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Technical Note

Global Bathymetry Validation Study[†].

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Abstract

A comparison of two global bathymetric data sets (2' resolution) has been carried out to determine which of the two data sets are most appropriate for application with the spectral wave model (WAVEWATCH III). The comparison has been limited to bathymetric depths that are important for short wave transformations. Bathymetric data from several different sources have been used to validate the two different global data sets. The comparisons have been limited to areas where other sources of bathymetric data were available, namely, the United States coastal region, the Bahamas and the French Polynesian islands in the South Pacific. In general the ETOPO2 data set compared better over the shelf, while the DBDB2 data set represented the coast lines much better. Differences between ETOPO2 and DBDB2 were also seen in the shelf regions of other parts of the world, but in the absence of any independent bathymetry data, no conclusions on which of the two data sets better represent the bathymetry for these regions have been made. Since coastal bathymetry significantly impacts wave transformations, it is recommended to use the ETOPO2 data set for wave propagation applications.

Acknowledgments. The authors would like to thank Dr. Fabrice Ardhuin at the Service Hydrographique et Oceanographique de la Marine (SHOM) for providing us with bathymetric data around the French Polynesian islands. We also thank Chris Chamberlin at the NOAA Center for Tsunami Research at the Pacific Marine and Engineering Laboratory (PMEL) in Seattle for providing us with high resolution bathymetry in Alaska. This report is available as a pdf file from

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

Contents

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1 Introduction

Developing a grid for WAVEWATCH III − a spectral wave model (Tolman, 2002) − for a specific region can be a daunting task, particularly if unresolved coastal features are represented by sub-grid scale obstructions. With the development of the multi-grid nested version of the WAVEWATCH III model (Tolman, 2006) an application of the model may require developing a number of consistent grids at different resolutions. However, many of the operations required in developing a computational grid can be automated. Our aim is to develop an automated grid generation package that can be used to generate the computational grid of the desired resolution, as well as an unresolved land mass obstruction grid. The development of this software package will be documented in a separate manuscript.

As a first step towards designing an automated grid generation package for WAVEWATCH III, we need a high resolution base bathymetric data set from which the computational grids can be derived. The requirements for this set are that it should cover the entire globe (for developing global as well as regional grids), be accurate in areas where the waves can feel the bottom (typically depths less than 300 m), and depict the coastlines accurately. Topography information is only important for applications with wave inundation, and even then the region of interest is rarely greater than 20m above MSL (mean sea level). Marks and Smith (2006) carried out a comparison of six publicly available global grids using the Woodlark basin (North East of Australia) as the benchmark test case. However, the water depths in this region were too deep for bathymetric differences to have a major impact for wave applications. Furthermore, for the region they considered the comparison essentially reduced to grids that were derived from the Smith and Sandwell (1997) data set vs those that were not. Since the two global bathymetric sets that we are interested in use the Smith and Sandwell (1997) data set in this region, the conclusions from their study do not apply for the applications that we are interested in.

In this report we compare two global bathymetry/topography data sets to determine which one of the two (or a combination of the two) would best serve as a base reference grid for developing computational grids for WAVEWATCH III. The bathymetric comparisons have been done keeping wave applications in mind and have thus been limited to depths between 20 m above and 500 m below MSL. Particular attention is also placed on proper representation of large scale shoals and canyons which can have strong impacts on wave refraction processes, as well as swell blocking island chains which play a very crucial role in sub-grid level wave obstruction. The focus of our study is in the coastal regions of United States as well as the island chains of French Polynesia (in the Pacific) and Bahamas (in the Atlantic).

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2 Global Grids and Reference data sets

Two separate base global grids are compared in this report − Naval Research Laboratory's Digital Bathymetry Data Base 2-minute resolution v 3.0 (**NRL DBDB2**, NRL 2006) and National Geophysical Data Center's 2-minute global relief data (**ETOPO2**, NGDC 2006a). Both data sets contain bathymetric and topographic information for the globe on a 2 minute grid resolution. Detailed information about the sources of the two data sets can be found in their respective websites and will not be reproduced here. The two data sets have been developed independently though they share some of the same data sources such as Smith and Sandwell (1997), Jakobsson et al. (2005) and NGDC (2006c).

To compare these two data sets we have obtained independent bathymetric data from several sources. The National Data Buoy Center (NDBC) provides bathymetric information at the locations where it deploys observational buoys. A significant number of these buoys are deployed in the continental shelf along the US coastline where the water depth is shallow enough to influence wave propagation. The advantage of using the data is that it helps us to compare bathymetric information at the locations where wave data are available for wave model validation as well. The disadvantage is that it does not provide us with any spatial bathymetric information. Spatial bathymetric information for the US coast lines are obtained from several different sources. The first is NGDC's Coastal Relief Model NGDC (2006b). This model provides bathymetric information on a 3-sec resolution and is based on bathymetry data obtained from several different sources. More detailed information can be obtained from the website. The second source is unpublished bathymetric data obtained from the NOAA Center for Tsunami Research at the Pacific Marine and Engineering Laboratory. The center develops high resolution bathymetric grids primarily for tsunami models and has provided these grids for us to compare with the global grids. Bathymetric data for the Bahamas in the form of digitized contour shape files have been obtained from the International Bathymetric Chart of the Caribbean Sea and the Gulf of Mexico (IBCCA). We have also received hydrographic data for the French Polynesian islands from Dr. Fabrice Ardhuin at the Service Hydrographique et Oceanographique de la Marine (SHOM). Finally, we use on line digital navigational charts from NOAA as a secondary source for verifying bathymetry.

Apart from the bathymetric data a global self-consistent hierarchical high-resolution shoreline (**GSHHS**) database (Wessel and Smith, 1996) has been used to compare how well the coastal boundaries are represented in the two global grids. This is particularly important for representing many of the islands in the Pacific and Atlantic Oceans.

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3 Validation

A thorough validation of these two data sets is beyond the scope of this report, and the validation study is limited to the current regions of interest for WAVE-WATCH III – namely, the United States coastal region (including Hawaii and Alaska), the Caribbean islands in the Atlantic Ocean and the French Polynesian islands in the Pacific. The latter area is of interest to NCEP as it blocks wave propagation from the Southern Pacific to the US west coast selectively.

