WS Wave Analysis Tools

User Guide

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CONTENTS

1   About This Guide

1.1   Purpose

The main purpose of this User Guide is to enable you to use the modules included in the WS Wave Analysis Tools package for analysis of data originating from physical model tests, field measurements or numerical simulations.

The following section, Section 2, Introduction, gives you a short description of the tools included in the WS Wave Analysis Tools package and the type of analysis they can be applied for.

Section 3 provides a dialog walk through for the WS Linear Spectral Analysis module including a description of the parameters appearing in the dialogs. The WS Digital Filtering Analysis module is described in Section 4, and Section 5 covers the WS Directional Wave Analysis module. Both modules are particularly useful for spatial analysis of numerical model data. Section 6 provides a walk through of the dialogs included in the WS Crossing Analysis module. The WS Reflection analysis module is described in Section 7. Besides the traditional reflection analysis the WS AWACS Reflection Analysis module covered in Section 8 is available. As a supplement to the digital filtering tool the WS Trend Removal module described in Section 9 may be applied.

An INDEX is found at the end of this User Guide.

1.2   Assumed User Background

Although the modules in WS Wave Analysis Tools have been designed carefully with emphasis on a logical and user-friendly interface, and although the User Guide contains procedures and various descriptions, common sense is always needed in any practical application.

In this case, "common sense" means a background in wave mechanics which is sufficient for you to be able to check whether the results from WS Wave Analysis Tools are reasonable or not. This User Guide is not intended as a substitute for - and it cannot replace - a basic knowledge of the area in which you are working: advanced time series analysis.

It is assumed that you are familiar with the basic elements of MIKE Zero file types and editors, the Plot Composer and the MIKE Zero Toolbox.

2   Introduction

2.1   Short Description

The WS Wave Analysis Tools (WSWAT) package includes a number of advanced modules for detailed wave analysis of time series data from physical model tests, numerical simulations or field measurements. WSWAT is developed and maintained by DHI and is based on DHI's well-established Wave Synthesizer technologies[1].

The package is integrated into DHI's well-known MIKE Zero framework, which in addition to giving you access to various modelling systems contains a large number of facilities for data editing and visualisation.
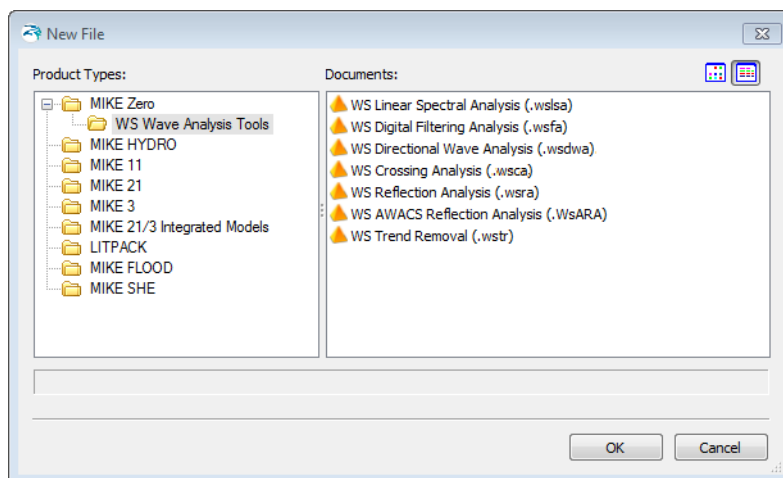
Figure 2.1   WS Wave Analysis Tools package is included in DHI's common framework MIKE Zero.

WS Wave Analysis Tools package includes following modules:

- WS Linear Spectral Analysis
- WS Digital Filtering Analysis
- WS Directional Wave Analysis
- WS Crossing Analysis
- WS Reflection Analysis
- WS AWACS Reflection Analysis
- WS Trend Removal

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1 See http://www.dhigroup.com/Solutions/MarineInfrastructureAndEnergy/ModelTestingTechnology.aspx for further information on DHI Model testing technologies
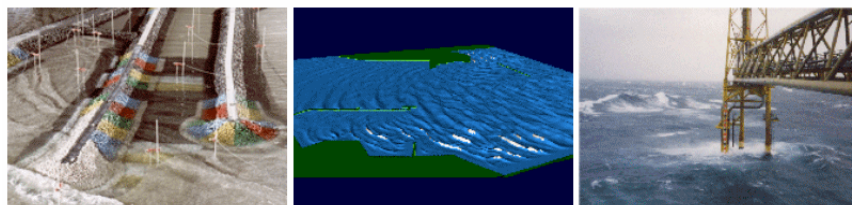
Figure 2.2   The WS Wave Analysis Tools can be used for analysis of time series data from physical model tests, numerical model simulations or field measurements

2.1.1   WS Linear Spectral Analysis module

With the WS Linear Spectral Analysis module it is possible to perform linear frequency domain analyses based on the Fast Fourier Transform (FFT) of time series data. Hence, it is presumed that the time series is a superposition of an infinite number of infinitesimal amplitude waves with uniformly and randomly distributed phases.

The module supports time series data of dfs0 type.

2.1.2   WS Digital Filtering Analysis module

The WS Digital Filtering Analysis module provides different digital filter options. Basically filtering is a process of selecting, attenuating, or suppressing certain frequency components of a time series signal by a desired amount, allowing a digital filter to shape the frequency spectrum of the signal.

The module uses a class of filters called Finite Impulse Response (FIR) filters also known as non-recursive filters. These filters are characterised by filter coefficients (in the time domain), which are derived from specified transfer functions in the frequency domain. The actual filter operation takes place in time domain by convoluting the input time series and the filter coefficients.

The module supports time series data of dfs0 and dfs2 type. This allows you to perform digital filtering analysis of grid time series from numerical model results, e.g. MIKE 21 BW Boussinesq Waves.

2.1.3   WS Directional Wave Analysis module

The WS Directional Wave Analysis module is an efficient tool for directional analysis of concurrent data of surface elevation and orthogonal velocities (or fluxes). The module is based on the Maximum Entropy Method (MEM) as described by Nwogu et al. (1987).

The module supports time series data of dfs0 and dfs2 type. This allows you to perform directional wave analysis of grid time series numerical model results, e.g. MIKE 21 BW Boussinesq Waves.

2.1.4   WS Crossing Analysis module

The WS Crossing Analysis module is a generalisation of the classical zero-crossing analysis. For a predefined threshold, the input time series item is divided into events, each of which is defined by the time series value crossing the reference level in upwards (or downwards) direction.

The module supports time series data of dfs0 type.

2.1.5   WS Reflection Analysis module

With the WS Reflection Analysis Module it is possible to perform a wave reflection analysis in connection with flume model tests. The analysis requires measurements from two or more wave gauges as basis for a frequency domain separation of the measured wave time series to provide an average spectrum of the incident and reflected waves.

The module supports time series data of dfs0 type.

2.1.6   WS AWACS Reflection Analysis module

The WS AWACS Reflection Analysis module is based on the feedback from DHI's digital wavemaker controller (AWACS) capable of determining the wave reflection and evaluating the wavemaker performance.

The analysis is based on the theory of the active absorption technique for the wavemaker controller (see Schäffer & Hyllested (1999)).

The module supports time series data of dfs0 type as generated by the AWACS wavemaker controller unit in DHI Wave Synthesizer.

2.1.7   WS Trend Removal module

The WS Trend Removal module complements the WS Digital Filtering Analysis module, as it is capable of removing trends that due to their infinite length not can be removed by traditional filtering.

The module supports time series data of dfs0 type.

3 WS Linear Spectral Analysis

3.1 Introduction

With the WS Linear Spectral Analysis module it is possible to perform linear frequency domain analyses based on the Fast Fourier Transform (FFT) of time series data. Hence, it is presumed that the time series is a superposition of an infinite number of infinitesimal amplitude waves with uniformly and randomly distributed phases (Goda, 1985).

The module provides the following spectra:

1. Auto spectrum
2. Cross spectrum (amplitude and phase)
3. Cross spectrum (real and imaginary parts)
4. Frequency response spectrum (gain and phase)
5. Coherent power spectrum
6. Coherence spectrum

The auto and cross-spectra, which correspond to the second moment of the time series, are used for generation of the remaining spectra. Spectra 2 through 6 are dual analyses and require two sets of time series data. For spectra 4 and 6 it is furthermore necessary to distinguish between input and output time series as the order makes a difference.

The analysis is based on the methods and definitions described in Bendat & Piersol (1986 and 1993).

The spectral analysis can be applied to data from:

- Physical model tests
- Field measurements
- Numerical simulations
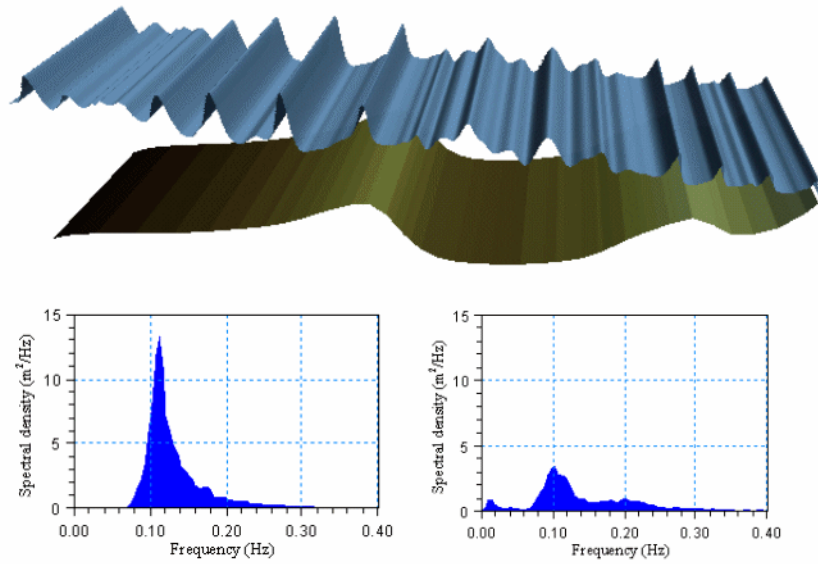
Figure 3.1   Transformation of irregular non-linear waves over a natural barred beach profile (upper panel) - simulations made by MIKE 21 BW. Offshore (left) and onshore (right) frequency wave spectra (lower panels) estimated by WS Linear Spectral Analysis module

3.2   Input File
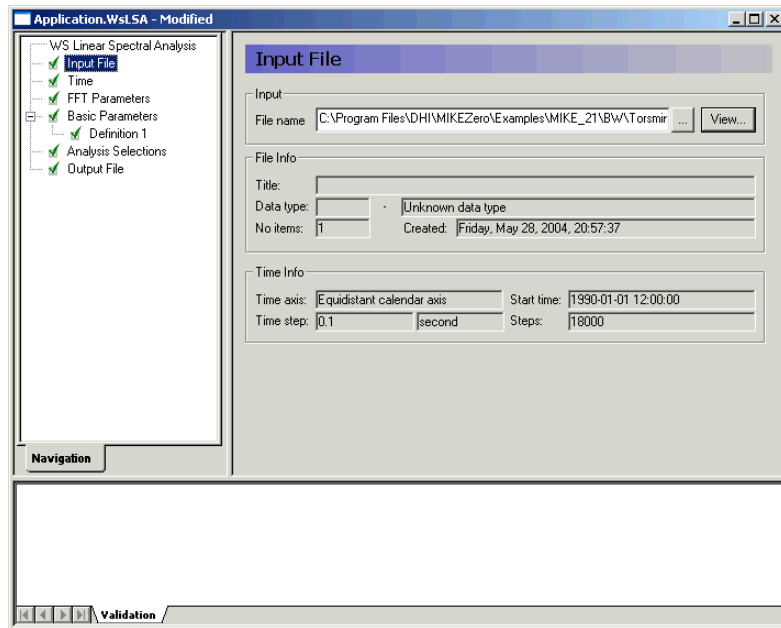
Figure 3.2   Input File dialog

The WS Linear Spectral Analysis module supports time series data with equidistant time step. At present the following two binary file formats are supported:

- dfs0 (DFS data file format)
- dt0 (old file format)

Please note that dt0 is included for backward compatibility, only.

Whenever the editor recognises the used file format an info box containing the files header information appears in the lower half of the dialog.

You can view the selected data file using the MIKE Zero Time Series editor by clicking on the "View" button.

3.3 Time

Figure 3.3   Time dialog

The period to be covered by the analysis is specified in the *Time* dialog.

3.3.1 Remarks & hints

For wind-waves it is recommended to perform spectral analysis on time periods greater than approximately 20 minutes. For longer period waves and low-frequency oscillations a longer analysis time is required for reliable estimation of the spectral parameters.

3.4 FFT Parameters
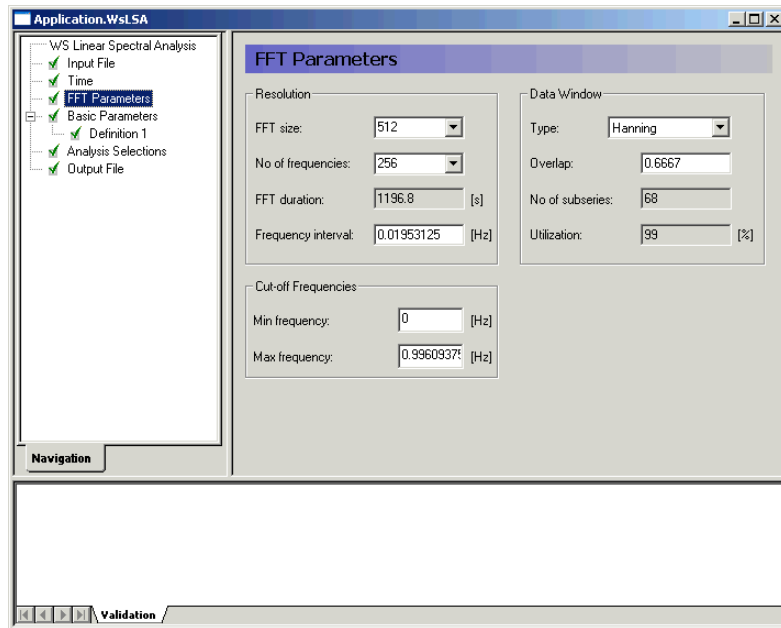
Figure 3.4   FFT Parameters dialog

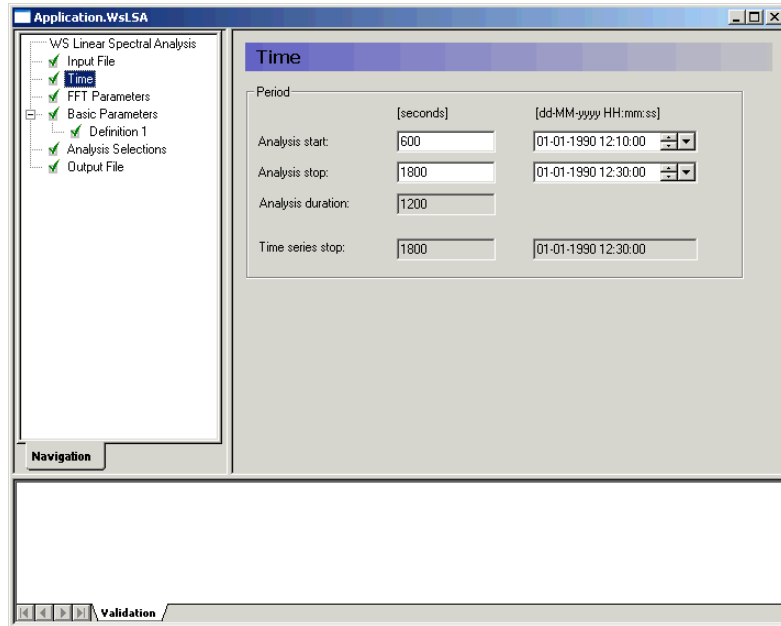The parameters given in the *FFT Parameters* dialog determines the frequency resolution and the degree of smoothing of the spectrum.

3.4.1 Resolution

FFT size:
Number of data points in each FFT block or subseries. The length must be a power of two and cannot exceed the total number of data points.

NOTE: A practical limit for the FFT size is 8192 in a 64 bit application. See also Number of subseries (p. 20).

Number of frequencies:
Is half of the FFT size

FFT duration:
Gives the length of the FFT analysis in seconds

Frequency interval:
The difference between two discrete adjacent frequencies. If manually changed, the value is automatically adjusted to the nearest possible value (function of time step and FFT size)

3.4.2 Data window

A phenomenon known as side-lobe leakage may lead to pronounced interaction between different frequencies with distorted spectra as a consequence. Applying a data window in the spectral analysis may reduce the influence of side-lobe leakage. The data window is a weight function used to taper a time series before the FFT analysis is initiated.

Type
Three different data windows are available:

- rectangular data window (i.e. without tapering)
- Hanning data window (default)
- Cosine squared

Overlap
The spectra (and response functions) are calculated using overlapping sub-series. The overlap controls the smoothing of spectra, but it also controls the weighting of the different parts of the input time series.

A value of zero corresponds to no overlap and with increasing overlap as the value tends towards unity. An overlap of 2/3 is used as default.

Number of subseries
Based on the specified FFT parameters the number of subseries can be calculated. It is almost always desirable to have a large number of subseries because it will reduce the variance of the spectral density and provide a smooth spectral estimate.

For non-overlapping time series the number of degrees of freedom for the spectral estimate is two times the number of subseries. Spectral estimates having 30-40 degrees of freedom is often used in practice.

Utilisation
Indicates the utilisation of the input data.

3.4.3 Cut-off frequencies

The cut-off frequencies determine the frequency range for which the spectra and spectral results are calculated.

Minimum frequency
The minimum cut-off frequency must be greater than or equal to zero.

