1D/2D/3D Modelling suite for integral water solutions

Delft3D Flexible Mesh Suite

Deltares systems

D-Waves

Deltares

Enabling Delta Life

User Manual

D-Waves

Simulation of short-crested waves with SWAN

User Manual

Delft3D Flexible Mesh

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Deltares
Boussinesqweg 1
2629 HV Delft
P.O. 177
2600 MH Delft
The Netherlands

telephone: +31 88 335 82 73
fax: +31 88 335 85 82
e-mail: info@deltares.nl
www: https://www.deltares.nl

For sales contact:
telephone: +31 88 335 81 88
fax: +31 88 335 81 11
e-mail: sales@deltaressystems.nl
www: http://www.deltaressystems.nl

For support contact:
telephone: +31 88 335 81 00
fax: +31 88 335 81 11
e-mail: support@deltaressystems.nl
www: http://www.deltaressystems.nl

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1 A guide to this manual

1.1 Introduction

This User Manual concerns the module D-Waves.

This module is part of several Modelling suites, released by Deltares as Deltares Systems or Dutch Delta Systems. These modelling suites are based on the Delta Shell framework. The framework enables to develop a range of modeling suites, each distinguished by the components and — most significantly — the (numerical) modules, which are plugged in. The modules which are compliant with the Delta Shell framework are released as D-*Name* of the module, for example: D-Flow Flexible Mesh, D-Waves, D-Water Quality, D-Real Time Control, D-Rainfall Run-off.

Therefore, this user manual is shipped with several modelling suites. In the start-up screen links are provided to all relevant User Manuals (and Technical Reference Manuals) for that modelling suite. It will be clear that the Delta Shell User Manual is shipped with all these modelling suites. Other user manuals can be referenced. In that case, you need to open the specific user manual from the start-up screen in the central window. Some texts are shared in different user manuals, in order to improve the readability.

1.2 Overview

In this manual advice is given on how to get started with the SWAN wave model. Furthermore, the manual gives a description on how to use the SWAN model within D-Waves.

Generally, the following items with respect to the use of the D-Waves module will be described in this manual.

Chapter 2: Introduction to D-Waves, provides specifications of D-Waves such as required computer configuration, how to install the software, as well as its main features.

Chapter 3: Getting started, introduces the D-Waves Graphical User Interface (GUI), used to define the input required for a wave simulation.

Chapter 4: Graphical User Interface, provides practical information on the selection of all parameters and the tuning of the model.

Chapter 5: Conceptual description, discusses the unit and co-ordinate system, the various grids, grid-numbering etc. In addition, a brief description is given on the physics and numerics that have been implemented in D-Waves.

References, provides a list of publications and related material on the D-Waves module.

Appendix A: Files of Delft3D-WAVE, gives a description of all the attribute files that can be used in the D-Waves input. This information is required for generating certain attribute files either manually or by means of other utility programs. For other attribute files this description is just for your information.

Appendix B: Definition of SWAN wave variables, the definition of the integral wave parameters is given.

Appendix C: Example of MDW-file Siu-Lam, an example of a Master Definition file for the Wave <∗.mdw> input file for the WAVE module is given.

1.3 Manual version and revisions

This manual applies to:

◇ the D-HYDRO Suite, version 2016
◇ the Delft3D Flexible Mesh Suite, version 2016

1.4 Typographical conventions

Throughout this manual, the following conventions help you to distinguish between different elements of text.

Example	Description
Waves **Boundaries**	Title of a window or sub-window. Sub-windows are displayed in the **Module** window and cannot be moved. Windows can be moved independently from the **Module** window, such as the **Visualisation Area** window.
Save	Item from a menu, title of a push button or the name of a user interface input field. Upon selecting this item (click or in some cases double click with the left mouse button on it) a related action will be executed; in most cases it will result in displaying some other (sub-)window. In case of an input field you are supposed to enter input data of the required format and in the required domain.
<\tutorial\wave\swan-curvi> <siu.mdw>	Directory names, filenames, and path names are expressed between angle brackets, <>. For the Linux and UNIX environment a forward slash (/) is used instead of the backward slash (\) for PCs.
“27 08 1999”	Data to be typed by you into the input fields are displayed between double quotes. Selections of menu items, option boxes etc. are described as such: for instance ‘select *Save* and go to the next window’.
`delft3d-menu`	Commands to be typed by you are given in the font Courier New, 10 points.
➢	User actions are indicated with this arrow.
[m/s] [-]	Units are given between square brackets when used next to the formulae. Leaving them out might result in misinterpretation.

1.5 Changes with respect to previous versions

This is the first edition which is published.

2 Introduction to D-Waves

2.1 SWAN wave model

2.1.1 Introduction

To simulate the evolution of random, short-crested wind-generated waves in estuaries, barrier islands with tidal inlets, tidal flats, lakes, channels etc., the D-Waves module can be used. D-Waves is based on the ***third-generation*** SWAN model - SWAN is an acronym for **S**imulating **WA**ves **N**earshore (see e.g. Holthuijsen *et al.* (1993); Booij *et al.* (1999); Ris *et al.* (1999)).

The SWAN model was developed at Delft University of Technology (The Netherlands). It is specified as the new standard for nearshore wave modelling and coastal protection studies. The SWAN model has been released under public domain. For more information about SWAN reference is made to the SWAN home page:

`http://www.swan.tudelft.nl/`

D-Waves computes wave propagation, wave generation by wind, non-linear wave-wave interactions and dissipation, for a given bottom topography, wind field, water level and current field in waters of deep, intermediate and finite depth.

2.1.2 Conceptual design of SWAN: an introduction

The SWAN model is based on the discrete spectral action balance equation and is fully spectral (in all directions and frequencies). The latter implies that short-crested random wave fields propagating simultaneously from widely different directions can be accommodated (e.g. a wind sea with super-imposed swell). SWAN computes the evolution of random, short-crested waves in coastal regions with deep, intermediate and shallow water and ambient currents. The SWAN model accounts for (refractive) propagation due to current and depth and represents the processes of wave generation by wind, dissipation due to whitecapping, bottom friction and depth-induced wave breaking and non-linear wave-wave interactions (both quadruplets and triads) explicitly with state-of-the-art formulations. Wave blocking by currents is also explicitly represented in the model.

To avoid excessive computing time and to achieve a robust model in practical applications, fully implicit propagation schemes have been applied. The SWAN model has successfully been validated and verified in several laboratory and (complex) field cases (see Ris *et al.* (1999); WL | Delft Hydraulics (1999, 2000)).

2.1.3 Coupling of SWAN with D-Flow Flexible Mesh

This is discussed in the D-Flow Flexible Mesh User Manual.

2.2 Areas of application

The D-Waves model can be used for coastal development and management related projects and for harbour and offshore installation design. It can also be used as a wave hindcast model. Typical areas for the application of the SWAN model may vary of up to more than 50 km $\times$ 50 km. Generally, the model can be applied in the following areas:

- ◇ estuaries
- ◇ tidal inlets
- ◇ lakes
- ◇ barrier islands with tidal flats
- ◇ channels
- ◇ coastal regions

2.3 Standard features

The SWAN model accounts for the following physics:

- ◇ wave refraction over a bottom of variable depth and/or a spatially varying ambient current
- ◇ depth and current-induced shoaling
- ◇ wave generation by wind
- ◇ dissipation by whitecapping
- ◇ dissipation by depth-induced breaking
- ◇ dissipation due to bottom friction (three different formulations)
- ◇ nonlinear wave-wave interactions (both quadruplets and triads)
- ◇ wave blocking by flow
- ◇ transmission through, blockage by or reflection against obstacles
- ◇ diffraction

Note that diffraction and reflections are now available in the present SWAN version under D-Waves.

2.4 Special features

A special feature is the dynamic interaction with D-Flow Flexible Mesh (i.e. two way wave-current interaction). By this the effect of waves on current (via forcing, enhanced turbulence and enhanced bed shear stress) and the effect of flow on waves (via set-up, current refraction and enhanced bottom friction) are accounted for.

2.5 Utilities

In using D-Waves, the following utilities are important:

module	description
RGFGRID	for generating grids.
Delft3D-QUICKPLOT	for visualising simulation results.
Muppet	for visualising simulation results.

For details on using these utility programs you are referred to the respective User Manuals.

3 Getting started

3.1 Introduction

The D-Waves plugin is part of the Delta Shell framework. For an introduction to the general look-and-feel and functionalities of the DeltaShell framework you are referred to the Delta Shell framework manual. This Chapter gives an overview of the basic features of the D-Waves plugin and will guide you through the main steps to set up a D-Waves model. For a more detailed description of the GUI features you are referred to **??**. For technical documentation you are referred to the D-Waves manual.

3.2 Overview of D-Waves plug-in

Delta Shell is only available for Windows operating systems. You can either install the msi-version or copy the zip-version. For the msi-version first follow the steps in the installatio guide. Consequently, open Delta Shell by double-clicking the Delta Shell icon in programs or the short-cut on your desktop. For the zip-version you don't have to install anything. First unpack the zip, consequently go to bin and double-click DeltaShell.Gui.exe to open Delta Shell.

When you open Delta Shell for the first time the lay-out will look like Figure 3.1. The basic lay-out consists of the following items:

- ◇ project tree - upper left
- ◇ map tree and data window - lower left
- ◇ central (map) window - upper centre
- ◇ message window and time navigator - lower centre
- ◇ region and chart window - upper right
- ◇ properties and undo/redo window - lower right

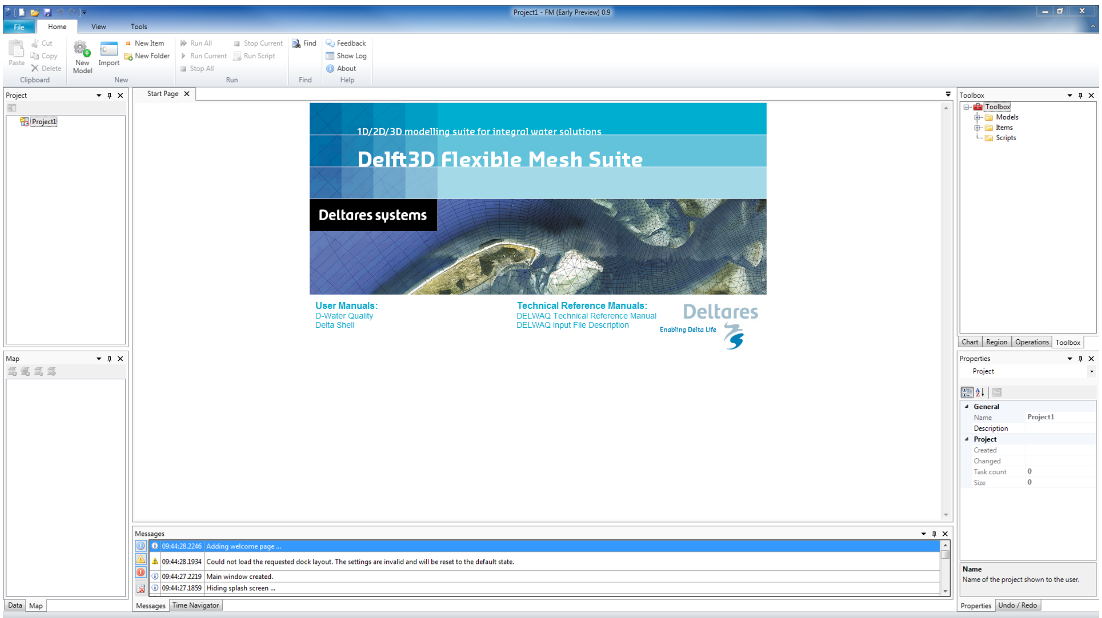


Figure 3.1: *Start-up lay-out Delta Shell framework*

All the windows can be customized/hidden according to your own preferences. These settings will be automatically saved for the next time you open Delta Shell. The most important windows for the D-Waves plugin are the project tree, central (map) window, map tree, the message window and time navigator. The contents of these windows are briefly discussed in the subsections below.

3.2.1 Project tree

After adding or importing a Delft3D-WAVE model (see section âĂę), the project tree will be extended with wave model specific features (see Figure 3.2). The project tree provides you with the basic steps to set up a Delft3D-WAVE model.

The project tree consists of the following features:

General	general model information such as description, model coordinate system, simulation mode, directional convention, etc.
Area	geographical (GIS based) features, such as observation points and curves and obstacles
Domain (outer)	model grid and bathymetry (multiple in case of nested model)
Hydrodynamics	variables to be copied from FLOW model in case of a coupled model
Spectral resolution	default spectral settings
Time Frame	time points and (time-varying) hydrodynamic and wind conditions
Boundary conditions	wave boundary conditions and spectrum specification
Physical parameters	physical settings for processes such as setup, wave breaking, refraction, triads, etc.
Numerical parameters	numerical simulation settings
Output parameters	output specification
Output	output after running the simulation

Upon clicking the items in the project tree the corresponding tab (in case of GIS/map-independent model settings), attribute table (in case of GIS/map-dependent model settings) or editor view (in case of advanced editing options) will open. Using the right mouse button (RMB) gives options such as importing/exporting model data.

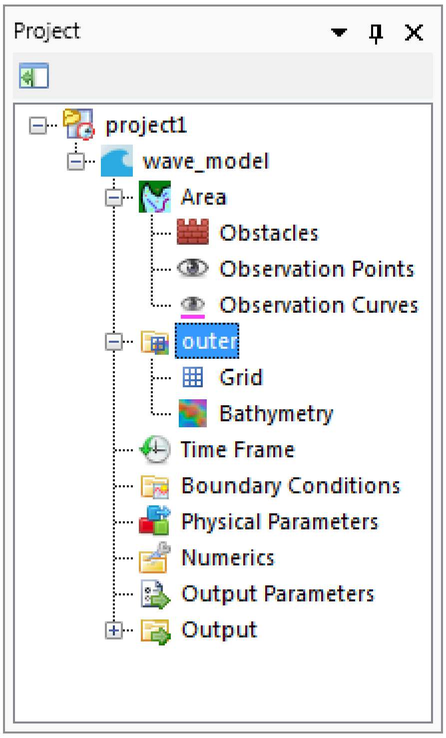


Figure 3.2: *Project tree of D-Waves plugin*

3.2.2 Central (map) window

The central window shows the contents of the main editor you are working with. In most cases this will be the central map with tabulated input fields (see Figure 3.3). The map is used to edit GIS dependent model data, the tabulated input fields to edit overall model settings. Moreover, the contents of the central window can also be a specific editor such as the time point editor or the boundary condition editor. Each of these editors will open as a separate view.

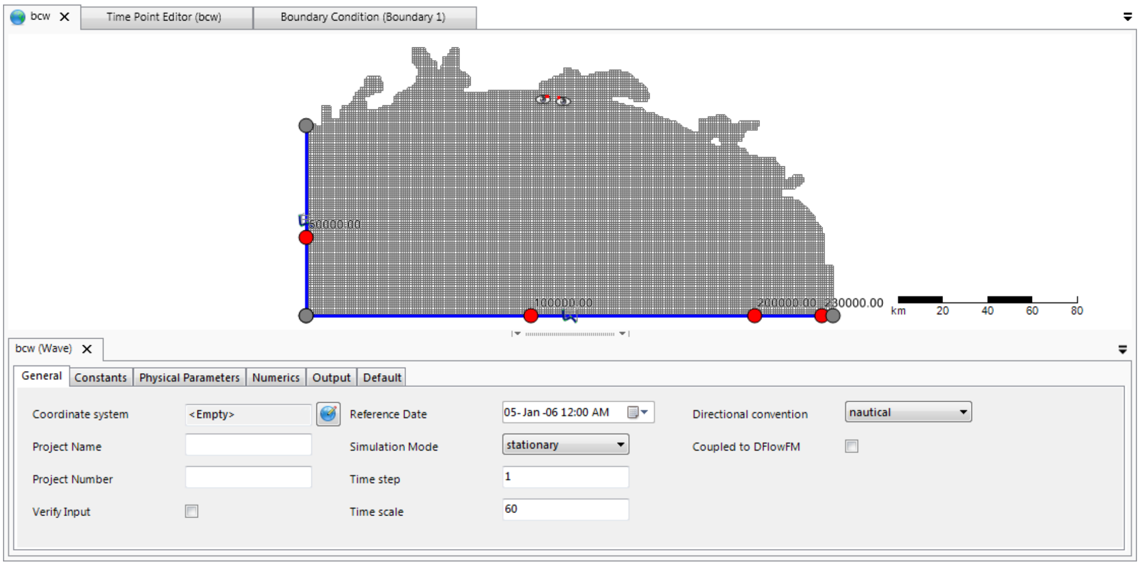


Figure 3.3: Central map with contents of the D-Waves plug-in

3.2.3 Map tree

The map tree allows the user to control the visibility of the contents of the central map using checkboxes. Furthermore, the user can add (wms) layers, such as satellite imagery (see Figure 3.4).

Note: : Please note that the map usually has a different coordinate system than the model. In rendering the model attributes they are transformed to the map coordinate system (for visual inspection on the map), but the model will be saved in the model coordinate system.

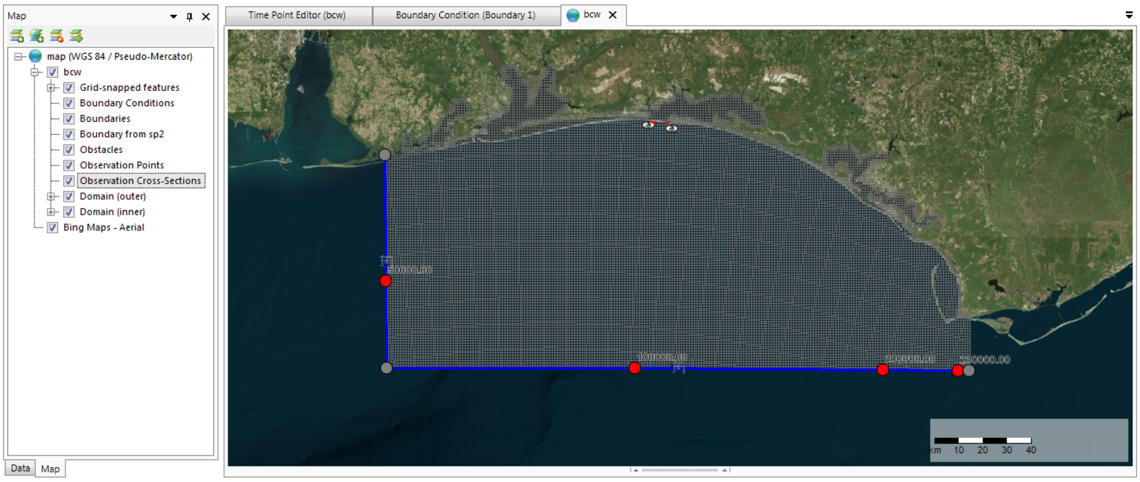


Figure 3.4: Map tree controlling map contents

3.2.4 Message window

The message window (Figure 3.5) provides a log of information on the recent activities in Delta Shell. It also provides warning and error messages.

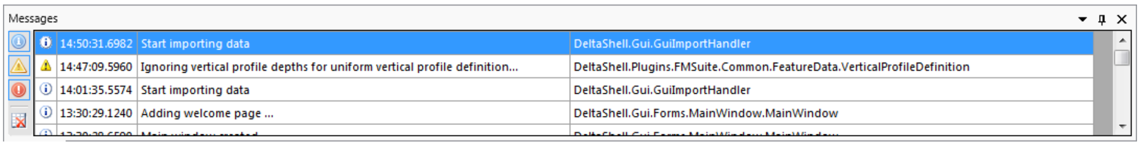


Figure 3.5: Log of messages, warnings and errors in message window

3.2.5 Time navigator

The time navigator (Figure 3.6) can be used to step through time dependent model output and other time dependent GIS features on the map.

Figure 3.6: Time navigator in Delta Shell

3.3 Setting up a D-Waves model (basic steps)

This section shows the basic steps to set up a D-Waves model. For a more detailed description of the steps and GUI features you are referred to chapter 4.

3.3.1 Add a D-Waves model

After starting up Delta Shell, the start page will open with a default project (i.e. "project1", see Figure 3.1). To add a D-Waves model to the project you have the following options:

- ◇ click "New Model" in the "Home"-ribbon (Figure 3.7)
- ◇ use the Right Mouse Button (RMB) on "project1" in the project tree, go to "Add" and "New Model' (Figure 3.8)

From the list of available models (which can vary depending on your installation), select "Wave model" (Figure 3.9).

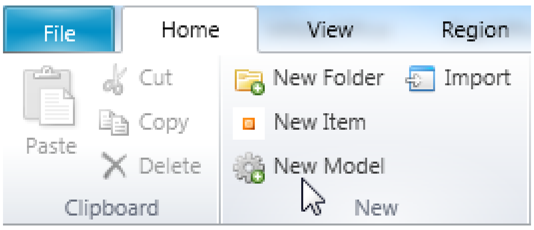


Figure 3.7: Adding a new model from the ribbon

3.3.2 Set up a D-Waves model

To set up the wave model follow the steps in the project tree. For a more detailed description, see chapter 4.

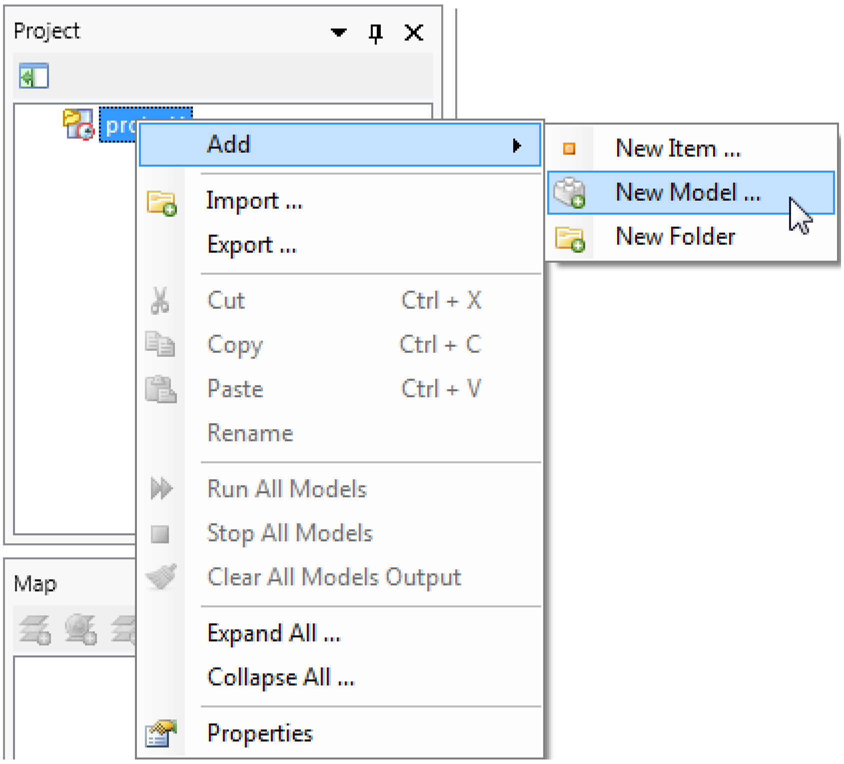


Figure 3.8: *Adding a new model using the Right Mouse Button on "project1" in the project tree*

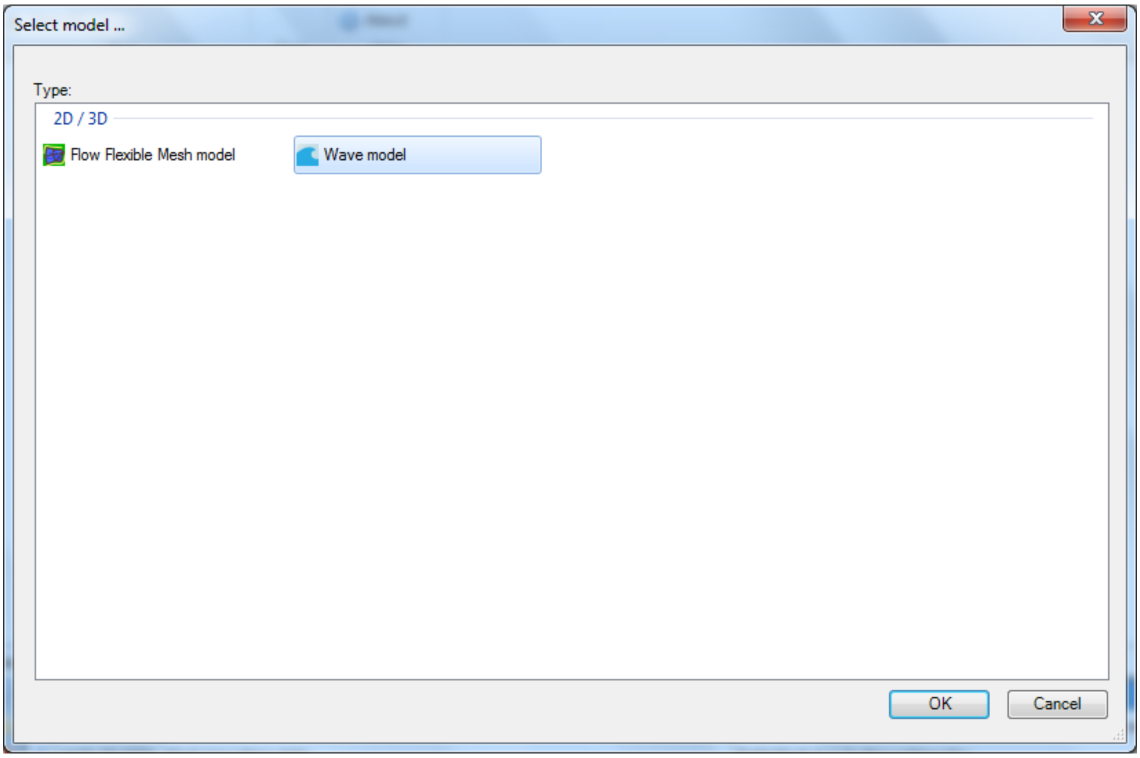


Figure 3.9: *Select "Wave model"*

3.3.3 Validate D-Waves model

You can check whether your model setup is valid by using the RMB in the project tree and select "Validate" (Figure 3.10). This will produce a validation report (Figure 3.11). Red exclamation marks indicate the parts of the model that are still invalid. By clicking the hyperlink you will be automatically redirected to the invalid step in the model setup, so that you can correct it.

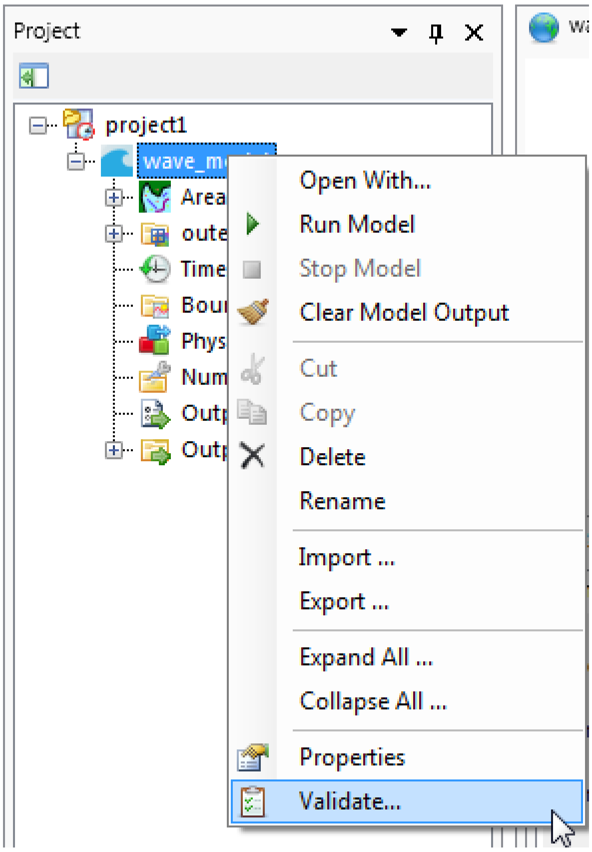


Figure 3.10: *Validate model*

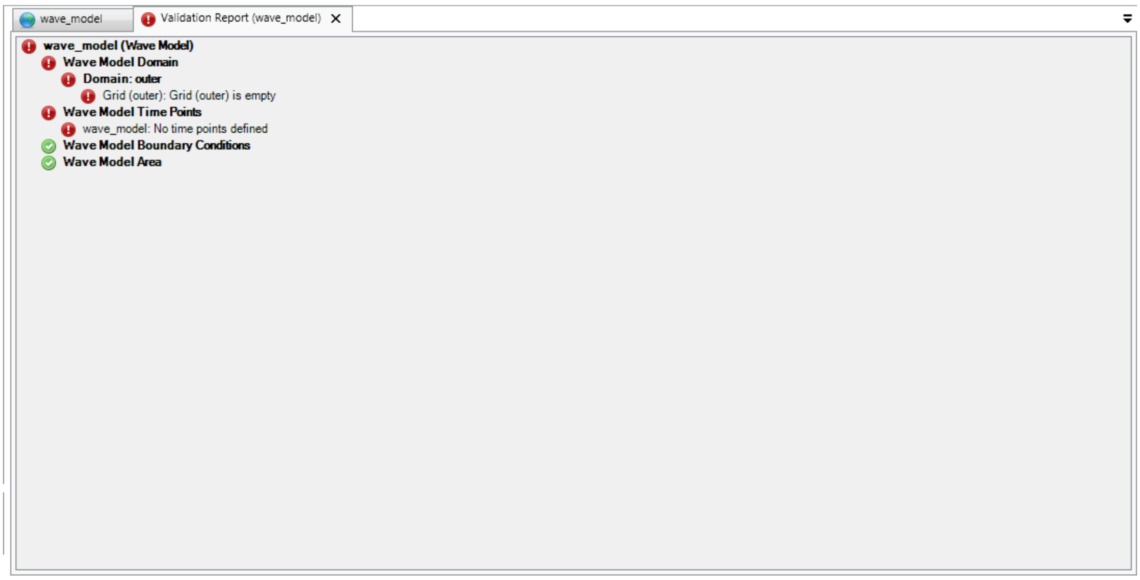


Figure 3.11: *Validation report*

3.3.4 File tree (to be implemented)

To check the file paths and names of the attribute files which are linked to your model, you can select "File tree" using the RMB on your model in the project tree.

3.3.5 Run D-Waves model

If you are satisfied with the model setup, you can run it from Delta Shell using the RMB on model and select ”Run model” (Figure 3.12).

Note: it is also possible to run Delft3D-WAVE outside Delta Shell using the command line.

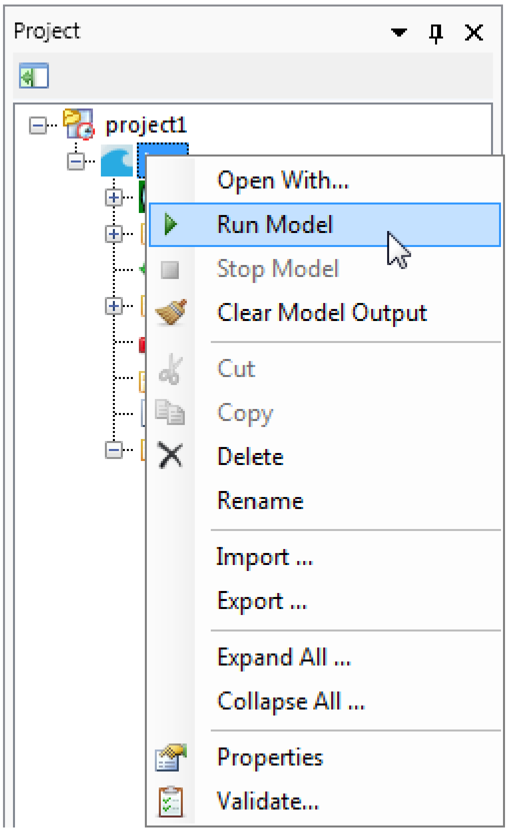


Figure 3.12: *Run model*

3.3.6 Inspect model output

The simulation will start and the output will be stored in the output folder in the project tree (Figure 3.13). Delta Shell provides some basic tools to inspect the model output. For more extensive and advanced options you are referred to Quickplot and Muppet.

3.3.7 Import/export or delete a D-Waves model

To import an existing Delft3D-WAVE model either use the RMB on the project level in the project tree (Figure 3.14) or go to the ”File”-ribbon and press the "Import" (Figure 3.15). Likewise you can export a model or delete a model.

For the steps in the project tree that are linked to attribute files (observation points, grid, bathymetry, etc.) you can use the RMB to import or export these attribute files.

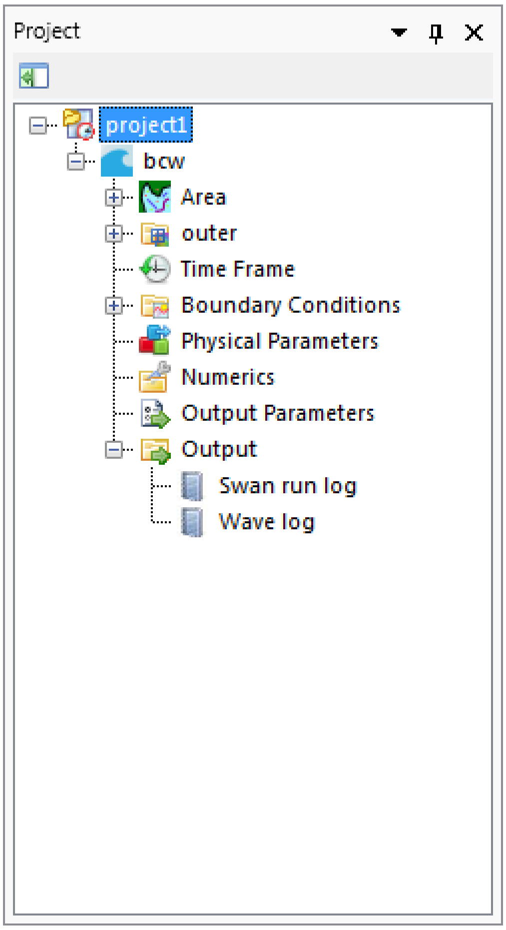


Figure 3.13: *Output of wave model in project tree*

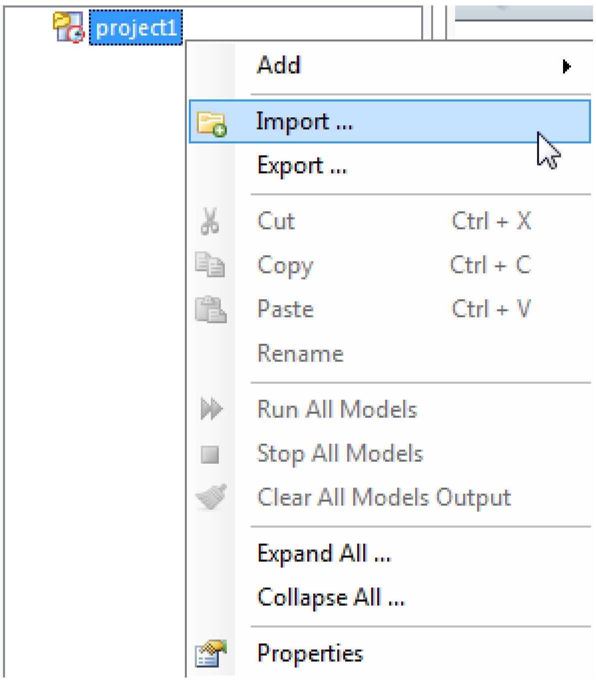


Figure 3.14: *Import wave model from project tree*

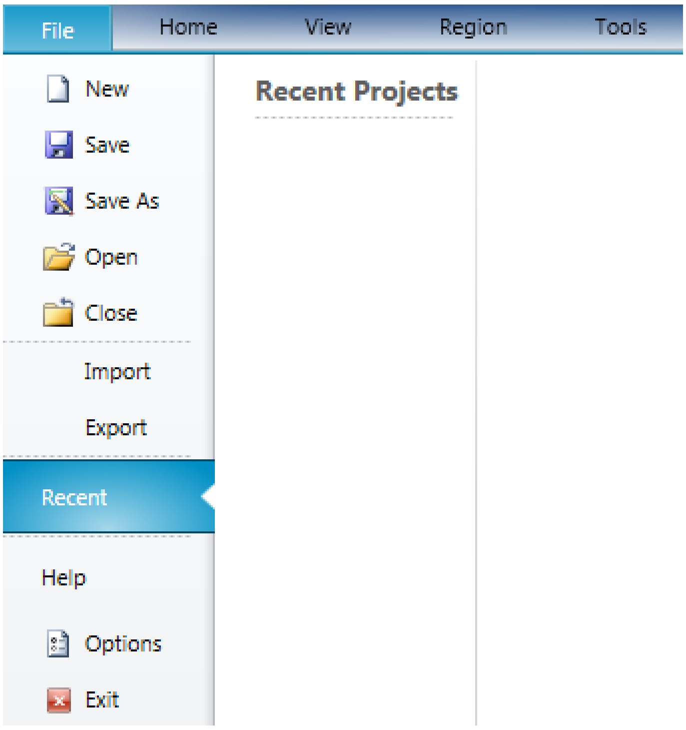


Figure 3.15: *Import wave model from file ribbon*

3.3.8 Save project

To save the project (and, hence, the model) use the disk-icon on the Quick Access Toolbar or the "File"-ribbon (Figure 3.15). If you would like to save the project under a different name use "Save as".

3.3.9 Exit Delta Shell

If you are finished you can exit Delta Shell using the red cross or pressing the "Exit" button in the "File"-ribbon (Figure 3.15).

3.4 Important differences and new features compared to the former GUI (Delft3D-Waves)

The differences between the former D-Waves GUI and the D-Waves plugin in Delta Shell in lay-out and functionality are numerous. Here, we address only the most important differences in the workflow.

3.4.1 Project vs model

The entity "project" is new in the Delta Shell GUI. In the hierarchy the entity "project" is on a higher level than the entity "model". A project can contain multiple models, which can either run standalone or coupled. The user can run all models in the project at once (on project level) or each model separately (on model level). When the user saves the project, the project settings will be saved in a *.dsproj configuration file and the project data in a *.dsproj_data folder. The *.dsproj_data folder contains folders with all input and output files for the models within the project. There is no model intelligence in the *.dsproj configuration file, meaning that the models can also be run outside the GUI from the *.dsproj_data folder.

