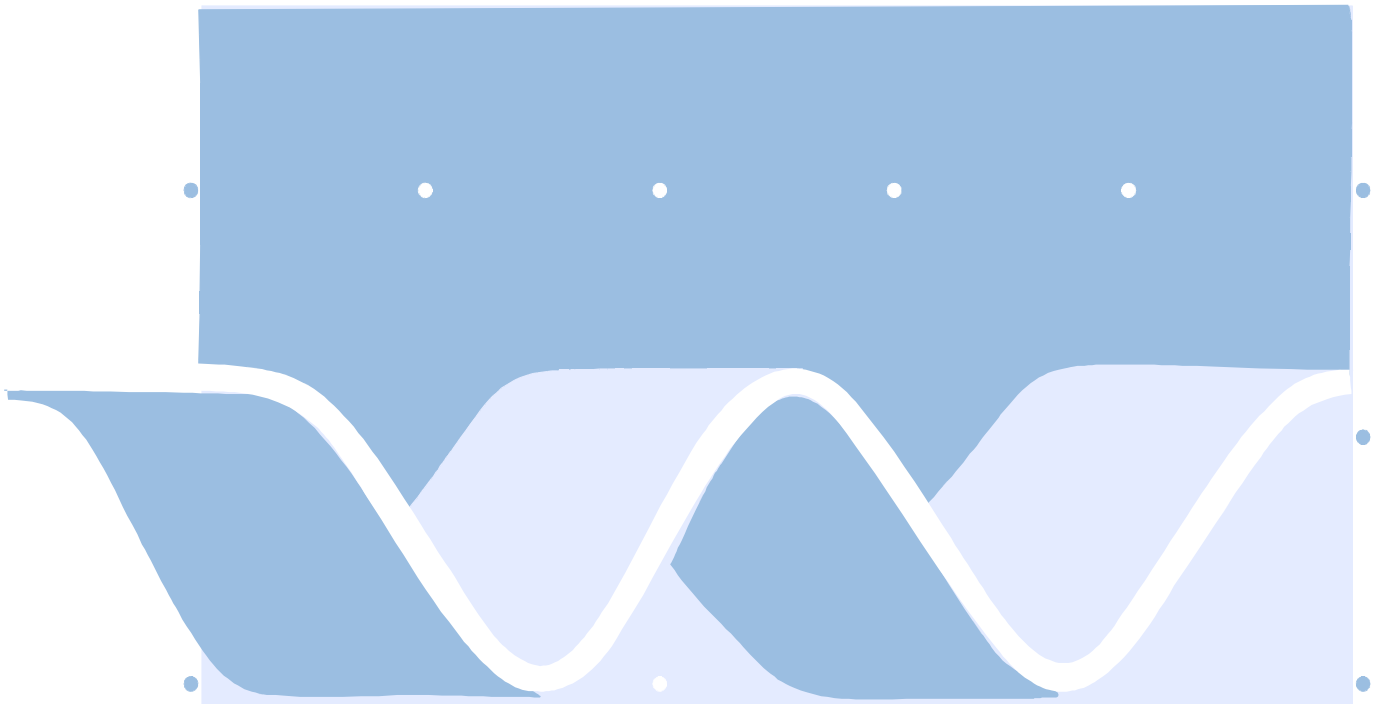

Prepared for:

Rijksinstituut voor Kust en Zee - RIKZ

Benchmarking database for Delft3D

Report

November, 2006

Z4099

WL | delft hydraulics

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D.J.R. Walstra and L. Koster

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ABSTRACT:

Numerical models have become one of the corner stones of coastal engineering and are often applied tools to obtain answers or solutions for a specific coastal question or problem. Essential phases in a proper modelling framework are calibration and validation. Calibration involves model parameter tuning such that optimum agreement with measurements is obtained. During the validation no optimisation of model performance is allowed, but the model with settings obtained during calibration is tested on other data. This gives an indication of the model's predictive capabilities for the problem under consideration.

This report describes the progress made of the short term morphology project with the collaborative research agreement between WL | Delft Hydraulics and RIKZ (VOP) concerning the Delft3D Testbank. This report focuses on the structural improvements made to the Delft3D testbank (adding cases, improving pre- and post-processing tools). Besides of that a description of the included datasets, processing tools and how to use the testbank is provided.

The testbanks primary purpose is to facilitate testing and validation activities using the Delft3D model. It provides ready made input files, pre- and postprocessing facilities which can consistently be applied for all (or a selection) of the available testcases. The testbank is designed for experienced modellers developing and improving Delft3D, also a basic understanding of Matlab is required.

REFERENCES: RKZ-1597 (VOP Raamwerk Z3944)

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1 Introduction

1.1 General

This report describes the progress made of the short term morphology project with the collaborative research agreement between WL | Delft Hydraulics and RIKZ (VOP) concerning the Delft3D Testbank. This report focuses on the structural improvements made to the Delft3D testbank (adding cases, improving pre- and post-processing tools). Besides of that a description of the included datasets, processing tools and how to use the testbank is provided.

The testbanks primary purpose is to facilitate testing and validation activities using the Delft3D model. It provides ready made input files, pre- and postprocessing facilities which can consistently be applied for all (or a selection) of the available test cases. The testbank is designed for experienced modellers developing and improving Delft3D. To ensure flexibility, low level matlab scripts are available which require a basic understanding of Matlab. Furthemore no precautions have been with respect to applying unrealistic model settings.

Although the testbank is primarily designed for internal use at WL | Delft Hydraulics, external users can use the testbank freely. The testbank has an open structure which allows for an easy extension of the datasets or modification of data or input files. The testbank could even be used in combination with other models. However, this requires a modification of the pre- and postprocessing scripts.

This report provides a comprehensive description of the structure of the testbank, datasets, and pre- and postprocessing facilities. It is highly recommended to read this report in conjunction with the testbank itself installed.

1.2 Testbank objectives

Numerical models have become one of the corner stones of coastal engineering and are often applied tools to obtain answers or solutions for a specific coastal question or problem. Essential phases in a proper modelling framework are calibration and validation. Calibration involves model parameter tuning such that optimum agreement with measurements is obtained. During the validation no optimisation of model performance is allowed because the model with settings obtained during calibration is tested on other data. This gives an indication of the model's predictive capabilities for the problem under consideration.

Until recently, various model settings and model versions were calibrated and validated on different data sets, thereby obscuring model performance in general. To overcome this, a database with existing laboratory and field data sets was constructed for the process-based morphological model UNIBEST-TC (Roelvink et al., 2000) with the aim to:

- integrate model and measurements,

- facilitate easy testing of model settings and versions against a wide range of conditions, and
- identify shortcomings in understanding of physical processes, both considering model formulations and measurements.

The past years the Testbank has proven to be a valuable instrument to store datasets, share them amongst modellers and validate profile models. Due to the continuous development of Delft3D, many of the relevant cross-shore processes have been implemented. The present version of Delft3D has all the functionality of a profile model (such as Unibest-TC). This has resulted in a gradual decrease of the Unibest-TC applications whereas the application of Delft3D has increased. Therefore it was necessary to upgrade the existing Delft3D testbank with the relevant cases from the Unibest-TC testbank.

Another development has been the increased use of Matlab and its links with Delft3D. In the original Testbank fortran-based programs were used e.g. for data extraction, and error analysis, only for the graphical post-processing Matlab was used. In the upgrade described in this report all data processing has been migrated to the Matlab environment.

This report describes the updated database structure, the various implemented data sets and an example on how the database can be used with different model settings.

The new testbank has been improved on the following topics:
- Facilitating an easy way to prepare new models based on a certain basis setting and testing (a set of) different models settings (e.g. enhanced modification of input files);
- Analysing different combinations of model results by plotting them against measurements and showing the effect of different parameters (improved post processing and visualisation tools);
- Performing a statistical analyses on model and measured data to give a quantitative idea of the performance (statistical analysis now based on Matlab scripts);
- Creating Delft3D-input file for a number of experiments.

1.3 Readers guide

Chapter 2: Benchmarking database for Delft3D
This chapter describes the data base structure and outlines how a new data set can be implemented.

Chapter 3: Benchmarking data sets: I. Laboratory measurements
Here, the implemented laboratory data sets are discussed. The set-up of the cases and runs included per data is described. For this particular project, a ‘basic’ model version has been developed.

Chapter 4: Benchmarking data sets: 2. Field measurements
This chapter is devoted to a description of the implemented field data sets and the corresponding model-data comparison.

Chapter 5: Statistical analysis
The database is accompanied by a Statistical Analysis Tool which allows quantifying model-data differences. With model performance statistics the effect of the improvement or reduction in model skill for different model settings can be easily quantified. Chapter 5 provides an example on the use of SAT.

Finally a list of conclusions for the reference performance of Delft3D and a list of recommendations for further research are provided in *Chapter 7*.

2 Benchmarking database for Delft3D

2.1 Introduction

The benchmarking database of Delft3D is intended to include datasets of various tests (field and laboratory) against which the model can be tested automatically for a wide range of settings. In this stage only data sets for profile models are included to compute cross-shore sediment transport and the resulting profile changes along a coastal profile of arbitrary shape under wave attack. Variation in wave- and tide-induced longshore transport rates can also be accounted for. Main applications are the simulation of sand bar dynamics and seasonal profile changes, as well as the design of beach nourishment schemes. The datasets that will be incorporated in the database should enable a complete qualification of the accuracy of the description of the implemented physical processes and the accuracy and reliability of the final results: the computed longshore sediment transport and the predicted profile development.

The installation of the database (provided on the CD-ROM) involves a simple copying of the entire contents of the CD-ROM to the desired directory on a PC. Because running the model will produce new files, sufficient hard-disk space should be available. The database cannot be run from the CD-ROM itself or from a network drive for which the database user has no write-permission. Furthermore, it is necessary to have Matlab installed.

2.2 Data sets

The testbank contains a set of nine tests of which five of them are taken from the original database, four new cases are added:

Table 2.1 Overview of available datasets.

