Improving Global Surface and Internal Tides through Two-Way Coupling with High Resolution Coastal Models

PI Maarten Buijsman
Department of Marine Science
University of Southern Mississippi
Stennis Space Center, MS 39529
Phone: (228) 688-2385; Fax: (228)-688-1121
E-mail: maarten.buijsman@usm.edu
Award Number: N00014-15-1-2288

co-PI Brian K. Arbic
Department of Earth and Environmental Sciences, University of Michigan,
Ann Arbor, MI, 48109
Phone: (734) 615-4941; Fax: (734) 763-4690
Email: arbic@umich.edu
Award Number: N00014-15-1-2288

co-PI Alan J. Wallcraft
NRL Code 7323
Stennis Space Center, MS 39529-5004
Phone: (228) 688-4813; Fax: (228) 688-4759
Email: Alan.Wallcraft@nrlssc.navy.mil
Award Number: N00014-15-WX-01744

Co-PI James Richman
Center for Ocean-Atmospheric Prediction Studies, Florida State University
2000 Levy Avenue, Building A, Suite 292
Tallahassee, FL 32306-2741
Phone: (850) 644-4581; Fax: (850) 644-4841
james.richman@nrlssc.navy.mil

co-PI Jay Shriver
NRL Code 7323
Stennis Space Center, MS 39529-5004
Phone: (228) 688-4625; Fax: (228) 688-4759
Email: Alan. jay.shriver@nrlssc.navy.mil
Award Number: N00014-15-WX-01744

LONG-TERM GOALS

The Navy produces weekly global forecasts of the state of the ocean, updated daily. These forecasts are used to aid decision making and to provide boundary conditions for higher resolution regional models. Tides play an important role in the high frequency variability of the ocean, modulating acoustic propagation and loss. Tidal currents affect small boat and diver operations. At present, the barotropic tides are added to the boundary conditions to force tidal motions in the regional models. However, this approach fails to adequately forecast the internal tides. The present plans call for the Navy to transition a global 1/25° forecast system with embedded tides at the end of FY17. The current global 1/25° model has large errors for tides in the coastal ocean.

The long-term goals are to increase the accuracy of the tides in the global ocean forecast model using a two-way nesting technique. This technique has a significant advantage over the current one-way nesting approach with significantly lower cost than increasing the model resolution everywhere. Thus, the proposed research will advance the Navy forecasting capacity and improve the information provided to decision makers.

OBJECTIVES

In recent years much progress has been made with implementing, validating, and improving tides in global HYCOM. However, the root-mean square errors between predicted and observed tides in the North Atlantic remain much larger than in other ocean basins. These errors may be attributed to complex coastal shelf geometry on the Hudson and European shelves that is poorly resolved in 1/12.5º and 1/25º global HYCOM. The North Atlantic has strongly resonant tides that are very sensitive to coastal geometry. The tides near the coast are impacted by the incoming tides from the deep ocean. Additionally, the resonant tides over the shelf impact the deep ocean tides.

The objectives of this study are to improve the surface tides, and implicitly the baroclinic tides in HYCOM, through a two-way coupling of the coarse resolution parent HYCOM model with high-resolution nested coastal models. For this purpose, we will use the two-way coupling method OASIS.

APPROACH

Global HYCOM uses a tripole grid which is Mercator (square) south of 47º N. In order to accurately resolve the coastal shelf geometry and bathymetry, and hence the coupling between open-ocean and coastal tides in highly resonant regions, grid spacings smaller than 1/25º are required. To accomplish this we propose to nest coastal (HYCOM) models having a very high horizontal resolution of about 1 km inside global HYCOM. We will use OASIS, a Fortran package that facilitates two-way coupling of two concurrent running simulations. The two-way coupling is needed to allow surface and internal tides to radiate from the coastal model into the parent model, and vice versa. Since the resonance signal is large and basin-wide, we anticipate a significant difference in the two-way coupled case.

In a first step we will perform the coupling for tide-only, barotropic (one layer) HYCOM simulations. The coupling will occur between the 1/25° parent grid and the 1/75° high-resolution nest. These experiments will be compared with a global 1/75° barotropic simulation. In a next step we will execute the same coupling experiment, but for a 41-layer HYCOM simulation with realistic tides and atmospheric forcing. If time permits we plan to perform a global 1/50° 41-layer simulation that is initialized from a 1/25° simulation.

Initially we will nest higher resolution models of the Hudson and European shelves, North Atlantic regions that are highly resonant and that contribute substantially to the large RMS elevation errors in the North Atlantic. If this is successful, the two-way coupling technique can be applied to other regions as well.

The proposed experiments are summarized below:

- Apply OASIS 1/75° nests to Hudson Strait and European shelf embedded in the 1/25°, tide-only, barotropic (one layer) HYCOM parent simulations.
  GOAL: -confirm that OASIS handles tides
  -correctly capture the resonances in the North Atlantic

- Perform global 1/75° barotropic simulations
  GOAL: compare with two-way nesting (1/75° nest in 1/25° global model)

- Apply the OASIS 1/75° nests to a 41-layer 1/25° HYCOM simulation with realistic tides and atmospheric forcing
  GOAL: -verify that the barotropic improvements are maintained
  -diagnose impact on internal tides

- Perform a short global 1/50° 41-layer simulation initialized from 1/25°
  GOAL: quantify the effect of increased resolution everywhere (e.g. the barotropic tides, baroclinic tides, and internal gravity wave spectrum)

The key individuals involved in this research are given below.

