

**DANISH METEOROLOGICAL
INSTITUTE**

— TECHNICAL REPORT —

01-21

**Optimisation of a bathymetry
database for the North
European Shelf Seas**

Jesper Larsen and Jun She



Copenhagen 2001

ISSN 0906-897X (printed)
ISSN 1399-1388 (online)

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1 Introduction

A high quality fine resolution bathymetry data set has long been a priority for operational ocean modelers. Currently ten bathymetry data sets covering different parts of the North European Shelf Sea area are available at DMI. These data sets have different coverage, resolution, and accuracy in different areas (a detailed description follows in Section 2). Ongoing bathymetry projects have been carried out in many organizations, such as the EuroGOOS gridded bathymetry project (Nicolas Flemming, personal communication), Delft Hydraulics bathymetry investigation (Herman Gerritson, personal communication), and High Resolution Operational Model for the Baltic Sea (HIROMB) bathymetry optimization (Johan Mattson, personal communication).

During recent years of marine service we have faced a frequent demand of predictions of water levels, waves, currents etc. at very high resolution in many locations. There is therefore an increasing need for high resolution (down to several hundred meters) local models. A quick setup of this kind of models in a new region is a great asset in marine services such as navigation, search and rescue, and oil spill combating. An important premise of the new model setup is the presence of a bathymetry in the required resolution.

A database containing data sets covering the North European Shelf Seas (30W-30E and 40N-75N) has therefore been established based on existing bathymetry data at DMI (Figure 1).

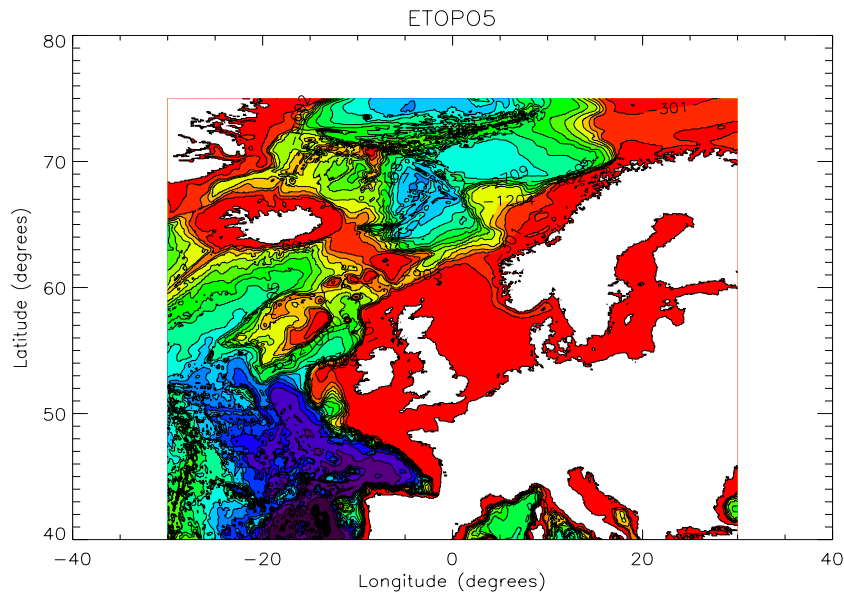


Figure 1. Database coverage: Contoured ETOPO5 bathymetry.

A software package has been developed to interpolate the data sets to a user defined spherical grid and subsequently merge the resulting interpolated data sets into a single predefined "best" bathymetry.

The data sets currently integrated into the database are described in Section 2 while the formats of the data sets are described in Section 3. In Section 4 the principles behind the interpolation algorithms and the merging procedure are described while conclusions have been drawn in Section 5. Finally, a simple example is described in Appendix A.

2 Data sets

Currently ten data sets have been assembled and integrated into the database. These are listed in the following table and shown in Figure 2. It is anticipated that more data sets will be incorporated into the database in the future.