3.1 NDBC Buoys

Bathymetric data from the moored NDBC buoys and the two global grids are compared in Fig 3.1. The top figure shows the bathymetry from three different sources and the bottom plot shows the corresponding error percentage. The buoys are moored at several different locations along the US West and East coast and only those buoys have been used which are in shallow waters (with a few exceptions). The error percentage indicates that overall the DBDB2 data set does a better job at the buoys, and some of the highest percentage errors occur in shallow water depths, which is to be expected. Fig 3.2 plots the bathymetry errors based on the buoy locations. Overall the two grids seem to do well along the US East Coast (with one exception). The Alaskan coastline, US West Coast and the US Gulf coast show some errors which will be looked at in greater detail in the following sections.

3.2 Hawaiian Islands

Bathymetric comparisons around the islands of Hawaii was done using the 3 sec coastal relief model as the ground truth. Major differences between ETOPO2 and the DBDB2 grids were found around the island of Molokai (see Fig 3.3). Also plotted in the figures are the coastlines from the corresponding grids as well as the coastline from the GSHHS database to compare how well the global grids represent the coastal features. While ETOPO2 shows a shallow ridge to the south-west of Molokai and the deeper channel between the islands of Molokai and Maui, these features are absent in the DBDB2 bathymetry. The features are also present in the high resolution grid and correspond very well with the ETOPO2 grid. Since both the ETOPO2 bathymetry and the high resolution CRM data are obtained from the National Geophysical Data Center, there was some concern that some inherent biases may have crept into both these bathymetric data sets. As an independent data source, we also used the NOAA navigational charts (Fig 3.4). The features seen in the ETOPO2 and CRM bathymetry are also seen in the navigational charts (referred to as Penguin Bank and Pailolo Channel respectively) with similar bathymetric values (bathymetry data in the NOAA

