

# Underwater Acoustic Simulator

Simulation of sound propagation

User Guide





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# 1 About This Guide

## 1.1 Purpose

The main purpose of this user guide is to enable you to use the Underwater Acoustic Simulator (UAS) in determining the sound spread from an underwater sound source.

The online help compliments this user guide.

Section 2, Introduction, gives you a short description of the UAS and the type of applications where it can be used.

Section 3, Getting Started, contains a step by step procedure which can be followed when working on an application.

Section 4, Examples, contains descriptive examples which can be used to get acquainted with UAS.

## 1.2 Assumed User Background

The Underwater Acoustic Simulator is designed with emphasis on a user-friendly interface.

We recommend that users have a basic background in underwater acoustics, which enables them to assess the results from UAS.

It is assumed that you are familiar with the basic elements of MIKE 21: file types and file editors, the plot composer and the bathymetry editor. An introduction to these can be found in the MIKE 21 Short Introduction and Tutorial.





## 2 Introduction

### 2.1 General Description

UAS is a **R**ange dependent **A**coustic **M**odel (RAM), with basis in the sound propagation model developed by (Collins, 1993). UAS accounts for the change in speed of sound in the water column. UAS accounts for volume attenuation in the water column, and provides the option to apply the empirical model by (Francois & Garrison 1982b; Francois & Garrison 1982a) which is based on information on salinity, temperature and pH in the water column.

For a realistic treatment of seabed effect on sound wave propagation in the ocean, it is necessary to include absorption in the bottom material. UAS includes propagation in the seabed, but handles only compressional waves and not shear waves, i.e. ocean bottom sediments are modelled as fluids. Besides accounting for attenuation constants in the bottom layers, it is important to include density changes at the water-bottom interface as well as within the bottom itself for a realistic treatment of bottom effects on propagation. A simplified bottom description based on a number of constant-density and constant thickness layers can be defined in UAS. The lower boundary condition involves termination of the physical solution domain by an artificial absorption layer of several wavelengths thickness to ensure that no significant energy is reflected from the lower boundary. A still water sea surface reflecting all sound is built into the model.

The sound source is modelled as an omnidirectional point source.

#### 2.1.1 Model Domain

The UAS is a 2D model, working in a vertical 2D plane ( $r,z$ -plane) termed a transect. See Figure 2.1.

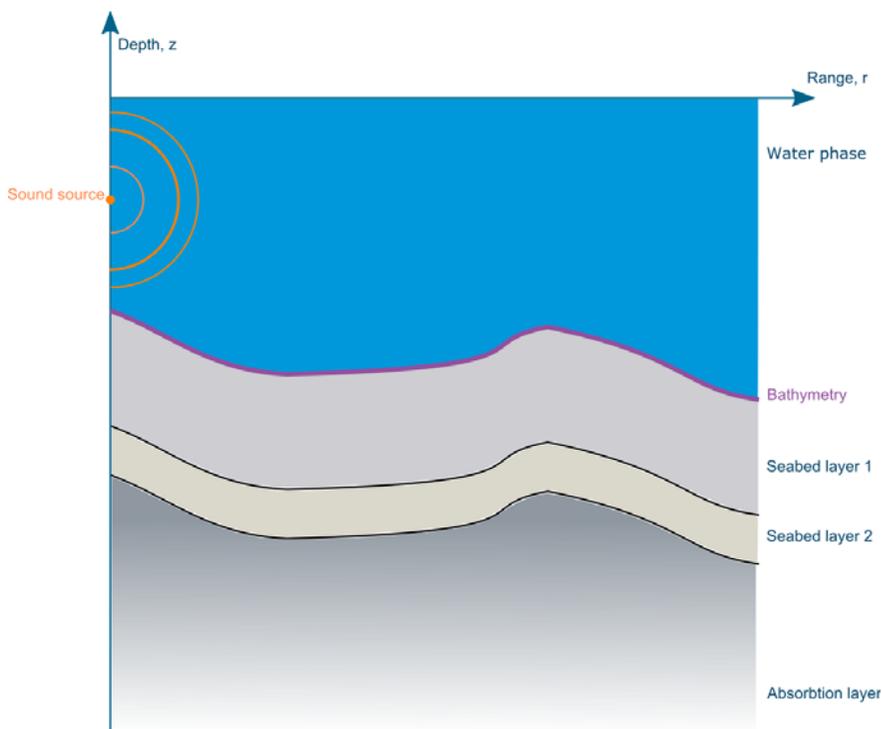


Figure 2.1 Sketch of the range-depth 2D plane, termed a transect.

## 2.2 Application

UAS is aimed at the study of sound propagation which can be used for example in all types of research projects or in environmental impact assessments (EIA) where one investigates the impacts of sound on aquatic life. The model is capable of handling both shallow and deep water model domains with frequencies of up to 40 kHz. However, computational time increases rapidly above 1 kHz.

UAS simulates the received sound level at all locations in the transect, including the seabed. This information can be used to determine impact ranges, based on noise exposure criteria.

Since the model does not include backscatter of energy, i.e. echo, it is not suitable for situations where echoes may have significant impact on the result, i.e. if the sound source is placed close to a vertical, reflective surface such as a rock wall.



## 3 Getting Started

### 3.1 General

The purpose of this section is to provide a general checklist which one can use when modelling sound propagation with UAS. The work usually consists of the tasks listed below:

1. Specifying input data
2. Setting up the model
3. Verifying the results
4. Presenting the results

### 3.2 Specifying Input Data

In order to model the sound propagation accurately, UAS needs information about the sound source and the physical environment.

#### 3.2.1 Domain

The domain is defined by the bathymetry described in a dfs1 file (1D-file) and the length of the transect. The bathymetry dfs1 file can be generated by extracting a line from a dfs2 or dfsu file or by using the *Profile series* tool under MIKE Zero toolbox. The length of the transect should be sufficient to ensure that the received sound levels have dropped below the background noise, or below the biological threshold values of interest. See Figure 3.1 for a generic background noise spectrum.

Table 3.1 Typical sound pressure levels at 1 m from the source for various sources ([www.arc.id.au/SoundLevels.html](http://www.arc.id.au/SoundLevels.html)). The corresponding sound exposure level (SEL) can readily be obtained using the time duration of the noise event.

Pressure (dB re 1 $\mu$ Pa)	Underwater sounds
240	Seismic air gun
220	Typical active sonar transmission level Sperm whale click
200	Large ship broadband
180	Dredging ship
170	Fin whale call
160	Large ship broadband (100 m)
120	Fish call (i.e. cod)



Table 3.1 Typical sound pressure levels at 1 m from the source for various sources ([www.arc.id.au/SoundLevels.html](http://www.arc.id.au/SoundLevels.html)). The corresponding sound exposure level (SEL) can readily be obtained using the time duration of the noise event.

