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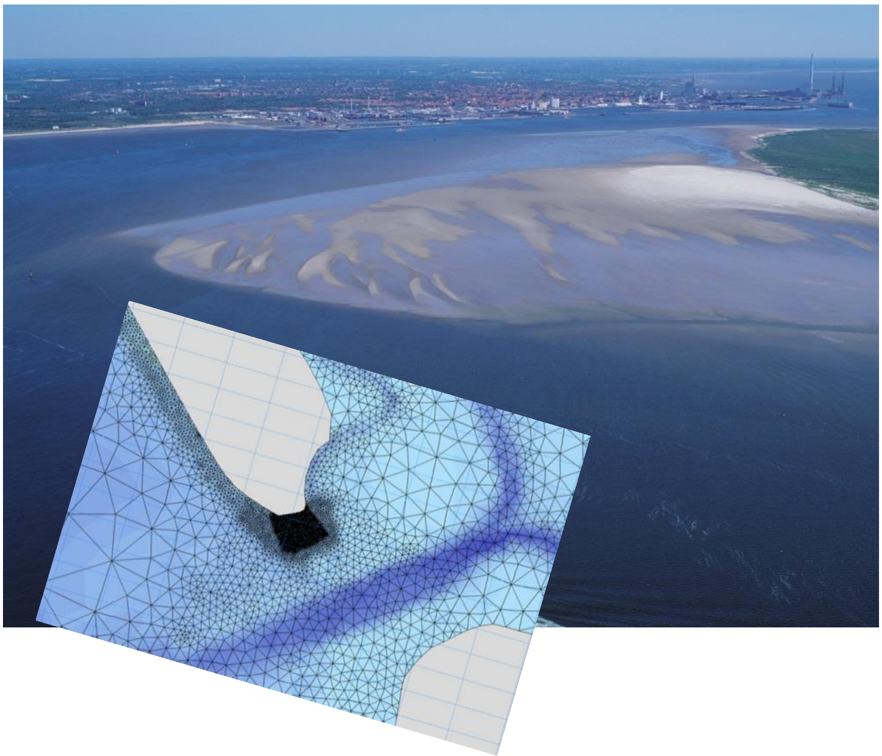

MIKE 21 & MIKE 3 Flow Model FM

Sand Transport Module

Short Description

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MIKE 21 & MIKE 3 Flow Model FM – Sand Transport Module

This document describes the Sand Transport Module (ST) under the comprehensive modelling system for two-dimensional and three dimensional flows, the Flow Model FM, developed by DHI.

The MIKE 21 & MIKE 3 Flow Model FM, Sand Transport Module (ST) is the module for the calculation of sediment transport capacity and resulting bed level changes for non-cohesive sediment (sand) due to currents or combined waves-currents.

The ST Module calculates sand transport rates on a flexible mesh (unstructured grid) covering the area of interest on the basis of the hydrodynamic data obtained from a simulation with the Hydrodynamic Module (HD) and possibly wave data (provided by MIKE 21 SW) together with information about the characteristics of the bed material.

The MIKE 21 & MIKE 3 Flow Model FM, Sand Transport Module, is a numerical tool for the assessment of non-cohesive sand transport ratesand morphological evolution

The simulation is performed on the basis of the hydrodynamic conditions that correspond to a given bathymetry. It is possible to include feedback on the rates of bed level change to the bathymetry, such that a morphological evolution can be carried out.

To achieve a full morphological model in case of combined waves and currents, the wave and flow modules are applied in the coupled mode. This mode introduces full dynamic feedback of the bed level changes on the waves and flow calculations.

Application Areas

The Sand Transport Module can be applied to quantify sand transport capacity in all areas where waves and/or currents are causing non-cohesive sediment movements. The ST module can be used on all scales from regional areas (10 kilometres) to local areas around coastal structures, where resolutions down to metres are needed.

Tidal inlets represent a complex water area where the coastal sections are fully exposed to waves and where the conditions upstream of and in the inlet are dominated by pure currents and where helical motions can have a significant impact on the resulting transport pattern. The Sand Transport Module is developed to span the gap from the river to the coastal zone.

Example of application area: Tidal Inlet

The ST module covers accordingly many different application areas: The most typical ones are:

- Shoreline management
- Optimization of port layouts
- Shore protection works
- Stability of tidal inlets
- Sedimentation in dredged channels or port entrances
- Erosion over buried pipelines
- River morphology

For example, the morphological optimization of port layouts, taking into consideration sedimentation at port entrances, sand bypassing and downdrift impact; detailed coastal area investigation of the impact of shore protection structures on adjacent shoreline; sand loss from bays due to rip currents, etc.

