Research on the relation between breaker bar movement and volume fluctuations along the Holland coast

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MSc. Thesis
December, 2008

TU Delft
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Photograph on the front page is taken from http://www.kustfoto.nl and is taken near Bergen aan Zee, North-Holland, the Netherlands

Preface

This thesis is the final part of my study Hydraulic Engineering at the TU Delft. This thesis is a description of my research to a relationship between the movement of sand bars in front of the Holland coast and the volume changes of the Holland coast and is performed in order to gain more understanding in the natural behaviour of the sand bars. For many people sand bars are just humps of sand, nothing more and nothing less. For this thesis I analysed data from the yearly coastal measurements (JARKUS database) of Rijkswaterstaat and found out that sand bars are more than that. They have their own lives and characteristics and are part of a complicated system of natural processes along sandy coasts.

During the process of writing this project I got the help and support from my graduating committee and from many other people, whom I would like to thank all. Some of those people I would like to emphasize. Dr. Ir. J. van de Graaff for all the time and advice he gave me, Dr. R. Spanhoff for coming up with the idea for this thesis and the sharing of his knowledge of breaker bars, Dr. Ir. M. van Koningsveld for his knowledge and support on Matlab and Mr. K.Karsen for helping me with my motivation during the difficult periods of the process. And of course, my parents and friends for their never ending support during my entire education.

Elmer Molendijk
December, 2008

Summary

The Holland coast is a sandy coast. Interaction between the North Sea and the sediment can cause local year-to-year fluctuations in the sediment budget. Studies on the long-term effect of these budget fluctuations have, in some cases, shown local shoreline retreat. To keep the coastline position stable and to protect the Dutch coast against structural erosion, sediment is artificially supplied to those eroding areas.
Since several years these nourishments are placed in front of the beach in the foreshore area. Due to the natural wave action and currents, these nourishments cause the sand budget of the coastline to be replenished. These nourishments are called shoreface nourishments.

Because the method of shoreface nourishment is rather new, there are still uncertainties about the behaviour of the supplied sediment. This is why the Dutch Directorate-General for public works and watermanagement (Rijkswaterstaat / RWS) is still evaluating the already placed nourishments. These evaluations showed that shoreface nourishment affects the behaviour of the system of breaker bars on the foreshore of the coast.

Breaker bars are sandbanks in front of the coast, which move with a certain regularity in a profile perpendicular to the coastline. All along the Holland coast breaker bars are present. Starting small at the waterline, growing during their seaward motion in size to die out at deeper water. This pattern repeats with a cycle time varying between roughly 4 and 15 years.
For the evaluation of the functioning of the nourishment it is important to understand the autonomous development. One of the uncertainties in this case is whether the sediment volume in a cross-shore profile depends on the position of the breaker bars.

Because this is still unclear, the guidelines for shoreface nourishment published by RWS (Van der Spek et al., 2007) give a recommendation which states: "in order to understand the effect of a shoreface nourishment on the behaviour of the breaker bars, it is of great importance to get full insight in the (possible changes of the) sand volume in a coast profile during a bar cycle. Is there a relation between the position of a bar and the sand volume in a coast profile?" The main goal of this thesis is to come to an answer on this question.

To come to a conclusion for this goal, first an exact cycle time of the breaker bars is calculated for seven different transects divided over 2 regions of the Holland coast (as described by Wijnberg, 1995) which differ in coastal behaviour. Six transects are located north of IJmuiden (transect 40.50, 40.75, 41.00, 45.25, 45.50 and 45.75), where the cycle time of the breaker bars varies between 12 and 15 years and the other transect is located south of IJmuiden, where the cycle time of the breaker bars varies between 3 and 5 years

The positions of the breaker bars are gathered from the JARKUS database. These cycle times are calculated by modelling the position of the breaker bar crests in time by a 2nd order polynomial and measuring the time between two successive breaker bars.
The calculated cycle times of the breaker bars in the region north of IJmuiden vary between 11.3 and 15.4 years. Remarkable is the fact that a decreasing trend in cycle time is observed from north to south. This difference in cycle time per transect will cause the breaker bars to create an angle with the shoreline. This angle is compensated by the so-called bar switch. In order to understand the bar switch, more research on to this phenomenon is recommended.

For the volume calculations the profiles are divided into a wet and a dry profile. The volume fluctuations (= total volume - trend) are calculated for both profiles as well as for the total profile.

The volume fluctuations and the cycle time of the breaker bars are compared using a sine function with free amplitude and phase combined with a period equal to the calculated cycle times.
The combination of amplitude and phase which gives the sine function with the smallest root mean squared deviation (RMS-error) from the volume residues is considered the best fit sine function. This RMS-error is compared to the RMS-error of the difference between the zero line and the volume fluctuations. If a relation between the cycle times of the breaker bars and the volume fluctuations in a transect exists the RMS-error of the sine function should be much smaller than the RMS-error of the zero line.

The ratios between the RMS-errors of the zero line and the RMS-errors of the best fit sine functions vary between 15% and 0%. However, most ratios lie above 95%. Calculations with a period varying in a margin of 2 years from the calculated cycle times have also shown very little improvement in RMS-error.

Therefore it can be said that the influence of the cycle time of the breaker bars on the volume of a transect is not dominant. Other processes that have influence on the volume fluctuations play a bigger role.

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1 Introduction

1.1 Problem description

The Holland coast is a sandy coast. Interaction between the North Sea and the sediment can cause local year-to-year fluctuations in the sediment budget. Studies on the long-term effect of these budget fluctuations have, in some cases, shown local shoreline retreat. To keep the coastline position stable and to protect the Dutch coast against structural erosion, sediment is artificially supplied to those eroding areas.
Since several years these nourishments are placed in front of the beach in the foreshore area. Due to the natural wave action and currents, these nourishments cause the sand budget of the coastline to be replenished. These nourishments are called shoreface nourishments.

Because the method of shoreface nourishment is rather new, there are still uncertainties about the behaviour of the supplied sediment. This is why the Dutch Directorate-General for public works and watermanagement (Rijkswaterstaat / RWS) is still evaluating the already placed nourishments. These evaluations showed that a shoreface nourishment affects the behaviour of the system of breaker bars on the foreshore of the coast.

Breaker bars are sandbanks in front of the coast, which move with a certain regularity in a profile perpendicular to the coastline. Along most of the Holland coast breaker bars are present. Starting small at the waterline, growing during their seaward motion in size to die out at deeper water (at the so-called "bar-cemetery"). This pattern repeats with a cycle time varying between roughly 4 and 15 years.
Once a shoreface nourishment is applied on a coastal stretch where breaker bars are present, the natural pattern of these bars changes. Because of the nourishment the sediment volume of this stretch will change as well. For the evaluation of the functioning of the nourishment it is important to understand the autonomous development. One of the uncertainties in this case is whether the sediment volume in a cross-shore profile depends on the position of the breaker bars.
Because this is still unclear, the guidelines for shoreface nourishment published by RWS (Van der Spek et al., 2007) gives a recommendation which states: "in order to understand the effect of a shoreface nourishment on the behaviour of the breaker bars, it is of great importance to get full insight of the (possible changes of the) sand volume in a coast profile during a bar cycle. Is there a relation between the position of a bar and the sand volume in a coastal profile?" This recommendation is the base of this thesis.

1.2 Research objectives

The main objective of this thesis is to sort out if a sinusoidal relation between the natural seaward movement of the breaker bars in front of the Holland coast and the yearly fluctuating sediment budget of the Holland coast can be found using the JARKUS database for the period 1965-2006.

To come to a conclusion, the data of the JARKUS database is used for the period 1965-2006. Using this database, 2 questions will be answered.

1. Is it possible to find a cycle time of the breaker bars per transect?
2. How does the volume of a transect fluctuate on a yearly basis?

The answers on these 2 questions will be used to find out if a relation as described in the main objective can be found.

1.3 Layout of the report

Chapter 2 offers some background information gained from other theses and reports on subjects that are important in order to understand this thesis. The subjects discussed in this chapter are: the Holland coast, the breaker bars in front of the Holland coast, the sediment transport processes and nourishments.
Chapter 3 presents the approach of the executed research. The research consists of the calculation of the cycle times of the breaker bars in one transect of the Holland coast, the analysis of the volume fluctuations in a transect and the search for a relation between the two. This research is executed in three locations along the Holland coast. Two of these locations lie north of IJmuiden, where the cycle times of the breaker bars are much larger than south of IJmuiden, where the third location lies.
Chapter 4 describes the results of the research executed as described in Chapter 3 for the two locations north of IJmuiden.
Chapter 5 gives the results of the research executed as described in Chapter 3 for the location south of IJmuiden.
Chapter 6 states the general conclusions of this thesis and gives some recommendations for further research.

2 Theoretical background

This chapter gives some background information on subjects that are important in order to understand this thesis. It starts by a short description of the Holland coast, followed by the information gathered from previous theses and reports about the behaviour of the breaker bars in front of the Holland coast. The third subject of this chapter are the processes that cause coastal sediment to move and influence the volume of a coastal profile. Finally some information about nourishments is given.

2.1 The Holland coast

2.1.1 Introduction

The coastal zone of the Netherlands can be divided into three major regions (TAW, 1995).

1 the Wadden area
2 the Holland coast
3 the Delta area

Figure 2-1 is an overview of the Dutch coast with the three major regions. For this thesis the main area of interest will be the Holland coast. The Holland coast is a sandy, inlet-free, wave-dominated coast. Neighbouring coastal stretches of a comparable scale are the coastal stretch consisting of a chain of barrier islands (the Wadden area) and the coastal stretch consisting of a set of peninsulas separated by estuaries and tidal basins (the Delta area). These three regions differ both in morphological appearance and in the dominance of related physical processes (Nipius, 2002).

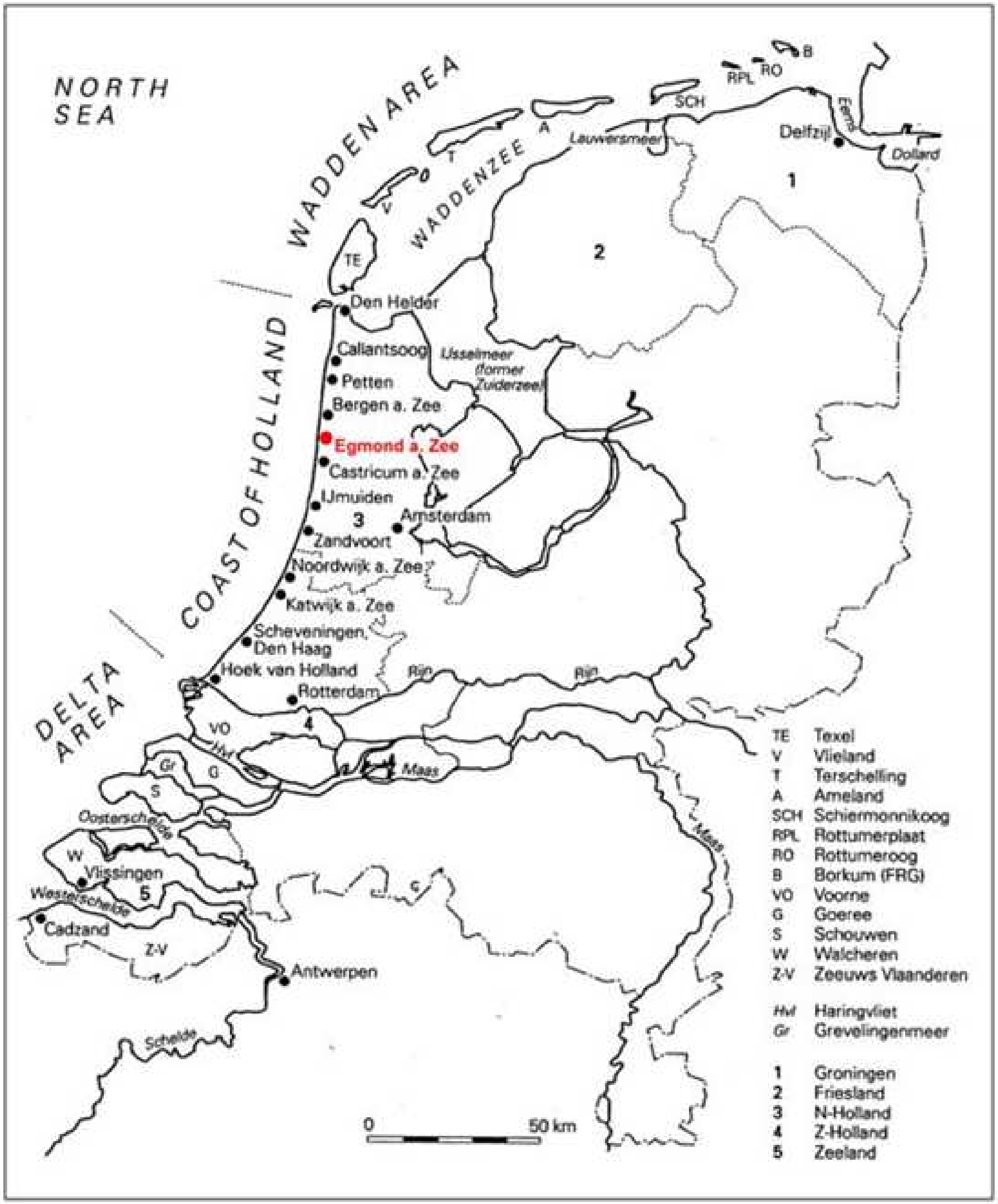

Figure 2-1: The Dutch coast.

2.1.2 Man made structures along the Holland coast

Since the middle ages, several sea defences have been placed by men along the Holland coast. Man made structures like the harbour moles of IJmuiden en Hoek of Holland, the Hondsbossche and Pettemer Sea defence and groynes all affect the morphological behaviour of the coast. For that reason they should be taken into account while looking at the natural developments of the Holland coast. Table 2-1 gives an overview of the structures along the Holland coast and Figure 2-2 shows the locations of the structures.

Table 2-1: Man made structures along the Holland coast (Wijnberg, 1995)

	Activity	Period	Spatial scale
Seawalls			
Hondsbossche and Pettemer Seadefence (km 20 – km 26)	construction most recent relocation	about 1550 1823	? 6 km (alongshore)
Scheveningen (km 102)	construction extension	1895/ 1896 1896, 1902 and 1907	140 m (alongshore) Total length: 2.5 km (alongshore)
Groynes			
Km 2 – km 31 Km 98 – km 118	construction construction	1838-1935 1776-1896	
Harbour moles			
IJmuiden (km 55/56)	construction extension	1865-1879 1962-1967	1.5 km (cross-shore) southern mole +1.5 km northern mole +1 km
Scheveningen (km 102)	construction extension	1900-1908 1968-1970	 mole length +0.5 km
Hoek van Holland (km 118)	construction extension	1864-1874 1968-1972	2 km (cross-shore) northern mole +3 km
Discharging sluice			
Katwijk (km 86)	construction increase discharge capacity	1807 1984	

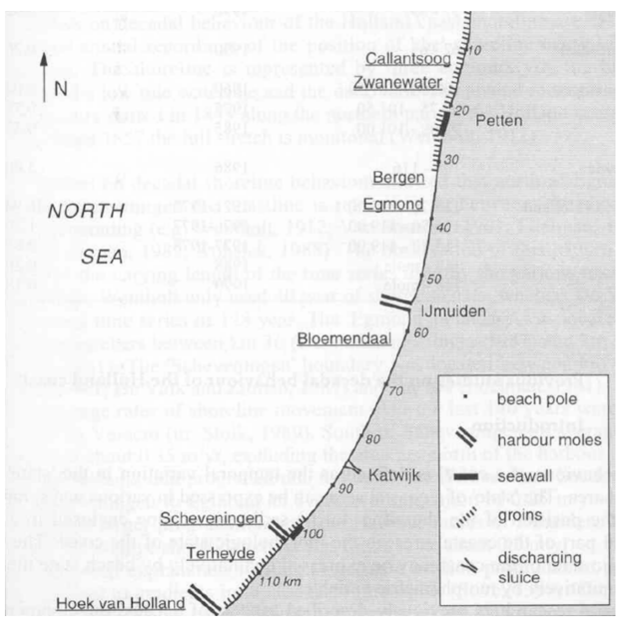

Figure 2-2: Location of man made structures along the Holland coast (Wijnberg, 1995)

2.1.3 Regions of the Holland coast

Partly due to the man made structures, the behaviour of the Holland coast is not uniform. Based on the analysis of the yearly measurements of the Holland coast (JARKUS, see Section 3.1), Wijnberg (1995) was able to distinguish 5 regions which differ in coastal behaviour. Her characteristization of these five areas is given below. The boundaries are the distance in km from Den Helder (= km 0).

Region 1: km 3 – km 8

- shoreline retreat;
- profile steepening;
- small, onshore moving bar.

Region 2: km 8 – km 23

- shoreline retreat and local propagation (due to beach nourishments);
- profile flattening changing into profile steepening in time;
- stable bar position.

Region 3: km 23 – km 55

- shoreline retreat and stable shoreline position; temporal and spatial coherent fluctuations in shoreline position;
- profile steepness fluctuations on a time span of 10 to 20 years;
- periodic behaviour of multiple bar system, typical time span of 15 years.

Region 4: km 56 – km 98

- stable shoreline position with small year-to-year fluctuations;
- stable profile steepness with small year-to-year fluctuations;
- periodic behaviour of multiple bar system, typical time span of 4 years.

Region 5: km 98 – km 118

- small shoreline fluctuations, except for man-induced shoreline progression due to harbour mole extensions near Scheveningen and Hoek van Holland and related extensive beach nourishment km 116 – 119;
- profile steepness fluctuations (related to human interventions?);
- low bars sometimes present.

The locations of the 5 regions are schematised in Figure 2-3.

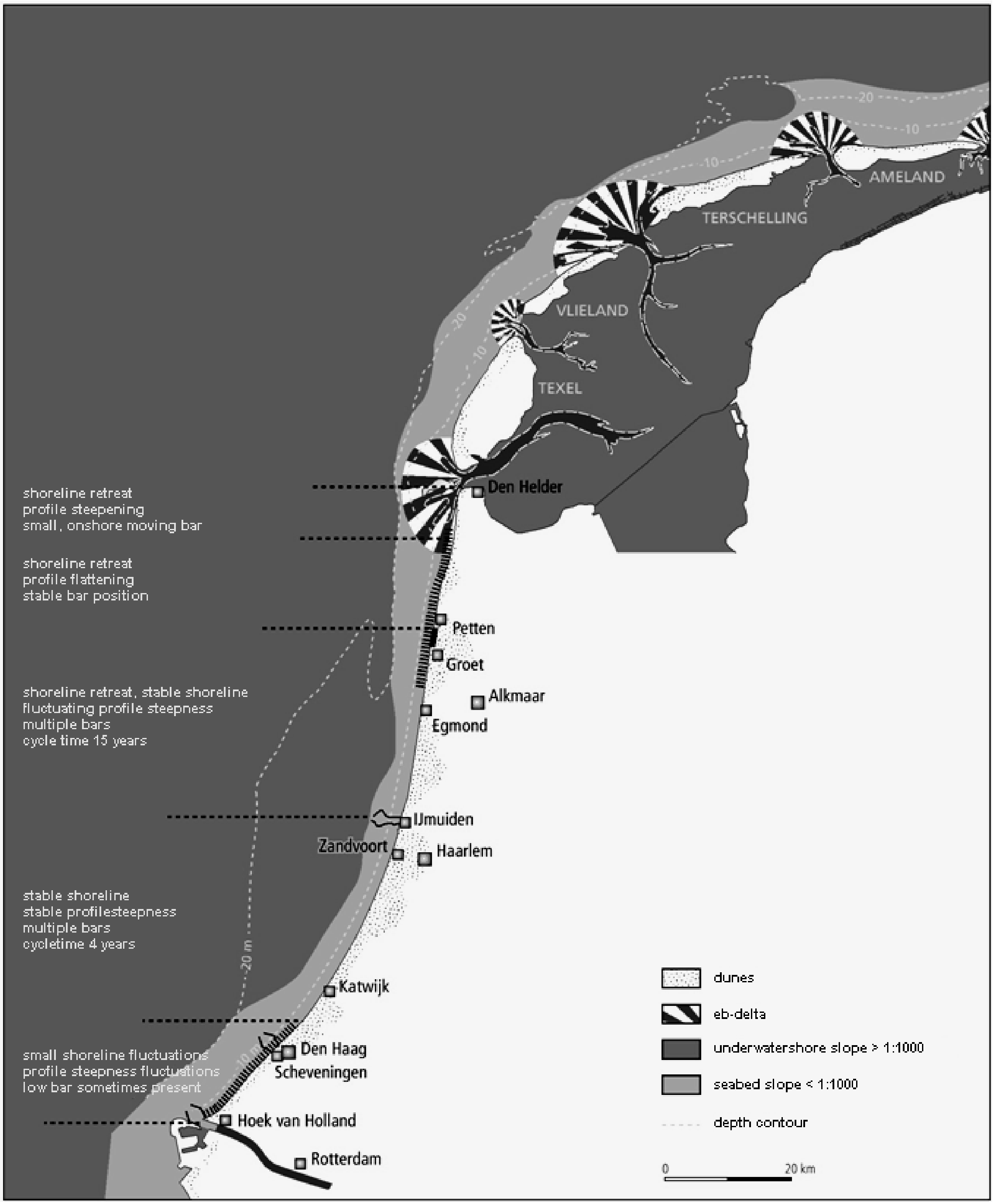

Figure 2-3: 5 Regions with different characteristics along the Holland coast (Augustinus, 1999).

2.2 Breaker bars in front of the Holland coast

2.2.1 Introduction

In front of the Holland coast, like in front of most sandy coasts, sandbars are present in the nearshore area. Soundings of the sandy Holland coast have demonstrated the presence of a multiple bar system that exhibits cyclic, offshore-directed migration on the time scale of years (Ruessink and Terwindt, 2000).

A sandbar can be defined as an elevation above the average cross-shore profile. With this definition in mind, a low can be detected between two successive bars, a so-called trough. This trough moves with the bar. As the bar grows higher, the trough will become deeper, and as the bar dies the trough will die as well. Nearshore sandbars (alongshore ridges of sand in 2-10 m water depth which are typical of micro tidal, storm-dominated coasts) might serve as a natural protection for beaches by causing waves to break away from the shoreline. This is why these sandbars are often referred to as breaker bars. Figure 2-4 shows an example of a coastal profile with three breaker bars present.

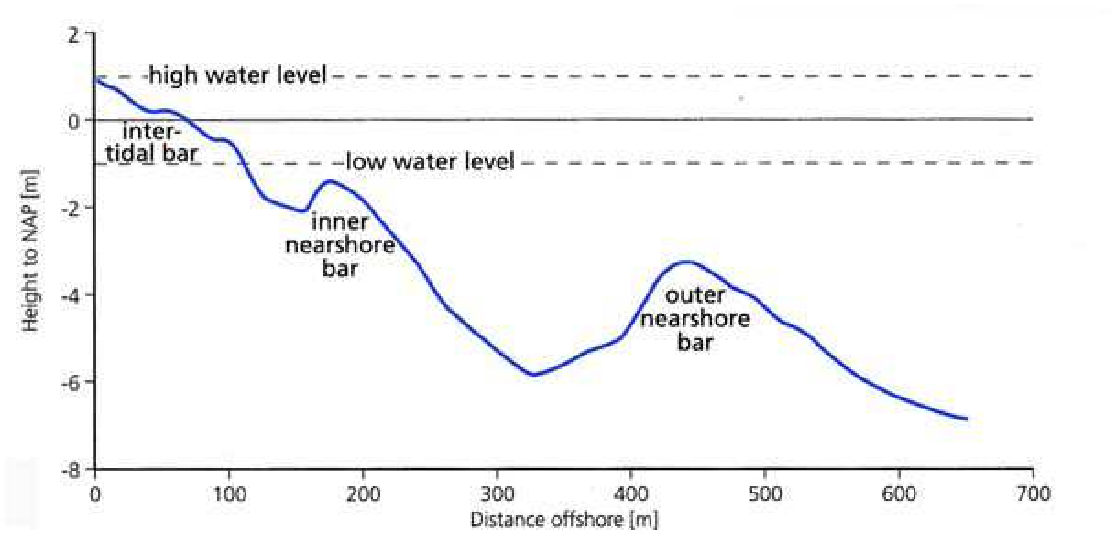

Figure 2-4: Example of a cross-shore profile of a barred coast.

2.2.2 Cross-shore characteristics of breaker bars

Breaker bars move with a regularity in a profile perpendicular to the coastline. Starting small at the waterline, growing during their seaward motion in size and dying at deeper water (at the so-called "bar-cemetery"). This pattern repeats with a so-called (pattern-repetition) cycle time varying between roughly 4 and 15 years, depending on the site location. The total life span of a bar at the Holland coast can be described into 3 stages according to Wijnberg (1995). These 3 stages are:

1. Generation close to the shore; the bar may remain within the inner 300 m of the nearshore bar zone for several years.
2. Net seaward migration through the surf zone towards about 1000 m from the shoreline; bar volume can be up to 150 m^3/m.
3. Degeneration at the outer margin of the nearshore zone.

Figure 2-5 shows the three stages in a schematic view.

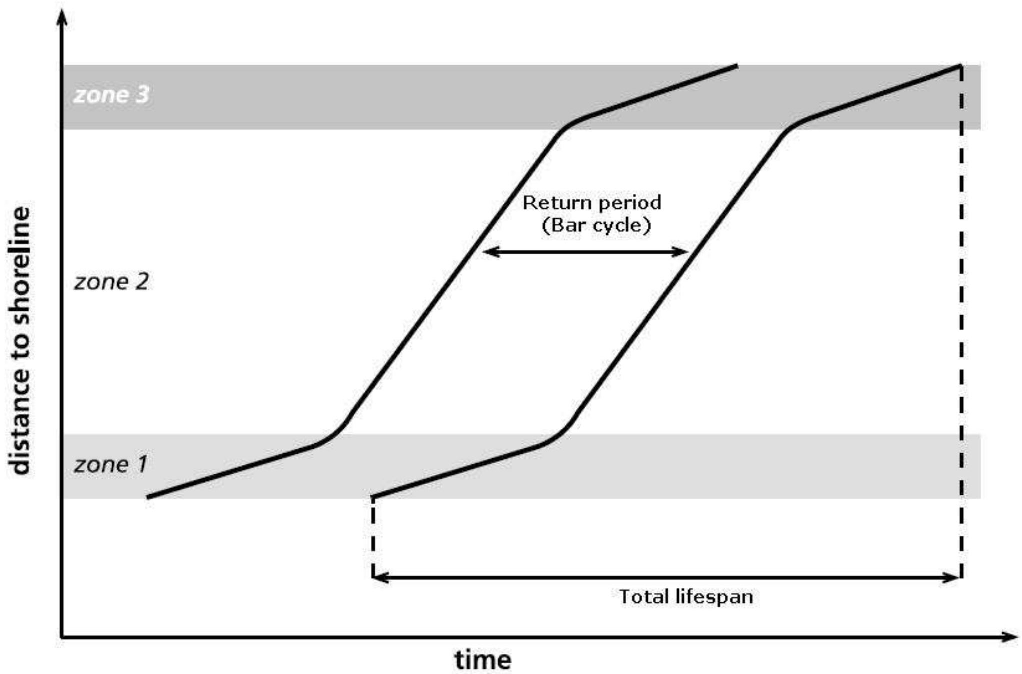

Figure 2-5: Theoretical bar movement in time.

The return period, or bar cycle, can vary from 4 years south of IJmuiden and 15 years north of IJmuiden. The total lifespan can be up to 40 years. In front of the Holland coast, there are usually 2 or 3 bars present in one cross-shore profile. The cross-shore width of the breaker bars varies from 300 to 400 m north of IJmuiden to 200 to 240 m south of IJmuiden (Short, 1991).

Cross-shore sandbar behaviour is governed by the feedback between nonlinear hydrodynamics, sediment transport processes, and the sandbars themselves. This feedback causes sandbars to migrate offshore by up to 20 m/day during storms, while they migrate onshore slowly (1 to 5 m/day) during more quiescent conditions[1].
According to Wijnberg (1997), changes of the outer bar topography usually occur during the stormy season in the winter (September to March). As long as the

[1] http://www.onderzoekinformatie.nl/nl/oi/nod/onderzoek/OND1310721/

outer bar stays in position, the inner bars cannot move seaward. The ongoing degeneration of the outer bar can be explained by the interaction between conditions that cause the degeneration of the outer bar (asymmetric waves on the outer bar; mild storm conditions) and conditions that are necessary for the survival of the outer bar (breaking waves on the outer bar; heavy storm conditions). (Van de Rest, 2004). Figure 2-6 shows the near bed currents at a barred beach (with 2 breaker bars present) that cause the bars to migrate, according to Dyhr-Nielsen and Sørensen (1970).

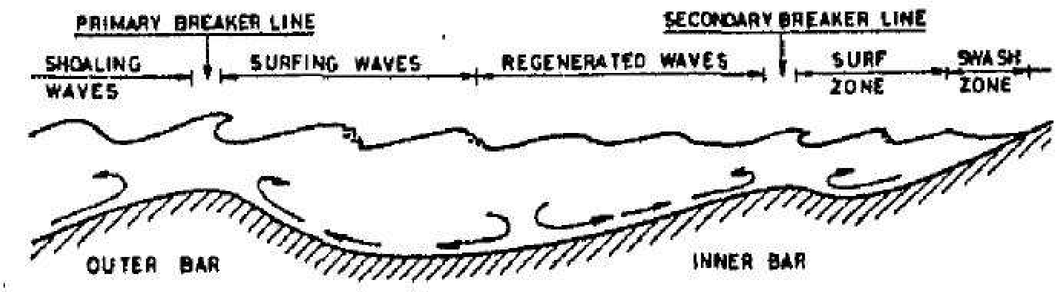

Figure 2-6: Bed currents at a barred beach with 2 bars present (Dyhr-Nielsen and Sørensen, 1970).

2.2.3 *Longshore characteristics of breaker bars*

Breaker bars are situated perpendicular to the coastline. The longshore length of these bars can be up to multiple kilometres. This longshore length differs per region. Figure 2-7 shows a coastal stretch along the Holland coast of 10 km (km 65-75) with breaker bars with a longshore length which cover the entire 10 km.

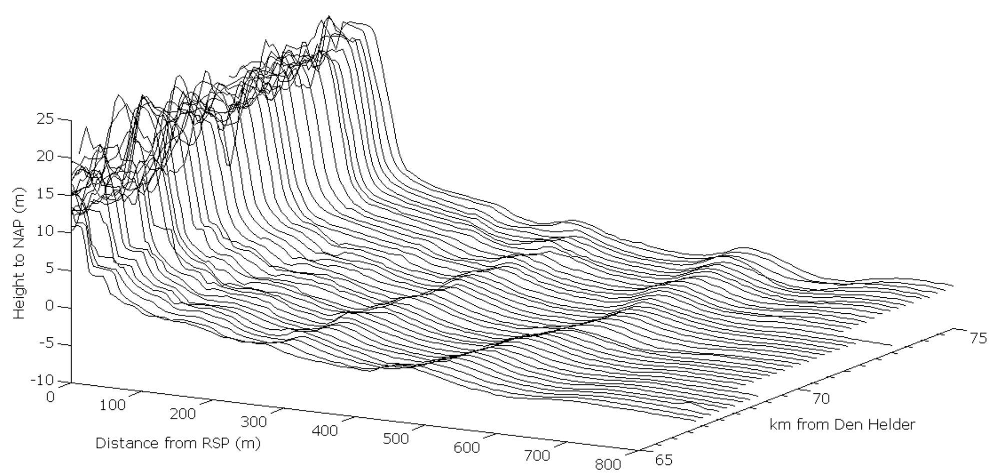

Figure 2-7: Km 65-75 of the Holland coast in 1982

In region 4 of the Holland coast, the longshore length of the bars usually stretches the entire area and can be 30 to 35 km. In region 3 of the Holland

coast, the bars have a more open structure and usually don't stretch the entire area (Knoester, 1990).
According to Bakker and De Vroeg (1988), the breaker bars can have a small angle with the coastline. Table 2-2 gives the angle of the breaker bars along the Holland coast.

Table 2-2: Angle of breaker bars with the shoreline along the Holland coast (Bakker and De Vroeg, 1988).

Area	Angle with the shore
Bergen - IJmuiden	0°
Zandvoort – Noordwijk	-3° to 2°
Noordwijk - Scheveningen	0°

2.3 Sediment budget studies

2.3.1 Introduction

To protect The Netherlands from the sea, it is important to keep track of the changes in the sand budget along the Holland coast. Because of this, many studies of the behaviour of the sediment in front of the Holland coast have been done. To get some insight in the sediment processes in front of the Holland coast, this section will give a brief overview of the sediment balance of the Holland coast.

2.3.2 Sediment transport processes

The sediment transport in the nearshore zone can be divided into 2 types of transport; cross-shore transport and longshore transport (see Figure 2-8).

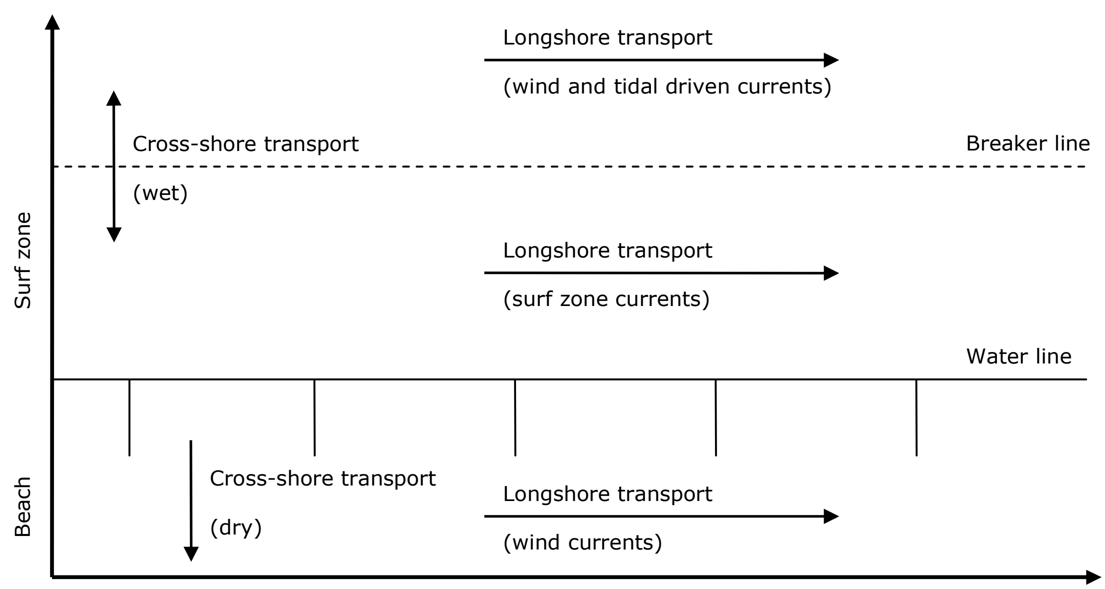

Figure 2-8: Cross-shore and longshore sediment transport (Van de Rest, 2004)

The cross-shore transport can be divided in to two categories:

- ‘dry’ transport; the wind causes an interaction between the sediment on the beach and in the dunes, this process is mainly dependent on the local wind characteristics.
- ‘wet’ transport; there is intensive cross-shore transport in the surfzone caused by breaking waves.

Sediment from deeper water can be deposited on the beach and from there it can be blown into the dunes by the wind. So there is a lot of interaction between the dry and the wet transport.

The longshore transport is mainly caused by oblique incoming waves and wind and tidal driven currents

2.3.3 Accretion / erosion of the Holland coast

The processes described in this chapter can cause large year to year fluctuations in the sediment budget of the coast. Many studies have been done to the long-term trend of these fluctuations. The long-term trend shows if a coast profile is structurally eroding or accreting. A lot of those studies give different values for the trend, due to the different databases used and the changes due to nourishment. Figure 2-9 shows the trends in volume changes along the Holland coast according to Stive and Eysink (1989) in the period 1965-1985, using the JARKUS database. This figure gives some insight in the erosion and accretion along the Holland coast.

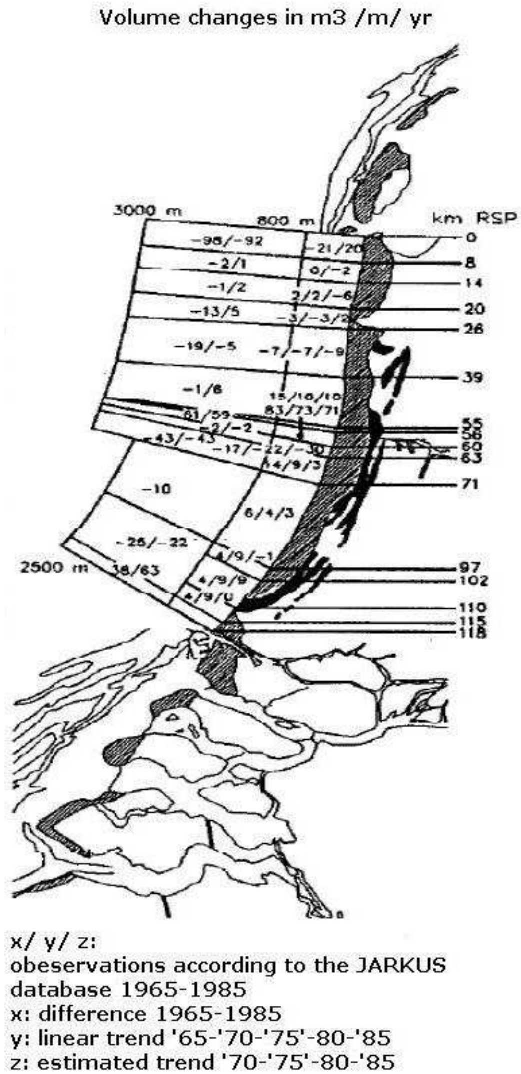

Figure 2-9: Volume changes along the Holland coast in the period 1965-1985 (Stive and Eysink 1989).

2.4 Nourishment studies

2.4.1 Introduction

To fight the erosion of the Dutch coast, the Dutch ministry of public works pursue the policy of dynamic maintenance. This policy means that the sediment that erodes from a coast profile is replenished. There are three main methods for the nourishing a profile:

- Backshore nourishment
- Beach nourishment
- Shoreface nourishment

Figure 2-10 shows these three methods. A short explanation of the methods follows in the next sections.

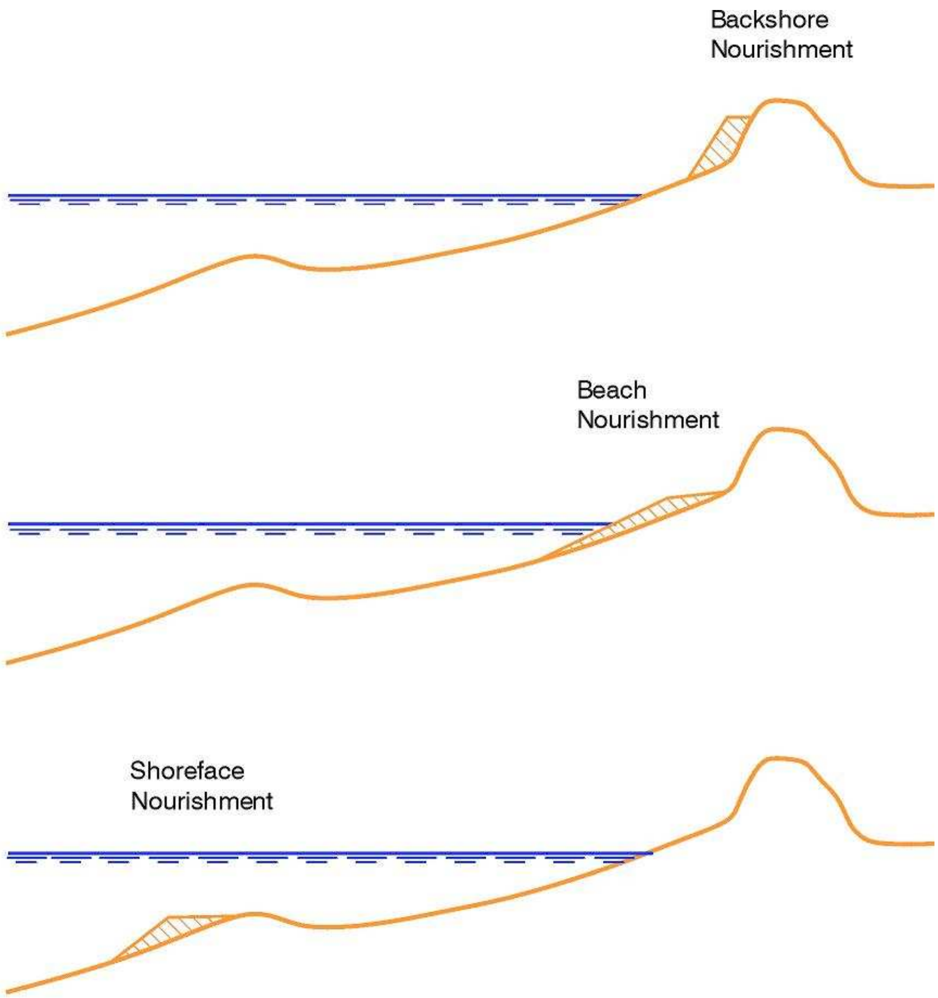

Figure 2-10: Schematic view of 3 methods of nourishment.

2.4.2 Backshore nourishment

Backshore nourishment is the strengthening of the upper part of the beach by placing nourishment on the backshore or at the foot of the dunes. The main objective of backshore nourishment is to strengthen the backshore/dune against erosion and breaching during extreme events. The material is stockpiled in front of the dunes and acts as a buffer, which is sacrificed during extreme events. This kind of nourishment works more by volume than by trying to restore the natural wide beach. The loss is normally large during extreme events, whereby steep scarps are formed. Backshore nourishment can be characterised as a kind of emergency measure against dune setback/breach; it cannot, therefore, be characterised as a sustainable way of performing nourishment and it does not normally look very natural[2].

[2] Text from http://www.encora.eu/coastalwiki

2.4.3 Beach nourishment

When the dredged sediment is placed directly on the beach, it is called beach nourishment. Where backshore nourishments are used as a coastal protection measure, beach nourishments are usually applied to replenish the total volume of sediment in the profile. The beach nourishment puts the sediment at once in the profile, which makes it suitable to solve acute problems with erosion. After the sediment is placed the total sand budget is instantly higher than before, but will start to decrease immediately.

2.4.4 Shoreface nourishment

Since 1970, research has been done on shoreface nourishments and the offshore berm was introduced in South Africa by Zwamborn et al. (1970). Shoreface nourishment can be seen as a submerged structure such as a soft reef or a submerged breakwater. In the Netherlands, the placed berm, is used as an active feeder berm. This means that the berm is placed at a nearshore site in relatively shallow water (water depth < 8 m), where it will show significant dispersal of sediment during the initial period. It is supposed to act as a feeder berm for the adjacent beaches resulting in widening of the beaches (Koster, 2006). The sediment for the nourishment is usually placed seaward of the outer bar (see Figure 2-11). After a shoreface is nourished, the profile has to find a new equilibrium in which the natural bar system changes together with the new nourished bar. This can cause the natural bars to move landward in stead of the usual seaward movement in the undisturbed situation. This has change in behaviour of the abrs has been seen by the evaluation of several shoreface nourishments along the Holland coast by Spannhof and Van De Graaff (2006), the same happened with a shoreface nourishment in the Wadden area (Alkyon, 2005).

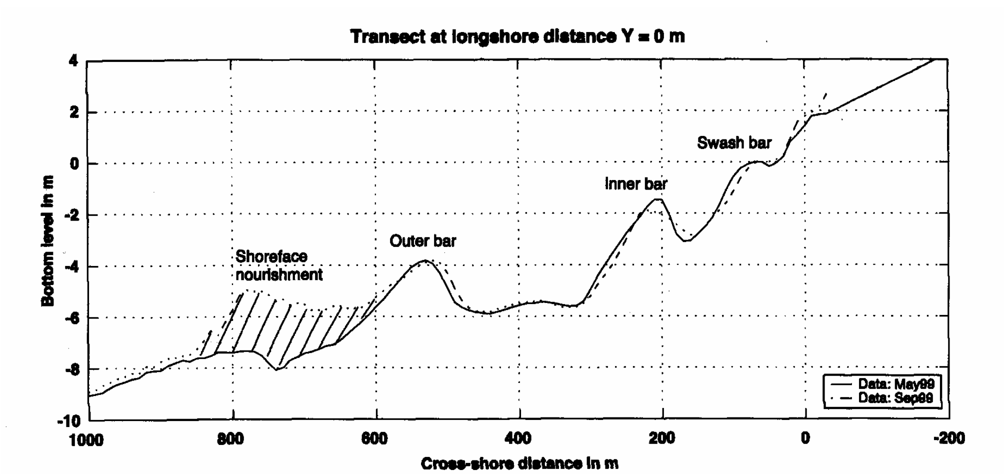

Figure 2-11: Location of shoreface nourishment.

3 Research approach

This chapter will explain how the research will be approached. Sections 3.1 and 3.2 give some information about the JARKUS database and how the information is processed. Section 3.3 describes in which order the transects will be analysed. Section 3.4 explains how the seaward movement of the breaker bars is captured with the data from the JARKUS database. Using the seaward movement of the breaker bars found in Section 3.4, the cycle time of the breaker bars can be calculated. This calculation is explained in Section 3.5. Section 3.6 explains how the volume fluctuations of the profiles are calculated. The calculated cycle time of the breaker bars in a transect and volume fluctuations are compared to see if there is a relation between the seaward movement of the breaker bars and the sediment budget fluctuations in a transect. This comparison is further explained in Section 3.7.

3.1 The JARKUS database

The data used for this thesis are gathered from the JARKUS (JAaRlijkse KUStmetingen, Eng.: yearly coastal measurements) database. This is a database of Rijkswaterstaat (The Dutch department of public works), which contains all data gathered from yearly measurements of the Dutch coast.

The coastal measurements for the JARKUS database are executed for the entire Dutch part of the North Sea coast. It started in 1963 with only a small part of South-Holland and since 1965 the entire Dutch part of the North Sea coast is monitored. The Dutch coast is divided into different sections (see Figure 3-1), which have their own reference point from where the measured profiles (transects) are numbered. Every transect is numbered by the distance from the reference point. The measurements are done for transects with an interval between 200 and 250 m along the Rijks Strand Palen lijn (RSP). The RSP line is an imaginary line along the Dutch coast, which starts at every reference point and is set to be the zero-line for the cross-shore measurements.

Figure 3-1: Different sections of the Dutch coast.

The Holland coast, which is of particular interest for this thesis, consists of the sections Noord-Holland, Rijnland and Delfland. The RSP line for the Holland coast starts at Den Helder (= km 0) and ends at Hoek van Holland (= km 118). Figure 3-2 shows the kilometre points for the Holland coast with the most important places named. All transects are measured perpendicular to the RSP line. Points seaward of the RSP line have a positive sign, while the landward points have a negative sign.

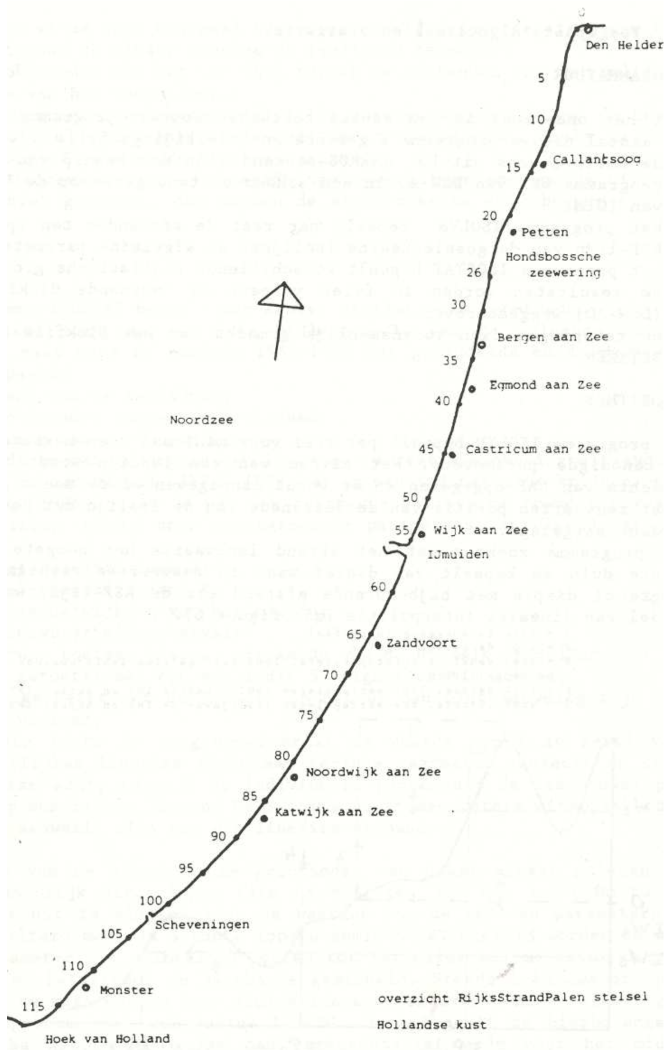

Figure 3-2: RSP line of the Holland coast. (Knoester, 1990)

The under water part of the profiles has an interval of 10 or 20 m between two successive measurements and the measurements of the dry part of the profile had an interval of 10 m in the beach area and an interval of 5 m in the more steep sections of the profile (Knoester, 1990). These intervals are important for the accuracy of the determination of the location of a bar crest and the calculation of the sand volume in a profile.

