BOI Zandige Keringen: XBeach testbed Internal BOI beta release 2020

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1 Introduction

This document reports on the morphodynamic skill of the XBeach model that is to be applied in the BOI Zandige Keringen project. This document is part of the XBeach testbed (alongside the trunk default skillbed) and is generated automatically any time the model code is updated. The XBeach testbed is an environment, which automatically executes simulations, analyses simulations and generates reports with the results. The XBeach source code is hosted on a SVN repository, which is publicly available (open source). A new commit to this repository starts the trigger to create this report. The date and revision number of the XBeach model code used in this report is given on the cover of this skillbed report.

The function of this skillbed report is twofold. The validation cases show the performance of the BOI XBeach model for multiple applications in terms of quantitative statistical scores and visualizations. Apart from the performance, this report can also be used to track the code development and verify the impact of a commit in the source code.

The morphodynamic skill of the XBeach model is determined by comparison to laboratory experiments (current report) and field measurements (to be added to this report in Fase 1 of the BOI Zandige Keringen project). The BOI parameter settings derived in De Bakker *et al.* (2020) and given below in Table 1.1 are applied. As this version of the skillbed report contains many of the experiments used to derive the default settings, this document should not be considered a model validation document. Rather, the report provides quantitative insight into the ability of the model to reproduce the calibration dataset with a uniform set of model parameters. In Table 1.2 it is indicated which tests are applied to calibrate the parameters. The derived BOI settings are applied in all the described validation cases to show the performance of the BOI XBeach model. Note that these parameters are derived for the Dutch coast and, therefore, do not always correspond to the XBeach default parameters.

In this report the results are not discussed since the results can change between different versions of XBeach. For a discussion of the results a reference is made to De Bakker *et al.* (2020). Moreover, a supplementary document of this skillbed will discuss the results when this report is part of a release version of XBeach.

The validation cases and source code are publicly available in the OSS XBeach repository:
https://svn.oss.deltares.nl/repos/xbeach

Moreover, after each commit the skillbed reports are published on the XBeach website:
https://oss.deltares.nl/web/xbeach/

1.1 BOI settings

The BOI settings are a set of hydrodynamic and morphodynamic parameters that have been derived using laboratory datasets (De Bakker *et al.*, 2020). The Boers and GLOBEX experiments were applied in the optimization of the hydrodynamic parameters, and the morphodynamic parameters were derived from large scale dune experiments. Table 1.1 shows the BOI parameters of XBeach.

The XBeach defaults are applied for the other parameters, except for case specific parameters, such as the boundary conditions and grid related parameters.

Keyword	BOI parameters	XBeachX default parameters
bedfriction	Manning	Chezy
bedfriccoef	0.02	55
waveform	vanthiel	vanthiel
facSk	0.13	0.1
facAs	0.10	0.1
wetslp	0.25	0.3
beta	0.11	0.1
break	roelvink daly	roelvink2
gamma	0.51	0.55
gamma2	0.31	0.3
alpha	1.37	1.0

Table 1.1: *Overview of the BOI parameters and XBeachX default parameters. See the online manual for the explanation of the parameters (https://xbeach.readthedocs.io/en/latest/user_manual.html).*

1.2 Reader's guide

The hydrodynamic validation is shown in chapter 2 and the the morphodynamic validation in chapter 3. The morphodynamic validation is divided into a part about large scale laboratory tests (this report) and field cases (to be added in Fase 1 of the BOI Zandige Keringen project). An explanation of the model performace statistics is shown in Appendix A. Furthermore, in Appendix C a comparison of detailed properties is shown for selected cases.

Test	Type	Applied in the calibration
Long wave propagation	Hydrodynamics	no
1D wave runup	Hydrodynamics	no
High- and low-frequency wave transformation over a barred beach	Hydrodynamics	yes
High- and low-frequency wave transformation over a gentle sloping beach	Hydrodynamics	yes
H4357: Delta Flume 2006	Morphodynamics	yes
M1797: Delta Flume 1981	Morphodynamics	yes
M1263 III: Delta Flume 1984	Morphodynamics	yes
LIP11D: Delta Flume 1994	Morphodynamics	yes
LIP11D: Delta Flume 1994	Morphodynamics	yes
H4731: Delta flume 1998	Morphodynamics	yes
Grosse Wellen Kanal 1998	Morphodynamics	no

Table 1.2: *Overview of the tests in this report.*

2 1D Hydrodynamics

The hydrodynamics form the basis for the morphodynamic behaviour. In this chapter the hydrodynamic results of XBeach are presented. All tests are run without the morphological module and the analysis is focused on the wave propagation and transformation computed by XBeach.

First, two analytical solutions are reproduced by XBeach. Subsequently, laboratory experiments of a barred beach and gentle sloping beach are presented. For the latter, the short-wave height, infragravity-wave height and setup are compared to the measurements.

The observed wave height is computed on the basis of the energy density spectrum in the frequency range of $f_p/2$ until the Nyquist frequency,

$$H_{m0,HF} = 4\sqrt{m_{0,f>f_p/2}} \tag{2.1}$$

Where $m_{0,f>f_p}$ is the zero-moment of the energy density spectrum where the frequency is larger than the cutoff-frequency ($f_p/2$). In XBeach, the short wave height is computed as,

$$H_{m0,HF} = \text{rms}(H)\sqrt{2} \tag{2.2}$$

where H is the computed instantaneous short-wave height, which is computed in XBeach as we do not directly simulate the wave height. The infragravity-wave height in both the observations and the computations is defined as,

$$H_{m0,HF} = 4\sqrt{m_{0,f_p/20<f<f_p/2}} \tag{2.3}$$

where $m_{0,f_p/20<f<f_p/2}$ is zero-moment of the energy density spectrum for energy in the infragravity region. Since XBeach also resolves the infragravity waves, the same definition is applied to compute the infragrvaity wave height from the XBeach results.

Similar as the infragravity wave height, both the observed and computed mean water level (setup) can be computed with the same formulation,

$$\text{setup} = \text{mean}(\eta) \tag{2.4}$$

where η is the surface elevation signal.

2.1 Long wave propagation

The purpose of the this test is to check whether the NSWE numerical scheme is not too dissipative and that it does not create large errors in propagation speed.

A long wave with a small amplitude of 0.01 m and period of 80 s is sent into a domain with a length of 1 km, a depth of 5 m and a grid size of 5 m. Since only long waves are modelled a grid size of 5 m can be applied (more than 100 points per wave length). At the end, a fully reflecting wall is imposed. The wave length in this case should be $\sqrt{g \cdot d} \cdot T = \sqrt{9.81 \cdot 5} \cdot 80 = 560m$. The velocity amplitude should be $\sqrt{g/h} \cdot A = \sqrt{9.81/5} \cdot 0.01 = 0.014m$, because the these waves are shallow water waves. After the wave has reached the wall, a standing wave with double amplitude should be created.

The computed surface elevation and velocity snapshots before the waves reach the end of the domain is shown in Figure 2.1. The surface elevation and velocity snapshots with the standing wave pattern are shown in Figure 2.2. The computed and analytical wave amplitudes and wave lengths are shown in Table 2.1. Note that the maximum velocity and surface elevation amplitude is found at the wall.

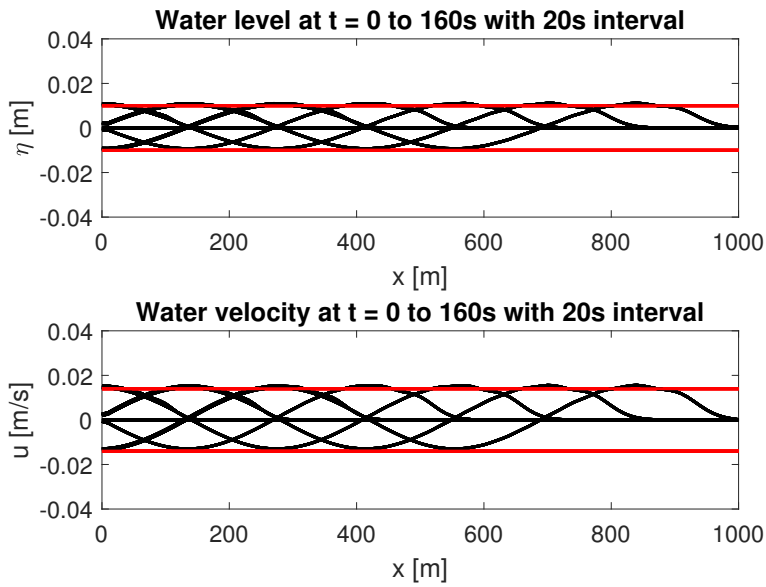

Figure 2.1: *Water levels and velocities from the start of the experiment until the wave just reaches the end of the flume. The amplitude of the analytical solution is shown with a red line.*

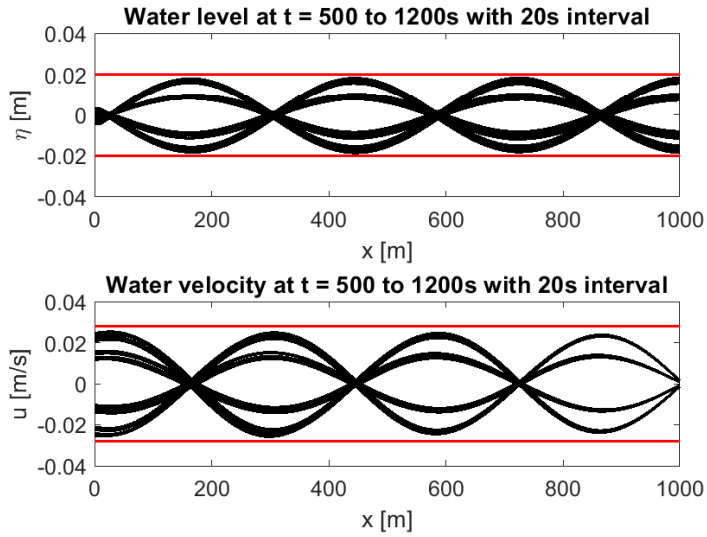

Figure 2.2: *Snapshots of water levels and velocities showing a standing wave pattern. The amplitude of the analytical solution is shown with a red line.*

Table 2.1: *The XBeach and analytical wave heights and wave lengths. The amplitude without reflection is computed for the period t=0 to t=600s. The amplitude for the standing wave pattern is computed for the period t=500 to t=1200. The amplitude is defined as the maximum water level/velocitie in the domain for the given time period.*

	Amplitude [m]	Amplitude (Standing wav) [m]	velocitie amplitude [m/s]	Velocitie amplitude (Standing wave) [m/s]	Wave length [m]
XBeach	0.011	0.021	0.016	0.029	560.000
Analytical solution	0.010	0.020	0.014	0.028	560.000

2.2 1D wave runup (analytical solution)

The purpose of this test is to check the ability of the model to represent runup and rundown of non-breaking long waves. To that end, a comparison was made with the analytical solution of the non-linear shallow water equation (NSWE) by Carrier and Greenspan (1958), which describes the motion of harmonic, non-breaking long waves on a plane sloping beach without friction.

A free long wave with a wave period of 32 seconds and wave amplitude of half the wave breaking amplitude ($a_{in} = 0.5 \cdot a_{br}$) propagates over a beach with constant slope equal to 1:25. The wave breaking amplitude is computed as $a_{br} = 1/\sqrt{128} \cdot \pi^3 \cdot s^{2.5} \cdot T^{2.5} \cdot g^{1.25} \cdot h_0^{-0.25} = 0.0307m$, where s is the beach slope, T is the wave period and h_0 is the still water depth at the seaward boundary. The grid is non uniform and consists of 160 grid points. The grid size Δx is decreasing in shoreward direction and is proportional to the (free) long wave celerity ($\sqrt{g \cdot h}$). The minimum grid size in shallow water was set at $\Delta x = 0.1m$.

A comparison of surface elevation and velocity snapshots is shown in Figure 2.3. The maximum and minimum values of the analytical solution and the XBeach computations are shown in Table 2.2

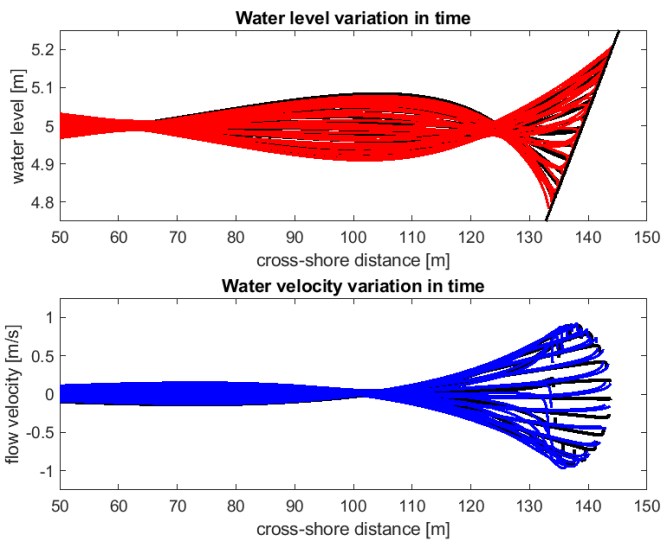

Figure 2.3: *Snapshots of water level and velocity*

Table 2.2: *The maximum and minimum surface elevation and velocities in the runup.*

	max(η) [m]	min(η) [m]	max(u) [m/s]	min(u) [m/s]
XBeach	5.20	4.80	0.90	-0.91
Analytical solution	5.21	4.78	0.92	-0.97

2.3 High- and low-frequency wave transformation over a barred beach

Experiment description

Boers (1996) performed experiments with irregular waves in the physical wave flume at Delft University of Technology. The flume has a length of 40 meters and a width of 0.8 m. The fixed concrete beach profile represents the beach profile of the LIP 11D-experiment 1B (excluding mega-ripples), on a scale of 1:28 with respect to prototype. This profile has a breaker bar and a surf zone trough. The still water level during the experiments is z = 0.75 m above the bottom of the wave flume. The flume is equipped with a hydraulically driven, piston type wave generator with second-order wave generation and Active Reflection Compensation. Measurements were taken at 20 Hz. Three irregular wave conditions were studied (See Table 2.3). The surface elevation was measured at 70 locations shown in Figure 2.4. It is important to note that the waves are breaking from the start in Tests 1A and 1B. In addition, not a complete jonswap spectrum could be imposed at the boundary due to restrictions with the waveboard. Therefore, the XBeach model is forced with measured timeseries, rather than with a jonswap spectrum.

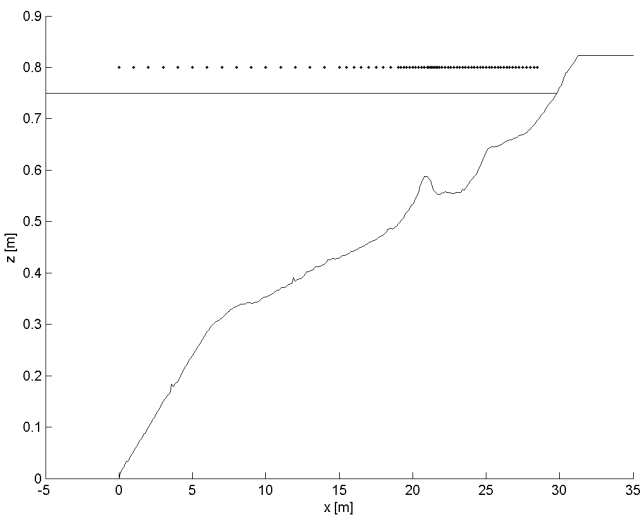

Figure 2.4: *Locations of surface eleveation measurements*

Test	H_{m0}[m]	T_p [s]
1A	0.157	2.1
1B	0.206	2.1
1C	0.103	3.4

Table 2.3: *The Boers (1996) wave conditions.*

Results

The comparison between the model and the observations for the wave height transformation of the short waves, the infragravity waves and the setup is shown in Figure 2.5, Figure 2.6 and Figure 2.7. The short-wave height and infragravity wave height are shown in the upper panel. The setup is shown in the second panel and the bathymetry is shown in the last panel. The XBeach boundary is located at the 9th wave gauge since this location contains velocity and surface elevation measurements and the model is forced with the incoming measured wave signal. Note that the setup for these small-scale tests is very small (maximum of several millimetres), which causes the scatter in the observations.

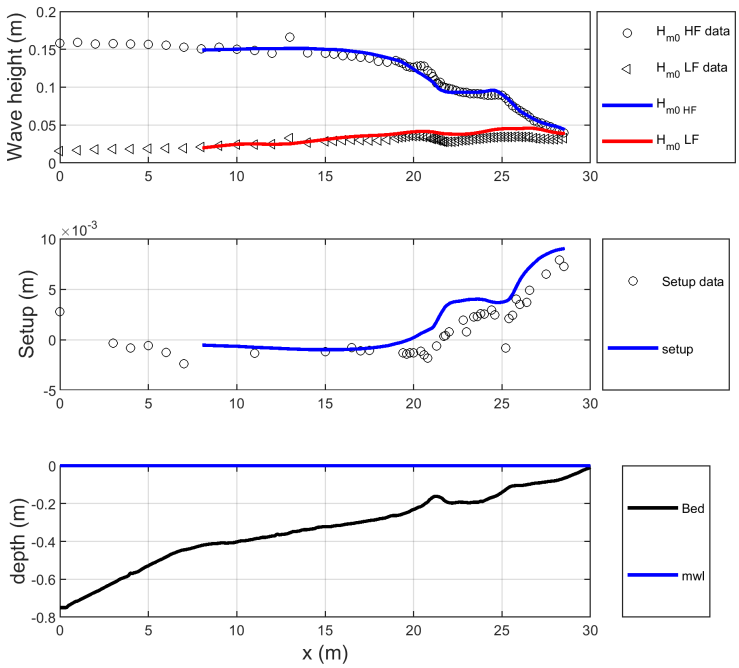

Figure 2.5: *Wave hydrodynamics during experiment 1A. The observed short-wave height (dots) and observed infragravity wave height (triangles) are compared to the XBeach results (blue and red line) in the upper panel. The observed setup (dots) is compared to the setup computed with XBeach (blue line) in the second panel and the bathymetry is shown in the third panel.*

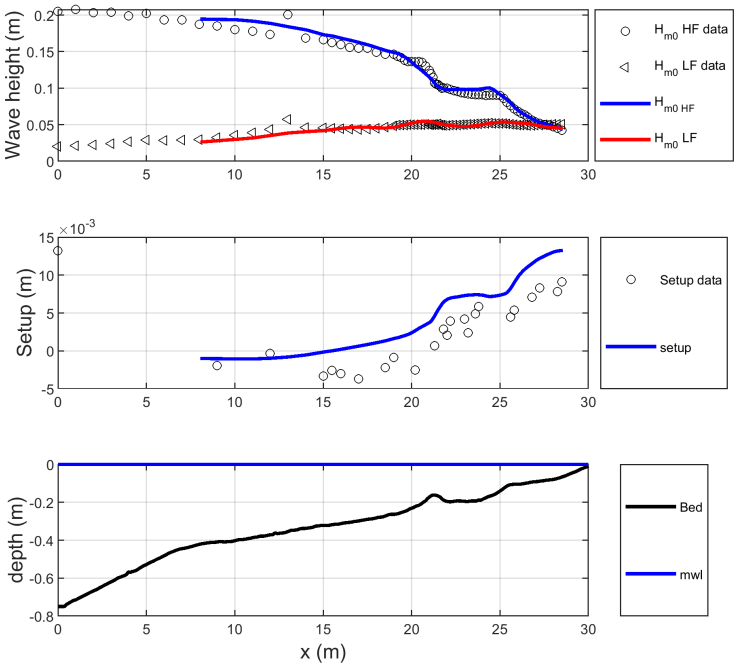

Figure 2.6: *Wave hydrodynamics during experiment 1B. The observed short-wave height (dots) and observed infragravity wave height (triangles) are compared to the XBeach results (blue and red line) in the upper panel. The observed setup (dots) is compared to the setup computed with XBeach (blue line) in the second panel and the bathymetry is shown in the third panel.*

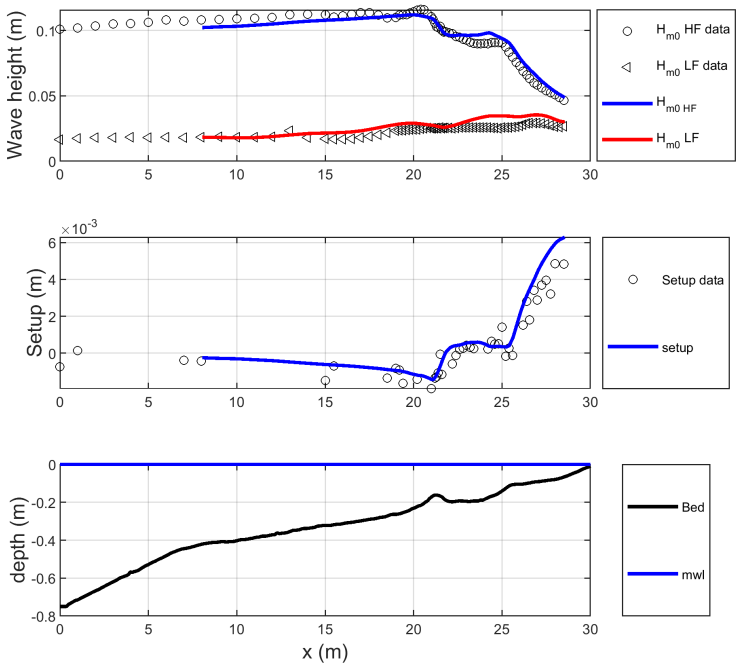

Figure 2.7: *Wave hydrodynamics during experiment 1C. The observed short-wave height (dots) and observed infragravity wave height (triangles) are compared to the XBeach results (blue and red line) in the upper panel. The observed setup (dots) is compared to the setup computed with XBeach (blue line) in the second panel and the bathymetry is shown in the third panel.*

Overview

An overview of the skill scores is shown in Figure 2.8 and Table 2.4, where the relative bias and scatter index of the short-wave height, infragravity-wave height and setup are shown for the different Boers experiments.