Solution Methods

The MIKE 21 & MIKE 3 Flow Model FM, Sand Transport Module covers the range from pure currents to combined waves and currents including the effect of wave breaking.

The numerical implementation is different for the case of pure current and the combined wave-current case.

The sand transport calculations in a 3D model set-up are carried out using a mean horizontal velocity component. The sand transport calculations are thus not truly three-dimensional. However, the findings that a more detailed 3D hydrodynamic model can give of the hydrodynamic conditions near the bed are included either by the depth-integrated currents of the 3D flow field or by using the bottom stress value to calculate a corresponding mean horizontal velocity component.

Sand transport in combined waves and currents – the quasi-3D approach

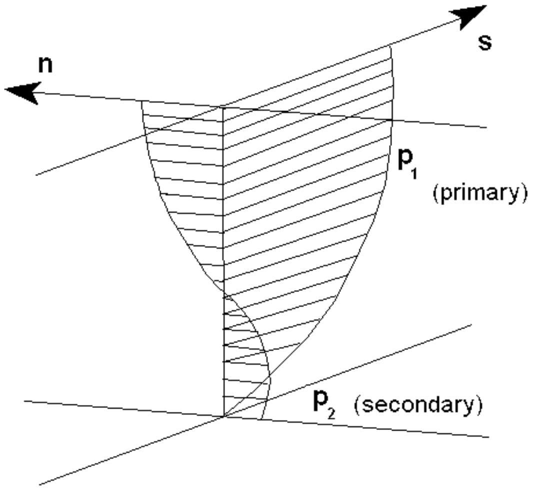
In case of combined waves and currents the sand transport rates are found by interpolation in a table created prior to the simulation. The generation of the transport rates in the table are based on the quasi-3D approach, where the local wave conditions, current profile and grain properties are considered. The effects of the following parameters on the local current profile and thereby on the sand transport can be included in the model:

1. the angle of propagation of waves relative to the flow direction
2. the loss of energy due to wave breaking
3. the gradation of the bed material
4. the formation of ripples on the sea bed
5. the slope of the sea bed
6. undertow
7. wave asymmetry
8. streaming

The inclusion of the effects of 4 – 9 is optional and offers flexibility for the user to design the most appropriate model set-up for the actual application.

The 'quasi-3D' refers to the details of the modelling approach: The vertical sediment diffusion equation is solved on an intrawave period grid to provide a detailed description of the non-cohesive sediment transport for breaking/non-breaking waves and current.

The input to the sand transport model is a mean horizontal velocity component, typically depth-integrated currents. However, as suspended sand transport takes place in the turbulent boundary layer, which is thin in case of waves and covers the whole depth in fully developed steady currents, a description of the vertical distribution of the flow is required. This is obtained by a local 'point model', which includes enough computational points over the water column to resolve the wave boundary layer and the distribution of suspended sediment. The secondary flow profile is also having a significant impact on the sand transport



Primary and secondary velocity profiles

The transport rates are then found by interpolation in the tables using the local depth, wave conditions, mean horizontal velocity component and properties of the bed material. The sand transport model is a 'sub-grid model', which resolves processes not captured by the hydrodynamic model(s).

Sand transport in pure currents

The sand transport description in pure currents is a state-of-the-art model capable of including lag-effects from the flow and the suspended load in the morphological development.

The lag-effects on the suspended load are determined from an advection-dispersion equation that includes effects from over-loading or under-loading of the concentration of the suspended sediment and the helical flow pattern. This approach is often referred to as a non-equilibrium sediment description, where erosion and deposition of the bed is controlled by under-loading and over-loading of the suspended sediment in the water column.

The inclusion of helical flow (in 2D) and the non-equilibrium sediment description is optional, i.e. the model can also be executed as a 'point model' where lag-effects are disregarded (equilibrium sediment description) or only used to adjust the direction of the bed load.

