TOWARD THE THIRD RELEASE OF WAVEWATCH III; A MULTI-GRID MODEL VERSION [1]

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1 INTRODUCTION

WAVEWATCH III has been a successful wind wave forecast and hindcast model for nearly a decade, with its first public release in 1999 (Tolman, 1999) and a second public release in 2002 (Tolman, 2002). This model has been the operational wave model at NOAA/NCEP since 1999, with global and regional model implementations (Tolman et al., 2002), and with specialized hurricane wave model implementations for the North Atlantic Ocean since 2001 and for the Eastern North Pacific Ocean since 2003 (Chao et al., 2005; Tolman et al., 2005). This summer, an ensemble version of the global wave model using 10 ensemble members, and an additional operational implementation for the Great Lakes have been added to the model suite.

Like most operational models, WAVEWATCH III is subject to constant development. Since the 2002 release, assimilation of buoy and altimeter data has been added to the global operational wave model at NCEP (Chen et al., 2004), model I/O has been adapted to be suitable for non-parallel file systems on clusters (Tolman, 2003) and a model version with a continuously moving grid has been developed (Tolman and Alves, 2005). The latter two modification are available in a limited release (model version 3.04), which can be made available in particular to users having access to non-parallel file systems only.

In the last two years, a large part of the development has focused on the functionality of the model. With respect to hurricane wave modeling, it was deemed desirable to develop a wave model that features telescoping nests with two-way data flow between grids centered on a hurricane. Because hurricanes are not stationary, such grids should be dynamically relocatable. Such a wave modeling system would mimic the modeling capabilities of advanced deterministic three-dimensional hurricane models (e.g., Kurihara et al., 1995).

Recent research indicates that hurricane modeling will benefit from full coupling between ocean, wind waves and atmosphere (e.g., Bender and Ginis, 2000; Bao et al., 2000; Moon et al., 2004a,b,c, 2006). At NCEP, such a coupled approach to hurricane modeling has been pursued for several years (e.g., Ginis et al., 2006). This research is culminating in the development of the Hurricane Weather Research and Forecasting (HWRF) coupled ocean-wave-atmosphere model (Surgi, 2004; Surgi et al., 2006), which is the next generation hurricane forecast system, which is scheduled for operational implementation at NCEP in 2007. The present version of WAVEWATCH III has been designed specifically with inclusions in the HWRF in mind.

Additional benefits of such a technology are that the need for large regional models no longer exists, and that, consequently, higher coastal resolutions become economically feasible. In turn, selective application of high-resolution grids makes reduction of resolution for ensemble modeling more straightforward. After two years of software development, the multi-grid version of WAVEWATCH III is approaching maturity. It is scheduled for operational implementation at NCEP and public release in 2007. The development of the multi-grid model will be the main focus of the manuscript. In section 2, basic features of model version 3 will be presented. Sec-

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tion 3 focuses on the nesting techniques developed for WAVEWATCH III, and practical examples of the two-way nested model will be given in Section 4. Finally, a brief outlook is given in Section 5.

2 MODEL VERSION 3

Two significant additions introduced in model version 3 have already been identified above; I/O suitable for non-parallel file systems on distributed computer architectures, and a model version with a continuously moving grid. The main focus of model version 3, however, is the development of a two-way nested wave model approach. Such an approach is not new. Gomez and Carretero (1997) have presented a version of the WAM model featuring a stepwise increased resolution in a conventional structured grid, which has been used operationally in Spain for a decade. Alternatively, unstructured grids (e.g., Benoit et al., 1996; Ardhuin et al., 2001; Hsu et al., 2005) could be used to increase resolution locally. Note that dynamically adjusted unstructured grids have also been used in other geophysical fluid dynamics applications (e.g., Gopalakrishnan et al., 2002).

For the operational environment at NCEP it is most efficient to build upon existing capabilities. With this in mind, NCEP has chosen to develop a wave model capability where a single wave model driver is capable of addressing the evolution of the wave field on an arbitrary number of conventional structured grids, while simultaneously accounting for all interactions between the grids. Such an approach is sometimes identified as mosaic approach to variable model resolution. An additional benefit/requirement for this development is to maintain as much as possible the downward compatibility to conventional single-grid model applications.

The development of a multi-grid or mosaic version of WAVEWATCH III has consisted of several major tasks.

First, a data structure was developed that allows for running multiple wave model grids independently in a single wave model program. This data structure is based on an array of wave model grids together with a pointer technique to dynamically select one of the wave model grids. The development and testing of this data structure represents a major software effort, as virtually every wave model routine had to be adapted to the new dynamic data structure. For the conventional single-grid version of WAVEWATCH III, this dynamic data structure transparently replaces the static data structure with negligible computational overhead.

Second, the relation between individual grids needs to be established. For this reason, a grid rank is introduced. The lowest rank is used to identify the grid with the lowest resolution, and higher ranks identify higher resolutions. Grids that share ranks have similar, but not necessarily identical resolution. This results in three type of data flow identifying interactions between grids; (i) data flow from low to high resolution, (ii) data flow from high to low resolution , and (iii) data flow between grids with similar resolution. The techniques to properly model these interactions between grids will be discussed in more detail in Section 3.