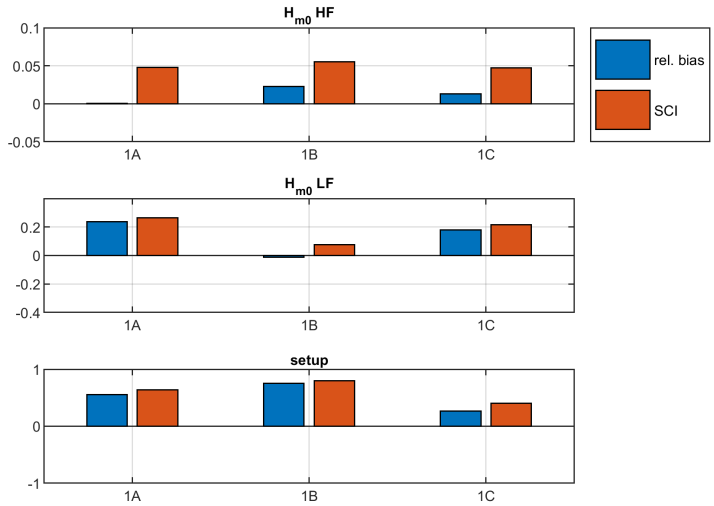

Figure 2.8: *Overview of the statistical scores of the Boers experiments. The relative error and scatter index for the short-wave height (upper panel), infragravity wave height (second panel) and setup (third panel) are shown for the different Boers experiments.*

Table 2.4: *The statistical scores for the Boers experiments. The scatter index (SCI) and relative bias (rel. bias) are shown for the short-wave height, infragravity wave height and setup.*

	1A	1B	1C
$H_{m0,HF}$ Rel. bias	0.00	0.02	0.01
$H_{m0,HF}$ SCI	0.05	0.06	0.05
$H_{m0,LF}$ Rel. bias	0.24	-0.01	0.18
$H_{m0,LF}$ SCI	0.27	0.08	0.21
setup Rel. bias	0.56	0.76	0.27
setup SCI	0.64	0.80	0.41

2.4 High- and low-frequency wave transformation over a gentle sloping beach

Experiment desciption

The laboratory data set was obtained during the GLOBEX project (Ruessink *et al.*, 2013). The experiments were performed in the Scheldegoot in Delft, The Netherlands, in April 2012. The flume is 110 m long, 1 m wide and 1.2 m high and has a piston-type wave maker equipped with an Active Reflection Compensation (ARC) to absorb waves coming from the flume and hence prevent their re-reflection from the wave maker. A fixed, mild-sloping (1:80) concrete beach was constructed over almost the entire length of the flume (with a fixed sandy upper layer), except for the first 16.6 m that were horizontal and where the mean water level was 0.85 m (Fig. 2.9). At the cross-shore position x = 16.6 m (x = 0 m is the wave-maker position at rest), the sloping bed started and intersected with the mean water level at $x \approx$ 84.6 m. The profile, and the conditions were on a 1:20 scale with respect to prototype. As detailed in Ruessink *et al.* (2013), the experimental program comprised 8 wave conditions. Here we will focus on the 3 irregular-wave cases: an intermediate energy sea-wave condition ($A1$; H_s = 0.1 m, T_p = 1.58 s), a high-energy sea-wave condition ($A2$; H_s = 0.2 m, T_p = 2.25 s), and a narrow-banded swell condition ($A3$; H_s = 0.1 m, T_p = 2.25 s). All wave-paddle steering

signals included second-order wave generation, and were based on a JONSWAP spectrum with a peak enhancement factor γ of 3.3 for $A1$ and $A2$, and 20 for $A3$. Each condition had a duration of 75 minutes with 21 wave gauges and 5 flow meters sampling at 128 Hz, followed by a rest period of about 15 minutes. After all wave conditions were completed, most instruments were repositioned and the conditions were repeated with the same wave paddle signal. Altogether, the conditions were each repeated 10 times, resulting in a total of 190 positions with water level (η) data and 43 positions with cross-shore flow-velocity (u) data, with an instrument spacing varying from 2.2 m offshore, to 0.55 m in the middle section and 0.37 m inshore, see Figure 2.9. See Ruessink *et al.* (2013) for further details and initial data processing.

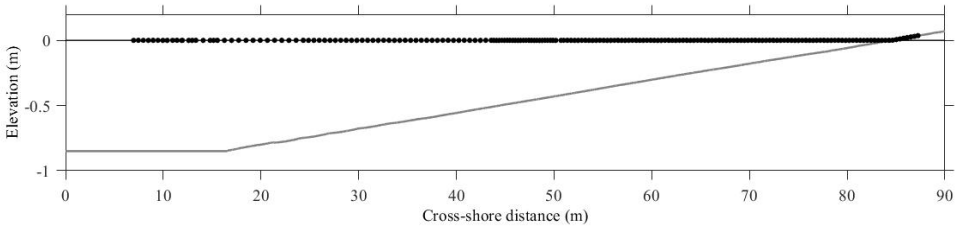

Figure 2.9: *Elevation z versus cross-shore distance x in the Scheldegoot during the GLOBEX project. Here, x = 0 is the location of the wave-maker at rest, and z = 0 corresponds to the still water level. At x = 84.6 m the still water level intersected with the bed. The 190 dots are the positions of the wave gauges.*

Results

The comparison between the model and the observations for the wave height transformation of the short waves, the infragravity waves and the setup is shown in Figure 2.10, Figure 2.11 and Figure 2.12.

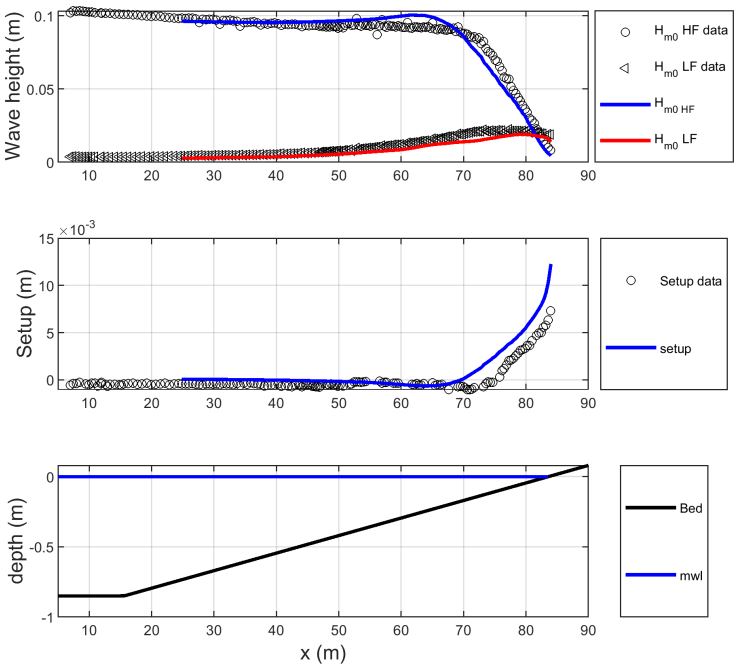

Figure 2.10: *Wave hydrodynamics during experiment A1. The observed short-wave height (dots) and observed infragravity wave height (triangles) are compared to the XBeach results (blue and red line) in the upper panel. The observed setup (dots) is compared to the setup computed with XBeach (blue line) in the second panel and the bathymetry is shown in the third panel.*

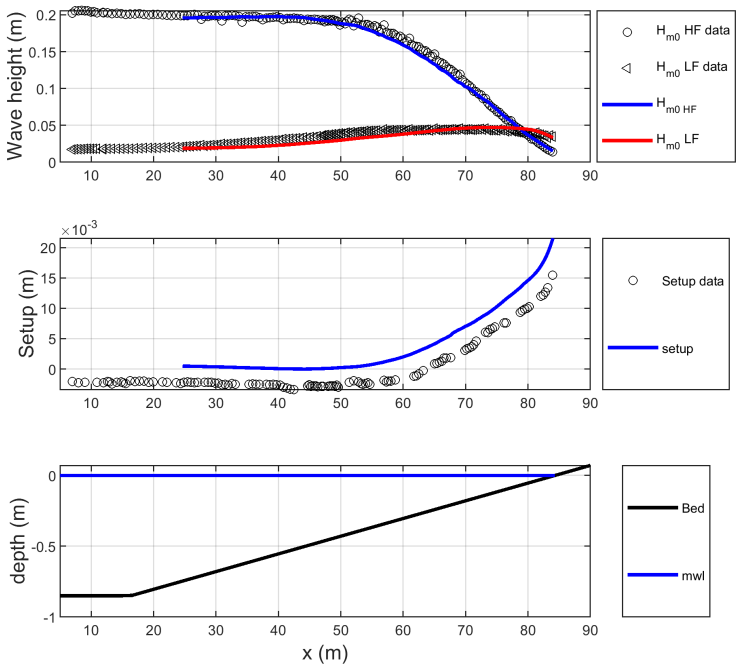

Figure 2.11: *Wave hydrodynamics during experiment A2. The observed short-wave height (dots) and observed infragravity wave height (triangles) are compared to the XBeach results (blue and red line) in the upper panel. The observed setup (dots) is compared to the setup computed with XBeach (blue line) in the second panel and the bathymetry is shown in the third panel.*

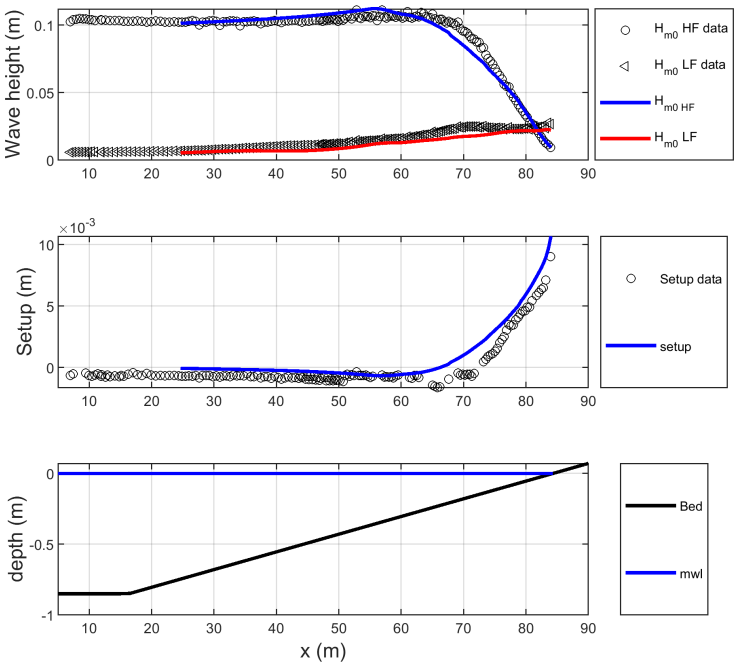

Figure 2.12: *Wave hydrodynamics during experiment A3. The observed short-wave height (dots) and observed infragravity wave height (triangles) are compared to the XBeach results (blue and red line) in the upper panel. The observed setup (dots) is compared to the setup computed with XBeach (blue line) in the second panel and the bathymetry is shown in the third panel.*

Overview

An overview of the statistical scores is shown in Figure 2.13 and Table 2.5 , where the relative bias and scatter index of the short-wave height, infragravity wave height and setup are shown for the different GLOBEX experiments.

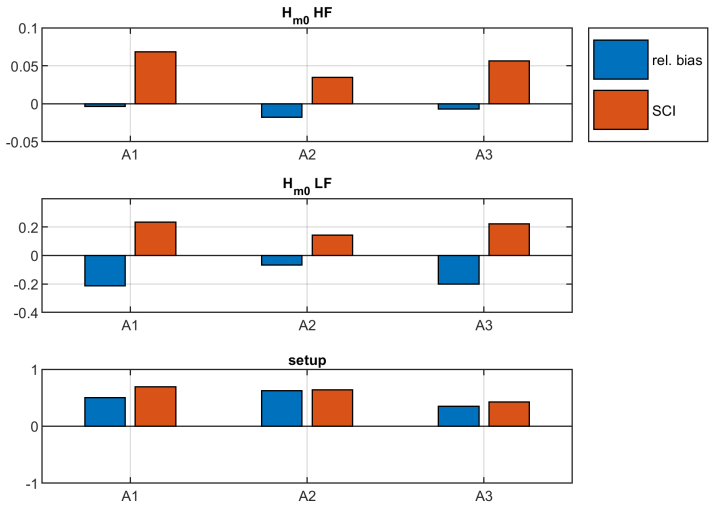

Figure 2.13: *Overview of the statistical scores of the GLOBEX experiments. The relative error and scatter index for the short-wave height (upper panel), infragravity wave height (second panel) and setup (third panel) are shown for the different GLOBEX experiments.*

Table 2.5: *The statistical scores for the GLOBEX experiments. The scatter index (SCI) and relative bias (rel. bias) are shown for the short-wave height, infragravity wave height and setup.*

	A1	A2	A3
$H_{m0,HF}$ Rel. bias	-0.00	-0.02	-0.01
$H_{m0,HF}$ SCI	0.07	0.03	0.06
$H_{m0,LF}$ Rel. bias	-0.21	-0.07	-0.20
$H_{m0,LF}$ SCI	0.23	0.14	0.22
setup Rel. bias	0.50	0.62	0.35
setup SCI	0.69	0.64	0.43

3 Morphodynamics

In this chapter, the performance of XBeach is compared to results obtained from physical model tests performed in a variety experiments (this report) and field measurements (to be added in Fase 1 of the BOI Zandige Keringen project). Many of those tests are part of fundamental research to dune erosion and other morphological processes. Research took place at different laboratory scales, mainly depending on the size of the facility used. Since large-scale experiments show a more realistic dune erosion profile, only large scale physical experiments are shown.

The accuracy of XBeach is quantitative verified for three indicators of the morphology see De Bakker *et al.* (2020). Based on the profiles on several moments in time (t), the berm slope indicator, dune retreat indicator and erosion volume are compared to the observed indicator (See Figure B.2, Figure B.1 and Figure B.3). The definition of these indicators is given in Appendix B. The relative error of these indicators is computed for every moment in time where observations are available,

$$V_{rel} = (V_{xb,t} - V_{data,t})/V_{data,t_{end}} \tag{3.1}$$

$$S_{rel} = (slope_{xb,t} - slope_{data,t})/slope_{data,t} \tag{3.2}$$

$$dx_{rel} = (dx_{xb,t} - dx_{data,t})/dx_{data,t_{end}} \tag{3.3}$$

where V is the erosion volume above maximum still water level, $slope$ the berm slope and dx the dune retreat. The quantities computed with XBeach are indicated with xb and the observed quantities are indicated with $data$. Next to the relative error with respect to the last timestep for the erosion volumes and dune retreat, the relative errors with the corresponding time is also computed:

$$V_{rel,t} = (V_{xb,t} - V_{data,t})/V_{data,t} \tag{3.4}$$

$$dx_{rel,t} = (dx_{xb,t} - dx_{data,t})/dx_{data,t} \tag{3.5}$$

The root-mean-squared value of these series of relative errors is used to obtain a single error measure per indicator for all moments in time (except for the data points in the first hour of an experiment). The relative errors in the first hour are ignored since this relative error can be large compared to the other moments in time and the fact that these initial errors are not important for the dune assessment (similar as described in De Bakker *et al.* (2020)).

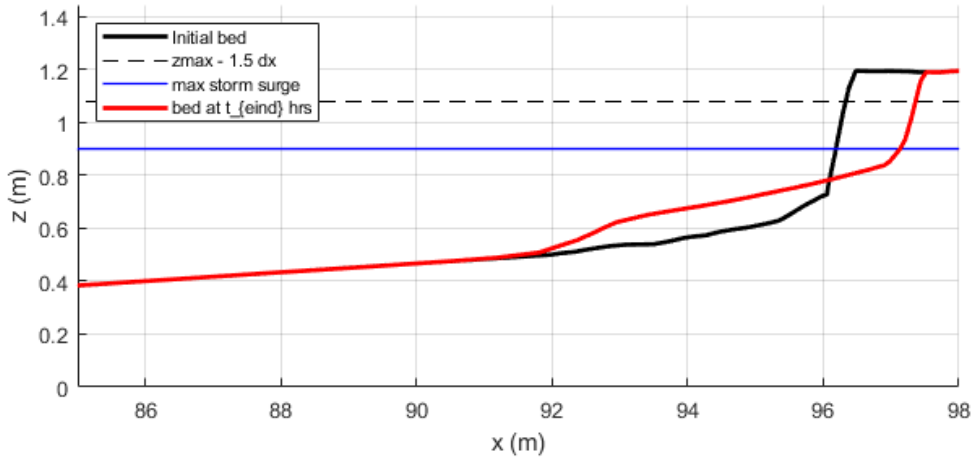

Figure 3.1: *Dune retreat indicator. See the Appendix for the definition of this indicator.*

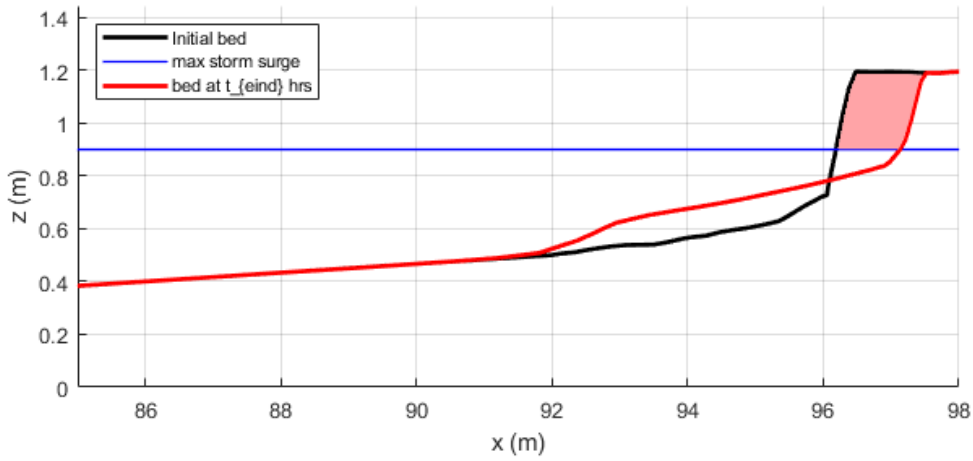

Figure 3.2: *Definition of erosion volume. See the Appendix for the definition of this indicator.*

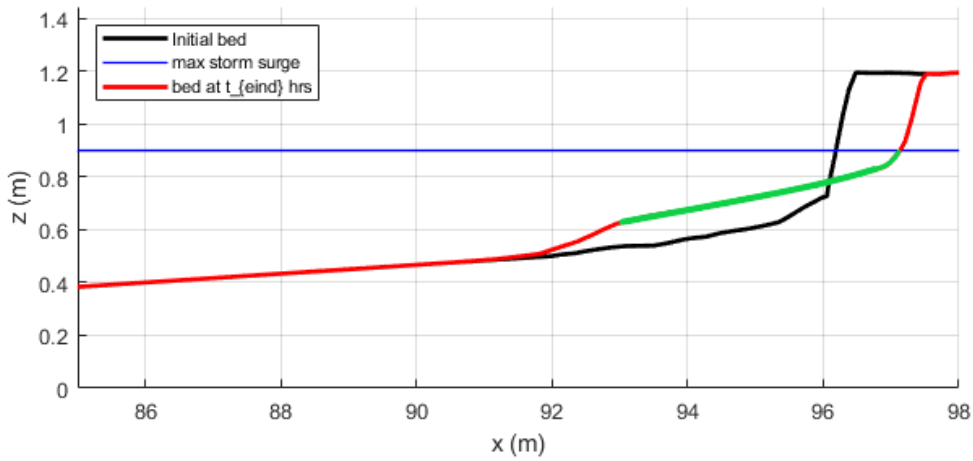

Figure 3.3: *Berm slope indicator. See the Appendix for the definition of this indicator.*

3.1 Large scale laboratory tests

3.1.1 H4357: Delta Flume 2006

Experiment description

Van Gent *et al.* (2008) and Van Thiel de Vries *et al.* (2008) describe large-scale laboratory experiments that have been performed to study the influence of the wave period on the dune erosion process. They concluded that not only short waves, but also (wave group generated) long waves are important in the dune erosion process. Initially, about 30% of the dune erosion is due to long-wave energy, but this amount increases throughout the storm, with the development of an erosion profile. Moreover, an increase of the wave period was seen to increase the resulting dune erosion volumes.