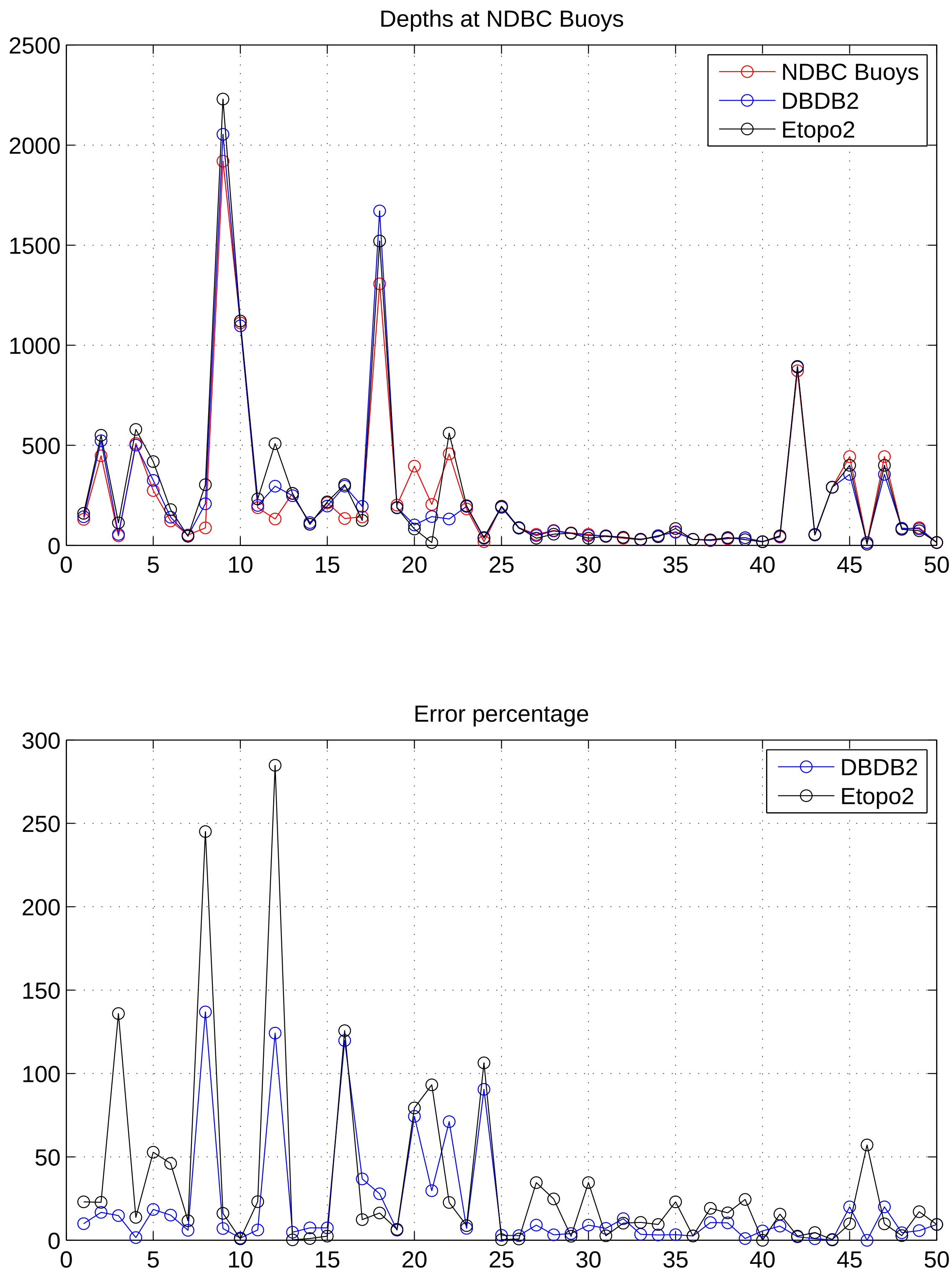


Fig. 3.1 : Bathymetric comparisons at the NDBC Buoys

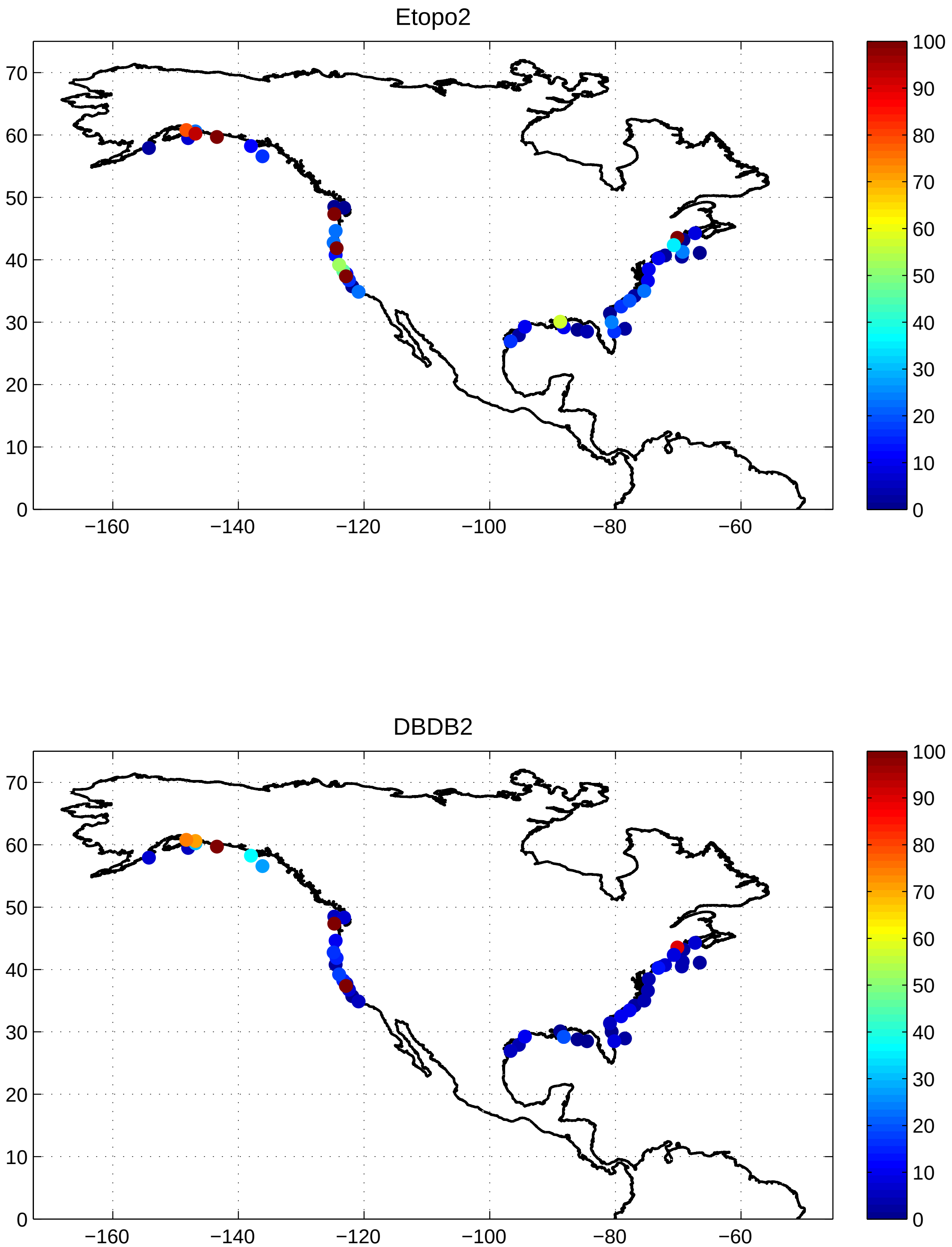


Fig. 3.2 : Bathymetric error percentages based on buoy locations

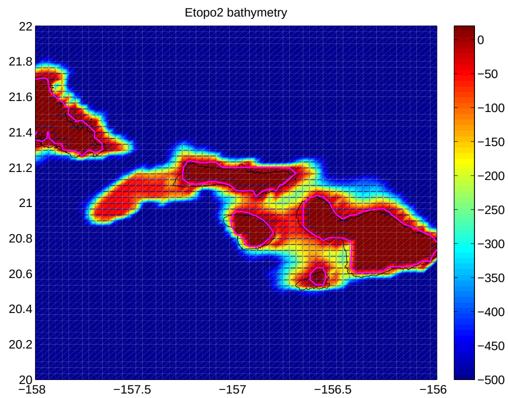
charts is given in fathoms). This increases our confidence in the validity of the ETOPO2 bathymetry for this region. The significant bathymetric differences in these shallow waters will have a significant impact on the shoaling and refraction characteristics of the waves. Thus around the islands of Hawaii, DBDB2 is not a very suitable choice to represent the bathymetry.

3.3 Alaska

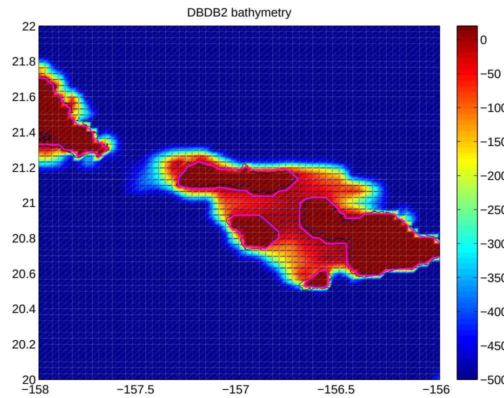
The Alaskan coastal region was the other area where significant differences between the ETOPO2 and DBDB2 data was found. The CRM data did not extend this far north and we have relied on high resolution grids provided by the NOAA Center for Tsunami Research at the Pacific Marine and Engineering Laboratory (PMEL) for validation purposes. These are unpublished grids that were developed primarily for tsunami inundation studies. They are available for two parts of Alaska − South central Alaska that includes Kodiak island and South eastern Alaska around Juneau.

Bathymetric comparisons for South Central Alaska is shown in Fig 3.5. There are two regions with prominent differences between the two global grids. The first is the area to the south of Kodiak island (the big island around $57°N$ and $154°W$) where both ETOPO2 and tsunami grids indicate the presence of shallow banks which is absent in the DBDB2 grid. The second region is to the north of the island near the entrance of the Cook inlet. Again both ETOPO2 and the tsunami grids show very similar bathymetric features that are different from the ones seen in the DBDB2 grid. In both the ETOPO2 and the tsunami grids the deeper channel extends further closer to the entrance to the Cook inlet than in the DBDB2 grid after which the depth reduces more than in the DBDB2 grid. Again, since our validation tsunami grid is unpublished data we turned to the NOAA navigational charts for a second validation. Fig 3.6 shows images from the NOAA charts. The charts confirm the existence of the banks along the southern coast of Kodiak island (referred to as the Albatross and Portlock banks) as well as the deeper channel further up into the entrance to the Cook inlet. Thus, increasing our confidence in the tsunami grid. The significant bathymetric differences in these shallow waters is again a cause for concern as they will have a significant effect on refraction processes.