Data set	Resolution	Coverage	Coordinate
ETOPO5	5'x5' (lon x lat)	30W-30E, 40N-75N	Spherical
WAM	5'x5' (lon x lat)	40W-30E, 45N-70N	Spherical
ETOPO2	2'x2' (lon x lat)	30W-30E, 40N-72N	Spherical
BSH-Nordsee	10'x6' (lon x lat)	4W-14E, 51N-59N	Spherical
BSH-Kuesten	1'40"x1' (lon x lat)	8E-14E, 52.5N-54N	Spherical
DYNOCS	1nm	4W-30E, 51N-60N	UTM-32
Mike21	1nm	Danish Straits	UTM-32
Mike21	1nm	Wadden Sea	UTM-32
Mike21	750m	Limfjorden	UTM-32
Mike21	1/3nm	Little Belt	UTM-32

The data sets are stored in either spherical or Universal Transverse Mercator (UTM) coordinates (Hager et al., 1989).

ETOPO5 is a global topography which has been extracted for the entire area of interest (Edwards, 1988). The operational wave model at DMI uses a version of ETOPO5 which has been improved at Skagen. This bathymetry has been denoted WAM. The ETOPO5 data set is generally of poor quality in shallow waters.

Recently another global bathymetry, ETOPO2, with an even higher resolution has become available (Smith and Sandwell, 1997). This bathymetry is based on satellite altimetry and is like ETOPO5 of poor quality in shallow waters.

Two bathymetries used in the operational German ocean general circulation model BSH-cmod have also been incorporated into the database (Kleine, 1994). The first of these covers the North Sea and the Baltic Sea areas and has a relatively coarse resolution of 10'x6' while the other covers German near-shore areas and Danish Straits with a fine resolution of 1'40"x1'.

The DYNAMics Of Connected Seas (DYNOCS) project provided a high resolution bathymetry for a large area covering the North Sea and the Baltic Sea (Weiergang, 1995). The storm surge model at DMI has applied the DYNOCS 1nm bathymetry in the Danish Straits and in the Wadden Sea. At both places the bathymetries have been successfully improved. The resulting bathymetries are denoted Mike21 (Danish Straits/Wadden Sea). Bathymetry data for Limfjorden and Little Belt has been obtained and interpolated to high resolution at DMI. These data were kindly provided by The Royal Danish Administration of Navigation and Hydrography.

Besides considering the resolution of a data set one must also check the quality. As an example here we discuss differences between the DYNOCS and the Mike21-Danish Straits bathymetries. In Figure 3 the two bathymetries have been plotted for the Danish Straits.

The quality of the Mike21 bathymetry is clearly higher than that of the DYNOCS bathymetry. For example Roskilde and Odense Fjords are much better represented