These experiments have been performed in the Deltaflume of Delft Hydraulics, currently known as Deltares, using the reference profile for the Holland coast on a scale of 1:6. This is a schematized profile that is considered representative for the Holland coast. Furthermore, a significant wave height 1.50 m (corresponding to 9 m on proto-type scale) and a water depth of 4.50 m is used. The test programme is given in Table 3.1. During Test T01, T02 and T03 a single dune has been tested, whereas during test T08, the storm impact on a profile with a double dune row was analysed.

Table 3.1: *Overview of experiments*

Experiment	T_p	$T_{m-1,0}$	Spectrum
T01	4.90	4.45	Pierson-Moskowitz
T02	6.12	5.56	Pierson-Moskowitz
T03	7.35	6.68	Pierson-Moskowitz
T08	7.35	6.68	Pierson-Moskowitz

Results

The comparison between the observed and numerically predicted beach profiles with the BOI parameter settings is shown in Figure 3.4, Figure 3.6, Figure 3.8 and Figure 3.10. The observed profiles are represented by a dashed line and the computed profiles through a solid line. The line color indicates the moment in time. Table 3.2 to Table 3.5 show the results for the different indicators. In Figure 3.5, Figure 3.7, Figure 3.9 and Figure 3.11, the relative error is plotted as a function of time. Besides a comparison of the observed and predicted beach profiles, also a detailed hydrodynamic and morphodynamic analysis is performed, which is presented in Appendix C.1.

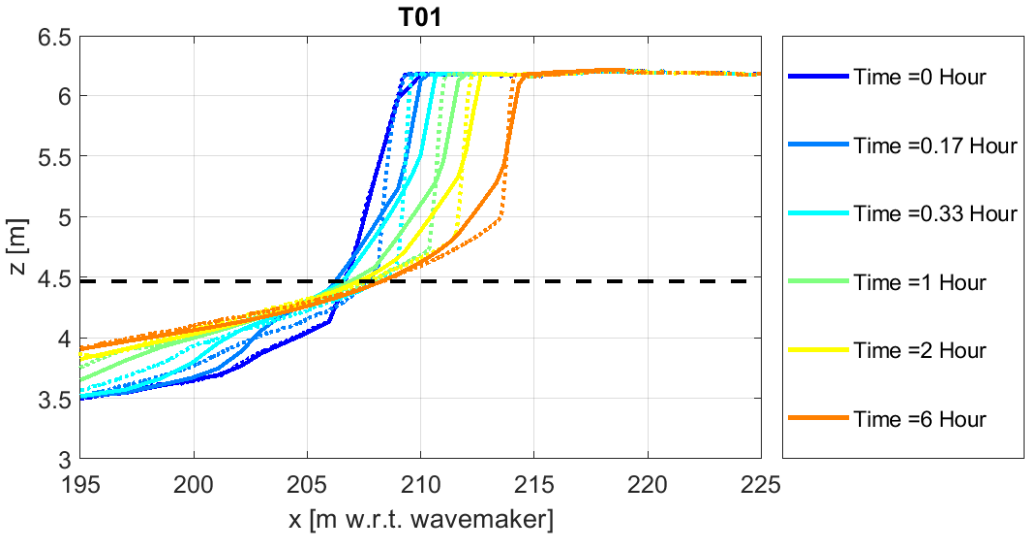

Figure 3.4: *Comparisons of profiles from experiment T01 for different moments in time. Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.2: *The computed and observed volume (V) and berm slopes (S) for T01. Volumes (V) are given in m^3/m. The relative error is expressed in a percentage. Both the relative error in terms of the same time (rel,t) and the final time are shown (rel).*

Time[hour]	V_{xb} $[m^3/m]$	V_{data} $[m^3/m]$	V_{rel} $[\%]$	$V_{rel,t}$ $[\%]$	S_{xb} $[-]$	S_{data} [-]	S_{rel} $[\%]$	dx_{xb} $[m]$	dx_{data} $[m]$	dx_{rel} $[\%]$	$dx_{rel,t}$ $[\%]$
0.17	1.19	0.96	3	25	0.11	0.09	29	1.00	0.33	12	200
0.33	1.94	2.21	-3	-12	0.09	0.07	31	1.67	1.00	13	67
1	3.72	4.29	-7	-13	0.07	0.06	18	2.67	2.33	6	14
2	5.12	5.94	-9	-14	0.05	0.05	4	3.67	3.33	6	10
6	8.03	8.68	-7	-7	0.04	0.04	10	5.33	5.33	0	0

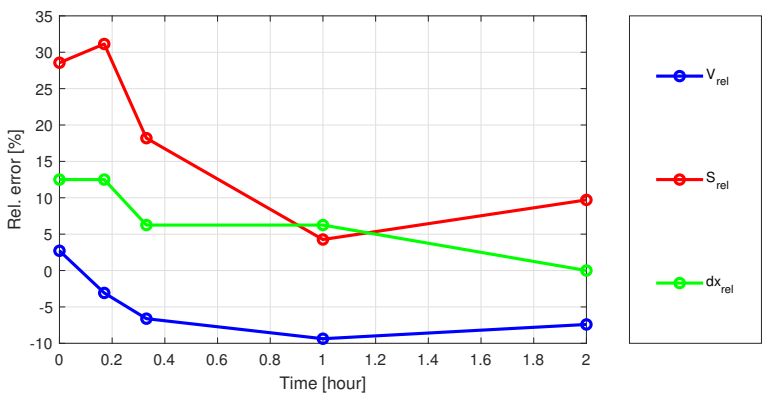

Figure 3.5: *Temporal development of the relative error for the three indicators.*

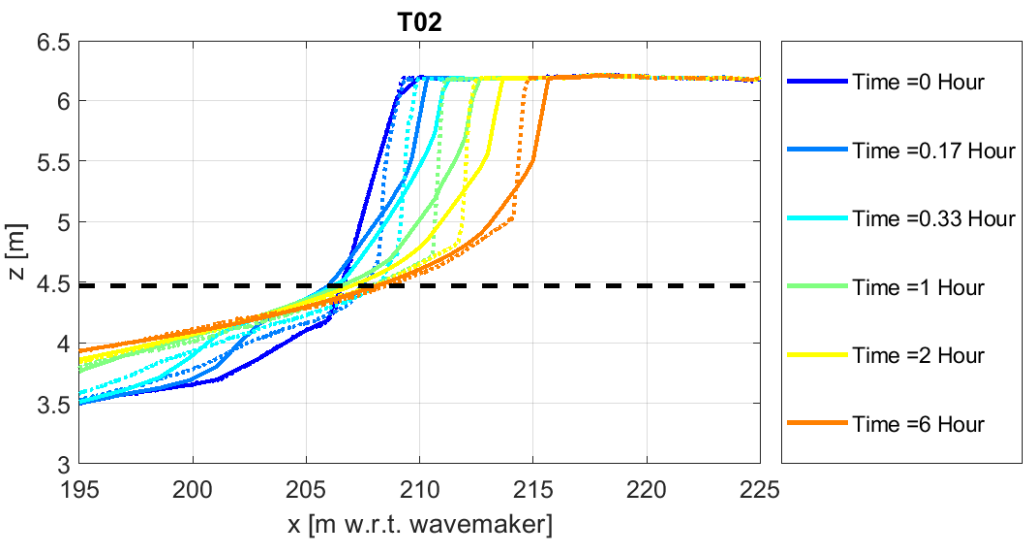

Figure 3.6: *Comparisons of profiles from experiment T02 for different moments in time. Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.3: *The computed and observed volume (V) and berm slopes (S) for T02. Volumes (V) are given in m^3/m. The relative error is expressed in a percentage. Both the relative error in terms of the same time (rel,t) and the final time are shown (rel).*

Time[hour]	V_{xb} $[m^3/m]$	V_{data} $[m^3/m]$	V_{rel} $[\%]$	$V_{rel,t}$ $[\%]$	S_{xb} $[-]$	S_{data} [-]	S_{rel} $[\%]$	dx_{xb} $[m]$	dx_{data} $[m]$	dx_{rel} $[\%]$	$dx_{rel,t}$ $[\%]$
0.17	1.49	1.04	5	43	0.12	0.09	34	1.33	0.33	17	300
0.33	2.41	2.34	1	3	0.09	0.07	42	2.00	1.00	17	100
1	4.69	4.63	1	1	0.06	0.06	9	3.67	2.33	22	57
2	6.44	6.37	1	1	0.05	0.05	8	4.67	3.67	17	27
6	9.86	9.63	2	2	0.04	0.04	1	6.67	6.00	11	11

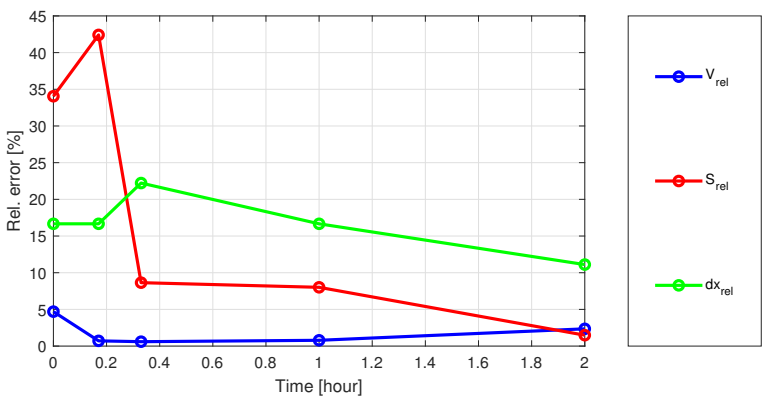

Figure 3.7: *Temporal development of the relative error for the three indicators.*

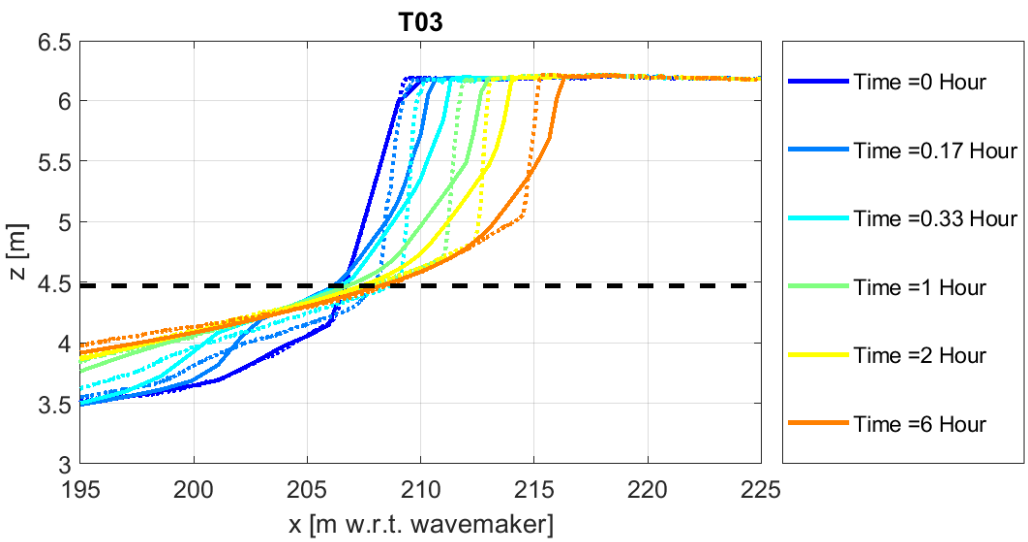

Figure 3.8: *Comparisons of profiles from experiment T03 for different moments in time. Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.4: *The computed and observed volume (V) and berm slopes (S) for T03. Volumes (V) are given in m^3/m. The relative error is expressed in a percentage. Both the relative error in terms of the same time (rel,t) and the final time are shown (rel).*

Time[hour]	V_{xb} $[m^3/m]$	V_{data} $[m^3/m]$	V_{rel} $[\%]$	$V_{rel,t}$ $[\%]$	S_{xb} $[-]$	S_{data} [-]	S_{rel} $[\%]$	dx_{xb} $[m]$	dx_{data} $[m]$	dx_{rel} $[\%]$	$dx_{rel,t}$ $[\%]$
0.17	1.65	1.22	4	36	0.10	0.08	26	1.33	0.33	16	300
0.33	2.61	2.60	0	0	0.09	0.06	36	2.33	1.00	21	133
1	4.98	5.41	-4	-8	0.06	0.05	13	3.67	3.00	11	22
2	6.82	7.21	-4	-5	0.05	0.04	15	5.00	4.33	11	15
6	10.18	9.96	2	2	0.04	0.04	-1	7.33	6.33	16	16

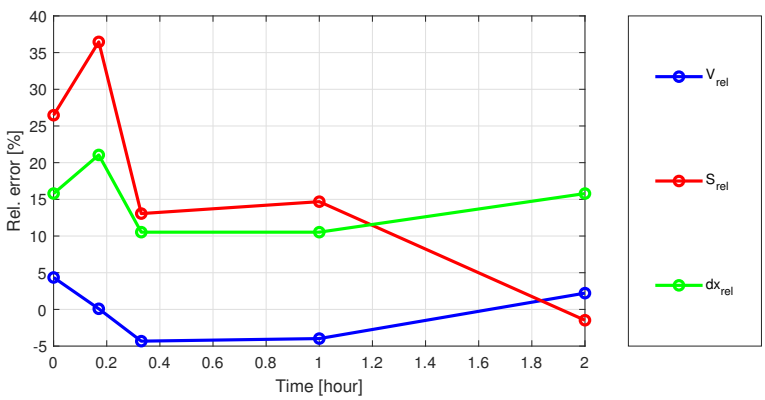

Figure 3.9: *Temporal development of the relative error for the three indicators.*

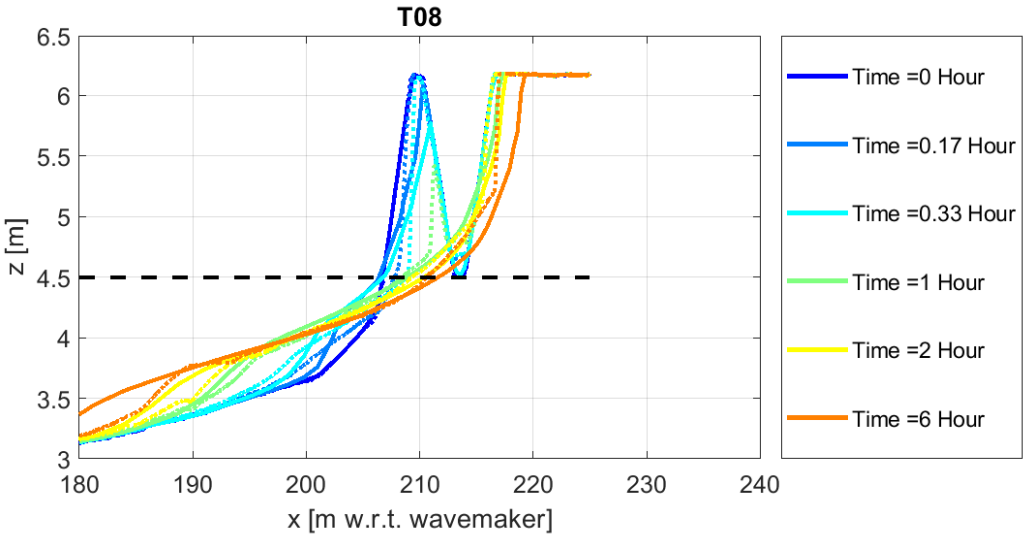

Figure 3.10: *Comparisons of profiles from experiment T08 for different moments in time. Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.5: *The computed and observed volume (V) and berm slopes (S) for T08. Volumes (V) are given in m^3/m. The relative error is expressed in a percentage. Both the relative error in terms of the same time (rel, t) and the final time are shown (rel).*

Time[hour]	V_{xb} $[m^3/m]$	V_{data} $[m^3/m]$	V_{rel} $[\%]$	$V_{rel,t}$ $[\%]$	S_{xb} $[-]$	S_{data} [-]	S_{rel} $[\%]$	dx_{xb} $[m]$	dx_{data} $[m]$	dx_{rel} $[\%]$	$dx_{rel,t}$ $[\%]$
0.17	1.47	1.19	4	24	0.12	0.09	42	1.33	0.33	12	300
0.33	2.49	2.29	3	9	0.09	0.07	40	2.33	1.00	16	133
1	6.04	4.84	17	25	0.05	0.05	-5	8.00	7.33	8	9
2	6.87	5.88	14	17	0.04	0.05	-17	8.67	7.33	16	18
6	9.20	7.03	31	31	0.03	0.04	-15	10.00	8.33	20	20

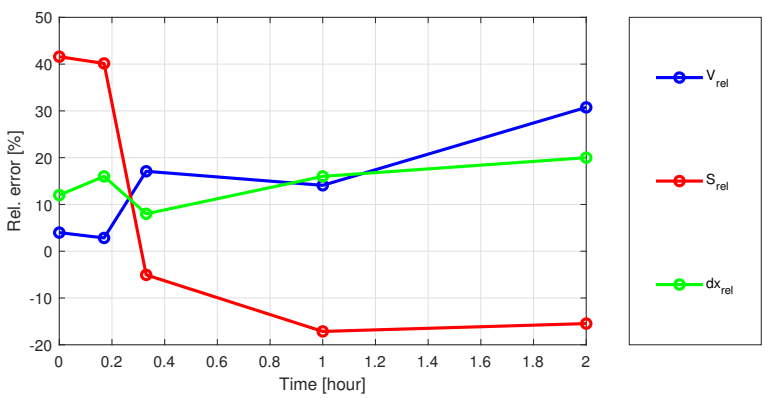

Figure 3.11: *Temporal development of the relative error for the three indicators.*

Overview

An overview of the statistical scores is shown in Figure 3.12 and Table 3.6.

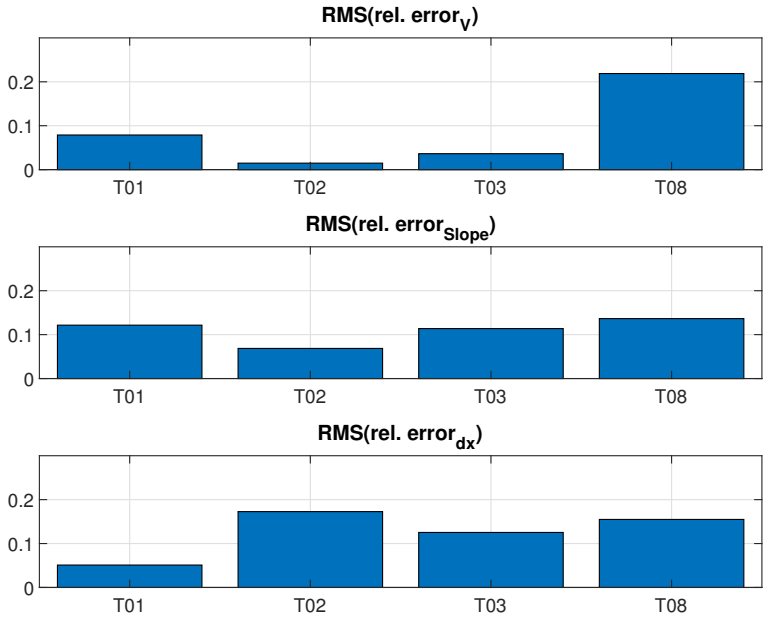

Figure 3.12: *Overview of statistical scores for the Deltagoot 2006 experiments.*

Table 3.6: *Deltagoot 2006 statistical scores.*

	T01	T02	T03	T08
$RMS(rel.volume)$	0.08	0.01	0.04	0.22
$RMS(rel.slope)$	0.12	0.07	0.11	0.14
$RMS(rel.retreat)$	0.05	0.17	0.13	0.15

3.1.2 M1797: Delta Flume 1981

In 1981, Delta Flume experiments were performed to gain insight in the effect of a dune revetment on the morphological behaviour of the dune, however, experiments were also carried out without a dune revetment. The profile in question is based on a stretch of coast called the Noorderstrand at Schouwen, the Netherlands (Vellinga, 1981). Two large scale experiments (depth scale of 2) were performed, one with and one without dune revetment. The latter is depicted in Figure 3.13. Table 3.7 shows the results for the indicators at different moments in time.

