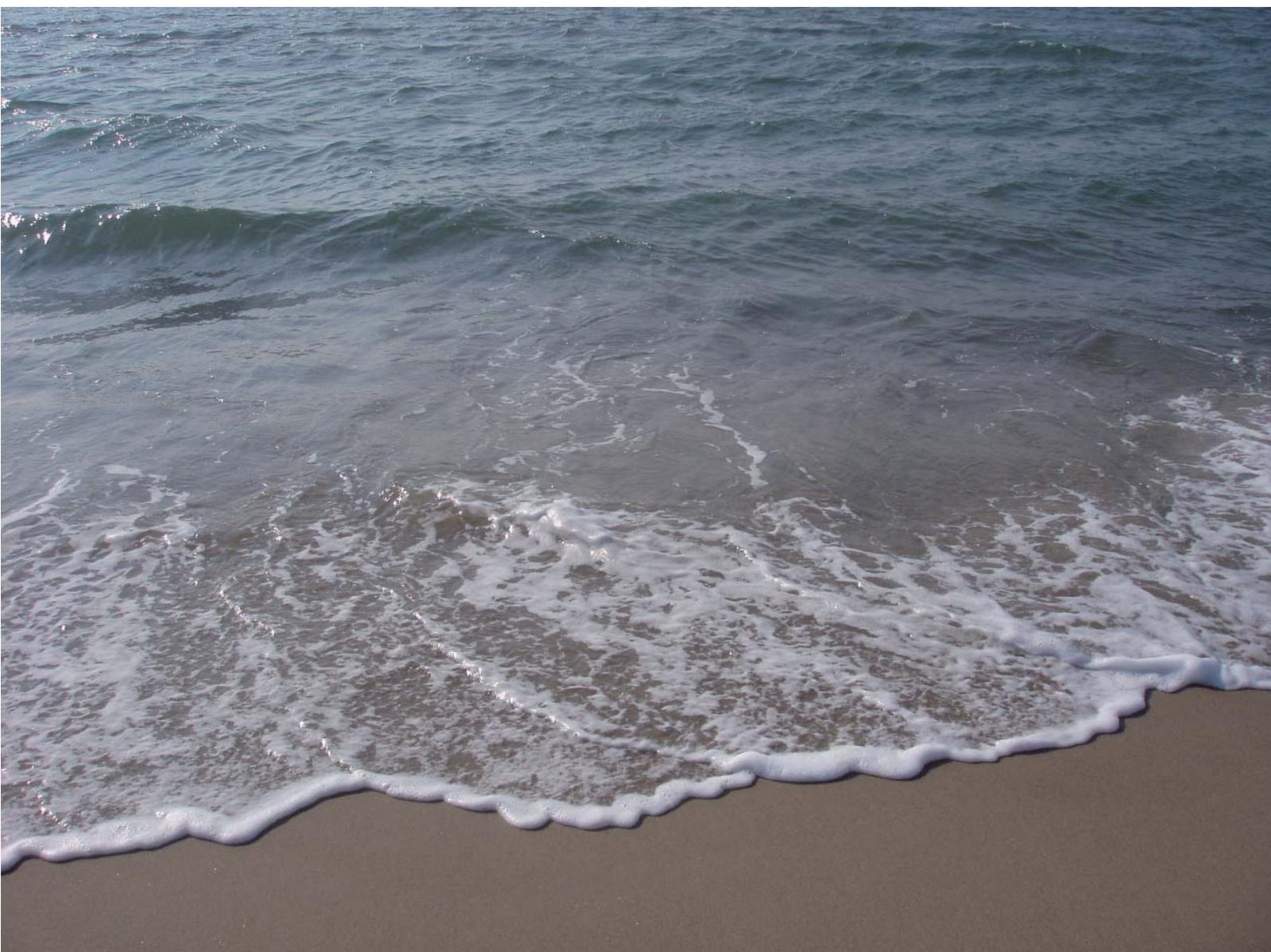


COADAPT

- Danish Coast and Climate Adaptation

Bar Analysis – Husby Klit to Houvig

Februar 2012



Project	COADAPT
Start date	September 2009
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Project responsible	Carl-Christian Munk-Nielsen
Project Manager	Per Sørensen
Project team	Marianne Skov Per Sørensen Søren Bjerre Knudsen Irene Andersen
Time register	60110240
Accounting	60110240
Approved	

Title	Bar Analysis - Husby Klit to Houvig
Authors	Marianne Skov
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Bar Analysis - Husby Klit to Houvig

Aim of study

This study is a part of the COADAPT funding. The aim of this study is to analyze the influence of bar nourishment on bar development and bar migration. The period of analysis is from 2007 to 2009, where three bar nourishment activities took place.