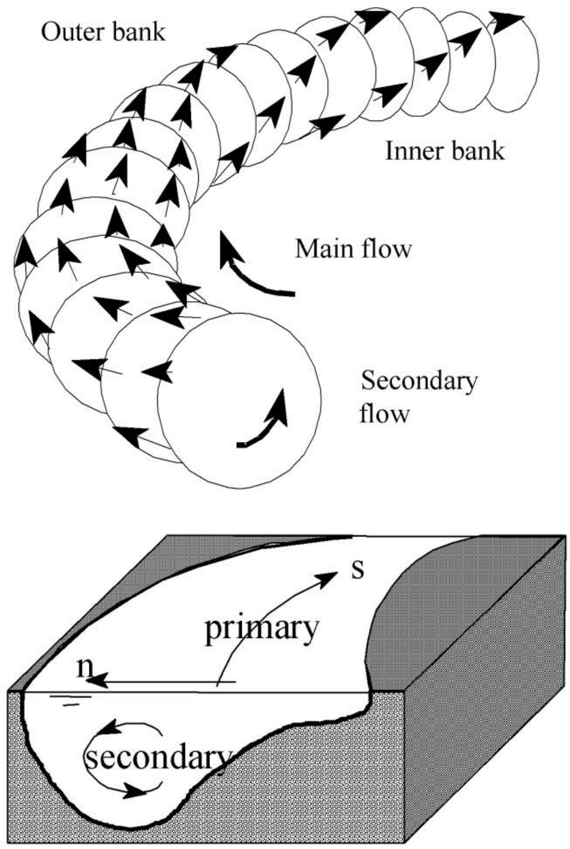


Illustration of helical flow

The bed load description includes gravitational effects forced from longitudinal and lateral bed slopes. Furthermore, it will adjust for the deviation of the bed shear stress from the mean flow, if helical flow is included in the model.

Four different sand transport formulas are available for determination of the equilibrium bed load capacity, while three formulas are available for the suspended load:

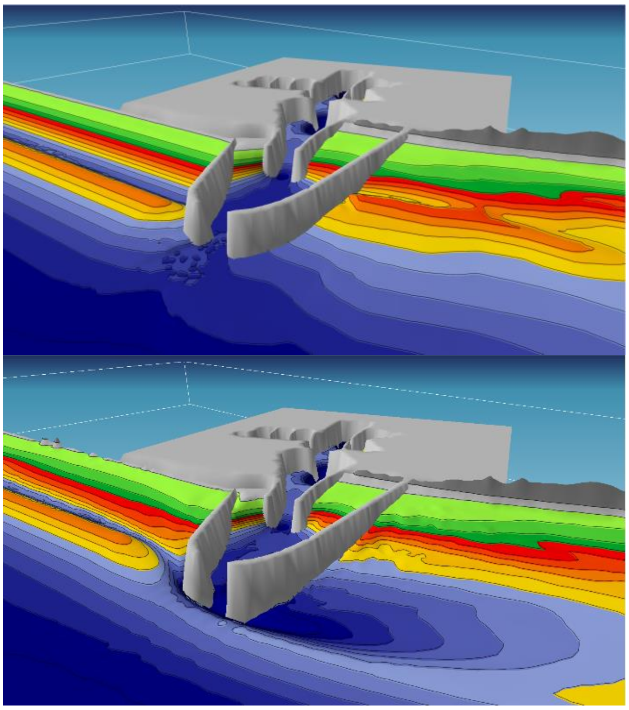
- the Engelund-Hansen total load transport theory
- the Engelund-Fredsøe total load (bed load plus suspended load) transport theory
- the Van Rijn total load (bed load plus suspended load) transport theory
- the Meyer-Peter and Müller bed load transport theory

The equilibrium sand transport capacities are calculated on the basis of local water depth, mean horizontal velocity component, Manning number/ Chezy number and properties of the bed material (median grain size and gradation), which may vary throughout the model area.

Morphology

Morphological evolution is imposed by increasing/decreasing the bed level of each mesh element in accordance with the sedimentation rate/ erosion rate. Changes to the bed affect directly the wave transformation and flow during model execution.

The morphological feedback to flow and waves introduces a completely new level of freedom in the model, which makes model setup and interpretation increasingly difficult but the added value of the results are highly valuable.



Example of morphological evolution (Grunnet et al., 2009) Bypass around Hvide Sande Port. Top: initial bathymetry. Bottom: Simulated bathymetry. Visualised in DHIs MIKE Animator Plus.