-- Maarten Buijsman of the University of Southern Mississippi (USM) is the PI on this research project. In the last three years Buijsman has collaborated with researchers at Naval Research Laboratory (NRL) and University of Michigan (UM) to improve tides in HYCOM. Buijsman has worked on re-tuning the topographic wave drag in HYCOM (*Buijsman et al, 2015*), he has developed tidal energy diagnostics for HYCOM (*Buijsman et al, 2016*), and he has investigated the causes of internal tide incoherence (*Buijsman, to be submitted*). Buijsman works closely with collaborators, listed below, to coordinate the progress of the HYCOM two-way nesting project. For this purpose, weekly conference calls with the collaborators have been established. Buijsman will diagnose the model solutions, write papers, supervise full-time graduate students Victoria Young and Heather McCain, supervise post-docs Chan-Hoo Jeon and Gordon Stephenson, keep track of the milestones, write annual reports, manage the subcontract to Brian Arbic of the University of Michigan, and collaborate with Arbic, Jim Richman of Florida State University, and Jay Shriver and Alan Wallcraft of the Naval Research Laboratory. Buijsman will also act as the liaison between NRL and the PIs of the other NOPP projects and Inner Shelf DRIs and handle their requests for access to HYCOM model data.

--Chan-Hoo Jeon, a South Korean National, was hired in June 2016 as a postdoctoral scholar to implement the OASIS nesting package to allow for HYCOM to HYCOM two-way nesting. He is currently learning to run HYCOM and has already started with implementing the OASIS nesting package. Jeon's work is also relevant for the NOPP project "Arctic Shelf and Large Rivers: Seamless Nesting in Global HYCOM".

--Gordon Stephenson was hired in April of 2016 as a postdoctoral scholar. He is performing and analyzing 1/12.5° HYCOM simulations with a new modal wave drag. Stephenson is also involved with setting up and running 2D HYCOM simulations as part of the NOPP project 'Russian Dolls: Nesting a turbulent Large Eddy Simulation within a nonhydrostatic Adaptive Grid Model within a 1/25° HYCOM model' led by A. Scotti.

--Victoria Young started in the fall of 2015 as Buijsman's graduate student at USM. Young has been running the tidal and internal tide energy diagnostics, developed by Buijsman, on the HPC of DOD for existing 1/12.5° simulations performed by Joseph Ansong. In these simulations the effect of the wave drag strength on the tides and internal tides is scrutinized.

--Heather McCain started in the summer of 2016 at USM. She is funded by an NSF grant to study the evolution of Hybrid Kelvin Edge waves on continental shelves in 1/25° HYCOM. She has been diagnosing the 1/25° HYCOM simulations on the HPC. Her analysis is valuable for improving our understanding of HYCOM's surface and internal tide energetics.

--Brian K. Arbic is a co-PI on this grant. Arbic has worked, and continues to work, with NRL collaborators to understand and improve several aspects of the HYCOM tides simulations, including self-attraction and loading, topographic wave drag, implementation of the ASEKF SAL, examination of the impact of stratification on the barotropic tidal field, and examination of the internal gravity wave continuum in HYCOM. Arbic generally leads the agenda of the weekly telecons with NOPP collaborators Buijsman, Shriver, and Richman. Arbic and his group members have led several analyses of the HYCOM results as described below. Arbic's subaward for the new grant N00014-15-1-2288 includes funding for two U.S. citizen graduate students, Anna Savage and Conrad Luecke.

--Anna Savage is a graduate student in the UM Applied Physics Program. Savage is comparing sea surface height frequency spectra in HYCOM versus tide gauges and moored instruments, and is comparing the widths of tidal peaks in sea surface height frequency spectra in tide gauges versus simulations with and without eddies as an alternative method for quantifying internal tide non-stationarity. She has performed three analyses of relevance for the planned wide-swath satellite altimeter mission (SWOT; Surface Water Ocean Topography). She has begun using HYCOM to test tidal aliasing issues for SWOT. She has computed frequency-wavenumber spectra of sea surface height, in order to determine whether high-frequency internal waves versus lower frequency motions dominate particular portions of the wavenumber spectrum. Finally, Savage has also constructed global maps of the sea surface height signatures of the internal gravity wave continuum.

--Conrad Luecke, graduate student in the UM Department of Earth and Environmental Sciences: Luecke is working with Arbic and NRL collaborators to compare both low-frequency and high-frequency temperature variance in HYCOM with those in historical temperature records. After Luecke has published his methodology for model/data comparisons of isopycnal fluctuations, he will constuct global three-dimensional maps of potential and kinetic energy in different frequency bands (geostrophic/mesoscale, near-inertial, and tidal) from our HYCOM simulations. Luecke will also compare slopes, and non-stationarity, of the spectra of high-frequency kinetic energy and temperature variance (e.g., in the internal gravity wave band) in HYCOM with those in historical current meter and temperature records, respectively.

-- Jay Shriver has also contributed to most of the projects described in this document. He is currently running the new HYCOM 1/25° and 1/75° tidal simulations, and has led global comparisons of HYCOM to the TOPEX/POSEIDON-Jason along-track altimetric tidal analysis of Richard Ray, and an examination of the temporal stationarity of internal tides, both topics of great interest to NASA.

--Alan Wallcraft has collaborated with Arbic to insert tides into the HYCOM code. Wallcraft has participated in most of the projects described in this document. He has prepared the 1/75° one-layer HYCOM simulations. Wallcraft and Shriver are assisting Jeon with the implementation of the OASIS package for the two-way nesting. The two-way nesting capabilities will also be applied in the "Arctic Shelf and Large Rivers: Seamless Nesting in Global HYCOM" project, led by Eric Chassignet with Pat Hogan, Jim Richman, and Alan Wallcraft.

--Jim Richman has been an active contributor to most of the projects described in this document, and took the lead on examining the impact of internal tides on the wavenumber spectra of sea surface height, a subject of great interest to NASA as it prepares for the wide-swath satellite altimeter.

--Luis Zamudio of the Naval Research Laboratory is running some of the new HYCOM tide simulations, and helps with the post processing of the large data sets. He has provided critical assistance to various projects described in this document.

WORK COMPLETED

This project is now just past the beginning of its second year, and since the last reporting cycle we have accomplished new results. In this and the next section we highlight completed tasks and present results for existing HYCOM solutions.

Shriver, Wallcraft and Buijsman have performed global one-layer barotropic 1/75° HYCOM simulations to test the high resolution bathymetry and to tune the wave drag needed in these simulations. The high resolution bathymetry will be used in the regional 1/75° domains that are nested in the coarser 1/25° global model.