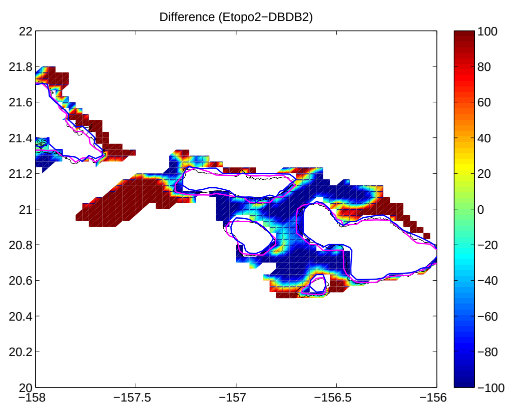
Fig 3.7 compares the bathymetric information between the two global grids for South Eastern Alaska. This is the other area in Alaska where there are significant differences between the ETOPO2 and DBDB2 grids. Just like in the case of South Central Alaska, the tsunami grid representation corresponds with the ETOPO2 grid representation. The two major areas of differences are in the Chattam Strait (the narrow long straight channel around $56°N$ and $134°W$) and the continental shelf to the North. Once again the NOAA nautical charts confirmed (figure not shown here) that the Chattam Strait channel is too shallow in the DBDB2 grid.



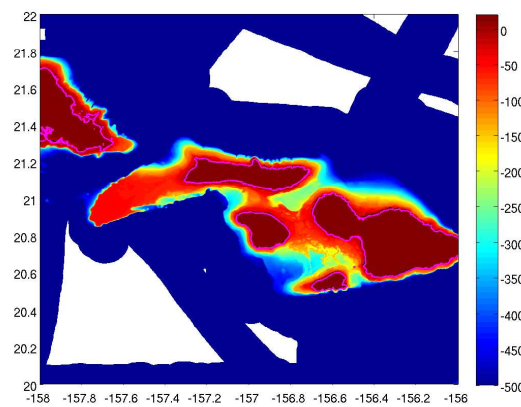
(a) *ETOPO2 Bathymetry*



(b) *DBDB2 Bathymetry*

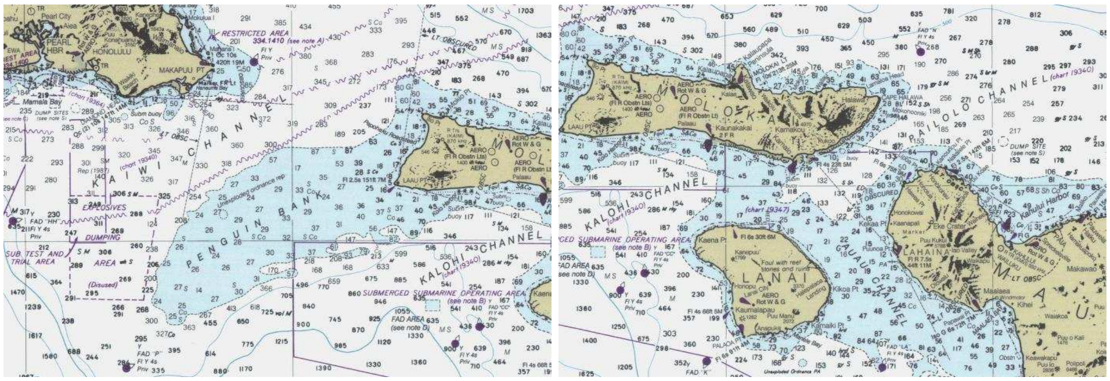


(c) *Bathymetry difference (ETOPO2 - DBDB2)*



(d) *Coastal Relief Model*

Fig. 3.3 : Bathymetric comparisons between ETOPO2 and DBDB2 around the Hawaiian islands of Oahu (top island in the figure), Molokai (second island from top), Lanai and Maui (largest island in the bottom right hand corner). In the bathymetry plots (panels a,b and d) shoreline from the respective grid is given by the magenta colored line and shoreline from the GSHHS database is given by the black line. In the bathymetry difference plot, differences are only computed between the 20 m and -500 m depths and the shorelines from ETOP02, DBDB2 and GSHHS are given by the magenta, blue and black lines respectively



(a) *Molokai – Oahu region* (b) *Molokai – Maui region*

Fig. 3.4 : NOAA navigational charts around the island of Molokai showing the existence of both the Penguin Bank and the Pailolo Channel (bathymetric values are given in fathoms)

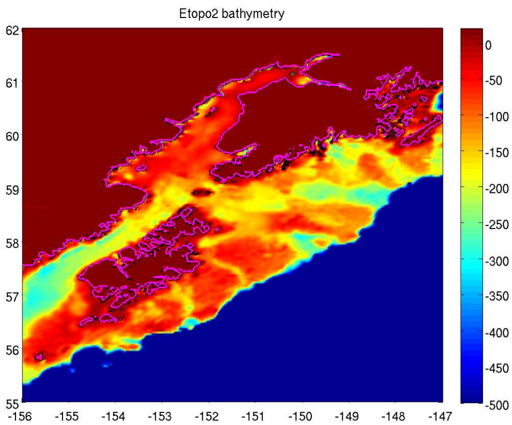
This is not critical to wave modeling as the Strait is not expected to play a very crucial role in wave propagation. But the entrance to the Strait as well as the Continental Shelf to the north are expected to play important roles in wave processes and we are better served by using the ETOPO2 grid in this region.

From an analysis of these two regions of Alaska it seems that ETOPO2 does a better job in representing the Alaskan bathymetry than DBDB2. Both do a reasonable job in representing the shoreline information.

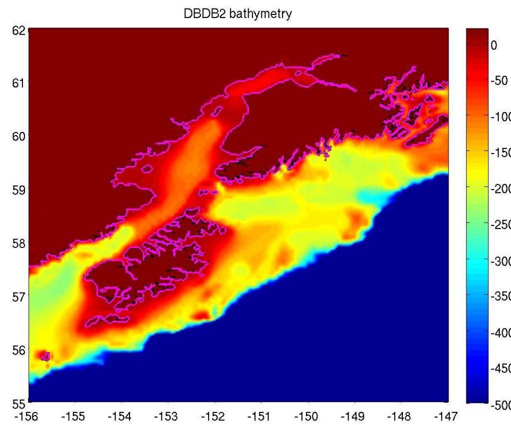
3.4 US Pacific Northwest

From the comparisons with NDBC buoys (Fig 3.1) the other regions along the US coastline where there are bathymetric differences are the Pacific Northwest coastline, along the California coast, and isolated spots along the Gulf coast and the US East coast. Of these only the Pacific Northwest region shows any significant spatial features. CRM data for this region is available and is used as reference data for validation.