Laboratory measurements	Field measurements
• Boers	• Egmond / Coast3D
• Lip11d-hydr	• Duck94, US
• Lip11d-morph	• Sand-ridge
• Reniers	• Grays Harbor, US
• H4357	

From Table 2.1 five data sets were part of the Unibest TC database and were converted to Delft3D models. Four new datsets were added in the present database, the H4357 dune erosion experiment and field experiments from Grays Harbor, Duck94 and the sand-ridge. The various data will be discussed more detailed in chapter 3 and 4.

The datesets mentioned so far are all cases with only 1 horizontal dimension (cross-shore or transect models). If other interesting datasets become available these can easily be included.

2.3 Structure

The database structure is similar to that of the Unibest-TC database (Roelvink et al., 2000) and mainly consists of three levels:

1. The primary level contains various test directories and the executable for the Benchmarking Tool;

The benchmarking tool is a Matlab based tool providing a simple way to work with the database. The objective is to facilitate a method for creating new models and analysing model results without having to enter all directories. With a simple double-click on the testbank-executable "testbank.bat", Matlab will guide the user through a number of possibilities. The matlab scripts are all stored in a directory named 'work', which is located at the level of the test-directories so copying of the full database will include access to the tool. For a more elaborated description, see Appendix A.

2. Within a test directory different case directories are present. The different cases are for example different initial bathymetries or different boundary (test) conditions. The case directories contain measured data and various Delft3D model directories. At this level an analysis directory is created as soon as the first plots are stored with the benchmarking tool.
3. The model directories contain the different models and its output in the form of the standard output together with the formatted output files created by the tool.

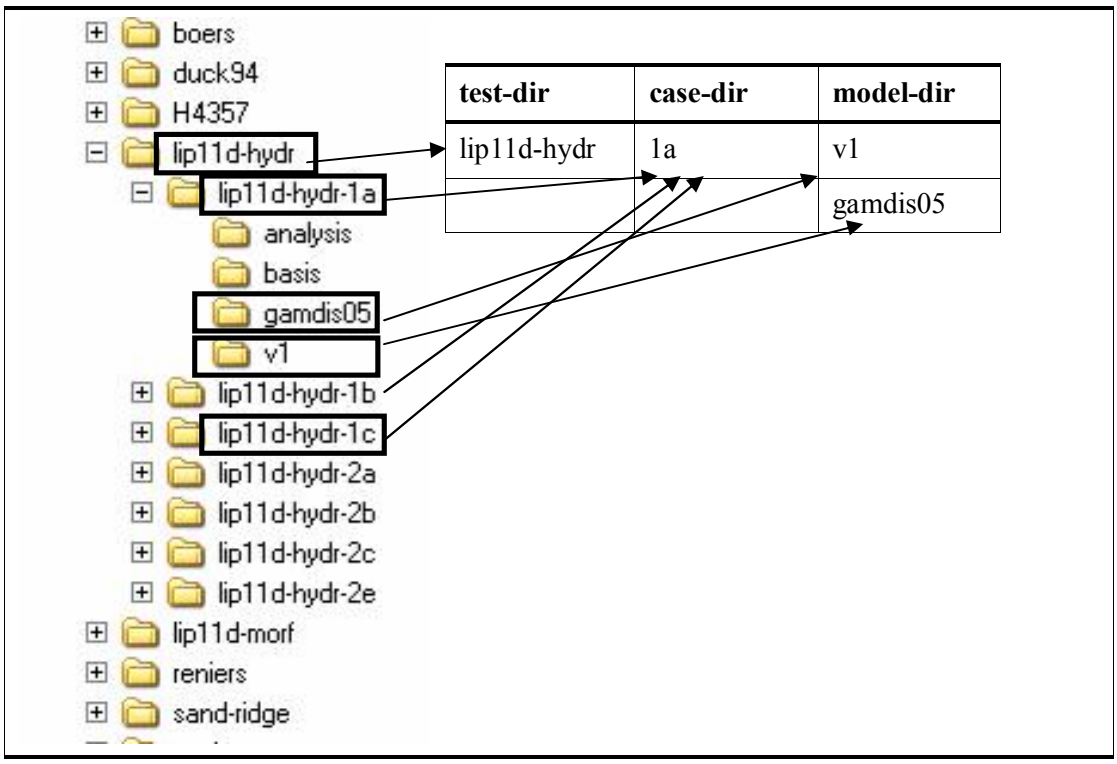

Figure 2-1 Database structure

Figure 2-1 illustrates the structure of the database. Test *Lip11d-hydr* contains 7 cases (1a*,1b,1c,2a,2b,2c* and *2e*). Case *1a* contains two Delft3D models: *v1* and *gamdis* which are based on the *basis* model located on the same level. Different plots and text files are stored in the *analysis* directory.

2.3.1 Case directories

The case directory contains the measured data on which the models are calibrated. These data are stored in a simple TEKAL-format, each containing only one physical parameter. The TEKAL-format comprises one data block with two columns. The first column is a time or space vector and the second is the measured parameter *e.g.* hrms or depth. The file names are standardised, which is necessary for the tool to recognise them and for further processing of the Delft3D output. The general layout of the names is as follows:

parameter	distribution	description
rtfX065	f(z)	Return flow profiles
concX065	f(z)	Concentration profiles
depth	f(x)	Profile depth
hrms	f(x)	Root mean square wave height
eta	f(x)	Water level
stotx	f(x)	Total transport in x-direction
uymean	f(x)	Mean velocity in y-direction
zt0001	f(x)	Profile depth at time
ztyear1997	f(x)	Profile depth in year

- <param> .tek time and location independent
- <param>Xxxx.tek at location x, time independent
- <param>Ttttt.tek at time t, location independent

2.3.2 Model directories

The basis directories contain the model files needed to run Delft3D (initial conditions, boundary conditions, parameters grids etc.). With the benchmarking tool new models can be created with a basis setting as reference. After running the model Delft3D output can be processed and the model data (results) are written to the described TEKAL-formats. Names of measured data- and model data-files are identical but on two different levels, making it easy to compare results.

Profile modelling

The modelling system applied in this study is the Sediment Online version of Delft3D, which is described in detail in Lesser et al. (2004). A crucial extension to the Delft3D-FLOW model, for coastal applications, is the capability to allow for alongshore water level gradients to be applied at lateral model boundaries (Roelvink and Walstra, 2004). To make the solution well posed a water level boundary is required at the seaward model boundary. Roelvink *et al.* (2004) demonstrated that applying Neumann boundary conditions allowed for reliable predictions to be made when using only one grid cell in the alongshore direction

(i.e. effectively reducing a 2DH/3D model to a 1DH/2DV model) under the combined forcing of (breaking) waves, wind and tide.

All profile models are run in 2DV mode with a varying horizontal grid resolution. The vertical grid consists of σ-layers with an increased resolution near the bed and water surface to accurately account for hydrodynamic and sedimentological phenomena (e.g. turbulence production due to breaking waves, streaming near the bed, and suspended sediment transport) in the flow equations and the associated turbulence model (k-ε, Walstra *et al.,* 2000). The roller model is used to obtain an accurate cross-shore wave forcing distribution. Snell's Law (implemented in Flow module) provides the wave direction across the profile. The state-of-the-art transport formulations of TR2004 (Van Rijn et al., 2004) including bed roughness predictors were applied to estimate transport rates and bed evolution. All model settings are initially set to default values.

2.3.3 Entering new dataset in database

The database has a very straight and clear structure in which model data and measurement data are stored at different levels. To ensure that the benchmarking-tool can be run, this structure should be preserved. Installation of the database involves copying of the entire database to a local disk after which running of the tool is possible. Together with the database Matlab and Delft3D are necessary. For successful usage of the database a number of steps have to be taken in case of entering a new dataset:

- Making a new test directory at highest level <test-dataset>;
- Dividing the test directory in cases. If only one case is tested a case directory has to be made as well <case>;
- Filling the case-dir with measured data in the described format of TEKAL-files;
- Making a basis Delft3D model with the directory-name 'basis'. The batch file must be named **run1.bat** <model>
- If the entering of the new dataset is finished successful, testing and analysing can begin.

3 Benchmarking datasets: 1. Laboratory measurements

3.1 Overview

In Table 3.1 an overview is given of the implemented laboratory measurements. A description of each data set and of the model-data comparison is provided in Sections 3.2 - 3.5.

Table 3.1 Overview of laboratory data sets and parameters

	Code	Waves and set-up	Current (2DV)	Current (3D)	Concen-trations and transport	Bottom change
Dune Erosion Delta Flume	H4357	*	*	*	*	z (x,t)
Arcilla et al. (1994) Delta Flume	LIP11D	Hrms Eta	u(z) urms guss, guls		c(z) Stotx	z (x,t)
Reniers et al. (1997)	Reniers	Hrms Eta		u,v urms		
Boers (1996)	Boers	Hrms Eta	u(z) urms guss, guls			

Hrms = root-mean-square wave height
Eta = set-up/down
u, v = cross-shore and longshore velocity
z = vertical (i.e., vertical profiles are available)
urms = root-mean-square cross-shore velocity
guss = short-wave velocity moment
guls = short-wave long-wave interaction velocity moment
c = sediment concentration
Stotx = total cross-shore sediment transport
*) = will be added later if data becomes available (expected early 2007).

3.2 Arcilla et al. (1994), Roelvink and Reniers (1995)

3.2.1 Dataset description

Arcilla et al. (1994) conducted a series of comprehensive morphological tests in the large-scale Delta Flume at Delft Hydraulics. Seven tests were carried out in two series. The first series, tests 1a, 1b and 1c, were carried out from an initial Dean-type profile, with a mildly sloping dry beach; the second series was carried out starting from an initial profile with a dune at the waterline but the same underwater profile. Extensive measurements were carried out of wave heights, water levels, flow profiles, wave asymmetry and long waves, concentration profiles and bottom changes. The latter were used to derive total transport

rates. Each test lasted 12 to 21 hrs and measurements were carried out throughout every wave hour.

The incident wave height, wave period, water level and sub-test duration for the different sub-tests are presented in Table 3.2.

