Development of sediment sorting near the large scale nourishment 'The Sand Motor'

Executing and analysing new measurements in relation to previous campaigns

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Additional Master of Science Thesis

TU Delft Delft University of Technology

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Front cover: *the aerial view of the Sand Motor in July 2013, with the sample transects and locations of the latest measurement campaign indicated by red lines and green pins. Image retrieved from Google Maps.*

Development of sediment sorting near the large scale nourishment 'The Sand Motor'

Executing and analysing new measurements in relation to previous campaigns

Additional thesis as part of the Master specialisation
Coastal Engineering
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by

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Summary

The sediment composition of the sea bed is of relevance for various coastal properties such as bed forms, beach slopes and marine ecology. Furthermore it may significantly influence the morphological evolution of the coast. The sediment sorting processes at natural beaches are, however, difficult to distinguish since there can be a both a large temporal variability in bed composition as well as considerable spatial heterogeneity resulting from geological history. Often encountered problems are the lack of knowledge concerning the initial bed composition and the low spatial and temporal sampling for most field surveys. While latter is generally insufficient to analyse the sorting processes at natural beaches with some certainty, a lot of data is available for the Sand Motor, a large scale nourishment near the coast of Kijkduin.

Before, during and after the construction of the Sand Motor sediment sampling measurements have taken place, whether or not in combination with other research (e.g. fauna development). To continue the insights in the sediment sorting near the Sand Motor a new measurement campaign was set-up in February 2014. The 173 measurement points were chosen based on general coastal theory, previous measurements and model simulations. The whole campaign was merely intended to indicate the spatial variability of sediment composition: strategic transects were sampled very densely (sampling interval of 20 meter) to indicate the precise location of grain size gradients. An additional feature is the inclusion of alongshore transects, to be able to analyse alongshore variability.

The results of the campaign showed the presence of a large fine patch in the north of the Sand Motor, a smaller fine patch just south, coarse sediments in the swash zone and very course sediments in the most energetic part of the nourishment. In addition, gradients in alongshore direction proved to be of similar order as in cross-shore. The direct inter-comparison between previous campaigns showed to be rather difficult due to the variety in number of samples and the different methods of sample analysis; therefore the campaign in this research particularly supports observations made with the help of previous measurements. However, a general tendency towards the initial situation could be observed: where the measurements just after the construction of the Sand Motor showed (on average) much coarser material than measured before construction, all campaigns thereafter were consecutively finer when considering the overall sediment composition. Although the maximum inaccuracy of the sampling method is not very large (order 3%) the uncertainties in representativity of the samples are thought of to be quite influential. Especially in campaigns with only a few samples precaution should be taken when stating conclusions. In future research it is recommended to take undisturbed depth samples, with for example a corer.

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Preface

Fieldwork is rather laborious, physically demanding and at some times quite dusty; but as later seen in this research indispensable for interpretation of model results and above all very satisfactory: seeing the results of the whole measurement campaign for the first time turned out to be an exciting moment.

This additional thesis provided the perfect opportunity to work in both a larger scale research - the PhD research of my supervisor - as well as doing some fieldwork to substantiate the modelling study I perform for my graduation. The latter research is also used in this report quite elaborately to substantiate the hypothesis and in return, this report will serve as data reference for the model validation. Since the measurement campaign took a large part of the available time for this report, a part of the analysis of the data is presented in the final thesis.

Next to the content this research also proved to be good for the overall awareness of measurements errors, the scale of the nourishment called the Sand Motor and to develop a good sense for grain sizes. The large amount of data was both helpful and challenging at times, making it sometimes difficult to manage all the information, but also had the pleasant side effect of never being out of work.

August 2014,

Jelle

Acknowledgements

As stated above, the gathering of sediment samples is physically quite demanding, and I would like to thank both my daily supervisor Bas Huisman as well as Saulo Meirelles Nunes Da Rocha, Lodewijk de Vet and Gerwin Stam for their effort in getting all samples; both at the boat and at the beach. In addition, I would like to thank Bram van Prooijen for his input in sampling locations, interpretation of results and supervision in general.

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Chapter 1

Introduction

In March 2011 the 'Monitoring program and Evaluation Pilot Sand Motor' was published, stating the hypotheses towards the future of the Sand Motor (Van der Valk et al., 2011). The hypothesis were divided into four areas of interest, namely: (1) strengthening the natural dune growth, (2) generating knowledge concerning the added value of the Sand Motor towards nature and recreation, (3) the development of a recreational and natural area to the coast and (4) the collection of knowledge to control the Sand Motor and its surroundings in a proper way.

To test the hypotheses, various monitoring campaigns were planned, including three campaigns - without a time schedule - for measuring sediment compositions. In addition to the three planned campaigns, additional measurements have been taken by combining sediment sampling with other measurements (e.g. ecology). All measurement campaigns contributing to sediment grading samples are listed in Table 1.1 and will be discussed in Section 2.3.

Sediment sorting as such was not an initial research topic for the Sand Motor pilot, but the large amount of data, quickly changing morphology and an abrupt change in sediment composition (to a more or less uniform composition) when building the Sand Motor creates a perfect opportunity to look at both spatial and temporal sediment sorting scales. The observations so far have been researched by both Huisman et al. (2014) and Sirks (2013), but to strengthen and elaborate the outcomes of those papers, measurements have to be continued. In this research a new measurement campaign is executed, which makes it possible to both complement previous research and to state new findings concerning the hydrodynamic forcing of sediment sorting. The data of this research can also be used for validating and/or calibrating numerical modelling of changes in bed sediment composition, as is done by Van der Zwaag (2014).

Table 1.1 *Measurement campaigns in the past.*

Name	Month	Year	Executed by
T0	N.a.	'93-'01	TNO
T0	October	2010	IMARES
T0	November	2010	Medusa
T1	April-November	2011	Boskalis
T2	August	2012	IMARES
T3	February	2013	NEMO (TU Delft & Deltares)
T4	October	2013	IMARES

1.1 Problem definition

In the previous section it was stated that sediment sorting processes are important for various reasons, but especially for the sediment transport (see Van Rijn et al. (1995) and Gao and Collins (1992)) and morphological features of the considered coast (Dean, 1991; Medina et al., 1994; Guillén and Hoekstra, 1996). It is therefore a field of interest for modelling studies: which bed composition will occur where and how does that influence the behaviour of the nourishment? Before any model can be used however, it has to be calibrated with field data. Although the concept of using field data to validate a model is not that difficult, it is much harder to obtain data that can actually be used for the purpose of validation. A simple example is the choice for the number and location of samples, but also a method to state conclusions about the bed composition is needed. While there have been measurements near the Sand Motor, especially in the past 3 years such as seen in Table 1.1, it is expected that the current data set is insufficient to be used as a reference for validation of a numerical model.

The first reason for additional measurement campaigns in the extra information that is gathered over the temporal behaviour: how did the spatial distribution change in time? So not only the sediment composition at that moment, but also the trend lines towards the sediment sorting processes in time become more clear. Nevertheless, the sediment grading at that moment is interesting as well: which hydrodynamic conditions cause this specific composition, and should it be taken into account in further computations? This is also important for aspects that have to do with again temporal processes: after a storm a different sediment composition will be observed than after months of calm weather.

Considering the above, continuation of measurements is important for both strengthening previous research, as well as finding new processes that are important for future computations. Some trend lines could already be observed in previous campaigns, but the last measuring campaign of which data was available before executing this field campaign was performed in February 2013, which implies that the characteristics near the Sand Motor (which is highly dynamic and constantly reshaping) will be different at this moment. By setting up a new measuring campaign the available data can be extended and compared with previous measurements in the winter, providing better possibilities to predict the sediment sorting near the Sand Motor and future nourishments.

Combining the above the goal for this research is quite broad: both the development of the sediment sorting in time as such, as well as searching for new features that have not been observed before can be researched. Combining the latter leads to the problem definition defined as:

> How is the sediment sorting near the Sand Motor developing?

1.2 Research questions

The mentioned problem definition is divided in several research questions, namely:

1. What information is available from literature sources concerning the impact of hydrody-

namics on sediment sorting processes?

2. How can the current knowledge of sediment sorting be used to optimize the sampling procedure (location, density etc.)?

3. What is the observed sediment composition (e.g. spatially, gradients and storm impact) at the Sand Motor?

4. Can data be intercompared? And what uncertainties can we expect in the data?

1.3 Outline of the Thesis

This report is written following the structure of the research questions as well as 'theory - hypothesis - measurements - analysis - conclusions'. The first step is gathering knowledge about the measurement site, historical measurements and relevant processes, as is done in Chapter 2; answering research question 1. According to those findings and the problem definition, hypotheses are stated in Chapter 3. To validate the hypotheses the actual measurement campaign is set-up in Chapter 4 (research question 2), where after the results of this campaign are presented in Chapter 5 and Appendix B (research question 3, 4). With the help of the results the hypotheses can be validated, where after conclusions and recommendations can be stated in respectively Chapter 6 and Chapter 7.

Chapter 2

Theoretical background

The title of this report already indicated the main subject of the Thesis: sediment sorting processes, in particular near the Sand Motor. In order to interpret the results of this research, as well as the approach and validation, some background knowledge is valuable. To do so, this chapter elaborates several aspects of measuring near the Sand motor, starting with a short introduction to the general concept of the Sand Motor. The development of the Sand Motor is then defined in somewhat more detail by describing the occurring hydrodynamics in the past 2,5 years after the construction of the Sand Motor.

Since the report is mainly about the interpretation of the measurements, no specific knowledge concerning sediment transport and coastal processes is provided. It is assumed that the reader possesses some knowledge concerning this theory, if not, reference is made towards Van Rijn (1993), Bosboom and Stive (2013) and Nielsen (1992).

After the general information concerning the Sand Motor, this chapter will continue with the available methods to actually measure the sediment sorting in coastal areas. This information will be used in Chapter 4 to set-up the measurement campaign for this research. Finally, results of previous measurements - stated in the introduction and in Table 1.1 - will be discussed, to state conclusions concerning the development of the sediment sorting in a later stage. The analysis of previous results is partially based on the research of Huisman et al. (2014) and Sirks (2013), who already did extensive research towards these measurements.

With this chapter research question 1 is answered and a funded basis is provided for research question 2.

2.1 Sand Motor description and hydrodynamic influences

To provide some background information, a short introduction in the general idea of the Sand Motor is written down, directly followed by some additional information concerning the hydrodynamics forcing the Sand Motor. These forcings are the direct cause of sediment to sort out, making it an important aspect for the later interpretation of results.

(a) *July 2011* **(b)** *July 2012* **(c)** *July 2013*

Figure 2.1 *Development of the Sand Motor in the first 2 years (Beeldbank, 2013).*

2.1.1 Sand Motor in general

The Dutch coastline is prone to (increasing) erosion due to both sea level rise as well as land subsidence, which primarily undermines the safety against flooding. To counter this erosion, Dutch Legislation states that the coastline should maintain the 'Basic Coastline' ,which is the coastline as observed in the year 1990. This goal is achieved by means of regular nourishments with a total amount of 12 million cubic meters a year (Verkeer en Waterstaat, 1990).

To optimize these nourishments a new coastal maintenance strategy, which is based on the natural redistribution of sand near the coast (the so called 'Building with Nature'), was proposed. In 2008 the first specific agreements were made, proposing a program which facilitates 'Coastal growth by the addition of excess sand to the coastal system, using natural current patterns in the North Sea', referred to as the Sand Motor (Verkeer en Waterstaat, 2008). The main goal of the Sand Motor concerns the combination of long term safety with more room for nature an recreation near the Randstad. Secondary goals include gaining knowledge concerning natural ways of coastal development and to set-up a collaboration structure between the different parties involved in the coastal defence.

In August 2011 the Sand Motor was completed, by suppletion of 22 million cubic meters of sand in a hook shape near Kijkduin, The Netherlands, as seen in Figure 2.1a. The sand was accumulated 10 kilometre offshore, by means of two trailing suction hopper dredges. It should be noted that since it concerns a pilot, the Sand Motor did and does not replace regular coastal nourishments.

To fulfil the secondary goal of the whole operation (gaining knowledge) a monitoring plan was developed, described in Van der Valk et al. (2011). This monitoring plan included the sediment sampling for both ecology and sediment grading. After construction, the Sand Motor rapidly started to deform: sand was transported to the north, where after the 'hook' more or less connected to the beach and an area with several channels developed, see Figures 2.1b and 2.1c. This process is described in somewhat more detail in Subsection 2.1.2.

2.1.2 Hydrodynamics near the Sand Motor

Two important forcings near the Sand Motor concern the tide and wave action. The tide is semi-diurnal, with a maximum and minimum value of respectively about 120 and -100 cm versus NAP, see Figure 2.2 (Rijkswaterstaat, 2014). From this figure it is also clear that the water level is largely influenced by the temporal water set-up, which can cause much higher water levels than expected on basis of the astronomical tide. Much lower water levels do not often occur due to the normally smaller easterly winds (see also below). The tide along the Dutch coast propagates northwards, around the amphidromic point between Denmark and the UK. The flood velocities are higher than the ebb velocities, resulting in a residual current to the north (Van Rijn, 1997). Notwithstanding this residual current, Van de Meene and Van Rijn (1994) measured very little sediment transport during (spring) tidal fair weather conditions. This observation would indicate that sediment sorting processes will be dominated by (storm) waves, especially due to the relatively small scales considered. The wave height over time, starting from the start of the Sand Motor in 2011, is shown in Figure 2.3, clearly showing more energetic conditions during the winter (November - February).

To analyse the hydrodynamics near the Sand Motor, it is important to notice the spatial location of the nourishment. In Figure 2.4a it can be seen that the maximum fetch is very limited for winds between 30 and 300 degrees. It is therefore expected that the highest waves and thus the most energetic conditions resolve from the northwest and southwest direction. This is confirmed by Figure 2.5, where the wave height is plotted against the wave direction for the observed wave conditions at the Euro-platform, starting in August 2011 up to January 2014. In combination with 2.4b it can be stated that the wind and thus wave conditions from 45 to 225 degrees are not relevant for this research.

The actual functioning of the Sand Motor can also be explained with the help of the hydrodynamics (leaving out the aeolian transport): the shape of the Sand Motor causes contraction of the present currents, which in turn depend on the wave direction and the tidal cycle. Both the alongshore current and the tidal current are affected by this contraction, causing higher flow velocities near the seaward part of the Sand Motor. Part of the time these currents interfere, causing additional turbulence when the tidal flow is opposite to the alongshore current. Just after construction of the Sand Motor, a sharp 'hook' was present at the north side. Since the flow velocity is related to the water depth, currents (partially) refract around this hook, causing additional flow contraction. The higher flow velocities cause larger sediment transport, transporting excess sand to the north. When the flow velocities decrease, sediment is deposited. Eventually this leads to a distribution of the sediments over northern part of the beach. Besides the large currents, also smaller phenomena can be observed, of which the most important is the occurrence of the sheltered areas with low flow velocities at the north and south concave bends. The low flow velocities cause sediments to settle, while the vortex movement conserves the fine sediments. Theoretically this leads to fine sediment patches near the sheltered areas, see Figure 2.6.

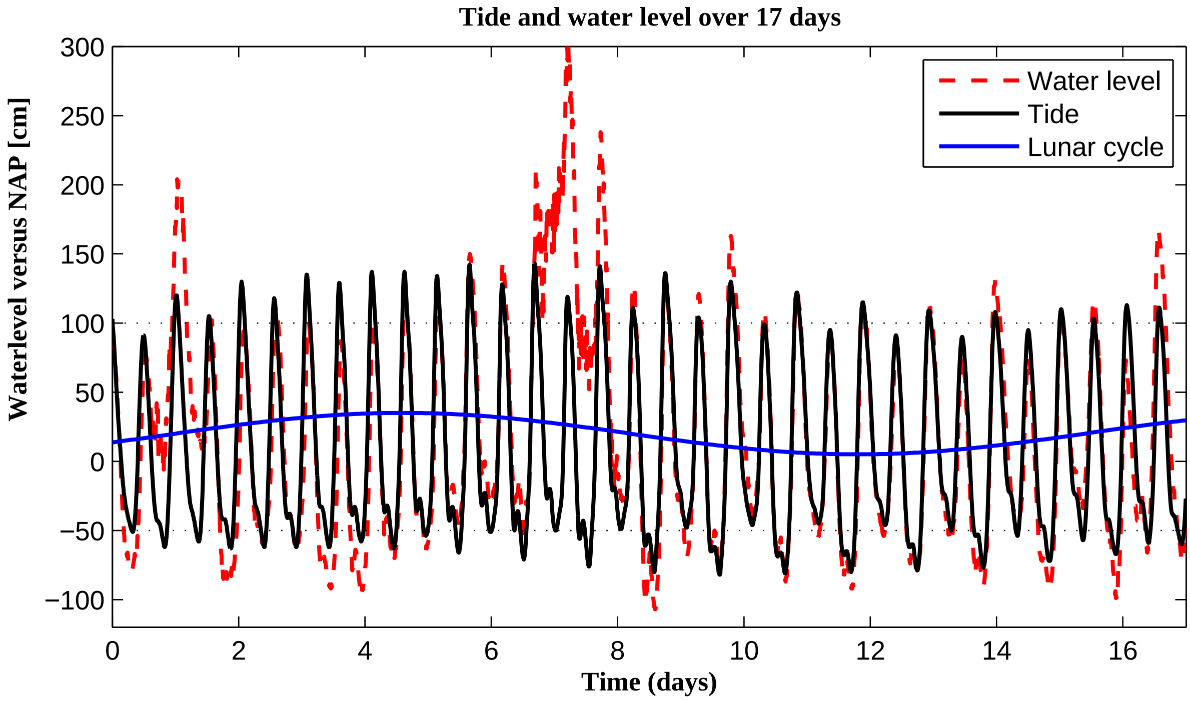


Figure 2.2 *Tide and water level for 17 days near Scheveningen (Rijkswaterstaat, 2014).*