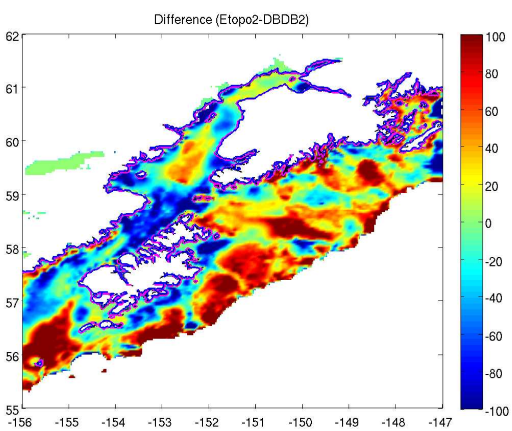
Figs 3.8 shows the bathymetric information for the different grids. Unlike the examples in Hawaii and Alaska, it is not clear which is the better grid here. While ETOPO2 compares better than DBDB2 in the southern part (around $45°N$) it fares worse in the northern part (around $47°N$). Also there are a number of holes and shoals in the Continental Shelf for the ETOPO2 grid that are not seen in the reference grid. In contrast the DBDB2 bathymetric data (with one exception) is fairly clean over the Continental Shelf. The coastal features at the entrance to the harbors and estuaries are also much better represented by DBDB2 and will play an important role in local scale wave modeling (though not so much in



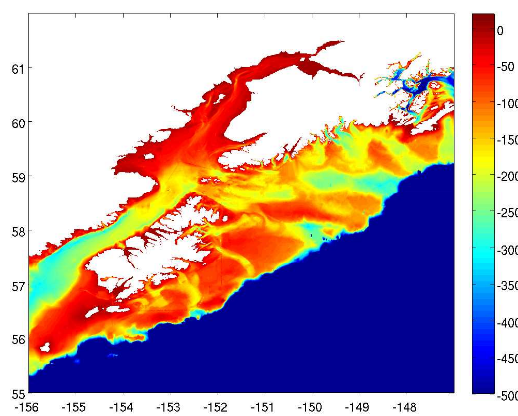
(a) *ETOPO2 Bathymetry*



(b) *DBDB2 Bathymetry*

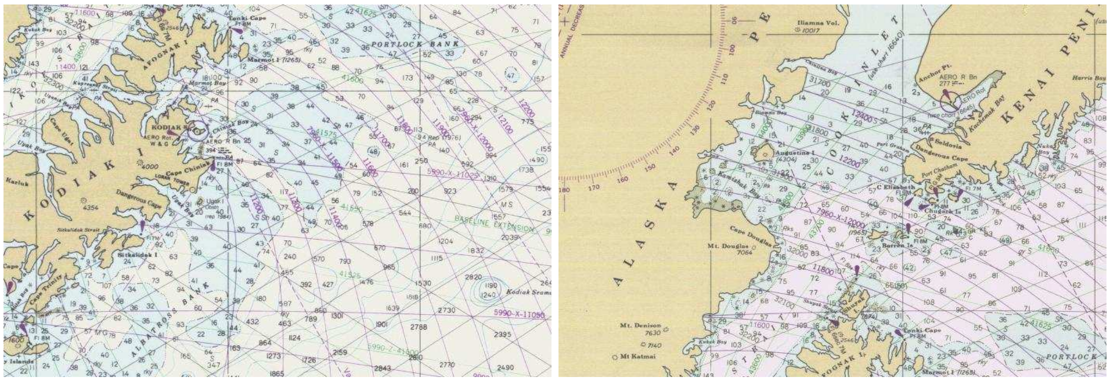


(c) *Bathymetry difference (ETOPO2 - DBDB2)*



(d) *PMEL Tsunami grid*

Fig. 3.5 : Bathymetric comparisons between ETOPO2 and DBDB2 around South Central Alaska (see caption for Fig 3.3 for detailed explanation).



(a) *Kodiak Island* (b) *Cook Inlet*

Fig. 3.6 : Nautical charts for the region around Kodiak island and the entrance to Cook inlet (depth values are in fathoms)

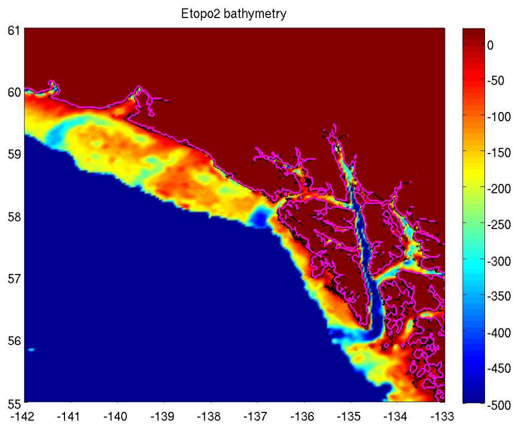
larger scale modeling as wave propagation into local harbors and estuaries is not of vital importance).

3.5 Islands

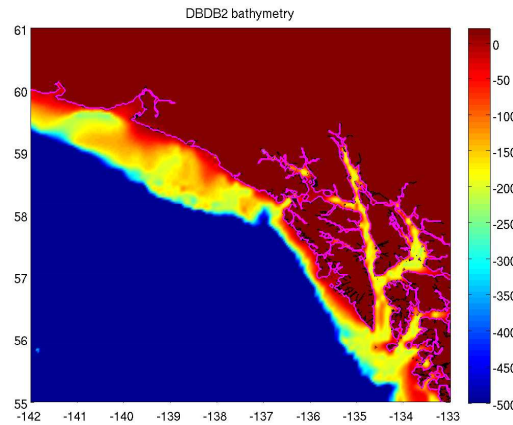
The ability to accurately represent smaller scale coastal features becomes more important with islands in the swell propagation direction as they can effectively block ocean swells (Tolman, 2003). With that in mind comparisons between the two global grids have also been done for the Bahamas in the Atlantic Ocean and the French Polynesian island chains of Marquesas and Tuamotu in the Pacific Ocean.

