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Technical Note

Example of WAVEWATCH III® for the Alaska area [†].

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Abstract

This is a progress report on the generation of a nested set of wave models intended to provide a long term data set of spectral near-coast wave conditions for Alaska. This data set can be the basis of climatological studies, and can provide boundary data for higher-resolution coastal wave models. The present report discusses the generation of three grids, to be run as a single two-way nested wave model, and available forcing for such a wave model. It furthermore discusses validation strategies and strategies to provide the spectral wave data base. Model bathymetry etc. and scripts will be packaged separately and made available as needed.

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This report is available as a pdf file from

http://polar.ncep.noaa.gov/waves

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1 Introduction

A sample case of the nested-grid full-spectral wind-wave model WAVEWATCH III® was tested for the Alaska region. These grids are intended to become a baseline model for producing near-coast wave climatologies for the Alaskan region. A set of three nested grids were developed, covering from 100E—70W and 78S—78N. To show the impact of the resolution of the input wind fields, separate runs were performed with different input wind fields for the month of January 2000. Mean wave height was requested every 3 hours, and compared to historical NDBC buoy data.

The WAVEWATCH III® model is described in the user manual and system documentation (Tolman, 2002b). The manual describes the governing equations, numerical approaches, installation, compilation, and running of the model. The nested-grid driver is described in Tolman (2007a,b), and the grid generation tools used are described in Chawla and Tolman (2007, 2008).

2 Nested Grids

A set of three nested grids (Figure 3.1 and Table 3.1) was produced for the Pacific Ocean and the Alaskan region. The full resolution ETOPO2 bathymetry was used as the reference grid, with the Strait of Juan de Fuca, Puget Sound, Columbia River Estuary, and San Francisco Harbor excluded. The lowest resolution grid (PAC) covers the Pacific Ocean. Nested inside are the intermediate (AK_int) and highest resolution (AK_cos) grids which cover only the Alaskan region.

Three files were created for each grid: a bathymetry, a mask, and an obstruction grid which accounts for wave attenuation by unresolved islands. For the PAC and AK_int grids, the masks allow all data points. To use it's high resolution efficiently, the AK_cos mask is designed to limit the active grid to points within 250 km of the shoreline (Figure 3.2).

3 Input Wind Fields

3.1 NCEP Global Reanalysis

The first wind forcing data set considered was the NCEP Global Reanalysis winds from the 40 year (1957–1996) NCEP/NCAR reanalysis described in Kalnay et al. (1996). These are 10m winds analyzed using the forecast model and Global Data Assimilation System (GDAS) versions fixed for the reanalysis project. Data are available for 90N—90S, 0E—357.5E on a 2.5 degree latitude x 2.5 degree longitude global grid, every 6 hours (0Z, 6Z, 12Z, and 18Z). These NCEP-reanalysis winds

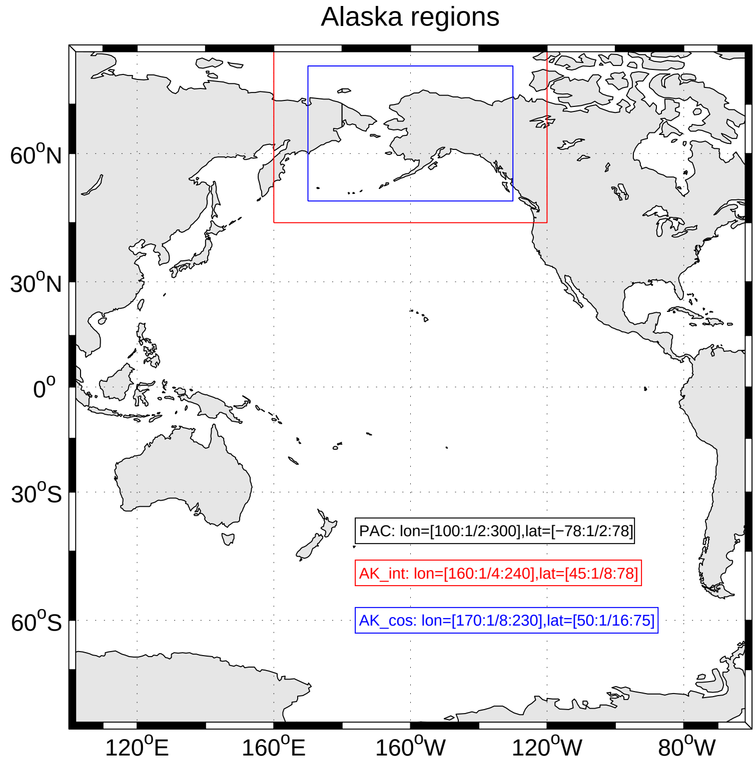

Fig. 3.1 : Set of nested grids for the Pacific Ocean and Alaska.

do not contain the influence of scatterometer retrievals. An example of this data can be seen in Fig. 3.3.

3.2 NCEP North American Regional Reanalysis Winds

WAVEWATCH III® allows various input wind fields. For example, global winds might be used for the area covered by the global grid, and higher resolution winds used for the intermediate and coastal grid areas. Since the Global Reanalysis winds are of such coarse resolution, the NCEP North American Regional Reanalysis (NARR) winds were considered for the Alaska region. These winds are generated

Table 3.1: Grid range and resolution.