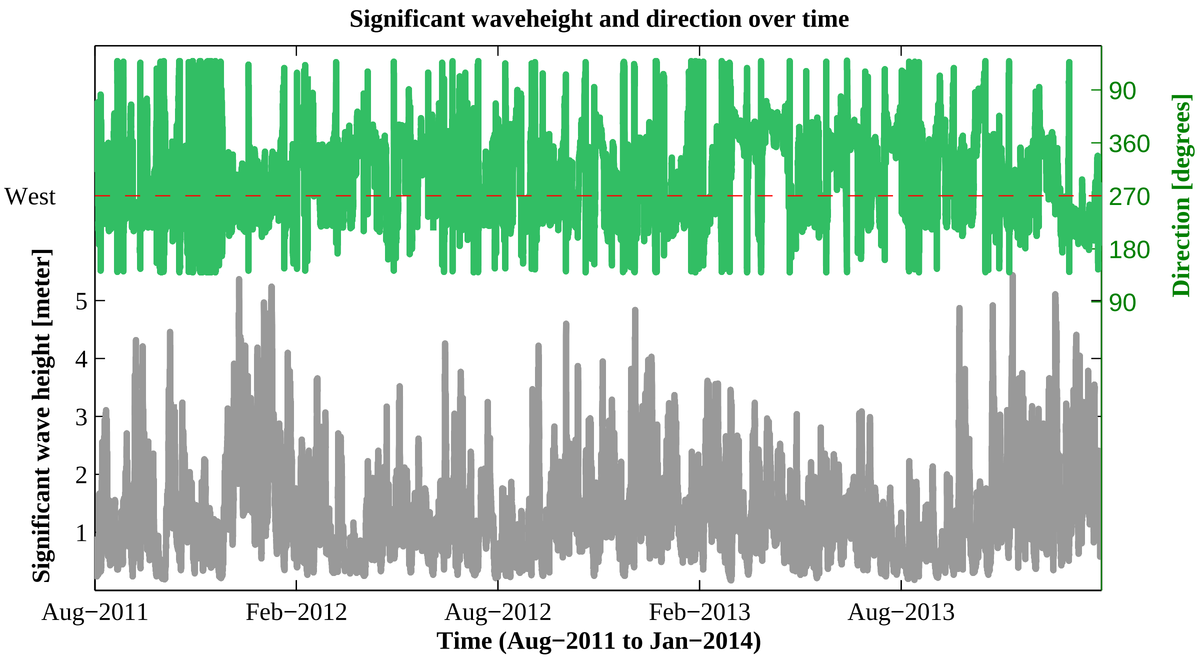
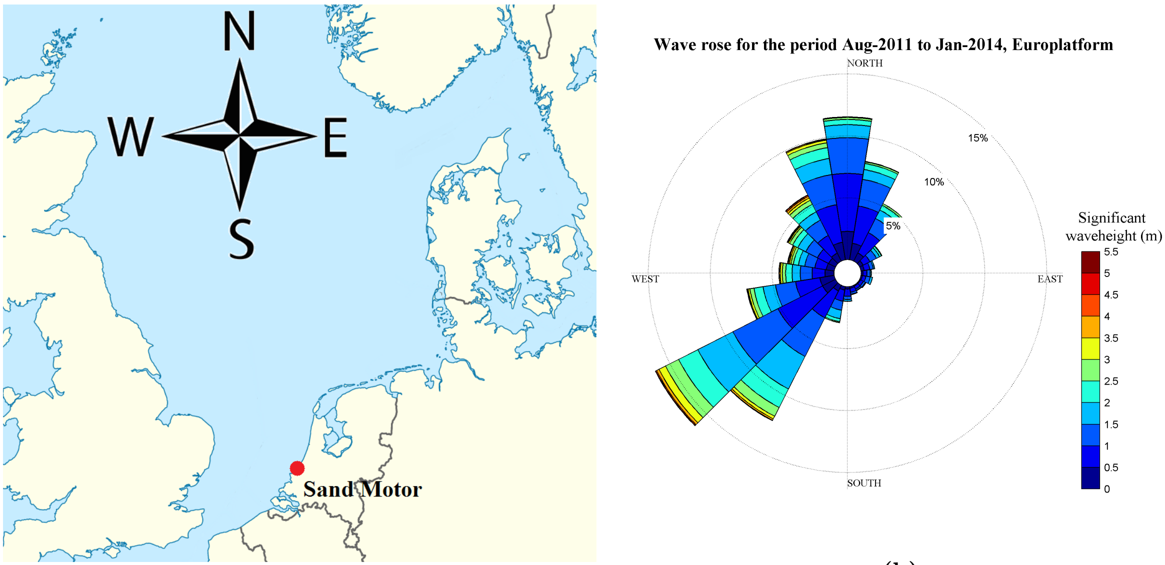


Figure 2.3 *Significant wave height and direction from August 2011 up to January 2014 (Deltares, 2013).*



(a) (b)

Figure 2.4 *Location of the Sand Motor and the corresponding wave rose.*

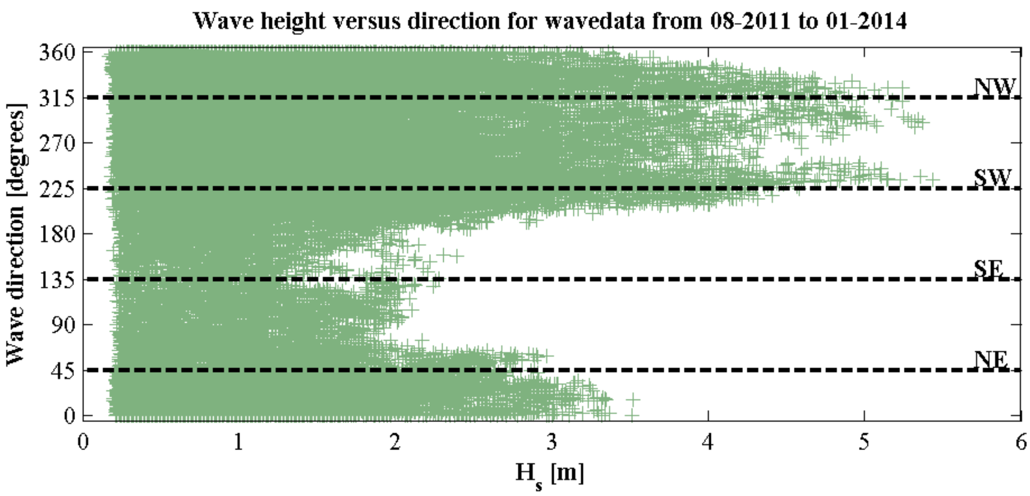


Figure 2.5 *Wave height versus wave direction. It is clear the the highest waves originate from the northwest and southwest direction, which is in line with the maximum fetch.*

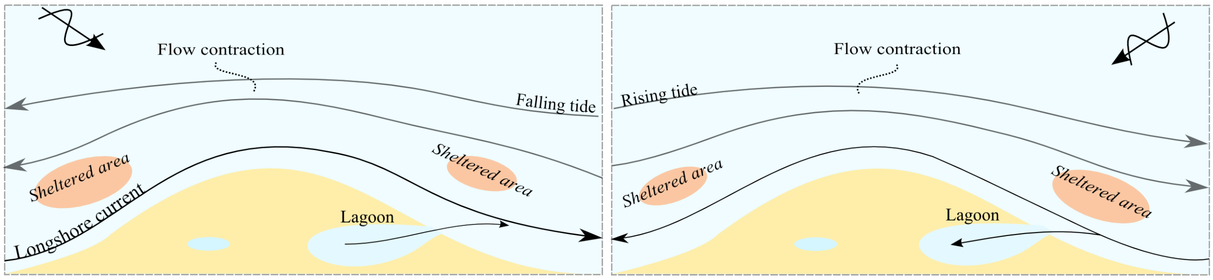


Figure 2.6 *Contracting flows cause higher flow velocities, while the tidal flow may be directed in opposite direction. In the concave bends eddies may occur part of the time, with low flow velocities and thus settling (fine) sediments. During severe storms the alongshore current is considerably stronger, and fine material will be transported more offshore.*

2.2 Measurement methods

Returning to the main aim of this research, sorting of grain sizes, it is a must to have actual field data. While taking sediment samples on dry land is relatively easy, it becomes much more complicated to do so at a sea bed, especially near a nourishment with breaking waves and strong currents. Nevertheless, taking samples can be done in several ways, which will be described below - including the possibilities concerning the sample analysis.

Taking samples

- Corer: this concerns taking depth samples with a sort of tube. Preservation of the sample (unmixed) is its biggest advantage, making it possible to analyse the sediment composition over depth. However, the weight of this device (for sand starting at 1500 kg) makes it not suitable for small scale measurement campaigns.

- Echo Sounder: echo sounders can be used to analyse the sediment composition up to a certain depth. This means that no samples have to be analysed and a continuous measurement can be performed. To use an (expensive) echo sounder an installation on a boat has to be built, and the boat has to be rather stable. Both requirements cannot be met for a small/short measurement campaign. In addition, the results of the analysis need additional calibration.

- Van Veen Grabber: the Van Veen Grabber takes mixed samples from the top layer of the bed. The device is easy to handle and does not need special requirements. The main disadvantage is the mentioned sampling from the top layer. Single events like a storm can have a big influence on the overall result of the campaign, since historical information of the bed composition is only preserved deeper in the bed.

Considering the above mentioned methods, the Van Veen Grabber is the most suitable measurement device, especially since it is also applied in previous measurements. The functioning of the 10-15 kg weighing Van Veen Grabber is illustrated in Figure 2.7. With a volume of 2.5 liter a quite considerable amount of sediment is sampled, which guarantees that the minimum sample volume of 0.1 liter is provided. Although the penetration depth may vary per sample, it

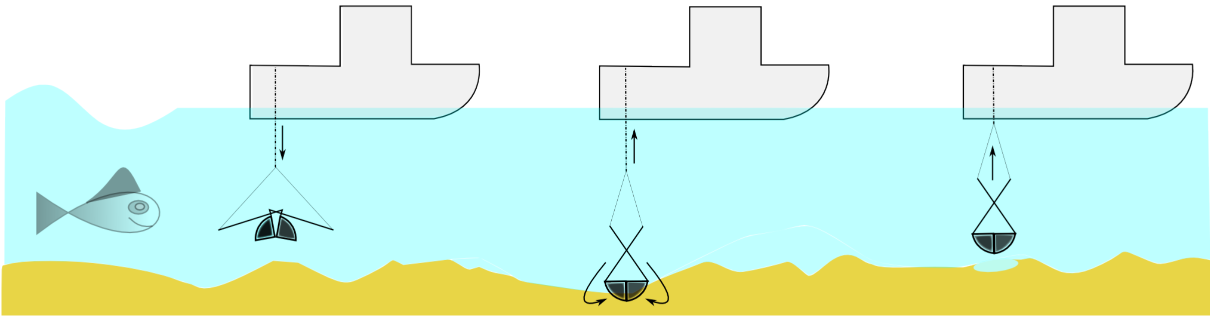


Figure 2.7 *Functioning of the Van Veen Grabber. When the device touches the bottom it closes, where after a sample is collected.*

is assumed that all samples are such shallow that this is not of influence on the characteristics of the sample. The whole sampling process is described in Chapter 4.

Analysing samples

When the samples are collected, they need to be analysed to obtain a so-called sieve curve, which plots the grain diameter versus the percentage of the total mass that is finer than the considered grain diameter. To construct a sieve curve several fractions have to be measured, which can be done with the help of:

- Sieving: this method concerns drying of the sample, where after a separation of different sizes of grains is obtained by sieves with different pore sizes. The smallest sieve consists out of pores with a diameter of 63 μm, which means that fines (<63 μm) are not analysed further. In case of much fines a wet sieving analysis is more appropriate. While the method itself is quite basic, it sometimes needs some additional actions:
  - Wet sieving: this method is similar to dry sieving, with one additional step: after the sample is dried, it is washed with water to remove all fines. After this treatment the sample is dried again, which means that the difference in weight are particles smaller than 63 μm. For the samples taken near the Sand Motor, it is assumed that fines are not present in large quantities, so the wet sieving method is not the default method. However, when necessary (e.g. considerable amount of fines) it will be applied.
  - Shell removal: samples can be 'contaminated' with shells, which influences the measured sediment composition. The removal of shells is quite laborious, since the sample has to be treated with a high concentration of hydro chlorine; which dissolves the carbonate of the shells and leads to a soluble salt.
- Laser diffraction (malvern): This method is used in several campaigns to determine the sediment composition. The main principle is that smaller particles reflect light with a larger angle. By measuring the reflection angle and applying a Fourier analysis, a grain size distribution can be constructed. The results of this technique are generally somewhat coarser and less sorted than dry sieving (Rodríguez and Uriarte, 2009). For more details reference is made to McCave et al. (1986), Agrawal and Riley (1984) and Weiner (1971).

- Fall tube: this method, better known as the settling tube or automated rapid sand analysis (ARSA) is based on the different settling velocities of sand particles. Sediment is released in a column with clear water, where after a computer registers the time for each particle to reach the bottom. With this method a detailed sieve curve can be constructed within 5 minutes (intervals of 0.25 ϕ). Only a small amount of sediment (teaspoon) is required and allowed, since a high sediment concentration would influence the settling velocity of individual particles (Syvitski, 1991). This both means that small samples can be analysed, but also questions the representativity of the results.

2.3 Previous measurements and results

In Table 2.1 the previous measurement campaigns are listed. Although al campaigns provide data concerning the sediment gradation, it is difficult to directly compare the results: the measurements are taken in both winter and summer, have a different spatial spreading and density and are analysed by different institutes, methods and companies.

2.3.1 Previous measurement campaigns

The first campaign taken into account is the so called T0 campaign (T0-1 in Table 2.1), which was a research towards mainly the (amount of) ecology in the Sand Motor area performed in October 2010 (Wijsman and Verduin, 2011). The measurement area consisted out of 12 cross-shore transects every 800 to 1000 meter, on which samples were taken with both a Van Veen Grabber and a slicer. Some of the samples taken were also analysed concerning the sediment composition.
Not all transects in this research are relevant for the sediment sorting, so only transects 5 to 10 (see Figure 2.9), containing a total of 31 analysed sediment samples, are used. The location and results of the measurement points are shown in Figure 2.8a.

The second campaign (T1) was actually not a real measurement campaign, but a check for the dredging companies to see if the nourished sediment met the requirements concerning the diameter (being that the D_{50} should be between 200 and 300 μm). 25 samples were taken (Figure 2.8b) both at the dredging hoppers and on the newly nourished beach, which resulted in a random pattern of locations. These measurements provide a starting point concerning the initial composition of the Sand Motor sediment characteristics, but due to the random locations it is not used to state conclusions about the development of sediment sorting as such.

The third dataset, T2, was obtained during August 2012, with measurement locations at the same rays as described in the T0 campaign. This campaign resulted in more samples (60, Figure 2.8c) and provides a good insight in the sediment sorting after one year in especially cross-shore direction.

In February 2013, 65 samples were taken at slightly different transects than during the T0 and T2 campaign, see Figure 2.8d and Figure 2.9. Multiple samples were taken at each location, making it possible to estimate the error within one sample location. Since this campaign was during the winter, differences between the T2 and T3 campaign can be observed.

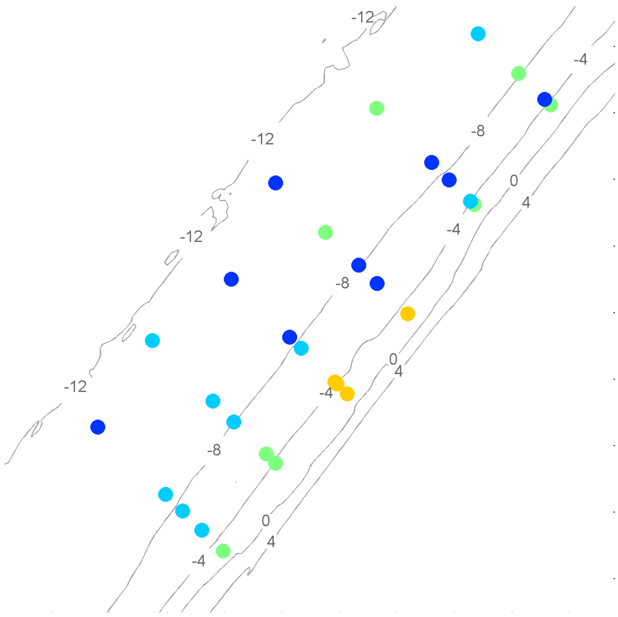
Table 2.1 *Previous measurement campaigns. T0-0 is considered not to be representative for this study, due to the outdated data. T0-2 concerned only 7 samples, which resulted in very large distances between measurement points. Therefore only the T0-1 campaign is taken into account.*

Name	Month	Year	Executed by	With method
T0-0	N.a.	'93-'01	TNO	
T0-1	October	2010	IMARES	
T0-2	November	2010	Medusa	
T1	April-November	2011	Boskalis	
T2	August	2012	IMARES	Malvern
T3	February	2013	NEMO (TU Delft & Deltares)	Sieving
T4	October	2013	IMARES	Malvern
T5*	February	2014	NEMO (TU Delft & Deltares)	Sieving

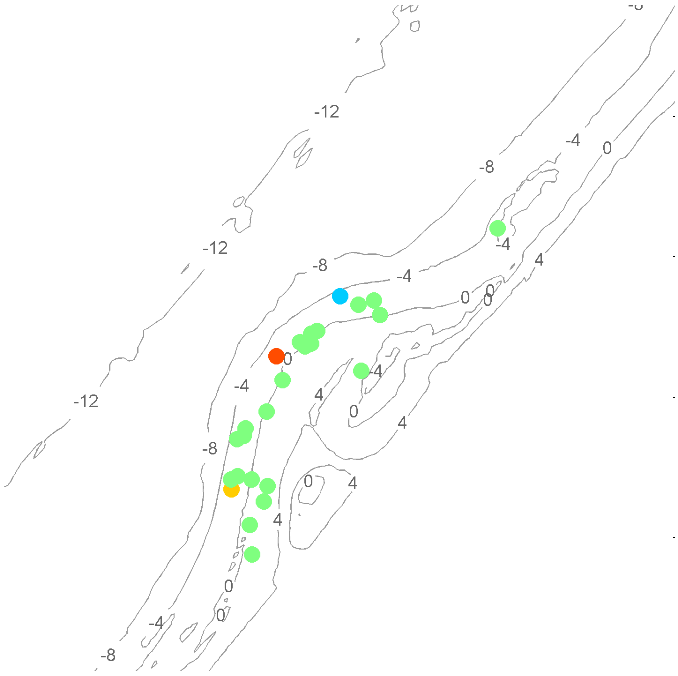
**Performed during this research*

Following the T2 campaign, Imares took a lot of new samples in October 2013, of which 178 in the area of interest of this research. Of those 178 samples, a part was taken on the beach and in the lagoon resulting in approximately 130 relevant measurements. In addition to the transects in the T2 campaign, also '.5' transects were measured, meaning a very nice spatial coverage. Due to the spatial coverage however, large spaces between the measurement points were inevitable. The data of this campaign was not available before the T5 campaigns was commenced, so observations from this data set were not used in the considerations of Chapter 4.