Maximum frequency

The maximum cut-off frequency must be less than or equal to the Nyquist frequency, which is determined entirely by the sampling frequency f_s of the input data:

$$f_{max} = 0.5\, f_s = \frac{1}{2\Delta t}$$

<div align="right">(3.1)</div>

Here Δt is the time step of the input data. If the value is out of range a warning is issued and the invalid maximum cut-off frequency is automatically adjusted to the Nyquist frequency.

3.4.4 Remarks & hints

Please note that if data window tapering is omitted, pronounced interaction between frequencies might occur due to side-lobe leakage. It is recommended to use the Hanning data window for all practical applications.

It is important to realise that the various dialogs are all synonyms for the FFT size, and that changing one parameter also will affect the others.
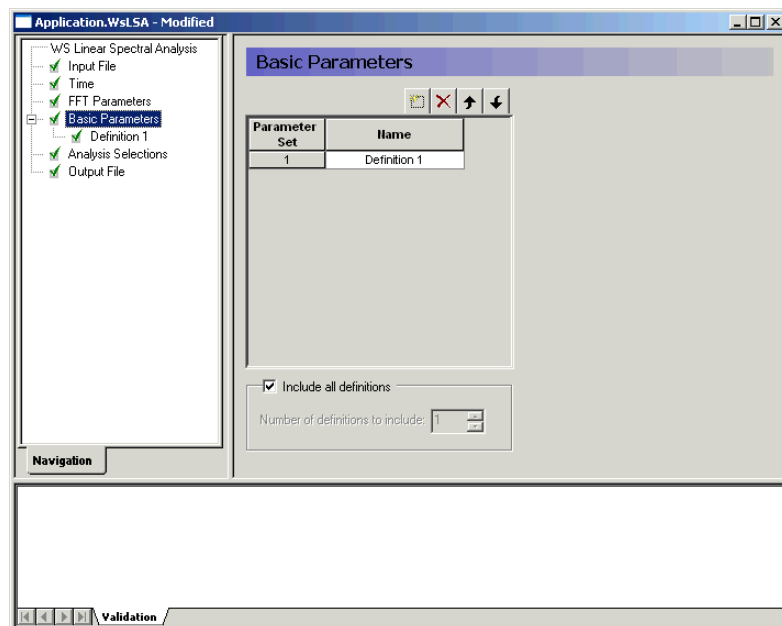
3.5 Basic Parameters

Figure 3.5   Basic Parameters dialog

In the *Basic Parameters* dialog you specify the name of the various parameter-setting definitions.

3.5.1 Parameter definition
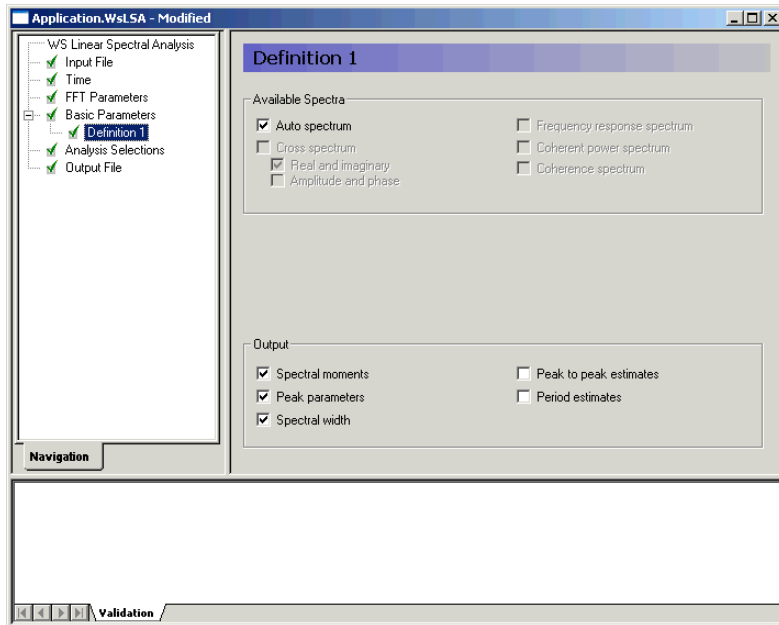
Figure 3.6   Parameter Definition dialog

For each specified *Definition* you select the spectra and the output to be calculated.

Available Spectra

Auto spectrum

The auto spectrum gives the spectral density of the variance of the time series as a function of the frequency. The auto spectrum is also referred to as the frequency spectrum, power spectrum or variance spectrum.

Cross-spectrum

The cross-spectrum gives the correlation between the input and output time series, i.e. for frequencies with spectral values of zero the input and output is completely uncorrelated. For positive phase angles the output time series leads to the input time series and vice versa. Output is available as amplitude and phase values or real and imaginary parts of the generally complex spectra.

Frequency response spectrum

The frequency response spectrum describes the relation between input and output time series at a given frequency by a gain factor and a phase, i.e. amplification and phase shift of the input signal.

Coherent power spectrum

The coherent power spectrum, which is a product of the coherence spectrum and the auto spectrum, gives the part of the spectral density in the output time series that is due to the input time series.

Coherence spectrum

The coherence spectrum may be interpreted as the fraction of the output time series that is linearly due to the input time series. A spectral value of unity at a given frequency indicates a fully linear coupling, whereas for zero value no linear relationship can be expected. Values between zero and unity indicates that the time series are noise-affected, the relation between the time series are not linear or the output time series is a function of several input time series.

Output

You specify which type of integral spectral parameters to be calculated. The estimates are saved in the log file, which as default is automatically opened after execution.

Spectral moments

The first four spectral moments are calculated. The spectral moment is defined as

$$m_n = \int_{f_{min}}^{f_{max}} S_X(f) \; f^{\,n} \; df \qquad (3.2)$$

where $S_X(f)$ is auto spectrum and f frequency.

Peak parameters

The spectral peak frequency f_p is the frequency corresponding to the maximum spectral density.

The spectral peakedness factor Q_p is defined as

$$Q_p = \frac{2}{m_0} \int_{f_{min}}^{f_{max}} f \, |S_X(f)|^2 \; df \qquad (3.3)$$

Q_p describes the peakedness of a wave spectrum. Q_p is infinity for a single or extremely narrow-banded spectrum and is unity for a white noise spectrum

Spectral width

The spectral width (or broadness) parameter is defined as

$$\varepsilon_4 = \sqrt{1 - \frac{m_2^2}{m_0 m_4}} \qquad (3.4)$$

Peak-to-peak estimates

The significant wave height is defined as

$$H_{m0} = 4\sqrt{m_0} \qquad (3.5)$$

The wave height with exceedance probability of p is defined as

$$H_p = \sqrt{8 m_0 \ln \frac{1}{p}} \qquad (3.6)$$

where p is set to 10%, 1%, 0.1% and 0.01%.

Period estimates

The peak wave period T_p defined as

$$T_p = \frac{1}{f_p} \qquad (3.7)$$

where f_p is the frequency corresponding to the maximum spectral density.

The mean wave period T_{01} defined as

$$T_{01} = \frac{m_0}{m_1} \qquad (3.8)$$

The mean wave period T_{02} defined as

$$T_{02} = \sqrt{\frac{m_0}{m_2}} \qquad (3.9)$$

The mean wave period T_{24} defined as

$$T_{24} = \sqrt{\frac{m_2}{m_4}} \qquad (3.10)$$

3.5.2 Remarks & hints

It should be noticed that all peak-to-peak estimates are based on the assumption that wave heights are Rayleigh distributed.

The parameters and estimates generally follow the nomenclature given by the International Association for Hydraulic Research (IAHR, 1986).
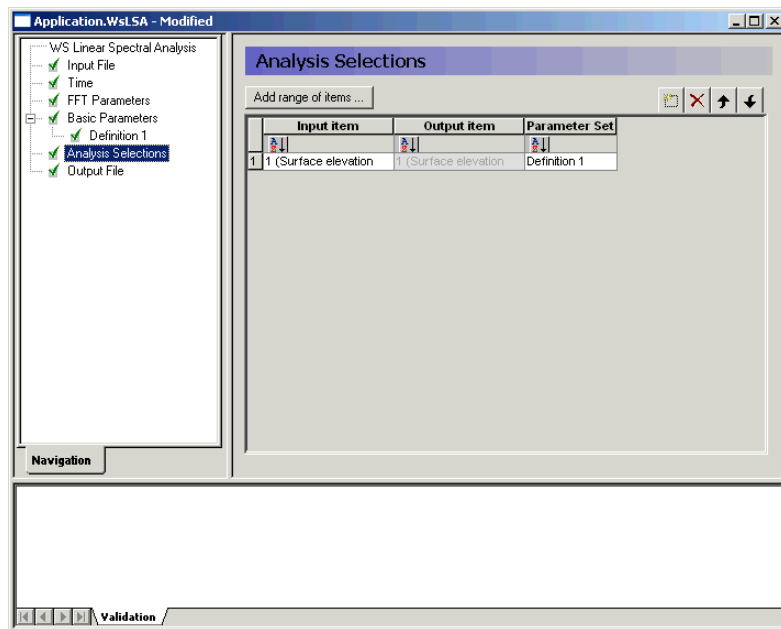
3.6 Analysis Selections

Figure 3.7   Analysis Selections dialog

The selection of items for analysis is chosen from a dynamic table containing information about the selected data file. The two left columns contain item names for input and output items (dual item analysis only). The rightmost column contains a combo box for each item, by which it is possible to state if the item should be included in the analysis.

Single Item Analysis
In case of single item analysis (auto spectrum only), the item selection requires that at least one item is selected for analysis, i.e. one of the items in the status column is selected.

Dual Item Analysis
In case of dual item analysis, the item selection requires that at least two items are selected for analysis, i.e. one of the items in the input section and one of the items in the output section.

The "*Parameter set*" is set to "None" for disregarding the current setting.

3.6.1 Remarks & hints

It is possible to perform not only one but several spectral analyses for different items set. This is particularly relevant for output from a numerical model where time series are extracted at various points and saved in the same dfs0-file.
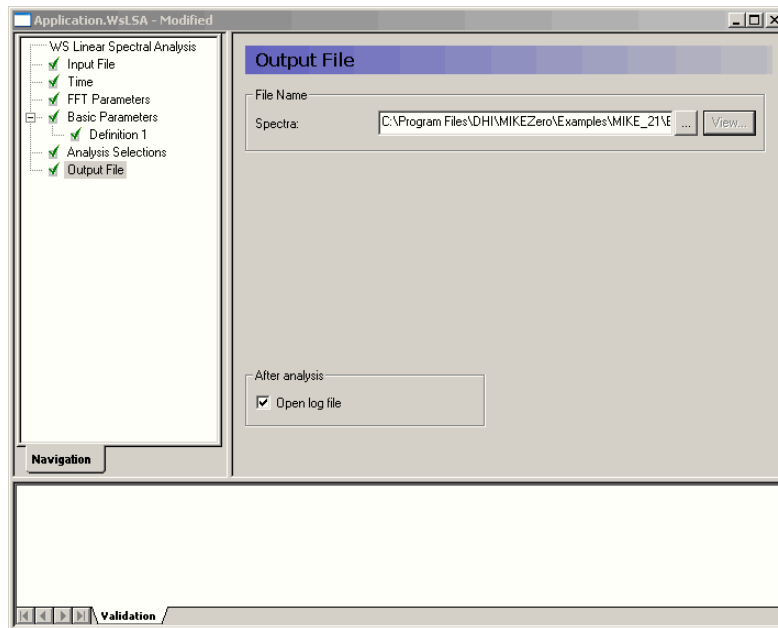
3.7 Output File

Figure 3.8   Output File dialog

In the *Output File* dialog you specify the output file name and folder where to place the data file.

Log file
You may choose to open the log file after model execution.

3.8 Scientific Documentation

The WS Linear Spectral Analysis module is based on well-accepted methods and procedures. For further references see Bendat and Piersol (1986, 1993).

3.9 References

Bendat, J.L. and Piersol, A.G., 1986. Random Data. Analysis and Measurement Procedures. John Wiley & Sons.

Bendat, J.L. & Piersol, A.G., 1993. Engineering Applications of Correlation and Spectral Analysis. John Wiley & Sons.

Goda, Y. /1985/ Random Seas and Design of Offshore Structures. University of Tokyo Press.

IAHR - International Association for Hydraulic Research (1986) List of Sea State Parameters. Supplement to Bulletin No. 52.

4   WS Digital Filtering Analysis

4.1   Introduction

The Digital Filtering Analysis module provides different digital filter options. Basically filtering is a process of selecting, attenuating, or suppressing certain frequency components of a time series signal by a desired amount, allowing a digital filter to shape the frequency spectrum of the signal.

The Digital Filtering Analysis module uses a class of filters called Finite Impulse Response (FIR) filters also known as non-recursive filters. These filters are characterised by filter coefficients (in the time domain), which are derived from specified transfer functions in the frequency domain. The actual filter operation takes place in time domain by convoluting the input time series and the filter coefficients.

The digital filtering can be applied to data from:

- Physical model tests
- Field measurements
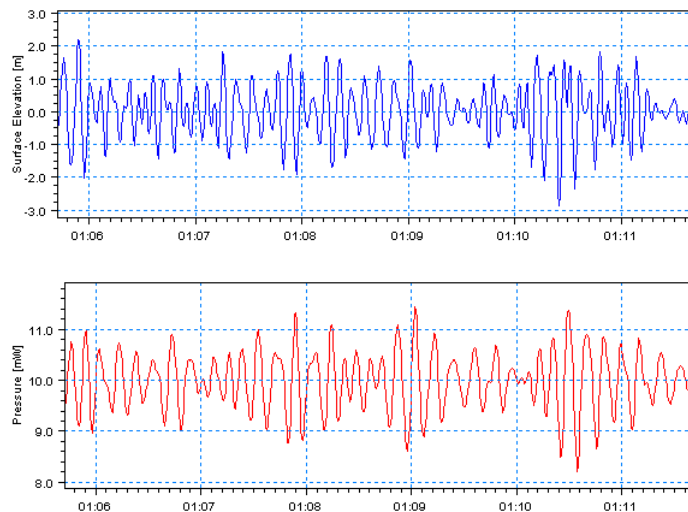- Numerical simulations

Figure 4.1   The figure shows a time series of pressure converted to a time series of surface elevation by digital filtering
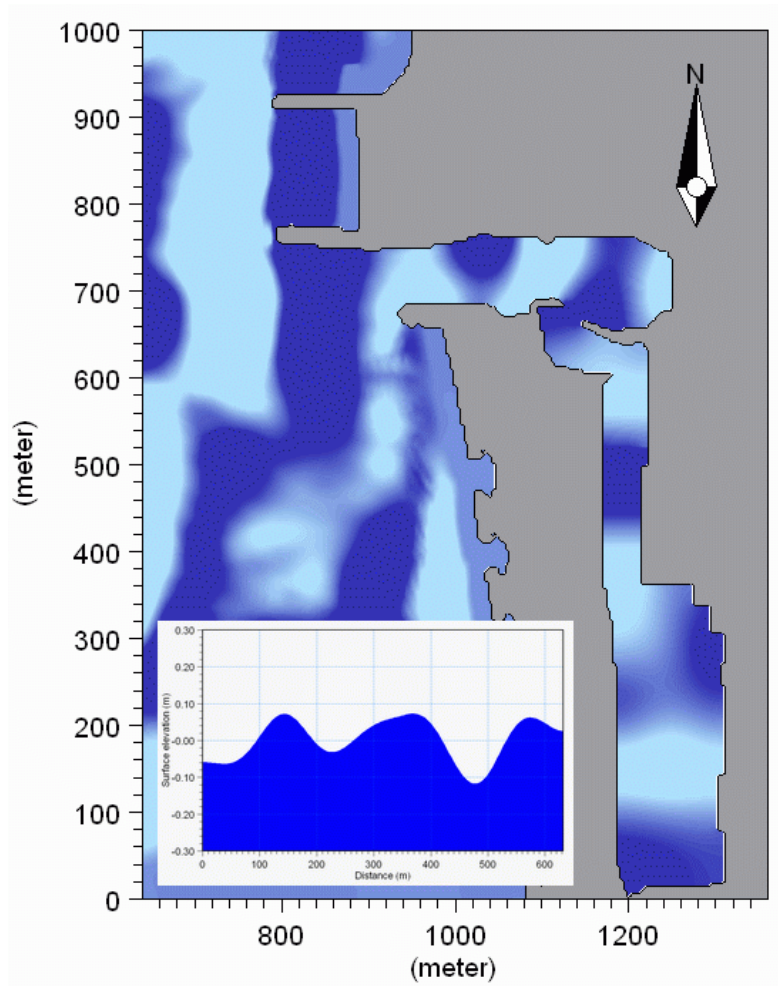
Figure 4.2   Band-pass filtered surface elevation on top of a bathymetry. A length-
wise profile of the inner harbour is inserted in the lower left corner. Input
data is based on a MIKE 21 BW Boussinesq Waves simulation
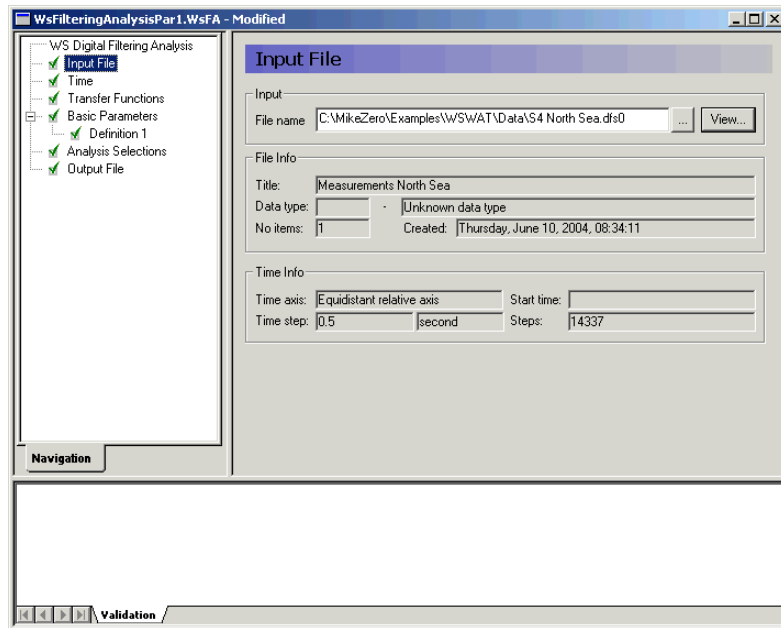
4.2   Input File

Figure 4.3   Input File dialog

The WS Digital Filtering Analysis module supports two types of binary input files:

1.   a dfs0-file including one or more equidistant time series.