Area description

The test site, stretching from Husby Klit to Houvig, is located on the Danish North Sea Coast between Torsminde and Hvide Sande. The area monitored is approximately 9km long and 2km wide, *Figure 1*. The coastal profile has a slope of approximately 1:109 and is characterized with 1-3 offshore bars. The net littoral drift is in the order of 1.7mill m³/year and southward directed with a mean grain size of approximately 0.7mm (COADAPT – Husby Mega nourishment). The beach width vary greatly accordingly to hydrodynamic processes and morphological responses. The dune ridge is relatively wide and confined with heights in the order of magnitude 3-5 m.



Figure 1: Sidselbjerg beach, Danish West Coast, Denmark

Hydrodynamics and meteorology

The general wave climate is moderate with waves dominating from the northwest, wave heights of 1.5-2 m and periods of 6-8 s. The tidal range is approximately 0.8m (COADAPT – Husby Mega nourishment). Beyond the depth of 6-8m a north directed current is present.

The area is exposed to frequent storm surges, especially from the west and northwest. Storm surges with wave heights exceeding 4m during the study period is depicted in *Figure 2*. The wave directions are grouped in relation to the coastline orientation, 190°N, *Figure 3*. Yearly storm surges reach sea levels in the order of magnitude 2.01m DVR90 at Hvide Sande Harbour just 30 km to the south of the study site, where as an

extreme storm surge incident with a 50-year return period raises the sea level to 3,02m DVR90 (DCA – Extreme sea level statistics for Denmark, 2007).

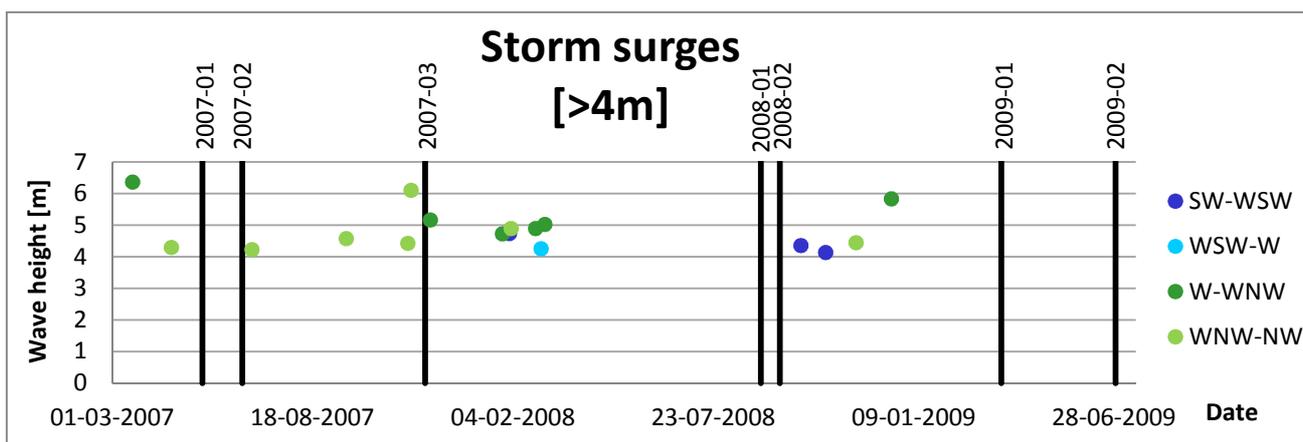


Figure 2: Storm surges >4m

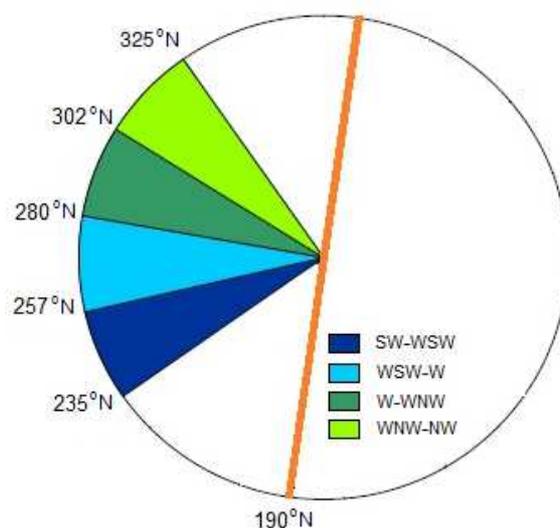


Figure 3: Wave rose in relation to the coastline orientation

Human interventions

Additional coastal protection schemes have been implemented over the years. For over a decade nourishment activities have occurred, but especially the three bar nourishments in 2007 are studied in relation to bar behavior and migration. At the investigation site a total sand volume of 892120 m³ was divided into three separate depositions of 296166m³ and 299411m³ and 296543m³ designated, north, central and south bar nourishment, respectively. Approximately 400m³ pr. m is deposited. Each nourishment is deposited 300-500m offshore, where the south nourishment being the closest to shore. The initial bar volume of the north and central bar were larger than the nourish volume, whereas the nourishment volume exceed the initial bar volume of the southern bar.