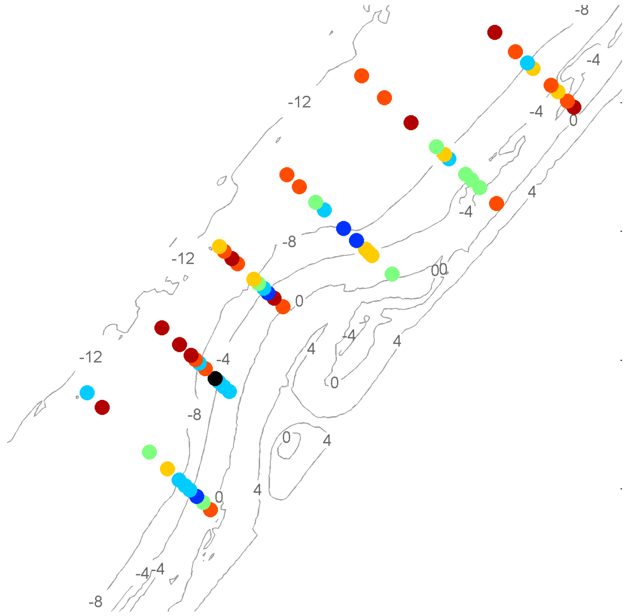
The last measurement campaign available is set-up in the context of both this thesis and the PhD research of B.J.A. Huisman. The campaign consisted out of 173 sample locations, taken at the same transects as the T3 campaign, but with some additional alongshore transects as seen in Figure 2.9. Since the error within samples is already estimated by the T3 campaign, it is chosen to take samples with a larger density at certain transects, instead of multiple samples at one location (T3) or covering the whole area (T4).



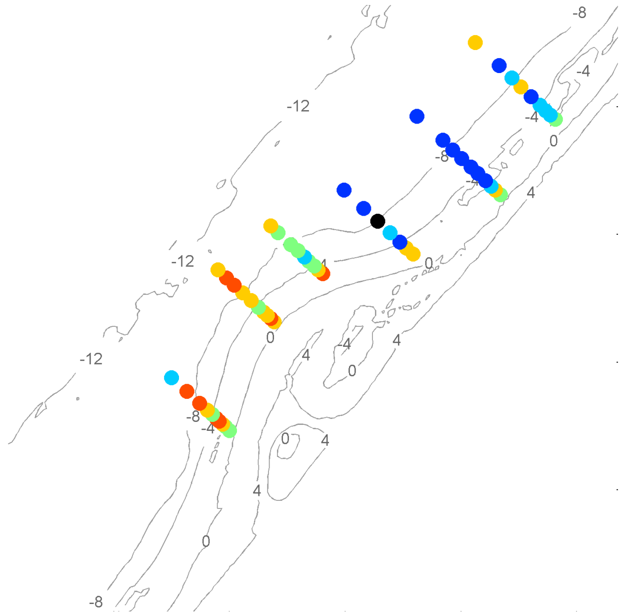
(a) *T0*



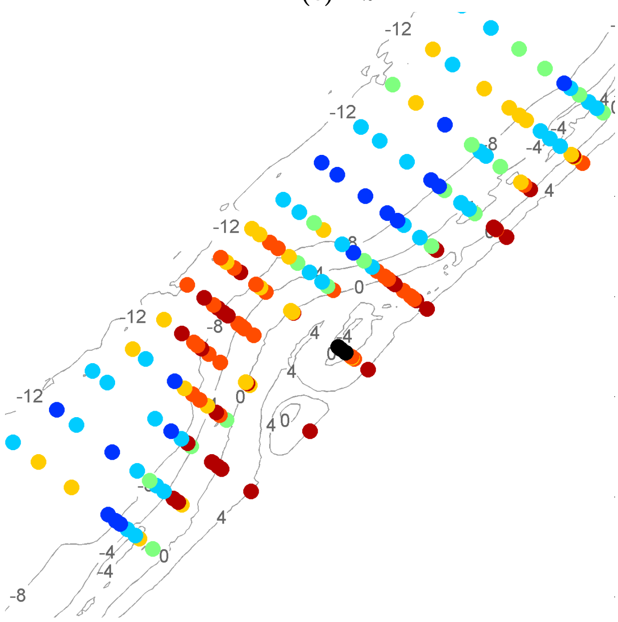
(b) *T1*



(c) *T2*



(d) *T3*



(e) *T4*

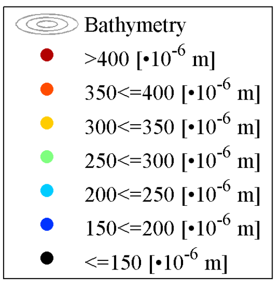


Figure 2.8 *Sample locations and results of previous measurement campaigns. All figures concern the same area and are plotted on the bathymetry of that moment.*

2.3.2 Intercomparison of surveys

As stated before, comparing the results is a rather treacherous, but necessary act to be able to discuss the results. All measured transects during the previous campaigns are shown in Figure 2.9. The measurement campaigns T3 and T5 contain the most detailed offshore transects in the vicinity of the Sand Motor and are taken at the same rays. Therefore, other measurement points are placed on those rays (Rays A to J). This requires some assumptions for the T0, T2 and T4 measurement campaigns, as listed in Table 2.2. The analysis done by Huisman et al. (2014) indicated that a better spatial coverage of the bed sampling would be beneficial. The current survey therefore has some more detailed transects as well as coast parallel transects to improve understanding of the spatial gradients in bed sediment composition.

Table 2.2 *Assumptions made in favour of comparing previous measurements.*

Intended transect	Assumed to be equal to	For campaign	With ratio
A	10		-
B	8 and 9	T0, T2	0.24 to 0.76
	8 and 8.5	T4	0.5
C	7 and 8	T0, T2	0.5
	7.5	T4	-
D	7		-
E	5 and 6	T0, T2	0.23 to 0.77
	5.5 and 6	T4	0.5 to 0.5
F	9		-
G	5		-

2.3.3 Analysing bed sediment composition evolution

The next step is to compare the results of the different campaigns. There are several options available to do this in a spatial sense, each with their (dis)advantages:

Depth versus D_{50}
This would be the most straightforward comparison, since is it easy to compare the measured values at a certain depth. In addition, no reference points have to be chosen. This method however, has some large disadvantages. The first being that distance is not taken into account, so small slopes result in large gradients in the observed D_{50}. A second disadvantage is the occurrence of sand banks or breaker bars. When the depth partially increases offshore, the chart becomes rather useless. This due to the fact that the values of the measured D_{50} are plotted above the values more onshore, which would develop circular patterns as seen in Figure 2.10.

Relative distance versus D_{50}
This method avoids the disadvantages described above: no steep gradients due to small slopes occur and no strange plots develop due to breaker bars. However, with this method it is very difficult to compare the values at a certain location: since the morphology changes, the depth will also change, shifting the curves in time. This can be resolved by choosing a reference point for each transect, at each measurement campaign (for example where the depth equals zero),

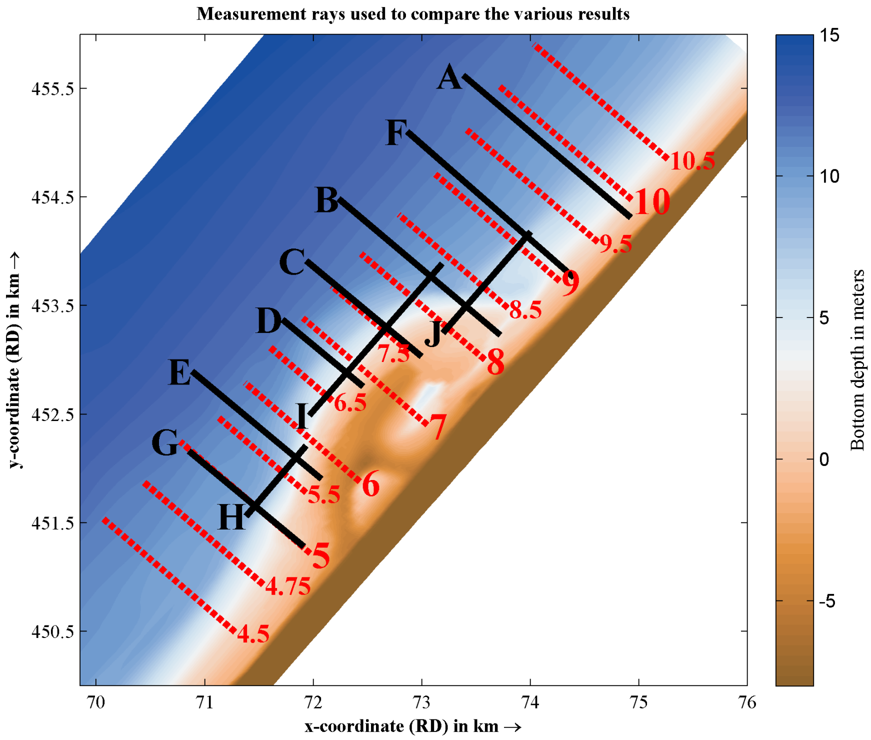


Figure 2.9 *Measured transects used during the various measurement campaigns. After the assumptions of Table 2.2 only the black (solid) rays are left.*

although the determination of this reference point is rather difficult.

Exact location versus depth versus D_{50}

For this option both a 2D and a 3D option is available. The 2D option consists out of a surface with the depth values in colours, while the measurement locations are represented by markers. The colour of the markers indicates the D_{50}, as done in Figure 2.8. This option provides all information, but it is hard to compare the D_{50} visually. The 3D option consists out of an axis with the distance (x), and axis with the depth (y) and an axis with the D_{50} (z). This makes a 3D line, which is usable for one plot, but becomes rather unclear with multiple lines.

2Dh plot with depth and D_{50} at measurement locations with a colour scale

This option is the best for papers, since is provides all information in a clear overview. For interpretations it is somewhat less useful, since gradients are difficult to interpret.

Considering the options above, it is chosen to plot the D_{50} versus the distance, with the depth contour of -3 meters as reference point. To compare the depth values, the depth is also plotted versus the distance. The -3 meter depth contour is taken as reference since a lot of samples are taken at exactly this depth, which results in less interpolation. This does mean that measurement errors result in a wrong reference point. Depth values are however considered to be reliable.

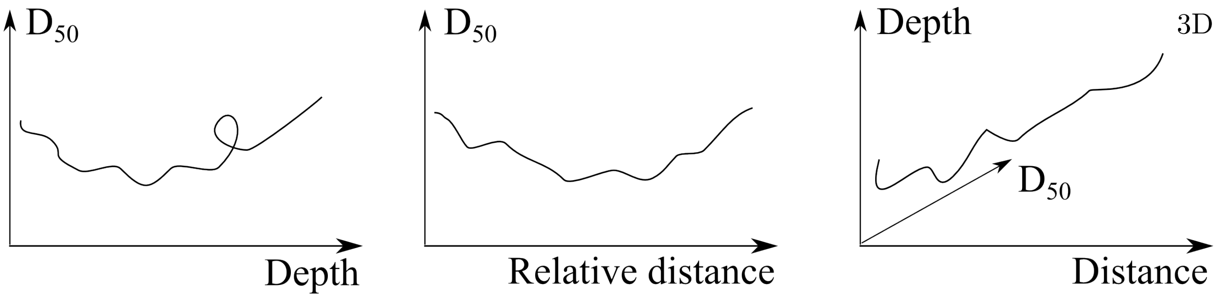


Figure 2.10 *Options to plot the D_{50} versus depth, distance (relative to a depth contour) and in 3D. D_{50} versus depth may cause spurious graphs, while the 3D plot is rather hard to interpret.*

Considering these graphs, and the actual information from the samples as seen in Table 2.3, it is possible to state some observations for both spatial- and temporal development. This analysis is done extensively by Sirks (2013) and Huisman et al. (2014), which will not be repeated as a whole here. However, a general description of the developments will be given, to provide some insight in the developments so far.

Table 2.3 *Results of previous measurement campaigns.*

Name	Month	Year	Number of samples	Average D50 [μm]
T0	October	2010	31	232
T1	April-Nov.	2011	25	278
T2	August	2012	60	301
T3	February	2013	65	268
T4	October	2013	130	299
T5*	February	2014	173	264

**Will be described in Chapter 5*

2.3.4 Temporal development

From previous tables it can be seen that the measurement campaigns are performed in different seasons, meaning that different processes play a role. It is therefore difficult to directly compare the spatial development of the processes. While this is still done in the next subsection (2.3.5), it is first analysed which parts of the observation can be appointed to the seasonal impact.

Seasonal impact can be mostly observed at coasts driven by a storm wave climate (as is the case for the Sand Motor) since there is a large difference in hydrodynamic conditions between the summer and winter season. The seasonal impact can be mostly observed by (Quartel, 2007), (Bosboom and Stive, 2013):

- A relative narrow and steep beach profile with a small surfzone in summer due to onshore transport of (fine) sediments);
- A flattened and thus wider beach in winter, due to offshore transport of sediments by strong undertow, see Figure 2.11;

- Breaker bars move onshore during summer, while migrating offshore during winter;
- The summer profile is forced by less energetic conditions, causing a less dynamic profile than in the winter.

When considering the aspects above, it is likely that during the summer months a more widely graded bed composition will be observed: while the beach profile is steeper, also (fine) sediments are transported onshore. During winter higher waves, stronger currents and offshore transport of sediments would imply a more uniform sediment mixture: in the more energetic areas fine sediments are washed away, while causing coarse and fine sediments to focus at certain areas. The further temporal analysis will be done when comparing the new results with the previous measurements in a more quantitative manner in Chapter 5.

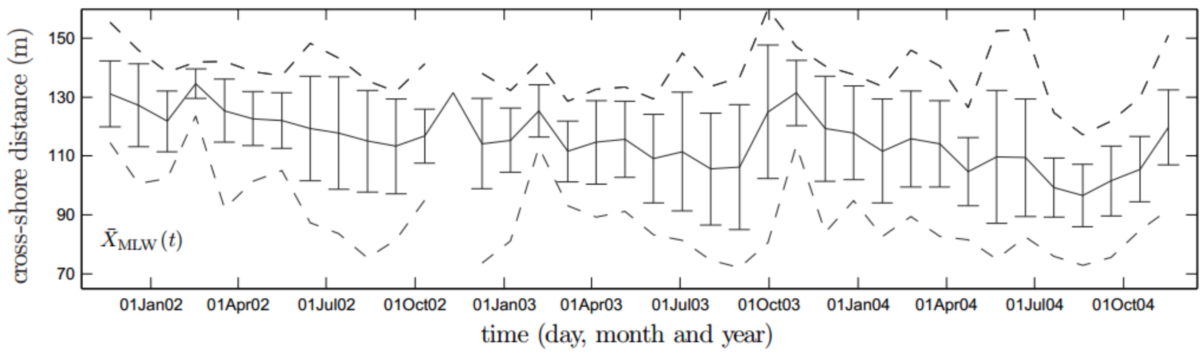


Figure 2.11 *Observed (with the Argus camera) cross-shore positions of the MLW line at the Sand Motor area during the period November 2001 - November 2004. The solid line is the average value, the error bars show the standard deviation and the dotted lines represent the observed maximum and minimum. From Quartel (2007).*

2.3.5 Spatial development

While the fact that the measurement campaigns are taken at different seasons is important, it is intended to show the more general occurrence of coarse and fine areas in a spatial analysis, neglecting the temporal effects.

The measurement campaigns are all performed on cross-shore transects, as described in Subsections 2.3.1 and 2.3.2. This consequently means that the density of measurement points in alongshore direction is too low to state funded observations concerning alongshore variation. However, current measurements take place at a large scale nourishment, which has quite persistent and static patterns of erosion and sedimentation throughout the year. Although the magnitude of the sediment fluxes differs per season, the coast is quite uniform in alongshore direction, especially during winter profiles (although the seasonal variability in the Netherlands is not that significant) (Wright and Short, 1984), (Van Rijn et al., 2003). So although the density of the samples is low, they are assumed to be representative for a large area in alongshore direction.

The T0 campaign shows a more or less uniform distribution of the D_{50}, with a value of about 270 μm in the intertidal area decreasing to 200 μm offshore. This observation is in accordance to what one would expect due to shoreward increase of energy dissipation and alongshore currents: white-capping, depth-induced breaking and bed roughness generate turbulence which in turn initiates sediment transport. This observation is also substantiated by Medina et al. (1994) and Niedoroda et al. (1985). Only one large disturbance can be observed in this pattern: offshore ($\sim$1000 meter from the coast at 11 meters depth) at transect A and F (see Figure 2.8a) a relatively coarse area is present. No specific reason for this coarse area can be found, but since this area is located outside the surfzone, it is not expected to be of influence on later observations.

The samples taken during construction represent a D_{50} - with the exception of 3 samples - between 250 and 290 μm and therefore show a rather small standard deviation. Since the samples are taken randomly over the area, the results are close together and the whole area is more or less covered, it is assumed that all of the Sand Motor area consists out of this gradation of sediment. Notice that the average value is larger than the initial sediment from the T0 campaign, which implies that sorting is likely to take place.

That sediment sorting processes occur is immediately seen in the T2 campaign. Figure 2.8c shows large(r) variations in cross-sections, with some fine sediment ($<$220 μm) just north and south of the Sand Motor, and more coarse sediment at the most active part of the nourishment. Despite these small fine areas, most of the area is rather course, even far offshore. Especially in the most northern transect (A) a course patch is observed, which was not clearly present in the T0 campaign. The general characteristics become much more pronounced in the T3 and T4 campaign, with mainly a much larger fine patch in the north. In the T4 campaign a large fine area in the south can be observed, which is located out of the reach of the T3 campaign.

From all the campaigns it can be noted that fine material is very seldom observed at depth smaller than 4 meters e.g. in the surfzone no fine sediments are settled. In addition, sediments located on the beach are in general coarser than submerged sediments, possibly due to aeolian transport.

Chapter 3

Hypotheses

To determine the measurement locations and the amount of samples, hypotheses are stated concerning the research questions as described in Section 1.2. To do so, several resources are available: (1) literature, (2) hydrodynamic observations, (3) previous measurements and (4) model runs. All four resources will be applied to get a funded hypothesis for the problem definition (”*how is the sediment sorting developing*”). Both previous measurements as well as literature is already largely covered in Chapter 2, so these parts will be combined with the interpretation of the hydrodynamic conditions. The use of a model is covered quite extensively, since it is a powerful tool to substantiate the information based on the available field data. Eventually the actual hypotheses can be stated, in which a distinction between cross-shore, alongshore and temporal processes will be made.

3.1 Trend analysis of previous measurements

A comprehensive analysis concerning the previous measurements was performed in Chapter 2. The last measurement campaign was six months ago, meaning that the situation might have changed. In fact, change seems inevitable due to the severe hydrodynamics of the fall and winter of 2013. Instead of using the most recent T4 campaign as starting point (October 2013), the T3 campaign (February 2013) is taken as a basis: both the T3 as T5 campaign (February 2014) were taken in the same month, so the T3 campaign is assumed to be more representative. Nevertheless, the T4 campaign can function as a mean time validation of the applied theory.