Pressure (dB re 1 $\mu$ Pa)	Underwater sounds
100	Ambient noise, sea state 4
80	Ambient noise, sea state 2
60	Ambient noise, sea state 0 (flat calm)
40	
20	
0	

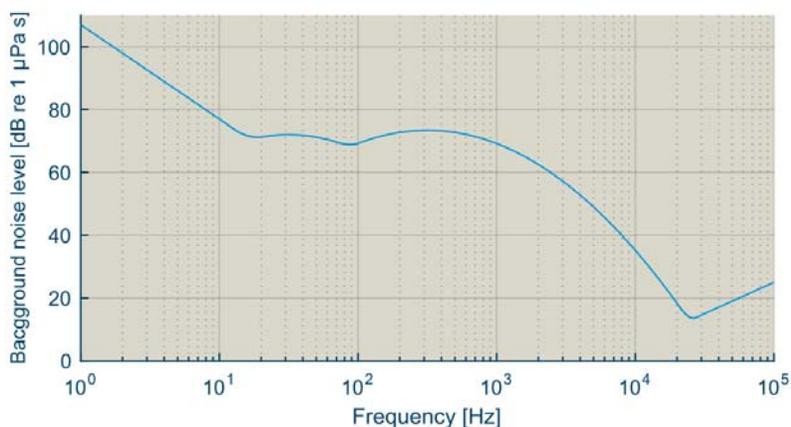


Figure 3.1 Generic background noise spectrum, including turbulence noise, shipping noise, surface agitation noise and thermal noise. (Coates 2006)

### 3.2.2 Spectral Discretisation

UAS is capable of solving the sound propagation of multiple frequencies in a single run, and accounts for frequency sensitivity to environmental properties. This is useful as human made noise sources often are broadband of nature with varying energy level in each frequency band.

The discretisation is specified in either octave bands, 1/3 octave bands, or 1/12 octave bands, with a minimum and maximum centre frequency.

It is possible to define a frequency range from 16 Hz to 40 kHz. Note that computational time increases with increasing frequency. Hence, it is important to determine the maximum relevant frequency.



### 3.2.3 Sound Source

The sound source is defined by its sound level and the location in the water column. The sound source is by definition located on the leftmost boundary of the domain (see Figure 2.1).

The sound level can be defined in three ways:

1. Constant value, i.e. one sound level
2. Spectrum, i.e. the sound energy varies per frequency band, as defined in a dfs0 file
3. Scaled spectrum, the sound level varies per frequency as defined in a dfs0 file, but the overall sound level is defined as a constant

### 3.2.4 Water

The water holds two properties that are important for the propagation of sound: The speed of sound and the attenuation of sound. The sound speed can be described by either a constant value or as a profile in a dfs1 file. The attenuation can be defined in four ways:

1. As a constant value
2. Calculated from constant salinity, temperature and pH
3. As an attenuation profile
4. Calculated from profiles of salinity, temperature and pH

### 3.2.5 Seabed

The seabed is defined as a number of layers of constant thickness, following the seabed. See Figure 2.1. Each layer has four properties:

- Thickness [m]
- Density [kg/m<sup>3</sup>]
- Compressional sound speed [m/s]
- Compressional sound attenuation [dB/λ]

You need to define at least one layer, and it is possible to define as many as you like.

An artificial absorption layer will automatically be added below the defined layers to prevent artificial bottom reflection contaminating the sound field.



### 3.3 Setting up the Model

Setting up the model is actually another way of saying transforming real world events and data into a format which can be understood by the numerical model, UAS.

The set-up of a model is described in more detail in the examples in Section 4, Examples.

### 3.4 Verifying the Results

An important task involved in any modelling project is to verify the results. In the UAS this includes an inspection of the plots of transmission loss for each frequency, and check if everything seems reasonable. As a first check the transmission should in most cases be larger than predicted by the cylindrical spreading law:

$$TL = 10\log_{10}r \quad (3.1)$$

and less than predicted by the spherical spreading law:

$$TL = 20\log_{10}r \quad (3.2)$$

where  $r$  is the distance from the source.

The transmission loss should increase gradually throughout the domain, and the effect of e.g. a seamount or other features of the bathymetry should be visible in the results. Further, the sound should attenuate rapidly in the seabed, especially for frequencies above 250 Hz. On the other hand, volume attenuation should be visible on frequencies above 2 kHz.

### 3.5 Presenting the Results

In the MIKE Zero Plot composer you can create plots of the 2D transect (grid plot) and the 1D profiles (profile plot). See the **Plot Composer User Guide**, Sections 3 and 4.



## 4 Examples

We have included two examples which can be used to get acquainted with UAS.

The specification and data files for the examples are included with the installation of MIKE Zero. For each example a folder is provided. You can use the MIKE Zero start page to install the examples applied with the installation to a directory of your choice. The folder names are as follows:

### Pile driving in the Baltic

.\examples\UAS\BalticWindFarm

### Lloyds mirror

.\examples\UAS\LloydsMirror

### 4.1 Baltic Wind farm

In this example sound emission from impact pile driving is considered at a fictitious wind farm installation located at ~30 m water depth in the Baltic Sea.

#### 4.1.1 Model Description

A 50 km long transect is considered. The noise signature of the pile driving activity is of broad band nature varying from 20 Hz to 1 kHz.

In the water phase the vertical profile of the sound speed depends on salinity temperature and pH for the attenuation.

The seabed consists of a thin layer of sand on a layer of clay before we reach the bedrock.

#### 4.1.2 Setting up the Model

UAS can be started by selecting 'Underwater Acoustic Simulator' from the Start menu. This will open the UAS Editor, Figure 4.1.

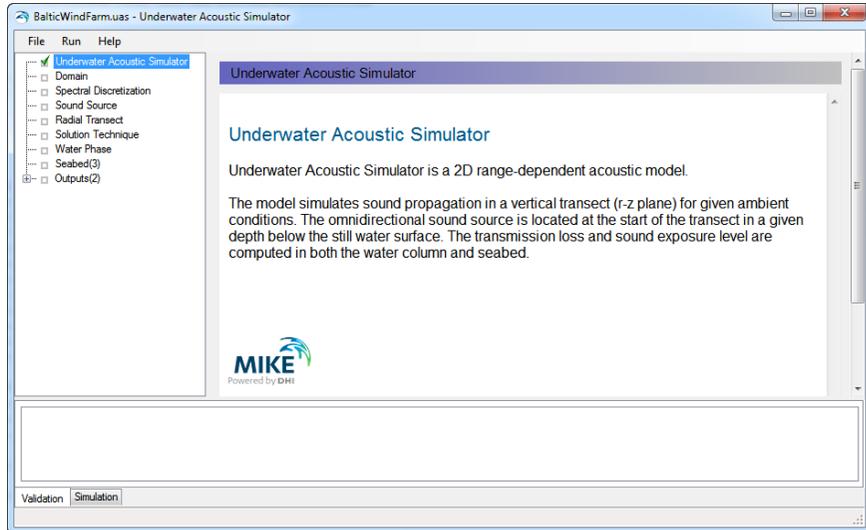


Figure 4.1 UAS Editor

To get help with the dialog pages, one can press F1 at any time.

The set-up is grouped in eight headings:

- Domain
- Spectral discretization
- Sound sources
- Radial transects
- Solution technique
- Water phase
- Seabed
- Outputs

The domain dialog asks for the bathymetry as a dfs1 file. For this example, one selects the BalticBathymetry.dfs1 file, Figure 4.2.