In general, the depth soundings of the wet part are executed as far as 800 m offshore from the RSP line. Since 1985 however, for some transects this survey is extended to 1000 m offshore from RSP. In the profiles of a km transect, an extended survey with a distance of roughly 2500 m offshore from the RSP line are carried out every three till five years.

All measurements are executed between early April and late September. This implies that the time interval between two successive profile soundings at a particular location can vary between 0.5 and 1.5 year. This means that the measurements can be executed during different seasons. Generally along the Dutch coast, spring and summer (April to September) are less stormy seasons than autumn and winter (Augustijn et al. 1990, Zwart et al., 1997). Nevertheless, Kroon (1994) observed hardly any seasonal differences in the mean profile shape and the width and height of the sweep zone, determined over a 17-year period near km 40. Similar observations were made by Terwindt (1969) over a 4 year period near km 98-108. Furthermore, profiles surveyed during a more than average stormy spring may have characteristics of profiles during a less than average stormy winter. Therefore, it is expected that the biased sampling does not cause a strong bias in the shapes of the profiles. Seasonal changes can cause deviations with yearly comparisons, long term trends should however, become visible (Wijnberg 1995).

3.2 Processing JARKUS data using UCIT

The Universal Coastal Intelligence Toolkit (UCIT) is a program written in a Matlab environment. This program is able to process the data extracted from the JARKUS database. Using UCIT, the measured profiles can be plotted and calculations can be made. In this way profiles from different transects can be compared to each other. (For more information on UCIT, see Appendix A). Figure 3-3 shows a JARKUS profile plotted with UCIT. In this figure, the breaker bars can be detected, as well as the troughs between the bars.

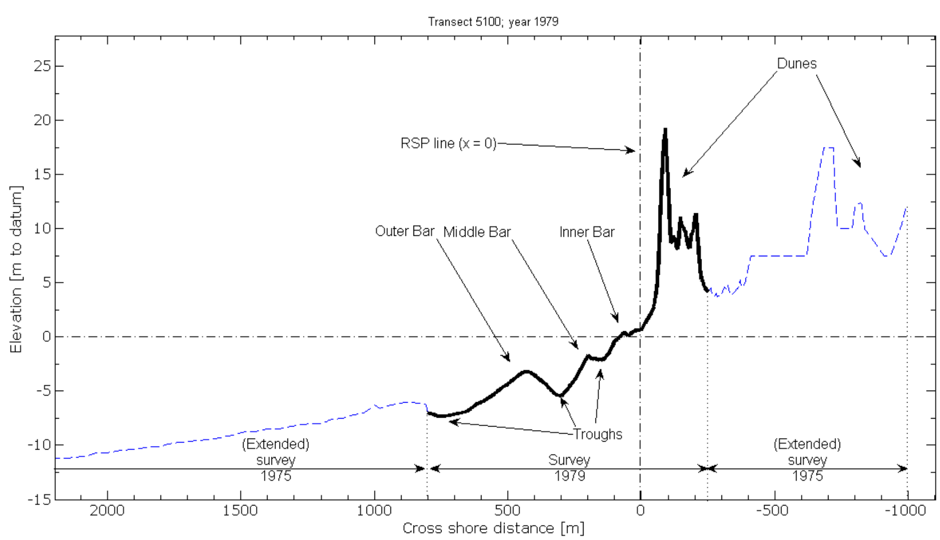

Figure 3-3: Example of a transect profile plotted with UCIT.

It can be seen that the plot contains data from -1000 m from RSP to over +2000 m from extended JARKUS survey performed in 1975. The real profile of 1979 is formed by the thick black line in the middle part of the plot, going from +800 m

from RSP to -250m from RSP. This means that for this profile part of the trough in front of the outer bar is situated outside the measured profile.
The profiles plotted by UCIT can be used to visualize the behaviour of the breaker bars. Figure 3-4A and B show 2 profiles of transect 40.75 in the years 1984 and 1988. Figure 3-4C shows both profiles in one figure. From this figure it can be seen that the outer bar damps out and the middle bar moves seaward while the inner bar shows little movement in these four years. This corresponds to the observations described in Section 2.2.2.

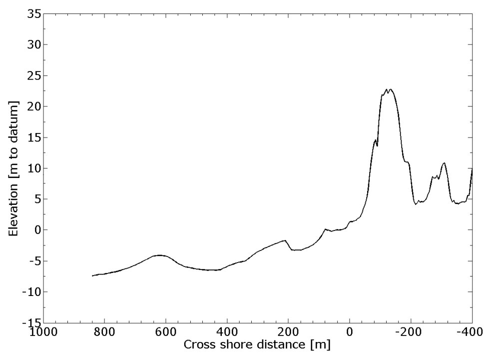

Figure 3-4A: Transect 40.75; 1984

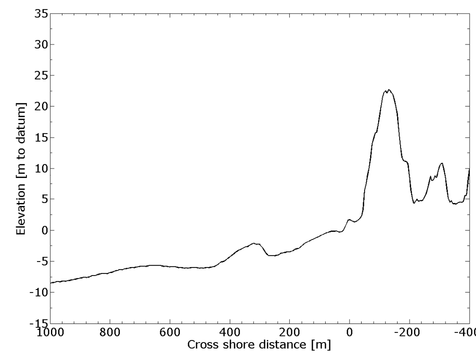

Figure 3-4B: Transect 40.75; 1988

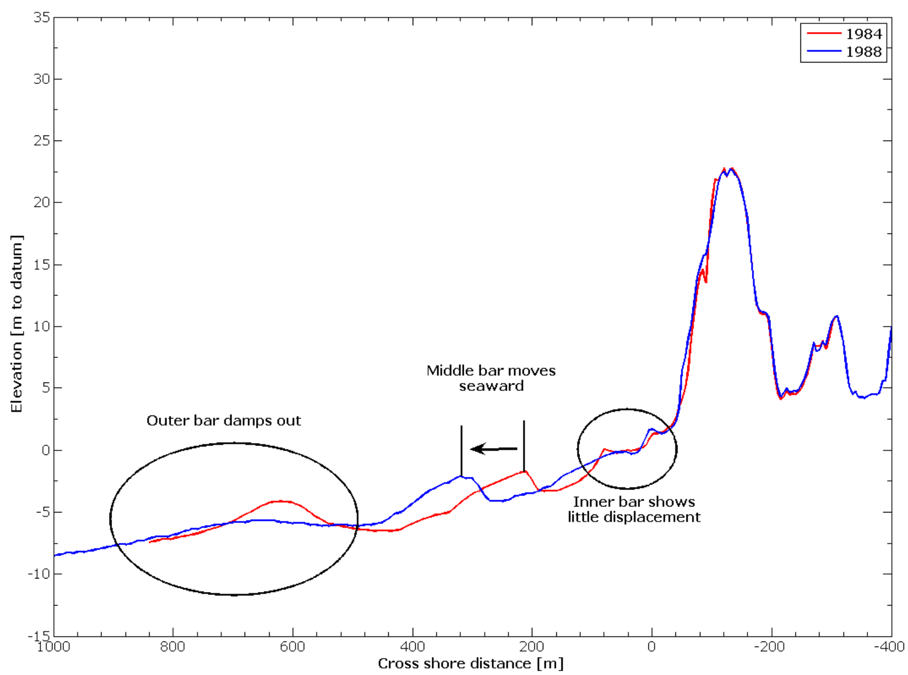

Figure 3-4C: Transect 40.75; 1984 and 1988

Figure 3-4: Transect 40.75; 1984 and 1988 compared.

Figure 3-5 shows the profiles of transect 40.75 over the period 1965-2006. From this figure it can be seen that the bars move in time. The red arrows indicate the movement of a single bar in time.

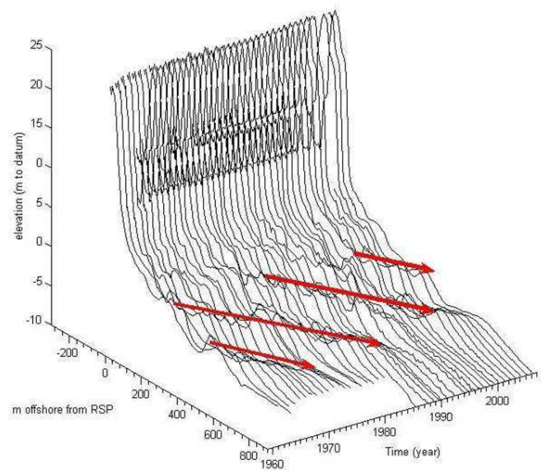

Figure 3-5: Profiles of transect 40.75 over the period 1965-2006.

Using Matlab and UCIT, multiple profiles can be placed in one plot to get a better view of the breaker bar behaviour. Figure 3-6 shows a plot of multiple transects in one year (transect 30.00 to 50.00, year 1982). From this figure it can be seen that the breaker bars in this area have a longshore length that covers many transects.

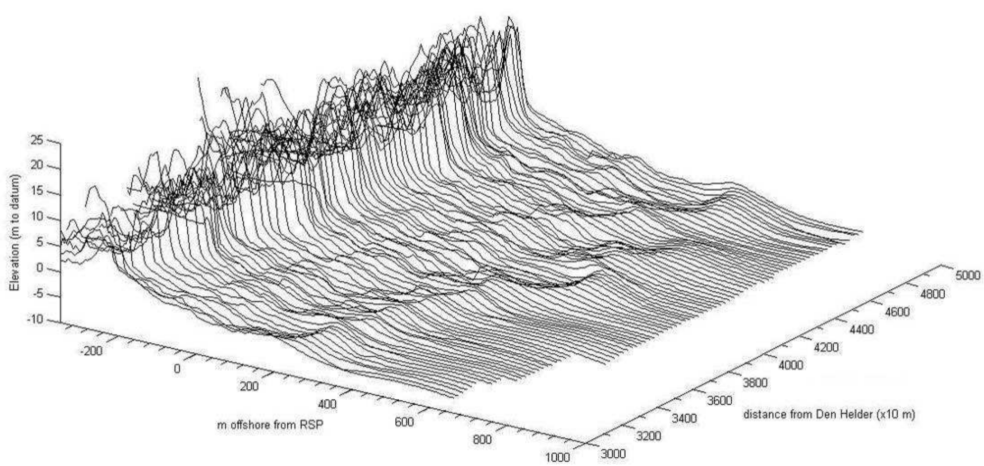

Figure 3-6: Profiles of the Holland coast in the year 1982; transect 30.00-50.00

3.3 Work area definition

The 5 regions along the Holland Coast identified by Wijnberg (1995) (see Section 2.1.3) show that there are 2 regions with a clear breaker bar pattern present. Region 3 (km 23 - 55) and region 4 (km 56 - 98) both have a clear system of breaker bars, while the other three regions have one bar present at the most. Therefore regions 3 and 4 are used for the analysis of this thesis.
Both regions have 3 to 4 bars present in a profile, which behave like the theory described in Section 2.2.2. The difference between the behaviour of the beaker bars in these 2 regions is the cycle time. The cycle time in Region 3 (km 23 - 55) is somewhere around 14 to 15 years, while the cycle time of the bars in region 4 (km 56 - 98) is somewhere around 3 to 4 years. Because of this difference in cycle time, both regions will be analysed separately.
Since the cycle time of the breaker bars in region 3 is much larger than the cycle time of the breaker bars in region 4, there are more surveys per lifespan of a breaker bar in region 3. Therefore the research will start by analyzing profiles in region 3. Information gathered from this analysis can then be used to understand the behaviour of the bars in region 4.

Because the volume of a cross-shore profile is affected by a nourishment and the behaviour of breaker bars in a cross-shore profile may change after the profile has been nourished (Alkyon, 2005), the only profiles that are useful for analyzing the autonomous movement of the breaker bars are the profiles which haven't been nourished yet. An overview of all nourishments done until 2006 can be found in Appendix C. From this Appendix it can be read that between km 38.80 and km 46.20 no nourishments have been applied yet. This is a coastal stretch with a length of more than 7 km, the longest, not nourished stretch in region 3. For region 4, the longest not nourished stretch has a length of 5.5 km and lies between km 67.5 and 73.
The research will start by analyzing two transects that lie in the nourishment free stretch of region 3. The first two transects chosen are 40.75 and 45.50. These transects have some distance from the boundaries of the nourishment free stretch to reduce the chances of influences of nourishments placed adjacent to the stretch. The results of these two transects will later be compared with the results of the adjacent transects (transect 40.50 and 41.00; and 45.25 and 45.75). The results of these adjacent transects are expected to be close to the results of the initial transects, since the breaker bars have a longshore dimension of over 500 m. Figure 3-7 is a schematic view of region 3, with the not nourished stretch and the analysed transects.

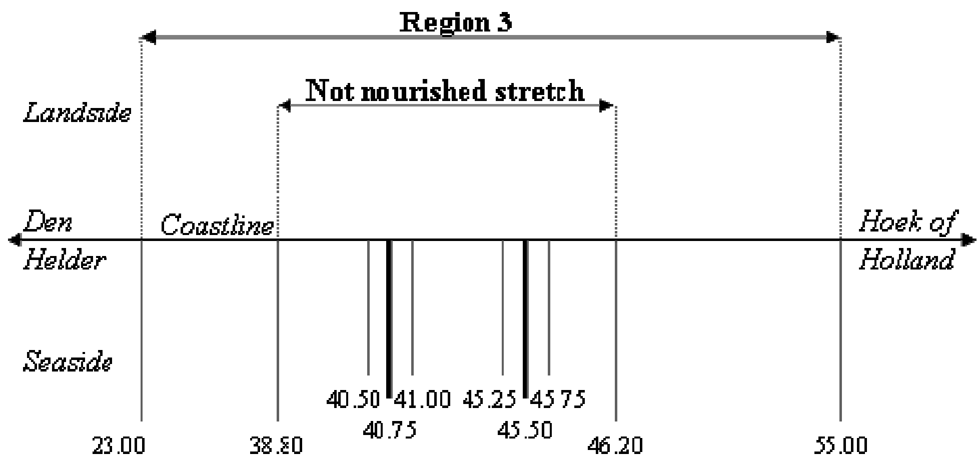

Figure 3-7: Sketch of region 3 of the Holland coast.

After the research of transects in region 3 is completed, the nourishment free stretch in region 4 can be analyzed. Here the analysis will start with transect 70.50. This transect lies in the middle of the not nourished stretch of region 4. If the analysis of the transect in region 3 and transect 70.50 show no indication of a relation between the natural seaward movement of the breaker bars and the yearly fluctuating sediment budget the analysis of the transects adjacent to transect 70.50 is considered unnecessary.

3.4 Seaward movement of the breaker bars

For this thesis the seaward movement of the breaker bars in time is of importance. Figure 3-8 shows the profile depths in time for transect 40.75. Here the breaker bars can be distinguished by the shallow, seaward moving blurs. It can also be seen that the outer bar damps out at approximately 800 m offshore of RSP.

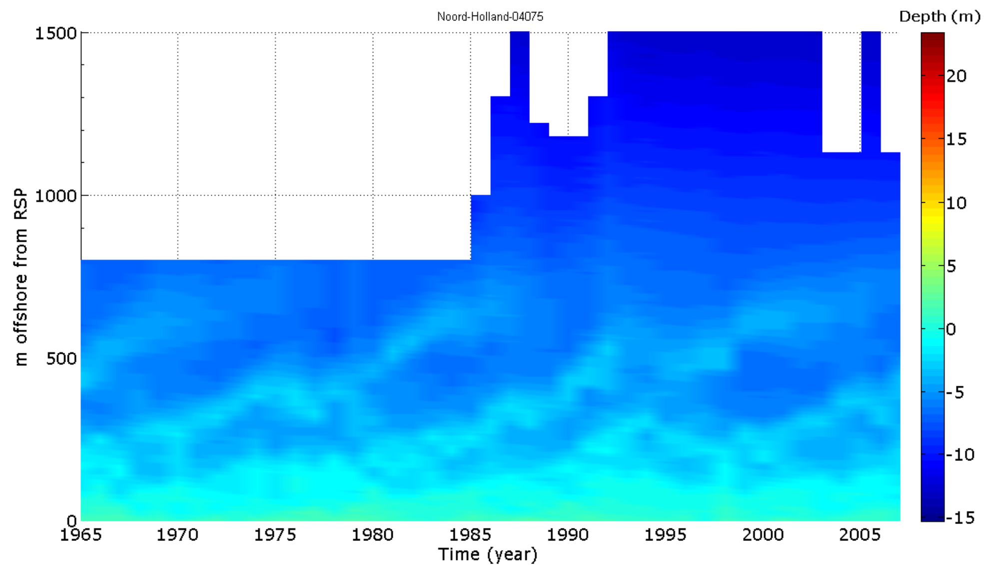

Figure 3-8: Depth chart of transect 40.75 in the period 1965-2006.

To analyse the seaward movement of the breaker bars, the position of the breaker bars must be located per year. This movement can be detected by locating the breaker bars in the profiles of a transect. The locations of the breaker bars can be collected from the profiles of UCIT, using the Matlab script 'BatchBarDetection' (written by Van Koningsveld).
This script locates the bar positions for one transect over a given period and joins the locations over time per bar. The position of a breaker bar in a profile is found by averaging all profiles of the transect and by taking the difference between a surveyed profile and the constructed average profile, as seen in Figure 3-9. The position of a breaker bar is now defined as the position of the single highest elevation of a breaker bar in the surveyed profile above the constructed average profile.

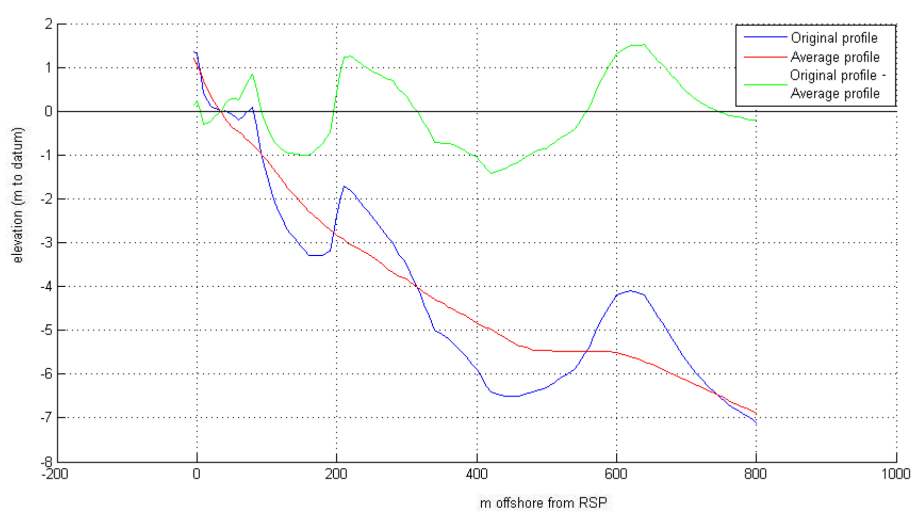

Figure 3-9: Surveyed and average profile, transect 40.75, year 1980.

From the original profile in Figure 3-9 it can be seen that the depth of the crest of the outer bar is around 4 m below NAP and at 800 m offshore from RSP the seabed lies at 7 m below NAP. The green line in Figure 3-9 shows that the outer bar crest lies 1.5 m above the average profile and has a length of roughly 200 m, the volume of the outer bar is approximately 150 m^3/m. The cross-shore distance between the crests of the outer bar and the middle bar is about 400 m. The trough between these two bars has a maximum depth of roughly 6.5 m below NAP and 1.4 m below the average profile, the volume of this trough is also around 150 m^3/m The locations of the bar crests of the three present breaker bars are roughly 80, 220 and 620 m offshore from RSP. The main interest for this thesis is the offshore position of the breaker bars

Appendix B gives an explanation of the script 'BatchBarDetection'. Figure 3-10 shows a plot of the outcome of 'BatchBarDetection' for transect 40.75, in the period 1965-2006. The dots in Figure 3-10 represent the location of a bar crest on the date of survey. Because the JARKUS database has an interval of 10 to 20 m between the datapoints of the bathymetry, the plotted position of the barcrests has a margin of 10 to 20 m.

The lines connect the dots that belong to one bar, in this way, the movement of a bar crest in time is visible. From this figure it can be seen that every year, there are 3 to 4 bars present in the profile. The year to year movement of a bar crest can be landward or seaward, but the overall movement shows seaward going bar crests.

Over the total period of the figure, 5 bars can be seen. Over the period 1965-2006, none of the 5 lines covers a complete lifespan of a bar, but the second and the third line do pas all three stages of the theoretical lifespan of a breaker bar (as seen in Figure 2-5).

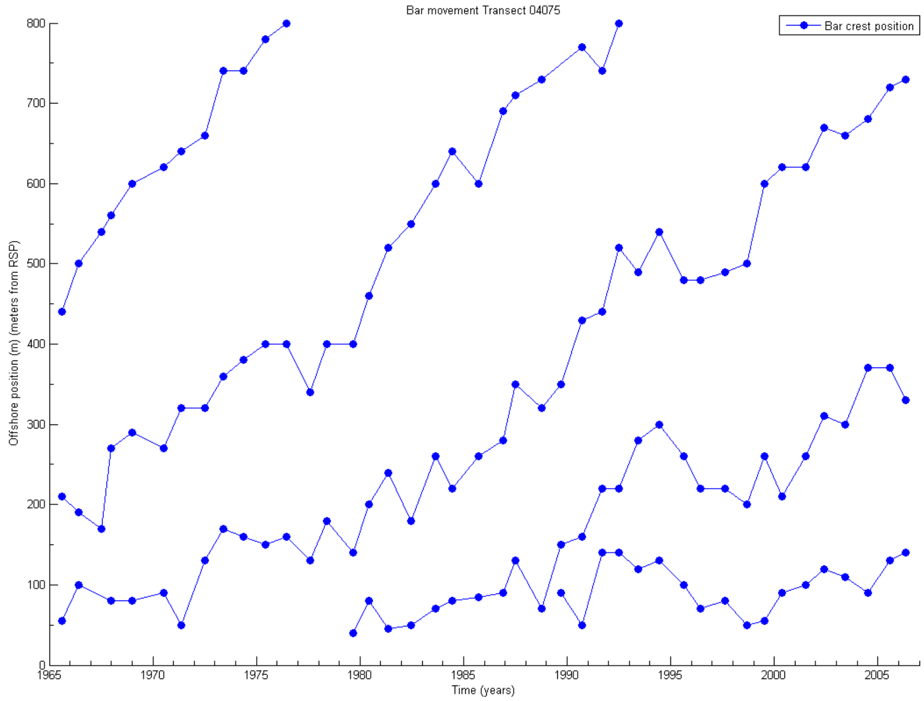

Figure 3-10: Seaward movement of the breaker bars in time, transect 40.75.

3.5 Cycle time calculation

From the movement of the breaker bars shown in Figure 3-10 the cycle time of the breaker bars in a transect can be calculated. This cycle time of the breaker bars in the transect can later be used to see if the volume of a transect fluctuates in the same time scale as the cycle time of the breaker bars.
The long term movement of the breaker bars shows a clear seaward motion; the year to year movement however, shows a very jumpy movement. To be able to compare the seaward movement of different breaker bars, and calculate the cycle time, a curved line is fitted through the breaker bar positions (blue dots) of Figure 3-10.
In order to get the curved line to describe the seaward movement as good as possible, the only useful breaker bars are the ones that pass the three stages of the theory in Section 2.2.2. In Figure 3-10 this leaves the second and the third line. The curved lines are described by a 2nd order polynomial with the form of Equation 1.

$$p = at^2 + bt + c \qquad [1]$$

Where: p = offshore position of the polynomial
a, b, c = polynomial coefficients
t = time in years.

The best fitted 2nd order polynomials are drawn in Figure 3-11. Both polynomials have different coefficients to describe the seaward movement of the breaker bars.

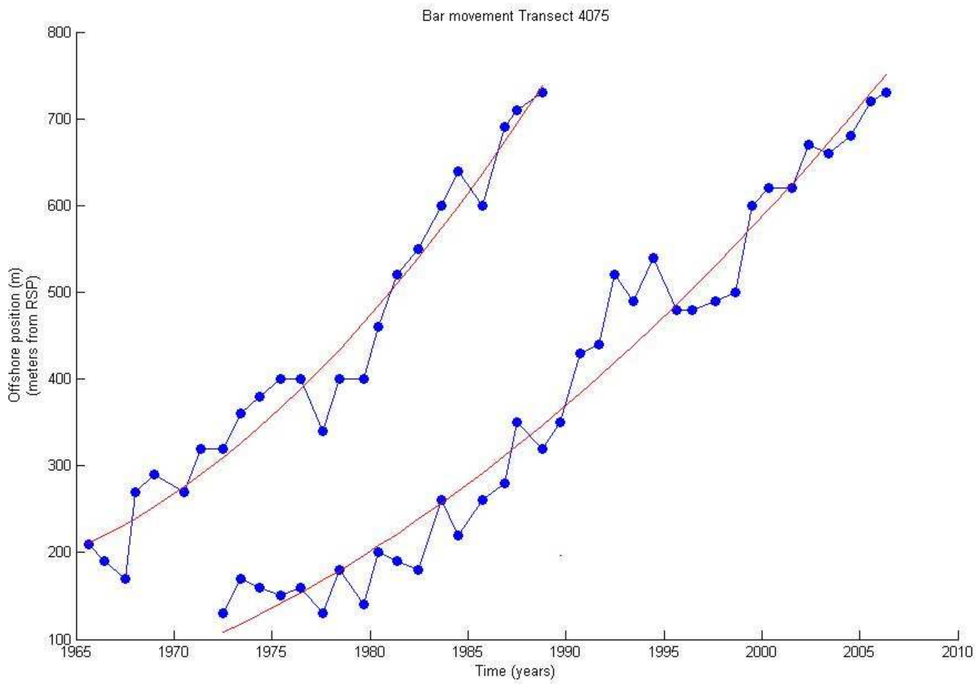

Figure 3-11: Calculated breaker bar movement.

The deviation of the calculated polynomials from the measured points will give an indication of the validation of this method. This deviation is calculated by means of the root mean square error (RMS-error). Equation 2 shows the calculation of the RMS-error.

$$rmserror = \frac{\sqrt{\left(\sum_{i=1}^{n}\left(y_{i_{barcrest}} - y_{i_{polynomial}}\right)^2\right)}}{\sqrt{n}} \quad [2]$$

Where: $y_{barcrest}$ = measured position of the barcrest for a given date
$y_{polynomial}$ = calculated value of the polynomial for the same given date
n = number of bar crest position

The dimension of the RMS-error is length. Dividing the RMS-error by the total distance covered by the breaker bar gives a relative value for the error in the polynomial.

To compare these two polynomials it is important to know whether the position of the coastline in a transect is stable in time. Since the offshore position of a bar crest is measured from RSP. The RSP line is fixed in place, while the position of the waterline can vary in time due to erosion or accretion in time of the coast.

This means that the distance from the shoreline to RSP can vary in time. Since breaker bars start their 'lives' close to the shoreline and move offshore from there on, it is important to check whether the shoreline moves in time with respect to RSP. Figure 3-12 shows the position in time for transect 40.75 of the waterline, as well as for the points in the profile of NAP +1 m, NAP +2 m and NAP +3 m (the dunefoot). The linear trend of these points is less than 0.5 m/year landward for the steepest line (the red line). So in the case of transect 40.75, no correction of the polynomials is needed.

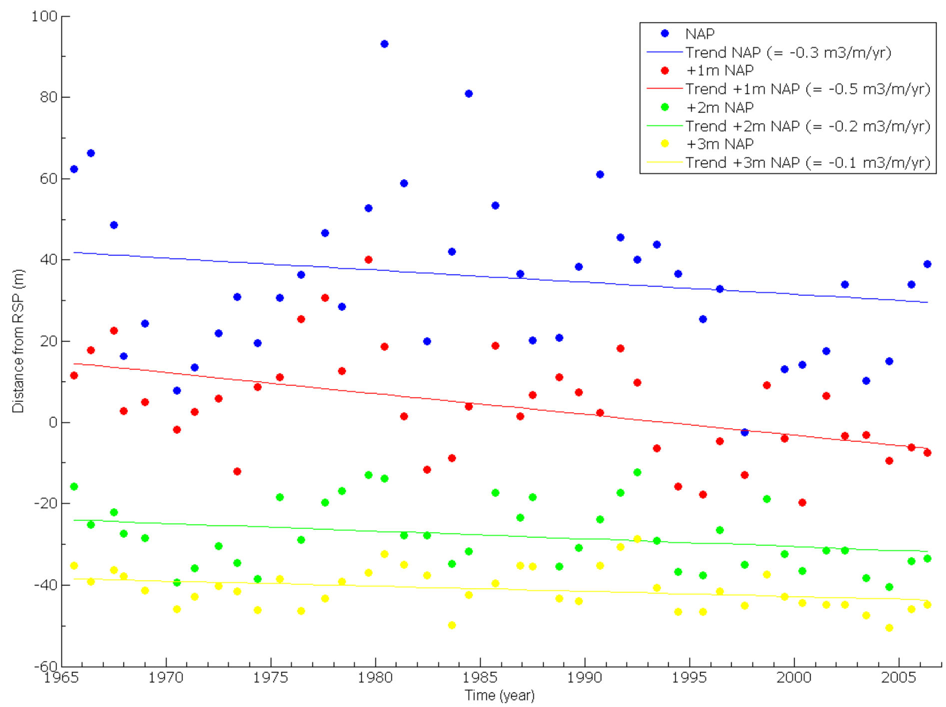

Figure 3-12: Waterline movement in time; transect 40.75.

The polynomials shown in Figure 3-11 can now be compared to see whether the bars used for the construction of the polynomials are representative for all bars in the transect. This is done by averaging the coefficients of the created 2nd order polynomials as shown in equation 3.

$$p_{average}(x) = \frac{1}{n}\left(\sum_{i=1}^{n} a_i t^2 + \sum_{i=1}^{n} b_i t + \sum_{i=1}^{n} c_i\right) \qquad [3]$$

Where:
- $p_{average}$ = offshore position of the average polynomial
- a, b, c = polynomial coefficients
- t = time in years
- n = number of polynomials

This average polynomial is then fitted through the points of the breaker bars in such a way that the RMS-error is as small as possible (Appendix D explains how this is done). If this RMS-error shows little difference from the RMS-error of the original polynomials, the average polynomial is considered representative for the whole transect. The cycle time of the breaker bars in a transect can now be calculated by measuring the time between the fitted average polynomials. Figure 3-13 shows the polynomials of transect 40.75, as well as the best fitted average polynomials and the cycle time.

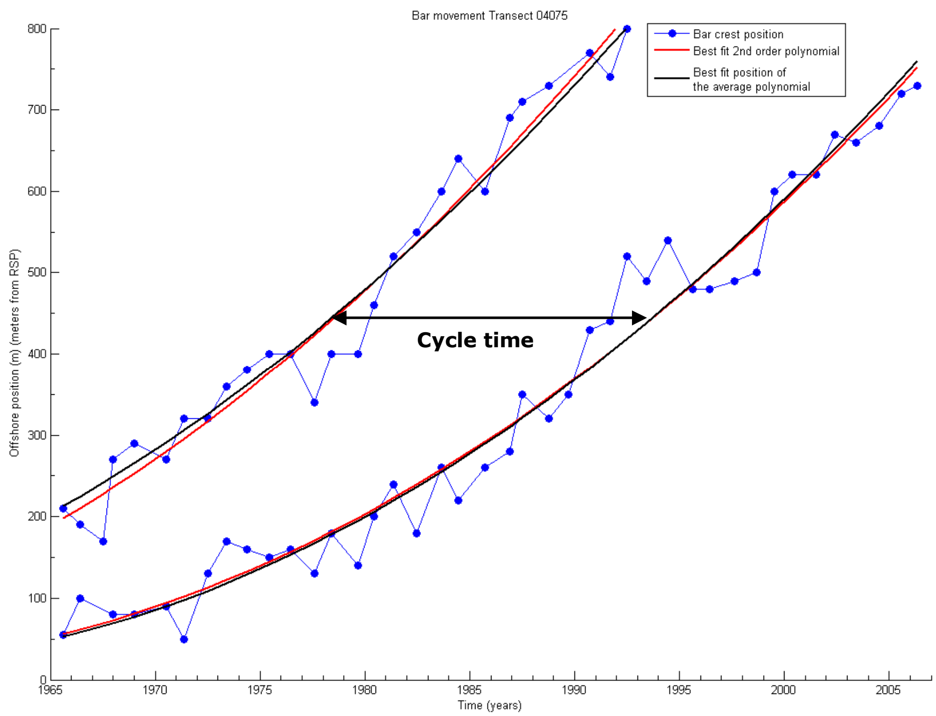

Figure 3-13: Calculation of the cycle time; transect 40.75.

From Figure 3-13 it can be seen that the best fitted average polynomials (the green lines) lie close to the original polynomials. For transect 40.75, the biggest RMS-error of the average polynomials is only 3.4% larger than the RMS-error of the original polynomial. The cycle time of the breaker bars in transect 40.75 as drawn in Figure 3-13 is about 15 years.

3.6 Volume calculation

The sediment volume of the profiles can be calculated using UCIT. UCIT contains a function to calculate the volume of any given profile or part of a profile. By calculating the volumes of all profiles of a transect over the period 1965-2006 the fluctuations can be analyzed and compared with the cycle times of the breaker bars in the transects.

Because there is interaction between the wet and the dry sediment transport, the volume is calculated for the total profiles of a transect. These profiles include the wet part as well as the dune area of the transect. Since the breaker bars 'live' underwater in the nearshore area, it is interesting to see if there is a difference between the fluctuations of the sediment volume of the wet part and the dune area of the profiles. Therefore the volume fluctuations are analysed for these two parts of the profiles separately as well.
To be able to compare the volumes of the profiles in successive years, all the profiles have the same boundaries. Since the surveys of the JARKUS database are executed till 800 m offshore from RSP during the period 1965-1985, the offshore boundary of the profiles is set to 800 m offshore from RSP for all profiles. The landward boundary is set to a point behind the first dunes at 305 m onshore from RSP. For this thesis the separation point of the wet profile and the dune profile is chosen at the dunefoot (NAP +3 m) location. Since the position of the dunefoot is not fixed in time, per transect a fixed point in time is chosen using the Figure 3-12. In the case of transect 40.75 the dunefoot position is set to 40 m onshore from RSP.

The lower boundary of the profiles is chosen in such a way that the lowest point of the measured profile is still taken into account in the calculation. Because the total amount of sand volume is not of interest, but only the volume change per year, it doesn't matter how far the lower boundary is beneath the lowest point, as long as it is below the lowest point in all calculations. To make sure that this is true for every year, the lower boundary is set to NAP -15 m, to compensate any possible yearly fluctuations of the lowest point. Figure 3-14 shows an example of the volumes of the three profiles for one year in transect 40.75

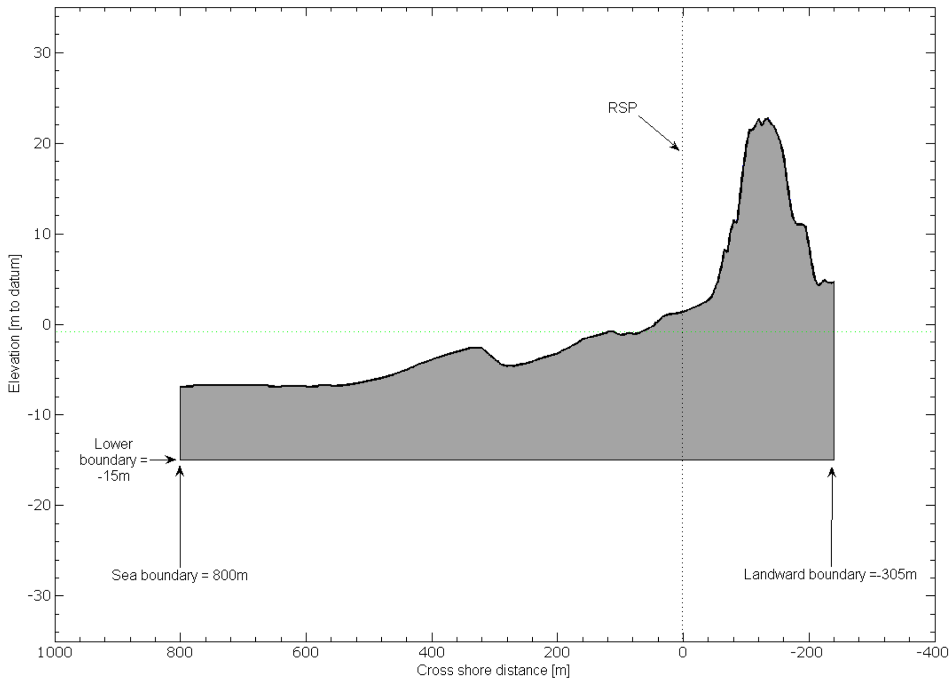

Figure 3-14A: Total profile volume.

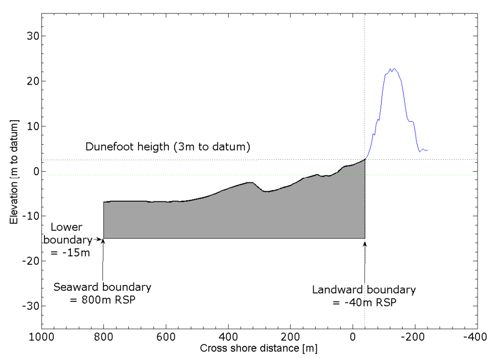

Figure 3-14B: Wet profile volume.

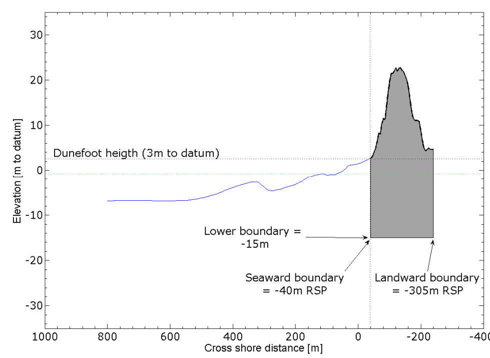

Figure 3-14C: Dry profile volume.

Figure 3-14: Calculation of the volumes in a profile.

The total volume of a profile calculated as above can be divided into 2 parts. The first part is the linear trend; the second part consists of the fluctuations (residues). Or, in formula:

$$V_{profile}(t) = \bar{V}_{profile}(t) + \tilde{V}_{profile}(t) \qquad [4a]$$

Here, the overbar is used to indicate the trend, while the tilde is used for the residues. The trend gives an indication of the growth of the volume of the profile over a longer period of time. In this case linear regression is used to calculate the trend. The residues are calculated with:

$$\tilde{V}_{profile}(t) = V_{profile}(t) - \bar{V}_{profile}(t) \qquad [4b]$$

The most interesting part for the analysis of the relation between the seaward movement of breaker bars and the changes in sediment volume are the fluctuations of the sediment volume. Figure 3-15 shows the total volume of the profiles ($V_{profile}$) in time and the linear trend ($\bar{V}_{profile}$) over the period 1965-2006 for transect 40.75. Figure 3-16 shows the volume residues calculated with equation 4b.

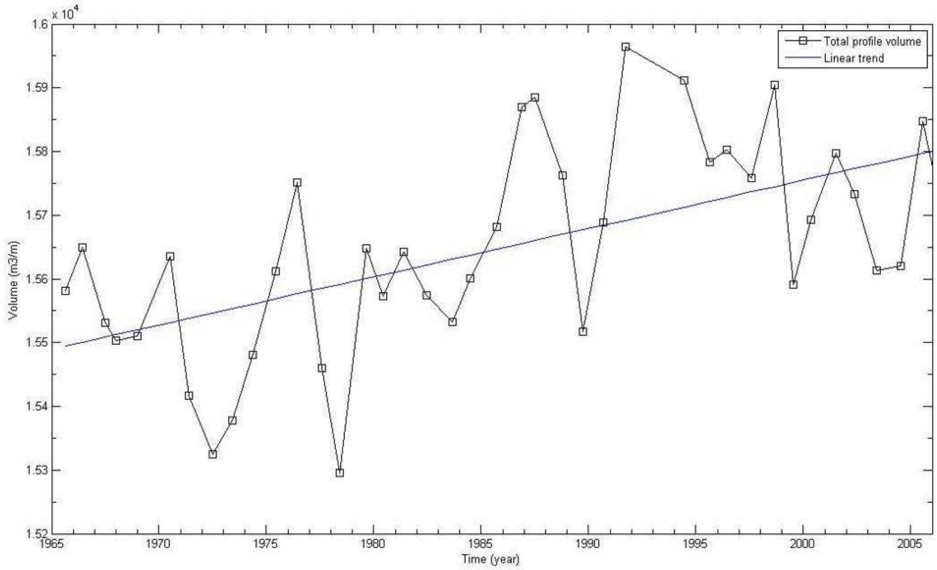

Figure 3-15: Profile volume in time; transect 40.75.

The trend of the volumes in Figure 3-15 indicates a slowly accreting coast with approximately 4 m^3/m per year in transect 40.75.

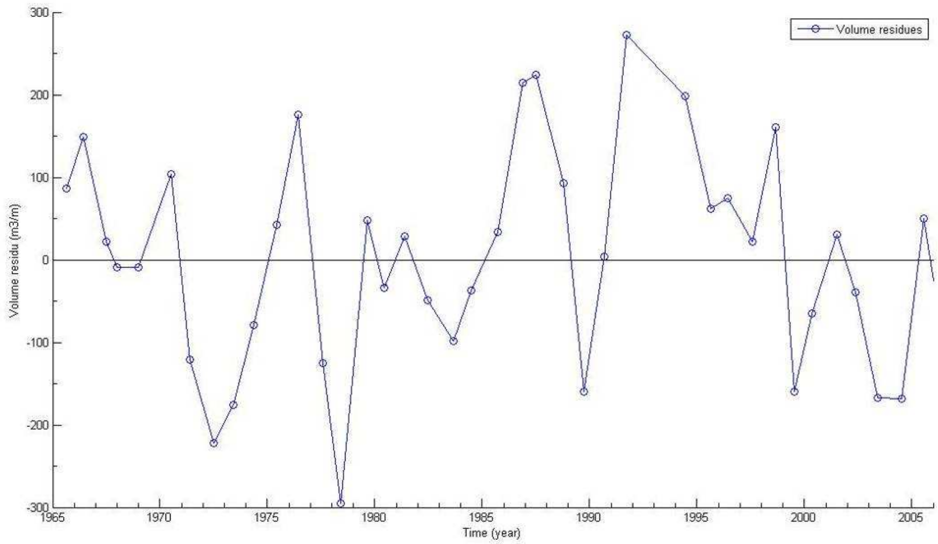

Figure 3-16: Profile volume residues in time; transect 40.75.

Figure 3-16 shows that the volume residues of transect 40.75 fluctuate in a bandwidth of roughly 300m^3/m. The biggest fluctuations per year are in the order of 300 m^3/m (1976-1977), while in other years there is hardly any difference in the residues (1968-1969).

3.7 Comparison of cycle time and volume fluctuations

If there is a relation between the natural seaward movement of the breaker bars in front of the Holland coast and the year to year fluctuating sediment volume of the Holland coast, the sediment budget fluctuations should show periodic changes that match the periodic behaviour of the breaker bars. To see if this is true, a sine function with the form of equation 5 is fitted through the volume residues.

$$y(x) = A \cdot \sin(\omega x + \theta) \qquad [5]$$

Where: A = amplitude
ω = frequency (= 1/period)
θ = phase

The period of the sine function is set equal to the cycle time of the breaker bars as calculated in Section 3.5. This leaves two degrees of freedom for the sine function: the amplitude and phase. The best combination of those two degrees of freedom is found using Matlab. The amplitude varies between 0 to the biggest value of the residues plus one time the standard deviation of the residues, the phase varies between 0 and 2 times pi, as shown in Figure 3-17.

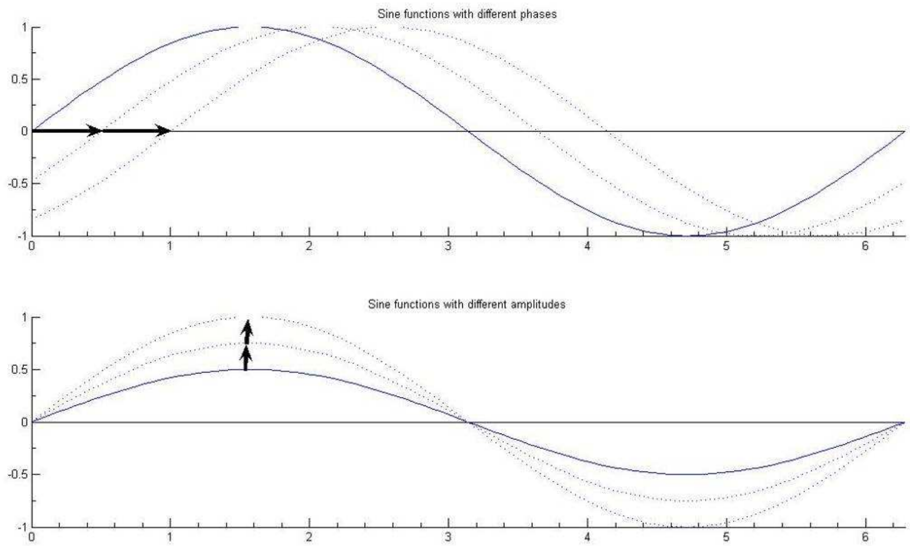

Figure 3-17: Variation of amplitude and phase.

For every combination of amplitude and phase the RMS-error of the difference between the volume residues and the sine function is calculated (as explained in equation 2). The combination of amplitude and phase with the smallest RMS-error is considered the best fitted sine function. The RMS-error of the best fitted sine function is then compared to the RMS-error of the difference between the volume residues and the zero line. Figure 3-18 shows the volume residues and the best fit sine function. The left arrow (number 1) indicates the difference between one residue and the best fit sine function, the right arrow (number 2) indicates the difference between the residues and the zero line.

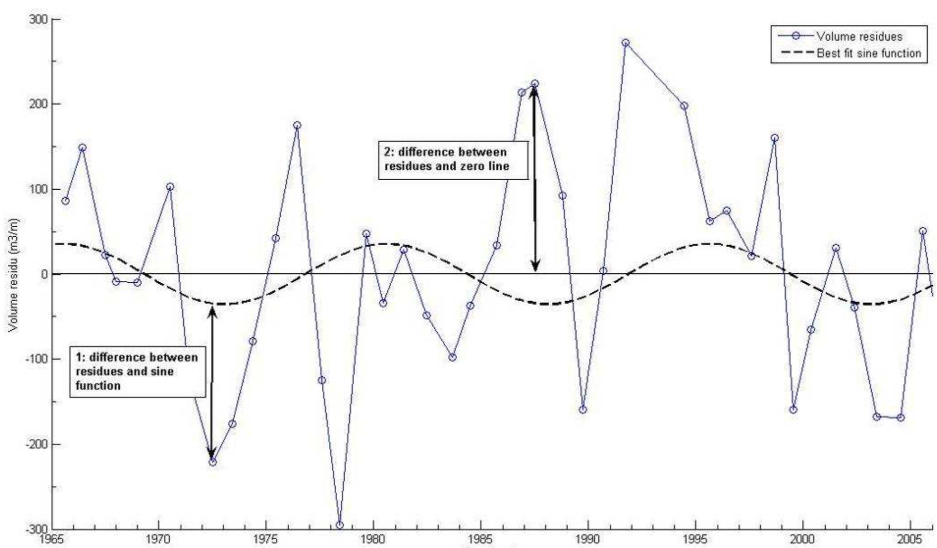

Figure 3-18: Best fit sine function; transect 40.75.

If there is a relation between the fluctuations of the volume residues and the periodic cycle of the breaker bars in this transect, the RMS-error of the best fit sine function should be significantly smaller than the RMS-error of the zero line in all transects.