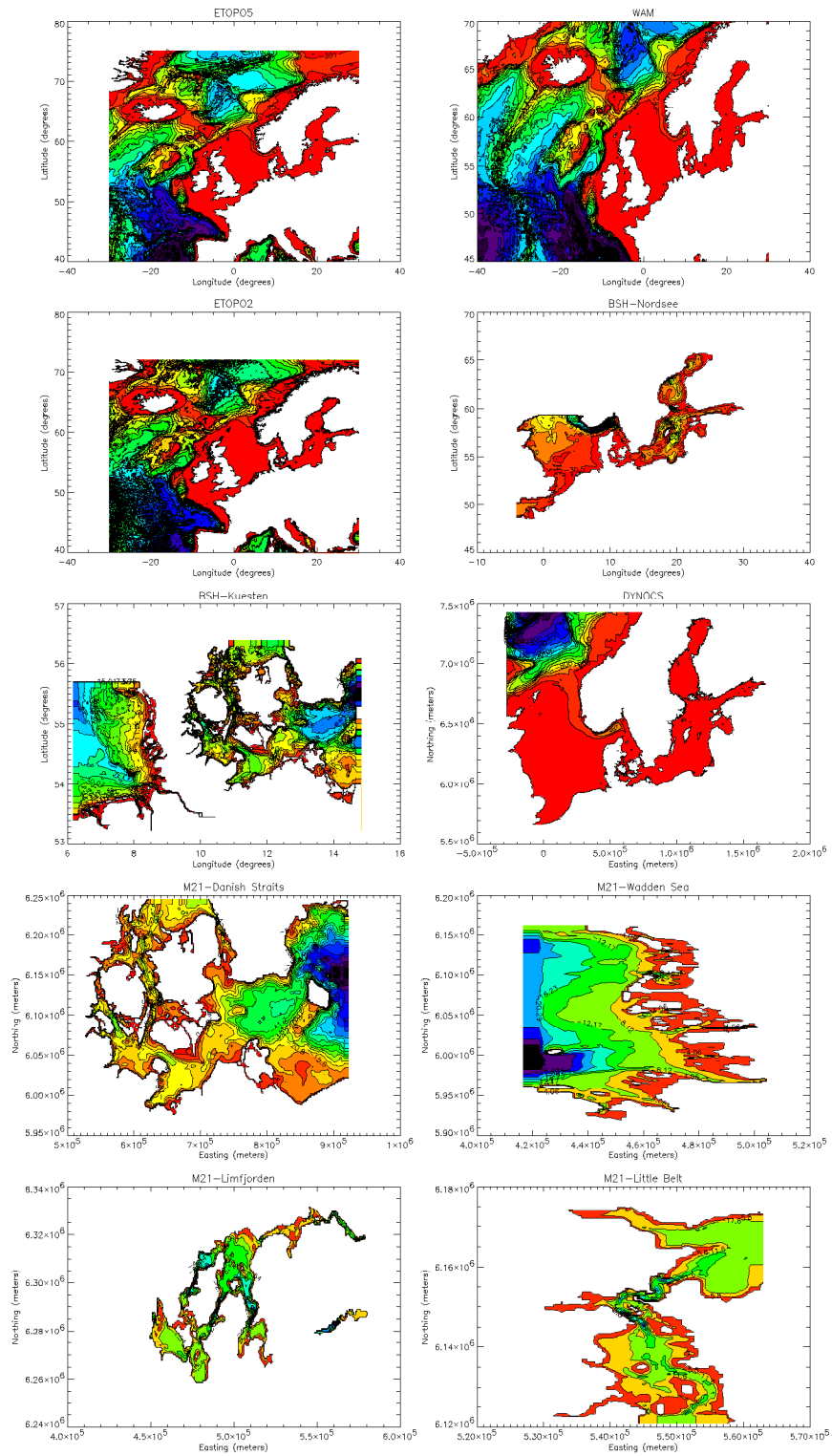


Figure 2. Bathymetries already integrated into the database. The bathymetries are (from left to right) ETOPO5, WAM, ETOPO2, BSH-Nordsee, BSH-Kuesten, DYNOCs, M21-Danish Straits, M21-Wadden Sea, M21-Limfjorden, and M21-Little Belt.