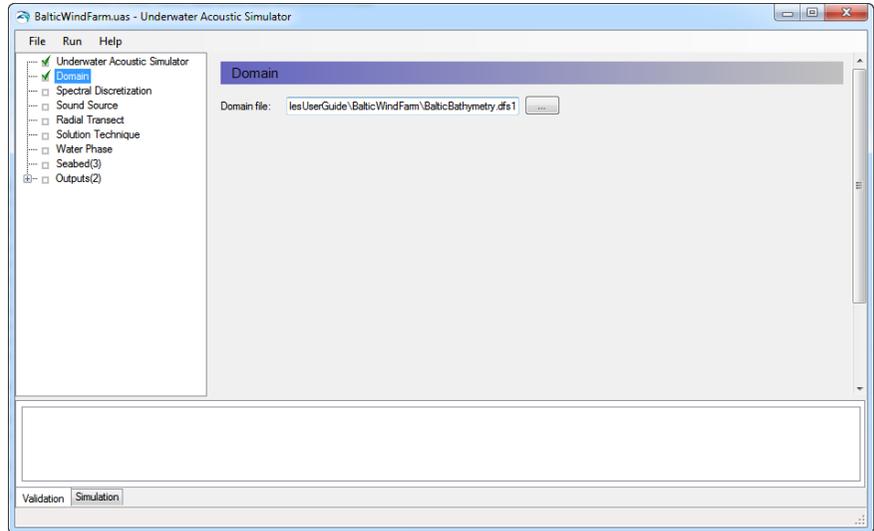


Figure 4.2 Domain pane

When selecting the dfs1 file, one will be prompted to select the correct item, containing the bathymetry, Figure 4.3. In this case, the file only contains one item.

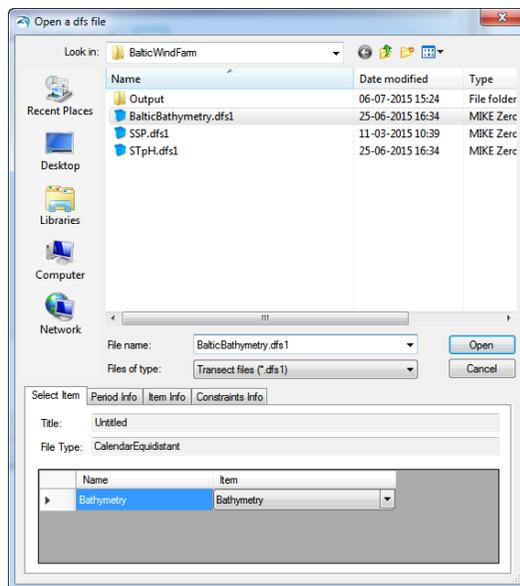


Figure 4.3 Selecting the correct items

For the **spectral discretization** one can choose between 1/1 octave, 1/3 octave, or 1/12 octave bands and centre frequencies from 16-40 kHz. For this example, choose 1/3 octave bands from 20 Hz-500 Hz.



In this example the **sound source** is placed at  $z = -25$  m. The sound source level can be specified either as a constant value in all frequency bands, or by a sound spectrum. Select Format: Spectrum and select the Sound-Source.dfs0 file. Again one will be prompted to select the items for the frequency and sound level, respectively.

There is also the possibility to scale the sound spectrum to a specific overall level. In this example, choose the scaled spectrum to an overall SEL of 204 dB as shown in Figure 4.4.

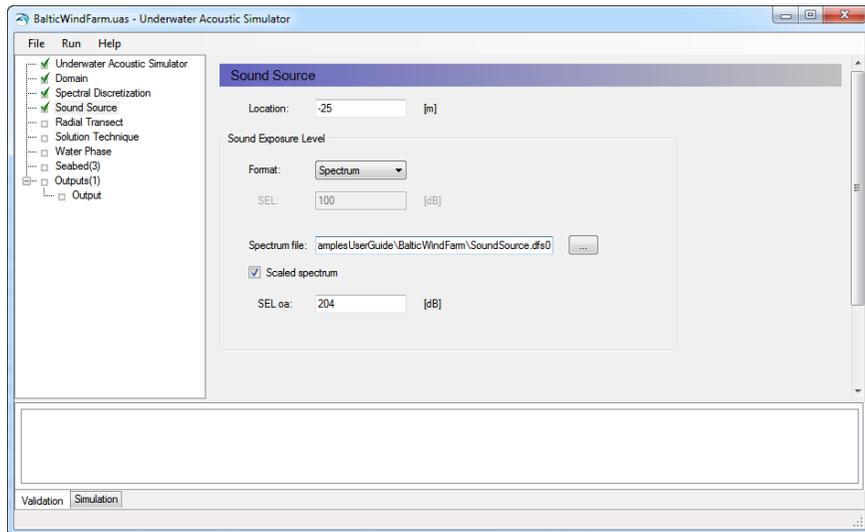


Figure 4.4 Specify sound source

The **Radial Transect** is set to have an overall length of 50000 m. The minimum water depth is kept at the default value. The minimum water depth is used to terminate the calculations if the water depth gets below the specified value. This is useful if the modelled transect is heading towards land.

Proceed to select the **solution technique**. For this case, the *normal* solution is selected.

In the Water Phase panel, define the sound speed profile and the attenuation properties of the water. It is possible to define a constant sound speed, or load the sound speed profile from a dfs1 file. In this example, select *Format: Vertical Profile* and load the SSP.dfs1 file, which contains the sound speed profile in Figure 4.5.

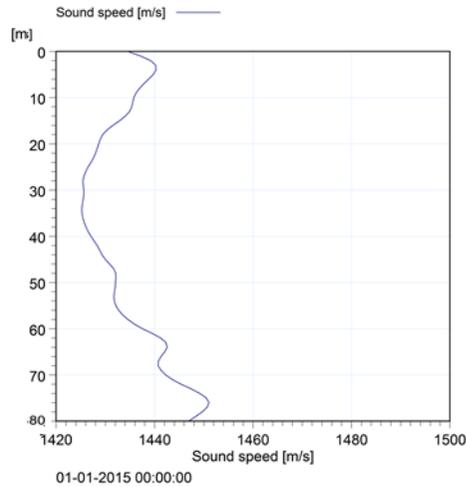


Figure 4.5 Sound speed profile in the Baltic Sea

The attenuation in this example is calculated from vertical profiles of temperature, salinity and pH. Select *Type: Calculated from (T, S, pH)* and *Format Vertical Profile*, and load the STpH.dfs1 file, which contains the profiles from Figure 4.6.

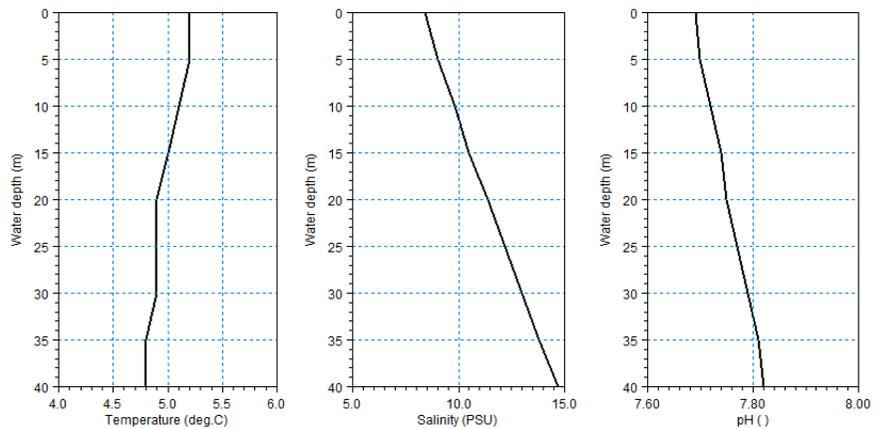


Figure 4.6 Temperature, salinity and pH profiles.