2.   a dfs2-file including one or more equidistant time series within a domain.

Most often the latter type is only relevant for filtering of data originating from a numerical time domain model like MIKE 21 BW.

Whenever the editor recognises the used file format an info box containing the files header information appears in the lower half of the dialog.

You can view the selected data file using the MIKE Zero Time or Grid Series editor by clicking on the "View" button.

4.3   Area

The *Area* dialog is only active when a dfs2-type data file has been specified as input. You can choose to make an analysis on the entire domain (i.e. by selecting every grid point) or just a number of points by specifying the model coordinates (j,k).

4.3.1   Remarks & hints

Digital filtering for an area usually requires a huge amount of input data. It is recommended to keep the size of the input file less than the size of the internal memory in your PC, i.e. less than 0.5-2 GB. For investigation of long period phenomena it may be possible to limit the files size by saving the time series data in a coarser grid (e.g. every 2nd grid point).
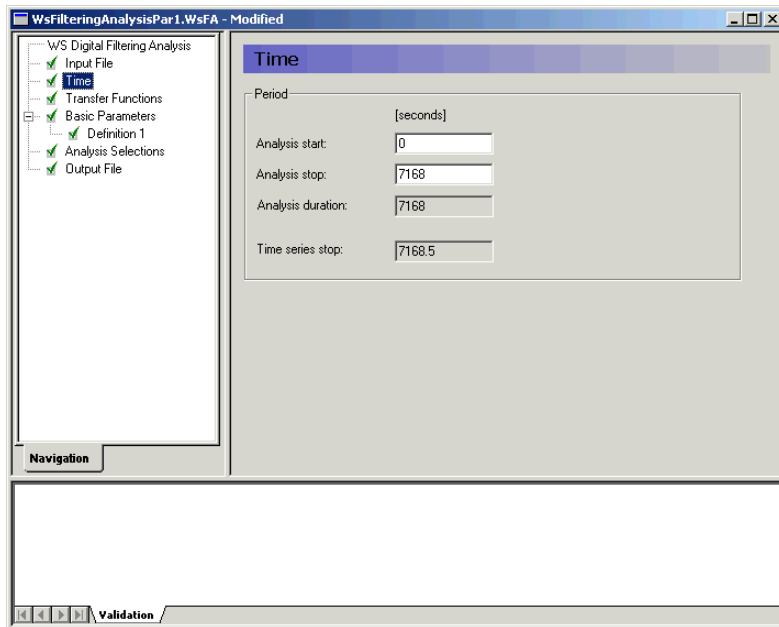
4.4   Time

Figure 4.4   Time dialog

The period to be covered by the analysis is specified in the *Time* dialog.

4.4.1   Remarks & hints

The period to be covered by the analysis is partly determined by the minimum cut-off frequency and filter width.
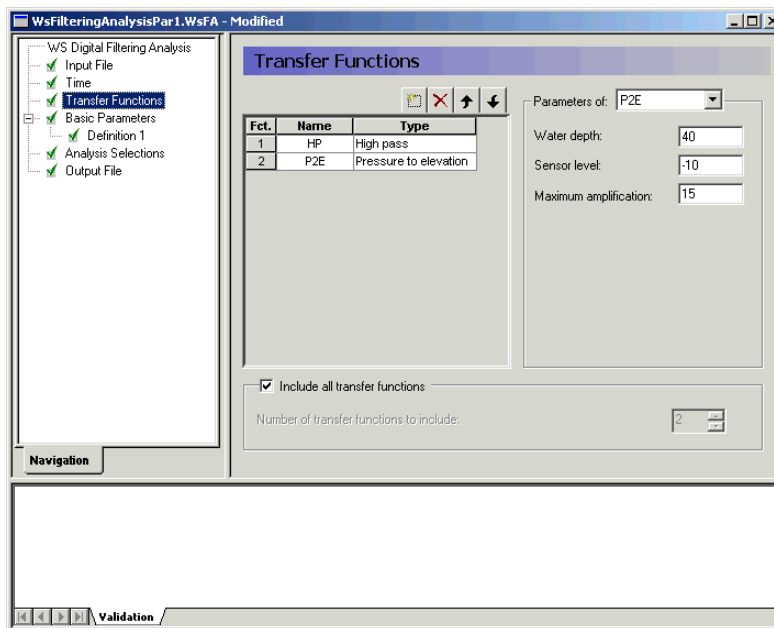
4.5   Transfer Functions

Figure 4.5   Transfer Functions dialog

In the *Transfer Functions* dialog you specify the name and define one or more filter components. All filter components (transfer functions) are defined in the frequency domain. Already defined transfer function can be temporarily excluded from the analysis by setting the number of transfer functions to include.

The available basic transfer functions and parameters are listed below.

Low-pass
The transfer function for a low-pass filter suppresses all frequency components of the time series above the cut-off frequency.

High-pass
The transfer function for a high-pass filter suppresses all frequency components of the time series below the cut-off frequency.

Band-pass
The transfer function for a band-pass filter lets all frequency components of the time series between the lower and higher cut-off frequencies pass.

Band-stop
The transfer function of a band-stop filter suppresses all frequency components of the time series between the lower and higher cut-off frequencies.

Differentiation

The transfer function for a differentiation filter differentiates the input time series to a given order.

Integration

The transfer function for an integration filter integrates the input time series to a given order.

Notch

The transfer function for a notch filter suppresses a specific frequency component of the time series.

Pressure to surface elevation

The transfer function for a pressure to surface elevation filter attenuates all frequency components of a pressure time series to an equivalent time series of surface elevation.

$$H_{p\eta}(f) = \frac{\cosh(kh)}{\cosh(k(z + h))} \tag{4.1}$$

in which z is the distance from still water level to the pressure sensor (must be negative). As the transfer function increases rapidly with frequency and potentially causes a dramatic amplification of measurement noise a maximum amplification factor may be given. The wave number k is given by the dispersion relation:

$$(2\pi f)^2 = gk \tanh(kh) \tag{4.2}$$

The above definition are based on linear wave theory.

Moving average

The transfer function for a moving average filter defines an equivalent weighting of the time series data within the period.

Biésel (piston)

The transfer function for a Biesel (piston) filter attenuates all frequency components of a piston position time series for a piston type wave maker (with zero deviation) to an equivalent time series of surface elevation (Biésel, 1951).

$$A_{X\eta}(f) = \frac{4\sinh^2(kh)}{2kh + \sinh(2kh)} \tag{4.3}$$

Evanescent (piston)

The transfer function for an evanescent mode (piston) filter produces the frequency dependent local disturbance due to a varying piston position of a piston type wave maker (with zero deviation) (Schäffer et. al., 1994).

$$D_{X\eta}(f) = \sum_1^\infty \frac{4\sinh^2(kh)}{2kh + \sinh(2k_jh)} \tag{4.4}$$

where k_j is an evanescent-mode wave number given by the j'th solution to:

$$(2\pi f)^2 = -gk_j\tan(k_jh) \tag{4.5}$$

Bartlett (low-pass)

The transfer function for a Bartlett or triangular filter yields a low-pass filter for which the attenuation above the cut-off frequency smoothly decreases towards zero.

Surface elevation to pressure

The transfer function for the elevation to pressure filter attenuates all frequency components of a surface elevation time series to an equivalent time series of pressure.

$$H_{\eta p}(f) = \frac{\cosh(k(z+h))}{\cosh(kh)} \tag{4.6}$$

In which z is the distance from still water level to the level at which the pressure should be calculated (must be negative and not exceed the water depth). The wave number k is given by the dispersion relation.

$$(2\pi f)^2 = gk\tanh(kh) \tag{4.7}$$

The above definitions are based on linear wave theory.

Elevation displacement

The transfer function of a filter for displacement of a surface elevation a certain distance in the propagation direction produces a phase shift of all frequency components (no attenuation occurs).

$$B_x(f) = -kx \tag{4.8}$$

In which x is the displacement in the propagation direction (can be negative). The wave number k is given by the dispersion relation.

$$(2\pi f)^2 = gk\tanh(kh) \tag{4.9}$$

The above definitions are based on linear wave theory.

The filter transfer function is specified in terms of basic transfer functions which may be superposed. One example is the conversion of time series data from a pressure sensor located at the sea bottom to an equivalent time series of surface elevations. This operation can be performed swiftly by combining the transfer function for pressure to surface elevation with a high-pass filter. The latter automatically removes tidal variations and subtracts the still water level.
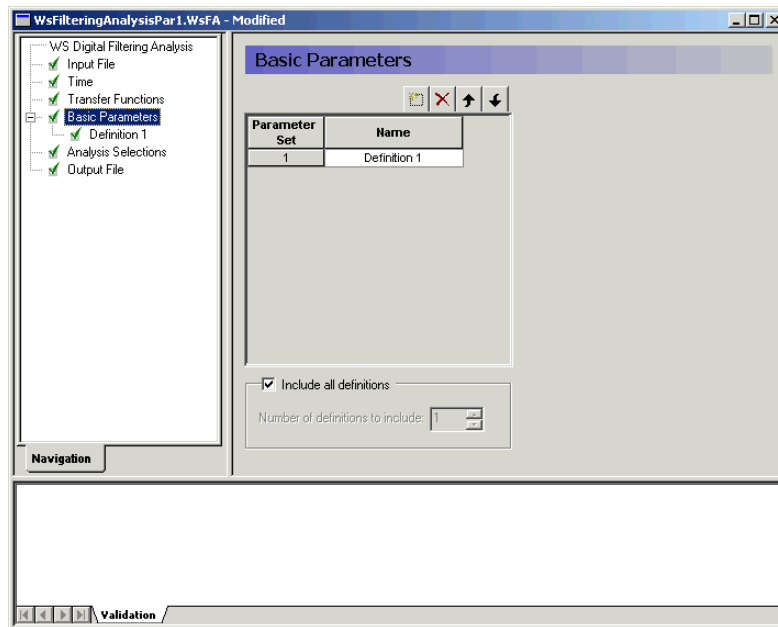
4.6   Basic Parameters

Figure 4.6   Basic Parameters dialog

In the *Basic Parameters* dialog you define one or more parameter sets (definitions) for the analyses. Already defined parameter sets can be temporarily excluded from the analysis by setting the number of definitions to "Include all definitions".
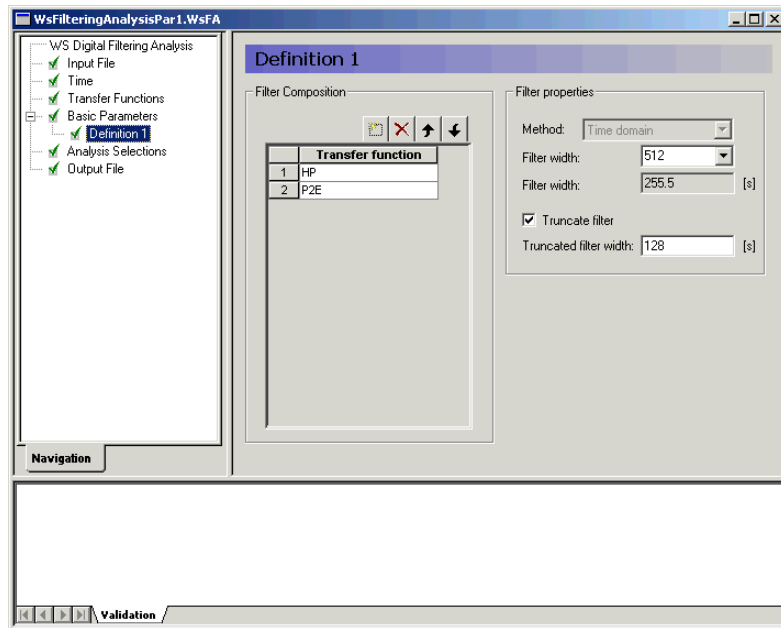
4.6.1   Definitions

Figure 4.7   Definition dialog

For each *Definition* dialog you select which of the defined transfer functions that composes the filter. The FIR filter coefficients for a given filter definition must be generated to match the time step of the input time series. For each definition a filter width, and possibly a truncated filter width, must be specified.

Filter width
The filter width is as minimum given by the required frequency domain resolution as the frequency interval must be less than the minimum cut-off frequency:

$$\Delta f = f_{min} = \frac{1}{2^N \Delta t}$$

(4.10)

$$w = 2^N \Delta t$$

with the filter width *w* given in the time domain.

Truncate filter
When filter coefficients are generated it is important to notice the possibility of truncating the filter coefficients. For filters that do not have very low cut-off frequencies, the transfer function will only be marginally affected, but the

computational efficiency may be improved considerably. If the filter coefficients are truncated, the filter coefficients corresponding to the largest time lag are omitted.

The truncated filter coefficients should normally be used for filtering.

4.6.2 Remarks & hints

As the transfer functions are specified in the frequency domain they may be superposed. This can be utilised for the conversion of time series data from a pressure sensor located at the sea bottom to an equivalent time series of surface elevations. The operation can be performed swiftly by combining the transfer function for pressure to surface elevation with a high-pass filter, where the latter automatically removes tidal variations and subtracts the still water level.

Truncating the filter coefficients will shorten the sequence of delete values that always will appear at the start and end of the filtered time series.
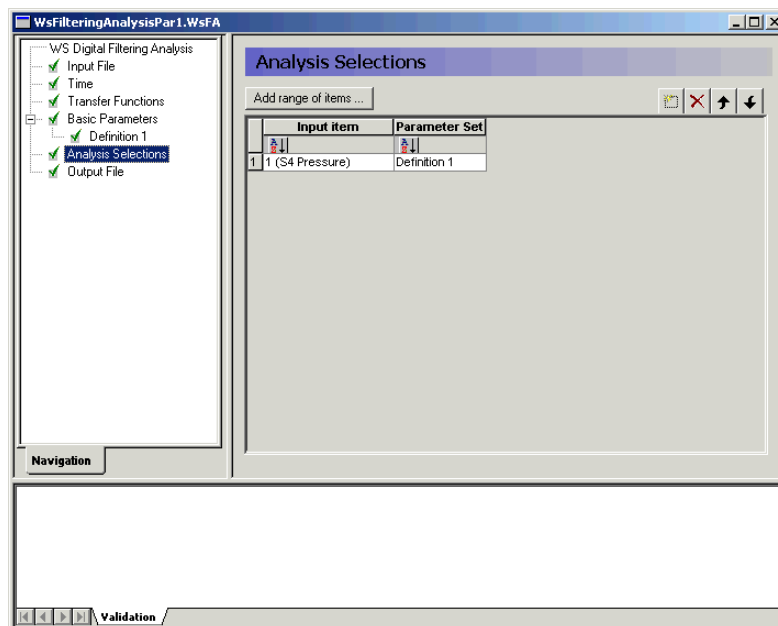
4.7 Analysis Selections

Figure 4.8   Analysis Selections dialog

The selection of items for filtering is chosen from a dynamic table containing information about the selected data file. The left column contains item names for input items. The rightmost column contains a combobox for each item, by which it is possible to state, which of the defined parameter sets (filters) that

should be used for filtering of the selected item. To exclude the item from the analysis the "Parameter set" must be set to "None".
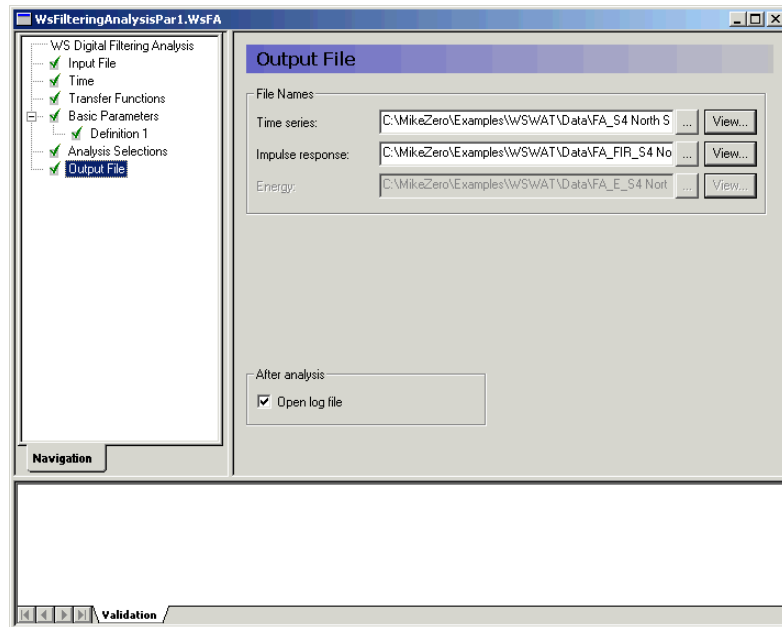
4.8   Output File

Figure 4.9   Output File dialog

In the *Output File* dialog you specify the output file name and folder where to place the data files containing the filtered time series and finite impulse response functions (FIR). Further for dfs2-type input data the energy of the filtered time series is calculated at all grid points. If one of the output files already exist you can view the selected data files using the MIKE Zero Time Series or Grid Editor by clicking on the "View" button.

Log file
You may choose to open the log file after model execution.

4.9   References

Biésel F. (1951) 'Les appareils générateurs de houle en laboratoire' La Houille Blance, Vol 6, Nos 2, 4 et 5.