3.4.2 Load/save vs import/export

The user can load an existing Delta Shell project, make changes in the GUI and, consequently, save all the project data. Loading and saving means working on the original project data, i.e. the changes made by the user overwrite the original project data. Alternatively, use "save as" to keep the original project data and save the changes project data at another location (or with another name).

Import/export functionality can be used to copy data from another location into the project (import) or, vice versa, to copy data from the project to another location (export). Import/export is literally copying, e.g.:

◇ import: changes on the imported data will only affect the data in the project and not the source data (upon saving the project)
◇ export: the model data is copied to another location ”as is”, changes made afterwards will only affect the data in the project not the exported data (upon saving the project)

3.4.3 Working from the map

One of the most important differences with the former GUI is the central map. The central map is comparable with the former ”visualization area”, but with much more functionality and flexibility. The map helps you to see what youâĂŹre doing and inspect the model at all times. You can use the ”Region” and ”Map” ribbons to add/edit model features in the map.

3.4.4 Coordinate conversion

With the map as a central feature, functionality to convert model and map coordinates is an indispensable feature. In the ”General” tab you can set the model coordinate system. In the map tree you can set the map coordinate system using the RMB (Figure 3.16). The coordinate systems are subdivided in geographic and projected systems. Use the quick search bar to find the coordinate system you need either by name or EPSG code (Figure 3.17).

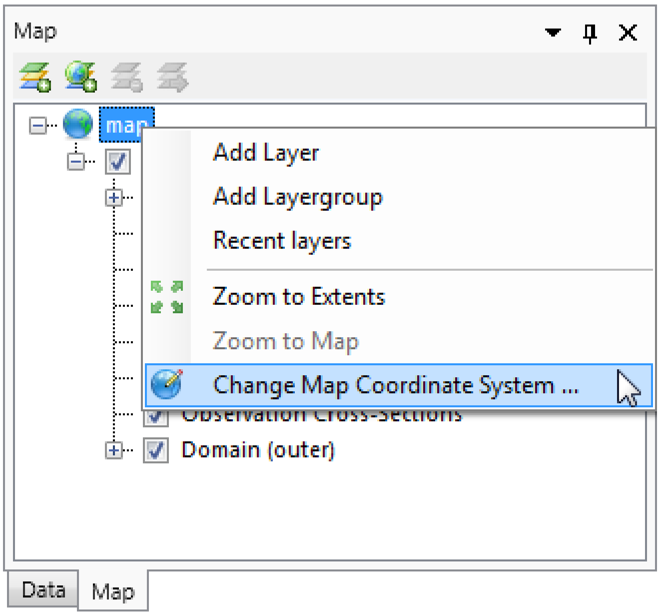


Figure 3.16: *Set map coordinate system using RMB*

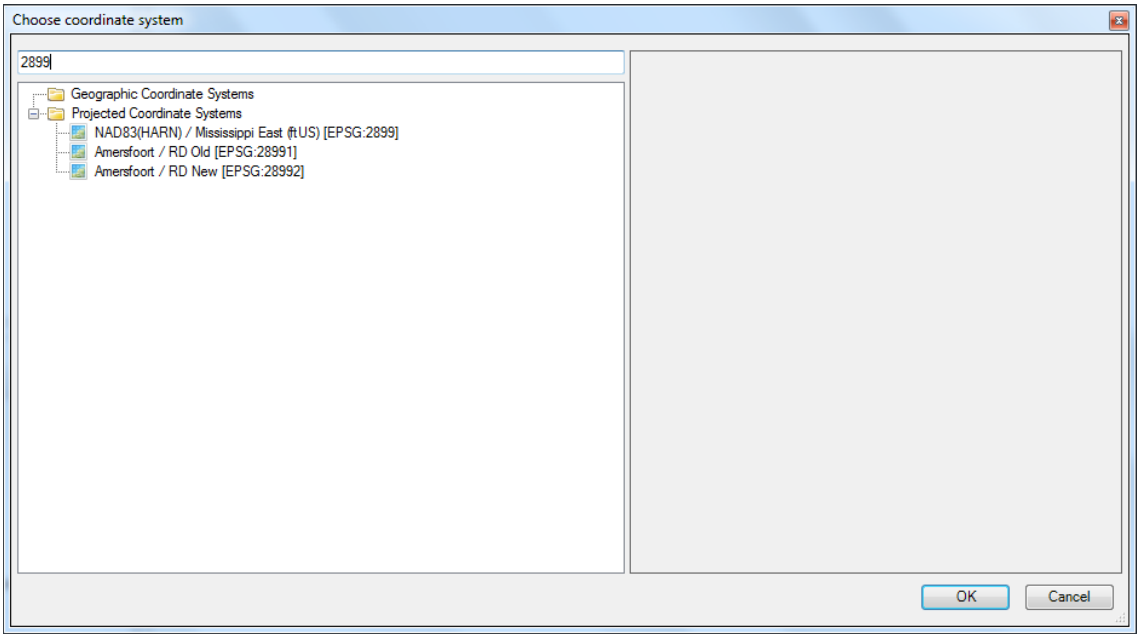


Figure 3.17: *Select a coordinate system using the quick search bar*

3.4.5 Model area

The model area contains geographical (GIS based) features, such as observation points & curves and obstacles. In contrast to the former GUI, these features can even exist without a grid or outside the grid and they are not based on grid coordinates, implying that their location remains the same when the grid is changed (for example by (de-)refining).

Finally, for the computations, the SWAN computational core interpolates the features to the grid. In the future we would like to show to which grid points the features are snapped before running the computation. However, this requires some updates in the SWAN computational core.

3.4.6 Ribbons (hot keys)

Delta Shell makes use of ribbons, just like Microsoft Office. You can use these ribbons for most of the operations. With the ribbons comes hot key functionality, providing shortcuts to perform operations. If you press "ALT", you will see the letters and numbers to access the ribbons and the ribbon contents (i.e. operations). For example, "ALT" + "H" will lead you to the "Home"-ribbon (Figure 3.18).

Note: : Implementation of the hot key functionality is still work in progress.

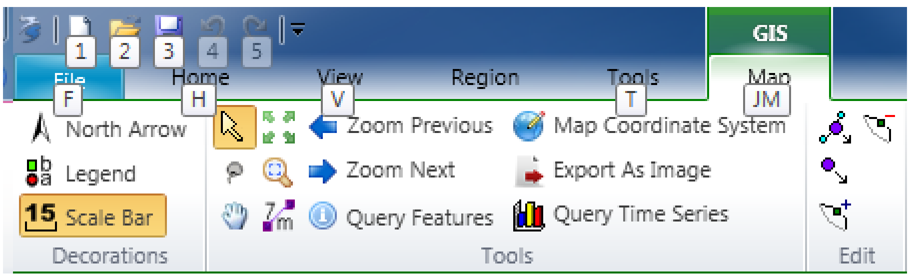


Figure 3.18: *Perform operations using the hot keys*

3.4.7 Context menus (RMB)

Context menus are the menus that pop up using the right mouse button (RMB). These context menus provide you with some handy functionality and shortcuts specific for the selected item. The functionality is available in all Delta Shell windows and context dependent. You can best try it yourself to explore the possibilities.

3.4.8 Scripting

Delta Shell has a direct link with scripting in Iron Python (NB: this is not the same as C-Python). This means that you can get and set data, views and model files by means of scripting instead of having to do all manually. Scripting can be a very powerful tool to automate certain steps of your model setup or to add new functionality to the GUI. You can add a new script by adding a new item, either in the "Home"-ribbon or through the RMB.

4 Graphical User Interface

4.1 Introduction

In order to set up a wave model you must prepare an input file. The input file stores all the parameters used for a wave computation with D-Waves. The parameters can be divided into three categories:

1 parameters that define the physical processes being modelled,
2 parameters that define the numerical techniques used to solve the equations that describe the physical processes,
3 parameters that control the wave computation and store its results.

Within the range of realistic values, it is likely that the solution is sensitive to the selected parameter values, so a concise description of all parameters is required. The input data (defined by you) is stored into an input file which is called the Master Definition file for Wave or MDW-file.

In section 4.2 we discuss some general aspects of the MDW-file and its attribute files. section 4.3 discusses shortly the filenames and their extension. In section 4.4 we explain how to work with the WAVE Graphical User Interface in Delta Shell, including is input parameters, their restrictions and their valid ranges or domain.

4.2 MDW file, attribute files and file formats

The Master Definition Wave file (MDW-file) is the input file for the wave program. It contains all the necessary data that is required to define a wave model and run a wave computation. Some of the parameter values are given directly in the MDW-file. Other parameters are defined in attribute files, referred to by specific statements in de MDW-file. The latter is particularly the case when parameters contain a large number of data (e.g. spatially varying data such as a variable wind or friction field). The user-defined attribute files are listed and described in Appendix A.

The D-Waves plugin in Delta Shell is a tool that is used to assign values to all the necessary parameters or to import the names of the attribute files into the MDW-file. When the data you entered is saved, an mdw-file, containing all the specified data, is created in the selected working directory.

Although you are not supposed to work directly on the mdw-file (with a text editor) it is useful to have some idea of what its structure is, as it reflects the idea of the designer on how to handle large amounts of input data. For an example of an MDW-file, see Appendix C.

The basic characteristics of an MDW-file are:

- It is an ASCII file.
- The file is divided in datagroups.
- It is keyword based.

The mdw-file is an intermediate file between the D-Waves plugin and the D-Waves module (e.g. the computational core). As it is an ASCII-file, it can be transported to an arbitrary hardware platform. Consequently, the wave module and the WAVE Graphical User Interface program do not necessarily have to reside in the same hardware platform.

As explained before, input parameters that contain a lot of data are defined in attribute files. How to set up these attribute files is explained elsewhere in this chapter. The mdw-file only contains permanent input parameters and references to these attribute files. The formats of all attribute files (and of the mdw-file itself) are described in detail in Appendix A.

The mdw-file and its attribute files form a complete set, defining a simulation. When storing your simulation input, always make sure you include the complete set of MDW-file and attribute files.

4.3 Filenames and coventions

The names of the mdw-file and its attribute files have a specific structure, some aspects are obliged while others are only advised or preferred.

The name of an mdw-file must have the following structure: <run-id.mdw>. The <run-id> consists of an arbitrary combination of (maximum 252) letters and numbers. This <run-id> will be part of the result files to safeguard the link between an mdw-file and the result files.

Restriction:

◇ The maximum length of the <run-id> is 252 characters!

The names of the attribute files follow the general file naming conventions, i.e. they have the following structures: <name>.<extension>. Where:

- <name> is any combination of characters allowed for filenames, except spaces.
- There is no limitation other than the platform dependent limitations; you are referred to your platform manual for details. We suggest to add some continuation character, for instance <-number> to the <name> to distinguish between various updates or modifications of the file.
- The <extension> is mandatory as indicated below.

Quantity	**Filename and mandatory extension**
Bathymetry or water depth	<name>.dep
Curvilinear grid	<name>.grd
Grid enclosure	<name>.enc
Wind field	<name>.wnd
Spiderweb wind field	<name>.spw
Spectral wave boundary	<name>.bnd
Wave boundary conditions	<name>.bcw
1D wave spectrum	<name>.sp1
2D wave spectrum	<name>.sp2
Curves	<name>.pol
Output locations	<name>.loc
Obstacles	<name>.obs
Obstacles locations	<name>.pol

4.4 Setting up a D-Waves model

In this section, all input parameters in the data groups of the mdw-file will be described in the order in which they appear in the project tree of D-Waves. We will describe all data groups in consecutive order. For each input quantity we give:

◇ A short description of its meaning. In many cases we add a more comprehensive discussion to put the quantity and its use in perspective.
◇ The restrictions on its use.
◇ The range of allowed values, called its domain, and its default value.

4.4.1 General

In the general tab (Figure 4.1) you can set the basic settings of your model, i.e.:

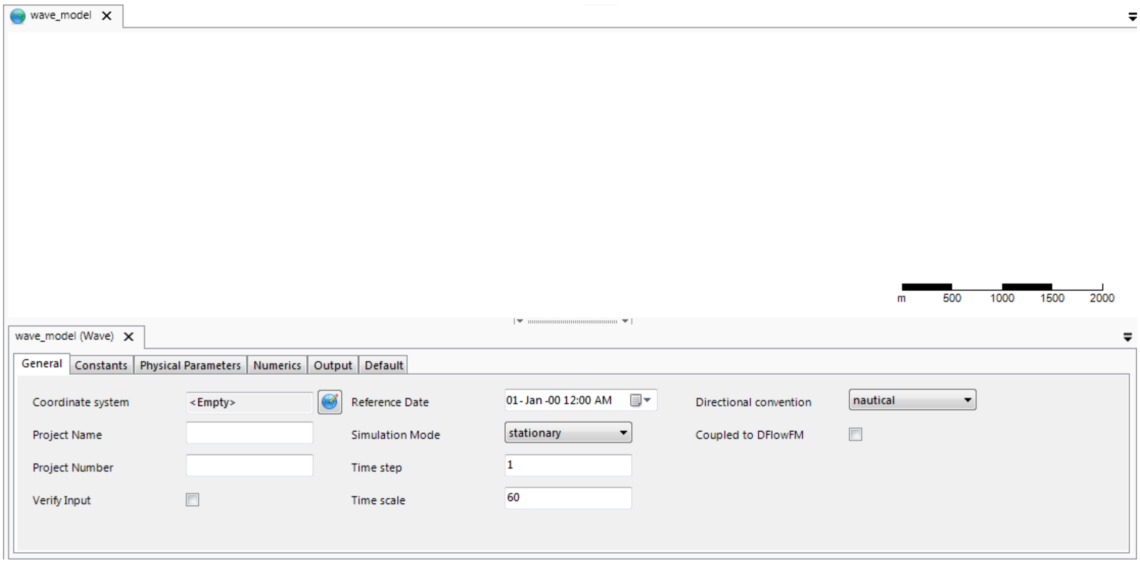


Figure 4.1: *Overview of the general tab*

Model coordinate system (default: <Empty>)

By clicking the earth icon, you can select the coordinate system (CS) for your model. Use the quick search bar to find your CS either by name or EPSG code (Figure 4.2). The list of CS that you select is limited to those that are supported by SWAN (the computational core of D-Waves), i.e. only the WGS84 geographic CS and most projected CS.

Note: Please note that the CS is not (yet) a property in the D-Waves import files. At the moment it is only used to convert geographical model information to the map CS.

Project name (default: <Empty>)

The name of the project may not be longer than 16 characters (restriction of the SWAN computational core).

Project number (default: (default: <Empty>)

The project number may not be longer than 4 characters (restriction of the SWAN computational core).

Verify input (default: no)

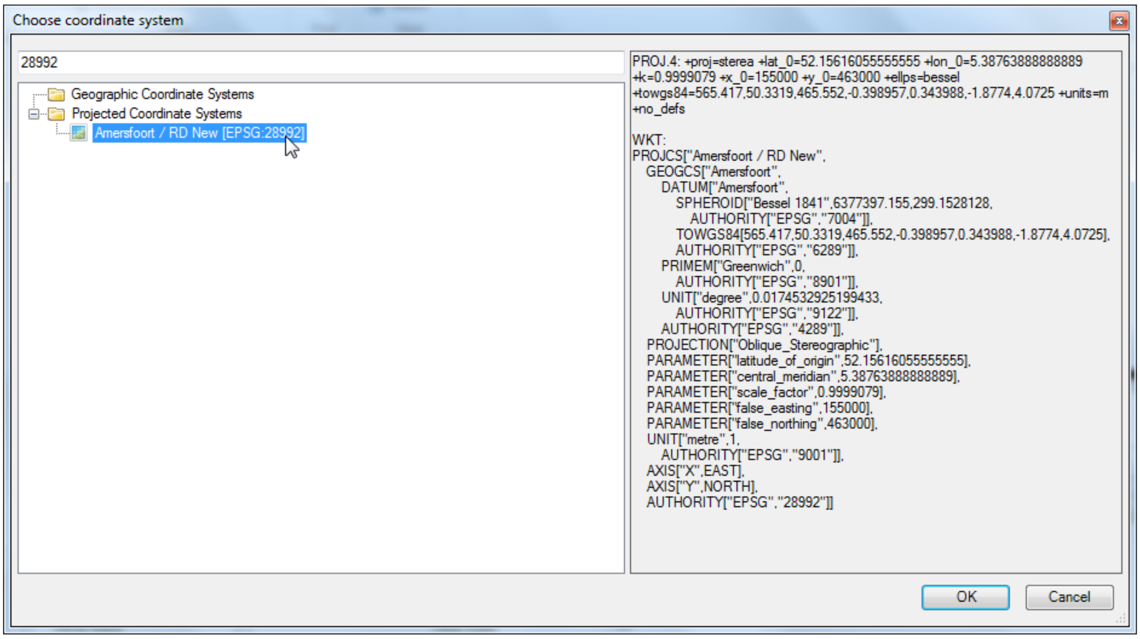


Figure 4.2: *Set the model coordinate system*

During pre-processing SWAN checks the input data. Depending on the severity of the errors encountered during this pre-processing, SWAN does not start a computation.

Reference date (default: 01-Jan-00 12:00 AM)

This is the reference date relative to which the time points are defined. For accuracy reasons choose the reference date not too far away from your time points.

Simulation mode (default: stationary)

You can choose between stationary, quasi-stationary and non-stationary. The stationary mode is considered to be justified when the residence time of the simulated waves âĂŞ the time that waves require to travel through the model domain âĂŞ is small relative to the time scale of changes in the wave boundary conditions and forcing (e.g. wind and currents). As the model domain increases or time scale of changes in boundary conditions and forcing decreases, non-stationary simulations become more appropriate. In case of non-stationary simulations you have to provide the time step and time interval of the non-stationary simulations.

Note: To do quasi-stationary

Time step (default: 5 minutes)

The time step for non-stationary simulations

Time interval (default: 0 minutes)

The time interval for non-stationary simulations

Time scale (default: 60 minutes)

Unit of time

Directional convention (default: nautical)

In the input and output of SWAN the direction of wind and waves are defined according to either the *Cartesian* convention or the *Nautical* convention (see Figure 5.1 for definitions).

◇ *Cartesian*
This option indicates that the Cartesian convention for wind and wave direction (SWAN input and output) will be used. The direction is the angle between the vector and the positive x-axis, measured counter-clockwise (the direction where the waves are going to or where the wind is blowing to).

◇ *Nautical*
This option indicates that the nautical convention for wind and wave direction will be used. The direction of the vector from the geographic North measured clockwise + 180°. This is the direction where the waves are coming from or where the wind is blowing from.

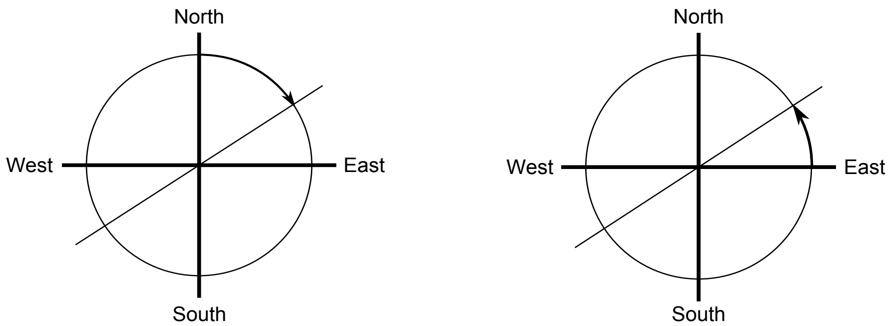


Figure 4.3: *Nautical convention (left panel) and Cartesian convention (right panel) for direction of winds and (incident) waves*

Couple to Delft3D-FM (default: no)

You can specify a FLOW computation from which the results are to be used as input for the wave computation (so-called offline coupling). If you want to do this, this is the place to define the FLOW computation to be used.

All needed results are stored in the communication file (com-file) produced by the FLOW computation Therefore, the FLOW com-file has to be present in your working directory.

Remarks:

◇ When using a FLOW model, make sure that the selected mdf-file and its associated com-file are located in your working directory, since the two modules will communicate with each other by this com-file.

◇ During the computations, D-Waves determines the water depth from the bottom level, the water level and the water level correction. Bottom levels are defined as the level of the bottom relative to some horizontal datum level (e.g. a still water level), positive downward. Water levels are defined with respect to the same datum as the bottom; the water level is positive upward.

4.4.2 Area

The model area contains geographical (GIS based) features, such as observation points & curves and obstacles. These features can be added using the "Region"-ribbon (see FrefFig:RegionRibbon and FrefFig:MapAreaFeatures). You can also import and export the attribute files using the RMB in the project tree (**Note:** NB: still to be implemented). If you would like to change the locations of the features use the "Edit" section of the "Map"-ribbon (see FrefFig:EditMapFeatures). You can delete features by selecting them and simply using the <delete> button. By selecting a feature from the map and double clicking it, the attribute table will open with feature specific properties (see Figure 4.7 for obstacles).

All the features defined in Area can exist without a grid and they are not based on grid coordinates, implying that their location remains the same when the grid is changed (for example by (de-)refining).

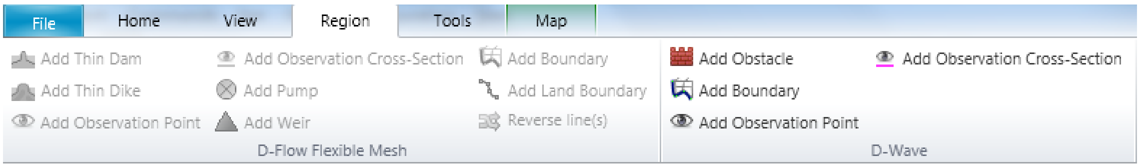


Figure 4.4: *Add Area features using the Region ribbon*

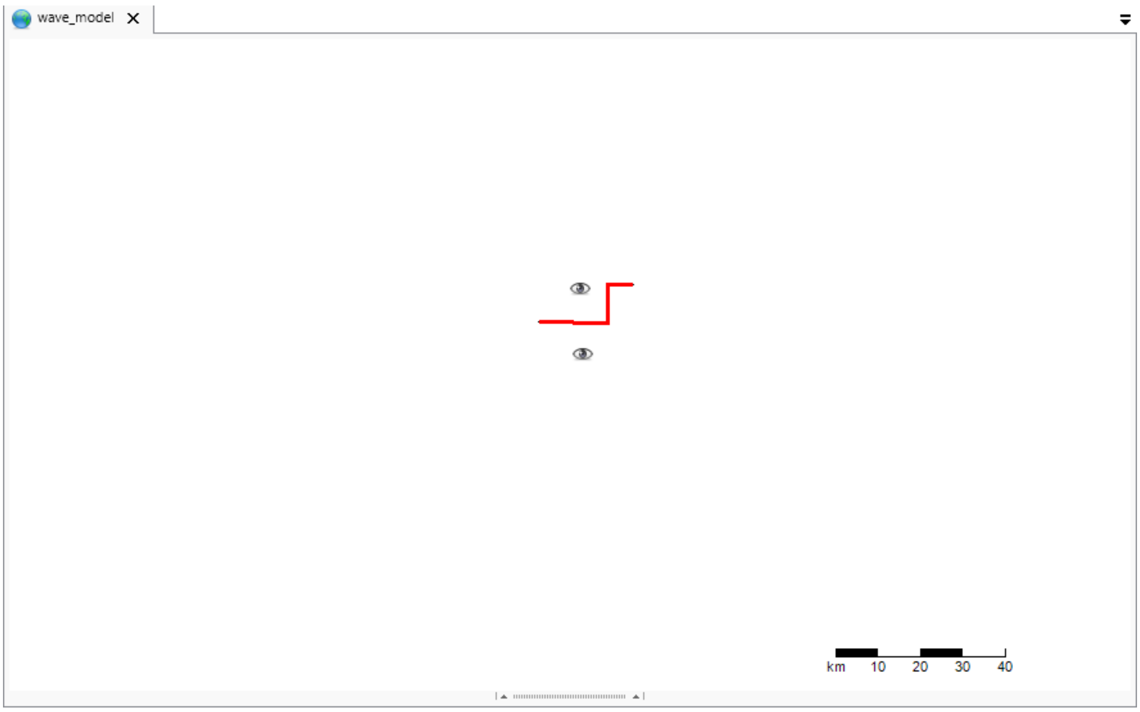


Figure 4.5: *Area features added to map*

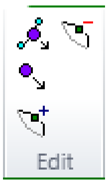


Figure 4.6: *Edit Area features using the Edit section of the Map ribbon*

4.4.2.1 Obstacles

Obstacles are sub-grid features through which waves are transmitted or against which waves are reflected or both at the same time (see FrefFig:ObstaclesProperties). The location of the obstacle is defined by a sequence of corner points of a polyline. The obstacles interrupt the propagation of the waves from one grid point to the next wherever this obstacle line is located between two neighbouring grid points of the computational grid (the resolution of transmission or blockage is therefore equal to the computational grid spacing).

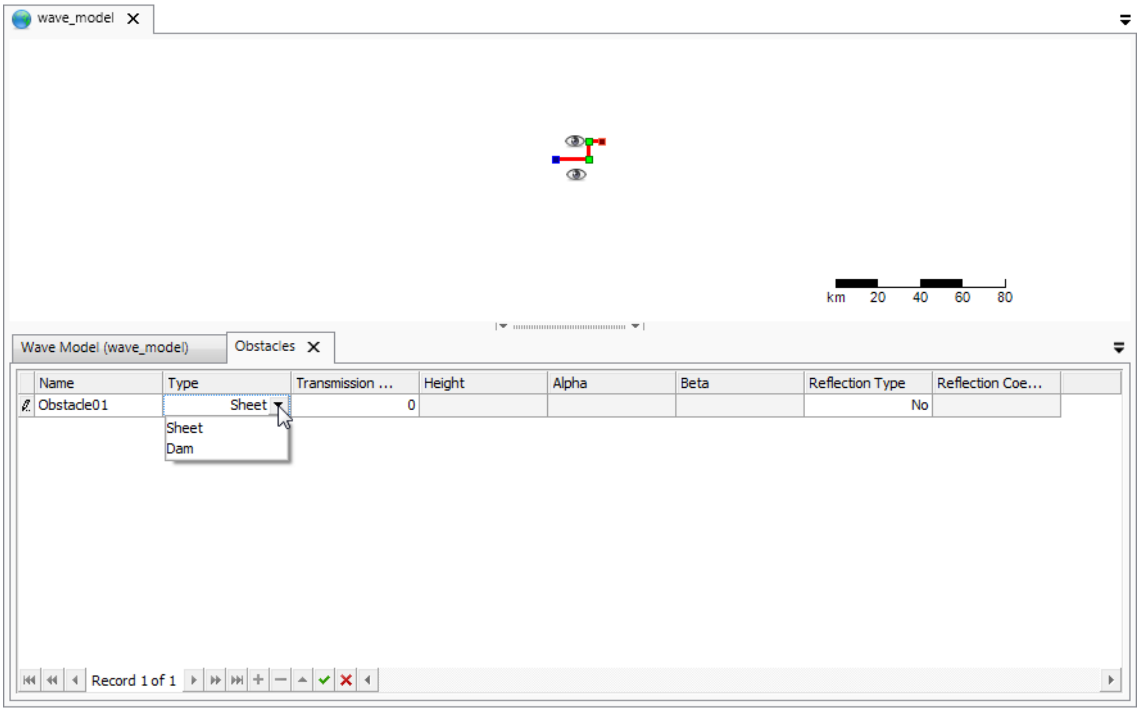


Figure 4.7: *Attribute table with properties of obstacles*

With respect to the type of the obstacle, the following options are available:

- *Sheet*: With this option you indicate that the transmission coefficient is a constant along the obstacle.
- *Dam*: With this option you indicate that the transmission coefficient depends on the incident wave conditions at the obstacle and on the obstacle height (which may be submerged).
- *Reflections*: With this option you can specify if the obstacle is reflective (specular or diffusive; possibly in combination with transmission) and the constant reflection coefficient.
- *Reflection coefficient* (default = 0)
  The reflection coefficient is formulated in terms of ratio of reflected significant wave height over incoming significant wave height.
- *Transmission coefficient* (default = 1.0)
  is the transmission coefficient for the significant wave height (coefficient = 0.0: no transmission = complete blockage).
- *Height* (default = 0.0)
  The elevation of the top of the obstacle above the reference level (same reference level as for bottom etc.); use a negative value if the top is below that reference level (possibly in case of submerged obstacles).
- *Alpha* (default = 2.6)
  Coefficient determining the transmission coefficient depending on the shape of the dam.
- *Beta* (default = 0.15)
  Coefficient determining the transmission coefficient depending on the shape of the dam.

Remark:

◇ When *Reflections* at obstacles are activated, then for each computational grid the directional space should be *Circle* or *Sector* covering the full circle of 360°.

When a lot of obstacles have to be defined, the procedure described above can be quite cumbersome. Therefore, it also possible to define a number of obstacles by importing a polyline file in which you defined the corner points of the obstacles. **Note:** Still to be implemented.

Remarks:

◇ Reflections will only be computed if the spectral directions cover the full 360°.
◇ In case of specular reflection the angle of reflection equals the angle of incidence.
◇ In case of diffuse and scattered reflection in which the angle of reflection does not equal the equal the angle of incidence.

Domain:

Parameter	**Lower limit**	**Upper limit**	**Default**	**Unit**
Reflection			**No**	
Reflection coefficient	0.0	1.0	0.0	-
Sheet (max number = 250):				
Transmission coefficient	0	1	1.0	-
Dam (max number = 250):	.			
Height	-100.	+100.	0.	m
Alpha	1.8	2.6	2.6	-
Beta	0.1	0.15	0.15	-

4.4.2.2 Observation Points

With *Observation Points* you can specify (monitoring) locations at which wave output should be generated by D-Waves, similar to the observation points in Delft3D FM. The values of the output quantities at the observation points are interpolated from the computational grid and written to a *Table* file. You can add, edit and delete these curves using the ribbons. Alternatively, you can import the locations from a <∗.loc> file. The format of the <∗.loc> file should be:

$$\begin{array}{ll} x_1 & y_1 \\ x_2 & y_2 \\ \vdots & \vdots \\ x_n & y_n \end{array}$$

4.4.2.3 Observation Curves

With *Observation Curves* you can specify a (curved) output curve at which wave output should be generated by D-Waves. Actually this curve is a broken line, defined by you in terms of segments. The values of the output quantities along the curve are interpolated from the computational grid. You can add, edit and delete these curves using the ribbons.

Remark:

◇ The names of output curves and/or curve segments as displayed in the attribute table, are not input for SWAN. The names are only displayed for your convenience. Moreover, the number in the names does not determine the sequence. The first curve in the list is the first curve specified, the second curve in the list is the second curve specified, though the name may suggest differently. Reloading this scenario will renumber the names of curves and segments but not the order.

4.4.3 Hydrodynamics from flow - currently default tab

In case FLOW results have been selected to be coupled to D-Waves, the results are read from the com-file and interpolated from the computational FLOW grid to the computational WAVE grid. Usually the FLOW grid is chosen smaller than the WAVE grid. Therefore an option is available to extend the values at the boundary of the FLOW grid to the boundary of the WAVE grid. Furthermore, you specify which hydrodynamic results should be extended.

When the FLOW computation is performed in 2DH mode, for each of the options *Water level*, *Current*, *Bathymetry* and *Wind* the following three options can be chosen, see Figure 4.8:

◇ *Don't use* Don't use the quantity for the wave simulation
◇ *Use but don't extend* Use this quantity in the wave simulation but don't extend
◇ *Use and extend* Use this quantity in the wave simulation but don't extend

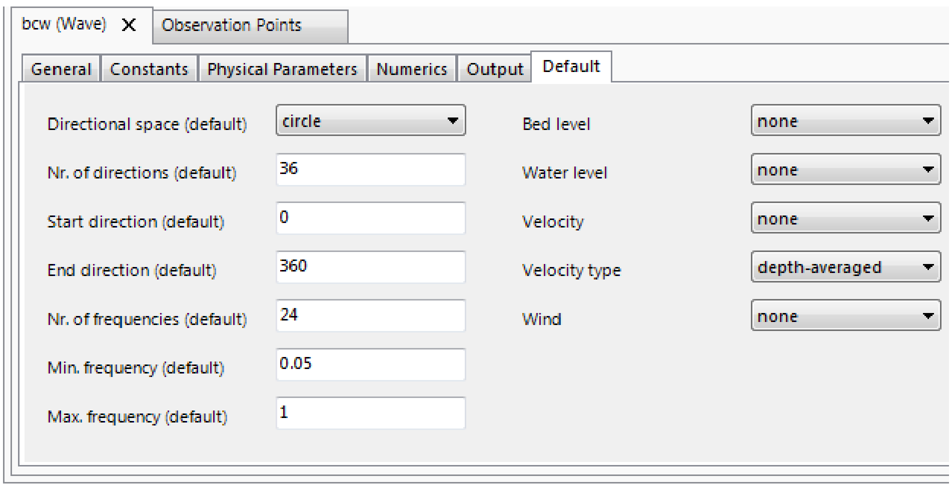


Figure 4.8: *Select which quantities should be used from FLOW computation*

If the the FLOW computation is performed in 3D mode then an additional *Current type* needs to be specified. This current type can have the following values:

◇ *depth averaged* Use the depth averaged flow-velocity for the wave simulation.
◇ *surface layer* Use the flow-velocity in the surface layer for the wave simulation.
◇ *wave dependent* A weighted flow-velocity will be used, the velocity is dependent on the orbital velocity of the wave and is especially of interest for stratified flows, see Kirby and Chen (1989).

4.4.4 Spectral resolution (deafult) - currently default tab

For each computational grid the spectral resolution in both directional and frequency space needs to be specified. SWAN only assigns wave energy to the wave directions and wave frequencies specified in the spectral resolution. In this tab you can set the default setting for the spectral resolution (see Figure 4.8). By default these settings will be assigned to all computational grids. However, the spectral resolution can be made domain dependent (see section 4.4.5.5).

Directional space

◇ *Circle*
This option indicates that the spectral directions cover the full circle. This option is default.

◇ *Sector*
This option means that only spectral wave directions in a limited directional sector are considered. The range of this sector is given by *Start direction* and *End direction*.

◇ *Start direction*
This is the first direction (in degrees) of the directional sector. It can be defined either in the Cartesian or the Nautical convention (see Figure 5.1), but this has to be consistent with the convention adopted for the computation, to be defined in the Data Group *Physical parameters*.

◇ *End direction*
It is the last direction of the sector (required for option Sector; Cartesian or Nautical convention, but in consistency with the convention adopted for the computation).

Remarks:

- ◇ The *Start direction* should be smaller than the *End direction*.
- ◇ When *Reflections* at obstacles are activated, then the spectral directions must cover the full circle of 360°.

◇ *Number of directions*
This is the number of bins in the directional space. For *Circle* this is the number of subdivisions of a full circle, so the spectral directional resolution is

$$\Delta\theta = 360^\circ / (\text{Number of directions})$$

In the case a directional sector is used, the spectral directional resolution is

$$\Delta\theta = (\text{End direction - Start direction}) / (\text{Number of directions})$$

Frequency space

◇ *Lowest frequency*
This is the lowest discrete frequency that is used in the calculation (in Hz).

◇ *Highest frequency*
This is the highest discrete frequency that is used in the calculation (in Hz).

◇ *Number of frequency bins*
The number of bins in frequency space is one less than the number of frequencies. It defines the resolution in frequency space between the lowest discrete frequency and the highest discrete frequency. This resolution is not constant, since the frequencies are logarithmically distributed. The number of frequency bins depends on the frequency resolution Δf that you require (see SWAN (2000), pages 39 and 49).

Domain:

Parameter	**Lower limit**	**Upper limit**	**Default**	**Unit**
Start direction	-360	360	0	degree
End direction	-360	360	0	degree
Number of directions	4	500	36	-
Lowest frequency	0.0	-	0.05	Hz
Highest frequency	0.0	-	1	Hz
Number of frequency bins	4	-	24	-

4.4.5 Domain

Under <domainname> in the project tree you define the geographic location, size and orientation of the computational grids by creating or importing one or more attribute grid files, which are curvilinear grids generated with RGFGRID (grd-file). The grids can be defined in a common Cartesian co-ordinate system or in a spherical co-ordinate system.

Remarks:

◇ The computational grid must be much larger than the domain where wave results are needed, because of the 'shadow' zone on both sides of the wave incident direction.

◇ A grid that is created in RGFGRID always has an associated enclosure file (∗.enc). This file is not imported in the WAVE-GUI, but it will be used in case computational grids are nested, so it has to be present in the working directory.

4.4.5.1 Import and export grids and bathymetries

You can import and export a (previously generated) grid using the RMB on the <domainname> (see Figure 4.9). Likewise, import and export a bathymetry for the domain. The imported grid/bathymetery can be viewed and inspected in the central map (see Figure 4.10).

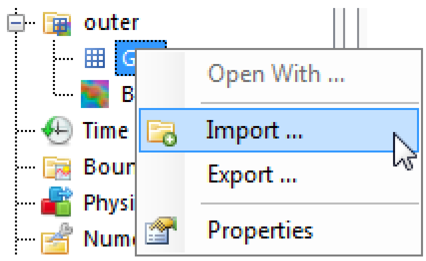


Figure 4.9: *Import a RGFGRID file from the project tree*

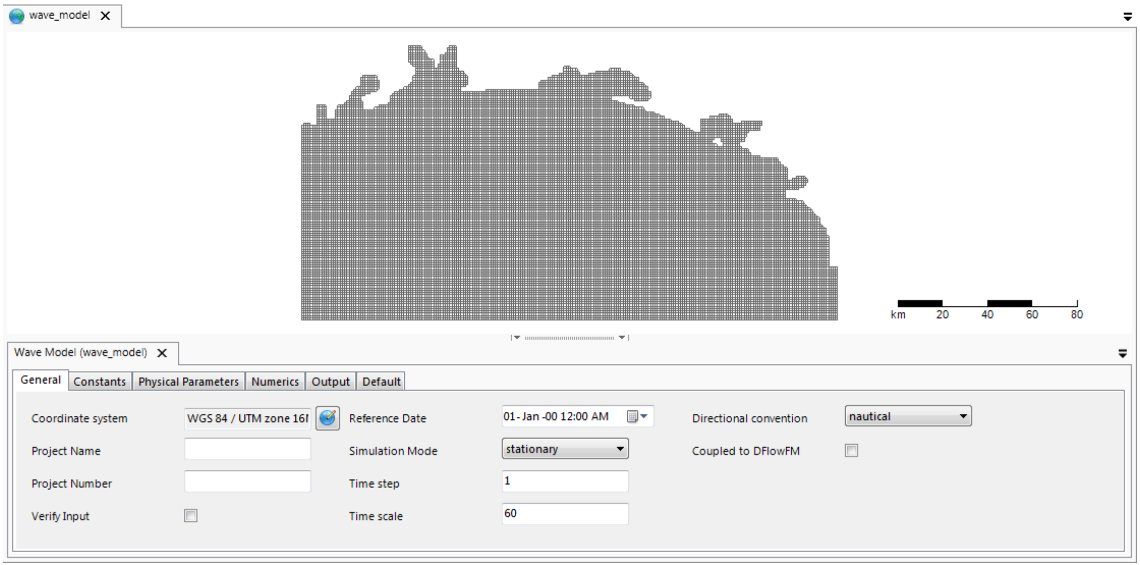


Figure 4.10: *Visualize the D-Waves grid on the central map*

4.4.5.2 Create and/or edit grids in RGFGRID

To generate a grid from scratch or edit an imported grid, double click on "Grid" under <domainname> in the project tree and RGFGRID will open (see Figure 4.11). You can use RGFGRID to create and edit the grid. See the RGFGRID manual for more information.