In Figure 3.1 the significant wave heights, including their directions, as observed from the T3 campaign until the T5 campaign are shown. From this figure it can be seen that the conditions up to the T4 campaign were rather mild, but became rough very quickly for a rather long time just after the T4 up to the T5campaign; one could even say the whole period is one westerly directed storm. This means that the coast in a matter of speaking did not have the time to recover between different storms. Processes observed during a single storm (see Subsection 3.2, Van Rijn (2003), Soltau (2009) and Celikoglu et al. (2006)) are therefore expected to be present in an exaggerated form, since the conditions for the T3 campaign were less severe. This implies that:

- Fine sediments are settled relatively far offshore due to high waves: a large onshore mass transport causes larger return currents and large waves interfere with the bed at greater depths. The settling of those fine sediments will be at area’s with low flow velocities, which in this case concerns the north and south part of the Sand Motor;

- The westerly directed waves will cause the southern fine patch to be smaller than in the north;
- The swash zone is very coarse, since fine sediments are washed out;
- Bedforms (especially breaker bars) will be dominantly present.

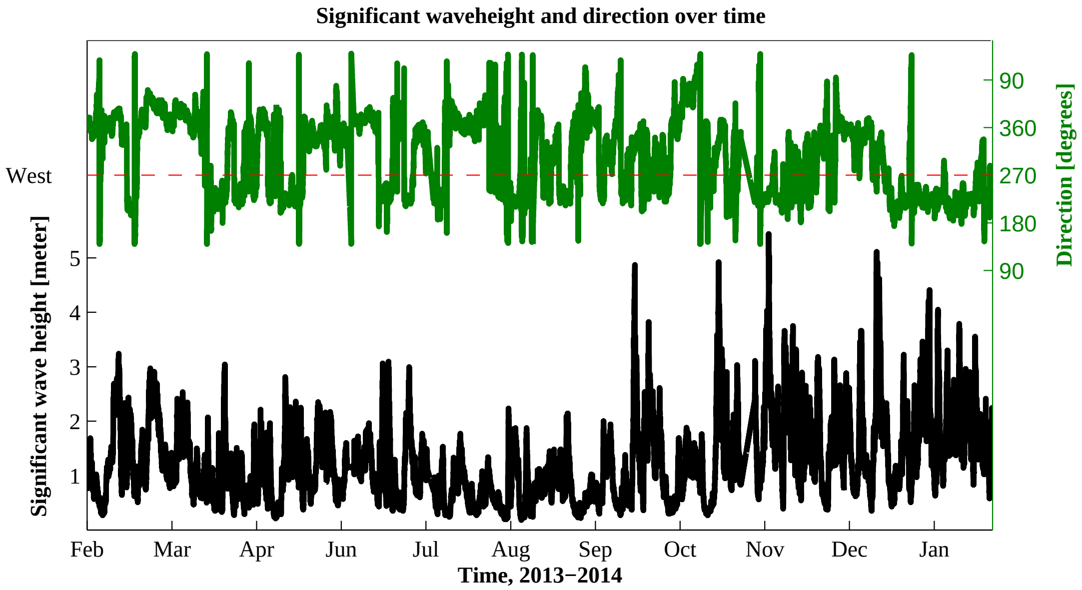


Figure 3.1 *Wave height and direction from February 2013 to January 2014 (Rijkswaterstaat, 2014).*

3.2 Model analysis to substantiate hypothesis

In addition to the previous analysis, a detailed 2DH model is applied to give a rough estimate of the sediment sorting since the last measurements. The model is described extensively by Van der Zwaag (2014), and will therefore only be mentioned here briefly. The model is set up in Delft3D, with a hydrodynamic grid of either 153 x 129 or 76 x 65 grid cells, depending on the time scale of the computation. The hydrodynamic scale is nested in a much coarser grid for wave computations. SWAN (acronym for Simulating Waves Near Shore) iterates every (computational) 30 minutes, taking into account all wave conditions with a higher significant wave height than 1 meter. The wave conditions itself are obtained from the Europlatform. For computations starting from the beginning of the Sand Motor the bathymetry measured in August 2011 is used, while computations later than October 2013 are started with the bathymetry of that moment. All runs are started with an initial sediment composition based on the T1 campaign, described by (Sirks, 2013). Bottom roughness is computed every timestep (12 seconds) as is the bed level.

The model has been researched for the sensitivity of several parameters, but is not validated on the previous data (yet). Although this implies that the grain sizes cannot be anticipated exactly, general patterns do correspond with previous measurements (see Chapter 2).

As stated above, some important simplifications are applied in the use of this model: the grid is rather coarse, which is a necessity to be able to perform computations for a sufficient time period. In addition, a 2D computation is performed, meaning that 3D processes such as undertow are not accounted for. This is artificially counteracted to a certain extend, but nevertheless means that inaccuracies are likely to emerge. Another important shortcoming to be mentioned here is the absence of a spatially varying initial bed composition, since it is assumed that the whole area is consisting out of the (uniformly mixed) sediment suppleted to construct the Sand Motor. A final remark is made to the absence of aeolian transport: as observations outside confirm, wind can transport (fine) sediment over quite some distance. Since this is not taken into account in this model, coarser areas might not be supplemented with fine sediment such as one might expect.

To acquire some additional input for the hypothesis, it is considered which model runs should be performed. When both the research question from Section 1.2 and the objective to perform new measurements are taken into account, we want to acquire knowledge concerning:

1. Sediment transport patterns: it is useful to know transport patterns, as it gives insight in which parts of the Sand Motor are more exposed that others. With some theory it is then possible to give a more funded hypothesis concerning the location of coarser and finer material;

2. Development of sediment sorting in between measurements: although the measurements are performed on a quite regular basis, it is impossible to measure during a storm. A model can give insight in how the sediment sorting develops between two measurements: is it a gradual process, or do a few hydrodynamic events dominate?

3. Sediment sorting during a temporal scale of a storm: in addition to the previous note, it is possible to estimate the impact of a single storm e.g. is it gainful to measure directly after a storm, or is the impact too small to show actual changes in composition?

4. Spatial distribution of fine and coarse areas: to determine the sampling points it is convenient to have an idea of the spatial distribution of certain grain sizes. Strong gradients in grain size are for example interesting to measure, but hard to get out of previous data due to the relatively large distances between subsequent measurement points.

To account for the mentioned goals above, three model runs, as listed in Table 3.1 are executed. Each of the runs represents a different time scale, years to seasons to days, making it possible to look at different processes. At the end a loop can be made: how do processes during single hydrodynamic events come back in the longer term computations? To save some computational time, all significant wave heights hat have almost no effect on the sorting processes are left out e.g. significant wave heights under 1 meter are not taken into account.

Table 3.1 *Model runs performed to substantiate the hypothesis.*

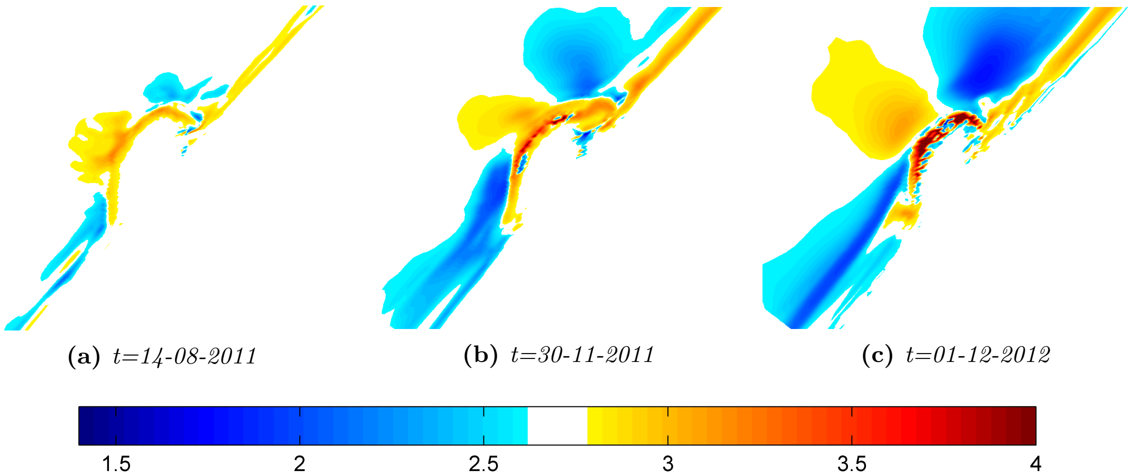
Model run	Modelled time period	Main goal
Spatial	Aug 2011 - Aug 2013	Obtain insight in sediment transport patterns, spatial distribution of sediment grain sizes and the development of sediment sorting up to the T2 campaign.
Winter	October 2013 - January 2014	Get insight in the development of sediment sorting during the (energetic) fall and winter of 2013. Also, the influence of (single) storms can be researched. The hydrodynamic input is a part of the conditions seen in Figure 3.1. The sediment composition from February 2013 is used, which is slightly coarser that the original composition.
Storm	December 2013	Running for a smaller time period means that a higher level of detail can be attained. This provides the opportunity to indicate the processes during a single hydrodynamic event.

Results of the 'Spatial' run
From Figure 3.2 several observations can be stated:

- Sediment is getting coarser at the most energetic part of the Sand Motor while fine sediment is accumulated in the north and south;
- South of the Sand Motor a strip of fine sediment occurs from the -3 meter depth contour up to 8 meters of depth. This is also the case at the more active part of the Sand Motor, although the strip there is very small and is directly followed by a more coarser area offshore;
- North, a constantly increasing patch of fine sediment develops, with steep gradients in grain size at the southern part of this patch. The most distinct difference with the southern part of the Sand Motor is the coarsening of the intertidal area;
- Especially at the most energetic part temporary (extreme) coarsening might occur, accompanied by large gradients in grain size diameter. These events are probably caused by storms, but the temporal scale is too large to justify that statement. Also, the spatial distribution after 6 months is quite equal to the final situation. This would indicate that a sort of equilibrium situation occurs.

'Winter' run
From this model run the following observations can be made:

- After a small spin up time (18 modelled hours), most characteristics as described in in the Spatial run are observed, which in turn seem to be in a sort of equilibrium: during relatively calm conditions (significant wave height under 2 meters) no noticeable events occur;



(a) *t=14-08-2011* **(b)** *t=30-11-2011* **(c)** *t=01-12-2012*

(d) D_{50} *in* $10^{-4}m$

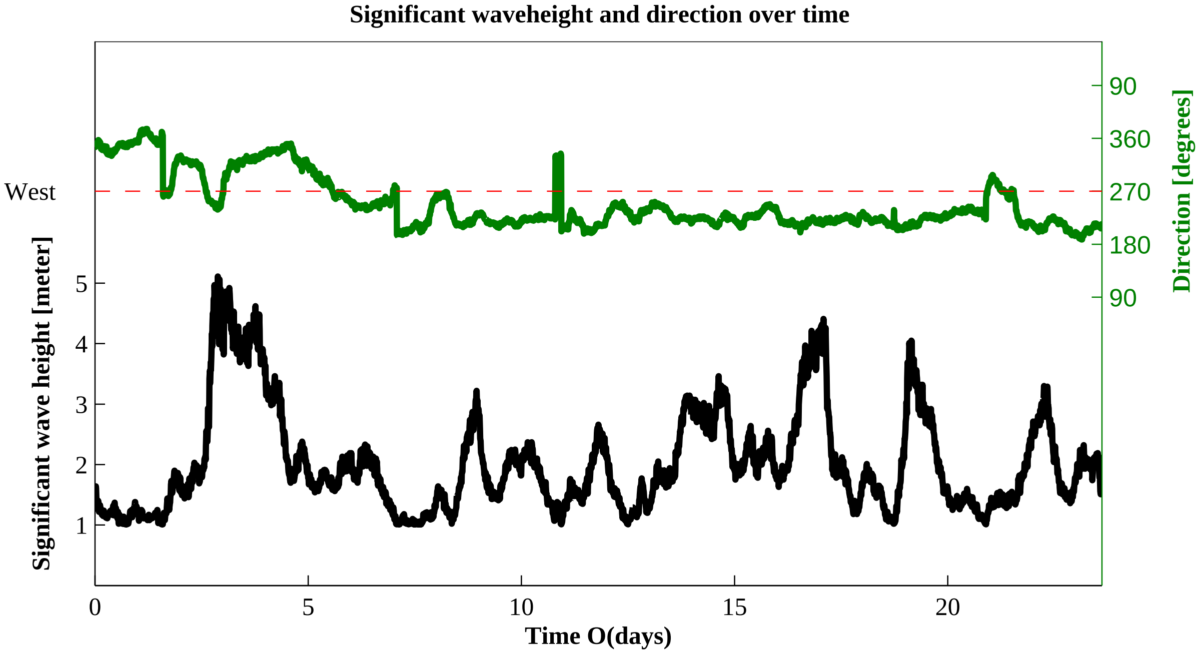
Figure 3.2 *The development of sediment sorting processes according to the applied model during 1.3 years.*

- During storms with a significant wave height up to 3.5 meters, the intertidal area coarsens, while the fine sediments are 'pushed back' to both the north and the south concave bend. The distribution in fine sediments between the north and south area depends on the direction of the waves: waves from north to west cause more fining in the southern area, while waves from the west to south cause more fining in the northern area;
- During southwest storms with a significant wave height over 5 meters, fine sediments are pushed back even further, while the direction of the waves seems to be of less influence: the coarse patches extend further in both the north and the south.

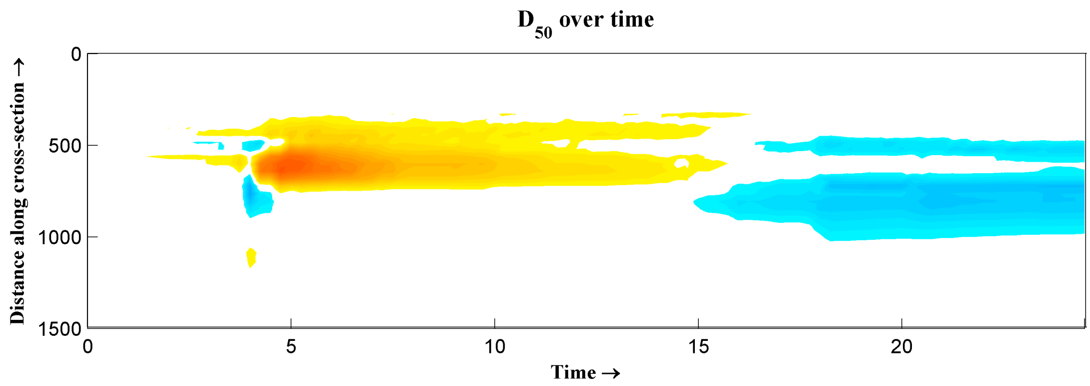
'Storm' run

Only December 2013 is covered, which in fact is a close-up of the Winter run. The hydrodynamic conditions are shown in Figure 3.3 and consist merely out of significant wave heights over 2 meters, coming from an almost constant west-south-west direction. In Figure 3.3b the response of a cross-section just north of the Sand Motor can be seen:

- Storms cause an almost immediate response in sediment sorting: northerly directed storms cause coarsening (hitting the north side of the Sand Motor), while more southerly directed storms cause fining;
- In between storms only little recovery in composition takes place. In fact, a new storm only expands the impact of earlier storms. The only exception beholds the case when the wind direction is changing, which consequently changes the angle of impact;
- Only waves higher than 3 meters cause a noticeable impact.



(a) *Imposed hydrodynamic conditions for the Winter run.*



(b) *Sorting respons to the hydrodynamics.*

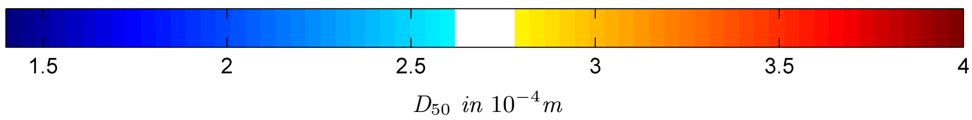
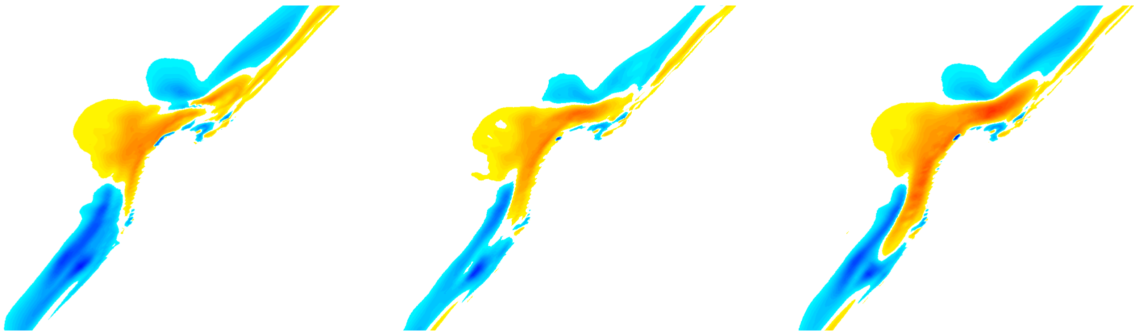


Figure 3.3 *Imposed hydrodynamic conditions for the Winter run (a) and corresponding behaviour at a cross-shore transect just north of the Sand Motor. The sediment sorting responds with a small lag to the hydrodynamic forcing, but is also forced very swiftly.*



(a) *Calm conditions* **(b)** *H_s 3.5m* **(c)** *H_s 5m*

(d) *D_{50} in $10^{-4}m$*

Figure 3.4 *Characteristics of the Winter run.*

3.3 Hypotheses

The previous two sections gave an elaborate view on the possible development concerning the grain sorting in the period between the T4 and T5 campaign. Combining the information as described earlier, hypothesis can be stated concerning a general part, cross-sectional sorting and sorting in the alongshore direction.

3.3.1 General

- 'Special' spatial features, such as the coarse patch that was observed in the offshore part of transect A during the T2 (and partly by the T1 and T3) campaign will not be affected by the conditions, and still be present. However, it is expected that the D_{50} of the patch will have decreased, due to settling of finer sediments that are brought into suspension by the energetic conditions and are transported offshore;
- The overall D_{50} is expected to be similar to the T3 campaign. Although more energetic conditions have hit the coast, it is also considered that more of the native material (which was finer than the suppleted sediments) has come to the surface;
- The breaker bars that are normally present in the cross-shore profile are expected to be located further offshore than during the T2 and T4 campaigns, which was performed in the summer.

