

# MIKE 3 Toolbox

User Guide





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# M3 TOOLS: HYDRODYNAMICS



The HYDRODYNAMIC tools in the M3 Toolbox include the facilities:

- Border Adjustment
- Digitizing





# 1 Border Adjustment

“Border Adjustment” is a pre-processing tool developed to aid adjusting nested bathymetries prior to a nested MIKE 3 Flow Model simulation.

## 1.1 General Description

“Border Adjustment” is a pre-processing tool developed to aid adjusting nested bathymetries prior to a nested MIKE 3 Flow Model simulation.

There are a number of rules to obey when preparing nested bathymetries to obtain compatibility between a **subarea** (fine grid) and its **enclosing area** (coarse grid), see the MIKE 3 Flow Model HD reference manual for more details. The “Border Adjustment” tool makes sure that some of these rules are fulfilled, i.e.:

- The ratio between the horizontal spatial resolution at one level to the next level must be **3**, i.e.

$$\Delta X_{COARSE} = 3\Delta X_{FINE} \quad (1.1)$$

- **Corners** of sub-areas must be placed in grid points (integer values) of the respective enclosing grid. This means that, in each horizontal direction, every third grid point of the fine grid is common to a grid point in the coarse grid, a so-called **common grid point**.
- The water depths in common grid points **along borders** between areas must be equal in the coarse grid and in the fine grid. The water depths in the two border grid points of the fine grid next to the common grid point must have values which equal the water depth of the common grid point.
- To avoid instabilities, it has been chosen to demand that the water depths **across borders** should be equal within a band of  $\Delta X_{COARSE}$  on each side of the border. This means that the water depth in the coarse grid must be equal in three points orthogonal to the border (one point at on the border and one point on each side). In the fine grid, the water depth in the first four grid points orthogonal to the border should be equal. If the border is land, this rule does not need to be satisfied.
- Finally, all **interior common points** should have equal water depth in the coarse grid and in the fine grid. As the nested model does not perform any coarse grid calculations in the area covered by the fine grid, this rule is only included in order to ease pre- and post-processing. Fine grid solutions of any model quantity are always copied to the coarse grid.



## 1.2 Bathymetry Input

First you specify the two bathymetry data files:

This tool takes as input two type 2 bathymetry data files, corresponding to a fine grid and its enclosing coarser grid.

### Origo Specification

Additionally, you specify the origin of the fine grid in coarse grid coordinates.

## 1.3 Bathymetry Output

Finally you specify the names of the two adjusted bathymetry data files.

Two new type 2 bathymetry data files, corresponding to the adjusted fine and coarse grids, are produced.

## 1.4 Overview

The overview page presents you with a summary of all the input parameters you have specified. You should inspect the parameters to check they are correct, - and if not go back and change them.

From the page you can either *Finish* the set-up, which will transfer your set-up definition to the current toolbox file, or execute the set-up.

## 1.5 Remarks

Since the produced modifications are not necessarily the most ideal, it is strongly recommended always to check the new bathymetries – coarse as well as fine grid – along borders that cross a land-water boundary. Possibly you need to edit the bathymetries using e.g. the Grid Edit tool.

If you plan to apply the MIKE 3 Flow Model with more than one sub-level, you should apply the border adjustments 'inside-out'. That is, considering the example sketched in Figure 1.1, the sequence of border modifications should contain: Apply the border adjustment program with areas 3 and 5, then apply border adjustment on the main area (i.e. area 1) and the modified area 3.