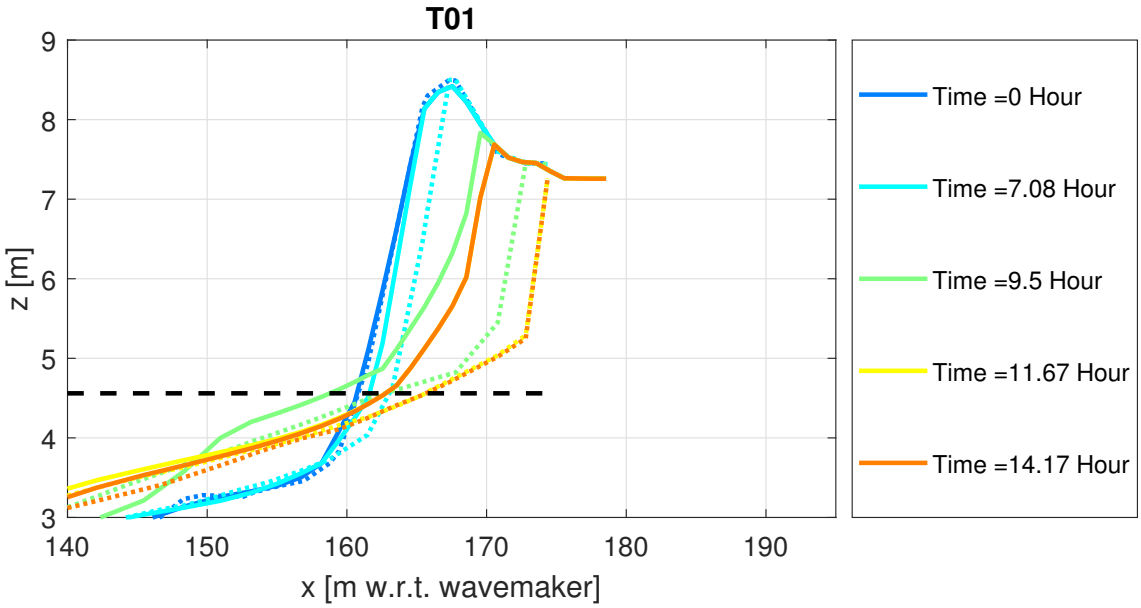

Figure 3.13: *Comparison of profile during experiment T01. Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.7: *The computed and observed volume (V) and berm slopes (S) for T01. Volumes (V) are given in m^3/m. The relative error is expressed in a percentage. Both the relative error in terms of the same time (rel, t) and the final time are shown (rel).*

Time[hour]	V_{xb} $[m^3/m]$	V_{data} $[m^3/m]$	V_{rel} $[\%]$	$V_{rel,t}$ $[\%]$	S_{xb} $[-]$	S_{data} [-]	S_{rel} $[\%]$	dx_{xb} $[m]$	dx_{data} $[m]$	dx_{rel} $[\%]$	$dx_{rel,t}$ $[\%]$
7.08	1.92	7.24	-16	-74	0.06	0.06	5	0.00	2.00	-67	-100
9.5	13.39	28.28	-45	-53	0.07	0.06	19	4.00	7.00	-100	-43
11.67	18.27	33.04	-44	-45	0.06	0.06	-0	5.00	3.00	67	67
14.17	18.27	33.23	-45	-45	0.06	0.05	18	5.00	3.00	67	67

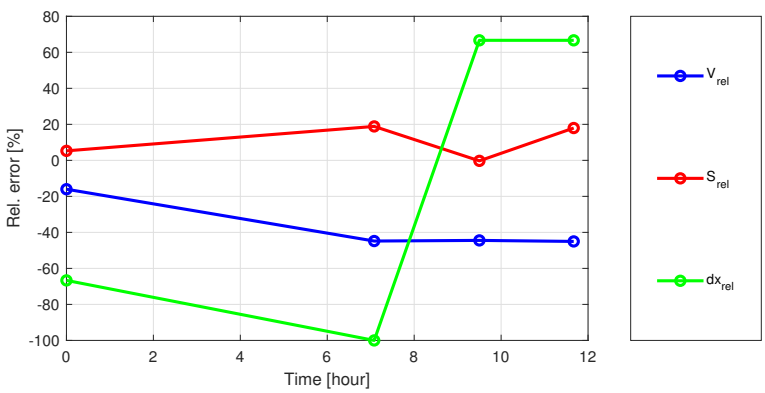

Figure 3.14: *Temporal development of the relative error for the three indicators.*

3.1.3 M1263 III: Delta Flume 1980-1981

Experiment description

The purpose of research programme M1263-3 was to verify the scale relations and the reliability of the deterministic dune erosion method according to Vellinga (1986), (Vellinga, 1984). In total 5 tests were performed in the Delta Flume of WL | Delft Hydraulics in the period of November 1980 till May 1981. Test 1 and Test 2 were performed at a depth scale of 5 and with a constant water level. In Test 1 the Dutch reference profile (see Figure 1.1) was used as initial profile with a geometric contraction of S_0 = 3, while in Test 2 a geometric contraction of S_0 = 2 was applied. Test 3 was performed at the same depth scale as Test 2 and with the same initial profile, but with a varying water level. In Test 4 the storm surge of 1953 in The Netherlands was reproduced at a depth scale 3.27. Test 5 can be considered as a full-scale replica 1:1 of a moderate storm in nature; the reference profile was used with a steepness factor of S 0 = 2.47. The Delta Flume is approximately 230 m long, 5 m wide and 7 to 9 m deep. At the time these tests were performed the wave board in the Delta flume was not yet equipped with active reflection compensation (ARC) nor with second-order wave steering.

The five experiments are presented in Table 3.8. Tests 1, 2 and 5 had a constant surge level, while tests 3 and 4 had a variable surge level with a course depicted in Figure 3.15 and Figure 3.16 respectively.

Table 3.8: *Overview of experiments*

Experiment	Depth-scale	Profile contraction	Sediment diameter	Water depth	Wave height	Wave period
1	5	1.91	225	4.2	1.50	5.4
2	5	1.27	225	4.2	1.50	5.4
3	5	1.27	225	4.2	1.50	5.4
4	3.27	1.91	225	4.2	1.85	5.0
5	1	1	225	5.0	2.00	7.6

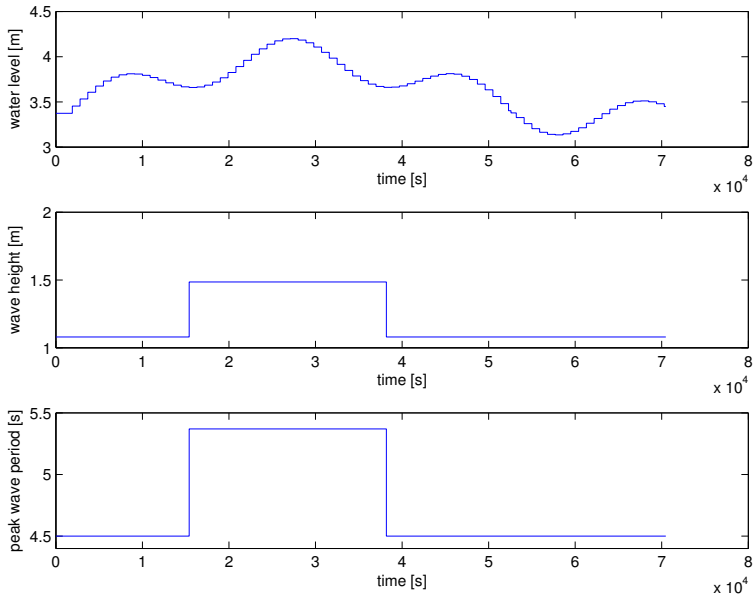

Figure 3.15: *Boundary conditions for test 3. The storm development is shown for the water level (upper panel), the wave height (second panel) and the peak period (lower panel) as a function of time.*

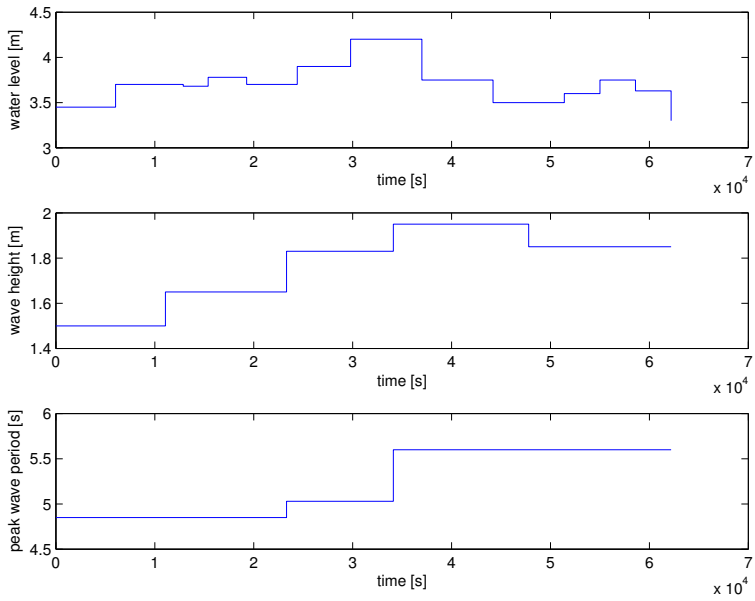

Figure 3.16: *Boundary conditions for test 4. The storm development is shown for the water level (upper panel), the wave height (second panel) and the peak period (lower panel) as a function of time.*

Results

The profile developments are shown in Figure 3.17 to Figure 3.25. In Table 3.9 to Table 3.13, the indicators for different moments in time are shown. Next to the profiles, the relative errors as a function of time are shown in Figure 3.18, Figure 3.20, Figure 3.22, Figure 3.24 and Figure 3.26. Note that the depth-scale factor is relatively small for Test-4 and Test-5. This means that the grid resolution is also relatively large compared to the others tests, which affects the dune retreat indicator since the dune retreat is defined as the 1.5 grid cell below

the maximum dune height. Therefore, the dune retreat indicator is not shown for these two tests since it does not represent correctly dune retreat.

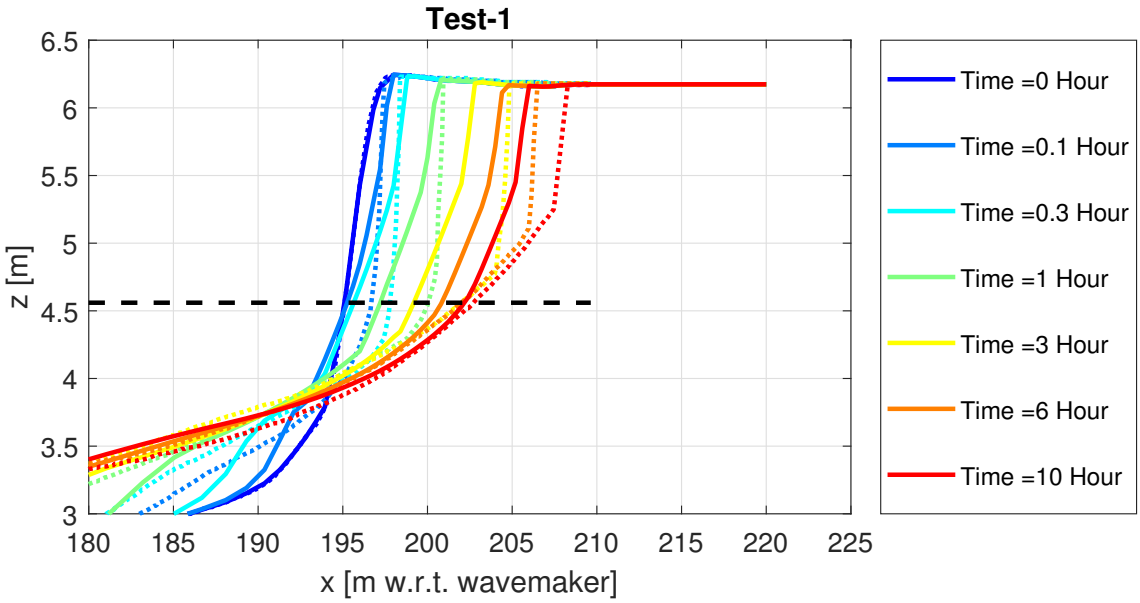

Figure 3.17: *Comparisons of profiles from experiment Test-1 for different moments in time. Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.9: *The computed and observed volume (V) and berm slopes (S) for Test-1. Volumes (V) are given in m^3/m. The relative error is expressed in a percentage. Both the relative error in terms of the same time (rel, t) and the final time are shown (rel).*

Time[hour]	V_{xb} $[m^3/m]$	V_{data} $[m^3/m]$	V_{rel} $[\%]$	$V_{rel,t}$ $[\%]$	S_{xb} $[-]$	S_{data} [-]	S_{rel} $[\%]$	dx_{xb} $[m]$	dx_{data} $[m]$	dx_{rel} $[\%]$	$dx_{rel,t}$ $[\%]$
0.1	1.25	1.85	-3	-32	0.25	0.11	132	1.20	1.20	0	0
0.3	2.61	3.52	-5	-26	0.16	0.08	90	2.00	2.00	0	0
1	5.43	7.70	-13	-29	0.09	0.07	37	3.60	4.80	-10	-25
3	8.98	13.67	-26	-34	0.06	0.05	25	6.00	8.40	-21	-29
6	11.71	15.66	-22	-25	0.05	0.05	17	7.60	10.00	-21	-24
10	14.10	17.69	-20	-20	0.05	0.04	16	9.20	11.60	-21	-21

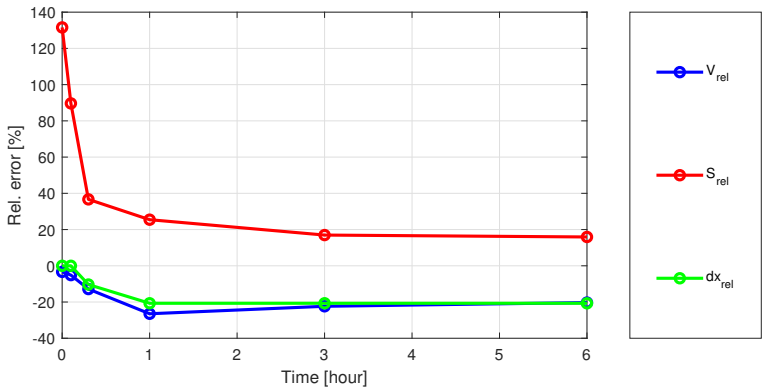

Figure 3.18: *Temporal development of the relative error for the three indicators.*

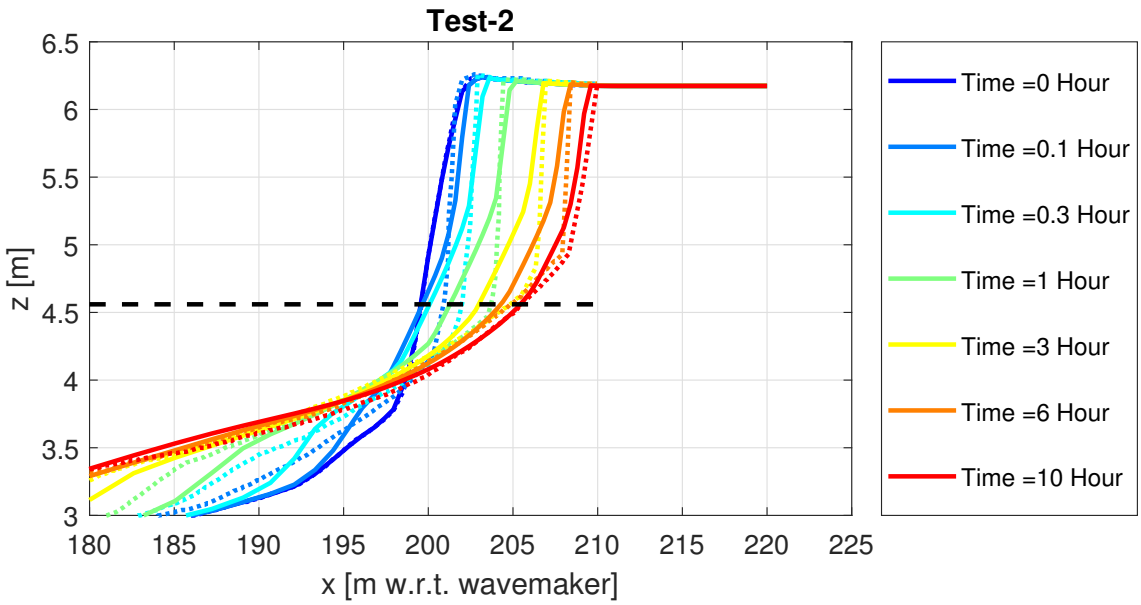

Figure 3.19: *Comparisons of profiles from experiment Test-2 for different moments in time. Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.10: *The computed and observed volume (V) and berm slopes (S) for Test-2. Volumes (V) are given in m^3/m. The relative error is expressed in a percentage. Both the relative error in terms of the same time (rel, t) and the final time are shown (rel).*

Time[hour]	V_{xb} $[m^3/m]$	V_{data} $[m^3/m]$	V_{rel} $[\%]$	$V_{rel,t}$ $[\%]$	S_{xb} $[-]$	S_{data} [-]	S_{rel} $[\%]$	dx_{xb} $[m]$	dx_{data} $[m]$	dx_{rel} $[\%]$	$dx_{rel,t}$ $[\%]$
0.1	1.16	1.00	1	16	0.21	0.11	99	0.80	0.40	5	100
0.3	2.42	2.92	-4	-17	0.14	0.08	78	1.60	1.60	0	0
1	4.81	5.64	-6	-15	0.09	0.06	39	3.20	3.20	0	0
3	7.82	9.55	-13	-18	0.06	0.06	11	5.20	5.60	-5	-7
6	10.19	11.61	-11	-12	0.05	0.05	7	6.80	7.20	-5	-6
10	12.22	13.26	-8	-8	0.05	0.04	14	8.00	8.00	0	0

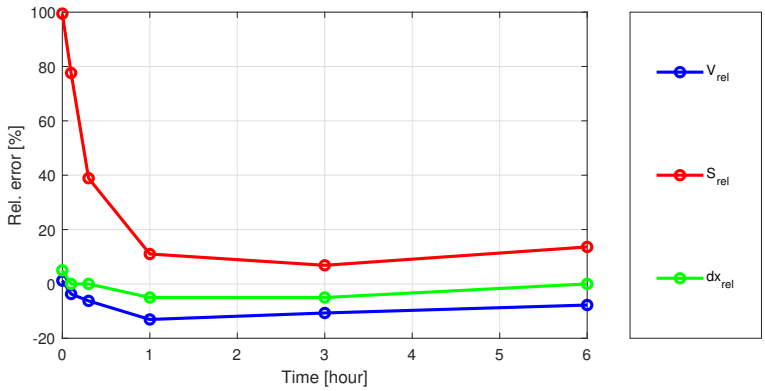

Figure 3.20: *Temporal development of the relative error for the three indicators.*

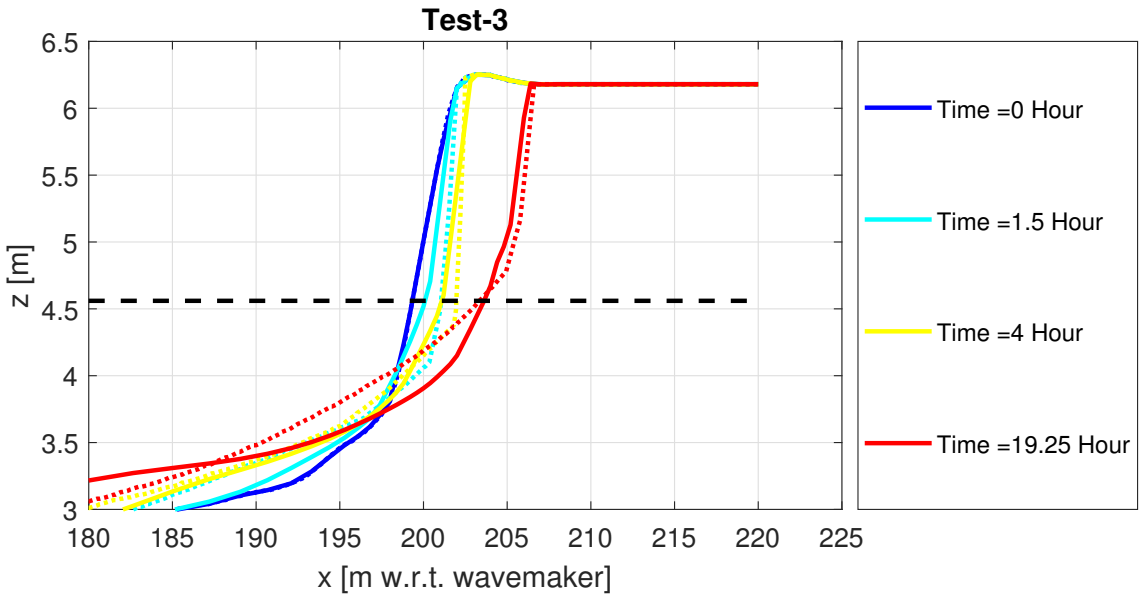

Figure 3.21: *Comparisons of profiles from experiment Test-3 for different moments in time. Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.11: *The computed and observed volume (V) and berm slopes (S) for Test-3. Volumes (V) are given in m^3/m. The relative error is expressed in a percentage. Both the relative error in terms of the same time (rel, t) and the final time are shown (rel).*

Time[hour]	V_{xb} $[m^3/m]$	V_{data} $[m^3/m]$	V_{rel} $[\%]$	$V_{rel,t}$ $[\%]$	S_{xb} $[-]$	S_{data} [-]	S_{rel} $[\%]$	dx_{xb} $[m]$	dx_{data} $[m]$	dx_{rel} $[\%]$	$dx_{rel,t}$ $[\%]$
1.5	0.78	1.58	-9	-51	0.14	0.08	66	0.40	0.80	-8	-50
4	2.25	2.62	-4	-14	0.08	0.06	33	1.20	1.20	0	0
19.25	7.78	8.67	-10	-10	0.05	0.05	-2	4.80	5.20	-8	-8