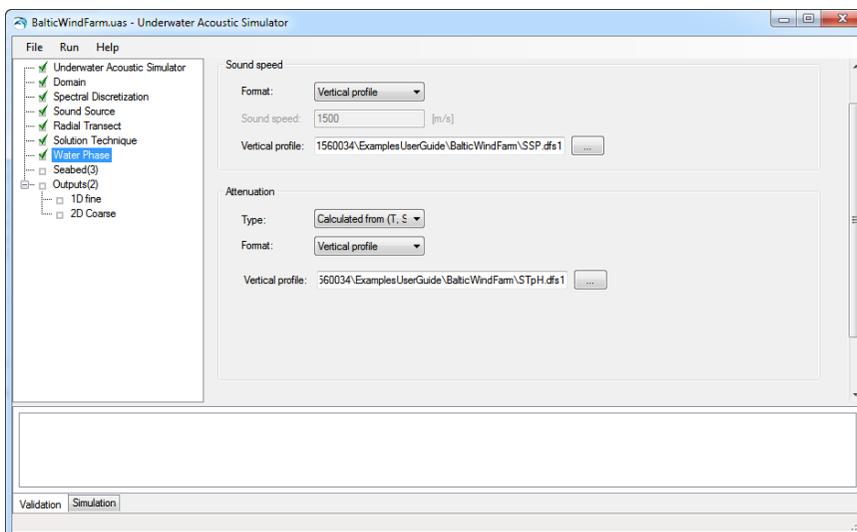


Figure 4.7 Water phase pane

The seabed consists of three layers, as listed in Table 4.1 and Figure 4.8.

Table 4.1 Overview of seabed geo-acoustic profile used for the modelling ( $C_p$  = compressed wave speed,  $\alpha$  = compressional attenuation,  $\rho$  = density)

Layer thickness	Material	Geo-acoustic property
2	Sand	$C_p = 1650$ m/s $\alpha = 0.8$ dB/ $\lambda$ $\rho = 1900$ kg/m <sup>3</sup>
20	Glacial deposits and coarse sediments	$C_p = 1950$ m/s $\alpha = 0.4$ dB/ $\lambda$ $\rho = 2100$ kg/m <sup>3</sup>
10	Hard sediments / bedrock	$C_p = 2400$ m/s $\alpha = 0.1$ dB/ $\lambda$ $\rho = 2200$ kg/m <sup>3</sup>

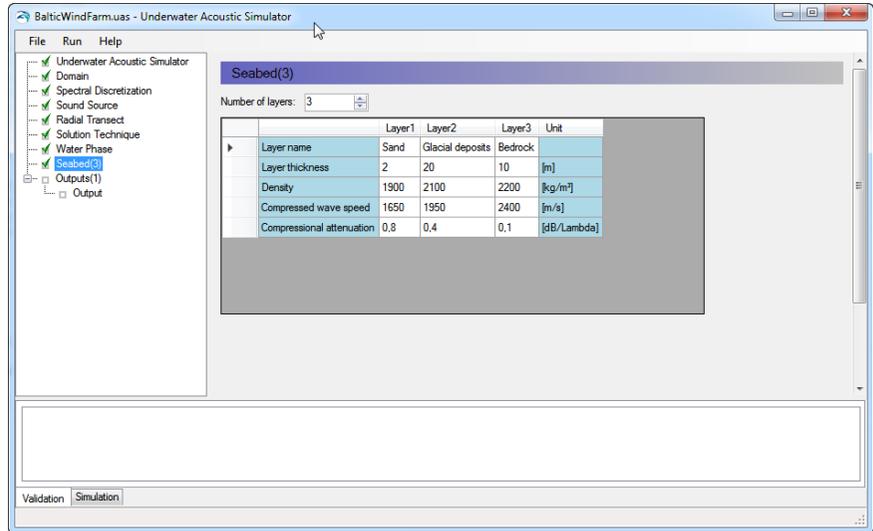


Figure 4.8 Seabed panel

Finally, the **output** can be defined. The output is generated on a *mother grid* which has to be defined by means of horizontal and vertical spacing and maximum depth. The resolution of the data in result files is determined by the mother grid resolution. The length of the domain is defined by the length of the transect.

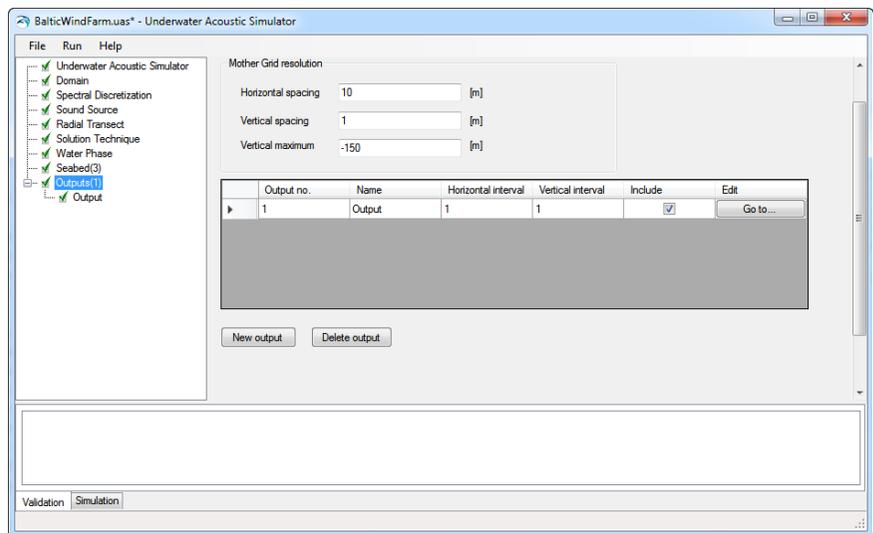


Figure 4.9 Specify mother grid

Click the *New output* button to generate a new output. The output will show up in the table, where the output can be decimated in relation to the mother grid. By pressing “Go to...” the preferred output items can be specified.



In this example a single output is created with decimation factor 1, see Figure 4.9, by pressing the “Go to...” and specifying the location and contents of the 2D and 1D output, respectively. Select the SEL per frequency and overall for the 2D output. For the 1D output select the maximum SEL over depth, per frequency, the depth of the maximum SEL, as well as the overall SEL.