A group of 15 breakwaters were constructed in the northern part of the study area in 2004 and are still present today, as 14 old groynes where rearranged.

Data

Bathymetric surveys were conducted in seven separate field campaigns between 26th Marts 2007 and 29th June 2009, see table below for further detailed information. The data is surveyed in tracks with a spacing of 200m or 100m, *Figure 4*. The more detailed survey spacing of 100m at selected places is a result of the implemented nourishments. The data sampling is done each 2m to a depth of approximately 12m with a standard deviation of 5.

Field campaign	Survey start	Survey end
2007-01	26 marts 2007	16 May 2007
2007-02	18 June 2007	19 June 2007
2007-03	20 November 2007	21 November 2007
2008-01	5 may 2008	1 September 2008
2008-02	15 September 2008	17 September 2008
2009-01	17 February 2009	24 Marts 2009
2009-02	23 June 2009	29 June 2009

The position of the bar nourishments are displayed in *Figure 4* and listed in the table below.

Date	Bar	Position
14 th July – 13 th August 2007	North bar	E445382, N6229535 E445322, N6228842
22 th April – 13 th June 2007	Central bar	E445111, N6227114 E444957, N6226427
18 th August – 7 th October 2007	South bar	E444917, N6224811 E444831, N6224122

The central bar nourishment, which was the first nourishment action took place after the first bathymetric survey campaign (2007.01). The second nourishment was the north bar which was initiated during the 2007.02 survey campaign but not completed. When the third bathymetric survey campaign (2007.03) was carried out both the north and south nourishment were completed. Five bathymetric survey campaigns followed after the completion of all nourishment actions.

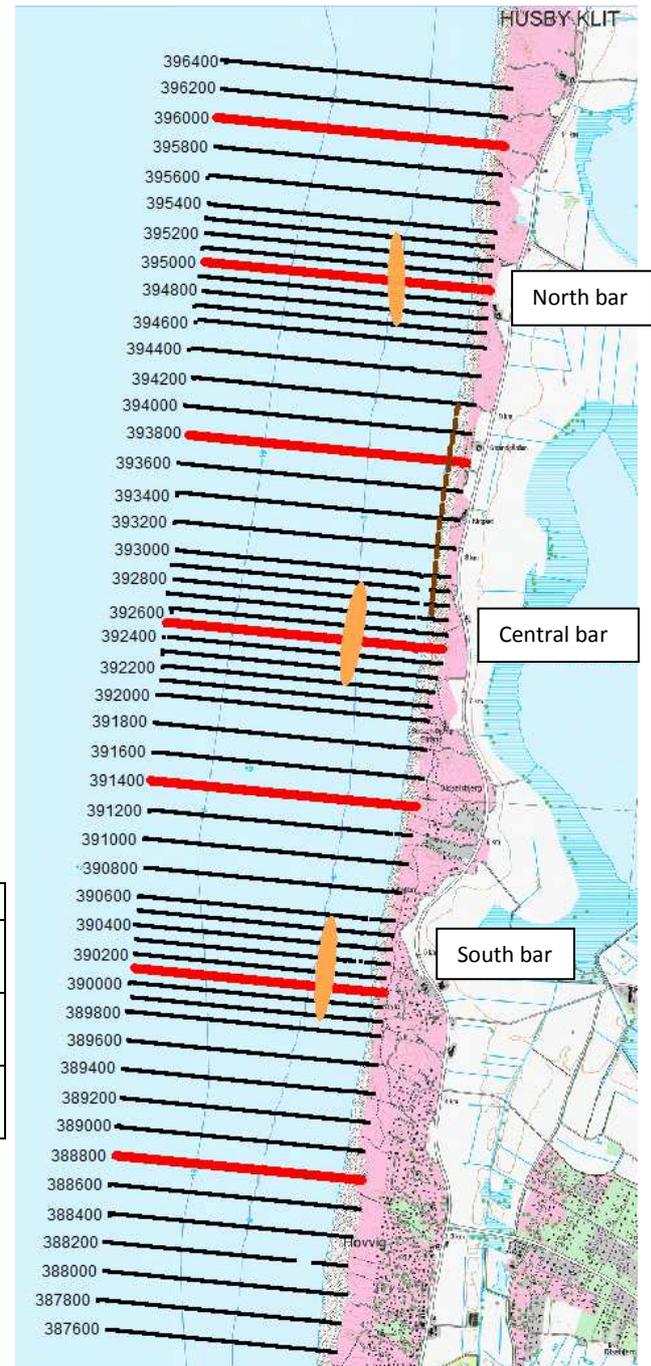


Figure 4 : Area of research: Survey tracks, highlighted and numbered in black. Cross-sectional profiles for further investigation is highlighted in red. Bar nourishment sites circled in orange. Breakwaters are brown.

