some obvious directions to pursue.
Development required: A relatively simple place to start would be to revisit and resurrect the anisotropic-GM and near surface mixing schemes for high-resolution, and test the sensitivity to tidal mixing and NIW schemes implemented but not yet tested at high resolution.

Requirement: Accommodation of floating sea ice
Priority: Medium
Background: It is unclear if drag between sea ice and ocean and the mixing driven by that interaction is accurately represented when the ocean surface is unable to fully respond to the pressure loading of sea ice above. This is linked to the natural boundary condition on freshwater as described above as well.
Development required: A flexible vertical coordinate that can accommodate several meters depression of sea surface height without undue loss of accuracy would allow exploration of this issue.

Requirement: Accommodation of floating ice shelves
Priority: Medium
Background: The coupling of the ocean to floating ice sheet models requires a generalization of the treatment of the upper boundary condition – similar to, but in a more extreme scenario -- as described above for sea ice.

Development required: The extreme sea surface displacements associated with ocean modeling under ice shelves probably requires allowance for the boundary between ice and uppermost ocean to be placed within what would otherwise be the ocean interior – such that the sea surface is no longer restricted to lie above the uppermost level of the model.