Schäffer, H.A., Stolborg, T. & Hyllested, P. (1994) 'Simultaneous generation and active absorption of waves in flumes', Proceedings of Symposium 'Waves - Physical and Numerical Modelling', Vancouver, British Columbia, Canada, August 1994, pp 90-99.

5 WS Directional Wave Analysis

5.1 Introduction

The WS Directional Wave Analysis module is an efficient tool for directional analysis of concurrent data of surface elevation and orthogonal velocities (or fluxes). Hence the directional wave analysis can be performed for data from

- Physical model tests
- Field measurements
- Numerical simulations

The module is based on the maximum entropy method (MEM) as described by Nwogu et al. (1987).
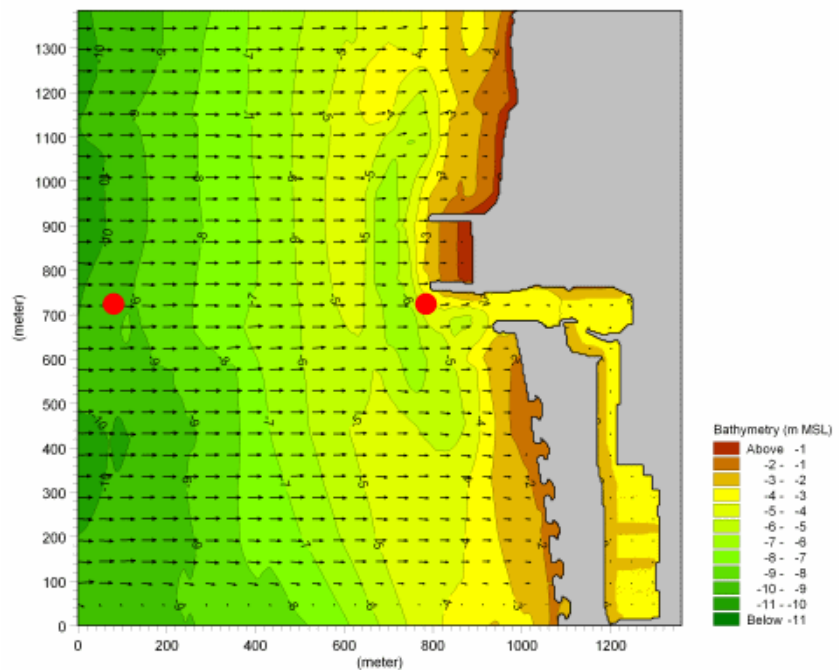

Figure 5.1   The calculated mean wave direction on top of a bathymetry. The input data is based on a MIKE 21 BW Boussinesq Waves simulation with directional wave input
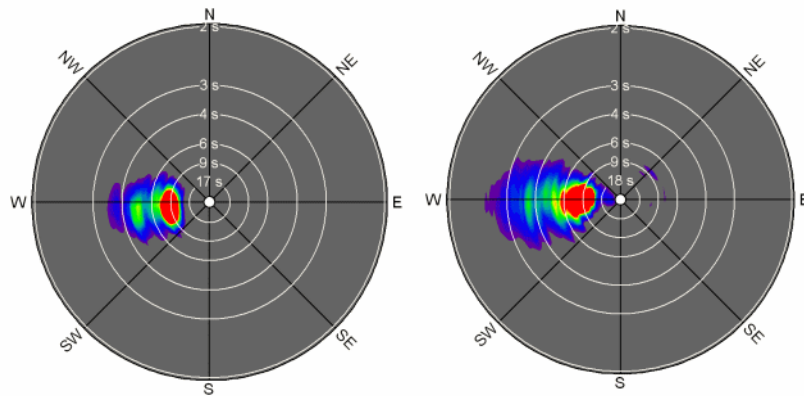
Figure 5.2   Calculated directional spectrum at the two read dots indicated on the map above

The module provides the following different spectra, functions and properties:

- Directional spectrum or directional spreading function

- Directional energy distribution or directional distribution (frequency integrated)

- Surface elevation spectrum (directional integrated)

- Mean wave direction function and spreading function

- Spectral values

- Mean wave direction and directional spreading
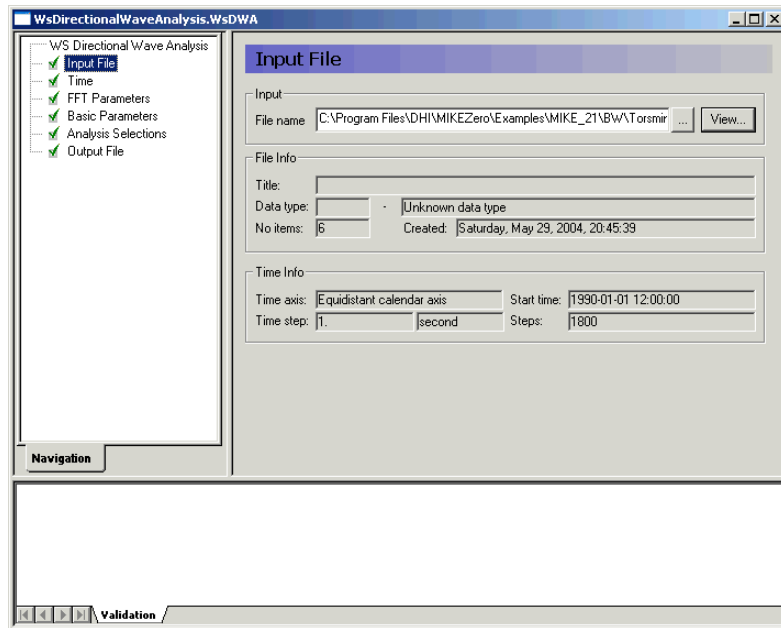
5.2 Input File

Figure 5.3   Input File dialog

The Directional Wave Analysis Module supports two types of input files:

1. a dfs0-file including a time series of surface elevation (or water depth) and two orthogonal velocity components (or fluxes) at the same position.

2. a dfs2-file including time series of surface elevation (or water depth) and two orthogonal velocity components (or fluxes) in a domain.

Most often the latter type is only relevant for analysis of data originating from a numerical time domain wave model like MIKE 21 BW.

When the data file is loaded an overview of file information is provided in the dialog.

You can view the selected data file using the MIKE Zero Time or Grid Series editor by clicking on the "View" button.

5.2.1 Remarks & hints

For directional analysis of results obtained from a MIKE 21 BW Boussinesq Waves simulation you can use:

- Data files including surface elevation, P flux and Q flux

- Data files including water depth, P flux and Q flux

It is recommended to use the first procedure.

Directional analysis for an area usually requires a huge amount of input data. It is recommended to keep the size of the input file less than the size of the internal memory in your PC, i.e. less than 0.5-2 GB. The most efficient way to limit the file size is to save data on a coarser grid (e.g. very 5th grid point).
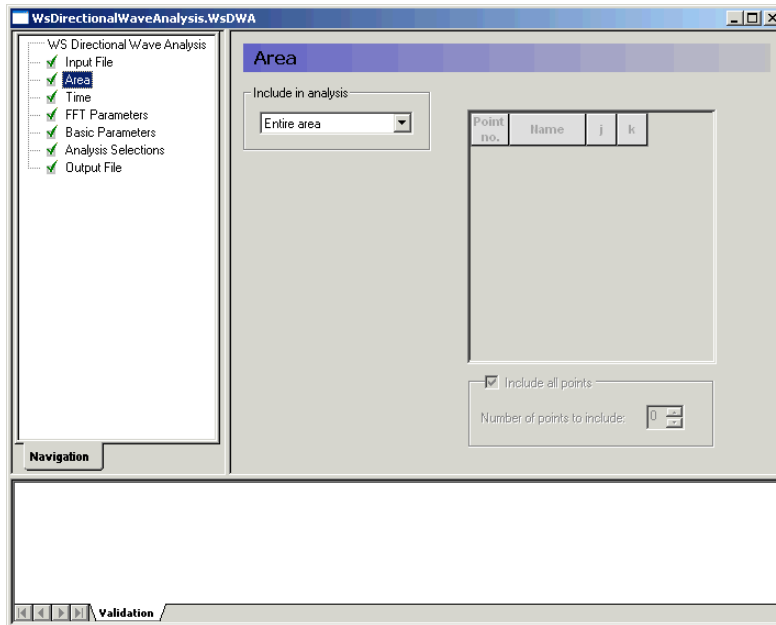
5.3   Area

Figure 5.4   Area dialog

The *Area* dialog is only active when a dfs2-type data file has been specified as input. You can choose to make an analysis on the entire domain (i.e. by selecting every grid point) or just a number of points by specifying the model co-ordinates (j,k).

Most often you will make an analysis for all data in the domain for assessment of the spatial variation of e.g. the mean wave direction.
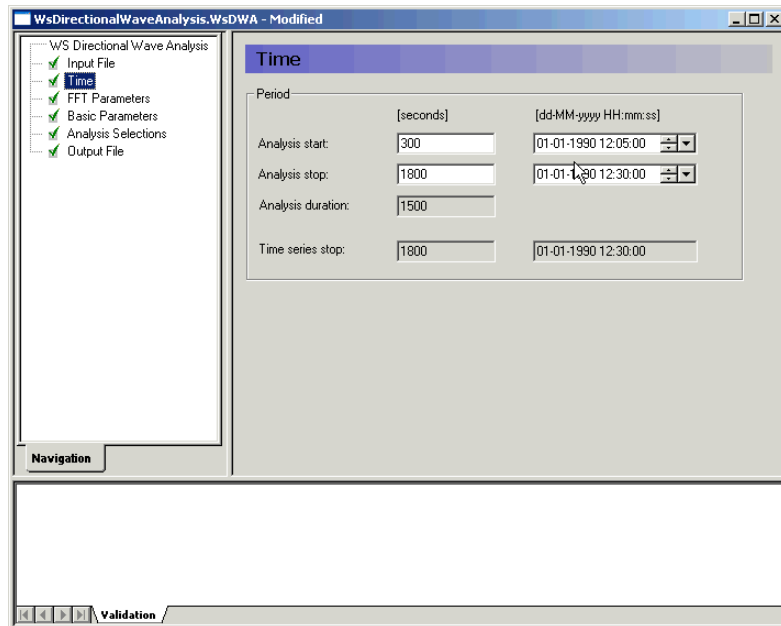
5.4 Time

Figure 5.5   Time dialog

The period to be covered by the analysis is specified in the *Time* dialog.

5.4.1 Remarks & hints

For wind-waves it is recommended to perform directional analysis on time periods greater than approximately 20 minutes. For longer wave periods and low-frequency oscillations, a longer analysis time is required for reliable estimations of directional and spectral parameters.
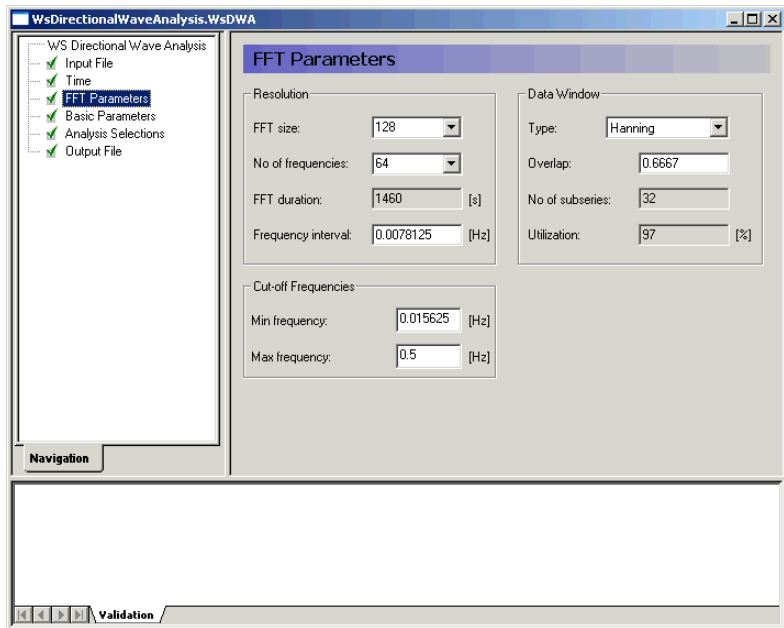
5.5 FFT Parameters

Figure 5.6   FFT Parameters dialog

The parameters given in the *FFT Parameters* dialog determines the frequency resolution and the degree of smoothing of the spectrum.

5.5.1 Resolution

FFT size:
Number of data point in each FFT block or subseries. The length must be a power of two and cannot exceed the total number of data points

Number of frequencies:
Is half of the FFT size

FFT duration:
Gives the length of the FFT analysis in seconds

Frequency interval:
The difference between two discrete adjacent frequencies. If manually changed, the value is automatically adjusted to the nearest possible value (function of time step and FFT size)

5.5.2   Data window

A phenomenon known as side-lobe leakage may lead to pronounced interaction between different frequencies with distorted spectra as a consequence. Applying a data window in the spectral analysis may reduce the influence of side-lobe leakage. The data window is a weight function used to taper a time series before the FFT analysis is initiated.

Type
Three different data windows are available:

- rectangular data window (i.e. without tapering)
- Hanning data window (default)
- Cosine squared

Overlap
The spectra (and response functions) are calculated using overlapping subseries. The overlap controls the smoothing of spectra, but it also controls the weighting of the different parts of the input time series.

A value of zero corresponds to no overlap and with increasing overlap as the value tends towards unity. An overlap of 2/3 is used as default.

Number of subseries
Based on the specified FFT parameters the number of subseries can be calculated. It is almost always desirable to have a large number of subseries because it will reduce the variance of the spectral density and provide a smooth spectral estimate.

For non-overlapping time series the number of degrees of freedom for the spectral estimate is two times the number of subseries. Spectral estimates having 30-40 degrees of freedom is often used in practice.

Utilisation
Indicates the utilisation of the input data.

5.5.3   Cut-off frequencies

The cut-off frequencies determine the frequency range for which the spectra and spectral results are calculated.

Minimum frequency
The minimum cut-off frequency must be greater than or equal to zero.

Maximum frequency

The maximum cut-off frequency must be less than or equal to the Nyquist frequency, which is determined entirely by the sampling frequency f_s of the input data:

$$f_{max} = 0.5\, f_s = \frac{1}{2\Delta t} \tag{5.1}$$

Here Δt is the time step of the input data. If the value is out of range a warning is issued and the invalid maximum cut-off frequency is automatically adjusted to the Nyquist frequency.

5.5.4 Remarks & hints

Please note that if data window tapering is omitted, pronounced interaction between frequencies might occur due to side-lobe leakage. It is recommended to use the Hanning data window for all practical applications.

It is important to realise that the various dialogs are all synonyms for the FFT size, and that changing one parameter also will affect the others.
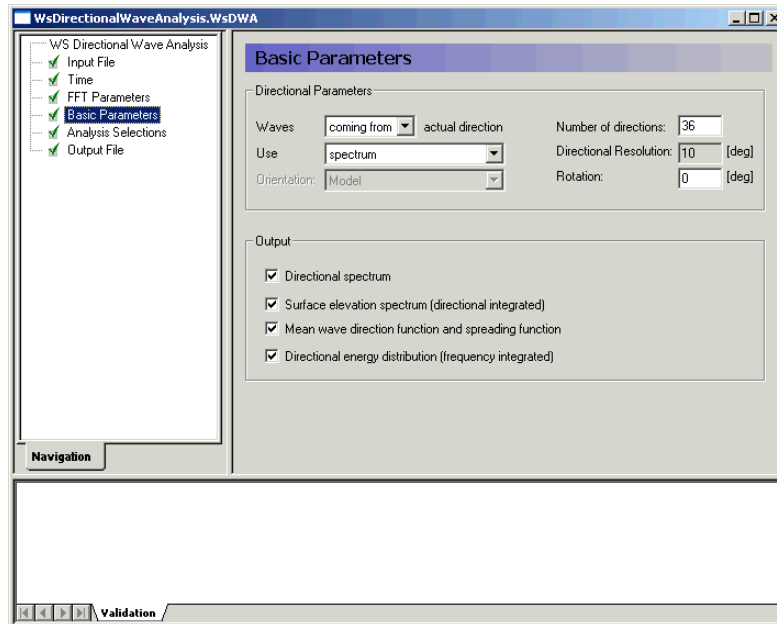
5.6 Basic Parameters

Figure 5.7   Basic Parameters dialog

In the *Basic Parameters* dialog you specify general parameters for the directional analysis and output types.

5.6.1 Directional parameters

Waves coming from/going to actual direction
Definition of wave direction. The most common standard is "waves coming from" (default).

Use spreading or spectrum (dfs0-type only)
Selection of type of output:

- directional spreading function (default)
- directional spectrum

Orientation (dfs2-type data only)
The default orientation is taken from model orientation. Alternatively you specify UTM north as orientation.

Number of directions and directional resolution
The default number of directions is 36, which results in a directional resolution of 10 degrees.

Rotation (dfs0-type data only)
You may change the default rotation (0 degrees) to a value representing the true north direction. This is particularly relevant for dfs0-type input as the data format does not include information on the orientation of the co-ordinate system where the velocities (or fluxes) refer.
The value of the rotation angle depends on the chosen convention of the wave direction.
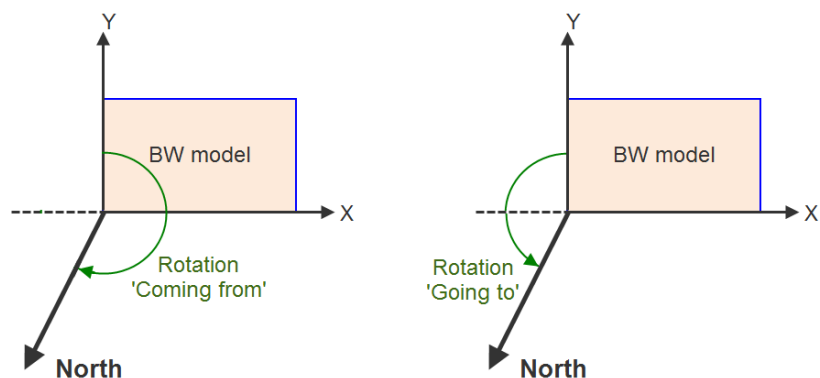

Figure 5.8   Definition of rotation angle
Left: Rotation angle when wave direction is 'Coming from'
Right: Rotation angle when wave direction is 'Going to'

5.6.2   Output (dfs0-type data only)

The following types of output is available.

