



## MIKE 21 & MIKE 3 Flow Model FM

ABM Lab Module

Short Description



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## MIKE 21 & MIKE 3 Flow Model FM - ABM Lab Module

Dynamics and functions of many aquatic ecosystems arise from traits of individual organisms and particles and their interactions with the environment. Examples include:

- foraging behaviour
- predator-prey interactions
- flocking
- mating
- migrations
- bioenergetics
- transport
- ageing

Agent-based Modelling (ABM) is used for advanced simulations of behaviour and states of individuals or particles (which act as the agents driving aquatic ecosystem dynamics). Individuals in an ABM model comprise both small organisms (such as planktonic species and larvae) as well as larger organisms (including macro-algae, seabirds, fishes and whales). The impact of anthropogenic disturbances on these organisms can be evaluated by analysing the pattern of individual responses.

The MIKE 21 & MIKE 3 Flow Model FM - ABM Lab Module offers a unique integration of agent based modelling with classical water quality and hydrodynamic modelling in 2D and 3D ecosystems.

The combination of a user-friendly interface, open access to the governing equations and the coupling of ABM Lab to the MIKE 21 & MIKE 3 Flow Model FM makes the ABM Lab Module a powerful tool.

The Lagrangian ABM Lab is fully integrated with the Eulerian MIKE ECO Lab and runs in conjunction with our most advanced flexible hydrodynamic modelling software – MIKE 21/3 FM. ABM Lab offers full access to model algorithms through an open equation solver interface – for editing existing ABM model descriptions or building new ABM models from scratch. MIKE 21/3 FM utilises flexible mesh for defining the computational grid, thereby allowing ABM to be applied to both freshwater and marine ecosystems

MIKE 21 & MIKE 3 Flow Model FM – ABM Lab is typically used for advanced simulations of behaviour and states of individuals or particles in water environments.

ABM Lab (among others) allows for:

- discrete representations of unique individuals
- local interactions
- use of adaptive, fitness-seeking behaviour
- explicit representation of how individuals and their environment affect each other
- representation of full life cycles

These can for instance, be used to predict the behaviour of large marine animals or identify hot-spots for connectivity between key habitats by studying the dispersal of larvae or spores. Agent (animals, larvae and so on) movements and states can be described as a response to local conditions or gradients, such as current velocities, water temperature, water quality, food availability and anthropogenic pressures.

ABM Lab may also be used to back-track agents (for example, the origin of fish larvae or eggs found in a particular area).



Reproduction and succession mechanisms determining the re-colonisation of eelgrass (*Zostera marian*) in Danish marine waters

## Application Areas

ABM Lab is the ideal software for:

- Numerical modelling of the impacts of dredging plumes on coral spawning and recruitment
- Modelling eelgrass succession patterns and determining the recolonisation of eelgrass
- Modelling the migration of salmonid fish larvae through different wetland construction designs
- Modelling of bull shark migration patterns in a semi-enclosed ecosystem

Examples of specific applications of the MIKE 21 & MIKE 3 Flow Model FM – ABM Lab Module are:

### ADVANCED EIAs FOR AQUATIC ORGANISMS

ABM Lab offers advanced solutions to Environmental Impact Assessments (EIAs) for aquatic organisms – whether it involves the behaviour of large animals such as mammals & fish or dispersal units like larvae, seeds and spores of aquatic organisms. For example, the response of large animals to disturbances like underwater noise from drilling or seismic surveys should preferably be based on baseline behaviour modelling. This takes into account seasonal migrations as well as meteorological and hydrodynamic changes.