4 Analysis of region 3 of the Holland coast

In this chapter the results of the research as described in Chapter 3 are discussed for the analysed transects (40.50 to 41.00 and 45.25 to 45.75) in region 3 of the Holland coast (km 23 - 55). The results are discussed in the same order as described in Chapter 3. First the cycle time of the breaker bars in the transects 40.75 and 45.50 is calculated. The results are then compared with the results of the analysis of the adjacent transects. Later the volume fluctuations of all six transects are calculated and compared with the cycle times.

4.1 Cycle time analysis

At first the cycle times of the breaker bars in the transects 40.75 and 45.50 are calculated as described in Sections 3.4 and 3.5. Figure 4-1 shows the locations of the breaker bars crests per year in transects 40.75 and 45.50 as found by using ‘BatchBarDetection’ (Appendix B) over the period 1965-2006.

The lines in Figure 4-1 show that there are 5 breaker bars present during the period 1965-2006. None of the 5 lines show the complete lifespan of a bar. For both transects the most left bar came into the system far before 1965 but damps out during the period of the graph. The same holds for the second line from the left. The middle line of both figures originated just before 1965. In transect 40.75 this bar hasn’t damped out yet, while in transect 45.50 the bar damped out between 2005 and 2006. The other two lines in both figures show bars that originate close to the shoreline. The first line in Figure 4-1B ends in a horizontal line of five years long. This line is caused because the breaker bar crest damps out just over 800 m offshore from RSP where the survey ends.

To see if the positions of the bar crests of Figure 4-1 need to be corrected for a seaward or landward moving waterline, the position of NAP, NAP +1 m, NAP +2 m and NAP +3 m (the dunefoot) in time for transect 40.75 and transect 45.50 are plotted in Figure 4-2. These plots indicate a slightly landward moving trend of the waterline for transect 40.75 (0.3 m/year) and a slightly seaward moving trend of the waterline for transect 45.50 (0.5 m/year). Since these changes are considered small over a 40 year period, no correction is applied in Figure 4-2.
One thing that attracts attention in Figure 4-2 is the position of the dunefoot (NAP +3 m) with respect to its linear trend. In first perspective it appears that the position of the dunefoot moves with a period regularily around the trend line. In (Jeuken et al., 2001) is stated that a connection between the breaker bars and the dunefoot dynamics is plausible and further research on this relation is recommended. This matter is examined further in Section 4.3 on Page 78 and Appendix G on page 137.

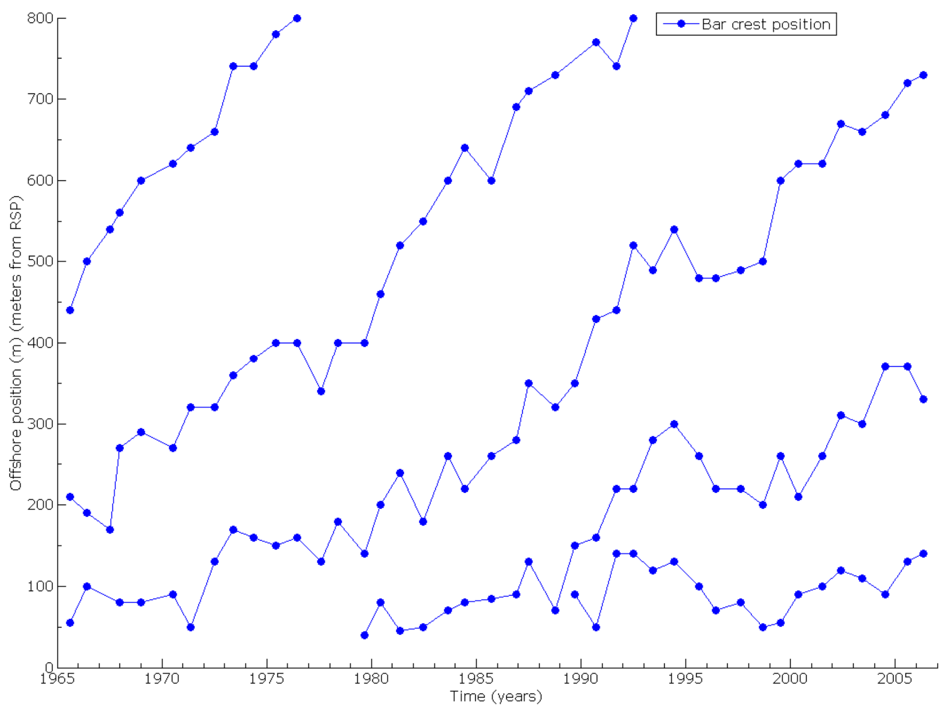

Figure 4-1A: Movement of the breaker bar crests; transect 40.75.

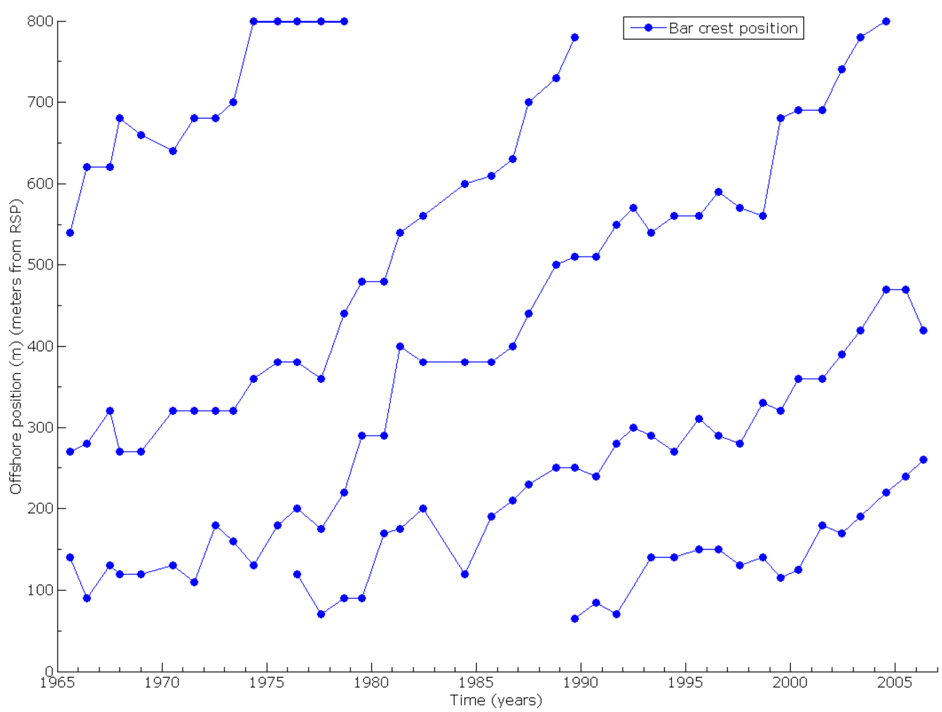

Figure 4-1B: Movement of the breaker bar crests; transect 45.50.

Figure 4-1: Movement of the breaker bar crests; transects 40.75, 45.50.

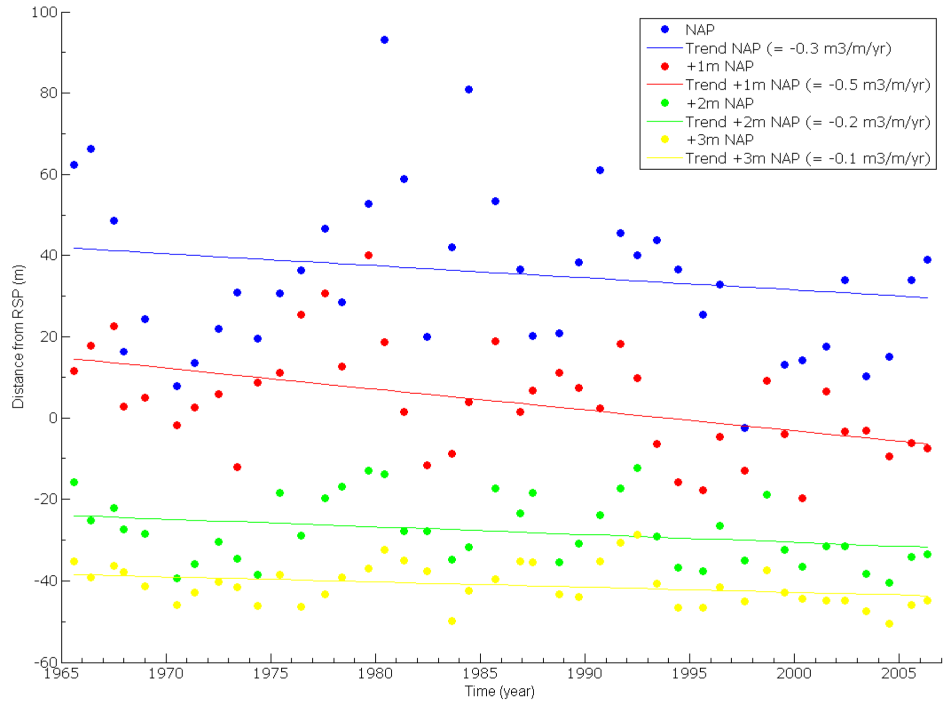

Figure 4-2A: Waterline movement in time; transect 40.75.

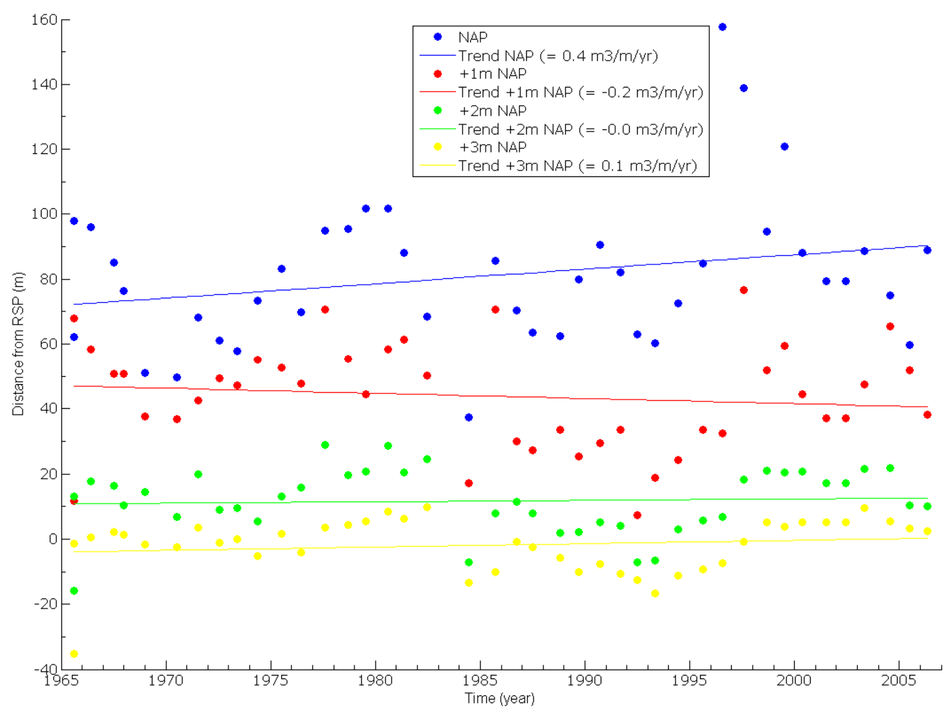

Figure 4-2B: Waterline movement in time; transect 45.50.

Figure 4-2: Waterline movement in time; transects 40.75 and 45.50.

As explained in Section 3.5, the calculation of the cycle time of the breaker bars starts by fitting a 2nd order polynomial through the 2 lines which passes all 3 stages of the lifespan of a breaker bar. Figure 4-3 shows the polynomials for the 2 longest lines of transect 40.75 and 45.50. The RMS-errors of these polynomials, calculated with equation 2 are shown in Table 4-1. The RMS-error is an indication of the average deviation of the polynomial from the surveyed points. To give an indication of the size of the RMS-error, it is compared with the total length that the bars travel during the period 1965-2006 (measured as the distance between the surveyed positions of the most landward bar crest and the most seaward bar crests). The results of this comparison are given in the last column of Table 4-1.

Table 4-1: RMS-error of best fit polynomials in transects 40.75 and 45.50.

Transect	Bar	Length (m)	RMS-error (m)	RMS-error / Length
40.75	1	630	35.5	5.6%
	2	680	36.3	5.3%
45.50	1	510	21.1	4.1%
	2	710	38.4	5.4%

From Table 4-1 it can be seen that the RMS-errors of the polynomials lie between 20 and 40 m. All RMS-errors differ less than 6% from the total distance covered by the bar crests. With these percentages it seems fair to schematise the bar crest movement by a 2nd order polynomial.

To see if the movement of the breaker bar crests is uniform in one transect, the polynomials of one transect are averaged as explained in Section 3.5 and equation 3. Figure 4-4 shows these averaged polynomials best fitted through the bar crests positions. Table 4-2 shows the RMS-errors of these averaged polynomials compared with the RMS-errors of the polynomials of Table 4-1.

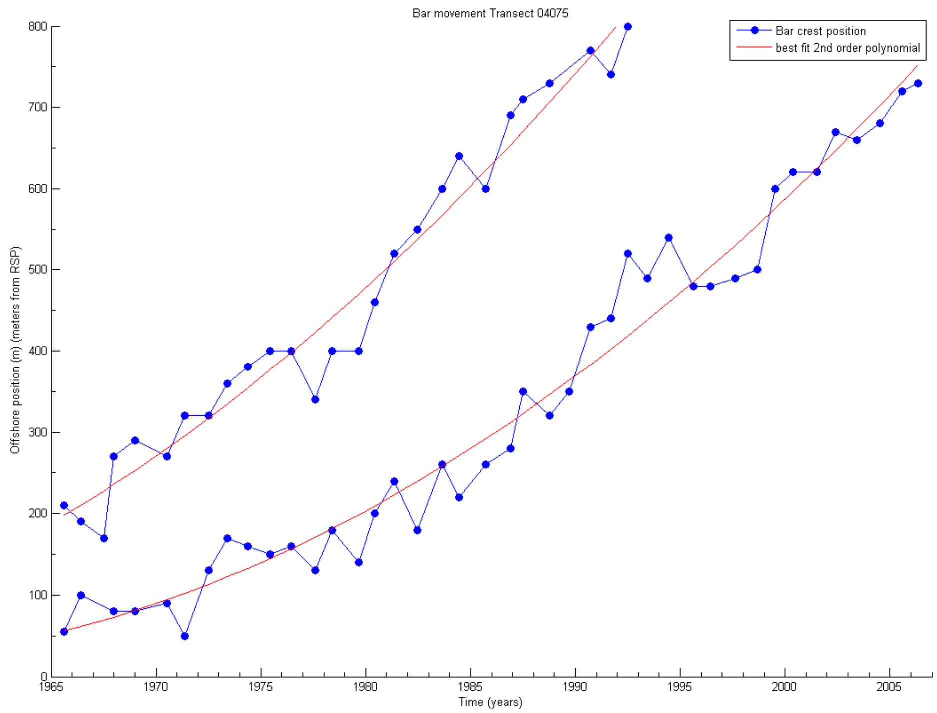

Figure 4-3A: Calculated breaker bar movement; transect 40.75.

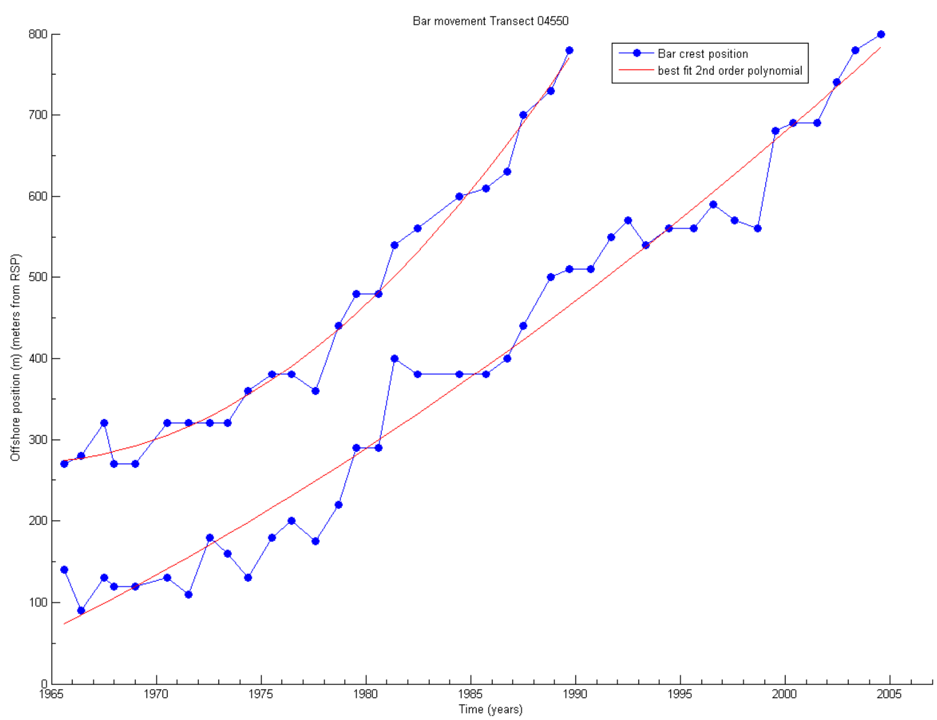

Figure 4-3B: Calculated breaker bar movement; transect 45.50.

Figure 4-3: Calculated breaker bar movement; transects 40.75, 45.50.

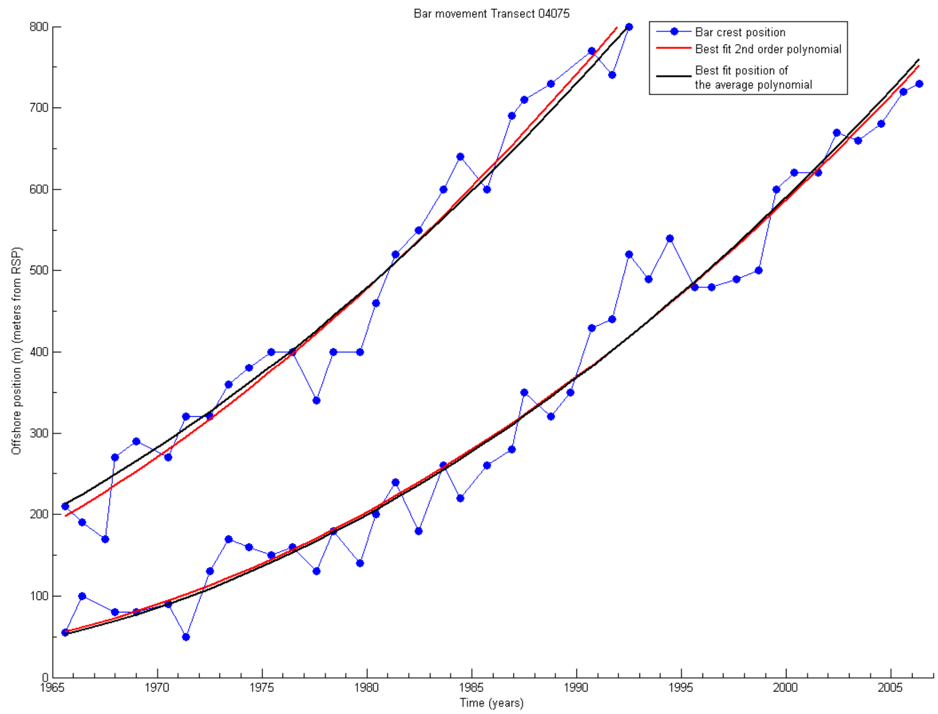

Figure 4-4A: Best fit position of the average polynomial; transect 40.75.

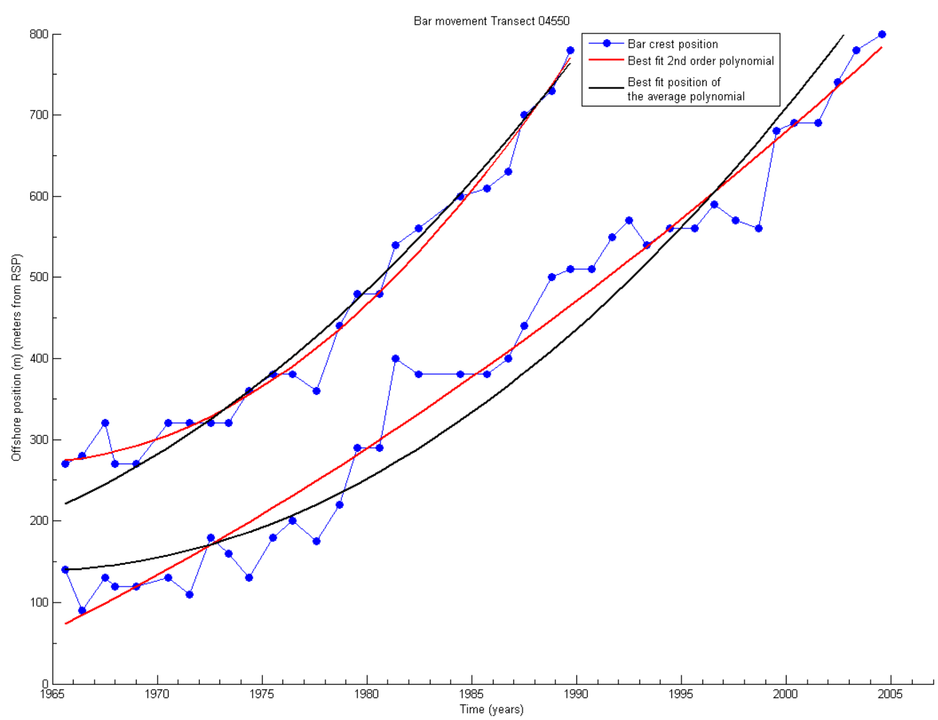

Figure 4-4B: Best fit position of the average polynomial; transect 45.50.

Figure 4-4: Best fit position of the average polynomial; transects 40.75, 45.50.

Table 4-2: RMS-errors of the best fit and average polynomials in transects 40.75 and 45.50.

Transect	Bar	Length (m)	RMS-error (m)	RMS-error / Length	RMS-error av. Poly (m)	RMS-error av. Poly/ Length	RMS-error difference (m)	Relative RMS-error difference
40.75	1	630	35.5	5.6%	36.7	5.83%	1.2	3.4%
	2	680	36.3	5.3%	36.5	5.37%	0.2	0.6%
45.50	1	510	21.1	4.1%	29.9	5.86%	8.8	41.7%
	2	710	38.4	5.4%	53.1	7.48%	14.7	38.3%

The RMS-errors of the averaged polynomials in transect 40.75 differ very little from the RMS-error of the first polynomials. In transect 45.50 there is a bigger variation between the RMS-errors of the averaged polynomials and the RMS-errors of the original polynomials. This can be caused by the fact that the left bar in Figure 4-4 misses a part of the first period of its lifespan. The RMS-errors are nevertheless still less than 7.5% of the total distance travelled by the breaker bar. Therefore the seaward movement of the breaker bars in both transects is assumed to be uniform during the period 1965-2006 and the averaged polynomials are considered to give an accurate reflection of the seaward movement of the breaker bars in the transects 40.75 and 45.50.

Table 4-3 shows the coefficients of the average polynomials (according to equation 3, page 29) of transect 40.75 and 45.50. Here it can be seen that coefficient a of transect 40.75 is approximately 1.5 times smaller than the coefficient a of transect 45.50. This means that the polynomial of transect 45.50 has a stronger curvature. The difference in coefficient c indicate a higher minimum value of the polynomial in transect 45.50 and thus a start point further offshore from RSP.

Table 4-3: Average polynomial coefficients

transect	a	b	c
40.75	0.2711	-1054.7	1.0260×10^6
45.50	0.4405	-1723.9	1.6867×10^6

To see if the average polynomial of Figure 4-4 is representative for all breaker bars in the transects, Figure 4-5 shows the average polynomials of Figure 4-4 fitted through all 5 breaker bars of the transects 40.75 and 45.50.

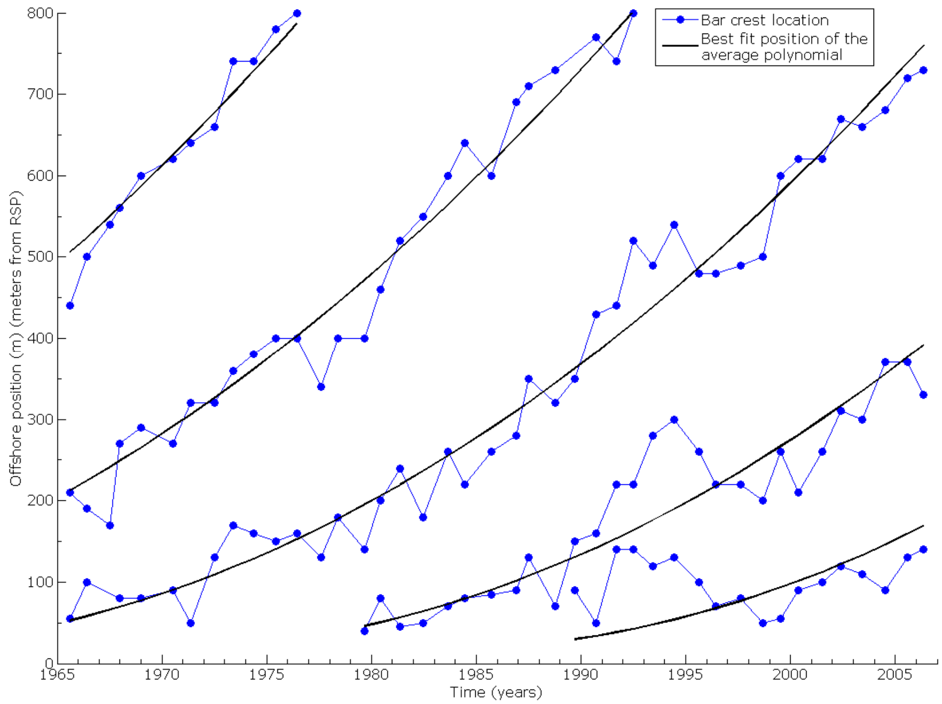

Figure 4-5A: Average polynomial fits; transect 40.75

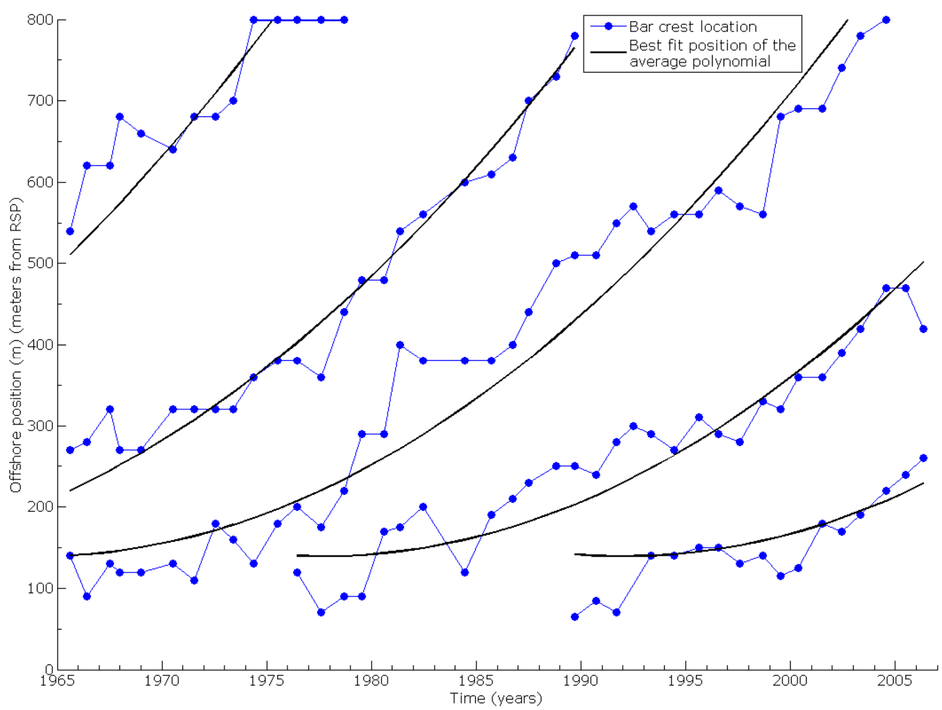

Figure 4-5B: Average polynomial fits; transect 45.50

Figure 4-5: Average polynomial fits.

From Figure 4-5A it can be seen that the average polynomial of transect 40.75 fits nicely through all 5 breaker bars. The fifth breaker bar (from 1989 to 2006) seems to have the biggest deviations from the polynomial. This bar is just in the first stage of its lifespan, in which it stays close to the shore and the real offshore movement of the 2nd stage hasn't started yet.
Figure 4-5B shows the average polynomial of transect 45.50 plotted through all 5 breaker bars present in the period 1965-2006. The polynomial seems to start further offshore than the breaker bars do. The rest of the polynomial seems to cover the movement of the bar crests nicely. Just like the polynomial of transect 40.75 the crests of the fifth breaker bar seem to have the biggest difference from the polynomial. This is also a breaker bar which is only in the first stage of its total lifespan.

From the polynomials in Figure 4-5 multiple cycle times can be calculated per transect. Table 4-4 shows these calculated cycle times. Here it can be seen that for transect 40.75 all cycle times lie close to each other, while for transect 45.50 there is more variation in cycle time. This variation can be caused by the fact that most of the bars in Figure 4-5 have no completed life spans during the period of the database. Therefore the cycle times as calculated before are used for further calculations.

Table 4-4: All cycle times per transect.

transect	cycle times (yr)			
40.75	15.3	15.0	15.1	13.8
45.50	14.5	12.0	13.0	14.4

To verify the data of transects 40.75 and 45.50, the same analysis is done for the adjacent transects (40.50 and 41.00, 45.25 and 45.75). Figure 4-6 shows the positions of the bar crests during the period 1965-2006 for these six transects. Figure 4-6A shows the seaward movement of the breaker bars in transects 40.50, 40.75 and 41.00 and Figure 4-6B shows the seaward movement of the breaker bars in transects 45.25, 45.50 and 45.75.

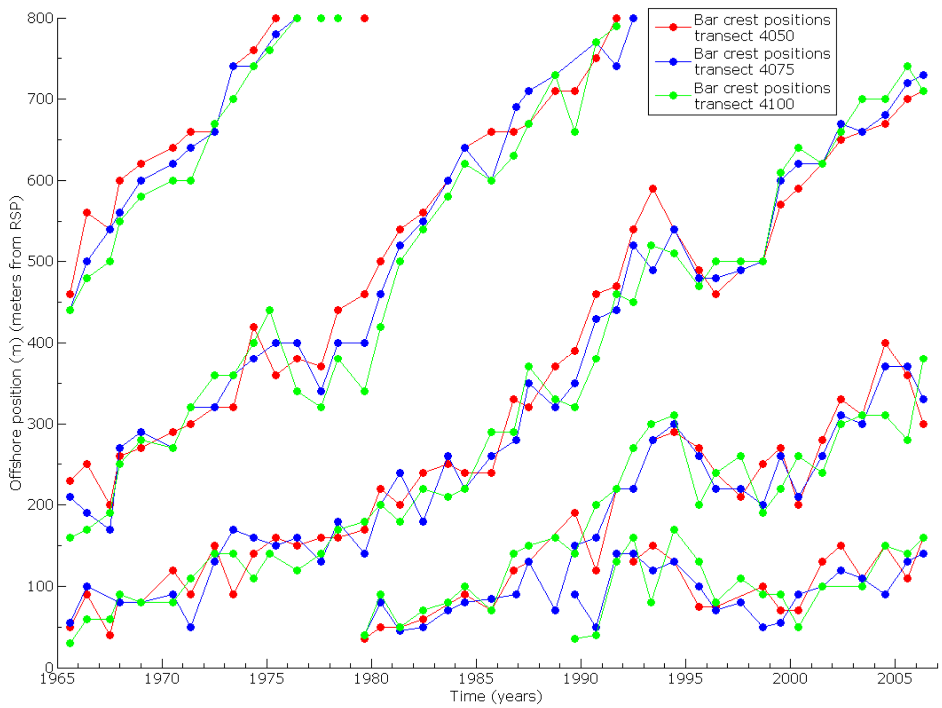

Figure 4-6A: Bar crest positions in time; transects 40.50, 40.75 and 41.00.

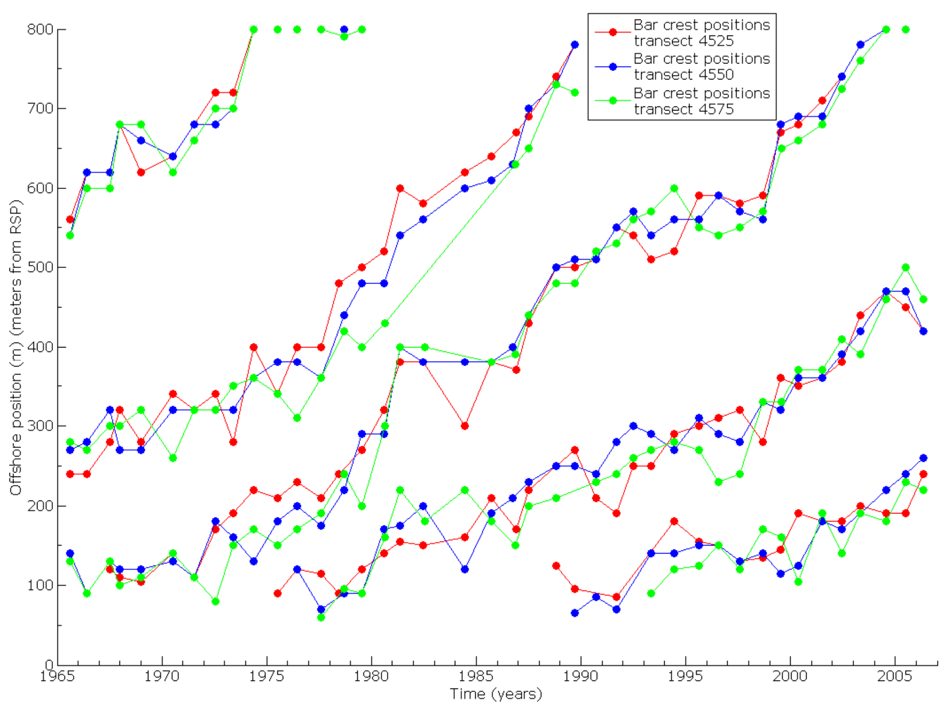

Figure 4-6B: Bar crest positions in time; transects 45.25, 45.50 and 45.75.

Figure 4-6: Bar crest positions in time; transects 40.75, 45.50 and adjacent transects.

The lines of transects 40.50 and 41.00 in Figure 4-6A correspond to the line of transect 40.75. This indicates uniformity in these 3 transects which validates the calculations of the theoretical breaker bar positions, using 2nd order polynomials for transect 40.75. The same calculations can now be executed for transects 40.50 and 41.00. The same holds for the breaker bar positions of transect 45.25, 45.50 and 45.75.

The cycle time of the breaker bars in the six transects can be calculated as done for transects 40.75 and 45.50. For these six transects a new averaged polynomial is created to describe the seaward movement of the breaker bars. Using these average polynomials a cycle time can be calculated for each transect. Table 4-5 gives the calculated cycle times of all six transects, calculated using the seaward movement of the breaker bars according to Figure 4-6A and B.

Table 4-5: Cycle time of the breaker bars in region 3.

transect	cycle time (yr)
40.50	15.4
40.75	15.0
41.00	14.7
45.25	12.3
45.50	12.0
45.75	11.7

From Table 4-5 it can be read that the calculated cycle time in a transect decreases towards the south. This would mean that a profile in transect 45.50 repeats itself faster than a bar 5 km northward, in transect 40.50.
This can be possible if these are 2 different bars, but than there has to be some rip channel between these two bars to separate them. It can also be seen that the cycle time of two adjacent transects also show a decrease in cycle time towards the south. It is very unlikely that the breaker bars have a longshore length of less than 250 m. This means that one breaker bar in front of the Holland coast moves offshore with different speeds.
Figure 4-7 shows the calculated cycle times of Table 4-5 plotted against the location along the Holland coast. Here the linear trend of the calculated cycle times of the 6 analysed transects is plotted to show the decrease in cycle time. To verify this decrease, the cycle time of transect 42.00 is also calculated (indicated by the blue cross in the figure). The cycle time of transect 42.00 is 13.8 years and validates the decreasing cycle time in southward direction of the breaker bars in region 3 of the Holland coast.

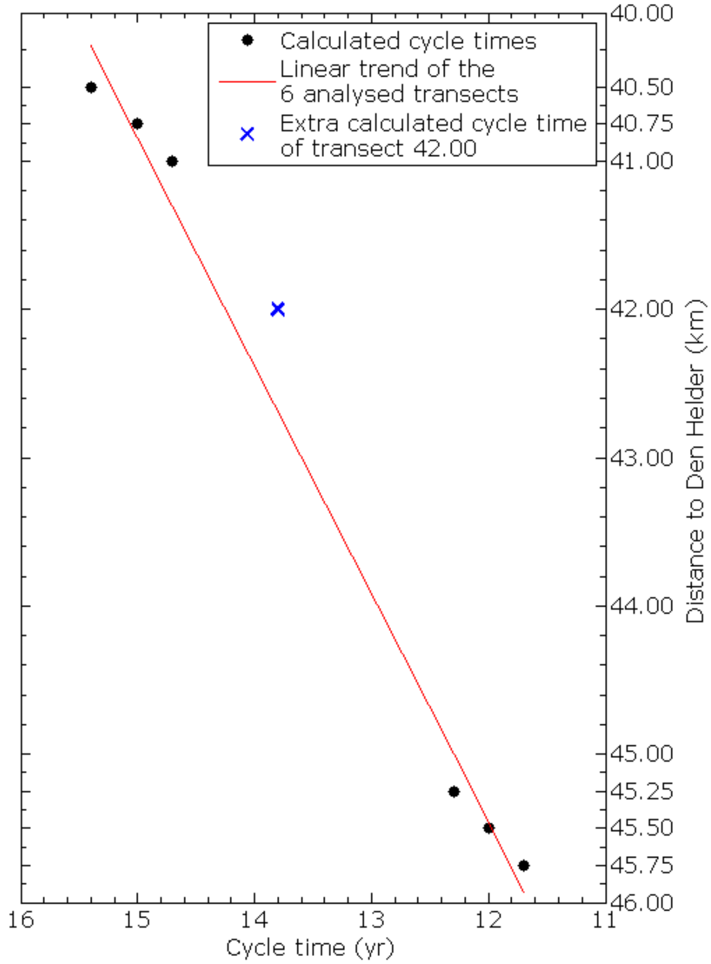

Figure 4-7: Cycle time of the breaker bars in region 3.

Decreasing cycle times mean that the period between 2 successive bar crests on a specific distance from the shore differs per transect. This situation is shown schematically in Figure 4-8 for a three bar system.
Figure 4-8A shows the start position; here the 3 bars lie parallel to the shoreline. The bars will move with a cycle time of 10 years at the left side and a cycle time of 15 years at the right side of the figure and a linear path in between.
In Figure 4-8B it is 10 years later, when the bars have completed one cycle at the left side and 2/3rd of a cycle at the right side. The start position is indicated by the grey dashed lines; the new position is given by the thick black dashed line.
Figure 4-8C shows the position at 15 years after the start position of Figure 4-8A. Here it can be seen that the bars have just completed one cycle at the right side of the figure, while at the left side, the bars have completed one and a half cycle. The outer bar in Figure 4-8C has already damped out at the left side

and a new bar is underway, while on the right side the same bar as in Figure 4-8B is still in progress.

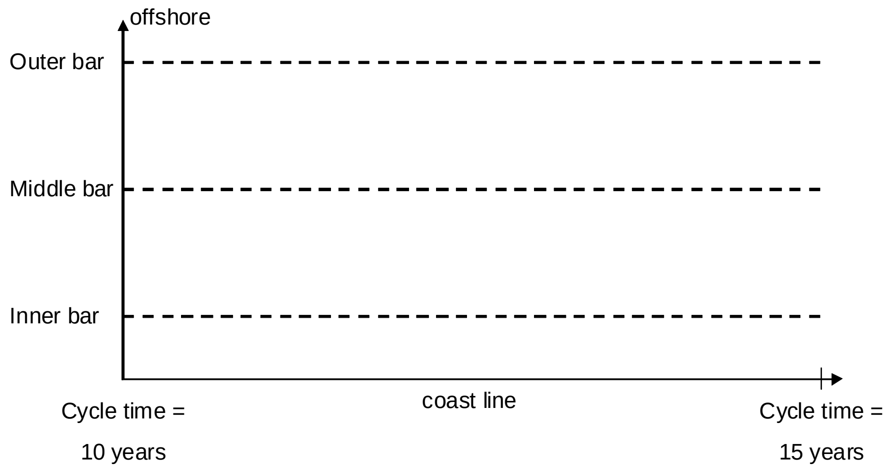

Figure 4-8A: Phase 1; breaker bars perpendicular to the shoreline

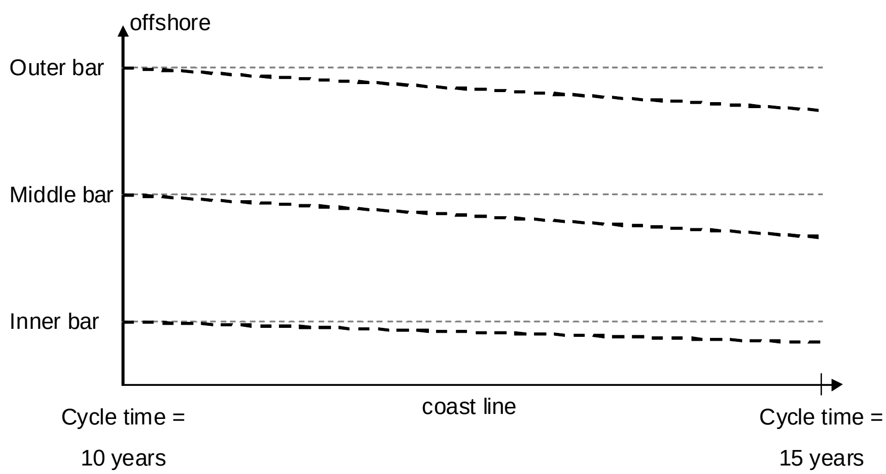

Figure 4-8B: Phase 2; situation after 10 years

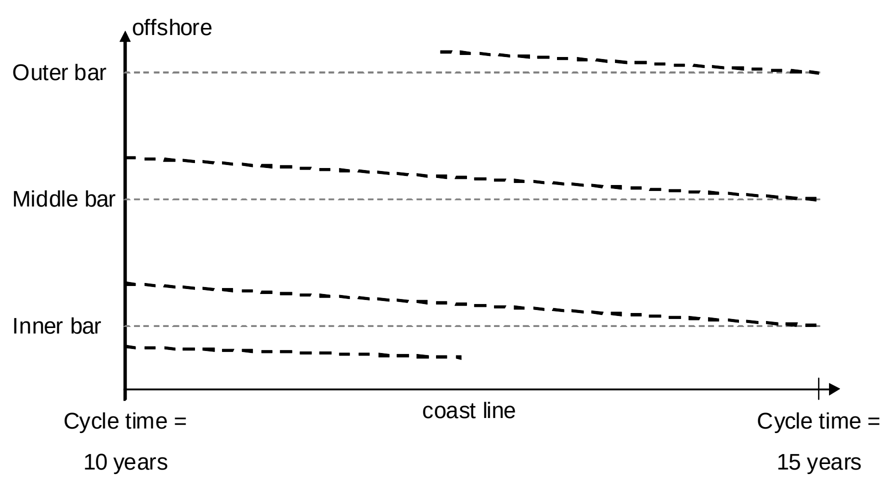

Figure 4-8C: Phase 3; situation after 15 years

Figure 4-8: One breaker bar with different cycle times.

If this process continues as shown in Figure 4-8, in theory the bars would end up perpendicular to the shore.In practice this is impossible, so therefore processes that prevent this from happening must occur. Which processes do occur is still unclear.
One of the processes that is thought to occur is a bar switch. This process is schematically shown in Figure 4-9. Figure 4-9A shows the same positions of the breaker bars as Figure 4-8C. Again, the left sides of the bars have a cycle time of 10 years and the right side of the breaker bars has a cycle time of 15 years. In Figure 4-9A the bars on the left side are a half phase in front of the bars on the right side of the figure. Figure 4-9B shows the bar switch. Here the bar that is the outer bar on the left side and the middle bar on the right side breaks in the middle and the left side takes a leap seaward, while the right side takes a small step landward. The same happens to the other bars, the faster left side takes a leap seaward and the slower right side takes a step back. Now three new bars are formed out of the original four. Figure 4-10 shows a bar switch near transect 45.50 by means depth charts of region 3 of the Holland coast from 1982 to 1986

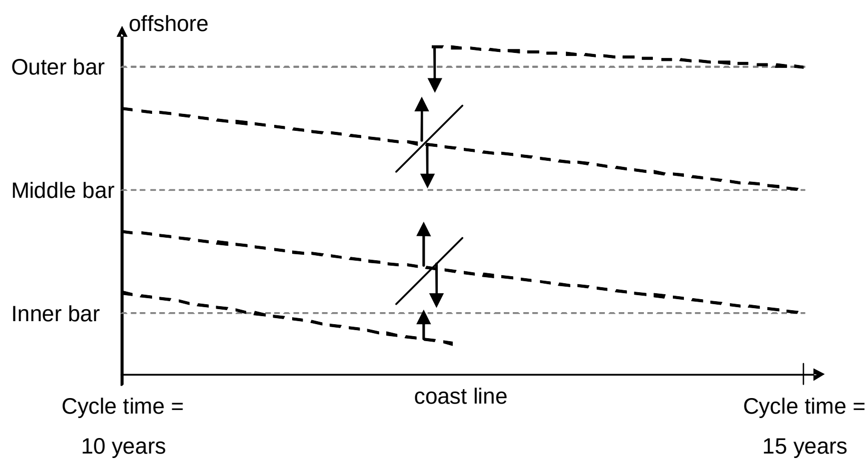

Figure 4-9A: Situation before the bar switch

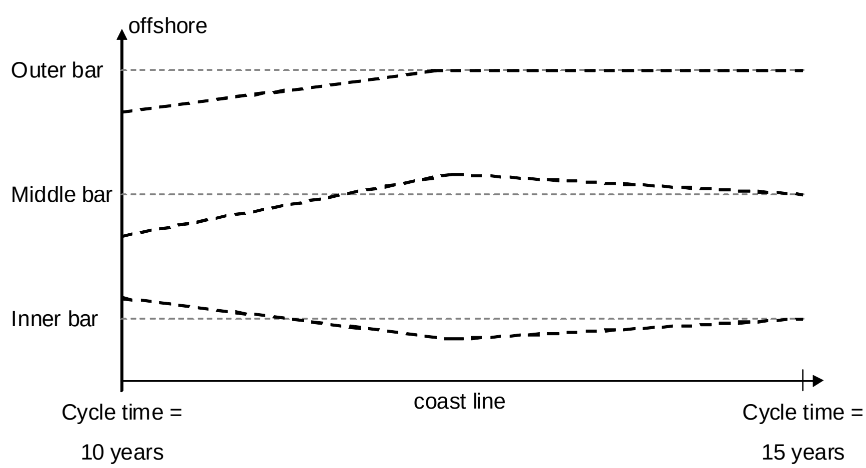

Figure 4-9B: Situation after the bar switch

Figure 4-9: Schematic explanation of the bar switch

The red lines in Figure 4-10 show the position of the breaker bars per depth chart. The black lines show the position of the breaker bars of the previous year. The plotted years are 1982, 1984, 1985 and 1986. The year 1983 is not plotted because of missing data of this year.