Third, an algorithm needs to be developed to automatically and properly evaluate wave conditions on all individual grids, as well as all interactions between the grids. Such an algorithm can be designed when the basic actions needed to process all grids are considered and properly ordered. For a selected grid, these actions are presented in Fig. 1. The grid interactions will be discussed in some more detail in the following section. Only step 3 requires simultaneous consideration of multiple grids. The data assimilation in step 7 is presently included as a placeholder only, and might need to be moved to another positions in the list, depending on the assimilation techniques used. The individual actions are the basis of a fully automated algorithm to manage computations on all grids, as well as all interactions between grids. Details of this algorithm will be presented elsewhere.

step	action
1	Update external input
2	Update input from lower ranked grids
3	Update time step for grid
4	Run wave model for grid (no output)
5	Reconcile with grids with same rank
6	Reconcile with grids with higher rank
7	Data assimilation for grid
8	Run wave model (output only)

Fig. 1: Consecutive steps to be completed for each individual grid, defining the algorithm that controls the multi-grid wave model driver.

During the development of the multi-grid version of WAVEWATCH III, several additional features have been (or will be) added to the model.

1) Grid points can be taken out of the computation by marking them as either land or as 'excluded'. The latter new option allows for the 'carving out' of arbitrarily shaped computational areas in a structured, rectangular grid.
2) Inundation and drying out of grid points is introduced (controlled by input water levels). Note that most conventional source terms for surf-zone physics have not been introduced yet, but that the model is prepared for inclusion of such physics.
3) On-the-fly change of spectral resolution between grids is introduced.
4) The linear growth term of Cavaleri and Malanotte-Rizzoli (1981) as modified by Tolman (1992) is introduced to consistently start the model from a quiescent sea, and to improve initial wave growth characteristics.
5) Depth-limited breaking will be introduced. This is deemed essential at NCEP for operational hurricane wave modeling at 25km spatial resolution, and will become increasingly important for higher spatial resolutions near the coast.

Furthermore, several features are considered for implementation in the next public release of the model. All these extensions to the WAVEWATCH III code are explored though collaboration between NCEP and external partners. The lead partners for each subject and their affiliations are shown in brackets for each item.

1) Separation of wave spectra into individual wave fields (Hanson and Phillips, 2001) for each grid point as an additional output option (Jeff Hanson, USACE-ERDC).
2) Updated exact interaction approaches (Gerbrant van Vledder, Alkyon).
3) Additional input and dissipation source term options from WAM cycle 4 (Fabrice Ardhuin, SHOM).
4) Addition of a bottom scattering source term (Fabrice Ardhuin, SHOM).
5) Additional shallow water (surf-zone physics) source terms (Henrique Alves, Metocean Engineers).
6) Providing an Earth System Modeling Framework (ESMF) wrapper for standardizing coupling with other geophysical fluid dynamics models. (Tim Campbell, NRL Stennis).
7) Providing post processing to pack model results in netCDF format (Sander Hulst, Argoss).

3 TWO-WAY NESTING

The choice to build the multi-grid model as a set of essentially independent grids has a profound impact on the nesting techniques that can be applied. It implies that an order of computation has to be assigned to the grids making up the complete wave model. With the traditional one-way nesting employed in wave models, the solution for lower resolution grids is addressed first, after which the lower resolution grid provides boundary conditions for a higher resolution grid. Building upon existing techniques, this approach is also used here (see Subsection a). Because iterative computations between grid would adversely impact model economy, the lower resolution grid can only be reconciled with the higher resolution grid after computations for each individual grid have been completed (see Subsection b). This defines the order of actions for each grid as outlined in Fig. 1.

A special form of interaction occurs if overlapping grids are of similar resolution (same rank, see Subsection c). In this case no clear order of computation between grids can be defined. Hence, overlapping grids with identical ranks need to be reconciled after wave evolution computations have been completed for the individual grids. Allowing grids with similar resolution to overlap and exchange information is particularly useful for two applications. First, a long and narrow shelf described in a single regular grid will results in a very sparsely populated grid (assuming that unneeded offshore grid points are removed from the computations as outlined above). A much more efficient usage of grids is introduced if the shelf is described by a set of smaller overlapping grids. Second, longitudinal resolutions can be modified stepwise with latitude if grids are split in latitudinal bands, thus circumventing CFL economy issues for spherical grids at higher latitudes.

