COADAPT

- Analysis of local high water dune erosion by use of the dune erosion model X-Beach

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Chapter 1

Introduction

Previous investigation into events of extreme dune erosion along Denmark's west coast has been carried out for the period of 1977 to 2011 (Danish Coastal Authority, 2013). This investigation identified many extreme erosion events but offered no commonly applicable explanation as to their occurrence. A correlation was however found between the prevalence of offshore sand bars and a declining tendency in the size of experienced extreme dune erosion. This report investigates in close detail the significance of an offshore bar system on dune erosion.

In January 2007 there was an example of local dune erosion of more than 10 m at a 400-500 m long stretch of the coast at the southern Holmsland Tange (south of the harbour Hvide Sande), while no erosion was seen at the neighbouring stretches. Good profile survey data before and after is available along this stretch of coast in the period 2005-07.

This report firstly consists of a traditional morphological analysis of the phenomenon and secondly the use of the numerical model XBeach to simulate the resultant erosion or lack of during conditions under which the morphological changes occurred.

Chapter 2

Summary

Morphological investigation into the pre dune erosion bathymetry from 06/07/2006 (Figure 3.3.1) and the post erosion bathymetry 25/01/2007 (Figure 3.3.2) showed several differences. The bathymetric survey from before the erosion events showed a relatively regular bar system with a well defined inner bar that started out at the coastline and moved progressively offshore towards the south of the study area. This summer bathymetry also showed a straight and regular coastline without undulations. The bathymetry surveyed in January just after the erosion occurred showed a different picture. The bar system surveyed in January was much less regular offering an explanation for the irregular dune erosion. The coastline had also developed an undulation in front of the profiles that exhibited the extreme dune erosion.

XBeach was run using the significant wind, sea level and wave conditions recorded in the period between surveys. The model was run for a variety of input profiles using the July (summer) bathymetry, January (winter bathymetry) as well as profiles with the addition of theoretical sand bars. Results using the January bathymetry showed the most realistic results with the XBeach simulated erosion magnitudes comparing well to those experienced in reality. There was however a general tendency towards over estimation of beach and dune erosion. An explanation to these discrepancies could in part be found to result from the lack of long shore sediment transport and interactions in these individual profile based simulations.

This study showed that XBeach can be used to reproduce the different magnitudes of dune erosion that occur in the same area during the same storm conditions. It also highlighted the models sensitivity to the input profile; this reinforces the importance of an appropriately timed survey if the model is to be used in the future to explain extreme erosion events.

Morphological analysis

3.1 The study area and survey program

The 11 km long stretch at the southern Holmsland Tange, see Fig. 3.1 was surveyed about every 3 months in the period 2005-07. Beach surveys were carried up to 6 times a year with full bathymetric surveys at least twice a year. Full surveys of dune, beach and bathymetry were carried out with a spacing of 200m. Beach profiles were measured at a closer interval of 100m.In this study focus will be on the 1.4km stretch from profile 4013600 to 4015000 because the severe dune erosion was seen in the middle of this stretch in profiles 4014200 and 4014400. For this 1.4km stretch the bathymetries from July 2006 and January 2007 are shown in Fig. 3.3.1 and 3.3.2.

Fig 3.1 Surveyed stretch of coast with study profiles shown in green.

3.2 The dune erosion incident

The dune erosion measured as the horizontal retreat of the dune face in the level +5 - +6 m is summarized in table 3.2.1 it appears that the erosion is concentrated in 2 profiles.

Profile no.	Dune erosion (m)
4015000	0
4014800	0
4014600	0
4014400	10.4
4014200	10.4
4014000	0
4013800	0
4013600	0

Table 3.2.1 Dune erosion from December 2006 to January 2007

The possible water level and wave conditions responsible for the erosion are shown in table 3.2.2 The water levels are quite ordinary with return periods of below 1 year.

Date	Water level (m)	Wave height Hm0 (m)
01-01-2007	1.8	6.1
12-01-2007	2.1	6.0
14-01-2007	1.6	6.1
20-01-2007	1.6	5.8

Table 3.2.2 Combinations of high water levels and wave heights

3.3 Analysis of the coastal morphology

The autonomous retreat for the stretch is 1.8 m/year. Because the configuration of the bar system is crucial for the explanation of the local dune erosion, a detailed description of the bar system is given for the bathymetries before and after the dune erosion.

Bathymetry 06.07.2006 before dune erosion

Generally there are two bars in this bathymetry. The form and position of these is described in detail below.

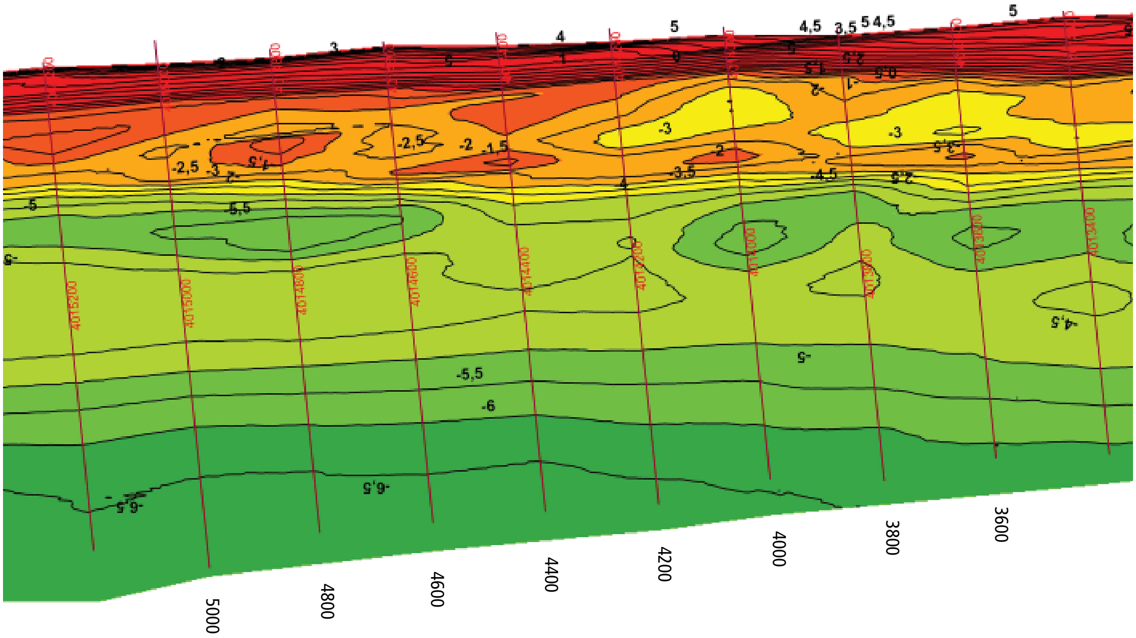


Fig. 3.3.1 Bathymetry surveyed on the 06/07/2006

Profile 4013600:
The outer bar is not very distinct with a height of only 0.9 m. The inner bar is clear with a height of 1.7 m. The water depth over this bar is 1.8 m.

Profile 4013800:
Again the outer bar is not very distinct with a height of only 1.0 m. The inner bar is not as clear as with the previous profile. The height of the inner bar is only 0.9 m and the water depth over it is 2.3 m.

Profile 4014000:
The outer bar is now 1.3 m high. The inner bar is 1.9 m high and the water depth over it is only 1.7 m.

Profile 4014200:
There is almost no outer bar, its height is only 0.3 m. The inner bar is 1.1 m high and the water depth over it is 2.2 m.

Profile 4014400:
Again the outer bar is very weak with a height of only 0.5 m. Over the inner bar the water depth is only 1.3 m and the bar height is 0.9 m.

Profile 4014600:
The outer bar is 1.3 m and the inner is 1.1 m. The water depth over the inner bar is 1.9 m.

Profile 4014800:
In this profile both bars are high. The outer bar is 1.9 m and the inner 1.6 m. There is only a water depth of 1.1 m over the inner bar.

Profile 4015000:
The outer bar is 1.5 m high and the inner is 0.5 m. The depth over the inner is 2.2 m.

Summary for this bathymetry:

The inner bar is clear in all profiles with a height between 0.9 and 1.9 m. The water depth over this bar is 1.3-2.2 m. The outer bar varies in height between 0.3 and 1.9 m. The water depth over this bar is between 4.0 and 4.6 m. The shallowest depths are seen where the bars heights are largest.

There is a tendency for the inner bar to start out at the coastline in the north of the study area and move progressively offshore as we move towards the south of the study area where it ends up being located around 160 m from the coastline.

Other observations:

When the 0 m contour line is drawn it appears that there are no undulations along the stretch as is the case for the bathymetry from 25.01.2007 just after the dune erosion.

Bathymetry 25.01.2007 after dune erosion

In this bathymetry profiles can be seen to have 1, 2 or 3 bars. The outer bar is seen in all profiles. However, the inner bar disappears in one profile and develops as two bars in two other profiles. Below is a detailed description of the position and height of the sand bars in each profile from south to north.