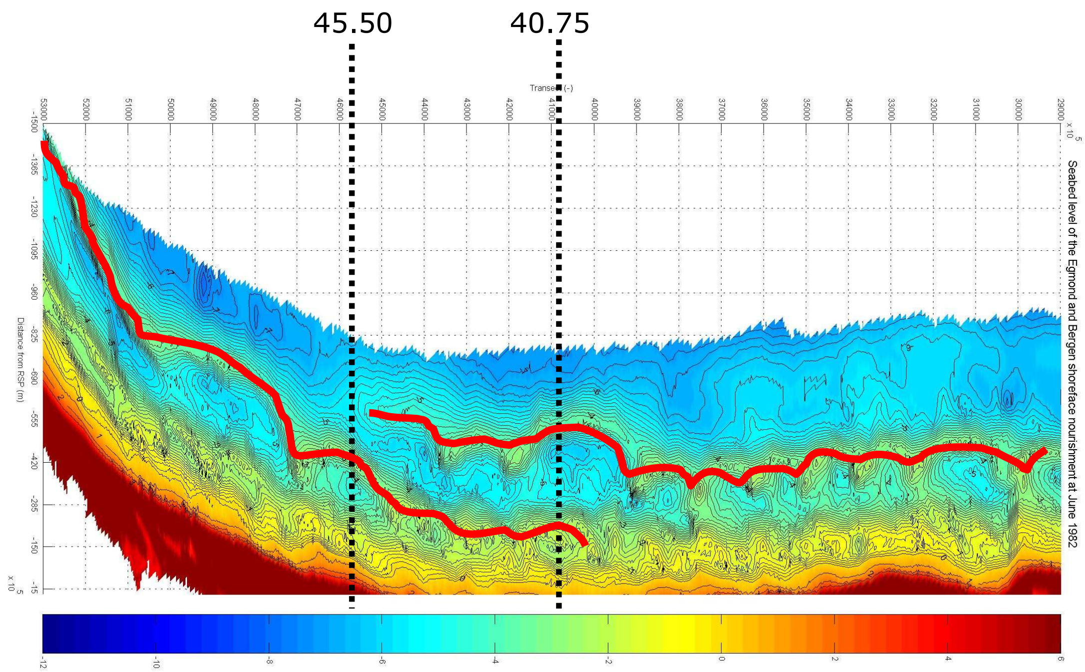

Figure 4-10A: Bar positions in region 3 of the Holland coast, 1982

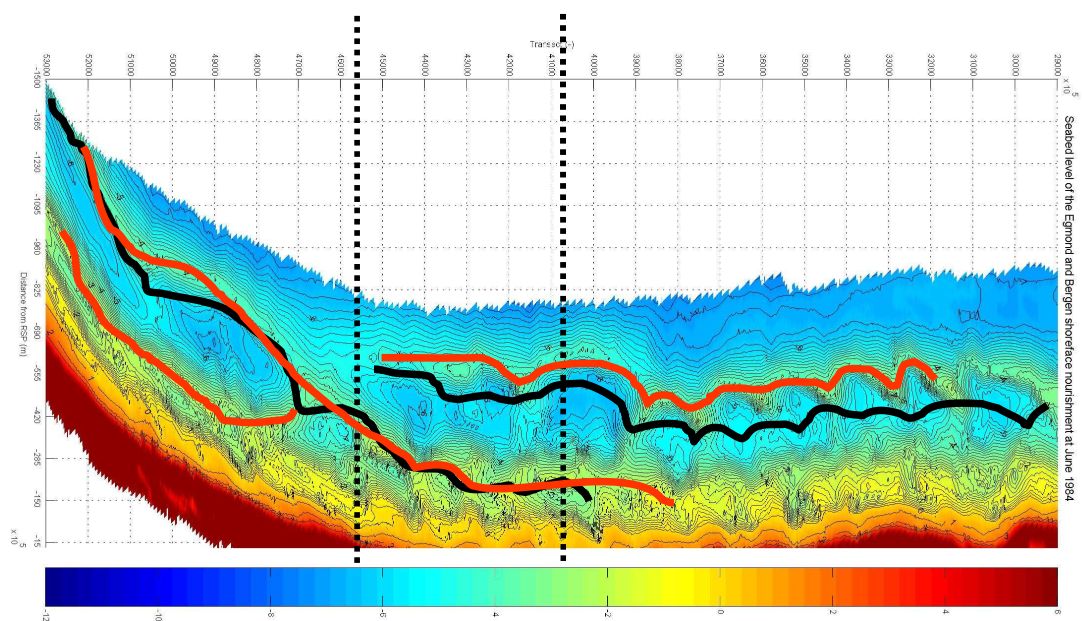

Figure 4-10B: Bar positions in region 3 of the Holland coast, 1984

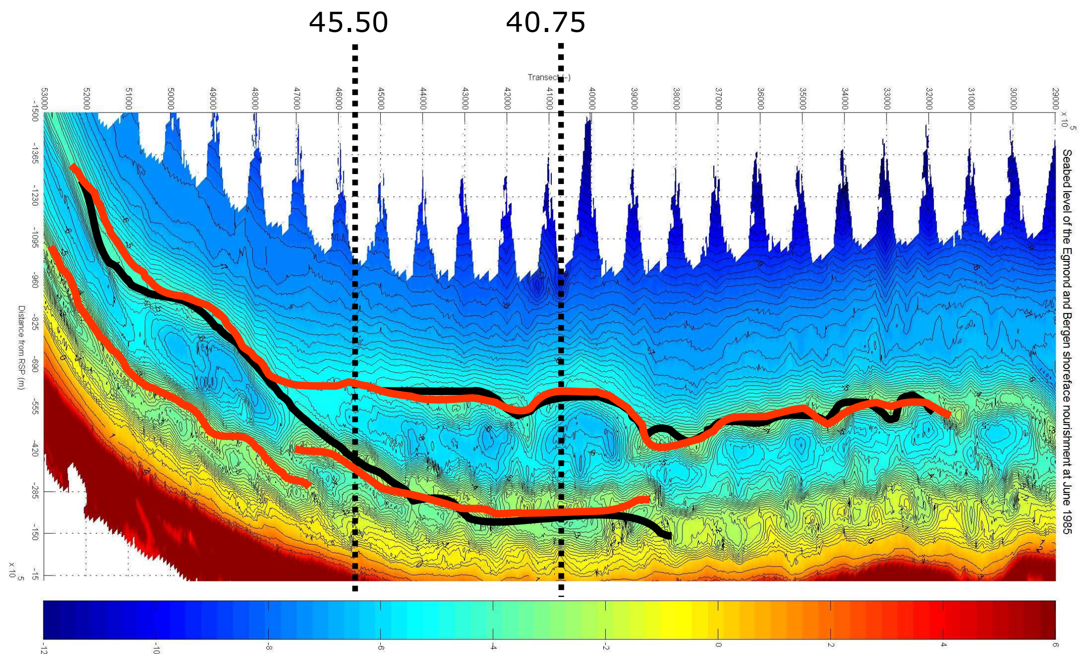

Figure 4-10C: Bar positions in region 3 of the Holland coast, 1985

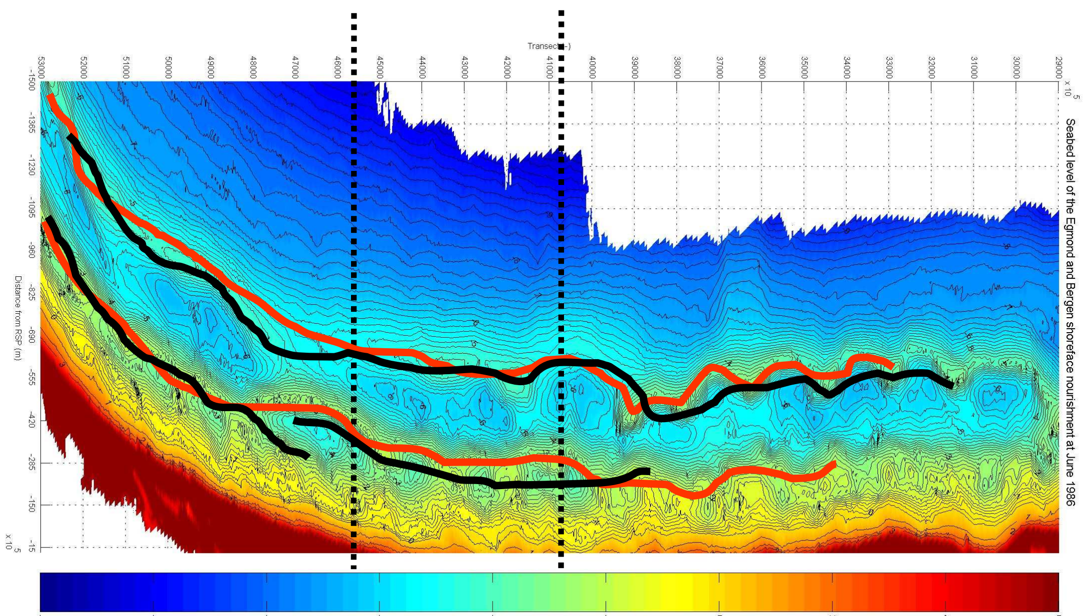

Figure 4-10C: Bar positions in region 3 of the Holland coast, 1986

Figure 4-10: Barswitch in region 3 of the Holland coast.

From Figure 4-10A it can be seen that the outer bar on the left of the figure is the same bar as the inner bar in transect 40.75. In Figure 4-10B this is still the case, but one year later (Figure 4-10C) this bar is and the left part has joined the bar that is the outer bar in transect 40.75 and the left part has joined the inner bar of transect 40.75. This process is completed in 1986 (Figure 4-10D). To get more insight in this process further research is recommended.

4.2 Volume calculations

The volumes of the transects can now be calculated as explained in Section 3.6. First the dunefoot position must be roughly determined for the boundaries of the wet and dry part of the profile. Figure 4-2 shows the movement of the NAP +3 m (the dunefoot) point. To compare all profiles of a transect, a fixed value for the position of the dunefoot must be chosen. This point is determined using Figure 4-2. The chosen boundaries are given in Table 4-6.

Table 4-6: Profile boundaries in region 3.

transect	wet		dry
	Seaward boundary (m from RSP)	Dunefoot position (m from RSP)	Landward boundary (m from RSP)
40.50	-800	-40	-305
40.75	-800	-40	-305
41.00	-800	-40	-305
45.25	-800	0	-305
45.50	-800	0	-305
45.75	-800	0	-305

With these boundaries, the volume fluctuations can be calculated using UCIT and equation 4. Again, first transects 40.75 and 45.50 are analysed and later the results of these transects are compared with the results of the adjacent transects. Figure 4-11 shows the total volumes in time for transects 40.75 and 45.50. Here it can be seen that some years show unusual volumes compared to the other volumes in the transect (like 1992 in transect 40.75) and some years have an unusual large difference in volume with the adjacent years (like 2006 in transect 45.50). These profiles need to be examined before further calculations can be done.

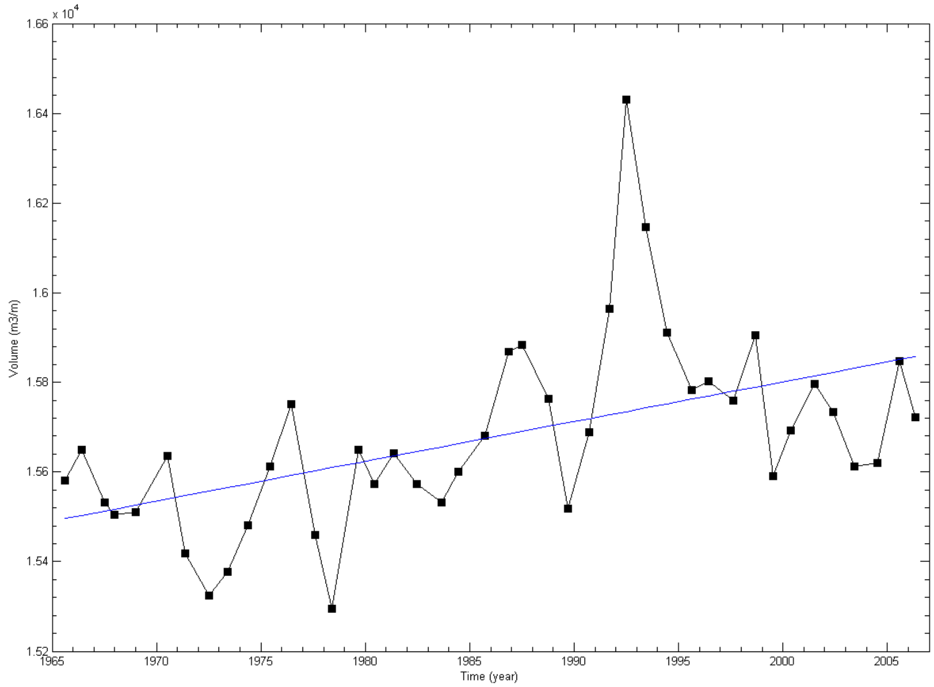

Figure 4-11A: Total profile volumes in time; transect 40.75

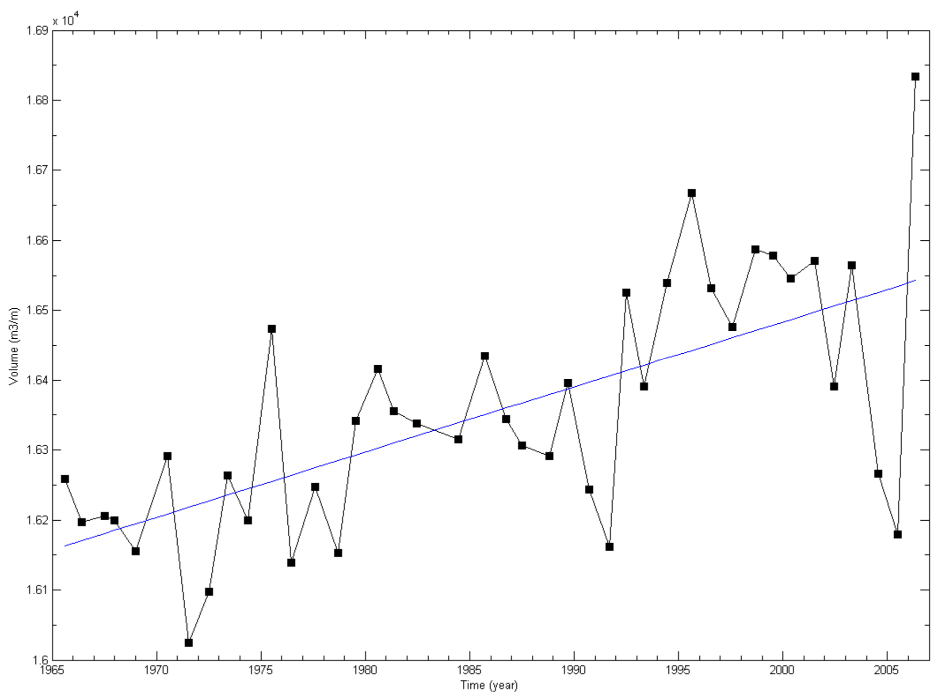

Figure 4-11B: Total profile volumes in time; transect 45.50

Figure 4-11: Total profile volumes in time; transects 40.75, 45.50.

Figure 4-11A shows a big peak for the volume of the profile of 1992 and 1993 in transect 40.75 and Figure 4-11B shows a big difference between the years 2005 and 2006. This can hint to an error in the survey of the wet profiles. Therefore all profiles are checked for errors. Figure 4-12 shows the profiles of transect 40.75 in 1992 and 1993, compared to the profile of 1990, which has been found correct. Here it can be seen that the wet profiles of 1992 and 1993 lie somewhat above the profile of 1990. This can be caused by a fault in the execution of the surveys and gives volumes which are higher than they are in reality. Therefore the volume calculations of transect 40.75 in 1992 and 1993 are deleted from the database used in Figure 4-11. Since the error only occurs under water, the years 1992 and 1993 are not deleted from the calculations of the volume of the dune profiles.

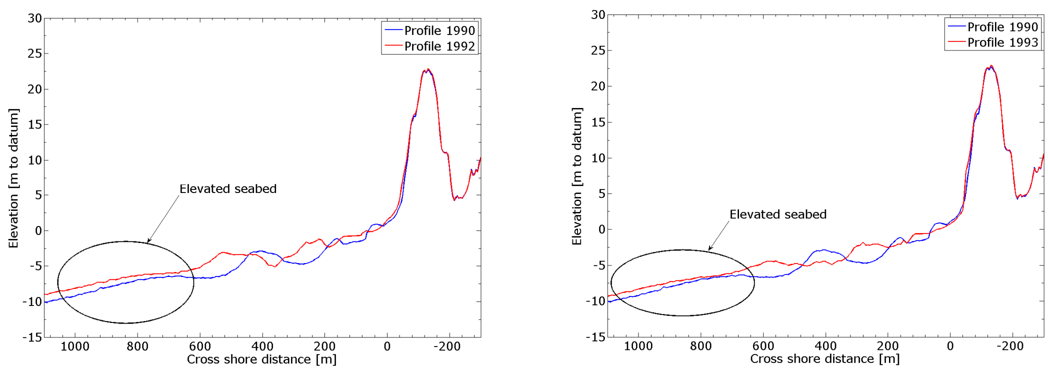

Figure 4-12: Comparison of profile 1990-1992 and 1990-1993; transect 40.75.

The profiles of transect 45.50 of the years 2005 (correct) and 2006 are compared in Figure 4-13. This figure shows a big hump in the profile of 2006 where in 2005 bars are located. This is caused by a gap in the survey data, which is filled by a linear interpolation (approximately between 200 m and 400 m offshore of RSP). Therefore volume calculation of transect 45.50 in 2006 is deleted from the database used in Figure 4-11. Appendix E shows larger plots of all deleted profiles.

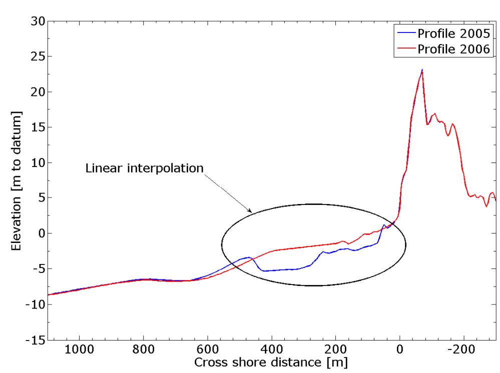

Figure 4-13: Comparison of profile 2005 and 2006; transect 45.50.

Deleting these profiles from the database gives a new graph with new trends. These graphs are plotted in Figure 4-14.

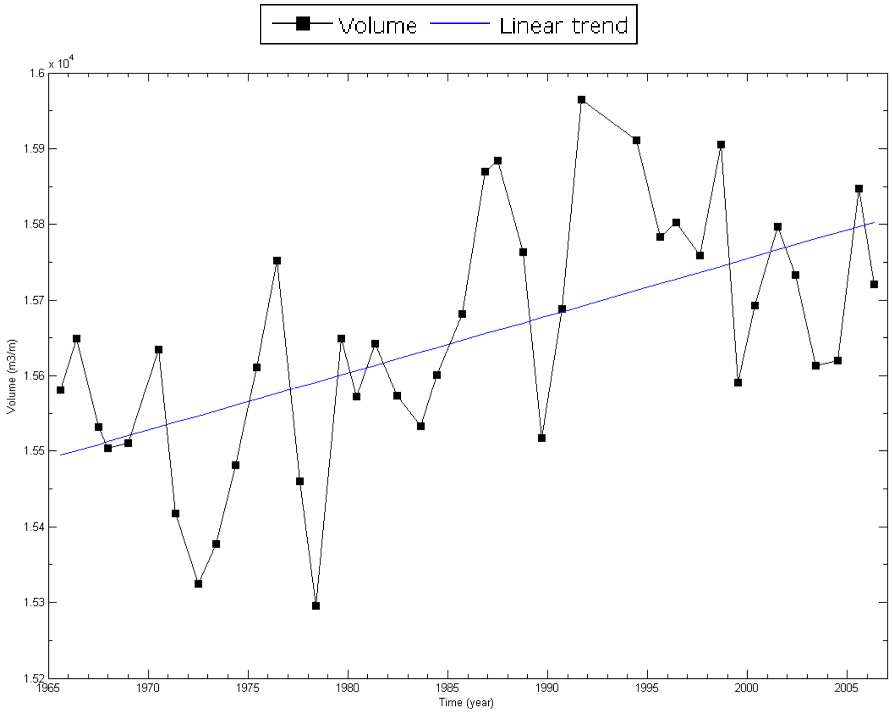

Figure 4-14A: Total profile volume in time; transect 40.75, revised

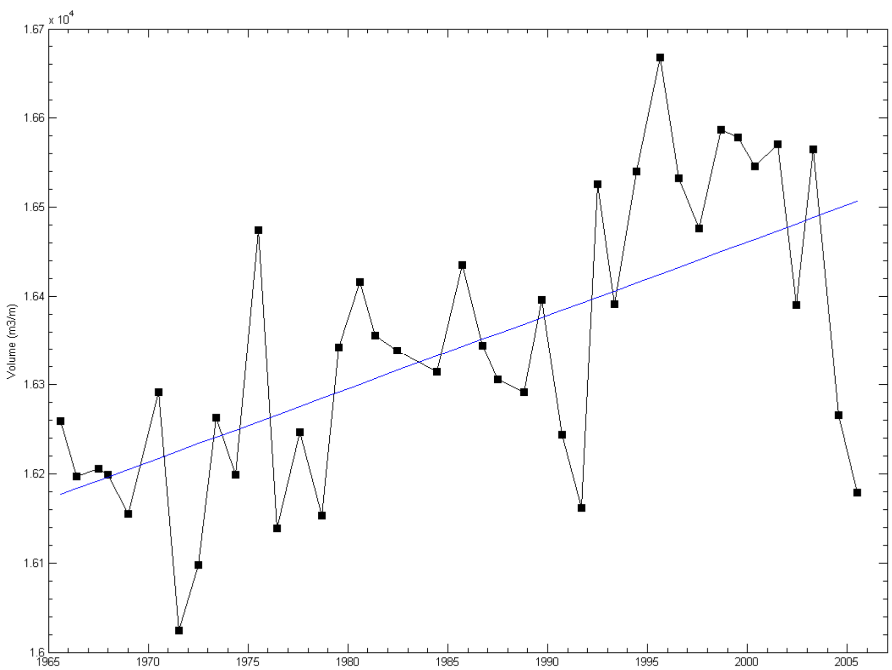

Figure 4-14B: Total profile volume in time; transect 45.50, revised

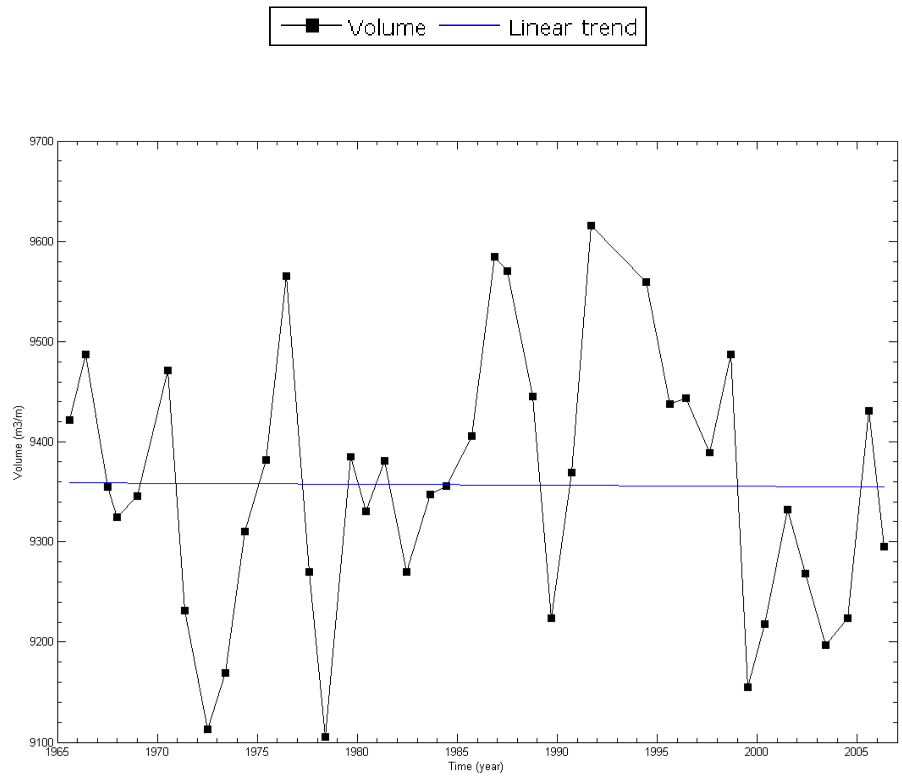

Figure 4-14C: Wet profile volume in time; transect 40.75, revised

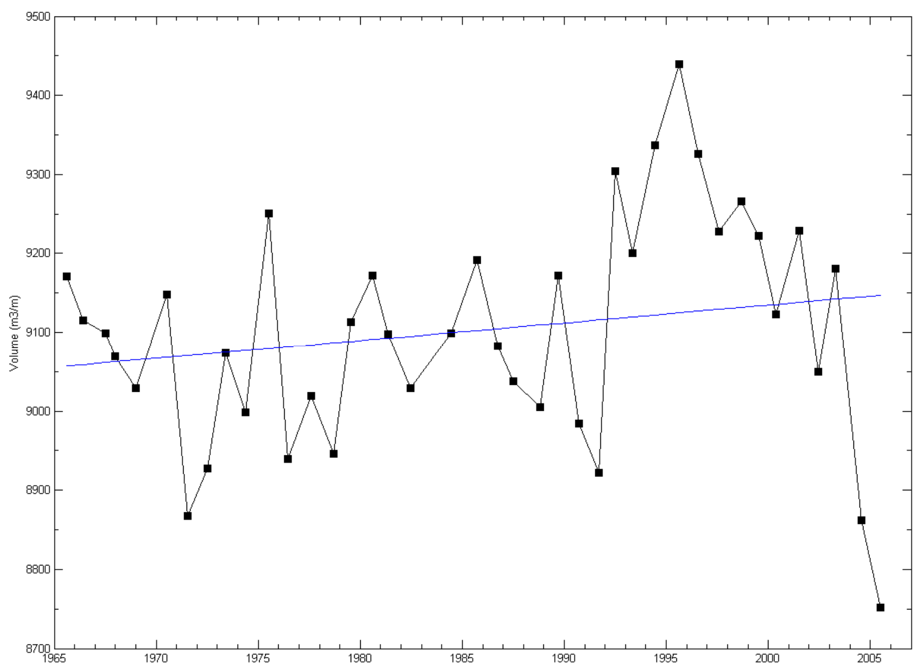

Figure 4-14D: Wet profile volume in time; transect 45.50, revised

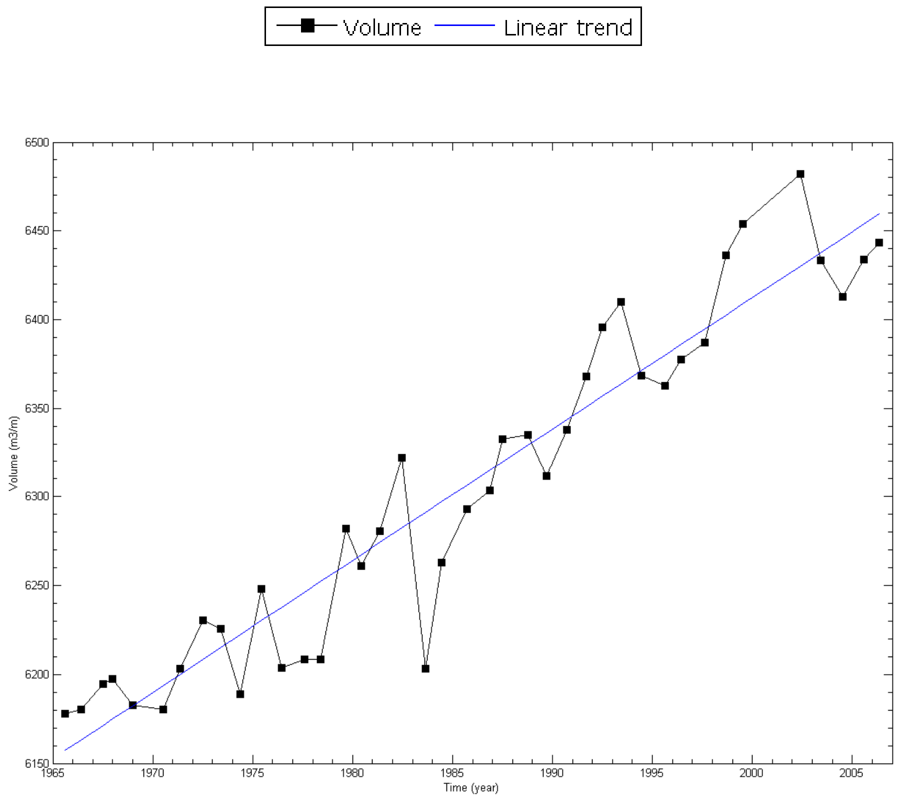

Figure 4-14E: Dune profile volume in time; transect 40.75

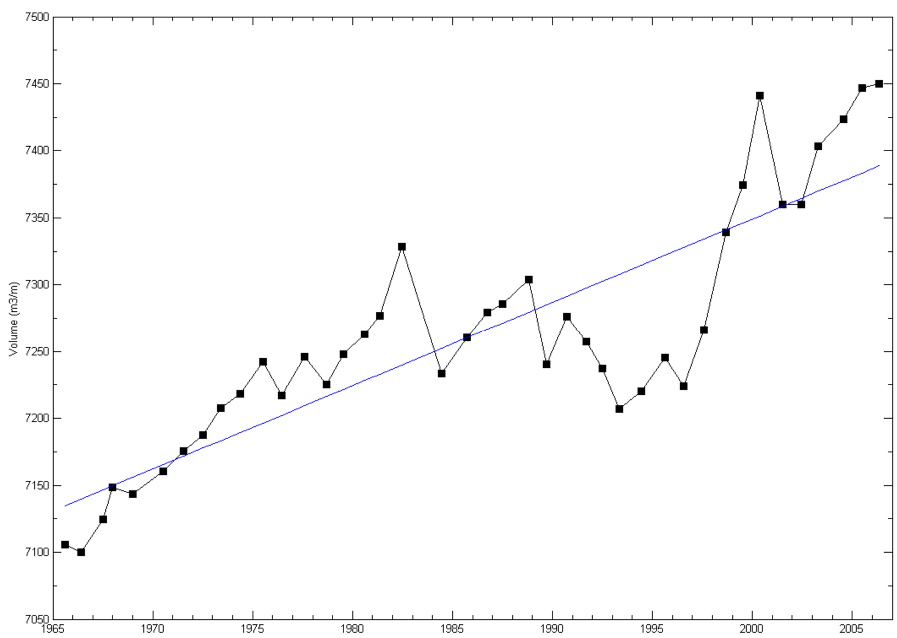

Figure 4-14F: Dune profile volume in time; transect 45.50

Figure 4-14: Total, wet and dune volumes in time; transects 40.75, 45.50, revised.

The new trend of the volume changes in time in transect 40.75 as plotted in Figure 4-14A is approximately 7.5 m^3/m per year and the new trend of the volume changes in time in transect 45.50 as plotted in Figure 4-14B is approximately 8 m^3/m per year. This still indicates accretion of the coast in both transects.
From Figure 4-14C, D, E and F it can be seen that for both transects most of the accretion in the transect occurs in the dune areaand that the wet profiles show little accretion.

Using equation 4, the volume residues can be calculated and plotted. Figure 4-15 shows the volume residues in time of transect 40.75 and 45.50 for the total, the wet and the dune profile. Both transects have fluctuations in a bandwidth of roughly 600 m^3/m for the total and the wet volume residues and a bandwidth of roughly 200 m^3/m for the dune volume transects.

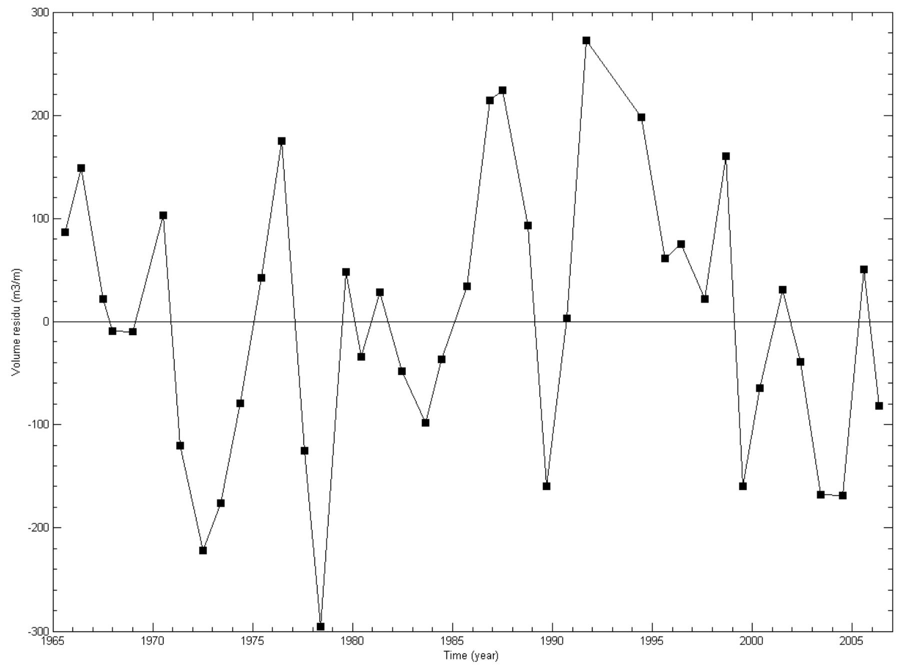

Figure 4-15A: Total profile volume residues in time; transect 40.75

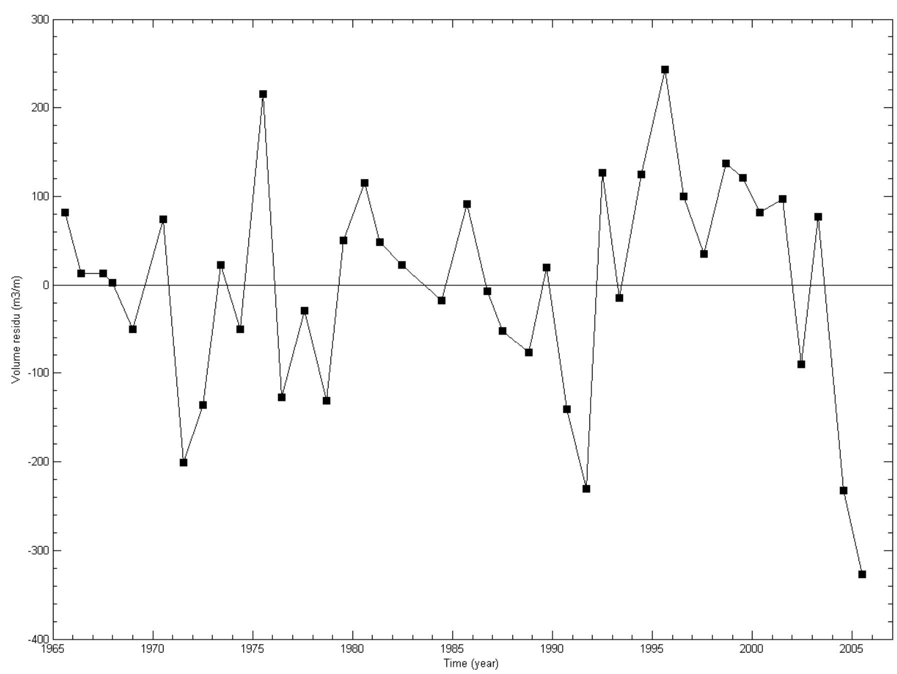

Figure 4-15B: Total profile volume residues in time; transect 45.50

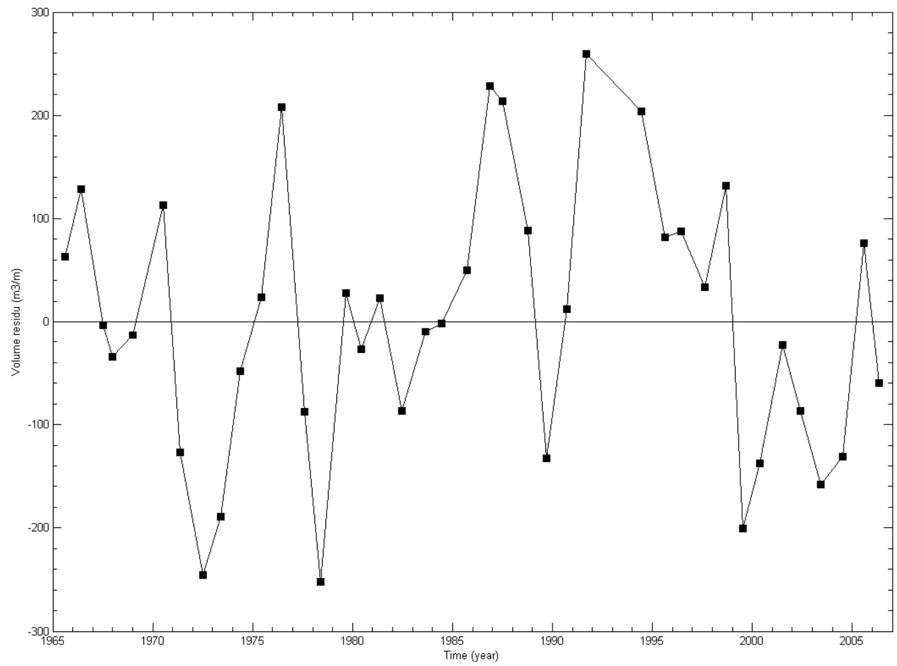

Figure 4-15C: Wet profile volume residues in time; transect 40.75

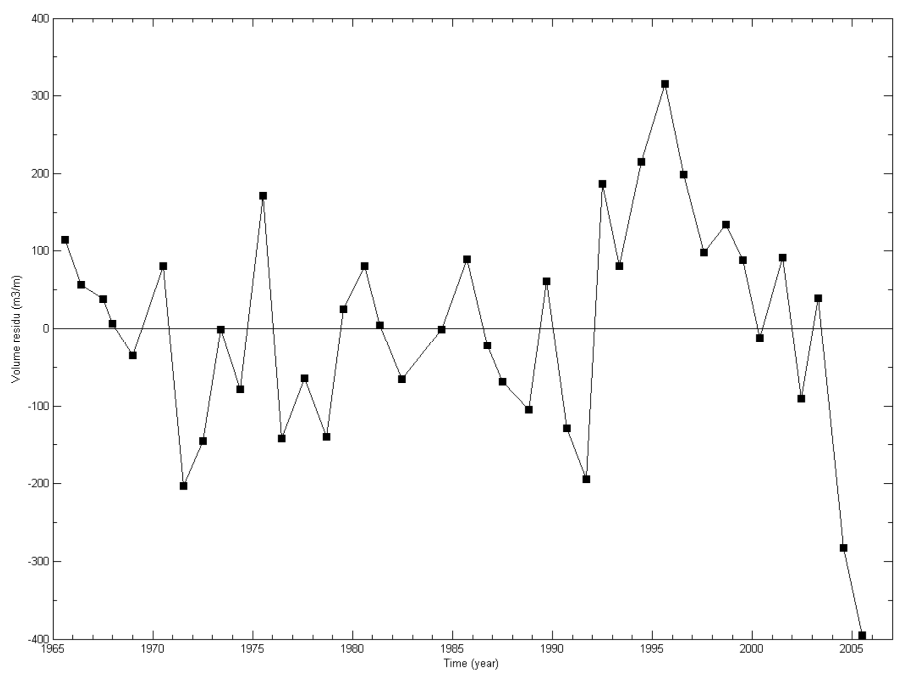

Figure 4-15D: Wet profile volume residues in time; transect 45.50

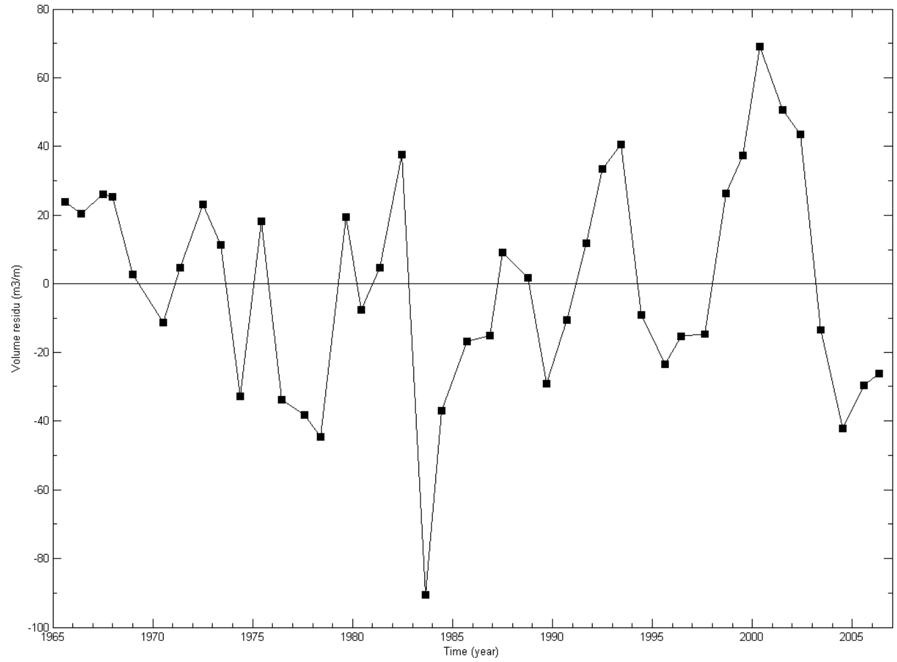

Figure 4-15E: Dune profile volume residues in time; transect 40.75

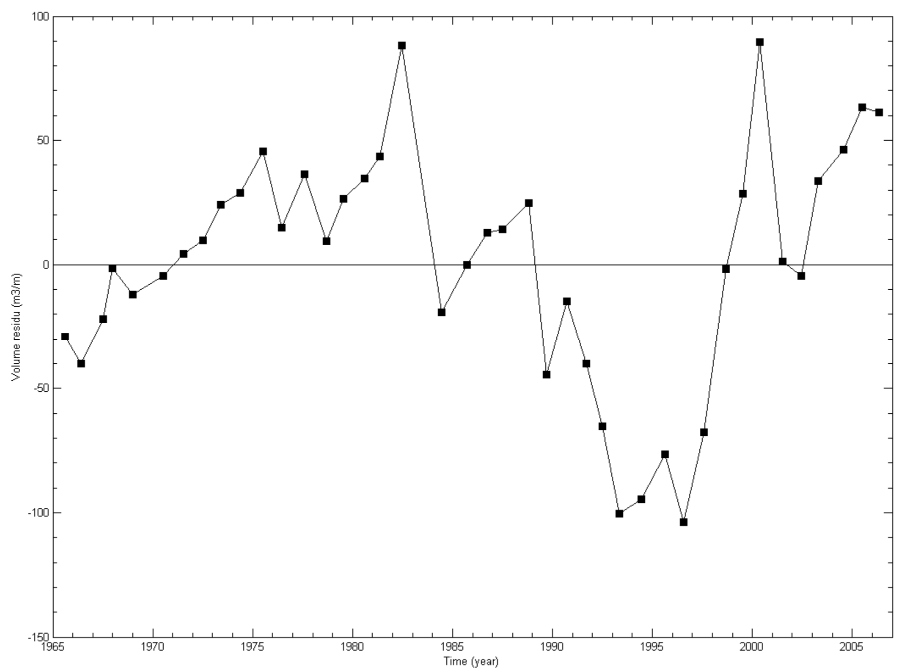

Figure 4-15F: Dune profile volume residues in time; transect 45.50

Figure 4-15: Total, wet and dune volume residues in time; transects 40.75, 45.50.

The next step is to see if the volume fluctuations in the adjacent transects are comparable with the volume fluctuations of transects 40.75 and 45.50. Just like for transects 40.75 and 45.50 some profiles are deleted from the database. All deleted profiles are given in Table 4-7. The deleted profiles are plotted in Appendix E to show the error.

Table 4-7: Profiles deleted from the JARKUS database.

transect	deleted years	
40.50	1992	1993
40.75	1992	1993
41.00	1992	1993
45.25	1992	1993
45.50	2006	-
45.75	-	-

The linear trends of the total volumes of the profiles in time are given in Table 4-8. The volume residues calculated with equation 4b (page 33) are plotted in Figure 4-16 (total profile volume residues), Figure 4-17 (wet profile volume residues) and Figure 4-18 (dune profile volume residues). The transects 40.50, 40.75 and 41.00 are plotted in Figures A and the transects 45.25, 45.50 and 45.75 in Figures B.

Table 4-8: Linear trend of the volume in six transects.

Transect	Volume trends (m3/m per year)		
	Total profiles	Wet profiles	Dune profiles
40.50	4.0	-0.8	4.7
40.75	7.5	-0.1	7.6
41.00	13.6	4.6	9.0
45.25	10.7	5.7	4.7
45.50	8.3	2.3	6.2
45.75	4.3	2.6	1.7

From Table 4-8 it can be seen that all six transects have an accreting trend for the total profile volumes with a minimum of 4.0 m^3/m per year and a maximum of 13.6 m^3/m per year, this is a difference of almost 10 m^3/m per year over 40 years. Remarkable is the fact that the transects of this minimum and maximum trend are only 500 m separated from each other. From the other columns in Table 4-8 can be read that the trend of the dune profiles of the three most northward transects is much larger than the trend of the wet profiles of these transects. The trend of the dune profiles and the trend of the wet profiles of the three southern profiles are more even.

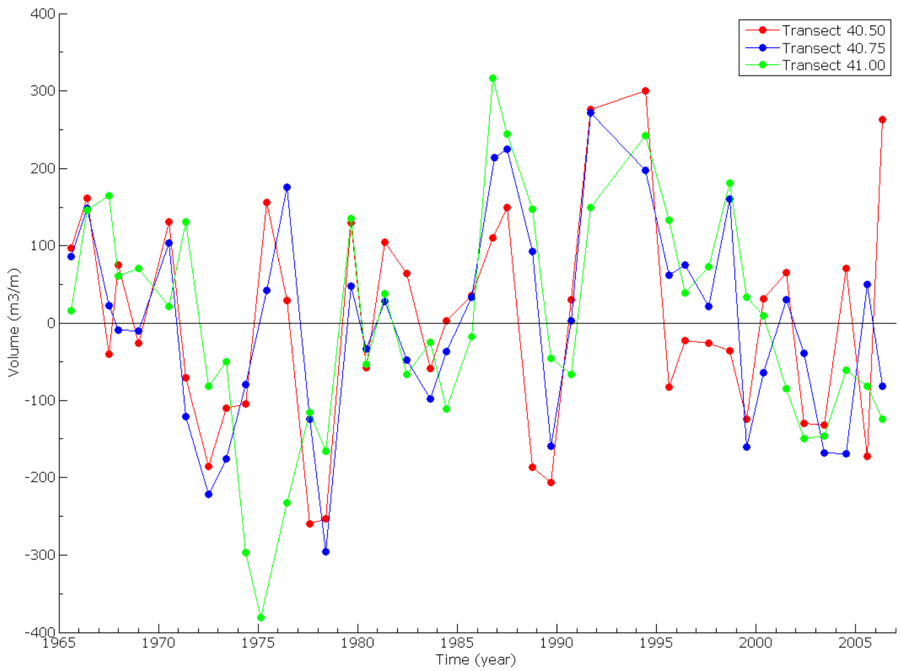

Figure 4-16A: Total profile volume residues; transects 40.50, 40.75 and 41.00.

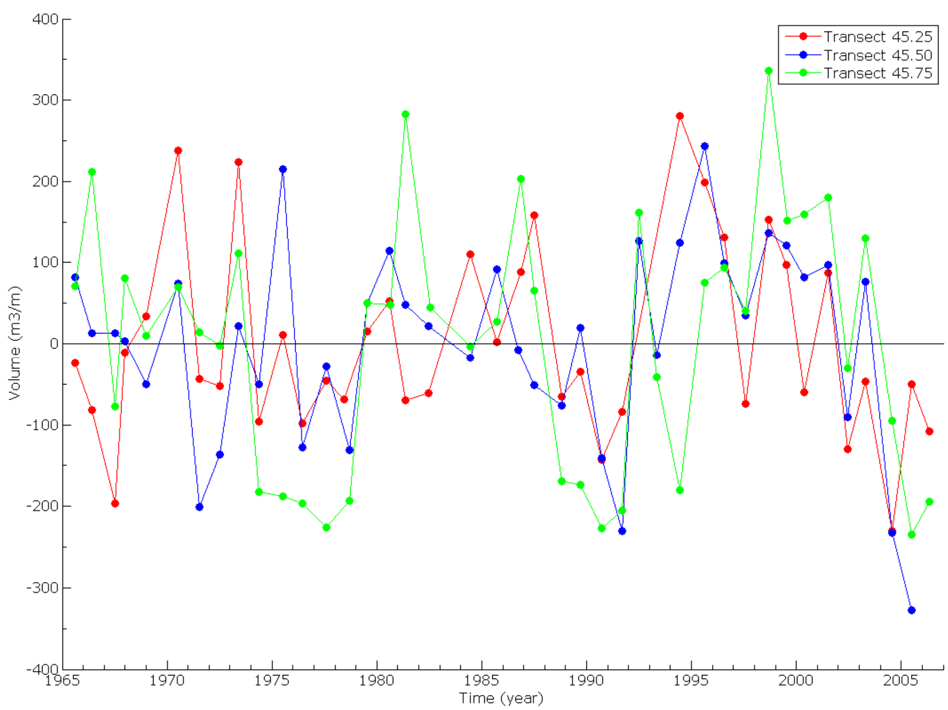

Figure 4-16B: Total profile volume residues; transects 45.25, 45.50 and 45.75.