Presently, all above nesting techniques for static grids have been implemented and tested in the single processor model version, and development and testing for the distributed (MPI) model version is

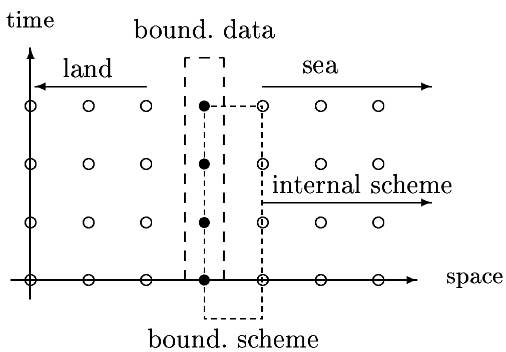

Fig. 2: Traditional one-way nesting approach as used in present and previous versions of WAVEWATCH III. One-dimensional representation in space and time, symbols represent grid points.

nearing completion. Moving (relocatable) grid approaches will be developed in the coming months.

Note that the fact that all grid are essentially treated as independent models greatly simplifies the inclusion of relocatable grids methods. In fact, the two main issues with relocatable grids are the initialization of wave conditions in areas that were previously not covered by a relocated grid, and the (re)initialization of the nesting techniques already employed for static grids.

3.a Traditional one-way nesting

In the traditional one-way nesting approach as used in previous versions of WAVEWATCH III the lower ranked grid provides boundary data for the higher ranked grid, if necessary, by spatial interpolation of wave spectra from the surrounding grid points of the lower ranked grid. The inclusion of the boundary data in the higher ranked grid is illustrated in Fig. 2.

In the higher ranked grid a distinction is made between land or otherwise excluded grid points, grid points where boundary data are prescribed from the lower ranked grid (• in the figure), and active sea points for which the wave evolution is evaluated. Between the boundary data points and the first sea point (short-dashed box in Fig. 2) a first order boundary data scheme is employed. This scheme propagates information from the boundary points into the active sea points for propagation directions into the grid, and effectively absorbs outgoing wave energy. For all other sea points, the selected propagation scheme is used. In WAVEWATCH III, this is typically the third order ULTIMATE-QUICKEST scheme of Leonard (1979, 1991).

For a model using a first order scheme and nesting grids with identical resolution and coinciding grid points, results for individual grids or a compatible single grid should be identical in this approach. Such a test revealed an erroneous time shift corresponding to the model time step Δt of the nested solution in the the presently distributed version of WAVEWATCH III. This error will be fixed in the next release of WAVEWATCH III. Note furthermore that the first order boundary scheme will introduce a minor local degeneration of the propagation scheme for higher order propagation schemes. In practical applications, however, such a degeneration is generally negligible (e.g., Fletcher, 1988)

3.b Extended two-way nesting

Two-way nesting is traditionally not considered in wave modeling. Due to the choice of working with a mosaic of grids, while retaining the original one-way nesting techniques, two way nesting becomes efficient only if the lower ranked grid is reconciled with the higher ranked grid after the computation for both grids have reached the same model valid time.

Considering that the resolution of the lower ranked grid by definition is lower that the resolution of the higher ranked grid, a natural way to estimate the wave energy in the lower ranked grid $E_{l,i}$ from energy in the higher ranked grid $E_{h,j}$ is

$$E_{l,i} = \sum w_{i,j} W_{h,j} \quad , \tag{1}$$

where i and j are grid counters in the two grids, and where $w_{i,j}$ are averaging weights. The weights can be defined consistent with conservation of wave energy as the surface of the grid box j in the higher ranked grid that covers the grid box i in the lower ranked grid, normalized with the surface of the lower ranked grid box i. To avoid circular reconciliation, grid points in the lower ranked grid that contribute to the boundary data in the higher ranked grid are not updated in this manner.

This completes the basic two-way nesting technique. Note that neither the conventional one-way nesting described in the previous subsection, nor the averaging technique described in Eq. (1) and in Fig. 3 require integer ratios between grid resolution.

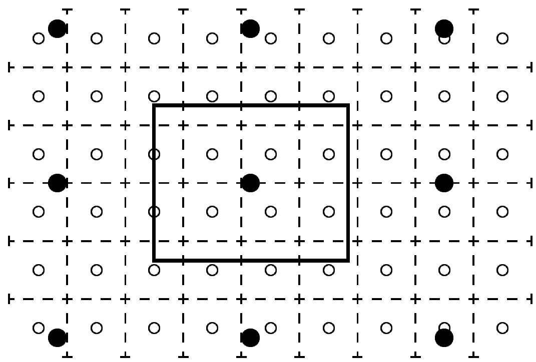

Fig. 3: Concept for reconciling lower ranked grid with higher ranked grid in two-way nesting approach. ◦ and hashed lines represent the higher ranked grid points and grid boxes, respectively, • and solid lines represent lower ranked grid and central grid box.

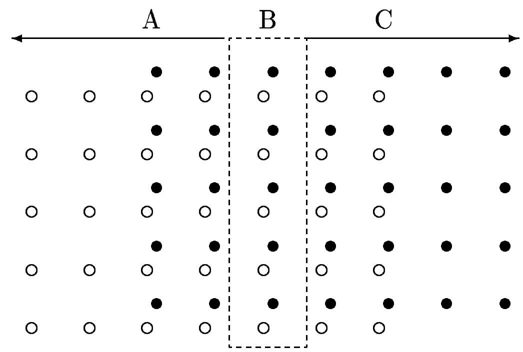

Fig. 4: Concept for reconciling grids with identical rank and therefore similar resolution. ◦ represents points of grid 1, • represents grid 2.