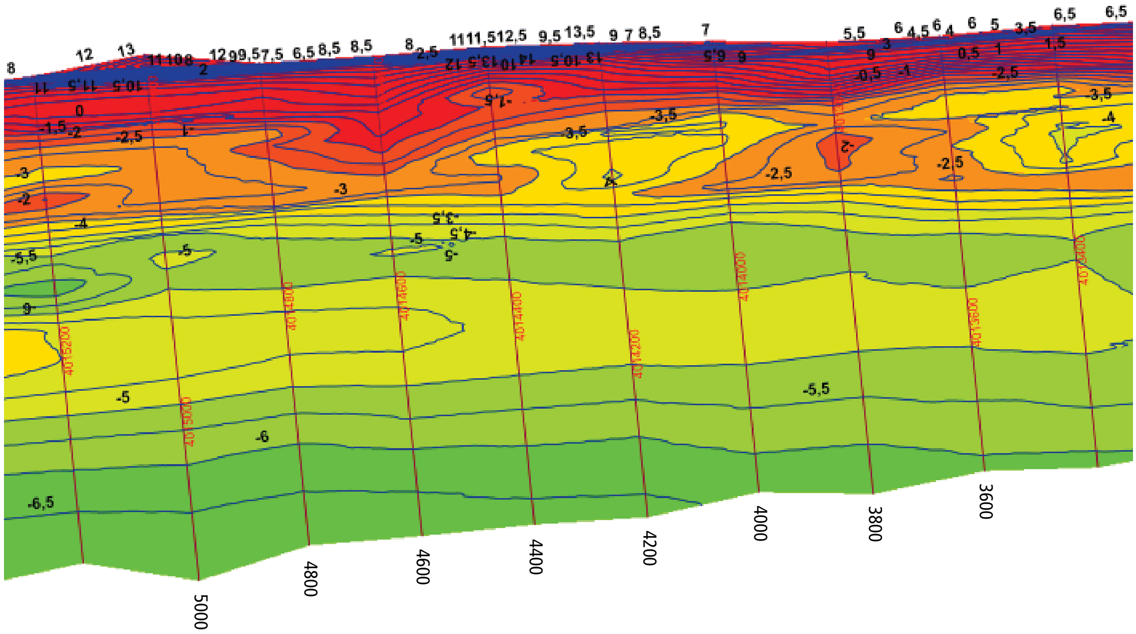


Fig. 3.3.2 Bathymetry surveyed on the 25/01/2007

Profile 4013600:

Both the outer and the inner bar are weak with heights of only 0.4 m and 0.6 m. The inner bar has developed into a double bar with an interval of 80 m.

Profile 4013800:
Again the outer bar is not very clear with a height of only 0.3 m. The inner bar is 1.1 m high and the top is rather wide. This is probably because it is about to split up into two as seen in profile 4013600.

Profile 4014000:
The outer bar is now 0.8 m high. The inner bar is 1.2 m and the water depth over the bar is 2.3 m.

Profile 4014200:
Again the outer bar is weak with a height of 0.4 m. The inner bar is 1.1 m. Inside this distinct bar there is a small trace of a bar with a height of only 0.1 m.

Profile 4014400:
Here we have three bars. The outer is 0.8 m high, the middle and the inner are both 1.0 m high.

Profile 4014600:
The outer bar is 0.8 m and the inner has disappeared.

Profile 4014800:
In this profile there are again three bars with the heights 1.0, 0.5 and 0.7 m. There is only a water depth of 1.6 m over the inner bar.

Profile 4015000:
Again three bars. The outer is 1.0 m high and the middle and inner 0.7 and 0.4 m respectively.

Summary for this bathymetry:
It is characteristic for this bathymetry that the bar zone is less regular than that of the first bathymetry. This irregularity is probably the main reason for the also very irregular dune erosion just a few weeks before the bathymetric survey.

Other observations:
When the 0 m contour line is drawn it appears that there is an inward undulation in the profiles 4014200 and 4014400, where the dune erosion occurred. The undulation has a size of 60 m when compared to the straight coastline. The coastline undulation includes the depth contours to 3 m. It has also been examined if there is an undulation on the dune face in the longshore direction but it does not seem to be the case.

3.4 Summary of the morphological analysis

There is a marked difference between the pre storm bathymetry measured in July and that measured just after the erosion events in January. The 2006.03 bathymetry shows more regular sand bars across all of the profiles and no substantial undulations. The survey taken in January 2007 just after the erosion events tells a different story. This profile shows an irregular dip in the inner bar system just in front of the two profiles where dune erosion is observed. Another observation is that the zone between the coastline and the 3 m depth contour also has an inward undulation of 60 m at the stretch in front of the same two profiles.

Both phenomena cause more wave energy at the dune foot. This is however a qualitative statement. If the increase in wave energy is enough to explain the dune erosion demands calculation. The XBeach model is used to analyse the reason for the dune erosion quantitatively.

Chapter 4

Description of XBeach model setup and input data

The following section of this report describes the use of XBeach to assess the differences between the individual cross sectional profiles. XBeach is run using wind and wave data recorded during the storm period in which the dune erosion took place.

4.1 The XBeach model

XBeach (standing for Extreme beach behaviour) is a numerical model developed by Unesco IHE, the Delft University of Technology, and Deltares, The Netherlands. XBeach has been developed as a more advanced version of previous numerical models DUROS and DUROS+ (Dano Roelvink, 2008). It is an open source program that is under constant development, for this investigation the Xbeach release from 02/11/2011 has been used as this is known from previous work to be stable and reliable. XBeach is designed to model near shore processes, dune erosion, breaching and over wash, the model incorporates time varying tide, wave and wind parameters and computes their resultant impact on a coastal profile. Further information on XBeach's inputs can be found in the XBeach Manual (Unesco-IHE Institute for Water Education, 2013).

XBeach has been tested in numerous cases and proved to provide good results particularly for complicated coastlines. There have been studies carried out comparing the performance of the new XBeach model to that of previously tested Duros models (Heijer, 2010). Real storm events have also been modelled using XBeach showing comparisons between actual results and the modelled results (Annelies Bolle, 2010). For the purposes of this investigation XBeach has been run on separate 1D profiles and not as a full 2D model so from this investigation there remains further potential to achieve a more accurate simulation and cover a combined section of coastline.

4.2 Model Runs

Due to the length of the study period between measurements (37 days) the wave and sea level data has been split up into 3 sections. Simulations are run for each storm section with the output profiles being re introduced for the next phase. The wave and sea level of these three storm sections can be seen below. Sections where sea level and wave height were low have been disregarded.

This method allows a relatively long period of sea storm conditions to be simulated, however this does not account for the periods of calmer weather where the beaches would have a chance to recover a little and build up before the next storm. This may result in a little extra dune erosion as XBeach does not simulate sedimentation.

Below the sea level and wave heights can be seen for the period between the beach survey carried out on the 19/12/2006 and the full profile survey carried out on the 25/01/2007. It can be seen that there are four clear peaks in wave height that are coupled to small rises in water level. The grey areas on the graph below show the simulated sections of this period.

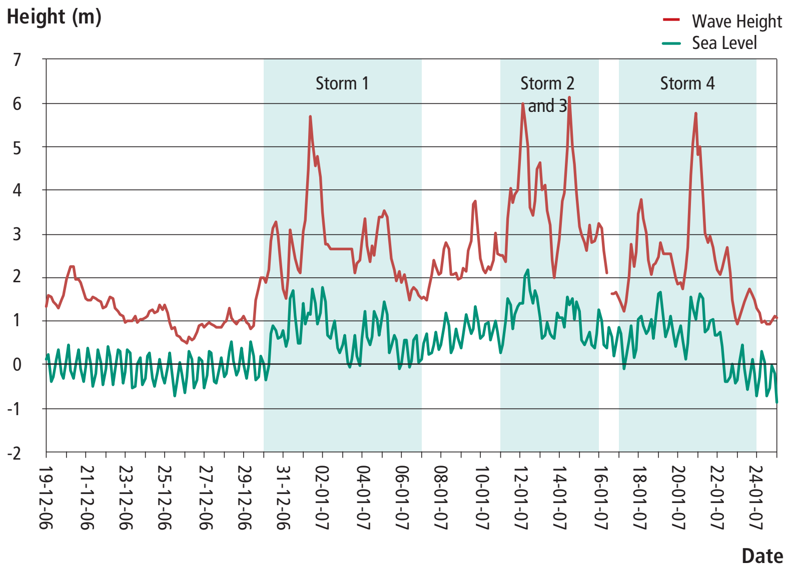


Fig. 4.2.1 Sea level and wave height conditions between profile surveys

4.2.1 Wave Data

The wave data is inputted into XBeach at an offshore boundary point. The Wave station used lies 14km offshore at a depth of 20m. The Nymindegab station is only a little south of the study area (see figure 3.1) so wave conditions are assumed to be the same for each of the test profiles at a point 14km offshore. The wave station provides inputs of wave period, height and angle every 10 minutes which have been inputted into the XBeach simulations during the storm periods of interest. Graphs showing wave height and sea level for the different simulation scenarios run in XBeach can be found in appendix A.

