Development of Two-Way Nesting in the Navy Coastal Ocean Model

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Abstract

We report on an ongoing effort to implement and test two-way embedding schemes in the Navy Coastal Ocean Model (NCOM), which can run as a stand-alone ocean model, as well as a component within the Coupled Ocean/Atmospheric Mesoscale Prediction System (COAMPS). While COAMPS provides a framework for one- and two-way coupling among atmosphere, ocean, and wave models, embedded coupling between coastal and regional scale ocean models is needed to advance the operational capability across multi-scales in nearshore waters; in particular, in regions that are bathymetrically complex and strongly influenced by riverine, estuary, and wetland processes. We shall discuss the nesting strategy, the results of implementing various schemes and boundary conditions at the grid interface, and issues associated with bathymetry inconsistency between the coarse and fine grids. Evaluations are based on idealized experiments and real coastal simulations with tides and atmospheric surface forcing. Needs for improvements are addressed.

Background

NCOM was developed at NRL to meet the Navy's needs for coastal ocean simulation and prediction (Martin, 2000). It is a part of the Navy's COAMPS, which uses the Earth System Modeling Framework (ESMF) to couple atmosphere, ocean and wave models. NCOM has a free surface, and solves the primitive equations on an Arakawa C grid. The horizontal grid is curvilinear, while the vertical grid uses sigma and z-level coordinates. The propagation of surface waves and vertical diffusion are treated implicitly. The Mellor-Yamada Level 2 and 2.5 turbulence models are implemented for vertical mixing.

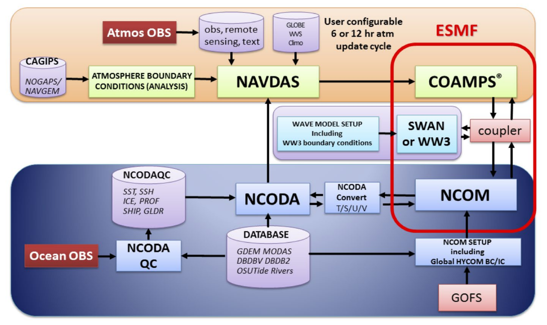


Fig. 1 A schematic of COAMPS®

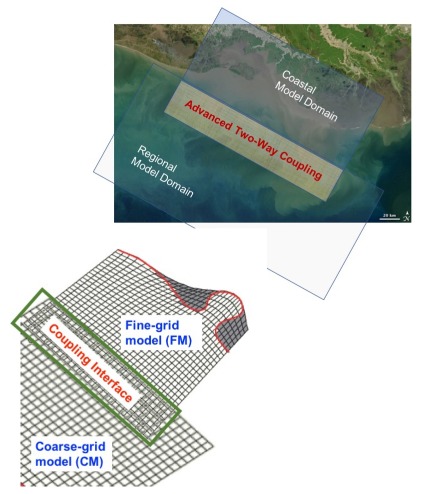


Fig. 2 Nesting of regional and coastal models.

An efficient way to model the multiscale dynamics in coastal oceans is to use embedding or nesting techniques, where a hierarchy of structured-grid models can interact with each other (e.g., Penven et al. 2006, Debreu & Blayo 2008, Debreu et al. 2012, Haley & Lermusiaux 2010). In NCOM, a 1-way embedding procedure has been implemented and fully evaluated, where the parent/coarse-grid (CM) model solutions are interpolated at the open boundaries of the child/fine-grid (FM) model domain. The existing strategy for NCOM 2-way nesting is to update the scalar field (T,S) on the CM grids using the FM solutions, and assume that the velocity field will adjust according to the geostrophic balance, $\mathbf{f} \times \mathbf{v} = \nabla p(\rho)/\rho_0$. This works reasonably well in some situations, but in regions where strong relative vorticity develops, e.g., due to complex topography, the model solutions can be inaccurate and/or noisy.

This work is to improve NCOM's 2-way nesting capability by implementing update schemes for feeding the FM velocity field and surface elevation back to the CM domain.