Table 3.2 Test conditions for Arcilla *et al.* (1994)

Test code	Initial geometry	H_{mo} (m)	T_p (s)	water level (m)	Duration (h)
1a	Dean-type	0.9	5	4.1	12
1b	result of 1a	1.4	5	4.1	18
1c	result of 1b	0.6	8	4.1	13
2a	Dean-type with dune	0.9	5	4.1	12
2b	result of 2a	1.4	5	4.1	12
2e	result of 2b	1.4	5	4.6	18
2c	result of 2e	0.6	8	4.1	21

As the table shows the final profiles of test 1a and 1b are applied as initial profile for test 1b and 1c. The same is true for case 2 wherein the sequence is some different. The figure shows the initial profiles of the first and the last tests within the two cases.

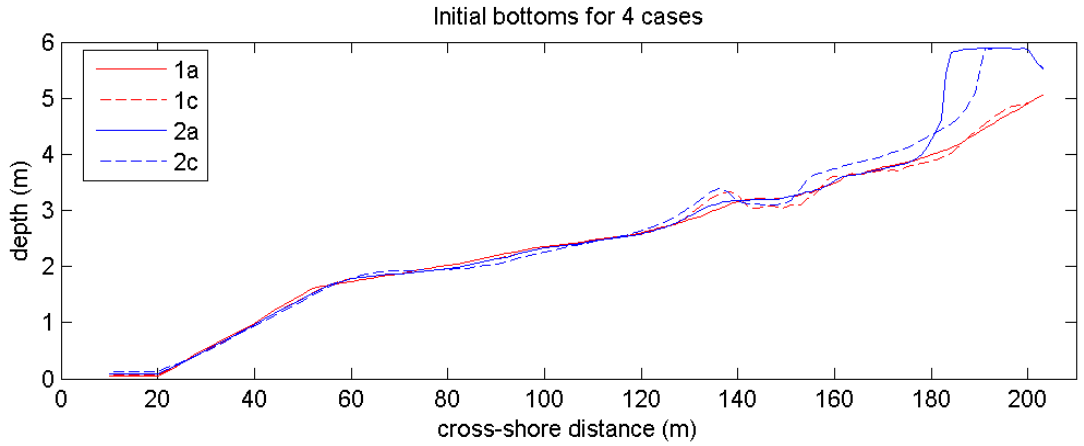

Figure 3-1 Initial profiles (solid) and final profiles (dots) for test 1 and 2

3.2.2 Model setup

In order to reduce the number of morphodynamic cases, the morphological and hydrodynamic results have been split over two datasets with different models, lip11d-hydr and lip11d-morf. Each hydrodynamic test was carried out for one profile somewhere in the middle (near 6 wave hours). Although not all data were collected at the same time this discrepancy was not too severe. Rather than carrying out complete morphological runs the sediment transports derived from the measured bed level changes is compared with the computed total transport rates. This reduces the data set to 7 cases.

3.2.3 Results

To show the functionality of the database in combination with the tool, an example is given for the standard model together with two variations on the gamma-expression (wave height to water depth ratio for breaking waves). In appendix 3.2 the results are plotted for both the hydrodynamic as the morphodynamic models with the following variation:

Table 3.3 Parameter settings for different model runs

Name	Parameter	Value
v1 (basis settings)	gamdis	ruessink *et al.* (2002)
gamdis05	gamdis	0.5
gamdis07	gamdis	0.7

In chapter 5 some more sensitivity testing is done and the performance has been analysed in a more quantitative, statistic way.

Hydrodynamics

Figure 3.2.1 shows the vertical velocity profile in cross-shore direction. Best predictions are seen for gamma =0.7 and Ruessink *et al.* (2002). However different locations show different results. Especially on deeper water little agreement is seen. Apparently calibration of the model is needed to get better results on sediment transports. Fig. 3.2.3 shows results on wave height and water level elevation. The effect of the gamma – expression is most clear for the wave heights. The lower plot shows the total sediment transport in x direction.

Morphodynamics

In case of bottom updating, Appendix 3.2.4, it is seen that different gamma-expression does not give large variation on the cross-shore profile. Overall the agreement with the measurements is good. For the gamma =0.7 and Ruessink *et al.* (2002) situations bar forming is seen at shallow water. The Ruessink expression shows the best results.

3.3 Reniers et al. (1997)

3.3.1 Dataset description

This dataset refers to experiments in the multi-directional wave basin at Delft Hydraulics, aimed at the study of shear instabilities of the longshore current. For this purpose, a barred beach was constructed at an angle of 30 degrees with respect to the wave paddles. The wave-generated longshore current was recirculated using a pump system and a careful layout of the inflow and outflow sections, resulting in quite uniform mean flow conditions. Most of the tests were carried out with regular waves, except for case SO014, which was done with random, unidirectional waves. The latter case has been included in the database.

Table 3.4 Test conditions for Reniers *et al.,* (1997)

Test code	H_s (m)	T_p (s)	water level (m)
SO014	0.1	1.2	0.55

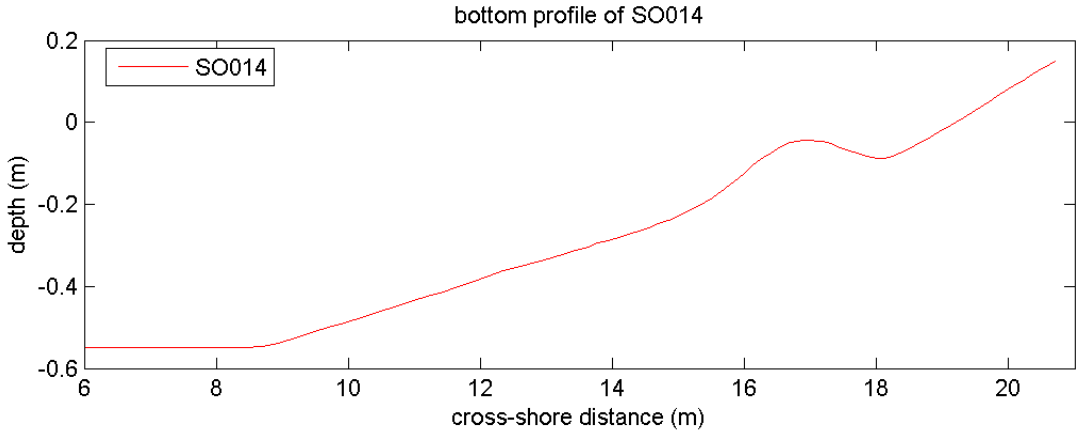

Figure 3-2 Profile Reniers *et al.* (1997), test SO014

3.4 Boers (1996)

3.4.1 Dataset description

This is an extremely detailed, high-quality set of hydrodynamic data in a wave flume at Delft University. This fixed-bed dataset is a reproduction of the mobile-bed dataset of LIP11D, allowing much more detailed study of the hydrodynamic parameters. Only a selection of the full dataset has been chosen for comparison with Delft3D:

- Hrms wave height
- Eta, wave setup
- RTFX, vertical profiles of the time-averaged horizontal velocity
- C, wave celerity across profile
- Guls, guss, velocity moments.
- Q, fraction of breaking waves (derived from video images)

Table 3.5 shows the different boundary conditions under which the Boers profile is exposed. The profile in the figure is the scaled profile of Lip11d-1a.

Table 3.5 Test conditions Boers (1996)

Test code	H_s (m)	T_p (s)	water level (m)
Boers-1a	0.15	2	0.75
Boers-1b	0.2	2	0.75
Boers-1c	0.1	3.3	0.75

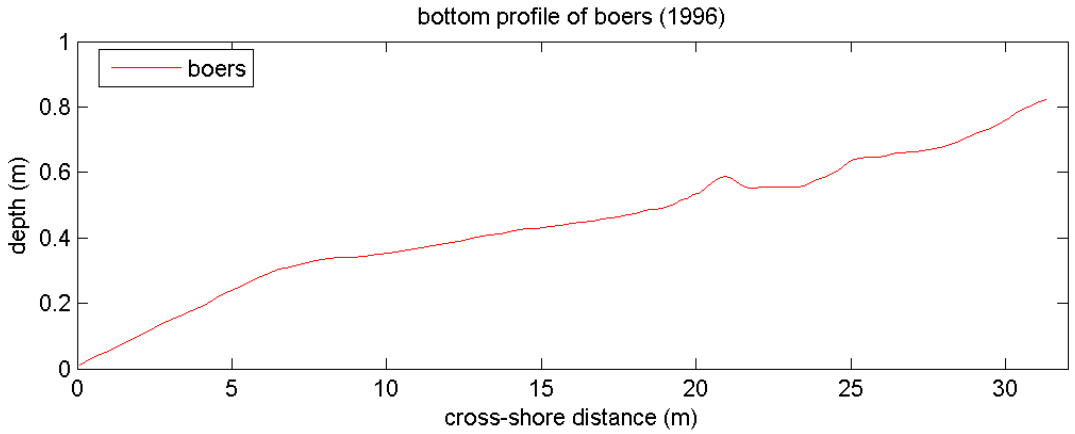

Figure 3-3 Profile Boers (1996)

3.5 H4357 Dune erosion

3.5.1 Dataset description

The objective of the physical model was to properly simulate dune erosion of a prototype coastal profile consisting of sediment characteristics representative for the situation at the Dutch coast during an extreme storm event. The scale at which the model was set up was aimed to be as close to prototype as possible to minimise scale effects. The wave flume in which the large scale physical model tests were carried out is the Delta flume of WL | Delft Hydraulics (WL | Delft Hydraulics, 2006). To translate the prototype situation to a model that fits in this flume, use is made of the scaling relations derived by Vellinga (1986).

The coastal profile which was used in the tests is based on the reference profile which is considered to be characteristic for the Dutch coast. The flume has an effective length, width and height of 225 m, 5 m and 7 m respectively. The scale at which the tests could be performed were restricted by the dimensions of the wave flume and on the capacity of the wave generator in the flume given the coastal profile and the hydraulic conditions expected during an extreme storm event at the Dutch coast.