Methodology

The bathymetric surveys give a still picture of the bar development and bar migration pattern. A bar is identified and mapped when a 1m criteria between the bar trough and bar top is fulfilled. The bars are detected analyzing from the coastline offshore. Bars not fulfilling the criteria on the onshore side are therefore not detected. One may argue that initiating bars will not be detected and the criterion is too conservative. *Figure 5* indicates bars that have not been identified but is clearly affecting the hydrodynamics.

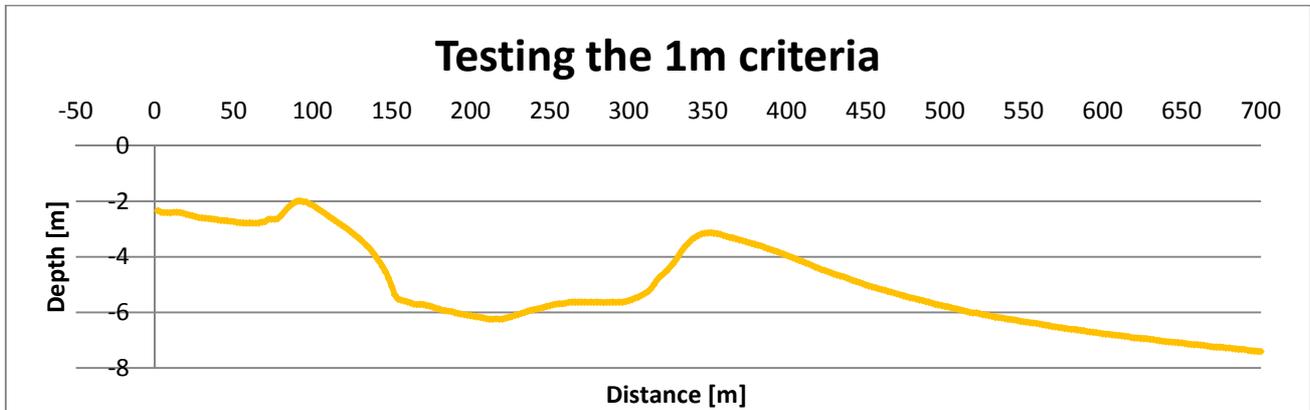
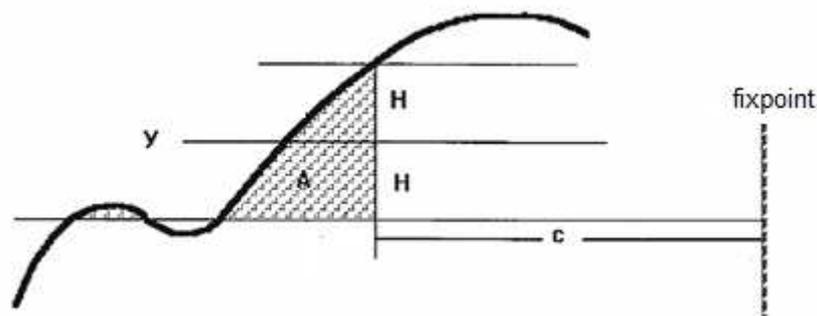


Figure 5: Unidentified inner bar, cross-sectional profile Track no. 396000, 2008.01

This bar analysis takes its stand from the 2007.01 field campaign. The observed bar development and migration is therefore in relation to 2007.01 measures to allow comparison. The coastline position is determined calculated by in-house developed software: KI-Menu, using the following relations, *Figure 6*.



$$Y = c + A/2H$$

Y = Coastline position

C = Distance from fixpoint to measuring point

H = area of calculation

A = area below profile

Figure 6: Sketch of KI-Menu determination of coastline position

A further cross-shore analysis is carried out for seven selected profiles, track no. 388800, 390100, 391400, 392500, 393800, 395000 and 396000, *Figure 4*. The chosen profiles are selected to anticipate temporal bar development.

Analysis

The initial bar conditions at Husby can be viewed in *Figure 7*. It is worth noticing that the bar system is discontinuous. To the north a single bar is present at a distance 300-450m from the shoreline. Moving towards the south a double bar system develops. The inner bar structure can be found with distances of 150-300m from the shoreline while an outer bar is present 400-700m from the shoreline.