Note: Do not forget to save the RGFGRID project before closing RGFGRID to save the changes and transfer them to Delta Shell.

Remark:

◇ The formats of the grid files are defined in Appendix A.

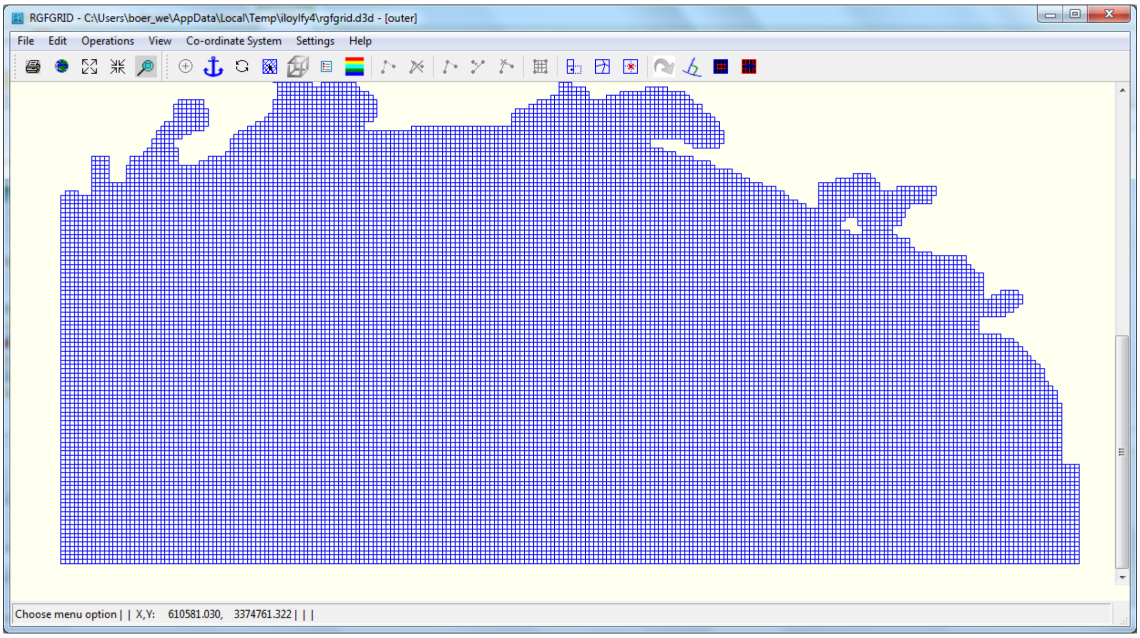


Figure 4.11: *Create and/or edit the grid using RGFGRID*

4.4.5.3 Create and/or edit bathymetries using the spatial editor

To generate a bathymetry from scratch or edit an imported bathymetry, double click on "Bathymetry" under <domainname> in the project tree and the spatial editor will open (see Figure 4.12). You can use the spatial editor to create and edit the bathymetry. See the Appendix .... for more information.

Remark:

◇ The formats of the depth files are defined in Appendix A.

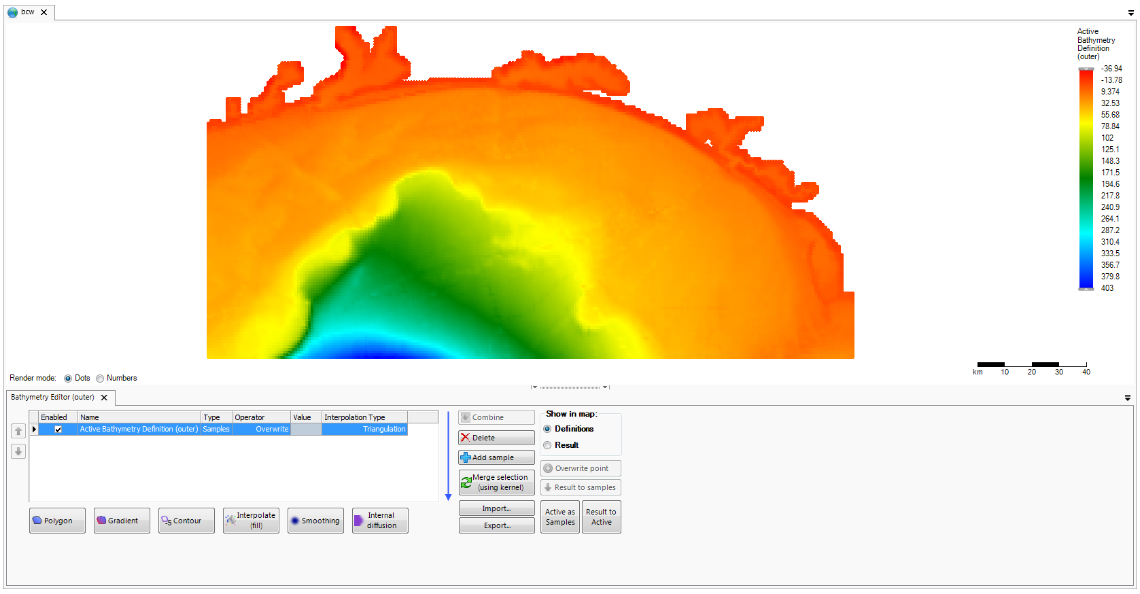


Figure 4.12: *Create and/or edit the grid using the spatial editor*

4.4.5.4 Nest domains

D-Waves supports the use of nested computational grids in one wave computation. The idea of nesting is to have a coarse grid for a large area and one or more finer grids for smaller areas. The coarse grid computation is executed first and the finer grid computations use these results to determine their boundary conditions. Nesting can be repeated on ever decreasing scales.

When you want to use the nesting option, you have to create multiple domains. This can be done using the RMB on the<domainname> in the project tree (see Figure 4.13). You can add either an interior or exterior domain. A popup will show up in which you can enter the name of the new domain (Figure 4.14). Consequently, the <domainname> with the corresponding grid and bathymetry features will show up in the project tree (see Figure 4.15). The grids and bathymetries can be added, edited and imported in the same way as described before for one domain.

Remarks:

◇ The first grid cannot be nested in another one. For this grid, boundary conditions must be specified in the Data Group *Boundaries*.

◇ A grid cannot be nested in itself. An error message will pop up if you try this.

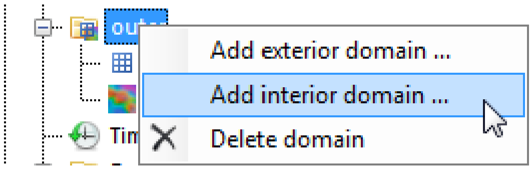


Figure 4.13: *Create or edit the grid using RGFGRID*

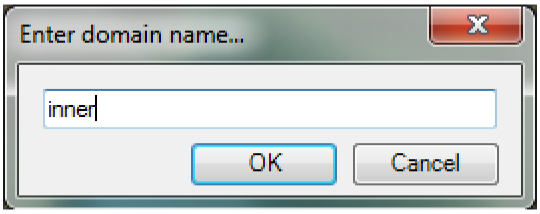


Figure 4.14: *Create or edit the grid using RGFGRID*

4.4.5.5 Spectral resolution and wind (per domain)

By double clicking the <domainname> in the project tree the domain tab will open. In the domain tab you can specify whether you would like to use the default settings for the spectral resolution (section 4.4.4) and wind (section 4.4.6) or set these properties specific for the domain.

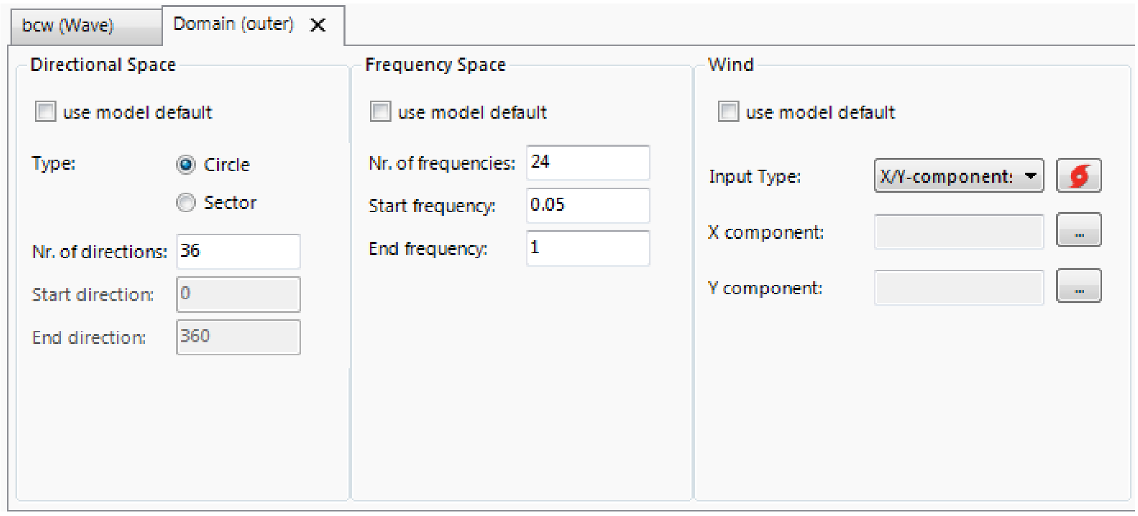


Figure 4.16: *Specify spectral resolution and wind per domain*

4.4.6 Time Frame, Hydrodynamics and Wind

In the *Time frame* tab you can specify the time points on which wave computations have to be carried out, hydrodynamic conditions (water level and currents) and wind conditions.

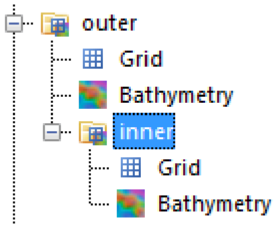


Figure 4.15: *Create or edit the grid using RGFGRID*

Time points

There are three options: you want to perform a standalone wave computation, you want to perform an offline coupling with Delft3D-FM, or you want to perform an online coupling with Delft3D-FM (in the latter two cases, you specified a FLOW computation in the tab *General*). Time steps must be specified for a standalone wave computation. For a coupled flow-wave (online or offline) computation the time steps (and corresponding hydrodynamics and wind) are usually copied from the flow computation.

In the time point editor you can add time points in the following ways:

◇ *Using the table*
  Here you can add time points step by step (Figure 4.17)
◇ *Pasting copied time series*
  Using the RMB you can paste copied time series (Figure 4.18)
◇ *Using the time series generator*
  Note: Still to be implemented
◇ *Synchronizing with the boundary conditions*
  Using the synchronizing button (Figure 4.19) you can use the time points that are specified for the boundary conditions.

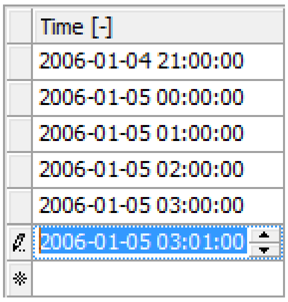


Figure 4.17: *Adding time points using the table*

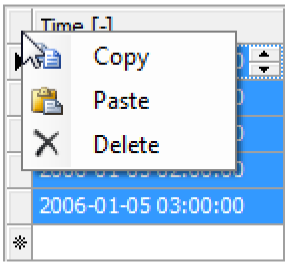


Figure 4.18: *Pasting time points from another series or program, for example Excel*

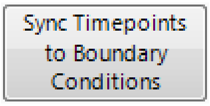


Figure 4.19: Synchronizing the time points with the time points specified for the boundary conditions

Hydrodynamics

If the hydrodynamics are not copied from a Flow computation, they have to specified here. You have two options:

◇ *Constant*
  Specify constant hydrodynamics for all time points (Figure 4.20)
◇ *Per time point*
  Specify time point specific hydrodynamics (Figure 4.21)

Note: These are the hydrodynamics for all domains.

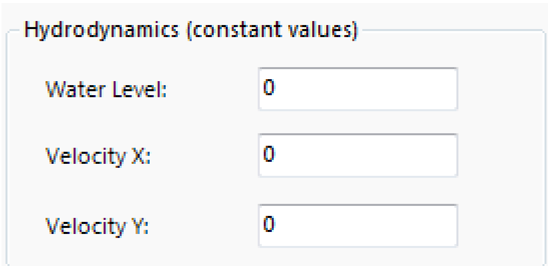
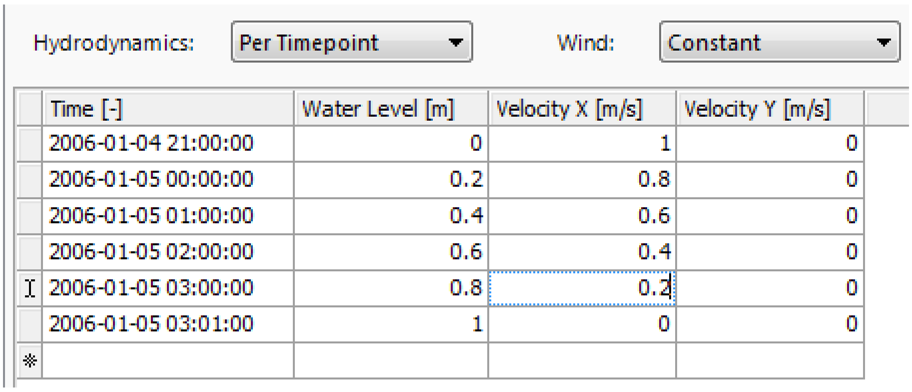


Figure 4.20: Specification of constant hydrodynamics



Time [-]	Water Level [m]	Velocity X [m/s]	Velocity Y [m/s]
2006-01-04 21:00:00	0	1	0
2006-01-05 00:00:00	0.2	0.8	0
2006-01-05 01:00:00	0.4	0.6	0
2006-01-05 02:00:00	0.6	0.4	0
2006-01-05 03:00:00	0.8	0.2	0
2006-01-05 03:01:00	1	0	0

Figure 4.21: Specification of hydrodynamics per time point

Wind

If the wind conditions are not copied from a Flow computation, they have to specified here. You have three options:

◇ *Constant*
  Specify constant wind for all time points (Figure 4.22)
◇ *Per time point*
  Specify time point specific wind conditions which are uniform in space (Figure 4.23)
◇ *From file*
  Include wind conditions from a file (Figure 4.24). The wind conditions can be variable

in space and time. Optionally, you can add a spiderweb wind field (usually used for the specification of cyclone winds) on top of the (background) wind field (Figure 4.25).

Note: These are the default settings for all (nested) domains. Alternatively, these settings can be made domain dependent (see section 4.4.5.5)

The ranges for the (uniform) wind conditions are as follows:

Domain:

Parameter	**Lower limit**	**Upper limit**	**Default**	**Unit**
Wind speed	0.0	50.0	0.0	m/s
Wind direction	-360.0	360.0	0.0	deg

Remark:

◇ If the wind speed is larger than zero, and in *Physical Parameters* the third generation mode is selected, then the Quadruplets will be activated.

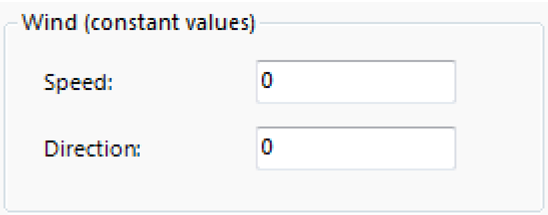
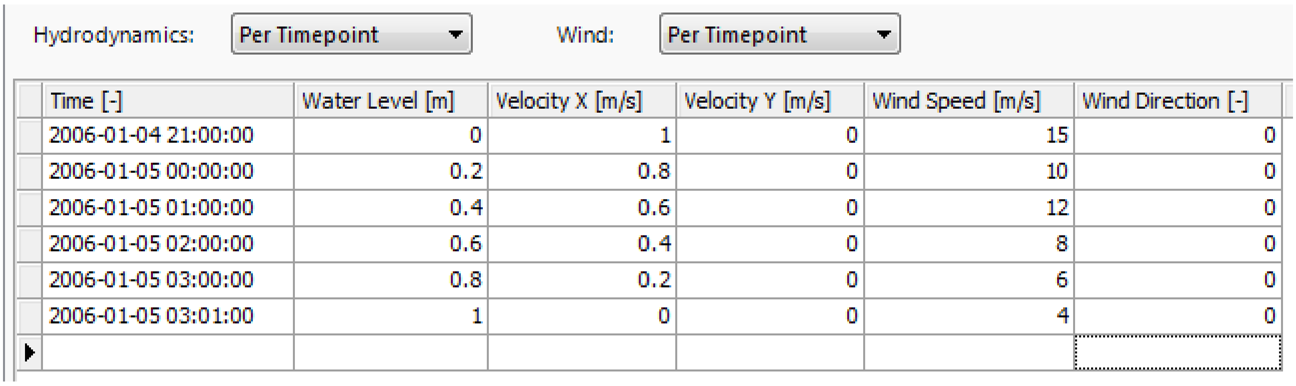


Figure 4.22: *Specification of constant wind*



Time [-]	Water Level [m]	Velocity X [m/s]	Velocity Y [m/s]	Wind Speed [m/s]	Wind Direction [-]
2006-01-04 21:00:00	0	1	0	15	0
2006-01-05 00:00:00	0.2	0.8	0	10	0
2006-01-05 01:00:00	0.4	0.6	0	12	0
2006-01-05 02:00:00	0.6	0.4	0	8	0
2006-01-05 03:00:00	0.8	0.2	0	6	0
2006-01-05 03:01:00	1	0	0	4	0

Figure 4.23: *Specification of wind per time point*

4.4.7 Boundary Conditions

Under *Boundary Conditions* in the project tree the incident wave conditions at the boundary of the first, and only the first, computational grid are prescribed. All other computational grids (i.e. the nested grids) obtain their boundary information from other grids.

In the D-Waves computations, wave boundary conditions may be specified at different sides. The general procedure to specify boundary conditions is the following. For each of the boundaries:

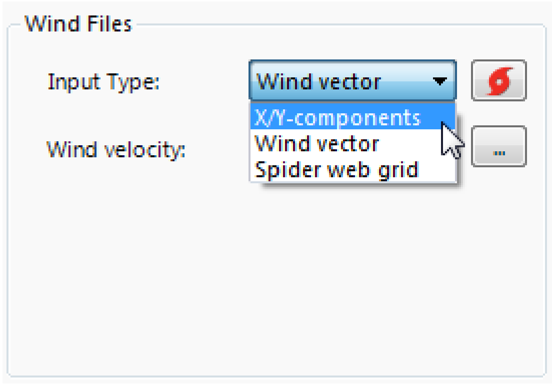


Figure 4.24: *Specification of wind (field) from file*

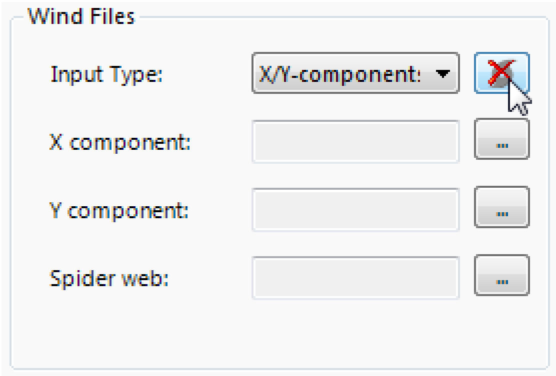


Figure 4.25: *Add a spiderweb wind field*

1. Draw the boundary location(s) in the central map (can be multiple support points).
2. Specify whether the values of the incident wave conditions are *Uniform* or *Spatially varying* along the boundary.
3. Specify whether the values of the incident wave conditions are *Parameterized (Constant in time)*, *Parameterized (Timeseries)* or *Spectrum based (from file)*.
4. Activate the support point(s) that you want to put conditions on.
5. Set the spectrum settings (if not loaded from file).
6. Specify the condtions (which may be time series)

Below, each of the six steps described above is explained further.

Remark:

◇ Alternatively, you can select a (pre-processed) 2-dimensional spectrum file that is providing the spectral data along the boundary directly (optionally varying in time).

Boundary location(s)

You can specify the boundary locations by selecting *Add Boundary* from the *Region* ribbon (see Figure 4.26) and cosequently drawing the boundary or boundaries on the central map (see Figure 4.27). In contrast to the previous D-Waves GUI boundaries can only be specified in terms of xy coordinates, not in grid coordinates or by orientation. After drawing the boundaries they will be automatically snapped to the grid. The boundaries are added to the project tree under *Boundary Conditions* (Figure 4.28).

Figure 4.26: *Select* Add Boundary *from* Region *ribbon*

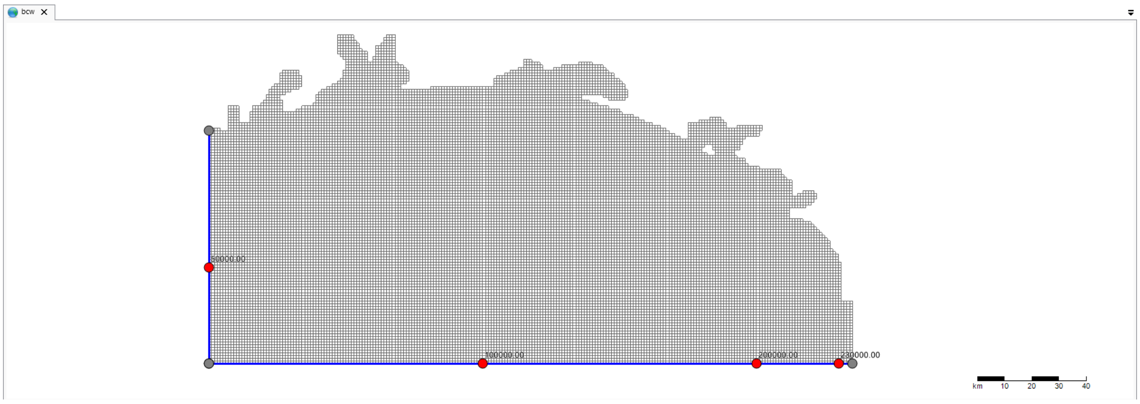


Figure 4.27: *Draw the boundary support points on the map*

Spatial definition

The spatial definition can be set in the attribute table (see Figure 4.29) of the boundary, which you can open by double clicking *Boundary Conditions* in the project tree. Alternatively, you can set the spatial definition in the boundary condition editor (see Figure 4.30), which is opened by double clicking the *Boundary* in the project tree or double clicking the boundary in the map view. The boundary condition may be *Uniform* along a boundary, but it may also be *Space-varying:*

◇ *Uniform*
  With this option the wave conditions are uniform along a boundary.
◇ *Space-varying*
  With this option the wave spectra can vary along the boundary. The incident wave field is prescribed at a number of support points along the boundary. These points are characterised by their distance from the begin point of the boundary (inidcated by the numbers). The wave spectra for grid points on the boundary of the computational grid are calculated by SWAN by spectral interpolation.

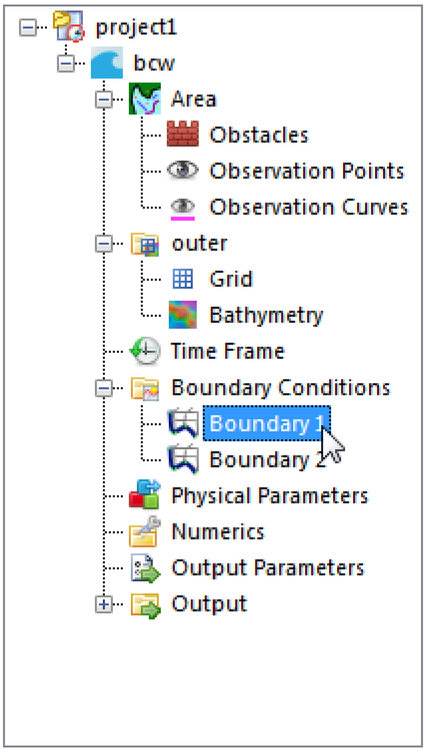


Figure 4.28: *Boundaries are added to the project tree under* Boundary Conditions

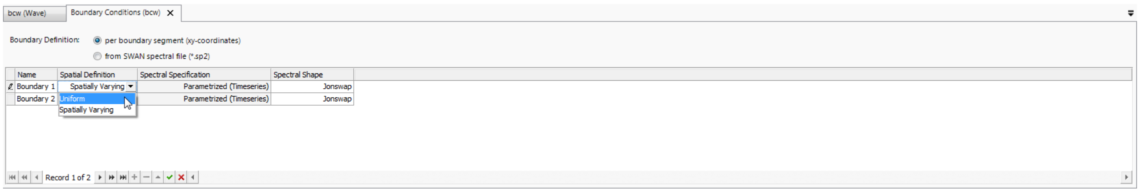


Figure 4.29: *Edit the spatial definition in the attribute table*

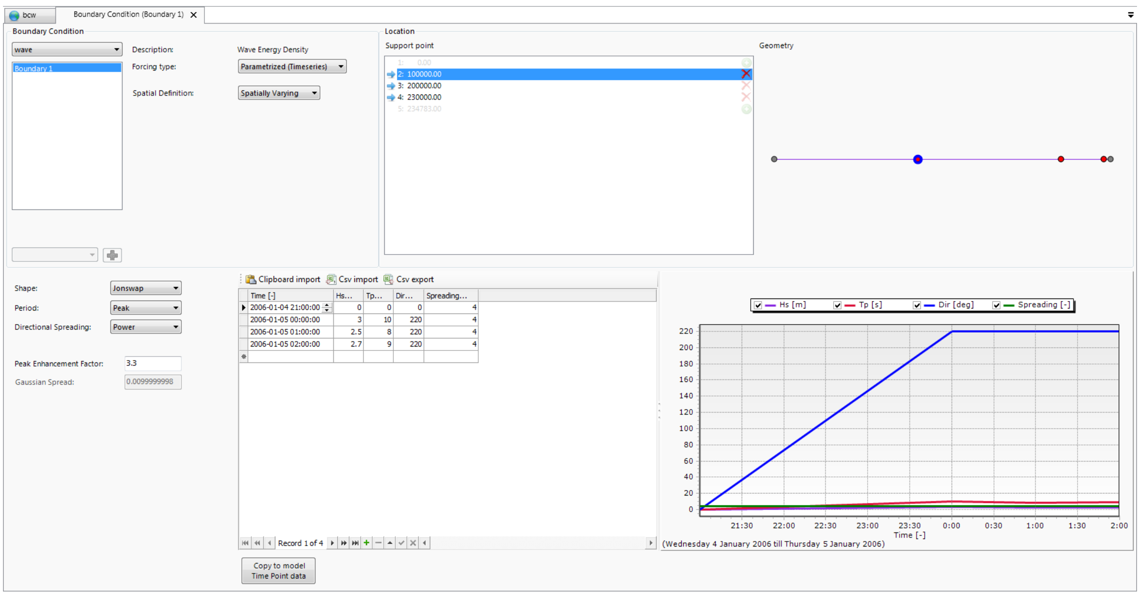


Figure 4.30: *Overview of the boundary conditions editor*

Spectral specification

The boundary conditions in SWAN can be specified in terms of integral wave parameters (*Parameterized (Constant in time or time series)*) or they can be read from an external file (*Spectrum based (from file)*). You can select this in the boundary condition editor.

◇ *Parametric*
  With this option you define the boundary condition as parametric spectral input.
◇ *From file*
  With this option the boundary condition are read from an external file (bnd-file).

Activate support points

In order to put conditions on the boundaries you first have to activate one (or multiple) support point(s) from the list by clicking the green "+"-button (see Figure 4.31). In the geometry panel next to it you can see which of the points along the boundary is selected (Figure 4.31).

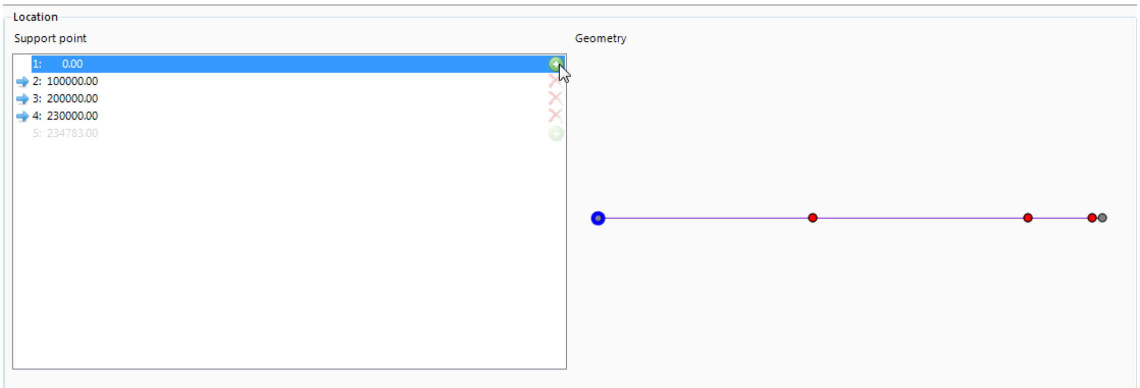


Figure 4.31: *Activate a support point in the boundary condition editor and inspect the location of the selected support point in the* Geomtery *view*

Spectrum settings

In the spectrum panel the spectrum shape and settings can be selected and set (see Figure 4.32):

Shape: With this option you can define the shape of the input spectra.

◇ *JONSWAP* (default)
  This option indicates that a JONSWAP type spectrum is assumed.
  Peak enh. Fact.
  This is the peak enhancement parameter of the JONSWAP spectrum. The default value is 3.3.
◇ *Pierson-Moskowitz*
  This option means that a Pierson-Moskowitz type spectrum will be used.
◇ *Gauss*
  This option indicates that a Gaussian-shaped frequency spectrum will be used. If this option is used, the width of the spectrum in frequency space has to be specified. Selecting this option the *Spreading* box will be enabled.
  Spreading
  Width of the Gaussian frequency spectrum expressed as a standard deviation in [Hz].

Period: With this input you can specify which wave period parameter (i.e. *Peak* or *Mean* period) will be used as input.

◇ *Peak* (default)
The peak period T_p is used as characteristic wave period.
◇ *Mean*
The mean wave period T_{m01} is used as characteristic wave period. For the definition see Appendix B.

Directional spreading: With this input you can specify the width of the directional distribution. The distribution function itself is: $\cos(\theta - \theta_{peak})$.

◇ *Cosine power* (default)
The directional width is expressed with the power m itself.
◇ *Degrees (standard deviation)*
The directional spreading is expressed in terms of the directional standard deviation of the $[\cos(\theta - \theta_{peak})]$ distribution (for a definition see Appendix B).

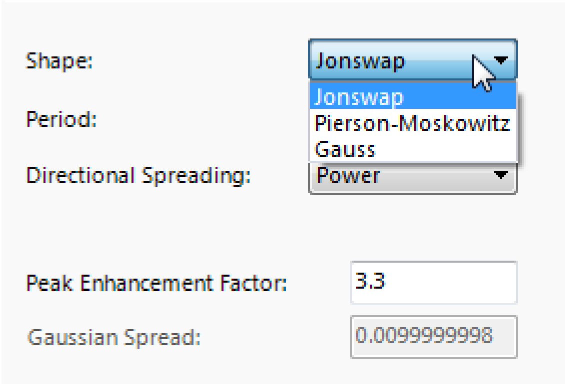


Figure 4.32: *Select spectrum shape and set corresponding properties*

Edit conditions

In case of a parameterized wave spectrum, the (time-dependent) conditions can be set in the conditions table and inspected in the corresponding graph (Figure 4.33).

The wave conditions are specified in terms of:

◇ *Significant wave height*
The significant wave height specified in m.
◇ *Wave period*
The characteristic period of the energy spectrum. It is the value of the peak period (in s) if option *Peak* is chosen in the *Spectral space* sub-window or it is the value of the mean period if option *Mean* is chosen in the above same sub-window.
◇ *Direction*
Mean wave direction (direction of wave vector in degree) according to the Nautical or Cartesian convention.
◇ *Directional spreading*
This is the directional standard deviation in degrees if the option *Degrees* is chosen in the **SWAN Spectral Space** window; or it is the power *m* if the option *Cosine power* is chosen in the same window.

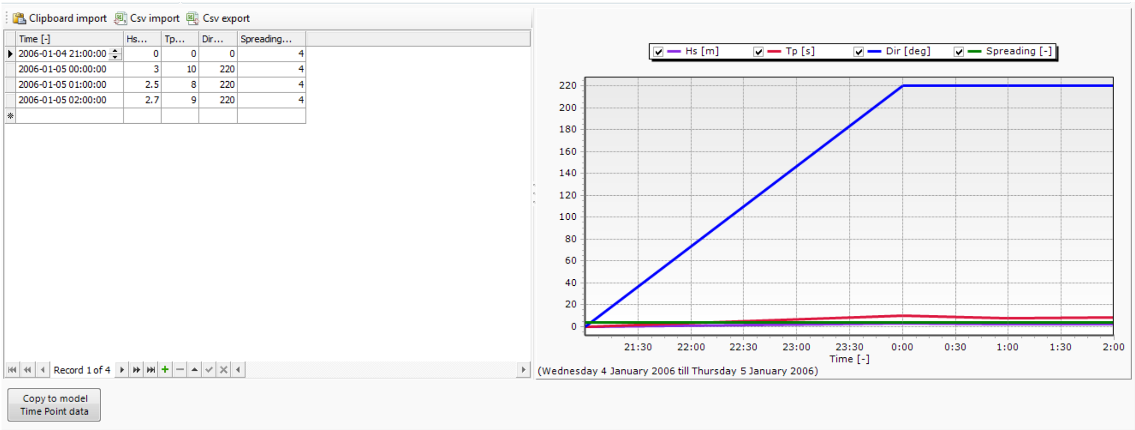


Figure 4.33: Specify parameterized wave boundary conditions and inspect in graph

Defaults and ranges

Domain:

Parameter	**Lower limit**	**Upper limit**	**Default**	**Unit**
Number of points to specify boundary	0	300	0	-
Spectral peak factor	1.	10.	3.3.	-
Distance from corner point	0.	Y-length	0.	m
Significant wave height	0.	25.	0.	m
Spectral peak period	0.1	20.	1.	s
Wave direction	-360	360.	0.	$^\circ$
Directional width (m)	1.	100.	4.	-

4.4.8 Physical parameters

In the tab *Physical parameters* you can specify a number of physical parameters. These are:

- ◇ *Constants*: Here you can specify constants such as the gravitational constant and the water density
- ◇ *Processes*: With these parameters you can influence some of the physical processes of SWAN (i.e.type of formulation, dissipation processes, non-linear wave-wave interactions).

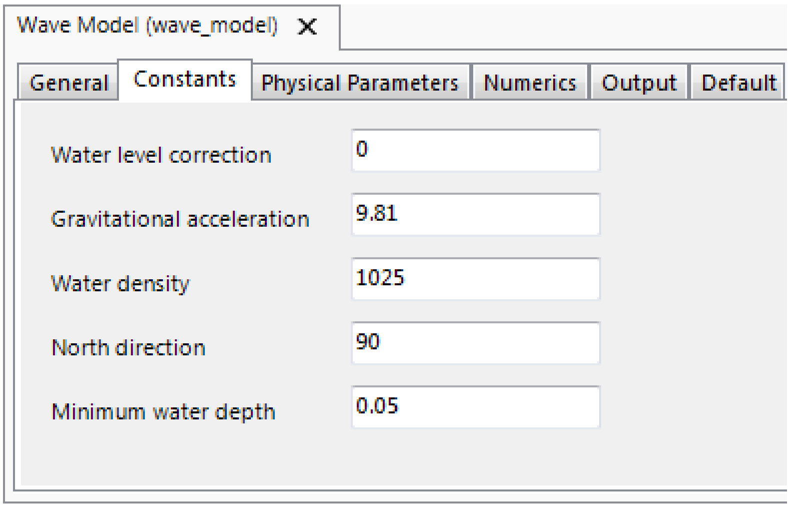


Figure 4.34: *Overview of physical* Constants

4.4.8.1 Constants

In the tab *Constants* you can specify the following parameters (see Figure 4.34):

Gravity
The gravitational acceleration in m/s^2. The default value is 9.81 m/s^2.

Water density
The water density ρ in kg/m^3. The default value is 1025 kg/m^3.

North
The direction of North with respect to the x-axis (Cartesian convention). The default value is 90° i.e. x-axis pointing East.

Minimum depth
The threshold depth in [m]; in the computation any positive depth smaller than this threshold depth is set to the threshold depth. The default 0.05 m.