The morphological evolution can furthermore controlled by:

- Morphological speedup factor
- Bed porosity
- Sediment layer thickness

The morphological model is typically useful in areas where 2D morphological evolution is expected, e.g.:

- Response to greenfield port construction, and port expansion
- Bypass around detached breakwaters and groynes
- Shoreface nourishments
- Tidal estuaries and canals

Model Input Data

The necessary input data can be divided into the following groups:

- Domain
  - bathymetry data (incl. map projection)
  - simulation length
- Hydrodynamic data
  - water depth and flow fields (provided by the Flow Module)
- Wave data (if required)
  - wave height, period, direction (provided by the Spectral Wave Module or similar)
- Sediment properties
  - size and gradation of bed material
- Morphology parameters
  - update frequency
  - slope failure
  - sediment layer thickness

The main task in preparing the input data for the ST module is to generate a bathymetry and to assess the hydrodynamic and wave conditions.

In case of sand transport in combined wave and current a sand transport table, that contains a representative number of sand transport rates for interpolation during the simulation, is required as input. The sand transport tables can be generated using the MIKE 21 Toolbox program 'Generation of Q3D Sediment Tables'.

In case of wave influence, a DHI wave module (MIKE 21 PMS or MIKE 21 SW) can simulate the radiation stresses necessary for generating the wave-driven current.

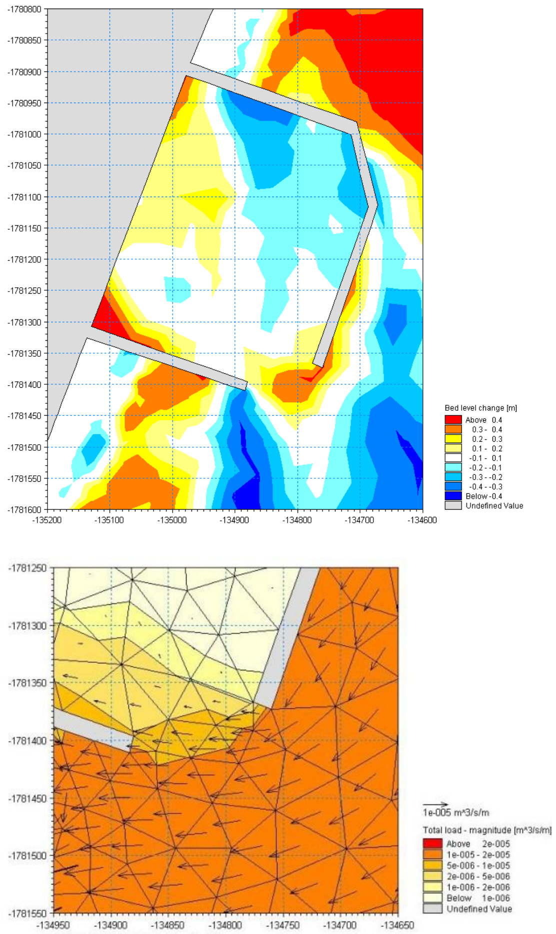
If the simulation is to be run in coupled mode, the MIKE 21 SW module is set up to generate the wave conditions by using the Coupled Model FM input editor.

Per default the hydrodynamic conditions are simulated together with the sand transport rates.

However, for the coupled model it is possible to run in de-coupled mode, providing the hydrodynamic conditions and wave conditions as external data files.

Model Output Data

Two types of output data can be obtained from the model; sediment transport rates and resulting morphological changes.



Simulated morphological change by a harbour and detail of sand transport rates at the harbour entrance

The format of the data may be as points, lines or areas and in any subset required. In the Outputs dialog, output variables are selected between lists of basic and additional output variables. The basic output variables are for example; SSC, bed load-, suspended load- and total load in x- and y-direction including rate of bed level change, bed level change and bed level. The additional output variables are for example transport variables given as magnitude and direction as well as accumulated values, including input hydrodynamic and wave variables.