Testing the existing NCOM nesting strategy in Chesapeake Bay

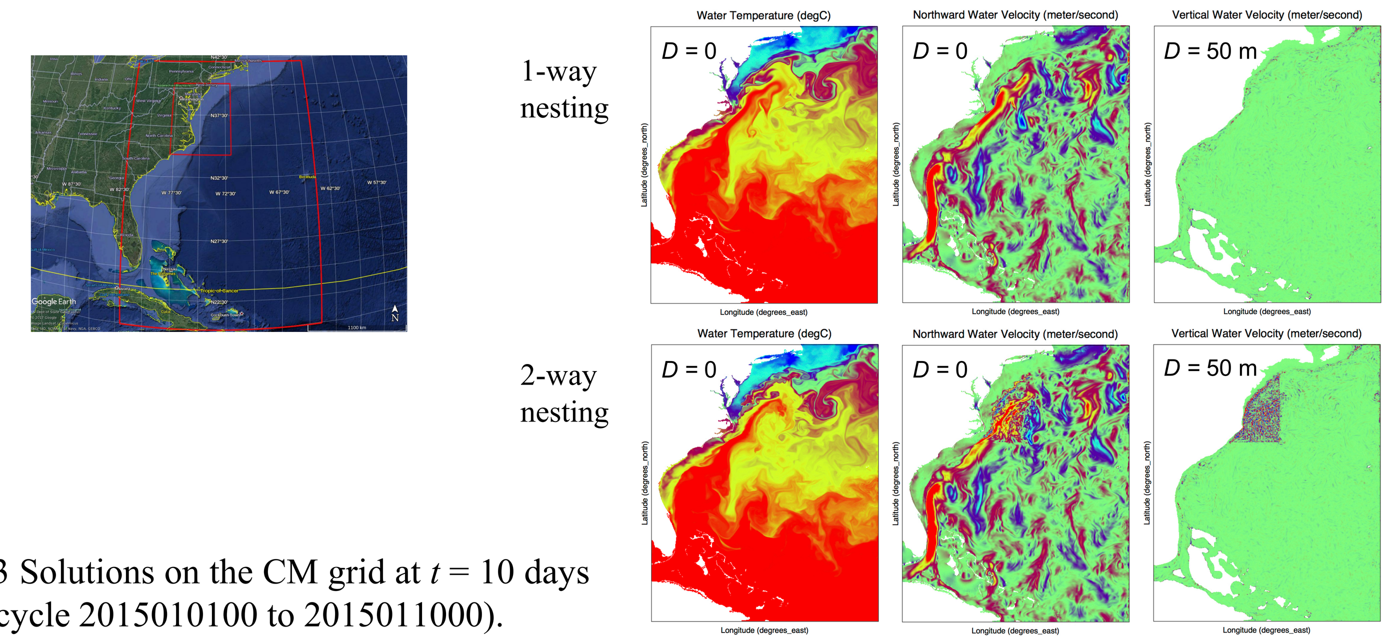


Fig. 3 Solutions on the CM grid at t = 10 days (run cycle 2015010100 to 2015011000).

Implementation

Separation of dynamic and feedback interfaces

- The dynamic interface is where the boundary conditions for the FM domain are provided.
- The feedback interfaces are the outer boundaries of the region within which the CM solutions are updated: feedback interfaces need to be defined for TS-pts, u-pts, v-pts, and eta-pts.

Feedback (restriction) operators

- Nesting ratio is 3:1 in time and space.
- For T, S and eta: use a simple average of the 9-FM cells.
- For u, v, and the depth-integrated velocity (vd) use: a) a simple average of the 3-FM u- or v-pts along the CM-cell boundary; b) a weighted average of the 9-FM u- and v-pts; c) a simple average of the 9-FM pts surrounding the CM point.

Results

Test case: Southwestward propagation of a baroclinic vortex

This physical problem has been used to evaluate the performance of 1- and 2-way nesting of ocean models in the literature. In this idealized experiment, an initially axisymmetric baroclinic vortex is centered at 38.5N, 38.5E in a basin of uniform depth of 5000 m. The initialization is done using the theoretical solutions.