4.2.2 Wind Data

Wind data has been recorded at the nearby harbour Hvide Sande (see figure 3.1). Here wind speed and direction has been recorded every 10 minutes during the storm periods of interest. This time, velocity and angle has been inputted into XBeach to ensure the model can simulate the extra energy transferred to the waves as they travel the 14km from the offshore boundary to the shore. Testing showed that a change in wind speed from 5 to 15m/s resulted in over a meters difference in dune erosion for one test profile. The wind data series was not complete for every scenario so an extrapolation was carried out to fill in the gaps in the data. Graphs showing the wind speeds can be seen in Appendix (B).

4.2.3 Sea Level Data

Sea level data has been taken from the measuring station outside the harbour of Hvide Sande (see figure 3.1). This as with the wind and wave information has been in inputted into XBeach as a time series. Individual graphs showing the sea level fluctuations for the simulation period can be found in appendix A.

4.2.4 Sediment size

A D50 sediment size of 0,3mm and a D90 of 0,43mm have been selected as typical for this area. These values have been taken from an investigation into Aeolian transport (Schlappkohl, 2009) carried out on sand dunes in Thorsminde, the nearest harbour town on the Danish west coast to the north of Hvide sande.

4.3 Test profiles

Dune profiles have been constructed by combining the bathymetry from the survey carried out on the 6th of June 2006 with the shore and dune survey taken on the 19th of December 2006. The maximum dune height has also been established through using a national height model. In the cases where the dune has not been surveyed to its peak, this height allows for an extrapolation to be carried out ensuring that the correct dune volume is used.

4.3.1 Profile construction

The bathymetry of the input profiles is taken from the survey carried out in July 2006 and joined to the December 2006 beach profile. The survey carried out in December 2006 only covered the beach section from the shoreline to in the best cases a height of around 6 metres (some cases only up to a height of around 2 meters). To construct an input profile for the XBeach model the section above the

December 2006 beach profile is either extrapolated or the shape of the upper section from the January 2007 survey used. The January 2007 dune shape is shifted to align with the highest measurement from the December 2006 beach measurement to ensure the sand dune is placed in the correct position. See example below

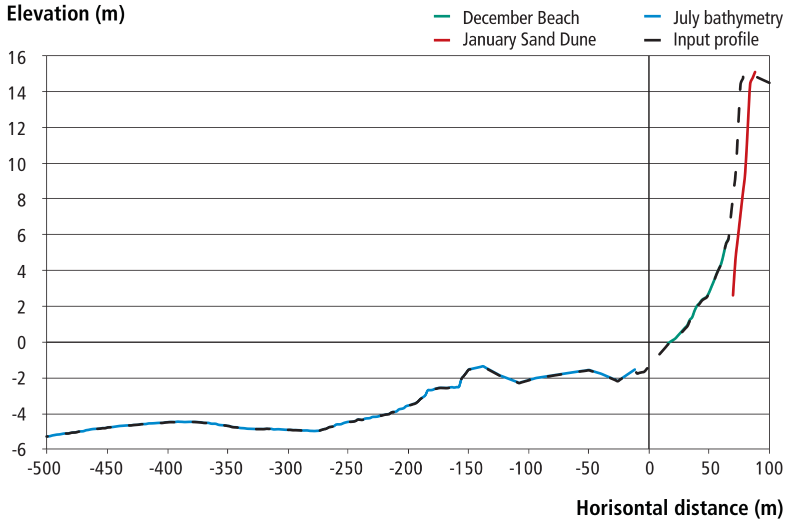


Fig. 4.3.1.1 Input profile construction (profile 4400)

This method could not be used for every profile as this can result in the January sand dune being placed behind the position measured in the January survey. As can be seen in the example below an extrapolation is required from the highest point of the December beach profile up to the almost vertical face of the January sand dune. The position of the July survey acts to reinforce that the January dune position is appropriate.

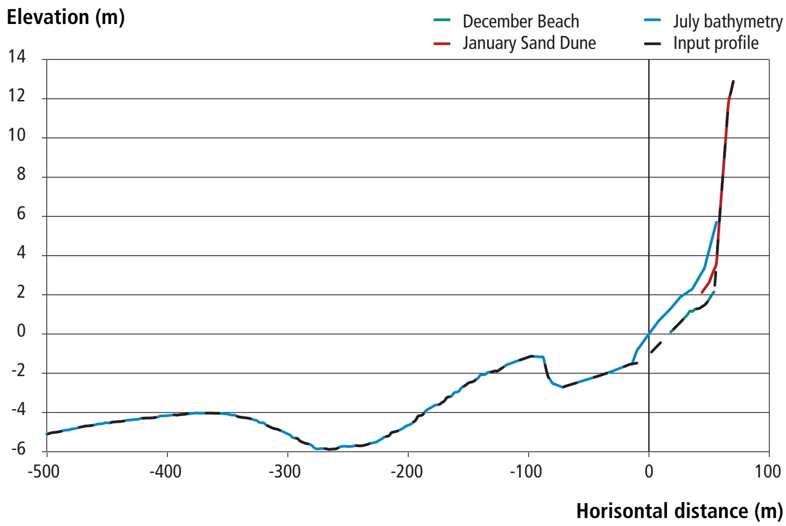


Fig. 4.3.1.2 Input profile construction (profile 4800)

4.3.2 Profiles using the January bathymetry

To gain an insight into the effects a winter and summer bathymetry have on dune erosion, input profiles were constructed using the bathymetry from January, beach measurement from December and as described previously the sand dune shape from January. To join the December beach profile to the January bathymetry an extrapolation was carried out from the lowest point on the beach to meet the January bathymetry. Where possible a gradient of 1:10 has been used, this was not possible in all cases, in these few exceptions the smoothest possible extrapolation was carried out.

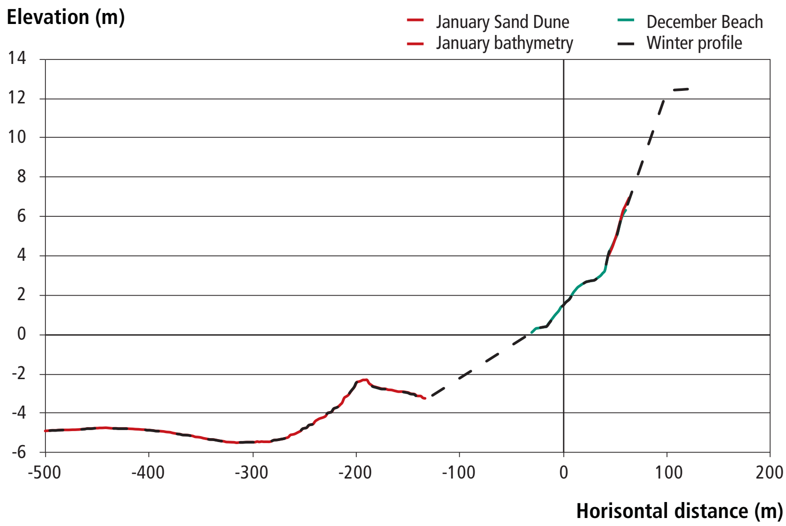


Fig. 4.3.2.1 Winter input profile (Profile 4000)

4.3.3 Summer and winter profile tests

The last bathymetric survey carried out before the storm period under investigation was measured in July. This gives several months for the bathymetry to change and produce a different set of conditions that can alter the results produced by XBeach. In order to test this theory simulations have been run where the July bathymetry has been replaced by the bathymetry measured in January. Both the July and January bathymetries feature the same beach and dune section taken from the beach measurement in December so it is only the below water sections of the test profiles that differ. Test profiles using the July bathymetry are referred to here as the summer profile and test profiles using the January bathymetry are referred to here as a winter profile. Testing the difference between the winter and summer bathymetry will offer an insight into how seasonal bathymetric changes effect dune erosion during a storm period.

XBeach simulation results

This section describes the results of testing using the storm periods, data and profiles defined in the previous section.

3600

In profile 3600, there are no measurements for the upper part of the dune above 6m elevation. If this section was made steeper it could have resulted in less erosion. As minimal erosion was experienced above 6m the inaccuracies in the dune profile above this elevation are off little significance.