In the Caribbean the main difference between the ETOPO2 and DBDB2 bathymetries was in a region called the Greater Bahama Bank, which extends between Cuba and the Bahama island chain to the Northwest (Fig 3.9). While the ETOPO2 grid shows regions with fairly deep water inside the bank, the DBDB2 grid shows the bathymetry to be relatively shallow in the whole bank. Digital contour plots (obtained from the IBCCA) show the bank to be relatively shallow, in line with the observations in the DBDB2 grid (Fig 3.10). For most larger scale processes these differences in bathymetry would not be important as most of the wave action would be blocked by the outer Bahama island chains. However, for studies where detailed wave propagation through the Bahamas is important then the DBDB2 grid should be used. Comparing the coastline information with the GSHHS data base it is very obvious that DBDB2 does a better job in representing the different island chains than ETOPO2, which either badly misrepresents the islands or entirely misses them.

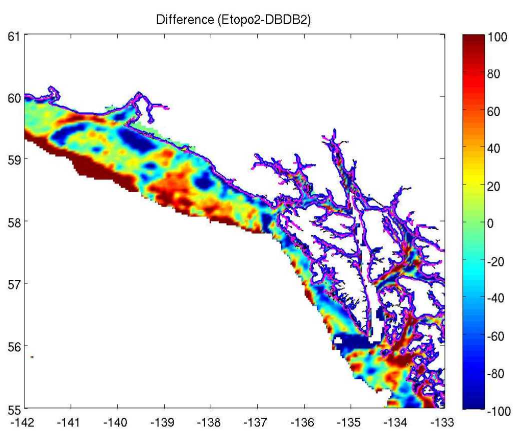
In the Pacific Ocean, bathymetric comparisons have been done for the French



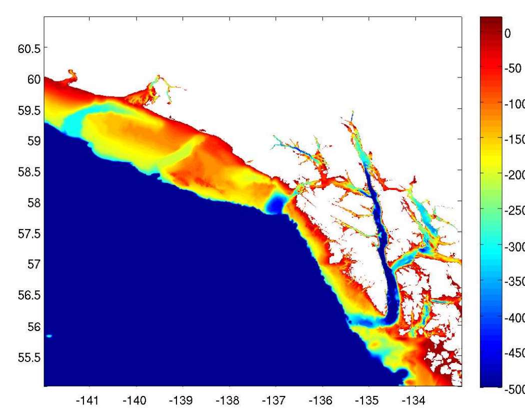
(a) *ETOPO2 Bathymetry*



(b) *DBDB2 Bathymetry*

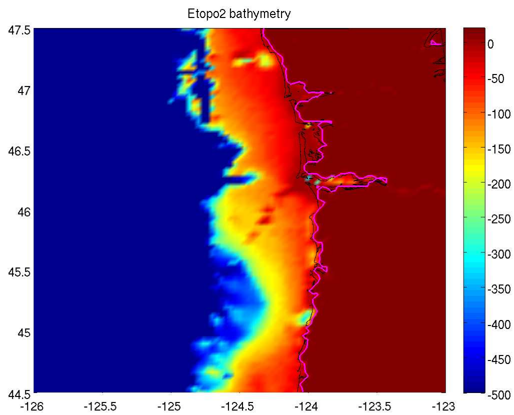


(c) *Bathymetry difference (ETOPO2 - DBDB2)*

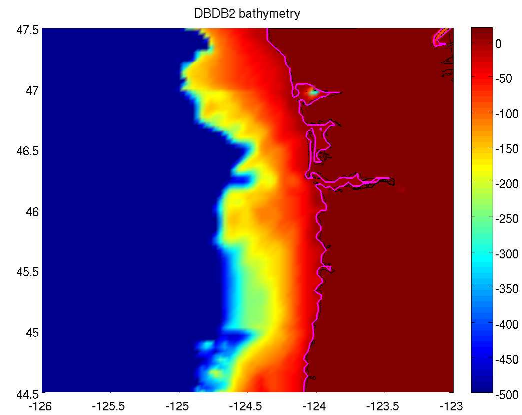


(d) *PMEL Tsunami grid*

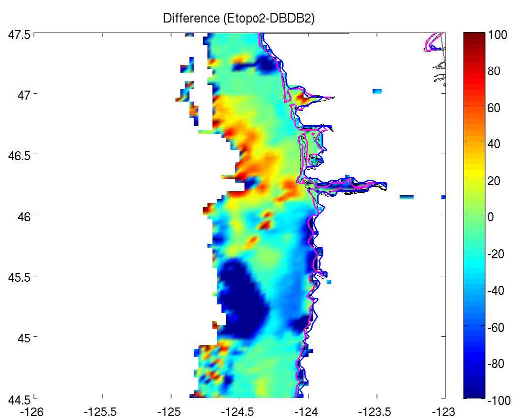
Fig. 3.7 : Bathymetric comparisons between ETOPO2 and DBDB2 around South East Alaska (see caption for Fig 3.3 for detailed explanation).