Domain:

Parameter	**Lower limit**	**Upper limit**	**Default**	**Unit**
Acceleration of gravity	9.8	10.	9.81	m/s^2
Density of water	950.	1050.	1025.	kg/m^3
North	-360.	360.	90.	deg
Minimum depth	-	-	0.05	m

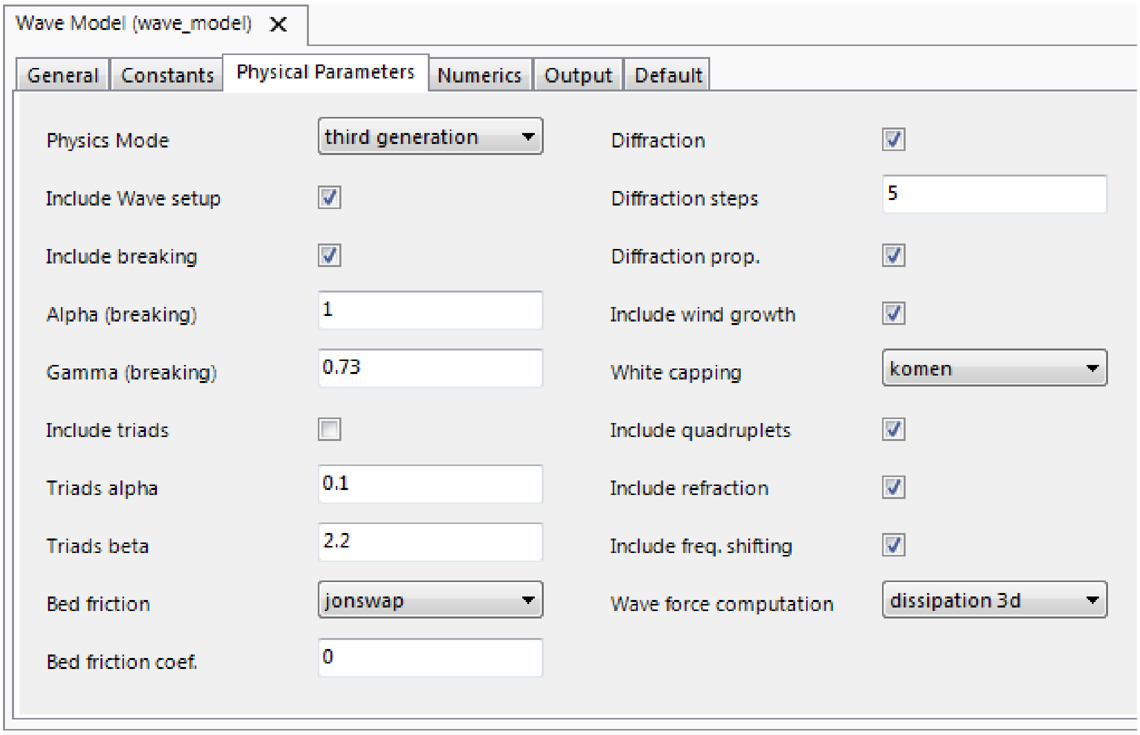


Figure 4.35: *Overview of physical* Processes

4.4.9 Physical processes

SWAN contains a number of physical processes (see Figure 4.35) that add or withdraw wave energy to or from the wave field. The processes included are: wave growth by wind, white-capping, bottom friction, depth induced wave breaking, non-linear wave-wave interactions (quadruplets and triads). SWAN can run in several modes, indicating the level of parameterisation. For initial SWAN runs, it is strongly advised to use the default values as shown in Figure 4.35. First it should be determined whether or not a certain physical process is relevant to the result. If this cannot be decided by means of a simple hand computation, you can perform a SWAN computation without and with the physical process included in the computations, in the latter case using the standard values chosen in SWAN.

◇ *Generation mode for physical formulations*:
1st generation
With this option you indicate that SWAN should run in first-generation mode.
2nd generation
With this option you indicate that SWAN should run in second-generation mode (for more information, reference is made to the SWAN manual).
3rd generation
With this option you indicate that SWAN should run in third-generation mode. Activated are wind input, quadruplet interactions and white-capping. Triads, bottom friction and depth-induced breaking are not activated by this option.

Remark:

◇ If SWAN runs in third generation mode and the wind speed is larger than zero, then the Quadruplets in Sub-data Group *Various* will be activated.

None
With this option you indicate that no deep water physical processes (i.e. wind, white-capping and quadruplets) are activated.

◇ *Wave set-up*
If this option is activated, the wave induced set-up is computed and accounted for in the

wave computations (during the computation it is added to the depth that is obtained from the bottom and the water level). This option should only be used if SWAN is applied as standalone model or if wave-induced set-up is not accounted for in the flow computations.

◇ *Depth-induced breaking*
With this option you can influence depth-induced wave breaking in shallow water in the SWAN model (see section 5.3.1). Ticking off this depth-induced term is usually unwise, since this leads to unacceptably high wave heights near beaches (the compute wave heights 'explode' due to shoaling effects).
B&J model
This option means that to model the energy dissipation in random waves due to depth-induced breaking, the bore-based model of Battjes and Janssen (1978) is used. In this option a constant breaker parameter is to be used.
Alpha
The coefficient for determining the rate of dissipation. Default = 1.0.
Gamma
The value of the breaker parameter defined as H_m/d. Default = 0.73.

◇ *Non-linear triad interactions (LTA)*
With this option you can activate the triad wave-wave interactions in the SWAN model (see section 5.3.1). Ticking off this feature means that the non-linear wave-wave interactions due to the triads are not taken into account. *LTA* means that the Lumped Triad Approximation (LTA) of Eldeberky and Battjes (1996) is used.
Alpha
The value of the proportionality coefficient α_{EB}. The default value is equal to 0.1.
Beta
This controls the maximum frequency that is considered in the computations. The value determines the ratio of the maximum frequency over the mean frequency, for which the interactions are computed. The default value is 2.2.

◇ *Bed friction*
With this option you can activate bed friction (see section 5.3.1). If this option is not used, SWAN will not account for bed friction. In SWAN three different formulations are available, i.e. that of Hasselmann *et al.* (1973) (*JONSWAP*), Collins (1972); Madsen *et al.* (1988)). The default option is *de-activated*.
JONSWAP
This indicates that the semi-empirical expression derived from the JONSWAP results for bottom friction dissipation (Hasselmann *et al.*, 1973) will be activated.

- *Coefficient*
  The coefficient of the JONSWAP formulation. It is equal to 0.067 m^2s^{-3} for wind sea conditions (default value) and equal to 0.038 m^2s^{-3} for swell conditions.

Collins
This indicates that the expression of Collins (1972) will be activated.

- *Coefficient*
  The Collins bottom friction coefficient, default = 0.015.

Madsen et al.
This indicates that the expression of Madsen *et al.* (1988) is activated.

- *Coefficient*
  The equivalent roughness length scale of the bottom. Default = 0.05 m.

◇ *Diffraction*
With this option you can activate diffraction in the wave computation. The default option is de-activated. The diffraction implemented in SWAN is based on a phase-decoupled refraction-diffraction approximation (Holthuijsen *et al.*, 1993). It is expressed in terms of the directional turning rate of the individual wave components in the 2D wave spectrum.

The approximation is based on the mild-slope equation for refraction and diffraction, omitting phase information.
Smoothing coefficient
During every smoothing step all grid points exchange [smoothing coefficient] times the energy with their neighbours. Default = 0.2.
Smoothing steps
Number of smoothing steps. The default value is equal to 5.
Adapt propagation
Switch to turn on or off the adaption of propagation of velocities in geographic space due to diffraction. The default value is activated (when diffraction is activated).

Remark:

◇ The process diffraction can only be solved accurately when a detailed grid is applied. Several studies (e.g. Ilic (1994)) have shown that the grid size should be about $1/10$ of the wave length; so, $dx = L/10$. In case of much coarser grids, the SWAN computation can become unstable and results are not reliable. So, use diffraction with care!

◇ *Wind growth*
If this option is activated, wind growth is included in the computation. **Note:** Only if wind is included in the computation.

◇ *White-capping*
For the white capping two model descriptions are possible:
buttonoff (default)
button(Komen *et al.*, 1984)
button(Van der Westhuysen, 2007)

◇ *Quadruplets*
If this option is activated, quadruplets are included in the computation. **Note:** Only if wind is included in the computation.

◇ *Refraction*
If this option is activated, refraction is included in the computation.

◇ *Frequency shifting*
If this option is activated, frequency shifting is included in the computation

◇ *Wave force computation*
With the integration of the *fully spectral* SWAN model under the Delft3D model it is possible to compute the wave forces on the basis of the energy wave dissipation rate or on the gradient of the radiation stress tensor (SWAN, 2000).

Domain:

Parameter	Lower limit	Upper limit	Default	Unit
Generation mode			**3rd generation**	
Wave set-up			**inactive**	
Depth-induced breaking:			**B&J model**	
Alfa	0.1	10	1.0	-
Gamma	0.55	1.2	0.73	-
Non-linear triad interactions			**inactive**	
Alfa	0.001	10	0.10	-
Beta	0.001	10	2.2	-
Bottom friction			**JONSWAP**	
Bottom friction coefficient			0.067	m^2/s^3
Diffraction			**inactive**	
Smoothing coefficient	0	1.0	0.2	-
Smoothing steps	1	999	5	-
Adapt propation			active	
Wind growth			**inactive**	
White capping			**Komen et al**	
Quadruplets			**inactive**	
Refraction			**active**	
Frequency shift			**active**	
Wave forces			**Radiation stress**	

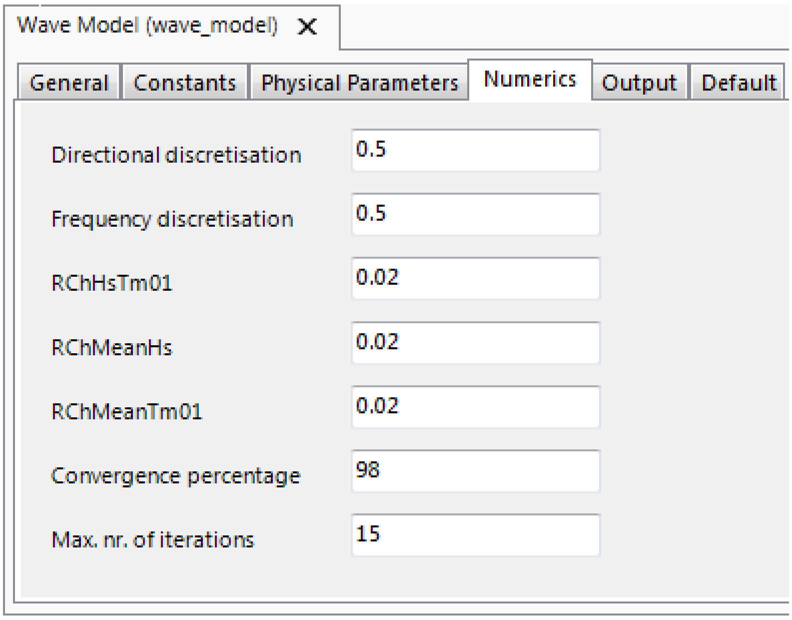


Figure 4.36: *Overview of* Numerical parameters

4.4.10 Numerical parameters

In the *Numerical parameters* tab you can modify parameters that affect the stability and accuracy of the numerical computation (see Figure 4.36). To obtain robust results with acceptable accuracy, apply the default diffusion parameters.

◇ *Spectral space*
In this sub-window you can control the amount of diffusion of the implicit scheme in the directional space through the *Directional space (CDD)* parameter and frequency space through the *Frequency space (CSS)*.
Directional space
A value of CDD = 0 corresponds to a central scheme and has the largest accuracy (diffusion ≈ 0) but the computation may more easily generate spurious fluctuations. A value of CDD = 1 corresponds to an upwind scheme and it is more diffusive and therefore preferable if (strong) gradients in depth or current are present. The default value is CDD = 0.5.
Frequency space
A value of CSS = 0 corresponds to a central scheme and has the largest accuracy (diffusion ≈ 0) but the computation may more easily generate spurious fluctuations. A value of CSS = 1 corresponds to an upwind scheme and it is more diffusive and therefore preferable if (strong) gradients in current are present. The default value is CSS = 0.5.

◇ *Accuracy criteria (to terminate the iterative computations)*
With these options you can influence the criteria for terminating the iterative procedure in the SWAN computation (for convergence criteria of SWAN see section 5.5.1). SWAN stops the iteration if:

a) The change in the local significant wave height (Hs) from one iteration to the next is less than:

   - fraction *Relative change* of that wave height or
   - fraction *Relative change w.r.t. mean value* of the average significant wave height (averaged over all wet grid points)

b) and if the change in the local mean wave period from one iteration to the next is less than:

  - fraction *Relative change* of that period or
  - fraction *Relative change w.r.t. mean value* of the average mean wave period (averaged over all wet grid points)

c) and if the conditions a) and b) are fulfilled in more than fraction *Percentage of wet grid points %* of all wet grid points.

Relative change
The default value is 0.02.
Relative change w.r.t. mean value
The default value is 0.02, for both H_s and T_{m01}.
Percentage of wet grid points
The default value is 98%.
You can also control the terminating procedure by giving the maximum number of iterations *Max. number of iterations* after which the computation stops.
Max. number of iterations
The default value is 15.

Domain:

Parameter	**Lower limit**	**Upper limit**	**Default**	**Unit**
Diffusion θ-space (directional)	0.	1.	0.5	-
Diffusion σ-space (frequency)	0.	1.	0.5	-
Relative change	0.	-	0.02	-
Relative change w.r.t. mean value (H_s and T_{m01})	0.	-	0.02	-
Percentage of wet grid points	0.	100%	98%	-
Max. number of iterations	1	-	15	-

4.4.11 Output parameters

In the tab *Output parameters* (see Figure 4.37) you can determine to which grid (i.e. WAVE or FLOW grid) output is written and to which extent the computations should be monitored. The latter option can be used to specify that D-Waves should produce intermediate (model) results during a SWAN run (test output) if the program produces unexpected results.

There are a couple of options available to monitor the SWAN computation:

Level of test output (Default: 0)
For values up to 50 test output is made that can be interpreted by you. For values above 50, information for the programmer is produced. For values under 100 the amount is usually reasonable, for values above 200 it can be huge.

Trace subroutine calls (Default: off)
In case an error occurs, the name of the subroutine where the error occurred is written.

Write and use hotstart file (Default: no)
This option can be used to write the entire wave field at the end of a computation to an initialisation file and use this field as initial condition in a subsequent SWAN run. In many

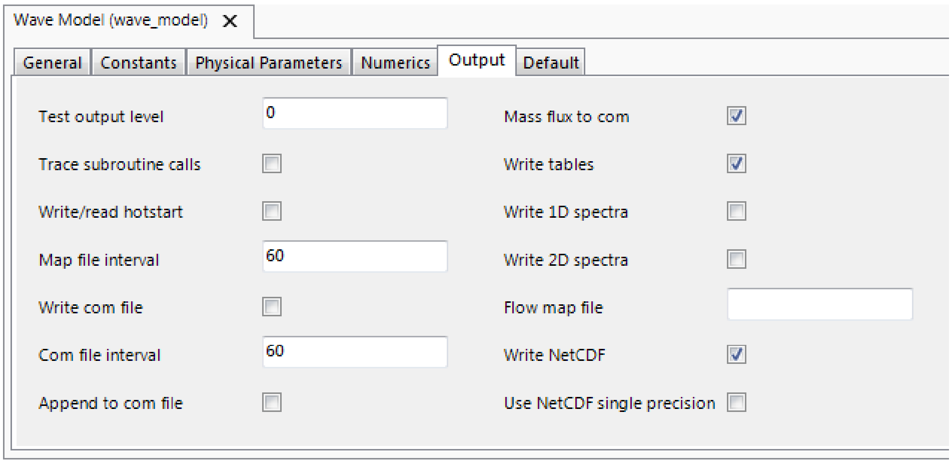


Figure 4.37: *Overview of* Output parameters

cases with a series of wave runs, this option can save significantly amount of computational time. In case of a FLOW-WAVE coupling with a frequent update, the hydrodynamic conditions have not changed a lot since a previous wave computation. Therefore SWAN can use the results of a previous SWAN run as the initial condition for the wave field.

The format of the hotstart file is identical to the format of the files written by the 2D-spectrum output in the pre-defined locations.

Remarks:

- It is recommended to gradually vary the wave directions in the <wavecon> file. When computing a wave condition using an existing HOT-file, which is generated during a wave computation with a large different wave direction, the use of a HOT-file can lead to unrealistic wave fields. Check the wave results carefully.
- When applying only one wave condition (e.g. during a flow-wave coupling) it can be wise to increase the required accuracy (in % of wet points) initially. The subsequent wave computations may be completed faster in this way, although the first wave computation will probably need more computational time.

Only verify input files (Default: no)
During pre-processing SWAN checks the input data. Depending on the severity of the errors encountered during this pre-processing, SWAN does not start a computation. You can influence the error level above which SWAN will not start computations. The error level is coded as follows:

- Warnings
- Errors (possibly automatically repaired or repairable by SWAN)
- Severe Errors

D-Waves offers two options to save the results of the calculation: on the communication file (if available) and on an output file.

- *Output for FLOW grid* (Default: off)
  Click in the check box to turn this option on or off. If you select *Output for FLOW grid*, a communication file is available and will be updated. The FLOW model (and other modules) can read and use the wave data directly, since the information is automatically converted to the curvilinear grid definition by the wave module. In **??** a description of the output parameters on the communication file is given.

A curvilinear grid file (FLOW grid) is required to enable this conversion. In case hydrodynamic results from a FLOW simulation are used, the flow input file has been selected. The grid definition is read from this file. If no hydrodynamic results are used, a *Select grid file* button is displayed and a grid file can be selected. If a grid file is selected, still a communication file is needed. The WAVE simulation will expect that the communication file <com-*name*> is available. The communication file can be generated by running a stand-alone FLOW simulation or a online FLOW/WAVE simulation.

◇ *Output for computational grids* (Default: off)
If this option is chosen, detailed output is generated on one or more computational grids. This output is written to a NEFIS file with basename WAVM (waves map file). In **??** a description of the output parameters on the <wavm-∗.dat> file is given.

◇ *Output for specific locations*
For the locations defined as observation points you can have three types of output: *Table*, *1D spectra* or *2D spectra*.
The parameters written to the *Table* file are:

XP, YP	co-ordinates of output location (with respect to the problem co-ordinates)
DEPT	water depth [m]
HSIG	significant wave height [m]
DIR	mean wave direction [°]
Tpeak	peak wave period [s]
TM01	mean wave period (T_{m01}) [s]
DSPR	directional spreading of the waves [°]
UBOT	root-mean-square value of the maximum of the orbital motion near the bottom [m/s]
XWindv, YWindv	wind components [m/s]
Xvel, Yvel	current velocity components [m/s]

The parameters written in the *1D spectra* file are:

- absolute frequencies [Hz]
- energy densities [J m^{-2} Hz^{-1}]
- average nautical direction [degrees]
- directional spreading [degrees]

The parameters written in the *2D spectra* file are:

- absolute frequencies [Hz]
- spectral nautical directions [degrees]
- energy densities [J m^{-2} Hz^{-1} deg^{-1}]

Remarks:

◇ The Table output for specific locations is stored in files <*run-id*nit0j>.tab in case of multiple grids and multiple time points. For the overall computational grid $i = 1$, for the first nested grid $i = 2$, etc. For the first time point $j = 1$, for the second $j = 2$, etc.
◇ The 1D spectra output for specific locations is stored in files <*run-id*nit0j.sp1>.
◇ Similar for the 2D spectra output in <*run-id*nit0j.sp2> files.
◇ In case of only one grid and multiple time points the files are <*run-id*t0j.tab>, <*run-id*t0j.sp1> and <*run-id*t0j.sp2>.
◇ In case of multiple grids and only one time points the files are <*run-id*ni.tab>, <*run-id*ni.sp1> and <*run-id*ni.sp2>.
◇ In case of only one grid and only one time points the files are <*run-id*.tab>, <*run-id*.sp1> and <*run-id*.sp2>.

◇ *Output curves*

The following output quantities will be generated by D-Waves at the output locations along a curve.

XP, YP	co-ordinates of output location (with respect to the problem co-ordinates)
DIST	distance along the output curve (m)
DEPT	depth (in m)
HSIG	significant wave height (in m)
PER	mean wave period (T_{m01}) in s
DIR	mean wave direction (degrees)
DSPR	directional spreading of the waves (in degrees)
DISS	dissipation rate (J m^{-2} s^{-1})
WLEN	mean wave length (in m)
U,V	current velocity (in m/s)

All the data of each output curve is presented in a table and will be saved in only one file, named: <curves.*run-id*>.

4.4.12 Output

Note: Yet to be specified

5 Conceptual description

5.1 Introduction

The purpose of this chapter is to give some general background with respect to the unit and co-ordinate system, the grids (resolution, orientation etc.) and the boundary conditions of the SWAN model. Advice will be given how to choose the basic input for Delft3D-WAVE for the SWAN computations.

A brief description is given with respect to the physics (see section 5.3) and numerics (section 5.4) that have been implemented in the SWAN model. This description has been copied - with permission of Delft University of Technology, The Netherlands (personal communication with dr N. Booij and dr L.H. Holthuijsen, 1999) - from the SWAN manual for SWAN version 40.41. The description given here is indicative only. For a full and proper description reference is made to SWAN (2000).

5.2 General background

5.2.1 Units and co-ordinate systems

Delft3D-WAVE expects all quantities that are input by the user, to be expressed by means of the S.I. system of units: m, kg, s and composites of these with accepted compounds, such as Newton [N] and Watt [W]. Consequently the wave height and water depth are in [m], wave period in [s] etc. Directions and spherical co-ordinates are in degrees [°] and not in radians. Delft3D-WAVE can operate in a flat plane and on a spherical earth.

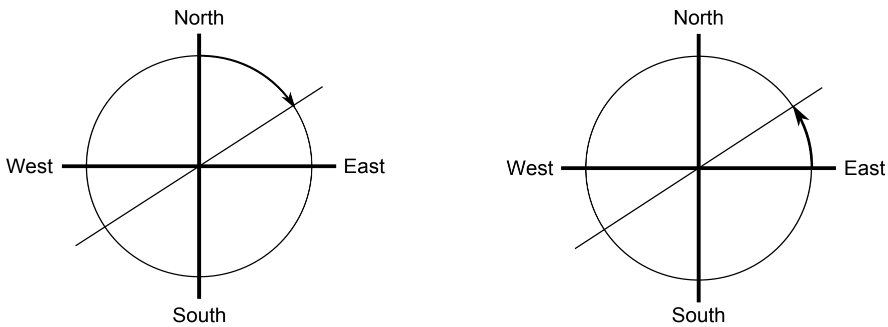


Figure 5.1: *Nautical convention (left panel) and Cartesian convention (right panel) for direction of winds and (incident) waves*

In the input for Delft3D-WAVE the directions of winds and (incident) waves are defined relative to the co-ordinate system according to a Nautical convention or Cartesian convention, see Figure 5.1 (for definitions reference is made to Appendix B).

In the Cartesian system, all geographic locations and orientations in SWAN, e.g. for the computational grid or for output points, are defined in one common Cartesian co-ordinate system with origin (0,0) by definition. This geographical origin may be chosen totally arbitrarily by you.

In the spherical system, all geographic locations and orientations in Delft3D-WAVE are defined in geographic longitude and latitude. Both co-ordinate systems are designated in this manual as the problem co-ordinate system. Figure 5.2 shows how the locations of the various grids are determined with respect to the problem co-ordinates.

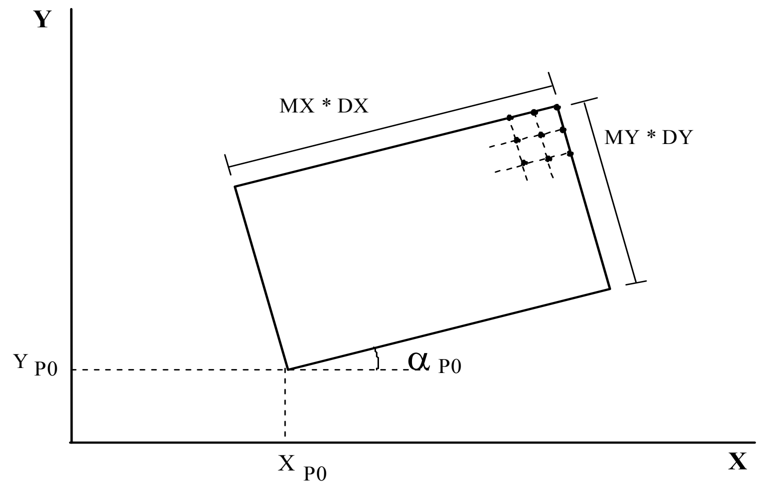


Figure 5.2: Definition of grids (input, computational and output grids) in Delft3D-WAVE

5.2.2 Choice of grids and boundary conditions

For your convenience Delft3D-WAVE accepts input and provides output on different grids.

It is not uncommon that a bottom grid is available as an existing data set without any relation whatsoever to Delft3D-WAVE. You may want output on an entirely different grid (but in the same region of course), whereas the computations in Delft3D-WAVE may require a different grid altogether.

For these reasons Delft3D-WAVE operates with different grids (each may have a different origin, orientation and resolution).

Input grids on which the bathymetry, current field and wind field (if present) are given by you; one computational grid on which Delft3D-WAVE performs the computations, and one (or more) output grid(s) on which you require output of Delft3D-WAVE.

During the computations (on the computational grid) Delft3D-WAVE obtains bathymetry and current information by bilinear interpolation from the input grid. The output on the output grid is in turn obtained in Delft3D-WAVE by interpolation from the computational grid. These interpolations will cause some loss of accuracy.

Input grids

Bathymetry and current input need to be provided to Delft3D-WAVE on so-called input grids (they need not be identical with the computational, the output grids or other input grids). It is best to make an input grid larger than the computational grid, in fact, so large that it completely covers the computational grid for every expected situation. In the region outside the input grid Delft3D-WAVE assumes that the bottom level and friction coefficient are identical to those at the nearest boundary of the input grid (lateral shift from that boundary). In the regions not covered by this lateral shift (i.e. in the outside corner quadrants of the input grid), a constant field equal to the value at the nearest corner point of the input grid is taken.

You should choose the resolution for the input grid such that relevant spatial details in the bathymetry and in the current pattern are well resolved. Special care is required in cases with sharp and shallow ridges in the sea bottom. In such cases the shallowest parts are of vital importance to obtain good Delft3D-WAVE results (during propagation the waves are ‘clipped’ by surf breaking at some maximum value determined by the minimum depth). To represent these shallowest parts in the bottom grid, you may want to have one grid line coincide with the ridge top (even if this means "moving" the ridge to the nearest line in the bathymetry grid). If this is not done, the computed wave height behind the shoal may well be computed higher than it is in reality, because the ridge is seen deeper in Delft3D-WAVE than it actually is (too coarse resolution to see shallow peak of the ridge).

Computational grid and boundary conditions

The computational grid is a grid in four dimensions: x-, y- and θ-, σ- space. The computational grid in x-, y-space must be chosen by you with care. You should choose the location of the up-wave boundary in water so deep that refraction effects have not (yet) influenced the wave field. However, a deep water up-wave boundary is not a strict requirement for Delft3D-WAVE. This advice is not applicable if the incoming waves are provided by a model which takes refraction into account, for instance Delft3D-WAVE itself (in a nested mode).

The computational grid must be larger than the area where you want to know the wave parameters. The length (in x-direction) needs not be longer than from the up-wave boundary to the most down-wave point of interest. The width (in y-direction) must be larger than that of the area of interest, because along each lateral side of the grid (if there is an open boundary along that side) a region exists where the wave field is disturbed (in Delft3D-WAVE) by an import of zero energy from the lateral boundaries (see Figure 5.3). This is not the case if the wave conditions along the lateral boundaries are specified by you or obtained from a previous Delft3D-WAVE run or if that boundary is closed (e.g. by land). The angle of the line dividing the disturbed area from the undisturbed area from the up-wave corner points (of the computational grid) is approximately equal to the half-power width of the directional energy distribution of the waves (this half-power width is typically 20° to 40° for waves generated by the local wind or 5° to 10° for swell).

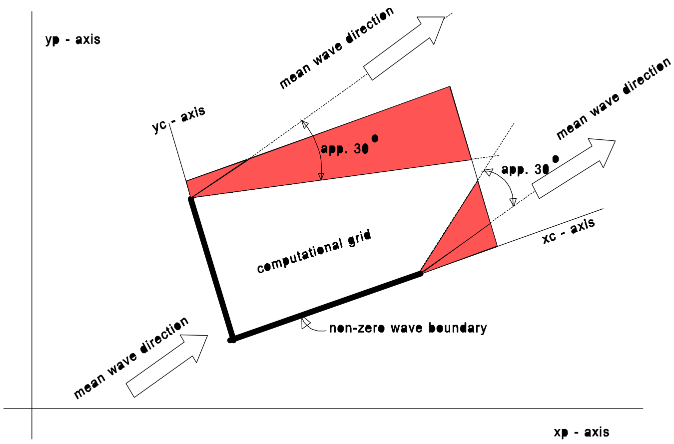


Figure 5.3: *Disturbed regions in the computational grid*

The spatial resolution of the computational grid should be sufficient to resolve relevant details of the wave field. Usually a good choice is to take the resolution of the computational grid approximately equal to that of the input (bathymetry/current) grid.

The computational spectral grid needs also to be provided by you. In frequency space it is simply defined by a minimum and maximum frequency and the frequency resolution which is proportional to the frequency itself (e.g. $\Delta f = 0.1f$). In the frequency domain this lowest frequency and highest frequency and the number of frequencies must be chosen. The value of lowest frequency must be slightly smaller than 0.6 times the value of the lowest peak frequency expected. The value of the highest frequency must be at least 2.5 to 3 times the highest peak frequency expected; usually it is chosen less than or equal to 1 Hz.

In directional space the directional range is the full 360° unless you specify a limited directional range. This may be convenient (less computer time and/or space) when waves travel towards a coast within a limited sector of 180°, say. The directional resolution is determined by the number of discrete directions that is provided by you. For wind seas with a directional spreading of typically 30° on either side of the mean wave direction, a resolution of 10° seems enough whereas for swell with a directional spreading of less than 10°, a resolution of 2° or less may be required. If you are confident that no energy will occur outside a certain directional sector (or is willing to ignore this energy), then the computations by SWAN can be limited to the directional sector that does contain energy. This may often be the case of waves propagating to shore within a sector of 180° around some mean wave direction.

Nonstationary situations are simulated with the SWAN model as quasi-stationary with repeated model runs. This implies that as e.g. the flow computations progress in time, a (stationary) wave computation is performed at specified, intermediate time levels. Such stationary wave computations are usually considered to be acceptable since the travel time of the waves from the seaward boundary to the coast is mostly relatively small compared to the time scale of variations in incoming wave field, the wind or tidal induced variations in depth and currents.

5.2.3 Output grids

Delft3D-WAVE can provide output on the computational grids or on grids that are independent from the computational grid like the Delft3D-FLOW grid. It must be pointed out that the information on a flow grid is obtained from the computational grid by spatial interpolation. Therefore it is wise to choose a resolution that is fine enough to show relevant spatial details.

The spatial interpolation implies that some inaccuracies are introduced. It also implies that bathymetry or current information on an (output) plot has been obtained by interpolating twice: once from the input grid to the computational grid and once from the computational grid to the output grid. If the input, computational and output grids are identical, then no interpolation errors occur.

In the regions where the output grid does not cover the computational grid Delft3D-WAVE assumes output values equal to zero.

5.3 Physical background of SWAN

5.3.1 Action balance equation

In SWAN the waves are described with the two-dimensional wave action density spectrum, even when non-linear phenomena dominate (e.g., in the surf zone). The rational for using the spectrum in such highly non-linear conditions is that, even in such conditions it seems possible to predict with reasonable accuracy this spectral distribution of the second order moment of the waves (although it may not be sufficient to fully describe the waves statistically). The spectrum that is considered in SWAN is the action density spectrum $N(\sigma, \theta)$ rather than the energy density spectrum $E(\sigma, \theta)$ since in the presence of currents, action density is conserved whereas energy density is not (Whitham, 1974). The independent variables are the relative frequency σ (as observed in a frame of reference moving with the current velocity) and the wave direction θ (the direction normal to the wave crest of each spectral component). The action density is equal to the energy density divided by the relative frequency: $N(\sigma, \theta) = E(\sigma, \theta)/\sigma$. In SWAN this spectrum may vary in time and space.

In SWAN the evolution of the wave spectrum is described by the spectral action balance equation which for Cartesian co-ordinates is (e.g., Hasselmann *et al.* (1973)):

$$\frac{\partial}{\partial t}N + \frac{\partial}{\partial x}c_x N + \frac{\partial}{\partial y}c_y N + \frac{\partial}{\partial \sigma}c_\sigma N + \frac{\partial}{\partial \theta}c_\theta N = \frac{S}{\sigma} \tag{5.1}$$

The first term in the left-hand side of this equation represents the local rate of change of action density in time, the second and third term represent propagation of action in geographical space (with propagation velocities c_x and c_y in x- and y-space, respectively). The fourth term represents shifting of the relative frequency due to variations in depths and currents (with propagation velocity c_σ in σ-space). The fifth term represents depth-induced and current-induced refraction (with propagation velocity c_θ in θ-space). The expressions for these propagation speeds are taken from linear wave theory (Whitham, 1974; Mei, 1983; Dingemans, 1997). The term S $(= S(\sigma, \theta))$ at the right-hand side of the action balance equation is the source term in terms of energy density representing the effects of generation, dissipation and non-linear wave-wave interactions. A brief summary of the formulations that are used for the various source terms in SWAN is given next.

The following processes are accounted for in SWAN:

- generation by wind,
- dissipation by whitecapping, bottom friction and depth-induced breaking,
- non-linear wave-wave interaction (quadruplets and triads).

In addition wave propagation through obstacles and wave-induced set-up of the mean sea surface can be computed in SWAN. These phenomena are addressed separately below (see Sections 5.3.2 and 5.3.3).

Wind input

Transfer of wind energy to the waves is described in SWAN with a resonance mechanism (Phillips, 1957) and a feed-back mechanism (Miles, 1957). The corresponding source term for these mechanisms is commonly described as the sum of linear and exponential growth:

$$S_{in}(\sigma, \theta) = A + BE(\sigma, \theta) \tag{5.2}$$

in which A and B depend on wave frequency and direction, and wind speed and direction. The effects of currents are accounted for in SWAN by using the apparent local wind speed and direction. The expression for the term A is due to Cavaleri and Malanotte-Rizzoli (1981) with a filter to avoid growth at frequencies lower than the Pierson-Moskowitz frequency (Tolman, 1992a). Two optional expressions for the coefficient B are used in the model. The first is taken from an early version of the WAM model (known as WAM Cycle 3, the WAMDI group (1988)). It is due to Snyder *et al.* (1981), rescaled in terms of friction velocity U_* by Komen *et al.* (1984). The drag coefficient to relate U_* to the driving wind speed at 10 m elevation U_{10} is taken from Wu (1982). The second expression for B in SWAN is taken from the most recent version of the WAM model (known as WAM Cycle 4, Komen *et al.* (1994)). It is due to Janssen (1991a) and it accounts explicitly for the interaction between the wind and the waves by considering atmospheric boundary layer effects and the roughness length of the sea surface. The corresponding set of equations is solved (as in the WAM model) with the iterative procedure of Mastenbroek *et al.* (1993).

Dissipation

The dissipation term of wave energy is represented by the summation of three different contributions: whitecapping $S_{ds,w}(\sigma,\theta)$, bottom friction $S_{ds,b}(\sigma,\theta)$ and depth-induced breaking $S_{ds,br}(\sigma,\theta)$.

Whitecapping is primarily controlled by the steepness of the waves. In presently operating third-generation wave models (including SWAN) the whitecapping formulations are based on a pulse-based model (Hasselmann, 1974), as adapted by the WAMDI group (1988):

$$S_{ds,w}(\sigma,\theta) = -\Gamma\tilde{\sigma}\frac{k}{\tilde{k}}E(\sigma,\theta) \tag{5.3}$$

where Γ is a steepness dependent coefficient, k is the wave number and $\tilde{sigma}$ and $\tilde{k}$ denote a mean frequency and a mean wave number, respectively (cf. the WAMDI group (1988)). Komen *et al.* (1984) estimated the value of Γ by closing the energy balance of the waves in fully developed conditions. This implies that this value depends on the wind input formulation that is used.

An alternative description for whitecapping in SWAN is given by Van der Westhuysen *et al.* (2007) and Van der Westhuysen (2007), which is an adapted form of the expression of Alves and Banner (2003). The latter is based on the apparent relationship between wave groups and whitecapping dissipation. This adaption is due to the fact that it can also be applied to mixed sea-swell conditions and in shallow water. This was done by removing the dependencies on mean spectral steepness and wavenumber in the original expression, and by applying source term scaling arguments for its calibration (see below). This led to the following expression for whitecapping dissipation:

$$S_{ds,w}(\sigma,\theta) = -C'_{ds}\left(\frac{B(k)}{B_r}\right)^{p/2}(\tanh(kh))^{(2-p_0)/4}\sqrt{gk}E(\sigma,\theta) \tag{5.4}$$

in which the density function B(k) is the azimuthal-integrated spectral saturation, which is positively correlated with the probability of wave group-induced breaking. It is calculated from frequency space variables as follows:

$$B(k) = \int_0^{2\pi} c_g k^3 E(\sigma,\theta)d\theta \tag{5.5}$$

and $B_r = 1.75 \times 10^{-3}$ is a threshold saturation level. The proportionality coefficient is set to $C'_{ds} = 5.0 \times 10^{-5}$. When $B(k) > B_r$, waves break and the exponent p is set equal to a calibration parameter p_0. For $B(k) \leq B_r$ there is no breaking, but some residual dissipation proved necessary. This is obtained by setting $p = 0$.

Depth-induced dissipation may be caused by bottom friction, by bottom motion, by percolation or by back-scattering on bottom irregularities (Shemdin *et al.*, 1978). For continental shelf seas with sandy bottoms, the dominant mechanism appears to be bottom friction (e.g., Bertotti and Cavaleri (1994)) which can generally represented as:

$$S_{ds,b}(\sigma,\theta) = -C_{bottom}\frac{\sigma^2}{g^2\sinh^2(kd)}E(\sigma,\theta) \tag{5.6}$$

in which C_{bottom} is a bottom friction coefficient. A large number of models have been proposed since the pioneering paper of Putnam and Johnson (1949). Hasselmann *et al.* (1973)

suggested to use an empirically obtained constant. It seems to perform well in many different conditions as long as a suitable value is chosen (typically different for swell and wind sea; Bouws and Komen (1983)). A non-linear formulation based on drag has been proposed by Hasselmann and Collins (1968) which was later simplified by Collins (1972). More complicated, eddy viscosity models have been developed by Madsen *et al.* (1988) (see Weber (1991a)) and by Weber (1989, 1991a,b). Considering the large variations in bottom conditions in coastal areas (bottom material, bottom roughness length, ripple height etc.), there is no field data evidence to give preference to a particular friction model (Luo and Monbaliu, 1994). For this reason, the simplest of each of these types of friction models has been implemented in SWAN: the empirical JONSWAP model of Hasselmann *et al.* (1973), the drag law model of Collins (1972) and the eddy-viscosity model of Madsen *et al.* (1988). The effect of a mean current on the wave energy dissipation due to bottom friction is not taken into account in SWAN. The reasons for this are given by Tolman (1992b) who argues that state-of-the-art expressions vary too widely in their effects to be acceptable. He found that the error in finding a correct estimate of the bottom roughness length scale has a much larger impact on the energy dissipation rate than the effect of a mean current.