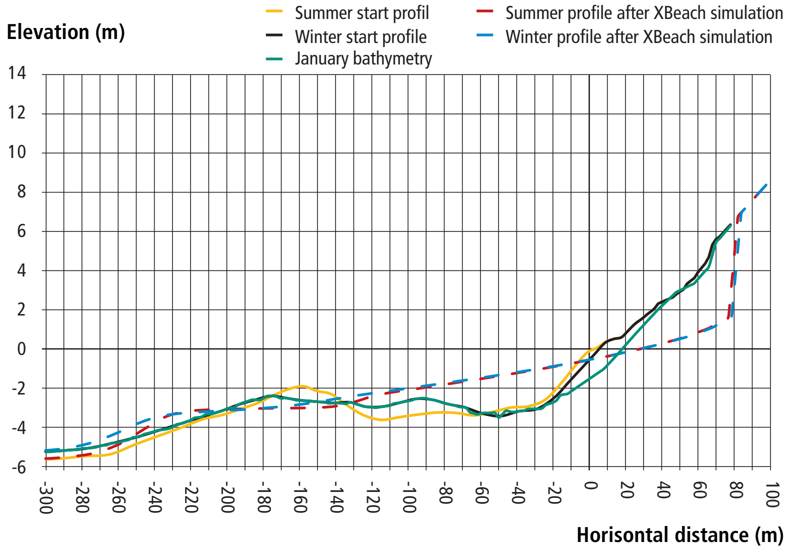


Fig. 5.0.1 Profile 3600

This profile showed almost no change between the January and December surveys. In contrast to this XBeach shows significant beach and dune erosion. Both winter and summer bathymetries are smooth with no apparent berm explaining the similarity in the XBeach results. The surveys for this profile are only measured up to height of 6m.

Consequently the extrapolated dune profile used has a shallow gradient and low volume contrasting to the other dunes along this stretch. If the dune had been measured more extensively it could well have proven to be steeper and have a larger volume which would in turn have reduced the erosion calculated by XBeach.

3800

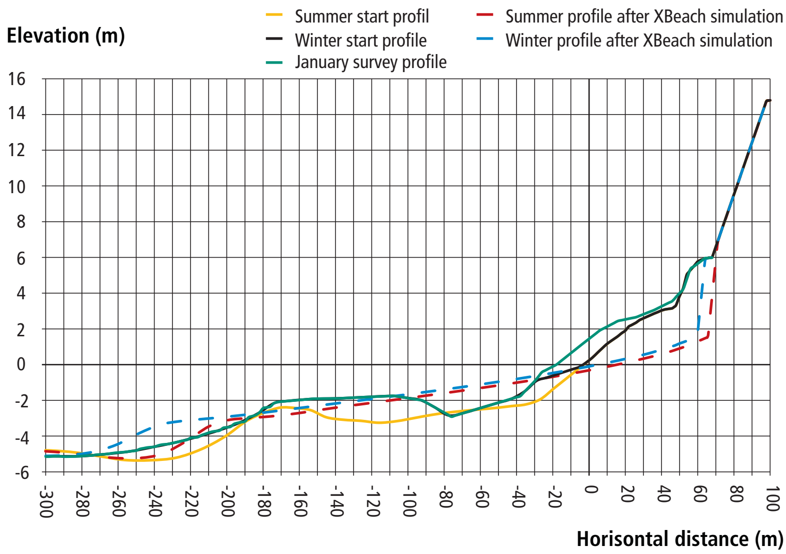


Fig. 5.0.2 Profile 3800

XBeach simulations on profile 3800 show aggressive beach erosion with the use of both winter and summer bathymetries. The simulated erosion is less for the test carried out using the winter bathymetry, the winter bathymetry shows a slightly higher sand bar and a larger beach volume in comparison to that of the summer. The Dune above 6m in this profile was constructed through extrapolation as there were no available survey results above a height of 6 meters. Again with this profile it is possible that the sand dune in reality was steeper and had a larger volume that would have resulted in a slight reduction of the erosion calculated by XBeach.

4000

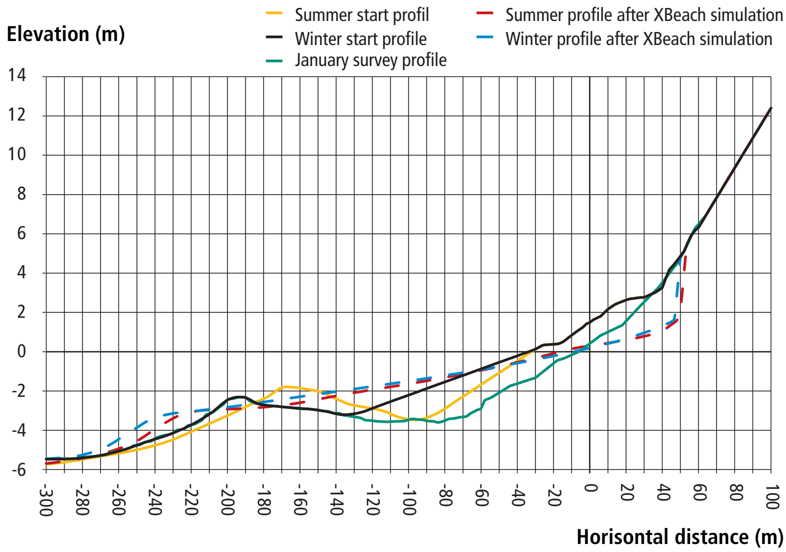


Fig. 5.0.3 Profile 4000

Profile 4000 shows little change between the July and January profile surveys, just a small shift in shape. Significant erosion of the beach can be seen in the result of the XBeach simulation as well as a noticeable smoothing of the offshore sand bar. The erosion produced by XBeach is however limited to the beach area and only effects the lower section of dune. XBeach testing using the winter bathymetry produced slightly less erosion here. This appears to be the result of the increased sand volume just offshore where the winter profile has smoothed over the dip at around 100m offshore. It is worth noting that measurements for this profile were only available up to a height of 6m, an extrapolation was therefore carried out from this height. It is likely that the dune slope from 6m upwards was actually steeper, however as even the most aggressive erosion shown by XBeach did not reach this point the extrapolated section of the profile will not have affected the simulation results.

4200

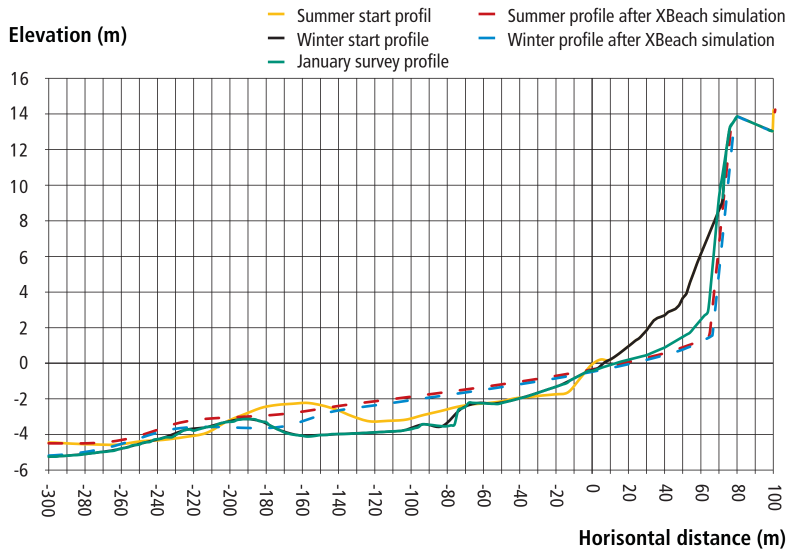


Fig. 5.0.4 Profile 4200

The erosion distances in this profile are well matched by Xbeach. There is also only a relatively small change in dune erosion between the simulations run using the summer and winter bathymetry. The fact that the summer bathymetry produced slightly less erosion in XBeach ties in well with the visibly higher sand bar that can be seen in the summer bathymetry.

4400

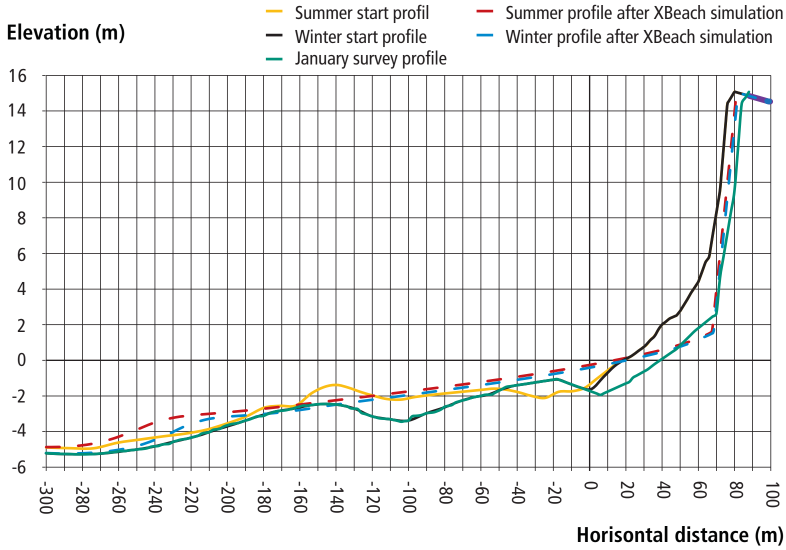


Fig. 5.0.5 Profile 4400

From comparing the surveys carried out in December and January it can be seen that this profile exhibited substantial erosion. The dune erosion shown by both XBeach simulations match the actual erosion well between a height of 2-6 meters. There is also remarkably little difference between the XBeach results run with summer and winter profiles. Both the summer and winter bathymetries here are relatively smooth, their similarity offering a good explanation for the almost matching results produced by XBeach.