Linking movement behaviour modelling of Bull sharks (*Carcharhinus leucas*) with observation data from acoustic tagging of juvenile sharks in a semi-enclosed ecosystem, Australia

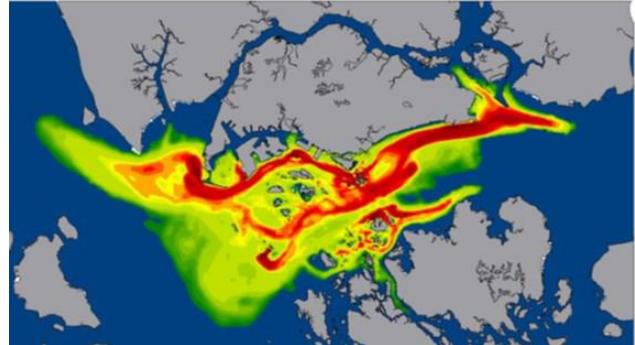
### EVALUATING THE IMPORTANCE OF MARINE PROTECTED AREA NETWORKS

Marine protected areas are important for protection of the local environment. However, the importance of the network is related to the role of these protected areas as sources or sink areas for the dispersal of plants and animals. Using ABM Lab, it's possible to determine the connectivity between such areas and define the importance of the protected area networks.

For example, models of coral larvae dispersal can be developed, simulating:

- mortality
- larvae settlement
- individual reaction to environmental and anthropogenic gradients

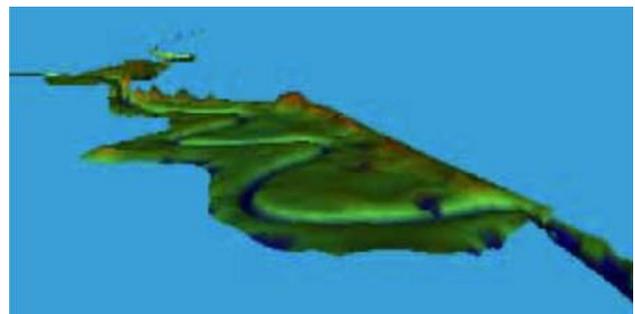
Important connectivity corridors between coral reefs can then be identified based on these models.



Connectivity corridors between five selected reefs shown as cumulative densities of larvae over a five-day period after spawning. Red coloration marks high concentration areas

### PLANNING RESTORATION MEASURES

ABM Lab can be used in the planning phase for projects aiming to restore natural habitats and enhance abundance & survival of fish, for instance. An example: ABM modelling of the migration of salmonid fish larvae (*Coregonus oxyrinchus*) through two different wetland reconstruction designs was used to evaluate which of the two designs had the most positive effects on larvae retention in the wetland. In another example, ABM was used to study the factors determining re-colonisation of eelgrass.



ABM used for testing wetland reconstruction designs

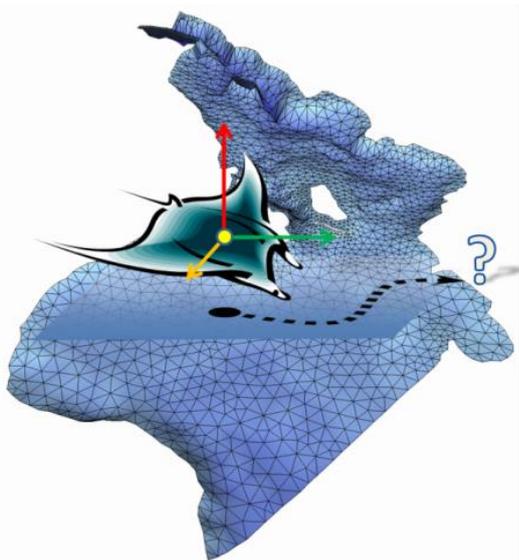
## Computational Features

With the ABM Lab module you can model:

- **Movement**, which can be passive (drift) or active (depending on other model parameters). The resulting movement can be the sum of several independent movement vectors
- **Sensing**, where the individual's sensing of the environment and of other agents is done through 'Restricted Area Search Functions'
- **Interaction** with other elements, including functions such as create, split, remove, eliminate and transfer

The use of these functions permits modelling of complicated behaviours such as:

- Complicated horizontal and vertical movement
- Migration and swarming
- Foraging and breeding
- Growth, death and predator-prey relations