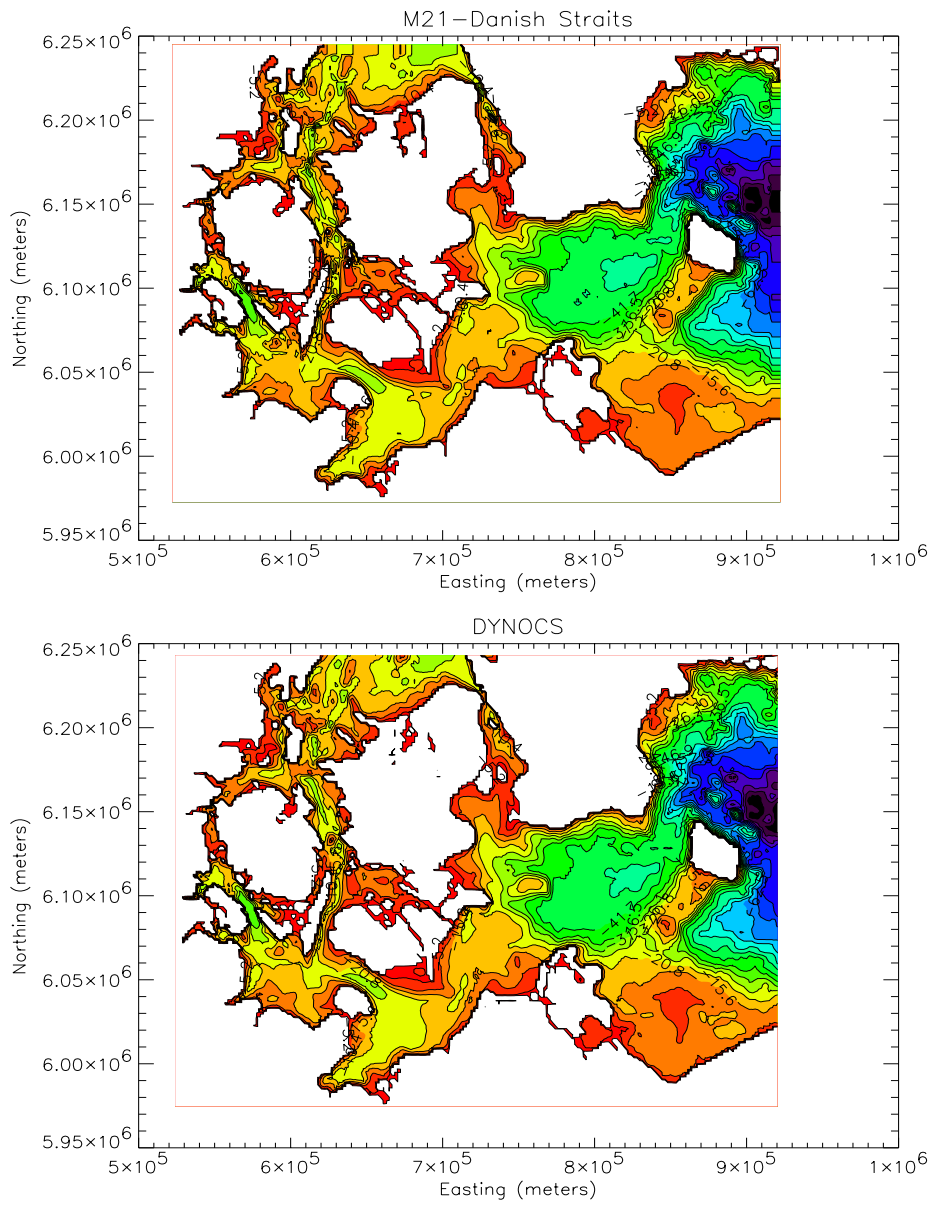


Figure 3. Top figure: Mike21-Danish Straits bathymetry. Bottom figure: DYNOCS bathymetry.

in the Mike21 bathymetry. Øresund Strait is also enlarged/improved in the Mike21 bathymetry.

3 Formats

Two data formats have been defined, one for spherical data sets and one for UTM-32 data sets. Data in spherical coordinates are in the following format (columns separated by a single space):

Longitude	Latitude	Δ lon	Δ lat	Depth	Flag
f9.4	f9.4	f6.4	f6.4	f8.2	i2

The first and second columns denote the position of the center of the grid cell in degrees longitude and latitude. The third and fourth columns contain the size of the grid cell in degrees while the depth is written in the fifth column in meters. Negative values denote grid cells points below sea level while positive values denote land grid cells. A height may not exceed 10 meters which is defined as 'true' land. The last column is a flag column which is presently not used and can be left empty. The first row of the data file contains information about the south-western most point. Following this line is data incremented in longitude primary (fastest) and latitude secondary (slowest).

