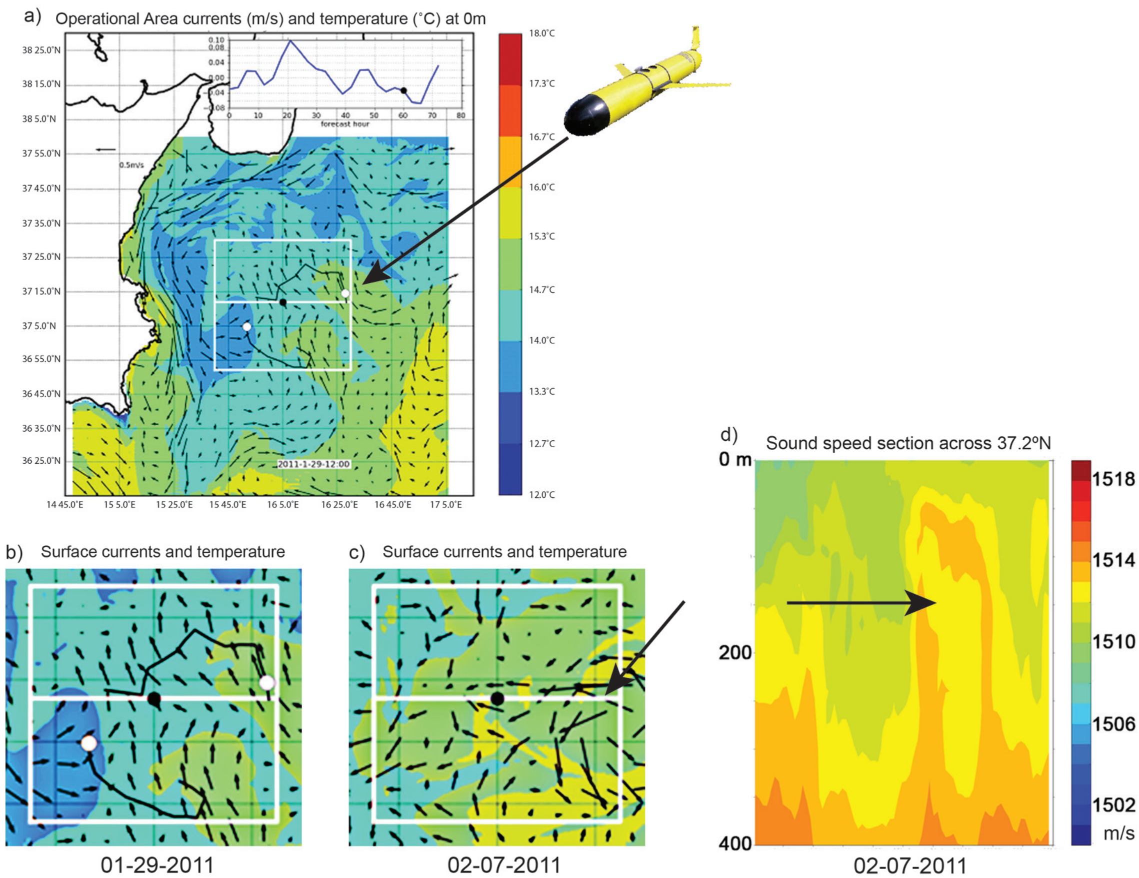

FIGURE 10
Example of feature definition mission: Surface currents and temperature before (a,b) and after (c,d) assimilation of observations from GOST-directed gliders during the NATO exercise Proud Manta in 2011 off the east cost of Sicily. The gliders identified a cold-core ring (arrows) that significantly modifies currents (c) and sound speed (d) in the operational area.

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WAVEWATCH III® Transition to Naval Operations

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Supporting the Mission: Knowledge of the sea state and thus predictions of wave conditions in real time are important for naval operations. Two operational centers provide such support. Fleet Numerical Meteorology and Oceanography Center (FNMOC) in Monterey, California, produces and delivers wave forecasts covering large spatial scales and long time scales — for example, global 120-hour forecast fields of significant wave height — to support general operations. The Naval Oceanographic Office (NAVOCEANO) at Stennis Space Center, Mississippi, provides small-scale wave forecasts covering shorter intervals to support specific missions involving littoral waters and surf zones.