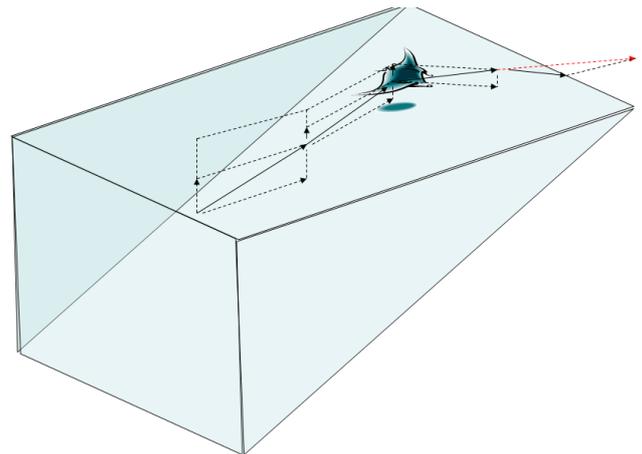
An ABM model describes the autonomic behaviour and states of agents, objects or individuals

## Model Equations

The agents are modelled using basic particle-tracking algorithms, but with particles (agents) that can sense and react to Eulerian variables.

The Lagrange algorithm is independent of model grid and handles the following in MIKE:

- Exact position (x,y,z)
- Movement - direction
- Movement - speed
- States (volume, mass, etc.)
- Rules (death, birth etc.)
- Sensing (restricted area search)
- Feedback between Euler and Lagrange



Behaviour of agent in Lagrangian model

State variables represent elements of an individual agent that can change due to some associated process. The change of the state variable is computed according to the given differential state variable equation.

$$\frac{dSymbol}{dt} = Process1 + Process2 + Process3$$

### Symbol list

Symbol	The value of the ABM lab agent state variable
Process	User specified expression containing arguments such as mathematical functions, built-in functions, numbers, forcings, constants, and state variables

The ordinary differential equation summarises the processes involved for the specific state variable. If a process affect more than one state variable, or the state variables affect each other, the set of ordinary differential equations are said to be coupled.

Processes always describe the rate at which something changes. In this context constants are values always constant in time, and forcings are values that can be varying in time.

Some constants and forcings are already calculated in the hydrodynamic model, e.g. temperature and salinity. These results can be used as so-called built-in forcings and constants in the MIKE ECO Lab expressions. Other constants could be e.g. thresholds or growth rates.

Sensing functions represent the remote sensing abilities of an agent and can be used to query magnitudes and directions of remote concentration gradients around an individual and relations to other neighbouring individuals.

The output from the ABM Lab Module presents a numerical solution for the state variables. The solution can output the state of the individual particles as well as a discretized solution into a computational grid, which is common with the hydrodynamic model.



Computational mesh applied in Odense Estuary, Denmark

### Predefined MIKE ECO Lab templates

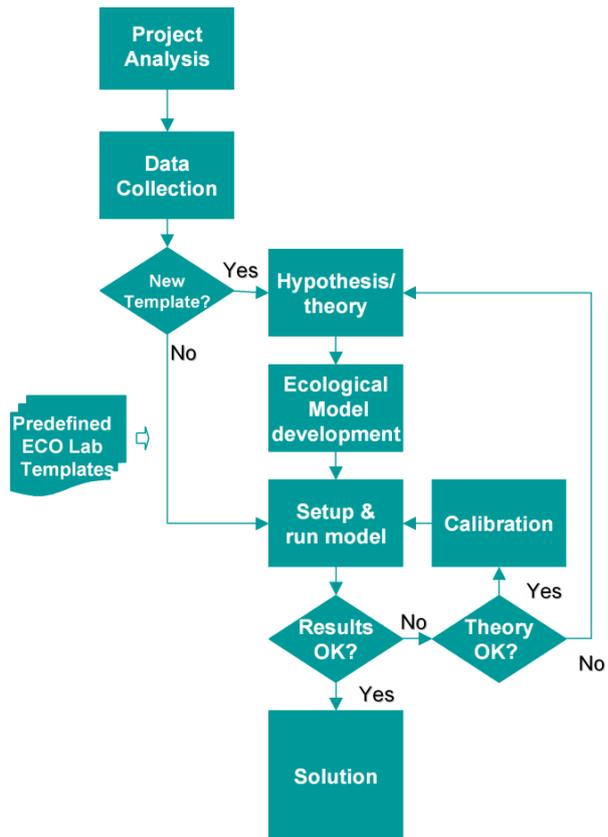
A predefined MIKE ECO Lab template for modelling agents is supplied with the DHI Software.