For data in UTM-32 coordinates the data are stored in a similar format:

Easting	Northing	Δ E	Δ N	Depth	Flag
i8	i8	i7	i7	f8.2	i2

Here the first two columns denote the positions of the grid cells in easting and northing. Easting is measured in meters and is defined as 500.000 meters easting at 9 degrees east for the UTM-32 projection. Values higher than 500.000 meters are thus east of the 9 degrees meridian while lower values indicate positions west of the meridian. Northing is measured in meters north of the equator (for the northern hemisphere). The next two columns contain the size of the grid cells in meters while the remaining two columns are identical to those used for spherical coordinates. The data are sorted as described above for spherical coordinates with easting incremented primary and northing secondary.

3.1 Parameter file

In principle all necessary information about the data files can be obtained from the data files themselves. In practice however it can be very time consuming to extract some of this information and it is therefore included in a parameter file. In this file some additional information needed for the interpolation of new bathymetries is also included. A simple example of a parameter file is displayed below:

```
etopo5.sphere
-30.0 40.0 0.0833333 0.0833333 721 421 1
-30.0 30.0 30.0 70.0

bsh_nordsee.sphere
-4.083333333 48.5500 0.1667 0.10 207 174 2
```

```
16.0 52.0 31.0 56.0
```

```
dynocs.utm-32
```

```
-277840 5667120 1852 1852 1051 951 3
```

```
0.0 50.0 31.0 52.0
```

This reduced bathymetry database consists of three data sets only, namely ETOPO5, BSH-Nordsee, and DYNOCs. Parameter values for each data set are separated by an empty line. The first line for each data set contains the name of the input data file (the extension is used to identify which coordinate system is used in the data file). In the second line information about the data set is written while the following line(s) contain information used to determine where to use the bathymetry in the interpolation.

The first two values in the second line define the coordinates of the origin of the data set (lower-left corner) while the third and fourth values hold the grid size. Depending on the coordinate system used in the data set either degrees (spherical coordinates) or meters (UTM-32 coordinates) are used as units for the data fields. The fifth and sixth values contain the number of data points in each of the coordinate directions. The last field is an identifier for each data set. This value is used in the flag column of the interpolated data set and should be set between 1 and 99 (0 is used for the merged data set).

The grid of a data set is calculated based on these parameters. It is therefore necessary to specify the grid sizes with a high accuracy as a round-off error in one of these parameters will sum up over the grid. The magnitude of the maximum error in a coordinate direction can be calculated by multiplying the number of grid points in the direction by the error for a single grid cell. In the above example we have specified the longitudinal grid size of the ETOPO5 data set as 0.0833333. We thus have an error of order 10^{-8} for a single grid cell. The maximum error will then become of the order of $721 \cdot 10^{-8} \sim 10^{-5}$ degrees longitude.

Each data set in the parameter file is interpolated as described in Section 4 and a merged data set based on these interpolated data sets is produced. The parameter file therefore also contains information used to determine where and which data set to use in the merged bathymetry. For each data set in the parameter file zero or more bounding boxes are specified (in spherical coordinates). Inside each box interpolated data from the specified data set are used for the merged data set. The western limit of the bounding box is specified first, followed by the southern, eastern, and northern limits (see above example).

4 Bathymetry creation

In a case of generating a new bathymetry, the following steps have to be made:

- Choosing existing data sets which will be used to produce the new data set.
- Interpolating and merging the selected bathymetry data sets onto the required area, resolution, and quality.
- Checking the quality of the newly generated bathymetry.

4.1 Choosing data sets for interpolation

Recognizing that existing bathymetry data have different coverage (availability), resolution and quality, it is recommended to specify the first input data set as a base map covering the entire area of interest and let the following data sets be nested inside this area based on quality and resolution. It is important to check that a data set is covering the entire bounding box. If this is not the case spurious output might occur. The data set that is specified last in the parameter file takes precedence when bounding boxes overlap. If the base map is specified as the first data set in the parameter file all other data sets would thus be used although they always overlap the base map.