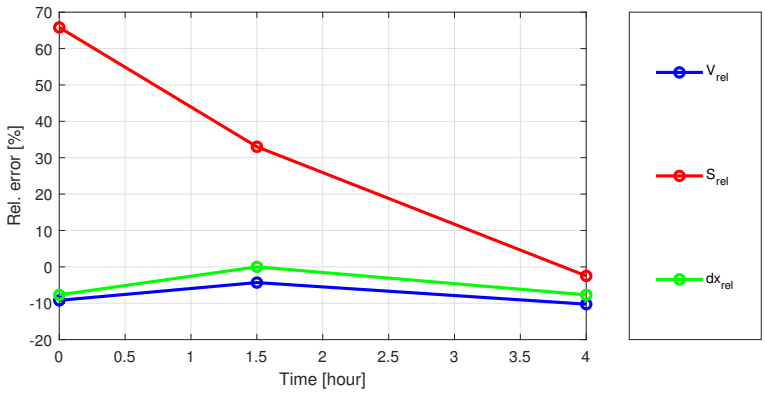

Figure 3.22: *Temporal development of the relative error for the three indicators.*

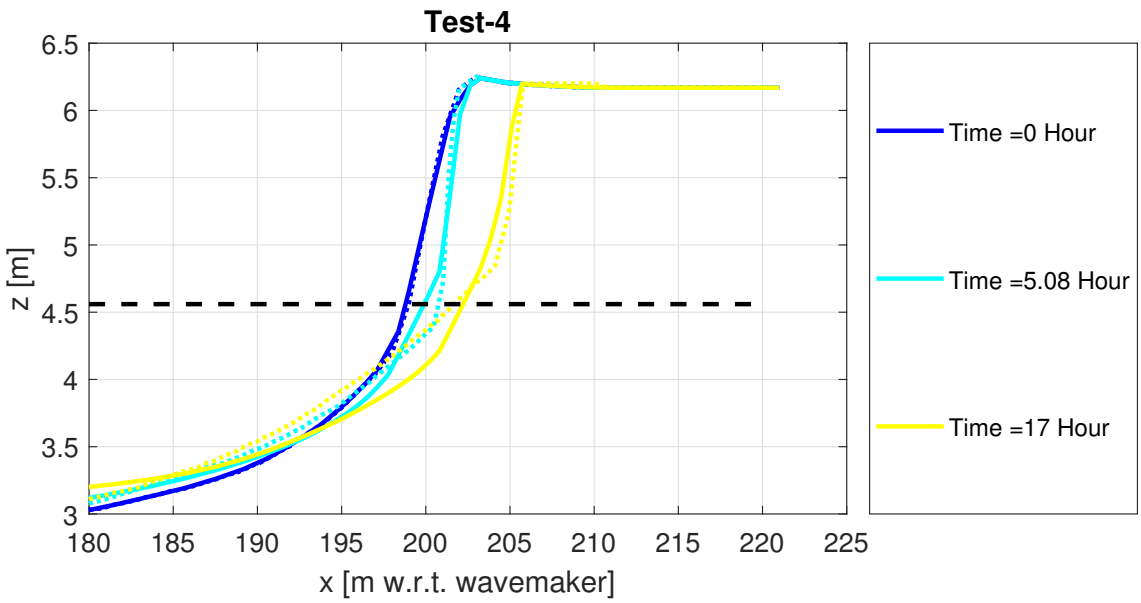

Figure 3.23: *Comparisons of profiles from experiment Test-4 for different moments in time. Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.12: *The computed and observed volume (V) and berm slopes (S) for Test-4. Volumes (V) are given in m^3/m. The relative error is expressed in a percentage. Both the relative error in terms of the same time (rel, t) and the final time are shown (rel).*

Time[hour]	V_{xb} $[m^3/m]$	V_{data} $[m^3/m]$	V_{rel} $[\%]$	$V_{rel,t}$ $[\%]$	S_{xb} $[-]$	S_{data} [-]	S_{rel} $[\%]$
5.08	1.65	1.57	1	5	0.05	0.05	13
17	6.44	7.52	-14	-14	0.04	0.04	-2

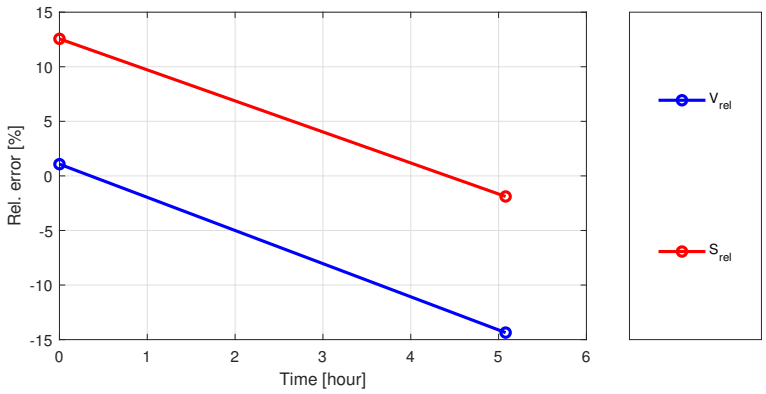

Figure 3.24: *Temporal development of the relative error for the three indicators.*

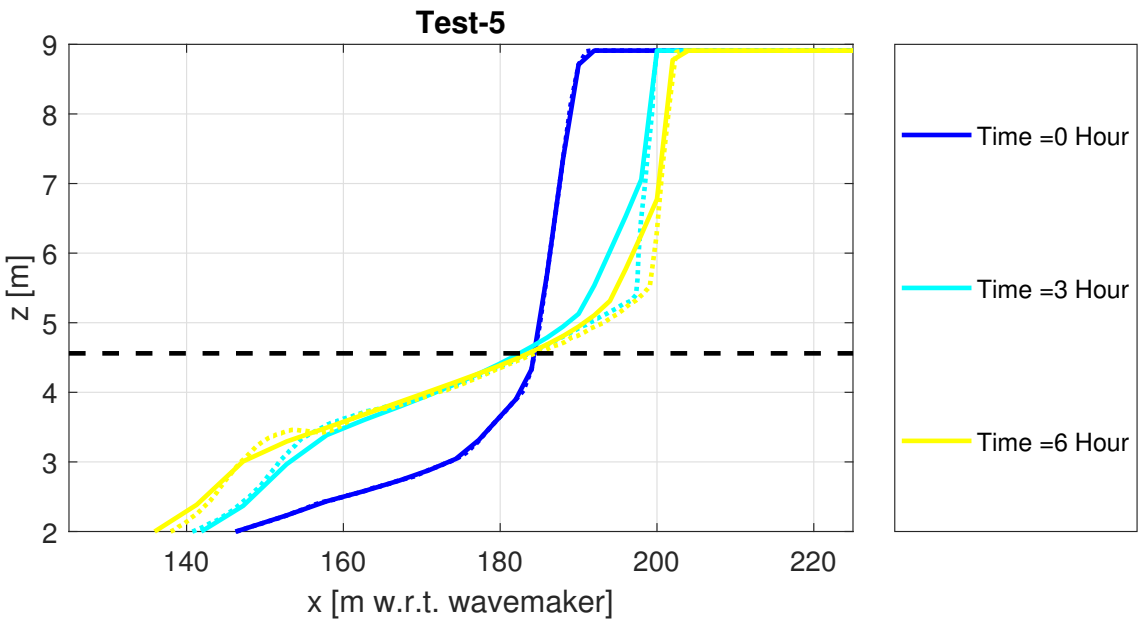

Figure 3.25: *Comparisons of profiles from experiment Test-5 for different moments in time. Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.13: *The computed and observed volume (V) and berm slopes (S) for Test-5. Volumes (V) are given in m^3/m. The relative error is expressed in a percentage. Both the relative error in terms of the same time (rel, t) and the final time are shown (rel).*

Time[hour]	V_{xb} $[m^3/m]$	V_{data} $[m^3/m]$	V_{rel} $[\%]$	$V_{rel,t}$ $[\%]$	S_{xb} $[-]$	S_{data} [-]	S_{rel} $[\%]$
3	34.78	42.13	-14	-17	0.05	0.05	15
6	45.56	50.99	-11	-11	0.04	0.04	4

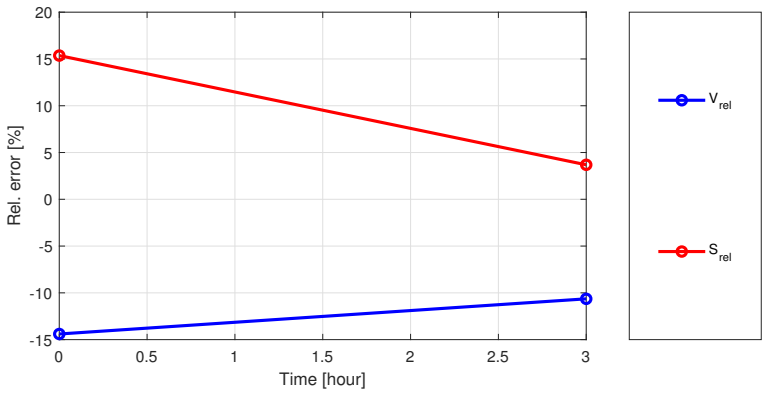

Figure 3.26: *Temporal development of the relative error for the three indicators.*

Overview

The statistical scores for all experiments are shown Figure 3.27 in Table 3.14.

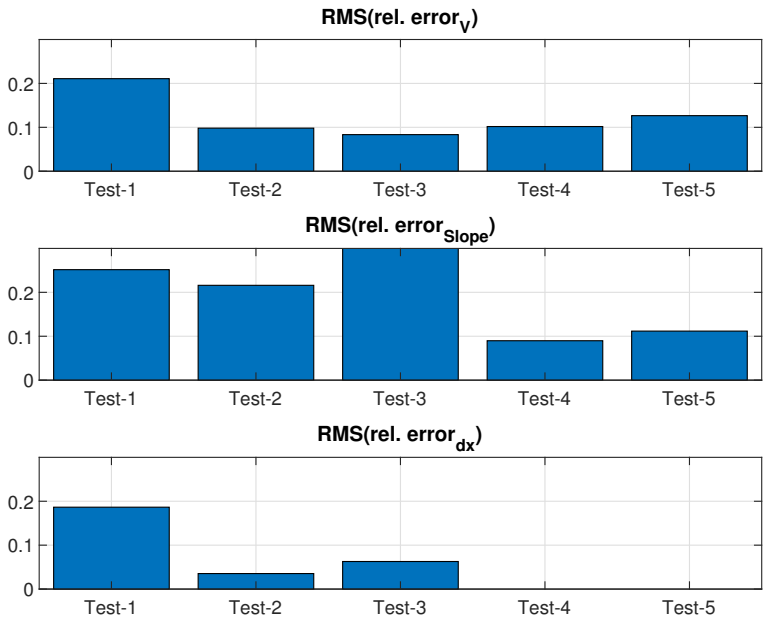

Figure 3.27: *Overview of the statistical scores for M1263 experiments.*

Table 3.14: *M1263 III statistical scores.*

	Test-1	Test-2	Test-3	Test-4	Test-5
$RMS(rel.volume)$	0.21	0.10	0.08	0.10	0.13
$RMS(rel.slope)$	0.25	0.22	0.43	0.09	0.11
$RMS(rel.retreat)$	0.19	0.04	0.06	NaN	NaN

3.1.4 LIP11D: Delta Flume 1994

The purpose of research programme LIP 11D was the generation of high quality and high resolution data on hydrodynamics and sediment transport dynamics on a natural 2DV beach under equilibrium, erosive and accretive conditions. In total 7 tests were performed in the Delta Flume of WL | Delft Hydraulics in the period of April 1993 till June 1993. Test 2E is

incorporated in the skillbed, because the profiles and hydraulic conditions in this test correspond rather well to the Dutch situation. Since there is no direct agreement with the reference profile, scale factors or steepness factors cannot be determined in a similar way as in the research programmes in the 1980's. We assume a scale factor of 1:5. The wave board in the Delta Flume was equipped with active reflection compensation (ARC) at the time these tests were performed, and it is assumed that no second-order wave steering was applied. Waves were measured at a location 20 m from the wave board where the bed level was still horizontal. The sand had a diameter of D_{50} = 220 µm.

The model test 2E, also described in Arcilla *et al.* (1994), concerns extreme conditions with a raised water level at 4.6 m above the flume bottom, a significant wave height, H_{m0}, of 1.4 m (corresponding to some 7 m on prototype scale) and peak period, T_p, of 5 s (corresponds to 11 s on prototype scale). During the test substantial dune erosion took place.

Based on the integral wave parameters H_{m0} and T_p and a standard Jonswap spectral shape, time series of wave energy were generated and imposed as boundary condition. Since the flume tests were carried out with first-order wave generation (no imposed super-harmonics and sub-harmonics), the hindcast runs were carried out with the incoming, bound long waves set to zero as well. Active wave reflection compensation (ARC) was applied in the physical model, which has a result similar to the weakly reflective boundary condition in XBeach, namely to prevent re-reflecting of outgoing waves at the wave paddle (offshore boundary).

The comparison between the observed profiles and computed profiles is shown in Figure 3.28 and the results for the indicators are shown in Table 3.15. The relative errors from Table 3.15 are also shown in Figure 3.29.

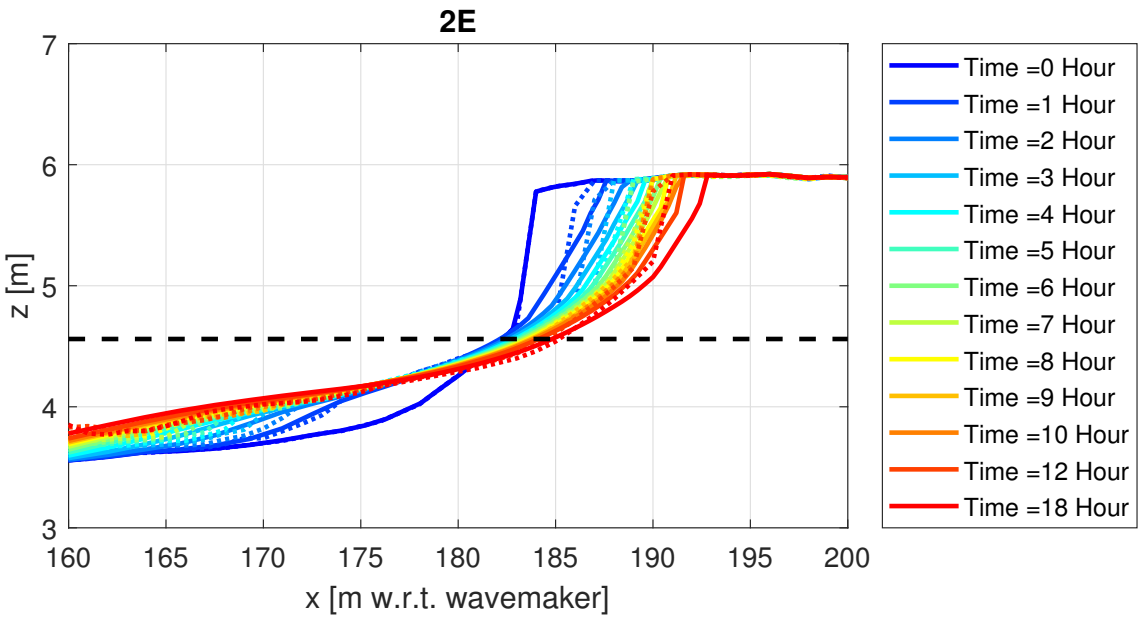

Figure 3.28: *Comparisons of profiles from experiment LIP 2E for different moments in time. Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.15: *The computed and observed volume (V), slope (S) and retreat (dx) for 2E. Volumes (V) are given in m^3/m and retreat distances (dx) in m. The relative error is expressed in a percentage.*

Time [hour]	V_{xb}	V_{data}	rel. error V [%]	S_{xb}	S_{data}	rel. error S [%]	dx_{xb}	dx_{data}	rel. error dx [%]
1	2.41	2.50	-1	0.06	0.06	10	2.40	2.40	0
2	3.44	3.50	-1	0.05	0.05	-3	3.20	3.20	0
3	4.12	4.16	-0	0.05	0.05	-11	4.00	4.00	0
4	4.67	4.73	-1	0.04	0.04	3	4.40	4.40	0
5	5.13	4.99	2	0.04	0.04	-8	4.80	4.80	0
6	5.53	5.15	5	0.04	0.04	-2	5.20	4.80	6
7	5.90	5.61	4	0.04	0.03	31	5.60	5.20	6
8	6.24	5.80	6	0.04	0.03	27	5.60	5.60	0
9	6.55	5.92	8	0.04	0.03	27	6.00	5.60	6
10	6.83	6.15	9	0.03	0.03	24	6.40	6.00	6
12	7.35	6.38	13	0.03	0.03	23	6.80	6.00	12
18	8.65	7.39	17	0.03	0.03	26	7.60	6.80	12

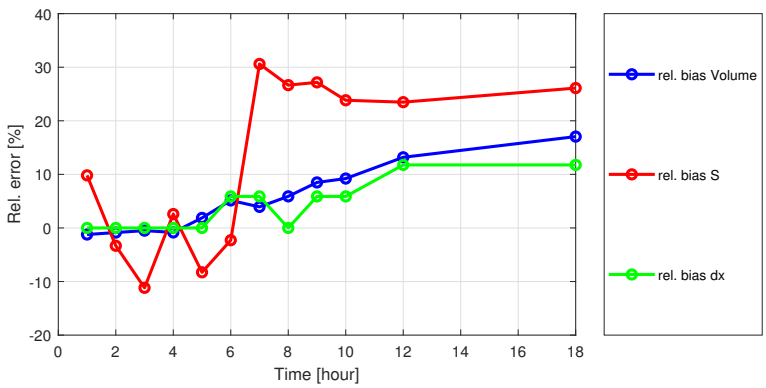

Figure 3.29: *Temporal development of the relative error for the three indicators.*

3.1.5 Deltaflume H4731

In the H4731 Delta flume experiments, it was studied how a collapsed dune revetment affects dune erosion (Van Gent and Coeveld, 2007). Four large-scale experiments were performed in the Delta flume with a depth scale of n_d equals 6. A wave height of 9 m (prototype) and peak period of 12 s (prototype) were forced at the wave maker. The test without a revetment (T14) is modelled with XBeach (Figure 3.30). The results for the indicators for different moments in time are shown in Table 3.16. Note that the observed dune retreat is zero since the dune front does not erode in the observed profiles. This means that the relative error in dune retreat cannot be computed.

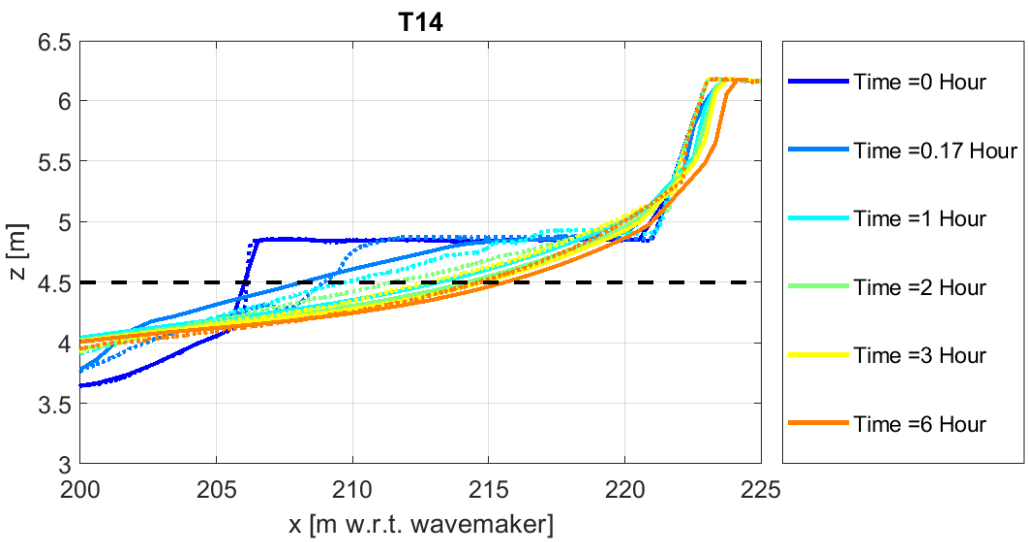

Figure 3.30: *Comparison of profile during experiment T14 Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.16: *The computed and observed volume (V) and berm slopes (S) for T14. Volumes (V) are given in m^3/m. The relative error is expressed in a percentage. Both the relative error in terms of the same time (rel,t) and the final time are shown (rel).*

Time[hour]	V_{xb} $[m^3/m]$	V_{data} $[m^3/m]$	V_{rel} $[\%]$	$V_{rel,t}$ $[\%]$	S_{xb} $[-]$	S_{data} [-]	S_{rel} $[\%]$	dx_{xb} $[m]$	dx_{data} $[m]$	dx_{rel} $[\%]$	$dx_{rel,t}$ $[\%]$
0.17	1.87	1.28	16	46	0.08	0.08	4	0.40	0.00	Inf	Inf
1	3.53	2.36	31	50	0.04	0.06	-38	0.80	0.00	Inf	Inf
2	3.90	3.04	23	28	0.04	0.05	-27	0.80	0.00	Inf	Inf
3	4.17	3.32	22	26	0.03	0.04	-14	0.80	0.00	Inf	Inf
6	4.85	3.79	28	28	0.03	0.03	5	1.20	0.00	Inf	Inf

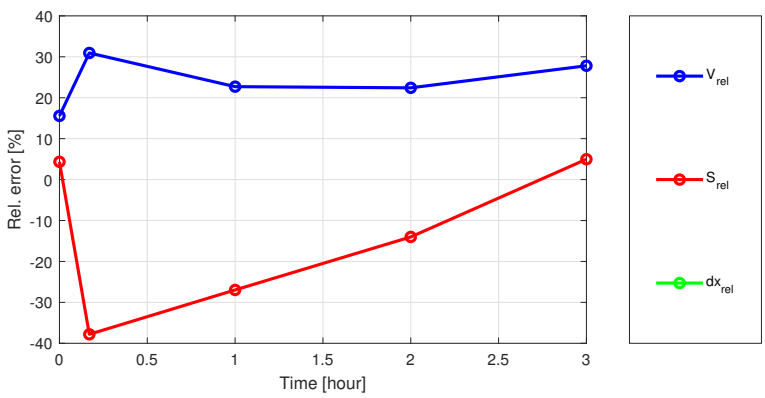

Figure 3.31: *Temporal development of the relative error for the three indicators.*

3.1.6 Grosse Wellen Kanal 1998

Experiment description

The purpose of research programme GWK98 was to improve the methods of design and performance assessment of beach nourishments. In total 24 tests were performed in the wave flume in Hannover (Grosse Wellen Kanal) in the period of November 1996 till August 1997.