The Naval Research Laboratory (NRL) at Stennis Space Center has been the primary transition partner with NAVOCEANO and FNMOC for enabling technologies in wave forecasting for small and large scales. Now, in cooperation with the National Centers for Environmental Prediction (NOAA/NCEP), the latest version (v. 4.10) of the WAVEWATCH III® (WW3) wave model is being transitioned to NAVOCEANO and FNMOC, with additional updates coming later in 2013.

As part of this transition, NRL has developed and tested a system that uses the multi-grid implementation of WAVEWATCH III® at NAVOCEANO as an improvement to the current systems in place; NAVOCEANO runs a set of large-scale domains around the world to provide wave energy boundary conditions to smaller scale regional wave models. In addition, NRL is providing upgrades to the system to include curvilinear gridded domains, e.g., to cover the Arctic Ocean.

Multi-grid Model: WAVEWATCH III®[1,2] is a third-generation wave model developed at NOAA/NCEP that incorporates sophisticated features not available in predecessors, such as modular Fortran90 and highly scalable parallel programming, dynamic time-stepping, third-order propagation schemes, irregular grids, triangular grids, and two-way communication between domains. The model solves the random phase spectral action density balance equation for wavenumber-direction spectra. Being a phase-averaged model, there is an implied assumption that properties of the forcing, as well as the wave field itself, differ on space and time scales that are much larger than individual waves.

During the past five years, WW3 has evolved such that it can now be regarded as a community model, though primary responsibility and authority for the code is still with NOAA/NCEP, and is freely available as Version 3. The development code currently designated as Version 4 is being used to update systems operational in the U.S. Navy. For wind input, wave breaking, and swell dissipation source functions, the physics package of Ardhuin et al.[3] will be used.

The multi-grid (or mosaic grid) feature of WW3 allows for the two-way communication of energy across domain boundaries. Traditionally, as it is with older versions of WW3, a low-resolution host model passes wave energy through the boundary to high-resolution nest domains and whatever happens within the nest domains does not affect the host. With two-way communication, the predictions from the high-resolution model — potentially using better winds and better bathymetry — are shared with what could be considered the host domain and other high-resolution domains. Figure 11 illustrates this.

The current real-time configuration includes a global domain with 0.5° resolution and nine regional domains with resolutions of either 0.1° or 0.2°. Figure 12 illustrates the layout of all the domains. Winds forcing the global domain come from the Navy Operational Global Atmospheric Prediction System (NOGAPS) and the winds for the regional domains come from the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS™), both running at FNMOC. This modeling system now runs on an IBM iDataPlex Linux system at the Navy DoD Supercomputing Resource Center, where forecast grids of significant wave height, wave direction, and wave period are produced automatically every 12 hours.

In addition, in a recent version developed at NRL, it is now possible that domains with dissimilar grid types (e.g., curvilinear grids and regular grids) can be run together, passing wave energy across the boundaries in both directions, as illustrated in Fig. 13. This removes the problem of running a regular latitude-longitude mesh too far north, decreasing the need to run a very small time step to accommodate for the convergence of the meridians. An Arctic curvilinear mesh can be incorporated into the operational system just like any of the other domains.

Implications and Conclusion: One advantage to running the multi-grid version of WW3 is that domain configuration is more efficient than in conventional methods, using computational resources more where needed, i.e., minimizing the redundancy. Any given geographic location is modeled by only one grid point except where there is overlap within buffer zones around boundaries. Compared to a conventional setup, the current configuration turnaround time has improved by about a factor of 3.

Since the multi-grid system runs multiple domains together instead of the traditional approach of running individual domains separately and sequentially, the model setup is less tedious, obviating the need to specify individual points in the host domain about the nest to which information is to be shared.

Comparisons of WW3 wave height output were made with in situ observations and altimeter measurements. Statistics from a number of buoy wave measurements provided by the NOAA Data Buoy Center (NDBC) and plotted in terms of mean bias, standard deviation, correlation coefficient, slope, and scatter index showed good results.

With the transition of the WW3 multi-grid system, wave modeling will be more streamlined, saving processing time, and forecast accuracy is expected to improve.

Acknowledgments: The authors thank Paul Wittmann for his advice during the WW3 transition. Funding provided by the Office of Naval Research through the National Oceanographic Partnership Program for continued development of WW3 is appreciated.