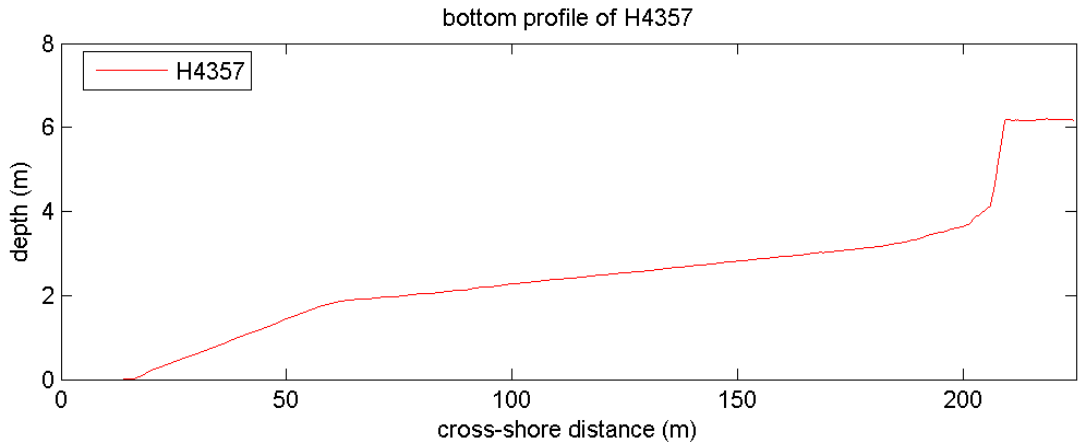

Figure 3-4 Initial profile for H4357 tests

Three dune erosion tests were carried out with a water depth of 4.5 m in the flume near the wave board. A water depth of 4.5 m corresponds with a water depth of 27 m in prototype. With a storm surge level of NAP +5 m, this results in a bed level of NAP 22 m near the wave board. The total duration of each test was 6 hours. In all three tests use was made of the same initial profile. Sediments with a diameter of $D_{50} = 200.10^{-6}$ m, wave heights of H_{m0} = 9 m and wave periods varying from T_p = 12 s to T_p = 18 s were applied and test conditions were determined for the scale of the flume, see Table 3.6. Profile, wave and flow velocity measurements were carried out.

Table 3.6 Test conditions H-4357

Test code	H_s (m)	T_p (s)	water level (m)
H4357-Test-01	1.5	4.9	4.5
H4357-Test-02	1.5	6.12	4.5
H4357-Test-03	1.5	7.35	4.5

4 Benchmarking data sets: 2. Field measurements

4.1.1 Overview

An overview of the implemented field data sets is provided in Table 4.1.

Table 4.1 Overview of laboratory data sets and parameters

	Code	Waves and set-up	Current (2DV)	Current (3D)	Concen-trations and transport	Bottom change
Sand ridge	Sand-ridge					z(x,t)
	Duck94	Hrms (t)		Uxmean, Uymean		z(x,t)
Grays Harbor						z(x,t)
Coast3D	Egmond Hyd	Hrms		u,v urms guss, guls	c(z)	z(x,t)
	Egmond Morph					z(x,t)
Egmond	Egmond Long					z(x,t)

Hrms = root-mean-square wave height
u, v = cross-shore and longshore velocity
(z) = vertical (i.e., vertical profiles are available)
z(x,t) = cross-shore bottom profiles (various moments in time)
urms = root-mean-square cross-shore velocity
guss = short-wave velocity moment
guls = short-wave long-wave interaction velocity moment
c = sediment concentration

4.2 Sand-ridge (Tonnon, 2005)

4.2.1 Data set description

From 1982 to 1986 dumpings at Hoek van Holland created an artificial sand ridge, known as sand ridge Hoek van Holland, of about 3600 m normal to the peak tidal current and the shore, (location Hoek van Holland in an area with depths between 15 m and 23 m on the northern side of the approach channel. In all, 3.5 million m^3 sand was dumped over the period 1981 to 1986 (Van Woudenberg, 1996). The ridge dimensions just after creation of the ridge were: length of about 3600 m; toe width between 250 m and 370 m; height between 1.3 and 4 m; slopes between 1:50 and 1:100 on the southern flank and between 1:20 and 1:50 on the northern flank; d50 between 0.15 mm and 0.45 mm. The landward end of the ridge is about 6300 m from the shoreline.

The sand ridge Hoek van Holland is located close to Loswal Noord, which is a dumping site for class I and II silt from the Rotterdam harbour mouth. The ridge is perpendicular to the coast and thus normal to the tidal flow. Primary goals were to study the stability of a submerged ridge, normal to the tidal flow and to study the effect of the ridge on shoreface sand transport. Also the possible use of submerged ridges as silt traps for backflow of silt from Loswal Noord to the port of Rotterdam was an issue. Furthermore similarities with sand waves were to be investigated.

Figure 4-1 shows a schematic plan view of the sounding area and sections, sections are 400 m apart and run over the entire length of the sounding area, which is about 2200 m.

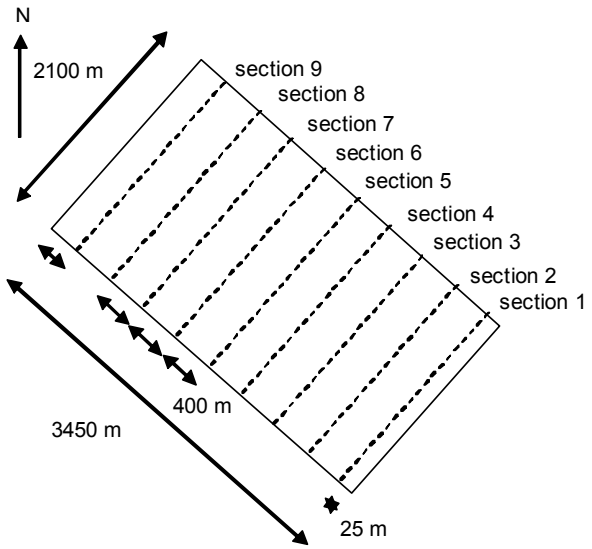

Figure 4-1Schematic plan view of the sounding area and sections (section 1 is about 6 km from the coast)

4.2.2 Cases and model set-up

Case

For the reproduction of morphological development section 4 has been chosen. Nearly every year bathymetric surveys were carried out. The dataset contains depth measurements for section 4, over the period 1986-2000. Figure 4-2 shows the morphological development of section 4 in 14 years time. The profile measurements in the dataset are named *e.g.* Ztyear1996.

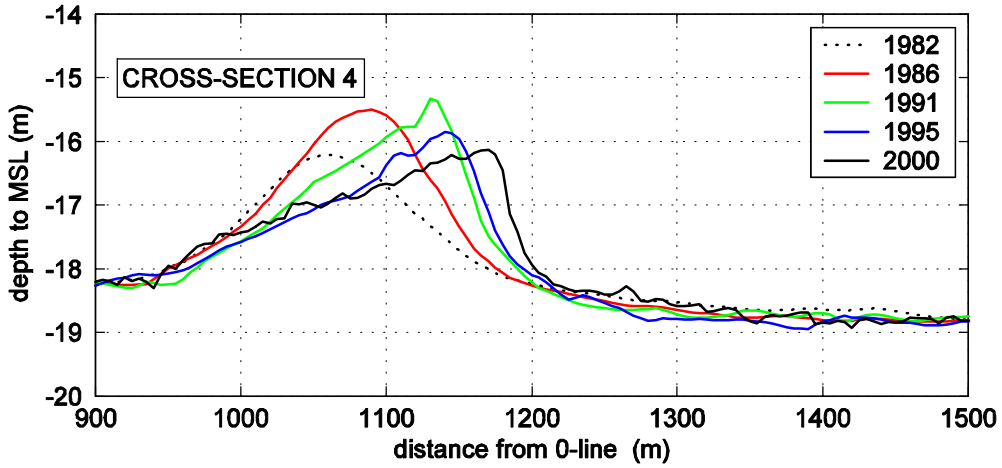

Figure 4-2 Measured bed level developments for section 4

Model set-up

For the database the model of Tonnon (2005) has been transformed to a transect model (oriented East-West). The 2DV model consists of 20 layers with a bottom layer thickness of 2% at the bottom.

Boundary conditions

To reduce computational time, a representative, morphological tide was derived using the method of Latteux (1995). The morphological tide gives an optimal representation of the residual (e.g. yearly averaged) sediment transports. The harmonic components are described in the input file: morphtide4.bch. The single representative wave from Walstra et al. (1997) was derived to give the best representation of the overall, yearly wave climate at location Euro-Maas channel by applying the Latteux method to evaluate residual transports.

Table 4.1 Applied wave schematisation

Wave schematisation	H_s (m)	T_p (s)	Direction (^{0})
Walstra *et al.* (1997)	2.25	6.6	335

Parameter settings

Main differences with the general parameter settings are the following:

Table 4.2 Different parameter settings for Sand-ridge model

Parameter	Setting
D50	300 μm
Turbulence model	Algebraic
sus, bed, susw and bedw	0,4

4.2.3 Results

Appendix 4.2 shows the best result of Tonnon (2005). Most important finding of this model is that the bed roughness has a dominant effect on the ratio of bed load and suspended load transport, on the net annual transport rate and on the migration rate of the ridge; the bed evolution after 15 years can be very well represented by using a variable bed roughness (based on a predictor) neglecting the effect of megaripples resulting in C-values of about 80 $m^{0.5}/s$.

4.3 Grays Harbor (Walstra et al., 2005)

4.3.1 Data set description

During the Grays Harbor Sediment Transport Experiment (Landerman et al., 2005) instrumented tripods collected time series of waves, near-bottom velocities, and proxies for suspended sediment concentrations at 6 locations on the inner shelf and upper shoreface (Figure 4-3). Between 4 May and 11 July 2001, the tripods measured conditions during the relatively mild rebuilding phase of the beaches. Data from two stations, (MIA/MIB) in relatively shallow water (~8 m MLLW) and placed approximately 50 m apart, are used in this data set for the boundary conditions. During the field deployment, the mean significant wave height was 1.7 m with waves approaching generally from the WNW, conditions suggesting southerly longshore sediment transport.