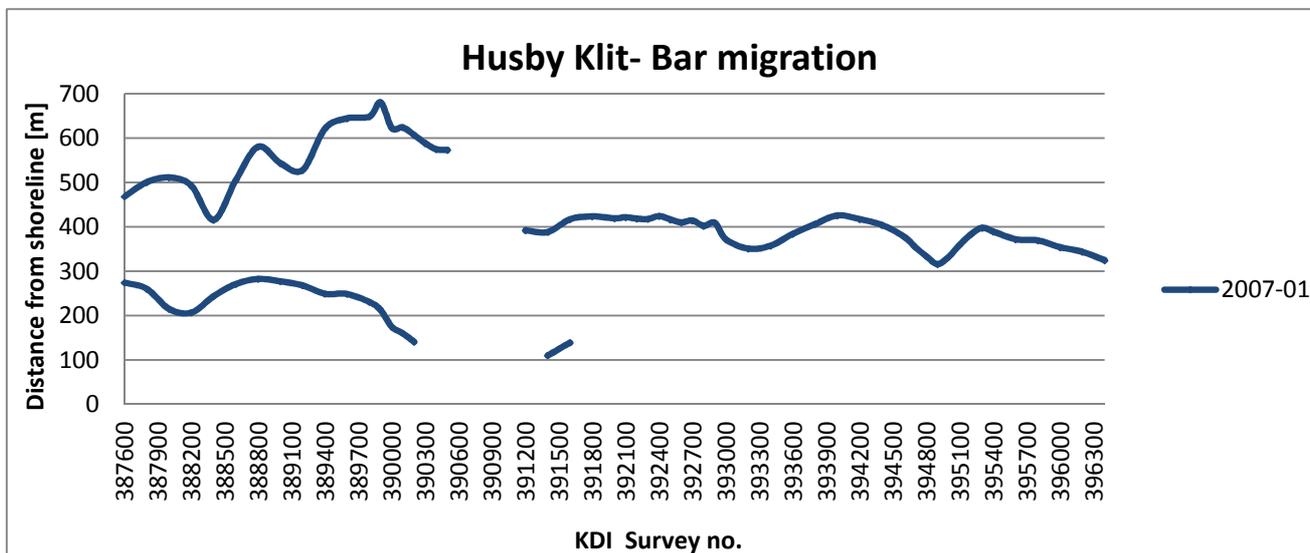


Figure 7: Initial bar conditions, 2007-01

Likewise should the bar height be noted. Despite the south outer bar system is stretching across wide areas the bar top height is relatively confined around at a depth of 5.5m, *Figure 8*. The south inner bar top on the other hand varies more in relation to the shore distance.

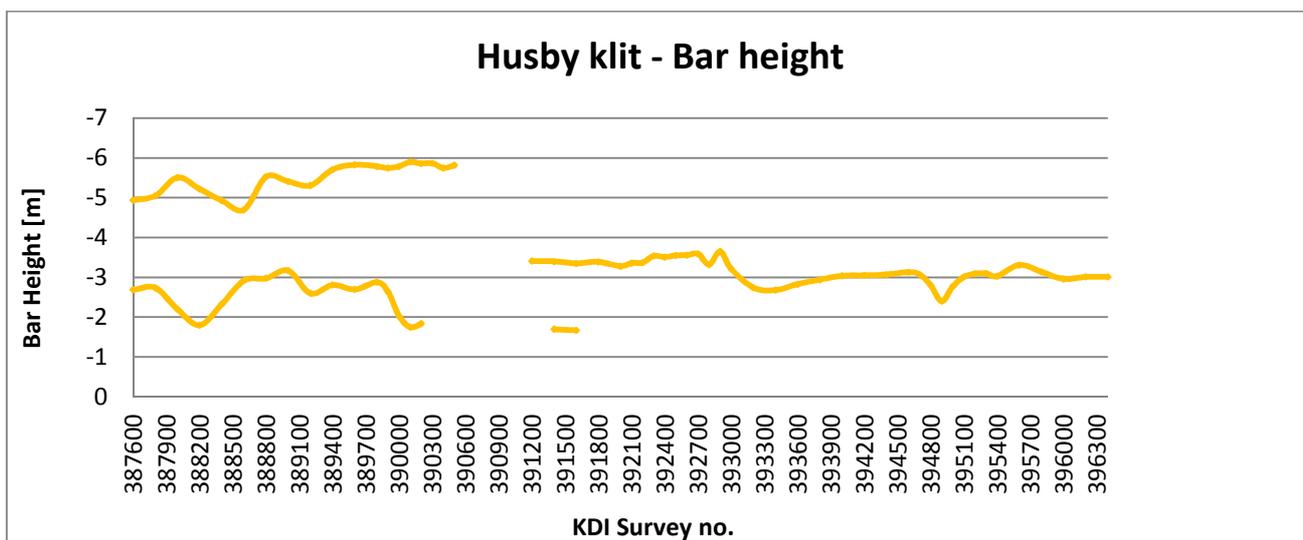


Figure 8: Bar top height, 2007.01

Comparing the first bar pattern results with data from the second field campaign multiple changes can be detected. For most areas it can be seen that the bars migrate slightly towards the south, *Figure 9*. However onshore and offshore migration can be detected. Between the first and second survey the central bar nourishment has been completed and the north bar nourishment has been initiated.