To provide boundary conditions for our own two-way nesting projects, and our NOPP and DRI collaborators, Shriver and NRL collaborators have been performing global 3D simulations of the non-assimilative and assimilative 1/25° models. The assimilative simulation has been run from November 2013 to August 2014. The non-assimilative simulation has been run from November 2013 to mid-October 2014. The objective is to complete at least a full year for both simulations. The model data that is stored are hourly SSH and barotropic velocity fields, daily-mean 3D fields, and monthly startup files. For the non-assimilative simulation, hourly 3D fields have been stored for September 2014. An analysis by Buijsman highlighted thermobaric instability issues that we are presently working to resolve. We also collaborated with scientists at several institutions (including WHOI, Scripps, U. Washington) who assisted in vetting the nonassimilative 1/25° HYCOM with tides simulation through two refereed journal submissions that utilize these results. Their work highlighted code/script bugs that were fixed.

RESULTS

Similar to the 1/12.5° tuning experiments (*Buijsman et al, 2015*), Buijsman and NRL collaborators have performed and analyzed tuning experiments with the global barotropic 1/75° tidal simulations. These simulations are performed for 5 tidal constituents, a high resolution GEBCO bathymetry, and a spatially varying scalar self-attraction and loading term. The drag scale is varied from 0.225 to 0.450, and a value of 0.3 yields the lowest Root-Mean Square Error of 2.9 cm for the M_2 tidal constituent (Figure 1). Figure 1 shows the tuning curves as a function of RMS error and wave drag dissipation in deep water and the bottom drag dissipation in shallow water. On the shallow shelves the bottom drag dissipation is larger when the total velocity based on all tidal constituents is applied, whereas it is lower when the dissipation is computed from the sum of the individual constituents. Hence, we crudely correct the M_2 dissipation in shallow water (blue dashed line) to account for this nonlinear coupling, bringing the results in closer agreement with the M_2 dissipation estimated from TPXO8-atlas. The RMS errors of the 1/12.5° tuning experiments, as represented by the black dashed line in Figure 1, are significantly higher than the 1/75° simulations. This illustrates that a higher model resolution and a more accurate representation of the coastal geometry yields more accurate tides. The question that we aim to address is whether the two-way nesting of resonant coastal areas, such as the Hudson Strait, can result in similar improvements.

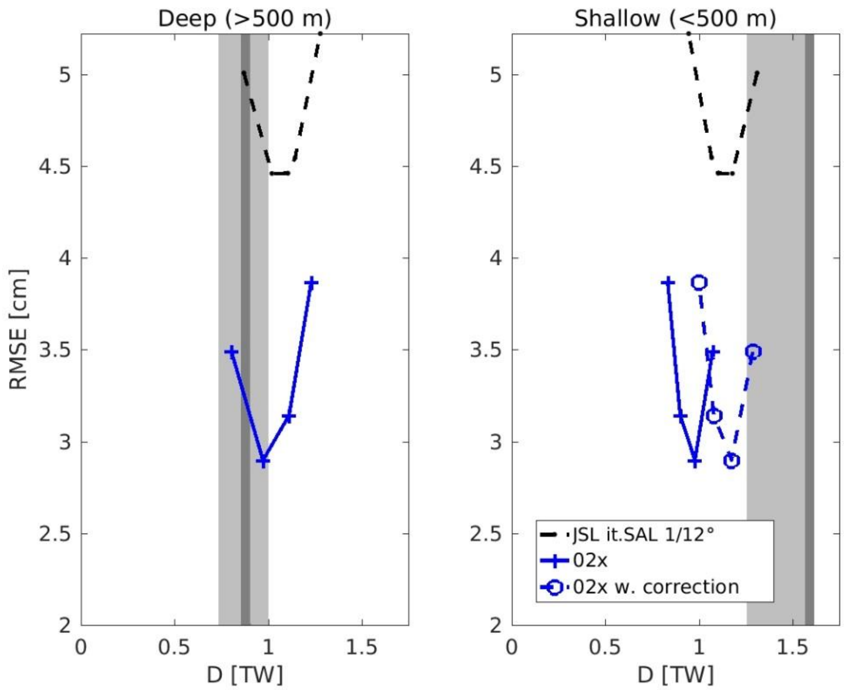

Figure 1. The deep water (H>500 m) and shallow water (H<500 m) HYCOM dissipation rates vs. Root-Mean Square Error (RMSE) as a function of scale factor. The RMS error is computed between HYCOM and TPXO8-atlas M_2 sea surface heights for H>1000 m and equatorward of 66°. The range of the TPXO dissipation rates is marked by the light gray box and TPXO8-atlas (the most recent TPXO inverse model) by the dark gray line. A minimal RMSE of 2.9 cm is obtained for a scale factor of 0.3.

Buijsman has implemented diagnostics in FORTRAN to better understand the tidal and internal tidal 3D energetics in HYCOM. He has applied these diagnostics to 1/12.5° and 1/25° simulations. The application of these diagnostics to an older 1/12.5° simulation have now been published (*Buijsman et al, 2016*). The main findings of this work are that HYCOM does not dissipate enough barotropic tidal energy on the coastal shelves through quadratic bottom friction and that too much barotropic tidal energy is lost in the deep ocean, when compared with TPXO, an altimetry constrained inverse tidal model. It was also found that a wave drag is needed to dampen the internal tides (see also *Ansong et al., 2015*). In recent 1/12.5° simulations, the wave drag has been tuned in the baroclinic simulations and the barotropic energetics have improved, albeit that the shelves are still not dissipative enough.