Name	Latitude	Longitude	Resolution (lat x lon)
PAC	$78^oS : 78^oN$	$100^oE : 60^oW$	1/2 x 1/2 deg
AK_int	$45^oN : 78^oN$	$160^oW : 120^oW$	1/8 x 1/4 deg
AK_cos	$50^oN : 75^oN$	$170^oW : 130^oW$	1/16 x 1/8 deg

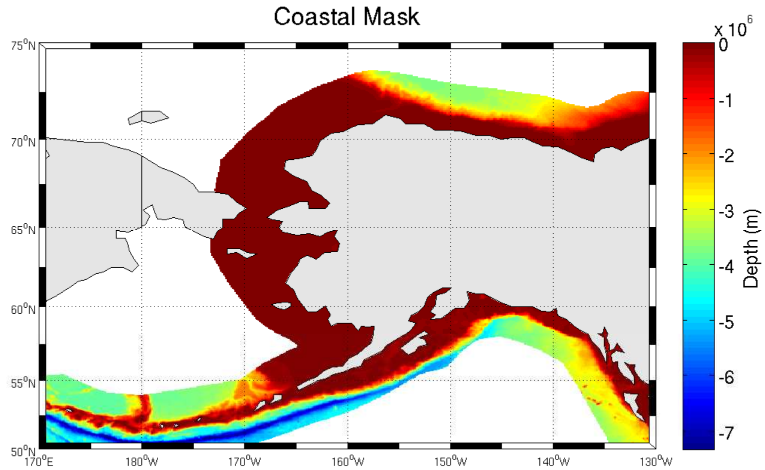

Fig. 3.2 : Mask for the AK_cos grid.

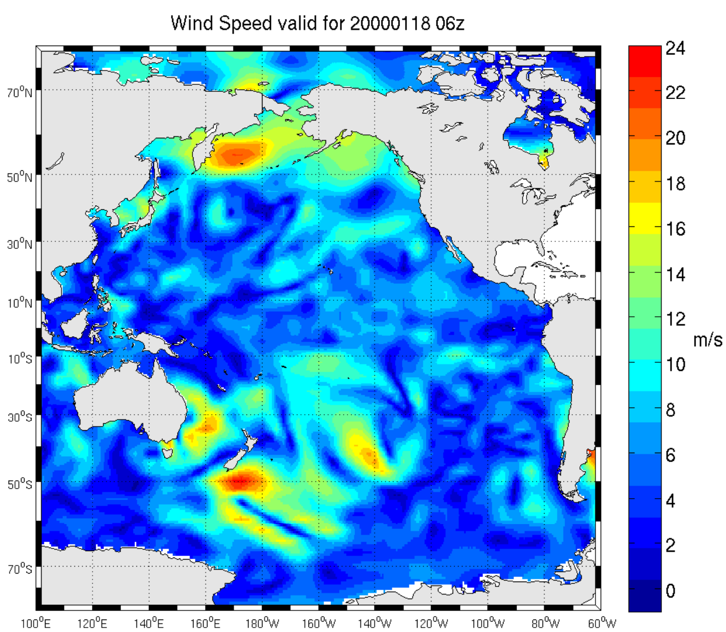

Fig. 3.3 : NCEP Global Reanalysis winds valid 2000/01/18 06z.

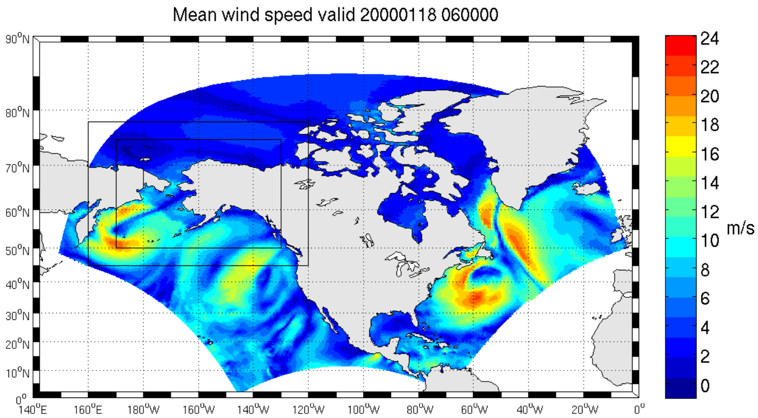

Fig. 3.4 : NCEP North American Regional Reanalysis winds valid 2000/01/18 06z.

with much the same data as the Global Reanalysis, but are of much higher resolution (approximately 0.3 degree at the Equator). The data are saved in a Northern Lambert Conformal Conic grid that covers the North American region, and are available every 3 hours (Figure 3.4).

The first step is to re-format this data into the style that WAVEWATCH III® expects. A simple linear-interpolation was used to regrid the data to 0.3 degree square grid. The resulting winds were then plotted over the Global Reanalysis winds to see if there were any differences at the boundaries. For most of the days in January 2000, these wind fields were comparable (Figure 3.5). But on days with strong storm systems, the highest values of the wind speeds did not cross over the grid boundaries (Figure 3.6).

Because of the discrepancy in the wind speeds across grid boundaries, it was decided to use only the Global Reanalysis winds in this example. To show the impact of input wind resolution, a separate run was made using higher resolution NWW3 global winds and the results compared.

3.3 NWW3 Winds

The NWW3 winds are the operational winds that have been archived from WAVEWATCH from 1997 to present. These winds are 1 degree resolution in latitude and 1.25 degree resolution in longitude, and available every 3 hours. They cover the globe from 78S—78N. Note that these winds represent an evolution of atmospheric models, both in physics, assimilation, and resolution, and should therefore not be considered as a statistically homogeneous climatological dataset. These winds are used here to illustrate the capability of high resolution global weather models and analyses.