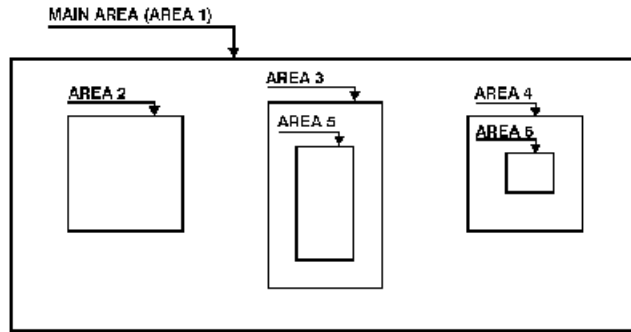


Figure 1.1 Sketch showing possible nesting of bathymetries





## 2 Digitizing

With this tool you can interpolate irregularly spaced ASCII data into a regular three-dimensional grid and save the results in a type 3 data file.

The tool interpolates/extrapolates horizontally and vertically from a finite number of irregularly spaced measurements of e.g. salinity and temperature without definitive knowledge of the spatial variation of the field between the observing locations. The analysed field is represented as discrete values on a regular grid, convenient as an initial field for numerical modelling with a finite difference technique as used in MIKE 3.

### 2.1 Specify Input Files

In this dialog you specify which data to use. The input data must be a type 2 bathymetry data file and an ASCII data file with coordinates and values of the data to be interpolated.

The ASCII data file must contain four columns of data: x-, y-, and z-coordinates and a value at that location. An example is shown in Input Data (p. 15). x, y and z must be in unit meter, whereas the value data must be provided in the first registered unit of the item type you want the values to be associated with.

You must also specify the projection system in which the coordinates of the ASCII data are given.

Make sure that you use the correct projection zone. If an incorrect zone is applied, the results will – at best – be erroneous, possibly containing only delete values. In the worst cases, the program may use all available memory, physical as well as virtual memory. That happens because the program will attempt to allocate memory corresponding to a three-dimensional grid of the specified resolution covering the bathymetry area and the total geographical extent of the ASCII data.

A similar situation may occur if your ASCII data covers a geographical area much larger than the bathymetry area: Outliers in the data may force the program to allocate unnecessary (possibly far too much) memory. So make sure that you only enter the amount of data that is needed to produce the type 3 data file.

### 2.2 Calculation Description (One of Two Interpolation Methods)

In this dialog you specify the horizontal search radius and the vertical extrapolation distances (to top and bottom of the bathymetry), and you choose which of the two methods, “Bilinear interpolation” and “Objective analysis”, you prefer to apply.



For a description of the Objective Analysis, see The Objective Analysis Method (p. 16)

## 2.3 Specify Objective Analysis Parameters

If you have chosen the objective analysis scheme, you must supply a number of parameters: zero-crossing distance, decay distance, error variance, minimum data value, maximum data value, number of filter operations, and the correlation sample size. These parameters are described in The Objective Analysis Method (p. 16).

## 2.4 Calculation Description

The horizontal extent of the grid is determined by the specified bathymetry, while the user must set the vertical resolution.

## 2.5 Output Specifications

The output data file is a type 3 data file. You must name the output file and may optionally give it a descriptive title.

You must also specify an item type for the dfs3 output file, to represent the value data in the 4th column of the (xyz) input data file - which now has been spatially interpolated into the dfs3 file.

See also Output Data (p. 20).

## 2.6 Overview

The overview page presents you with a summary of all the input parameters you have specified. You should inspect the parameters to check they are correct, - and if not go back and change them.

From the page you can either *Finish* the set-up, which will transfer your set-up definition to the current toolbox file, or execute the set-up.

## 2.7 Converting ASCII Data to Type 3 Data

### 2.7.1 General Description

With the "Digitizing" tool in the MIKE 3 Toolbox you can interpolate irregularly spaced ASCII data into a regular three-dimensional grid and save the results in a type 3 data file.



The tool interpolates/extrapolates horizontally and vertically from a finite number of irregularly spaced measurements of e.g. salinity and temperature without definitive knowledge of the spatial variation of the field between the observing locations. The analysed field is represented as discrete values on a regular grid, convenient as an initial field for numerical modelling with a finite-difference technique as used in MIKE 3 Flow Model.