These tests were not carried out with an initial profile similar to the Dutch reference profile, nor with hydraulic conditions characteristic for the Dutch coast. Scale factors or steepness factors can therefore not be determined in a similar way as in the research programmes in The Netherlands in the 1980's. We assumed wave-height scaling with respect to super-storm conditions for the Dutch coast (wave-height of 9 m), which resulted in a scale of 1:8. In total 8 series of tests were performed with different initial profiles with and without supporting structures. Imposed wave heights for all tests was 1.16 m (estimated as 9 m on prototype scale), with a wave period of 6.4 s (corresponding to 18 s on prototype scale). In total 5 tests without structures are incorporated in the skillbed, which have a dune-type cross-shore profile and hydraulic conditions large enough to cause significant erosion. First order wave steering was applied, and ARC compensation was present.

Results

The profile development is shown in Figure 3.32 to Figure 3.40. The results for the indicators for different moments in time are shown in Table 3.17 to Table 3.21. Note that the profile measurements do not show a clear dune retreat. Therefore, the dune retreat is not included in shown tables.

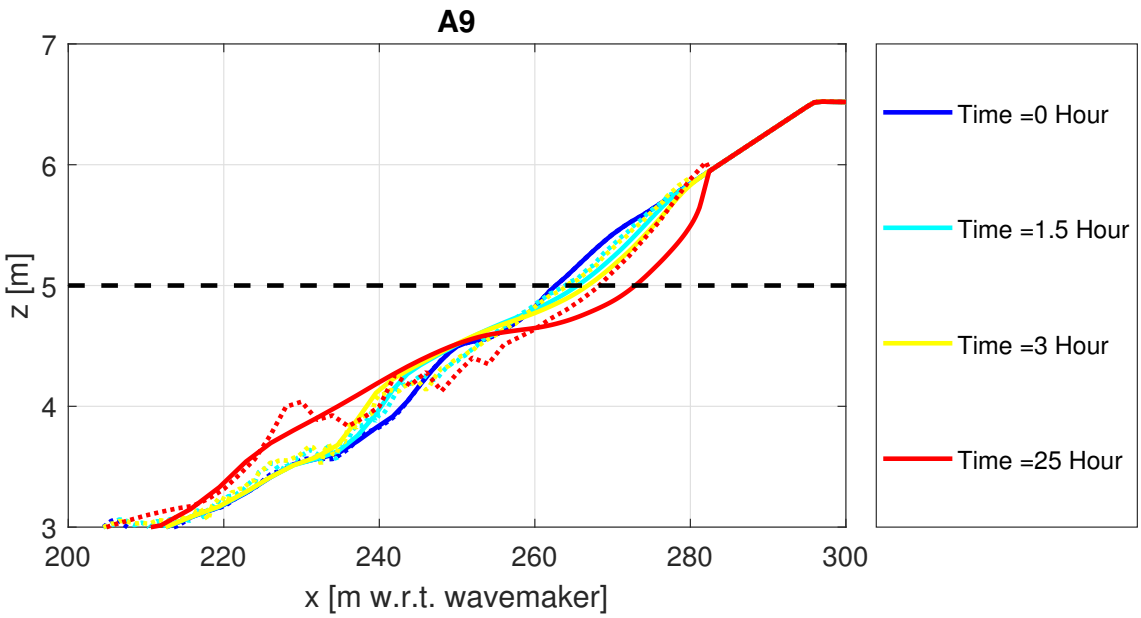

Figure 3.32: *Comparisons of profiles from experiment A9 for different moments in time. Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.17: *The computed and observed volume (V) and berm slopes (S) for A9. Volumes (V) are given in m^3/m. The relative error is expressed in a percentage. Both the relative error in terms of the same time (rel, t) and the final time are shown (rel).*

Time[hour]	V_{xb} $[m^3/m]$	V_{data} $[m^3/m]$	V_{rel} $[\%]$	$V_{rel,t}$ $[\%]$	S_{xb} $[-]$	S_{data} [-]	S_{rel} $[\%]$
1.5	1.88	0.90	32	110	0.04	0.04	5
3	2.80	1.15	53	144	0.04	0.04	-12
25	6.82	3.12	119	119	0.03	0.03	-0

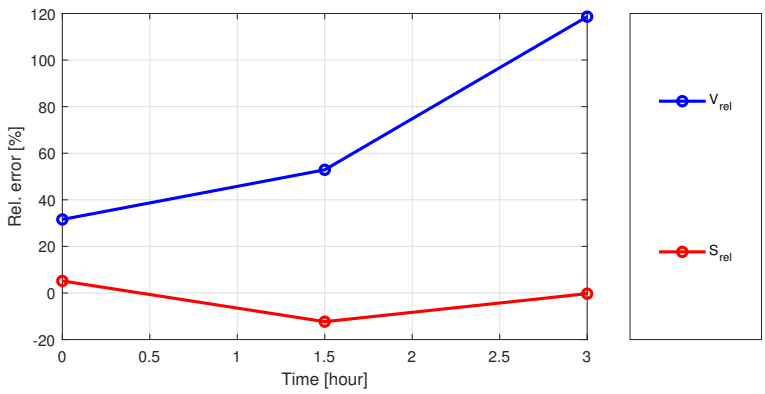

Figure 3.33: *Temporal development of the relative error for the three indicators.*

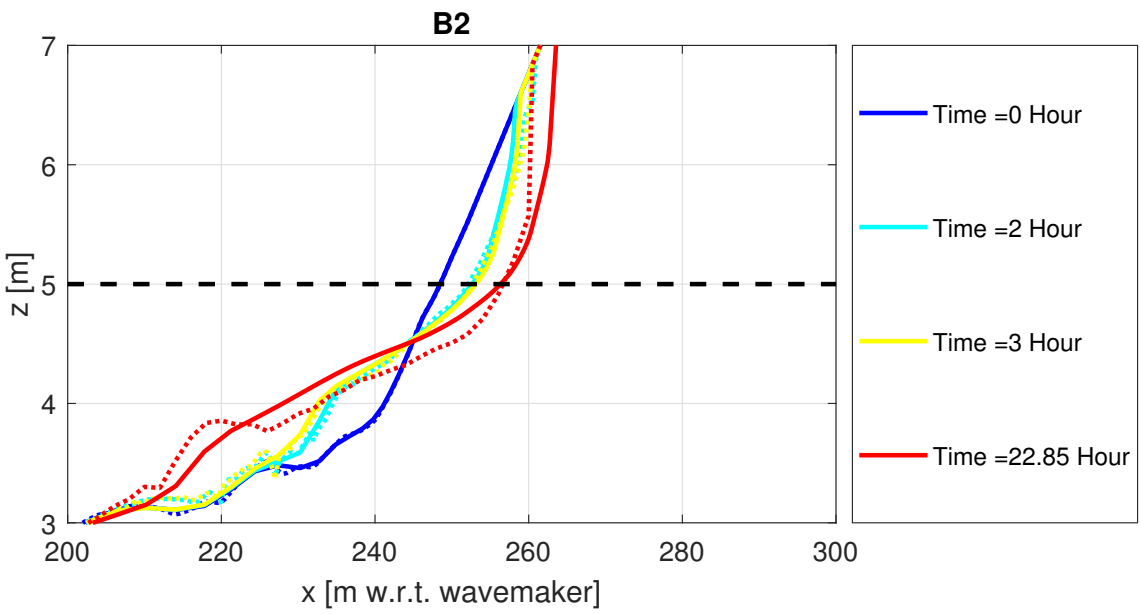

Figure 3.34: *Comparisons of profiles from experiment B2 for different moments in time. Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.18: *The computed and observed volume (V) and berm slopes (S) for B2. Volumes (V) are given in m^3/m. The relative error is expressed in a percentage. Both the relative error in terms of the same time (rel, t) and the final time are shown (rel).*

Time[hour]	V_{xb} $[m^3/m]$	V_{data} $[m^3/m]$	V_{rel} $[\%]$	$V_{rel,t}$ $[\%]$	S_{xb} $[-]$	S_{data} [-]	S_{rel} $[\%]$
2	4.40	5.56	-12	-21	0.06	0.06	-7
3	5.36	5.98	-7	-10	0.05	0.06	-2
22.85	13.46	9.40	43	43	0.04	0.03	6

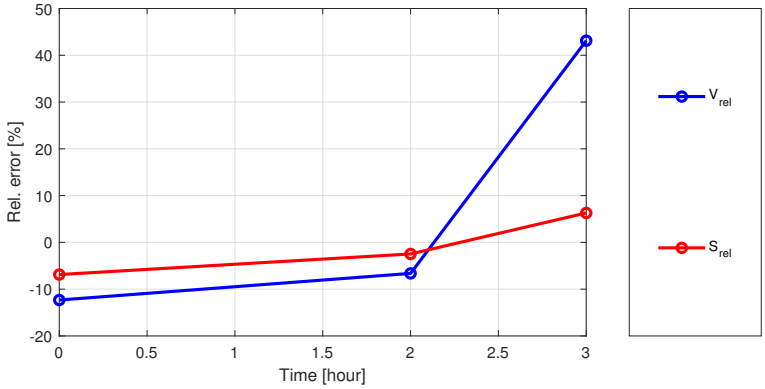

Figure 3.35: *Temporal development of the relative error for the three indicators.*

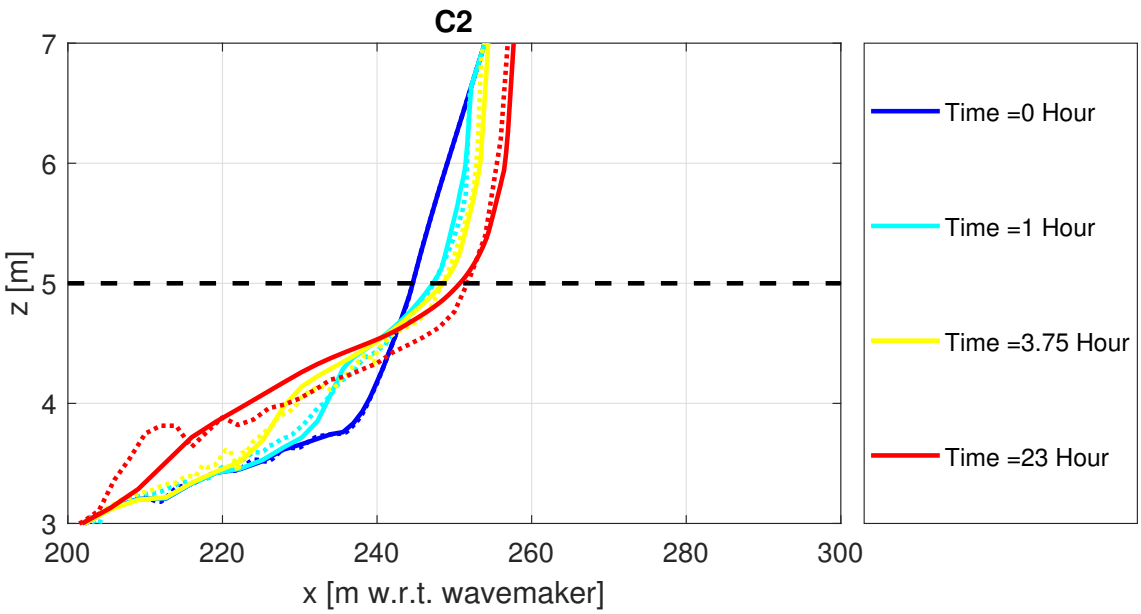

Figure 3.36: *Comparisons of profiles from experiment C2 for different moments in time. Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.19: *The computed and observed volume (V) and berm slopes (S) for C2. Volumes (V) are given in m^3/m. The relative error is expressed in a percentage. Both the relative error in terms of the same time (rel,t) and the final time are shown (rel).*

Time[hour]	V_{xb} $[m^3/m]$	V_{data} $[m^3/m]$	V_{rel} $[\%]$	$V_{rel,t}$ $[\%]$	S_{xb} $[-]$	S_{data} [-]	S_{rel} $[\%]$
1	3.73	4.19	-3	-11	0.07	0.07	1
3.75	7.17	6.13	8	17	0.05	0.05	-6
23	15.09	13.40	13	13	0.04	0.03	20

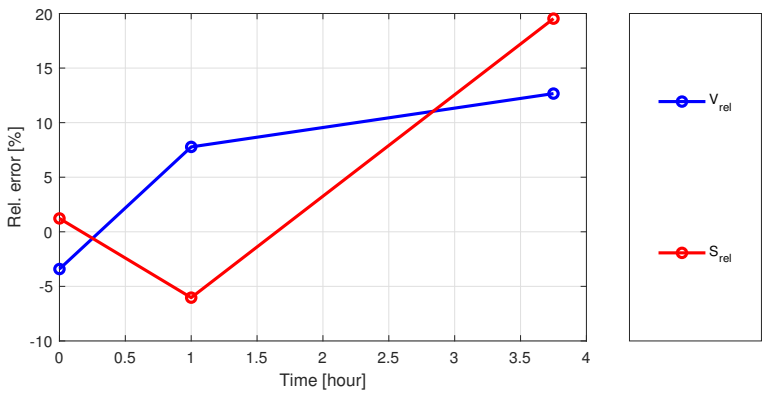

Figure 3.37: *Temporal development of the relative error for the three indicators.*

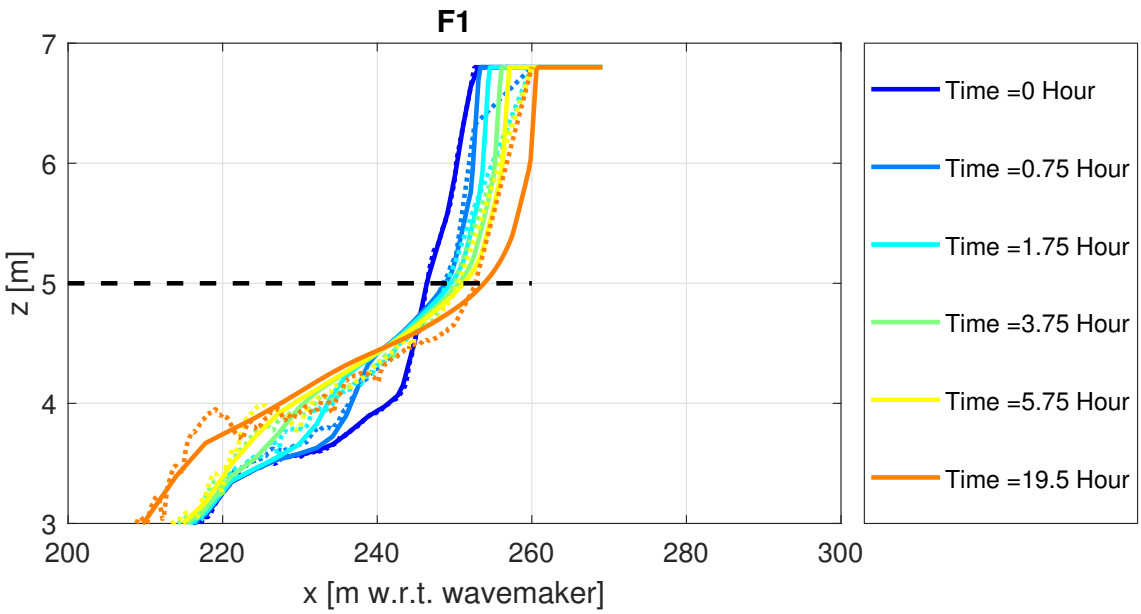

Figure 3.38: *Comparisons of profiles from experiment F1 for different moments in time. Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.20: *The computed and observed volume (V) and berm slopes (S) for F1. Volumes (V) are given in m^3/m. The relative error is expressed in a percentage. Both the relative error in terms of the same time (rel, t) and the final time are shown (rel).*

Time[hour]	V_{xb} $[m^3/m]$	V_{data} $[m^3/m]$	V_{rel} $[\%]$	$V_{rel,t}$ $[\%]$	S_{xb} $[-]$	S_{data} [-]	S_{rel} $[\%]$
0.75	3.62	6.88	-19	-47	0.08	0.08	-2
1.75	5.77	12.12	-36	-52	0.06	0.06	-4
3.75	8.26	13.79	-32	-40	0.05	0.05	5
5.75	9.96	14.75	-27	-32	0.05	0.04	20
19.5	16.02	17.43	-8	-8	0.04	0.04	3

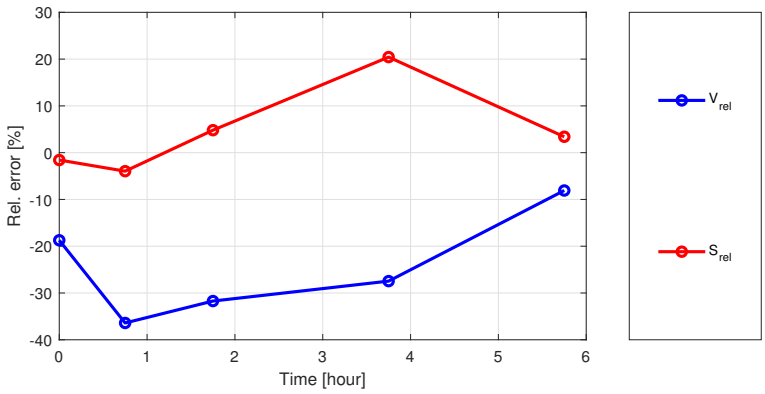

Figure 3.39: *Temporal development of the relative error for the three indicators.*

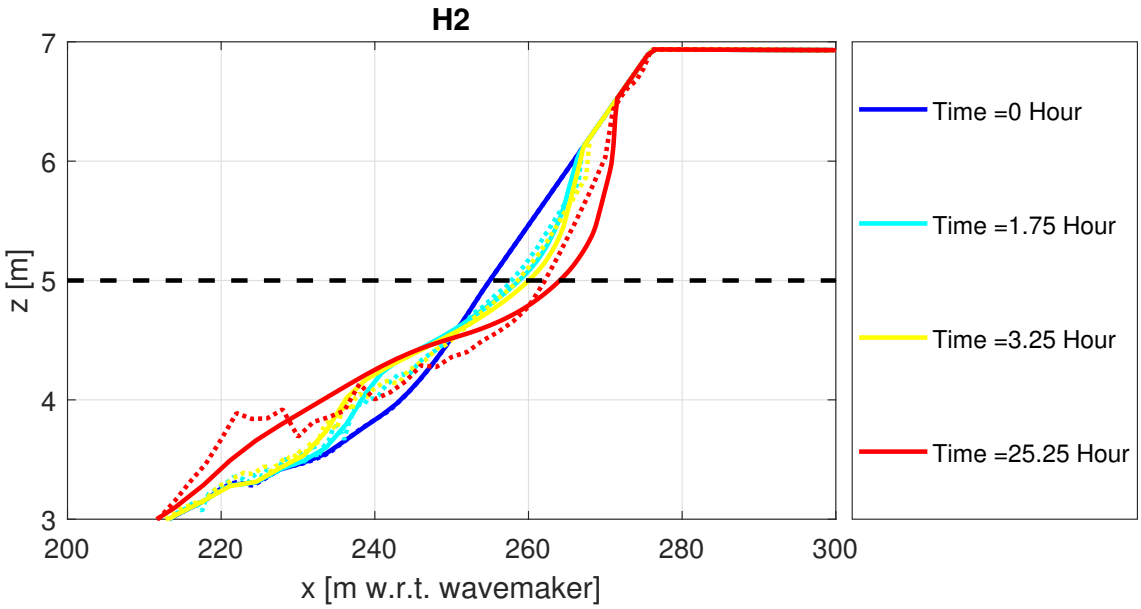

Figure 3.40: *Comparisons of profiles from experiment H2 for different moments in time. Observed profiles are shown with a dashed line and the XBeach profiles with a solid line. The storm surge level is shown with a black dashed line.*

Table 3.21: *The computed and observed volume (V) and berm slopes (S) for H2. Volumes (V) are given in m^3/m. The relative error is expressed in a percentage. Both the relative error in terms of the same time (rel, t) and the final time are shown (rel).*

Time[hour]	V_{xb} $[m^3/m]$	V_{data} $[m^3/m]$	V_{rel} $[\%]$	$V_{rel,t}$ $[\%]$	S_{xb} $[-]$	S_{data} [-]	S_{rel} $[\%]$
1.75	3.10	2.80	4	11	0.05	0.05	-12
3.25	3.98	3.68	4	8	0.04	0.05	-14
25.25	9.38	6.95	35	35	0.03	0.03	-3

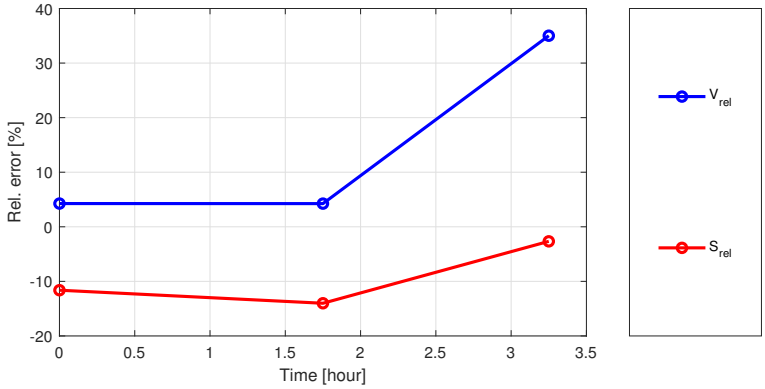

Figure 3.41: *Temporal development of the relative error for the three indicators.*

Overview

An overview of the statistical scores is shown in Figure 3.42 and Table 3.22. Note that dune retreat is not shown and that only the errors in dune erosion volume and berm slope are shown.