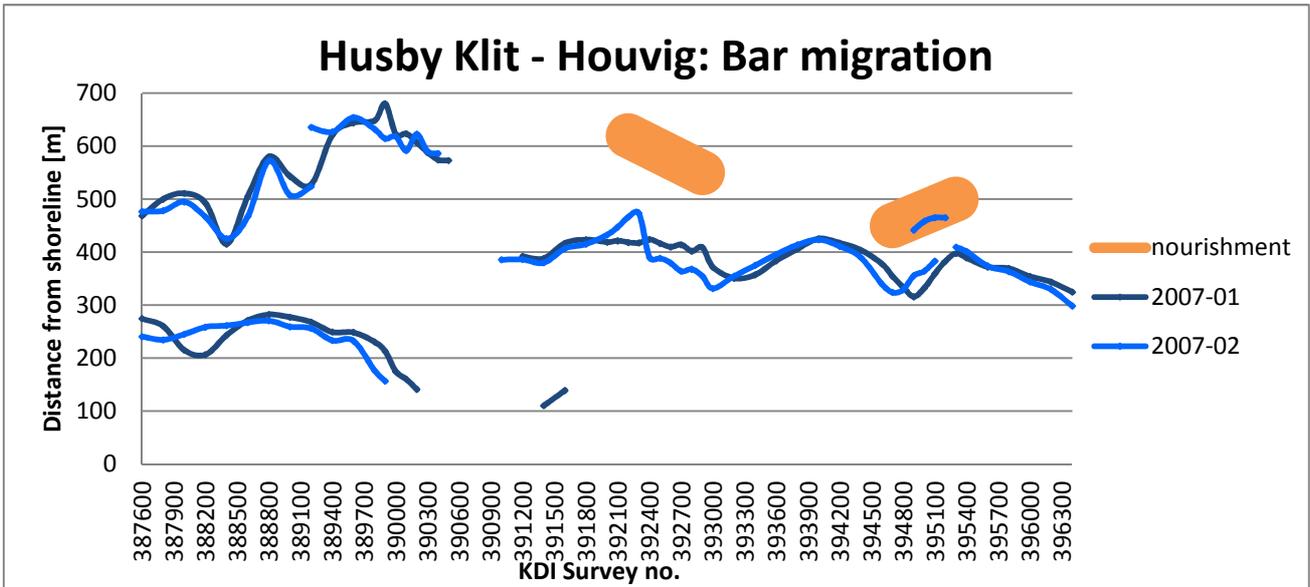


Figure 9: Bar positions, 2007-01 – 2007-02. Central bar [left]. North bar [right]

Nourishment of the central bar is as just stated completed, but its full-scale cannot be detected when using the 1m criteria. However when analyzing a cross-section of the central bar nourishment, the nourishment can easily be identified, Figure 10.