Using spreading function:

- Directional spreading function, which includes a directional histogram of wave energy, representing an empirical spreading function
- Surface elevation spectrum (directional integrated)
- Mean wave direction function and spreading function
- Directional distribution (frequency integrated)

Using spectrum:

- Directional spectrum
- Surface elevation spectrum (directional integrated)
- Mean wave direction function and spreading function
- Directional energy distribution (frequency integrated)

5.6.3   Remarks & hints

If, for example, the input dfs0-type data is obtained from a MIKE 21 BW simulation where the bathymetry orientation is 0 degrees, the rotation should be set to 180 degrees if the wave direction convention for the output data is defined as 'Going to'.
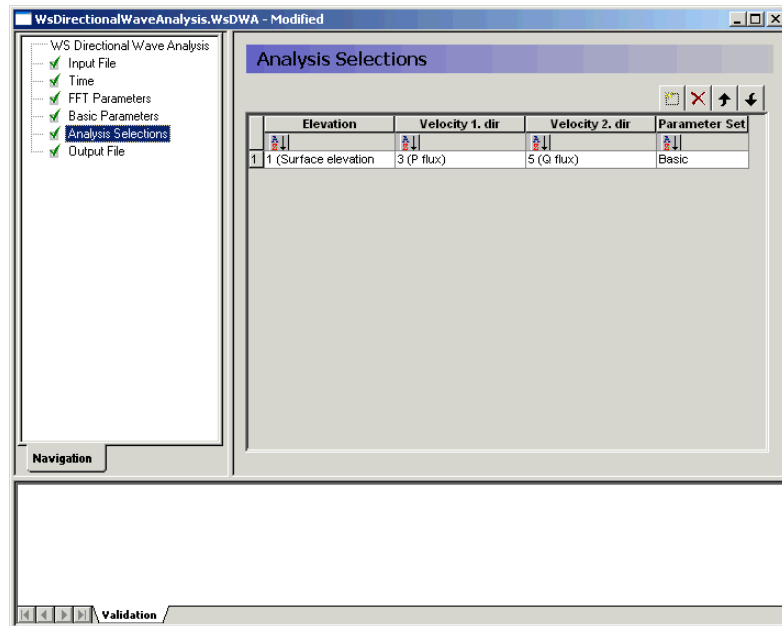
5.7 Analysis Selections

Figure 5.9   Analysis Selections dialog

In the *Analysis Selections* dialog you specify which items (in the input data files) the directional analysis should be based on. You specify:

1. The elevation (or water depth) item

2. The velocity (or flux) item in the 1. direction (**y**-component)

3. The velocity (or flux) item in the 2. direction (**x**-component)

The "*Parameter set*" is set to "Basic" for analysis or "None" for disregarding the current setting.

5.7.1 Remarks & hints

It is possible to perform not only one but several directional analyses for the different items set. This is particularly relevant for output from a numerical model where time series (for surface elevation and fluxes) are extracted at various points and saved in the same dfs0-file.
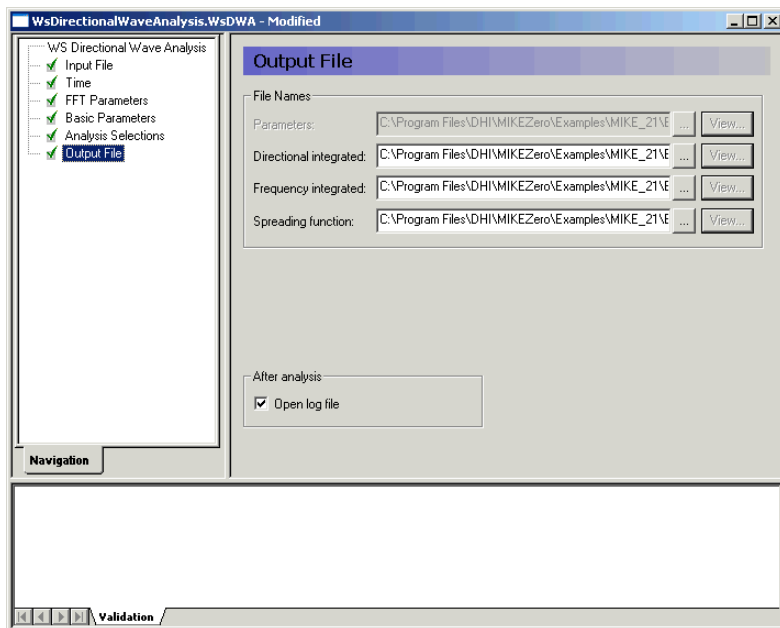
5.8 Output File

Figure 5.10   Output File dialog

In the *Output File* dialog you specify the output file name and folder where to place the data files.

Parameters

For dfs2-type input data following parameters are calculated at each grid point:

- mean wave direction, *MWD*

- mean directional spreading, *DSD*

- significant wave height, H_{m0}

- mean wave period, T_{02}

- spectral peak period, T_p

- x-component of H_{m0} (i.e. $H_{m0} \cos(MWD)$)

- y-component of H_{m0} (i.e. $H_{m0} \sin(MWD)$)

The calculation of mean wave direction and spreading complies with the suggestions and definitions given by Frigaard et al. (1997).

The definitions are:

- Mean wave direction

$$MWD = \bar{\theta}_X = \arg\left(\int_{f_{min}}^{f_{max}} \frac{S_X(f)}{m_{0,X}} \exp(i\theta_{m,X}) df\right) \tag{5.2}$$

- Mean directional spreading

$$DSD = \bar{\sigma}_{\theta,X} = \int_{f_{min}}^{f_{max}} \frac{S_X(f)\sigma_{\theta,X}(f)}{m_{0,xX}} df \tag{5.3}$$

$$\sigma_{\theta,X}^2 = 2(1 - |c_1|)$$

$$|c_1|^2 = \left(\int_0^{2\pi} D_X(f,\theta)\sin\theta \, d\theta\right)^2 + \left(\int_0^{2\pi} D_X(f,\theta)\cos\theta \, d\theta\right)^2$$

- Significant wave height

$$H_{m0} = 4\sqrt{m_0} \tag{5.4}$$

$$m_0 = \int_{f_{min}}^{f_{max}} S_X(f) df$$

- Mean wave period

$$T_{02} = \sqrt{\frac{m_0}{m_2}} \tag{5.5}$$

$$m_2 = \int_{f_{min}}^{f_{max}} S_X(f) f^2 df$$

- Spectral peak period

$$T_p = \frac{1}{f_p} \tag{5.6}$$

where f_p is the frequency corresponding to the maximum spectral density.

Log file
You may choose to open the log file after model execution.

5.9   Scientific Documentation

The WS Directional Wave Analysis Module calculates a directional spectrum using the maximum entropy method (MEM) as described in Nwogu (1989). Basically, the requirements for the MEM analysis are auto-spectra and co-spectra (real part of the complex cross-spectrum) for one surface elevation and two orthogonal velocity components take at the same position.

For further introduction to directional analysis, reference is made to Nwogu (1989) and Hashimoto (1997).

5.10   References

Nwogu, O., 1989. Maximum entropy estimation of directional wave spectra from an array of wave probes. App. Ocean Res., 11, 176-182.

Frigaard, P., Helm-Petersen, J., Klopman, G., Stansberg, C.T., Benoit, M., Briggs, M.J., Miles, M., Santas, J., Schäffer, H.A. & Hawkes, P.J. /1997/ IAHR List of Sea state parameters - an update for multidirectional waves. Proceedings of 27th IAHR Seminar, San Francisco, USA

Hashimoto, N., 1997. Analysis of the directional wave spectra from field data. Advances in Coastal and Ocean Engineering Vol. 3, ed. Liu, P.L.F. World Scientific, Singapore, 103-143.

Bendat, J.L. and Piersol, A.G., 1986. Random Data. Analysis and Measurement Procedures. John Wiley & Sons.

Bendat, J.L. & Piersol, A.G., 1993. Engineering Applications of Correlation and Spectral Analysis. John Wiley & Sons.

6 WS Crossing Analysis

6.1 Introduction

The WS Crossing Analysis module is a generalisation of the classical zero-crossing analysis. For a predefined threshold, the input time series item is divided into events, each of which is defined by the time series value crossing the reference level in upwards (or downwards) direction.

For each event, the following properties can be determined:

- Peak to peak value
- Crossing level to crest
- Crossing level to through
- Zero to crest
- Zero to through
- Standard deviation within event
- Crossing time
- Duration (period) of event

The properties of the detected events may be presented directly by scatter diagrams or processed further, e.g. fitting to a given probability distribution or establishment of histograms.
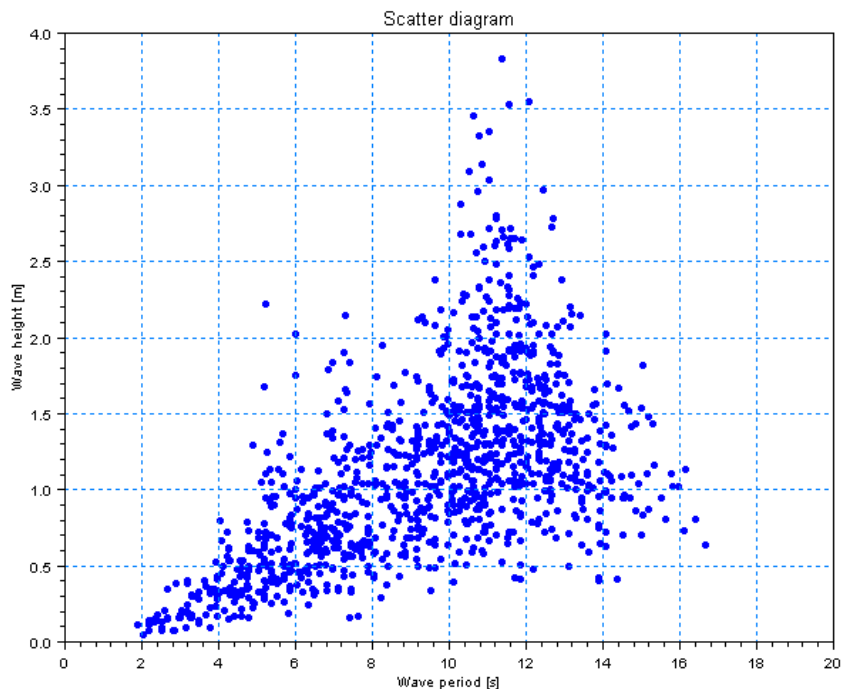
Figure 6.1   Scatter diagram for wave heights and periods detected within a time series acquired during a physical model test

To eliminate false crossings caused by low-level measurement noise it is possible to define a crossing filter. A threshold level and a threshold period define the crossing filter. Hence, the threshold level defines a small amount by which the reference level must be exceeded before the beginning of an event is accepted. Correspondingly, the threshold period defines a duration that must be exceeded before the event can be accepted.

6.2 Input File
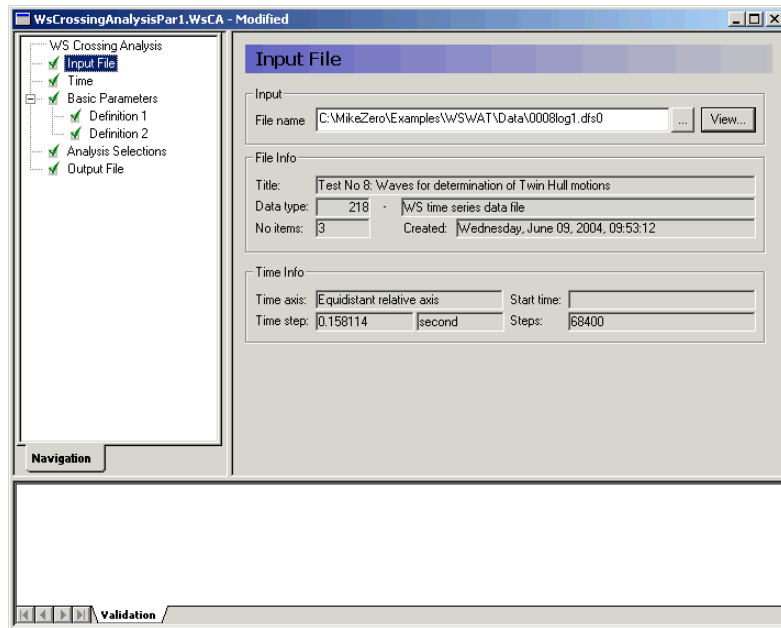
Figure 6.2 Input File dialog

The WS Crossing Analysis module supports time series data with equidistant time step. At present the following two binary file formats are supported:

- dfs0 (DFS data file format)
- dt0 (old file format)

Please note that dt0 is included for backward compatibility, only.

Whenever the editor recognises the used file format an info box containing the files header information appears in the lower half of the dialog.

You can view the selected data file using the MIKE Zero Time Series editor by clicking on the "View" button.

6.3 Time
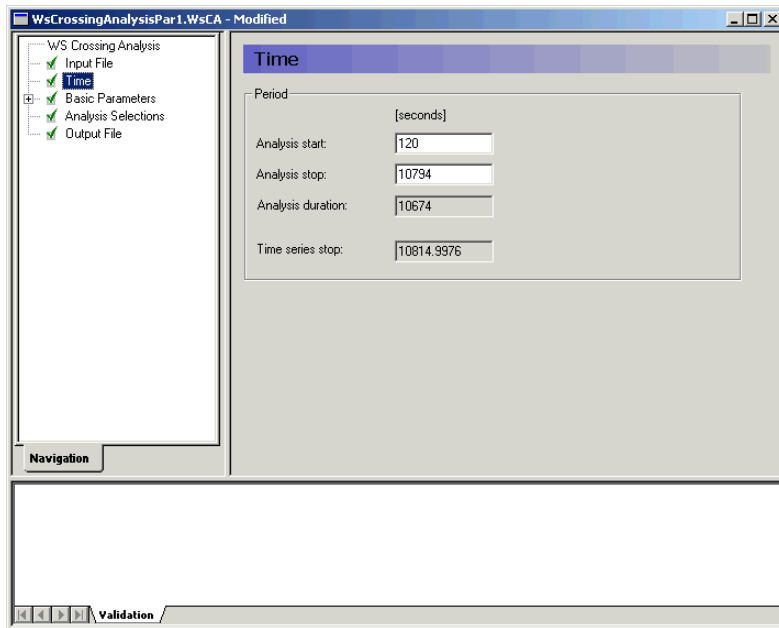
Figure 6.3   Time dialog

The period to be covered by the analysis is specified in the *Time* dialog.

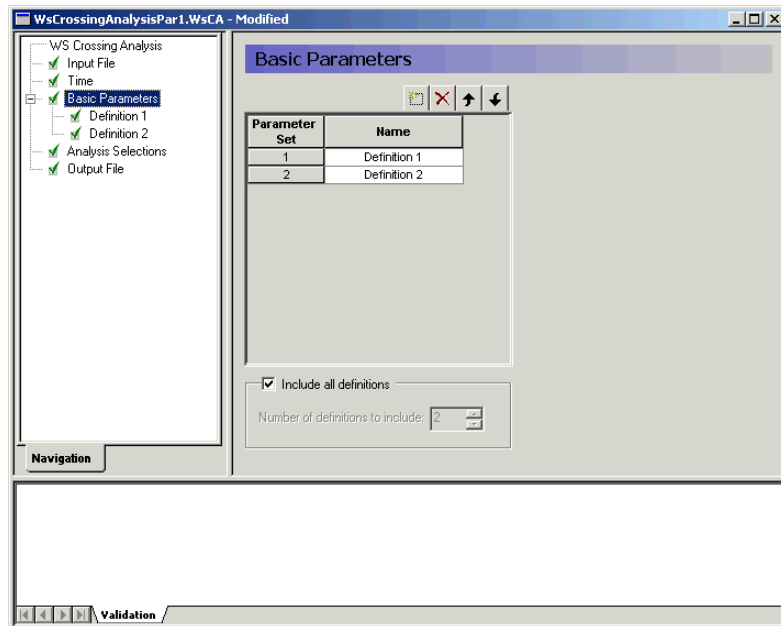## 6.4 Basic Parameters

In the *Basic Parameters* dialog you define one or more parameter sets (definitions) for the analyses. Already defined parameters sets can be temporarily excluded from the analysis by de-selection of "Include all definitions", and setting the "Number of definitions to include" to a value smaller than the maximum.
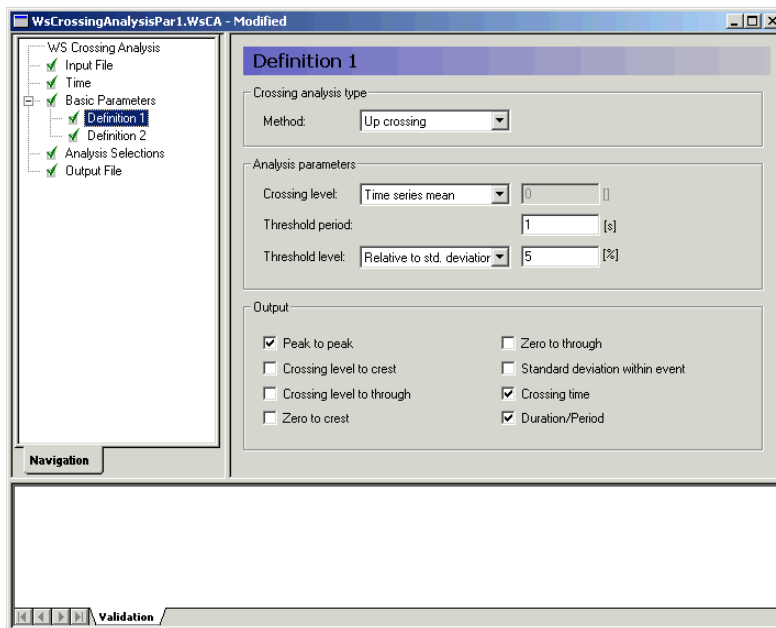
6.4.1 Definitions

Figure 6.5   Definition dialog

For each *Definition* dialog you select method, parameters and output from the crossing analysis.