3.3.2 Cross-shore sorting

- The swash zone is anticipated to be (very) coarse, while the surf zone might be somewhat finer due to the offshore transport of fine materials. This fining will continue in offshore direction due to decreasing energetic conditions;
- Very fine material (<200 mu) is expected to be settled relatively far offshore, being from the -7 meter depth contour, in a relatively narrow band. An exception on this prospect is

transect G and F, which can show a much larger band of fine sediments: they intersect the areas which functions as a sort of basin, enabling fine sediments to settle;

- In deeper water (i.e. NAP<-8m), it is expected that the sediments are gently coarsening again, as the depositional area of the fine sediments does not reach this depth;
- Near transect D a coarser patch than in the surrounding areas is expected offshore. Although this is not clearly seen in the previous measurements.

3.3.3 Alongshore sorting

- Based on the model results, no steep gradients are expected in alongshore direction (following the depth contours), but rather gentle transitions: gradients will be smoothed by the relatively large currents and high waves;
- Since the depth contours are a sort of distorted e.g. do not follow the coast uniformly, the previous point beholds some exceptions. In the north a very sharp transition is foreseen around transect F, from the coarse material in the most energetic zone to fine material in a more or less sheltered concave bend. This transition should be clearly visible in both alongshore transect I and J;
- While the area of fine material is expected to be somewhat smaller in the south, also there a transition into fine material is expected between transect G and E. This transition should be seen in transect H.

3.4 Approach for validating the hypotheses

The hypotheses stated in Section 3.3 will be validated by taken new samples at and around the Sand Motor. To get actual results, each sample will be processed in order to obtain a sieve curve per sample. With these sieve curves the D_{10}, D_{50}, D_{60}, D_{90} and eventually the C_u (D_{60} over D_{10}) can be obtained. By comparing the uniformity coefficients, depth contours and D_{50} values with previous measurements, a conclusion can be stated about the development of the sediment sorting near the Sand Motor. In Chapter 4 a detailed description is given concerning the choice of sampling locations and the measurement method.

Chapter 4

Measurement set-up and execution

Section 3.4 already briefly described the approach to validate the stated hypotheses. In this chapter the choice for sampling locations, considerations concerning the amount and method of sampling, the execution of the sampling and the post processing procedure is described, answering research question 2. It is chosen to do the sampling during February 2014, which is exactly one year after the previous winter campaign and six months after the last campaign. This provides the opportunity to see differences at the time scale of a year (at a moment with more or less the same hydrodynamic conditions such as a year earlier) as well as the seasonal impact by comparing the results of a summer campaign with the winter campaigns.

4.1 Measurement locations

The choice for measurement locations is based on similar aspects as used in Chapter 3 (observation of hydrodynamic events, model runs, previous measurements and insights of the supervisors), with a few additional boundary conditions: to be able to compare results to previous campaigns, (some) sample points should be placed on the same transects as sampled in for example the T3 campaign. This is not an issue since the transects are placed at the cross-sections of interest. However, the transects as used in the T3 campaign do not cover the whole area. Mainly alongshore phenomena, including transitions between coarse and fine areas as seen in Figure 3.2, cannot be observed with only cross-shore sampling. A final important consideration is the number of samples per location. In the T3 campaign three samples were taken per location, to give an good estimate for the spreading within the samples. In this case it is believed that spatial density is more important than sample-error-analysis. In addition, the error analysis from the T3 campaign can be used to give an estimate of the error in this campaign.

Summarizing the above, the sample locations are positioned as seen in Figure 4.1 and 4.2. The main characteristics are:

- Both along- and cross- shore rays are sampled to make interpolation more trustworthy;
- It is chosen to sample more points than in the T3 campaign (173 versus 65), but with only one measurement per location;
- Alongshore transects are placed in both the swash zone (transect I) and on places where steep gradients are expected (transect J and H);

- Transects as measured during the T3 campaign (A-F) are sampled again, with the addition of transect G, which is located on transect 5 in the T2 campaign;
- Transect B and D consist out of a large number of sample points, which provides detailed information over the bottom profile, variation between samples, the spatial scale coastal properties such as coarse areas and a more accurate location of transitions between grain sizes. It is chosen to sample two locations in more detail (sample distance about 15-20 meter in cross-shore direction). Transect B is chosen since it is located north of the Sand Motor, where an area with fine sediments is anticipated. Transect D can indicate if and where a possible coarse area is located;
- All cross-shore transects contain a few far offshore points to indicate the extend of hydrodynamic influences.

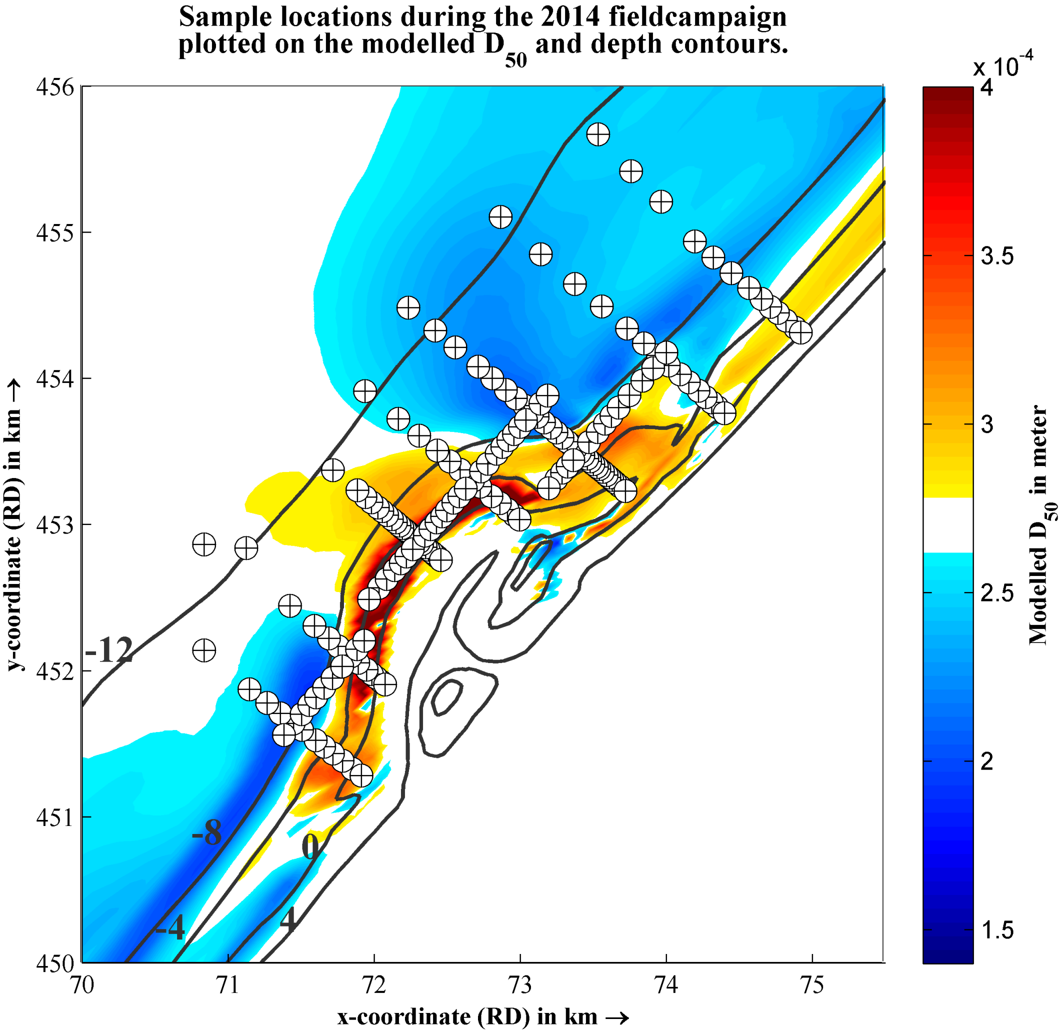


Figure 4.1 *Sample locations of the T5 campaign plotted on the modelled D_{50} with the 4, 0, -4, -8 and -12 meter depth contour lines.*

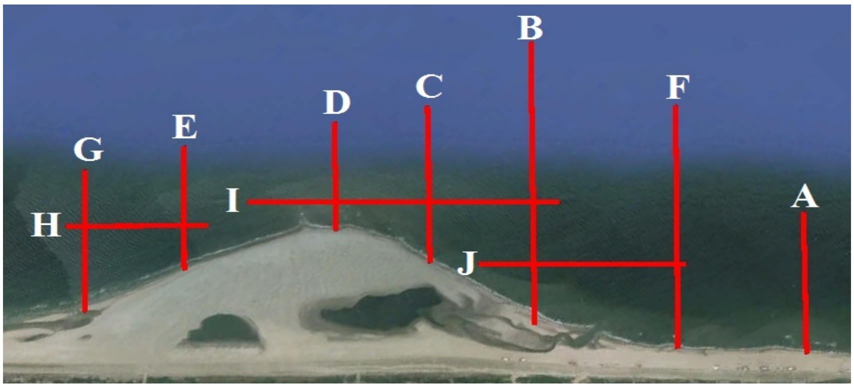


Figure 4.2 *The transects of the T5 campaign plotted at the latest (August 2013) satellite photo of Google Earth.*

4.2 Execution and analysis

The surplus of the actual sampling is done with the use of a Van Veen Grabber deployed from a boat. The Van Veen Grabber is chosen since other methods are not applicable for this scale, as explained in Section 2.2. The whole sampling process is as follows:

1. The boat is located at the predefined sample location with the help of GPS;
2. The Van Veen Grabber is thrown overboard;
3. When the Van Veen Grabber touches the bottom the depth is noted from the on-boat sonar;
4. The retrieved sample is collected in a sample bag, marked with the location number and placed in a crate.

12 samples were located at too shallow areas and are taken by hand, using a Leica GS15 positioning system. This system locates the plotted point at an accuracy in the order of centimetres, which is more accurate than taking samples with the boat.

When all samples are collected, the sieve curve of each sample has to be determined. After taking into account the possibilities described in Section 2.2 and considering the fact that laser diffraction techniques were not available, it is chosen to analyse the samples with the help the sieving method. Despite some drawbacks of this method - it requires more sediment, is more time consuming and is sometimes considered less physical correct than a settling tube (Middleton, 1976) - it is considered to be the most trustworthy. Main considerations are that the executing can be checked with common sense and that the sieving analysis is in line with previous measurements. In addition, the samples contain enough material to justify the use of a sieve analysis. The latter argument introduces a final note: the fall tube only used a teaspoon of sediment, which the author does not considers to be representative for the sample.

Most of the samples are sieved with the dry sieving method, but when necessary the wet sieving method is applied. The procedure for the whole analysis is as follows:

1. Drying of about 150 grams of the collected sample by placing it in a over at 140 degrees Celsius for 24 hours;
2. Pounding/crushing the dried sample to get rid of any cluttered grains;
3. Weighing the dried sample at an accuracy of 0.1 gram;
4. Placing the dried sample on the 'sieve tower', which is build up out of sieves with nominal diameters of 2.000, 1.180, 0.600, 0.425, 0.300, 0.212, 0.150 and 0.063 mm;
5. Each of the fractions is weighed, when the passing of material trough the 0.063 mm sieve is considerable (order of a few percent), the sample is marked to apply wet sieving;
6. In case of wet sieving: the sample is washed with water on the 0.063 mm sieve, to wash out all the fines. After this removal the analysis is started again from step 1;
7. Shells and other objects that remained on the 2.000 mm sieve are subtracted from the initial mass, so they are not taken into account in the analysis;
8. The D_{10}, D_{30}, D_{50}, D_{60} and D_{90} are determined with the help of linear interpolation, see Equation 4.1 and Figure 4.3;
9. With the D_{10} and D_{60} the uniformity coefficient (C_u) is derived.

Photos of both the sampling and analysis can be found in Appendix A.

In general more samples are taken nearshore than offshore, meaning that - in case that the sample density of the different transects is not perfectly equal - taking the straight average of the D_{50} of the various samples induces errors. To overcome this the so called 'nearest neighbour approach is used at every transect, which in this situation comes down to first dividing the the not-sampled area equally between the closest measurement locations, where after it is assumed that the area corresponding to a certain measurement point has the same grading, see Figure 4.4. At the boundaries of the transect the area is double of that to the nearest point, since no better assumption is available. Next, to determine the weighed average D_{50}, weighing factors are applied on each sample. This weighing factor is equal to the percentile area that the sample in question represents; relative to the whole area, see Equation 4.2. The same approach is used to analyse previous campaigns.

$$D_z = D_i + \frac{\left(n_z - \sum_{0}^{i-1} n\right)}{\left(\sum_{0}^{i} n - \sum_{0}^{i-1} n\right)} \left(D_{i+1} - D_i\right) \tag{4.1}$$

In which:

D_i	= sieve diameter of sieve i	[m]
D_z	= unknown sediment diameter	[m]
n_i	= mass percentage at sieve i	[%]
n_z	= required passing percentage	[%]

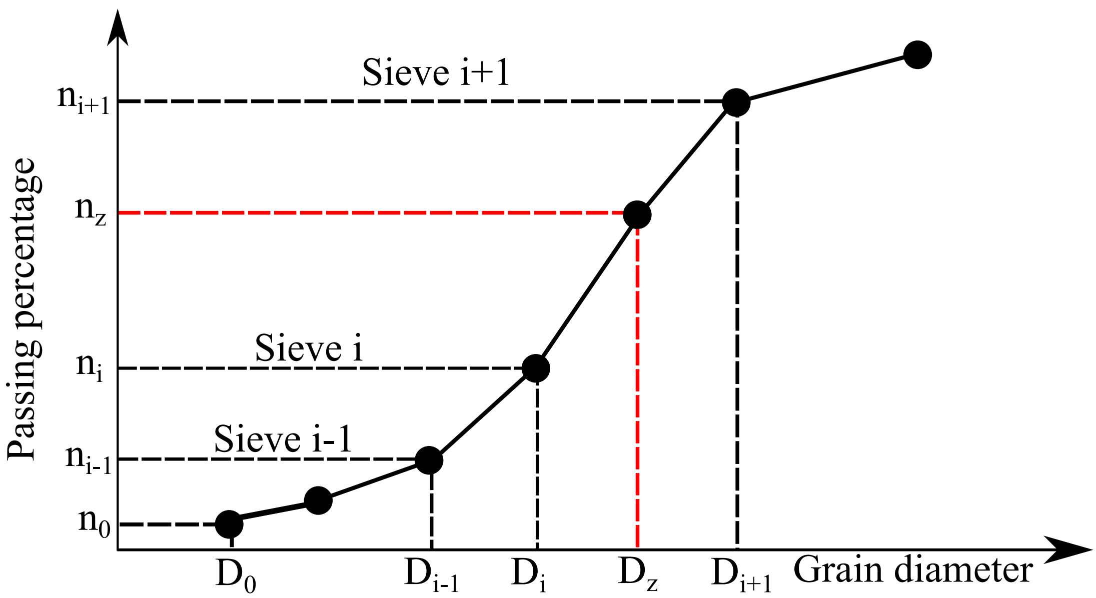


Figure 4.3 *The determination of a certain grain size (D_z) based on the mass percentages (n) on the sieves (i). Use is made of linear interpolation, as seen in Equation 4.1.*

For the whole campaign the average D_{50} is taken of all (cross-shore) transects. Per transects the weighed average over z samples is calculated as:

$$D_{50,weighed} = \sum_{i=1}^{i=z} \left(\frac{weighing\ factor_i}{L_{tot}} D_{50,i} \right)$$

$$L_{tot} = \sum_{i=1}^{i=z} \begin{pmatrix} n_{i+1} - n_i\ for\ i = 1 \\ \sum_{i=2}^{i=z-1} \frac{1}{2} (n_{i+1} - n_{i-1}) \\ n_i - n_{i-1}\ for\ i = z \end{pmatrix} \tag{4.2}$$

In which:

n	= length from a certain reference point up to the sample location	[m]
i	= sample number	[-]
L_{tot}	= total length of the transect - including boundaries. This is equal to the sum of the individual weighing factors	[m]
z	= total number of samples	[-]

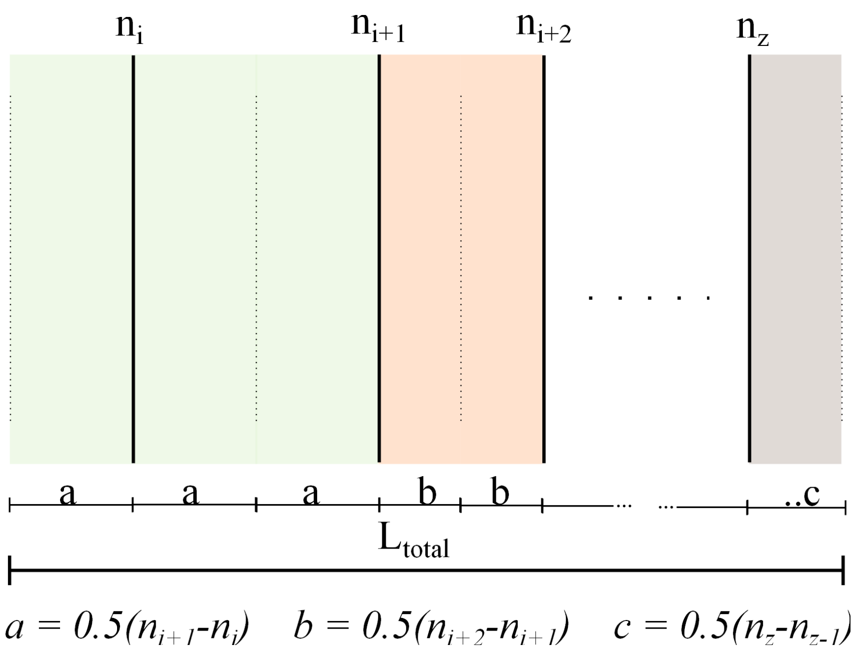


Figure 4.4 *The principle of the nearest neighbour approach, to attain a weighed average of the D_{50} over the transect. See also Equation 4.2.*

Chapter 5

Results and analysis

With the execution of the field campaign as described in Chapter 4, a new data set is obtained providing both information about the current situation and the development during the previous campaigns, but especially for the T3 campaign which was performed in the same month a year earlier.

In Section 5.1 a short description about the general observations of this (the T5) campaign is provided, to give an impression of the spatial distribution of grain sizes. The general observations are followed by a more specific approach towards both the cross-shore and alongshore measurements. With these observations it is possible to state conclusions towards research question 3. After the description of the new results, a comparison with previous campaigns can be made in Section 5.2, answering the last research question, number 4. In this thesis the main focus will be on the similarities and differences between the T3 and T5 campaign, although the results of previous campaigns are also included in the tables.

In Appendix B all the available data is provided, visualised in distance-D_{50} and distance-depth graphs, as explained in Subsection 2.3.2.

5.1 Results of this campaign

5.1.1 General (spatial) observations

In line with the results of the previous campaigns (e.g. Figure 2.8), Figure 5.2 shows the measured D_{50} values, plotted on the depth contours of the August 2013 bathymetry. In addition, Table 5.1 shows both the average as weighed D_{50} (based on the 'closest neighbour' approach) per transect.