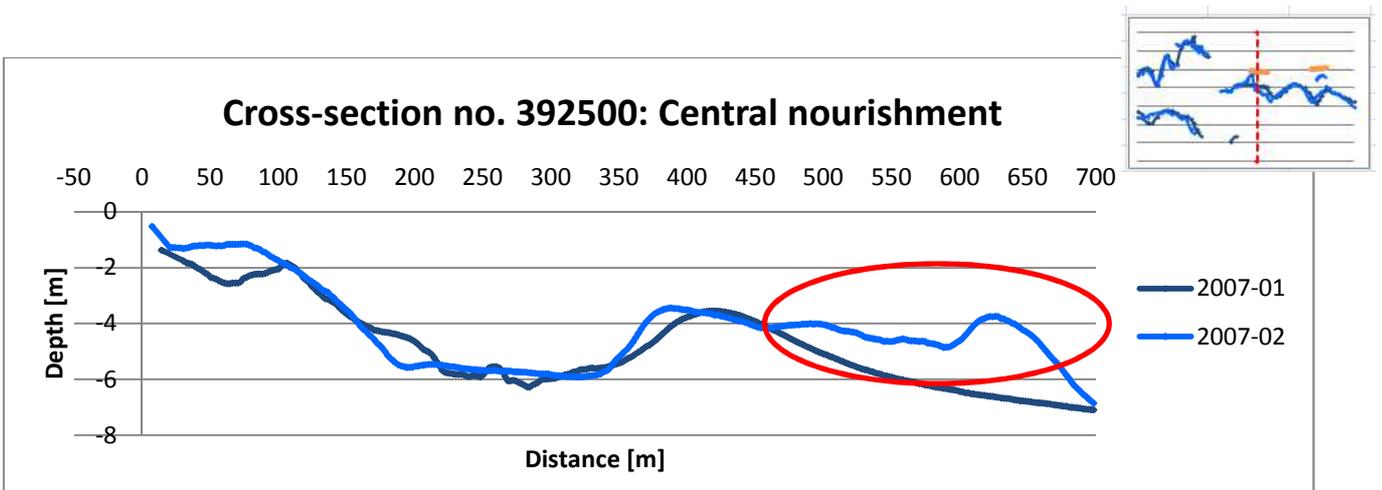


Figure 10: Cross-sectional profile of the central bar, track no. 392500 (2007.01-2007.02)

It should also be noted that the effects of the initiated north bar nourishment can already be seen, Figure 11.

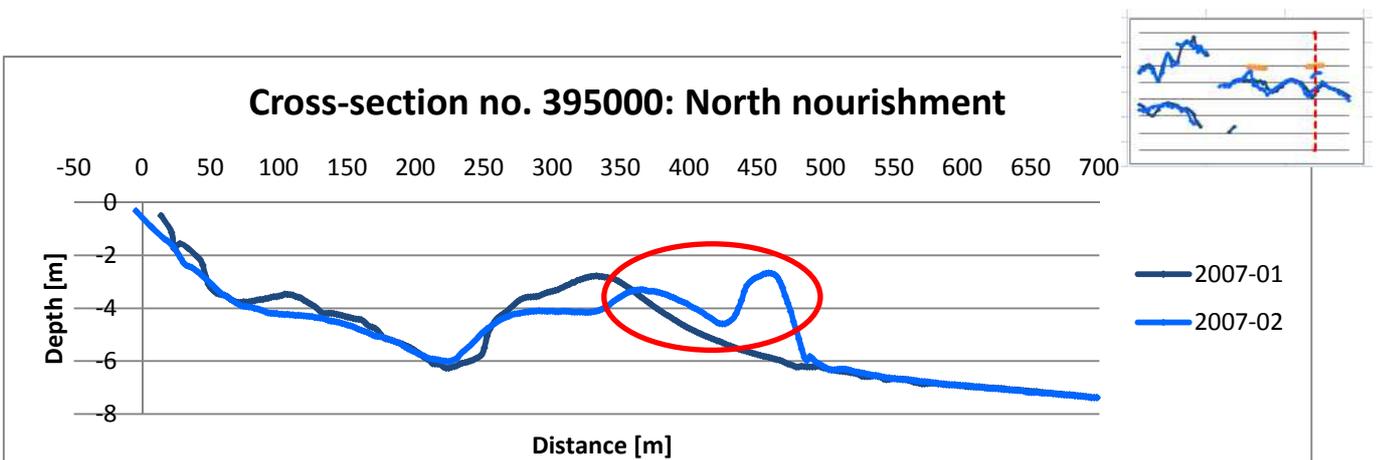


Figure 11: Cross-sectional profile of the north bar, track no. 395000 (2007.01-2007.02)

A rapid change of the bar systems can be observed when analyzing the 2007.03 field campaign data, *Figure 12*. Since the last field campaign all three bar nourishments have been completed. The nourished bar deposits are not confined and clearly evident when studying the bar positions, but however possible to identify when looking closer at the cross-sections, *Figure 13*, *Figure 14* and *Figure 15*.

Strong meteorological and hydrological conditions have rearranged the sediment, placing deposits up to 700m offshore, *Figure 13*. The northern bar system has migrated between 50-150m offshore subsequently because of the nourishments and the additional storm surges from northwesterly directions (*Figure 2*). New inner bars have developed in the north and central part which is quite interesting as the location and extension almost correspond to the location of the bar nourishment just further onshore, *Figure 12* – circled in red.

The southern outer bar system is no longer continuous or reach the same extent which supposedly is a response after the storm surges forcing wave breaking on the outer bar and altered sediment dynamics. The sediment transport dynamics are also likely to be affected by the north directed Jutland stream. The southern inner bar system has however for most stretches developed and migrated onshore. The sheltered condition when waves directed from the northwest are likely also to have favored bar development and onshore migration of inner bars, *Figure 12*. The south inner bar system has supposedly favored beach widening, *Figure 15*. However as moved further offshore and towards the south both beach erosion and offshore bar migration can be observed, *Figure 16*.