4.2 Interpolation

An area weighting interpolation algorithm is used. The depths of the output grid cells are calculated by averaging the depths of the input cells weighed by the fraction of the output cell area that is covered by each input cell. This process is applied both when the output grid is finer than the input grid and when the opposite is true (Figure 4).

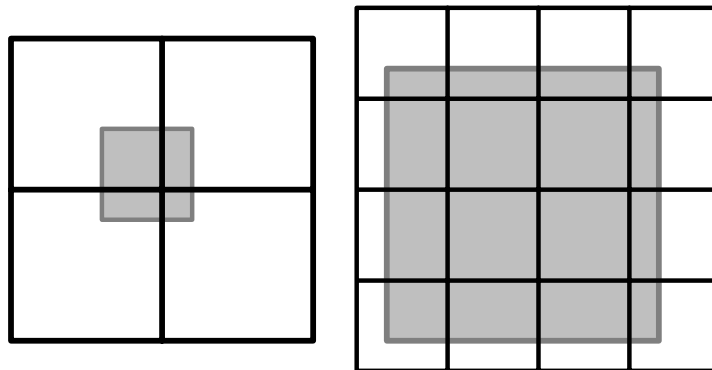


Figure 4. Area weighting interpolation for spherical to spherical coordinates. The left hand figure shows an interpolation from a coarse grid (black lines) to a fine grid (gray lines). The value of each input box is weighed by the fraction of the output box that is covered by the input box (shaded area). The right hand figure shows an interpolation from a fine grid to a coarse grid.

Land areas are included in the calculations using a maximal value of +10 meters. If land (in the input grid cells) is covering more than half the output grid cell area the depth is set to +10 meters.

For spherical to spherical interpolations the convergence of meridians is taken into account when calculating areas. The only degradation of data therefore stems from the implicit smoothing in the interpolation process.

It is somewhat more complicated to interpolate data from UTM-32 coordinates to spherical coordinates. As illustrated in Figure 5 the UTM-32 input grid is generally rotated compared to the spherical output grid. The angle of rotation is a function of both longitude and latitude (Hager et al., 1989).

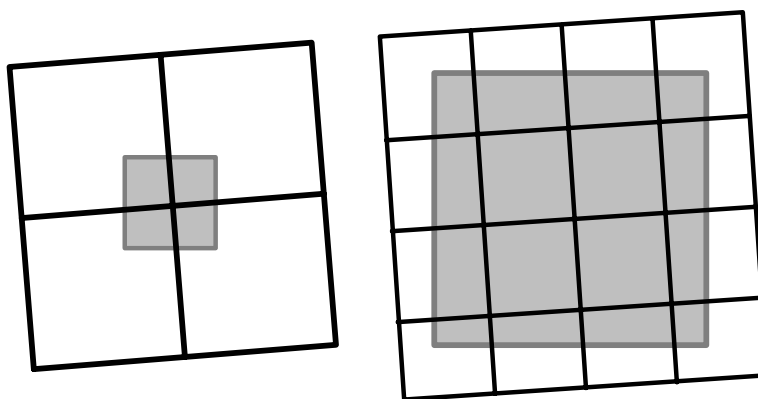


Figure 5. Area weighting interpolation for UTM-32 to spherical coordinates. The left hand figure shows an interpolation from a coarse grid (black lines) to a fine grid (gray lines). The value of each input box is weighed by the fraction of the output box that is covered by the input box (shaded area). The right hand figure shows an interpolation from a fine grid to a coarse grid.

In the interpolation the coordinates of the corners of the spherical output grid cell are transformed to UTM-32 coordinates. Neglecting the curvature of a single output grid cell these corner coordinates define a rectangular box in the UTM-32 grid. Each input grid cell depth is then weighed by its area inside the rectangular box.

4.3 Limitations

It is self-evident that the best results are obtained by using input bathymetries of high quality and with the finest possible resolution. The interpolation algorithms will produce good results as long as the input bathymetry is of comparable or finer resolution than the output bathymetry. If the output bathymetry is much finer than the input bathymetry "staircase" coastlines and isobaths will probably emerge. The problem can be understood by looking at the left hand side of Figure 4. It is clear from the figure that if the output grid cell is much smaller than the input grid cell then the depths of most of the output grid cells will just be the value of the input grid cell inside which they are (fully) contained. Only at the borders the depths will be calculated using more than one input grid cell.