Many possible interpolation/extrapolation methods exist. The methods applied here are a simple bi-linear interpolation scheme and an optimal statistical objective analysis scheme. The objective analysis (OA) scheme employs least-squares criteria for the difference between the analysed and the observed field. It is based on certain explicitly stated statistical assumptions (see Refs. /1/ and /2/).

## 2.7.2 Input Data

A type 2 data file containing the bathymetry and an ASCII data file containing the data to be interpolated. For each data set a line with four numbers should be given: the two horizontal coordinates given in a specified projection system (e.g. UTM-32) in metres, the depth coordinate in metres (positive upwards from the reference level) and the data value.

An example is shown below:

354405.0	6166144.	-8.2	22.7
354377.0	6166228.	-7.9	22.6
354219.0	6166034.	-5.4	22.29998
354512.0	6166738.	-2.5	22.0

## 2.7.3 Specifications

First you specify which data to use. The input data have to be a type 2 bathymetry data file and an ASCII file with coordinates and values of the data to be interpolated.

You must also specify the projection system in which the coordinates of the ASCII data are given.

Then you specify the horizontal search radius and the vertical extrapolation distances (to top and bottom of the bathymetry), and you choose which of the two methods "Bilinear interpolation" or "Objective analysis" you like to apply.

If you have chosen the objective analysis scheme, you must supply a number of parameters: zero-crossing distance, decay distance, error variance, minimum data value, maximum data value, number of filter operations and the



correlation sample size. These parameters are described in the section “The Objective Analysis Method”.

The horizontal extent of the grid is determined by the specified bathymetry, while the user must specify the vertical resolution.

#### Remark I

The interpolation (bilinear or OA) is performed in the horizontal plane only. Interpolation is always linear in the vertical direction.

#### Remark II

Make sure that you use the correct projection zone. If an incorrect zone is applied, the results will – in the best cases – be erroneous, possibly containing delete values only. In the worst cases, the program may use all available memory, physical as well as virtual memory. This happens because the program will attempt to allocate memory corresponding to a three-dimensional grid of the specified resolution covering the bathymetry area and the total geographical extent of the ASCII data.

A similar situation may occur if your ASCII data covers a geographical area much larger than the bathymetry area: A few outliers in the data may force the program to allocate unnecessary (possibly far too much) memory. So make sure that you only enter the amount of data that is needed to produce the type 3 data file.

## 2.7.4 The Objective Analysis Method

Optimal linear estimation is the core of the objective analysis procedure. The goal is to estimate the value  $q_x$  of a scalar variable  $q(x)$  at a general (grid) point  $x$  from measurements  $j_r$  at a limited number of data points  $x_r$ ,  $r = 1, 2, \dots, N$ . The estimated value  $\hat{\theta}_x$  is expressed as a linear combination of the measured values

$$\hat{\theta}_x = \sum_{r=1}^N a_{xr} \varphi_r \quad (2.1)$$

where the coefficients  $a_{xr}$  are so determined that the error variance

$$\langle (\theta_x - \hat{\theta}_x)^2 \rangle \quad (2.2)$$

is minimised. The angle brackets denote mean value. The positions of the observations  $x_r$  and the analysis point  $x$  are kept constant during this process. The formulation is oriented towards spatial interpolation, but if both spatial interpolation and temporal interpolation are required, the position  $x$  must be interpreted as a “position” in both space and time.