To verify the accuracy of the wind fields, the data were compared with

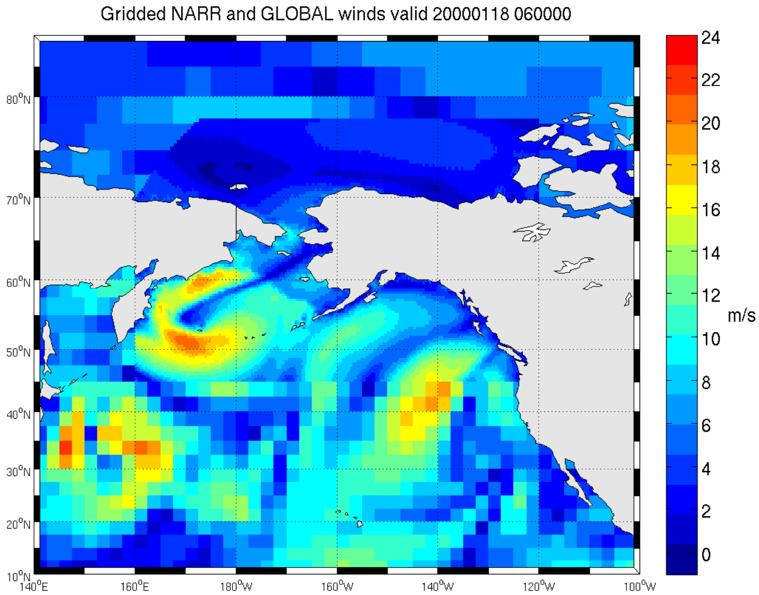

Fig. 3.5 : NCEP Global Reanalysis and NARR winds valid 2000/01/18 06z.

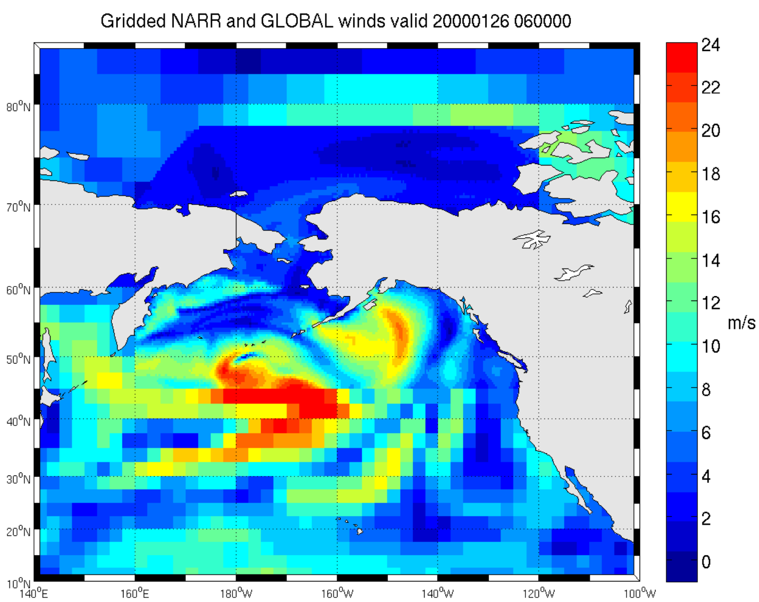

Fig. 3.6 : NCEP Global Reanalysis and NARR winds valid 2000/01/26 06z.

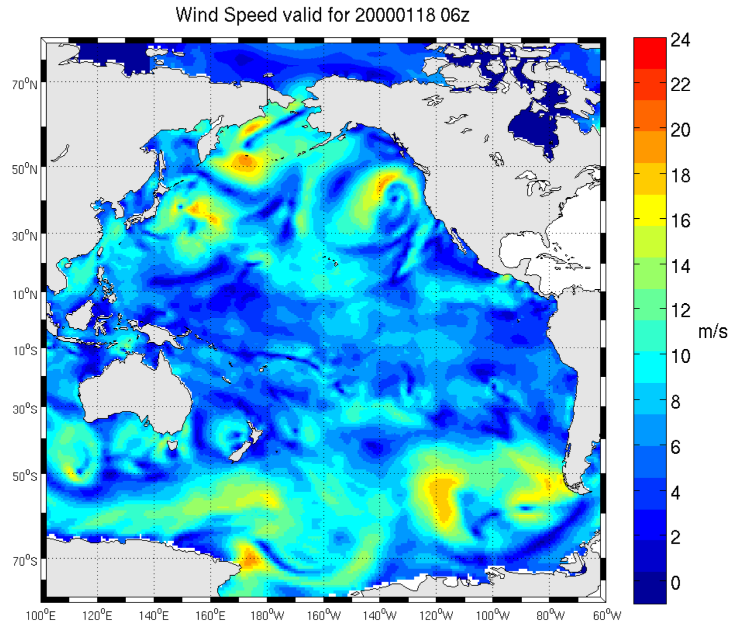

Fig. 3.7 : NWW3 winds valid 2000/01/18 06z.

independent wind speed data for the same area. For example, the DMSP Special Sensor Microwave/Imager (SSM/I) surface wind speed for January 18, 2000 (Figure 3.8) shows the same structure as the NWW3 wind speed for the same day (Figure 3.7). Note that the color bars are different between the figures, but similarities are still discernible. For example, there are three systems in the north of the basin with wind-speeds between 15–20 m/s. There is also a feature off the south-west coast of Australia with wind-speeds between 10–15 m/s, and a feature off the south-west coast of South America with wind-speeds between 15–20 m/s.