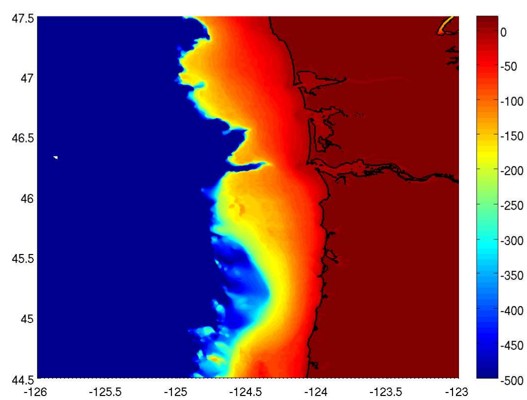
(a) *ETOPO2 Bathymetry*



(b) *DBDB2 Bathymetry*

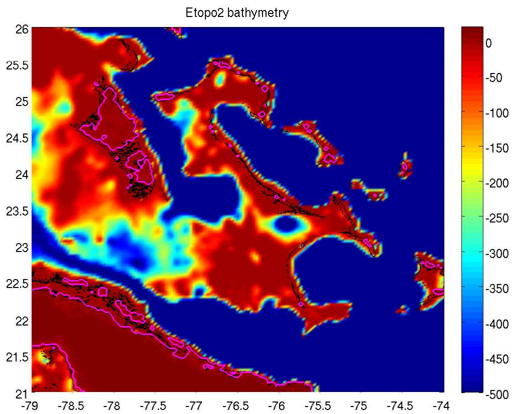


(c) *Bathymetry difference (ETOPO2 - DBDB2)*

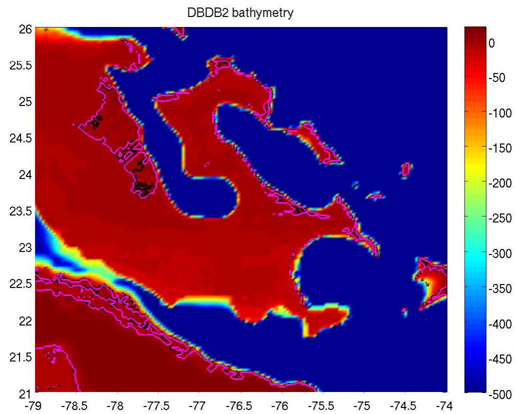


(d) *Coastal Relief Model*

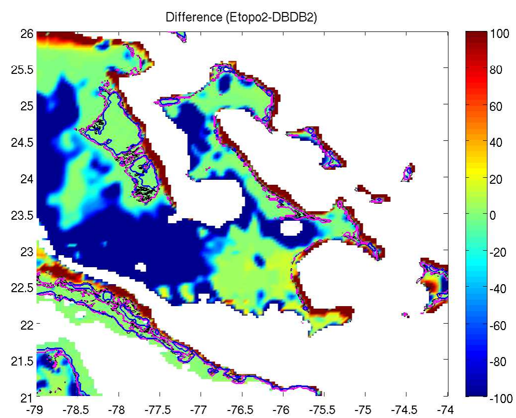
Fig. 3.8 : Bathymetric differences between the ETOPO2 and DBDB2 grid around the Pacific Northwest



(a) *ETOPO2 Bathymetry*



(b) *DBDB2 Bathymetry*

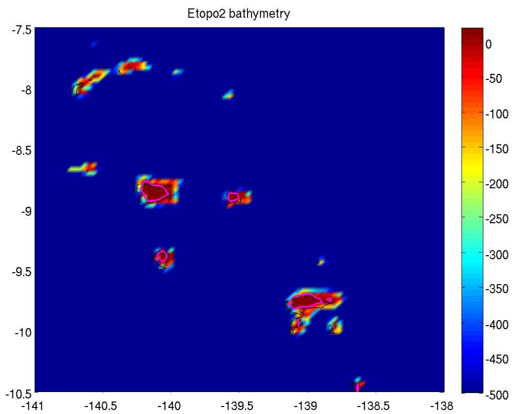


(c) *Bathymetry difference (ETOPO2 - DBDB2)*

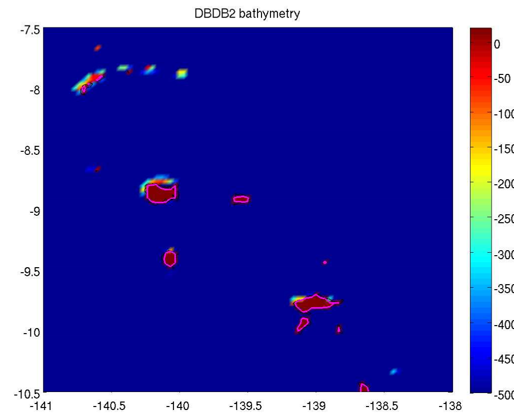
Fig. 3.9 : Bathymetric differences between ETOPO2 and DBDB2 in the Bahamas. Biggest difference seen in the Greater Bahama Bank between the island of Cuba in the South West corner of each panel and the Bahama island chain to the North West.

Fig. 3.10 : Digital contour plot of the Greater Bahamas Bank from the International Bathymetric Chart of the Caribbean Sea and the Gulf of Mexico

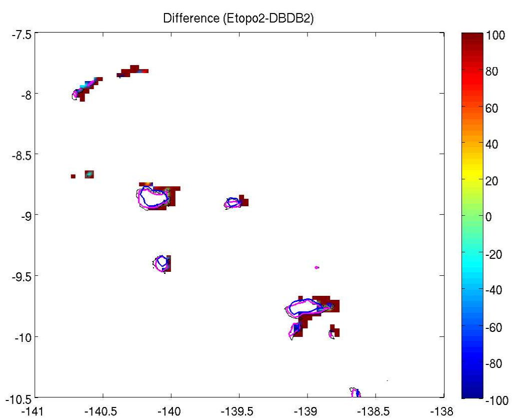
Polynesian island chains of Marquesas and Tuamotu (Figs 3.11 and 3.12). Validation data was made available to us from Dr. Fabrice Ardhuin at the Service Hydrographique et Oceanographique de la Marine (SHOM). Most of the water depth in this region is fairly deep to have any major impact on wave transformation, and considerable regions of shallow water are not represented in the validation data set. From the limited available data set we can see that ETOPO2 does a better job in representing the bathymetry than DBDB2 in both the cases. However, when it comes to representing the islands (from the coast line data), DBDB2 data set does a much better job. The French Polynesian island chains act as effective barriers for swell propagation and hence a proper representation of the islands is important. In this respect we find that DBDB2 works better than ETOPO2, which is unable to represent most of the island chains, particularly for Tuamotu. However, even though DBDB2 works better, it still cannot represent the island chain of Tuamotu very well, which is crucial to accurately represent wave obstruction effects. Added to that DBDB2 is unable to reproduce some of the shelves seen around the island chains. Thus, if the GSHHS database is directly used to represent the coastal boundaries it would be better to rely on the ETOPO2 grid to determine the bathymetry for this region.