Furthermore, main grid axes, in principle, need not coincide between grid. However, in the present implementation in the experimental version of WAVEWATCH III, coinciding grid axes are assumed.

3.c Overlapping grids

A situation with overlapping grids with similar resolution is illustrated in Fig. 4. For grid 1 (◦ in Fig. 4) two areas can be distinguished. In area C, the influence of the boundary has propagated into the grid since the last reconciliation. The actual depth of penetration depends on the stencil width of the numerical scheme, and the number of propagation time steps. In areas A and B, information from the boundary has not yet penetrated, and this area can be considered as the 'interior' of grid 1. Similarly, area A represents the boundary penetration depth for grid 2 (• in Fig. 4) whereas B and C represent the interior of grid 2. A simple and consistent reconciliation between grid 1 and 2 uses data from grid 1 exclusively in area A (interpolating data from grid 1 to grid points in grid 2 as necessary), and uses data from grid 2 exclusively in area C. In area B, where interior parts of both grids overlap, a consistent solution can be found by using weighted averages from both grids. Note that this approach is easily extended to multiple overlapping grids.

Note that for explicit numerical propagation schemes and overlapping grids with identical resolution and coinciding grid points, solutions for overlapping grids and the compatible single grid can be identical, as long as the overlap areas are sufficiently wide.

4 EXAMPLE APPLICATIONS

Results for three test cases using the multi-grid version of WAVEWATCH III are presented. The first is a case including wave-current interactions in a high-resolution inner grid. The second case considers modeling of a moving hurricane using telescoping nests. The third case considers modeling of waves penetrating in a Norwegian fjord with a set of grids covering the entire North Atlantic Ocean. For all computations, the standard settings of WAVEWATCH III version 2.22 (Tolman, 2002) are used, unless specified differently.

4.a Swell propagating over a current ring

In the first test case, propagation of swell with a mean period of 10s and narrow spectral energy distributions in wave frequency and direction is considered, using three grids as illustrated in Fig. 5. The swell propagates from left to right through the grid. In the first grid (Fig. 5a) initial conditions are given on the left of the grid (purple line). One-dimensional propagation in the horizontal direction is considered to compute the dynamical evolution of lateral boundary conditions for a second grid (Fig. 5b). Both grids have a resolution of $\Delta x = \Delta y = 10$km. In the second grid, full two-dimensional propagation

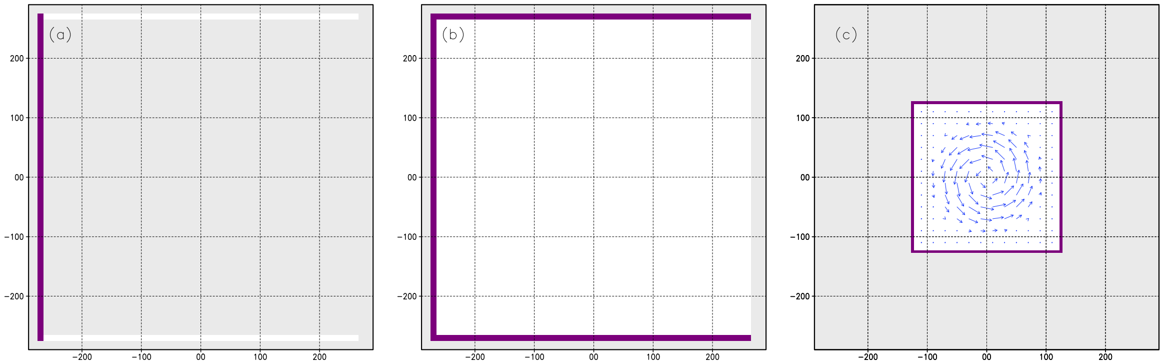

Fig. 5: Layout of grid for wave-current interaction case. (a) Outer grid for generating dynamic lateral boundary conditions only. (b) Outer full grid without current. (c) Inner grid with current ring with a maximum current velocity of 1ms^{-1}. White: active sea point. Grey; points excluded from grid or points outside grid. Purple; points where boundary data is provided to grid. Axes in km.