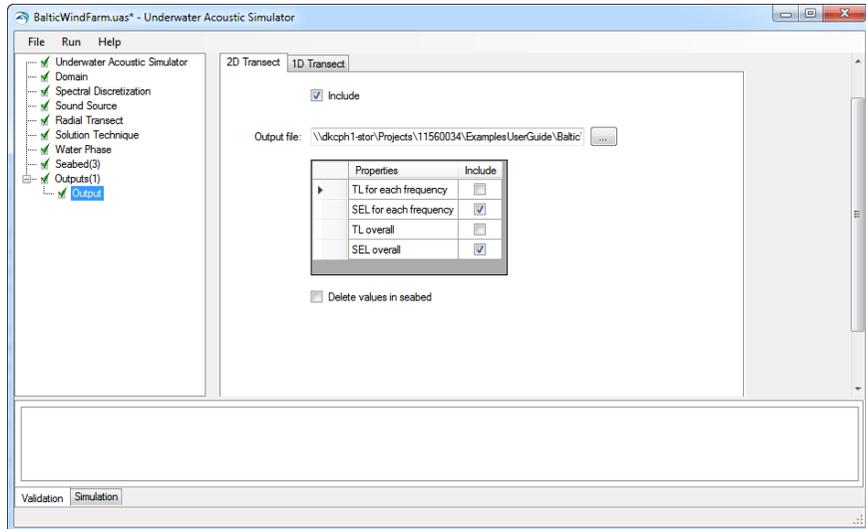


Figure 4.10 Select items for 2D output

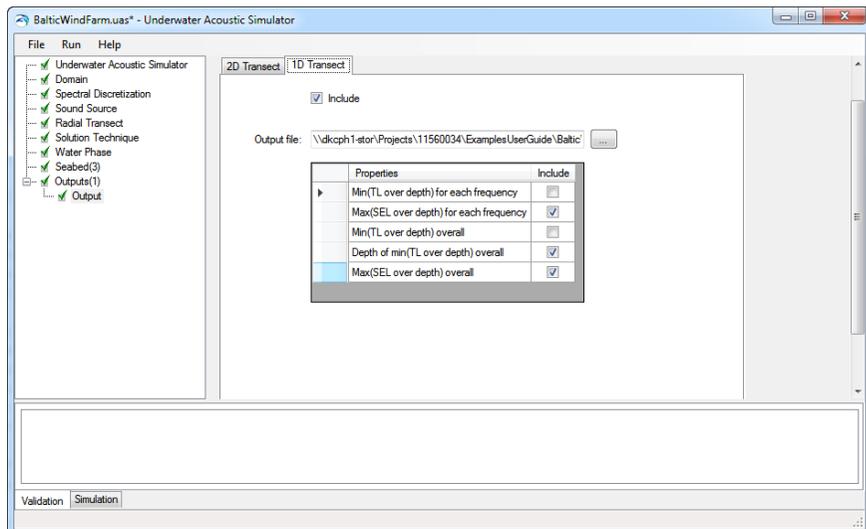


Figure 4.11 Select items for 1D output.

The simulation can now be executed by clicking **Run -> Start simulation**.



When the simulation has finished, check the **Baltic.log** file created in the same folder as the **Baltic.uas** specification file, as it contains information about warnings and errors that may have occurred during the simulation.

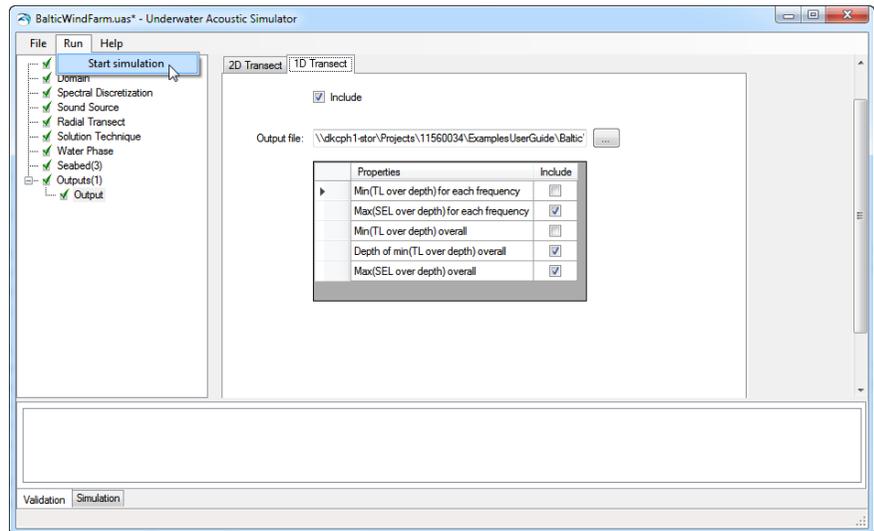


Figure 4.12 Run the simulation

### 4.1.3 Presenting the Results

In the MIKE Plot Composer one can create plots of both transects and lines.

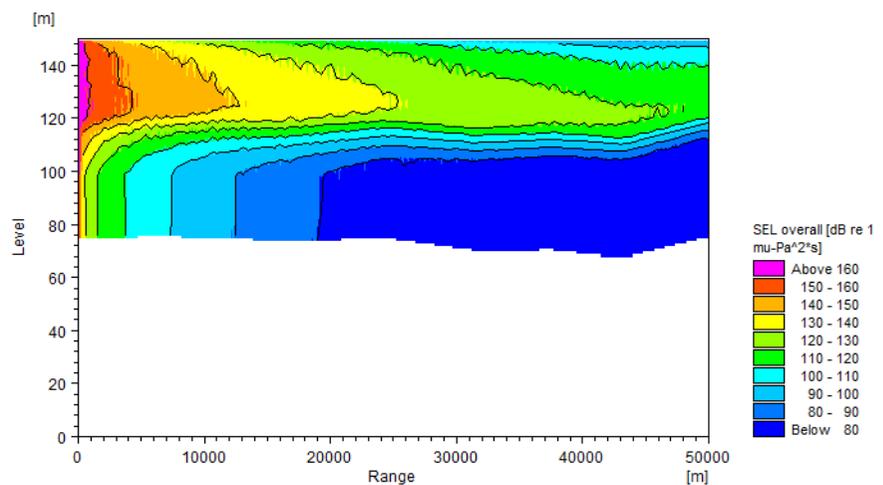


Figure 4.13 Transect plot

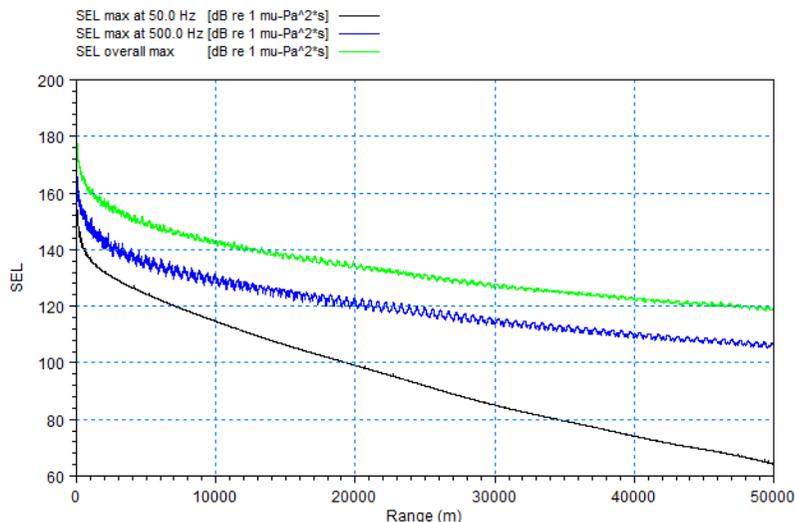


Figure 4.14 Line plot

## 4.2 Lloyds Mirror

This example is a test with an analytical solution (see **UAS Scientific Documentation**).

The Lloyds mirror case simulates the acoustic interference pattern created by a point source placed near a smooth, perfectly reflecting sea surface in a deep water domain with a flat, absorbing bottom. The resulting beam pattern arises as an interference effect between the two possible sound paths from source to receiver, i.e. the direct path and the surface reflected path.

The pattern can be derived analytically, see e.g. (Jensen et al. 2011)

### 4.2.1 Model Description

The model domain has a constant water depth of 5000 m and a maximum range of 30 km. In the water column a constant sound speed of 1500 m/s and an attenuation of zero are applied. In order to minimize reflections at the sea floor the bottom description comprises a bed layer with a thickness of 50 m (sound speed of 1500 m/s; density of 1200 kg/m<sup>3</sup>; compressional attenuation of 0.5 dB/ $\lambda$ ).