Method
Defines whether the crossing analysis must be performed in upward (default) or downward direction.

Crossing level
Is the level, at which the up- or down crossing of which detects a new event. You can specify a value or use the time series mean value (default).

Threshold level
The threshold level is a part of a low-level crossing filter for elimination of noise. The threshold level defines a small amount by which the reference level must be exceeded before the beginning of an event is accepted. You can specify an absolute value or define a level relative to the standard deviation of the time series (default).

Threshold period
The threshold period is a part of a low-level crossing filter for elimination of noise. The threshold period defines a duration that must be exceeded before the can event can be accepted. An absolute value must be given (default is zero).

Output

For each event the following output is available:

- Peak to peak value

- Crossing level to crest (maximum value during the event minus the crossing level)

- Crossing level to through (crossing level minus the minimum value during the event)

- Zero to crest (maximum value during the event)

- Zero to through (minimum value during the event)

- Standard deviation within event

- Crossing time (time at which the event starts)

- Duration (period) of event
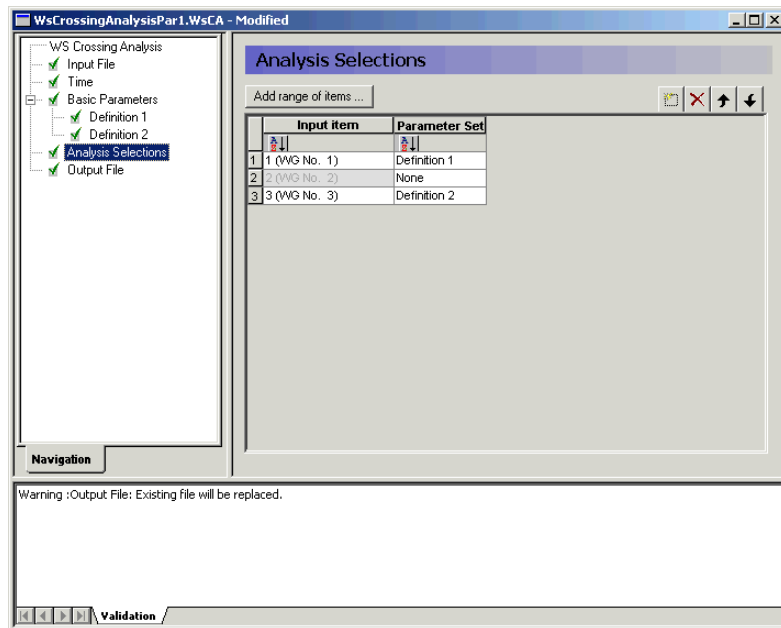
6.5 Analysis Selections

Figure 6.6　Analysis Selections dialog

The selection of items for analysis is chosen from a dynamic table containing information about the selected data file. The left column contains item names for input items. The rightmost column contains a combo box for each item, by which it is possible to state which of the defined parameter sets that should be used for analysis of the selected item. To exclude the item from the analysis the "Parameter set" must be set to "None".

6.5.1 Remarks & hints

It is possible to perform the different analysis on different items by defining multiple parameter sets. This is particularly relevant for output from physical model tests were gauges measure relative or absolute values, e.g. for crossing analysis of time series of mooring forces the pretension should be used as crossing level, whereas a time series of surface elevation would be analysed with a crossing level equal to the time series mean value.
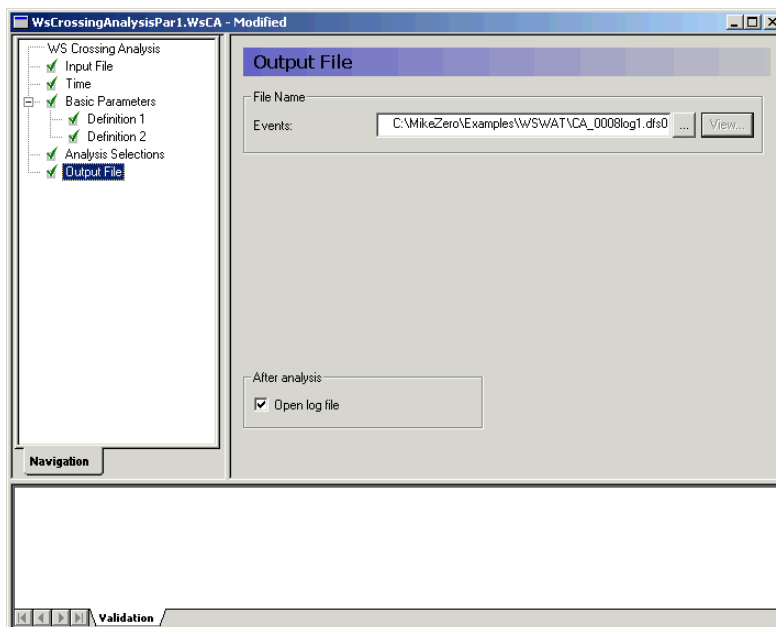
6.6 Output File

Figure 6.7   Output File dialog

In the *Output File* dialog you specify the output file name and folder where to place the data file. If the output file already exists, you can view the selected data file using the MIKE Zero Time Series editor by clicking on the "View" button.

Log file
You may choose to open the log file after model execution.

7 WS Reflection Analysis

7.1 Introduction

With the WS Reflection Analysis Module it is possible to perform a wave reflection analysis in connection with flume model tests. The analysis requires measurements from two or more wave gauges as basis for a frequency domain separation of the measured wave time series to provide an average spectrum of the incident and reflected waves.

The reflection analysis calculates the following spectra and properties:

1. Spectrum for incident waves
2. Spectrum for reflected waves
3. Spectrum at the wave gauges (incident and reflected)
4. Reflection function
5. Average reflection coefficient
6. Spectral values

The frequency domain separation handles concurrent recordings from several wave gauges as it solves the governing equations by use of a least squares fit approach. The basic method is described by Mansard & Funke (1980, 1987) and extended by Zelt & Skjelbreia (1992).
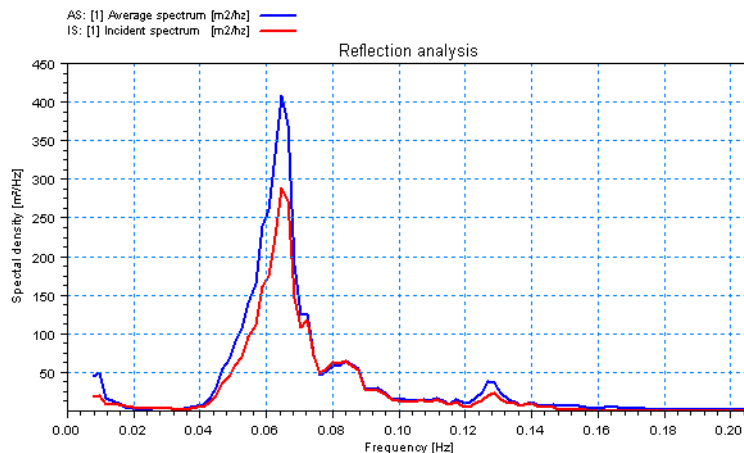
Figure 7.1 The figure shows incident and reflected spectra calculated from data acquired during physical model testing.
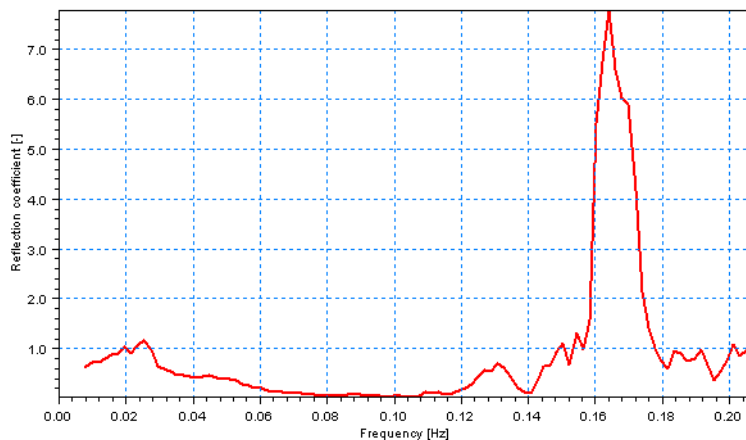
Figure 7.2   The figure shows the reflection function calculated from data acquired during physical model testing.

7.2   Input File

The WS Reflection Analysis module supports time series data with equidistant time step. At present the following two binary file formats are supported:

- dfs0 (DFS data file format)
- dt0 (old file format)

Please note that dt0 is included for backward compatibility, only.

Whenever the editor recognises the used file format an info box containing the files header information appears in the lower half of the dialog.

You can view the selected data file using the MIKE Zero Time Series editor by clicking on the "View" button.
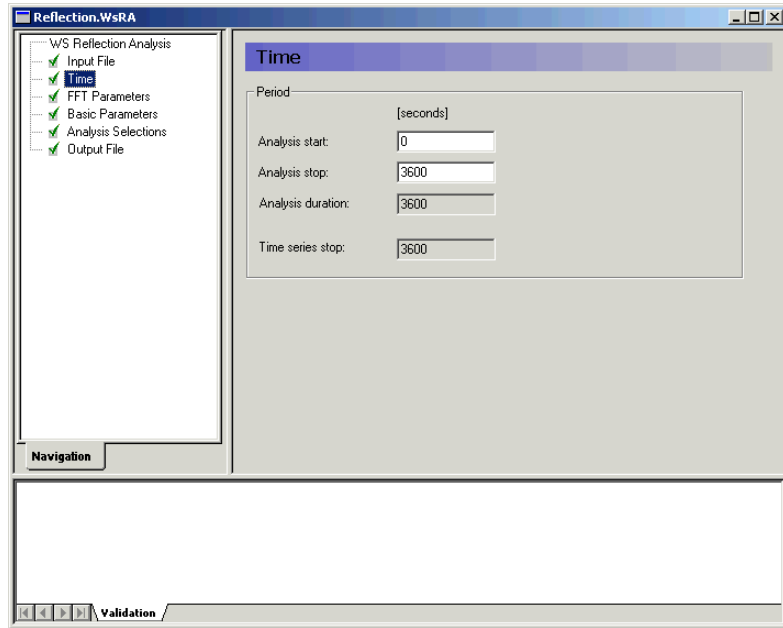
7.3   Time

Figure 7.3   Time dialog

The period to be covered by the analysis is specified in the Time dialog.
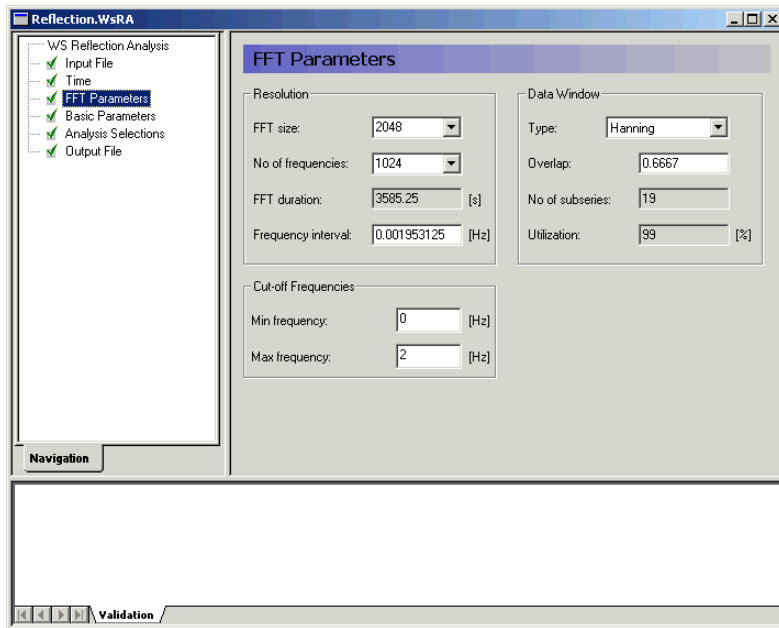
7.4 FFT Parameters

Figure 7.4   FFT Parameters dialog

The parameters given on the FFT Parameters dialog determines the frequency resolution and the degree of smoothing of the spectrum.

7.4.1 Resolution

FFT size
Number of data point in each FFT block or subseries. The length must be a power of two and cannot exceed the total number of data points.

Number of frequencies
Is the half the FFT size.

FFT duration
Gives the length of the FFT analysis in seconds

Frequency interval
The difference between two discrete adjacent frequencies. If manually changed, the value is automatically adjusted to the nearest possible value (function of time step and FFT size).

7.4.2 Data window

A phenomenon know as side-lobe leakage may lead to pronounced interaction between different frequencies with distorted spectra as a consequence. Applying a data window in the spectral analysis may reduce the influence of side-lobe leakage. The data window is a weight function used to taper a time series before the FFT analysis is initiated.

Type
Three different data windows are available;

- rectangular data window (i.e. without tapering)
- Hanning data window (default)
- Cosine squared

Overlap
The spectra (and response functions) are calculated using overlapping subseries. The overlap controls the smoothing of spectra, but it also controls the weighting of the different parts of the input time series.

A value of zero corresponds to no overlap and with increasing overlap as the value tends towards unity. An overlap of 2/3 is used as default.

Number of subseries
Based on the specified FFT parameters the number of subseries can be calculated. It is almost always desirable to have a large number of subseries because it will reduce the variance of the spectral density and provide a smooth spectral estimate.

For non-overlapping time series the number of degrees of freedom for the spectral estimate is two times the number of subseries. Spectral estimates having 30-40 degrees of freedom is often used in practice.

Utilisation
Indicates the utilisation of the input data.

7.4.3 Cut-off frequencies

The cut-off frequencies determine the frequency range for which the spectra and spectral results are calculated.

Minimum frequency
The minimum cut-off frequency must be greater than or equal to zero.

Maximum frequency

The maximum cut-off frequency must be less than or equal to the Nyquist frequency that is determined entirely by the sampling frequency f_s of the input data:

$$f_{max} = 0.5\, f_s = \frac{1}{2\Delta t} \tag{7.1}$$

Here Δt is the time step of the input data. If the value is out of range a warning is issued and the invalid maximum cut-off frequency is automatically adjusted to the Nyquist frequency.

7.4.4   Remarks & hints

Please note that if data window tapering is omitted pronounced interaction between frequencies might occur due to side-lobe leakage. It is recommend using the Hanning data window for all practical applications.

It is important to realise that the various dialogs are all synonyms for the FFT size, and that changing one parameter will also affect others.

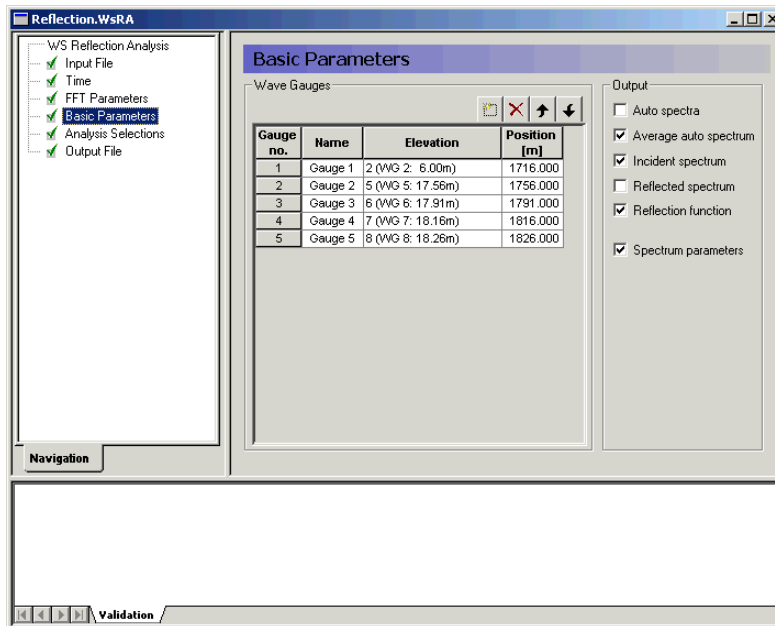## 7.5   Basic Parameters

Figure 7.5   Basic Parameters dialog

In the Basic Parameters dialog you define wave gauges that may be included in the reflection analysis and the analysis output.

Wave gauges

The reflection analysis requires that two or more wave gauges and their position in the flume are defined. Wave gauges are chosen from a dynamic table containing information about the selected data file. The left column contains item names for input items. The rightmost column contains an editable field for each item, in which the position of the wave gauge is specified (in prototype measures).

Wave gauge positions must be given along a co-ordinate axis with positive orientation in the wave propagation direction.