#### Simple Particle Assessment

The Simple Particle Assessment (SPA) model template can be used to simulate the fate of a spilled substance subject to decay and evaporation while at the water surface. The movement of the spilled substance is simulated using a Lagrangian particle drift model, based on the advanced possibilities of the DHI Particle Tracking/Oil Spill model core. The decay/ evaporation of the substance is the combination of a simple 1st order background decay process and a complex, age and wind speed dependent surface decay process.

### The ABM Lab Work Flow

The work will normally consist of the tasks illustrated in the following diagram:



As the diagram illustrates there can be different ways to reach the solution of your project.

Some tasks are mandatory, such as:

- **Project analysis:** defining and limiting the ABM Lab model
- **Data collection**
- **Set up and run the model**
- **Calibration**
- **Solution:** Running the production simulations and presenting the results

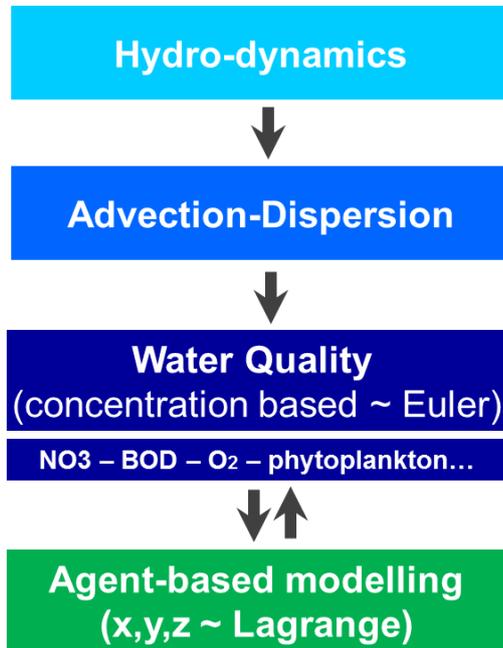
Other tasks in your project are optional and depend on your choice: will you create your own MIKE ECO Lab template or will you use a predefined one. In some cases a predefined template covering your specific problem does not exist, and then a new MIKE ECO Lab template has to be developed. If you choose to develop your own MIKE ECO Lab template, your project will include also the following tasks:

- **Development of hypothesis/theory:** Literature study and formulation of equations
- **Implementation of theory** into a MIKE ECO Lab template using the MIKE ECO Lab editor

### Solution Technique

The ABM Lab simulation is executed using the MIKE ECO Lab engine and a MIKE ECO Lab oil spill template. The execution comprises Lagrangian particle tracking (including weathering processes).

In combination with MIKE ECO Lab, the simulation can also include Eulerian advection-dispersion computations (depends on template).



Combined use of MIKE ECO Lab and ABM Lab

An ABM Lab simulation may either be run as a coupled model together with the MIKE 21 or MIKE 3 Flow Model FM or in the de-coupled mode. In order to save time the decoupled mode, where flow data from a previous MIKE 21 or MIKE 3 FM simulation are re-used, is normally used.

The spreading of an agent spill is calculated by dividing the agent into discrete parcels, termed particles.

The movements of the agent particles are given as a sum of a displacement determined by the hydrodynamic flow field (and optionally the wind) and a dispersive component as a result of random processes (e.g. turbulence in the water).

### Model Input

ABM Lab modelling requires data as model input. Some parameters can be measured and some are calibration parameters.