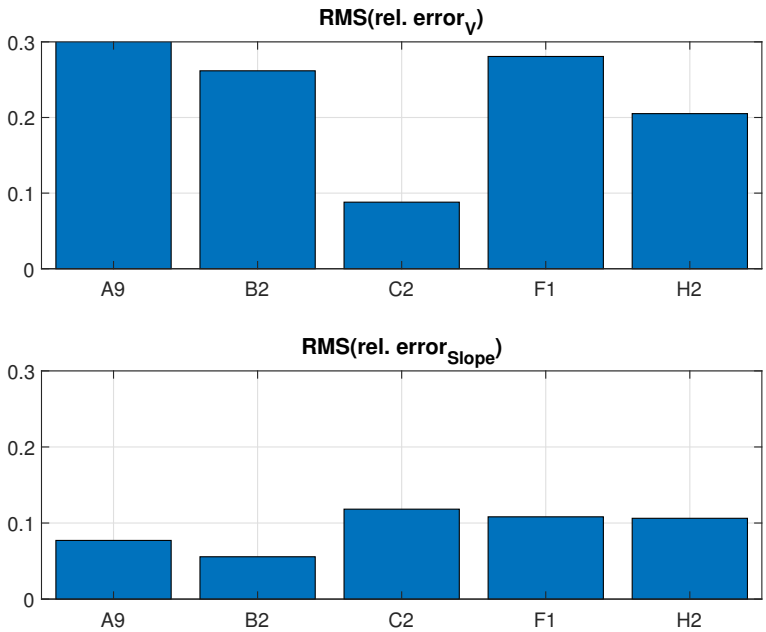

Figure 3.42: *GWK overview*

Table 3.22: *Statistical scores for the Grosse Wellen Kanal experiments.*

	A9	B2	C2	F1	H2
$RMS(rel.volume)$	0.77	0.26	0.09	0.28	0.21
$RMS(rel.slope)$	0.08	0.06	0.12	0.11	0.11

3.2 Field measurements

Validation of the XBeach model using field observations will be carried out in Fase 1 of the BOI Zandige Keringen project. This section is a placeholder for the validation cases of Fase 1.

4 References

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A Model Performance Statistics

A.1 Introduction

In this Appendix the theory behind the Model Performance Statistics (MPS) used in the XBeach skillbed is explained. The MPS are used to quantify the performance of model results based on a comparison with measurement data. Different MPS parameters are used as each parameter has its own characteristics.

First an overview is given of the MPS parameters used in the XBeach skillbed, summarized in table form including some basic characteristics. Consequently, each MPS parameters listed in the overview table is further explained in separate sections.

A.2 MPS parameters

An overview of the MPS parameters used in the XBeach skillbed is given in Table A.1.

Table A.1: *MPS parameters*

Parameter	Description	Ranges
ME & STD	Mean Error & Standard Deviation	0: perfect prediction
Rel. bias	Systematic error relative to the mean	low value: good performance
Sci	Scatter Index	low values: performance

Each parameter listed in the table is further explained in the following paragraphs.

A.3 Mean Error & Standard Deviation

The Mean Error (ME) and the Standard Deviation (STD) of the error of a timeseries are a useful measure to quantify model performance for parameters such as wave heights or water levels. The SD is in general not so useful when applied to morphological parameters such as the bed leve evolution.

$$ME = \frac{1}{N}\sum_{i=1}^{N}(f_{comp.,i} - f_{meas.,i}) \tag{A.1}$$

$$STD = \sqrt{\frac{1}{N-1}\sum_{i=2}^{N}(f_{comp.,i} - f_{meas.,i} - ME)^2} \tag{A.2}$$

A.4 Relative Bias

The Relative Bias (Rel. Bias) is the systematic error relative to the mean. Relative low values of the mean can cause high vales of the Rel. Bias.

$$Rel.Bias = \frac{\sum_{i=1}^{N}(f_{comp.,i} - f_{meas.,i})}{\sum_{i=1}^{N} \bar{f}_{meas.}} \tag{A.3}$$

A.5 Scatter Index

The Scatter index (SCI) is the standard deviation relative to the mean value of the measured signal. Relative low values of the mean can cause high vales of the SCI.

$$Sci = \frac{\sqrt{\frac{1}{N-1}\sum_{i=2}^{N}(f_{comp.,i} - f_{meas.,i} - ME)^2}}{\bar{f}_{meas.}} \tag{A.4}$$

B Morphology indicators

B.1 Erosion volume

The dune erosion volume is defined as the volume per running meter between the initial bed level and the bed level at a given time. For both the initial bed level and the bed level at a given time, the maximum water level is applied as lower limit (See Figure B.1).

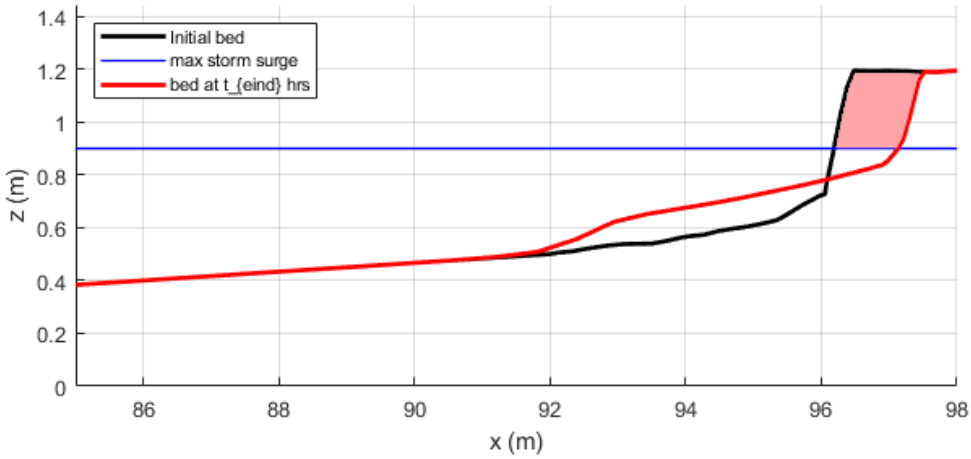

Figure B.1: *Definition of erosion volume*

B.2 Dune front retreat

The dune front retreat is defined as the horizontal displacement at a given reference height in the considered time period. The reference height is defined as the 1.5 times the grid resolution below the maximum initial bed level (See Figure B.2). This height is representative for the dune front and low enough to capture all the dune front of all the observed profiles. The dune height can reduce during an experiment due to erosion.

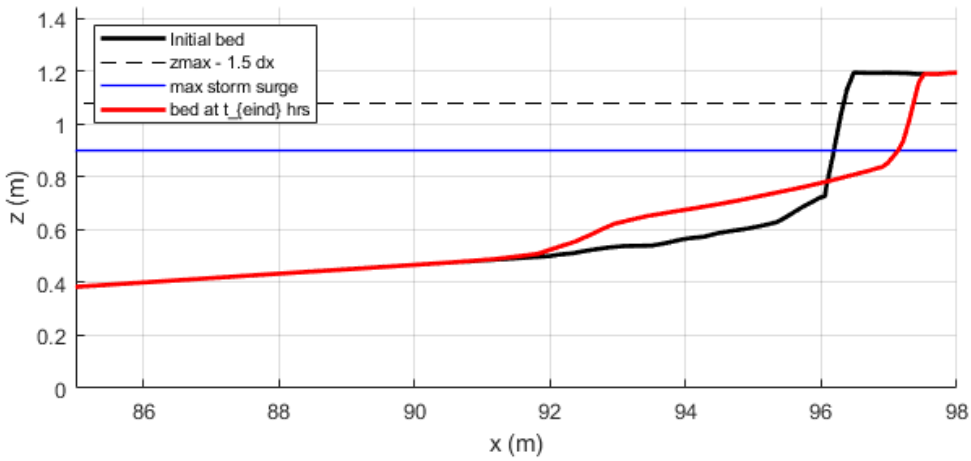

Figure B.2: *Dune retreat indicator.*

B.3 Berm slope

The berm slope is defined as the mean slope in the deposition zone. The upper limit is defined as the maximum water level and the lower limit is equal to the most seaward point of

the deposition zone, where the deposition is equal to 50% of the maximum vertical deposition (See Figure B.3). The mean of this slope is computed after interpolating the bed level to a uniform grid. This interpolation is required to prevent that the mean berm slope is affected by the spatial variation in the grid.

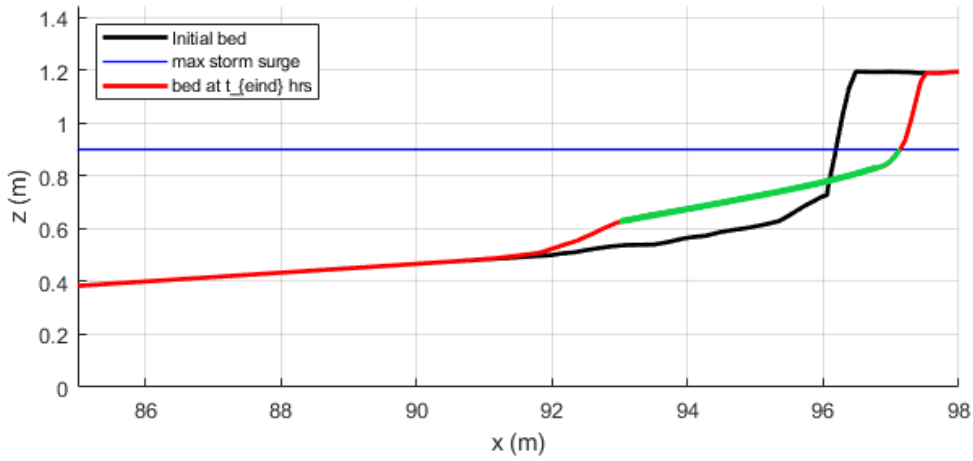

Figure B.3: *Berm slope indicator*

C Detailed analysis

This Appendix shows a detailed analysis selected physical experiments for which detailed hydrodynamic and morphodynamic data are available.

C.1 Deltagoot 2006

In this section, a detailed comparison between simulated physics over an evolving bathymetry and the measurements obtained during the Deltaflume experiment in 2006 (Van Gent *et al.*, 2008) is made.

The observed and computed wave height transformation and the setup are shown in Figure C.1 to Figure C.3. These wave height transformations results in a flow pattern, which affect the sediment transport rates. The comparison of the flow velocities is shown in Figure C.4 and Figure C.5. Note that the comparison of the velocities of test T02 is not shown, because the observed velocities are not available.

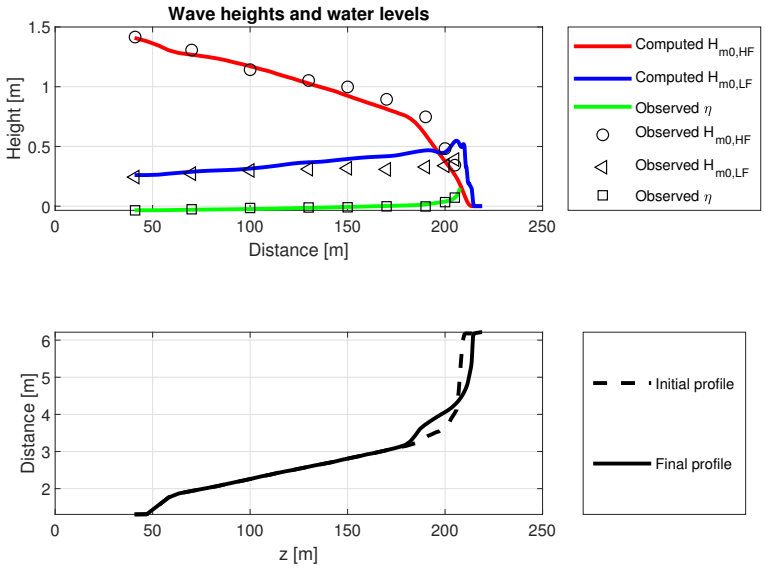

Figure C.1: *Computed and observed short wave height transformation, infragravity wave height transformation and mean water level (upper panel) for test T01. The lower panel shows the initial and final computed profiles.*

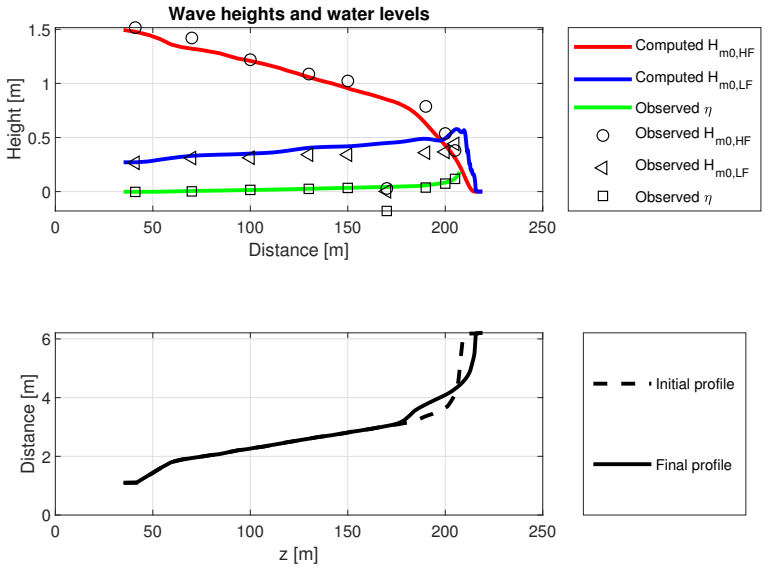

Figure C.2: *Computed and observed short wave height transformation, infragravity wave height transformation and mean water level (upper panel) for test T02. The lower panel shows the initial and final computed profiles.*

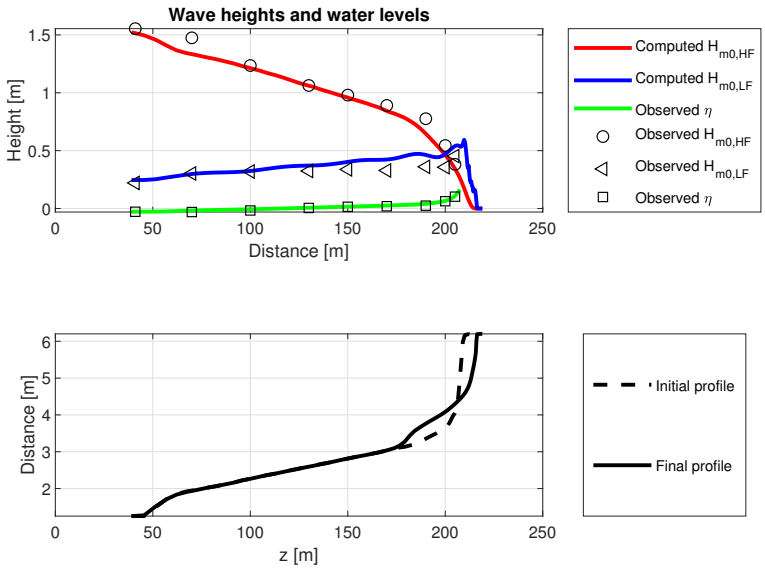

Figure C.3: *Computed and observed short wave height transformation, infragravity wave height transformation and mean water level (upper panel) for test T03. The lower panel shows the initial and final computed profiles.*

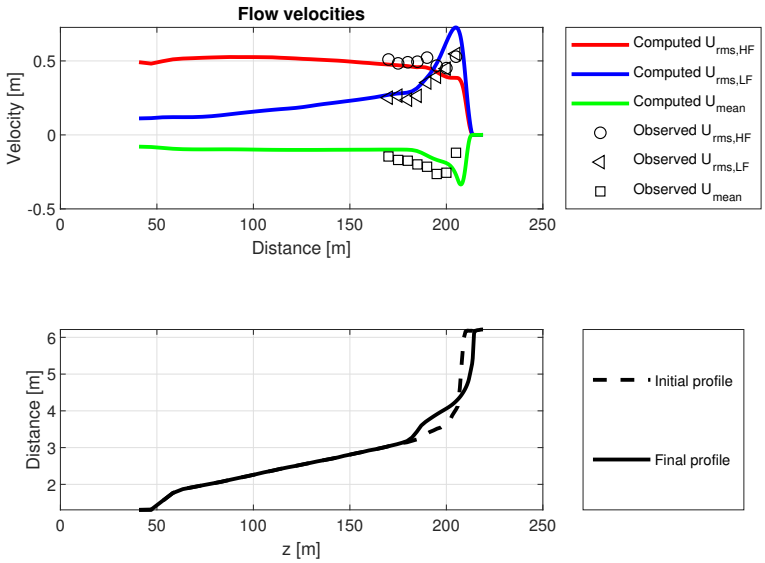

Figure C.4: *Computed and observed high and low frequency root-mean-squared velocity and mean velocity (upper panel) for test T01. The lower panel shows the initial and final computed profiles.*

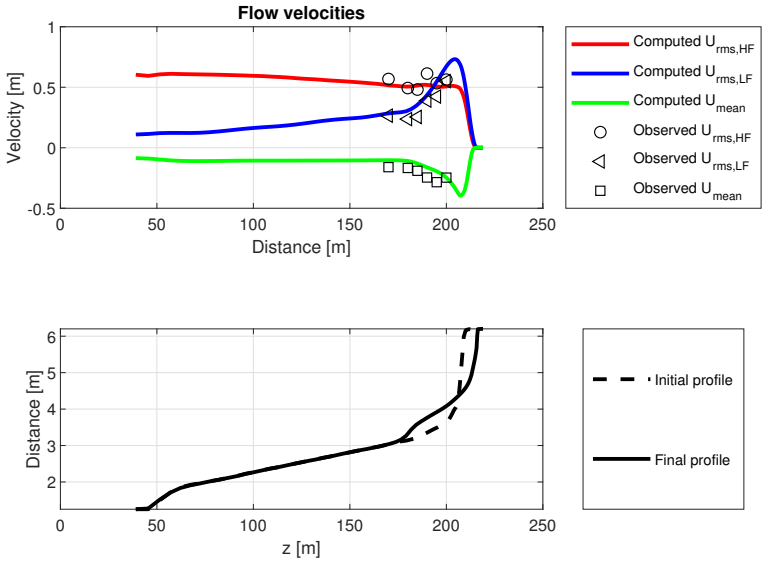

Figure C.5: *Computed and observed high and low frequency root-mean-squared velocity and mean velocity (upper panel) for test T03. The lower panel shows the initial and final computed profiles.*

XBeach does not resolves the short wave shape, but an approximation is applied to include the effects of nonlinear waves on the sediment transport rates. The wave shape which is expressed in terms of skewness, asymmetry is shown in Figure C.6, Figure C.7 and Figure C.8. In general, the wave shape changes when the water depth decreases. In shallow water the waves become more asymmetrical (sawtooth shape) and more skewed (higher peaks), which is also visible in the computed and observed wave shapes.