4600

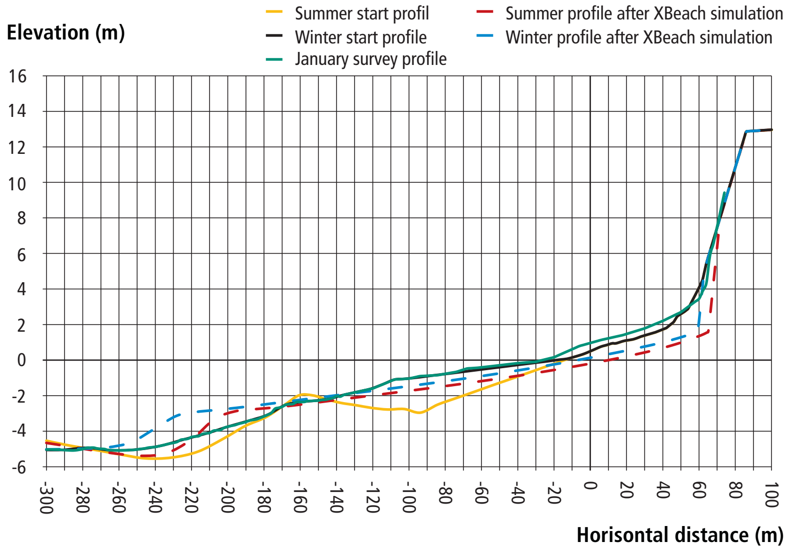


Fig. 5.0.6 Profile 4600

Profile 4600 showed almost no erosion in reality and in the dune section this is mostly replicated by XBeach in both tests with the summer and winter profiles. XBeach does in this case produce an overestimation of beach erosion in comparison to the position of the profile survey in January.

4800

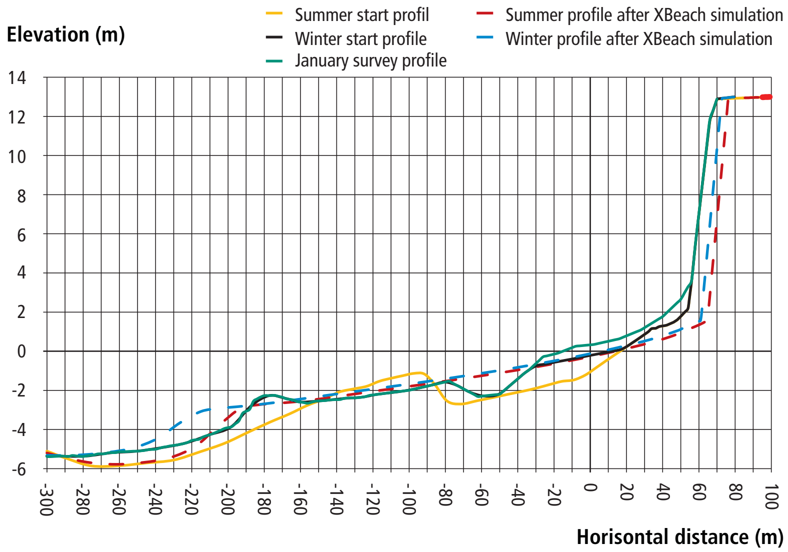


Fig. 5.0.7 Profile 4800

This profile features a particularly low beach and only a small berm in both the winter and summer input profiles. The december beach survey on this profile is only measured up to a height of 2 meters when combining this with the position of the sand dune in January gives a very small beach with a rapid transition to a steep sand dune. It can be easily seen from both the summer and winter input profiles substantial dune erosion could be expected here, which is confirmed by the XBeach simulation results. In contrast to the input profiles, the actual erosion experianced at this location is surprisingly minimal.

5000

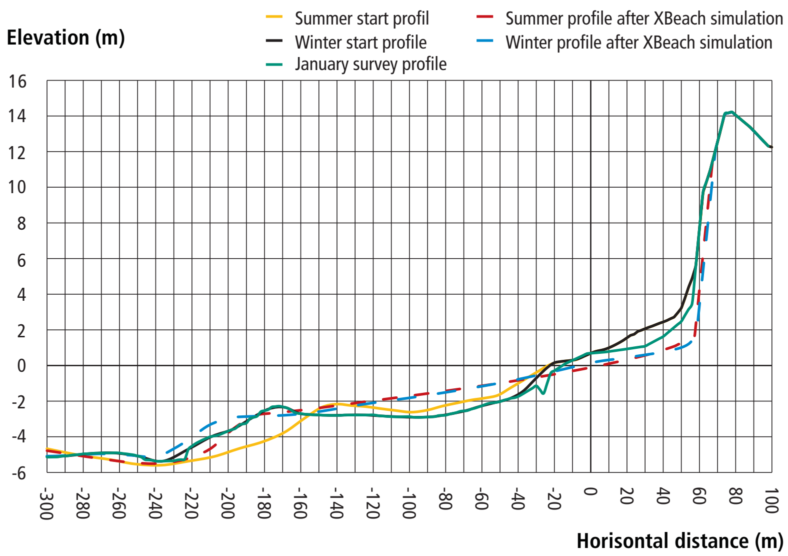


Fig. 5.0.8 Profile 5000

Erosion here is seen to be very minimal when comparing the before and after surveys, this was also mirrored by XBeach which could be explained by the long beach and shallow sloping near shore. The XBeach simulated erosion is however larger than the measured erosion especially in the lower sections of the beach. There is very little change between the summer and winter bathymetries in this profile which is reflected by the minimal difference in dune erosion shown by XBeach.

5.1 Sand bar test setup

The erosion shown in the results of the Xbeach simulations has in some profiles e.g. 143800 and 145000, shown much more erosion than was recorded in reality. One possible explanation of this could be that since the last profile bathymetric survey was carried out in July (06-07-2006) a larger sand bar had developed that could explain the lack of erosion at this location. For this test the offshore sand bar in profiles 3600, 3800, 4800 and 5000 have been raised so they are 1 m under the normal sea level. In the profile 3600 the existing berm shape has been lifted by 1m. The other three profiles have had a flat topped berm added above the location of the existing berm.