3.4 CFSRR Winds

The new NCEP Climate Forecast System Reanalysis Reforecast (CFSRR) entails a coupled reanalysis of the atmospheric, oceanic, sea-ice and land data from late 1979 through 2009, and a reforecast run with this reanalysis (Saha et al, 2010). This Reanalysis has much higher horizontal and vertical resolution of the atmosphere than the Global and the North American Reanalyses. The high resolution winds used here are 10m hourly with 1/2 degree in spatial resolution, and cover the globe from 90S—90N.

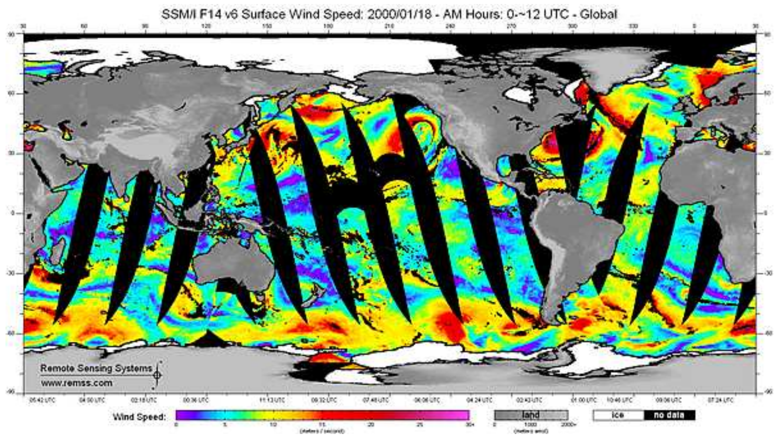

Fig. 3.8 : SSMI surface wind speed for January 18, 2000 (taken from the website http://www.ssmi.com/ssmi/ssmi_data_daily.html).

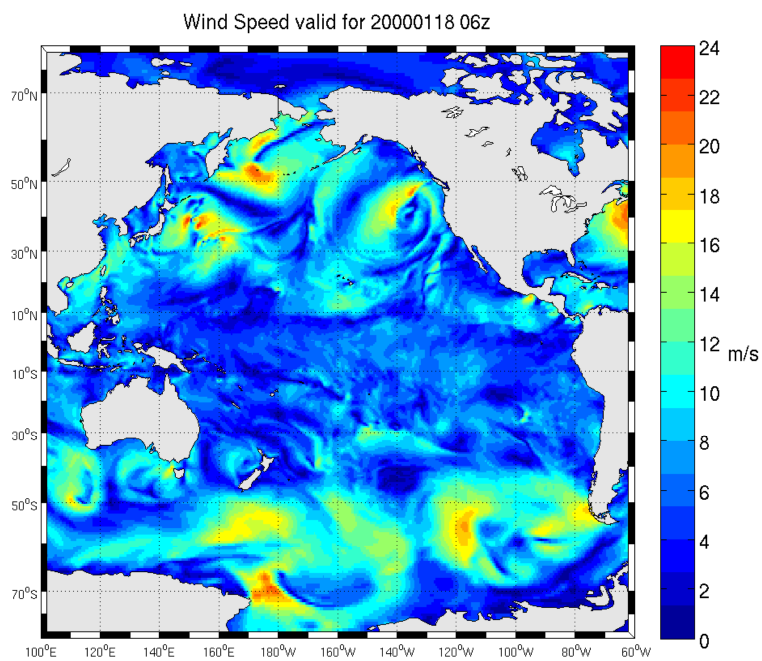

Fig. 3.9 : CFSRR winds valid 2000/01/18 06z.

Table 4.1: Time steps for each grid.

Grid	Δt_g	Δt_{xy}	Δt_k	Δt_S
PAC	900	450	450	15
AK_int	300	100	100	15
AK_cos	150	70	75	15

4 Running the wave model

The model was started from calm conditions, run for the month of January 2000, and the output significant wave height requested every three hours. Since it takes approximately two weeks for the model ocean to spin up from calm, only the data from the 15th to 31st of January were requested and will be shown in the final section.

The model requires spectral information that determine the frequencies that will be considered: a frequency increment factor, first frequency (Hz), number of frequencies (wavenumbers), and directions, and the relative offset of the directional increment. In this case, the following were used:

1.1 0.035 29 24 0.5

Here the model is intended to study wind waves with a period of no more than 29 seconds, so the first frequency is 0.035 Hz.

There are four time steps that must be specified in the model: global, spatial, directional, and the source term time step, all of which are defined in seconds. Δt_{xy} is the time step for spatial propagation, and as such must satisfy the Currant-Friedrich's-Levy (CFL) criterion: the speed of fastest waves in the model must be less than or equal to the grid spacing divided by the time step. Therefore each grid is going to have its own Δt_{xy} determined by the grid's resolution, the maximum latitude in the grid, and the first frequency (this last is the same for all grids).

The global time step Δt_g, by which the entire solution is propagated in time, is set to approximately 2 or 3 times the Δt_{xy}. Note that although there is a different Δt_g for each grid, it is at these time steps that the grids will exchange information. Therefore Δt_g is chosen for each grid in such a way that they intersect at given times (Table 4.1). Note that the model will adjust time steps to generate such intersections, however, if user-defined time steps are multiple-integer fractions of each other, then the time steps are used exactly as defined by the user.

Once Δt_g has been determined, then the directional time step is set to

$$\Delta t_k \ = \ 1/2 \Delta t_g$$

The source time step is adjusted internally and $\Delta t_S \ = \ 15$ seconds is the minimum allowed value.