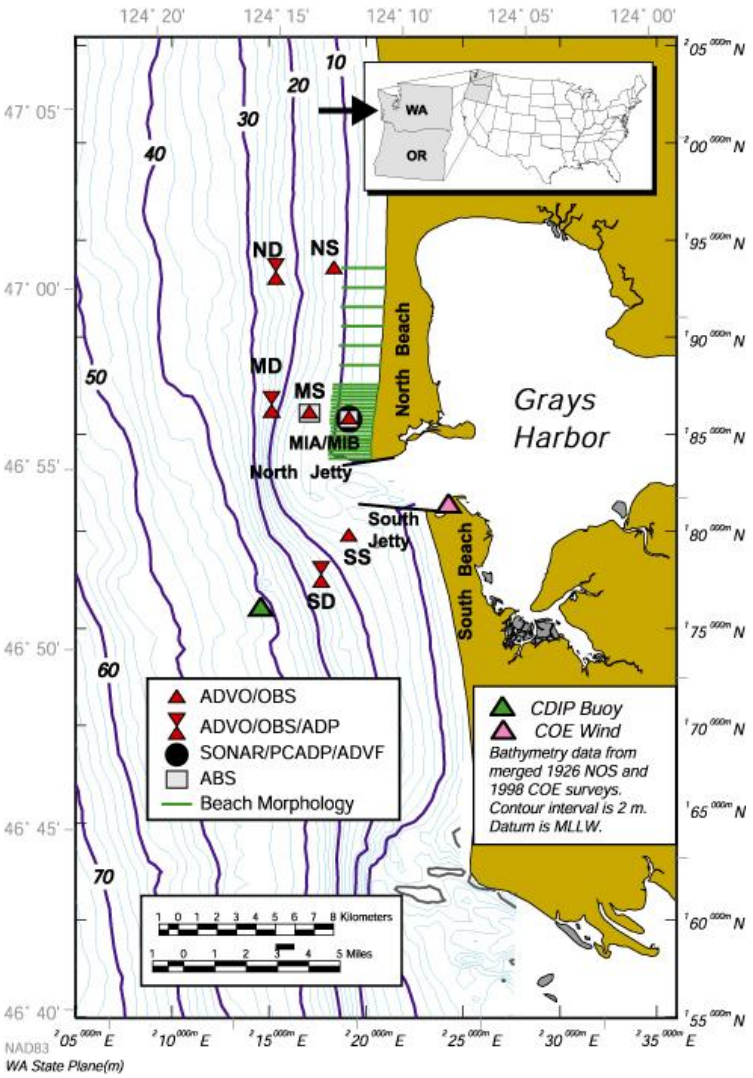

Figure 4-3 Chart of study area near Grays Harbor Transect lines for nearshore bathymetric surveys are shown in green (after Ruggiero et al., 2003).

Regular topographic and bathymetric surveys quantified both the beach and sandbar change during the transition from winter to summer conditions (Ruggiero et al., 2005). Weekly topographic surface maps (10 surveys) and monthly nearshore bathymetric surveys (5 surveys, profiles spaced at 200 m) mapped the active nearshore planform from the toe of the primary dune (~ 5 m MLLW) to below the limit of measurable annual change (~12 m MLLW) within 4 km of the Grays Harbor North Jetty.

4.3.2 Cases and model set-up

Cases

Two individual cross-shore transects located only 2 km apart illustrate this alongshore variability in the response of the outer bar (Tran 11 and Tran 20). At Transect 11 the outer bar migrated onshore approximately 175 m between 29 March and 6 August 2001. At Transect 20 the outer bar migrated onshore only approximately 40 m during this same time period (Figure 4-4).

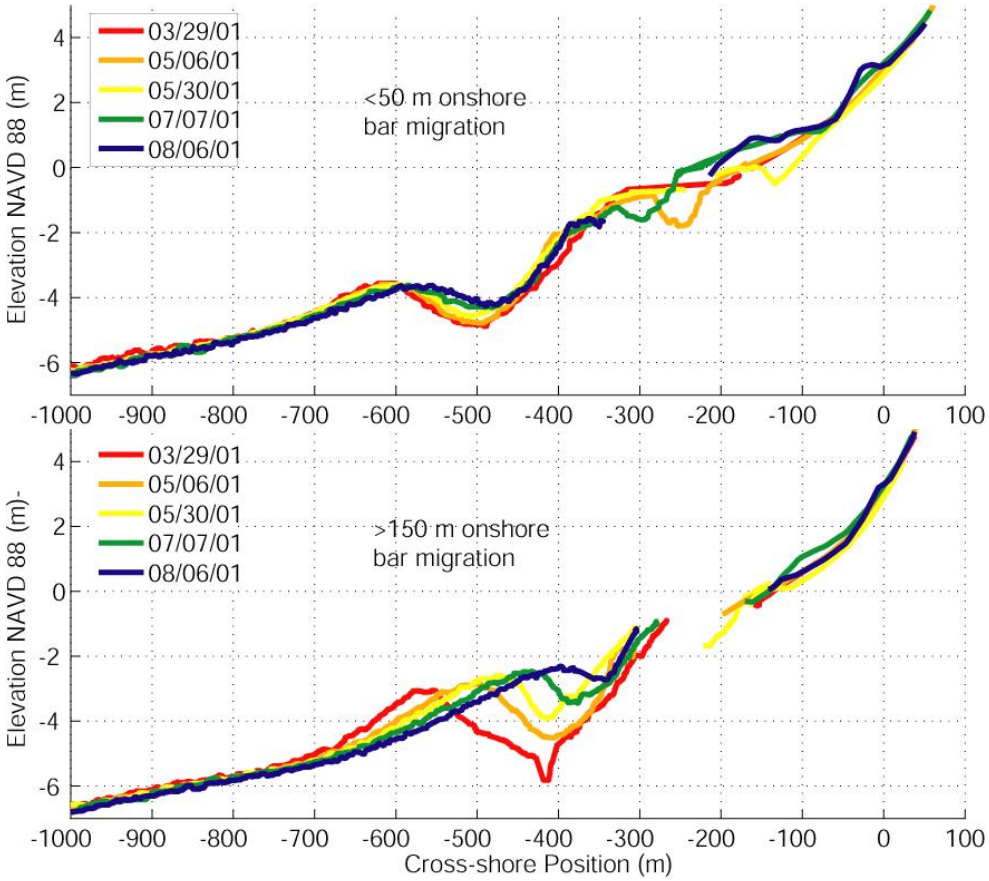

Figure 4-4 Observed cross-shore profile changes during the Spring 2001 experiment (Top: Transect 20, Bottom: Transect 11).

Model set-up

The profile evolution model is run in 2DV mode with a horizontal grid resolution increasing from 50 m at the offshore boundary to about 5 m in the surf zone. The vertical grid consists of ten σ-layers with an increased resolution near the bed and water surface. The profile evolution model performance was evaluated in Walstra *et al.* (2005) at both Transects 11 and 20 (identical forcing, but different initial profiles) by varying tuning parameters on the predicted transports and wave induced streaming, increasing the amount of (breaker) delay built into the roller model, and varying the sediment characteristics. In total 40 combinations were investigated at both cross-sections, leading to the following model parameters:

Table 4.3 Model parameters for Grays Harbor basis model

Parameter	Description	Setting
$f_{s,c}$	factor on suspended transport due to currents	0.3
$f_{b,c}$	factor on bed load transport due to currents	1.0
$f_{s,w}$	factor on suspended transport due to wave motion	1.0
$f_{b,c}$	factor on bed load transport due to wave motion	0.8
f_{lam}	breaker delay expressed in local wave length	2.0
$f_{streaming}$	Scaling factor on wave induced streaming	0.5
D_{50}	Median sediment diameter	220

4.4 Duck (1994)

4.4.1 Data set description

The data were collected during September and October 1994 near Duck, North Carolina on a barrier island exposed to the Atlantic Ocean. Wave statistics (H_{rms}, peak period, and energy) were estimated from a two-dimensional array of 15 bottom-mounted pressure sensors at 8 meter depth. Pressure and velocity observations were obtained at 13 cross-shore positions extending from near the shoreline to 4.5-m depth. Spatially extensive bathymetric surveys obtained occasionally with an amphibious vehicle and cross-shore depth profiles obtained continuously with altimeters (Gallagher *et al.*, 1998) show that the bar migrated offshore 120 m during the experiment, but only 50 m during the first 1000 hrs. Alongshore non-uniformities in the bar were small for t < 1000 hr, when a broad cross-shore channel developed near the measurement transect. Hereafter large offshore development was seen as a result of storm conditions (Figure 4-5).

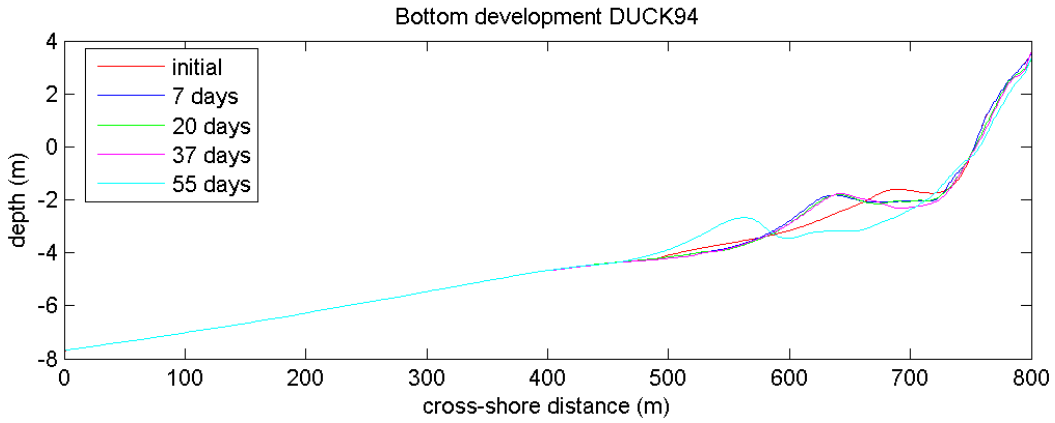

Figure 4-5 Bottom profile measurements for DUCK94

The dataset of DUCK94 includes the following parameters: HrmsX, zTtttt (in hours), UxmeanX and UymeanX.