The process of depth-induced wave-breaking is still poorly understood and little is known about its spectral modelling. In contrast to this, the total dissipation (i.e., integrated over the spectrum) due to this type of wave breaking can be well modelled with the dissipation of a bore applied to the breaking waves in a random field (Battjes and Janssen, 1978; Thornton and Guza, 1983). Laboratory observations (e.g., Battjes and Beji (1992), Vincent *et al.* (1994); Arcilla *et al.* (1994) and Eldeberky and Battjes (1996)) show that the shape of initially unimodal spectra propagating across simple (barred) beach profiles, is fairly insensitive to depth-induced breaking. This has led Eldeberky and Battjes (1995) to formulate a spectral version of the bore model of Battjes and Janssen (1978) which conserves the spectral shape. Expanding their expression to include directions, the expression that is used in SWAN is:

$$S_{ds,br}(\sigma,\theta) = -\frac{D_{tot}}{E_{tot}}E(\sigma,\theta) \tag{5.7}$$

in which E_{tot} and D_{tot} is the rate of dissipation of the total energy due to wave breaking according to Battjes and Janssen (1978). Adding a quadratic dependency on frequency as suggested by Mase and Kirby (1992) (supported by Elgar *et al.* (1997)) seems to have no noticeable effect on the SWAN results. Chen and Guza (1997) inferred from observations and simulations with a Boussinesq model that the high-frequency levels are insensitive to such frequency dependency because an increased dissipation at high frequencies is compensated approximately by increased non-linear energy transfer (but they did find the frequency dependency to be relevant in time domain). The value of D_{tot} depends critically on the breaking parameter $\gamma = H_{max}/d$ (in which H_{max} is the maximum possible individual wave height in the local water depth d). In Delft3D-WAVE a constant value is available equal to $\gamma = 0.73$ (the mean value of the data set of Battjes and Stive (1985).

Non-linear wave-wave interactions

In deep water, quadruplet wave-wave interactions dominate the evolution of the spectrum. They transfer wave energy from the spectral peak to lower frequencies (thus moving the peak frequency to lower values) and to higher frequencies (where the energy is dissipated by white-capping). In very shallow water, triad wave-wave interactions transfer energy from lower frequencies to higher frequencies often resulting in higher harmonics (Beji and Battjes, 1993) (low-frequency energy generation by triad wave-wave interactions is not considered here).

A full computation of the quadruplet wave-wave interactions is extremely time consuming and not convenient in any operational wave model. A number of techniques, based on parametric methods or other types of approximations have been proposed to improve computational speed (see Young and Van Vledder (1993) for a review). In SWAN the computations are carried out with the Discrete Interaction Approximation (DIA) of Hasselmann *et al.* (1985). This DIA has been found quite successful in describing the essential features of a developing wave spectrum (Komen *et al.*, 1994). For uni-directional waves, this approximation is not valid. In fact, the quadruplet interaction coefficient for these waves is nearly zero (G.Ph. van Vledder, personal communication, 1996). For finite-depth applications, Hasselmann and Hasselmann (1981) have shown that for a JONSWAP-type spectrum the quadruplet wave-wave interactions can be scaled with a simple expression (it is used in SWAN).

A first attempt to describe triad wave-wave interactions in terms of a spectral energy source term was made by Abreu *et al.* (1992). However, their expression is restricted to non-dispersive shallow water waves and is therefore not suitable in many practical applications of wind waves. The breakthrough in the development came with the work of Eldeberky and Battjes (1995) who transformed the amplitude part of the Boussinesq model of Madsen and Sørensen (1993) into an energy density formulation and who parameterised the biphase of the waves on the basis of laboratory observations (Battjes and Beji, 1992; Arcilla, Roelvink, O'Connor, Reniers and Jimenez, 1994). A discrete triad approximation (DTA) for co-linear waves was subsequently obtained by considering only the dominant self-self interactions. Their model has been verified with flume observations of long-crested, random waves breaking over a submerged bar (Beji and Battjes, 1993) and over a barred beach (Arcilla *et al.*, 1994). The model appeared to be fairly successful in describing the essential features of the energy transfer from the primary peak of the spectrum to the super harmonics. A slightly different version, the Lumped Triad Approximation (LTA) was later derived by Eldeberky and Battjes (1996). This LTA is used in SWAN.

5.3.2 Propagation through obstacles

SWAN can estimate wave transmission through a (line-)structure such as a breakwater (dam). Such an obstacle will affect the wave field in two ways, first it will reduce the wave height locally all along its length, and second it will cause diffraction around its end(s). The model is not able to account for diffraction. In irregular, short-crested wave fields, however, it seems that the effect of diffraction is small, except in a region less than one or two wavelengths away from the tip of the obstacle (Booij *et al.*, 1992). Therefore the model can reasonably account for waves around an obstacle if the directional spectrum of incoming waves is not too narrow. Since obstacles usually have a transversal area that is too small to be resolved by the bathymetry grid in SWAN, an obstacle is modelled as a line. If the crest of the breakwater is at a level where (at least part of the) waves can pass over, the transmission coefficient K_t (defined as the ratio of the (significant) wave height at the down-wave side of the dam over the (significant) wave height at the up-wave side) is a function of wave height and the difference in crest level and water level. The expression is taken from Goda *et al.* (1967):

$$K_t = 0.5\left[1 - \sin\left(\frac{\pi}{2\alpha}\left(\frac{F}{H_i} + \beta\right)\right)\right] \quad \text{for} \quad -\beta - \alpha < \frac{F}{H_i} < \alpha - \beta \tag{5.8}$$

where $F = h - d$ is the freeboard of the dam and where H_i is the incident (significant) wave height at the up-wave side of the obstacle (dam), h is the crest level of the dam above the reference level (same as reference level of the bottom), d the mean water level relative to the reference level, and the coefficients α, β depend on the shape of the dam (Seelig, 1979):

Case	α	β
Vertical thin wall	1.8	0.1
Caisson	2.2	0.4
Dam with slope 1:3/2	2.6	0.15

The above expression is based on experiments in a wave flume, so strictly speaking it is only valid for normal incidence waves. Since there is no data available on oblique waves it is assumed that the transmission coefficient does not depend on direction. Another phenomenon that is to be expected is a change in wave frequency since often the process above the dam is highly non-linear. Again there is little information available, so in the model it is assumed that the frequencies remain unchanged over an obstacle (only the energy scale of the spectrum is affected and not the spectral shape).

5.3.3 Wave-induced set-up

In a (geographic) 1D case the computation of the wave induced set-up is based on the vertically integrated momentum balance equation which is a balance between the wave force (gradient of the wave radiation stress) and the hydrodynamic pressure gradient (no wave-induced currents exist).

$$F_x + gd\frac{\partial \bar{\eta}}{\partial x} = 0 \tag{5.9}$$

where d is the total water depth (including the wave-induced set-up) and $\bar{\eta}$ is the mean surface elevation (including the wave-induced set-up).

In a 2D case, computations are also based on the vertically integrated momentum balance equation (in two geographic dimensions), supplemented with the observation of Dingemans *et al.* (1987) that the wave-induced currents are mainly driven by the divergence-free part of the wave forces whereas the set-up is mainly due to the rotation-free part of these forces. To compute the set-up, it would then be sufficient to compute the set-up as if the currents are zero, which implies that the divergence of all forces considered would be zero:

$$\frac{\partial F_x}{\partial x} + \frac{\partial F_y}{\partial y} + \frac{\partial}{\partial x}\left(gd\frac{\partial \eta}{\partial x}\right) + \frac{\partial}{\partial y}\left(gd\frac{\partial \eta}{\partial y}\right) = 0 \tag{5.10}$$

Note that divergence = 0 is only an approximation of the true divergence. These two equations have been implemented in SWAN. The 2D set-up module can be activated within Delft3D-WAVE.

5.3.4 Diffraction

To accommodate diffraction in SWAN simulations, a phase-decoupled refraction-diffraction approximation is suggested (Holthuijsen *et al.*, 1993). It is expressed in terms of the directional turning rate of the individual wave components in the 2D wave spectrum. The approximation is based on the mild-slope equation for refraction and diffraction, omitting phase information. It does therefore not permit coherent wave fields in the computational domain.

5.4 Full expressions for source terms

The complete expressions for the physical processes of generation, dissipation and non-linear wave-wave interactions that are available in the SWAN model are given here.

5.4.1 Input by wind

Wave growth by wind is described by:

$$S_{in}(\sigma, \theta) = A + BE(\sigma, \theta) \tag{5.11}$$

in which A describes linear growth and BE exponential growth. It should be noted that the SWAN model is driven by the wind speed at 10 m elevation U_{10} whereas the computations use the friction velocity U_*. For the WAM Cycle 3 formulation the transformation from U_{10} to U_* is obtained with:

$$U_*^2 = C_D U_{10}^2 \tag{5.12}$$

in which C_D is the drag coefficient from Wu (1982) **?** :

$$C_D(U_{10}) = \begin{cases} 1.2875 \times 10^{-3} & \text{for} \quad U_{10} < 7.5 \text{ m/s} \\ (0.8 + 0.065\,[s/m] \times U_{10}) \times 10^{-3} & \text{for} \quad U_{10} \geq 7.5 \text{ m/s} \end{cases} \tag{5.13}$$

The expression for B is due to Komen *et al.* (1984). Their expression is a function of U_*/c_{ph}:

$$B = \max\left(0, 0.25\frac{\rho_a}{\rho_w}\left(28\frac{U_*}{c_{ph}}\cos(\theta-\theta_w)-1\right)\right)\sigma \tag{5.14}$$

in which c_{ph} is the phase speed and ρ_a and ρ_w are the density of air and water, respectively. This expression is also used in WAM Cycle 3 (cf. the WAMDI group (1988)).

5.4.2 Dissipation of wave energy

Whitecapping

The processes of whitecapping in the SWAN model are represented by the pulse-based model of Hasselmann (1974). Reformulated in terms of wave number (rather than frequency) so as to be applicable in finite water depth (cf. the WAMDI group (1988)), this expression is:

$$S_{ds,w}(\sigma,\theta) = -\Gamma\tilde{\sigma}\frac{k}{\tilde{k}}E(\sigma,\theta) \tag{5.15}$$

where $\tilde{\sigma}$ and $\tilde{k}$ denote the mean frequency and the mean wave number (for expressions see below) respectively and the coefficient Γ depends on the overall wave steepness. This steepness dependent coefficient, as given by the WAMDI group (1988), has been adapted by Günther *et al.* (1992) based on Janssen (1991a,b):

$$\Gamma = \Gamma_{KJ} = C_{ds}\left((1-\delta)+\delta\frac{k}{\tilde{k}}\right)\left(\frac{\tilde{s}}{\tilde{s}_{PM}}\right)^p \tag{5.16}$$

For $\delta = 0$ the expression of Γ reduces to the expression as used by the WAMDI group (1988). The coefficients C_{ds}, δ and m are tunable coefficients, $\tilde{s}$ is the overall wave steepness (defined below), $\tilde{s}_{PM}$ is the value of $\tilde{s}$ for the Pierson-Moskowitz spectrum (1964; $\tilde{s}_{PM} = (3.02 \times 10^{-3})^{1/2}$). This overall wave steepness $\tilde{s}$ is defined as:

$$\tilde{s} = \tilde{k}\sqrt{E_{tot}} \tag{5.17}$$

The mean frequency $\tilde{\sigma}$, the mean wave number $\tilde{k}$ and the total wave energy E_{tot} is defined as (cf. the WAMDI group (1988)):

$$\begin{aligned} \tilde{\sigma} &= \left(E_{tot}^{-1}\int_0^{2\pi}\int_0^{\infty}\frac{1}{\sigma}E(\sigma,\theta)d\sigma d\theta\right)^{-1} \\ \tilde{k} &= \left(E_{tot}^{-1}\int_0^{2\pi}\int_0^{\infty}\frac{1}{\sqrt{k}}E(\sigma,\theta)d\sigma d\theta\right)^{-2} \\ E_{tot} &= \int_0^{2\pi}\int_0^{\infty}E(\sigma,\theta)d\sigma d\theta \end{aligned} \tag{5.18}$$

The values of the tunable coefficients C_{ds} and δ and exponent p in this model have been obtained by Komen *et al.* (1984) by closing the energy balance of the waves in idealised wave growth conditions (both for growing and fully developed wind seas) for deep water. This implies that coefficients in the steepness dependent coefficient Γ depend on the wind input formulation that is used. For the wind input of Komen *et al.* (1984) (corresponding to WAM Cycle 3; the WAMDI group (1988)):

$$C_{ds} = 2.36 \times 10^{-5}, \tag{5.19}$$

$$\delta = 0 \quad \text{and} \tag{5.20}$$

$$p = 4. \tag{5.21}$$

Bottom friction

The bottom friction models that have been selected for SWAN are the empirical model of JONSWAP (Hasselmann *et al.*, 1973), the drag law model of Collins (1972) and the eddy-viscosity model of Madsen *et al.* (1988). The formulations for these bottom friction models can all be expressed in the following form:

$$S_{ds,b}(\sigma,\theta) = -C_{bottom}\frac{\sigma^2}{g^2\sinh^2(kd)}E(\sigma,\theta) \tag{5.22}$$

in which C_{bottom} is a bottom friction coefficient that generally depends on the bottom orbital motion represented by U_{rms}:

$$U_{rms}^2 = \int_0^{2\pi}\int_0^{\infty}\frac{\sigma^2}{\sinh^2(kd)}E(\sigma,\theta)d\sigma d\theta \tag{5.23}$$

Hasselmann *et al.* (1973) found from the results of the JONSWAP experiment $C_{bottom} = C_{JON} = 0.038$ m^{2}s^{-3} for swell conditions. Bouws and Komen (1983) selected a bottom friction coefficient of $C_{JON} = 0.067$ m^{2}s^{-3} for fully developed wave conditions in shallow water. Both values are available in SWAN.

The expression of Collins (1972) is based on a conventional formulation for periodic waves with the appropriate parameters adapted to suit a random wave field. The dissipation rate is calculated with the conventional bottom friction formulation of Eq. 5.22 in which the bottom friction coefficient is $C_{bottom} = C_f g U_{rms}$ with $C_f = 0.015$ (Collins, 1972). (Note that Collins (1972) contains an error in the expression due to an erroneous Jacobean transformation; see page A-16 of Tolman (1990).)

Madsen *et al.* (1988) derived a formulation similar to that of Hasselmann and Collins (1968) but in their model the bottom friction factor is a function of the bottom roughness height and the actual wave conditions. Their bottom friction coefficient is given by:

$$C_{bottom} = f_w\frac{g}{\sqrt{2}}U_{rms} \tag{5.24}$$

in which f_w is a non-dimensional friction factor estimated by using the formulation of Jonsson (1966) (cf. Madsen *et al.* (1988)):

$$\frac{1}{4\sqrt{f_w}} + {}^{10}\log\left(\frac{1}{4\sqrt{f_w}}\right) = m_f + {}^{10}\log\left(\frac{a_b}{K_N}\right) \tag{5.25}$$

in which $m_f = -0.08$ (Jonsson and Carlsen, 1976) and a_b is a representative near-bottom excursion amplitude:

$$a_b^2 = 2\int_0^{2\pi}\int_0^{\infty}\frac{1}{\sinh^2(kd)}E(\sigma,\theta)d\sigma d\theta \tag{5.26}$$

and K_N is the bottom roughness length scale. For values of a_b/KN smaller than 1.57 the friction factor f_w is 0.30 (Jonsson, 1980).

Depth-induced wave breaking

To model the energy dissipation in random waves due to depth-induced breaking, the bore-based model of Battjes and Janssen (1978) is used in SWAN. The mean rate of energy dissipation per unit horizontal area due to wave breaking D_{tot} is expressed as:

$$D_{tot} = -\frac{1}{4}\alpha_{BJ}Q_b\left(\frac{\sigma}{2\pi}\right)H_m^2 \tag{5.27}$$

in which $\alpha_{BJ} = 1$ in SWAN, Q_b [-] is the fraction of breaking waves determined by:

$$\frac{1-Q_b}{\ln Q_b} = -8\frac{E_{tot}}{H_m^2} \tag{5.28}$$

in which H_m is the maximum wave height that can exist at the given depth and $\bar{\sigma}$ is a mean frequency defined as:

$$\bar{\sigma} = E_{tot}^{-1}\int_0^{2\pi}\int_0^{\infty}\sigma E(\sigma,\theta)d\sigma d\theta \tag{5.29}$$

Extending the expression of Eldeberky and Battjes (1995) to include the spectral directions, the dissipation for a spectral component per unit time is calculated in SWAN with:

$$S_{ds,br}(\sigma,\theta) = D_{tot}\frac{E(\sigma,\theta)}{E_{tot}} \tag{5.30}$$

The maximum wave height H_m is determined in SWAN with $H_m = \gamma d$, in which γ is the breaker parameter and d is the total water depth (including the wave-induced set-up if computed by SWAN). In literature, this breaker parameter γ is often a constant or it is expressed as a function of bottom slope or incident wave steepness (Galvin, 1972; Battjes and Janssen, 1978; Battjes and Stive, 1985; Arcilla and Lemos, 1990; Kaminsky and Kraus, 1993; Nelson, 1987, 1994). Since SWAN is locally defined, the dependency on incident wave steepness cannot be used.

In the publication of Battjes and Janssen (1978) in which the dissipation model is described, a constant breaker parameter, based on Miche's criterion, of $\gamma = 0.8$ was used. Battjes and Stive (1985) re-analysed wave data of a number of laboratory and field experiments and found values for the breaker parameter varying between 0.6 and 0.83 for different types of bathymetry (plane, bar-trough and bar) with an average of 0.73. From a compilation of a large number of experiments Kaminsky and Kraus (1993) have found breaker parameters in the range of 0.6 to 1.59 with an average of 0.79.

5.4.3 Nonlinear wave-wave interactions

Quadruplet wave-wave interactions

The quadruplet wave-wave interactions are computed with the Discrete Interaction Approximation (DIA) as proposed by Hasselmann *et al.* (1985). Their source code (slightly adapted by Tolman, personal communication, 1993) has been used in the SWAN model. In the Discrete Interaction Approximation two quadruplets of wave numbers are considered, both with frequencies:

$$\begin{aligned}\sigma_1 &= \sigma_2 = \sigma \\ \sigma_3 &= \sigma(1+\lambda) = \sigma^+ \\ \sigma_4 &= \sigma(1-\lambda) = \sigma^-\end{aligned} \tag{5.31}$$

where λ is a constant coefficient set equal to 0.25. To satisfy the resonance conditions for the first quadruplet, the wave number vectors with frequency σ_3 and σ_4 lie at an angle of $\theta_1 = -11.5°$ and $\theta_2 = 33.6°$ to the two identical wave number vectors with frequencies σ_1 and σ_2. The second quadruplet is the mirror of this first quadruplet (the wave number vectors with frequency σ_3 and σ_4 lie at mirror angles of $\theta_3 = 11.5°$ and $\theta_4 = -33.6°$.

Within this discrete interaction approximation, the source term $S_{nl4}(\sigma,\theta)$ is given by:

$$S_{nl4}(\sigma,\theta) = S^*_{nl4}(\sigma,\theta) + S^{**}_{nl4}(\sigma,\theta) \tag{5.32}$$

where $S^*_{nl4}(\sigma,\theta)$ refers to the first quadruplet and $S^{**}_{nl4}(\sigma,\theta)$ to the second quadruplet (the expressions for $S^{**}_{nl4}(\sigma,\theta)$ are identical to those for $S^*_{nl4}(\sigma,\theta)$ for the mirror directions) and:

$$S^*_{nl4}(\sigma,\theta) = 2\delta S^*_{nl4}(\alpha_1,\sigma,\theta) - \delta S^*_{nl4}(\alpha_2,\sigma,\theta) - \delta S^*_{nl4}(\alpha_3,\sigma,\theta) \tag{5.33}$$

in which $\alpha_1 = 1$, $\alpha_2 = (1+\lambda)$ and $\alpha_3 = (1-\lambda)$. Each of the contributions ($i = 1, 2, 3$) is:

$$\begin{aligned}&\delta S_{nl4}(\alpha_i\sigma,\theta) = C_{nl4}(2\pi)^2 g^{-4}\left(\frac{\sigma}{2\pi}\right)^{11} \\ &\left[E^2(\alpha_i\sigma,\theta)\left(\frac{E^2(\alpha_i\sigma^+,\theta)}{(1+\lambda)^4} + \frac{E^2(\alpha_i\sigma^-,\theta)}{(1-\lambda)^4}\right) - 2\frac{E^2(\alpha_i\sigma,\theta)E^2(\alpha_i\sigma^+,\theta)E^2(\alpha_i\sigma^-,\theta)}{(1-\lambda^2)^4}\right]\end{aligned} \tag{5.34}$$

The constant $C_{nl4} = 3\times10^7$. Following Hasselmann and Hasselmann (1981), the quadruplet interaction in finite water depth is taken identical to the quadruplet transfer in deep water multiplied with a scaling factor R:

$$S_{nl4,\text{finite}\,depth} = R(k_p d) S_{nl4,\text{infinite}\,depth} \tag{5.35}$$

where R is given by:

$$R(k_p d) = 1 + \frac{C_{sh1}}{k_p d}(1 - C_{sh2}k_p d)\exp(C_{sh3}k_p d) \tag{5.36}$$

in which k_p is the peak wave number of the JONSWAP spectrum for which the original computations were carried out. The values of the coefficients are: $C_{sh1} = 5.5$, $C_{sh2} = 6/7$ and $C_{sh3} = -1.25$. In the shallow water limit, i.e., $k_p d \to 0$ the non-linear transfer tends to infinity. Therefore a lower limit of $k_p d = 0.5$ is applied (cf. WAM Cycle 4; Komen *et al.* (1994), resulting in a maximum value of $R(k_p d) = 4.43$. To increase the model robustness in case of arbitrarily shaped spectra, the peak wave number k_p is replaced by $k_p = 0.75\bar{k}$ (Komen *et al.*, 1994).

Triad wave-wave interactions

The Lumped Triad Approximation (LTA) of Eldeberky and Battjes (1996), which is a slightly adapted version of the Discrete Triad Approximation of Eldeberky and Battjes (1995) is used in SWAN in each spectral direction:

$$S_{nl3}(\sigma,\theta) = S^-_{nl3}(\sigma,\theta) + S^+_{nl3}(\sigma,\theta) \tag{5.37}$$

with

$$S^+_{nl3}(\sigma,\theta) = \max\{0, \alpha_{EB} 2\pi c c_g J^2 |\sin(\beta)| \{E^2(\sigma/2,\theta) - 2E(\sigma/2,\theta)E(\sigma,\theta)\}\} \tag{5.38}$$

and

$$S^-_{nl3}(\sigma,\theta) = -2S^+_{nl3}(2\sigma,\theta) \tag{5.39}$$

in which α_{EB} is a tunable proportionality coefficient. The bi-phase β is approximated with

$$\beta = -\frac{\pi}{2} + \frac{\pi}{2}\tanh\left(\frac{0.2}{Ur}\right) \tag{5.40}$$

with Ursell number Ur:

$$Ur = \frac{g}{8\sqrt{2}\pi^2}\frac{H_s \bar{T}^2}{d^2} \tag{5.41}$$

with $\bar{T} = 2\pi/\bar{\sigma}$. Usually, the triad wave-wave interactions are calculated only for $0.1 \leq Ur \leq 10$. But for stability reasons, it is calculated for the whole range $0 \leq Ur \leq 10$. This means that both quadruplets and triads are computed at the same time. The interaction coefficient J is taken from Madsen and Sørensen (1993):

$$J = \frac{k^2_{\sigma/2}(gd + 2c^2_{\sigma/2})}{k_\sigma d\left(gd + \frac{2}{15}gd^3k^2_\sigma - \frac{2}{5}\sigma^2 d^2\right)} \tag{5.42}$$

Wave-induced set-up

In a geographic 1D case the computation of the wave induced set-up is based on the vertically integrated momentum balance equation which is a balance between the wave force (gradient of the wave radiation stress normal to the coast) and the hydrostatic pressure gradient (note that the component parallel to the coast causes wave-induced currents but no set-up):

$$\frac{dS_{xx}}{dx} + \rho g H \frac{d\bar{\eta}}{dx} = 0 \tag{5.43}$$

where $H = d + \bar{\eta}$ is the total water depth (including the wave-induced set-up), d is the bottom level, $\bar{\eta}$ is the mean surface elevation (including the wave-induced set-up) and

$$S_{xx} = \rho g \int \left(n\cos^2\theta + \frac{n-1}{2}\right) E \, d\sigma d\theta \tag{5.44}$$

is the radiation stress tensor.

Observation and computations based on the vertically integrated momentum balance equation of Dingemans *et al.* (1987) show that the wave-induced currents are mainly driven by the divergence-free part of the wave forces whereas the set-up is mainly due to the rotation-free part of these forces. To compute the set-up, it would then be sufficient to consider the divergence of the momentum balance equation. If the divergence of the acceleration in the resulting equation is ignored, the result is:

$$\frac{\partial F_x}{\partial x} + \frac{\partial F_y}{\partial y} + \frac{\partial}{\partial x}(\rho g H \frac{\partial\bar{\eta}}{\partial x}) + \frac{\partial}{\partial y}(\rho g H \frac{\partial\bar{\eta}}{\partial y}) = 0 \tag{5.45}$$

Diffraction

In a simplest case, we assume there are no currents. This means that $c_\sigma = 0$. Let denotes the propagation velocities in geographic and spectral spaces for the situation without diffraction as: $c_{x,0}$, $c_{y,0}$ and $c_{\theta,0}$. These are given by:

$$c_{x,0} = \frac{\partial\omega}{\partial k}\cos(\theta), \qquad c_{y,0} = \frac{\partial\omega}{\partial k}\sin(\theta), \qquad c_{\theta,0} = -\frac{1}{k}\frac{\partial\omega}{\partial h}\frac{\partial h}{\partial n} \tag{5.46}$$

where k is the wave number and n is perpendicular to the wave ray. We consider the following eikonal equation:

$$K^2 = k^2(1+\delta) \tag{5.47}$$

with δ denoting the diffraction parameter as given by:

$$\delta = \frac{\nabla(cc_g\nabla H_s)}{cc_g H_s} \tag{5.48}$$

Due to diffraction, the propagation velocities are given by:

$$c_x = c_{x,0}\bar{\delta}, \qquad c_y = c_{y,0}\bar{\delta}, \qquad c_\theta = c_{\theta,0}\bar{\delta} - \frac{\partial\bar{\delta}}{\partial x}c_{y,0} + \frac{\partial\bar{\delta}}{\partial y}c_{x,0} \tag{5.49}$$

where $\bar{\delta} = \sqrt{1+\delta}$.

5.5 Numerical implementation

The integration of the action balance equation has been implemented in SWAN with finite difference schemes in all five dimensions (time, geographic space and spectral space). In Delft3D-WAVE, SWAN is applied in a stationary mode so that time has been omitted from the equations. Below the propagation schemes in geographical and spectral space are briefly described.

The geographic space is discretised with a rectangular grid with constant resolutions Δx and Δy in x- and y-direction respectively (in fact, this rectangular grid is a special case of the curvi-linear grid that has been programmed in SWAN. The spectrum in the model is discretised with a constant directional resolution $\Delta\theta$ and a constant relative frequency resolution $\Delta\sigma/\sigma$ (logarithmic frequency distribution). For reasons of economy, an option is available to compute only wave components travelling in a pre-defined directional sector ($\theta_{min} < \theta < \theta_{max}$; e.g., those components that travel shorewards within a limited directional sector). The discrete frequencies are defined between a fixed low-frequency cut-off and a fixed high-frequency cut-off (the prognostic part of the spectrum). For these frequencies the spectral density is unconstrained. Below the low-frequency cut-off (typically $f_{min} = 0.04$ Hz for field conditions) the spectral densities are assumed to be zero. Above the high-frequency cut-off (typically 1 Hz for field conditions) a diagnostic f^{-m} tail is added (this tail is used to compute non-linear wave-wave interactions at the high frequencies and to compute integral wave parameters). The reason for using a fixed high-frequency cut-off rather than a dynamic cut-off frequency that depends on the wind speed or on the mean frequency, as in the WAM and WAVEWATCH III model, is that in coastal regions mixed sea states with rather different characteristic frequencies may occur. For instance, a local wind may generate a very young sea behind an island, totally unrelated to (but superimposed on) a simultaneously occurring swell. In such cases a dynamic cut-off frequency may be too low to properly account for the locally generated sea state. Based on physical arguments the value of m (the power in the above expression of the spectral tail) should be between 4 and 5 (Phillips, 1985). In SWAN $m = 4$ if the wind input formulation of Komen *et al.* (1984) is used (cf. WAM Cycle 3) and $m = 5$ if the wind input formulation of Janssen (1991a) is used (cf. WAM Cycle 4).

5.5.1 Propagation

The numerical schemes in SWAN have been chosen on the basis of robustness, accuracy and economy. Since the nature of the basic equation is such that the state in a grid point is determined by the state in the up-wave grid points, the most robust scheme would be an implicit upwind scheme (in both geographic and spectral space). The adjective ”implicit” is used here to indicate that all derivatives of action density (x or y) are formulated at one computational level, i_x or i_y, except the derivative in the integration dimension for which also the previous or up-wave level is used (x or y in stationary mode). For such a scheme the values of space steps, Δx and Δy would be mutually independent. An implicit scheme would also be economical in the sense that such a scheme is unconditionally stable. It permits relatively large time steps in the computations (much larger than for explicit schemes in shallow water). Several years of experience in using the second-generation HISWA shallow water wave model (Holthuijsen *et al.*, 1989) has shown that for coastal regions a first-order upwind difference scheme in geographic space is usually accurate enough. This experience, together with test computations with SWAN has also shown that in spectral space a higher accuracy than that of a first-order upwind scheme is required. This can be achieved by supplementing such a scheme with a second-order central approximation (more economic than a second-order upwind scheme). For SWAN therefore, implicit upwind schemes in both geographic and spectral space have been chosen, supplemented with a central approximation in spectral space.

The fact that in geographic space, the state in a grid point is determined by the state in the up-wave grid points (as defined by the direction of propagation), permits a decomposition of the spectral space into four quadrants. In each of the quadrants the computations can be carried out independently from the other quadrants except for the interactions between them due to refraction and non-linear wave-wave interactions (formulated in corresponding boundary conditions between the quadrants). The wave components in SWAN are correspondingly propagated in geographic space with the first-order upwind scheme in a sequence of four forward-marching sweeps (one per quadrant). To properly account for the boundary conditions between the four quadrants, the computations are carried out iteratively at each time step. The discretization of the action balance equation is (for positive propagation speeds; including the computation of the source terms but ignoring their discretisation):

$$
\begin{aligned}
&\left[\frac{[c_x N]_{i_x} - [c_x N]_{i_x-1}}{\Delta x}\right]^n_{i_y,i_\sigma,i_\theta} + \left[\frac{[c_y N]_{i_y} - [c_y N]_{i_y-1}}{\Delta y}\right]^n_{i_x,i_\sigma,i_\theta} \\
&+ \left[\frac{(1-\nu)[c_\sigma N]_{i_\sigma+1} + 2\nu[c_\sigma N]_{i_\sigma} - (1+\nu)[c_\sigma N]_{i_\sigma-1}}{2\Delta\sigma}\right]^n_{i_x,i_y,i_\theta} \\
&+ \left[\frac{(1-\eta)[c_\theta N]_{i_\theta+1} + 2\eta[c_\theta N]_{i_\theta} - (1+\eta)[c_\theta N]_{i_\theta-1}}{2\Delta\theta}\right]^n_{i_x,i_y,i_\sigma} = \left[\frac{S}{\sigma}\right]^{n^*}_{i_x,i_y,i_\sigma,i_\theta}
\end{aligned}
\tag{5.50}
$$

where i_x, i_y, i_σ and i_θ are grid counters and Δx, Δy, $\Delta\sigma$ and $\Delta\theta$ are the increments in geographic space and spectral space respectively. The iterative nature of the computation is indicated with the iteration index n (the iteration index for the source terms n^* is equal to n or $n-1$, depending on the source term, see below). Because of these iterations, the scheme is also approximately implicit for the source terms. For negative propagation speeds, appropriate + and - signs are required in Eq. 5.50.

The coefficients ν and η determine the degree to which the scheme in spectral space is upwind or central. They thus control the numerical diffusion in frequency and directional space, respectively. A value of $\nu = 0$ or $\eta = 0$ corresponds to central schemes which have the largest accuracy (numerical diffusion $\gg$ 0). Value of $\nu = 1$ or $\eta = 1$ correspond to upwind schemes which are somewhat more diffusive and therefore less accurate but more robust. If large gradients of the action density in frequency space or directional space are present, numerical oscillations can arise (especially with the central difference schemes) resulting in negative values of the action density. In each sweep such negative values are removed from the two-dimensional spectrum by setting these values equal to zero and re-scaling the remaining positive values such that the frequency-integrated action density per spectral direction is conserved. The depth derivatives and current derivatives in the expressions of c_σ and c_θ are calculated with a first-order upwind scheme. For very strong refraction the value of c_θ is reduced in each grid point and for each wave component individually with the square of the fraction of the grid spacing over which $kd < 3.0$.

The propagation scheme is implicit as the derivatives of action density (in x or y) at the computational level (i_x or i_y, respectively) are formulated at that level except in the integration dimension (x or y; depending on the direction of propagation) where also the up-wave level is used. The values of Δx and Δy are therefore still mutually independent.

The boundary conditions in SWAN, both in geographic space and spectral space are fully absorbing for wave energy that is leaving the computational domain or crossing a coast line. The incoming wave energy along open geographic boundaries needs to be prescribed by you. For coastal regions such incoming energy is usually provided only along the deep-water boundary and not along the lateral geographic boundaries (i.e., the spectral densities are assumed to be zero). This implies that such erroneous lateral boundary conditions are propagated into the computational area. The affected areas are typically triangular regions with the apex at the corners between the deep-water boundary and the lateral boundaries, spreading towards shore at an angle of 30° to 45° (for wind sea conditions) on either side of the deep-water mean wave direction (less for swell conditions; this angle is essentially equal to the one-sided width of the directional distribution of the incoming wave spectrum). For this reason the lateral boundaries should be sufficiently far away from the area of interest to avoid the propagation of this error into the area.

References

Abreu, M., A. Larraza and E. Thornton, 1992. “Nonlinear transformation of directional wave spectra in shallow water.” *Journal of Geophysical Research* 97: 15579-15589.

Alves, J. and M. Banner, 2003. “Performance of a saturation-based dissipation-rate source term in modelling the fetch-limited evolution of wind waves.” *J. Phys. Oceanogr.* 33: 1274-1298.

Arcilla, A. and C. Lemos, 1990. *Surf-Zone Hydrodynamics.* Centro Internacional de Métodos Numéricos en Ingenieria, Barcelona.

Arcilla, A., B. Roelvink, B. O’Connor, A. Reniers and J. Jimenez, 1994. “The Delta flume ’93 experiment.” In *Proceedings Coastal Dynamics Conference ’94*, pages 488-502.

Battjes, J. and S. Beji, 1992. “Breaking waves propagating over a shoal.” In *Proceedings 23rd International Conference Coastal Engineering, ASCE*, pages 42-50.

Battjes, J. and J. Janssen, 1978. “Energy loss and set-up due to breaking of random waves,.” In *Proceedings 16th International Conference Coastal Engineering, ASCE*, pages 569-587.

Battjes, J. and M. Stive, 1985. “Calibration and verification of a dissipation model for random breaking waves.” *Journal of Geophysical Research* 90 (C5): 9159-9167.

Beji, S. and J. Battjes, 1993. “Experimental investigation of wave propagation over a bar.” *Coastal Engineering* 19: 151-162.

Bertotti, L. and L. Cavaleri, 1994. “Accuracy of wind and wave evaluation in coastal regions.” In *Proceedings 24th International Conference Coastal Engineering, ASCE*, pages 57-67.

Booij, N., L. H. Holthuijsen and P. H. M. de Lange, 1992. “The penetration of short-crested waves through a gap.” In *Proceedings 23rd International Conference Coastal Engineering, Venice 4-9 Oct., 1992, New York, 1993*, pages 1044-1052.

Booij, N., R. Ris and L. Holthuijsen, 1999. “A third-generation wave model for coastal regions, Part I, Model description and validation.” *Journal of Geophysical Research* 104 (C4): 7649-7666.

Bouws, E. and G. Komen, 1983. “On the balance between growth and dissipation in an extreme, depth-limited wind-sea in the southern North Sea.” *Journal of Physical Oceanography* 13: 1653-1658.

Cavaleri, L. and P. Malanotte-Rizzoli, 1981. “Wind wave prediction in shallow water: Theory and applications.” *Journal of Geophysical Research* 86 (C11): 10 961-10 973.

Chen, Y. and R. Guza, 1997. “Modelling of breaking surface waves in shallow water.” *Journal of Geophysical Research* 102 (C11): 25 035-25 046.

Collins, J., 1972. “Prediction of shallow water spectra.” *Journal of Geophysical Research* 77 (15): 2693-2707.

Delft3D-FLOW, 2013. *Delft3D-FLOW User Manual.* Deltares, 3.14 ed.

Dingemans, M. W., 1997. *Water Wave Propagation over Uneven Bottoms, Vol. 1 and 2.* Advanced Series on Ocean Engineering, Vol. 13. World Scientific, London.

Dingemans, M. W., A. C. Radder and H. J. de Vriend, 1987. “Computation of the driving forces of wave-induced currents.” *Coastal Engineering* 11: 539-563.