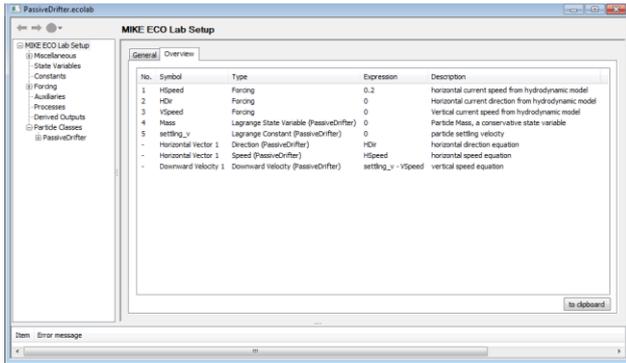


Flexible mesh applied in Ho Bay, Denmark

The following input data must be specified in the model setup:

- Computational mesh containing bathymetric data
- Time step and simulation period
- Hydrodynamic boundary data: e.g. water levels and/or current velocities
- Hydrodynamic forcings, e.g. wind
- MIKE ECO Lab template
- ABM Lab forcings (depend on the content of the MIKE ECO Lab template), e.g. solar radiation
- ABM Lab constants (depend on the content of the MIKE ECO Lab template).
- Dispersion coefficient
- Particle sources: spill location, depth and number of particles to be released. Each particle is defined by the state variables, with characteristics for the agent
- The agent spill may be specified as an instantaneous spill (at the outset of the simulation) or as a spill continuing for some time. The location may be fixed or moving.

The MIKE ECO Lab Template Editor is an efficient tool to formulate new agent based models in MIKE ECO Lab templates, which must be specified as input data in MIKE 21 & MIKE 3 Flow Model FM – ABM Lab.

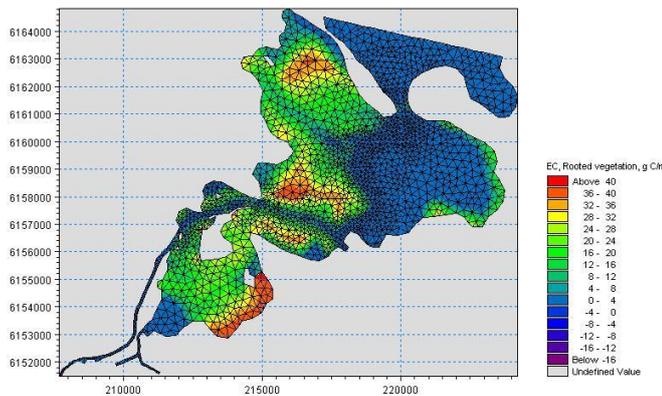


The graphical user interface of the MIKE ECO Lab template editor

### Model Output

After the setup of the model a simulation can be started. This will produce output data that include instant values of the state variables defined in the MIKE ECO Lab template.

It is possible to specify the format of the output files in MIKE 21 & MIKE 3 Flow Model FM – ABM Lab as time series of points, lines, areas, and volumes (only MIKE 3 FM).

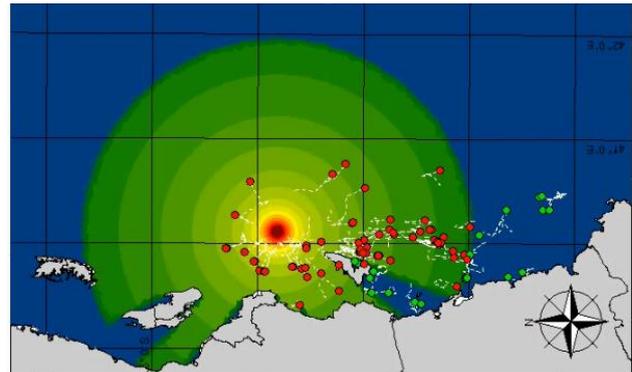


2D output: benthic vegetation in Odense Estuary, Denmark

Usually the model is calibrated against measured data. These might be measurements from different monitoring stations. Such data are important for documenting the capability and quality of the model.