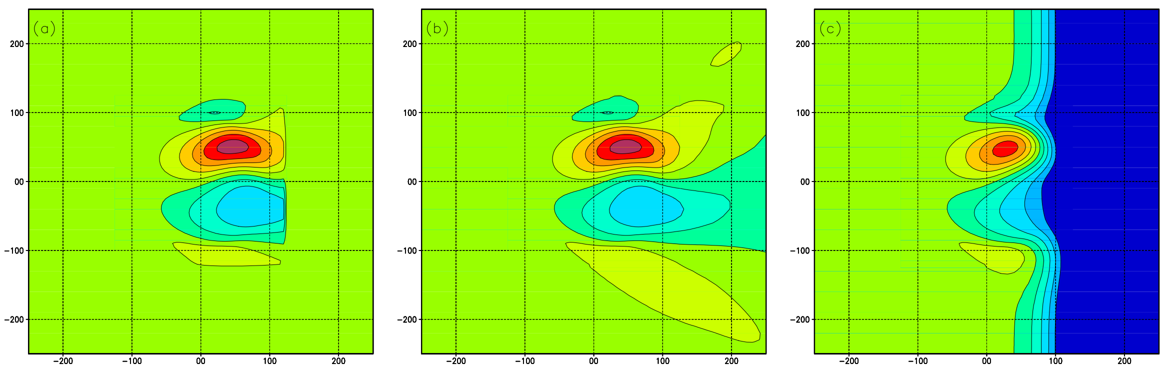

Fig. 6: Results for wave propagation in the set of grids presented in Fig. 5.Incoming wave height $H_s = 2.5$m, contour intervals at $\Delta H_s = 0.2$m. (a) Near-steady solution after 24h of model integration with conventional one-way nesting approach. (b) Idem for full two-way nested approach. (c) Developing solution for two-way nested approach after 12h of model integration.

in water with a constant depth is considered. The third and final grid has a resolution of $\Delta x = \Delta y =$ 5km, and includes a current ring with a maximum current velocity of 1ms^{-1} at a radius of 50km. Note that the information presented in Fig. 5, including the location of active boundary points and time step settings for each grid, is sufficient to fully automate the time stepping of all grids and the internal data transfers between grids.

Figure 6 presents resulting significant wave heights H_s obtained with several model options. The incoming wave height on the left is given as $H_s = 2.5$m. The green shading identifies 2.4m $< H_s <$ 2.6m, and all contour intervals are given as $\Delta H_s = 0.2$m. The figures are generated by plotting wave height fields for the grids in Figs. 5b and 5c consecutively in the same figure. Figure 6a shows the near-steady solution for the conventional one-way nested approach, obtained after 24h of model integration. Each consecutive grid obtains data from the previous grid, but no data flow to previous grids is accounted for. In this case, distinct wave-current interactions occur in the inner grid, with increased wave height in counter-current conditions (upper part of current ring), with reduced wave heights in following currents (lower part of ring), and with effects of current refraction behind the ring. However, the latter interactions are not transferred back to the outer grid. Figure 6b shows the corresponding results for a two-way nested approach. Clearly, the wave current interactions generated in the inner grid are seamlessly transferred to the outer grid. Finally, Fig. 6c gives an example of the transient solution of the swell front passing through the current ring after 12h of model integration. Clearly, the two-way nested approach results in a seamless solution between grids in these conditions too.

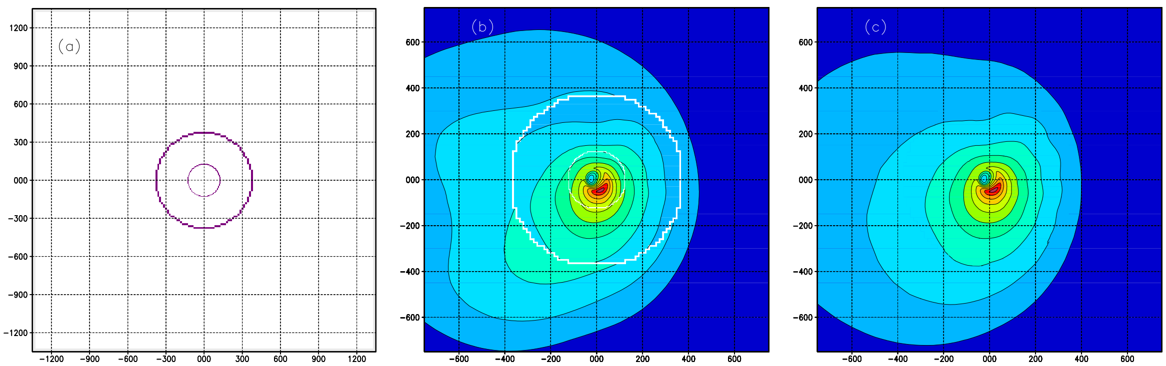

Fig. 7: Modeling a moving hurricane with three grids with resolutions of 50, 15 and 5km, respectively. (a) Superimposed grids (legend as in Fig. 5a). (b) Wave heights H_s after 24h for the three superimposed grids without interactions between grids. (c) Idem, with full interactions between grids. Wave height contours at intervals $\Delta H_s = 1$m. $H_{s,\max} > 10$m. Axes in km.