4.4.2 Model set-up

The boundary conditions were conducted from hourly measured water level and wave properties resulting in time series. The same parameter settings are applied for the model as for the other datasets in the database. A vertical grid with 11 layers and horizontal grid with 4 meter grid width on the seaward boundary to 2 meters on the dry beach was used for the computational model.

4.5 Egmond Hydrodynamic

4.5.1 Data set description

The Egmond site is located in the central part of the Dutch North Sea coast and is dominated by two well-developed shore-parallel bars intersected by rip channels. In the framework of the Coast3D project, two field campaigns were executed, a pilot campaign in spring 1998 and a main campaign in autumn 1998 (Van Rijn et al., 2002). During the experiments, a large variety of instruments, such as pressure sensors, wave buoys and current meters, were deployed. An overview can be found in Appendix B and in Ruessink (1999). Contrary to the pilot campaign, the main experiment witnessed severe conditions. Large waves, strong wind and water level rises due to storm surges were present, resulting in considerable morphological change (e.g. bar movement, lowering of bar crests and the presence of rip channels).

Two Coast3D data sets were added to the database: Egmond Hydrodynamic and Egmond Morphodynamic. For both data sets, four cases were defined: pre-storm, storm, post storm, and total period. Egmond Morphodynamic is described in Section 4.6.

4.5.2 Cases and model set-up

Cases

For the reproduction of the hydrodynamics at Egmond during the Egmond Main measurement campaign we have chosen the following cases:

	Burst nr.	Date-time	Tot. days
Pre-storm	9180-9324	18-10-98 12:00 - 24-10-98 12:00	6
Storm	9324-9492	24-10-98 12:00 - 31-10-98 12:00	7
Post-storm	9492-9780	31-10-98 12:00 - 12-11-98 12:00	12
Total period	9180-9780	18-10-98 12:00 - 12-11-98 12:00	25

The burst numbers are based on conventions regarding measurement administration in the COAST3D project. Burst numbers can be linked with actual dates and times. Burst number 9180 corresponds with noon 18 October 1998 and each burst is valid one hour exactly (e.g. burst number 9181 corresponds with 13:00, 18 October 1998). To facilitate comparison of model results and measurements we have chosen burst number 0 as the starting time of the modelling exercise. Consequently, burst numbers divided by 24, yield the corresponding input for our Delft3D model. For the geographical orientation we have chosen to take the offshore DIWAR buoy as the origin for the modelling exercise with the positive x-axis to be in the shoreward direction (see Figure 4.1). Positive y is directed alongshore in northward direction.

The cases of the hydrodynamic dataset include the following parameters: Hrms, Uxmean, Uymean, Guss and Guls. For Hrms, Uxmean, Uymean, Guss and Guls we include measurements from stations 7a, 2, 1a, 1b, 1c and 1d. The measurement stations are located at the following positions (Figure 4-6):

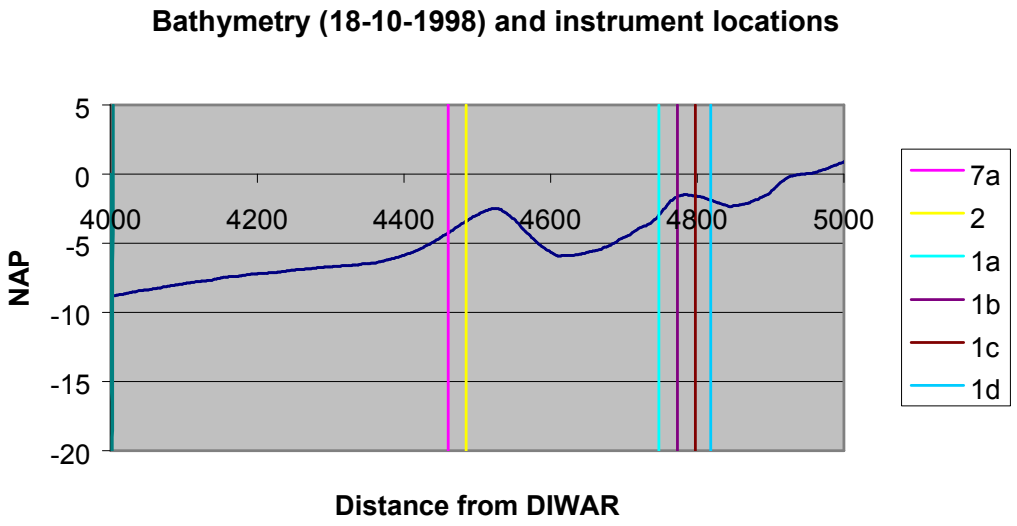

Figure 4-6 cross-shore profile and instrument locations

For these parameters we include measured profiles and time series. The time series are given at the measurement locations measured from DIWAR and are named HrmsXxxxx.tek, UxmeanXxxxx.tek, UymeanXxxxx.tek, GussXxxxx.tek and GulsXxxxx.tek, respectively. The profiles include the data from the measurement locations at a large number of time points evenly distributed over the case periods. The profiles are named HrmsTtttt.tek, UxmeanTtttt.tek, UymeanTtttt.tek, GussTtttt.tek and GulsTtttt.tek.

Model set-up

For the database a profile model was constructed (see Roelvink and Walstra, 2004). The 2DV model consists of 20 layers with a bottom layer thickness of 2% at the bottom. The model is forced with the measured wind and waves conditions. The tide is derived from the tidal station enclosing the Egmond site (IJmuiden and Petten). The model is driven by astronomical components derived using the method described in Roelvink and Walstra (2004).

4.6 Egmond Morphodynamic

4.6.1 Cases

For the reproduction of the morphodynamics at Egmond during the Egmond Main measurement campaign we have chosen the same cases as for the hydrodynamics.

4.6.2 Measurements

The bottom profiles for each case have been included.

4.6.3 Reference model

Reference model is identical to the hydrodynamic version. Futher tuning is expected to take place in the course of the present project. This section will be updated accordingly.

4.7 EgmondLong

4.7.1 Dataset description

This dataset consists of yearly profile measurements near Egmond, profile 39.500, over a period of 18 years from 1979 to 1997, and associated boundary conditions. A full description can be found in Boers and Walstra (1999).

4.7.2 Model setup

This model has not yet been verified, will be added later (but not in the course of the present project).

5 Statistical analysis

5.1 Statistical tool

The question of how well a model performs should be defined in a more quantitative manner than by judging model performance only visually. This is often sufficient during early stages of a project (e.g., parts of the calibration phase), but the final model qualificattion requires objective quantitative Model Performance Statistics (MPS). This chapter defines the statistical parameters which are applied in the benchmarking tool described in Appendix A. After selection of a number of models within one test case, the tool creates plot and a statistical file in which model performance for the various models is summarised. In this way a large number of model settings can be evaluated in one table or graph without having to go into detail of the underlying data. This will give insight into the quality of the predictions, but also provides information on the range of the predictions and the implications this may have for further use of the model. Later on in this chapter an example will show the functionality of the model statistical performance.

5.2 Model performance statistics

At present the following statistics have been implemented:

Table 5.1 Model performance statistics

Parameter	Description	Ranges
Bias	Systematic error of the mean	low value is low systematic error
SDEV	Standard deviation of the error	unbiased estimator of the variance
RMSE	Root Mean Square Error	0: perfect prediction
MAE	Mean Absolute Error	0: perfect prediction
r	Correlation	0: no correlation; 1: perfect correlation
BSS	Brier Skill Score	see below

The mean error $\left[ME = \frac{1}{N}\sum_{i=1}^{N}\left(f_{comp.,i} - f_{meas.,i} \right) \right]$ and standard deviation of the error $\left[SDEVE = \left(\frac{1}{N-1}\sum_{i=1}^{N}\left(f_{comp.,i} - f_{meas.,i} - ME \right)^2 \right)^{\frac{1}{2}} \right]$ of a time series at a point are a useful measure of model performance for quantities such as wave height or water level. The standard deviation is in general not so useful when applied to a bathymetry. A general form of the average difference between measurements is the Root-Mean-Square Error.

$$RMSE = \left(\frac{1}{N} \left(\sum_{i=1}^{N} \left(f_{comp.,i} - f_{meas.,i} \right)^2 \right) \right)^{1/2}$$

The Mean Absolute Error (*MAE*) is written as:

$$MAE = \frac{1}{N} \sum_{i=1}^{N} \left| f_{comp.,i} - f_{meas.,i} \right|$$

The presence of a few outliers will have a greater influence on *RMSE* than on *MAE* as RMSE squares the differences. The *MAE* is therefore less susceptible to the presence of outliers. The importance of the outliers may be emphasised by the use of *RMSE* if it is important not to have any points with very large differences between predicted and observed values. In general either one set of statistics or the other will be quoted. The set based on squared errors will, no doubt, become the most widely used due to familiarity, but the set based on mean absolute values is not so heavily skewed by a few outliers.

The correlation coefficient *r* is a measure of how strong a correlation is but not how significant the correlation is because the distributions of the series are not taken into account.

The performance of a model relative to a baseline prediction can be judged by calculating the Brier Skill Score. This skill score compares the mean square difference between the prediction and observation with the mean square difference between baseline prediction and observation.

$$BSS = 1 - \frac{MSE}{\overline{MSE}} \quad 1 - \frac{\frac{1}{N} \sum_{i=1}^{N} \left(z_{b,c} - z_{b,m} \right)^2}{\frac{1}{N} \sum_{i=1}^{N} \left(z_{b,0} - z_{b,m} \right)^2}$$

where $z_{b,c}$ is the computed bottom, $z_{b,m}$ is the measured bottom and $z_{b,0}$ is the initial bottom (variables taken at each cross-shore coordinate i).