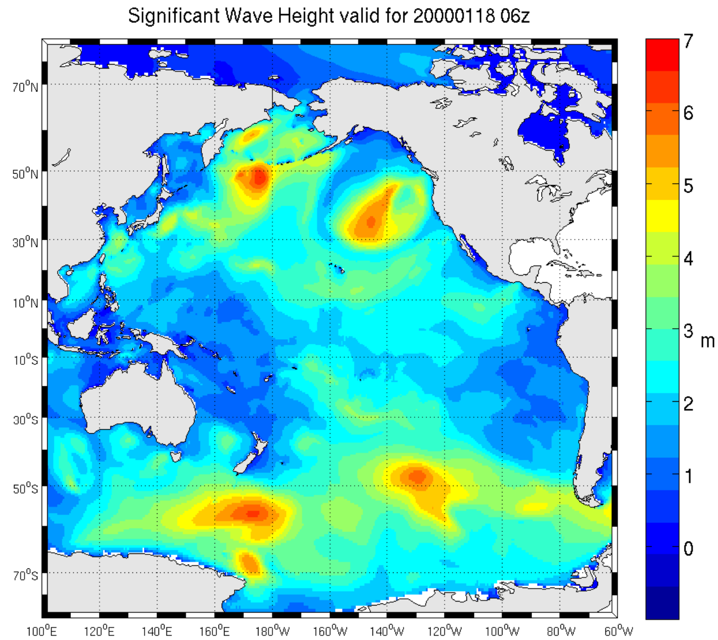

Fig. 4.1 : Model output significant wave height in meters. Note that all three grids are shown, with the coarsest resolution to the bottom of the figure, and the highest resolution along the Alaskan coast.

Output was requested in two ways: as a field, and as point output at specific buoy locations. Requesting point output basically asks the model to interpolate the wave spectra at the specified buoy locations and from that construct the wave parameters, which is different than interpolating the field output to those locations.

As an example of the output produced by the model, the significant wave heights are presented in Figure 4.1. First the output wave height for the lowest resolution grid is plotted for the entire basin, with the intermediate and coastal grid areas masked out. Then the intermediate grid wave height is plotted, and then the coastal wave height. Note that the 1/2 degree resolution patchiness is visible to the left of the figure, but that close to the Alaskan shore where the resolution is 1/16 x 1/8 degree the image is very smooth. Also note the effect of small islands on the wave propagation. For example, the Aleutian islands show how the wave energy is blocked by the islands. The same effect is seen in the center of the basin, between $30^o S$ to $10^o N$ and $170^o W$ to $140^o W$. Here the islands are too small to be resolved at 1/2 degree, but the obstruction grid still accounts for their presence.

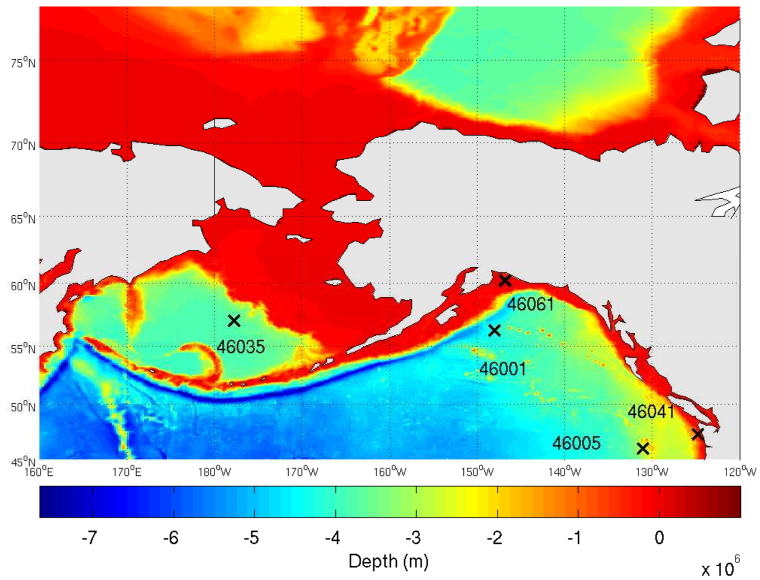

Fig. 5.1 : Locations of the test buoys.

5 Point output versus nearest grid point

Model results are routinely validated against buoy data, and a sample of five buoys was chosen along the coasts of Alaska and Vancouver Island (Figure 5.1) to illustrate this. The latitude, longitude, and depth of their positions was compiled from the National Data Buoy Center (NDBC) website. In order to see if point output would be necessary (versus using the nearest grid point from field output), wave height and wind speeds from the NDBC historic data and the the model point output and nearest grid point were compared. Which spatial grid is used depends on the location of the buoys. For example, coastal buoys are plotted on the 1/16 x 1/8 degree resolution grid, but because of the coastal mask buoys more than 250 km offshore are plotted on the 1/8 x 1/4 degree grid. In some cases the distance between the buoy locations and the nearest grid point is greater than 5 kilometers. Of the five buoys chosen, only one (Buoy 46041) falls on the highest resolution grid. For this report, the results from only the two shallowest buoys will be presented: Buoy 46041 and Buoy 46061.

Figure 5.2 shows the time series of wind speeds and wave heights for the shallow water Buoy 46041 using the Global Reanalysis winds, the results using the NWW3 winds, and the results using the CFSRR winds. Historic NDBC data for the buoy is plotted in a solid blue line, with model output at the nearest grid point plotted in a solid red line, with point output in a dotted black line. The agreement between the model output and the historical NDBC data improves dramatically with the use of the higher resolution (NWW3 and CFSRR) winds.