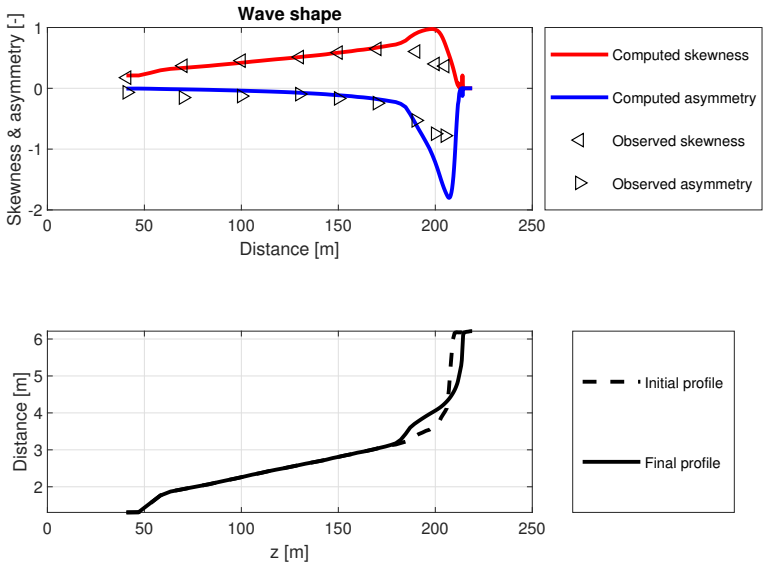

Figure C.6: *Computed and observed wave shape as a function of the cross-shore distance (upper panel).*

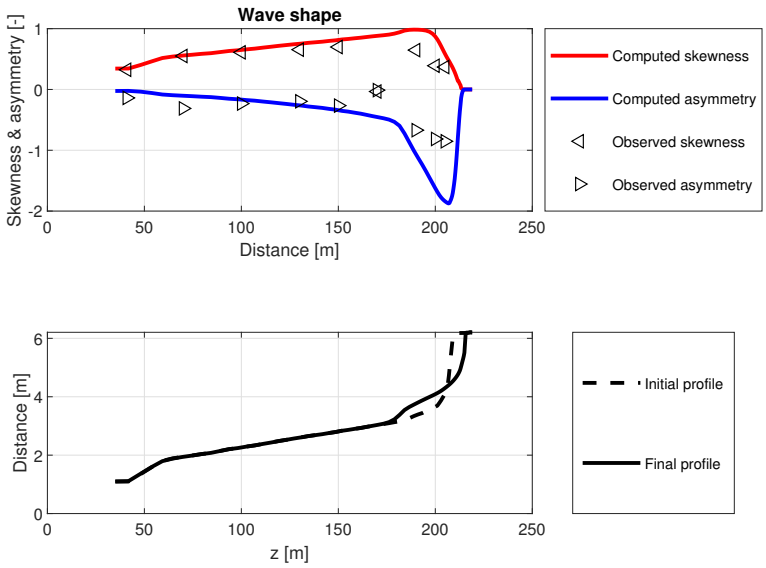

Figure C.7: *Computed and observed wave shape as a function of the cross-shore distance (upper panel)*

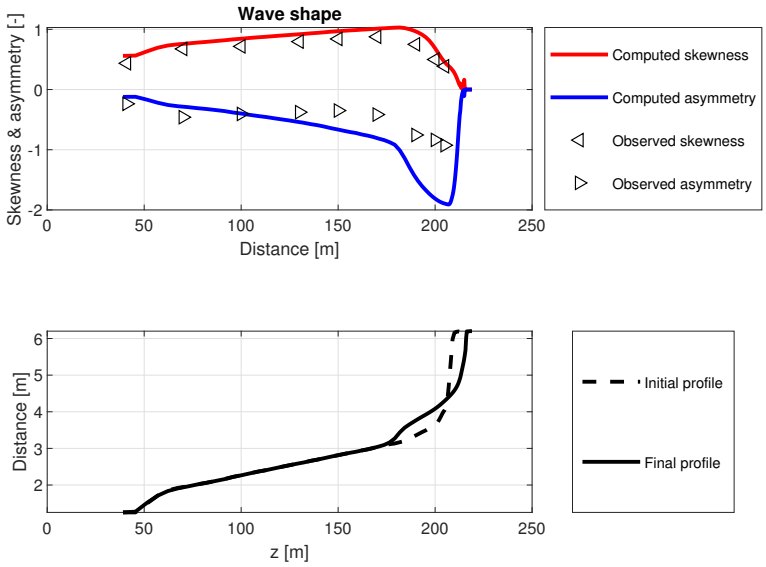

Figure C.8: *Computed and observed wave shape as a function of the cross-shore distance (upper panel)*

The observed and modelled sediment concentrations are shown in Figure **??** and **??**. The observed sediment concentrations are not available and, therefore, the results of test T02 are not shown.

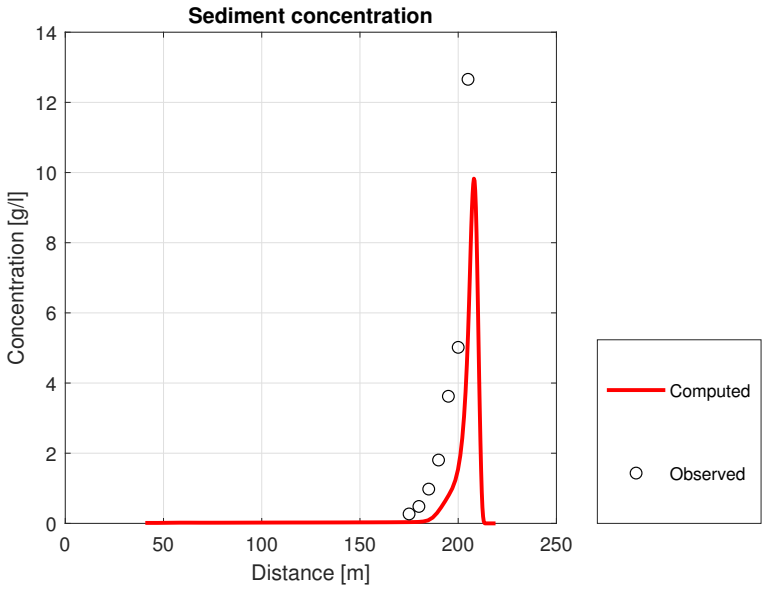

Figure C.9: *Sediment concentrations*

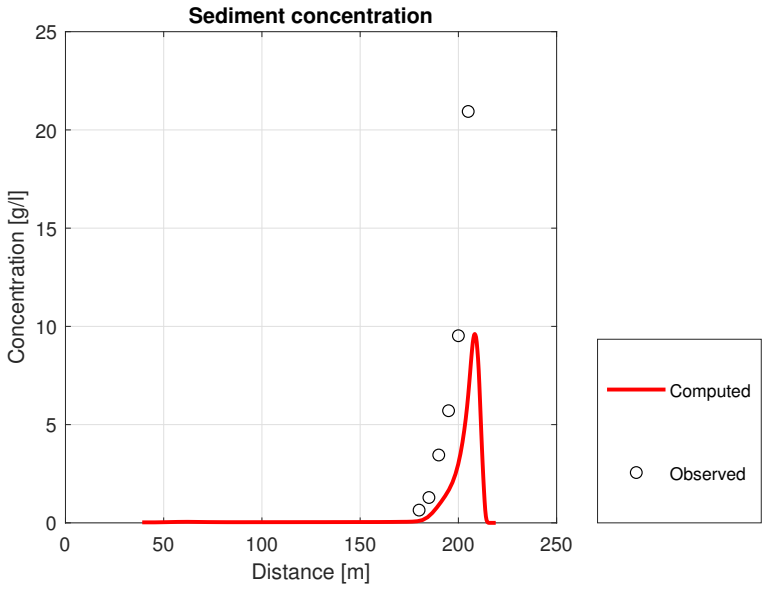

Figure C.10: *Sediment concentrations*

In Figure C.11 to Figure C.13, the observed and computed erosion and sedimentation patterns are compared. The bed level changes clearly show a erosion at the dune front and a deposition on the foreshore. The temporal plot of the erosion volumes is shown in Figure C.14 to Figure C.16.

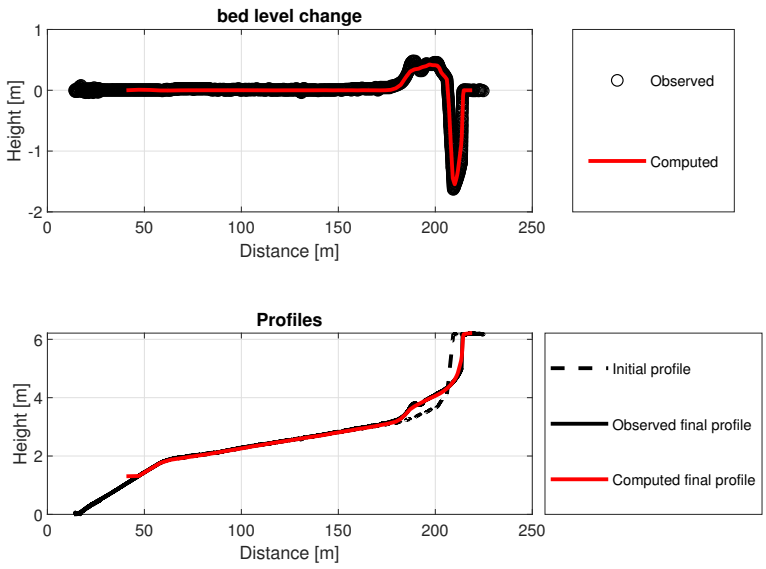

Figure C.11: *Erosion and sedimentation patterns (upper panel) and profiles (lower panel) for test T01*

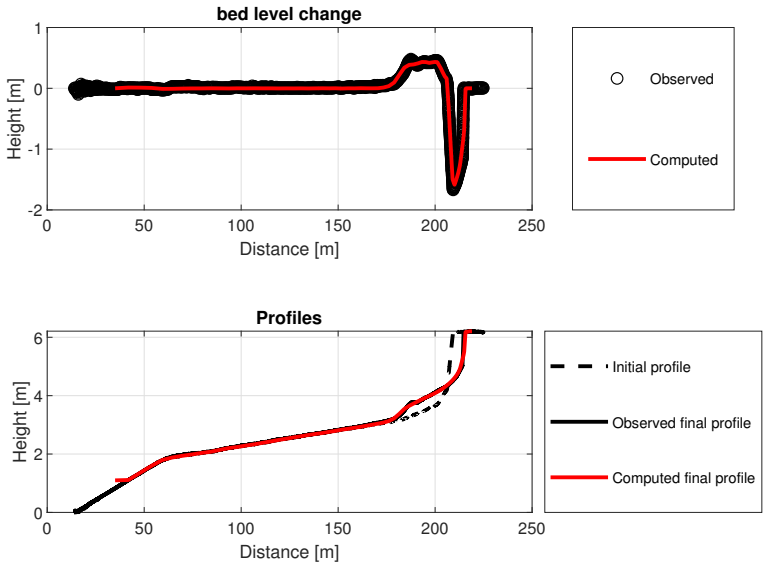

Figure C.12: *Erosion and sedimentation patterns (upper panel) and profiles (lower panel) for test T02*

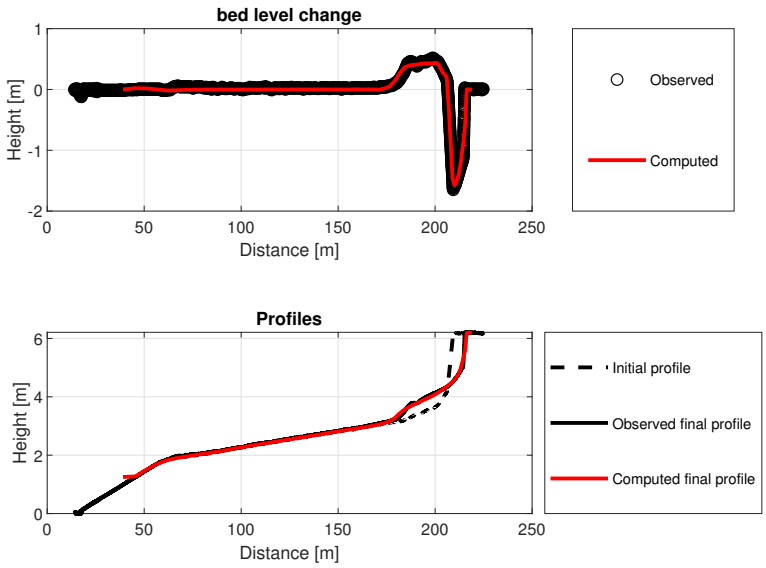

Figure C.13: *Erosion and sedimentation patterns (upper panel) and profiles (lower panel) for test T03*

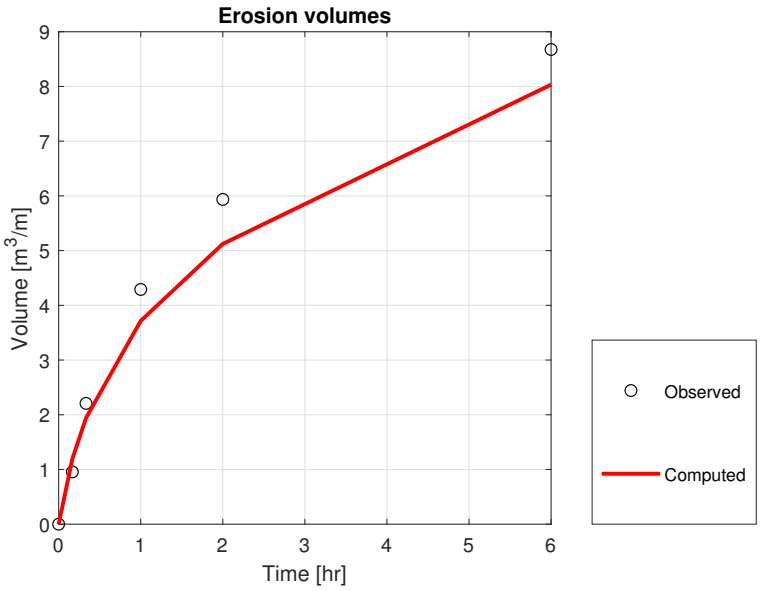

Figure C.14: *Erosion volumes as a function of time for test T01*

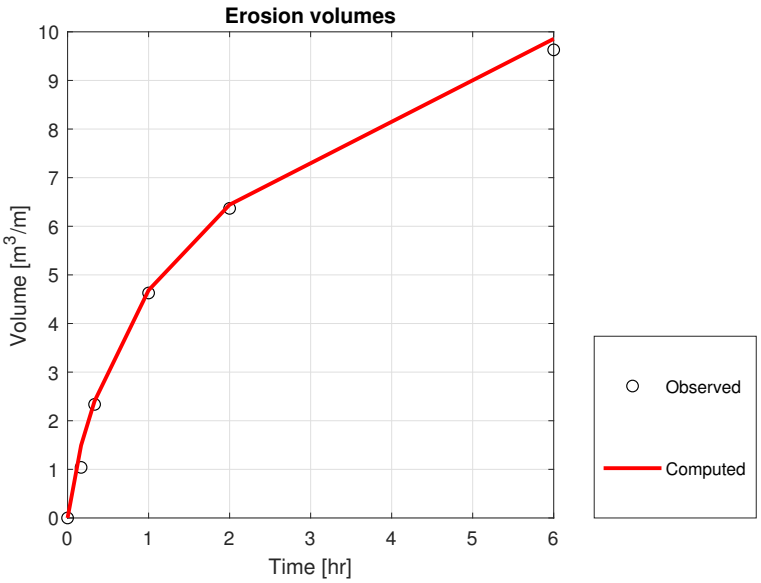

Figure C.15: *Erosion volumes as a function of time for test T02*

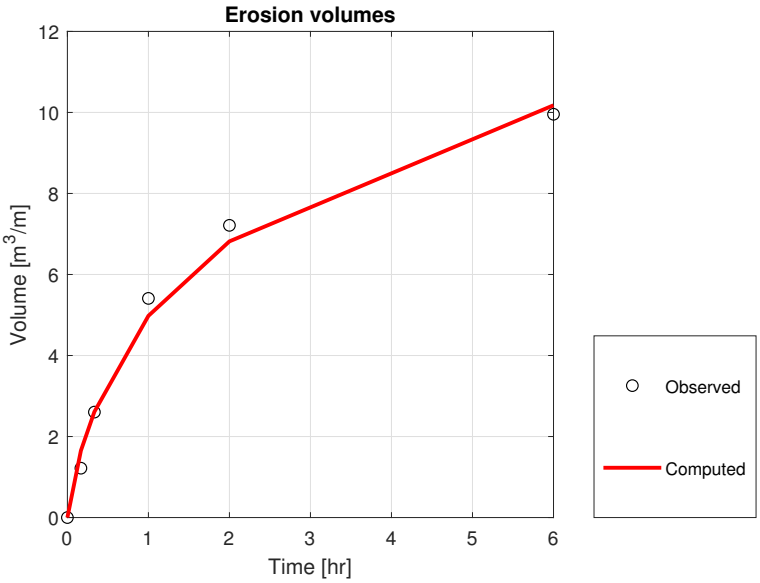

Figure C.16: *Erosion volumes as a function of time for test T03*

C.2 LIP

This section shows additional detailed comparison of the 2E test of the LIP 11D experiment (Arcilla *et al.*, 1994).

The observed and computed wave height transformation and the setup are shown in Figure C.17. The sedimentation and erosion patterns are shown in Figure C.18 and the erosion volumes as function of the time are shown in Figure C.19.

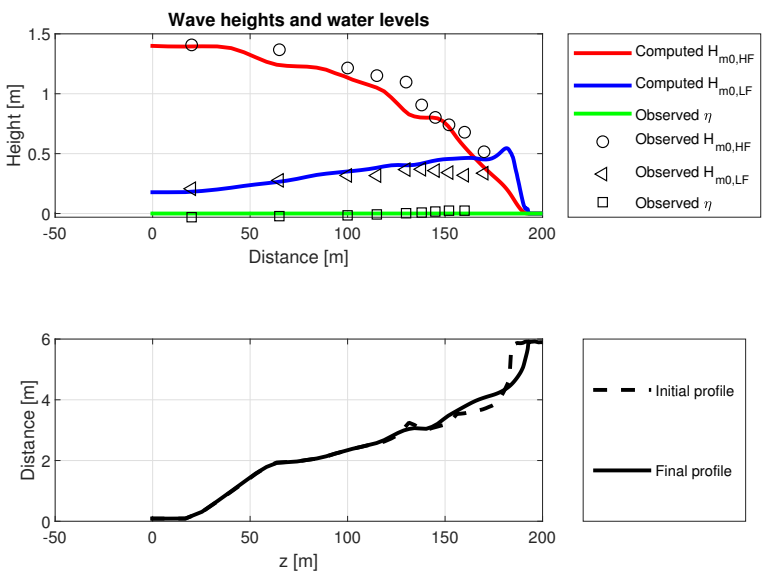

Figure C.17: *Computed and observed short wave height transformation, infragravity wave height transformation and mean water level (upper panel) for test 2E. The lower panel shows the initial and final computed profiles.*

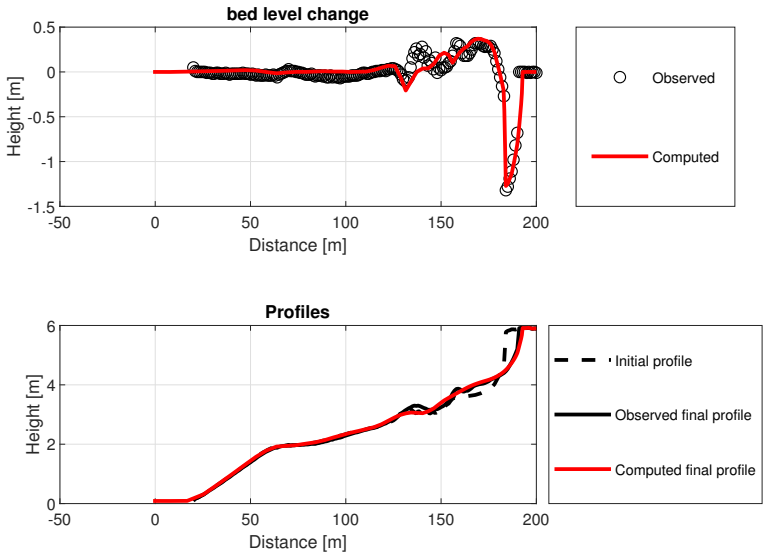

Figure C.18: *Erosion pattern and volumes and retreat distance during test 2E*

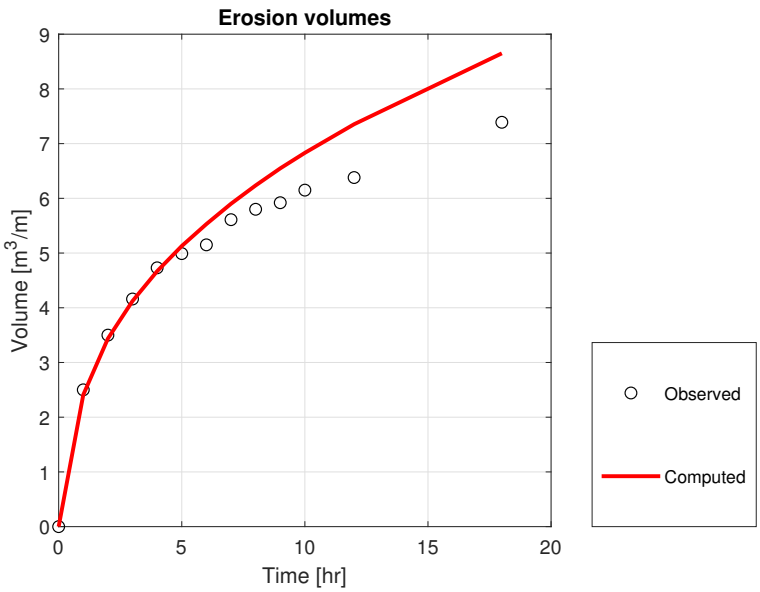

Figure C.19: *Erosion volumes as a function of time for test E2*