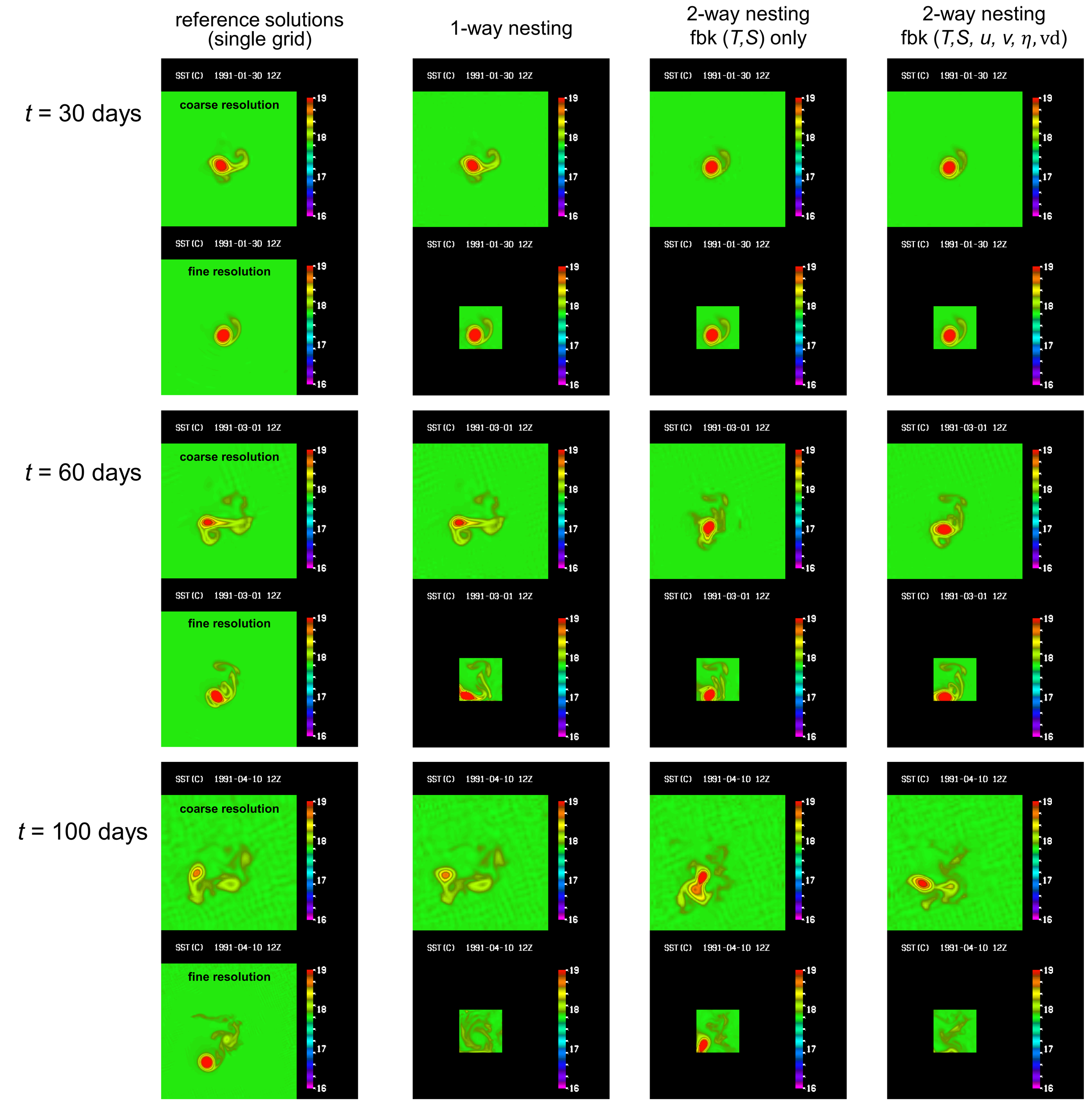


Fig. 4 Evaluation of the surface temperature in the CM and FM domains. A few remarks: (i) Feeding back the depth-integrated velocities, along with the 3D (u,v), improves the nesting performance. Once this is done, updating eta is insignificant. (ii) The velocity-feedback interfaces should be placed on the inner side of the TS-feedback interface, and the eta-feedback interface should be on the inner side of the u-,v-feedback interfaces. (iii) The numerical open boundary conditions for the FM can significantly affect the performance. (iv) The update operators do not have a significant effect.

Results (con't)

Test case: Eastward propagation of equatorial Kelvin wave over a topography

This idealized experiment is set up to show that the previous NCOM 2-way nesting strategy becomes inadequate in regions where strong relative vorticity develops, which breaks the assumption of geostrophic balance.