Examples of Applications and Results

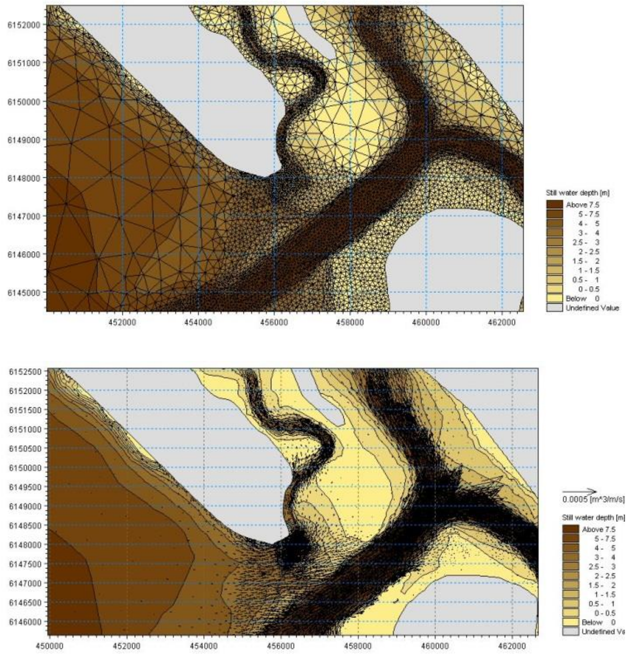
Location map for the examples: Grådyb and Torsminde

Grådyb

Grådyb is a tidal estuary facing the North Sea coast. A major port facility is located inside the estuary. An access channel with a depth of 12 m is maintained by dredging. About 1 million m^3 of sediment are dredged every year and bypassed to not destabilise the down drift coast.

Aerial view of Grådyb estuary. Copyright Port of Esbjerg

The following figures show a flexible grid bathymetry and a 'snap shot' of simulated sand transport in a subset of the model area.



Sub set of the flexible model grid and simulated sand transport

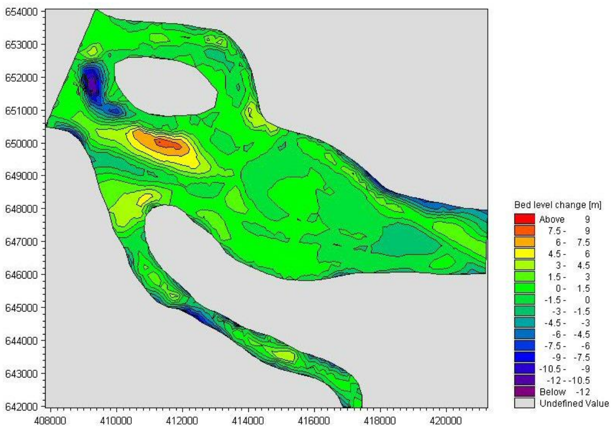
The plots illustrate the flexibility of the model set-up where the critical areas are covered with a very dense grid and the tidal flats are resolved by a somewhat coarser grid.

Gorai River

The Gorai River is a spill channel to the Ganges River. The morphological behaviour at the offtake is of great interest, because the Gorai River is an important source of fresh water supply in the region.

Aerial view of Gorai River

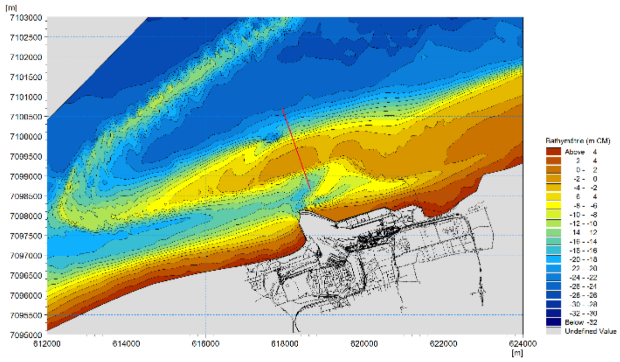
The non-equilibrium concept including helical flow was applied to estimate the morphological changes of the system after the time period of a monsoon.



Mesh bathymetry in 3D and Model predicted bed level changes induced by the passage of the 1999 monsoon

Calais harbour expansion

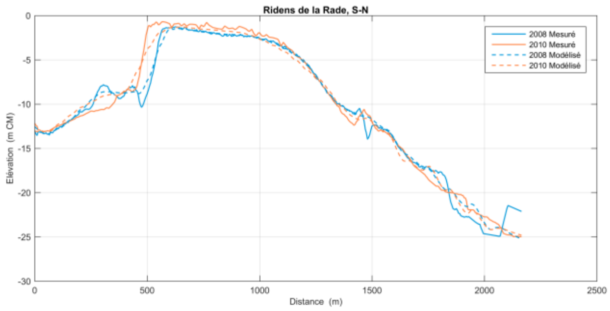
As part of a new major expansion of Calais harbour a model study of the development of the tidal banks in the vicinity of Calais harbour was undertaken in 2015-2017. The study involved calibration of the measured evolution of the tidal banks and a prediction of the bank evolution in response to the future expansion.