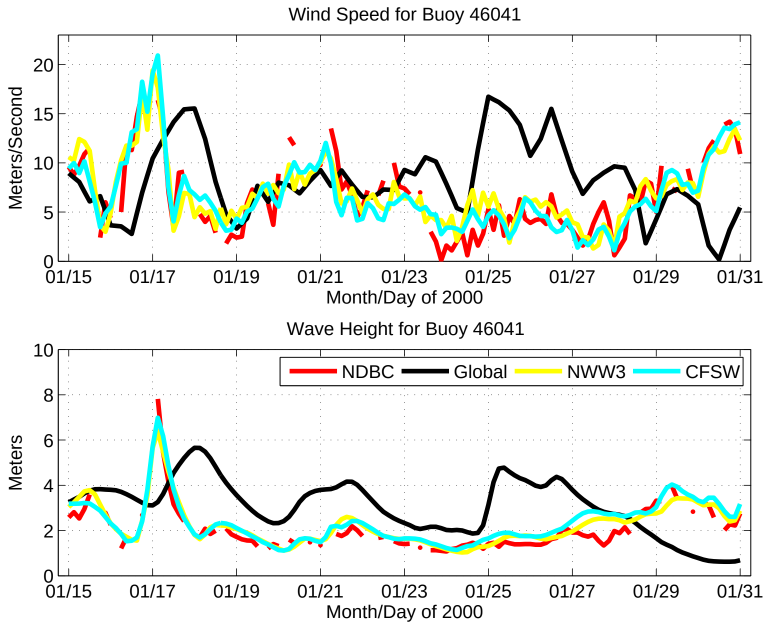

Fig. 5.2 : WAVEWATCH III® run with different wind products: output wind speed (m/s) and wave height (m) for shallow water buoy 46041.

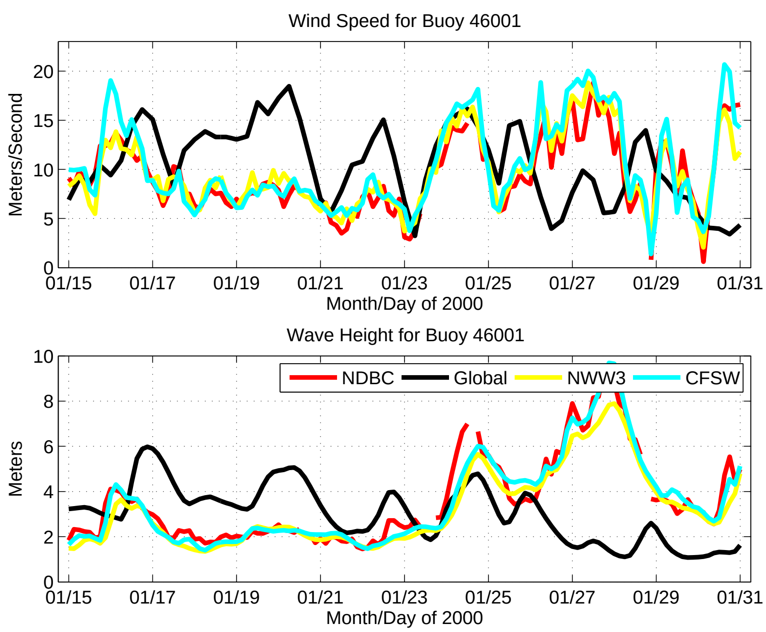

Fig. 5.3 : WAVEWATCH III® run with different wind products: output wind speed (m/s) and wave height (m) for deep water buoy 46001.

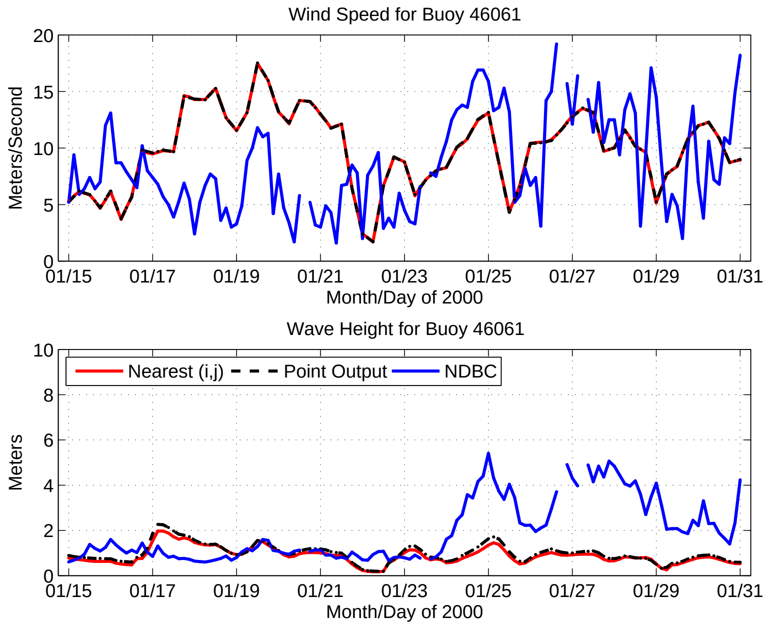

Fig. 5.4 : WAVEWATCH III® run with Global Reanalysis winds: output wind speed (m/s) and wave height (m) for shallow water buoy 46061.

Ocean depth is a very important variable when dealing with wave heights, especially in shallow water (say less than 200 meters depth). The two buoys presented here are in this range. The difference between the NDBC depth for the buoy and the model bathymetry interpolated for the buoy location must also be taken into account. For example, Buoy 46041 is reported to be in 132 meters depth but the model depth for it's point output is 401.5 meters. The difference for Buoy 46061 is even more important, since it's reported to be in 204 meters depth but it's model depth is 19.9 meters. This difference in depth is reflected in the difference of wave height for the point output versus that for the nearest grid point (Figure 5.5). Note the divergence of the red (nearest grid point) and dotted black (point output) lines - the difference is due to the very shallow depth of the buoy in the model.