### 4.2.2 Setting up the Model

UAS can be started by selecting 'Underwater Acoustic Simulator' from the Start menu. This will open the UAS Editor, Figure 4.15.

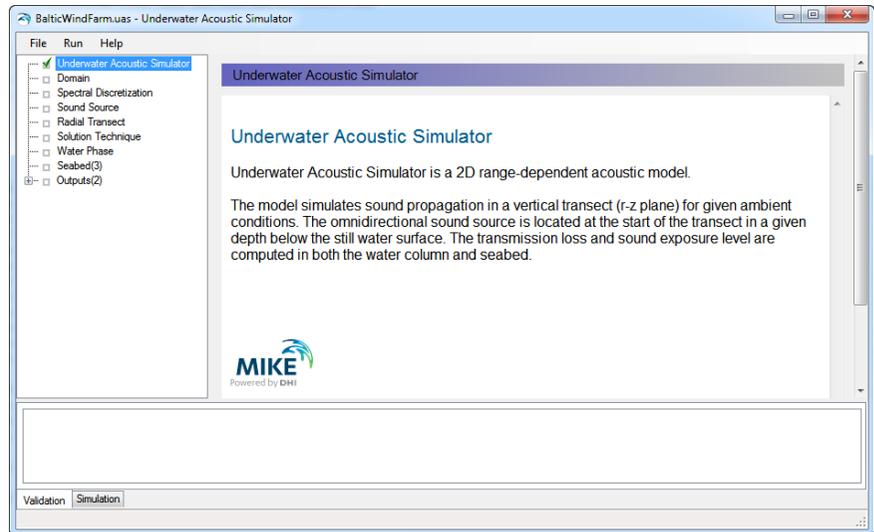


Figure 4.15 UAS Editor

The set-up is grouped in eight headings:

- Domain
- Spectral discretization
- Sound sources
- Radial transects
- Solution technique
- Water phase
- Seabed
- Outputs

The domain dialog asks for the bathymetry as a dfs1 file. For this example, you select the LM\_bathy.dfs1 file. Input files are described in the online-help.

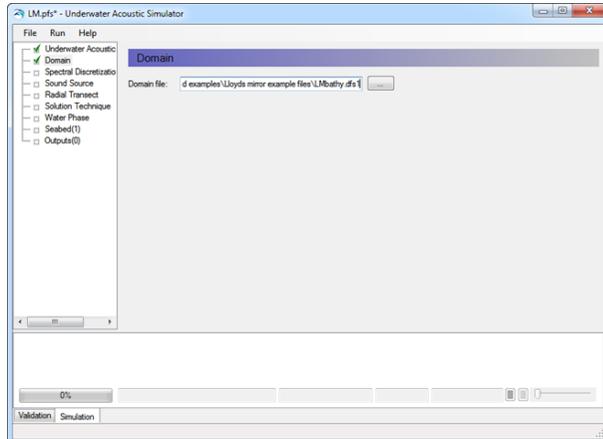


Figure 4.16 Selecting the bathymetry file

For the **spectral discretization** one can choose between 1/1 octave, 1/3 octave, or 1/12 octave bands and centre frequencies from 16-40 kHz. For this example, choose 20 Hz-125 Hz.

In this example the **sound source** is placed at  $z = -10$  m and has a constant sound level of 200 dB re  $1\mu\text{Pa}$  in all frequency bands, Figure 4.17. There is also the possibility to load a dfs0 file with the sound spectrum. Further, one can choose to scale the loaded spectrum to a specified overall sound level.

The **Radial Transect** is set to have an overall length of 30000 m. The minimum water depth is kept at the default value. It does not influence the current model since we have a flat bottom. The minimum water depth is used to terminate the calculations if the water depth gets below the specified value.

Proceed to select the **solution technique**. For this case, the deep water (limited bottom interaction) can be chosen.

The **water phase** is described by a uniform sound speed of 1500 m/s and no attenuation, Figure 4.18. There is also the possibility to load a dfs1 file with a sound speed profile. The attenuation parameter can be defined directly or calculated from temperature, salinity and pH, which in turn can be defined as either constant values or profiles.

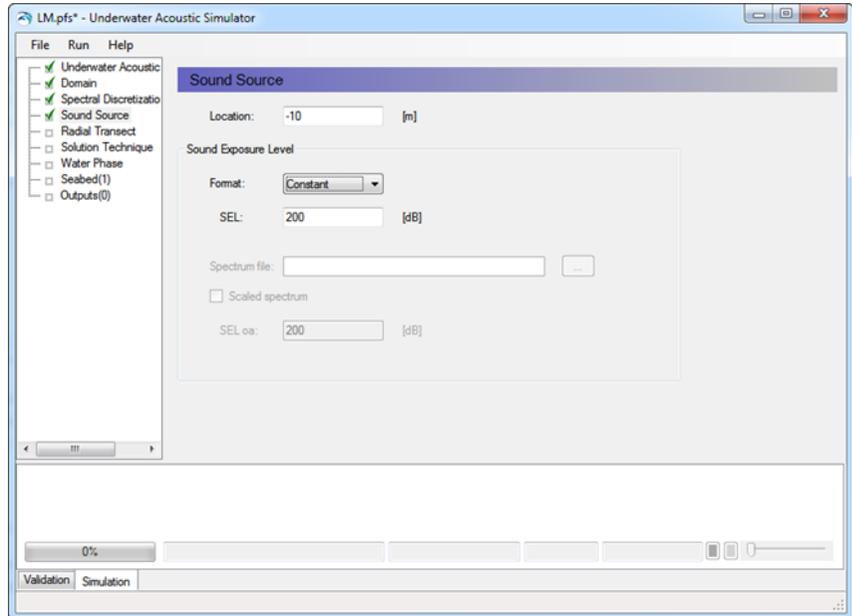


Figure 4.17 Description of the sound source

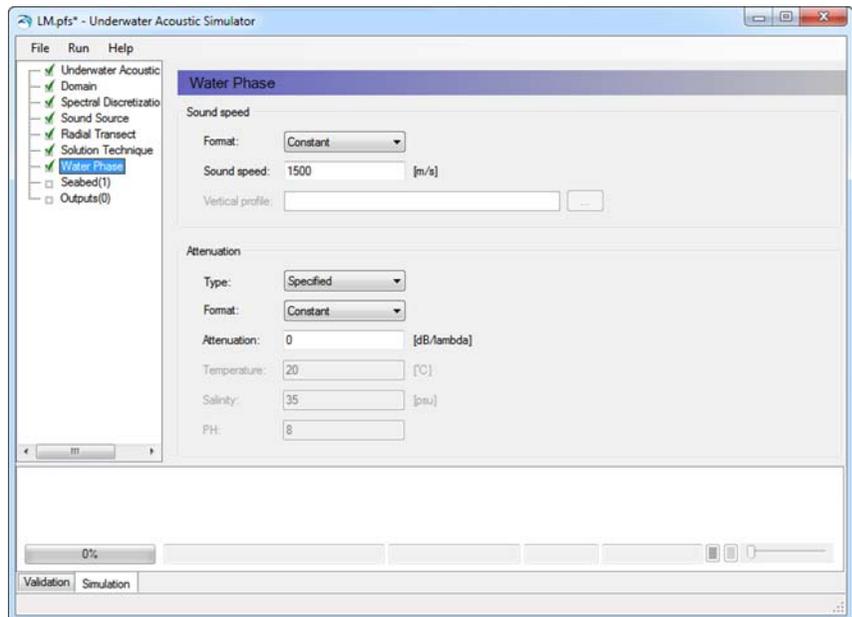


Figure 4.18 Describing the water phase

The **seabed** consists of a single layer of 50 m with the properties described in Section 4.1 and seen in Figure 4.19.