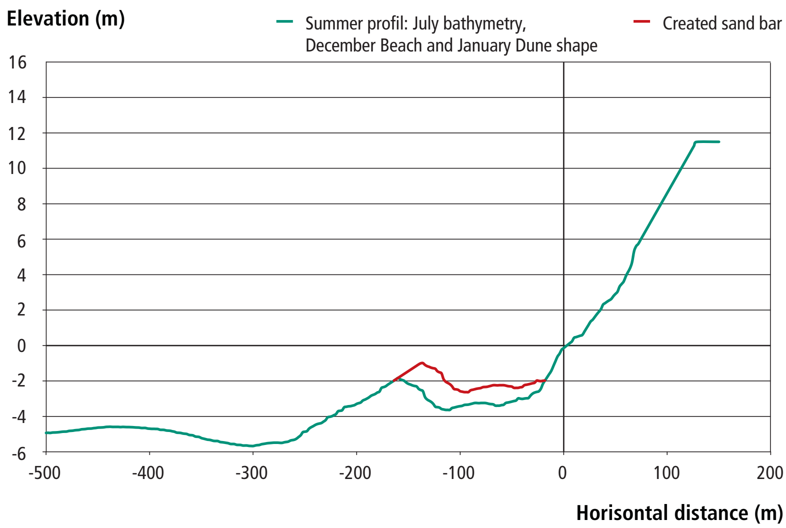


Fig. 5.1.1 #3600 Test profile with created sand bar

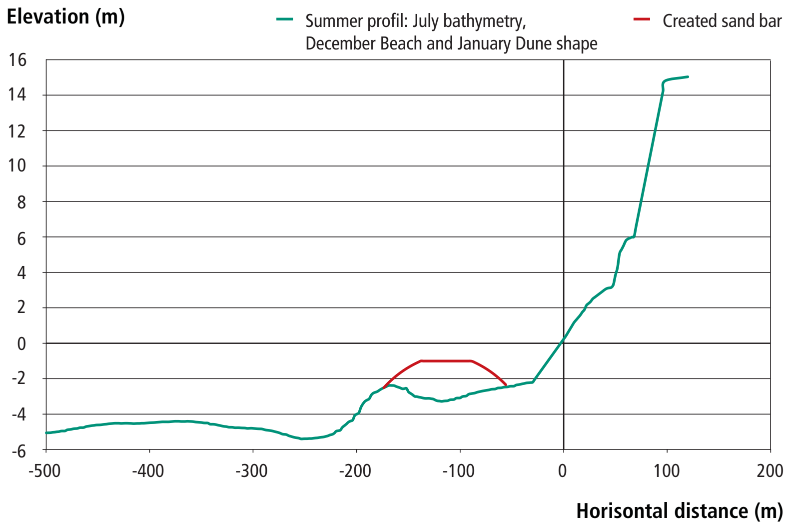


Fig. 5.1.2 3800 Test profile with created sand bar

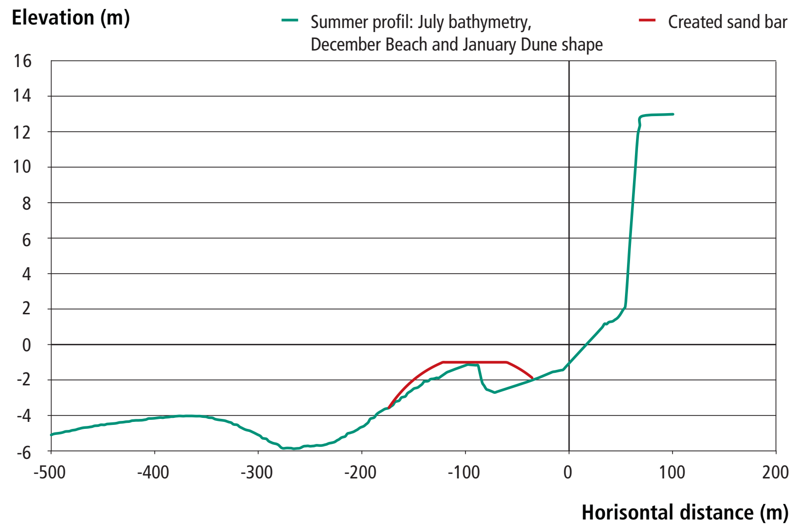


Fig. 5.1.3 4800 Test profile with created sand bar

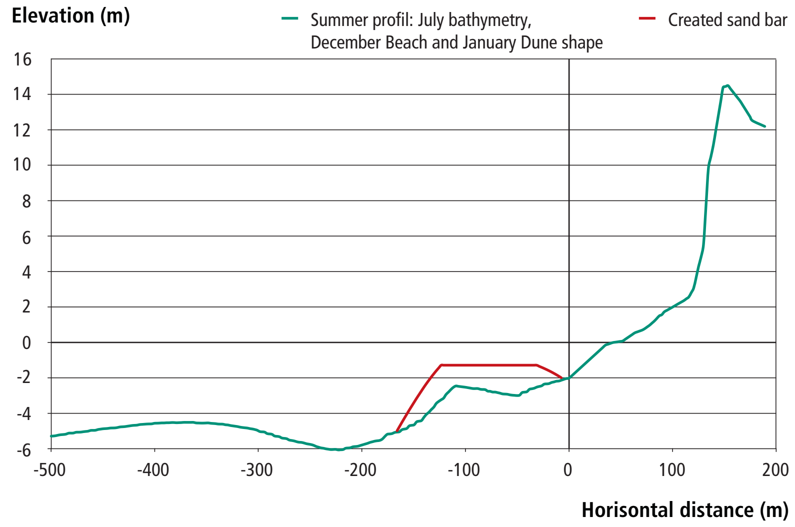


Fig 5.1.4 5000 Test profile with created sand bar

5.2 Sandbar test results

It can be seen below that the extension of the first sand bar did have a significant effect on the erosion profiles Xbeach produced.