Model domain for the morphological model at Calais harbour. The red line indicates the position of a cross-section shown below.

The geographical location of Calais harbour makes the wave and current conditions particularly dynamic. The large tidal range (up to 7m) generates strong tidal currents and modulates the nearshore waves over a tidal cycle.

The morphological modelling covered 20 years of evolution. A model strategy, which included a morphological tide combined with a schematisation of sea-states, was required to complete the detailed 2D modelling within a reasonable period.



Calibration: Comparison of modelled and measured southward movement of the bank: Ridens de la Rade from 2008-2010.

The morphological model results aided in the understanding of the hydrodynamic conditions of the area, which were necessary for design of the new harbour breakwaters. Further, a study of the incremental construction of the breakwaters was done to analyse pre-dredging strategies and back-filling rates.

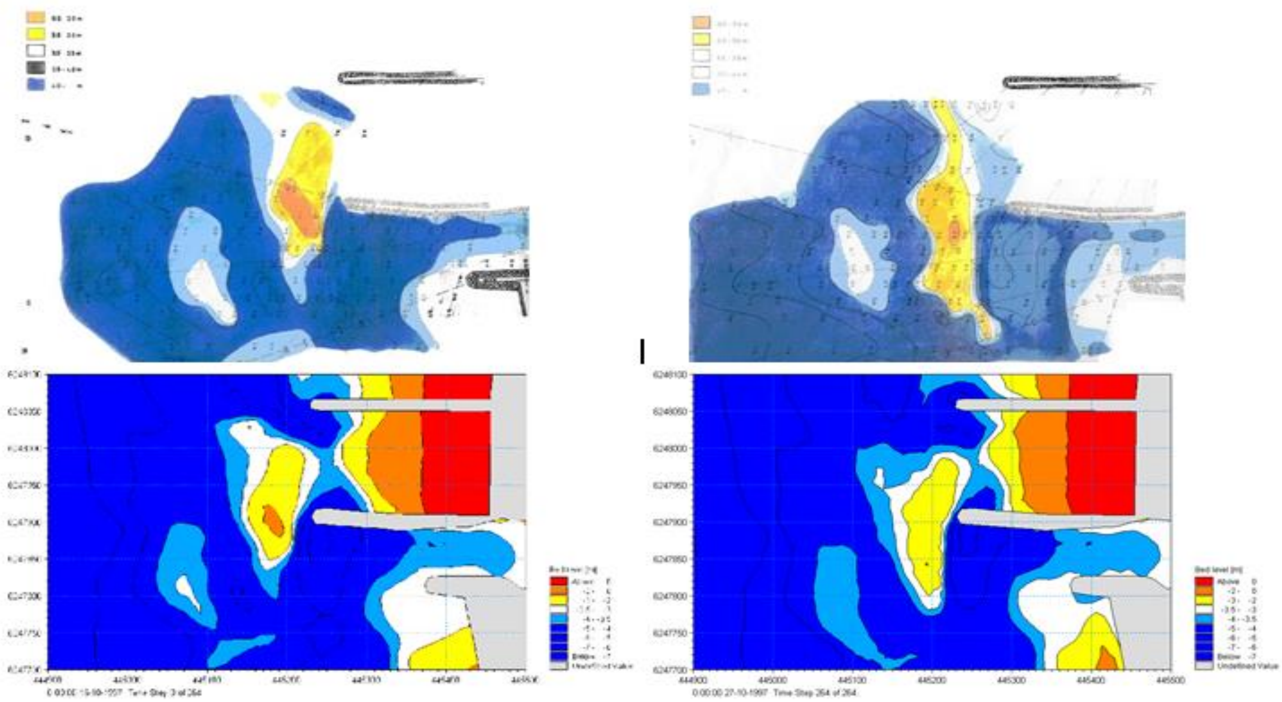
Torsminde Harbour

Torsminde fishery harbour is located at a tidal inlet on the west coast of Jutland, Denmark, on one of the narrow tidal barriers, which divide coastal lagoons from the sea. The port is located at the entrance to the coastal lagoon Nissum Fjord. Sluices regulate the water exchange between the lagoon and the sea. Torsminde harbour is located in the central part of a very exposed stretch, where the net littoral drift is southward with an order of magnitude of 0.4 million m^3/year, but where the gross transport is several times larger.

As a result, severe sedimentation and shoaling problems affected the harbour entrance and a need for alternative layout of the harbour made it necessary to make preliminary investigations of the sand transport pattern in the area.

