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WAVEWATCH III: Transition to Naval Operations (Session Paper)

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1. Introduction

Knowledge of the sea state and thus the wave conditions is important for naval operations calling for real-time operational support of wave forecasts. Two operational centers have been providing such support [1]. Fleet Numerical Meteorology and Oceanography Center (FNMOC) in Monterey, California, produce and deliver wave forecasts covering large spatial and long time scales to support general operations. Naval Oceanographic Office (NAVOCEANO) at Stennis Space Center, Mississippi, provide 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 for enabling technologies in wave forecasting for small [2] and intermediate scales [3][4]. And, in cooperation with National Centers for Environment Prediction, the larger scale WAVEWATCH III [5] model in its current state has been transitioned to FNMOC [6] with a newer version coming to both NAVOCEANO and FNMOC within this year.

To provide wave energy boundary conditions to smaller scale wave models such as SWAN (Simulating Waves Nearshore) [7], NAVOCEANO runs the WAM (WAve Model) [8] for a set of large scale domains around the world. Replacing the WAM, NRL is developing and testing a system that will implement the multi-grid model version of WAVEWATCH III [9] at NAVOCEANO. In addition, NRL is providing upgrades to the system at FNMOC to include curvilinear gridded domains, particularly to cover the Arctic Ocean [10].

In this paper, WAVEWATCH III is briefly described highlighting the characteristics of the multi-grid system as well as that of curvilinear grids. Then, the system at NAVOCEANO will be described and test results will be given.

2. Multi-grid Model

WAVEWATCH III [11] is a third-generation wave model developed at NOAA/NCEP which employs a third-order numerical propagation scheme in order to control numerical diffusion of swell. The wave growth and dissipation source terms are allow more rapid wave growth under the influence of strong wind forcing than in previous wave models.

WAVEWATCH III solves the spectral action density balance equation for wavenumber-direction spectra. The implicit assumption of these equations is that the wave field, water depth and surface current field vary on time and space scales that are much larger than the corresponding scales of a single wave. Furthermore, the propagation scheme used by the model is conditionally stable, which means that the model becomes inefficient with resolution finer than O(1 km).

The current public release version of WAVEWATCH III is v3.14. The multi-grid model allows for the two-way communication of energy across domain boundaries. Typically, as it is with older versions of WAVEWATCH III and with WAM, a host model passes wave energy through the boundary to a nest domain and whatever happens within the nest domain does not affect the host grid. This can have the effect of not allowing the computational results with significant events of a high resolution model—potentially using better winds and better bathymetry—to be shared with the host and other regions. Fig. 1 illustrates this.