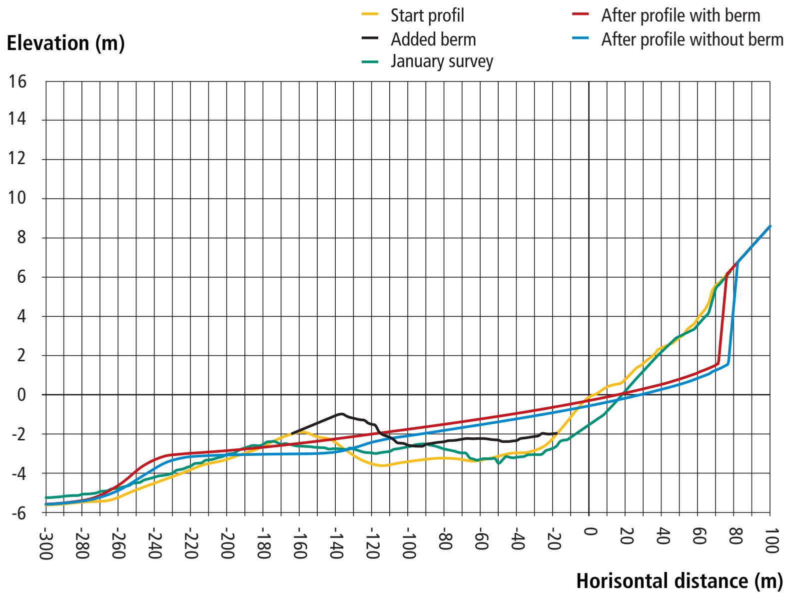


Fig. 5.2.1 Profile 3600 with and without berm

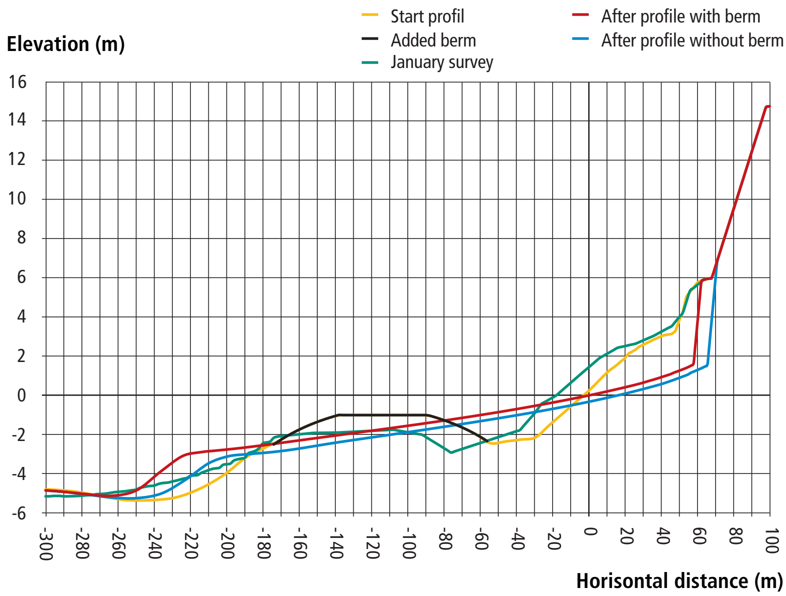


Fig. 5.2.2 Profile 3800 with and without berm

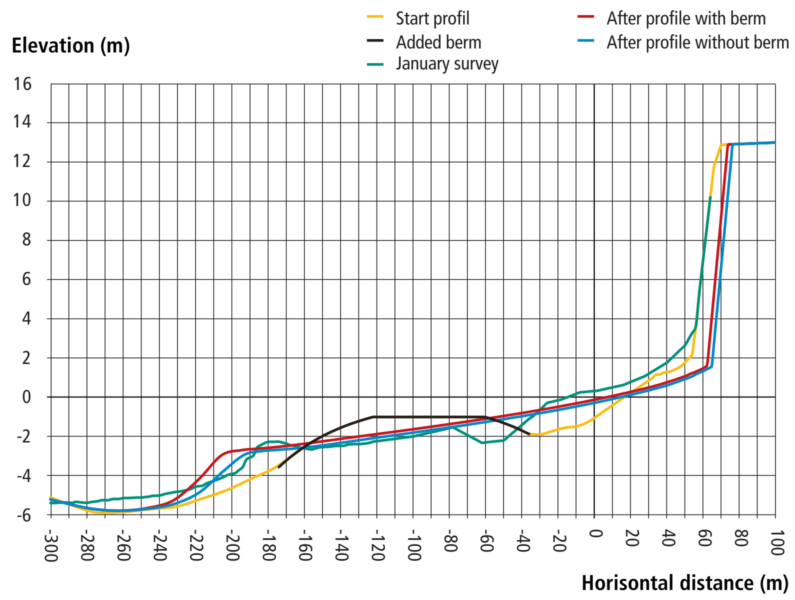


Fig. 5.2.3 Profile 4800 with and without berm

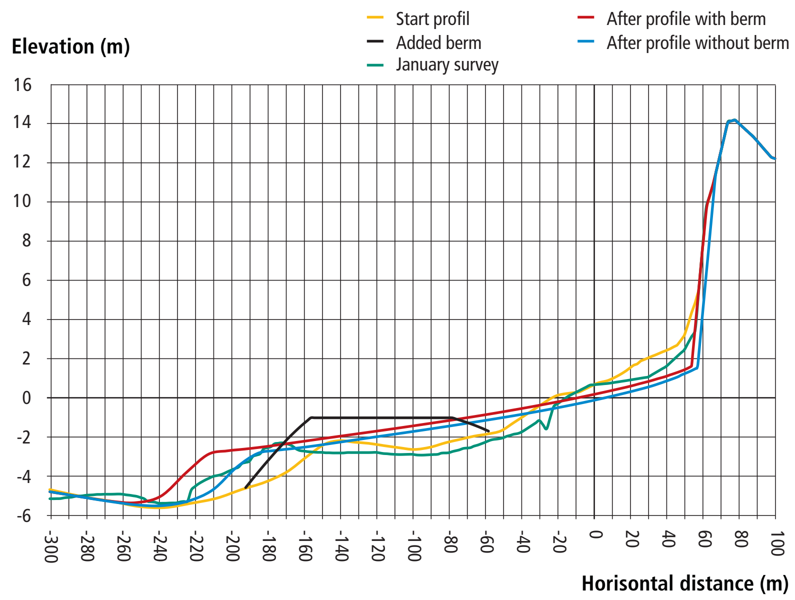
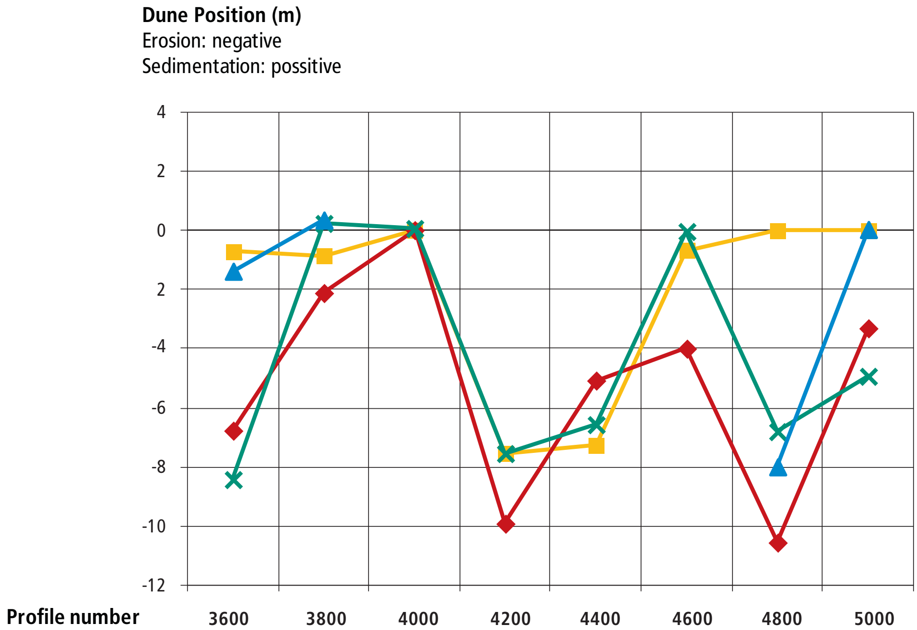


Fig. 5.2.4 Profile 5000 with and without berm

All of the profiles tested with the additional berm showed a significant reduction in dune erosion particularly in the upper dune sections. There is a common theme throughout all of the XBeach tests here for the beach section of the profile to be much more extensively eroded than the erosion shown by the beach surveys in December and January. The berm test on profile 4800 stands apart from the other profiles tested here as being least affected by the addition of a berm. Dune erosion was reduced by around 2m through the addition of the berm however this is significantly over the 0m of erosion shown by the beach surveys. It is particularly noticeable in this profile that the beach in the start profile is very narrow and low, meeting the dune at height of 2m. This almost nonexistent beach justifies the XBeach results of significant erosion suggesting that there were other factors that resulted in the lack of erosion at this location.

Chapter 6

Evaluation and conclusion



Profile number	3600	3800	4000	4200	4400	4600	4800	5000
Surveyed erosion between december and january	-0.7	-0.9	0.0	-7.5	-7.3	-0.7	0.0	0.0
XBeach results using july bathymetry	-6.8	-2.1	0.0	-9.9	-5.1	-4.0	-10.5	3.3
XBeach results using january bathymetry	-8.4	-0.2	0.1	-7.5	-6.6	-0.0	6.8	-4.9
XBeach berm test results	-1.4	-0.4					-8.0	0.0

Fig. 6.0.1 Dune Erosion Comparison (6 m height)

A marked difference can be seen between the simulation results using the January winter profile and the July bathymetry. XBeach clearly reproduces a more accurate reproduction of the actual dune erosion with the winter bathymetry. The significant difference in dune erosion between these two bathymetries highlights how big a role the unseen bathymetry plays on erosion. Although the January bathymetry is from after the modelled storms it is time wise much closer to the storm events than the bathymetry measured in July. The difference between these two bathymetries highlights the value of an accurate bathymetry that is measured just before a storm. It also highlights the models sensitivity to the bathymetric profile as in this case the exact pre storm conditions could not be reproduced which provides an explanation for the few simulated results (e.g. profiles 3600, 4800 and 5000) that are drastically different to what was experienced in reality.

The influence of the bathymetry on the erosion XBeach simulates is further reinforced by the results of the berm tests. The enlargement of the inner sand bar in the profiles where XBeach exhibited much larger erosion than that produced in reality acted to bring the simulated dune erosion much closer to the measured reality. This indicates that a different pre storm bathymetry existed before the storm events than either the measured bathymetries that were available for use in this study. The berm test indicates that the pre storm bathymetry was different to that of the measured bathymetries and that an enlarged sand bar offers an explanation to the lack of dune erosion at these locations. The contradiction for every test carried out in this investigation is profile 4800 where no erosion was measured in reality but where XBeach consistently produced results with large erosion. Changes in the bathymetry for the 4800 profile through using winter, summer and a berm profile did change the amount of dune erosion produced by XBeach. The closest result XBeach produced for this profile was still 6.8m more than the surveyed erosion. It appears that the most plausible explanation for XBeach calculating such aggressive erosion is the very low and narrow beach that was measured in December prior to the storm.

Although XBeach produced dune erosion distances that in most cases strongly matched the measured reality it is apparent in many profiles that XBeach produces more extreme beach erosion than shown by the pre and post storm beach surveys. This highlights some shortcomings in its cross shore sediment transport with all eroded material being moved much further offshore than in reality. This excessive could be the cause of the exaggerated dune erosion seen in some of the modelled cases as there is less beach volume in the latter stages of the simulations to absorb wave energy. It can be concluded the fast changing nature of offshore sand bars have a large influence on the dune erosion, the results of which can be effectively reproduced by XBeach however the accuracy of this reproduction is very reliant on a truly representative pre storm bathymetry that is in practice difficult to obtain.

6.1 Further development

It can be clearly seen through the results of this investigation that the bathymetry plays a large part in determining where dune erosion will occur and its severity, a constantly changing sand bar system offers a good plausible explanation as to the occurrence to extreme dune erosion at certain locations while little or no erosion is experienced at others. To build on the results of this investigation and gain further insights into the effect a sand bar system has on dune erosion would ideally require a bathymetric measurement much closer to the storm event so there can be little doubt over the shape of the offshore seabed just prior to a storm. The availability of a more reliable pre storm bathymetry would also justify the use of XBeach in a 2D format which would allow the interaction between sand bars and the effect on wave energy distribution to be investigated. Based on the ability of XBeach to reproduce the actual measured erosion in this study there is further potential to use XBeach to evaluate the width and height of dune required to resist a storm with a specific return period. XBeach could be run on for example the worst bathymetry and beach conditions with data from a storm the dune is required to resist. This would offer a good estimation for the width and height a dune must be to offer an acceptable level of protection. Investigation in this way would allow a dune strength guideline to be established that can be used as a simple guideline to ensure sand dunes that are relied upon as a sea defence are maintained to an adequate level.