The most important observations from Figure 5.2 are:

- Relative coarse material at the surfzone along the whole coast of the Sand Motor, starting at the -4 meter depth contour going onshore;
- A clear fine patch in the north, starting from the -4 meter depth contour to offshore, which is in line with the observations made in earlier campaigns;
- A more coarse area can be observed at the most energetic part of the Sand Motor, although the D_{50} values vary considerably;

- In the south a small fine patch is present;
- Steep gradients occur both within- and between transects: the most northern transect (A) contains a very coarse sample, while the finest sample of this campaign is at the same depth in transect F. In the two most southern transects (E and G) both fine and coarse samples are observed, implying that fine and coarse areas are succeeding each other quite fast.

And some additional remarks with the help of Table 5.1:

- Most transects have a smaller weighed D_{50} value than the average D_{50}, which, taking in account the fact that the sample density near the coast is bigger than more offshore, means that in general offshore points contain finer material. An exception is formed by transect A, which is merely influenced by one very coarse sample; something that can also be seen in the large standard deviation;
- The uniformity coefficients are close together, although samples at transect A are more poorly sorted than all other transects. An explanation could be the presence of fine samples in the area, making it plausible that a (thin) layer of fine sediments is settled on a bed of more coarse grains;
- While the uniformity coefficients are close together, the standard deviations differ up to a factor three. The main reason for a large standard deviation is the occurrence of coarse material near the coast, while finer material is found more offshore (in line with the first bullet). Since transect C and D contain nearly no fine samples, the standard deviation is smaller there. This in contradiction with transect E and G, which contains both very fine- and coarse samples;
- Despite the fact that the alongshore transects I and H do not have close-to-shore samples, they do cover a large difference in depth, causing the standard deviation of the samples to be in line with the cross-shore transect;
- Although the D_{50} value is normally quite closely related to the depth at uniform coasts, this is not the case near the depth contours of the Sand Motor. In Figure 5.1 the depth and D_{50} values of transect H are shown (the most southerly alongshore transect), showing that the average grain size varies considerably over more or less the same depth.

Table 5.1 *Results of the T5 campaign.*

Transect	Average D_{50} [μm]	Weighed D_{50} [μm]	Weighed C_u [-]	Stnd. deviation [μm]
A	279	241	2.5	91
F	206	198	1.8	56
B	229	209	2.0	66
C	292	284	1.7	49
D	317	324	1.9	33
E	305	315	1.8	94
G	264	198	2.0	87
I	273	272	1.7	75
H	278	282	2.1	83
J	228	225	2.0	38

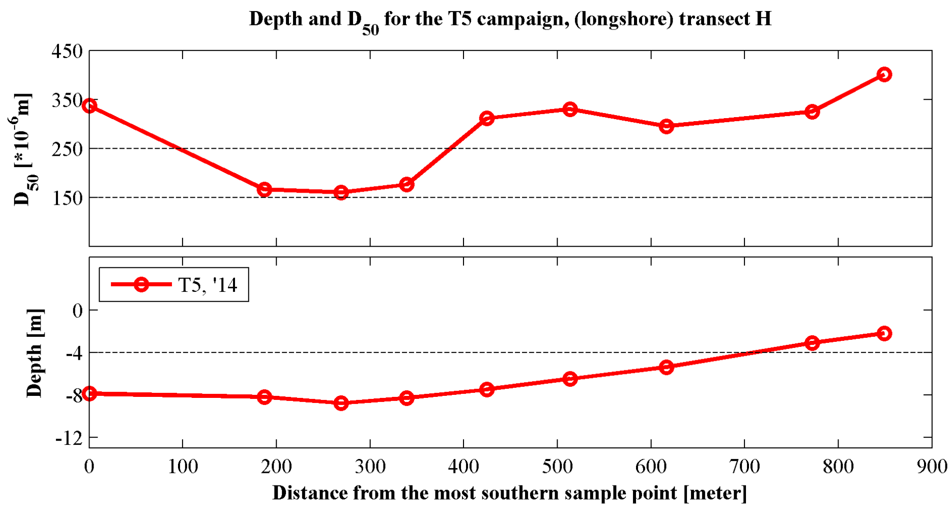


Figure 5.1 *Transect H; both D_{50} and depth are plotted versus the -3 meter depth contour.*

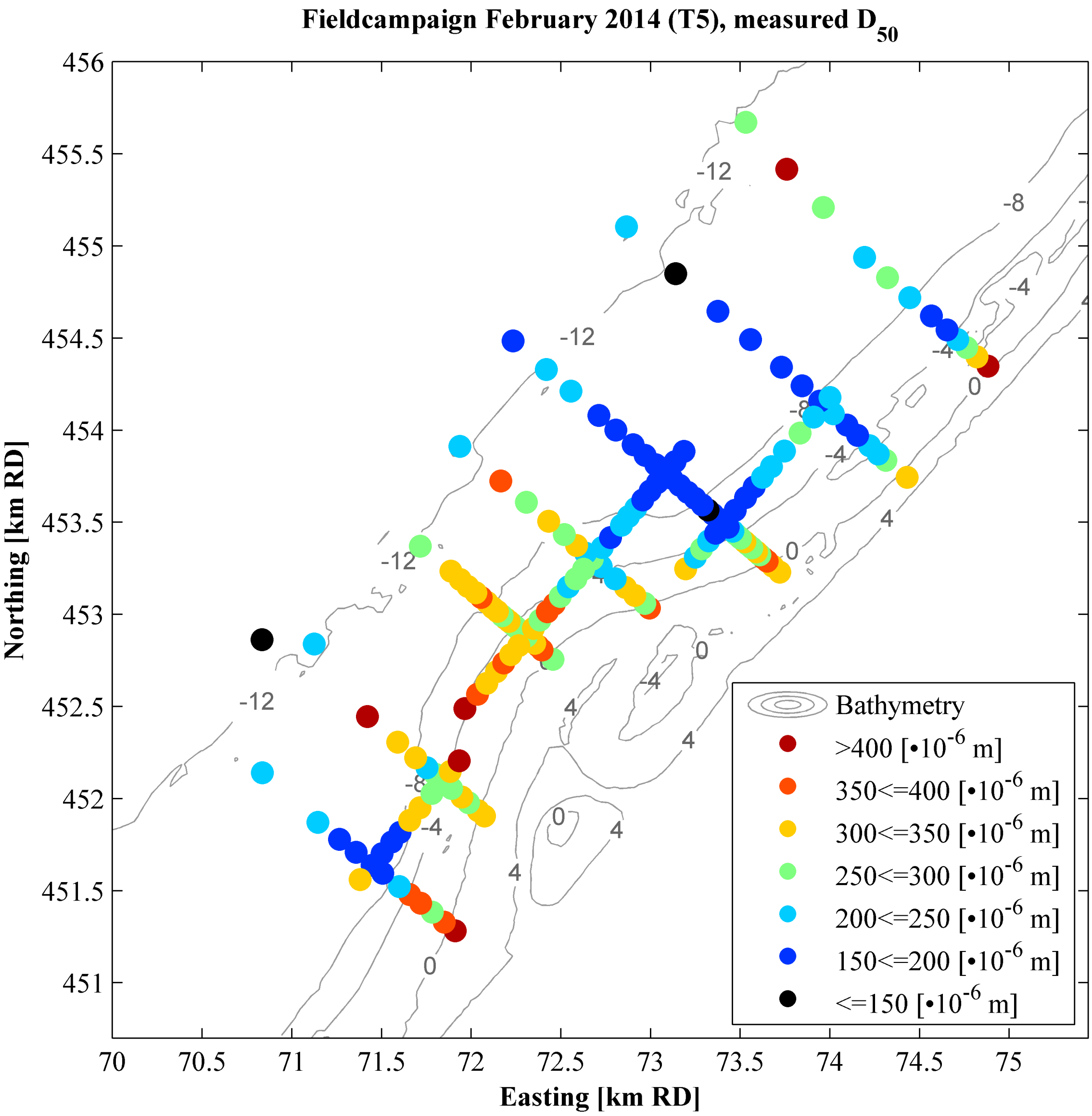


Figure 5.2 *Results of the T5 campaign; plotted on the bathymetry of August 2013. The transects are named as seen in Figure 4.2: from north to south in cross-shore direction A-F-B-C-D-E-G and in alongshore direction from south to north H-I-J.*

5.1.2 Interpretation of the differences between hypothesis and results

With the help of Figure 5.2 and the figures in Appendix B it is possible to observe some differences with the hypotheses as stated in Section 3.3. This analysis is a basis for the later conclusions on research question 3. The general hypotheses are confirmed: the overall grain size is similar to the T3 campaign, as is the presence of the coarse sample in transect A. In cross-shore direction the general trends - coarse material at the swash zone, finer grains in the surfzone and again coarser material more offshore - are also observed in nearly all transects. However, aspects that were different than expected concern:

- No clear difference in beach profile between the summer (T2 and T4) and winter (T3 and T5) can be observed. This might have to do with the density of sampling, but also in dense sampled transects no clear differences were observed. This indicates that the summer-winter profile is not so profound in this area;

- Although the general trend in fining and coarsening over the cross-shore is confirmed, large variations can be observed in for example transect C and D. This probably has to do with the high energetic conditions and the large sediment transport at those transects;
- In alongshore direction steep gradients do occur, in contradiction to what was hypothesized. The gradients are in similar order such as found in cross-shore direction (130 μm/100 meter) and are not strongly related to the depth;
- The sharp transition expected in the north was not clearly seen. Besides the rather smooth fining, the fine patch is also located more south than foreseen (between transect C and B, instead of F).

5.2 Comparison with previous campaigns

In Table 5.2 and 5.3 the results of all previous campaigns are summarized. The difficult part in comparing specific cross-sections of these campaigns is the different number of samples. While the first campaigns give a rather global idea of the location of different grain sizes, it is possible to give a more specific outcome with the T5 campaign, as was intended with this research.

The first thing that is noticed when looking at Table 5.3 is the overall coarseness of the T2 and T4 campaign. Since Rodríguez and Uriarte (2009) already mentioned that laser diffraction analyses show an overall coarser trend, a part of the T3 samples (55) were analysed by Imares, to compare the outcomes with the sieving method. From this comparison two influences should be taken into account: on average the 'malvern' samples were 20 μm coarser and the samples were much more skewed. The first point corresponds with the results, in which the T2 and T4 campaigns are more or less 20 μm coarser. The second point can be explained by the large tail of fine material, which is cut off by the sieving method, but which is taken into account with a malvern. Taking this into account, it is hard to compare the different campaigns, and nearly impossible to state conclusions concerning the seasonal impact.

Overall it can be stated that the general trend in D_{xx} values is stagnating, since only slight fining can be observed. After the T1 campaign, both the T3 and now T5 campaigns show an overall finer composition. The differences are however rather small. The same holds for the T2 and T4 campaign, which contain an almost same D_{50} value. Since these stagnating values are based on the whole campaign, it is save to assume that the different grain sizes might 'move around' in the Sand Motor area, but that the overall composition stays more or less the same.

A short view on the other campaign characteristics learns that the uniformity coefficient as well as the skewness show similar values for all the campaigns, but that the standard deviation is much smaller for the T4 and T5 campaign. This might have to do with the number of samples, making the average more profound, while the extremes are of similar order.

Table 5.2 *Characteristics of all measurement campaigns. D_{xx} values are based on weighed averages between the 0 and -10 meter depth contours, as performed by Huisman et al. (2014). The light gray rows indicate the campaigns analysed with a malvern, showing significantly coarser results.*

Name	Time	# of samples	D_{10} [μm]	D_{30} [μm]	D_{50} [μm]	D_{60} [μm]	D_{90} [μm]	σ [μm]**	C_u [-]*	Skew-ness [-]**
T0	Oct. '10	31	125	185	232	275	469	0.73	2.2	-0.07
T1	Apr. '11	25	151	204	278	309	482	0.64	2.0	0.06
T2	Aug. '12	60	166	240	301	360	591	0.70	1.8	0.01
T3	Feb. '13	65	157	218	268	295	459	0.61	1.9	-0.03
T4	Oct. '13	130	182	241	304	378	488	0.55	2.1	0.01
T5	Feb. '14	172	160	216	261	286	438	0.57	1.9	0.00

**Based on the average values of the D_{60} and D_{10}.*

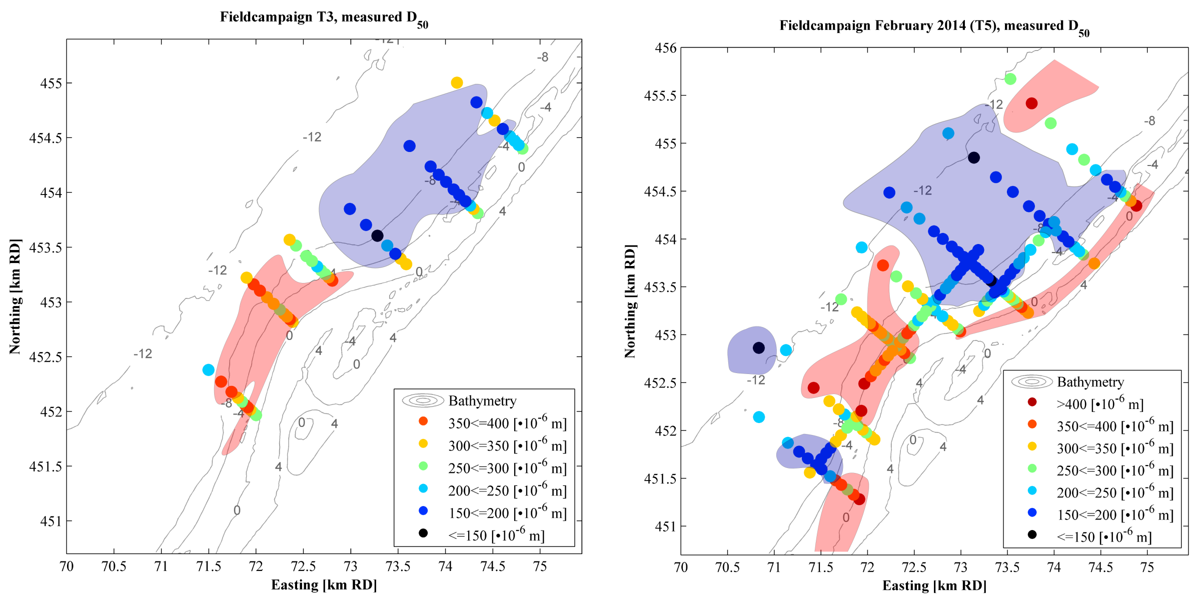
***Computed from the Phi values of the grain diameter (-log2($D_{\%}$))*

In Figure 5.3 a free interpretation is made of the T3 and T5 campaign results, indicating coarse >350 μm and fine <200 μm areas. The areas that are covered in both campaigns show large similarities: the coarse patch near transect C and D has a more or less similar shape, although both transect D and E contain finer samples in the T5 campaign. The samples between the -2 and 0 meter depth contour points are also similar in gradation, being in the midrange of 250-300 μm. The biggest difference can be found in transect A, which shows considerable coarser samples at the offshore part of the transect. In addition, the figure shows that the fine patch in the north is extending to more offshore areas, while the coarse patch is fairly persistent at the area seen in the T3 campaign. At the beach (above the 0 m depth contour) more coarse sediments are located, as is the single coarse sample in transect A.

The alongshore transects in the T5 campaign do not show new coarse/fine areas, but do confirm the location of gradients in composition. Especially at the two most southern transects this is clearly visible, but also the fine patch in the north seems to be extended more towards transect C than one would expect based on only the cross-shore transects. In Appendix B all cross-shore transects are visualised, with a short description of the temporal development.

Table 5.3 *Results of all measurement campaigns per transect. The D_{50} values are based on weighed averages between the 0 and -10 meter depth contours, as performed by Huisman et al. (2014). Again, the measurements analysed with a malvern are indicated with gray.*

Transect	T0 [μm]	T2 [μm]	T3 [μm]	T4 [μm]	T5 [μm]
A	241	381	251	293	241
F	207	302	197	235	198
B	242	262	189	234	207
C	-	-	287	300	284
D	227	324	343	383	324
E	240	286	320	353	315
G	227	262	-	279	198



(a) *T3 campaign* **(b)** *T5 campaign*

Figure 5.3 *Interpretation of the results of both the T3 (Feb. 2013) and T5 (Feb. 2014) campaign. The red spots indicate significantly coarse material, while the blue spots indicate significantly fine material. Be aware of the fact that the T5 campaign has an additional ray in the south (G) and sample locations on the beach.*

5.3 Discussion of results

5.3.1 (In)accuracies in the whole field campaign

As in every research, uncertainties are present concerning the accuracy of the results. In this research possible inaccuracies can emanate from four main domains:

1. Temporal density of measurements;
2. Spatial density of measurements;
3. Assumptions made in favour of interpretation;
4. Acquiring and processing of samples.

The aspects mentioned above are illustrated in Figure 5.4 and will be described separately, to place the results into perspective.

(1), (2) Temporal and spatial density of measurements
Although Table 2.3 shows that the number of samples for this kind of research is quite substantive, it remains a collection of 'snapshots', revealing hardly anything about intermediate phenomena, like additional nourishments south of the Sand Motor as indicated by Huisman et al. (2014). This should not be a long term problem, but questions how representative the actual measurement campaign is e.g. to what extend does the taken 'snapshot' justify the interpretation over the past half year. The same applies on a spatial scale, since it is assumed that the point measurements are representing a certain area, which is not always the case. While it is usually not possible to indicate to which extend the samples are representative in time (since no samples in between are available), it is possible to state something about the representativity of the area, by taking multiple samples on the same location. The average difference in grain size for these samples is 4.1%, with a maximum of 7.6%. For the considered samples this means a variation up to 15 μm, showing that substantial differences can be noticed within one location.

(3) Assumptions made in favour of interpretation
In Chapters 2 and 3 assumptions are made towards the different measured transects in the different campaigns (Table 2.2). These assumptions are necessary to compare the results in time, but also imply that rather large (50 meter) spatial shifts take place. In addition linear interpolation is applied between two sample points. Since there is no saying how bed levels or grain sizes vary between the sample points, a linear interpolation is equally right as any other interpolation. This does however cause coastal properties, such as breaker bars, to 'disappear' in the measurements.