Figure 4-16: Total profile volume residues.

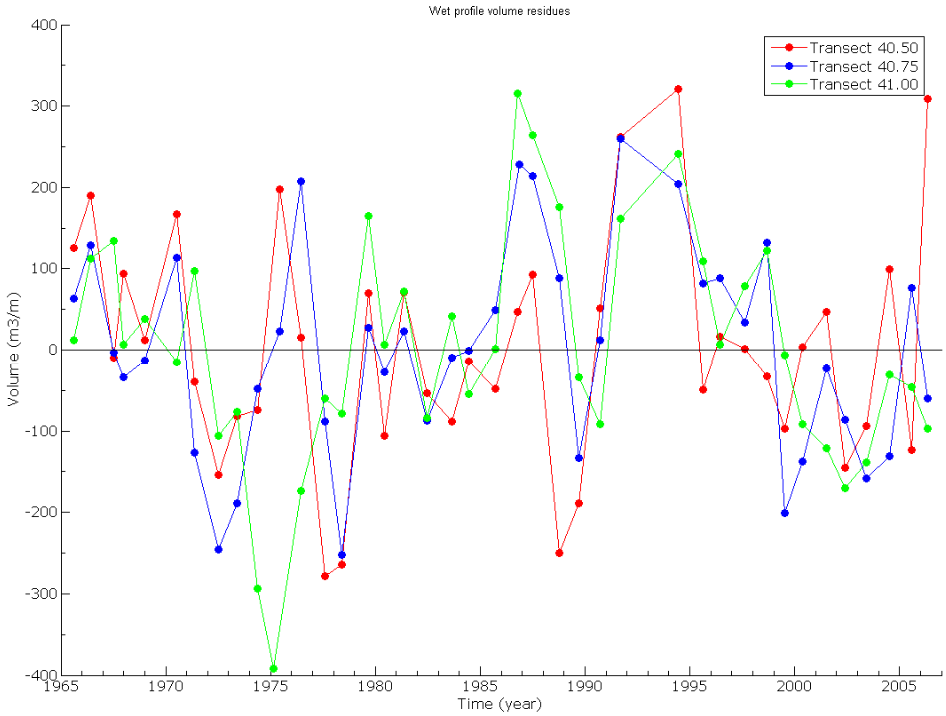

Figure 4-17A: Wet profile volume residues; transects 40.50, 40.75 and 41.00.

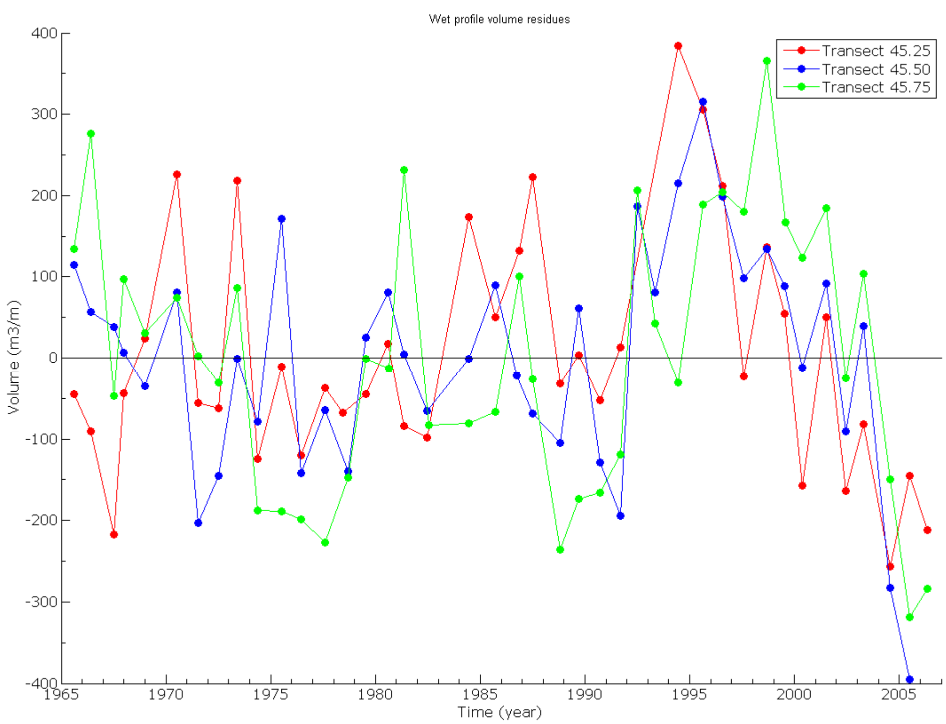

Figure 4-17B: Wet profile volume residues; transects 45.25, 45.50 and 45.75.

Figure 4-17: Wet profile volume residues.

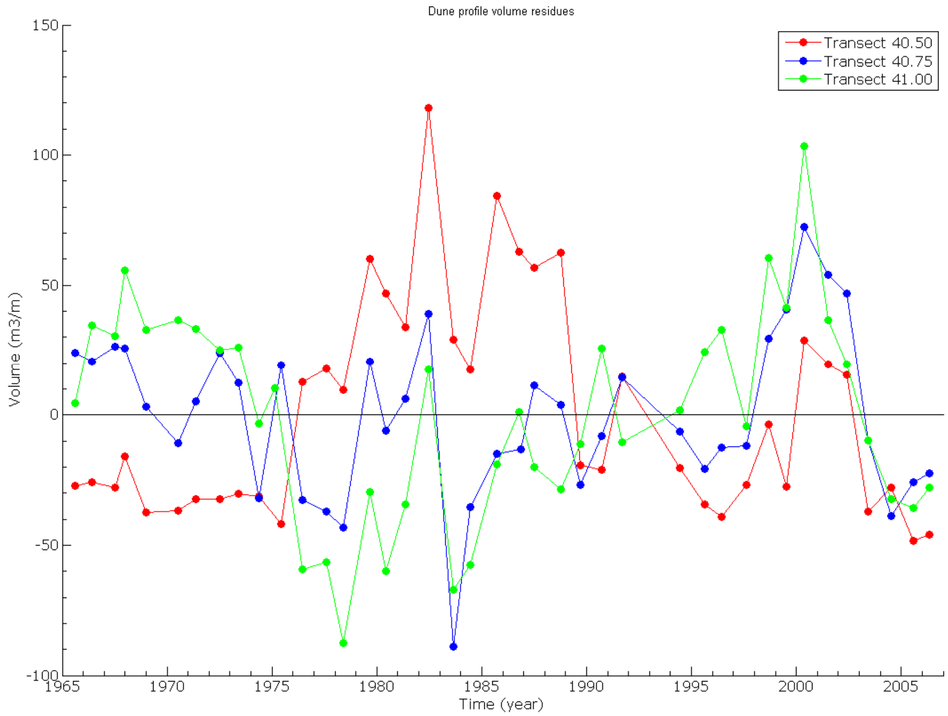

Figure 4-18A: Dune profile volume residues; transects 40.50, 40.75 and 41.00.

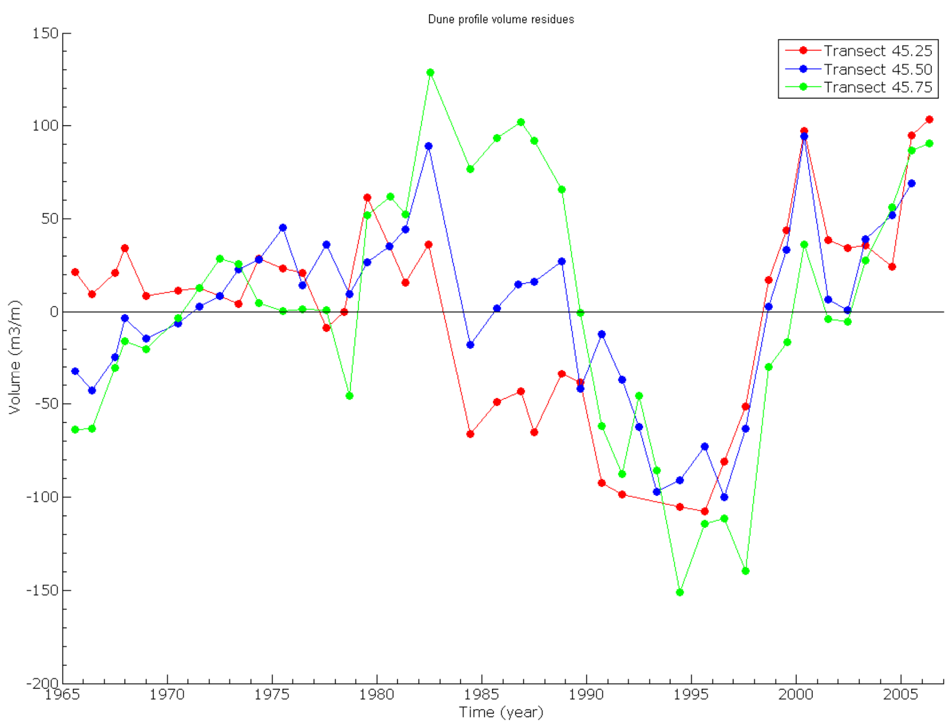

Figure 4-18B: Dune profile volume residues; transects 45.25, 45.50 and 45.75.

Figure 4-18: Dune profile volume residues.

From Figure 4-16, Figure 4-17 and Figure 4-18 it can be seen that the volume residues of the adjacent transects of transect 40.75 and 45.50 show similarity to the volume residues of transects 40.75 and 45.50.
Exceptions are the total and the wet profile volume residues of transect 41.00 during the period 1974-1976 (Figure 4-16A and Figure 4-17A) and transect 45.75 during the period 1974-1977 (Figure 4-16B and Figure 4-17B). Analysis of the profiles in these periods shows no obvious reason to reject these surveys.
The total and the wet profiles of 1992 and 1993 of transects 40.50 and 41.00 show the same fault as the profiles of transect 40.75 in these years as shown in Figure 4-12. Therefore these profiles are taken out of the calculations as well.
In Figure 4-16B and Figure 4-17B the profiles of 1992 and 1993 of transect 45.25 are missing as well. This is because these profiles show a similar deviation as the profiles of 1992 and 1993 of transects 40.50, 40.75 and 41.00.

4.3 Comparison of cycle time and volume fluctuations

The calculated cycle time of the breaker bars in the transects and the volume fluctuations of the transects can now be compared with each other to see if there is any relation between the two. This is done with the sine function of equation 5 as explained in Section 3.7. The best fit sine function for the volume residues of the total, wet and dune profiles of transects 40.75 and 45.50 are shown in Figure 4-19, Figure 4-20 and Figure 4-21, respectively.
To obtain these best fit sine functions the phase of the sine function is varied from 0 to 2pi in 500 equal steps. The amplitude is varied from 0 to the maximum of the volume residues plus the standard deviation of the volume residues, also in 500 equal steps. This means there are 500 x 500 = 2.5×10^5 sine functions tested. For every sine function, the RMS-error is calculated using equation 2. The combination of amplitude and phase which has the smallest RMS-error is considered the best fitted sine function. The best fitted sine functions for the total, the wet and the dune profile of transects 40.75 and 45.50 are plotted in Figure 4-19, Figure 4-20 and Figure 4-21.

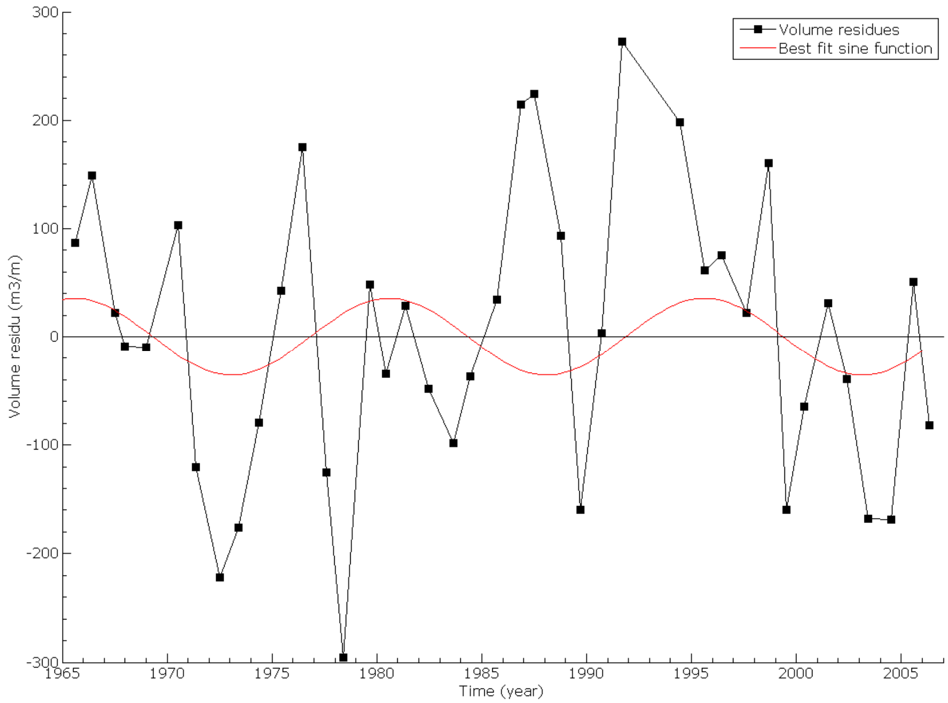

Figure 4-19A: Total profile volume residues, best fit sine function. transect 40.75.

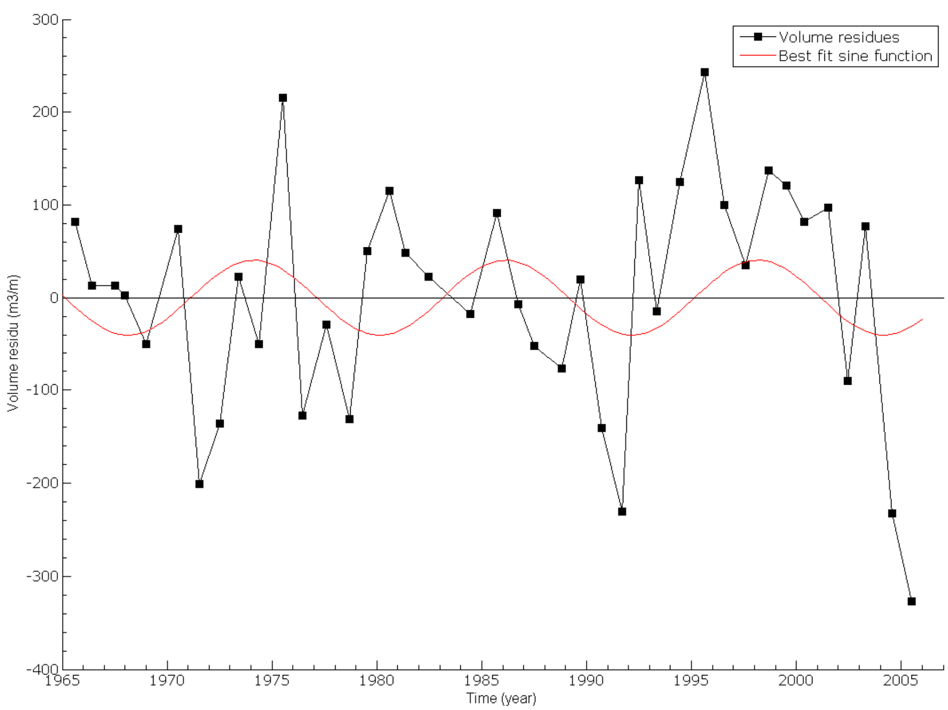

Figure 4-19B: Total profile volume residues, best fit sine function. transect 45.50.

Figure 4-19: Total profile volume residues, best fit sine function.

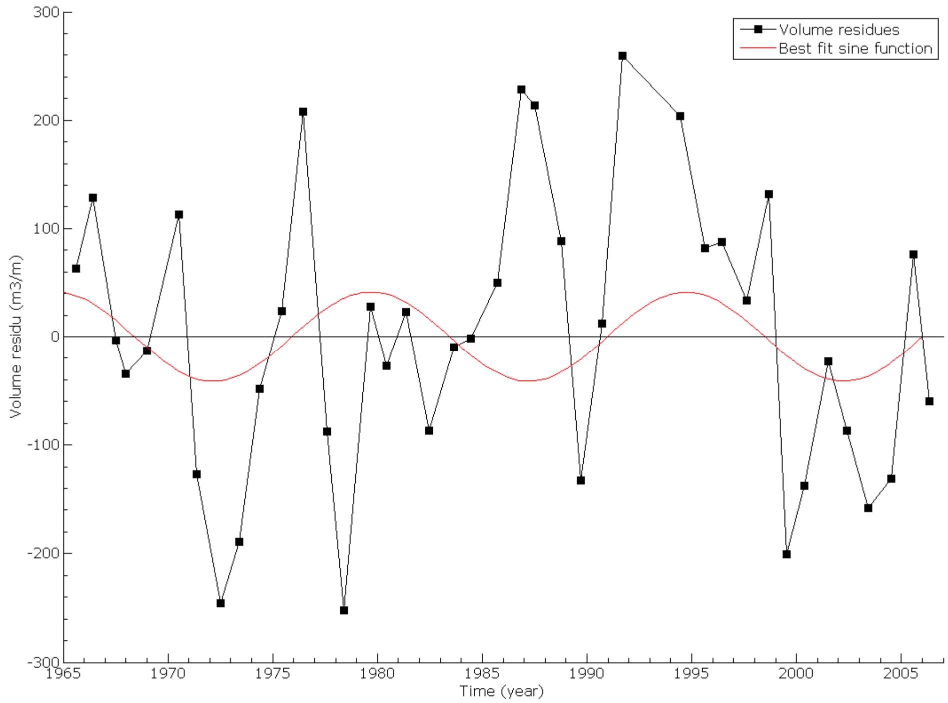

Figure 4-20A: Wet profile volume residues, best fit sine function. transect 40.75.

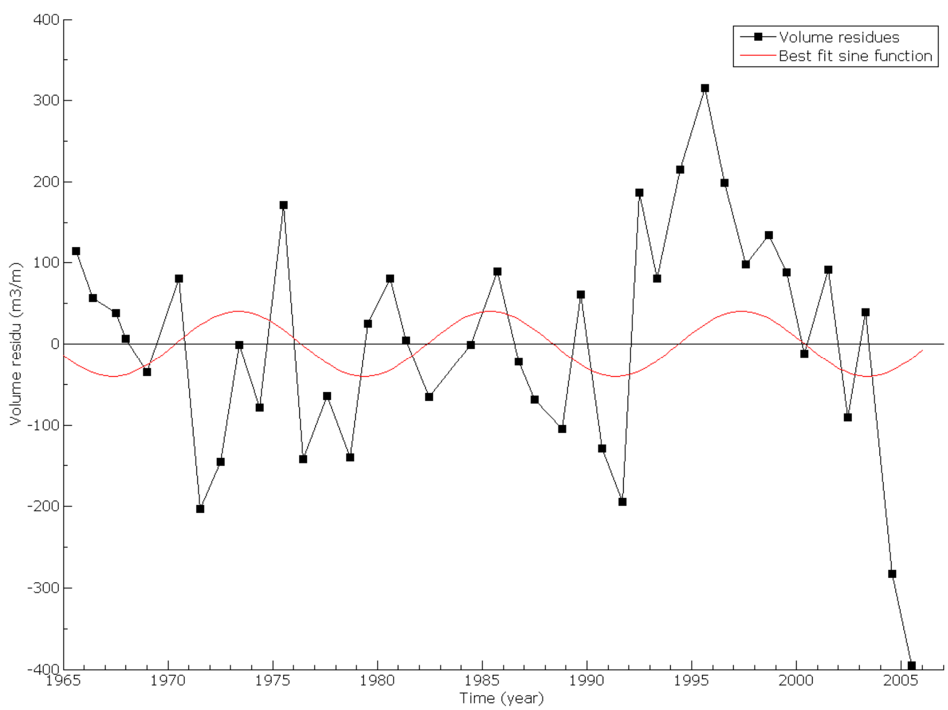

Figure 4-20B: Wet profile volume residues, best fit sine function. transect 45.50.

Figure 4-20: Wet profile volume residues, best fit sine function.

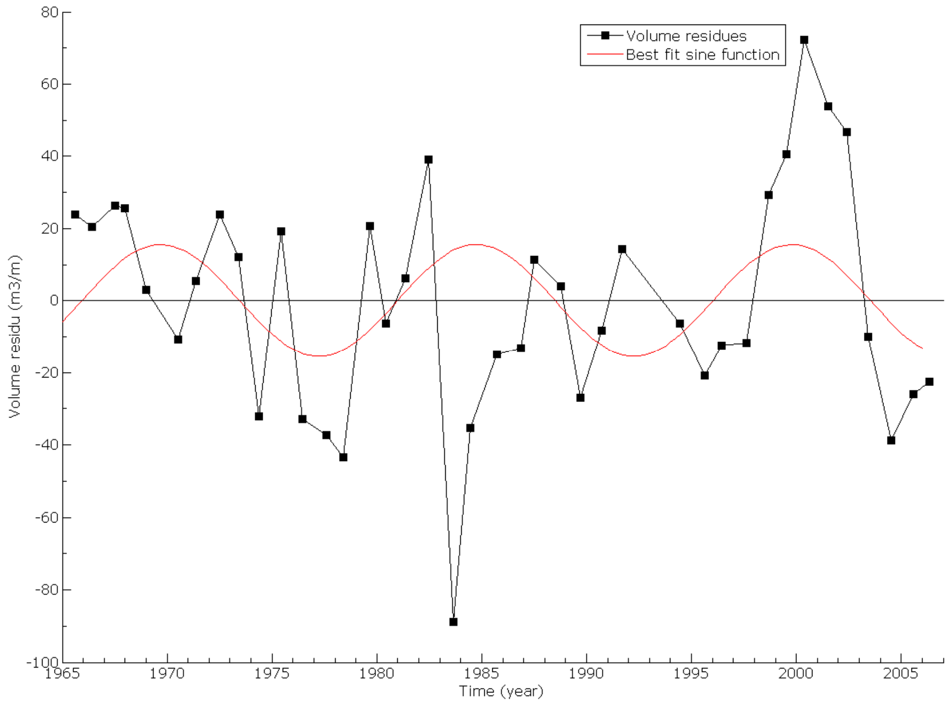

Figure 4-21A: Dune profile volume residues, best fit sine function. transect 40.75

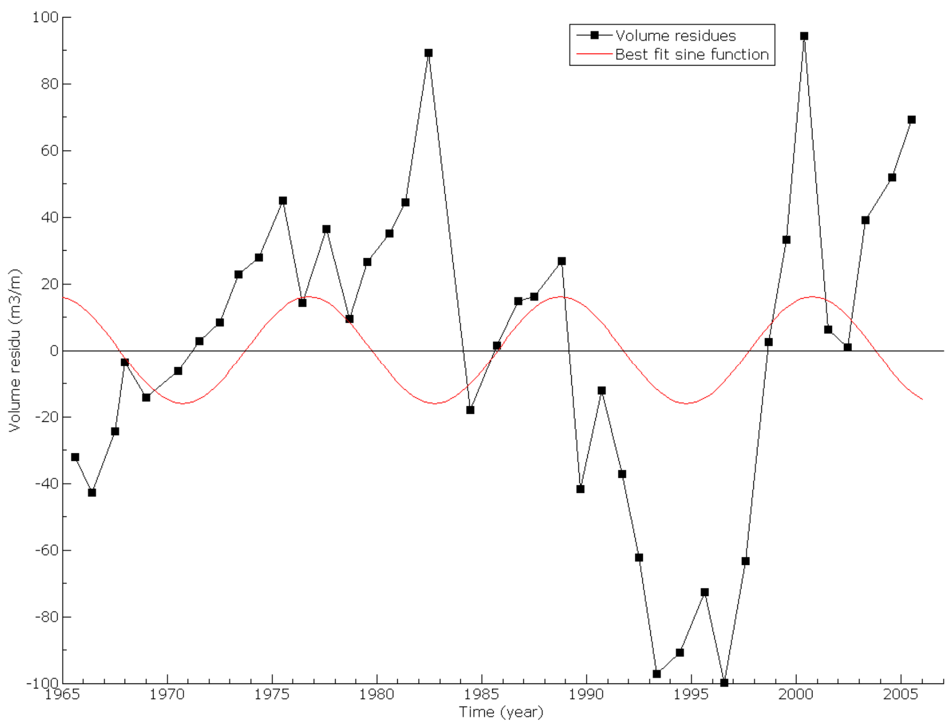

Figure 4-21B: Dune profile volume residues, best fit sine function. transect 45.50

Figure 4-21: Dune profile volume residues, best fit sine function.

The amplitudes of the best fit sine functions of transect 40.75 in Figure 4-19A, Figure 4-20A and Figure 4-21A are 35.5 m^3/m for the total profile volume residues, 41.3 m^3/m for the wet profile volume residues and 15.5 m^3/m for the dune profile volume residues. For transect 45.50 these values are 40.3 m^3/m (total profile), 40.2 m^3/m (wet profile) and 16.1 m^3/m (dune profile). This means that during one cycle time of the breaker bars in transect 40.75 the volume of the wet profile (the profile with the biggest amplitude of the best fit sine function of the six profiles plotted in Figure 4-19, Figure 4-20 and Figure 4-21) has a difference of 83 m^3/m between the maximum and the minimum elevation.
This value is considered rather small, since the measured residues have a bandwidth of almost 600 m^3/m Considering that the volume of a single breaker bar or a trough can be around 150 m^3/m (see Figure 3-9) the value of the amplitude of 41.3 m^3/m seems rather small to be caused by the movement of the breaker bars in the transect.

The RMS-error of the best fit sine function can be compared to the RMS-error of the zero-line to see how much better the sine function fits through the data than the zero line. The ratio between the RMS-error of the best fit sine function of the volume residues and the RMS-error of the zero line of the volume residues is called the relative RMS-error.
A relative RMS-error of 100% means that both RMS-errors are equal, a value of 0% means that the sine function connects all calculated volume residues, a value of 60% means that the sine function fits 40% better through the volume residues than the zero-line.

The RMS-errors of the best fit sine functions in Figure 4-19, Figure 4-20 and Figure 4-21 for transect 40.75 (total, wet and dune profile, the relative RMS-error is stated in brackets) are 127.2 m^3/m (98%), 128.4 m^3/m (97.5%) and 30.8 m^3/m (94%) For transect 45.50 the RMS-errors are (total, wet and dune profile) 118.1 m^3/m (97%), 136.3 m^3/m (97.7%) and 44.9 m^3/m (97.1%).

The relative values of the RMS-errors show very little improvement with respect to the RMS-error of the residues and the zero line (with a minimum of 2% for the total profile of transect 40.75 and up to a maximum of 6% for the dune profile of transect 40.75).
The RMS-errors of the best fit sine functions of the total profile volume residues of these 2 transects show an improvement of 2% and 3%. The improvement of the RMS-errors of the best fit sine functions of the wet profile volume residues of these 2 transects are both around 2.5%. The dune profiles have an improvement of the RMS-error of 3% and 6%.
The same calculations are made for the total, wet and dune profile of the 4 adjacent transects. The results of the calculations of all 6 transects are shown in Table 4-9 (total profile), Table 4-10 (wet profile) and Table 4-11 (dune profile).

Because the amplitudes of the best fit sine functions of transect 40.75 and 45.50 are small, it is interesting to see how sensitive the amplitude is. Figure 4-22 shows the amplitude plotted against the relative RMS-error for transects 40.75 and 45.50. The red line shows the results for sine functions with a phase equal to the phase of the best fit sine function in the transect. The blue area indicates the results for all other phases.

It can be seen that for a sine function with an amplitude of 0 m^3/m (thus a straight line) the relative RMS-error is 100% for all phases as can be expected and the minimum relative RMS-error is indeed the minimum of the red line in both Figure 4-22A and B.

In both Figure 4-22A and B the relative RMS-error stays below 100% for an amplitude between zero and twice the amplitude of the best fit sine function. After that, the relative RMS-error keeps growing in a flowing line.

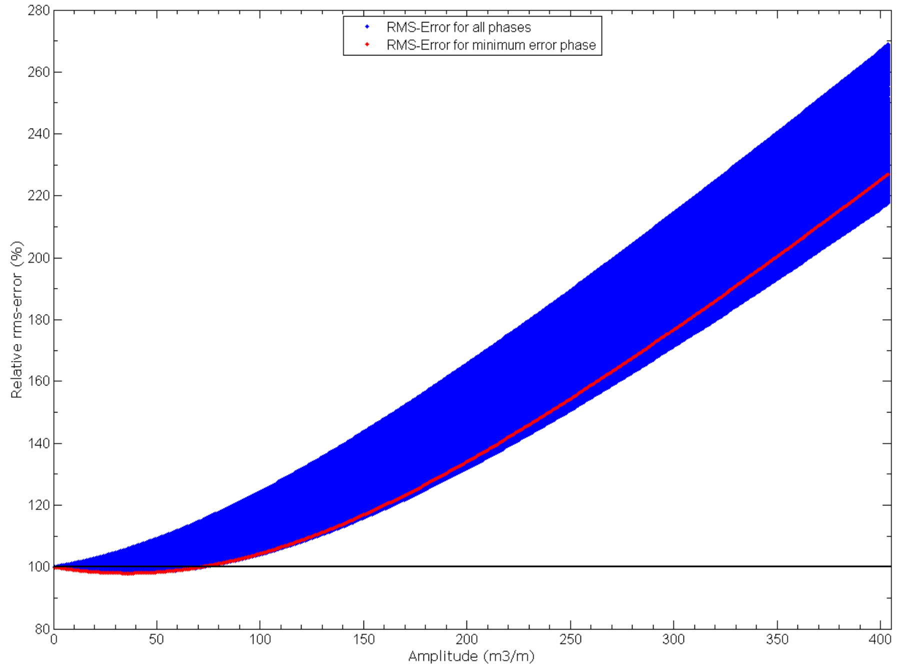

Figure 4-22A: Sensitivity of the best fit sine amplitude; transect 40.75

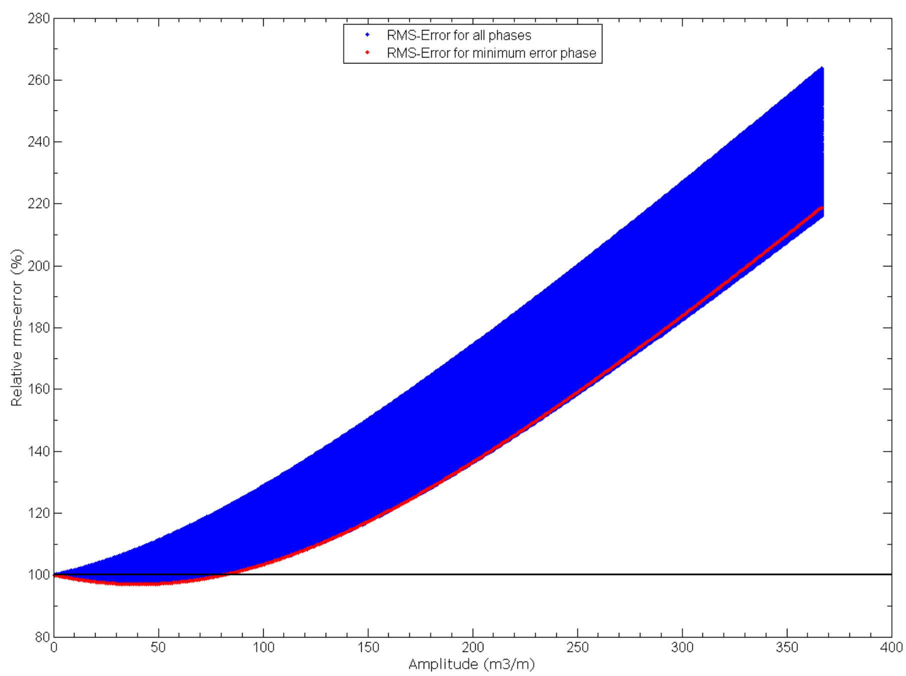

Figure 4-22B: Sensitivity of the best fit sine amplitude; transect 45.50

Figure 4-22: Sensitivity of the best fit sine amplitude; transects 40.75, 45.50

Table 4-9: Relative RMS-errors of the best fit sine functions and the total profile volume fluctuations.

Transect	RMS-error no fit (m3/m)	RMS-error best fit sine (m3/m)	Relative RMS-error	Sine amplitude (m3/m)	Sine phase (rad)
40.50	138.5	136.3	98.4%	34.4	4.1
40.75	129.8	127.2	98.0%	35.5	3.5
41.00	146.4	130.5	89.1%	91.0	1.1
45.25	118.2	101.0	85.4%	85.6	0.9
45.50	121.8	118.1	97.0%	40.3	5.5
45.75	152.2	150.9	99.1%	28.4	6.0

Table 4-10: Relative RMS-errors of the best fit sine functions and the wet profile volume fluctuations.

Transect	RMS-error no fit (m3/m)	RMS-error best fit sine (m3/m)	Relative RMS-error	Sine amplitude (m3/m)	Sine phase (rad)
40.50	141.0	139.0	98.6%	33.4	4.4
40.75	128.4	125.2	97.5%	41.3	3.9
41.00	140.9	129.3	91.8%	75.1	1.4
45.25	145.4	125.1	86.1%	103.1	0.9
45.50	139.4	136.3	97.7%	40.2	5.9
45.75	163.5	162.8	99.6%	21.2	5.8

Table 4-11: Relative RMS-errors of the best fit sine functions and the dune profile volume fluctuations.

Transect	RMS-error no fit (m3/m)	RMS-error best fit sine (m3/m)	Relative RMS-error	Sine amplitude (m3/m)	Sine phase (rad)
40.50	40.4	39.6	97.9%	11.5	2.8
40.75	30.8	29.0	94.0%	15.5	1.8
41.00	39.8	34.4	86.3%	29.6	0.2
45.25	53.7	52.1	97.1%	18.0	3.9
45.50	46.2	44.9	97.1%	16.1	4.1
45.75	67.7	67.5	99.7%	7.5	0.2

From Table 4-9 it can be seen that most best fit sine functions show only small improvement for the total profile volume residues. The RMS-error for the best fit sine function in transect 45.25 shows the largest improvement of 15%, the RMS-error for the best fit sine function in transect 41.00 shows an improvement of about 11%. The rest of the RMS-errors are improved by 0% to 3% only.

The amplitudes of the best fit sine functions in transects 41.00 and 45.50 are 91 m^3/m and 86 m^3/m. This means that the difference between a maximum and a minimum elevation is around 180 m^3/m. The amplitude of the best fit sine functions in the other transects are much smaller varying between 15 and 40 m^3/m.

The best fit sine functions all have different phases as well. For the total and the wet profiles it seems that the phases in transect 40.50 and 40.75 and 45.50 and 45.75 are close to each other but the phases of transect 41.00 and 45.25 for these profiles are completely different. For the phases of the dune profiles no coherence is noticeable.

Table 4-10 shows the same pattern as Table 4-9, the RMS-errors of the wet profile volume residues of transects 41.00 and 45.25 show an improvement of about 10% and 15% while the RMS-errors of the other transects show an improvement between 0% to 3%. The amplitudes of the best fit sine functions of transects 41.00 and 45.50 are 75 and 103 m^3/m and are again much larger than the amplitudes of the other best fit sine functions, which vary between 20 and 41 m^3/m.
Table 4-11 shows that transect 41.00 is the only transect of these 6 where the RMS-error of the best fit sine function shows a significant improvement (14%). The other transects show an improvement of the RMS-error of 0 to 6%. The amplitude of the best fit sine function in transect 41.00 is with 30 m^3/m larger than the other amplitudes which have a value between 9 and 18 m^3/m.
From the results shown in Table 4-9, Table 4-10 and Table 4-11 transects 41.00 and 45.25 are the only transects where the best fit sine function leads to a significant improvement of the RMS-error.

The sine functions are calculated with a period equal to the cycle times of the breaker bars in a transect. These cycle times are calculated as the difference in time between 2 succesive breaker bars in a transect. Because there are more breaker bars present in the period 1965-2006 and Figure 4-5 and Table 4-4 showed a small variation in cycle time in a single transect, the average difference between 2 breaker bars can differ slightly from the used cycle time. Therefore it is useful to see if a slightly bigger or smaller period for the sine function gives different RMS-errors. Table 4-12 to Table 4-14 give the relative RMS-errors of the best fit sine function for the total, wet and dune profiles of a sine function with periods with a 2 year margin from the calculated cycle times for all six transects with an interval of 0.5 year. The smallest relative RMS-error per transect is stated in the grey cells.

Table 4-12: Relative RMS-errors, period of sine function with 2 year margin; total profiles.

Transect	original period (year)	relative rms-error (%) period (years + original period) -2	-1.5	-1	-0.5	0	0.5	1	1.5	2
40.50	15.4	**96**	96	97	98	98	99	100	100	100
40.75	15.0	100	99	98	98	**98**	98	99	99	100
41.00	14.7	96	92	90	**89**	89	90	92	93	95
45.25	12.3	99	97	93	88	85	**84**	85	88	91
45.50	12.0	99	98	97	97	97	97	96	93	**91**
45.75	11.3	98	98	99	100	99	97	93	87	**82**

Table 4-13: Relative RMS-errors, period of sine function with 2 year margin; wet profiles.

Transect	original period (year)	relative rms-error (%) period (years + original period) -2	-1.5	-1	-0.5	0	0.5	1	1.5	2
40.50	15.4	**95**	95	96	98	99	99	100	100	100
40.75	15.0	99	98	98	**97**	97	98	98	99	99
41.00	14.7	96	93	92	**91**	92	93	94	95	97
45.25	12.3	99	96	92	88	86	**86**	87	90	93
45.50	12.0	99	98	97	97	98	97	95	92	**89**
45.75	11.3	98	99	99	100	100	98	94	89	**83**

Table 4-14: Relative RMS-errors, period of sine function with 2 year margin; dune profiles.

Transect	original period (year)	relative rms-error (%) period (years + original period) -2	-1.5	-1	-0.5	0	0.5	1	1.5	2
40.50	15.4	99	99	99	98	98	97	96	95	**94**
40.75	15.0	98	98	97	95	94	93	**93**	94	94
41.00	14.7	96	93	90	87	**86**	87	89	91	94
45.25	12.3	99	98	97	**97**	97	98	98	99	99
45.50	12.0	98	98	99	99	97	95	93	92	**91**
45.75	11.3	100	100	99	100	100	99	98	96	**93**

The results given in Table 4-12 to Table 4-14 show that there is a lot of diversity in the improvement of the RMS-error. The improvements of the RMS-errors for the total profile volume residues are the largest for transect 41.00 and 45.25, just like the results of Table 4-9. The biggest improvement for transect 41.00 is 11% for a sine function with a period 0.5 years less than the original calculated period of 14.7 years, for transect 45.25 the biggest improvement is 16% for a sine function with a period of 0.5 years more than the original calculated period of 12.3 years. The other transects show improvements of the RMS-errors smaller than 10% with one peak of 13% for transect 45.75 and a period of 2 years more than the calculated period.

From Table 4-13 it can be seen that the improvement of the RMS-errors of the wet profile volume residues shows the same pattern as the results for the improvements of the RMS-errors for the total profile volume residues given in Table 4-12. The RMS-error for transect 41.00 shows a maximum improvement of 9% for a sine function with a period of 0.5 less than the original calculated period. Transect 45.25 shows an improvement of the RMS-error of 14% for a sine function with a period of exactly the original calculated period and a period of 0.5 years more than the original calculated period.

For 5 of the 6 transects it holds that the biggest improvement of the RMS-error of the best fit sine function of the wet volume residues with respect to the RMS-error of the zero line of the wet profile volume residues are found with sine functions that have the same period as the best fit sine functions of Table 4-12.

The RMS-errors of the dune profiles given in Table 4-14 show something different. Here the RMS-error of transect 41.00 shows an improvement of 14%, while the other transects have an improvement of the RMS-error of between 3% and 9%.

From the results of Table 4-12, Table 4-13 and Table 4-14 it can be seen that the RMS-error of the best fit sine functions show improvements of maximum 16% (transect 45.25, total profile volume). For all 18 cases (3 profiles; 6 transects) there are only 7 cases which show an improvement of the RMS-error of more than 10%; 3 out of six for the total profile volume residues, also 3 out of 6 for the wet profile volume residues and 1 out of 6 for the dune volume residues. The average improvement of the RMS-error of the total profile volume and the RMS-error of the wet profile volume both are 9%, the average improvement of the RMS-error of the dune profile volume is even lower with an improvement of 7%. All these 18 cases have improvements of the RMS-error that are small and show a lot of scatter, varying between 2% and 16%. Therefore it can be concluded from the results of Table 4-12, Table 4-13 and Table 4-14 that there is no clear sinusoidal relation between the cycle time of the breaker bars and the volume fluctuations in a transect in region 3 of the Holland coast.

Since the results of Table 4-12, Table 4-13 and Table 4-14 give no indication of a sinusoidal relation between the cycle time of the breaker bars and the volume fluctuations in a transect in region 3 of the Holland coast it is interesting to see if the volume fluctuates according to a sinusoidal system. This is again done by placing a sine function through the volume residues of a transect and calculating the RMS-error, but instead of a fixed period, the period of the sine function will change between 0 and 45 year with an interval of 0.1 year. So the sine function will have 3 degrees of freedom. This calculation is executed for transects 40.75 and 45.50. Table 4-15 shows the results of this calculation.
The results of this table show that for all cases the improvement of the RMS-errors is approximately 15% except for the dune profiles of transect 45.50, which improve by 34%.
The periods of the best fit sine functions show more variance. The periods of the best fit sine functions of the total profiles and the wet profiles of a transect lie close to each other, while the best fit sine functions of the dune profiles have a period deviating from these other two periods. Both transects show different results for the periods of the best fit sine functions. For the total and wet profiles, transect 40.75 has a best fit sine function with a period of approximately 2 times the calculated cycle time of the breaker bars in the transect (30 years) while the best fit sine function of transect 45.50 have a period much closer to the calculated cycle time of the breaker bars in the transect (16 years). The periods of the best fit sine functions for the dune profiles are 7 years for transect 40.75 and 29 years for transect 45.50.

Table 4-15: Best fit sine function with free period; transects 40.75, 45.50.

	Transect	Period (year)	RMS-error no fit (m3/m)	RMS-error best fit sine (m3/m)	Relative RMS-error (%)	Amplitude (m3/m)
Total profiles	40.75	30.2	129.8	111.4	85.8	98.5
	45.50	16.8	121.8	102.8	84.4	92.4
Wet profiles	40.75	29.7	128.4	110.5	86.0	94.3
	45.50	16.2	139.4	117.5	84.3	104.1
Dune profiles	40.75	6.9	30.8	26.4	85.7	22.6
	45.50	28.7	46.2	30.7	66.4	49.4

From Table 4-15 it can be concluded that it is possible to get an improved RMS-error by placing a sine function through the volume residues of total, wet and dune profiles but the periods of the best fit sine functions in Table 4-15 show too much scatter to indicate a pattern valid for all transects.

The relation between the dunefoot dynamics and the breaker bar movement, as assumed from Figure 4-2 on page 39 can also be researched by comparing the RMS-errors of the residues and the trend line and the RMS-error of the residues and a best fit sine function. This analysis has been executed for the dunefoot of transect 40.75and is explained in Appendix G. The results are given in Table 4-16 by means of the relative RMS-error. Again, the period of the best fit sine function varies with a margin of 2 years from the calculated cycle time of the breaker bars.

Table 4-16: Relative RMS-errors of the Dunefoot dynamics.

Transect	original period	relative rms-error (%)								
		period (years + original period)								
	(year)	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2
40.75	15.0	97	97	96	96	**96**	96	97	97	98

The best relative RMS-error of this analysis is still 96% and therefore it can be concluded that there is no sinusoidal relation between the dunefoot dynamics and the breaker bar movement in transect 40.75.

Since the results of transect 40.75 are so obvious, no other transect have been analysed on this subject.

4.4 Conclusions

The general conclusion of this chapter is that the influence of the cycle time of the breaker bars on the volume fluctuationsof a transect along region 3 of the Holland coast is not dominant over other processes that cause the volume of a coastal profile to fluctuate

In this chapter, 6 transects in region 3 of the Holland coast (transects 40.75 and 45.50 and their adjacent transects) are analysed. These six transect have not been nourished up to 2006. Therefore the autonomous bar behaviour can be analysed in these transects

Cycle times

For every transect one unique 2nd order polynomial is created to represent the seaward movement of all breaker bars in that transect during the period 1965-2006. These polynomials are compared to the seaward movement of the breaker bars found using the profiles of the JARKUS database. This comparison shows that the Root Mean Squared deviation (RMS-error) of the modelled polynomials with respect to the surveyed movement of the breaker bars is between 5% and 8% of the distance covered by the breaker bars. From this it seems that in one transect, the breaker bars move in a uniform pattern.

The cycle times of the breaker bars in a transect are calculated by measuring the time between successive 2nd order polynomials in a transect. The cycle times of the breaker bars are different for every transect. Table 4-17 shows the calculated cycle time per transect.

Table 4-17: Breaker bar cycle times per transect

transect	cycle time (yr)
40.50	15.4
40.75	15.0
41.00	14.7
45.25	12.3
45.50	12.0
45.75	11.3

The calculated cycle times of the transects in region 3 show a decrease in cycle time towards the south. This means that a breaker bar in region 3 moves seaward with different speeds. The effect on the behaviour of the breaker bars of this speed difference is unclear and needs more research.

Volume calculation

The profiles for the volume calculation are defined 305 m onshore to 800 m offshore of the RSP line. In this profile, a distinction is made between the wet part (between 800 m offshore from RSP and the dunefoot) and the dry part (between the dunefoot and 305 m onshore of RSP). For every analysed transect the volume is calculated for these three profiles in time. From this volume calculation, the linear trend over the period 1965-2006 is determined (shown in Table 4-18) and the volume fluctuations with respect to the trend are calculated.

Table 4-18: Volume trend of six transects for the period 1965-2006.

Transect	Volume trends (m3/m) Total profiles	Wet profiles	Dune profiles
40.50	4.0	-0.8	4.7
40.75	7.5	-0.1	7.6
41.00	13.6	4.6	9.0
45.25	10.7	5.7	4.7
45.50	8.3	2.3	6.2
45.75	4.3	2.6	1.7

All six transects have an accreting trend for the total profile volumes with a minimum of 4.0 m^3/m per year and a maximum of 13.6 m^3/m per year. This is a difference of almost 10 m^3/m per year over 40 years. Remarkable is the fact that the transects of this minimum and maximum trend are only 500 m separated from each other. The trends of the dune profiles of the three most northward transects is for all three transects larger than the trend of the wet profiles of these transects. The trend of the dune profiles and the trend of the wet profiles of the three southern profiles are more evenly.

The volume residues have a deviation from the trend between +300 m^3/m and -300 m^3/m for the total profiles and the wet profiles for all six transects. The dune profiles show deviations from the trend between +100 m^3/m and -100 m^3/m.

Relation between cycle times and volume fluctuations

The existence of a sinusoidal relation between the cycle times of the breaker bars in a transect and the fluctuating of the volume of the profiles is examined by fitting a sine function through the volume residues. This sine function has free amplitude and phase and a period equal to the cycle time in a transect. The sine function with the combination of amplitude and phase that has the smallest root mean squared deviation from the volume residues is considered the best fit sine function. The existence of a sinusoidal relation is now sought by calculating the relative RMS-error. The relative RMS-error is the ratio between the RMS-error of the best fit sine function of the volume residues and the RMS-error of the zero line of the volume residues. A relative RMS-error of 100% means that both RMS-errors are equal, a value of 0% means that the sine function connects all calculated volume residues. Table 4-19 shows the relative RMS-errors of the best fit sine functions of the six analysed transects and their corresponding periods.

Table 4-19: Best fit sine function results per transect.

transect	calculated cycle time (year)	Total profile relative RMS-error (%)	Wet profile relative RMS-error (%)	Dune profile relative RMS-error (%)
40.50	15.4	98	99	98
40.75	15.0	98	98	94
41.00	14.7	89	92	86
45.25	12.3	85	86	97
45.50	12.0	97	98	97
45.75	11.3	100	100	100

It can be seen that there is very little improvement of the RMS-errors.
The improvement for the total profiles varies between 0% and 15%.
The improvement for the wet profiles varies between 0% and 14%.
The improvement for the dune profiles varies between 0% and 14%.