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Appendices

Tide and wave height data Appendix A

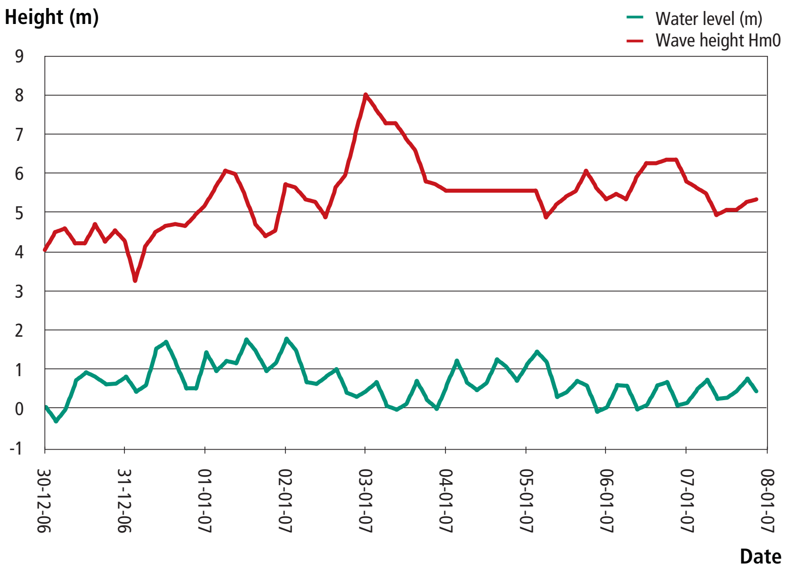

Fig. A.1 Storm section 1, 30.12.2006-08.01.2007

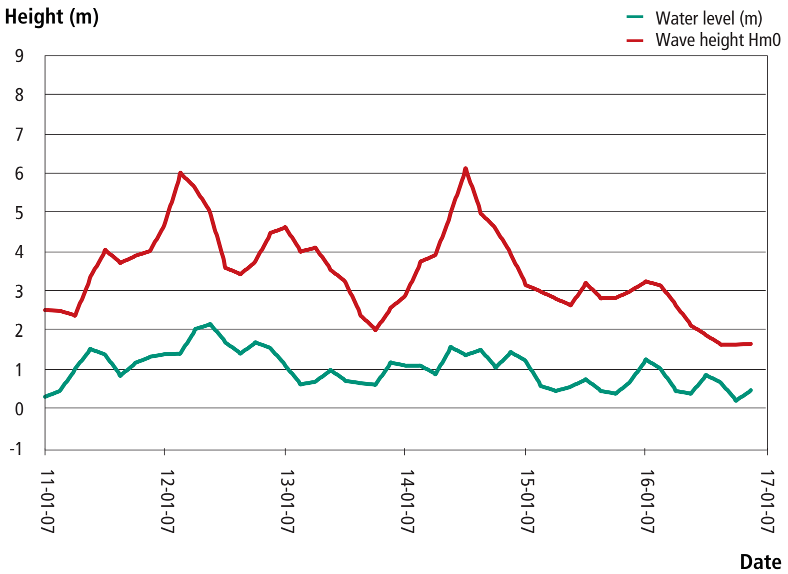

Fig. A.2 Storm section 2 and 3, 11.01.2007-17.01.2007

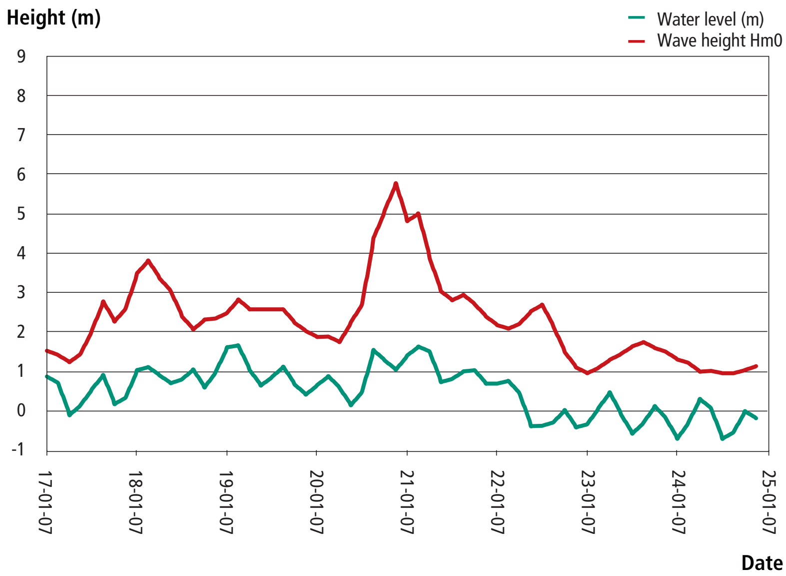

Fig. A.3 Storm section 4, 17.01.2007-25.01.2007

Wind speed data Appendix B

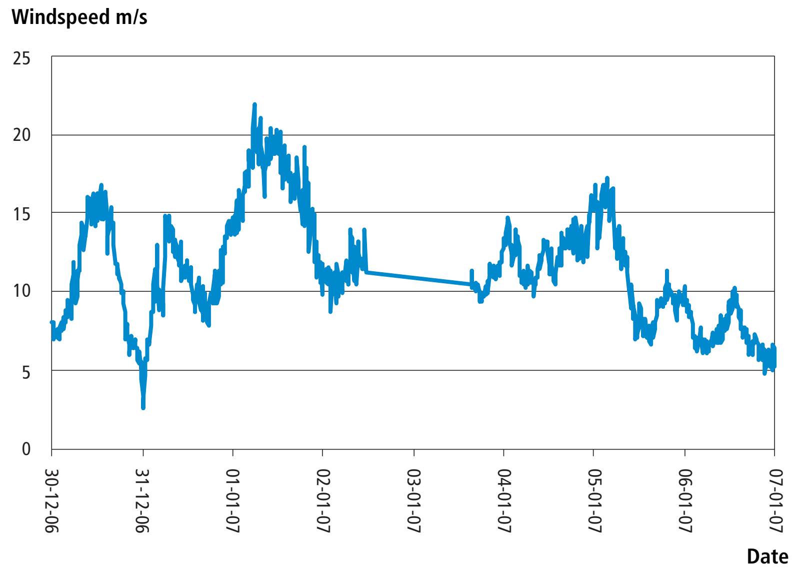

Fig. B.1 Wind Speed Storm 1

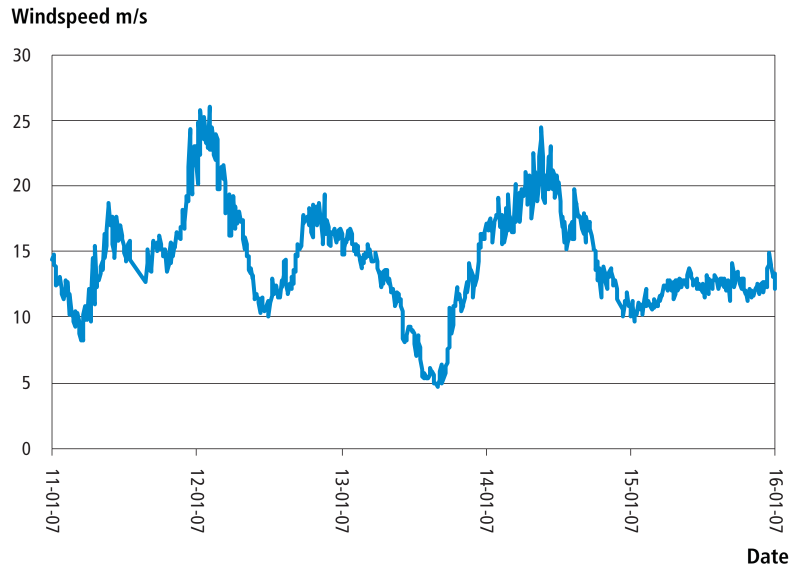

Fig B.2 Wind Speed Storm 2 and 3

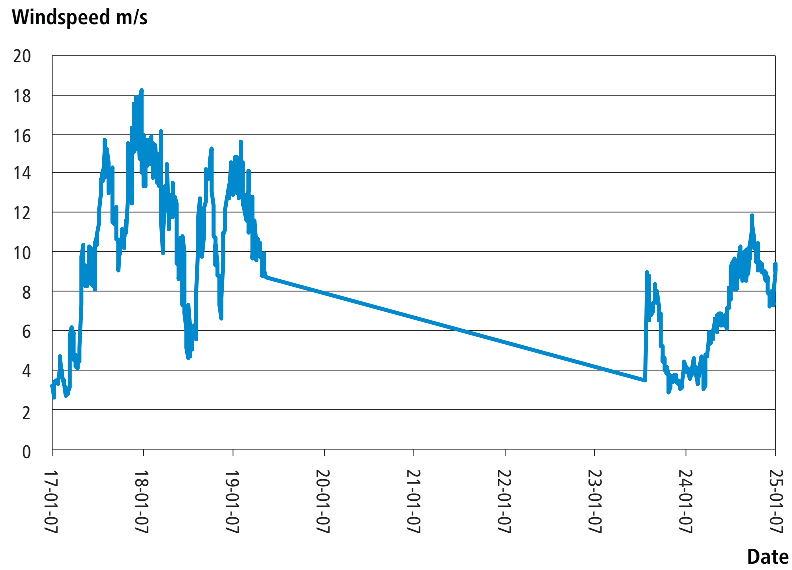

Fig. B.3 Wind Speed Storm 4