It is assumed that the measured value  $\varphi_r$  is the true point value of the field plus some random noise (e.g. instrument uncertainty)

$$\varphi_r = \theta(x_r) + \varepsilon_r \quad , r = 1, 2, \dots, N \quad (2.3)$$

where the errors  $\varepsilon_r$  are uncorrelated with one another and have a known variance  $E$

$$\langle \varepsilon_r \varepsilon_s \rangle = E \delta_{rs} \quad , r, s = 1, 2, \dots, N \quad (2.4)$$

where  $\delta_{rs}$  is the Kronecker delta. A further assumption in the signal-noise decomposition in Eq. (2.3) is that the errors are uncorrelated with the field

$$\langle \varepsilon_r \theta(x_s) \rangle = 0 \quad , r, s = 1, 2, \dots, N \quad (2.5)$$

The assumptions above imply that systematic errors and instrument calibration errors are not permitted, but must be dealt with separately. The final assumption is that the field  $\theta$  is one realisation out of an ensemble with known co-variance function

$$\langle \theta_x \theta_{x+y} \rangle = F(y) \quad (2.6)$$

In the general case, the mean of the field  $\theta$  is unknown and must therefore be estimated. The estimated mean  $\tilde{\theta}$  should be subtracted from each observation and then added back to the estimated value of the field, which can be derived as (see eg Ref /1/)

$$\hat{\theta}_x = \tilde{\theta} + \sum_{r=1}^N C_{xr} \left\{ \sum_{s=1}^N A_{rs}^{-1} (\varphi_s - \tilde{\theta}) \right\} \quad (2.7)$$

The different terms in Eq. (2.7) are described in the following. The estimated mean is calculated as

$$\tilde{\theta} = \frac{\sum_{r=1}^N \sum_{s=1}^N A_{rs}^{-1} \varphi_s}{A_{rs}^{-1}} \quad (2.8)$$



The matrix  $A$  of co-variance between all pairs of observations has components  $A_{rs}$  which, according to the assumptions in Eqs. (2.3) through (2.6), are given by

$$A_{rs} = \langle \varphi_r \varphi_s \rangle = F(x_r - x_s) + E\delta_{rs} \quad (2.9)$$

$A_{rs}^{-1}$  are the components of matrix  $A^{-1}$ , the inverse of  $A$ . The co-variance between the quantity  $\theta_x$  to be estimated and the measurement  $\varphi_r$  is also obtained from Eqs. (2.3) through (2.6) as

$$C_{xr} = \langle \theta_x \varphi_r \rangle = F(x - x_r) \quad (2.10)$$

Note that the estimated mean  $\hat{\theta}$  given by Eq. (2.8) is not the arithmetic average of the measured values, but gives the minimum error variance in the final estimate Eq. (2.7). This minimum is

$$\langle (\theta_x - \hat{\theta}_x)^2 \rangle = C_{xx} - \sum_{r=1}^N \sum_{s=1}^N C_{xr} A_{rs}^{-1} C_{sx} + \frac{\left( 1 - \sum_{r=1}^N \sum_{s=1}^N A_{rs}^{-1} C_{xs} \right)^2}{\sum_{r=1}^N \sum_{s=1}^N A_{rs}^{-1}} \quad (2.11)$$

The first term on the right hand side of Eq. (2.11) is the natural variation in the absence of any data and the second term is a measure of the information provided by the data. The last term is the increase associated with the uncertainty of the estimated mean, and the final variance estimate Eq. (2.11) is slightly larger than if the mean was known *a priori*.

Eq. (2.7) is the least squares optimum linear estimator for  $\theta(x)$ . For different realisations of the field  $\theta(x)$ , the estimate  $\hat{\theta}$  depends linearly on the observations  $\varphi_r$ . The estimator is 'optimal' in the sense that if the co-variance function is an accurate model of the spatial relationship of the data and if the assumptions about the noise reflect the level of actual noise in the data accurately, then no other analysis procedure could be better.

The confidence levels in this estimate are available through Eq. (2.11), which requires knowledge of the data points and the co-variance function  $F(x)$  and noise level  $E$ , but not of the data set itself.



It is noted that the optimal estimate at a data point does not necessarily equal the measurement there, but

$$\hat{\theta}_r = \varphi_r - E \sum_{s=1}^N A_{rs}^{-1} (\varphi_s - \tilde{\theta}) \quad (2.12)$$

The discrepancy proportional to  $E$  is an estimate of the error on the observation obtained by comparing with surrounding observations and the statistics for the data point.