A number of output types are available:

- 2D-maps or 3D maps (the latter only when running the ABM Lab Module in a 3D domain) containing the instantaneous value of the state variables defined in the template.
- Mass budget as a time series.
- Particle tracks and particle properties. These are useful for illustrating the spreading of the agent. An example is shown below.



Visualisation of agent trajectories from recent time steps on top of map of underwater sound impact

### Pre- and post-processing tools

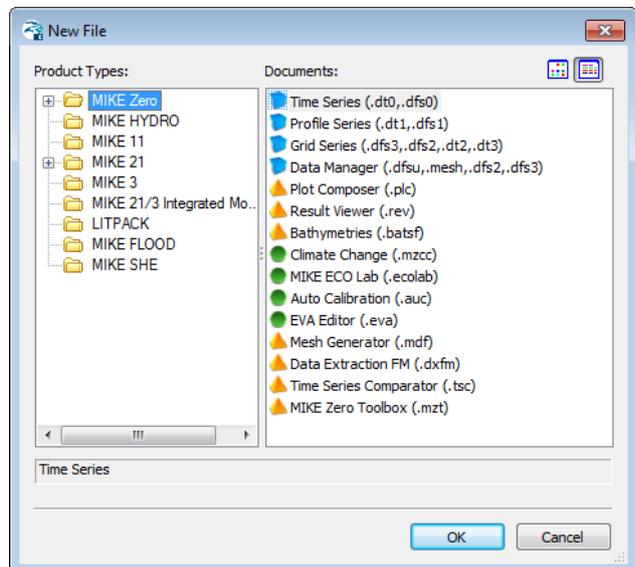
The Oil Spill/Particle Track toolbox contains facilities aimed for pre- and post processing of agent based model simulation output:

The toolbox tools can be used to reverse flow fields, to process and convert large quantities of data in XML files and to calculate connectivity between grid cells in a user-specified Cartesian grid.