Eldeberky, Y. and J. Battjes, 1995. “Parameterization of triad interactions in wave energy models, Gdansk, Poland.” In *Proceedings Coastal Dynamics Conference ’95*, pages 140-148.

Eldeberky, Y. and J. A. Battjes, 1996. “Spectral modelling of wave breaking: Application to Boussinesq equations.” *Journal of Geophysical Research* 101 (C1): 1253-1264.

Elgar, S., R. Guza, B. Raubenheimer, T. Herbers and E. Gallagher, 1997. “Spectral evolution of shoaling and breaking waves on a barred beach.” *Journal of Geophysical Research* 102 (C7): 15797-15805.

Galvin, C., 1972. “Waves on beaches and resulting sediment transport.” In *Wave breaking in shallow water*, pages 413-455. Academic Press Inc.

Goda, Y., H. Takeda and Y. Moriya, 1967. *Laboratory investigation of wave transmission over breakwaters*. Tech. Rep. 13, Rep. port and Harbour Res. Institution. (from Seelig, 1979).

Günther, H., S. Hasselmann and P. A. E. M. Janssen, 1992. *The WAM model Cycle 4 (revised version)*. Tech. Rep. 4, Deutsch. Klim. Rechenzentrum, Hamburg, Germany.

Hasselmann, K., 1974. “On the spectral dissipation of ocean waves due to whitecapping.” *Boundary-Layer Meteorology* 6 (1-2): 107-127.

Hasselmann, K., T. P. Barnett, E. Bouws, H. Carlson, D. E. Cartwright, K. Enke, J. Ewing, H. Gienapp, D. E. Hasselmann, P. Kruseman, A. Meerburg, P. Müller, D. J. Olbers, K. Richter, W. Sell and H. Walden, 1973. “Measurements of wind wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP).” *Deutsche Hydrographische Zeitschrift* 8 (12).

Hasselmann, K. and J. Collins, 1968. “Spectral dissipation of finite-depth gravity waves due to turbulent bottom friction.” *Journal of Marine Research* 26: 1-12.

Hasselmann, S. and K. Hasselmann, 1981. “A symmetrical method of computing the nonlinear transfer in a gravity-wave spectrum.” *Hamburger Geophysikalische Einzelschriften* 52 (8): 138p. Serie A.

Hasselmann, S., K. Hasselmann, J. Allender and T. Barnett, 1985. “Computations and parameterizations of the nonlinear energy transfer in a gravity wave spectrum. Part II: Parameterizations of the nonlinear transfer for application in wave models.” *Journal of Physical Oceanography* 15 (11): 1378-1391.

Holthuijsen, L., N. Booij and T. Herbers, 1989. “A prediction model for stationary, short-crested waves in shallow water with ambient currents.” *Coastal Engineering* 13: 23-54.

Holthuijsen, L., N. Booij and R. Ris, 1993. “A spectral wave model for the coastal zone.” In *Proceedings of 2nd International Symposium on Ocean Wave Measurement and Analysis, New Orleans*, pages 630-641.

Ilic, S., 1994. *The role of offshore breakwaters in the coastal defence: comparison of two measurement systems*. Tech. rep., University of Plymouth School of Civil and Structural Engineering.

Janssen, P., 1991a. “Quasi-linear theory of wind-wave generation applied to wave forecasting.” *Journal of Physical Oceanography* 21: 1631-1642.

Janssen, P. A. E. M., 1991b. *Consequences of the effect of surface gravity waves on the mean air flow*. Tech. rep., International Union of Theor. and Appl. Mech. (IUTAM), Sydney, Australia. 193-198.

Jonsson, I., 1966. “Wave boundary layers and friction factors.” In *Proceedings 10th International Conference Coastal Engineering, ASCE*, pages 127-148.

Jonsson, I. and N. Carlsen, 1976. “Experimental and theoretical investigations in an oscillatory turbulent boundary layer.” *Journal of Hydraulic Research* 14: 45-60.

Jonsson, I. G., 1980. “A new approach to rough turbulent boundary layers.” *Ocean Engineering* 7: 109-152.

Kaminsky, G. and N. Kraus, 1993. “Evaluation of depth-limited wave breaking criteria.” In *Proceedings of 2nd International Symposium on Ocean Wave Measurement and Analysis*, pages 180-193. New Orleans.

Kirby, J. T. and T.-M. Chen, 1989. “Surface waves on vertically sheared flows: approximate dispersion relations.” *Journal of Geophysical Research* 94: 1013-1027.

Komen, G., L. Cavaleri, M. Donelan, K. Hasselmann, S. Hasselmann and P. Janssen, 1994. *Dynamics and Modelling of Ocean Waves.* Camebridge University Press.

Komen, G., S. Hasselmann and K. Hasselmann, 1984. “On the existence of a fully developed wind-sea spectrum.” *Journal of Physical Oceanography* 14: 1271-1285.

Kuik, A., G. van Vledder and L. Holthuijsen, 1988. “A method for the routine analysis of pitch-and-roll buoy wave data.” *Journal of Physical Oceanography* 18: 1020-1034.

Luo, W. and J. Monbaliu, 1994. “Effects of the bottom friction formulation on the energy balance for gravity waves in shallow water.” *Journal of Geophysical Research* 99 (C9): 18501-18511.

Madsen, O., Y.-K. Poon and H. Graber, 1988. “Spectral wave attenuation by bottom friction: Theory.” In *Proceedings 21th International Conference Coastal Engineering, ASCE*, pages 492-504.

Madsen, P. and O. Sørensen, 1993. “Bound waves and triad interactions in shallow water.” *Ocean Engineering* 20 (4): 359-388.

Mase, H. and J. Kirby, 1992. “Hybrid frequency-domain KdV equation for random wave transformation.” In *Proceedings 23th International Conference Coastal Engineering, ASCE*, pages 474-487.

Mastenbroek, C., G. Burger and P. Janssen, 1993. “The dynamical coupling of a wave model in a storm surge model through the atmospheric boundary layer.” *Journal of Physical Oceanography* 23: 1856-1866.

Mei, C., 1983. *The applied dynamics of ocean surface waves*. Wiley, New York.

Miles, J., 1957. “On the generation of surface waves by shear flows.” *Journal of Fluid Mechanics* 3: 185-204.

Nelson, R., 1987. “Design wave heights on very mild slopes: An experimental study.” *Transactions of the Institution of Engineers, Australia, Civil Engineering* 29: 157-161.

Nelson, R. C., 1994. “Depth limited wave heights in very flat regions.” *Coastal Engineering* 23: 43-59.

Phillips, N. A., 1957. “A co-ordinate system having some special advantages for numerical forecasting.” *Journal of Meteorology* 14: 184-185.

Phillips, O., 1985. “Spectral and statistical properties of the equilibrium range in wind-generated gravity waves.” *Journal of Fluid Mechanics* 156: 505-531.

Putnam, J. and J. Johnson, 1949. “The dissipation of wave energy by bottom friction.” *Transactions - American Geophysical Union* 30: 67-74.

Ris, R., N. Booij and L. Holthuijsen, 1999. “A third-generation wave model for coastal regions, Part II: Verification.” *Journal of Geophysical Research* 104 (C4): 7649-7666.

Seelig, W., 1979. “Effects of breakwaters on waves: laboratory tests of wave transmission by overtopping.” In *Proceedings Conference Coastal Structures*, vol. 79:2, pages 941-961.

Shemdin, P., K. Hasselmann, S. Hsiao and K. Herterich, 1978. “Non linear and linear bottom interaction effects in shallow water.” In *Turbulent Fluxes through the Sea Surface Wave Dynamics and Prediction, NATO Conference Series*, no. 1 in V, pages 347-372.

Snyder, R., F. Dobson, J. Elliot and R. Long, 1981. “Array measurement of atmospheric pressure fluctuations above surface gravity waves.” *Journal of Fluid Mechanics* 102: 1-59.

SWAN, 2000. *SWAN Cycle III version 40.11 User Manual (not the short version)*. Delft University of Technology, Delft, The Netherlands, 0.00 ed.

Thornton, E. and R. Guza, 1983. “Transformation of wave height distribution.” *Journal of Geophysical Research* 88 (C10): 5925-5938.

Tolman, H., 1990. *Wind wave propagation in tidal seas*. Ph.D. thesis, Delft University of Technology, Department of Civil Engineering, The Netherlands.

Tolman, H. L., 1992a. “Effects of numerics on the physics in a third-generation windwave model.” *Journal of Physical Oceanography* 22: 1095-1111.

Tolman, H. L., 1992b. “An evaluation of expressions for the wave energy dissipation due to bottom friction in the presence of currents.” *Coastal Engineering* 16: 165-179.

Vincent, C., J. Smith and J. Davis, 1994. “Parameterization of wave breaking in models.” In M. Isaacson and M. Quick, eds., *Proceedings of International Symp.: Waves - Physical and Numerical Modelling*, vol. II, pages 753-762. University of British Columbia, Vancouver, Canada.

WAMDI group, 1988. “The WAM model a third generation ocean wave prediction model.” *Journal of Physical Oceanography* 18: 1775-1810.

Weber, S., 1989. *Surface gravity waves and turbulent bottom friction*. Ph.D. thesis, University of Utrecht, The Netherlands.

Weber, S. L., 1991a. “Bottom friction for wind sea and swell in extreme depth-limited situations.” *Journal of Physical Oceanography* 21: 149-172.

Weber, S. L., 1991b. “Eddy-viscosity and drag-law models for random ocean wave dissipation.” *Journal of Fluid Mechanics* 232: 73-98.

Westhuysen, A. J. Van der, 2007. *Advances in the spectral modelling of wind waves in the nearshore*. Ph.D. thesis, Delft University of Technology. Fac. of Civil Engineering.

Westhuysen, A. Van der, M. Zijlema and J. Battjes, 2007. *Nonlinear saturation-based whitecapping dissipation in SWAN for deep and shallow water*. Ph.D. thesis, Delft University of Technology.

Whitham, G., 1974. *Linear and nonlinear waves*. Wiley, New York.

WL | Delft Hydraulics, 1999. *Modification first-guess SWAN and bench mark tests for SWAN*. Tech. Rep. H3515, WL | Delft Hydraulics, Delft, The Netherlands, Delft.

WL | Delft Hydraulics, 2000. *Physical formulations SWAN and data for validation*. Tech. Rep. H3528, WL | Delft Hydraulics, Delft, The Netherlands, Delft.

Wu, J., 1982. "Wind-stress coefficients over sea surface from breeze to hurricane." *Journal of Geophysical Research* 87 (C12): 9704-9706.

Young, I. R. and G. van Vledder, 1993. "A review of the central role of nonlinear interactions in wind-wave." *Philosophical transaction of the Royal Society London A* 342: 505-524.

A Files of Delft3D-WAVE

A.1 MDW-file

A.1.1 General description

File contents	The Master Definition WAVE file (MDW-file) is the input file for the wave simulation program.
Filetype	ASCII
File format	Free formatted
Filename	<*name*.mdw>
Generated	WAVE-GUI or manually offline

The Master Definition WAVE file (MDW-file) is the input file for the wave simulation program. It contains all the necessary data required for defining a model and running the simulation program. In the MDW-file you can define attribute files in which relevant data (for some parameters) are stored. This is especially useful when parameters contain a large number of data (e.g. time-dependent or space varying data). The user-definable attribute files are listed and described in Appendix A.

The MDW-file has the following general characteristics:

- ◇ Each line contains a maximum of 300 characters.
- ◇ Each set of input parameter(s) is preceded by a chapter name enclosed in square brackets (e.g. [WaveFileInformation]).
- ◇ Each input parameter is preceded by a `Keyword`.
- ◇ A `Keyword` is a combination of numerical and alpha-numerical characters, but starting with an alpha-numeric character, followed by an equal sign "=".

The MDW-file is an intermediate file between the WAVE-GUI and the WAVE simulation program. As it is an ASCII-file, it can be transported to an arbitrary hardware platform. Consequently, the WAVE simulation program and the WAVE-GUI do not necessarily have to reside on the same hardware platform.

Generally, you need not to bother about the internal layout or content of the MDW-file. It is, however, sometimes useful to be able to inspect the file and/or make small changes manually. Therefore the MDW-file is an ordinary ASCII-file which you can inspect and change with your favourite ASCII-editor.

The MDW-file is self contained, i.e. it contains all the necessary information about the model concerned. It can therefore be used as model archive by storing/printing the file.

Here we list all the possible chapters and keywords of the MDW-file:

Record description:

Keyword	Format	Description
WaveFileInformation		
`FileVersion`	string	should be 02.00
General		
`ProjectName`	C*16	project name
		continued on next page

* May be specified multiple times
$^+$ Not supported by WAVE-GUI
R = Real; I = Integer; L = Logical; C = Character

continued from previous page

Keyword	Format	Description
ProjectNr	C*4	project number
Description*	C*72	description line
OnlyInputVerify	1 L	switch for input validation or simulation run: false = simulation run, or true = input validation only
SimMode	key-value	simulation mode: stationary, quasi-stationary, non-stationary
TimeStep	1 R	time step in case of non-stationary simulation
TScale+	1 R, optional	unit of time, default is 60.0)
FlowFile+	string	name of mdf-file containing FLOW input. If FlowFile is empty, FLOW is not running online. If FlowFile is non-empty, FLOW is running online.
FlowMudFile+	string	name of mdf-file containing FLOW input for the mud phase of a two phased FLOW model. If FlowMudFile is empty, MUD is not running online. If FlowMudFile is non-empty, MUD is running online.
FlowBedLevel	1 I	default usage of bed level from hydrodynamic computation by all domains: 0 = “don't use”, 1 = “use but don't extend”, 2 = “use and extend” if necessary. May be overruled by same keyword in group "domain". Not relevant when FlowFile is empty; default: 0
FlowWaterLevel	1 I	See description of FlowBedLevel above.
FlowVelocity	1 I	See description of FlowBedLevel above.
FlowVelocityType	key-value	method of velocity computation (depth-averaged, surface-layer, wave-dependent; default: depth-averaged)
FlowWind	1 I	See description of FlowBedLevel above.
DirConvention	key-value	direction specification convention: nautical, cartesian
ReferenceDate	C*10	reference date (string format: YYYY-MM-DD)
ObstacleFile	string	name of file containing obstacles
TSeriesFile	string	name of file containing time-dependent quantities
TimePntBlock	1 I, optional	number of table in TSeriesFile containing time points; only if TSeriesFile has been specified
MeteoFile*+	characters	Name of file containing meteo input
DirSpace	1 R, optional	default directional space: circle, sector
NDir	1 R, optional	default number of directional bins
StartDir	1 R, optional	default start direction in case of sector directional space
EndDir	1 R, optional	default end direction in case of sector directional space
NFreq	1 R, optional	default number of frequencies
FreqMin	1 R, optional	default minimum frequency
FreqMax	1 R, optional	default maximum frequency
WaterLevel	1 R	default water level
XVeloc	1 R	default velocity in x-direction
YVeloc	1 R	default velocity in y-direction
WindSpeed	1 R	default wind speed
WindDir	1 R	default wind direction
TimePoint* TimePoint should be specified if TimePntBlock is not included and not Online with FLOW.		
Time	1 R	time in minutes since refdate 0:00 hours
WaterLevel	1 R	water level at specified time point
XVeloc	1 R	velocity in x direction at specified time point
YVeloc	1 R	velocity in y direction at specified time point
WindSpeed	1 R	wind speed at specified time point
WindDir	1 R	wind direction at specified time point
Constants		
WaterLevelCorrection	1 R	Overall water level correction
Gravity	1 R	gravitational acceleration (default: 9.81 m/s^2)
WaterDensity	1 R	density of water (default: 1025 kg/m^3)
NorthDir	1 R	direction of north relative to x axis (default: 90°)
MinimumDepth	1 R	minimum water depth below which points are excluded from the computation (default: 0.05 m)
Processes		

continued on next page

* May be specified multiple times
+ Not supported by WAVE-GUI
R = Real; I = Integer; L = Logical; C = Character

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Keyword	Format	Description
GenModePhys	1 I	generation mode of physics: 1 for first-generation, 2 for second-generation, 3 for third-generation
WaveSetup	1 L	include wave setup (default: false)
Breaking	1 L	include wave breaking (default: true)
BreakAlpha	1 R	alpha coefficient for wave breaking (default: 1.0)
BreakGamma	1 R	gamma coefficient for wave breaking (default: 0.73)
Triads	1 L	include triads (default: false)
TriadsAlpha	1 R	alpha coefficient for triads (default: 0.1)
TriadsBeta	1 R	beta coefficient for triads (default: 2.2)
BedFriction	string	bed friction type (none, jonswap, collins, madsen et al., default: jonswap)
BedFricCoef	1 R	bed friction coefficient (default: 0.067 for jonswap, 0.015 for collins, 0.05 for madsen et al.)
Diffraction	1 L	include diffraction (default: true)
DiffracCoef	1 R	diffraction coefficient (default: 0.2)
DiffracSteps	1 I	number of diffraction smoothing steps (default: 5)
DiffracProp	1 L	include adaption of propagation velocities due to diffraction (default: true)
WindGrowth	1 L	include wind growth (default: true)
WhiteCapping	key-value	white capping: (Off, Komen, Westhuysen, default: Komen)
Quadruplets	1 L	include quadruplets (default: false)
Refraction	1 L	include refraction (default: true)
FreqShift	1 L	include frequency shifting in frequency space (default: true)
WaveForces	key-value	method of wave force computation (dissipation 3d, dissipation, radiation stresses <2013; default: dissipation 3d)
Numerics		
DirSpaceCDD	1 R	discretisation in directional space: 0 for central, 1 for upwind (default: 0.5)
FreqSpaceCSS	1 R	discretisation in frequency space: 0 for central, 1 for upwind (default: 0.5)
RChHsTm01	1 R	relative change of wave height or mean wave period with respect to local value (default: 0.02)
RChMeanHs	1 R	relative change of wave height with respect to model-wide average wave height (default: 0.02)
RChMeanTm01	1 R	relative change of mean wave period with respect to model-wide average mean wave period (default: 0.02)
PercWet	1 R	percentage of points included in simulation at which convergence criteria must be satisfied (default: 98%)
MaxIter	1 I	maximum number of iterations for convergence (default: 15)
Output		
TestOutputLevel	1 I	test output level (default: 0)
TraceCalls	1 L	trace subroutine calls (default: false)
UseHotFile	1 L	write and read hotstart files (default: false)
MapWriteInterval	1 R	interval for writing data to map file(s) in minutes
WriteCOM	1 L	write results to communication file(s) (default: false)
COMWriteInterval	1 R	interval for writing data to communication file(s) in minutes
AppendCOM	1 L	upon writing to communication file(s) overwrite the previous data (false) or append to the data series (true) (default: false)
MassFluxToCOM+	1 L, optional	write mass fluxes due to wave to communication file(s) (default: true)
LocationFile	string, optional	file name of output locations
CurveFile	string, optional	file name of output curves
WriteTable	1 L	write tables for output locations (default: false)
WriteSpec1D	1 L	write 1D spectra for output locations (default: false)
WriteSpec2D	1 L	write 2D spectra for output locations (default: false)
Domain*		
Grid	string	file name of computational grid
BedLevelGrid	string	file name of bed level grid (default: equal to computational grid)
BedLevel	string	file name of bed level data
DirSpace	1 R	directional space: circle, sector

continued on next page

* May be specified multiple times
+ Not supported by WAVE-GUI
R = Real; I = Integer; L = Logical; C = Character

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Keyword	Format	Description
NDir	1 R	number of directional bins
StartDir	1 R	start direction in case of sector directional space
EndDir	1 R	end direction in case of sector directional space
NFreq	1 R	number of frequencies
FreqMin	1 R	minimum frequency
FreqMax	1 R	maximum frequency
NestedInDomain	1 R	number of domain in which current domain is nested (required for domains 2 and following)
FlowBedLevel		See description of FlowBedLevel in group [General]
FlowWaterLevel		See description of FlowBedLevel in group [General]
FlowVelocity		See description of FlowBedLevel in group [General]
FlowVelocityType		See description of FlowBedLevel in group [General]
FlowWind		See description of FlowBedLevel in group [General]
MeteoFile*		Name of file containing meteo input
Output	1 L	write map file for current domain (default: true)
Boundary*		
Name	string	boundary name
Definition	key-value	definition type (orientation, grid-coordinates, xy-coordinates)
Orientation	key-value	boundary orientation in case of boundary definition by means of orientation (north, northwest, west, southwest, south, southeast, east, northeast)
DistanceDir	key-value	direction of distance measurements for boundary segments in case of boundary definition by means of orientation (clockwise, counter-clockwise; default: counter-clockwise)
StartCoordM	1 I	start m-coordinate of boundary in case of boundary definition by means of grid-coordinates
EndCoordM	1 I	end m-coordinate of boundary in case of boundary definition by means of grid-coordinates
StartCoordN	1 I	start n-coordinate of boundary in case of boundary definition by means of grid-coordinates
EndCoordN	1 I	end n-coordinate of boundary in case of boundary definition by means of grid-coordinates
StartCoordX	1 R	start x-coordinate of boundary in case of boundary definition by means of xy-coordinates
EndCoordX	1 R	end x-coordinate of boundary in case of boundary definition by means of xy-coordinates
StartCoordY	1 R	start y-coordinate of boundary in case of boundary definition by means of xy-coordinates
EndCoordY	1 R	end y-coordinate of boundary in case of boundary definition by means of xy-coordinates
SpectrumSpec	key-value	spectrum specification type (from file, parametric)
SpShapeType	key-value	spectrum shape type in case of parametric spectrum specification (jonswap, pierson-moskowitz, gauss)
PeriodType	key-value	wave period type in case of parametric spectrum specification (peak, mean)
DirSpreadType	key-value	directional spreading type in case of parametric spectrum specification (power, degrees)
PeakEnhancFac	1 R	peak enhancement factor in case of jonswap spectrum
GaussSpread	1 R	width of spectral distribution in case of gaussian spectrum
CondSpecAtDist*	1 R	distance along boundary at which boundary condition is specified, uniform boundary condition if not specified
WaveHeight*	1 R	wave height at specified distance or uniform value in case of parametric spectrum specification
Period*	1 R	wave period at specified distance or uniform valuein case of parametric spectrum specification
Direction*	1 R	wave direction at specified distance or uniform value in case of parametric spectrum specification
DirSpreading*	1 R	directional spreading at specified distance or uniform value in case of parametric spectrum specification
Spectrum*	string	file name containing spectrum (string) in case of spectrum specification from file

* May be specified multiple times
+ Not supported by WAVE-GUI
R = Real; I = Integer; L = Logical; C = Character

A.1.2 Offline calculation

When running WAVE offline using FLOW output, the following items are not supported by the WAVE-GUI and must be checked in the mdw-file with a text editor:

◇ The keyword `FlowFile` must be removed from the group `[General]`.
◇ A time point must be specified for each time for which a calculation must be performed

Example:

```
[Timepoint]
Time = 1440
[Timepoint]
Time = 1680
```

The specified time points must correspond with times written on the com-file.

A.2 Attribute files of Delft3D-WAVE

A.2.1 Introduction

In the following sections we describe the attribute files used in the input MDW-file of Delft3D-WAVE. Most of these files contain the quantities that describe one specific item, such as the bathymetry or the grid.

Most of the attribute files can be generated by the WAVE-GUI after defining an input scenario. Some files can only be generated by utility programs such as the curvilinear grid generated by RGFGRID . Still, we describe both types of files as it might be useful to know how the input data is structured to be able to generate (large) files.

For each file we give the following information (if relevant):

File content.
File type (free formatted, fix formatted or unformatted).
Filename and extension.
Generated by (i.e. how to generate the file).
Restrictions on the file content.
Example(s).

Remarks:
◇ The access mode of all attribute files is sequential.
◇ In the examples the file contents is printed in font Courier New 10 and comment (not included in the file) in font Times New Roman 9, unless stated explicitly differently.

A.2.2 Orthogonal curvilinear grid

File contents	The co-ordinates of the orthogonal curvilinear grid at the depth points.
Filetype	ASCII
File format	Free formatted
Filename	<*name*.grd>
Generated	RGFGRID

Record description:

Record	**Record description**
	Preceding description records, starting with an asterisk ($*$), will be ignored.
1	Record with `Co-ordinate System = Cartesian` or value `Spherical`
2	The number of grid *points* in m- and n-direction (2 integers).
3	Three real values (not used).
4 to K+3	A label and record number, the x-component of the world co-ordinates of all points in m-direction, starting with row 1 to row $nmax$, with as many continuation records as required by $mmax$ and the number of co-ordinates per record. The label and record number are suppressed on the continuation lines. This set of records is repeated for each row until $n = nmax$.
K+4 to 2K+3	A similar set of records for the y-component of the world co-ordinates.

K is the number of records to specify for all grid points a set of x- or y-co-ordinates.

Restrictions:

- ◇ The grid must be orthogonal.
- ◇ Input items in a record are separated by one or more blanks.

Example:

```
*
* Deltares, Delft3D-RGFGRID  Version 4.16.01.4531, Sep 30 2008, 23:32:27
* File creation date: 2008-10-01, 23:19:22
*
Coordinate System = Cartesian
       9       7
 0 0 0
 Eta=    1   0.00000000000000000E+00   1.00000000000000000E+02   2.000000...
             5.00000000000000000E+02   6.00000000000000000E+02   7.000000...
 Eta=    2   0.00000000000000000E+00   1.00000000000000000E+02   2.000000...
             5.00000000000000000E+02   6.00000000000000000E+02   7.000000...
 Eta=    3   0.00000000000000000E+00   1.00000000000000000E+02   2.000000...
             5.00000000000000000E+02   6.00000000000000000E+02   7.000000...
 Eta=    4   0.00000000000000000E+00   1.00000000000000000E+02   2.000000...
             5.00000000000000000E+02   6.00000000000000000E+02   7.000000...
 Eta=    5   0.00000000000000000E+00   1.00000000000000000E+02   2.000000...
             5.00000000000000000E+02   6.00000000000000000E+02   7.000000...
```

```
Eta=    6   0.0000000000000000E+00   1.0000000000000000E+02   2.000000...
            5.0000000000000000E+02   6.0000000000000000E+02   7.000000...
Eta=    7   0.0000000000000000E+00   1.0000000000000000E+02   2.000000...
            5.0000000000000000E+02   6.0000000000000000E+02   7.000000...
Eta=    1   1.0000000000000000E+02   1.0000000000000000E+02   1.000000...
            1.0000000000000000E+02   1.0000000000000000E+02   1.000000...
Eta=    2   2.0000000000000000E+02   2.0000000000000000E+02   2.000000...
            2.0000000000000000E+02   2.0000000000000000E+02   2.000000...
Eta=    3   3.0000000000000000E+02   3.0000000000000000E+02   3.000000...
            3.0000000000000000E+02   3.0000000000000000E+02   3.000000...
Eta=    4   4.0000000000000000E+02   4.0000000000000000E+02   4.000000...
            4.0000000000000000E+02   4.0000000000000000E+02   4.000000...
Eta=    5   5.0000000000000000E+02   5.0000000000000000E+02   5.000000...
            5.0000000000000000E+02   5.0000000000000000E+02   5.000000...
Eta=    6   6.0000000000000000E+02   6.0000000000000000E+02   6.000000...
            6.0000000000000000E+02   6.0000000000000000E+02   6.000000...
Eta=    7   7.0000000000000000E+02   7.0000000000000000E+02   7.000000...
            7.0000000000000000E+02   7.0000000000000000E+02   7.000000...
```

A.2.3 Time-series for wave boundary conditions

File contents	Time-series for wave boundary conditions.
Filetype	ASCII
File format	Fix format for header information; free format for time-series data.
Filename	<*name*.bcw>
Generated	FLOW-GUI, program Delft3D-NESTHD or manually offline

Record description:

Keyword	**Description**
location	location name (quoted string)
time-function	time function type (quoted string: "non-equidistant")
reference-time	reference time (yyyymmdd integer or quoted string: "from model")
time-unit	time unit (quoted string: "decades", "years", "days", "hours", "minutes", "seconds", "ddhhmmss", "absolute")
interpolation	interpolation type (quoted string: "linear" or "block")
parameter & unit	parameter name & unit

A.2.4 Obstacle file

File contents	Name of the polyline with obstacles.
Filetype	ASCII
File format	Fix formatted for text variables, free formatted for real and integer values.
Filename	<*name*.obs>
Generated	QUICKIN as land boundary, or manually offline

Record description:

A header block containing information about versions, and the name of the polyline file.

For each observation area the details.

Keyword	**Format**	**Description**
ObstacleFileInformation		
FileVersion PolylineFile	string string	version number of <∗.obs> file name of polyline file with polylines defining obstacles
Obstacle*		
Name Type TransmCoef Height Alpha Beta Reflections ReflecCoef	string key-value 1 real 1 real 1 real 1 real key-value 1 real	name of obstacle in polyline file type of obstacle (sheet, dam) transmission coefficient in case of sheet obstacle dam height in case of dam obstacle alpha in case of dam obstacle beta in case of dam obstacle type of reflections (no, specular, diffuse) reflection coefficient if reflections are activated

* May be specified multiple times

Restriction:

◇ The maximum record length in the file is 132.

Example:

The number of obstacles is 2. They are called ‘Breakwater West’, ’Breakwater East 2’ and ’Breakwater East 1’

```
[ObstacleFileInformation]
   FileVersion  = 02.00
   PolylineFile = breakwater.pol
[Obstacle]
   Name         = Breakwater West
   Type         = dam
   Height       =  0.0000000e+000
   Alpha        =  2.5999999e+000
   Beta         =  1.5000001e-001
   Reflections  = no
[Obstacle]
   Name         = Breakwater East 1
   Type         = dam
   Height       =  0.0000000e+000
   Alpha        =  2.5999999e+000
   Beta         =  1.5000001e-001
   Reflections  = no
[Obstacle]
   Name         = Breakwater East 2
   Type         = dam
   Height       =  0.0000000e+000
   Alpha        =  2.5999999e+000
   Beta         =  1.5000001e-001
   Reflections  = no
```

Example polyline file:

```
Breakwater West
```

```
   7      2
  1.9174138E+05   6.0961231E+05
  1.9190197E+05   6.1048831E+05
  1.9242755E+05   6.1140806E+05
  1.9321591E+05   6.1228400E+05
  1.9422327E+05   6.1301400E+05
  1.9536202E+05   6.1358338E+05
  1.9655916E+05   6.1394831E+05
Breakwater East 1
     2      2
  2.0846027E+05   6.0775812E+05
  2.0838540E+05   6.0968968E+05
Breakwater East 2
     2      2
  2.1022712E+05   6.0998915E+05
  2.1031696E+05   6.0765331E+05
```

A.2.5 Segment file

File contents	The coordinates of one or more polylines. Each polyline (piecewise linear) is written in a single block of data.
Filetype	ASCII
File format	Free formatted
Filename	<*name*.pol>
Generated	RGFGRID, QUICKIN, Delta Shell, etc

Record description:

Record	Record description
	Preceding description records, starting with an asterisk ($*$), and will be ignored.
1	A non blank character string, starting in column one.
2	Two integers N_r, N_c representing the numbers of rows and number of columns for this block of data.
	Two reals representing the x, y or λ, ϕ-coordinate, followed by remaining data values at that location (if $N_c > 2$).

Example:

```
*
* Polyline L007
*
L007
6  2
            132400.0    549045.0
            132345.0    549030.0
            132165.0    549285.0
            131940.0    549550.0
            131820.0    549670.0
            131585.0    549520.0
*
* Polyline L008
*
L008
4  2
```

```
           131595.0    549685.0
           131750.0    549865.0
           131595.0    550025.0
           131415.0    550175.0
*
* Polyline L009
*
L009
6  2
           131595.0    549655.0
           148975.0    564595.0
           150000.0    564935.0
           152105.0    565500.0
           153150.0    566375.0
           154565.0    567735.0
```

A.2.6 Depth file

File contents	The bathymetry in the model area, represented by depth values (in metres) for all grid points.
Filetype	ASCII
File format	Free formatted or unformatted
Filename	<*name*.dep>
Generated	FLOW-GUI (only for uniform depth values). Offline with QUICKIN and data from digitised charts or GIS-database.

Record description:

Filetype	**Record description**
Free formatted	Depth values per row, starting at N = 1 to N = Nmax, separated by one or more blanks. The number of continuation lines is determined by the number of grid points per row (Mmax) and the maximum record size of 132.
Unformatted	Mmax depth values per row for N = 1 to N = Nmax.

Restrictions:

- ◇ The file contains one M and N line more than the grid dimension.
- ◇ The maximum record length in the free formatted file is 132.
- ◇ Depth values from the file will not be checked against their domain.
- ◇ The input items are separated by one or more blanks (free formatted file only).
- ◇ The default missing value is: -999.0

Example:

File containing $16 * 8$ data values for a model area with $15 * 7$ grid points (free formatted file).

```
   1.0     2.0     3.0     4.0    -5.0    -5.0    -5.0     8.0     9.0    10.0    11.0
  12.0    13.0    14.0    -5.0  -999.0
   3.0     4.0     5.0     6.0     7.0    -6.0    -6.0    10.0    11.0    12.0    13.0
  14.0    15.0    16.0    17.0  -999.0
   5.0     6.0     7.0     8.0     9.0    10.0    -7.0    12.0    13.0    14.0    15.0
  16.0    17.0    18.0    19.0  -999.0
   7.0     8.0     9.0    10.0    11.0    12.0    13.0    14.0    15.0    16.0    17.0
  18.0    19.0    -7.0    19.0  -999.0
   9.0    10.0    11.0    12.0    13.0    14.0    15.0    16.0    17.0    18.0    19.0
```

```
  20.0   19.0   18.0   17.0 -999.0
  -7.0   12.0   13.0   14.0   15.0   16.0   17.0   18.0   19.0   20.0   19.0
  18.0   17.0   16.0   15.0 -999.0
  -8.0   -8.0   15.0   16.0   17.0   18.0   19.0   20.0   19.0   18.0   17.0
  16.0   15.0   14.0   13.0 -999.0
-999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0 -999.0
-999.0 -999.0 -999.0 -999.0 -999.0
```

The resulting 2D-matrix for the depth values is then (for simplicity all values are here transformed into integers, in reality this does not occur):

N-direction

↑ 8	-9	-9	-9	18	19	20	19	18	17	16	15	14	13	12	-9	-9
7	-8	-8	15	16	17	18	19	20	19	18	17	16	15	14	13	-8
6	-7	12	13	14	15	16	17	18	19	20	19	18	17	16	15	14
5	9	10	11	12	13	14	15	16	17	18	19	20	19	18	17	16
4	7	8	9	10	11	12	13	14	15	16	17	18	19	-7	19	18
3	5	6	7	8	9	10	-7	12	13	14	15	16	17	18	19	20
2	3	4	5	6	7	-6	-6	10	11	12	13	14	15	16	17	-6
1	1	2	3	4	-5	-5	-5	8	9	10	11	12	13	14	-5	-5
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

→ M-direction

A.2.7 Space-varying bottom friction (not yet implemented for Delft3D-WAVE)

File contents: Bottom friction coefficients values (induced by waves) for all grid points, starting from row number (y-direction) 1 for all points in the x-direction (1 to MMAX), until the last row number (NMAX). Note that for the bottom friction values also a constant value over the entire computational area can be applied (see **??**).

File type: free formatted / unformatted.

Restrictions: maximum record length in the (free) formatted file is 132. Bottom friction coefficients values from the file will not be checked against the ranges specified in **??** (domain of input parameters).

Example: (formatted file)

```
0.01   0.01   0.02   0.03
0.01   0.01   0.02   0.03
0.012  0.012  0.011  0.03
0.013  0.013  0.013  0.03
0.014  0.014  0.013  0.03
```

The resulting 2D-matrix for the bottom friction coefficients values:

N-direction

↑ 8																
7																
6	0.014	0.014	0.013	0.03												
5	0.013	0.013	0.013	0.03												
4	0.012	0.012	0.011	0.03												
3	0.011	0.011	0.01	0.03												
2	0.01	0.01	0.02	0.03												
1	0.01	0.01	0.02	0.03												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

→ M-direction

A.2.8 Wave boundary conditions

In Delft3D-WAVE the users could choose different sets of wave boundary conditions and wind conditions. However not all the features could be specified by the GUI. The functionalities could be used by adding keywords in <mdw>-file.

In the following subsections, 4 options are described:

1 Time-varying and uniform wave conditions in <wavecon.*rid*>.
2 Time-varying and space-varying wave boundary conditions using <bcw>-files
3 Space-varying wave boundary conditions using for UNIBEST coupling (<md-vwac> file)
4 Space-varying wave boundary conditions: Spectral input and output files

A.2.8.1 Time-varying and uniform wave conditions in <wavecon.*rid*> file

In some cases where e.g. the morphology is event-driven or design conditions for a structure are needed, a set of different wave conditions are to be calculated. These wave conditions can be specified in an additional file, called <wavecon.*rid*> (rid=runid of the <mdw>-file). This file can only be used when constant parametric boundary conditions are prescribed in the wave model. If other boundary conditions are specified, these will be adjusted into constant parametric boundary conditions. To use this *Wavecon* option, just simply add the <wavecon.*rid*> file to the working directory and the system will use the file automatically.

A WAVE computation is always performed on a certain time point (based on the reference date). If a <wavecon.*rid*> file exists in the working directory, it will get its wave boundary conditions (including wind and water level) from that file. The boundary condition values in the default <*rid*.mdw> file will not be used then. When the time point of the wave computation lies between two prescribed time points in the <wavecon.*rid*> file, it will interpolate the wave, wind and water level conditions between these two time points.

Remarks:

◇ If the wind speed is prescribed as 0 m/s, wind will not be taken into account in the wave computation.
◇ If the time point of the wave computation lies before the first prescribed time field in the <wavecon.*rid*> file, it will use the conditions of this first field.
◇ If a mean period is chosen in the default <*rid*.mdw> file, this period will be modified into the peak period (the value of the period will remain the same).
◇ If a variable boundary condition is chosen in the default <*rid*.mdw> file, this condition will be modified into a constant condition along the whole boundary.
◇ The defined wave boundary conditions are overruled by the prescribed wave conditions in the <wavecon.∗> file.