Realistically forced global models also give insight into how internal tides interact with mesoscale circulation such as jets and eddies. At generation, internal tides are coherent with the local barotropic forcing, but as the low mode waves propagate through an eddying ocean, their phases become incoherent with the forcing. While satellite altimetry can only map the coherent part of the internal tide, HYCOM captures both the coherent and incoherent parts. Hence, HYCOM can be used to distinguish between tidal and mesoscale variability in the altimetry data from the upcoming SWOT mission. One of the regions in the world where internal tides are strongly incoherent is the Equatorial

Pacific. In HYCOM 1/12.5° simulations, Buijsman has found that the jets in the equatorial Pacific Ocean yield a strong loss of phase coherence in semidiurnal internal tides that propagate equatorward from the French Polynesian islands and Hawaii. The loss of phase coherence is attributed to the time variability in the advection by the zonal jet velocities. For time scales longer than a year the coherent energy flux approaches zero values at the equator, while the total flux, comprising the sum of the coherent and incoherent fluxes, remains non-zero. The 1/12.5° model simulation suggests that low-frequency jets do not noticeably enhance the dissipation of the internal tide, but merely decohere and scatter it. Thus, the model results suggest that the apparent demise of coherent internal tides seen in satellite altimetry maps may be due to incoherence rather than dissipation. These results have been summarized in a paper that will be submitted to the Journal of Geophysical Research soon.

Postdoc Jeon has started with the implementation of the OASIS3-MCT coupling toolkit (*Valcke et al, 2015*). OASIS3-MCT is the enhanced version of the OASIS coupler that is interfaced with the Model Coupling Toolkit (MCT) developed by the Argonne National Laboratory (ANL, USA). OASIS3-MCT exchanges data between parallel components. As shown in Figure 2, OASIS3-MCT consists of two parts: Application Programming Interface (API) and configuration by 'namcouple'. The API part includes the OASIS module and MPI (Message Passing Interface) libraries for initialization, partition, grid and mask, field definition, data exchange by 'get' and 'put' actions, and termination. This API part is set up in the source code of components (models). The configuration by the file named 'namcouple' controls coupling time, type of log files, field status, interpolation methods, and lag time. The API part of OASIS3-MCT has been implemented as separate subroutines in a FORTRAN module. Since HYCOM uses rectangular partition tiles for domain decomposition, the box partition option in OASIS3-MCT has been applied using the information of the HYCOM tiles. Grid and mask files are automatically created by OASIS3-MCT based on the grid and mask points for P, U, and V grids in HYCOM. In field declaration, the number of components can be considered up to 9. The developed API part has been tested in the specific domains. When four data fields are sent from two separate components, the fields are received at the target components correctly. In a next step, the two-way coupling of barotropic and baroclinic data between global modeling and regional modeling will be tested, and its results will be compared to those of one-way coupling.

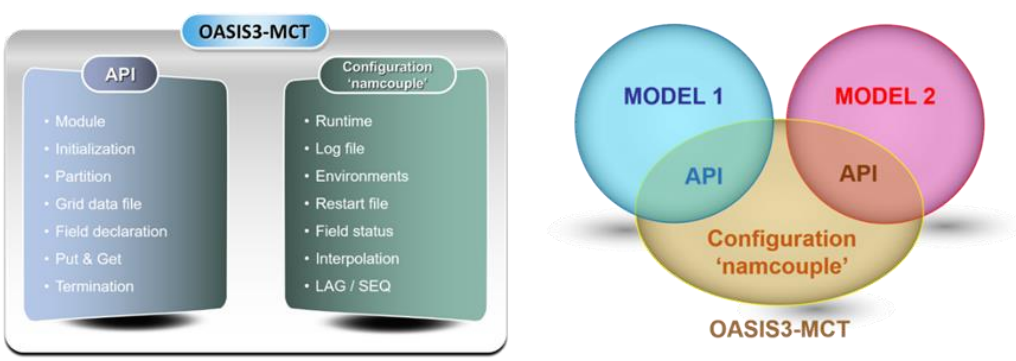

Figure 2. Two-way nesting coupler: OASIS3-MCT

Stephenson is investigating new internal wave drag schemes for HYCOM. The most optimal tidal results are obtained when a wave drag is included. Wave drag parameterizations in the literature represent the barotropic to baroclinic energy conversion to the full spectrum of baroclinic modes. Because low internal wave modes are resolved in a 1/12.5 degree model, the parameterized wave drag needs to be reduced with a scale factor (less than unity) to account for the unresolved high-mode generation. The coarser the model, the less modes are resolved, and the larger the scale factor (closer to unity). However, this approach does not realistically represent the physics governing the energy distribution into different baroclinic modes. Based on work by *Falahat et al (2014)*, Stephenson generated a modal wave drag field suitable for use in HYCOM. This field was used in 1/12.5 degree HYCOM simulations. He is comparing output from simulations with the new modal wave drag to results generated with the older drag fields.

Student McCain has analyzed the 1/25° simulations using Buijsman's energy diagnostic tools on the HPC. An initial energy analysis shows that more barotropic tidal energy is converted into the resolved baroclinic modes as compared to the coarser 1/12.5° simulations. The higher resolution simulations also show more detail than their coarser predecessors. As an example of this analysis we show the interaction between the baroclinic semidiurnal energy fluxes from Georges Bank and the Gulfstream front in Figure 3.

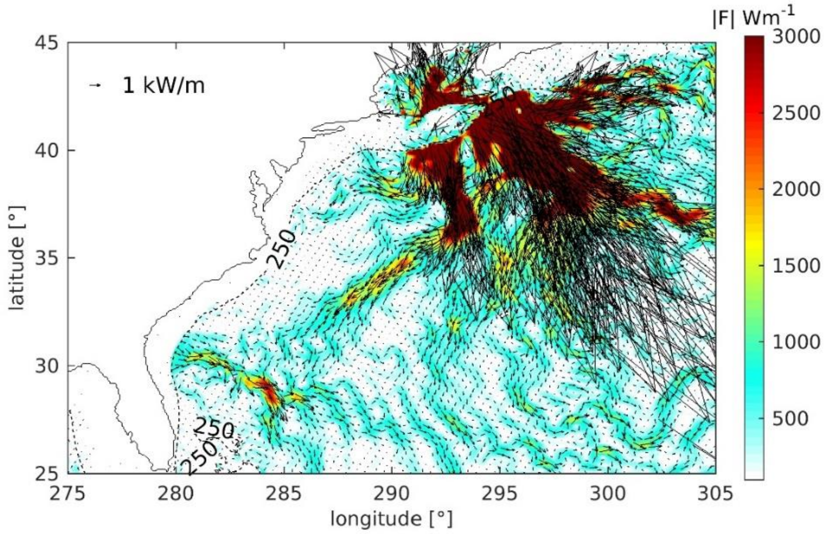

Figure 3. Semidiurnal baroclinic energy fluxes (colors and arrows) interacting with the Gulfstream Front in the 1/25° simulations. The energy flux that radiates southward from Georges Bank is reflected coastward on Gulfstream eddies (38°N, 290°E) and trapped along the Gulfstream front (34°N, 290°E). The 1/25° simulations reveal much more detail than the 1/12.5° simulations.