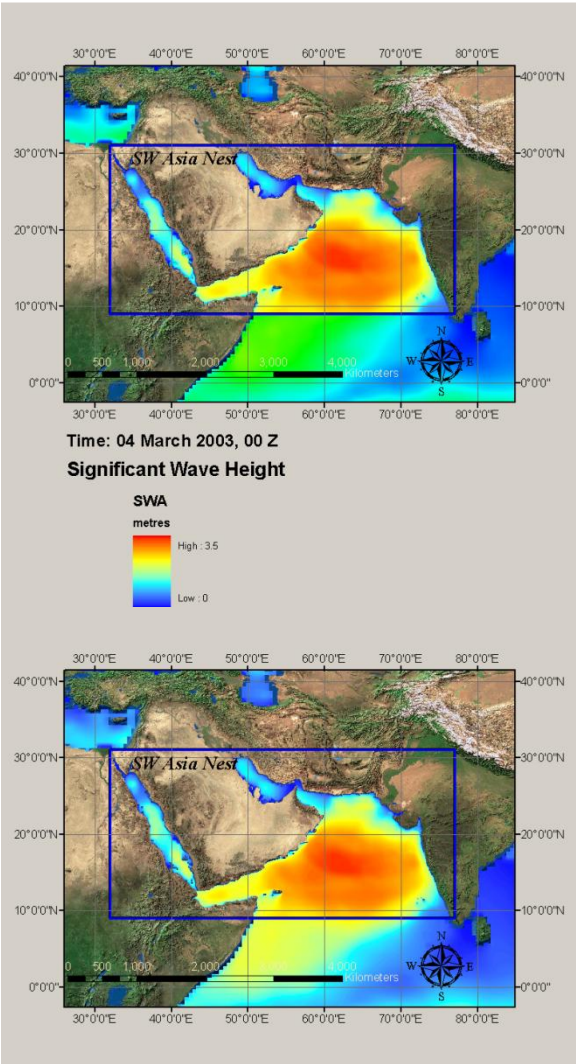

Figure 1. Example of a domain where in Panel a one-way nesting occurs, whilst results in Panel b are results from two-way nesting implemented in the multi-grid model.

An advantage to running the multi-grid version WAVEWATCH III is that domain configuration is more efficient, using computational resources more where it is needed, i.e. minimizing the redundant use of computational resources. With older model versions, the model computed for all water points in the host domain regardless of whether these points were already covered by a nest. Now, the nest domain points are mutually exclusive from others except where there is overlap within the buffer zone around the boundaries. In addition, in a development version of the code (4.10), it is now possible that domains with different grid types (specifically curvilinear grids vs. regular grids) can be run together passing wave energy across the boundaries in both directions.

As the name implies, the multi-grid system runs multiple domains altogether instead of the traditional approach of running individual domains and passing boundary condition information to nest domains and running those separately. Since everything is together, the model set up is less tedious obviating the need to specify individual points in the host domain about the nest to which information is to be shared. One-way nesting is still available and is appropriate for small nests, which can be WAVEWATCH III or other wave models such as SWAN.

3. Operational Implementation

NAVO has very specific requirements for how models are to run on their machines: specifically, requirements on timeliness of forecast products and the processing of data in the operational run-stream.

As soon as they are available wind fields from FNMOC arrive at NAVO and are processed to force the wave models. The arrival of the modelled wind fields is the primary factor that governs when any wave model can begin to run in any cycle. If it is certain that winds from a regional model such as the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) [12] will arrive late, then the back-up plan is to consider a different set of winds such as Navy Operational Global Atmospheric Prediction System (NOGAPS) [13] in order to maintain continuity between cycles.

On domains where it applies, ice concentrations from ice models such as the Polar Ice Prediction System (PIPS) [14] or the CICE model [15] can provide inputs to the model. Since, the ice field does not change significantly from one day to the next, it is not so critical to update the ice field daily in larger domains.

Restart files are used to maintain continuity between cycles. No model run for a cycle can start without either having a restart from a previous run, or by using a cold start (i.e. re-initializing with artificial conditions).

It gets a little more complicated for the system when running the multi-grid system. In this case all the wind fields from various meteorological models must be available before the multi-grid system can start. All the restarts in the system are made and used in tandem. For any one domain to be removed from the system a cold start must be implemented for all domains to continue, otherwise a void is left which the system cannot handle. Adding domains on the other hand can be done on the fly, since the energy of the original space over which the new domain is occupying is easily replaced with a cold start for that domain.

All models undergo some sort of pre- and post-processing with regards to the model run. This processing involves preparing the input data for the model run and taking the model output and converting it into other formats such as netCDF. For the multi-grid system, each individual domain can be processed before and after as if they were individual model runs. Links to files for the individual domains are used by the multi-grid system to access the files.

4. Transition to Operations

The wave forecast model system as has been described above is in the process of transition into operations. This means that the way NRL puts it together will be worked into the operational run stream at NAVO where operators will take over. Researchers at NRL and users at NAVO are coordinating the transition to best suit the needs of the operational customers.

A validation test report is provided to assure soundness of the model in typical scenarios. Some results of the validation are discussed below.

Once the model is installed in a way appropriate to operations, an operational evaluation and test are completed. In the operational test certain criteria that NAVO specifies must be met to consider the model ready for operations. The model being transitioned needs to meet and/or exceed the performance of existing capability.

5. Domain Coverage and Run Times

The current configuration for coverage of the world includes the globe at latitudinal and longitudinal grid spacing of 0.5 degrees and smaller domains at 0.2 and 0.1 degrees. Winds for the global domain come from NOGAPS, whilst the smaller domains are forced by COAMPS. The complete system (shown in Fig. 2) as of this writing consists of a global domain and six regional domains.