4.b Modeling a hurricane with moving grids

In the second test case the wave field generated by a moving hurricane is considered. The hurricane is modeled with a simple Rankine vortex with a maximum wind speed $U_{10} = 45\text{ms}^{-1}$ and a radius of maximum wind $R = 50$km. The hurricane moves to the right with a translation speed of 5ms^{-1}, ignoring the impact of the translation speed on the wind pattern. The moving grid approach of Tolman and Alves (2005) is used[3]. Three grids are considered with resolutions of $\Delta x = \Delta y = 50$, 15 and 5km, respectively, and with grid sizes of $2700 \times 2700\text{km}^2$, $750 \times 750\text{km}^2$, and $250 \times 250\text{km}^2$, respectively. The grids remain centered on the hurricane, with the eye coordinates at (0,0). To illustrate the capability of carving out arbitrary domains from these rectangular grids, the inner two grids are given circular computational domains. An overlay of the three grids is presented in Fig. 7a, with purple grid points identifying where each grid obtains its boundary data from the lower ranked grid.

Given the parameters describing the wind field, the outer (50km resolution) grid cannot resolve the wind conditions. The 15km grid represents a borderline adequate resolution, whereas the inner grid has sufficient resolution to resolve the maximum wind speeds. Consequently, wave conditions as modeled with these grids individually are expected to show significantly different results. This is illustrated in Fig. 7b, which presents a superposition of the wave model results for the three grids as computed without interactions between the grids. The grid boundaries are identified by the circular patters of white grid points. The results for the outer two grids are clearly incompatible.The results for the inner two grids show minor incompatibilities.

Figure 7c shows results obtained with full interaction between the three grids, For all practical purposes the three grids provide a consistent solution. In fact, a practically seamless solution is presented with a local resolution of 5km near the eye of the hurricane to 50km for swells propagating away from the hurricane. Note that the wave field becomes highly asymmetric due to the propagation of the wind field only, considering that the instantaneous wind field is fully symmetric.

Table 1: Grids used for modeling the approach to Trondheim, Norway.

grid	resolution	coverage
1	$1^\circ \times 1^\circ$	85°W - 0°W
		EQ - 70°N
2	$1/3^\circ \times 1/3^\circ$	35°W - 25°E
		40°N - 75°N
3	$1/5^\circ \times 1/10^\circ$	2°E - 16°E
		60.5°N - 67.5°N
4	$1/15^\circ \times 1/30^\circ$	6.5°E - 11.5°E
		62.73°N - 64.73°N
5	$0.009^\circ \times 0.0045^\circ$	7.50°E - 11.24°E
		63.08°N - 64.10°N

[3] using averaging weight of 2.5 in the GSE alleviation and capping the drag coefficient $C_d \leq 2.5\,10^{-3}$

4.c Wave penetration in a Norwegian fjord

The last example presented here considers wave prediction for the entrance of the natural harbor of Trondheim in Norway. A setup for a forecast system for this area was presented by Birgitte Furevik and Magnar Reistad of the Norwegian Meteorological Institute at the 2006 WISE meeting[4], with a case study for an extreme wave event on Jan 11, 2006. This study provided a practical application for a multi-grid mosaic approach as presented here. To provide a seamless wave model solution from Atlantic to coastal scales, five grids are considered as outlined in Table. 1. The first four grids were produced at NCEP using a simple sub-sampling technique from the 2min resolution DBDB2 version 3.0[5] data set. The fifth grid was provided by Birgitte Furevik, and originated from the above mentioned study.

It should be noted that these grids were generated mainly to show the potential and capability of the multi-grid approach. The grids have not been optimized to remove essentially unresolved features, and the capability to remove unneeded resolution by carving out irregular domain shapes within all grids has only been explored in an ad-hoc manner. A more refined version of this set of grids will be presented elsewhere.

Figure 8 presents the wave heights for the five individual grids for January 11, 2006, 1500UTC. The maximum offshore wave height is well over 13m at this time. Note the gray shaded areas in these maps. These areas denote grid points that have been excluded from the computations for one of two reasons. First unneeded 'offshore' areas have been manually excluded from computations by defining simple diagonal lines of input boundary points and by marking all grid points offshore of this line as excluded. Second, 'inshore' points are excluded by the model automatically when information at such grid points is updated from higher ranked grids before it can reach other regions of the grid. Hence, wave conditions for such grid points need not be computed for a consistent composite wave field. Note also that the final grid includes extremely shallow water, but no surf zone physics yet. Hence, unrealistically high wave heights occur occasionally on the coast.

Figure 8 showcases the range of resolutions covered by the five grids, ranging from approximately 100km for grid 1 in Table 1 to approximately 0.5km for grid 5. The consistency of the results for the five grids is illustrated in Fig. 9, which shows a superposition of the wave fields of the five grids for the northeastern part of the combined domain. The wave heights from all the grids are highly consistent. In fact, the location of the different domains can only be identified from the 'block-fill' representation of the coastlines.