Running the MIKE 21 Flow Model FM in coupled mode with the SW Module and ST module, the morphological changes during a specified period can be estimated.

The following figures show a comparison of the measured and simulated bathymetry in front of the harbour entrance, before and after a 10-day period in October 1997.

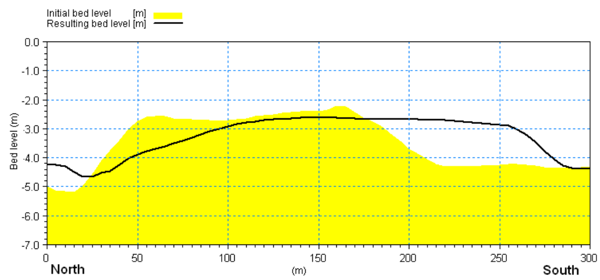


Comparison of measured and simulated bathymetries in front of the harbour entrance. Upper: measured. Lower: calculated. Left: before storm. Right: after storm

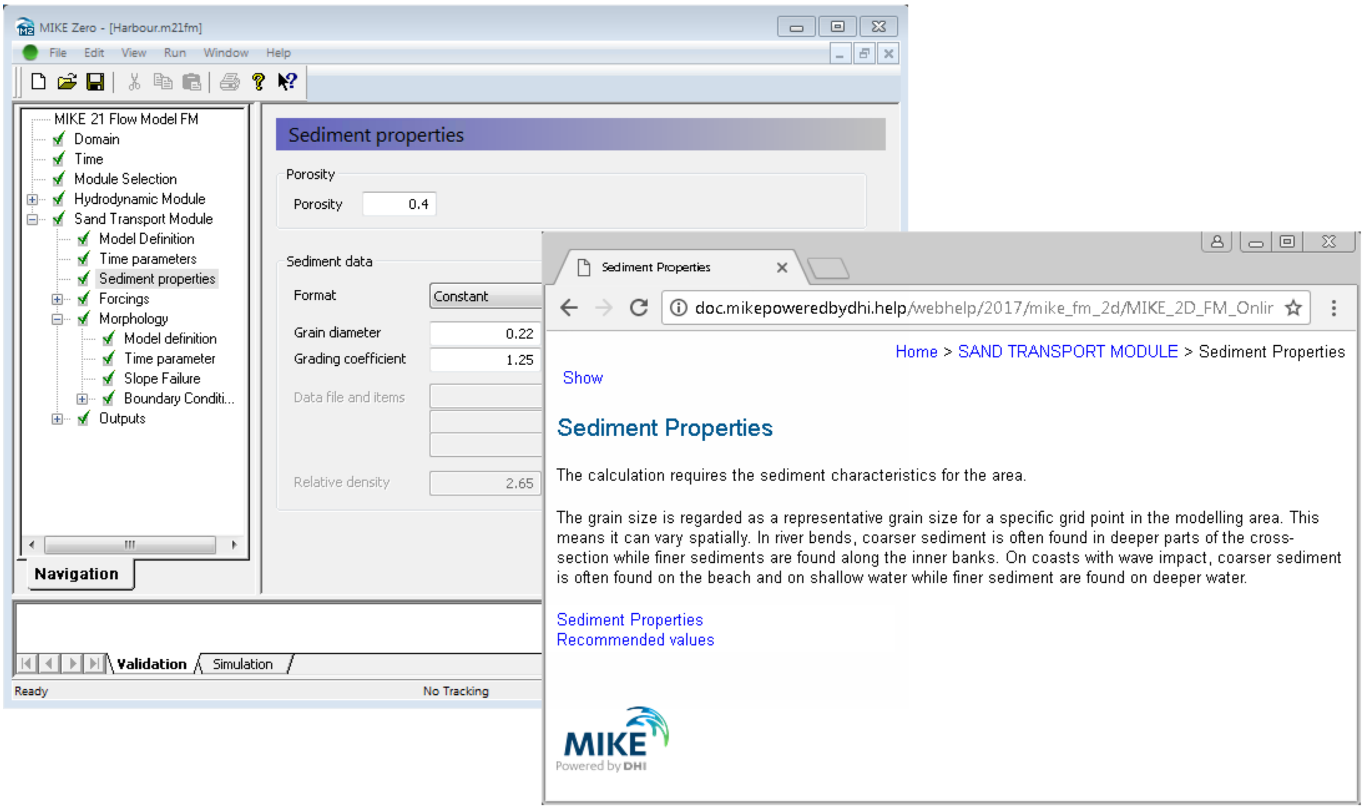
The pre-dominant wave direction during the simulation period was from the North-West. This caused the bar in front of the harbour entrance to migrate further south, thus blocking the harbour entrance.