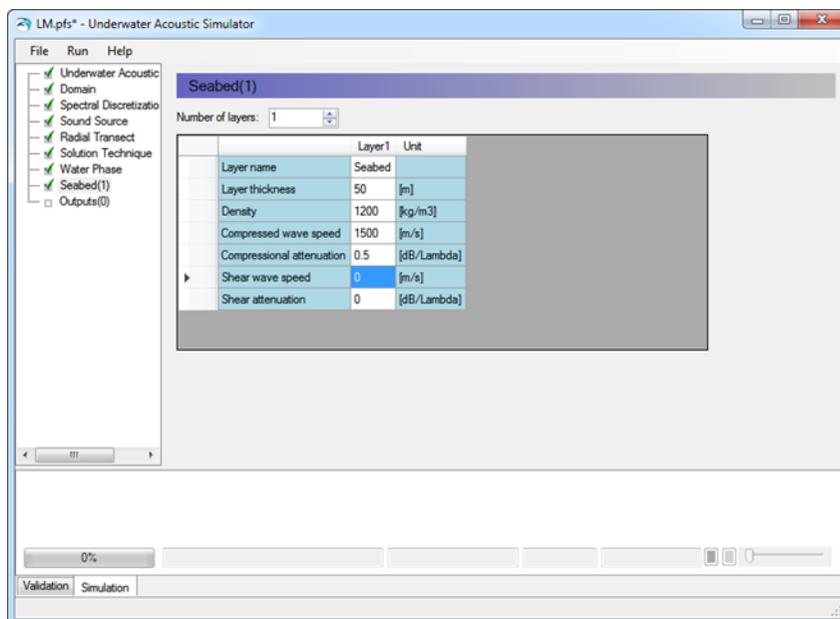


Figure 4.19 Setting up the seabed

Finally, the **output** can be defined. The output is generated on a mother grid which has to be defined by means of horizontal and vertical spacing and maximum depth. The resolution of the data in result files is determined by the mother grid resolution. The length of the domain is defined by the length of the transect.

Click the *New output* button to generate a new output. The output will show up in the table, where the output can be decimated in relation to the mother grid. By pressing “Go to...” the preferred output items can be specified.

For 2D output one can choose between Sound Exposure Level (SEL) and Transmission Loss (TL) either overall or per frequency or both. In this case we are interested in the SEL, both overall and per frequency, Figure 4.20. The option Delete values in seabed will place deleted values in the seabed, instead of the actual sound level. This is useful when plotting the transects if one is only interested in the sound levels in the water column.

For 1D output, we choose the maximum SEL over depth, and the location of minimum TL in the depth, see Figure 4.21.

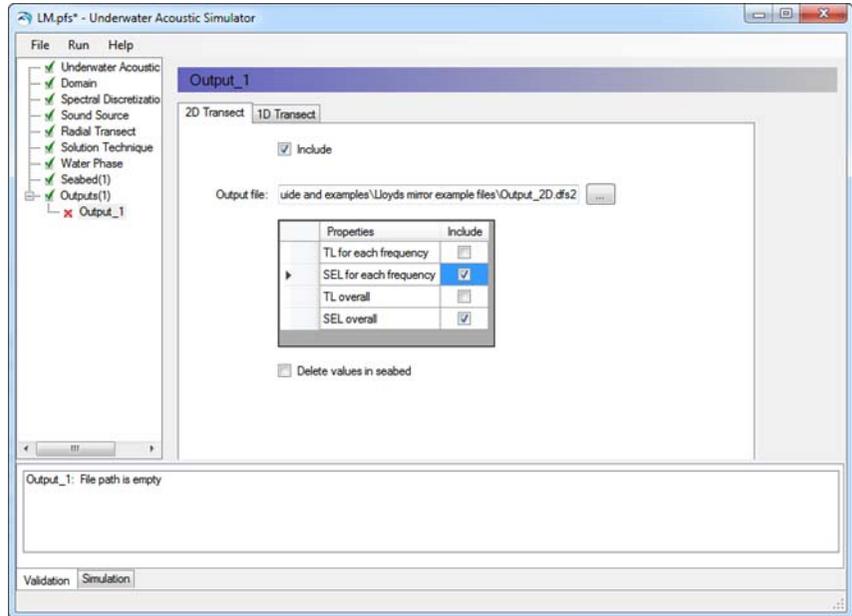


Figure 4.20 2D output selection

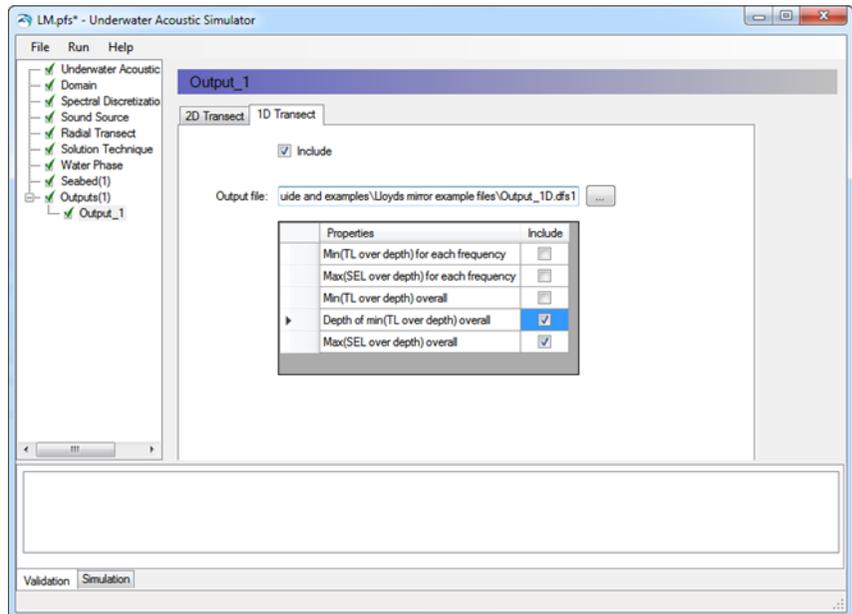


Figure 4.21 1D output selection

The simulation can now be executed by clicking Run -> Start simulation.



When the simulation has finished, you should check the LM.log file created in the same folder as the **LM.uas** specification file, as it contains information about warnings and errors that may have occurred during the simulation.

### 4.2.3 Presentation of Results

The model run has resulted in a dfs2 file with transects of SEL per frequency and overall, as well as a dfs1 file containing the line plots. You can plot and inspect the results in the MIKE Plot Composer.