Student Young has diagnosed 1/12.5° simulations that have been performed by *Ansong et al (2015)*. The aim of these simulations is to better understand the effect of the wave drag strength on the surface and internal tide propagation. In *Ansong et al (2015)* only the sea surface height expression was analyzed. Young is applying Buijsman's diagnostics to study the tide and internal tide energetics. Figure 4 shows two of the seven cases that have been diagnosed so far: one for a case with no drag and one case with a scaled wave drag. Internal waves propagate farther when the drag is turned off in Figure 4a. These simulations give us insight how much internal tide energy reaches the continental shelf areas, where it may influence local internal wave generation. Knowing this is relevant for shelf processes, such as studied in the Inner Shelf DRI.

a) No drag; drag scale is 0 **b) Drag scale is 0.7**

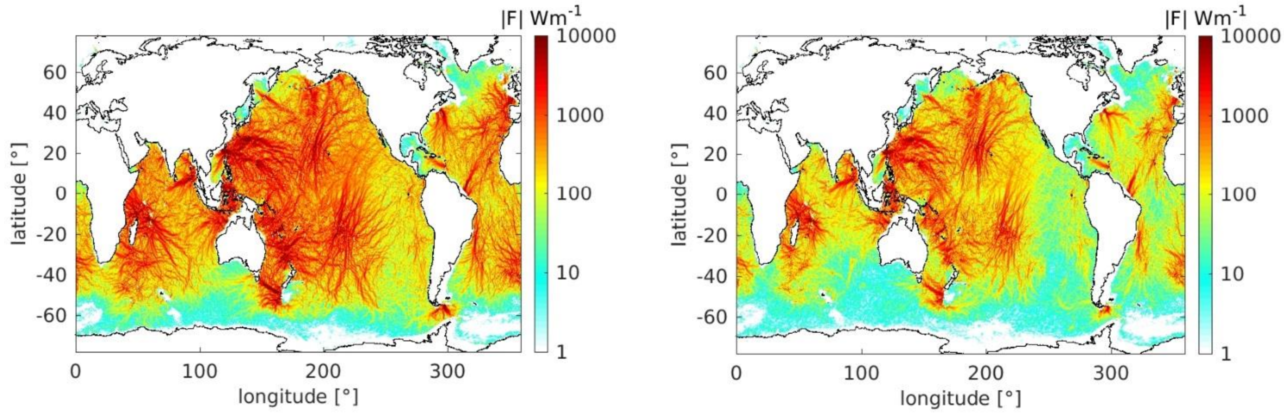

Figure 4. Semidiurnal baroclinic energy fluxes for 1/12.5° simulations with a) no linear wave drag (drag scale is 0) and b) a wave drag with a drag scale of 0.7. The stronger wave drag affects the barotropic tides as well as the internal tide propagation. The simulation without a wave drag has much stronger internal tides.

Brian Arbic has been collaborating with NRL scientists and other colleagues on the HYCOM tides simulations since 2006. A thorough accounting of our accomplishments can be found in the final report on Arbic's grant N00014-11-1-0487. To date, Arbic and HYCOM collaborators have published 20 papers together, with many more forthcoming. As one example of our collaborative work, Arbic's former subcontractor collaborator Malte Müller has computed frequency spectra of upper ocean kinetic energy in the internal wave band for both HYCOM and current meter data, in a region of the North Pacific Ocean (*Müller et al. 2015*). An example result, shown in Figure 5, indicates that HYCOM matches the near-inertial and tidal peaks reasonably well. The model match to the high-frequency end of the observed internal wave spectrum is much less good, but increasing the model resolution from 1/12.5° to 1/25° improves the model-data comparison. See *Müller et al. (2015)* for comparisons of HYCOM vs. current meter frequency spectra at 7 locations in the North Pacific Ocean.

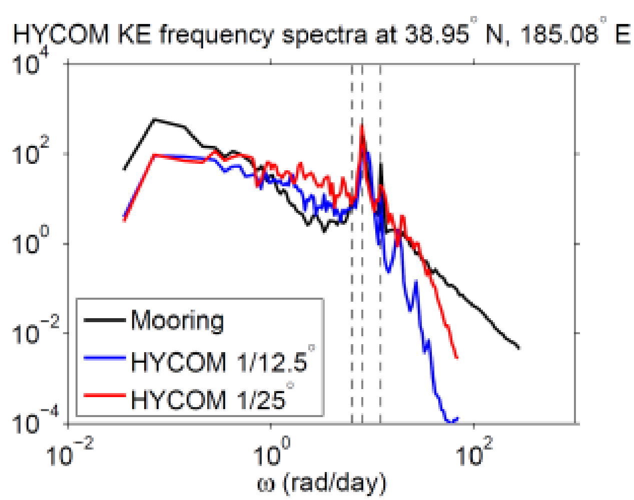

Figure 5. Frequency spectra of kinetic energy in 1/12.5° and 1/25° HYCOM, compared to spectra from a moored current meter in the North Pacific ocean. The near-inertial period, period of the largest semidiurnal tide M_2, and period of the largest diurnal tide K_1, are indicated by dashed vertical lines.