In addition, in a development version of WAVEWATCH III (v4.10), irregular grids are possible, and so the Arctic region can be covered by a curvilinear grid whose grid spacing is 16 km and has the additional input of ice concentration. A COAMPS grid covering the same regions provides the wind fields. The boundaries between the curvilinear and other grids behave just as was described earlier.

Many other areas surrounding the continents will be covered with a domain at 0.2 degrees grid spacing in order to provide the boundary conditions needed for small scale domains along many coasts. Except for the occasional coverage of COAMPS winds, most of these additional regions will be covered by NOGAPS.

The run cycles will almost always consist of runs every 12 hours, i.e. starting at 00 and 12 UST. Forecasts will run to at least 48 hours and potentially to 96 hours, depending on wind field availability.

The total wall time to run the system is quicker than the sum total of running the conventional individual runs. For a 48 hour forecast from start in the PBS to finish, the system wall clock time averaged about 1 hour and 13 minutes, where 64 processors were used.. This does not include the post processing as this could largely vary depending on the connectivity of the archive machine. Since the model scales very well, 256 processors may decrease the wall time by close to one fourth. The disadvantage to having the post-processing attached to the main run is that the latter process, though using only one processor, will cost the user all 64 (or 256) processor hours.

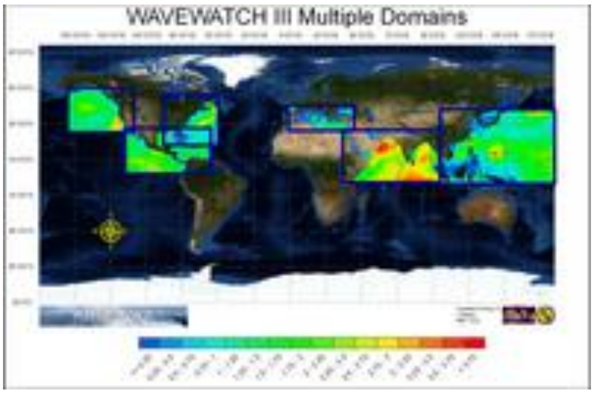

Figure 2. Global and regional domains used primarily for providing boundary conditions for smaller scale models.

6. Preliminary Validation Results

Comparisons of both WAM and WAVEWATCH III were made with in situ observations and altimeter measurements. For this paper, a buoy deployed into the waters of western Bermuda by the NOAA Data Buoy Center (NDBC), Buoy number 41048 located at 31°58'42" N 69°38'56" W was selected to evaluation the wave models at this location. Data and model runs for the time ranging from January through April were compiled. Results were plotted as time series, scatter plots, and wind roses. Table 1 shows a compilation of some of the results for TAU 00 (initial fields), including, mean bias (MB), standard deviation (SD), correlation coefficient (CC), slope(S) and scatter index (SI).

Results from this buoy show that the mean bias for WAVEWATCH III is always smaller than WAM, i.e. both wave models forecasts are low, but WAM is always lower.

Table 1. Statistics from comparing NDBC Buoy 41048 to WAM and WAVEWATCH III output.

Month	**Model**	**MB**	**SD**	**CC**	**S**	**SI**
Jan	WW3	-.27	.42	.93	.90	.17
	WAM	-.37	.43	.95	.82	.12
Feb	WW3	-.15	.35	.94	.94	.15
	WAM	-.32	.33	.96	.84	.11
Mar	WW3	-.21	.34	.90	.90	.15
	WAM	-.33	.37	.90	.82	.13
Apr	WW3	-.06	.33	.90	.82	.13
	WAM	-.28	.32	.93	.83	.12

7. Conclusion

Transition plans for WAVEWATCH III are now underway. The multi-grid system will be an improvement to the current wave modeling systems in place at NAVO and FNMOC, because the new configuration will save processing time and promises to increase forecast accuracy. Preliminary validation results seem to bear this out.

8. Acknowledgement

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