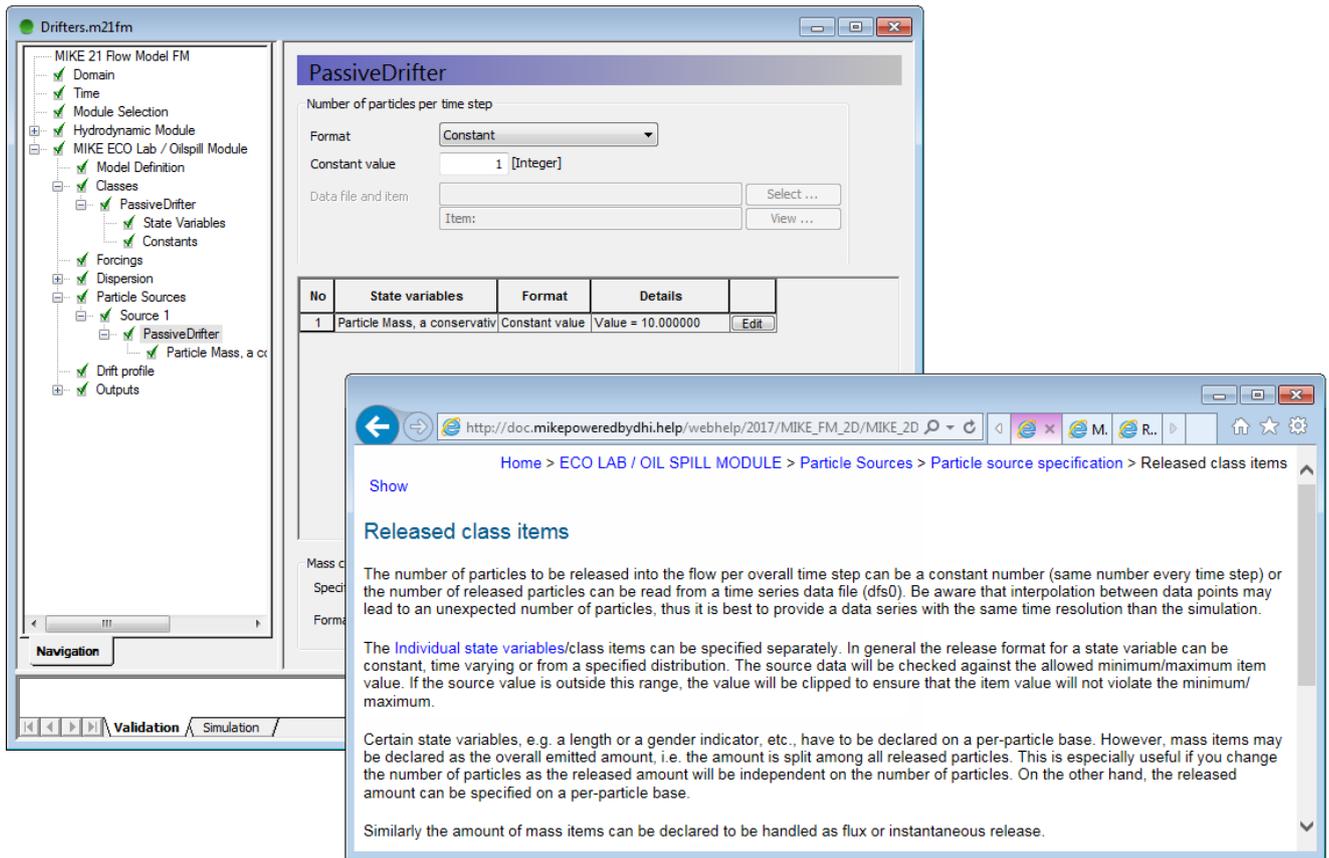
### Graphical User Interface

The MIKE 21 & MIKE 3 Flow Model FM – ABM Lab 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.



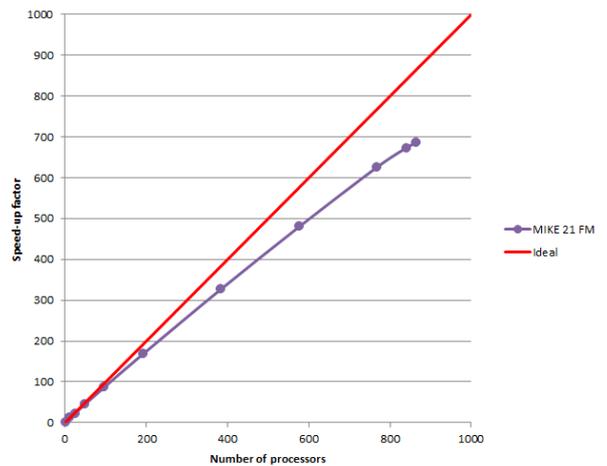
Overview of the common MIKE Zero utilities



Graphical user interface of the MIKE 21 & MIKE 3 Flow Model FM – ABM Lab Module, including an example of the Online Help System

### 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. It could be feasible to carry out ABM modelling using decoupled result files from a HD simulation.



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:	64 MB RAM (256 MB RAM or higher is recommended)
(GUI and visualisation)	

## Support

News about new features, applications, papers, updates, patches, etc. are available here:

[www.mikepoweredbydhi.com/Download/DocumentsAndTools.aspx](http://www.mikepoweredbydhi.com/Download/DocumentsAndTools.aspx)

For further information on MIKE 21 & MIKE 3 Flow Model FM – ABM Lab software, please contact your local DHI office or the support centre:

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## Further reading

Grimm, et al 2005. Pattern-oriented modelling of agent-based complex systems: lessons from ecology. *Science* 310, 987-991, 2015.

S.E. Jørgensen and G. Bendoricchio  
*Fundamentals of Ecological Modelling*  
3rd Edition, Elsevier

V.Grimm S.F. Railsback  
*Individual-based Modeling and Ecology*  
Princeton University Press

K.Soetaert, P.M.J. Herman 2009,  
*A Practical Guide to Ecological Modelling*  
Springer 2009

## Documentation

The MIKE 21 & MIKE 3 Flow Model FM modules are provided with comprehensive user guides, online help, scientific documentation, application examples and step-by-step training examples.