Output

For each reflection analysis (defined in Analysis selections) following output is available:

- Auto spectra for each of the defined wave gauges

- Average auto spectrum for the wave gauges included in the analysis

- Incident spectrum

- Reflected spectrum

- Reflection function (frequency dependent reflection coefficient)

- Spectrum parameters, e.g. spectral peak-to-peak and period estimates
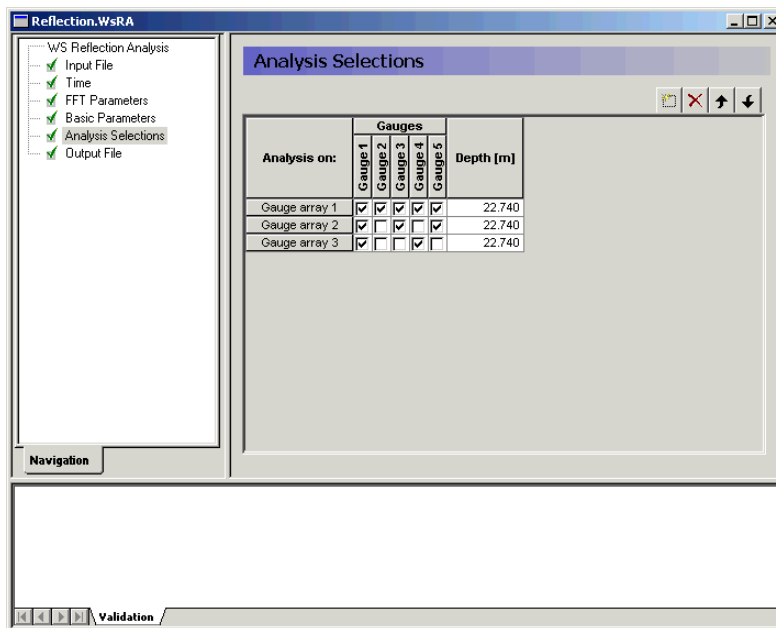
7.6 Analysis Selections

Figure 7.6   Analysis Selections dialog

In the Analysis Selections dialog you define one or more gauge arrays for which the reflection analysis must be performed. Each gauge array must consist of at least two wave gauges that are selected by use of the checkboxes below each of the wave gauges previously defined in the Basic Parameters dialog. The rightmost column contains an editable field, in which the water depth at the gauge array must be given (in prototype measures).

7.6.1 Remarks & hints

The analysis requires at least two wave gauges at different positions for determination of incident and reflected waves. The positioning of the wave gauges greatly affects the output of the analysis and for a two-gauge analysis singularities for frequencies representing an integer number of half wave lengths are produced:

$$2\frac{\Delta l_{12}}{L} = n, \quad n = 1,2,3...$$ (7.2)

where Δl_{12} is the internal gauge distance and L is the wave length at a given frequency. In practice, the governing equations of the analysis become illcon-

ditioned close to the singularity and Goda & Suzuki (1976) recommends that the following range of internal gauge distances should be avoided:

$$n - 0,1 < 2\frac{\Delta l_{12}}{L} < n + 0,1 \tag{7.3}$$

The above relation is based on regular wave experiments. For irregular waves this means that only approximately 80% of the frequencies will be included in the analysis. Hence, the two-gauge method cannot be recommended for irregular waves.

For irregular waves more wave gauges should be used as it would generally eliminate (a part of) the singular frequencies and improve the measurement quality due to simple over-determination.

An additional wave gauge yields another two internal gauge distances Δl_{13}, Δl_{23}, of which the latter must be chosen such that the largest possible frequency range for which the bands around the singularities (equation give above) do not coincide for all internal gauge distances. Numerical investigations has resulted in a number of appropriate choices, the best ones being:

$$\frac{\Delta l_{12}}{\Delta l_{23}} = \begin{cases} 1/10 \\ 3/10 \end{cases} \tag{7.4}$$

Analysis results may be improved further by four or five-gauge analysis as additional gauges are placed with different internal distances.
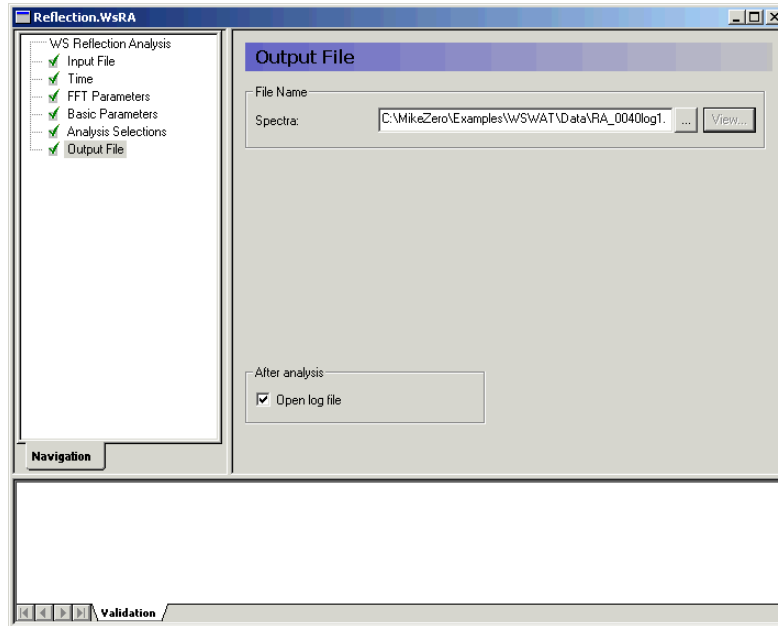
7.7 Output File

Figure 7.7   Output File dialog

In the Output File dialog you specify the output file name and folder where to place the data file. If the output file already exists you can view the selected data file using the MIKE Zero Time Series editor by clicking on the "View" button.

Parameters

For the auto, incident and reflected wave spectra the following parameters are calculated:

- significant wave height, H_{m0}
- mean wave periods T_{01} and T_{02}
- spectral peak period T_p
- spectral width ε_4
- average reflection coefficient C_R

A number of the parameters are based on the spectral moments:

$$m_n = \int_{f_{min}}^{f_{max}} S_X(f) f^n df \tag{7.5}$$

- significant wave height defined as

$$H_{m0} = 4\sqrt{m_0} \tag{7.6}$$

- mean wave periods defined as

$$T_{01} = \sqrt{\frac{m_0}{m_1}}$$
$$T_{02} = \sqrt{\frac{m_0}{m_2}} \tag{7.7}$$

- spectral peak period defined as

$$T_p = \frac{1}{f_p} \tag{7.8}$$

where f_p is the frequency corresponding to the maximum spectral density.

- spectral width or broadness parameter defined as

$$\varepsilon_4 = \sqrt{1 - \frac{m_2^2}{m_0 m_4}} \tag{7.9}$$

- Average reflection coefficient is always given in the log file for the analysis. The average reflection coefficient is defined by:

$$C_R = \sqrt{\frac{\int_{f_{min}}^{f_{max}} S_R(f)\,df}{\int_{f_{min}}^{f_{max}} S_I(f)\,df}} \tag{7.10}$$

where $S_R(f)$ and $S_I(f)$ are reflected and incident spectrum, respectively.

Log file
As default the log file is automatically opened after model execution. The file is opened in Notepad.

7.8 Scientific documentation

The WS Reflection Analysis Module calculates incident and reflected wave spectra by frequency separation using a least squares fit approach.

For further introduction to reflection analysis reference is made to Goda & Suzuki (1976), Mansard & Funke (1980, 1987) and Zelt & Skjelbreia (1992).

7.9   References

Goda, Y. & Suzuki, Y. (1976) Estimation of incident and reflected waves in random wave experiments. ICCE '76, Honolulu, Hawaii, pp. 828-845.

Mansard, E.P.D. & Funke, E.R. (1980) The measurement of incident and reflected spectra using a least squares method. ICCE '80, Sydney, Australia, pp. 154-172.

Mansard, E.P.D. & Funke, E.R. (1987) On the reflection analysis of irregular waves. Tech. Rep. TR-HY-017, NRCC No. 27522, National Research Council of Canada.

Zelt, J.A. & Skjelbreia, J.E. (1992) Estimating incident and reflected wave fields using an arbitrary number of wave gauges. Coastal Engineering, ASCE, pp. 777-789.

8 WS AWACS Reflection Analysis

8.1 Introduction

With the WS AWACS Reflection Analysis Module it is possible to determine wave reflection and evaluate wavemaker performance. The module requires that the feedback from DHI's digital wavemaker controller (AWACS[2]) is stored. Depending on the mode of operation of the wavemaker the following time series data will be available for analysis:

Position mode: desired paddle position, actual paddle position and surface elevation at the wavemaker paddle (requires that wave gauge on the paddle front are calibrated)

Absorption mode: actual paddle position, desired elevation and actual surface elevation at the wavemaker paddle.

Depending on the input time series the module will return parameters as:

1. Reflection coefficient
2. Servo delay
3. Incident and reflected wave spectra
4. Spectrum parameters, e.g. spectral peak-to-peak and period estimates
5. Reflection function (amplitude and phase)
6. Re-reflection function (amplitude and phase)
7. Generation function ((amplitude and phase)
8. Coherence spectrum

The module uses the theory of the active absorption technique (see Schäffer & Hyllested (1999)) to extract both the incident and reflected surface elevation, accounting for the influence of evanescent modes present in the surface elevation measured at the wavemaker paddle.
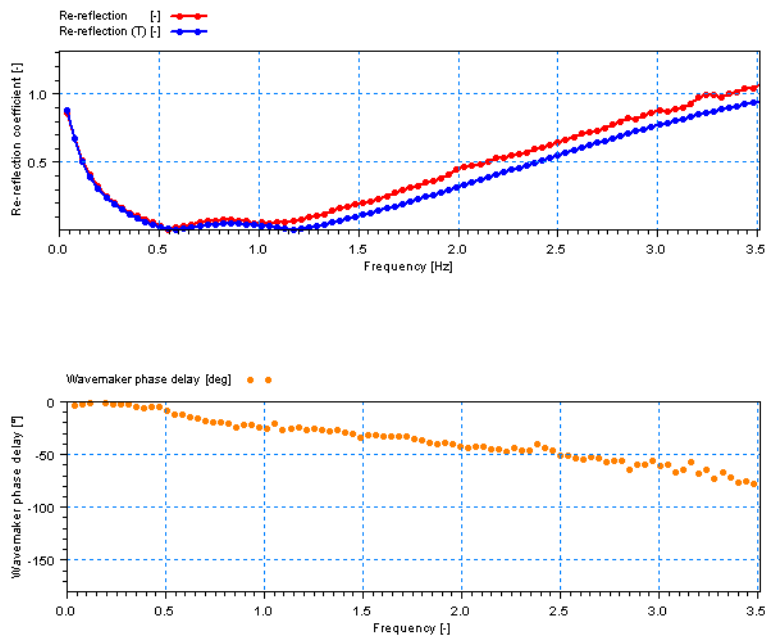
Figure 8.1   The figure shows wavemaker performance in terms of actual and theoretical re-reflection function and wavemaker phase delay calculated from wavemaker feedback.
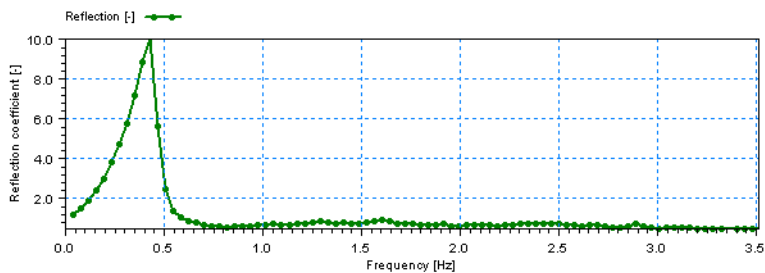

Figure 8.2   The figure shows the reflection function calculated from wavemaker feedback.
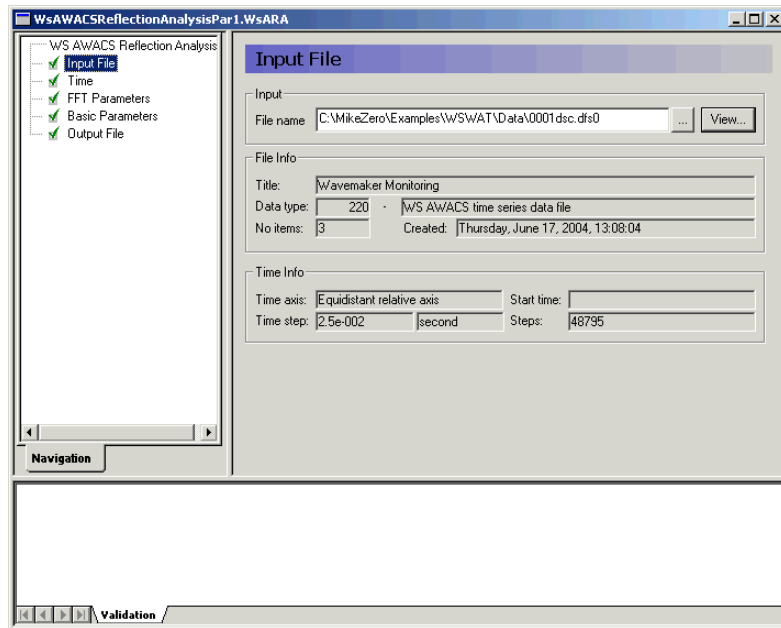
8.2   Input File

Figure 8.3   Input File dialog

The WS AWACS Reflection Analysis module supports time series data with equidistant time step. At present the binary dfs0-file format (DFS data file format) is supported.

Whenever the editor recognises the used file format an info box containing the files header information appears in the lower half of the dialog.

You can view the selected data file using the MIKE Zero Time Series editor by clicking on the "View" button.

8.2.1   Remarks & hints

The file must be a wavemaker monitor file from the program DHI Wave Synthesizer as it contain necessary information for synthesis of digital absorption filters.

8.3   Time
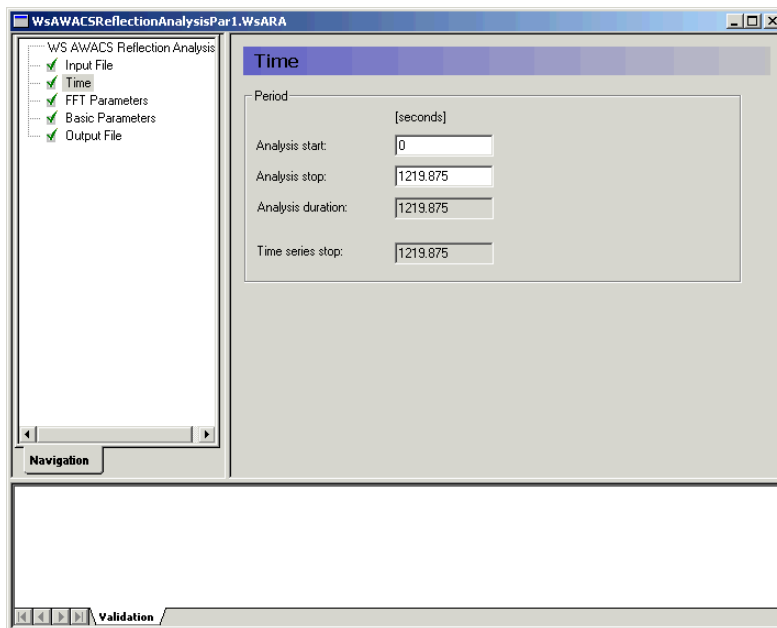
Figure 8.4   Time dialog

The period to be covered by the analysis is specified in the Time dialog.

8.4 FFT Parameters
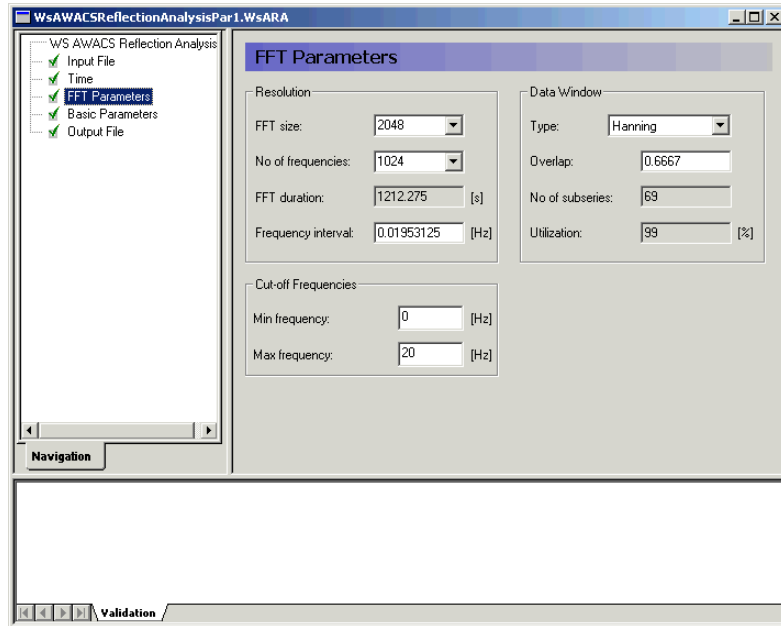
Figure 8.5   FFT Parameters dialog

The parameters given on the FFT Parameters dialog determines the frequency resolution and the degree of smoothing of the spectrum.

8.4.1 Resolution

FFT size
Number of data point in each FFT block or subseries. The length must be a power of two and cannot exceed the total number of data points.

Number of frequencies
Is the half the FFT size.

FFT duration
Gives the length of the FFT analysis in seconds

Frequency interval
The difference between two discrete adjacent frequencies. If manually changed, the value is automatically adjusted to the nearest possible value (function of time step and FFT size).

8.4.2   Data window

A phenomenon know as side-lobe leakage may lead to pronounced interaction between different frequencies with distorted spectra as a consequence. Applying a data window in the spectral analysis may reduce the influence of side-lobe leakage. The data window is a weight function used to taper a time series before the FFT analysis is initiated.

Type
Three different data windows are available,

- rectangular data window (i.e. without tapering)
- Hanning data window (default)
- Cosine squared

Overlap
The spectra (and response functions) are calculated using overlapping sub-series. The overlap controls the smoothing of spectra, but it also controls the weighting of the different parts of the input time series.

A value of zero corresponds to no overlap and with increasing overlap as the value tends towards unity. An overlap of 2/3 is used as default.