Perfect agreement gives a Brier score of 1, whereas modelling the baseline condition gives a score of 0. If the model prediction is further away from the final measured condition than the baseline prediction, the skill score is negative. The BSS is very suitable for the prediction of bed evolution. The baseline prediction for morphodynamic modelling will usually be that the initial bed remains unaltered. In other words, the initial bathymetry is used as the baseline prediction for the final bathymetry. A limitation of the BSS is that it cannot account for the migration direction of a bar; it just evaluates whether the computed bed level (at time t) is closer to the measured bed level (at time t) than the initial bed level. If the computed bar migration is in the wrong direction, but relatively small; this may result in a higher BSS compared to the situation with bar migration in the right direction, but much too large. The BSS will even be negative, if the bed profile in the latter situation is further away from the measured profile than the initial profile. The limitation shown here is that

position and amplitude errors are included in the BSS. Distinguishing position errors from amplitude errors, requires a visual inspection of measured and modelled profiles or the calculation of further statistics (Murphy and Epstein, 1989; Peet et al., 2002). The BSS can be extremely sensitive to small changes when the denominator is low, in common with other non-dimensional skill scores derived from the ratio of two numbers.

Table 5.2 Brier Skill Score quantification (Van Rijn et al., 2002).

Qualification	**Brier Skill Score**
Excellent	1.0 - 0.8
Good	0.8 - 0.6
Reasonable fair	0.6 – 0.3
Poor	0.3 – 0.0
Bad	< 0.0

5.3 Practical Example

In chapter 3 an example of the Lip11D-1A test was discussed. In the example variation on the gamma-expression, with the Ruessink-expression as reference, for wave breaking led to different results which were analysed visually. In the present case the factor for the gamma-expression was varied from 0.5 to 1.0 with inclusion of the ruessink expression. Analysing the root mean square wave height for the initial case and the bottom profile for the morphodynamic case shows the following statistical model performances:

Hrms

Figure 5-1 shows the wave heights in cross-shore profile for the 6 different factors for the gamdis which is included in the wave Roller model. The red dots represent the measured values. Statistical model performance analysis (Table 5.3) shows that a factor of 0.8 for the gamdis gives the best result for the wave height prediction. Remarkable is that even values of 0.7 and 0.9 give better predictions (based on MAE) than the Ruessink expression does.

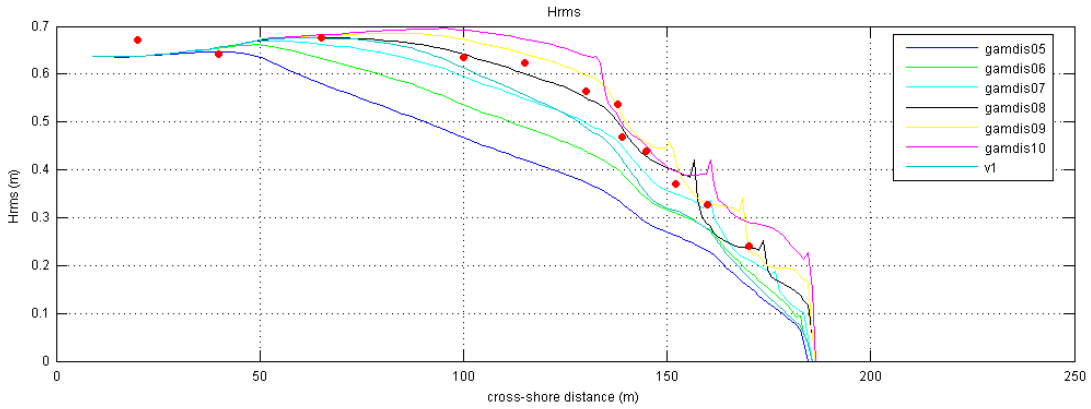

Figure 5-1 Hrms for 6 different settings of the gamma-expression

Table 5.3 Statistical model performance for the Hrms

Test	Correlation	MAE	RMSE
Gamdis = 0,5	0.9106	0.1198	0.1349
Gamdis = 0,6	0.9527	0.0719	0.0832
Gamdis = 0,7	0.9816	0.0339	0.0411
Gamdis = 0,8	**0.9904**	**0.0159**	**0.0201**
Gamdis = 0,9	**0.9904**	0.0244	0.0287
Gamdis = 1,0	0.9790	0.0348	0.0416
Ruessink *et al.* (2002)	0.9844	0.0430	0.0525

Bottom profile

In contrast with the performance for the wave height the bottom profile is best predicted for the Ruessink expression. Although the Brier Skill Score qualifies the model as Reasonable so more calibration of the model is needed, the Ruessink expression gives the best result here. For factors of 0.5, 0.8 and 0.9 values are negative, meaning that the predictions are bad and that the bed profile is further away from the measured profile than the initial profile. Remarkable is that a gamdis of 0.6 gives better results now than for factors of 0.7 and 0.8.



Figure 5-2 Bottom profile after 12 hours of morphological development

Table 5.4 Statistical model performance for bottom profile development

Test	**BSS**
Gamdis = 0,5	-0.0244
Gamdis = 0,6	0.2330
Gamdis = 0,7	0.0453
Gamdis = 0,8	-0.9576
Gamdis = 0,9	-3.1569
Gamdis = 1,0	-5.1029
Ruessink *et al.* (2002)	**0.3338**

It can be concluded that model performance for hydrodynamic and morphodynamic model do not automatically have to give similar results. As hydrodynamics differ during morphodynamic computing and have large impact on profile development it is of importance to predict hydrodynamics right before starting to update the bottom.

6 Recommendations

6.1 Application of the testbank

We think the overhaul of the testbank so that it can now be used for Delft3D is a major improvement. Its open structure will allow an easy modification or extension and increase the efficiency of validation/calibration studies.

Some of the included Delft3D models require further testing and calibration. Especially the morphological models will require constant updating because of changes in the code can have a relative large (cumulative) impact on the predicted morphology.

6.2 Data sets

The number of datasets has been reduced, only the datasets which benefit the validation have been included (e.g. similar types of datasets are not duplicated).

There are also opportunities to integrate data obtained with the Argus video technique. At the moment we are working on exploring various opportunities to couple the data generated with Argus and Delft3D. In the final report we will describe the outcome this activity.

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A Benchmarking – Tool

<matlab.m> is making reference to the matlab file in the work directory.

The benchmarking tool is a Matlab based tool providing a simple way to work with the database. The objective is to facilitate a method for creating new models and analysing model results without having to enter all directories. With a simple double-click on the testbank-executable "testbank.bat", Matlab will guide the user through a number of possibilities. The matlab scripts are all stored in a directory named 'work', which is located at the level of the test-directories so copying of the full database will include access to the tool.

Double-clicking of the executable will start the procedure and the first screen will provide a choice between the two main user functions: i) making new model run and ii) comparing model results. <overall.m>

A.1 Making new models

By choosing the option of making a new model run the user is guided to choose different cases within a test for which the new model is made. By choosing for example two cases, new models will be made with the same parameters for the two different cases. In this way the influence of various parameters can be checked on various cases. By entering finish a model name for the new models have to be entered. Within the chosen cases new directories are directly made with the name of the new models and the input files (model settings) of the basis model. The interface structure is given in Figure 7-1.

Next step is changing the input files per model. Step by step the user can enter a parameter within the input files (*.mdf, *.mor, *.sed and the wavecon) after which the value of this parameter can be changed. After entering 'finish' a new model is created for the different cases and (dependent on the number of new models) the next model is ready for adapting. Per model a file (report.txt) is created within the model directory in which information is given on the changes.

After finishing the preparation of the new models a batch file is created and stored at the level of the testbank-executable (run.bat). Double clicking will run the new models and terminate the Matlab tool.

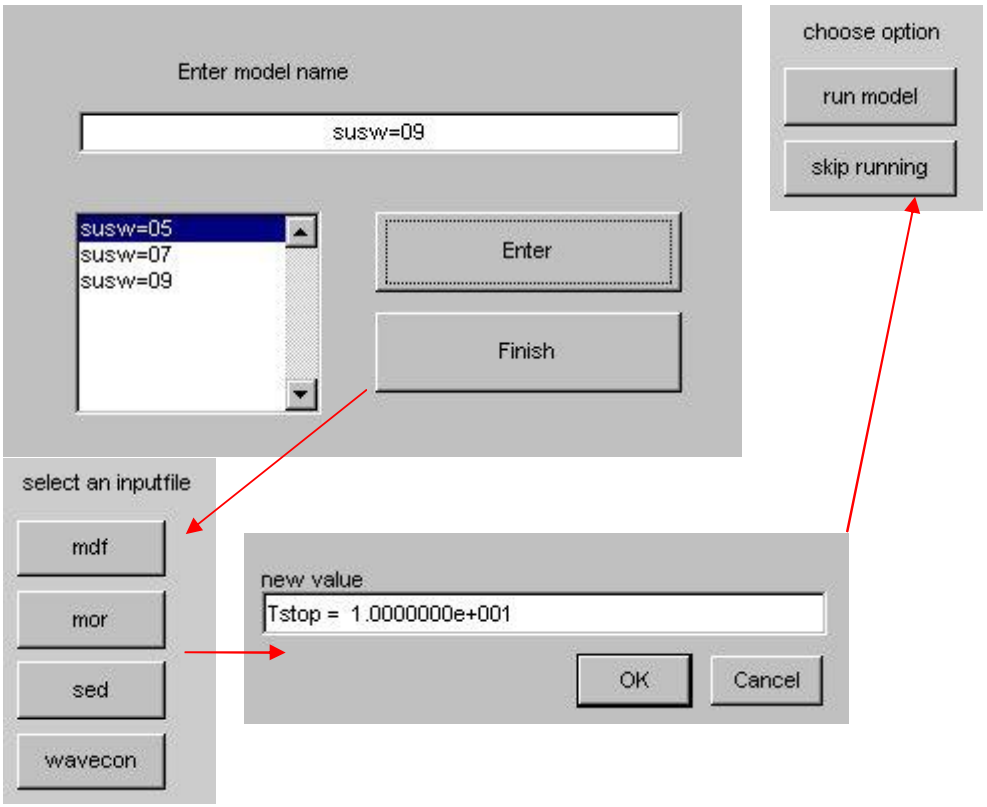


Figure 7-1 Interface structure for setting up new models

A.2 Comparing and analysing model results

By choosing the comparing option first of all the modelpath has to be chosen by selecting a test, a case and a number of models. The structure of the interface is given in Figure 7-2.
With the chosen paths, the measured data are read with the <readdata.m> function which is used as input for the further functions. From the names of the TEKAL-files information is stored into a structure array. This information comprises the type of file, the names, values belonging to a location or a time and input for the plotting of the data. If a TEKAL-file is read, named 'rtfx065.tek', the function directly reads all files starting with rtfx var(j).type, and stores the names in var(j).names, pulls out the values and stores them in var(j).values. Together with the <makevar.m> function, information matching the var(j).type is added into the structure:

var(i).type	rtfx
var(i).names	rtfx065.tek, rtfx100.tek, rtfx102.tek…….
var(i).values	65, 100, 102……..
var(i).fig	1
var(i).plottype	f(z)
var(i).mainstr	return flow profiles