In a submitted paper (*Savage et al. 2016*), Arbic's graduate student Savage used two simulations of the HYbrid Coordinate Ocean Model (HYCOM) to study the variability of sea surface height spectral density. The HYCOM output comes from a 1/25° simulation, and the sea surface output has been split into steric and non-steric sea surface height. The model is subsampled to ¼° resolution and frequency spectral densities, E(w), are computed at each gridpoint. The spectral densities are integrated over four frequency bands associated with different physical phenomena. Figure 6 displays the steric and non-steric sea surface height contributions from the supertidal band, spanning periods from two hours to twelve hours. The steric sea surface height contributions in this frequency band are associated with the internal gravity wave continuum, a field previously unmapped globally.

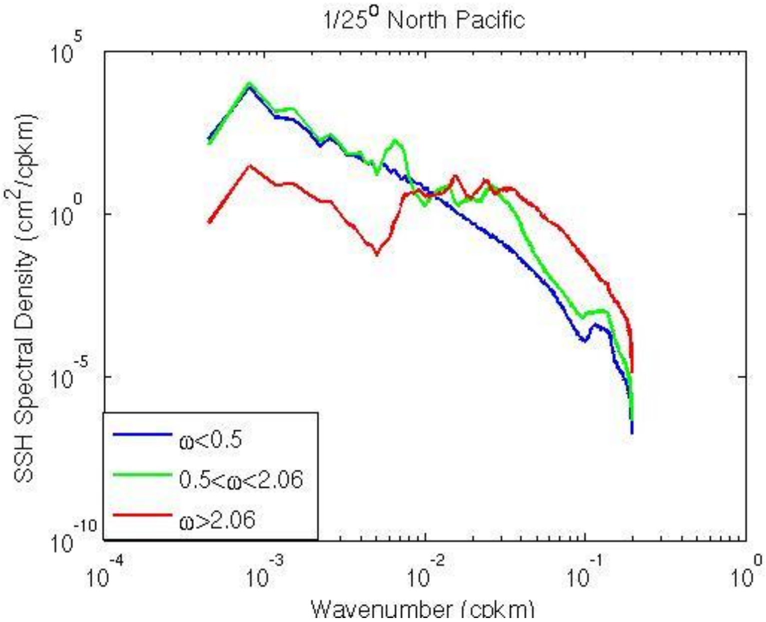

Figure 6. Steric and non-steric sea surface height (SSH) variance (cm^2) integrated over supertidal frequencies (frequencies exceeding 2.06 cpd) in global 1/25° HYCOM.

In another paper in preparation for submission by Savage, two high-resolution models, HYCOM and the MIT general circulation model, MITgcm, are used to study the spatio-temporal variability of sea surface height. Sea surface height frequency-wavenumber spectral densities are computed in seven locations in five simulations of the two different models. In Figure 7, we have taken the sea surface height frequency-wavenumber spectral density from a region in the North Pacific in 1/25° HYCOM and integrated it over three frequency bands; low-frequencies, tidal frequencies, and high-frequencies, where the high-frequencies are dominated by the internal gravity wave continuum. Here, we see that the high-wavenumber end of the wavenumber spectral density of sea surface height, a quantity of fundamental importance in testing theories of geostrophic turbulence, is dominated by high frequency motions. These results implicate the internal gravity wave continuum as an important contribution to small-scale sea surface height variability.

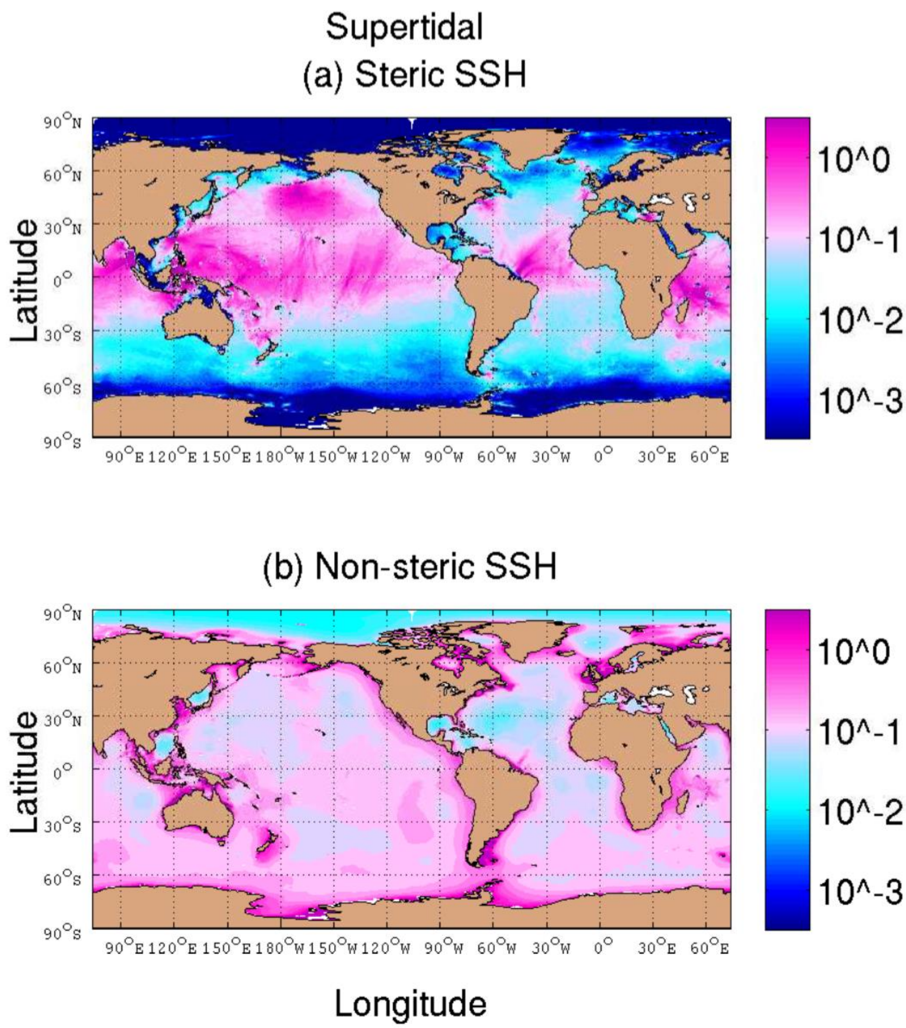

Figure 7. Wavenumber spectrum of sea surface height (SSH) variance in global 1/48° MITgcm simulations, integrated over low-frequencies (frequencies less than 0.5 cpd), tidal frequencies (frequencies between 0.5 and 2.06 cpd), and supertidal frequencies (frequencies exceeding 2.06 cpd).