To view the bar migration in detail the simulated bed levels are extracted along a north-south line extending from the northern jetty to past the harbour entrance.

The results are shown in the figure below.



Bed level across the harbour entrance: before and after simulation

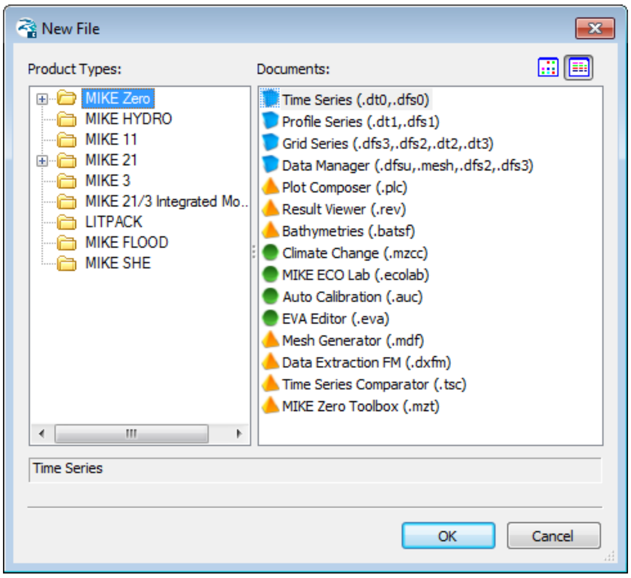


Graphical user interface of the MIKE 21 Flow Model FM, Sand Transport Module, including an example of the Online Help System

Graphical User Interface

The MIKE 21 & MIKE 3 Flow Model FM, Sand Transport Module is operated through a fully Windows integrated Graphical User Interface (GUI). Support is provided at each stage by an Online Help System.

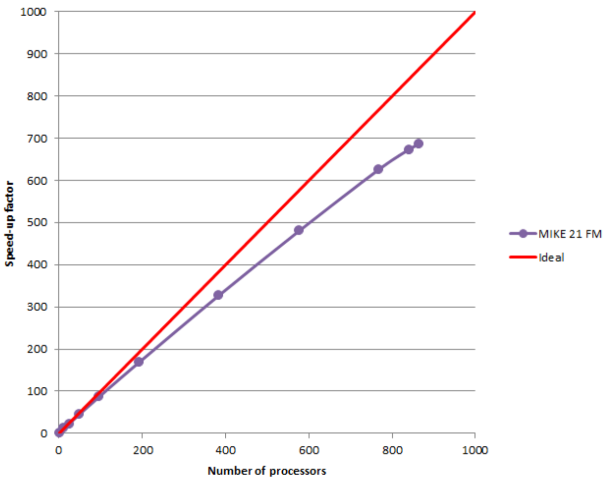
The common MIKE Zero shell provides entries for common data file editors, plotting facilities and a toolbox for/utilities as the Mesh Generator and Data Viewer.



Overview of the common MIKE Zero utilities

Parallelisation

The computational engines of the MIKE 21/3 FM series are available in versions that have been parallelised using both shared memory as well as distributed memory architecture. The latter approach allows for domain decomposition. The result is much faster simulations on systems with many cores.



Example of MIKE 21 HD FM speed-up using a HPC Cluster with distributed memory architecture (purple)

Hardware and Operating System Requirements

The MIKE Zero Modules support Microsoft Windows 7 Professional Service Pack 1 (64 bit), Windows 10 Pro (64 bit), Windows Server 2012 R2 Standard (64 bit) and Windows Server 2016 Standard (64 bit).

Microsoft Internet Explorer 9.0 (or higher) is required for network license management. An internet browser is also required for accessing the web-based documentation and online help.

The recommended minimum hardware requirements for executing the MIKE Zero modules are:

Processor:	3 GHz PC (or higher)
Memory (RAM):	2 GB (or higher)
Hard disk:	40 GB (or higher)
Monitor:	SVGA, resolution 1024x768
Graphics card: (GUI and visualisation)	64 MB RAM (256 MB RAM or higher is recommended)

Further reading

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