The specific correlation function (co-variance normalised by the co-variance at zero separation) is at present

$$F(x) = \left( 1 - \frac{x^2}{a^2} \right) e^{-x^2/b^2} \quad (2.13)$$

where  $a$  is the zero-crossing (or correlation) length and  $b$  is the decay scale. Usually  $b$  is around 2/3 of  $a$ . Other models may be considered.

The method uses a single estimate of the noise level  $E$  in the data, specified as the dimensionless ratio between noise variance and signal variance. The noise level may be different for different locations for different fields (i.e. salinity, temperature). Separate analysis might therefore be needed if different noise levels are assigned to different locations and/or fields.

Given  $F$  and  $E$  the procedure is quite straightforward for computing  $\hat{\theta}_x$  from a limited number of data. When the number of data  $N$  becomes too large the inversion of the full matrix  $A$  is impractical and it is often necessary to reduce the number of data points for the estimation of  $\theta$  at a point  $x$ . This is done in three steps. First, all data points which are positioned within one grid spacing in the output grid are replaced by one point with a data value equal to the arithmetic mean of the corresponding observations. Then, data points outside a given search radius from  $x$  are excluded. Finally, from the remaining data a number (say 10) of 'nearest' neighbours are selected. These 'nearest' neighbours are selected as the (10) data points most correlated with the analysis point  $x$  according to the correlation function  $F$  in Eq. (2.13).

The method described above is performed separately for each horizontal layer. Thus, if required, the measurements must be interpolated vertically to fit the vertical resolution of the three-dimensional grid. Different kinds of filters may be applied in order to smooth the estimated field horizontally. In the MIKE 3 Digitizing tool, an 8<sup>th</sup> order Shapiro filter is applied  $N_{\text{filt}}$  times, where  $N_{\text{filt}}$  is a user specified number. This amount to a 16<sup>th</sup> order row- and column-



wise Laplacian filter  $N_{\text{filt}}$  times in succession. The one-dimensional Laplacian filter (used in the row- and column-wise filters) is defined as

$$G_i^{\text{new}} = G_i^{\text{old}} + \frac{1}{2^{16}}(G_{i+1}^{\text{old}} - G_i^{\text{old}} + G_{i-1}^{\text{old}}) \quad (2.14)$$

## References

- /1/ Bretherton, F.P., Davis, R.E. and Fauday, C.B.: *A technique for Objective Analysis and Design of Oceanographic Experiments Applied to MODE-73*, Deep-Sea Research, Vol. 23, pp. 559-582, 1976.
- /2/ Thiebaut, H.J. and Pedder, M.A.: *Spatial Objective Analysis with Applications in Atmospheric Science*, Academic Press, Toronto, 1987.

### 2.7.5 Output Data

You must name the output file and optionally give it a descriptive title.

The output data from this tool is an uncompressed type 3 data file, i.e. values for the data item are stored at all grid points as a full, regular three-dimensional matrix

### 2.7.6 Example

From the irregularly distributed measurements of salinity around Iceland, see Figure 2.1, initial salinity distributions have been created for use in a MIKE 3 simulation with horizontal grid spacings of 20 km. The measurements are CTD data covering the period 1988 - 1995 and have been obtained from different sources.

The result of applying the OA method is shown in Figure 2.2. The corresponding salinity field obtained from simple bi-linear interpolation is shown in Figure 2.3. It is evident that the salinity field obtained by OA has a more continuous appearance, while individual measurements clearly show up in the bi-linearly-interpolated field.