Calculations with a period with a 2 year margin from the calculated cycle time also showed no indication of a relation between the cycle time and the volume fluctuations.

From these results it can be concluded that the influence of the cycle time of the breaker bars on the volume of a transect is not dominant. Other processes that have influence on the volume fluctuations play a bigger role.

Runs with a free period of the sine function have also shown no indication of any sinusoidal fluctuation of the volume residues in a transect in region 3 of the Holland coast.

5 Analysis of region 4 of the Holland coast

This chapter will discuss the results of the analysis of the relation between the seaward movement of the breaker bars and the volume fluctuations in a transect for region 4 (km 56-98) of the Holland coast (See Wijnberg, 1995 and Section 2.1.3). Since the results of the analysis of region 3 in Chapter 4 has shown no clear proof of a relation between the seaward movement of the breaker bars and the volume fluctuations in a transect, this analysis will concentrate on only one transect. The transect to be analysed is transect 70.50, this transect lies in a stretch of 5.5 km between km 67.5 and 73 in region 4 that hasn't been nourished yet (see Appendix C for an overview of all nourishments along the Holland coast up to 2006).

5.1 Cycle time analysis

The breaker bars in region 4 of the Holland coast move faster seaward than the breaker bars in region 3 of the Holland coast. While the cycle times of the breaker bars in region 3 lie roughly between 12 and 15 years, the cycle times of the breaker bars in region 4 lie roughly between 3 and 4 years. The lifespan of a breaker bar in region 4 (± 12 years) is also shorter than the lifespan of a breaker bar in region 3 (>40 years), therefore there are less data points per breaker bar available, but more breaker bars are present in the same period. Figure 5-1 shows an example of a profile in transect 70.50. This is the profile of 1975, the presence of three breaker bars is clearly visible in this profile.

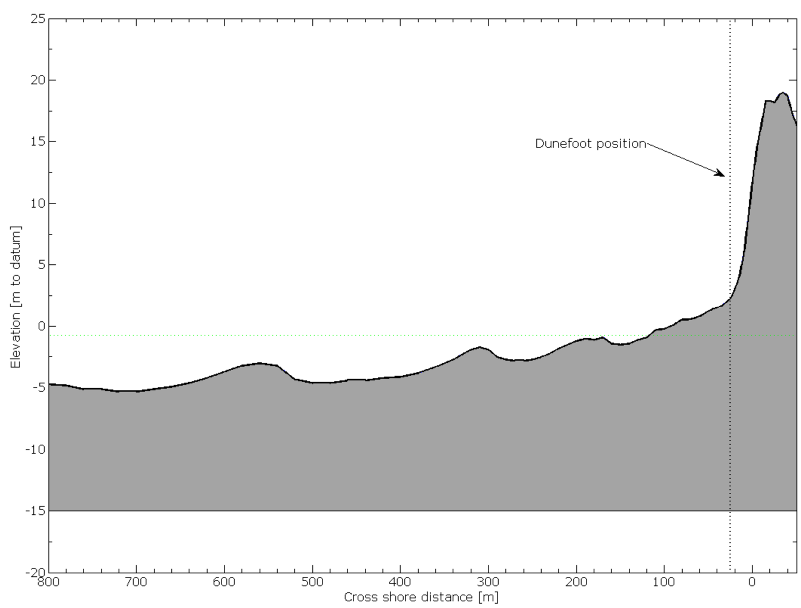

Figure 5-1: Transect 70.50, profile 1975.

The seaward movement of the breaker bars in transect 70.50 can be visualised using the script 'BatchBarDetection'. The JARKUS database has no data for the wet part in the years 1985, 1987 and 1988. The period between 1990 and 1995 gives a blur of points therefore the points in this period are deleted. This leaves the 7 breaker bars showed in Figure 5-2.

To calculate the cycle time of the breaker bars in transect 70.50 again 2nd order polynomials are drawn through the lines of Figure 5-2. To see if the waterline moves during the period 1965-2006, the position of the NAP line and the NAP +1 m line, the NAP +2 m line and the NAP +3 m line are plotted in Figure 5-3.
All lines in Figure 5-3 indicate accretion of the coast in transect 70.50. The NAP line has the largest increasing trend of 0.7 m3/m per year. This is considered small enough to be neglected. Therefore no correction was applied to Figure 5-2.

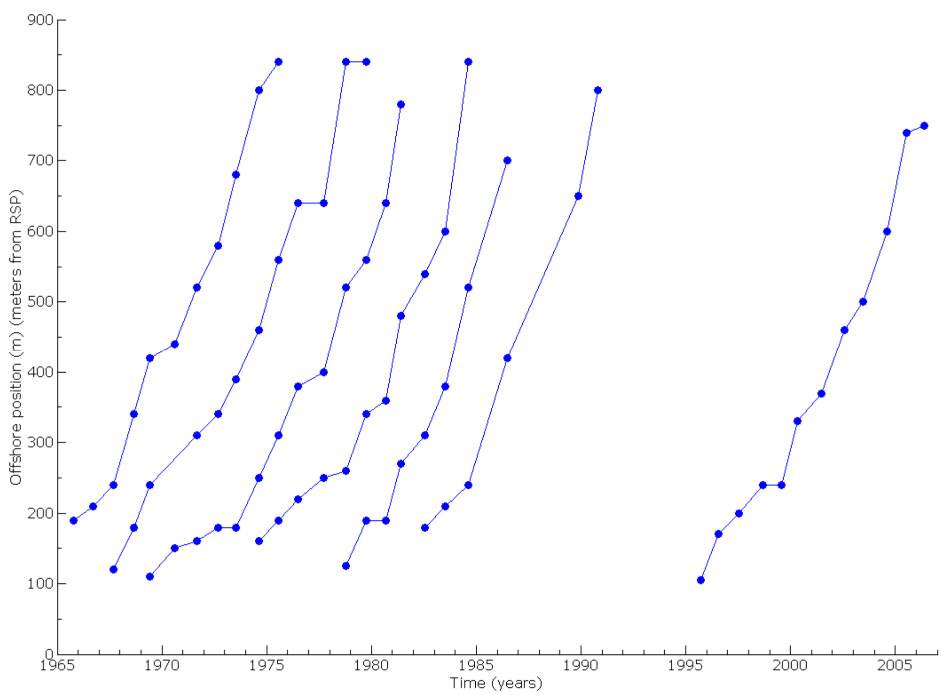

Figure 5-2: Movement of the breaker bar crests; transect 70.50.

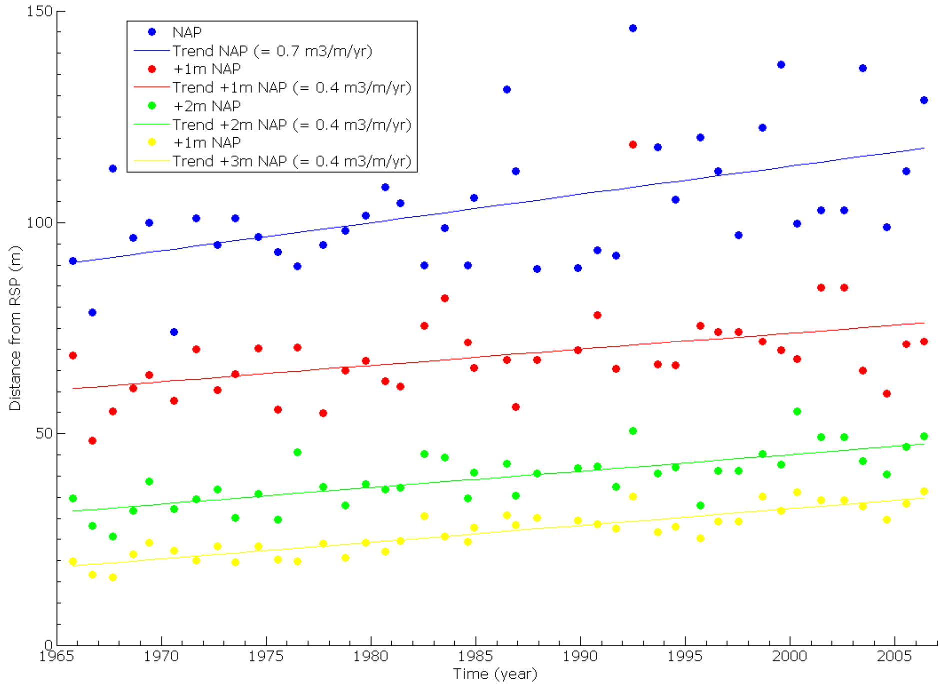

Figure 5-3: Waterline movement in time; transect 70.50.

The 2nd order polynomials (as in equation 1, page 27) that describe the seaward movement of the breaker bars in transect 70.50 are shown in Figure 5-4. Here it can be seen that the polynomials are all very steep. The breaker bars of which the first phase is captured by ‘BatchBarDetection’ (the 3rd and 4th bar) show a different shape of the polynomials than the other bars which seem to start to move offshore immediately. This can be caused by the fact that in the first phase of the life span a breaker bar is very small and not always indentified as a breaker bar by ‘BatchBarDetection’.

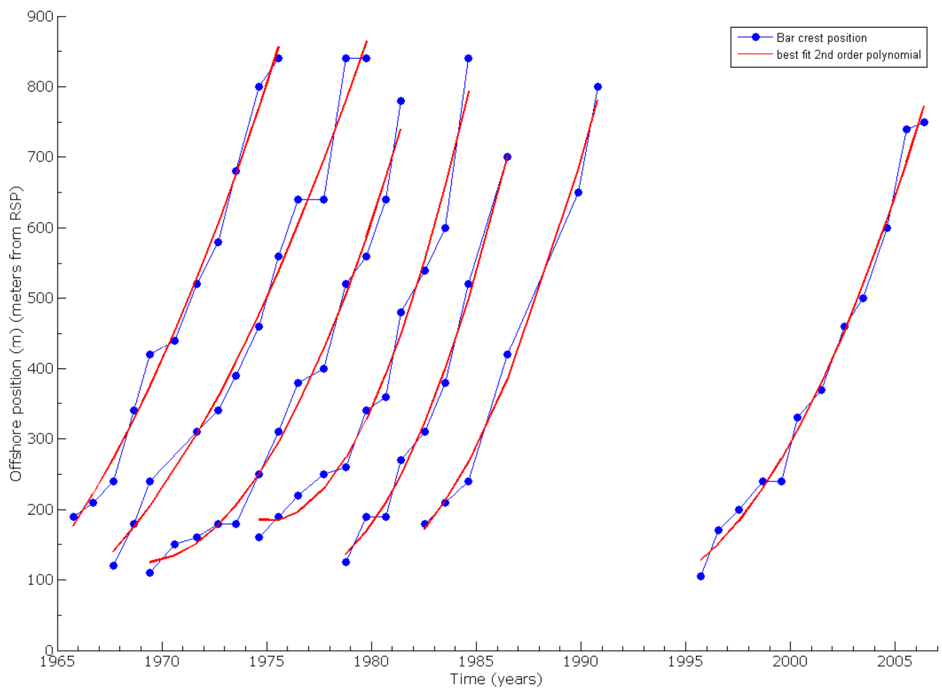

Figure 5-4: Calculated breaker bar movement; transect 70.50.

The RMS-errors of the polynomials in Figure 5-4 are given in Table 5-1. In this table the RMS-errors of the polynomials are compared to the distance covered by the breaker bars to give an idea of the size of the RMS-error.

Table 5-1: RMS-error of polynomials in transect 70.50.

Transect	Bar	Length (m)	RMS-error (m)	RMS-error / Length
70.50	1	650	22.5	3.5%
	2	720	31.3	4.3%
	3	670	22.8	3.4%
	4	680	29.7	4.4%
	5	575	17.2	3.0%
	6	620	23.4	3.8%
	7	645	22.0	3.4%

From the results in Table 5-1 it can be seen that the RMS-errors of the polynomials are small compared to the total distance of the life span of the breaker bars (all less than 5%). From these polynomials, an average polynomial is constructed to fit through all 7 breaker bars. This polynomial is constructed from the first 2 polynomials. In Figure 5-5 a polynomial constructed from the first 2 polynomials of Figure 5-4 is plotted together with the measured locations of the bar crests and the polynomials of Figure 5-4.

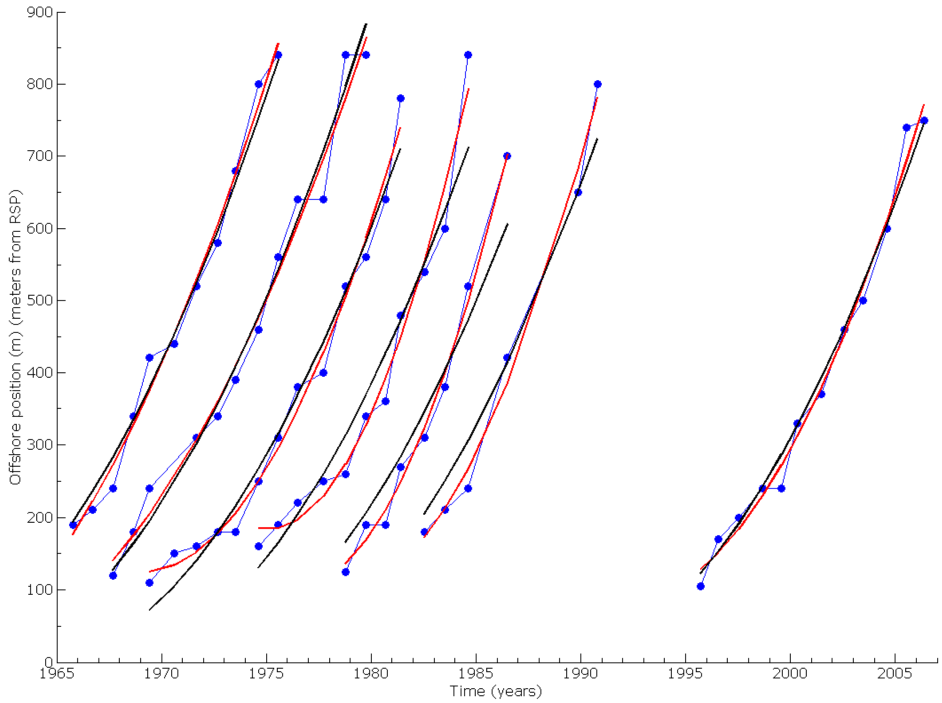

Figure 5-5: Best fit positions of the average polynomial, transect 70.50

The RMS-errors of the polynomials in Figure 5-5 are given in Table 5-2. The RMS-errors of the original polynomials and the RMS-errors of the average polynomial are compared to each other and to the total covered distance of the breaker bars.

Table 5-2: RMS-errors of the best fit and average polynomials in transect 70.50

Transect	Bar	Length (m)	RMS-error (m)	RMS-error / Length	RMS-error av. Poly (m)	RMS-error av. Poly/ Length	RMS-error difference (m)	Relative RMS-error difference
70.50	1	650	22.5	3.5%	25.6	3.9%	3.1	14.0%
	2	720	31.3	4.3%	32.8	4.6%	1.6	5.0%
	3	670	22.8	3.4%	31.8	4.7%	9.0	39.5%
	4	680	29.7	4.4%	49.6	7.3%	19.9	66.9%
	5	575	17.2	3.0%	47.3	8.2%	30.1	174.6%
	6	620	23.4	3.8%	45.5	7.3%	22.0	93.9%
	7	645	22.0	3.4%	25.4	3.9%	3.4	15.5%

The last column of Table 5-2 indicates large differences between the RMS-errors of the original and the average polynomials of breaker bar 4, 5 and 6. Compared to the distance covered by the breaker bars the RMS-error of the average polynomials of these breaker bars are only 8% maximum. Therefore the average polynomial is considered accurate enough to calculate the cycle time of the breaker bars.

To calculate the cycle times of the breaker bars in this transect, the average time between the first six polynomials is calculated. This calculated cycle time of the breaker bars in transect 70.50 is 3.4 years. The time between the last 2 breaker bars is 15.3 years. This is equal to 4.5 cycle times of 3.4 years.

5.2 Volume calculations

Just like in Section 4.2 the location of the dunefoot (NAP +3 m) is roughly determined using the figure with the waterline movement (Figure 5-3) to state the separation point for the wet and the dune profile. For transect 70.50 the separation point is set to 25m offshore from RSP.
The volume of the total profile, the wet profile and the dune profile can now be calculated with the same boundaries as used in Section 4.2 (seaward boundary = 800 m seaward from RSP; landward boundary is 305 m landward from RSP). Figure 5-6 shows the total volumes of the total profiles of transect 70.50 in time. In this figure all data are plotted. It can be seen that between 1986 and 1996 there are some years that seem to have unusual values for the volumes in comparison with the adjacent years.

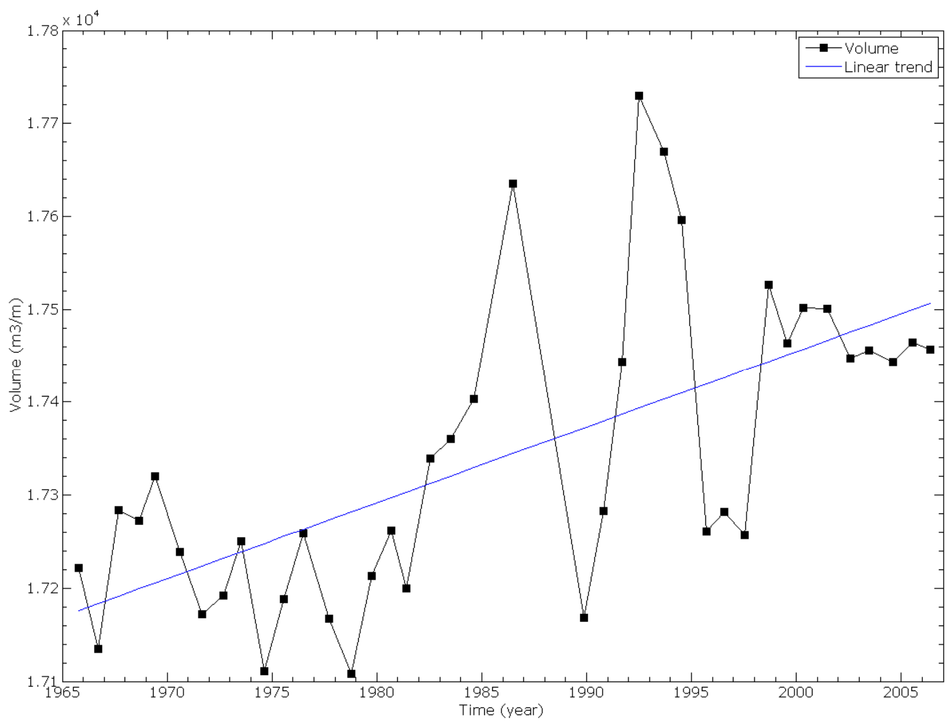

Figure 5-6: Total profile volumes of transect 70.50.

Since some of the volumes plotted in Figure 5-6 are unusual, the profiles of all years are compared with each other. From this comparison it can be concluded that some of the unusual values can be explained by survey errors. These

profiles are therefore deleted from the database. The years of the deleted profiles are 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1997 and 2002. More information on the survey errors of these profiles is given in Appendix E. The error of 1997 and 2002 has influence on both the wet and the dune profiles. Therefore the profiles of these two years are left out of all the volume calculations. All other found errors only influence the wet profiles and are deleted from both the database of the total profiles and the wet profiles, but are taken into account for the volume calculations of the dune profiles.
Figure 5-7 shows the volumes of the total profiles in time for transect 70.50 without the years in which a survey error is detected. Figure 5-8 and Figure 5-9 show the revised volumes of the wet and the dune profiles. These databases are used for further calculations.

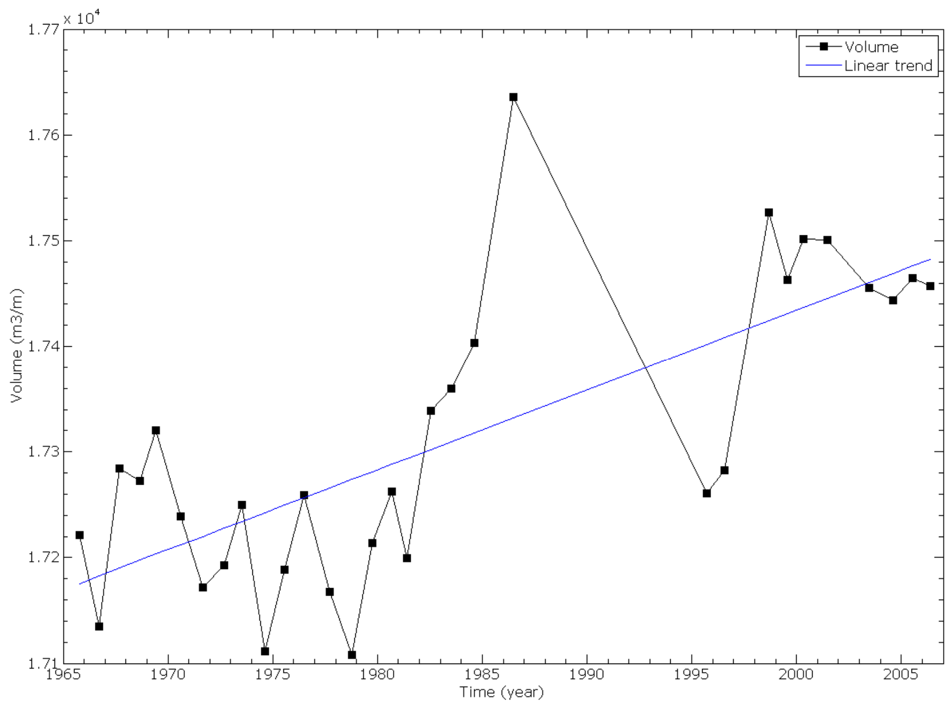

Figure 5-7: Total profile volumes of transect 70.50, revised.

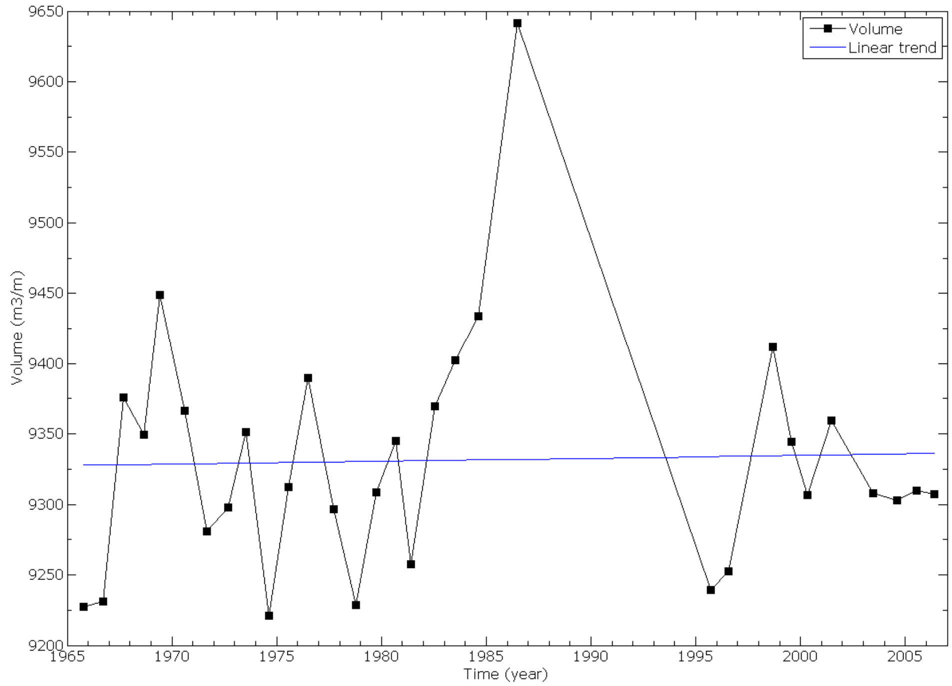

Figure 5-8: Wet profile volumes of transect 70.50, revised.

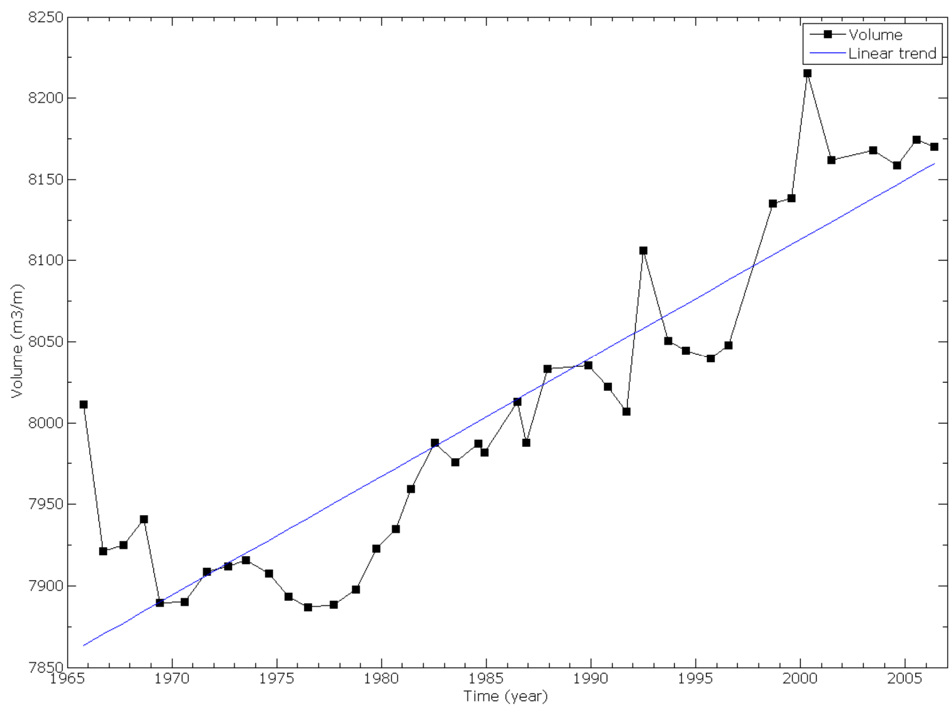

Figure 5-9: Dune profile volumes of transect 70.50, revised.

From Figure 5-7 it can be seen that the volume of the total profile over the period 1965-2006 has an accreting trend in transect 70.50. The trend of the total profile volumes is 7.5 m^3/m per year. The trend of the wet profile volumes is almost stable with 0.2 m^3/m per year and the dune profiles have an accreting trend of 7.5 m^3/m per year.
The volume residues (equation 4b, page 33) of the three profiles are plotted in Figure 5-10, Figure 5-11 and Figure 5-12.

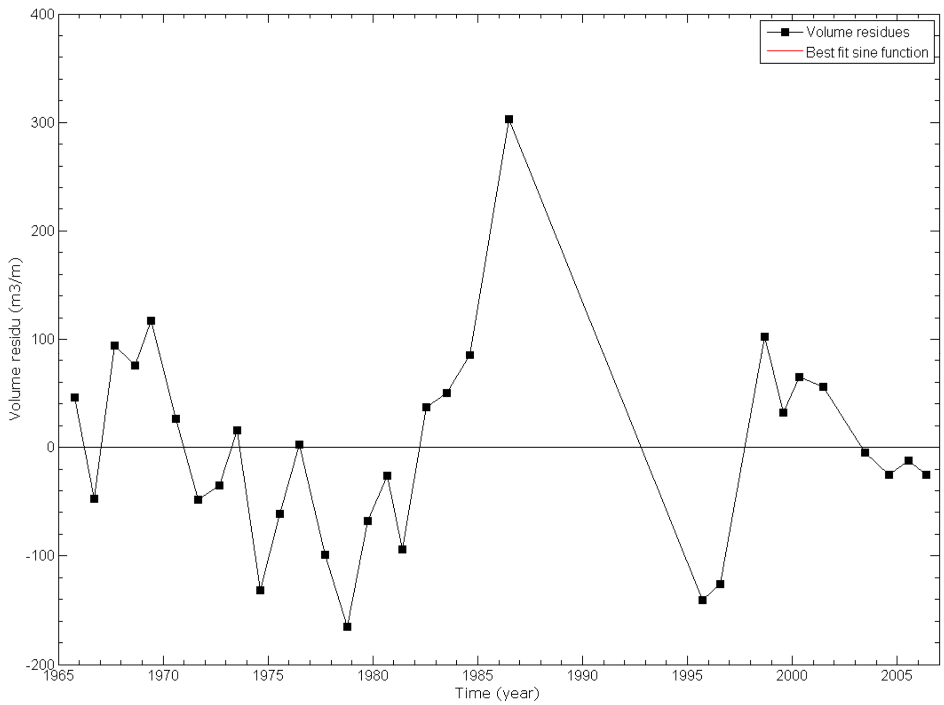

Figure 5-10: Total profile volume residues of transect 70.50

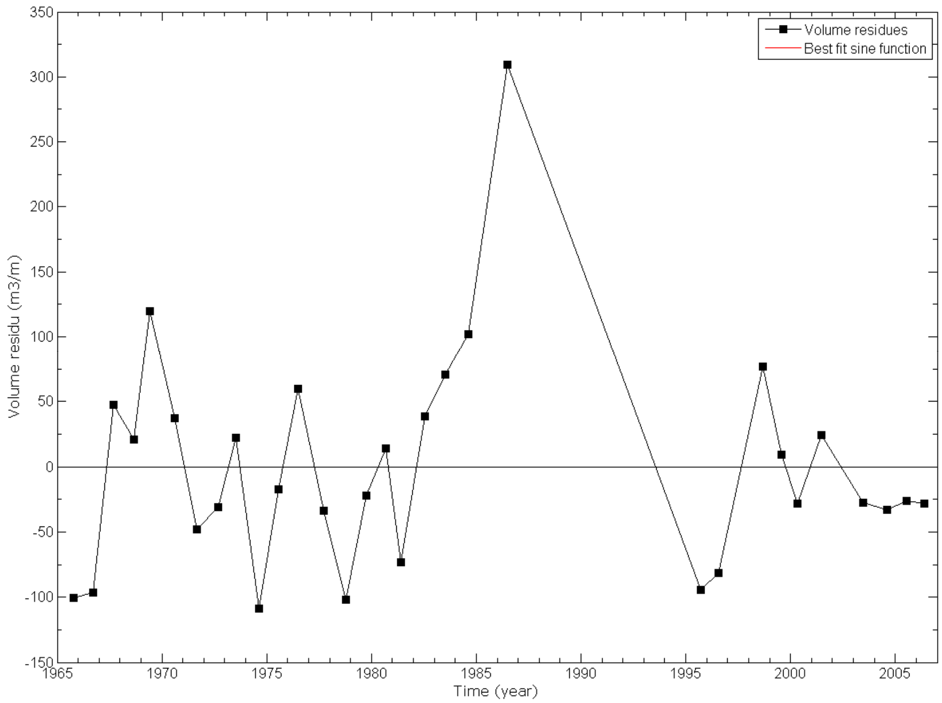

Figure 5-11: Wet profile volume residues of transect 70.50.

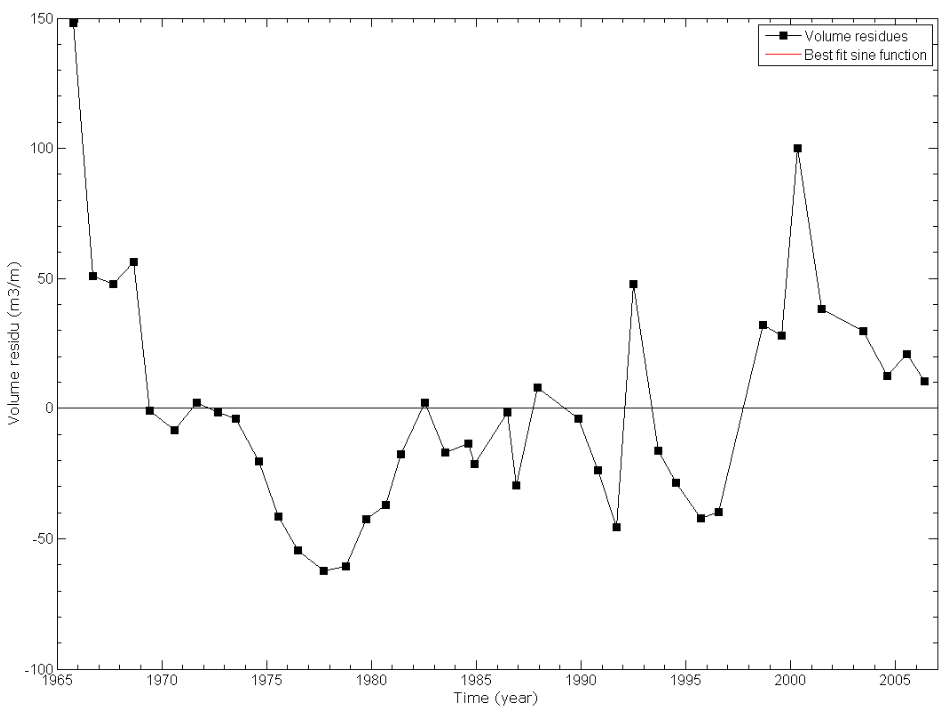

Figure 5-12: Dune profile volume residues of transect 70.50.

The volume residues of the total and the wet profiles in Figure 5-10 and Figure 5-11 have bandwidth of approximately 150 m^3/m with one peak of over 300 m^3/m in the year 1986. The profile of transect 70.50 in 1986 gives no indication of an error in the JARKUS data and is therefore taken along in the calculation. The volume residues of the dune profiles in Figure 5-12 have a bandwidth of approximately 100 m^3/m.

5.3 Comparison of cycle time and volume fluctuations

The calculated cycle time of the breaker bars (3.4 years) and the volume fluctuations of the transects can now be compared with each other to see if there is a clear relation between the two. This is done with the sine function of equation 5 as explained in Section 3.7. The best fit sine function for the volume residues of the total, wet and dune profiles are shown in Figure 5-13 to Figure 5-15. The values of the RMS-errors of the zero line (no fit) and the values of the RMS-errors of the best fit sine functions and the ratio between these two values (relative RMS-error) are given in Table 5-3.

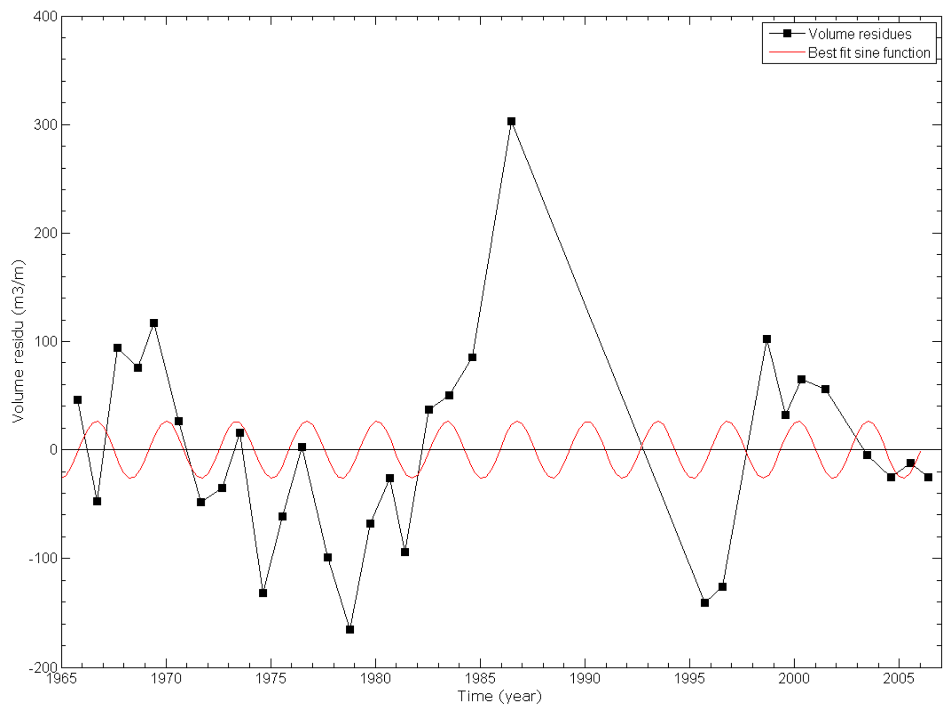

Figure 5-13: Best fit sine function, total profiles.

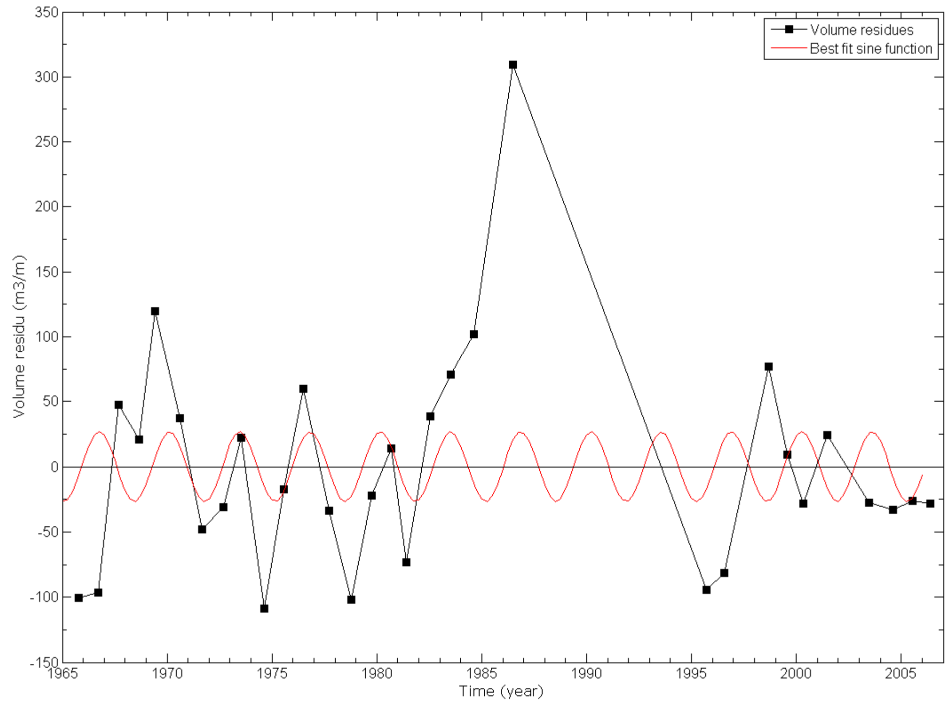

Figure 5-14: Best fit sine function, wet profiles

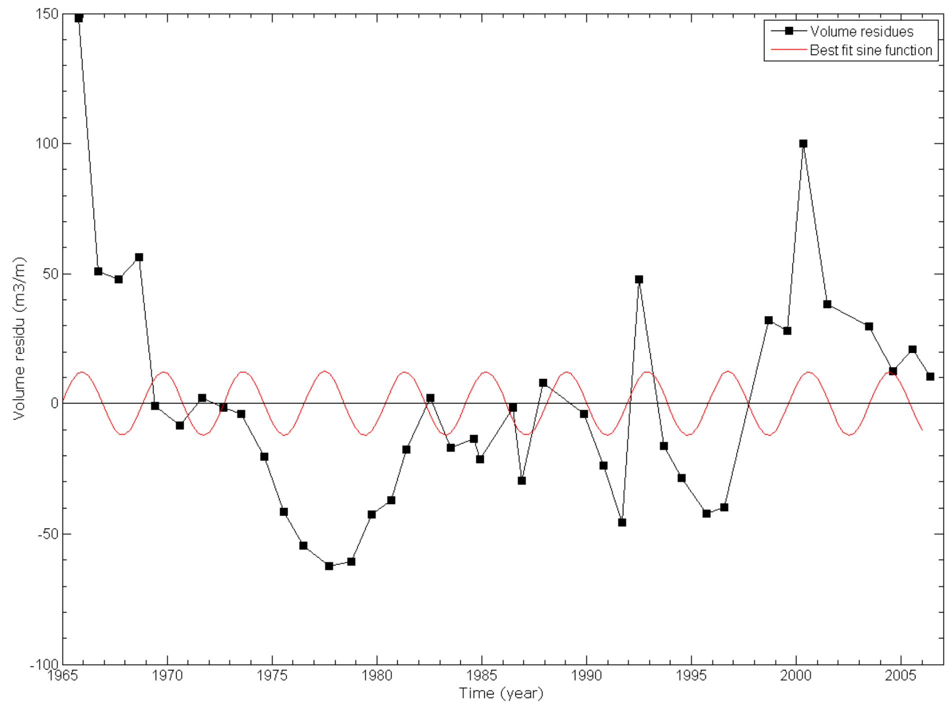

Figure 5-15: Best fit sine function; dune profiles

The best fit sine functions in Figure 5-13, Figure 5-14 and Figure 5-15 all have small amplitudes compared to the values of the volume residues. The amplitude of the sine functions in Figure 5-13 and Figure 5-14 is less than 27 m^3/m while the bandwidth of the residues is approximately 150 m^3/m. The amplitude of the sine function in Figure 5-15 is almost 11m^3/m with a bandwidth of the volume residues of 100 m^3/m. The calculated RMS-errors of these sine functions are given in Table 5-3.

Table 5-3: Relative RMS-errors of the best fit sine functions; transect 70.50.

Profile	RMS-error no fit (m3/m)	RMS-error best fit (m3/m)	Relative RMS-error (%)	Sine amplitude (m3/m)
Total	93.1	91.1	97.9	26.3
Wet	83.0	80.9	97.4	26.8
Dune	42.6	41.9	98.5	10.7

From the figures and the results in Table 5-3 it can be seen that improvement of the RMS-errors for the sine function of all three profiles is less than 2% and the amplitude of the best fit sine functions is 30 m^3/m at the most. From these numbers it can be concluded that for transect 70.50 there is no sinusoidal relation between the cycle time of the breaker bars in and the volume fluctuations in the period 1965-2006.

Like the analysis of the transects in region 4 it is interesting to see if a small difference in the period of the sine function gives bigger improvement of the RMS-error. Table 5-4 gives the relative RMS-errors for best fit sine functions with varying periods. The RMS-errors of the best fit sine functions are calculated for sine functions with a period between -1 and +1 year + the original calculated period of 3.4 years. The interval between 2 successive periods is 0.25 years.

Table 5-4: Relative RMS-errors, period of sine function with 1 year margin; transect 70.50

original period (year)	Profile	relative rms-error (%) period (years + original period)								
		-1	-0.75	-0.5	-0.25	0	0.25	0.5	0.75	1
3.4	Total	99	98	100	98	98	94	99	97	96
	Wet	99	99	99	94	97	94	98	98	95
	Dune	100	99	98	100	98	100	98	100	99

From the results in Table 5-4 it can be seen that the improvement of the RMS-errors is 6% at the most. This is for a sine functions with a period of 3.65 years through the volume fluctuations of the total profiles or a sine functions with a period of 3.15 years through the volume fluctuations of the wet profiles. Therefore it can be concluded that there is no clear indication of sinusoidal relation between the cycle time of the breaker bars and the volume fluctuations in transect 70.50.

Since the volume residues of the total profiles in Figure 5-13 still have some strange values for which no error could be detected, it is interesting to see if the RMS-error of a sine function can show significantly more improvement if these values are taken out of the calculation. Figure 5-16 shows the volume residues of the total profile volumes in time for the period 1965 to 1983. Here are no exceptionally large fluctuations. For the volume residues in this period a best fit sine function is calculated (also plotted in Figure 5-16).

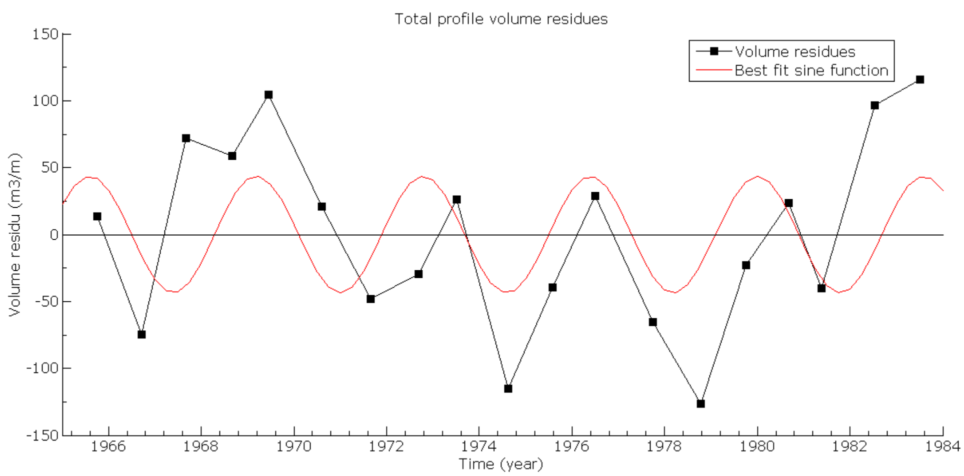

Figure 5-16: Best fit sine function, total profile volume residues; transect 70.50, 1965-1983.

The best fit sine function calculation is carried out for sine functions with a period between 2.4 and 4.4 years (1 year margin with the calculated cycle time of the breaker bars) with an interval of 0.25 year. The relative RMS-errors of these sine functions are given in Table 5-5. The calculation is executed for the total wet and dune profile.

Table 5-5: Relative RMS-errors; transect 70.50, 1965-1983

original period (year)	Profile	relative rms-error (%) period (years + original period)								
		-1	-0.75	-0.5	-0.25	0	0.25	0.5	0.75	1
3.4	Total	99	98	97	92	91	89	91	97	97
	Wet	99	100	97	95	94	93	90	93	97
	Dune	98	98	93	98	98	98	99	98	98

From the figures in Table 5-5 it can be seen that the RMS-error indeed has a bigger improvement if the database is restricted to the period 1965-1983. The improvement is still only 11% at the most for a sine function through the volume residues of the total profiles, with a period which is 0.25 year larger than the calculated cycle time of the breaker bars. The best fit sine function through the volume residues of the wet profiles shows an improvement of 10% with a period which is 0.5 year larger than the calculated cycle time of the breaker bars.

5.4 Conclusions

The general conclusion of this chapter is that the influence of the cycle time of the breaker bars on the volume fluctuationsof a transect along region 4 of the Holland coast is not dominant over other processes that cause the volume of a coastal profile to fluctuate

In this chapter, 1 transect in region 4 of the Holland coast (transect 70.50) is analysed. This transect has not been nourished up to 2006 and therefore the autonomous bar behaviour can be analysed in this transects.

Cycle time

In transect 70.50, 7 breaker bars where identified during the period 1965-2006. To describe the seaward movement of these breaker bars, one polynomial is created. This polynomial shows a root mean squared deviation from the surveyed breaker bars of 3% to 4% of the total distance covered by the breaker bars. Therefore it seems that the seaward movement is uniform for all seven breaker bars identified in transect 70.50.

The time between 2 successive breaker bars varies between 3 and 4 years. The average cycle time of the breaker bars in transect 70.50 is 3.4 years.

Volume calculation

For the volume calculations in transect 70.50 the same profiles as in Chapter 4 are used. The linear trend is calculated for the three profiles over the periods 1965-2006 and 1965-1983. Both databases show an accreting trend. During the period 1965-2006 the transect volume grows with an average 7.5 m^3/m per year. During the period 1965-1983 the volume trend indicates accretion of 2 m^3/m per year. Most of this accretion occurs in the dune area. The dune volume trend is 7.3 m^3/m per year during the period 1965-2006 and 0.9 m^3/m per year during the period 1965-1983.
The volume residues of the total and wet profiles fluctuate around the trend line in a bandwidth of 200 m. The volumes of the dune profiles fluctuate in a bandwidth of 100 m around the trend line.

Relation between cycle times and volume fluctuations

The existence of a sinusoidal relation between the cycle times of the breaker bars in a transect and the fluctuating of the volume of the profiles is examined by fitting a sine function through the volume residues. This sine function has free amplitude and phase and a period equal to the cycle time of the breaker bars in a transect.
The combination of amplitude and phase with the smallest Root mean squared deviation from the volume residues is considered the best fit sine function. The

existence of a sinusoidal relation is now sought by calculating the relative RMS-error. The relative RMS-error is the ratio between the RMS-error of the best fit sine function of the volume residues and the RMS-error of the zero line of the volume residues. Table 5-6 shows the relative RMS-errors of the best fit sine functions of the analysed profiles for both databases used.

Table 5-6: Relative RMS-errors and periods of the best fit sine functions in transect 70.50

period	Total profile relative RMS-error (%)	Wet profile relative RMS-error (%)	Dune profile relative RMS-error (%)
1965-1983	91	94	98
1965-2006	98	97	98

There is very little improvement for both databases with a maximum of only 3% for the database 1956-2006 and a maximum improvement of only 9% for the database of 1965-1983.

Calculations with a period with a 1 year margin from the calculated cycle time also showed no indication of a relation between the cycle time and the volume fluctuations.