Number of subseries
Based on the specified FFT parameters the number of subseries can be calculated. It is almost always desirable to have a large number of subseries because it will reduce the variance of the spectral density and provide a smooth spectral estimate.

For non-overlapping time series the number of degrees of freedom for the spectral estimate is two times the number of subseries. Spectral estimates having 30-40 degrees of freedom is often used in practice.

Utilisation
Indicates the utilisation of the input data.

8.4.3   Cut-off frequencies

The cut-off frequencies determine the frequency range for which the spectra and spectral results are calculated.

Minimum frequency
The minimum cut-off frequency must be greater than or equal to zero.

Maximum frequency

The maximum cut-off frequency must be less than or equal to the Nyquist frequency that is determined entirely by the sampling frequency f_s of the input data:

$$f_{max} = 0.5\,f_s = \frac{1}{2\Delta t} \tag{8.1}$$

Here Δt is the time step of the input data. If value is out of range a warning is issued and the invalid maximum cut-off frequency is automatically adjusted to the Nyquist frequency.

8.4.4 Remarks & hints

Please note that if data window tapering is omitted pronounced interaction between frequencies might occur due to side-lobe leakage. It is recommend using the Hanning data window for all practical applications.

It is important to realise that the various dialogs are all synonyms for the FFT size, and that changing one parameter will also affect others.

8.5 BasicParameters
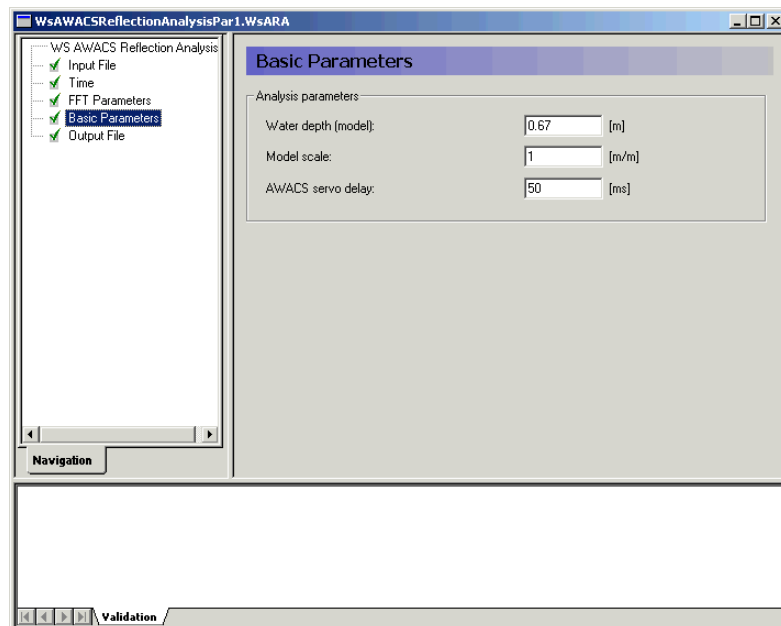
Figure 8.6   Basic In the Basic Parameters dialog you define the basic analysis parameters.

Analysis parameters

The model water depth is as default taken from the input file as this depth has been used for synthesis of the digital absorption filters. If the actual water depth for some reason is different you must enter the correct model water depth. Deviations between default and actual water depth will result in a decreased wavemaker performance.

The servo delay of wavemaker system should generally be adjusted to 50ms at prior to testing. Hence, the digital absorption filter presumes a delay of 50ms and deviations will reduce the efficiency of the AWACS system. You can evaluate the effect of an incorrect adjustment of the servo delay by entering the actual servo delay.

All measurements in the input file are stored in model scale. Output parameters may be scaled to prototype by entering the proper model scale.

8.6 Output File
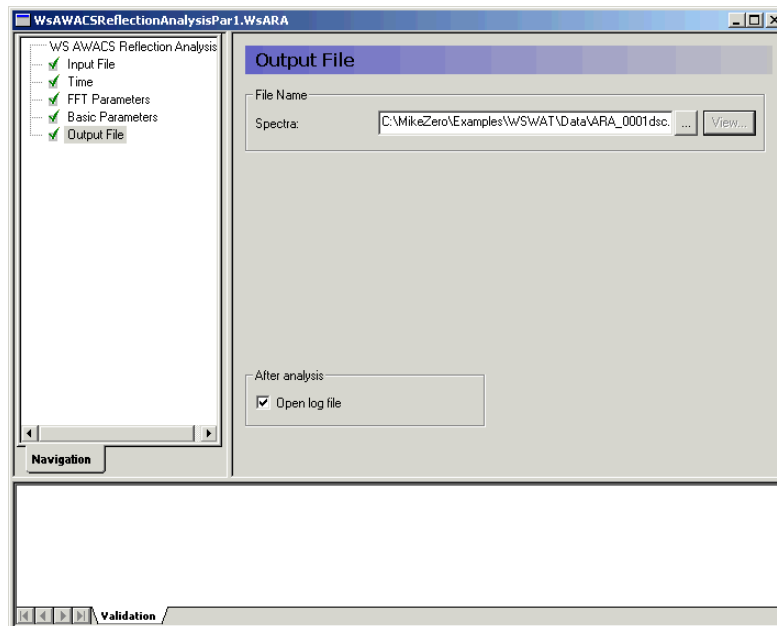
Figure 8.7 Output File dialog

In the Output File dialog you specify the output file name and folder where to place the data file. If the output file already exists you can view the selected data file using the MIKE Zero Time Series editor by clicking on the "View" button.

Parameters

For the auto, incident and reflected wave spectra the following parameters are calculated:

- significant wave height, H_{m0}
- mean wave periods T_{01} and T_{02}
- spectral peak period T_p
- spectral width ε_4
- average reflection coefficient C_R

A number of the parameters are based on the spectral moments:

$$m_n = \int_{f_{min}}^{f_{max}} S_X(f) f^n df \qquad (8.2)$$

- significant wave height defined as

$$H_{m0} = 4\sqrt{m_0} \qquad (8.3)$$

- mean wave periods defined as

$$T_{01} = \sqrt{\frac{m_0}{m_1}}$$

$$T_{02} = \sqrt{\frac{m_0}{m_2}} \qquad (8.4)$$

- spectral peak period defined as

$$T_p = \frac{1}{f_p} \qquad (8.5)$$

where f_p is the frequency corresponding to the maximum spectral density.

- spectral width or broadness parameter defined as

$$\varepsilon_4 = \sqrt{1 - \frac{m_2^2}{m_0 m_4}} \qquad (8.6)$$

- Average reflection coefficient is always given in the log file for the analysis. The average reflection coefficient is defined by:

$$C_R = \sqrt{\frac{\int_{f_{min}}^{f_{max}} S_R(f)\,df}{\int_{f_{min}}^{f_{max}} S_I(f)\,df}} \tag{8.7}$$

where $S_R(f)$ and $S_I(f)$ are reflected and incident spectrum, respectively.

A number of calculated parameters and functions are related to the performance of the AWACS system:

- re-reflection function (only available in absorption mode)
- generation function (only available in absorption mode)
- coherence (only available in absorption mode)
- wavemaker group delay and AWACS servo delay

The definition and interpretation of these are:

- the wavemaker group delay is calculated from desired and actual paddle positions and given as a frequency dependent phase shift. The AWACS servo delay is determined from the wavemaker group delay as a weighted fit within the primary working range of the wavemaker. For optimal performance of the AWACS system the delay must be close to 50ms.
- the re-reflection function is defined as the additional amplitude of waves emitted from the wavemaker due to reflections divided by the reflected wave amplitude at a given frequency. Practical and theoretical functions may be compared.
- the generation function is defined as the ratio of the generated and desired wave amplitude in case of no reflection. Practical and theoretical functions may be compared.
- the coherence spectrum is the fraction of the reflected time series of surface elevations that is linearly due to the incident time series of surface elevations. The AWACS system is based on linear wave theory and the coherence should generally be close to unity.

Log file

As default the log file is automatically opened after model execution. The file is opened in Notepad.

8.7   Scientific documentation

The WS AWACS Reflection Analysis Module is based on the theory of the active absorption technique for DHI's digital wavemaker controllers. For further introduction to the theory behind the active absorption technique reference is made to Schäffer & Hyllested (1999) and Schäffer & Jakobsen (2003).

8.8   References

Schäffer, H. A. & Hyllested, P. (1999) Reflection analysis using an active wave absorption control system. Coastal Structures '99, Santander, Spain, pp. 93-99.

Schäffer, H. A. & Jakobsen, K. P. (2003) Non-linear wave generation and active absorption in wave flumes. LWS 2003 (in parallel to XXX IAHR Congress), Thessaloniki, Greece

9 WS Trend Removal

9.1 Introduction

The WS Trend Removal Module is a useful supplement to the WS Digital Filtering Analysis Module. Hence, the traditional filtering cannot solve some simple problems, as the duration of a trend (which is infinite) is much longer than the duration of the filter (or time series).

One example is a measured surface elevation with a very slow, unilateral variation superimposed (e.g. due to a drifting sensor or leakage from a wave flume). The removal of the superimposed variation is accomplished by approximating the time series by an orthogonal polynomial fit of lower order that subsequently is subtracted from the time series.
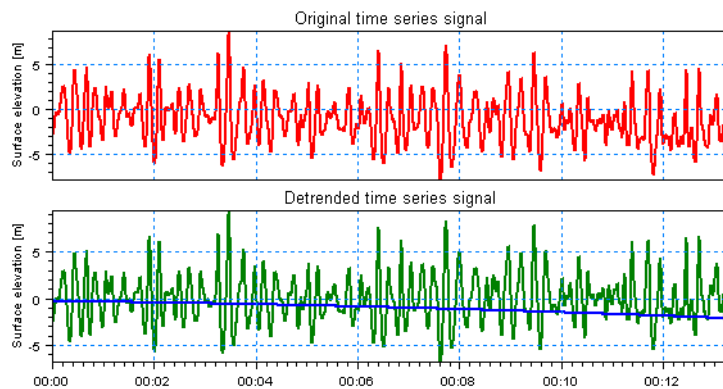
Figure 9.1   The upper figure shows a measured time series with a unilateral variation due to a drifting gauge. The lower figure shows the detrended time series and the removed trend.

9.2   Input File
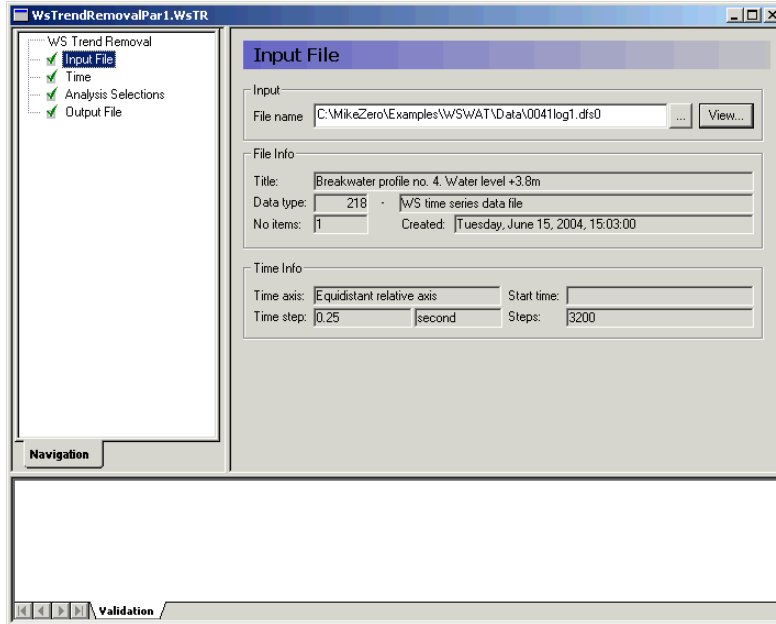
Figure 9.2   Input File dialog

The WS Trend Removal module supports time series data with equidistant time step. At present the following two binary file formats are supported:

- dfs0 (DFS data file format)
- dt0 (old file format)

Please note that dt0 is included for backward compatibility, only.

Whenever the editor recognises the used file format an info box containing the files header information appears in the lower half of the dialog.

You can view the selected data file using the MIKE Zero Time Series editor by clicking on the "View" button.

9.3　Time
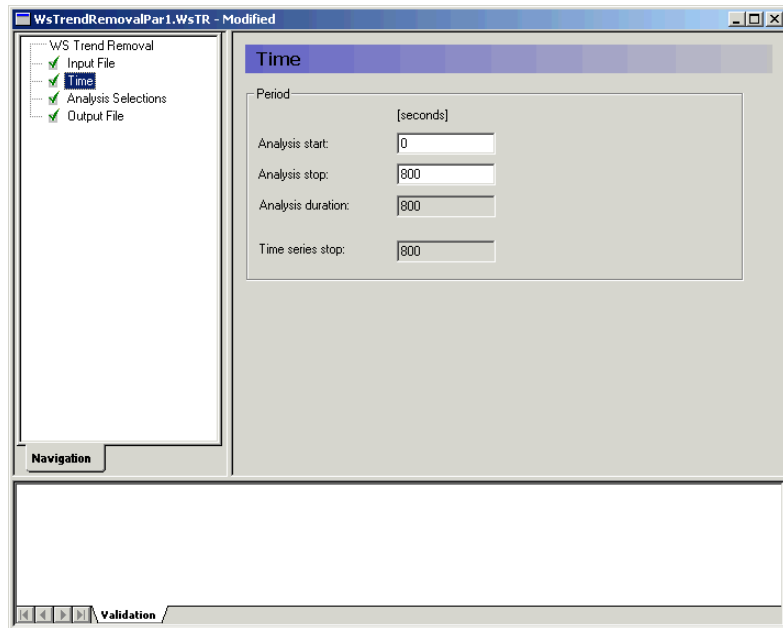
Figure 9.3　Time dialog

The period to be covered by the analysis is specified in the Time dialog.

9.4   Analysis Selections
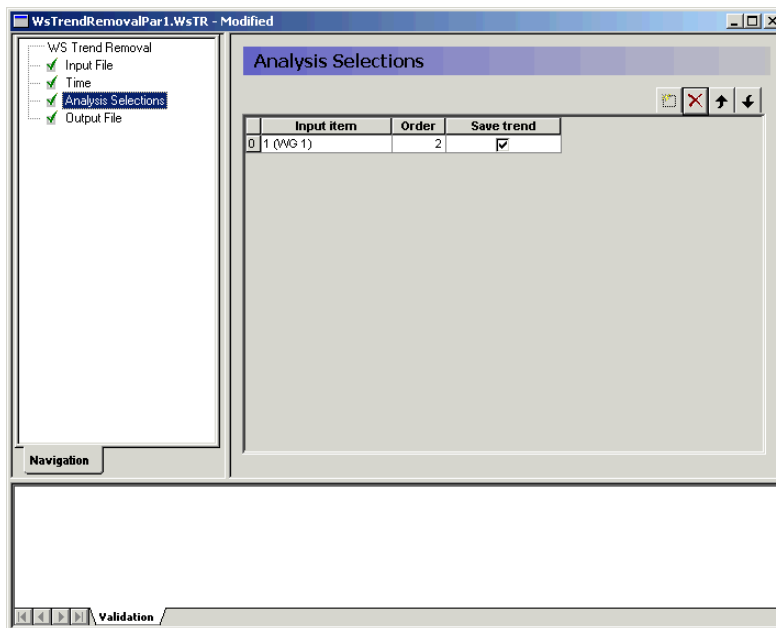
Figure 9.4   Analysis Selections dialog

In the Analysis Selections dialog you select the items for detrending from a dynamic table containing information about the selected data file. The middle column contains an editable field, in which the order of the polynomial fit must be given, i.e. 0 indicates a constant, 1 indicates a line etc. The rightmost column contains a checkbox that must be checked if the removed trend should be saved with the output time series signal.

9.4.1   Remarks & hints

The maximum order of the polynomial fit is three. More complex trends may be removed by higher-order polynomial fits, but fits with an order higher than three may result in removal of actual low-frequency information in the input time series signal.

9.5   Output File
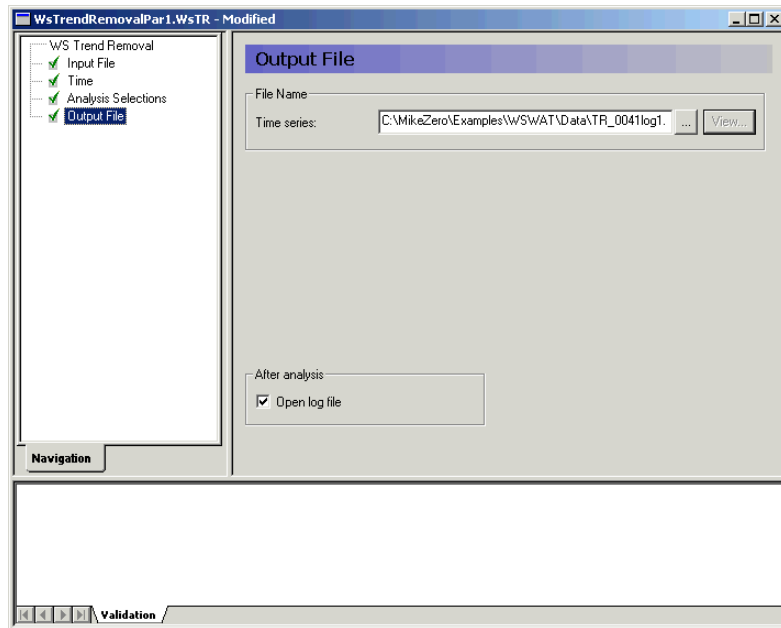
Figure 9.5   Output File dialog

In the Output File dialog you specify the output file name and folder where to place the data file. If the output file already exists you can view the selected data file using the MIKE Zero Time Series editor by clicking on the "View" button.

Log file

As default the log file is automatically opened after model execution. The file is opened in Notepad.

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