(4) Acquiring and processing of samples
Fieldwork can never be done with a perfect precision, so both in taking samples as well as in processing errors occur. Collecting samples cause small deviations towards the exact location. In this research the samples were taken in an interrupted campaign, with 15% of the samples taken a week later than the first. During this week changes in the spatial distribution of grain sizes might have occurred. Although it is difficult to make hard conclusions, two samples have been

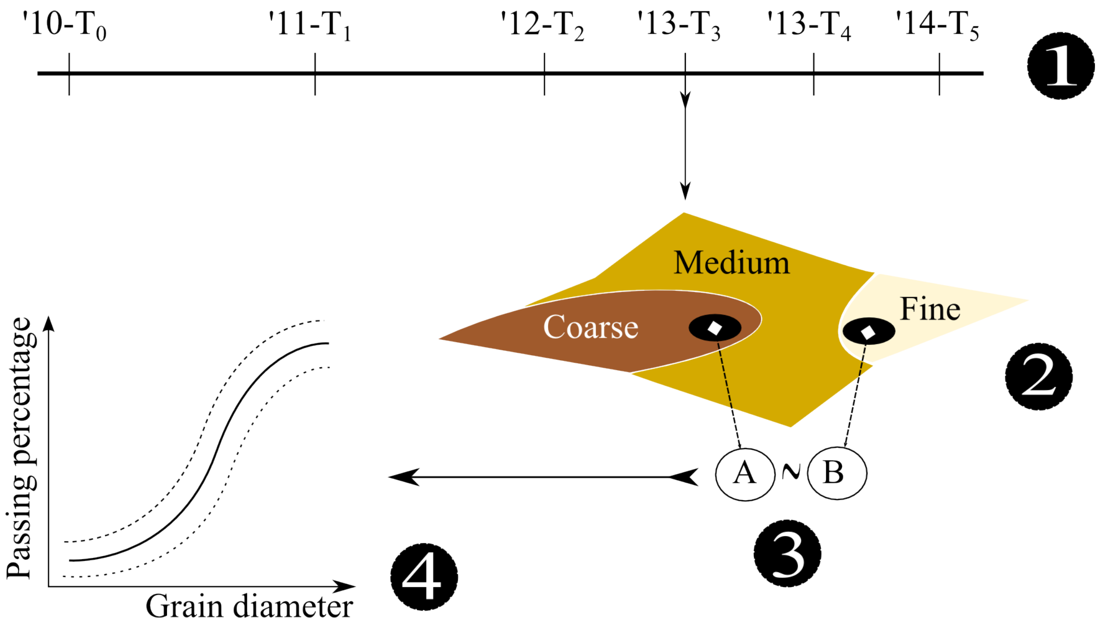


Figure 5.4 *Visualisation of the main inaccuracies: (1) the measurement campaigns are 'snapshots' of the whole time domain, (2) point measurements may not show all spatial differences, (3) assumptions for sake of comparison cause spatial different samples to be taken equal and (4) the methods to analyse the taken samples show some variability.*

taken at the same locations during the first and second time samples were taken, so with a week in between. The difference between the samples falls well within the accuracy range as described at point (1), so there is no reason to assume that there is an overall deviation between the two measurements. A final note is towards the depth of the samples: the Van Veen Grabber only samples the top layer of the bed, meaning that a sample might be largely influenced by a single hydrodynamic event just before the measurements.

The final link in the chain is the actual processing of the samples. As described in Chapter 4 this is done with the dry sieving method, which inevitably causes some inaccuracies:

i Both the original sample and the dry sample are assumed to be uniformly mixed, since only a part of the original sample was dried, and only a part of the dry sample was sieved;

ii To make the sieving process more efficient two identical mechanical sieving towers were used, although they were tuned slightly different;

iii The sieving duration differs slightly per sample, with a minimum of 5 minutes;

iv The sieving tower itself may show some variability;

v (Fine) grains are sometimes cluttered, causing additional mass on the 1180 and 600 μm sieve;

vi In some samples shell fragments were present, influencing the mass on a certain sieve;

vii The removal of the sediments out of the sieves causes for some loss of grains (on average 1.3%);

viii Linear interpolation is used to determine the actual D_{xx} values (Equation 4.1); which means that the mass percentage at a certain sieve is assumed to be uniformly distributed over the grain size interval. Although this is not exactly reality (in general a sieve curve shows a more or less smooth line), it is the most correct way to interpolate, since no other information is available. This also means that nothing can be said about the inaccuracy it causes, but it is assumed that this inaccuracy is rather small (order of a few μm).

For the aspects above an accuracy estimate is made based on an error analysis: by sieving the same sample several times on one machine, for different sieving times and on different machines, as well as taking samples from the same sample an rough accuracy interval can be made, as seen in Table 5.4.

When combining all inaccuracies, the range in D_{50} is rather large. The error range as such should however be interpreted with some common sense: considering that most inaccuracies can counteract each other, and the unlikely event that all inaccuracies occur in the same sample e.g. applying a normal distribution on the individual errors, it is save to assume that all (99%) of the samples are within a range of 9 μm. A final aspect to substantiate this statement is by noting that while the individual samples are independent, they do show a trend: an very coarse sample in between 10 very fine samples causes some suspicion, giving rise to re-analyse that sample. With this interpretation about 15% of the samples has been sieved more than once, to validate the results.

Table 5.4 *Accuracy analysis for the sieving method. The error range due to shell fragments is much smaller than derived by Huisman et al. (2014), which can be explained by the exclusion of particles larger than 2 mm in this analysis. The eventual error is smaller: the chance that all errors are applied at one sample is negligible.*

#	(In)accuracy	Maximum error found for the D_{10}, D_{50} and D_{60}* [%]	Approximate range (+/-) in D_{50} [μm]
i	Representativity of the sample**	3.6	8
ii	Use of two sieving machines**	1.8	5
iii	Sieving duration**	1.0	3
iv	Variability in the sieving tower	2.2	6
v	Cluttering of fine grains	2.2	5
vi	Shell fragments if applicable	1.5	3
vii	Loss of grains during sieving	0.8	2
	All combined	11.2	32

**The D_{90} and D_{30} are not taken into account, since no conclusions are based on these parameters.*
***Note that these errors are influenced by the error of the sieving tower; which is impossible to get rid of. It is therefore only an indication and/or rough estimate.*

5.3.2 Conclusions in relation with the inaccuracies

Towards the last research question, the following preliminary conclusions can be stated: all aspects described in the previous section are causing some sort of error, but not every aspects is equally influential on the total uncertainty. When looking at the 'bigger picture' the temporal uncertainty is the most important for this research: the *development* of the grain size distribution is researched, so it is important that the whole measurement campaign is representative. This cannot be said about the individual campaigns, since no comparison in a small time scale can be made. In addition, the actual time that the measurement campaign takes place influences all samples, which makes this more influential than the error in a single sample. However, it is noted that stating the hypotheses causes a certain perspective to develop: when the results of the campaign do not stroke with all hypotheses, it is a possibility that the whole measurement campaign is not representative.

When considering the other aspects, while putting the temporal aspects aside, it can be said that spatial and processing errors are not that large: sampling points were chosen in such a way (with both alongshore and cross-shore transects) that relatively accurate interpolation is possible. In addition, the large number of sampling points cause individual incorrect samples to be of small influence. The use of the Van Veen Grabber implies that only the top of the bed is sampled. While this causes uncertainty over the depth, the composition of the bed is the most important since it determines the bed-roughness. In addition, the Sand Motor is prone to quite persistent erosion and sedimentation areas which implies that the top layer composition is not very dynamic over time. A final comment is the mentioned fact that the samples were taken in two time periods, with an energetic time period in between. However the whole pre-sampling period was also energetic, so it is not considered to be of major influence.

The errors caused due processing of samples are taken into account by analysing both multiple samples at the same location as well as taking samples of a single sample ('sampling the sample') and show some variability. The author is however quite confident that the actual processing of the samples is trustworthy. A final aspect involves the assumptions made for interpretation. Although the assumptions as such are quite bold, common sense in used for interpretation and no hard conclusions are based on transects that are influenced by these assumptions; so although there are inaccuracies, they are accounted for where possible.

Chapter 6

Conclusions

From the previous chapters conclusions can be stated concerning different aspects: in the sampling itself, the analysis of the samples, the results of this campaign, the observed trends and observations during the fieldwork in general:

1. In cross-shore direction the observed grain size near the Sand Motor is depth dependent, showing a fining trend just outside the swash zone between the 7 and 4 meter depth contour and fining beyond the 10 meter depth contour. Within the swash zone (0 to 4 meters depth) coarsening is observed.
2. At depths smaller than 4 meters fine material (<250 μm) is absent in all campaigns, along the whole coast.
3. Small uniformity coefficients are observed in the most energetic area of the Sand Motor, meaning an absence of fine sediments. This is most likely caused due to the presence of strong currents, both caused by contraction of the currents and large alongshore currents.
4. Widely graded sediment compositions are observed in deeper water (i.e. 10 meters depths) just north of the Sand Motor. This is a result of accumulation of finer sands on top of the original medium and/or coarse grained sand.
5. The steepest observed gradients in bed sediment grain size in the T5 measurement campaign were of similar order in both cross- and alongshore direction, being $\sim$130 μm / 100 m.
6. In alongshore direction the relation between depth and grain size is not observed: while the depth variations are only small, the variation in grain size is of similar order as the cross-shore variation. It is expected that the gradients in alongshore direction are to be related to changes in the hydrodynamic forcing conditions and morphological activity of the coastline, rather than to the depth.
7. It is expected that the seasonal impact is very small due to small changes between the T3 (Feb-'13) and T5 (Feb-'14) campaign. The mentioned deviation due to the different analysis methods however, makes it hard to state conclusions about the seasonal impact.
8. The changes in grain sizes are stagnating for both the winter (T3 and T5) and summer (T2 and T4) campaigns. A slight fining trend is observed, but taking samples at a different location already causes larger uncertainties.

9. The bathymetry of the beach profiles shows a more or less equilibrium situation since a year after construction of the Sand Motor, with one exception in the southern part of the Sand Motor. While a precise cause of this exception is unclear, both the sediment is coarsening while the beach profile is getting steeper.

10. Several analysing techniques are available, but the sieving method (whether or not with additional steps) is considered to be the most reliably method, since results can be validated with own observations and errors are easily quantifiable. The use of the laser diffraction technique in the T2 and T4 campaign has probably led to significant deviations in the overall grain size, since a bias of $+/-20$ μm was present in the T2 and T4 versus the T3 and T5 campaigns.

11. Uncertainties in the February 2014 (T5) campaign are approximately 15 μm for the representativity of the sample, and 9 μm for the analysis method. Concerning the inaccuracies accepted in favour of interpretation and due to temporal intervals between measurements it is not possible to give a funded error estimate for the representativity of a whole campaign.

Chapter 7

Recommendations

Every research leads to new questions, as is the case here. Although these type of measurements cannot be improved much with the available resources, some thought on obtaining new and/or improved knowledge concern:

1. The same analysing method has to be applied, in order to compare summer and winter campaigns. Current deviations between methods are too large to state funded conclusions.

2. By sampling short transects very densely (15 meter interval) both maximum gradients, spatial variability and the location of boundaries between patches can be measured. Steep gradients are already observed, but mostly between two measurement points. This would indicate that even steeper gradients are present.

3. The combination of velocity data with the sediment samples near that location would provide a lot of insight in the effects of hiding and exposure, an aspect which is expected to be of major influence but which is hard to demonstrate in the field.

4. The placement of traceable sediment (with for example isotopes) at a specific location could provide insight in the sediment paths near the Sand Motor, and would provide unique insights in the sorting of the fractions of this sediment.

5. Taking samples with (for example) a corer would provide insight in the temporal sorting of sediments, which can be used to give more trustworthy insights in the temporal development. With the measurements taken by using a Van Veen Grabber it is hard to prove the settling of fines on top of coarse material, since the sample gets mixed. This would also provide the opportunity to determine if fine sediments are washed away, or if coarse material is transported towards a coarse patch and visa versa for fine patches.

6. Some of the boundaries of the fine and coarse patches are quite evident, but especially the boundaries on the south, north and offshore are not defined yet. These are interesting sample locations for a possible next campaign.

7. In a future campaign it would be interesting to see the storm impact, especially before and after a storm with a different wave direction than preceding storms. Due to logistical reasons it was not possible to take additional samples just after a storm in this campaign; this situation does however require some good luck...

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Appendix A

Photos of the measurements and analysis

The whole field campaign can be described in short by a few photos, starting with the majority of the work: gathering of sediment samples from the boat. As described in Chapter 4 the Van Veen Grabber is used for this part, seen in Figure A.1a. When the Van Veen Grabber touches the bottom it is closed by the impact and retained as seen in Figure A.1b. A part of the samples was located at shallow areas, and are therefore gathered with the help of a GPS during low water, see Figure A.1c. When all samples are collected, most of each sample is dried (Figure A.1d). Especially the finer sediments tend to stick together during the drying, so the dried samples need to be crushed thoroughly before being put in the 'sieve tower', see Figure A.1e and A.1f. Eventually, when the sample is sieved, several fractions can be weighed of which the desired D_{xx} values can be obtained. In Figure A.1g the shell fraction (>2mm) can be seen, as well as a few sediment clutters that are not crushed.

(a) *The Van Veen Grabber.*

(b) *Retaining the V.V. Grabber.*

(c) *Gathering samples on the beach.*

(d) *Drying of samples.*

(e) *Necessity of sample crushing.*

(f) *The 'sieve tower'*

(g) *Shell fraction.*

Figure A.1 *The gathering and processing of sediment samples.*

Appendix B

All results of previous campaigns per transect

For the completeness of this report, all available data concerning depth and D_{50} will be presented here, using the assumptions mentioned in Table 2.2. The data per transect will be plotted versus the -3 meter depth contour, to be able to compare the results. The most important observations, including information gathered during the T5 campaign, will be stated with each figure. Transects are mentioned cross-shore to alongshore, from north to south, as seen in Figure B.1. Transect B and E do not contain T4 samples, since transposing the actual measured transects was not appropriate for those locations.

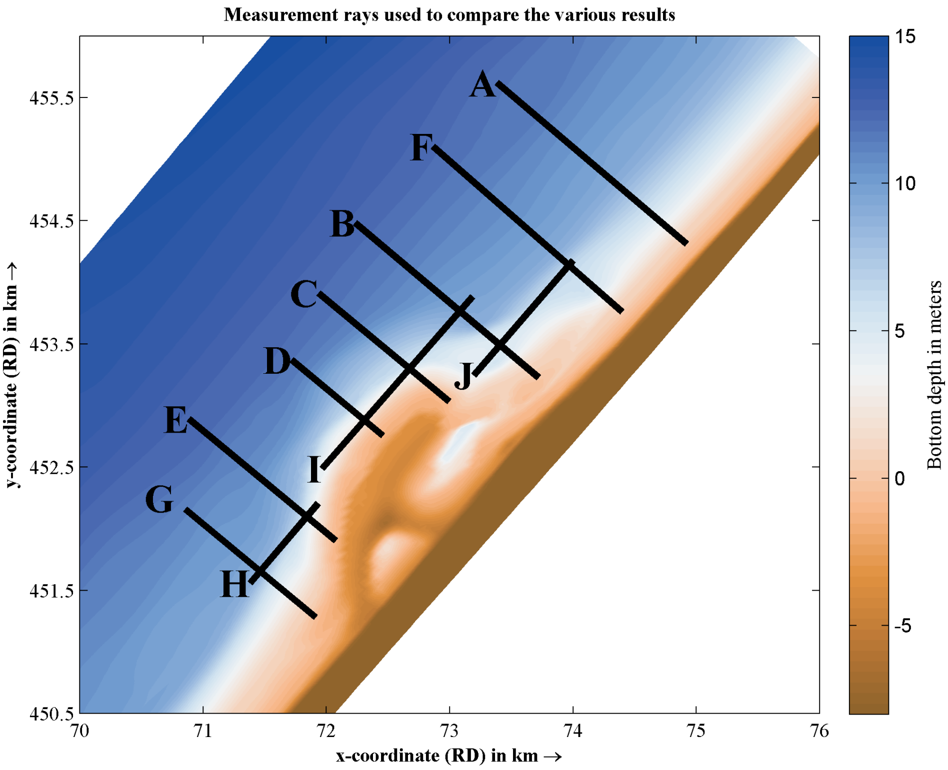

Figure B.1 *Measured transects used during the various measurement campaigns, after the assumptions of Table 2.2.*

Figure B.2 shows that the the T5 campaign nearly equals the T0 situation: the very coarse patch measured during the T2 campaign is becoming smaller. In addition, the campaigns show different results at some points, as seen just offshore at the -300 meter mark and further offshore around the -1300 meter point. This makes it plausible that the coarse patches in this transect are very local, or covered with finer material during a part of the time.

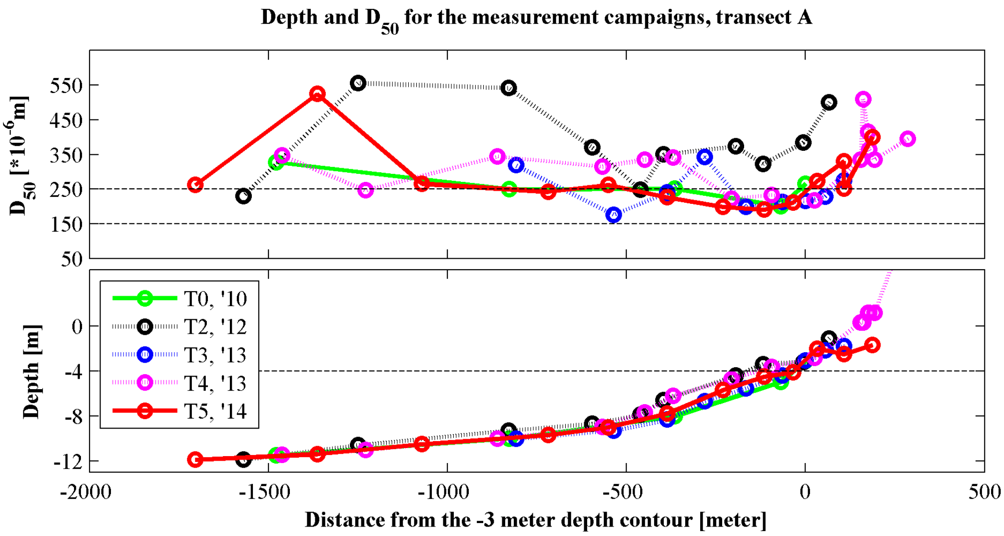

Figure B.2 *Transect A; both D_{50} and depth are plotted versus the -3 meter depth contour.*

Figure B.3 shows that the the samples in the T5 campaign in general contain more fine material than before, although between -400 and -500 meters the samples are somewhat coarser in the T5 campaign. In this profile a change in beach profile is visible; it is becoming more gentle in the nearshore area.