From these results it can be concluded that the influence of the cycle time of the breaker bars on the volume of a transect is not dominant. Other processes that have influence on the volume fluctuations play a bigger role.

6 Conclusions and recommendations

In this chapter the main conclusions of this study are summarised. Subsequently also some recommendations for further research are proposed.

6.1 Conclusions

The general conclusion of this chapter is that the influence of the cycle time of the breaker bars on the volume fluctuationsof a transect the Holland coast is not dominant over other processes that cause the volume of a coastal profile to fluctuate

This conclusion is the result of an analysis of 7 transects along the Holland coast. The analysed transects all have not been subject to sediment nourishment up to 2006, so the autonomous behaviour can be detected. The conclusions drawn from the analysis of these transects are stated below.

Breaker bars

Analysis of the seaward motion of the breaker bars in seven transects along the Holland coast shows that this movement can be modelled by a 2^{nd} order polynomial which differs per transect.

The cycle times of the breaker bars vary per transect. In region 3 of the Holland coast (km 23-55) six analysed transect have shown cycle times between 11 and 15 years. These cycle times decrease in southward direction.

The calculated cycle times of the transects in region 3 show a decrease in cycle time towards the south. This means that a breaker bar in region 3 moves seaward with different speeds. The effect on the behaviour of the breaker bars of this speed difference is unclear and needs more research.

The average cycle time of the breaker bars in transect 70.50 in region 4 of the Holland coast (km 56-98) is 3.4 years.

Volume calculations

The volume fluctuations in time are analysed for all 7 transects. For every transect 3 different profiles are analysed. These profiles are the total profiles (nearshore and dune area) the wet profiles (nearshore area until the dunefoot) and the dune area (the dunefoot until behind the dunes).
The analysed transect all lie in an unnourished coastal stretch along the Holland coast. The linear trends of the sediment volume in these transects all indicate

accretion during the period 1965-2006. Both the wet and the dune part of the profiles indicated an up going trend of the sediment volumes.

Relation between cycle times and volume fluctuations

The existence of a sinusoidal relation between the cycle times of the breaker bars in a transect and the fluctuation of the volume of the profiles is examined by fitting a sine function through the volume residues. This sine function has free amplitude and phase and a period equal to the calculated cycle time in a transect.
The combination of amplitude and phase with the smallest Root mean squared deviation from the volume residues is considered the best fit sine function. The existence of a sinusoidal relation is now sought by calculating the relative RMS-error. The relative RMS-error is the ratio between the RMS-error of the best fit sine function of the volume residues and the RMS-error of the zero line of the volume residues. A relative RMS-error of 100% means that both RMS-errors are equal, a value of 0% means that the sine function connects all calculated volume residues.

- The relative RMS-error of the total profiles varies between 85% and 100%
- The relative RMS-error of the wet profiles varies between 86% and 100%
- The relative RMS-error of the dune profiles varies between 86% and 100%

These relative RMS-errors and the period of the best fit sine function have shown a lot of scatter and therefore it can be concluded that there is no indication of a clear sinusoidal relation between the cycle time of the breaker bars and the volume fluctuations in a transect along the Holland coast.

Calculations with a varying period in a margin of 2 year from the cycle time of the breaker bars in the transects north of IJmuiden and a margin of 1 year from the cycle time of the breaker bars in transect 70.50 have also indicated no relation between the cycle time of the breaker bars and the volume fluctuations in a transect along the Holland coast..

Runs with a free period of the sine function have also shown no indication of any sinusoidal fluctuation of the volume residues in a transect.

6.2 Recommendations

To get a better understanding of the systems involved in this thesis the following is recommended:

'BatchBarDetection' still needs manual correction. Therefore on the following points improvement is needed for further use;

- The method to find the locations of the breaker bar crests needs improvement, now sometimes data points are wrongfully identified as bars.

- The method used to follow the movement of a single bar crest in time needs a lot of manual correction, this method can be improved.

- The location of a breaker bar crest is defined as the highest elevation above the average profile. To get more a more precise location a new method must be designed.[2]

Other recommendations for further research are:

- To get more insight in the cycle times of the breaker bars in Region 3 of the Holland coast, a bigger data base is needed to see whether the cycle time in a transect is stable per transect or whether it shows a big variation per breaker bar. The data needed can only be obtained if the monitoring of the coast, as done for the JARKUS database is continued in the future.

- The cause and effects (like the bar switch) of the decreasing cycle times along the northern part of the Holland coast needs further research to get more insight in the behaviour of breaker bars. For this it is also recommended to check for similar phenomena along the southern part of the Holland coast.

[2] A start for a new method is given in Appendix H

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Appendix A UCIT

The Universal Coastal Intelligence Toolkit (UCIT, pronounced as *Use it!*), is an information system developed by WL|Delft Hydraulics aimed at facilitating the use of data and (expert) knowledge in coastal problems. It does so by providing flexible access to and integration of various types of:

- measurement data (transect, grid, point and line data),
- analysis routines (i.e. state indicators on which decisions are based), and
- models (morphological, ecological etc.).

Heart of the system are a database and a Matlab toolbox with a great number of analysis routines. A primary benefit of the UCIT approach is an increased efficiency in dealing with the 'traditional' data problems (e.g. data format, structure and availability, basic analysis etc.) for which long standing approaches are in principle available; less "reinventing-the-wheel". A secondary but by no means lesser benefit is the analysis environment itself which facilitates the interaction within and between research teams; more "learning-from-others".
Potential applications of UCIT focus on: projects with significant amounts of data that require a well structured approach, areas where projects are carried out on a regular basis, R&D projects involving data and models etc. Figure A-1 shows the user interface of UCIT.

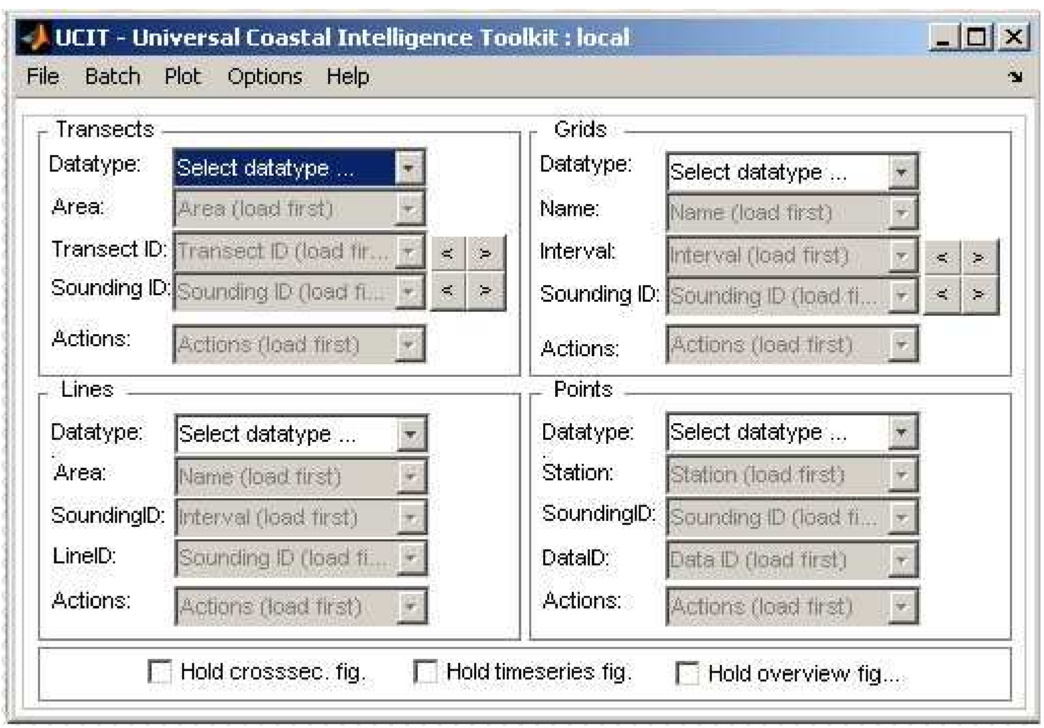


Figure A-1: User interface of UCIT.

Source: http://ucit.wldelft.nl/display/MCTDOC/UCIT

Appendix B BatchBarDetection

The position of a breaker bar is found by a MATLAB-procedure. The procedure to capture the location of a bar crest is not a standard procedure in UCIT. Especially written for this thesis by Van Koningsveld, is the MATLAB-procedure 'BatchBarDetection'. The procedure recognizes bars as follows: first all the data of a transect is collected from the JARKUS database with the help of UCIT. The second step is to make an averaged profile of a transect, by averaging the data points from all the years present.

The position of the bar crests can now be detected by checking for every profile for maximum elevations above the averaged profile. This is done by subtracting the height of the average profile from the original profile. Figure B-1 shows a plot of the original profile, the average profile and the difference between these two profiles.

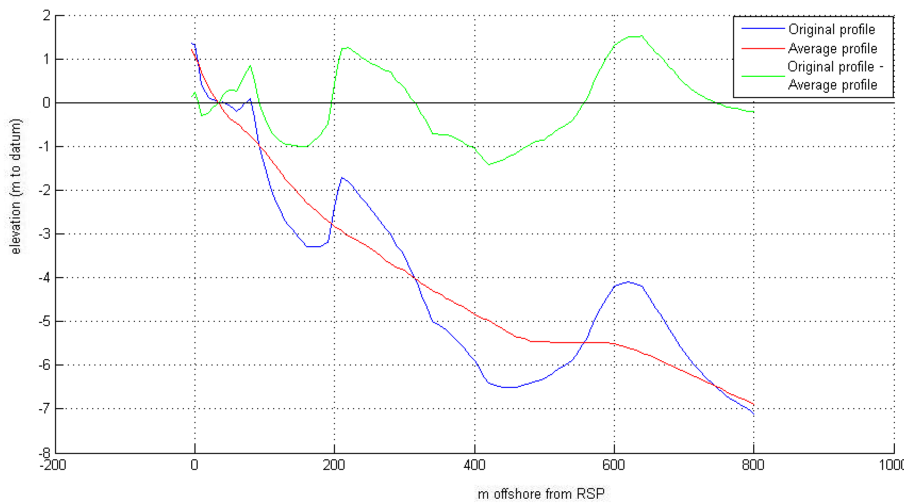


Figure B-1: Difference between surveyed profile and average profile

The green line in Figure B-1 shows that there are 3 bars in the profile. The location of a bar crest is defined by the single highest point of a bar. The offshore position of the bar crests is located by collecting local maxima in the subtracted profile (the green line in Figure B-1).

The local maxima are taken from a 100m stretch of the profile. The first stretch starts at the maximum offshore data point (so usually this is from 700 m to 800 m offshore of RSP). For the second stretch both the upper and lower boundary of the 100 m stretch move 20 m landward. Every situation gives a maximum elevation of the profile above the average profile.

Figure B-2 shows 3 steps of a random profile to illustrate this process. The blue line represents the elevation of the profile above the average profile, the grey area is the area in which the 100 m stretch lies and the red dot indicates the local maximum elevation. Figure B-2A shows a local maximum on the slope of the bar, not the maximum elevation of the bar. The 100 m stretch in Figure B-2B lies 60 m landward of the 100 m stretch in Figure B-2A (so this shot is taken 3 steps after the first shot). The local maximum here is the bar crest. In Figure B-2C the 100 m stretch is 5 steps (100 m) further landward from the previous step. Here, again, the local maximum is found on the slope of the bar.

To identify the real crests from all found maximums, a maximum is considered a crest if the two adjacent maximums have a lower elevation from the average profile than its own elevation. In the case of Figure B-2, this means that the position of the second maximum is the only one considered a bar crest and stored for further use (max1 < max2 > max3).

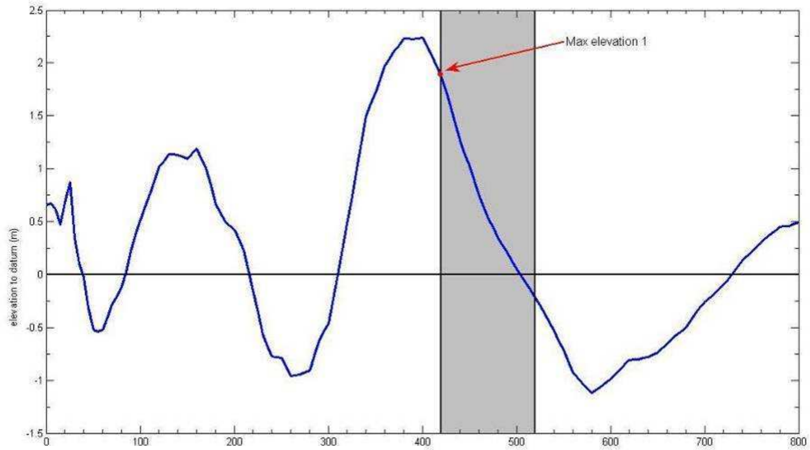


Figure B-2A: Maximum 1

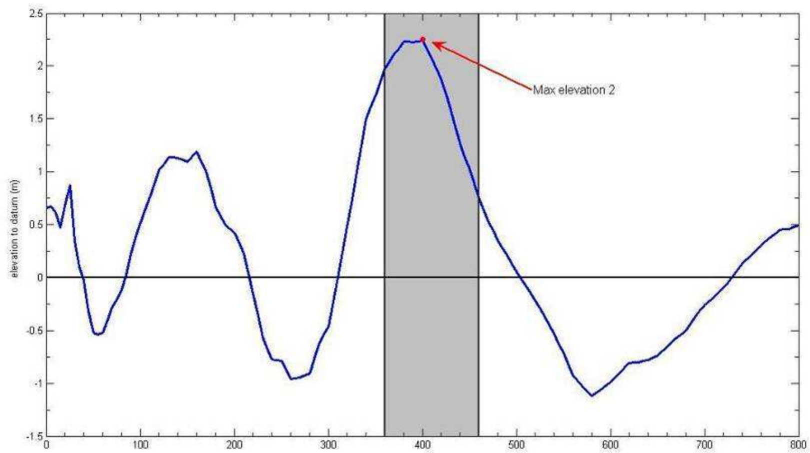


Figure B-2B: Maximum 2

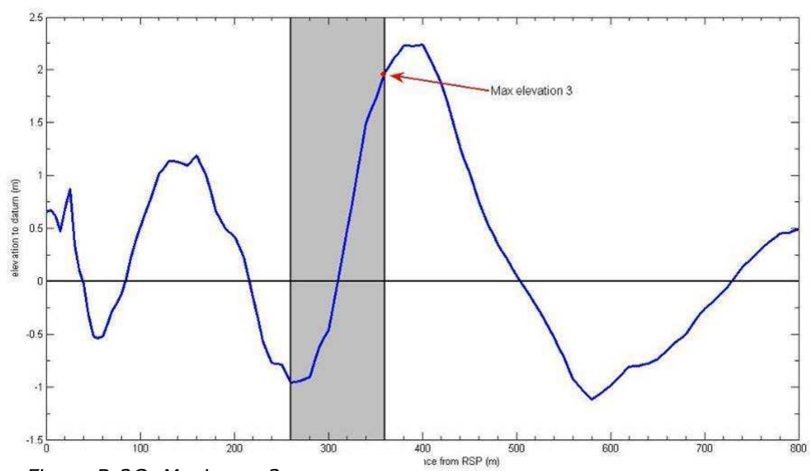


Figure B-2C: Maximum 3

Figure B-2: Locating bar crests

Once all bars have been identified, the entire lifespan of a bar can be constructed. Figure B-3 shows all profiles from 1965 to 2006 for transect 40.75. In this figure the breaker bars are clearly visible, and the seaward movement in time is also visible.

To get a better view of the seaward movement, the offshore location of the bar is plotted against the date of the measurement. From this plot the so-called bar lines are constructed. The locations of the bar crests of the first year are compared with the location of the bar crests of the second year. If the crests are close to each other, they will be identified as the same crest. In this way a bar line is constructed. There is a danger that the bar moves with such a speed that the next year, the bar is considered too far or the wrong bar is identified as the same bar. Another fault can occur if one year a barcrest isn't identified, this will break a bar line into 2 bar lines, this will give problems with the storing of the lines, and because of the storing problems it will give problems with the further processing of the data. These will give a wrong output, because of this, all lines have to be checked and, if necessary, corrected manually. Figure B-3 is the first, uncorrected, output for transect 40.75. The location of the breaker bars is symbolized with a dot, while the blue lines show the movement of a single bar in time (a bar line).

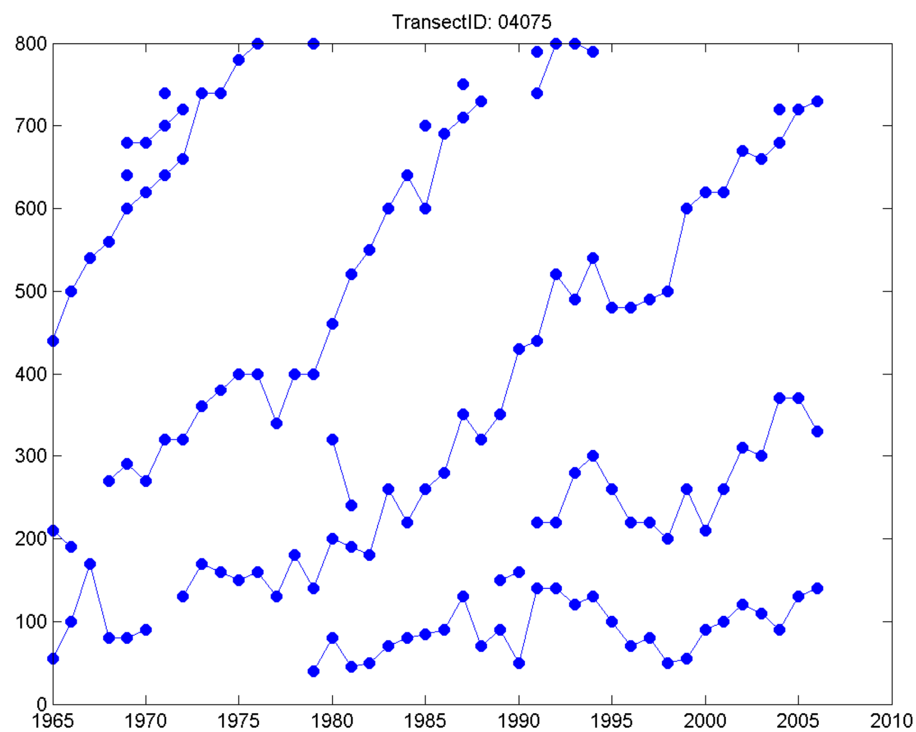


Figure B-3: Bar lines, original output, transect 40.75

It can be seen that the plot makes sense for most of the points. But still some measurements seem to miss (the outer bar in 1989 and 1990), and some maximums are identified as bars, that logically can't be part of the system of the breaker bars (the line between the points (1980, 300) and (1981, 230)). To get a useful result, all the odd points in the figure need to be checked manually. This is done using the yearly plots of the bar crest locations. The profile for 1990 is given in Figure B-4, together with the average profile and the difference.

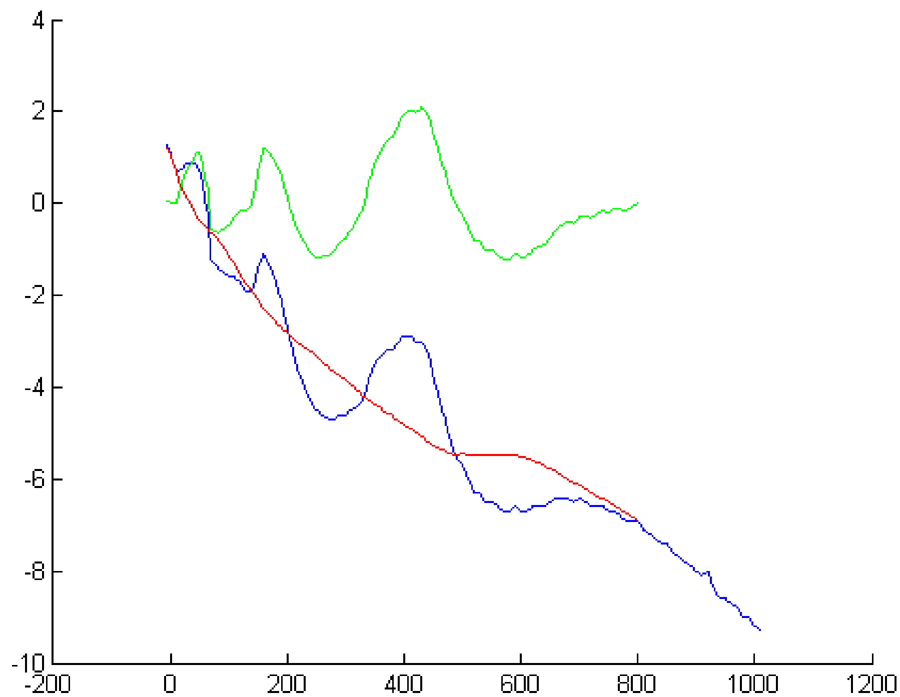


Figure B-4: Original and average profile (transect 40.75, year 1990)

The outer bar is still visible, but because the height of the bar is below the average profile, it is not identified as a bar crest. Since there is a visible bar, and the location of the crest is verifiable, the location of the crest is inserted manually. In some cases the location of the crest is not verifiable, but from the bar lines it is visible that the bar hasn't damped out yet, in that case there is no value inserted, but the bar line is extended through the year and connected with the next year. Figure B-5 gives the plot of transect 40.75 for the years 1979, 1980 and 1981, the identified bar crests are presented by the blue dots. In 1979, the end of the measurements is identified as a maximum, this isn't the location of the barcrest, which seems to lie beyond the extent of the measurements, for now this point will be used for the construction of a bar line. In the plot of 1980, there seem to be 2 middle bars. But since in the years before there is only one middle bar, there can be only one crest used for the construction of the bar line. In cases like this, the profile is compared with the adjacent points of the bar line and the profiles itself, the point most likely to represent the same bar as the one that is present in the rest of the bar line is chosen. For 1980, the left point of the 2 middle bars is taken as the real bar crest, because it fits the bar line the best of the 2 points. In 1981 both points fit the bar line quite good, but the most right point of the two seems to represent the barcrest the best in the profile, so this point is chosen as the real barcrest

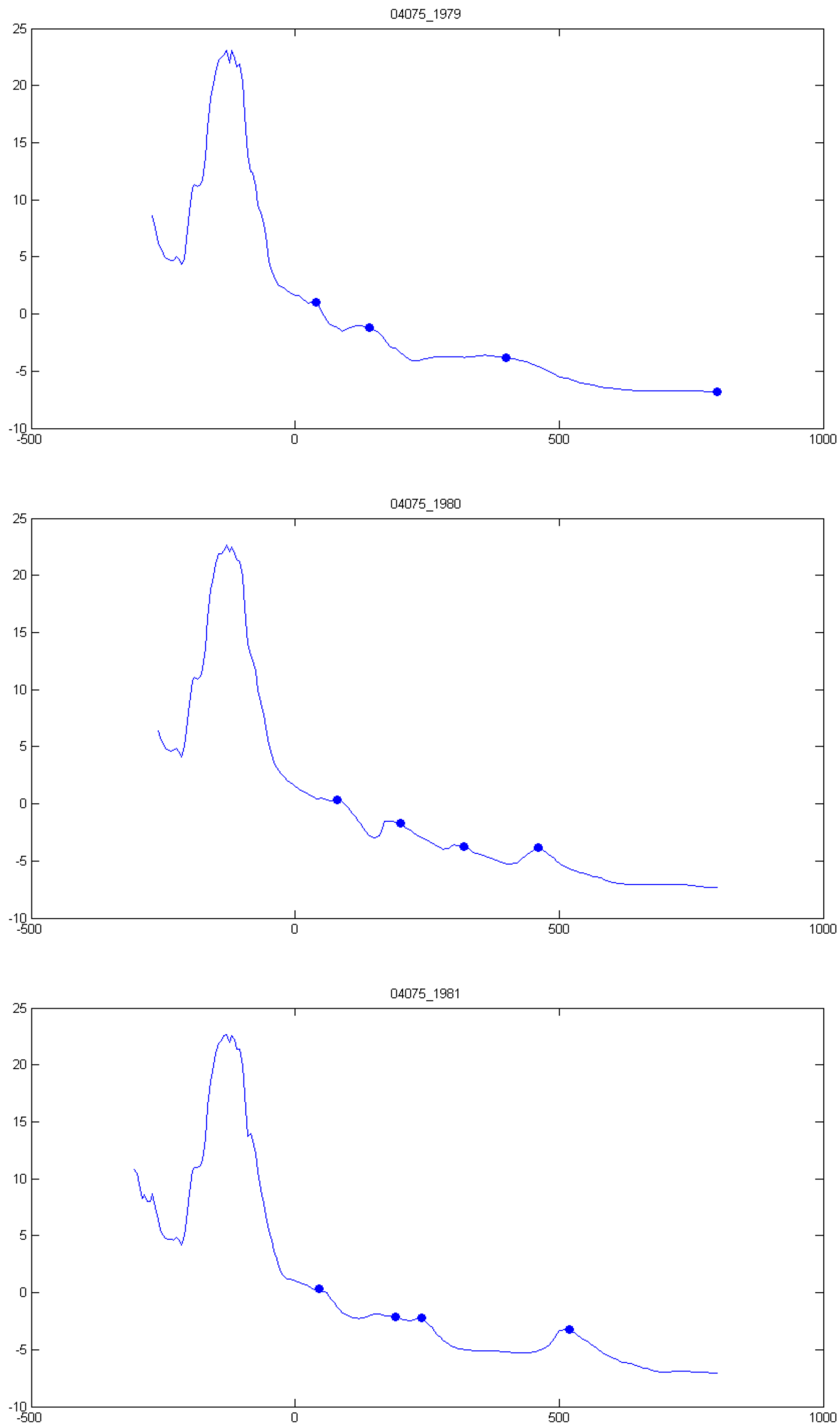


Figure B-5: Original output for the positions of bar crests (transect 40.75, years 1979, 1980, 1981)

Once all odd points are checked, the new, correct, bar lines can be constructed, by joining the old ones and inserting the new points. The corrected bar lines are plotted in Figure B-6. From these lines it can be seen that indeed as written in Section 2.2.2, the average cycle time (the time between two bars crossing a point) seems to be somewhere near the predicted 12-15 years (Wijnberg, 1995).

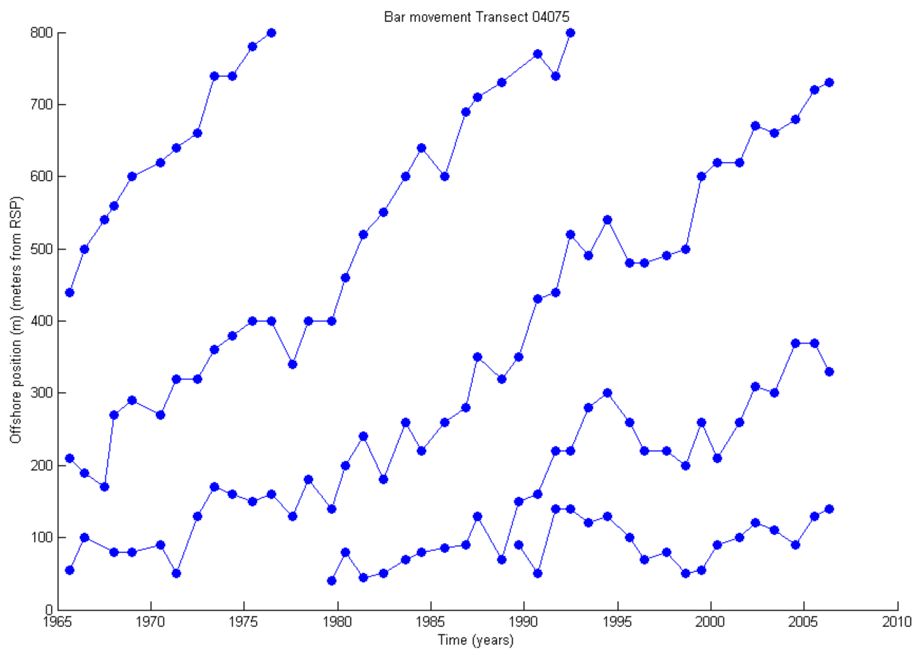


Figure B-6: Corrected bar lines, transect 40.75

Appendix C Nourishments along the Holland coast

Table C-1 is an overview all nourishments placed along the Holland coast in the period 1965–2006, sorted by transect, starting at Den Helder (= km 0). The last column shows any possible stretches without nourishment during this period.

Table C-1: Nourishments along the Holland coast.

start transect	end transect	start month	Start year	end month	end year	Volume ($x10^3$ m3)	Stretch without nourishment?
0.17	0.87	04	2001	06	2001	197	-
0.30	15.00	04	2005	06	2005	1000	-
0.40	0.85	05	1971	11	1971	206	-
0.84	3.19	01	1990	12	1990	415	-
0.84	3.19	01	1990	12	1990	15	-
0.95	6.42	01	1999	12	1999	560	-
1.00	2.60	04	2000	06	2000	401.002	-
1.00	7.50	08	1992	05	1993	615.527	-
1.16	2.10	03	2003	06	2003	61.912	-
1.20	3.00	05	1997	06	1997	510.804	-
1.35	4.05	04	2004	11	2004	502.353	-
1.46	1.71	01	1971	12	1971		-
1.50	7.50	08	1996	09	1996	400	-
1.50	5.68	06	2001	07	2001	1290.24	-
1.50	5.88	03	2003	05	2003	1305.46	-
1.59	1.90	01	1994	12	1994	89	-
1.60	2.20	06	1979	09	1979	300	-
1.80	2.20	01	1973	12	1973	210	-
1.89	3.08	08	1989	10	1989	227	-
1.89	3.08	08	1989	10	1989	245	-
1.89	3.08	08	1989	10	1989	926	-
2.00	3.20	05	2004	07	2004	390	-
2.00	3.60	01	2000	02	2000	524.47	-
2.00	3.00	01	1996	12	1996	130	-
2.10	3.80	01	1996	12	1996	435	-
2.20	3.65	05	1993	05	1993	411	-
2.40	3.12	05	1993	05	1993	90	-
2.59	2.93	01	1994	12	1994		-
2.60	4.20	04	2001	06	2001	168	-
2.90	3.52	07	1997	11	1997	185	-
3.27	4.77	03	2003	06	2003	201.847	-
3.28	5.68	05	1993	05	1993	280	-
3.67	6.43	01	1995	12	1995	818	-
3.95	6.28	01	1999	03	1999	287.48	-
4.00	6.00	01	1970	12	1970	200	-
4.85	5.50	05	1993	05	1993	225	-
5.07	5.70	04	2001	06	2001	52	-

start transect	end transect	start month	Start year	end month	end year	Volume ($x10^3$ m3)	Stretch without nourishment?
5.30	6.02	09	1989	11	1989	437	-
5.30	6.02	09	1989	11	1989		-
5.75	9.75	11	1977	10	1979	1600	-
6.00	10.02	11	2001	01	2002	1000	-
6.00	7.50	01	1978	12	1978		-
6.41	10.54	08	2000	10	2000	1100	-
6.50	10.02	10	1997	10	1997	2724.11	-
7.00	11.00	01	2000	12	2000		-
7.00	10.15	05	1996	12	1996	2045.2	-
7.00	8.30	12	1998	02	1999	1266.25	-
7.20	11.20	06	1996	09	1996	1554.51	-
7.50	10.00	04	2005	06	2005	1728.1	-
7.81	10.02	11	2000	02	2001	600.19	-
8.00	8.80	01	1974	12	1974		-
8.00	14.00	01	1984	12	1984	3400	-
8.00	9.20	04	2001	06	2001	132	-
8.06	9.18	01	1994	12	1994	348	-
8.80	10.63	09	2005	10	2005	301.384	-
8.80	12.50	10	1977	12	1977	1045	-
8.80	12.50	10	1977	12	1977	55	-
8.80	10.86	02	2000	03	2000	322.529	-
8.80	10.70	04	2004	11	2004	399.164	-
8.90	10.50	01	1996	12	1996	464	-
9.00	11.48	02	2003	08	2003	1213.1	-
9.00	10.40	01	1991	12	1991	100	-
9.00	9.40	01	1973	12	1973		-
9.01	10.11	09	1992	12	1992	1150	-
9.13	9.43	08	2003	08	2003	12.243	-
9.25	10.75	01	1998	12	1998	745.376	-
9.30	12.10	04	1994	05	1994	761.204	-
9.35	10.40	06	1993	07	1993	287	-
9.40	13.70	07	2003	11	2003	1430	-
9.40	13.40	05	1987	05	1987	3000	-
9.50	10.45	04	1984	04	1984	150	-
9.60	10.40	01	1973	12	1973		-
9.60	16.00	05	2005	06	2005	795.114	-
9.75	11.25	04	1978	06	1979	2000	-
9.94	15.33	03	2003	06	2003	125.22	-
10.00	16.00	10	1980	12	1980	2200	-
10.00	14.00	05	1999	06	1999	144	-
10.00	16.00	02	2003	05	2003	2572.64	-
10.00	17.00	01	2006	12	2006	1600	-
10.00	10.30	01	1990	12	1990	20	-
10.01	11.90	04	2000	06	2000	357.02	-
10.01	12.13	05	1996	06	1996	459	-
10.25	12.00	01	1994	12	1994	505.678	-
10.25	11.50	01	2004	12	2004		-
10.25	12.75	01	2004	12	2004	920	-

start transect	end transect	start month	Start year	end month	end year	Volume (x10^3 m3)	Stretch without nourishment?
10.37	11.78	04	1998	09	1998	314.045	-
10.38	11.43	01	1997	12	1997	340.038	-
10.40	11.10	11	1990	12	1990	368	-
10.40	11.10	11	1990	12	1990		-
10.40	11.10	11	1990	12	1990	270	-
10.45	11.30	04	2001	06	2001	123	-
10.50	12.50	01	1973	12	1973	250	-
10.57	13.46	01	1994	12	1994	560.4	-
10.60	13.60	01	1973	12	1973		-
10.68	10.92	01	1975	12	1975		-
10.83	13.73	08	1986	10	1986	1242.43	-
11.00	16.00	01	2006	12	2006	1000	-
11.00	14.00	05	1991	06	1991	538.404	-
11.08	14.01	06	2001	10	2001	1499.94	-
11.10	13.75	06	2003	07	2003	438.155	-
11.10	13.74	06	2004	07	2004	216.655	-
11.15	12.80	01	1979	12	1979	470	-
11.25	13.45	03	1988	06	1988	936.38	-
11.50	12.80	07	1992	09	1992	230	-
11.50	19.60	07	1992	09	1992	1442	-
11.50	13.40	01	1979	12	1979	150	-
11.58	12.83	01	1996	12	1996	733	-
11.60	14.40	10	1983	12	1983	440	-
11.75	12.05	08	1986	10	1986	77.913	-
11.80	13.60	04	1993	05	1993	160	-
11.84	17.27	07	1991	12	1991	2672.98	-
12.00	13.40	04	2001	06	2001	258	-
12.10	18.13	04	1993	07	1993	2245.23	-
12.20	14.10	05	1996	06	1996	459	-
12.40	17.00	08	1990	09	1990	930	-
12.50	12.70	03	1988	06	1988	93	-
12.60	15.20	01	1974	12	1974	150	-
12.60	13.60	04	1974	04	1974	110	-
12.60	13.60	09	1974	12	1974	110	-
12.62	12.62	01	1984	12	1984		km 12.62 - 12.80
12.80	14.30	01	1992	12	1992	637	-
12.98	13.75	09	1976	09	1976	342	-
12.98	16.44	04	2000	06	2000	701.731	-
13.00	21.00	04	1998	09	1998	2498.13	-
13.00	17.00	01	2006	12	2006	1500	-
13.00	15.00	01	1968	12	1968	800	-
13.20	15.60	04	1987	06	1987	1974	-
13.20	15.60	04	1987	06	1987		-
13.30	14.30	10	1990	11	1990	319	-
13.30	14.30	10	1990	11	1990	319	-
13.30	14.30	10	1990	11	1990	54.5	-
13.52	16.90	06	2005	09	2005	2600	-

start transect	end transect	start month	Start year	end month	end year	Volume ($x10^3$ m3)	Stretch without nourishment?
13.53	14.60	01	1997	03	1997	95	-
13.54	14.87	11	1992	12	1992	67	-
13.63	14.12	01	1979	12	1979		-
13.63	14.17	10	1994	11	1994	91	-
13.70	18.10	04	1993	11	1993	2000	-
13.76	18.10	04	1987	09	1987	1695	-
13.80	15.20	08	1990	09	1990	40	-
13.80	14.80	01	1974	12	1974		-
14.00	17.00	01	2006	12	2006	1000	-
14.00	14.01	01	1999	12	1999		km 14.01 - 14.06
14.06	18.83	01	2000	04	2000	886.127	-
14.30	15.85	01	1993	04	1993	318	-
14.33	16.05	01	1994	12	1994	453	-
14.40	15.40	06	1986	06	1986	1000	-
14.50	17.50	10	1973	02	1974	2300	-
14.50	17.50	10	1973	02	1974	1000	-
14.50	17.50	04	1977	07	1977	1267	-
14.50	17.50	08	1984	12	1984	330	-
14.50	17.50	05	1985	09	1985	530	-
14.65	18.85	04	2004	11	2004	777.565	-
14.70	17.84	04	1987	09	1987	155	-
14.75	17.25	01	1971	12	1971		-
14.81	15.83	04	1989	05	1989	201.258	-
14.81	15.83	04	1989	05	1989	9.272	-
14.81	15.83	01	1990	12	1990	245.517	-
15.00	16.00	01	1970	12	1970		-
15.00	17.00	01	1966	12	1966	150	-
15.01	16.01	11	1969	03	1970	401	-
15.01	16.01	05	1971	09	1971	610	-
15.26	18.73	06	1996	08	1996	1490.56	-
15.30	15.50	01	1987	12	1987		-
15.50	18.75	03	2005	04	2005	1150.64	-
15.64	17.42	01	1992	12	1992		-
15.98	17.28	03	2003	06	2003	870.237	-
16.12	17.35	01	1990	12	1990		-
16.20	17.20	01	1999	12	1999	105	-
16.24	17.60	09	1995	10	1995	306.84	-
16.26	16.88	01	2000	12	2000	120	-
16.37	17.32	01	1996	12	1996		-
16.48	17.35	09	1986	09	1986	200	-
16.48	17.35	09	1986	09	1986	25	-
16.50	17.25	01	1972	12	1972	100	-
16.86	18.89	01	1995	12	1995	550	-
17.00	23.00	03	2002	11	2002	5396.83	-
17.00	23.00	01	2006	12	2006	1500	-
17.00	17.41	04	1975	04	1975	112	-
17.03	18.33	04	2000	06	2000	245.223	-

start transect	end transect	start month	Start year	end month	end year	Volume ($x10^3$ m3)	Stretch without nourishment?
17.95	23.00	01	1986	12	1986	1300	-
18.00	20.18	09	1991	10	1991	371.418	-
18.13	24.00	07	1984	12	1984	3021.12	-
18.13	23.40	04	1991	09	1991	2008.9	-
18.14	21.85	01	1987	12	1987		-
18.27	20.35	04	2002	07	2002	500.561	-
18.50	19.00	01	1976	12	1976	50	-
18.75	19.00	01	1972	12	1972	100	-
18.78	20.91	01	1997	12	1997	658.846	-
18.80	20.40	09	1995	10	1995	361.74	-
19.25	20.50	10	1998	11	1998	228.901	-
19.83	20.58	06	2003	06	2003	230.577	-
19.83	20.58	06	2004	06	2004	98.953	km 20.58 - 21.80
21.80	25.90	01	1991	12	1991	788	-
21.85	27.07	04	1997	05	1997	700	-
21.90	23.80	09	2001	09	2001	393	-
22.00	35.00	01	2006	12	2006	1400	-
22.11	23.40	06	1996	08	1996	493.317	-
22.45	23.58	05	1988	10	1988	532.36	-
22.50	23.50	01	1991	12	1991		-
22.55	23.54	01	1988	12	1988	230	-
22.75	23.56	05	1984	06	1984	90	-
23.25	23.49	05	1975	05	1975		-
23.25	23.54	01	1988	12	1988	75	-
23.25	23.54	01	1988	12	1988	18.5	km 23.54 - 23.645
23.65	24.94	01	1990	12	1990	105	-
23.80	25.50	09	2001	09	2001	462	-
24.19	24.19	01	1988	12	1988	25	km 24.186 - 24.70
24.70	26.85	09	2005	11	2005	2557.81	-
24.70	25.30	01	2006	12	2006	1000	-
24.80	25.80	01	1988	12	1988	153	-
24.85	25.84	05	1988	10	1988		-
25.10	27.90	06	2004	09	2004	2400	-
25.40	30.40	06	1985	09	1985	2849.72	-
25.40	28.20	05	1994	08	1994	1331.23	-
25.40	27.10	03	2001	04	2001	354	-
25.50	27.80	07	2000	09	2000	883.683	-
25.50	26.02	01	1995	12	1995	54	-
25.60	31.20	09	1979	11	1979	3089.67	-
25.60	30.61	06	1990	11	1990	2543.02	-
25.62	26.41	08	2003	09	2003	357.788	-
25.65	26.41	09	2004	10	2004	194.955	-
25.93	27.83	01	1992	12	1992	192	-
26.00	28.60	07	1999	10	1999	1219.17	-
26.00	30.05	06	1997	07	1997	547	-

start transect	end transect	start month	Start year	end month	end year	Volume ($x10^3$ m3)	Stretch without nourishment?
26.20	38.50	05	1992	11	1992	1472.64	-
26.50	30.00	06	2002	10	2002	1972.27	-
27.63	29.57	03	1993	10	1993	619	-
28.20	29.60	04	1995	05	1995	835	-
28.20	33.95	04	1998	06	1998	563.55	-
28.32	30.00	06	2001	07	2001	511.127	-
29.40	34.75	02	2002	04	2002	1130	-
29.50	29.70	03	1987	03	1987	30	km 29.70 - 29.825
29.83	33.06	01	1995	12	1995	463	-
30.00	30.60	01	1995	12	1995	300	-
30.05	31.05	06	1997	06	1997	132.69	-
30.50	31.68	03	1993	10	1993		-
31.05	33.50	06	1998	06	1998	352	-
31.50	36.20	08	2005	09	2005	1500	-
31.60	34.63	01	1992	12	1992	169	-
32.25	33.75	05	1990	06	1990	385.774	-
32.25	33.75	05	1990	06	1990	60	-
32.25	34.25	04	2000	08	2000	994	-
32.50	33.75	04	1999	05	1999	205.793	-
32.50	33.75	04	2005	04	2005	300	-
32.60	33.40	01	1952	12	1952	775	-
32.63	33.63	05	1995	05	1995	306	-
32.75	33.25	06	2000	06	2000	225	-
32.90	33.50	06	1994	06	1994	100.683	-
33.15	33.75	09	2004	11	2004	67.117	km 33.75 - 33.93
33.93	34.70	03	1997	03	1997	125	-
34.00	34.40	04	1952	10	1952	50	-
34.00	34.40	01	1966	03	1966	32	-
34.00	34.40	01	1975	12	1975	45	-
34.00	34.58	01	1991	12	1991		-
34.50	35.75	05	1997	05	1997	158	km 35.75 - 36.20
36.20	40.20	06	2004	11	2004	1606.06	-
36.25	38.80	05	1997	05	1997	314	-
36.90	39.10	06	1999	09	1999	880.1	-
37.00	38.50	05	1990	05	1990	323.318	-
37.00	39.25	04	2005	05	2005	500	-
37.25	38.75	05	1995	05	1995	306	-
37.25	38.75	04	1999	04	1999	214.515	-
37.50	38.75	06	1998	07	1998	244.442	-
37.65	38.60	09	1992	11	1992	69.225	-
37.85	38.20	06	1994	06	1994	106.343	-
38.00	38.80	06	2000	07	2000	207.445	km 38.8 - 46.20
46.20	48.50	04	2001	08	2001	1000	-

start transect	end transect	start month	Start year	end month	end year	Volume ($x10^3$ m3)	Stretch without nourishment?
46.50	48.50	05	2005	06	2005	500	-
46.72	48.44	06	1997	10	1997	279.621	km 48.44 - 48.60
48.60	49.60	07	1994	10	1994	190	-
48.60	50.20	06	2005	09	2005	1159.15	-
48.90	50.10	04	2001	08	2001	500	-
49.65	50.43	02	1997	03	1997	304.45	-
50.43	51.00	10	1996	11	1996	180.05	km 51.00 - 53.70
53.70	54.40	06	1995	10	1995	111	-
53.70	54.40	06	1995	10	1995	80	-
53.70	54.40	06	1995	10	1995		-
53.70	54.40	06	1995	10	1995		-
53.74	54.60	01	1991	12	1991		km 54.60 – 57.00
57.00	57.00	01	1962	12	1967	1500	km 57.00 - 60.50
60.50	63.35	09	1993	05	1994	255.076	-
61.50	63.50	09	1998	10	1998	193.378	-
61.50	64.50	05	2001	06	2001	603.63	-
62.00	63.25	08	1990	10	1990	261.682	-
62.50	62.75	01	1962	12	1962		-
62.75	65.75	11	2004	01	2005		-
65.00	67.30	05	1994	06	1994	334.147	-
65.75	67.75	10	2004	12	2004	891.644	-
66.00	67.50	09	1998	10	1998		-
66.25	67.50	05	2001	05	2001	248.093	km 67.50 – 73.00
73.00	80.00	04	2002	12	2002	3000	km 80.00 - 80.50
80.50	83.50	01	1998	04	1998	1266.03	-
81.50	89.00	01	2006	12	2006	750	-
87.50	89.50	09	1998	02	1999	753.35	-
89.00	97.00	01	2006	12	2006	1000	-
91.00	93.50	01	1996	12	1996	500	-
91.00	97.00	02	2002	12	2002	3000	-
94.00	96.50	01	1997	12	1997	552.8	-
94.25	96.25	01	1994	12	1994	700	km 96.25 – 97.00
97.00	101.00	01	1996	12	1996	800	-
97.73	100.50	02	1999	06	1999	1425.78	-
97.81	101.39	02	1991	05	1991	1005.7	-
98.50	101.50	04	1975	08	1975	700	-
98.75	101.25	03	1985	04	1985	250	-
98.75	101.25	03	1985	04	1985	80	-
99.00	101.00	01	1981	12	1981	10	-
99.00	101.00	01	1982	12	1982	15.4	-
99.00	101.00	01	1987	12	1987	8	-

start transect	end transect	start month	Start year	end month	end year	Volume (x10^3 m3)	Stretch without nourishment?
99.30	101.10	01	2004	12	2004	778.5	-
100.00	101.50	09	1969	10	1969	45	-
100.50	101.50	01	1953	12	1953	70	km 101.50 - 106.23
106.23	112.21	06	1993	07	1993	1143	-
107.40	112.50	03	2001	11	2001	3581.9	-
107.50	112.50	01	1997	12	1997	834	-
107.73	115.61	05	1986	10	1986	1900	-
107.73	115.61	05	1986	10	1986	1300	-
107.73	113.19	09	2003	11	2003	1252.8	-
107.73	113.19	01	2004	12	2004	1150	-
108.00	112.00	04	2001	06	2001	801.178	-
108.00	113.00	10	2005	11	2005	1014.36	-
112.21	114.50	05	1995	06	1995	300	-
113.15	114.85	08	1997	11	1997	1028.95	-
114.00	118.75	03	1993	04	1993	463	-
115.70	118.75	01	1971	12	1971	18940	-
115.70	119.00	01	1976	12	1976	1500	-
115.70	118.75	01	1977	12	1977	870	-
117.00	118.00	01	1998	12	1998		-
117.00	118.00	01	2002	12	2002		-
117.50	118.50	01	2000	12	2000	200	-
117.50	118.50	01	2001	12	2001		-
117.50	118.50	01	2003	12	2003	213.606	-
117.50	118.50	01	2004	12	2004	230	-
117.75	118.75	01	1990	12	1990	183	-
117.75	118.75	01	1991	12	1991	223	-
117.75	118.75	01	1992	12	1992	560	-
117.75	118.75	01	1994	12	1994	200	-
117.75	118.75	01	1995	12	1995	200	-
117.75	118.75	01	1996	12	1996	200	-
117.75	118.75	01	1997	12	1997	200	-
117.75	118.50	01	1999	12	1999	200.68	-
118.00	118.50	01	1988	12	1988	200	-
118.00		01	1989	12	1989	100	-

Appendix D Average polynomial fit

The best fit for the average polynomial is found by trial and error. As starting point the average curve is moved towards the bar line, so that the average y-value of the bar line and the average y-value of the curve are the same. From this point on, 2 more polynomials are constructed, 1 that lies one year to the right of the average curve and one that lies one year to the left. For all 3 curves the RMS-error of the curve and the bar crests is calculated. For the next step, the curve with the smallest rms-error will be the start curve. From that start curve again 2 new curves are produced, one to the left and one to the right. If the start curve is the curve with the smallest RMS-error of the 3 curves, the space between the startcurve and the 2 new curves will be half the size of the space between the curves one step ago. If one of the 2 new curves has the smallest rms-error, the space between the curves will stay the same, but the start curve will change. This procedure is repeated until the space between 2 curves is smaller than 0.1 year. Figure D-1 gives the simplified structure of this procedure.