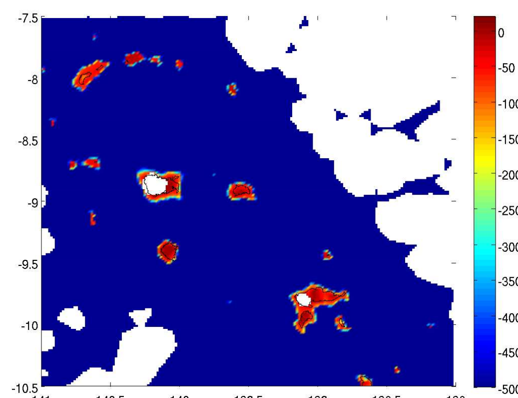
(a) *ETOPO2 Bathymetry*



(b) *DBDB2 Bathymetry*

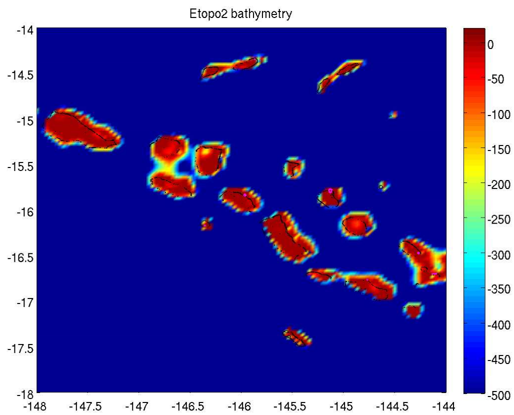


(c) *Bathymetry difference (ETOPO2 - DBDB2)*

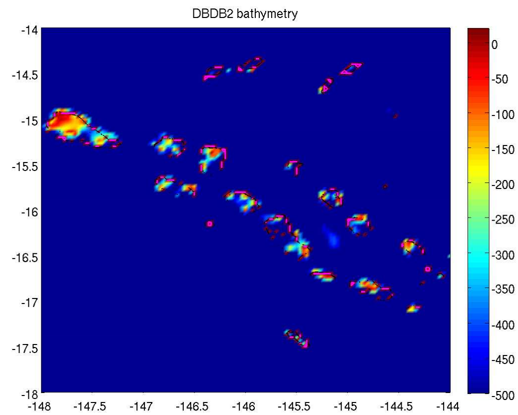


(d) *SHOM Data*

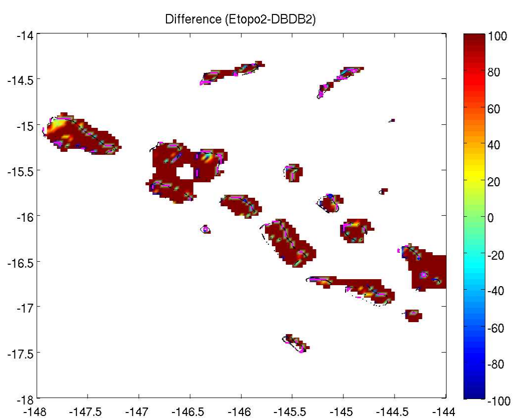
Fig. 3.11 : Bathymetry comparison for the French Polynesian island chain of Marquesas



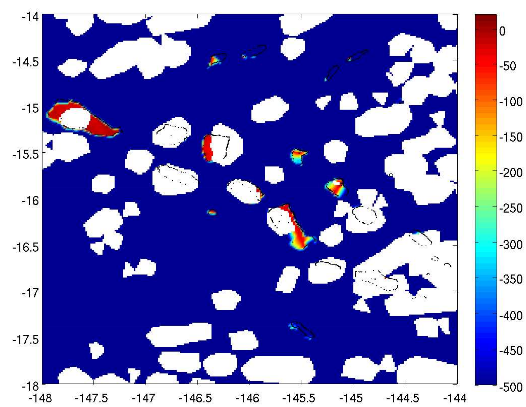
(a) *ETOPO2 Bathymetry*



(b) *DBDB2 Bathymetry*



(c) *Bathymetry difference (ETOPO2 - DBDB2)*



(d) *SHOM Data*

Fig. 3.12 : Bathymetry comparison for the French Polynesian island chain of Tuamotu

4 Conclusions

Two global bathymetric sets (ETOPO2 and DBDB2) were compared and verified with high resolution bathymetric data sets in select regions to determine which of the two bathymetric sets should be used as a base high resolution global grid for the automated grid generation software that is being designed for WAVEWATCH III. The criteria used for determining good bathymetric data sets are that they provide an accurate representation of shallow waters (depths less than 500 m) and coastal features. This study is not meant to be a thorough cataloging of the differences in the two bathymetric models, and is limited to our current regions of interest for WAVEWATCH III.

Bathymetry comparisons were made using depth information from the NDBC buoys and high resolution bathymetric information wherever available. Overall there were considerable differences between the DBDB2 and ETOPO2 data sets. DBDB2 does a better job of representing the coast line information, which plays an important role in developing an accurate sub-grid obstruction data set. Comparisons with NDBC buoy data indicate that the DBDB2 data sets have less errors than the ETOPO2 data sets, however, comparisons with high resolution bathymetry data in Hawaii and Alaska show that the DBDB2 data set clearly misses some important features over the shelf that can be critical for local wave modeling. This seeming inconsistency can be explained by the fact that the highest percentage errors at the buoy locations occur in buoys close to the coast (shallower waters), where due to a much better coastline representation DBDB2 performs better. But on the shelf it clearly seems to miss some important features. From coastline comparisons with the GSHHS database it is clear that DBDB2 provides a much better representation of the coastline, but even that fails for the smaller island chains of Tuamotu.

Based on the comparisons done in this study it seems that ETOPO2 provides better bathymetric information on the shelf while DBDB2 provides better information about the coastline. This however cannot be a general conclusion on these two sets as the region studied was very limited in scope. Differences between the two data sets have also been observed (but not shown here) along Antarctica, Southern and Eastern coast of Greenland, around Falkland and South Georgia and South Sandwich islands of the Southern Atlantic Ocean, Indian Ocean islands of Maldives, Seychelles, Lakshadweep, French Southern and Antarctic lands, Heard, McDonald and Andaman-Nicobar islands, and in the Pacific Ocean the Sea of Okhotsk, Aleutian island chain, Philippines and New Zealand. According to NRL (2006) the DBDB2 bathymetry set also includes high resolution bathymetry from other sources such as the Australian Geo sciences department's bathymetric and topographic data for Australian region and Prof. Choi's bathymetry for the region around Korea, and it is likely that in some of these areas DBDB2 will provide a better representation of the bathymetry.

Based on further validation studies it may become imperative in the near future to build a blend of these two global grids. That however is currently beyond the scope of this project. As of now it is recommended to use ETOPO2 as the base reference grid and directly use the GSHHS database to build the sub-grid obstruction data sets, since even DBDB2's enhanced coastline information is not reliable for the smaller island chains. The grid generation software will provide an option to choose either of these base grids to build the computational grids for WAVEWATCH III.

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