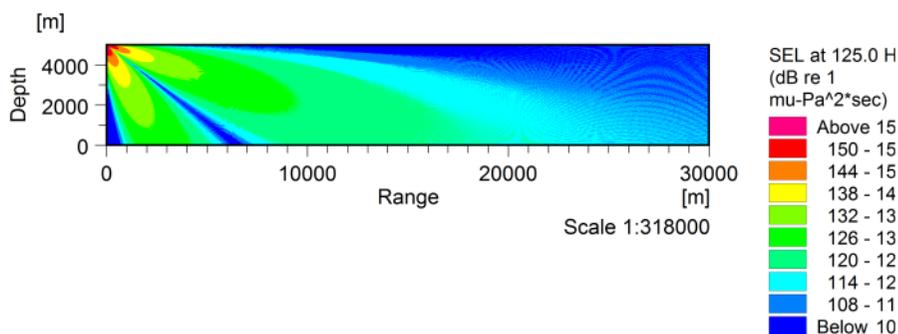


Figure 4.22 Transect plot of received SEL

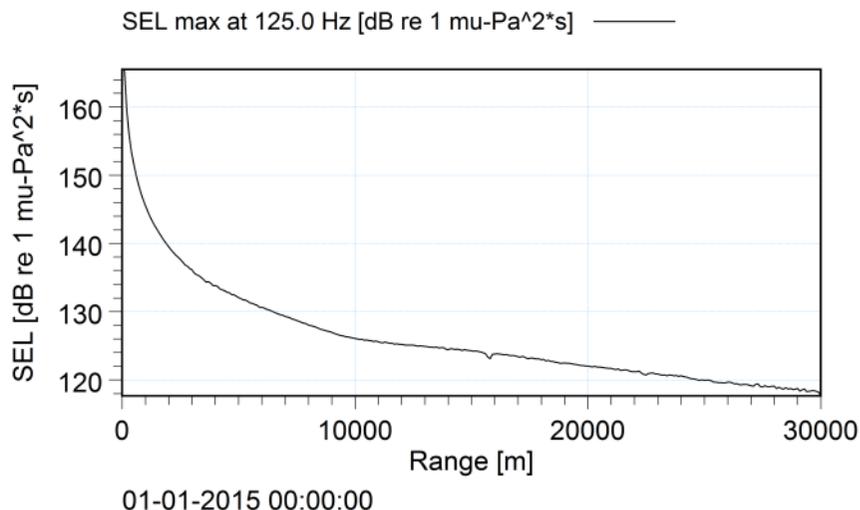


Figure 4.23 Line plot of received maximum SEL over depth.



## 5 Pro Tips

- By calculating the sound propagation along a number of transects originating from the same point, it is possible to create a pseudo 3D sound field and generate *sound maps*.
- UAS is only capable of running on a single core. If you have a multi core computer, you can run multiple simulation simultaneously by the use of a .bat file.

E.g. for running the two examples in the installation simultaneously you can create a .bat file in the UAS/BalticWindFarm folder with the following contents:

```
set Path=%Path%;%DHI_MIKE_2017%
start EngineUAS.exe BalticWindFarm.uas -x
start EngineUAS.exe ../LloydsMirror/LM.uas -x
```





## 6 Underwater Acoustic Simulator

### 6.1 Introduction

Underwater Acoustic Simulator (UA) is a 2D range-dependent acoustic model simulating sound propagation in a vertical transect (r-z plane) for given ambient conditions. The omnidirectional sound source is located at the start of the transect in a given depth below the still water surface. The transmission loss and sound exposure level are computed in both the water column and seabed.

### 6.2 Domain

The model bathymetry defines the geographical extent of the model in both horizontal and vertical direction. The level of the sea bed may vary along the horizontal computational transect.

The model bathymetry is specified as a dfs1 file with one item of type 'Bathymetry' representing the level of the sea bed. The spatial information of the file (number of grid points and grid spacing) defines the horizontal axis (r-axis for range) of the model starting at r=0. The vertical datum of the model bathymetry is mean sea level (MSL) and the vertical axis is positive upwards meaning that the bathymetry level have to be specified as negative values in the file.

### 6.3 Spectral Discretization

The model represents a certain sound spectrum by a number of frequency bands and their associated center frequencies. The frequency bands to be included in the simulation are defined by specifying the frequency resolution in terms of octave bands (1/1, 1/3 or 1/12 octave bands) as well as start and end frequencies.

### 6.4 Sound Source

The sound source is per definition located at the start of the computational transect (at r=0). The depth of the source relative to mean sea level is however specified by the user. The source may be located both in the water column and in any specified bed layers. Notice that the depth (z-level) has to be given as a negative number in meters.

The sound exposure level (SEL) at the source is specified as a constant for all frequencies or as a dfs0 file with relative axis containing pairs of frequency (Hz) and SEL (dB re 1  $\mu\text{Pa}^2\text{s}$ ) representing the sound spectrum. If SEL is given as a file the spectrum may optionally be scaled to fit a specified overall sound exposure level.



## 6.5 Radial Transects

The extent of the model transect may be adjusted by specifying an overall length (in meters), which is shorter than the transect length defined by the bathymetry file. In that case the length of the computational transect is reduced to the specified overall length.

Similarly a minimum water depth (meters) may be specified. In case the specified bathymetry contains water depths smaller than the minimum water depth the length of the transect is reduced to exclude the smaller water depths.

## 6.6 Solution Technique

The model includes two options for the numerical settings of the model:

- Normal
- Deep water (limited bottom interaction)

The deep water option is faster, but is only recommended for deep water cases with limited bottom interaction. As a rule of thumb, more than 200 [m] depth in the model can be considered as deep water model.

## 6.7 Water Phase

The water phase parameters comprise speed of sound and attenuation.

The speed of sound (m/s) in the water column may be specified as a constant both horizontally and vertically or as a dfs1 file representing the vertical profile. The spatial axis of the dfs1 file starts at the water surface (mean sea level) and points downward.

The attenuation (dB/lambda) in the water column is specified directly or as a function of temperature (°C), salinity (PSU) and pH in the water column and, similar to the speed of sound, it may be specified as a constant or as a dfs1 file representing the vertical profile. This means that there are 4 ways to specify the attenuation:

- Attenuation as constant;
- Attenuation as dfs1 file;
- Temperature, salinity and pH as constants;
- Temperature, salinity and pH as dfs1 file.

If temperature, salinity and pH is defined, the attenuation is derived from the model given by Francois and Garrison (1982)



## 6.8 Seabed

The seabed is defined as a number of horizontal layers each defined by:

- Name
- Thickness (m)
- Density (kg/m<sup>3</sup>)
- Compressed wave speed (m/s)
- Compressional attenuation (dB/lambda)

The different parameters are specified as constants per layer meaning that they vary between the layers but not horizontally or within the layer.

## 6.9 Output

The user may specify a number of output files containing various model output variables.

First the resolution (horizontal and vertical spacing in meters) and lower limit (vertical maximum given as a negative value in meters) of the so-called 'mother' (solution) grid is defined. During simulation the model solution corresponding to each included frequency is interpolated to the mother grid and after simulation the data of the mother grid may be saved to the output files. The resolution of the mother grid hereby defines the highest resolution of the output files and the extent of the mother grid defines the extent of the output files.

**Hint:** The resolution of the mother grid should be chosen to adequately resolve the relevant characteristics of the simulated sound field pattern. For higher frequencies the sound field pattern will generally contain more detail, and therefore a relatively finer mother grid may be considered

Next the number of outputs is specified. For each output the horizontal and vertical intervals defining the resolution of the output relative to the mother grid are given. Each output is further defined by clicking the Go to-button.

### 6.9.1 Output files

For each output both a 1D and 2D transect output file may be included. The 2D transect file is a dfs2 file and may include transmission loss (TL) and sound exposure level (SEL) for each frequency and for the whole spectrum (overall). Further the 2D transect file may include or exclude values in the seabed. The 1D transect file is a dfs1 file and may include

- Minimum TL over depth for each frequency and overall,
- Maximum SEL over depth for each frequency and overall and



- The depth of the minimum TL over depth overall.



## 7 References

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