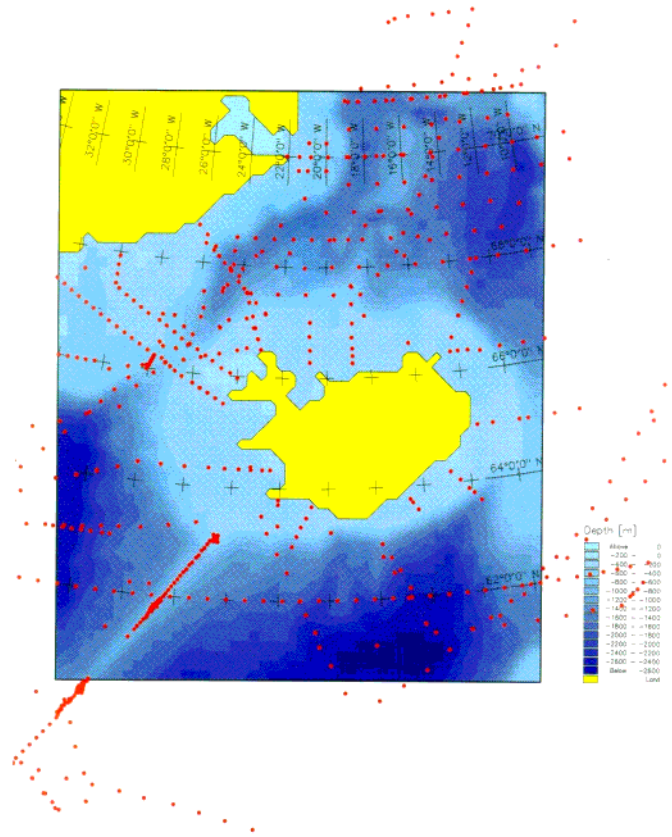
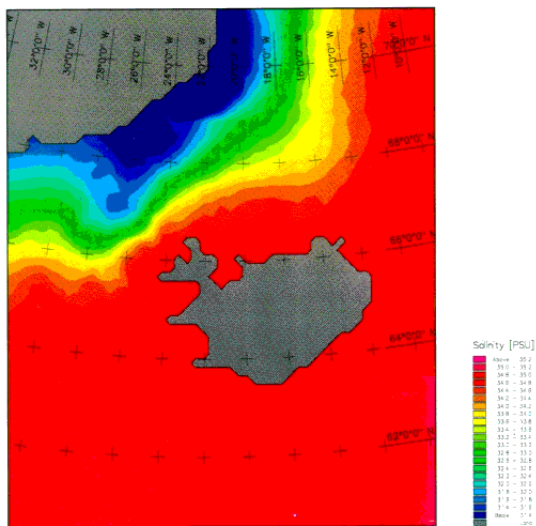
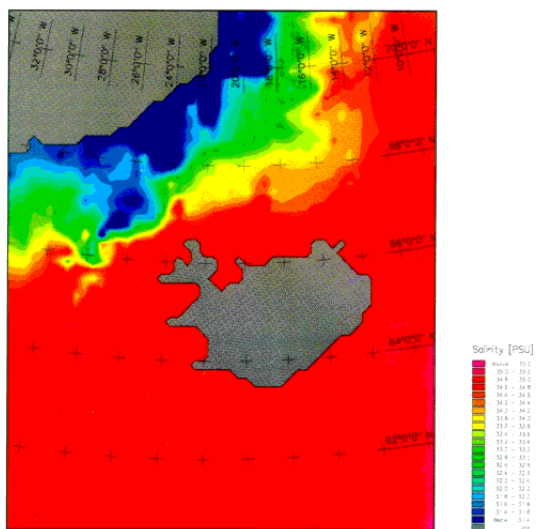


Figure 2.1 Bathymetry (UTM-31) with indication of geographical coverage of the measurements



1990/01/01 12:00:00

Figure 2.2 Surface salinity field obtained from objective analysis



1990/01/01 12:00:00

Figure 2.3 Surface salinity field obtained from bi-linear interpolation



# INDEX



**A**  
ASCII Data . . . . . 14