File contents:	List of wave and wind conditions
File type:	free formatted/unformatted.
Restrictions:	maximum record length in the (free) formatted file is 132.
Example:	formatted file of a <wavecon.*rid*>

```
* Itdate   Hs     Tp     Dir(°)   ms   wl     windspeed   wind dir.(°)
BL01
3 8 * number of rows    number of columns
0         0.01   1.0    270      10   0      0.0         270
60        1.00   7.0    270      4    1.26   10.0        270
240       0.01   10.0   270      10   0.70   5.0         270
```

Description of parameters:

Itdate [min]	Time point after reference date in minutes; should be given in minutes after the reference date (ITDATE), specified in the <*rid*.mdw> file.
H_s [m]	Significant wave height in metres; this value will be prescribed on all specified wave boundaries.
T_p [s]	Peak period of the energy spectrum. This value will be prescribed on all specified wave boundaries.
Dir [°]	Mean wave direction according to the Nautical or Cartesian convention (in degrees). This value will be prescribed on all specified wave boundaries.
ms [-] or [°]	Width energy distribution. This is the directional standard deviation in power or in degrees. If the option *Degrees* is chosen in the sub-window *Spectral space*, it is in degree. If the option *Cosine power* is chosen in the same above sub-window, it is in the power m.
Water level [m]	The additional water level over the entire wave model. The water level is measured positively upward from the same datum from which the bottom levels are taken.
Wind speed [m/s]	Wind velocity at 10 m elevation.
Wind direction [°]	Wind direction at 10 m elevation according to the convention, specified in the sub-window **Constants**.

Remarks:

- ◇ The defined wave boundary conditions in the mdw file are overruled by the prescribed wave conditions in the <wavecon.∗> file.
- ◇ If wavecon or <md-vwac> file is used as wave boundary condition, the width energy distribution *ms* is set (overwritten) to be power.

A.2.8.2 Time-varying and space-varying wave boundary conditions using BCW files

In Delft3D-WAVE, time series of wave boundary conditions have been implemented which are not able to be set in GUI yet. The users can include the keywords *TSeriesFile* in Datagroup *General* in MDW-file. The format of BCW-file refer to the section A.2.3. The segments of boundary conditions could be set using the keywords `CondSpecAtDist` in Datagroup *Boundary* in MDW-file. If the wave computations are carried out at multiple time points, the time point could be specified in Datagroup *Timepoint* in MDW-file.

The following examples showed different scenarios of spatial-varying and time-varying wave boundnary conditions. It is a stand-alone wave model with 2 boundaries, i.e., Boundary West and Boundary South. The Boundary West is devided into 6 segments and the Boundary South is devided into 9 segments. For each segments, different parameters such as Wave Height, Period, Direction, Dirspreading could be defined at different time point in the BCW-file.

The 3 examples show the following 3 scenarios:

1 Multiple time points and spatial uniform wave boundary conditions.
2 One/multiple time points and space-varying wave boundary conditions
3 Multiple time points and space-varying wave boundary conditions, with time-varying but spatial uniform wind field

Example 1

If one would like to have a wave model with uniform wave boundary conditions along one boundary line for multiple time points, one should add them to Datagroup *General* as follows:

```
[WaveFileInformation]
   FileVersion          = 02.00
[General]
   ProjectName          = Carrara
   ProjectNr            = 001
   Description          =
   Description          = Carrara test run
   OnlyInputVerify      = false
   SimMode              = stationary
   DirConvention        = nautical
   ReferenceDate        = 2006-01-05
   TSeriesFile          = timeseries.bcw
   WindSpeed            =  2.0
   WindDir              =  2.0
...
```

In Datagroup *TimePoint* the following should be added:

```
...
[TimePoint]
   Time                 =  6.0000000e+001
   WaterLevel           =  0.0000000e+000
   XVeloc               =  0.0000000e+000
   YVeloc               =  0.0000000e+000
[TimePoint]
   Time                 =  1.2000000e+002
   WaterLevel           =  0.0000000e+000
   XVeloc               =  0.0000000e+000
   YVeloc               =  0.0000000e+000
[TimePoint]
   Time                 =  1.8000000e+002
   WaterLevel           =  0.0000000e+000
   XVeloc               =  0.0000000e+000
   YVeloc               =  0.0000000e+000
[TimePoint]
   Time                 =  2.4000000e+002
   WaterLevel           =  0.0000000e+000
   XVeloc               =  0.0000000e+000
   YVeloc               =  0.0000000e+000
...
```

In Datagroup *Boundary* the following should be added:

```
...
[Boundary]
   Name                 = Boundary West
   Definition           = xy-coordinates
   StartCoordX          =  5.0000000e+005
   EndCoordX            =  5.0000000e+005
   StartCoordY          =  4.9274090e+006
   EndCoordY            =  4.7885805e+006
   SpectrumSpec         = parametric
   SpShapeType          = jonswap
   PeriodType           = peak
   DirSpreadType        = power
```

```
   PeakEnhanceFac        =  3.3000000e+000
   GaussSpread           =  9.9999998e-003
[Boundary]
   Name                  = Boundary South
   Definition            = xy-coordinates
   StartCoordX           =  5.0000000e+005
   EndCoordX             =  6.2226400e+005
   StartCoordY           =  4.7608150e+006
   EndCoordY             =  4.7608150e+006
   SpectrumSpec          = parametric
   SpShapeType           = jonswap
   PeriodType            = peak
   DirSpreadType         = power
   PeakEnhanceFac        =  3.3000000e+000
   GaussSpread           =  9.9999998e-003
...
```

The <bcw>-file, which is defined in section A.2.3, for the uniform boundaries with multiple time points should be then:

```
...
location             'Boundary West        '
time-function        'non-equidistant'
reference-time       20060105
time-unit            'minutes'
interpolation        'linear'
parameter            'time                 '                unit '[min]'
parameter            'WaveHeight'                           unit '[m]'
parameter            'Period'                               unit '[s]'
parameter            'Direction'                            unit '[N^o]'
parameter            'DirSpreading'                         unit '[-]'
   0.00   5.5300 8.2400 -171.0700 2.0000
  60.00   3.5300 8.2400 -171.0700 2.0000
 120.00   1.5300 8.2400 -171.0700 2.0000
 180.00   3.5300 8.2400 -171.0700 2.0000
 240.00   1.5300 8.2400 -171.0700 2.0000
location             'Boundary South       '
time-function        'non-equidistant'
reference-time       20060105
time-unit            'minutes'
interpolation        'linear'
parameter            'time                 '                unit '[min]'
parameter            'WaveHeight'                           unit '[m]'
parameter            'Period'                               unit '[s]'
parameter            'Direction'                            unit '[N^o]'
parameter            'DirSpreading'                         unit '[-]'
   0.00   1.2700 8.4700 -147.8800 2.0000
  60.00   3.2700 8.4700 -147.8800 2.0000
 120.00   1.2700 8.4700 -147.8800 2.0000
 180.00   3.2700 8.4700 -147.8800 2.0000
 240.00   3.2700 8.4700 -147.8800 2.0000
```

Example 2

If one would like to have a wave model with space-varying wave boundary conditions, one should add them to Datagroup *General* as follows:

```
[WaveFileInformation]
   FileVersion           = 02.00
[General]
   ProjectName           = Carrara
   ProjectNr             = 001
   Description           =
```

```
   Description          = Carrara test run
   OnlyInputVerify      = false
   SimMode              = stationary
   DirConvention        = nautical
   ReferenceDate        = 2006-01-05
   TSeriesFile          = timeseries.bcw
   WindSpeed            =  2.0
   WindDir              =  2.0
...
```

In Datagroup *TimePoint* the following should be added:

```
...
[TimePoint]
   Time                 =  6.0000000e+001
   WaterLevel           =  0.0000000e+000
   XVeloc               =  0.0000000e+000
   YVeloc               =  0.0000000e+000
...
```

In Datagroup *Boundary* the following should be added:

```
...
[Boundary]
   Name                 = Boundary West
   Definition           = xy-coordinates
   StartCoordX          =  5.0000000e+005
   EndCoordX            =  5.0000000e+005
   StartCoordY          =  4.9274090e+006
   EndCoordY            =  4.7885805e+006
   SpectrumSpec         = parametric
   SpShapeType          = jonswap
   PeriodType           = peak
   DirSpreadType        = power
   PeakEnhanceFac       =  3.3000000e+000
   GaussSpread          =  9.9999998e-003
   CondSpecAtDist       =  2.7765670e+004
   CondSpecAtDist       =  5.5531340e+004
   CondSpecAtDist       =  6.3297008e+004
   CondSpecAtDist       =  8.3297008e+004
   CondSpecAtDist       =  1.1106268e+005
   CondSpecAtDist       =  1.3882834e+005
[Boundary]
   Name                 = Boundary South
   Definition           = xy-coordinates
   StartCoordX          =  5.0000000e+005
   EndCoordX            =  6.2226400e+005
   StartCoordY          =  4.7608150e+006
   EndCoordY            =  4.7608150e+006
   SpectrumSpec         = parametric
   SpShapeType          = jonswap
   PeriodType           = peak
   DirSpreadType        = power
   PeakEnhanceFac       =  3.3000000e+000
   GaussSpread          =  9.9999998e-003
   CondSpecAtDist       =  0.0000000e+000
   CondSpecAtDist       =  1.0000000e+003
   CondSpecAtDist       =  1.0000000e+004
   CondSpecAtDist       =  2.0377330e+004
   CondSpecAtDist       =  4.0754660e+004
   CondSpecAtDist       =  6.1131988e+004
   CondSpecAtDist       =  8.1509320e+004
```

```
   CondSpecAtDist       =  1.0188665e+005
   CondSpecAtDist       =  1.2226398e+005
...
```

The <bcw>-file, which is defined in section A.2.3, should be like:

```
...
location             'Boundary West      '
time-function        'non-equidistant'
reference-time       20060105
time-unit            'minutes'
interpolation        'linear'
parameter            'time               '                       unit '[min]'
parameter            'WaveHeight'                                unit '[m]'
parameter            'WaveHeight'                                unit '[m]'
parameter            'WaveHeight'                                unit '[m]'
parameter            'WaveHeight'                                unit '[m]'
parameter            'WaveHeight'                                unit '[m]'
parameter            'WaveHeight'                                unit '[m]'
parameter            'Period'                                    unit '[s]'
parameter            'Period'                                    unit '[s]'
parameter            'Period'                                    unit '[s]'
parameter            'Period'                                    unit '[s]'
parameter            'Period'                                    unit '[s]'
parameter            'Period'                                    unit '[s]'
parameter            'Direction'                                 unit '[N^o]'
parameter            'Direction'                                 unit '[N^o]'
parameter            'Direction'                                 unit '[N^o]'
parameter            'Direction'                                 unit '[N^o]'
parameter            'Direction'                                 unit '[N^o]'
parameter            'Direction'                                 unit '[N^o]'
parameter            'DirSpreading'                              unit '[-]'
parameter            'DirSpreading'                              unit '[-]'
parameter            'DirSpreading'                              unit '[-]'
parameter            'DirSpreading'                              unit '[-]'
parameter            'DirSpreading'                              unit '[-]'
parameter            'DirSpreading'                              unit '[-]'
0.00    5.5300 1.8600 1.8600 1.9100 1.8400 1.7100...
        8.2400 8.2400 8.2400 8.2400 8.4700 8.4700...
        -171.0700 -173.5300 -173.5300 -167.2300 -160.5600 -154.3000...
        2.0000 2.0000 2.0000 2.0000 2.0000 2.0000
60.00   3.5300 3.8600 1.8600 3.9100 3.8400 3.7100...
        8.2400 8.2400 8.2400 8.2400 8.4700 8.4700...
        -171.0700 -173.5300 -173.5300 -167.2300 -160.5600 -154.3000...
        2.0000 2.0000 2.0000 2.0000 2.0000 2.0000
location             'Boundary South     '
time-function        'non-equidistant'
reference-time       20060105
time-unit            'minutes'
interpolation        'linear'
parameter            'time               '                       unit '[min]'
parameter            'WaveHeight'                                unit '[m]'
parameter            'WaveHeight'                                unit '[m]'
parameter            'WaveHeight'                                unit '[m]'
parameter            'WaveHeight'                                unit '[m]'
parameter            'WaveHeight'                                unit '[m]'
parameter            'WaveHeight'                                unit '[m]'
parameter            'WaveHeight'                                unit '[m]'
parameter            'WaveHeight'                                unit '[m]'
parameter            'WaveHeight'                                unit '[m]'
parameter            'Period'                                    unit '[s]'
parameter            'Period'                                    unit '[s]'
parameter            'Period'                                    unit '[s]'
parameter            'Period'                                    unit '[s]'
parameter            'Period'                                    unit '[s]'
```

```
parameter           'Period'                                   unit '[s]'
parameter           'Period'                                   unit '[s]'
parameter           'Period'                                   unit '[s]'
parameter           'Period'                                   unit '[s]'
parameter           'Direction'                                unit '[N^o]'
parameter           'Direction'                                unit '[N^o]'
parameter           'Direction'                                unit '[N^o]'
parameter           'Direction'                                unit '[N^o]'
parameter           'Direction'                                unit '[N^o]'
parameter           'Direction'                                unit '[N^o]'
parameter           'Direction'                                unit '[N^o]'
parameter           'Direction'                                unit '[N^o]'
parameter           'Direction'                                unit '[N^o]'
parameter           'DirSpreading'                             unit '[-]'
parameter           'DirSpreading'                             unit '[-]'
parameter           'DirSpreading'                             unit '[-]'
parameter           'DirSpreading'                             unit '[-]'
parameter           'DirSpreading'                             unit '[-]'
parameter           'DirSpreading'                             unit '[-]'
parameter           'DirSpreading'                             unit '[-]'
parameter           'DirSpreading'                             unit '[-]'
parameter           'DirSpreading'                             unit '[-]'
0.00  1.2700 1.2700 1.2700 1.2700 1.3600 1.6000 1.3400 3.3400 3.0500...
      8.4700 8.4700 8.4700 8.4700 8.1600 7.3500 7.1200 7.1200 7.0800...
      -147.8800 -147.8800 -147.8800 -147.8800 -178.7700  173.9500  175.0400  175.0400 -179.1200...
      2.0000 2.0000 2.0000 2.0000 2.0000 2.0000 2.0000 2.0000 2.0000
60.00 3.2700 1.2700 1.2700 3.2700 3.3600 3.6000 3.3400 3.3400 3.0500...
    8.4700 8.4700 8.4700 8.4700 8.1600 7.3500 7.1200 7.1200 7.0800...
    147.8800 -147.8800 -147.8800 -147.8800 -178.7700  173.9500  175.0400  175.0400 -179.1200...
    2.0000 2.0000 2.0000 2.0000 2.0000 2.0000 2.0000 2.0000 2.0000
```

Example 3

If one would like to have a wave model with space-varying wave boundary conditions, with time-varying but spatial uniform wind field, one should add them to Datagroup *General* as follows:

```
[WaveFileInformation]
   FileVersion          = 02.00
[General]
   ProjectName          = Carrara
   ProjectNr            = 001
   Description          =
   Description          = Carrara test run
   OnlyInputVerify      = false
   SimMode              = stationary
   DirConvention        = nautical
   ReferenceDate        = 2006-01-05
   TSeriesFile          = timeseries.bcw
...
```

In Datagroup *TimePoint* the following should be added:

```
...
[TimePoint]
   Time                 =  6.0000000e+001
   WaterLevel           =  0.0000000e+000
   XVeloc               =  0.0000000e+000
   YVeloc               =  0.0000000e+000
   WindSpeed            =  20.0
   WindDir              =  20.0
[TimePoint]
   Time                 =  1.2000000e+002
```

```
   WaterLevel          =  0.0000000e+000
   XVeloc              =  0.0000000e+000
   YVeloc              =  0.0000000e+000
   WindSpeed           =  15.0
   WindDir             =  15.0
[TimePoint]
   Time                =  1.8000000e+002
   WaterLevel          =  0.0000000e+000
   XVeloc              =  0.0000000e+000
   YVeloc              =  0.0000000e+000
   WindSpeed           =  10.0
   WindDir             =  10.0
[TimePoint]
   Time                =  2.4000000e+002
   WaterLevel          =  0.0000000e+000
   XVeloc              =  0.0000000e+000
   YVeloc              =  0.0000000e+000
   WindSpeed           =  2.0
   WindDir             =  2.0
...
```

In Datagroup *Boundary* the following should be added:

```
...
[Boundary]
   Name                = Boundary West
   Definition          = xy-coordinates
   StartCoordX         =  5.0000000e+005
   EndCoordX           =  5.0000000e+005
   StartCoordY         =  4.9274090e+006
   EndCoordY           =  4.7885805e+006
   SpectrumSpec        = parametric
   SpShapeType         = jonswap
   PeriodType          = peak
   DirSpreadType       = power
   PeakEnhanceFac      =  3.3000000e+000
   GaussSpread         =  9.9999998e-003
   CondSpecAtDist      =  2.7765670e+004
   CondSpecAtDist      =  5.5531340e+004
   CondSpecAtDist      =  6.3297008e+004
   CondSpecAtDist      =  8.3297008e+004
   CondSpecAtDist      =  1.1106268e+005
   CondSpecAtDist      =  1.3882834e+005
[Boundary]
   Name                = Boundary South
   Definition          = xy-coordinates
   StartCoordX         =  5.0000000e+005
   EndCoordX           =  6.2226400e+005
   StartCoordY         =  4.7608150e+006
   EndCoordY           =  4.7608150e+006
   SpectrumSpec        = parametric
   SpShapeType         = jonswap
   PeriodType          = peak
   DirSpreadType       = power
   PeakEnhanceFac      =  3.3000000e+000
   GaussSpread         =  9.9999998e-003
   CondSpecAtDist      =  0.0000000e+000
   CondSpecAtDist      =  1.0000000e+003
   CondSpecAtDist      =  1.0000000e+004
   CondSpecAtDist      =  2.0377330e+004
   CondSpecAtDist      =  4.0754660e+004
   CondSpecAtDist      =  6.1131988e+004
   CondSpecAtDist      =  8.1509320e+004
   CondSpecAtDist      =  1.0188665e+005
   CondSpecAtDist      =  1.2226398e+005
```

...

The <bcw>-file, which is defined in section A.2.3, should be the same as that in Example 2.

A.2.8.3 Space-varying wave boudnary conditions using for UNIBEST coupling (<md-vwac>-file)

For the coastline model UNIBEST, wave computations can be required representing a wave climate. Such a wave climate is schematized into several wave conditions and corresponding wind conditions. These wave and wind conditions can be defined all in one file: the so-called <md-vwac>-file. This file must be added to the working directory of the wave model. Only when this file is present in the working directory, wave computations will be carried out for all wave conditions in the <md-vwac>-file. In this way a large number of wave conditions can be computed in a batch mode.

File contents:	List of wave and wind conditions for UNIBEST model with no time points
File type:	free formatted/unformatted.
Restrictions:	maximum record length in the (free) formatted file is 132.
Example:	formatted file of a <md-vwac.*runid*>

```
* Name of main SCO file:  NZ_STORM.SCO
UNIBEST *(MORSYS/UNIBEST)
10 *total number of wave conditions
* Hm0  Tp    theta   ms   H0   U10    theta_wind
* (m)  (s)   (N°)    -    (m)  (m/s)  (N°)
1.0    5     330     4    0.2  0      0
1.5    5     310     4    0.1  0      0
3.0    8     350     4    0.4  0      0
2.2    7     270     4    0.3  0      0
```

Description of parameters:

H_{m0} [m]	Significant wave height in metres; this value will be prescribed on all specified wave boundaries.
T_p [s]	Peak period of the energy spectrum. This value will be prescribed on all specified wave boundaries.
theta [N°]	Mean wave direction according to the Nautical or Cartesian convention (in degrees). This value will be prescribed on all specified wave boundaries.
ms [-]	Width energy distribution. This is the directional standard deviation in degrees if the option *Degrees* is chosen in the sub-window *Spectral space* or it is the power m if the option *Cosine power* is chosen in the same above sub-window.
H0 [m]	The additional water level over the entire wave model. The water level is measured positively upward from the same datum from which the bottom levels are taken.
U10 [m/s]	Wind velocity at 10 m elevation.
Theta_wind [N°]	Wind direction at 10 m elevation according to the convention, specified in the sub-window **Constants**.

Remarks:

- ◇ On the third line of the md-vwac file the amount of wave conditions is given. In the mdw-file or in the WAVE-GUI an equal amount of time points must be prescribed matching with the amount of wave conditions in the md-vwac file.
- ◇ The defined wave boundary conditions are overruled by the prescribed wave conditions

in the md-vwac file.

A.2.8.4 Time- and space-varying wave boundary conditions: TPAR file

TPAR files containing non-stationary wave parameters. A TPAR file is for only one section of the boundaries. For space-varying, the user has to define multiple TPAR files. The TPAR file has the string TPAR on the first line of the file and a number of lines which each contain 5 numbers:

1 Time (ISO notation),
2 Hs,
3 Period (average or peak period depending on the choice given in the Swan Spectral Space under *Edit Spectral space*),
4 Peak Direction (Nautical or Cartesian, depending on the settings in the *Physical parameters*),
5 Directional spread (in degrees or as power of Cos depending on the choice given in the Swan Spectral Space under *Edit Spectral space*).

Example of a TPAR file (for example, the filename is TPAR01.bnd):

```
TPAR
19920516.1300 4.2 12.  -110. 22.
19920516.1800 4.2 12.  -110. 22.
19920517.0000 1.2  8.  -110. 22.
19920517.1200 1.4  8.5  -80. 26.
19920517.2000 0.9  6.5  -95. 28.
```

Thus in the mdw file, the corresponding segment is:

```
...
[Boundary]
   Name                 = Bound1
   Definition           = grid-coordinates
   StartCoordM          = 0
   EndCoordM            = 0
   StartCoordN          = 0
   EndCoordN            = 39
   SpectrumSpec         = from file
   Spectrum             = TPAR01.bnd
...
```

The boundary section is defined in MN format.

A.2.9 Spectral input and output files

There are two types of Spectrum files:

◇ files containing stationary or non-stationary 1D spectra (usually from measurements)
◇ files containing stationary or non-stationary 2D spectra (from other computer programs or other SWAN runs).

The structure of the files containing 1D or 2D spectra is described below (there is no relation with the definition of the boundary file generated by WAM or WAVEWATCH III). 1D and 2D files can be used for one or more than one location. The spectral frequencies (and directions in the case of a 2D spectrum) do not have to coincide with the frequencies and directions used in the present WAVE (SWAN) run (in a nested run SWAN will interpolate to these frequencies and directions). The co-ordinates of locations in the 1D and 2D files are ignored when SWAN reads this.

This appendix describes the format of the files for spectral input (command BOUNDARY) and output (commands SPEC and NEST) by SWAN. The files are recognised by SWAN or another reading program by the presence of the keyword SWAN and a version number on the first line of the file. This description is valid for version number 1.

These files contain the following information:

- ◇ co-ordinates of locations
- ◇ frequencies
- ◇ directions (if used for 2D)
- ◇ time (if time-dependent)
- ◇ spectral energy or variance densities (and aver. dir. and dir. spread if 1D)

Example of a 1D non-stationary spherical co-ordinates file:

```
SWAN 1                        Swan standard spectral file, version
$ Data produced by SWAN version 40.41
$ Project:'projname' ;        run number:          'runnum'
TIME                          time-dependent data
1                             time coding option
LONLAT                        locations in spherical co-ordinates
2                             number of locations
1.00  1.00
1.20  1.00
RFREQ                         relative frequencies in Hz
25                            number of frequencies
0.0418
0.0477
0.0545
0.0622
0.0710
0.0810
0.0924
0.1055
0.1204
0.1375
0.1569
0.1791
0.2045
0.2334
0.2664
0.3040
0.3470
0.3961
0.4522
0.5161
0.5891
0.6724
0.7675
0.8761
1.0000
QUANT
3                             number of quantities in table
VaDens                        variance densities in m2/Hz
m2/Hz                         unit
-0.9900E+02                   exception value
CDIR                          average Cartesian direction in degr
```

```
degr                          unit
-0.9990E+03                   exception value
DSPRDEGR                      directional spreading
degr                          unit
-0.9000E+01                   exception value
19680606.030000               date and time
LOCATION 1
0.3772E-03  190.1   6.3
0.1039E-02  190.2   6.5
0.2281E-02  190.3   6.7
0.3812E-02  190.3   6.7
0.4255E-02  190.3   6.6
0.2867E-02  190.1   6.3
0.1177E-02  189.6   5.8
0.3892E-03  192.0  15.2
0.8007E-03  244.5  22.9
0.6016E-02  251.4  11.5
0.1990E-01  251.0  11.0
0.3698E-01  249.9  10.9
0.3874E-01  248.1  12.1
0.2704E-01  246.6  13.0
0.1672E-01  247.0  13.5
0.1066E-01  247.7  13.7
0.5939E-02  247.3  14.0
0.3247E-02  246.5  14.6
0.1697E-02  245.9  14.9
0.8803E-03  245.6  15.1
0.4541E-03  245.5  15.3
0.2339E-03  245.4  15.5
0.1197E-03  245.5  15.6
0.6129E-04  245.5  15.7
0.3062E-04  245.3  15.9
LOCATION 2
0.7129E-02   67.2  25.3
0.3503E-01   67.5  21.7
0.1299E+00   68.2  19.7
0.5623E+00   69.7  18.0
0.1521E+01   71.4  18.0
0.3289E+01   74.0  18.8
0.4983E+01   77.2  20.3
0.4747E+01   79.9  22.0
0.2322E+01   79.4  30.7
0.1899E+01  341.1  56.2
0.1900E+01  314.6  39.4
0.6038E+01  324.3  31.9
0.8575E+01  326.1  31.0
0.4155E+01  325.1  30.5
0.1109E+01  322.8  32.9
0.7494E+00  323.1  33.3
0.4937E+00  323.1  33.3
0.2953E+00  323.3  33.7
0.1661E+00  323.6  34.0
0.9788E-01  323.7  33.8
0.5766E-01  323.8  33.6
0.3397E-01  324.0  33.5
0.2001E-01  324.1  33.4
0.1179E-01  324.2  33.3
0.6944E-02  324.2  33.2
```

Example of a 2D stationary Cartesian co-ordinates file:

```
SWAN 1                        Swan standard spectral file, version
$ Data produced by SWAN version 40.41
$ Project:'projname' ;        run number:'runnum'
```

```
LOCATIONS                      locations in x-y-space
2                              number of locations
0.00  0.00
22222.22  0.00
RFREQ                          relative frequencies in Hz
25                             number of frequencies
0.0418
0.0477
0.0545
0.0622
0.0710
0.0810
0.0924
0.1055
0.1204
0.1375
0.1569
0.1791
0.2045
0.2334
0.2664
0.3040
0.3470
0.3961
0.4522
0.5161
0.5891
0.6724
0.7675
0.8761
1.0000
CDIR                           spectral Cartesian directions in degr
24                             number of directions
7.5000
22.5000
37.5000
52.5000
67.5000
82.5000
97.5000
112.5000
127.5000
142.5000
157.5000
172.5000
187.5000
202.5000
217.5000
232.5000
247.5000
262.5000
277.5000
292.5000
307.5000
322.5000
337.5000
352.5000
QUANT
1                              number of quantities in table
VaDens                         variance densities in m2/Hz/degr
m2/Hz/degr                     unit
-0.9900E+02                    exception value
FACTOR
0.422574E-11
0  0  0  0  0  0  0  0  0  0  0  0     1    0  0
0  0  0  0  0  0  0  0  0
```

```
0  0  0  0  0  0  0  0  0  0  0  0     44     3  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0    817    60  1
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0   8018   574  9
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0 39230  2532 38
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0 92174  4477 68
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0 99010  1946 29
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0 47054   131  2
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0 13228     0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0 39417     0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0 61269     0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0 29738     0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0  2161     0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0      2     0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0      0     0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0      0     0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0      0     0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0      0     0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0      0     0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0      0     0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0      0     0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0      0     0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0      0     0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0      0     0  0
0  0  0  0  0  0  0  0  0
0  0  0  0  0  0  0  0  0  0  0  0      0     0  0
0  0  0  0  0  0  0  0  0
FACTOR
0.675611E-06
51 242 574 956 1288 1482 1481 1286 957 579 244 51 0 0 0
0 0 0 0 0 0 0 0 0
129 610 1443 2402 3238 3725 3724 3234 2406 1454 613 128 0 0 0
0 0 0 0 0 0 0 0 0
273 1287 3054 5084 6846 7872 7869 6837 5091 3076 1295 271 0 0 0
0 0 0 0 0 0 0 0 0
665 3152 7463 12402 16712 19229 19221 16690 12419 7518 3172 662 0 0 0
0 0 0 0 0 0 0 0 0
1302 6159 14608 24275 32688 37618 37603 32644 24309 14716 6198 1296 0 0 0
0 0 0 0 0 0 0 0 0
2328 10989 26020 43341 58358 67109 67080 58281 43401 26213 11058 2317 0 0 0
0 0 0 0 0 0 0 0 1
3365 15922 37712 62733 84492 97150 97110 84380 62820 37991 16021 3349 0 0 0
0 0 0 0 0 0 0 0 1
3426 16230 38440 63939 86109 99010 98969 85995 64027 38724 16331 3410 0 0 0
0 0 0 0 0 0 0 0 0
```

```
2027 9612 22730 37790 50909 58529 58505 50841 37843 22898 9672 2018 0 0 0
0 0 0 0 0 0 0 0 0
672 3178 7538 12535 16892 19440 19432 16870 12552 7594 3198 669 0 0 0
0 0 0 0 0 0 0 0 0
101 479 1135 1890 2542 2924 2923 2539 1892 1144 482 101 0 0 0
0 0 0 0 0 0 0 0 0
2 11 26 43 57 66 66 57 43 26 11 2 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 1 1 1 1 1 1 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
```

Note that the true variance or energy densities are obtained by multiplying each number with the factor given under the keyword FACTOR.

A.2.10 Space-varying wind field

This feature has been made available as a special feature in Delft3D-WAVE. It can not (yet) be switched on in the WAVE-GUI. The user can include this functionality by adding the keyword `Meteofile` in the MDW-file. The keyword should specify the file containing the space-varying wind data. If one wishes to specify wind fields that vary in space but are constant in time, one should simply incorporate the same wind field data block twice in one file. This generates a wind field that is constant in time.

Remarks:

- ◇ The keyword `Meteofile` can be added both in Datagroup *General* as in Datagroup *Domain*. When the keyword is added in Datagroup *General*, the wind will be incorporated in all domains. When the keyword is added in Datagroup *Domain*, the wind will be incorporated in that domain only.
- ◇ The `Meteofile` may occur more than once in the MDW-file to specify multiple sets of meteorological data (also within a Datagroup).

Example 1

If one would like to add two meteofiles containing an x-component and y-component for space-varying wind, respectively, and apply the wind to all domains of the WAVE simulation, one should add them to Datagroup *General* as follows:

```
[WaveFileInformation]
   FileVersion          = 02.00
[General]
   ProjectName          = Siu-Lam
   ProjectNr            = 001
   Description          = Tutorial Delft3D-WAVE
   Description          = Siu Lam model
   Description          = SWAN wave model using a curvilinear grid
   OnlyInputVerify      = false
   SimMode              = quasi-stationary
   DirConvention        = nautical
   ReferenceDate        = 2005-10-01
   ObstacleFile         = obst_data_keyw.obs
   MeteoFile            = xwind.wnd
   MeteoFile            = ywind.wnd
[TimePoint]
   ....
```

Example 2

If one would like to add the same meteorological files, but apply them only in the domain with grid *siu_lam_coarse.grd*, one should add them to Datagroup *Domain* as:

```
[WaveFileInformation]
   FileVersion          = 02.00
[General]
   ProjectName          = Siu-Lam
   ProjectNr            = 002
   Description          = Tutorial Delft3D-WAVE
   Description          = Siu Lam model, 2 domains
   Description          = SWAN wave model using 2 curvilinear grids
   OnlyInputVerify      = false
   SimMode              = quasi-stationary
   DirConvention        = nautical
   ReferenceDate        = 2005-10-01
   ObstacleFile         = obst_data_keyw.obs
[TimePoint]
   ....
[Domain]
   Grid                 = siu_lam_coarse.grd
   BedLevel             = siu_lam_coarse.dep
   DirSpace             = circle
   NDir                 = 36
   StartDir             =  0.0000000000000000e+000
   EndDir               =  0.0000000000000000e+000
   FreqMin              =  5.0000000745058060e-002
   FreqMax              =  1.0000000000000000e+000
   NFreq                = 24
   Output               = true
   MeteoFile            = xwind.wnd
   MeteoFile            = ywind.wnd
[Domain]
   Grid                 = siu_lam_fine.grd
   BedLevel             = siu_lam_fine.dep
   DirSpace             = circle
   NDir                 = 36
   StartDir             =  0.0000000000000000e+000
   EndDir               =  0.0000000000000000e+000
   FreqMin              =  5.0000000745058060e-002
   FreqMax              =  1.0000000000000000e+000
   NFreq                = 24
   Output               = true
[Boundary]
   ....
```

Remark:

◇ When applying space-varying wind in only one or some of the domains, the user should be aware of the fact that the transition in wind forcing from one domain to the other may be not smooth.

In many cases the space varying wind data is provided by a meteorological station. This data is often defined on a different grid than the computational grid used in Delft3D-WAVE. Translating these files into files defined on the (curvilinear) grid of the computational engine is often a lengthy process and can result in huge files. This special feature facilitates the reading of the meteorological data on its own grid and interpolates the data internally to the grid of Delft3D-WAVE.

Delft3D-WAVE can handle wind data on several different types of grids:

1 Space-varying wind on the computational (SWAN) grid
2 Space-varying wind on an equistant grid
3 Space-varying wind on a curvilinear grid
4 Space-varying wind on a Spiderweb grid

For these types of meteorological input, fixed formats have been set-up, that completely define a dataset. This form of meteorological input is also used by Delft3D-FLOW, see (Delft3D-FLOW, 2013). In Delft3D-FLOW, also the atmospheric pressure is read from the meteorological files and used in the simulation. This is not (yet) available in Delft3D-WAVE. In the following sections, generic descriptions of the formats of the meteorological input types are given. In these descriptions the atmospheric pressure is also considered. This is not relevant for Delft3D-WAVE and may be excluded. For *Space-varying wind on the computational (SWAN) grid*, both `x_wind`, `y_wind` and `air_pressure` are given in one file. Similarly, for *Space-varying wind on a Spiderweb grid*, both `wind_speed`, `wind_from_direction` and `p_drop` (atmospheric pressure drop) are specified in one file. This format must also be used for a Delft3D-WAVE simulation, for which the atmospheric pressure (drop) is then not used.

A.2.10.1 Space-varying wind on the computational (SWAN) grid

File contents	Time-series for space varying wind velocity components (east-west and south-north) and atmospheric pressure, defined on the computational grid. The file consists of a header, followed by datablocks containing the wind and pressure fields at times specified using a standardised time definition above each datablock. The header specifies the type of file and the input it contains using a number of keywords. The keywords are case insensitive and the order of the keywords is not fixed.
Filetype	ASCII or binary.
File format	Free formatted or unformatted, keyword based.
Filename	<*name*.wnd>
Generated	Some offline program.

Header description:

Keywords	**Value**	**Description**
`FileVersion`	1.03	version of file format
`Filetype`	meteo_on_computational_grid	meteo input on computational grid
`NODATA_value`	*free*	value used for input that is to be neglected
`n_quantity`	3	number of quantities specified in the file
`quantity1`	x_wind	wind in x-direction
`quantity2`	y_wind	wind in y-direction
`quantity3`	air_pressure	air pressure
`unit1`	m s-1	unit of `quantity1`, meters/second
`unit2`	m s-1	unit of `quantity2`, meter/second
`unit3`	Pa *or* mbar	unit of `quantity3`, Pa or millibar

Time definition and data block description

Keywords	**Value**	**Description**
`Time`	*fixed format described below*	time definition string

The time definition string has a fixed format, used to completely determine the time at which a dataset is valid. The time definition string has the following format:

TIME *minutes/hours since* YYYY-MM-DD HH:MM:SS TIME ZONE, e.g.

```
360 minutes since 2008-07-28 10:55:00 +01:00
```

The format of the string is completely fixed. No extra spaces or tabs can be added between the different parts of the definition. The time definition is followed by the datablock of input values corresponding to the specified time. The data block consists of three subsequent blocks containing the velocity component in M-direction, the velocity component in N-direction and the atmospheric pressure, respectively. All three quantities are given for *Nmax* by *Mmax* points, where the first value in the dataset corresponds to cell $(1, 1)$ on the grid. Every next line in the dataset then corresponds to a row on the grid. The time definition and the data block — for all three quantities — are repeated for each time instance of the time-series.

File version and conversion

The current description holds for `FileVersion` 1.03. The table below shows the latest modifications in the file format (and version number).

FileVersion	Modifications
`1.03`	No changes for this meteo input type, but for the meteo types *meteo_on_equidistant_grid* and *meteo_on_curvilinear_grid*
`1.02`	No changes for this meteo input type, but for the meteo type *meteo_on_spider_web_grid*
`1.01`	Changed keyword `MeteoType` to `FileType` Changed fixed value of input type (Keyword `Filetype`) from *Svwp* to *meteo_on_computational_grid* (*meteo_on_flow_grid* is also allowed)

Restrictions:
- ◇ Keywords are followed by an equal sign '=' and the value of the keyword.
- ◇ When a keyword has value *free* the value of this keyword is free to choose by the user. When only one value is given for a keyword, this keyword has a fixed value and when 2 or more options are shown, the user can choose between those values.
- ◇ Times must be specified exactly according to the time definition. See the examples shown in this section.
- ◇ The contents of the file will not be checked on its domain.
- ◇ The wind components are specified at the cell centres (water level points) of the computational grid.
- ◇ Input items in a data block are separated by one or more blanks (free formatted file only).

Remarks:
- ◇ The time definition in the meteorological file contains the number of minutes or hours since a reference data and time in a certain time zone. The reference time and time zone may differ from those of the simulation. The computational engine will search in the meteo file for the simulation time and interpolate between neighbouring times if necessary. Possible differences in time zone will be accounted for by shifting the meteo input data with the difference. The reference times within the time definition string may vary in a meteo file, i.e. it is possible to attach new input with a different reference time, behind the last data block.
- ◇ Comments can be added after #'s.

Example

Model area of $25 * 33$ grid points (Mmax = 25; Nmax = 33). The input data is printed in Courier, comments are printed behind #'s.