In general, differences in the wind speed at point output and nearest grid point are small, with most around 0.1 m/s (Figure 5.6), which ranges from 2% to 5% of the total wind speed for these buoys. The differences in wave height are even smaller (Figure 5.7), with most less than three centimeters in wave heights of around 3 meters. The biggest difference occurs in Buoy 46061 which is in the shallowest water, and is about 10% of the total wave height.

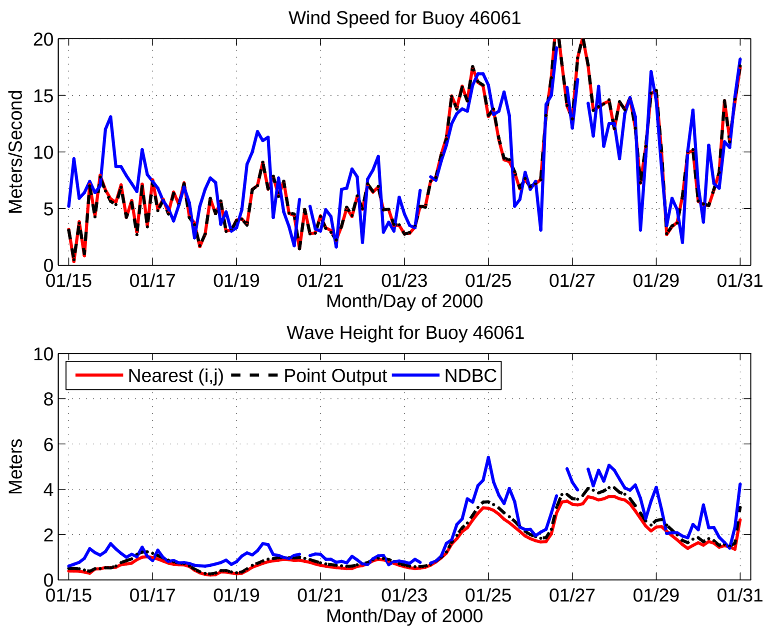

Fig. 5.5 : WAVEWATCH III® run with NWW3 winds: output wind speed (m/s) and wave height (m) for shallow water buoy 46061.

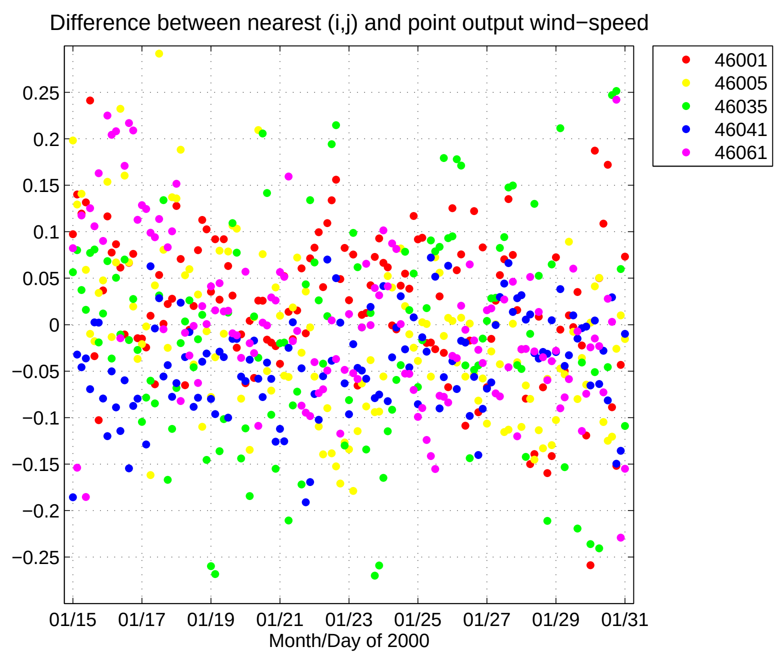

Fig. 5.6 : WAVEWATCH III® run with NWW3 winds: Difference between the model output wind speed in m/s at the buoy locations (point output) versus the nearest grid point (field output).

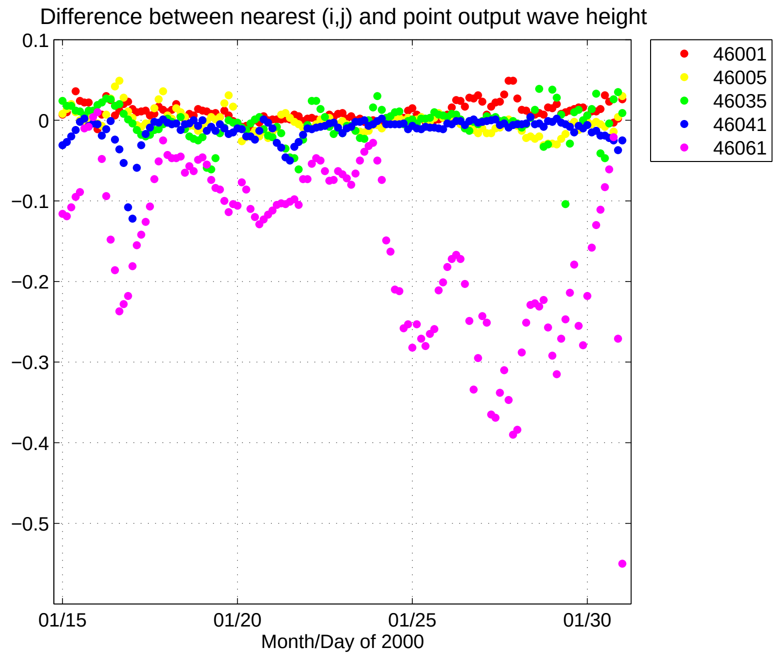

Fig. 5.7 : WAVEWATCH III® run with NWW3 winds: Difference between the model output significant wave height in meters at the buoy locations (point output) versus the nearest grid point (field output).