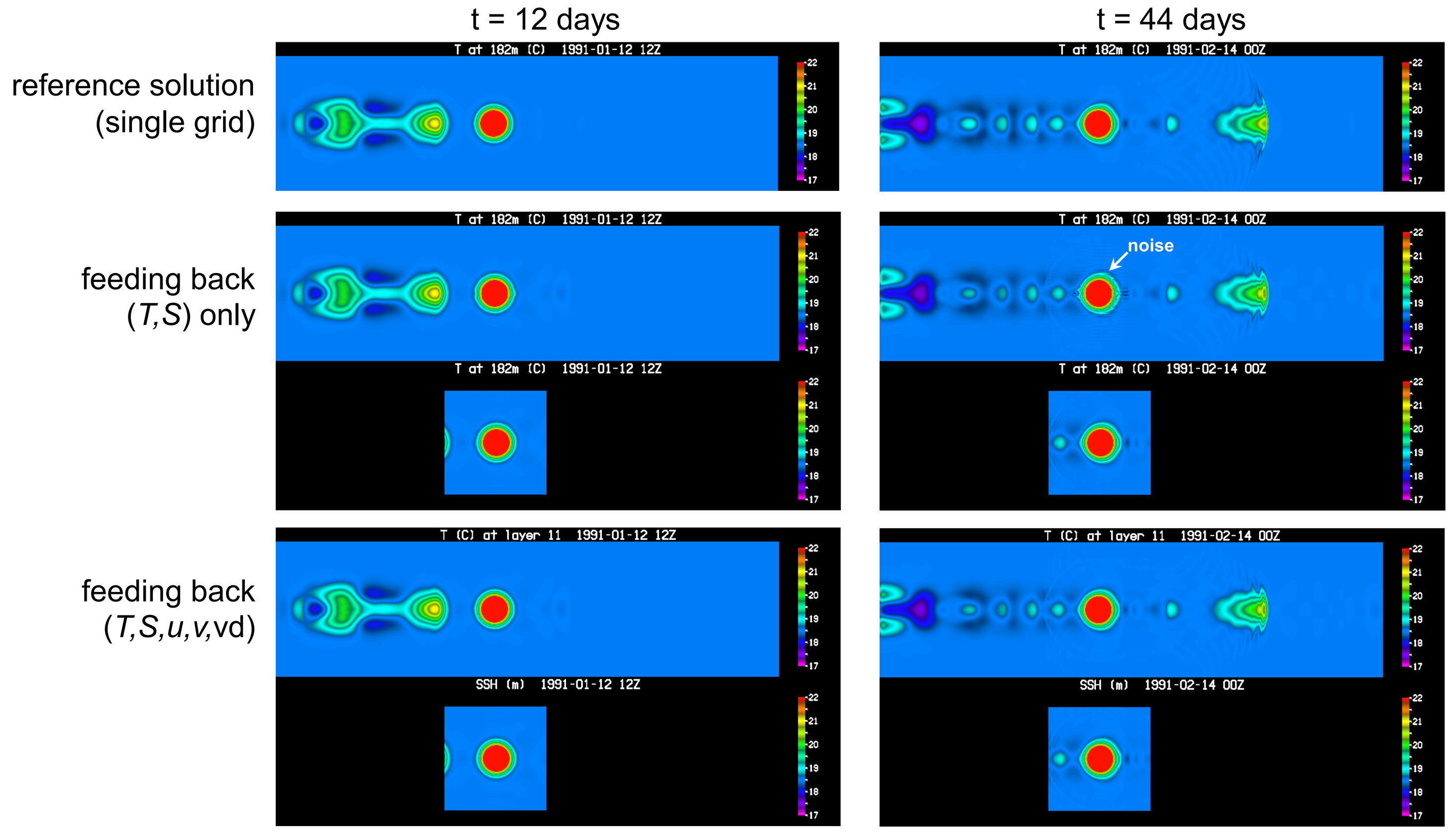
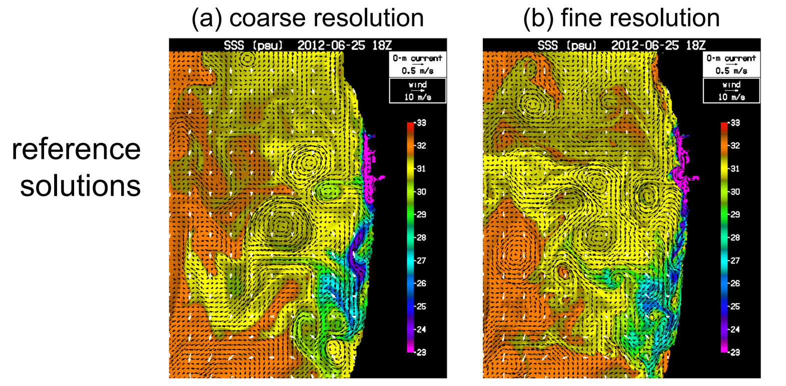