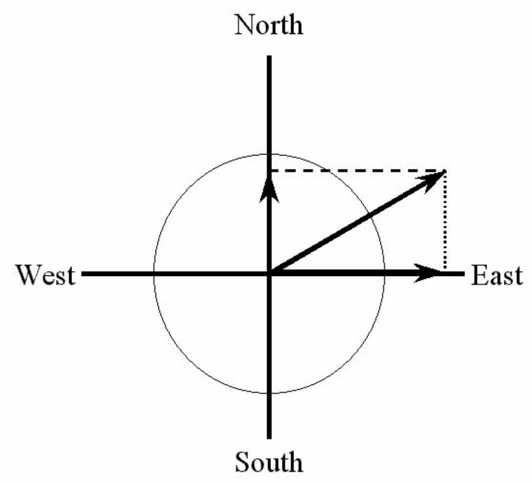


***Figure A.1:** Definition wind components for space varying wind*

```
Time = 0.0 minutes since 2008-09-20 10:30:00 +01:00       # Time definition
{33 records with 25 values each}                          # Wind component west to east
{33 records with 25 values each}                          # Wind component south to north
{33 records with 25 values each}                          # Atmospheric pressure
Time = 340.0 minutes since 2008-09-20 10:30:00 +01:00     # Time definition
{33 records with 25 values each}                          # Wind component west to east
{33 records with 25 values each}                          # Wind component south to north
{33 records with 25 values each}                          # Atmospheric pressure
Time = 600.0 minutes since 2008-09-20 10:30:00 +01:00     # Time definition
{33 records with 25 values each}                          # Wind component west to east
{33 records with 25 values each}                          # Wind component south to north
{33 records with 25 values each}                          # Atmospheric pressure
Time = 1240.0 minutes since 2008-09-20 10:30:00 +01:00    # Time definition
{33 records with 25 values each}                          # Wind component west to east
{33 records with 25 values each}                          # Wind component south to north
{33 records with 25 values each}                          # Atmospheric pressure
```

Remarks:
- ◇ To obtain the wind direction according to the nautical convention, the wind direction is reversed.
- ◇ The wind is specified in terms of its components along the west-east (`x_wind`) and south-north (`y_wind`) co-ordinate system, see Figure A.1. These definitions differ from the nautical convention (used for uniform wind), which is specified relative to true North, see Figure A.2.

A.2.10.2 Space-varying wind on an equistant grid

File contents	Time-series of a space varying wind and atmospheric pressure defined on an equidistant (Cartesian or spherical) grid.
File format	Free formatted or unformatted, keyword based.
Generated	Some offline program.

Remark:
- ◇ The keywords are case insensitive.

Keywords	Value	Description

Header description for the wind velocity files:

Keywords	Value	Description
`FileVersion`	1.03	version of file format
`Filetype`	meteo_on_equidistant_grid	meteo input on equidistant grid
`NODATA_value`	*free*	value used for input that is to be neglected
`n_cols`	*free*	number of columns used for wind datafield
`n_rows`	*free*	number of rows used for wind datafield
`grid_unit`	m *or* degree	unit of distances on the grid in both x- and y-direction
`x_llcorner`	*free*	x-coordinate of lower left corner of lower left grid cell (in units specified in `grid_unit`
`y_llcorner`	*free*	y-coordinate of lower left corner of lower left grid cell (in units specified in `grid_unit`
`x_llcenter`	*free*	x-coordinate of centre of lower left grid cell (in units specified in `grid_unit`
`y_llcenter`	*free*	y-coordinate of centre of lower left grid cell (in units specified in `grid_unit`
`dx`	*free*	gridsize in x-direction in units specified in `grid_unit`
`dy`	*free*	gridsize in y-direction in units specified in `grid_unit`
`n_quantity`	1	number of quantities specified in the file
`quantity1`	x_wind *or* y_wind	the velocity component given in unit `unit1`
`unit1`	m s-1	unit of `quantity1`: metre/second

The user must specify the location of the equidistant grid on which the meteorological data is specified. If one has the location of the lower left corner of the lower left grid cell, one can spec-

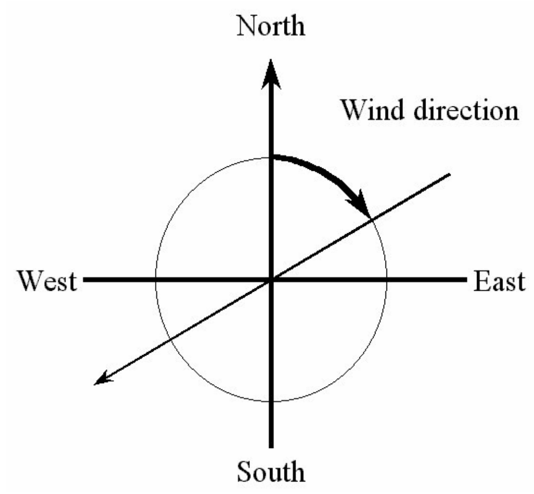


Figure A.2: *Definition sketch of wind direction according to Nautical convention*

ify the starting point of the grid using keywords `x_llcorner` and `y_llcorner`. If one has the location of the cell centre of the lower left grid cell, one should use the keywords `x_llcenter` and `y_llcenter`. Using the first option, the first data value is placed at (x_llcorner+$\frac{1}{2}dx$, y_llcorner+$\frac{1}{2}dy$), which is the cell centre of cell (1,1). Using the latter option, the first data value is placed at (x_llcenter, y_llcenter), which is again the cell centre of cell (1,1), i.e. the data values are always placed at the cell centres of the meteorological grid. Note that the lower left grid cell is defined to be the grid cell with index (1,1). When using the option of meteorological data on a separate curvilinear grid, the origin and orientation of the data set can be chosen freely with respect to the grid on which it is specified, see section A.2.10.3 for details.

Time definition and data block description for the wind velocity files

Keywords	**Value**	**Description**
`Time`	*fixed format described below*	time definition string

The time definition string has a fixed format, used to completely determine the time at which a dataset is valid. The time definition string has the following format:

TIME *minutes/hours since* YYYY-MM-DD HH:MM:SS TIME ZONE, e.g.

```
360 minutes since 2008-07-28 10:55:00 +01:00
```

The format of the string is completely fixed. No extra spaces or tabs can be added between the different parts of the definition. The time definition is followed by the datablock of input values corresponding to the specified time. The data block contains values for the wind velocity in x- or y-direction for *n_cols* by *n_rows* points, starting at the top left point. The time definition and the data block are repeated for each time instance of the time-series.

The atmospheric pressure file

The header for the atmospheric pressure is similar to that of the wind velocity files, except for the following differences.

Keywords	**Value**	**Description**
`quantity1`	air_pressure	air pressure
`unit1`	Pa *or* mbar	unit of `quantity1`: Pascal or

File version and conversion

The current description holds for `FileVersion` 1.03. The table below shows the latest modifications in the file format (and version number).

FileVersion	**Modifications**
`1.03`	Use of keyword `Value_pos` to indicate the position of the lower left corner of the grid replaced by use of the combination of keywords: `x_llcorner` and `y_llcorner` or `x_llcenter` and `y_llcenter`
`1.02`	No changes for this meteo input type, but for the meteo type *meteo_on_spiderweb_grid*
`1.01`	Changed keyword `MeteoType` to `FileType` Changed fixed value of input type (Keyword `Filetype`) from *ArcInfo* to *meteo_on_equidistant_grid*

Restrictions:

- ◇ The contents of the file will not be checked on its domain.
- ◇ Keywords are followed by an equal sign '=' and the value of the keyword.
- ◇ When a keyword has value *free*, the value of this keyword is free to choose by the user. When only one value is given for a keyword, this keyword has a fixed value and when 2 or more options are shown, the user can choose between those values.
- ◇ Times must be specified exactly according to the time definition. See the examples shown in this section.
- ◇ The atmospheric pressure file must use the same grid definition and time frame as the files for the wind velocity components.
- ◇ The unit of the meteo grid must be the same as the computational grid, i.e. both with `grid_unit` = [m] or both with `grid_unit` = [degree].
- ◇ Input items in a data block are separated by one or more blanks.
- ◇ The wind components are specified at the cell centres (water level points) of the numerical grid.
- ◇ The wind components are specified in the west-east (`x_wind`) and south-north directions (`y_wind`).

Remarks:

- ◇ The time definition in the meteo files contains the number of minutes or hours since a reference date and time in a certain time zone. The reference time and time zone may differ from those of the simulation. During a simulation the computational engine will search in the meteo file for the current simulation time and interpolate between neighbouring times if necessary. Possible differences in time zone will be accounted for by shifting the meteo input data. The reference times within the time definition string may vary in a meteo file, i.e. it is possible to attach new input with a different reference time, behind the last data block. Consecutive times must always be increasing in the input file.
- ◇ Comments can be added after pound signs (#). These are not read.

Example of a file containing wind in x-direction (west-east)

The data blocks in this example are the result of the following FORTRAN statements:

```
do j = nrows,1,-1
```

```
   write(out,*) (xwind(i,j),i=1,ncols)
enddo
```

The x-wind velocity file for a 3 (n_cols) by 4 (n_rows) grid has the following layout:

```
FileVersion      =    1.03
filetype         =    meteo_on_equidistant_grid
NODATA_value     =    -999.000
n_cols           =    3
n_rows           =    4
grid_unit        =    degree
x_llcenter       =    -12.000
y_llcenter       =     48.000
dx               =    0.12500
dy               =    0.083333333
n_quantity       =    1
quantity1        =    x_wind
unit1            =    m s-1
TIME =      0.0 hours since 2008-01-15 04:35:00 +00:00
2   3.0  3.6
3   4.5  2
2.2 1    2.3
1.2 0.7 -0.4
TIME =      6.0 hours since 2008-01-15 04:35:00 +00:00
-1.1 -2.3 -3.6
-3.2  0.8  1.1
 2.2 -1   -1.6
 1.2 -0.7 -0.4
```

This results in an x-component of wind velocity given - in [m/s] - on a spherical, 3 by 4, equidistant grid, with grid sizes given by *dx* and *dy* (in degrees) and where the centre point of the lower left cell of the grid lies in (longitude, latitude) (-12.0, 48.0) on the globe. Data is given at two times: 0 and 6 hours since January 15th, 2008, 4:35 AM, in UTC+0.

A.2.10.3 Space-varying wind on a curvilinear grid

File contents	Time-series of a space varying wind and atmospheric pressure defined on a curvilinear (Cartesian or spherical) grid.
File format	Free formatted or unformatted, keyword based.
Generated	Some offline program.

Remark:
◇ The keywords are case insensitive.

Header description for the wind velocity files:

Keywords	Value	Description
`FileVersion`	1.03	version of file format
`Filetype`	meteo_on_curvilinear_grid	meteo input on curvilinear grid
`NODATA_value`	*free*	value used for input that is to be neglected
`grid_file`	*free*.grd	name of the curvilinear grid file on which the data is specified

Keywords	Value	Description
`first_data_value`	grid_llcorner *or* grid_ulcorner *or* grid_lrcorner *or* grid_urcorner	*see example below*
`data_row`	grid_row *or* grid_column	*see example below*
`n_quantity`	1	number of quantities specified in the file
`quantity1`	x_wind *or* y_wind	the velocity component given in unit `unit1`
`unit1`	m s-1	unit of `quantity1`: metres/second

Time definition and data block description for the wind velocity files

For a description of the time definition and data block see section A.2.10.2.

The atmospheric pressure file

For a description of the atmospheric file see section A.2.10.2.

File version and conversion

The current description holds for `FileVersion` 1.03. The table below shows the latest modifications in the file format (and version number).

FileVersion	Modifications
`1.03`	Fixed bug in interpolation of data from meteo grid to computational grid: Conversion script mirrored data set erroneously. This was treated correctly by meteo module. Fixed both the conversion script and the meteo module together: Required modification in meteo input file: Change `first_data_value` = grid_llcorner into grid_ulcorner or vice versa or Change `first_data_value` = grid_lrcorner into grid_urcorner or vice versa
`1.02`	No changes for this meteo input type, but for the meteo type *meteo_on_spiderweb_grid*
`1.01`	Changed keyword `MeteoType` to `FileType` Changed keyword `Curvi_grid_file` to `Grid_file` Changed fixed value of input type (Keyword `Filetype`) from *Curvi* to *meteo_on_curvilinear_grid*

Restrictions:

◇ The restrictions for space varying wind and pressure on a separate curvilinear grid are the same as for space varying wind and pressure on an equidistant grid, described in section A.2.10.2. A differerence is that the data values on the curvilinear grid are not specified in the cell centres, but in the grid points (cell corners).

◇ The unit of the meteo grid must be the same as the computational grid, i.e. both with `grid_unit` = [m] or both with `grid_unit` = [degree].

Remark:

◇ The remarks for space varying wind and pressure on a separate curvilinear grid are the same as for space varying wind and pressure on an equidistant grid, described in section A.2.10.2.

Example:

A file for input of x-velocity (in west-east direction) on a 4 by 5 curvilinear grid, where the meteorological data is mirrored vertically with respect to the grid, has the following layout:

```
FileVersion       =    1.03
filetype          =    meteo_on_curvilinear_grid
NODATA_value      =    -999.000
grid_file         =    curviwind.grd
first_data_value =     grid_llcorner
data_row          =    grid_row
n_quantity        =    1
quantity1         =    x_wind
unit1             =    m s-1
TIME =       0.0 minutes since 1993-06-28 14:50:00 -02:00
 1   2   3   4   5
 6   7   8   9  10
11  12  13  14  15
16  17  18  19  20
TIME =       600.0 minutes since 1993-06-28 14:50:00 -02:00
 1   2   3   4   5
 6   7   8   9  10
11  12  13  14  15
16  17  18  19  20
```

This results in an x-component of velocity given - in [m/s] - on the curvilinear grid specified in file <curviwind.grd>. The data set will be mirrored such that the first value of the data (upper left corner, in the example '1') corresponds to the lower left corner of the grid (point (1,1)) and a row of data corresponds to a row on the grid, see Figure A.3. Data is given at two times: 0 and 600 minutes since June 28th, 1993, 14:50 PM, in UTC-2.

A.2.10.4 Space-varying wind on a Spiderweb grid

Cyclone winds are governed by a circular motion, combined with a cyclone track. This type of wind is generally very difficult to implement on a curvilinear grid. This feature facilitates the reading of the so-called Spiderweb files and interpolates the wind and pressure data internally to the computational grid. A special feature of the space varying wind and pressure on the Spiderweb grid is that it can be combined with one of the other meteorological input options described in this manual, i.e. to either uniform wind and pressure, or to one of the space varying wind and pressure options, see section A.2.10.

File contents	Time-series of a space varying wind and atmospheric pressure defined on a Spiderweb grid. This grid may be specified in Cartesian or spherical coordinates.

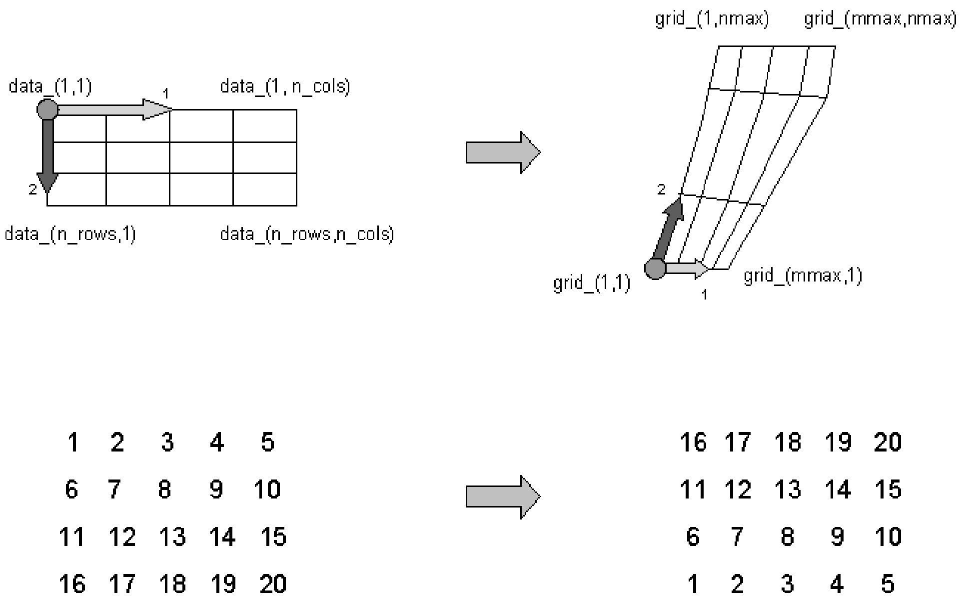


Figure A.3: *Illustration of the data to grid conversion for meteo input on a separate curvilinear grid*

File format	Free formatted or unformatted, keyword based.
Generated	Some offline program.

Remarks:
- ◇ The keywords are case insensitive.
- ◇ Space varying wind and pressure on a Spiderweb grid is added to other wind input and the wind fields are interpolated and combined in and around the cyclone.

Header description of the Spiderweb wind and pressure file:

Keywords	**Value**	**Description**
`FileVersion`	1.03	version of file format
`Filetype`	meteo_on_spiderweb_grid	meteo input on Spiderweb grid
`NODATA_value`	*free*	value used for input that is to be neglected
`n_cols`	*free*	number of gridpoints in angular direction
`n_rows`	*free*	number of gridpoints in radial direction
`grid_unit`	m *or* degree	unit of the Spiderweb grid
`spw_radius`	*free*	radius of the spiderweb given in units given by `spw_rad_unit`
`spw_rad_unit`	m	unit of the Spiderweb radius

Keywords	Value	Description
spw_merge_frac	[0.0,1.0]	fraction of the Spiderweb radius where merging starts of the background wind with the Spiderweb wind. Default is 0.5
air_pressure _reference	air_pressure_default_from _computational_engine *or free*	Both keyword and value are too long to fit on one line. Reference value related to p_drop is the default air pressure of the computional engine *or* the value specified. If missing, p_drop is extracted from the actual atmospheric pressure.
n_quantity	3	number of quantities specified in the file
quantity1	wind_speed	wind speed given in unit unit1
quantity2	wind_from_direction	direction where the wind is coming from given in unit unit2
quantity3	p_drop	drop in atmospheric pressure given in unit unit3
unit1	m s-1	unit of quantity1: metres/second
unit2	degree	unit of quantity2: degrees
unit3	Pa *or* mbar	unit of quantity3: Pascal or millibar

Time definition and data block description

For a description of the time definition see section A.2.10.2.

Cyclone track information:

For each time in the time series of space varying wind and pressure on a Spiderweb grid, the position of the cyclone eye (and thus also the spiderweb grid) must be given, as well as the drop of atmospheric pressure in the cyclone eye.

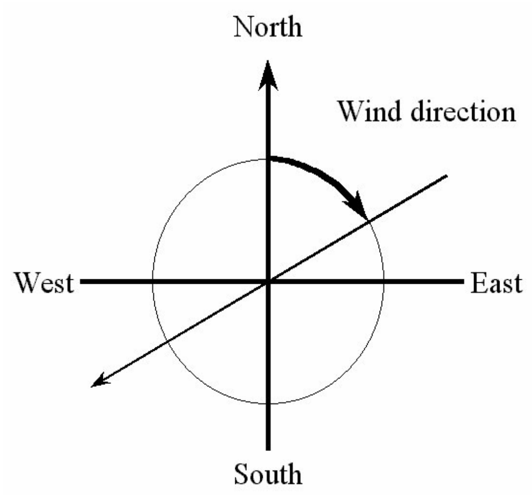


Figure A.4: *Wind definition according to Nautical convention*

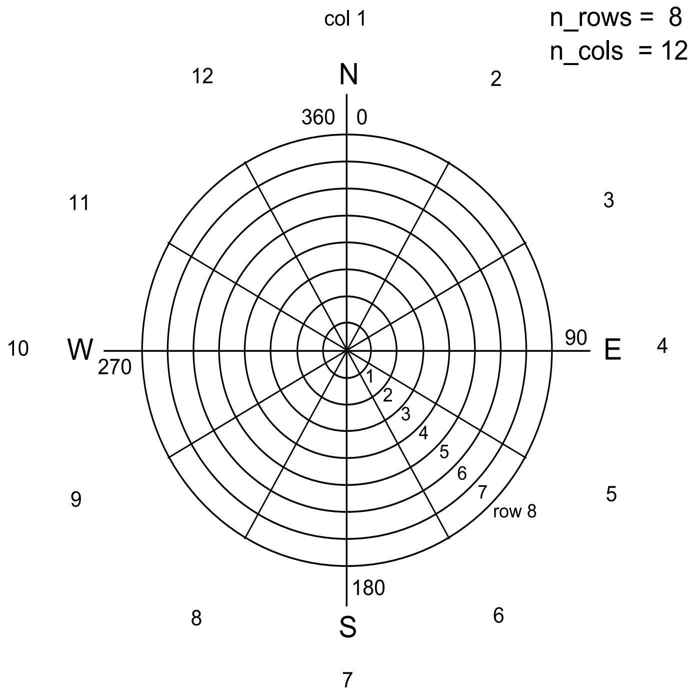


Figure A.5: *Spiderweb grid definition*

File version and conversion

The current description holds for `FileVersion` 1.03. The table below shows the latest modifications in the file format (and version number).

FileVersion	Modifications
`1.03`	No changes for this meteo input type
`1.02`	Changed the use of keyword `n_rows` and `n_cols`. The radius of the cyclone is divided in *n_rows* rings of width: spw_radius/n_rows [m] and the circle is divided in *n_cols* parts of $2\pi/n\_cols$ [rad].
`1.01`	Changed keyword `MeteoType` to `FileType` Changed fixed value of input type (Keyword `Filetype`) from *Spiderweb* to *meteo_on_spiderweb_grid*

Restriction:

◇ The restrictions for space varying wind and pressure on a Spiderweb grid are the same as for space varying wind and pressure on an equidistant grid, described in section A.2.10.2.

Remarks:

◇ The remarks for space varying wind and pressure on a separate curvilinear grid are the same as for space varying wind and pressure on an equidistant grid, described in section A.2.10.2.
◇ The Spiderweb grid is circular and the definitions of the number of rows `n_rows` and the number of columns `n_cols` is therefore different then for the other meteo input formats. For the Spiderweb grid, the number of rows determines the grid size in radial direction. The number of columns defines the grid size in angular direction. See Figure A.5.
◇ The wind is specified according to the nautical convention, i.e. wind from the true North has direction zero and the wind turns clockwise with an increasing angle. See Figure A.4.

Example:

A file for input of space varying wind and pressure on a 5x3 Spiderweb grid, has the following layout:

```
FileVersion              = 1.03
filetype                 = meteo_on_spiderweb_grid
NODATA_value             = -999.000
n_cols                   = 3
n_rows                   = 5
grid_unit                = degree
spw_radius               = 600000.0
spw_rad_unit             = m
air_pressure_reference = air_pressure_default_from_computational_engine
n_quantity               = 3
quantity1                = wind_speed
quantity2                = wind_from_direction
quantity3                = p_drop
unit1                    = m s-1
unit2                    = degree
unit3                    = Pa
TIME         =    0.0 hours since 1997-07-14 03:00:00 -06:00
```

```
x_spw_eye     = 115.1
y_spw_eye     = 18.9
pdrop_spw_eye = 5300.0
1.38999       1.38261       1.38315
1.28251       1.34931       1.22571
1.27215       1.31214       1.32451
1.38999       1.86592       2.87732
1.43899       1.24912       2.21519
60.0000       180.0000      270.0000
28.7500       20.0000       31.2500
42.5000       53.7500       65.0000
49.3400       60.2400       81.5200
51.4100       62.0000       43.1200
5301.280      5294.490      5156.240
5043.460      5112.040      5264.020
5140.020      5202.520      5411.210
5294.730      5285.760      5235.250
5242.530      5156.190      5124.240
TIME          =      1.0 hours since 1997-07-14 03:00:00 -06:00
x_spw_eye     = 114.8
y_spw_eye     = 18.8
pdrop_spw_eye = 5250.0
1.35763       1.35763       1.35763
1.35763       1.87273       2.24784
1.92214       2.47836       2.17266
1.87662       2.72116       2.82375
1.26585       2.24146       2.38722
159.0000      346.5200      290.6400
342.3200      282.1400      20.2400
10.7500       25.5300       36.4500
61.8400       81.6200       45.5100
49.5250       56.7500       75.1300
5314.520      5104.490      5287.240
5124.240      5285.760      5252.420
5152.460      5247.040      5222.020
5242.020      5223.520      5475.210
5244.270      5211.210      4998.110
```

This results in the following set of meteo data. Velocities given in [m/s] and pressure drops in [Pa] on a Spiderweb grid which is given in spherical coordinates (`grid_unit` = degree). The cyclone and spiderweb grid have a radius of 600 km. The grid is 5x3, which means the radius is divided in five parts of 120 km and the 360 degrees are divided in 3 parts of 120 degrees each. Wind speeds, wind directions and pressure drops are given at two times: 0 and 1.0 hour since July 14th, 1997, 03:00 AM, in UTC-6. Between these two times the cyclone eye moves from (longitude, latitude) (115.1, 18.9) to (114.8, 18.8) on the globe and the pressure drop in the cylcone eye decreases from 5300.0 [Pa] to 5250.0 [Pa].

B Definition of SWAN wave variables

In SWAN a number of variables, mostly related to waves are used in input and output. The definitions of these variables are conventional for the most part.

HSIGN — significant wave height (H_s in [m]), defined as:

$$H_s = 4\sqrt{\iint E(\omega,\theta)\; d\omega d\theta}$$

where $E(\omega,\theta)$ is the variance density spectrum

TM01 — mean absolute wave period (in s) of $E(\omega,\theta)$, defined as:

$$T_{m01} = 2\pi\left(\frac{\iint \omega E(\sigma,\theta)\; d\sigma d\theta}{\iint E(\sigma,\theta)\; d\sigma d\theta}\right)^{-1} = 2\pi\left(\frac{\iint \omega E(\sigma,\theta)\; d\omega d\theta}{\iint E(\sigma,\theta)\; d\omega d\theta}\right)^{-1}$$

where ω is the absolute radian frequency, determined by the Doppler shifted dispersion relation.

DIR — mean wave direction (in $^\circ$, Cartesian or Nautical convention), as conventionally defined (Kuik *et al.*, 1988).

$$[DIR] = \arctan\left(\frac{\int \sin(\theta)E(\sigma,\theta)\; d\sigma d\theta}{\int \cos(\theta)E(\sigma,\theta)\; d\sigma d\theta}\right)$$

RTP — relative peak period (in s) of $E(\sigma)$ (equal to absolute peak period in the absence of currents)

DSPR — the one-sided directional width of the spectrum (directional spreading or directional standard deviation, in 0), defined as:

$$DSPR^2 = \left(\frac{180}{\pi}\right)^2 \int_0^{2\pi} \left\{2\sin\left(\frac{\theta-\bar{\theta}}{2}\right)\right\}^2 D(\theta)\; d\theta$$

and computed as conventionally for pitch-and-roll buoy data (Kuik *et al.* (1988); this is the standard definition for WAVEC buoys integrated over all frequencies):

$$\left(DSPR\,\frac{\pi}{180}\right)^2 = 2\left\{1-\left(\left(\int \sin(\theta)\frac{\int E(\sigma,\theta)\; d\sigma}{\int E(\sigma)\; d\sigma}d\theta\right)^2 + \left(\int \cos(\theta)\frac{\int E(\sigma,\theta)\; d\sigma}{\int E(\sigma)\; d\sigma}d\theta\right)^2\right)^{1/2}\right\}$$

MS — As input to SWAN in the commands BOUNDPAR and BOUNDSPEC the directional distribution of incident wave energy is: $D(\theta) = A\{\cos(\theta)\}^{[MS]}$ at all frequencies. [MS] is not necessarily an integer number.
[MS] is, for this directional distribution, related to the one-sided directional spread of the waves (DSPR) as follows:

[MS]	dspr (in $^\circ$)
1.	37.5
2.	31.5
3.	27.6
4.	24.9
5.	22.9
6.	21.2
7.	19.9
8.	18.8
9.	17.9
10.	17.1
15.	14.2
20.	12.4
30.	10.2
40.	8.9
50.	8.0
60.	7.3
70.	6.8
80.	6.4
90.	6.0
100.	5.7
200	4.0
400	2.9
800	2.0

DISSIP — energy dissipation per unit time due to the sum of bottom friction, whitecapping and depth induced wave breaking (in W/m^2 of m^2/s, depending on command SET)

WLEN — the mean wavelength,

$$WLEN = 2\pi \left(\frac{\int k^p E(\sigma,\theta)\ d\sigma d\theta}{\int k^{p-1} E(\sigma,\theta)\ d\sigma d\theta} \right)^{-1}$$

see command QUANTITY (where $p = 1$ is default)

STEEPNESS — wave steepness, computed as:

$$\text{STEEPNESS} = \frac{\text{HSIGN}}{\text{WLEN}}$$

Qb — fraction of breakers [-] in expression of Battjes and Janssen (1978), see section 2.1.

TRANSP — energy transport with components $P_x = \iint \rho g c_x E(\sigma,\theta)\ \ d\sigma d\theta$ and $P_y = \iint \rho g c_y E(\sigma,\theta)\ d\sigma d\theta$ with x and y of the problem co-ordinate system, except in the case of output with `BLOCK` command in combination with command `FRAME`, where x and y relate to the x-axis and y-axis of the output frame.

VEL — current velocity with components in x and y direction of the problem co-ordinate system, except in the case of output with `BLOCK` command in combination with command FRAME, where x and y relate to the x-axis and y-axis of the output frame.

FORCE — wave induced force per unit surface area (gradient of the radiation stresses) with x and y of the problem co-ordinate system, except in the case of output with BLOCK command in combination with command FRAME, where x and y relate to the x-axis and y-axis of the output frame.

$$F_x = -\frac{\partial S_{xx}}{\partial x} - \frac{\partial S_{xy}}{\partial y}, \quad \text{and} \quad F_y = -\frac{\partial S_{yx}}{\partial x} - \frac{\partial S_{yy}}{\partial y}$$

where S is the radiation stress tensor:

$$S_{xx} = \rho g \int \left(n \cos^2 \theta + n - \frac{1}{2} \right) E \; d\sigma d\theta$$

$$S_{xy} = S_{yx} = \rho g \int n \sin \theta \cos \theta E \; d\sigma d\theta$$

$$S_{yy} = \rho g \int \left(n \sin^2 \theta + n - \frac{1}{2} \right) E \; d\sigma d\theta$$

and n is the ratio of group velocity over phase velocity.

URMS root-mean-square value of the orbital motion near the bottom

UBOT root-mean-square value of the maximum of the orbital motion near the bottom $U_{bot} = \sqrt{2} U_{rms}$

LEAK numerical loss of energy equal to $c_\theta E(\omega, \theta)$ across boundaries $\theta_1 =$[dir1] and $\theta_2 =$[dir2] of a directional sector (see command CGRID)

SETUP the elevation of mean water level (relative to still water level) induced by the gradient of the radiation stresses of the waves

TPS Smoothed Peak wave period. This value is obtained as the maximum of a parabolic fitting through the highest bin and two bins on either side of the highest one of the discrete wave spectrum. This 'non-discrete' or 'smoothed' value is a better estimate of the 'real' peak period compared to the quantity RTP.

Cartesian direction convention: the direction is the angle between the vector and the positive x-axis, measured counter-clockwise (the direction where the waves are going to or where the wind is blowing to).

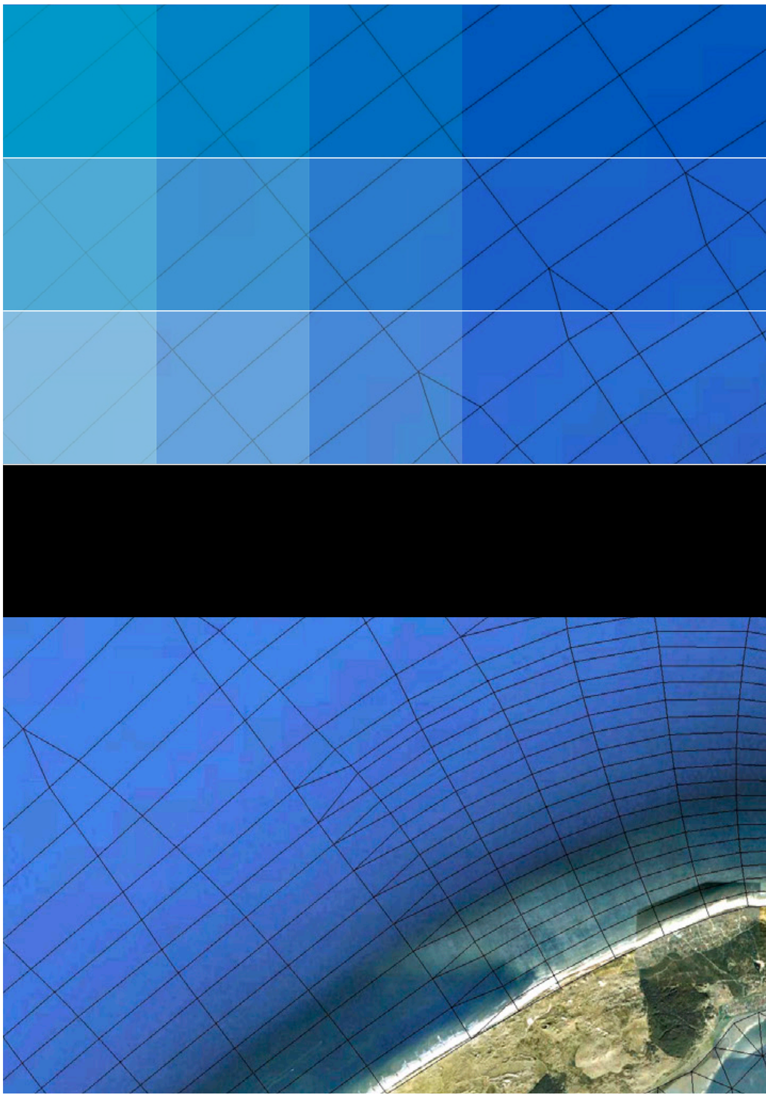
Nautical direction convention: the direction of the vector from geographic North measured clockwise + 180° (the direction where the waves are coming from or where the wind is blowing from).

C Example of MDW-file Siu-Lam

In this appendix the MDW-file for the Siu Lam case is provided <siu.mdw>. Generated by the WAVE-GUI 4.94.00:

```
[WaveFileInformation]
   FileVersion          = 02.00
[General]
   ProjectName          = Siu-Lam
   ProjectNr            = 001
   Description          = Tutorial Delft3D-WAVE
   Description          = Siu Lam model
   Description          = SWAN wave model using a curvilinear grid
   OnlyInputVerify      = false
   SimMode              = stationary
   DirConvention        = nautical
   ReferenceDate        = 2005-10-01
   ObstacleFile         = siu_lam_obstacles.obs
   WindSpeed            =  2.0000000e+001
   WindDir              =  2.5500000e+002
[TimePoint]
   Time                 =  1.0800000e+003
   WaterLevel           = -1.0000000e+000
   XVeloc               =  0.0000000e+000
   YVeloc               =  0.0000000e+000
[TimePoint]
   Time                 =  1.2600000e+003
   WaterLevel           =  0.0000000e+000
   XVeloc               =  0.0000000e+000
   YVeloc               =  0.0000000e+000
[TimePoint]
   Time                 =  1.4400000e+003
   WaterLevel           =  1.5000000e+000
   XVeloc               =  0.0000000e+000
   YVeloc               =  0.0000000e+000
[Constants]
   WaterLevelCorrection =  0.0000000e+000
   Gravity              =  9.8100004e+000
   WaterDensity         =  1.0250000e+003
   NorthDir             =  9.0000000e+001
   MinimumDepth         =  5.0000001e-002
[Processes]
   GenModePhys          = 3
   WaveSetup            = false
   Breaking             = true
   BreakAlpha           =  1.0000000e+000
   BreakGamma           =  7.3000002e-001
   Triads               = false
   TriadsAlpha          =  1.0000000e-001
   TriadsBeta           =  2.2000000e+000
   BedFriction          = jonswap
   BedFricCoef          =  6.7000002e-002
   Diffraction          = false
   DiffracCoef          =  2.0000000e-001
   DiffracSteps         = 5
   DiffracProp          = true
   WindGrowth           = true
   WhiteCapping         = Komen
   Quadruplets          = true
   Refraction           = true
   FreqShift            = true
   WaveForces           = dissipation
[Numerics]
   DirSpaceCDD          =  5.0000000e-001
   FreqSpaceCSS         =  5.0000000e-001
```

```
   RChHsTm01            =  2.0000000e-002
   RChMeanHs            =  2.0000000e-002
   RChMeanTm01          =  2.0000000e-002
   PercWet              =  9.8000000e+001
   MaxIter              = 4
[Output]
   TestOutputLevel      = 0
   TraceCalls           = false
   UseHotFile           = false
   WriteCOM             = false
   LocationFile         = siu.loc
   WriteTable           = true
   WriteSpec1D          = true
   WriteSpec2D          = true
[Domain]
   Grid                 = siu_lam.grd
   BedLevel             = siu_lam.dep
   DirSpace             = circle
   NDir                 = 36
   StartDir             =  0.0000000e+000
   EndDir               =  0.0000000e+000
   FreqMin              =  5.0000001e-002
   FreqMax              =  1.0000000e+000
   NFreq                = 24
   Output               = true
[Boundary]
   Name                 = Boundary 1
   Definition           = orientation
   Orientation          = west
   SpectrumSpec         = parametric
   SpShapeType          = gauss
   PeriodType           = peak
   DirSpreadType        = degrees
   PeakEnhanceFac       =  3.3000000e+000
   GaussSpread          =  3.3000000e+000
   DistanceDir          = counter-clockwise
   CondSpecAtDist       =  1.5000000e+003
   WaveHeight           =  0.0000000e+000
   Period               =  5.0000000e+000
   Direction            =  2.5500000e+002
   DirSpreading         =  4.0000000e+000
   CondSpecAtDist       =  9.0000000e+003
   WaveHeight           =  1.0000000e+000
   Period               =  5.0000000e+000
   Direction            =  2.5500000e+002
   DirSpreading         =  4.0000000e+000
```



Deltares systems

PO Box 177
2600 MH Delft
Boussinesqweg 1
2629 HV Delft
The Netherlands

+31 (0)88 335 81 88
sales@deltaressystems.nl
www.deltaressystems.nl