The problem could easily be alleviated by using an algorithm using the squared inverse

distance to the nearest four points (disregarding the actual sizes of the grid boxes). This algorithm would be poor for fine to coarse grid interpolations and the choice of interpolation algorithm would thus have to depend on the resolutions of the grids. For interpolations from UTM-32 to spherical coordinates this would result in a very severe complication as a single interpolation can contain both coarse to fine and fine to coarse interpolations (due to the convergence of meridians). It has therefore been decided to keep a single interpolation algorithm.

If the algorithm is used for this type of interpolation anyways, smoothing the resulting bathymetry might reduce the problem.

4.4 Merging bathymetries

As discussed in Section 3 a merged data set is produced by specifying where each data set is to be used. The depths in the grid points that are nearest the division lines between two data sets are calculated as the average of these data sets. This smooths the transition between the data sets somewhat.

It is possible that a more advanced merging/smoothing algorithm will be implemented in the future.

5 Conclusion

A database containing gridded bathymetries of different coverage and resolution has been established. A tool for interpolating the gridded bathymetries to a user defined spherical grid and subsequently merge the resulting bathymetries to a user defined optimal bathymetry has been developed.

An example interpolation has been presented in this report (Appendix A). Furthermore a bathymetry has been produced for a North Atlantic storm surge model at DMI and a bathymetry covering the Danish waters will be produced to extend the applicability of an operational 3D ocean model.

In the future more data sets will be integrated into the database and post processing tools for converting the output to specific formats required for various operational models at DMI will be developed.

An extension of the interpolation algorithm so that it is also able to interpolate to UTM coordinates might also prove useful in the future.

Data sets of higher quality and resolution will be assembled and integrated into the database as they become available. Presently the highest resolution is 1/3 nm in very limited areas. There is a clear need for higher resolution in large areas. More measurements are needed in certain areas as the offshore area and the shelf break. To produce these high resolution large area bathymetries it will be necessary to share bathymetry data between institutes and to improve the data exchange networks.

A Example

In this appendix a very simple example illustrating how to interpolate a bathymetry is reported.

Suppose we want a bathymetry in spherical coordinates with a resolution of 2'x2' for the waters surrounding Denmark. More precisely we want a bathymetry covering the area from 0-18 degrees east and 52-60 degrees north.

The most appropriate input bathymetry for this resolution and area is the DYNOCs bathymetry with a resolution of 1nm (see Figure 2 and the accompanying table). Some of the local bathymetries might improve the resulting bathymetry at various places but for this simple example these have not been used.

All data sets specified in the parameter file are then interpolated to this grid and merged to produce a "best" bathymetry. Both the merged bathymetry and the individual interpolated bathymetries are written to disk.

The bathymetry in the above example is interpolated by running the following script:

```
#!/bin/csh

# Make parameter file
cat << end_of_input > interpolation.par
dynocs.utm-32
-277840 5667120 1852 1852 1051 951 1
-1 51 20 60
end_of_input

# Interpolate bathymetries (has to be run on origin4)
rsh origin4 -l m21dev ' \\\
  cd /net/sinus/priv_1/jl/database/use/data/use ; \\\
  interpolation 0 52 0.0333333 0.0333333 540 240 '
```

The new interpolated bathymetry is created by specifying the coordinates of the desired grid as arguments for the interpolation program. More specifically the (south-western) origin of the grid (lon=0°E,lat=52°N), the resolution (dlon=1/30°,dlat=1/30°) and the number of points in each direction (nlon=540,nlat=240) must be given as command line arguments.

An extract of the DYNOCs bathymetry and the resulting bathymetry of the interpolation are plotted in Figure 6.

References

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