In a paper in preparation for submission, The Global Mesoscale Eddy Potential Field in Models and Observation (*Luecke et al. 2016*), Arbic's graduate student Luecke examines low-frequency Eddy Available Potential Energy (EAPE) in global runs of the HYbrid Coordinate Ocean Model (HYCOM) with in-situ moored historic observations. Both a simulation and reanalysis run of 1/12° non-tidal HYCOM are compared with global maps of EAPE using estimates made from Argo profilers (*Roullet et al. 2014*), and point-to-point at moored historical temperature observations. In the global comparison, modeled EAPE falls within a factor of 2.5 of Argo EAPE with globally integrated values of 264 cm^2s^{-2} and 212 cm^2s^{-2} for the simulation and reanalysis respectively, and 109 cm^2s^2 in Argo. The reanalysis also shows an improvement in the global spatial structure of EAPE as seen in Figure 8.

In our point-to-point comparisons at moored historic record locations, both model runs show reasonable agreement with observed values. Averaged over all locations with historic records, modeled EAPE is 15 percent lower than EAPE from moored instruments, and 20 percent higher than Argo estimates. Additionally, assimilation in the reanalysis improves the correlation of EAPE at individual locations, as well as the vertical structure and point-to-point correlation of modeled stratification. Although our point-to-point comparisons exhibit a large statistical scatter, we employ an idealized model in conjunction with previous theoretical results to illustrate that much of this scatter is to be expected given the chaotic nature of the mesoscale eddy field.

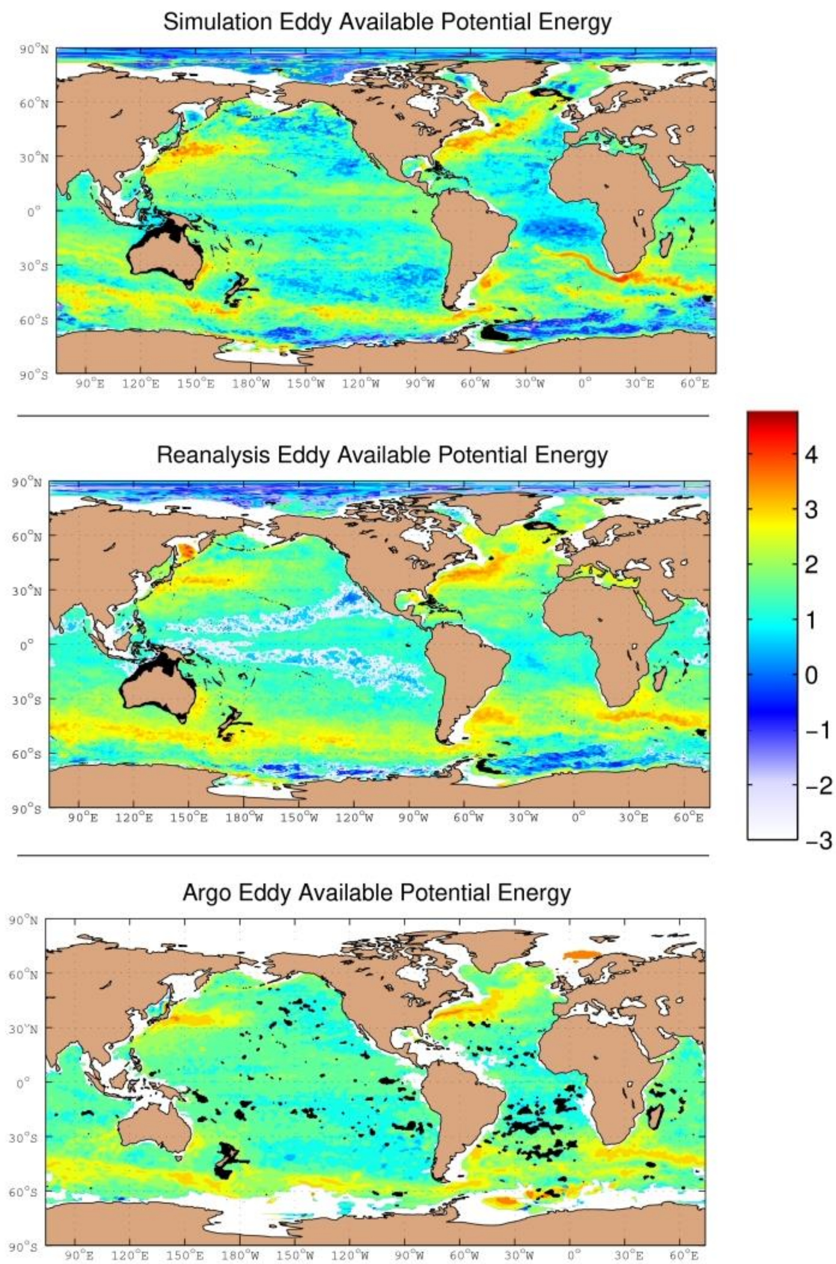

Figure 8. Global EAPE (Log_{10} [cm^2s^{-2}]) at a depth of 500 m calculated using 1/12.5° HYCOM (top), reanalysis (middle), and Argo (bottom; *Roullet et al., 2014*).

Wallcraft and Shriver have setup a small (658x1015) "same resolution" Hudson Strait subdomain of the 1/25° global region, and tested off-line one way nesting between the global and Hudson Strait regions. Figure 9a shows the Hudson Strait coastline and bathymetry, which is identical to the corresponding global case. This is part of the bipolar patch on the global tripole grid and so the grid is curvi-linear. This domain will be used for initial testing of 2-way nesting between the global and Hudson Strait models, with the latter then being replaced with a 3x finer 1/75° version.