6 Conclusions and outlook

Some initial results are presented for a nested wave model setup to produce coastal wind wave data for Alaska. A set of three grids was developed for the new multi-grid wave model driver of WAVEWATCH III®. Test results presented here indicate that the multi-grid approach indeed results in a seamless wave field solution with increasing resolution for the Alaskan coast. The resolution of the coastal grid is approximately 7km. This resolution appears sufficient to to accurately define a grid of offshore grid point on the continental shelf that can be used to generate offshore wave climatologies and to generate offshore boundary conditions for coastal wave models. When results of a wave model based on this set of three grids are validated with coastal wave observations with buoy data, the local resolution of the grid may not be sufficient to resolve the local depth at the buoy accurately (see buoy 46061 in Fig. 5.7). Validation data should therefore be generated with the point output option in the wave model. With this option, spectral data are generated at the actual location of the buoy. For the operational wave models at NCEP, the more realistic description of the local depth thus incurred were also found to produce better validation result for coastal buoys in shallow water with large and poorly resolved gradients in the bathymetry (see Tolman, 2002a, section6).

It has been well known for decades that the key to accurate wave modeling is the availability of accurate wind fields, and this is again confirmed here. Whereas the Global Reanalysis winds serve the purpose of providing a homogeneous product over the entire reanalysis period, the resolution in space and time is insufficient to capture individual storm events accurately. This is illustrated in Section 3. The North Atlantic Regional Reanalysis (NARR) provides higher resolution wind data near the coast, and can be blended with the Global Reanalysis to improve the forcing of the wave model. However, this does not improve the forcing in the Pacific Basin, where much of the swell energy striking the southern Alaskan coast is generated. Without a significant effort to enhance the description of individual storm systems in the reanalysis, it is expected that a wave model climatology based on these wind fields will have a severely limited accuracy and value.

Much higher quality wind fields are obtained from the NOAA WAVEWATCH III® (NWW3) wind archive. This archive covers the period of January 1997 to the present, and represents the operationally produced high-resolution global analysis wind fields from NCEP. These wind fields are available at a spatial resolution of $1{\times}1.25°$. and a temporal resolution of 3h. As shown in Section 3, these winds are of much higher quality that the reanalysis winds. However, they represent a continuous evolution of analysis and forecast technology. This makes the data set inhomogeneous and not suitable for producing climatologies. Nevertheless, this data set can be used to assess the potential accuracy of the wave model on the set of grids considered here with state-of-the-art wind fields.

Presently ongoing at NCEP is the Climate Forecast System Reanalysis and Reforecast Project (CFSRR, see web site[1] for details). This reanalysis considers a coupled atmosphere-ocean model. Most importantly, the atmospheric model represents the present operational Global Forecasts System (GFS) of NCEP, including its present operational resolution (T382 or approximately 35km). This reanalysis is intended to provide hourly surface wind fields at 0.5° spatial resolution from 1979 to the present, that are expected to be of equal or greater quality to the NWW3 winds as shown by the example of this study. However, the reanalysis will consider a much larger period (30 years compared to 10 years), and will represent a statistically homogeneous data set for the entire period. Hence, this data set appears to be the ideal wind forcing to base a wave climatology upon. Furthermore, in the context of the CFSRR, a 30 year daily ice analysis on a 0.5° resolution spatial grid is available. Obviously, a consistent ice analysis for the northern Alaskan Waters is crucial to address trends in wave climatology related to rends in ice coverage. The ice products for the CFSRR are presently available. The wind products are expected to be available in the Fall of 2010.

Considering the above, we propose the following plan of action to provide a wave data base of coastal spectral wave data to be the basis for Alaskan wave climatology studies and to provide boundary data for higher resolution coastal

[1] http://cfs.ncep.noaa.gov and click CFSRR link.

wave modeling studies.

1) Use NWW3 winds and ice data to do initial validation of the three-grid wave model system against NDBC buoy data, and possibly against archived altimeter data.

2) Use NWW3 winds and ice data to set up the spectral wave data base and produce an initial test data set from 1997 to the present based on these data.

3) When available, process CFSRR wind and ice data to provide forcing from 1979 to the present. Then use these forcing data to produce a 30 year archive of Alaskan near-coastal spectral wave data for climatology studies and forcing of near-shore wave hindcast studies.

Other issues to be considered are:

1) Presently, all test of this wave modeling system are set up and run at NCEP. The resulting spectral wave archive is tentatively scheduled to reside in Alaska at the regional super computing center. Transition of the codes, grids and model forcing to this center should be considered so that the archive can be generated locally in Alaska. This would also allow the easier adaptation of the archive to evolving local needs (new output points, new forcing).

2) The hindcast system could be converted to a semi-operational forecasts system to be run in Alaska with real time wind and ice forcing from NCEP. Such a set-up would allow much more flexibility to experiment with local wave models in Alaska, when compared to having such models being dependent on the central global operational wave models at NCEP.

3) The CFSRR will not stop running after the initial project is finished, but will keep adding near real time results to its archives. A mechanism should be designed to keep updating the Alaskan spectral wave data archive likewise.

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