5 OUTLOOK

The present study showcases the newly developed multi-grid approach in WAVEWATCH III. This approach will be the major new feature of the next model release, which is tentatively scheduled for the summer of 2007. However, many other features have been or will be added to this new model release. These features are discussed briefly in Section 2. With the listed additions to the model, it is also clear that WAVEWATCH III no longer is a development effort of NCEP only. A more formal cooperation between NOAA/NCEP, the US Army Corps of Engineers (USACE) and the US Navy is being developed, and several companies and individual wave modelers are contributing or planning to contribute to the source code. With this development, WAVEWATCH III is evolving into a wave modeling framework, with individual wave models within this framework being defined by selected numerical and physical approaches.

With the increased number of collaborators, version control of the code will become a bigger issue. Tentatively, NCEP is adopting version Subversion (Collins-Sussmann et al., sorg) for version control of all its software, and for collaboration with investigators outside NCEP. Tentatively, version 3 of WAVEWATCH III and subsequent model version will be maintained and distributed using Subversion.

A major topic for future development of WAVEWATCH III will be to include more shallow water physics, in particular surf-zone physics. For the present operational WAVEWATCH III hurricane wave applications at NCEP with 25km spatial resolution, the lack of such physics in the model already is clearly detrimental to the model behavior. With envisioned operational coastal resolutions of up to 5km in 2007, inclusion of surf-zone physics will become essential.

A second major topic will be the inclusion of al-

[4] Waves in Shallow Environments, April 23-27 2006, Venice, Italy.

[5] http://www7320.nrlssc.navy.mil/DBDB2_WWW/NRLCOM_dbdb2.html

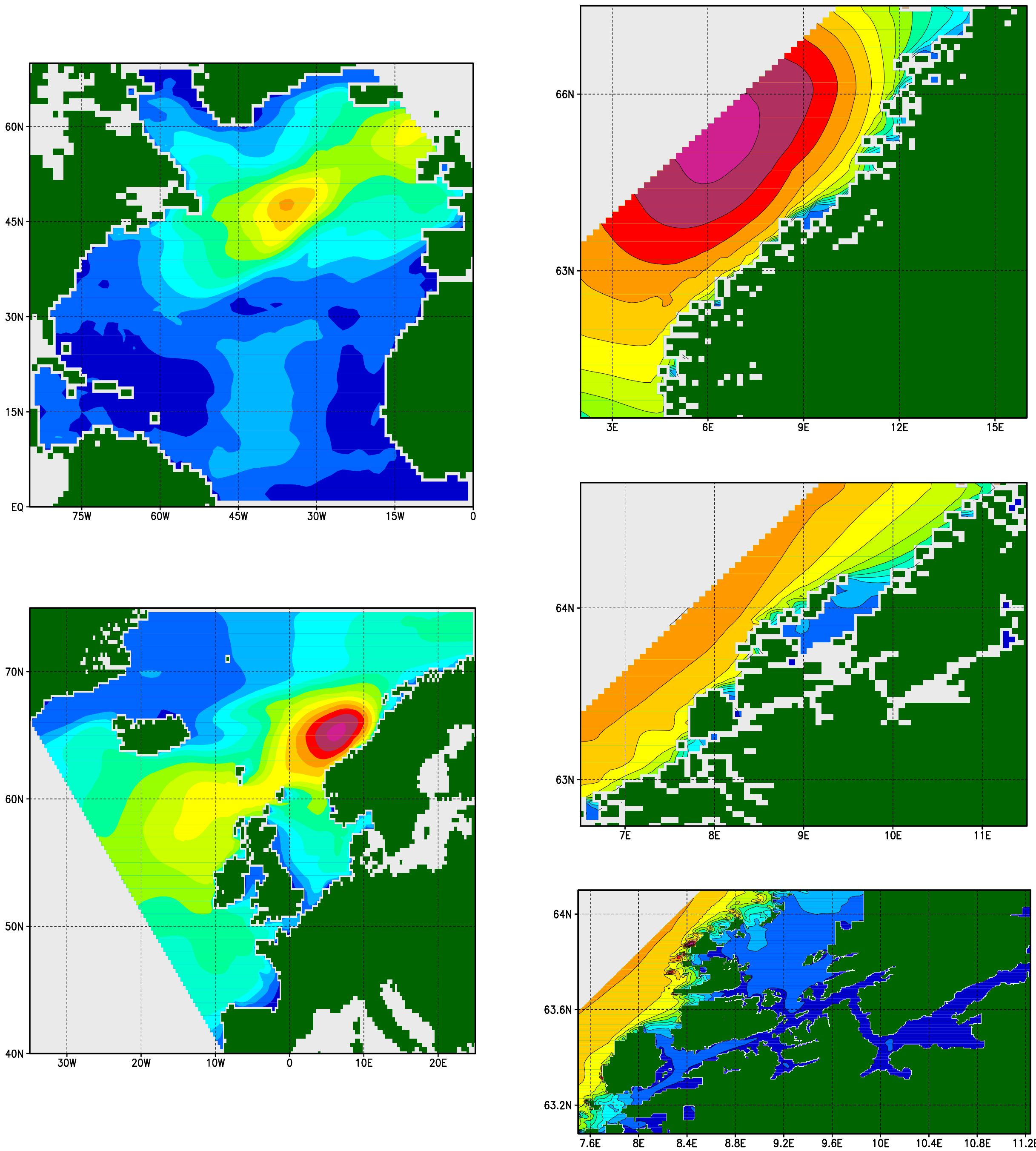

Fig. 8: Wave heights H_s for January 11 2006, 1500UTC for the five individual grids for the model for the entrance to the harbor of Trondheim. Wave height contours at 1m, $H_{s,\max} > 13$m.