The counter (i), refers to the number of data types. With the latter structure as start new TEKAL-files are created in the model directories. In case of cross-shore distribution of

physical data, the data are read from the Delft3D output (trim.dat) and written to a TEKAL format on the numerical grid (grid.grd), *e.g.* hrms.tek. If the data type is measured on a certain location the closest grid points of the grid are read and data is interpolated to the location and written to a TEKAL, *e.g.* rtfx065.tek. <readD3Doutput.m>

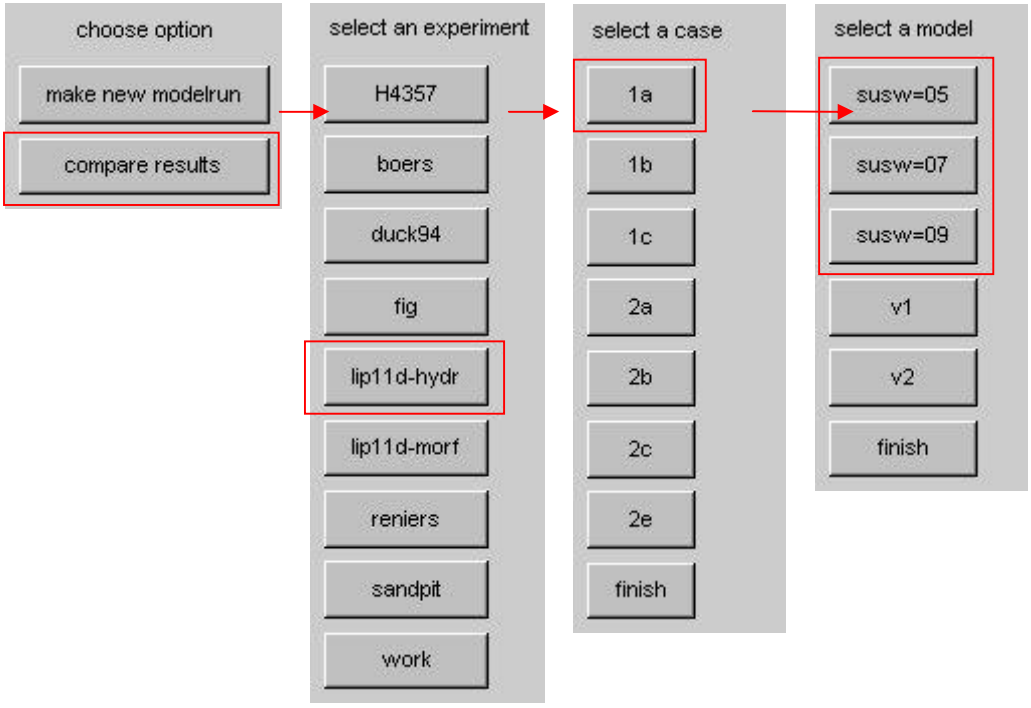


Figure 7-2 Interface structure for model comparison

Plotting model results

The chosen models for comparison are directly plotted with the <showbank.m> function. Within this function the figure names and the figure number have to be entered after which the figures are shown on the screen and stored as png-files into the analysis directory on the same database level.

In Figures 1.1-1.3 examples are shown of plotting results Test 1A of the LIP11D experiment. Two different models for the lip11d-hydr\1a model (v1 and gamdis 0,5) are illustrated by the blue and red line whereas the red dots represent the measurements.

Statistical analysis

A statistical tool is built in to compare the model performance of different runs. The statistical parameters are the following (Walstra 2004):

- Correlation (0: no correlation and 1 perfect correlation)
- BIAS (0: perfect prediction)
- Root-Mean-Square Error (0: perfect prediction)
- Brier Skill Score (0: poor result, 1: excellent results)

The Brier Skill Score (BSS) is only determined when morphological development is analysed. The parameters are directly stored into a txt-file in the 'analysis' directory. (see Table 7.1). In case of the return flow and the concentration extra files are made with the statistical parameters.

Table 7.1 Example of statistical result file.

```
*statistical parameters to evaluate performance, 24-Apr-2006 17:02:07
*for every block, colomns represent the various model results and rows the
different statistical methods.
*Line number indicates:
*Line 1: Correlation
*Line 2: RMS error
*Line 3: Brier Skill Score (only in case of morphology)
*Compared models are indicated by:
*Column 1:  lip11d-hydr\1a\v1
*column 2:  lip11d-hydr\1a\v2
hrms
 2 2
 0.985748106557224 0.985748106557224
 0.0524247202353265 0.0524247202353265
eta
 2 2
 0.955856590376756 0.955856590376756
 0.0193621375896943 0.0193621375896943
stotx
 2 2
 -0.280713401923819 -0.0575947449037833
 9.68688226468971e-006 7.34052150333561e-006
```

B Egmond Coast3D

B.1 Measurements and instrumentation

Data collected concerned:

- Waves — spectrum of wave height, period and direction, near bed orbital velocities, breaker type, fraction of breaking waves;
- Water Levels — tidal levels, storm surges, wave set-up;
- Currents — depth averaged currents, velocity profile;
- Water properties — salinity and temperature, density structures;
- Sediment properties — grain size distribution, settling velocity and density;
- Sediment transport — transport mode, rates and directions, concentration profiles;
- Morphology — bed levels before and after events, changes along cross-shore and longshore transects, cross- and longshore movement of large bed features such as nearshore breaker bars.

A range of instruments was deployed on site to perform these measurements:

WESP
The WESP (Water En Strand Profiler) is a 15 m high, motorised tripod on wheels with a platform at the top supporting engine and a cabin with facilities. Survey was conducted from the beach out to water depths of 8 m. It is valuable for collection of sand transport data and will be used for measuring the 3-dimensional bathymetry of the near shore zone. In this study the bathymetry data collected with the WESP is used.
The WESP made lanes with a spacing of 50 m in the longshore direction. Depending on the wave conditions measurements were made to a maximum depth of approximately 7 m. Bathymetry data obtained by a ship and measured on the beach was added to the WESP data in order to obtain a complete bottom profile.

CRIS
CRIS is a trailer towed by the WESP, carrying various instruments for measuring sediment transport, water levels, wave parameters and flow velocities. It also takes measurements of the sand concentration profiles. The CRIS is 3.5 meters squared and 2.5 meters high. The instruments are attached to a movable arm, which can be adjusted in vertical direction to position the sensors at the desired elevation above the bed.

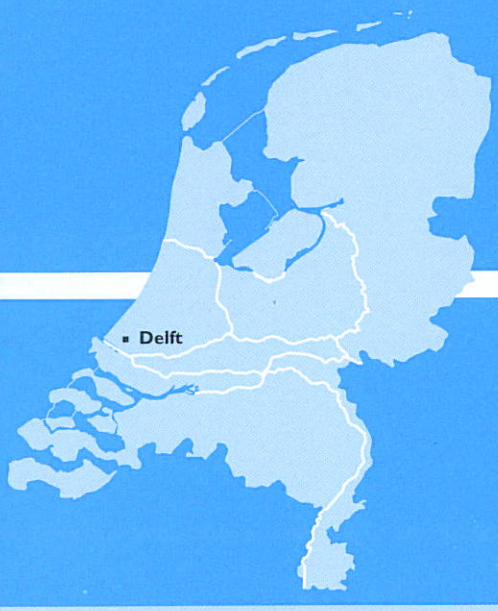
DIWAR
The DIWAR (Directional Wave Rider) buoy is located outside the Egmond area in (almost) deep water. It collects the wave data (height, period, direction). Data used were root-mean-square wave height (H_{rms}), peak period (T_p) and direction (θ). Gaps in DIWAR data were filled with measurements from other DIWAR buoys, located at the 'IJmuiden munitie-stortplaats' and the 'Europlatform'.

Measuring poles (7a-7f)
In total six poles were operating during the measurement campaigns. A number of local variables and boundary conditions are measured. For example, water level and meteorological data is collected, the wind velocity and direction measured at this pole were used in this report. The poles also form a physical barrier for ships and mark and protect the measurement site.

Maxi frames (2 and 1a-d)
The maxi frames measure several parameters. The data used in this study are wave heights, water levels and current velocities. The maxi frames are positioned in the so-called main transect in the area of interest. A fictive cross-section (normal to the shore-line) at the location of the maxi frames was defined as the main transect.

S4-instruments (18a-d, 13a-b, 14a-b, 15)
S4-instruments are current and pressure meters. Station 18a and station 18b are located in deeper water (seaward flank of outer bar), station 18c and station 18d are located in the surf zone. Data from station 18a and station 18b was used to estimate the deep water (at DIWAR location) tidal longshore currents. Station 14a and station 13a are located at the crest of the inner bar, station 14b and station 13b are located at the landward flank of the inner bar, near the inner channel.

Only a small selection of the data produced in the main campaign is used in this report. For our model performance check we only use bathymetry data and hydrodynamic data from measuring pole 7a and maxiframes 2 and 1a-d.



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