Fig. 5. Temperature at 182 m depth. IC: u=v=0, S = 35 psu, and Levitus $T(z)$ for equatorial Pacific at 180E, with a perturbation for Kelvin wave. No other forcing. Full sigma layers on both the CM and FM grids. The Gaussian-shaped submarine mountain is centered on the FM grid with the peak near the thermocline.

Test case: Columbia River, Pacific Northwest



The ICs are set up from an archived Global-NCOM database. The CM boundary conditions are interpreted from the daily Global-NCOM data. The surface atmospheric forcing is set up from archived NOGAPS-3 data. Tides are specified from the OSU US West Coast database. Run cycle: 2012040100 to 2012063000

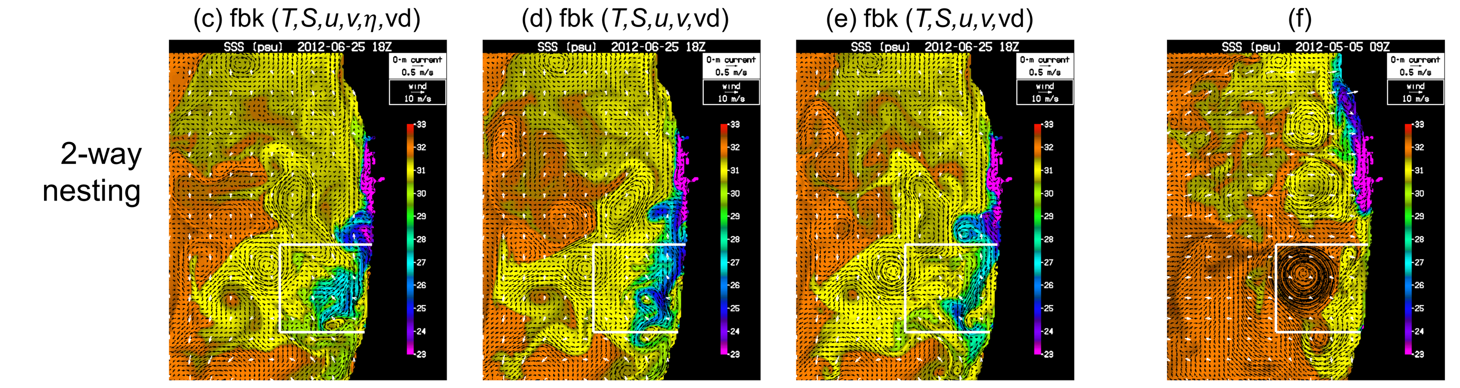


Fig. 6 Sea surface salinity. The weighted average update operator is used in (c) and (d), comparing with the simple 3-pt average used in (e). In (f), the simulation failed due to a slight increase of the relaxation time scale for the open boundary conditions on the FM grid (outlined in white).

Summary

- Algorithms for two-way embedded nesting have been implemented in NCOM. Initial tests show some improvements of the model solutions.
- Appropriate placement of the feedback interfaces for (T,S), (u,v), and eta, is important.
- Updating the depth-integrated velocities tends to reduce the influence of feeding back eta.
- The nesting performance can be sensitive to the numerical open boundary conditions, depending on the individual physical problem or system.
- It is difficult to achieve complete consistency between the CM and FM bathymetries when modeling a real coast. This can cause inconsistency between the baroclinic and depth-integrated velocities, triggering artificial strong vertical mixing (indicated by the large vertical CFL parameters). These problems must be addressed.

References

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