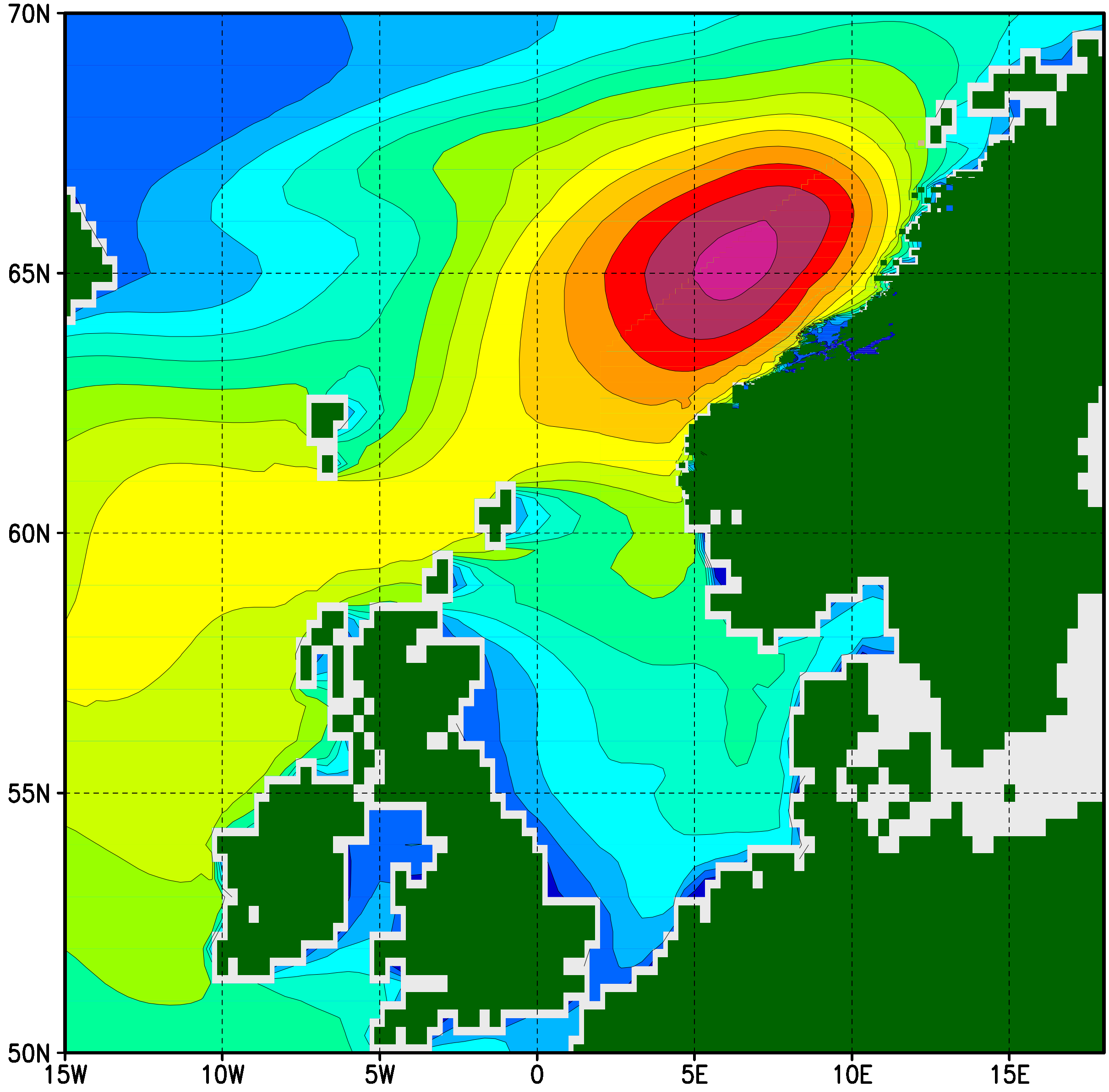

Fig. 9 : Composite wave heights H_s of all grids from Fig. 8.

ternative grid approaches, particularly for coastal (hurricane) applications and for coupling with surge and inundation models. We intend to explore alternative regular grid methods with appropriate mapping techniques, as well as unstructured approaches as discussed in the previous sections. Due to small coastal scales involved, quasi-steady approaches as pioneered in the SWAN (Booij et al., 1999) model may also need to be considered. Both topics will be addressed in the next five years through a cooperation project with the University of Southern Alabama.

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