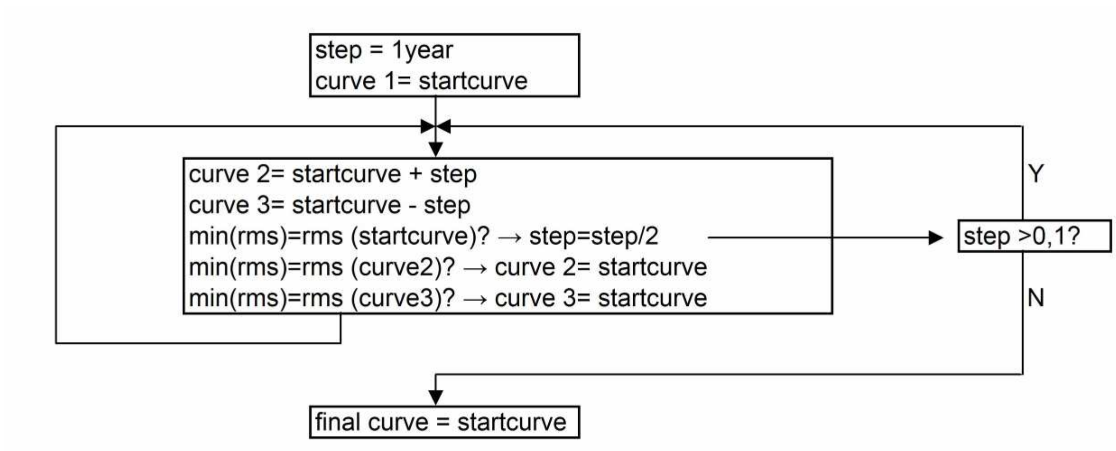


Figure D-1: Structure of fitting the average polynomials.

Appendix E Average polynomial coefficients

This appendix gives the coefficients a, b and c of the average fitted polynomials with the equation: $p = at^2 + bt + c$

Table E-1 gives the coefficients as plotted in Figure 4-5 for transect 40.75 and 40.50. The numbers 1 to 5 correspond to the breaker bars of Figure 4-5 from left to right.

Table E-2 gives the coefficients for the average polynomials of the other 4 transects analysed in this thesis in region 3 of the Holland coast (transects 40.50, 41.00, 45.25 and 45.75). Here only the 2 polynomials of the breaker bars used to calculate the cycle time are given.

Table E-1: Coefficients of the average fitted polynomials; transects 40.75, 45.50

		coefficient		
	Bar	A	B	C
Transect 40.75	1	0.2711	-1042.5	1002300
	2	0.2711	-1051.2	1019000
	3	0.2711	-1059.3	1034900
	4	0.2711	-1066.7	1049300
	5	0.2711	-1074.4	1064600
Transect 45.50	1	0.4405	-1705.7	1651300
	2	0.4405	-1720.3	1679700
	3	0.4405	-1728.3	1695400
	4	0.4405	-1740.2	1718800
	5	0.4405	-1758.4	1755000

Table E-2: Coefficients of the average fitted polynomials; four transects

Transect	Bar	coefficient		
		A	B	C
40.50	1	0.1764	-678.44	652200
	2	0.1764	-683.72	662390
41.00	1	0.3118	-1201.8	1158400
	2	0.3118	-1211.8	1177600
45.25	1	0.3084	-1187.8	1143600
	2	0.3084	-1197.9	1163100
45.75	1	0.5345	-2074.2	2012600
	2	0.5345	-2092.5	2048200

Appendix F Errors in JARKUS surveys.

This appendix shows the profiles of the deleted surveys of the following transects:

- 40.50, 40.75 and 41.00; page 127
- 45.25, 45.50 and 45.75; page 131
- 70.50; page 133

F.1 Transects 40.50, 40.75 and 41.00

The profiles that are deleted from the database of transects 40.50, 40.75 and 41.00 are:

Transect:	40.50	deleted years:	1992 and 1993
	40.75		1992 and 1993
	41.00		1992 and 1993

The errors are explained below on the basis of plots of the profile, together with a plot of a profile of the same transect which is free of errors.

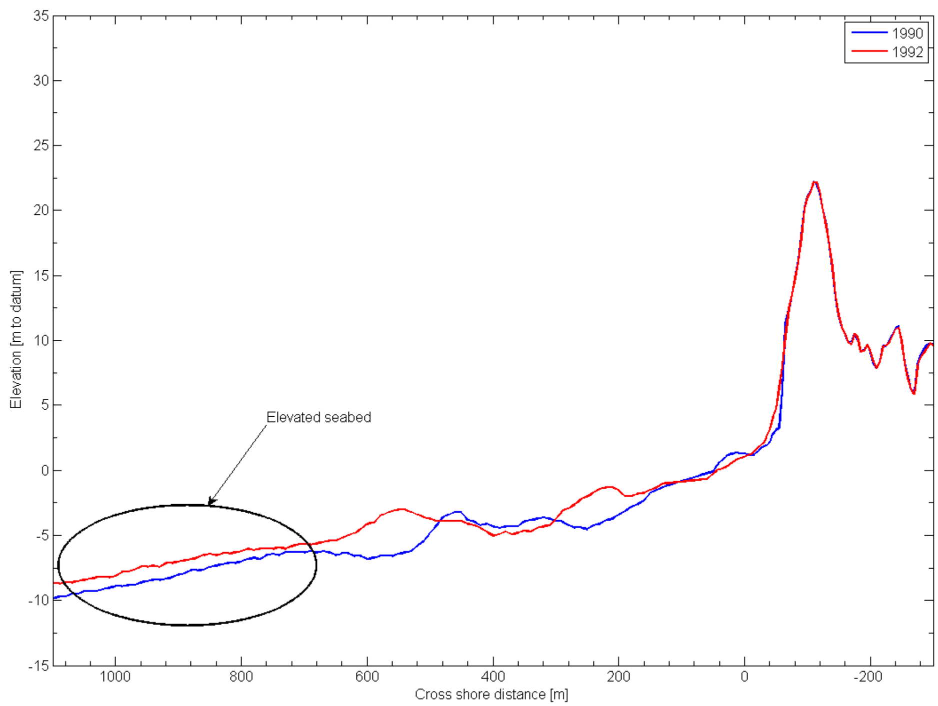


Figure F-1: Transect 40.50, profiles 1990 and 1992

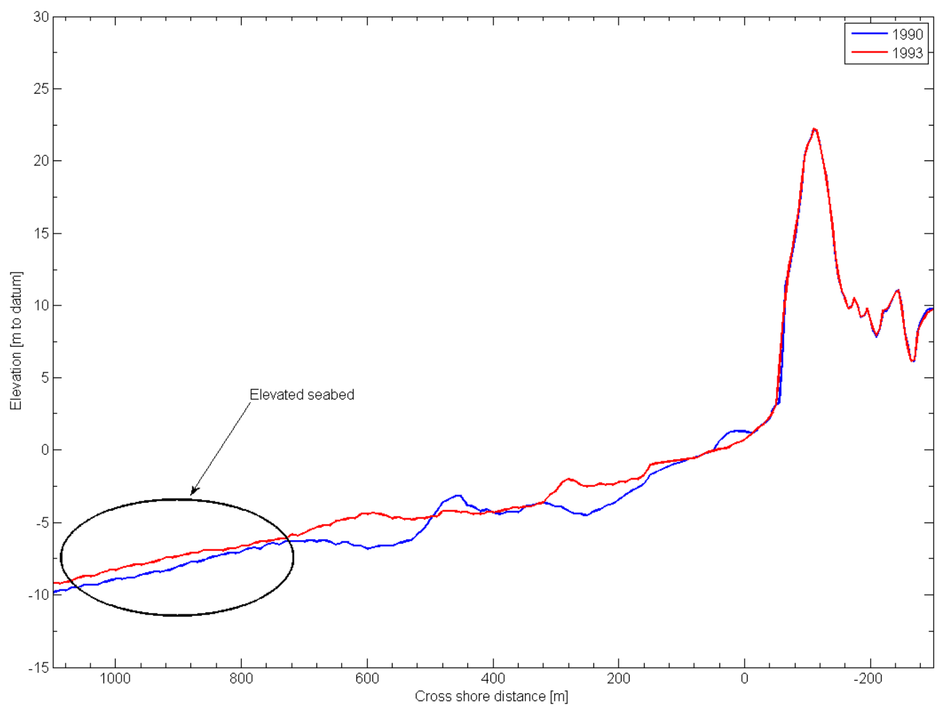


Figure F-2: Transect 40.50, profiles 1990 and 1993

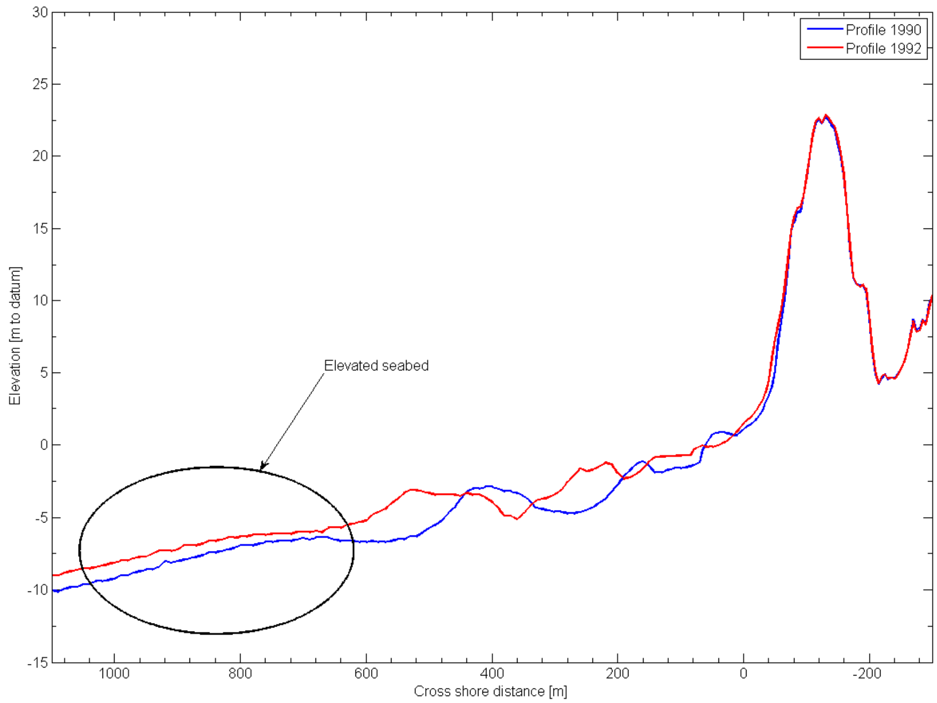


Figure F-3: Transect 40.75, profiles 1990 and 1992

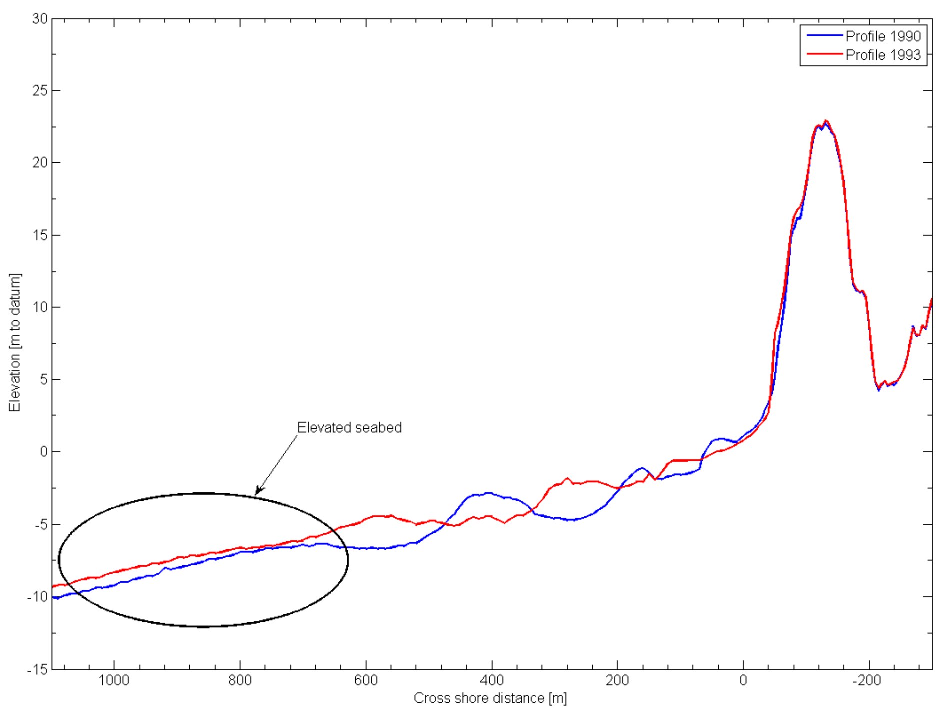


Figure F-4: Transect 40.75, profiles 1990 and 1993

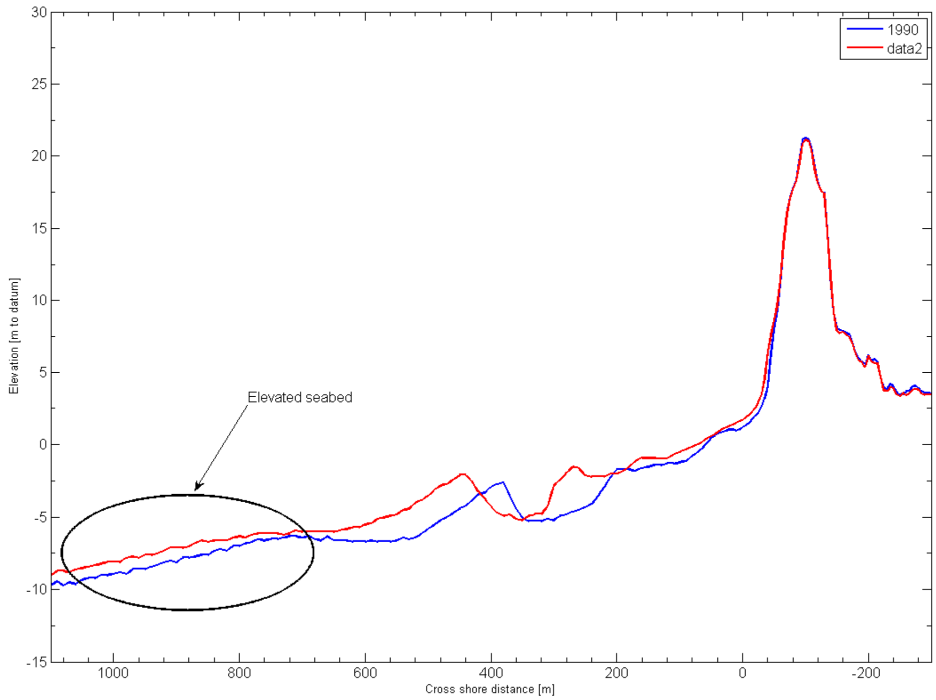


Figure F-5: Transect 41.00, profiles 1990 and 1992

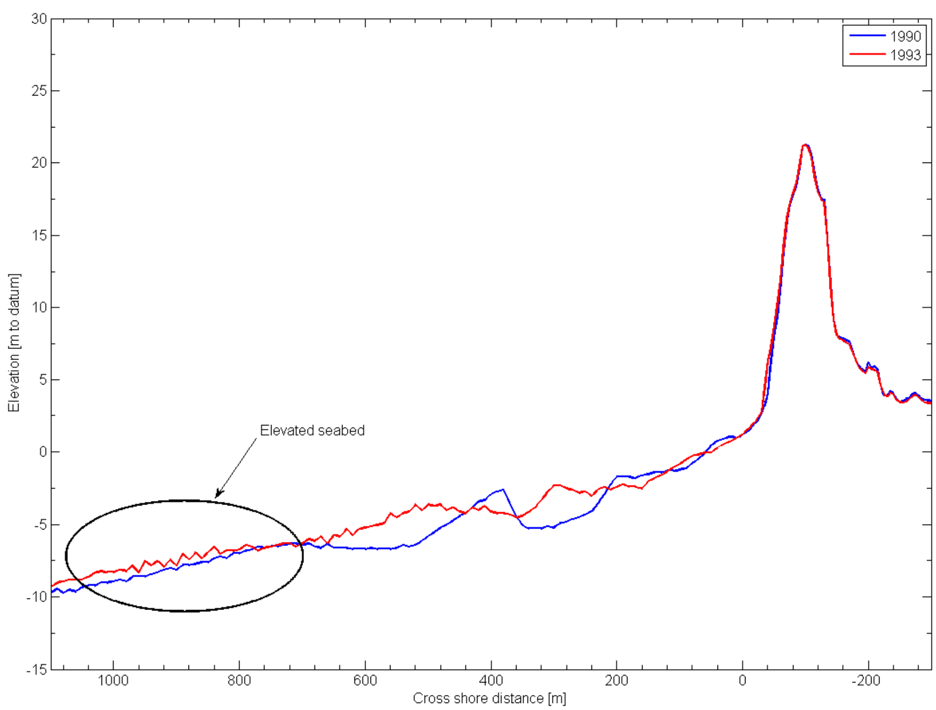


Figure F-6: Transect 41.00, profiles 1990 and 1993

F.2 Transects 45.25, 45.50 and 45.75

The profiles that are deleted from the database of transects 45.25, 45.50 and 45.75 are:

Transect:	45.25	deleted years:	1992 and 1993
	45.50		2006
	45.75		none

The errors are explained below on the basis of plots of the profile, together with a plot of a plot of a profile of the same transect which is free of errors.

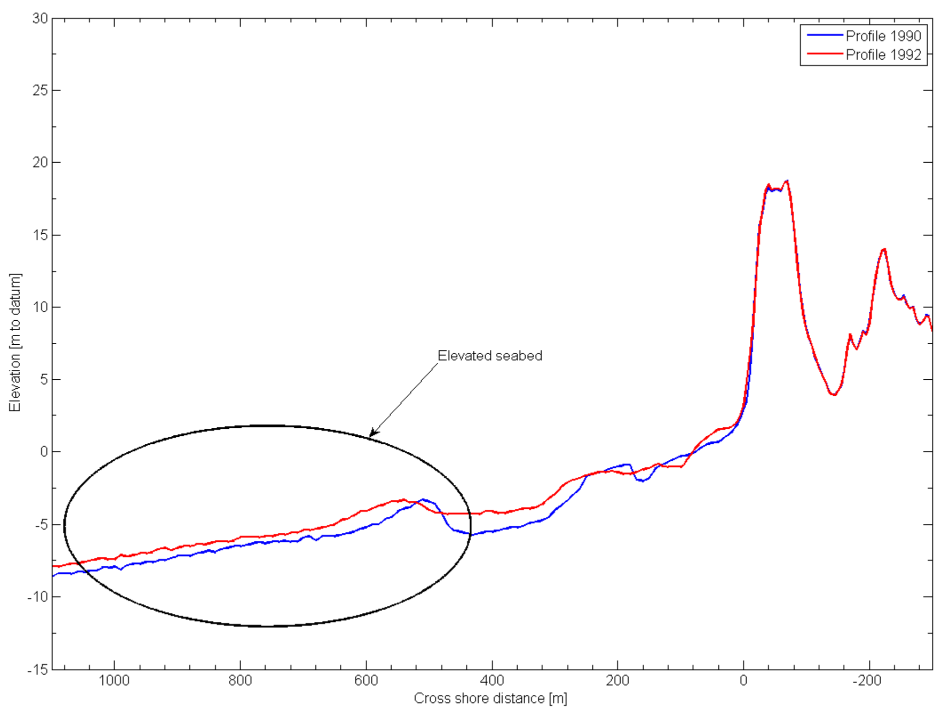


Figure F-7: Transect 45.25, profiles 1990 and 1992

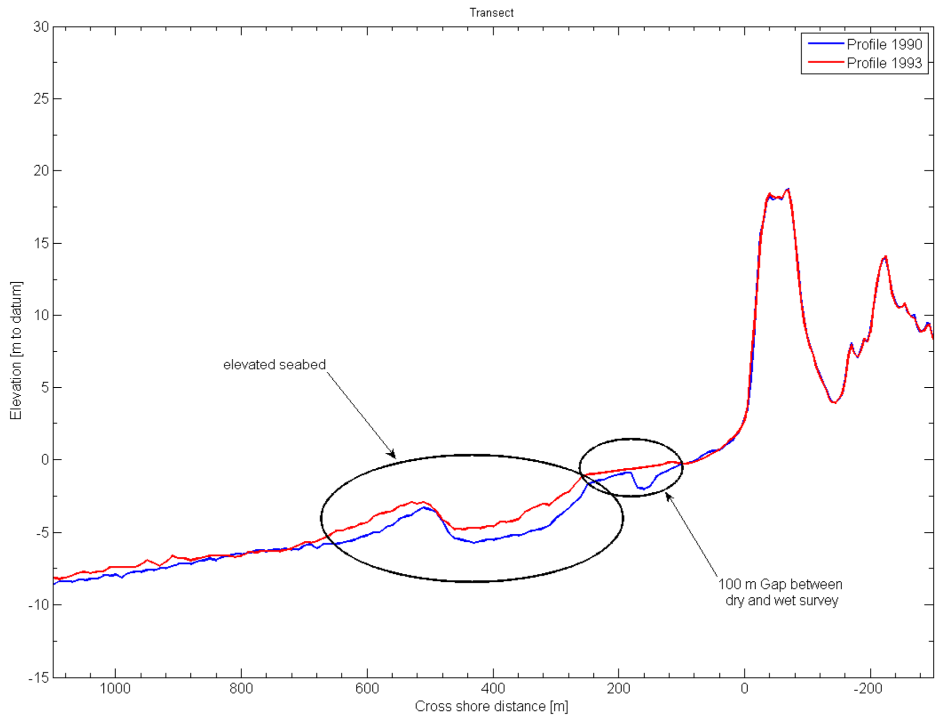


Figure F-8: Transect 45.25, profiles 1990 and 1993

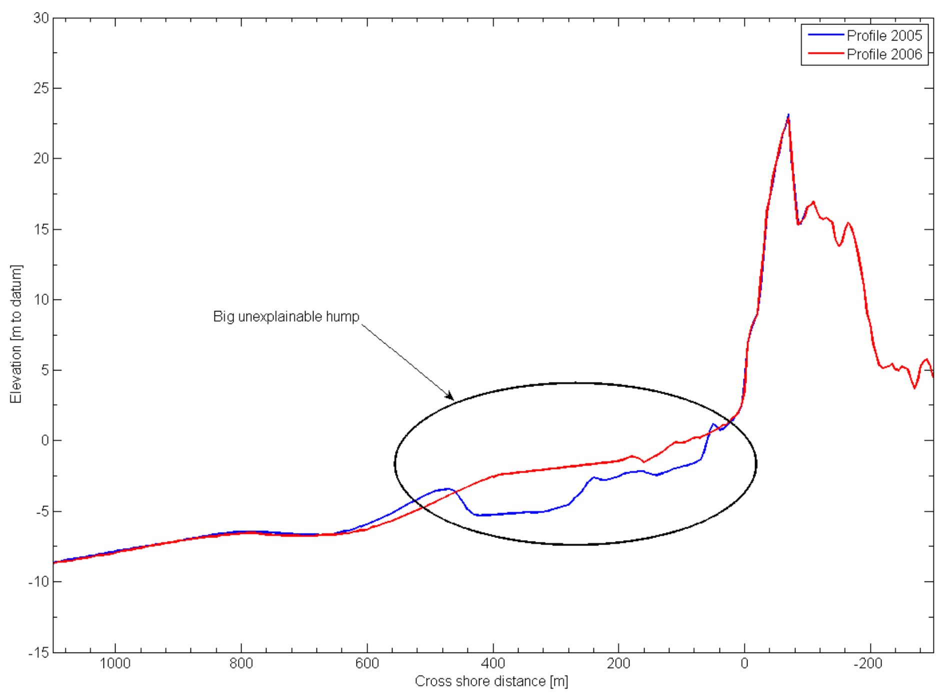


Figure F-9: Transect 45.50, profiles 2005 and 2006

F.3 Transect 70.50

The years 1985, 1987 and 1988 are deleted from the database of transect 70.50 because no data of the wet survey in these years is available. The data in the original database of these years is identical to the data of 1984 and 1986 respectively.

The years 1997 and 2002 are deleted from the database because no data of the dry survey in these years is available. The data in the original database of these years is identical to the data of 1996 and 2001 respectively.

The remaining profiles that are deleted are 1989, 1990, 1991, 1992, 1993 and 1994. Some of these errors are errors because the seabed of the profile is clearly lower than the seabed of the other profiles of the database. The other errors are caused by a gap between the dry and the wet measurements. This gap is filled with a straight line in the database. This line causes abnormal values of the profile volumes.

The errors are explained below on the basis of plots of the profile. If the error is caused by a reduced seabed, the profile is plotted together with a plot of the profile of 1986, which is free of errors.

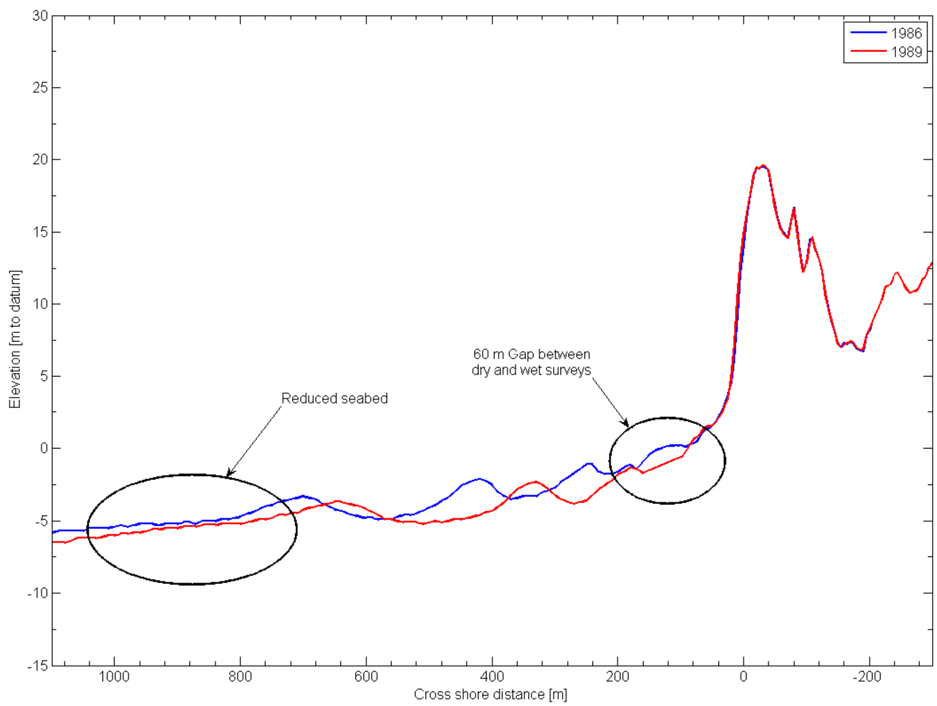


Figure F-10: Transect 70.50, profiles 1986 and 1989

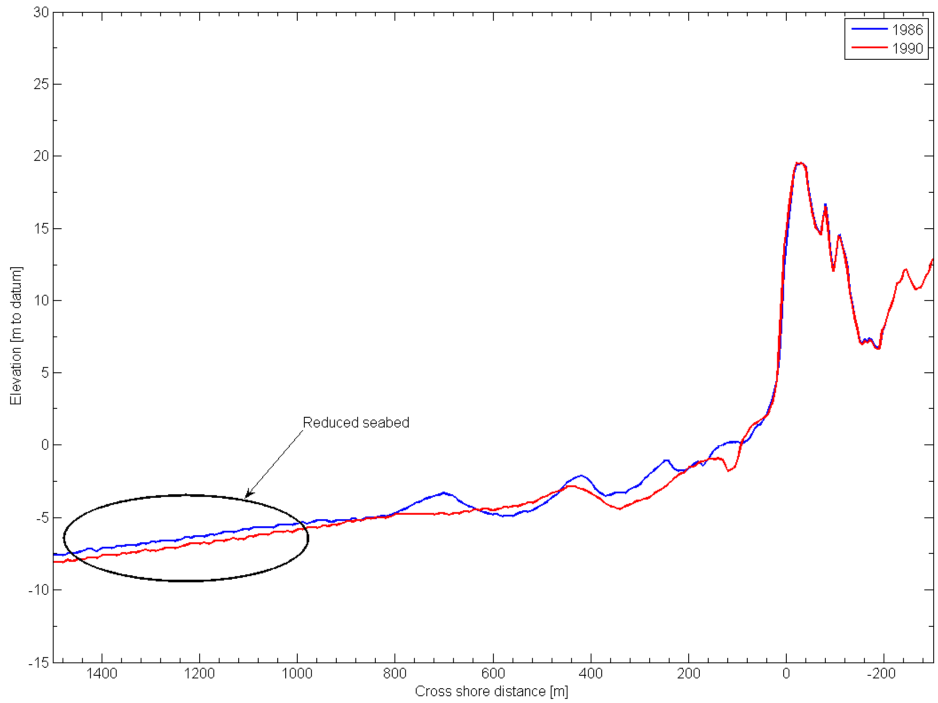


Figure F-11: Transect 70.50, profiles 1986 and 1990

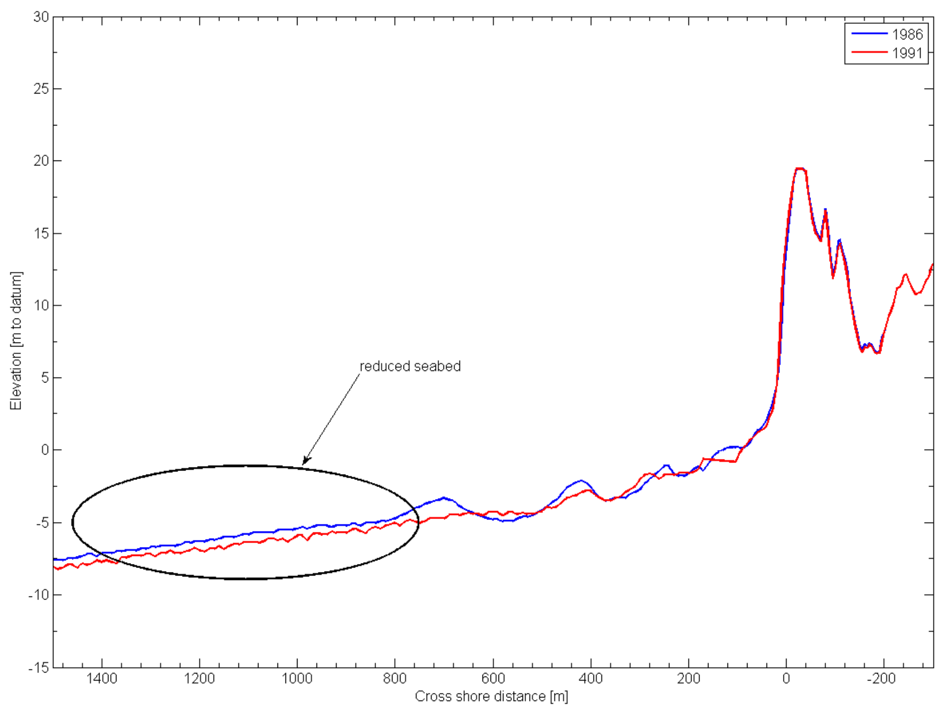


Figure F-12: Transect 70.50, profiles 1986 and 1991

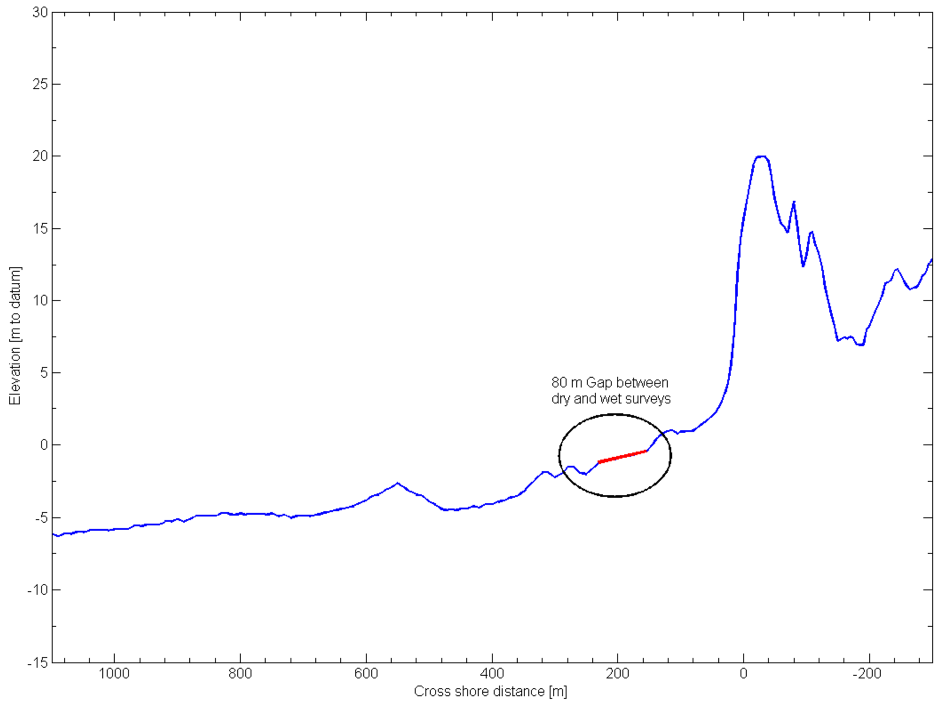


Figure F-13: Error in transect 70.50, 1992

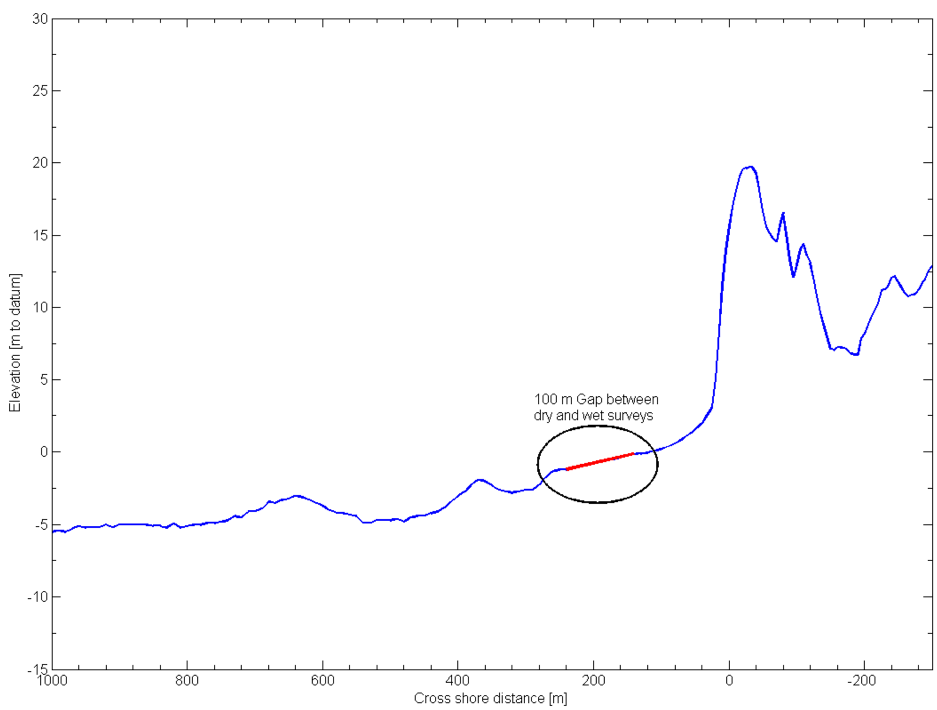


Figure F-14: Error in transect 70.50, 1993

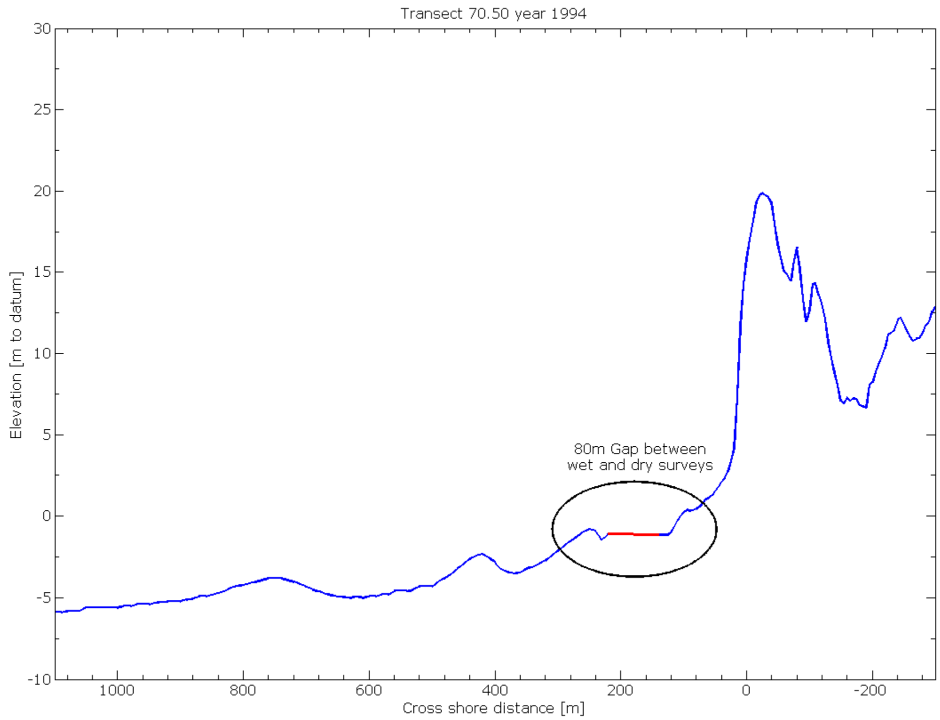


Figure F-15: Error in transect 70.50, 1994

Appendix G Dunefoot dynamics

The analysis of the waterline movement showed a movement of the dunefoot position in time which seemed to have a periodic pattern. The Figure of the waterline movement in time in transect 40.75 (as well as the movement of the NAP +1 m, NAP +2 m and the dunefoot) is plotted again in Figure G-1 The yellow dots represent the dunefoot position, on first sight they seem to move in a periodic pattern around the trend line. Jeuken et al. (2001) stated that it is plausible that there is a relation between the breaker bar movement and the dunefoot dynamics and recommend further research.

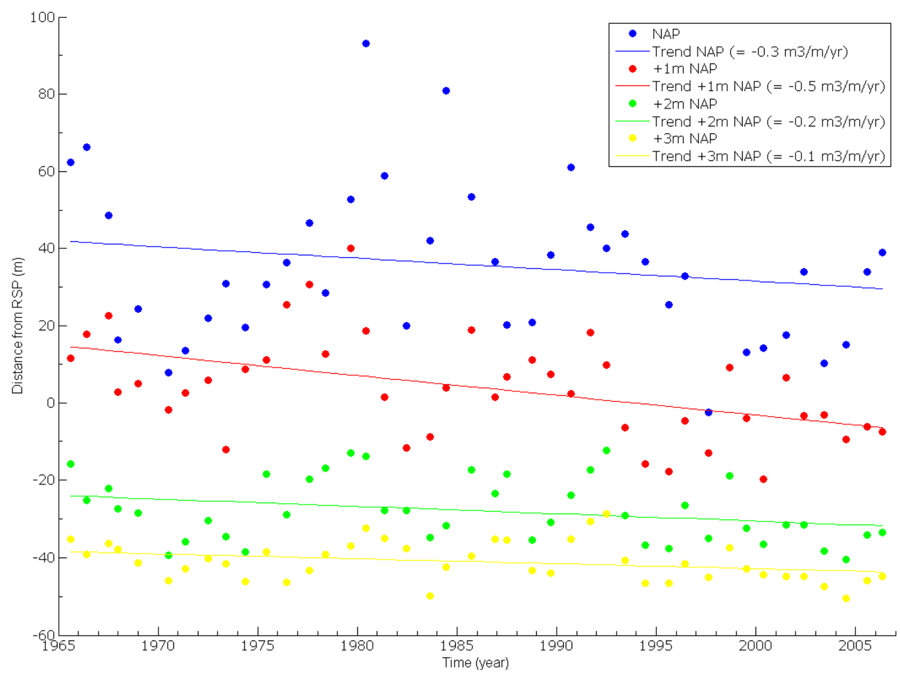


Figure G-1: Waterline movement in transect 40.75

The yellow dots represent the dunefoot position, on first sight they seem to move in a periodic pattern around the trend line. To see if there is a relation, a sine function with free amplitude and phase and a period equal to the cycle time of the breaker bars in the transect (with a 2 year margin) is plotted to the residues of the dunefoot position. Now the relative RMS-error can be calculated to find an indication for the relation of Jeuken et al. (2001). Figure G-2 shows the best fitted sine function and the residues. The relative RMS-errors per period are given in Table G-1.

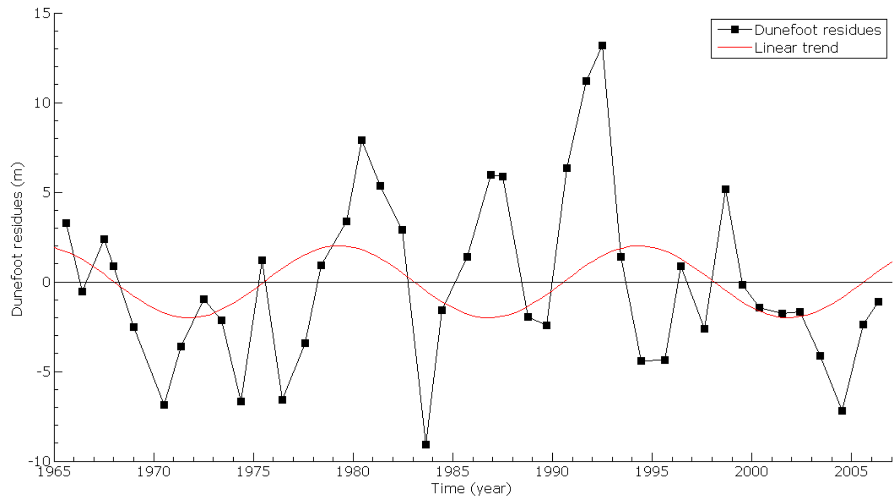


Figure G-2: Best fit sine function for the dunefoot residues of transect 40.75

From Figure G-2 it can be seen that the dunefoot has a variation of approximately 25 m and that the best fit sine function has an amplitude of 2 m.

Table G-1: Relative RMS-errors for best fit sine functions and dunefoot residues in transect 40.75

Transect	original period (year)	relative rms-error (%) period (years + original period)								
		-2	-1.5	-1	-0.5	0	0.5	1	1.5	2
40.75	15.0	97	97	96	96	**96**	96	97	97	98

The relative RMS-errors in Table G-1 vary between 96% and 98%. Therefore a sinusoidal relation between the dunefoot dynamics and the cycle time of the breaker bars in transect 40.75 doesn't seem to exist.

If the period of the sine function is not restricted to the cycle times of the breaker bars, the relative RMS-error is reduced to 73% with a period of 32.5 year.

Since the results of transect 40.75 are so obvious, no other transect have been analysed on this subject.

To see if there is a relation between the position of the breaker bars and the dunefoot, a more thorough research is needed.

Appendix H Modeling the breaker bars.

Te used method to locate the breaker bars still needs a lot of manual correction, therefore it is recommended to create a new method to locate the breaker bars. This appendix describes a new method, which is still under construction, created in Matlab by the author of this thesis and is still under construction. The new method is based on the idea of modeling the breaker bars as Gaussian curves, placed on a minimum profile and is explained below, two examples are plotted in Figure H-1.

First, an average profile is created by averaging all profiles of a transect and a minimum profile is created by taking the minimum values of all profiles per data point (every 5 m). The average profile is then modeled by a fitted 2nd order curve. Now for every profile, the difference profile is calculated by taking the difference between the measured data and the 2nd order polynomial. The minimum profile is modeled by a 3rd order polynomial and will serve as a base for every modeled profile.

In this difference profile, the zero points are located with:

```
if (residues(i2)>=0 && residues(i2+1)<=0) ||
   (residues(i2)<=0 && residues(i2+1)>=0

      count=count+1;
      idzeropointsTemp(count)=i2;
end
```

Here ‘residues’ stands for the difference profile and ‘idzeropoints’ is a vector which collects the location of the zero points.

The areas between the zero points is then checked to see if it’s a trough or a bar by collecting the minimum and the maximum value of the area. If the absolute value of the minimum value is bigger than the absolute value of the maximum value the area is stored as a trough, if it’s the other way round, the area is stored as bar.

On top of this minimum profile, the modelled bars are placed. The bars are modeled as a Gaussian profile with the form:

$$f(x) = A \cdot e^{-\frac{(x-\mu)^2}{2\sigma^2}} \qquad [5]$$

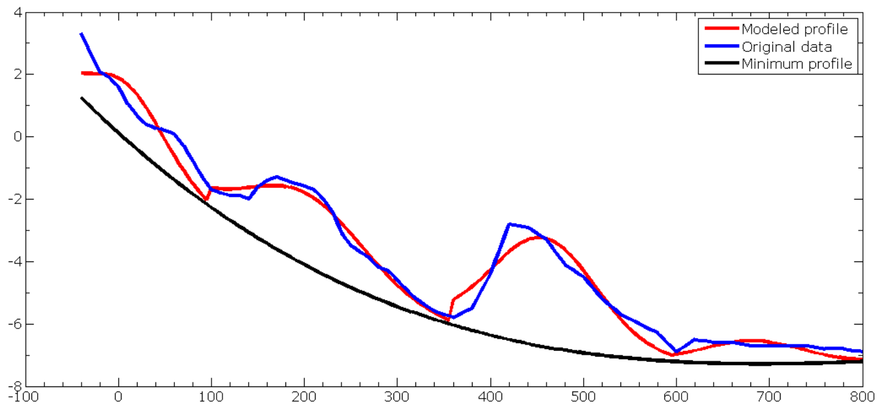
Where:

- f = bar profile
- A = Maximum bar elevation
- x = position from RSP
- μ = position of the peak
- σ = width factor

The Gaussian bars are placed between 2 successive minimum values of a trough and for every single bar a new unique Gaussian bar is modeled. For this modeling, bars are created with 3 degrees of freedom, A, μ and σ. The combination of these three degrees of freedom with the lowest RMS-error between the measured data and the modelled data is considered the best fitted bar.

The input consists of the number of the desired transect, the landward, and the seaward boundary with respect to RSP.
The output gives a file with the original and the modelled data for all profiles of a transect, which can be plotted per profile.

The big advantage of this method over the method used in this thesis is that this method smoothens the profile, so the data gives no extra, non-existing, bars.



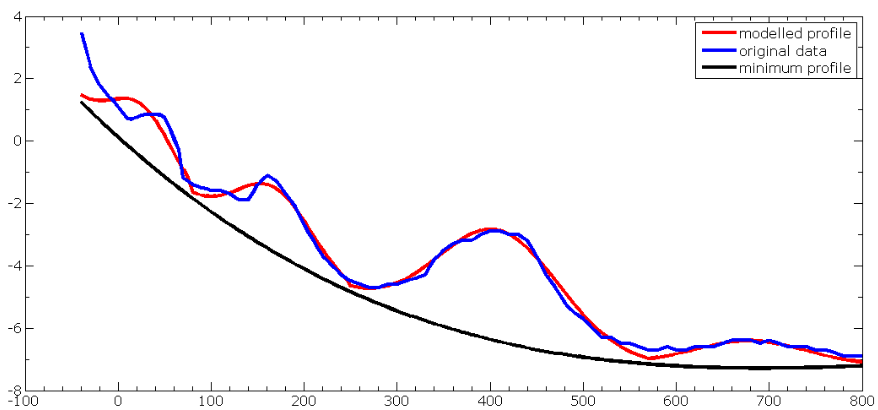


Figure H-1: Modelled profiles, transect 40.75; years 1965 and 1990.