[Sponsored by ONR]

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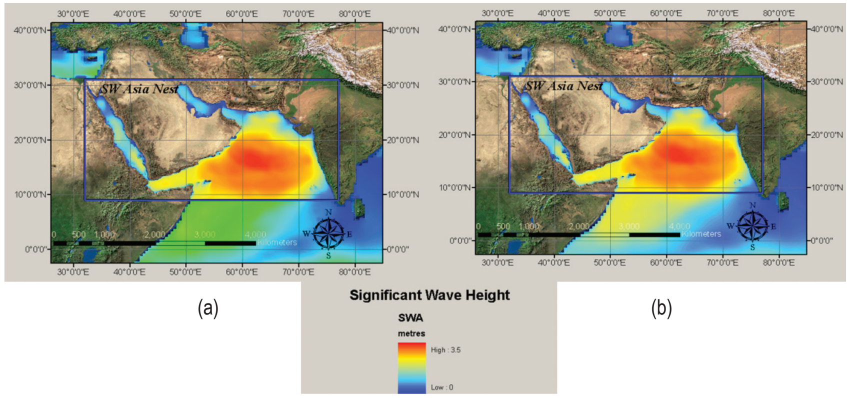

FIGURE 11
Example of a domain where in (a) one-way nesting occurs, while in (b) two-way nesting is implemented in the multi-grid model.

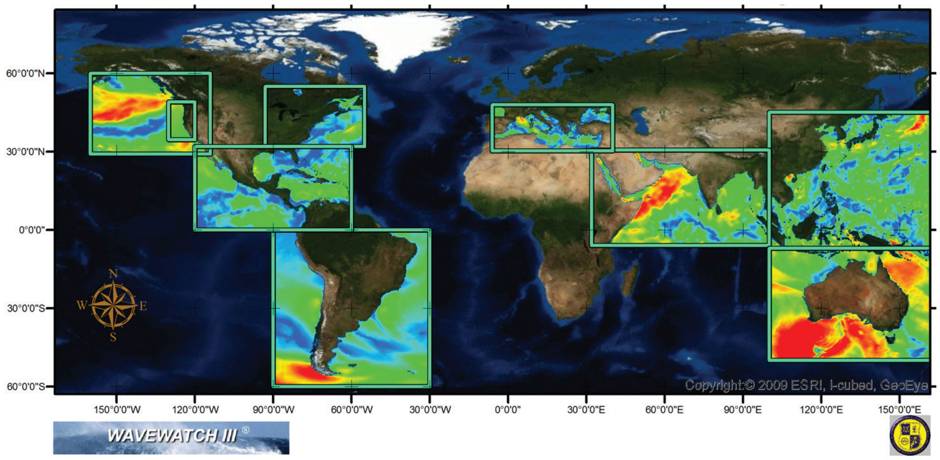

FIGURE 12
Global and regional domains used primarily for providing boundary conditions for smaller scale models.

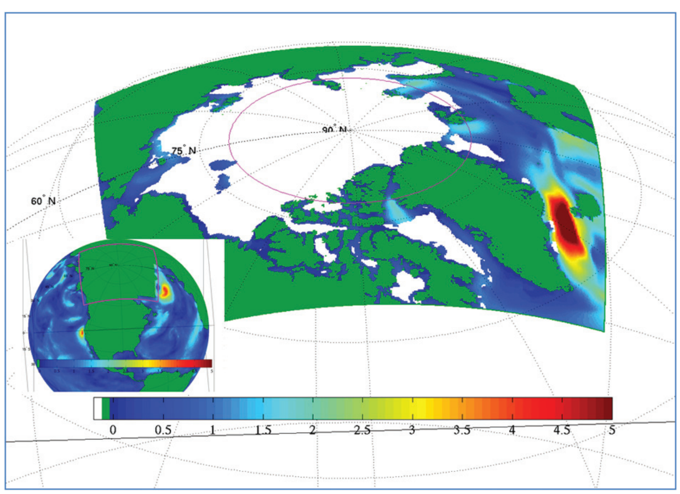

FIGURE 13
Two-way nesting test with the curvilinear grid Arctic domain (~16 km resolution) and full (0.5°) global domain. Wave height is in meters. The regular global domain is plotted in the inset where masked areas shown in green include the land, ice, and the Arctic domain.

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