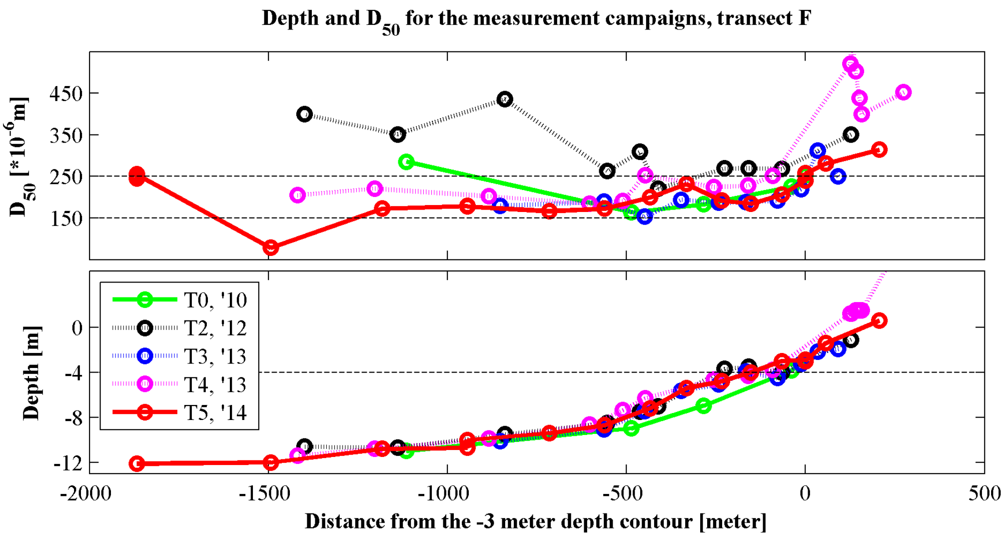

Figure B.3 *Transect F; both D_{50} and depth are plotted versus the -3 meter depth contour.*

At transect B, Figure B.4, it is observed that the T5 campaign is finer over the whole transect than the initial situation, but slightly coarser than the T3 campaign. This would suggest that the area is 'recovering' to its initial situation, although this is hard to substantiate due to the low number of samples in the T0 campaign. The gradients in this transect are quite small, which is save to say due to the large number of T5 samples.

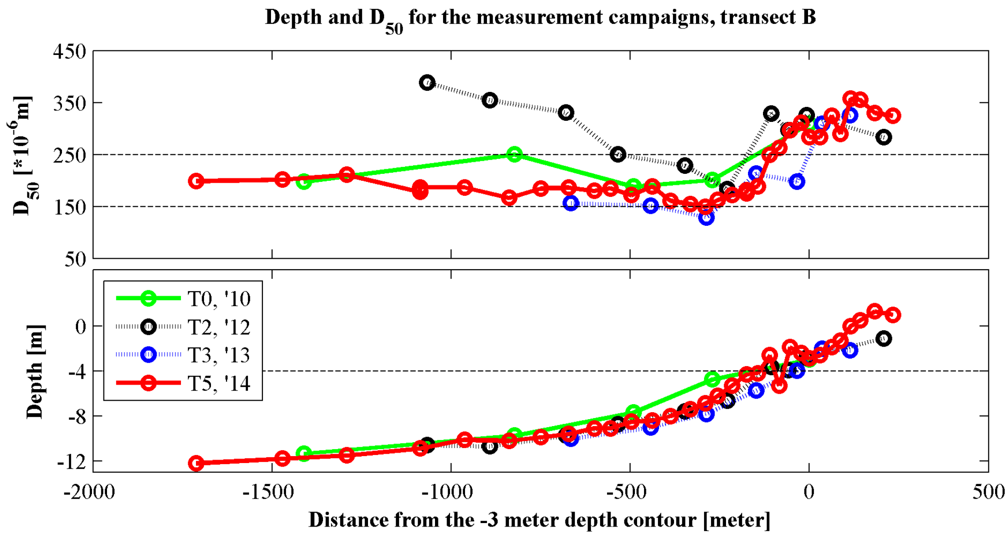

Figure B.4 *Transect B; both D_{50} and depth are plotted versus the -3 meter depth contour.*

In transect C a shift from coarse to fine material in the nearshore is observed, while offshore little variation is visible. The depth profiles are very similar for the T2 campaigns and onwards, indicating that the beach profile is in quite an equilibrium throughout the year; no strong seasonal profile can be observed from this data. Both the T2 and T4 campaign show coarser material between 400 and 800 meter offshore.

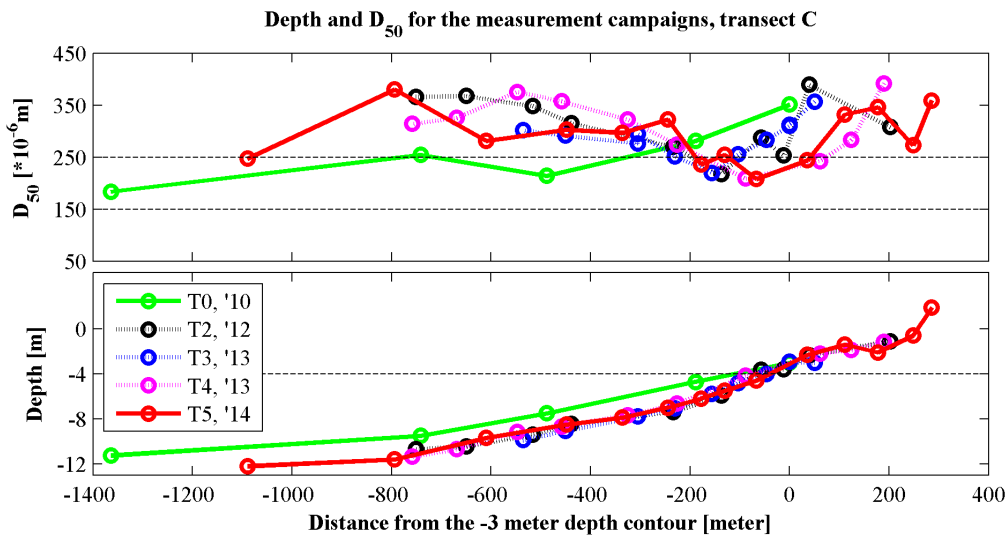

Figure B.5 *Transect C; both D_{50} and depth are plotted versus the -3 meter depth contour.*

Transect D shows large variability over the transect length (Figure B.6), starting coarse at the beach, fining (relatively, since the samples are still rather coarse) towards the nearshore and getting coarser again further offshore. From the -200 meter point going offshore a fining trend towards the T0 situation can be seen. Again, no seasonal variation is observed in the depth profiles.

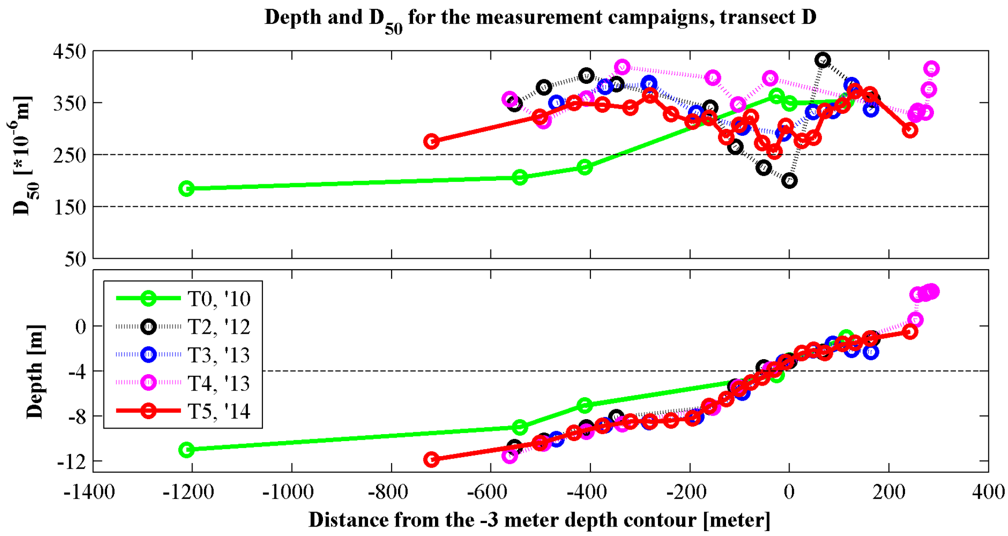

Figure B.6 *Transect D; both D_{50} and depth are plotted versus the -3 meter depth contour.*

In almost every transect the T2 campaign shows coarser material, but in Figure B.7 this is different: at the nearshore of transect E a fine area is seen that is not present in either the T3 or T5 campaign. As in most cross-sections the T5 campaign tends towards the T0 situation. Another notable observation concerns the beach profile, that changed considerably between the T2 and T3 campaign.

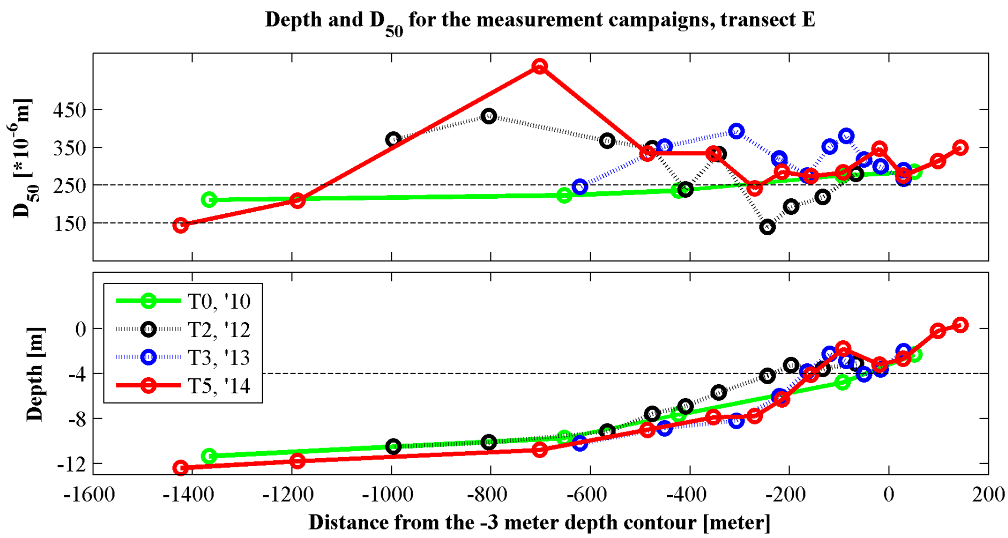

Figure B.7 *Transect E; both D_{50} and depth are plotted versus the -3 meter depth contour.*

In accordance with transect E, transect G (Figure B.8) shows fine material at the nearshore during the T2 campaign, which is not visible in the T4 and T5 campaign; even to such an extend that the measured material is much coarser than the initial situation in the T4 samples, which is not in line with the general trend (in which the T5 campaign tends to equal the T0 situation). This does not hold for the offshore part, where the T4 and T5 campaigns show similar values as the T0 campaign.

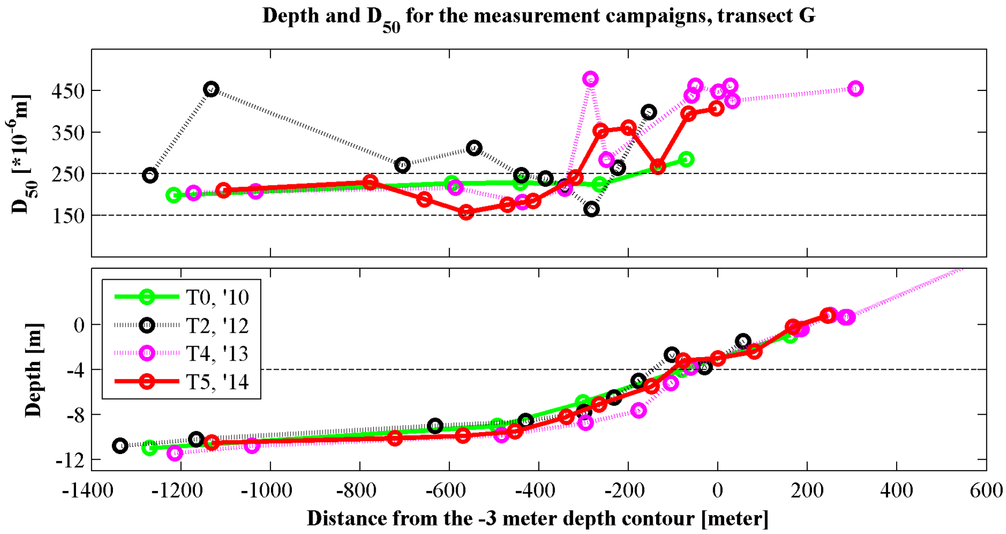

Figure B.8 *Transect G; both D_{50} and depth are plotted versus the -3 meter depth contour.*

In the most southern alongshore transect a gentle slope can be seen, with two steep gradients in sediment gradation. At the most southern end of the transect the material is quite coarse, then rapidly fines (difference of 200 μm in 200 meter). After 150 meter the material coarsens again with 150 μm in just 100 meters. Since these gradients are observed at more or less the same depth, it is likely that this sorting has to do with the local hydrodynamics (e.g. a sort of sheltered area) near the fine patch.

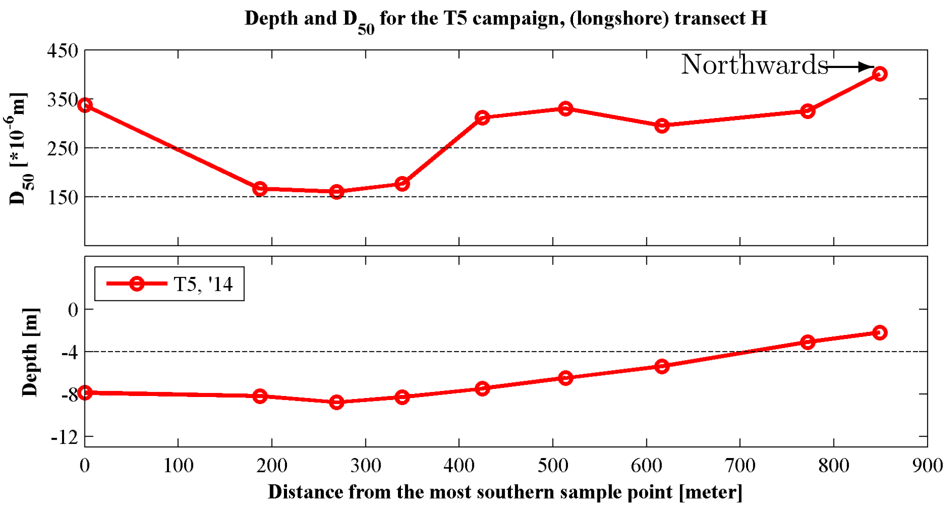

Figure B.9 *Transect H; both D_{50} and depth are plotted versus the -3 meter depth contour.*

The lengthy alongshore transect I shows a variable grain size, with a rather smooth depth profile. Notice the crossing of transect D (500m) C (1050m) and B (1700m). Especially between transect D and C steep gradients can be observed. This is in line with what one would expect, since a lot of erosion, and thus a lot of sediment transport, is taking place in this area.

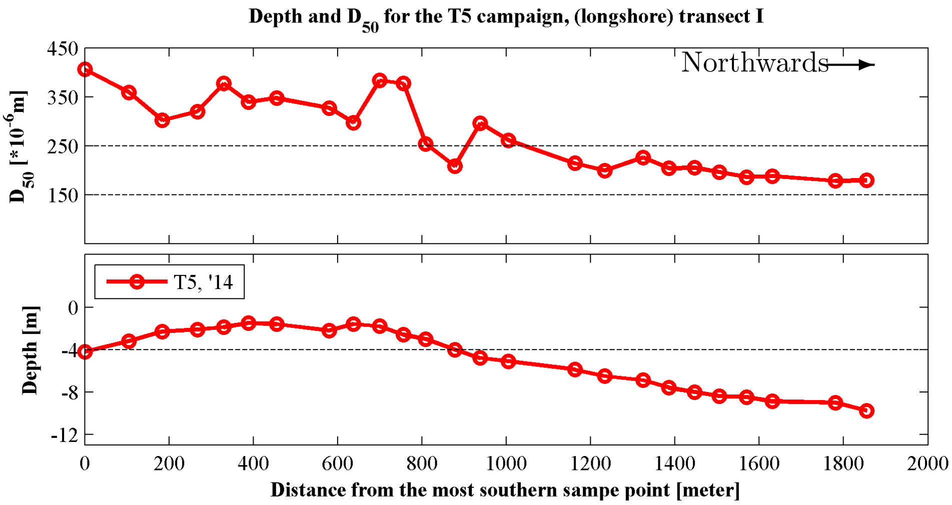

Figure B.10 *Transect I; both D_{50} and depth are plotted versus the -3 meter depth contour.*

The final transect concerns the longshore transect J, which shows less variation (but notice the different distance scale). From the 650 meter mark a grain size equal to the T0 grain size in transect A is observed, which makes it likely that at this point the influence of the Sand Motor on the grain size is diminishing.

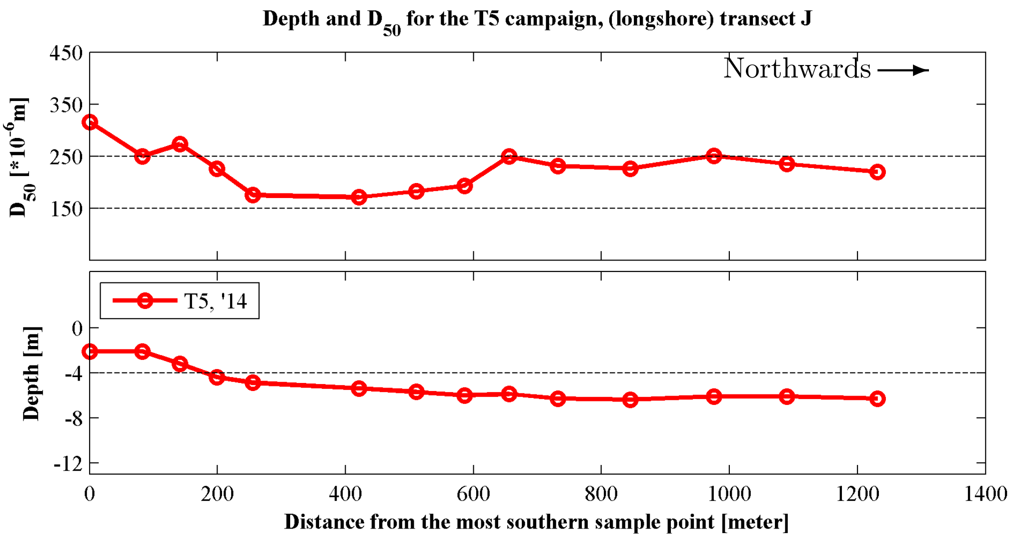

Figure B.11 *Transect J; both D_{50} and depth are plotted versus the -3 meter depth contour.*