In our initial tests the global and Hudson Strait models were both forced with atmospheric pressure forcing and the astronomical tidal potential. The nesting in the case depicted in Figure 9 has hourly 1-way exchange of information propagating from the global model into the Hudson Strait model. These tests show that the nested tidal solution isn't identical to the global solution, but that it isn't majorly different either. We would expect the errors to be smaller if we were coupling at a frequency greater that 1x/hour as was done in this test case. We have additional configurations for the nest boundary conditions that we plan to test. For testing and debugging, we also intend to replace the global region with an Arctic Cap region (poleward of 40°N) or perhaps an even smaller outer region.

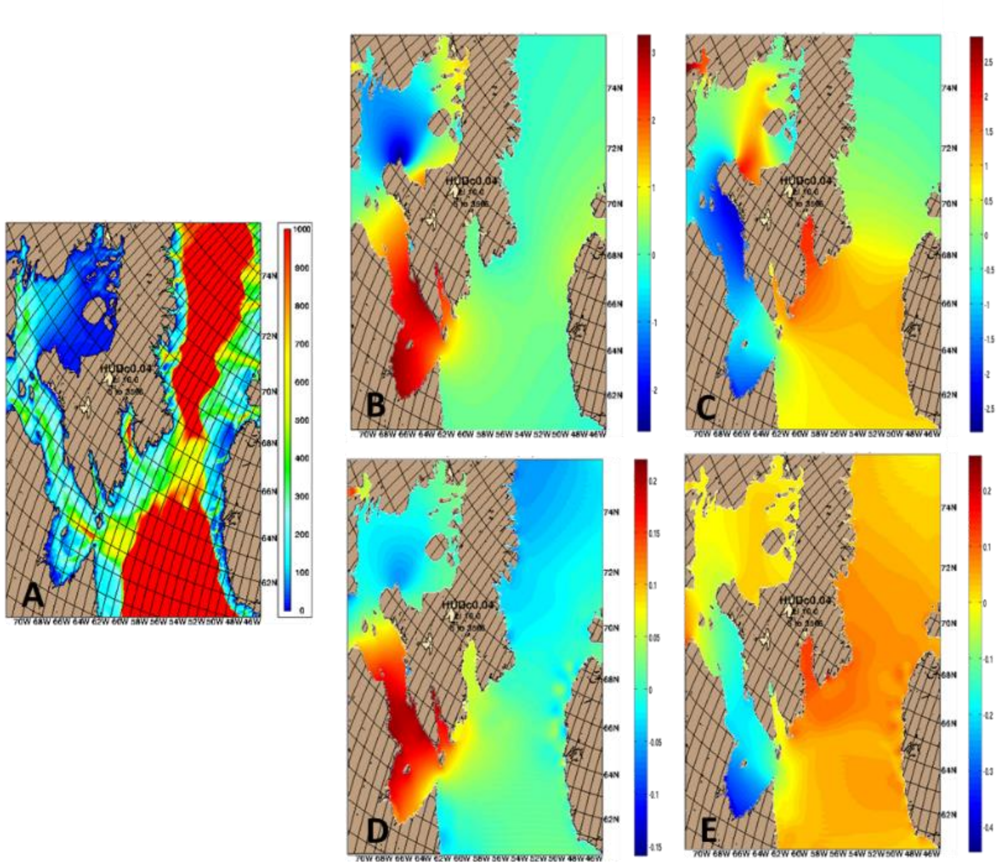

Figure 9. The Hudson Strait subregion coastline and bathymetry. b+c) the real and imaginary components of the M_2 tidal constituent from the global model. d+e) the real and imaginary M_2 tidal constituent differences between the global solution and the nested subregion.

IMPACT/APPLICATIONS

A successful implementation of the two-way nesting technique in HYCOM is highly beneficial for operational purposes. This technique has a significant advantage over the current one-way nesting approach with significantly lower cost than increasing the model resolution everywhere. The technique can be applied to areas where tidal resonance requires an accurate and detailed representation of the coastal geometry. In addition, the technique can be applied to regions that require a higher resolution of the ocean currents and stratification for U.S. Navy operational purposes.

RELATED PROJECTS

A related project that also studies two-way nesting with OASIS is the NOPP project "Arctic Shelf and Large Rivers: Seamless Nesting in Global HYCOM" led by Eric Chassignet with Pat Hogan, Jim Richman, and Alan Wallcraft. The nesting capabilities developed in this project may also be utilized for this HYCOM tides project.

Moreover, we are collaborating with NOPP and Inner Shelf DRI scientists to facilitate the access to HYCOM model data. Currently we have received such a requests from Pierre F.J Lermusiaux and

Brian Powell (NOPP), Falk Feddersen, Nirnimesh Kumar, Ata Suanda, James McWilliams (Innershelf RI).

Arbic, Buijsman, Richman, Shriver, and one other NRL scientist (Hans Ngodock), with Arbic as lead PI, leveraged the work done in HYCOM tides simulations to a position on the Science Team for the NASA/French space agency SWOT) mission. Our HYCOM work featured very prominently in the first meeting of the Science Team, held in June 2016, and Arbic was named co-chair of the High-Resolution Ocean Modeling Working Group for the SWOT Science Team.

Potential contribution to storage resources: Backed by a letter of support from NRL, Arbic is a "stakeholder" in a new $4.9M NSF Division of Advanced Cyberinfrastructure grant awarded to PI Shawn McKee at the University of Michigan. McKee's project (http://www.nsf.gov/awardsearch/showAward?AWD_ID=1541335&HistoricalAwards=false) is one of 3 such grants awarded around the US, and aims to improve the way in which large datasets are shared between institutions. McKee's grant is targeted mostly at sharing data between 3 research institutions within the state of Michigan, but Arbic's role is to use McKee's infrastructure as a testbed for sharing HYCOM data on a large system with no access restrictions. There is potential for hundreds of TB of HYCOM output to be stored on this system, which could be useful for investigators of the NOPP project N00014-15-1-2288, and/or for other scientists around the world who are interested in our HYCOM tides simulations but who do not have accounts on DoD HPC machines.

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