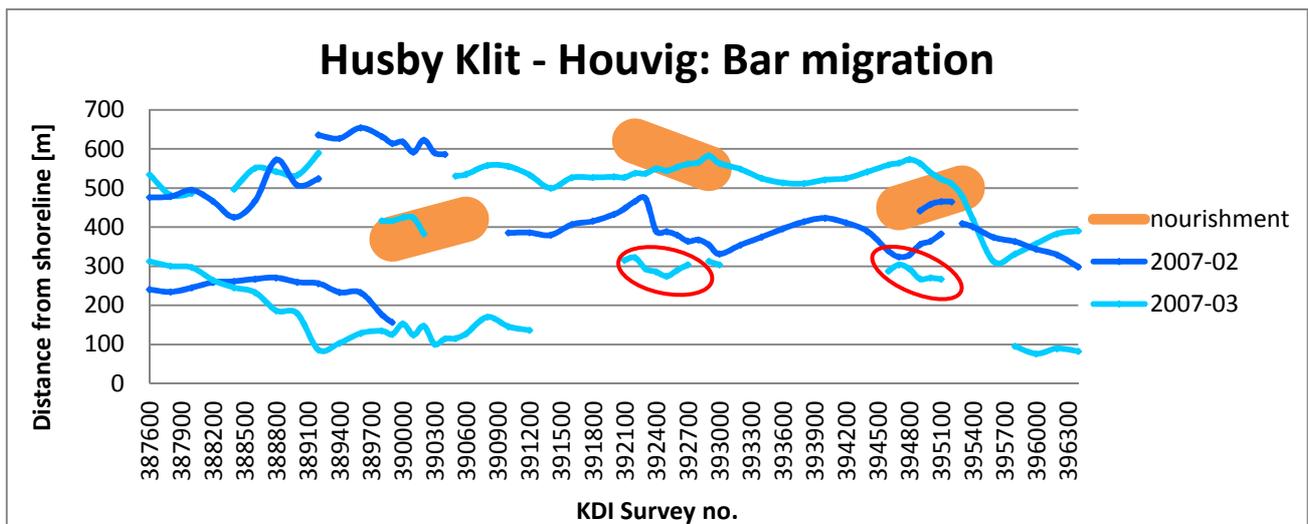


Figure 12: Bar positions, 2007.02 – 2007.03. South bar [left]. Central bar [middle]. North bar [right].
Circled in red are new developed inner bars

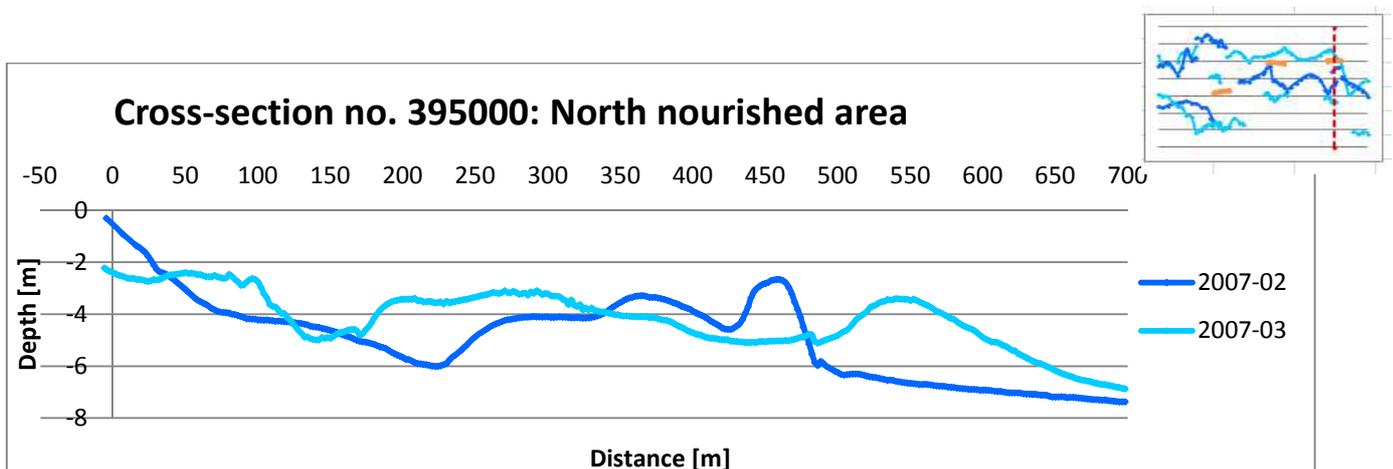


Figure 13: Cross-section of the north nourished area, Track no. 395000 (2007.02 - 2007.03)

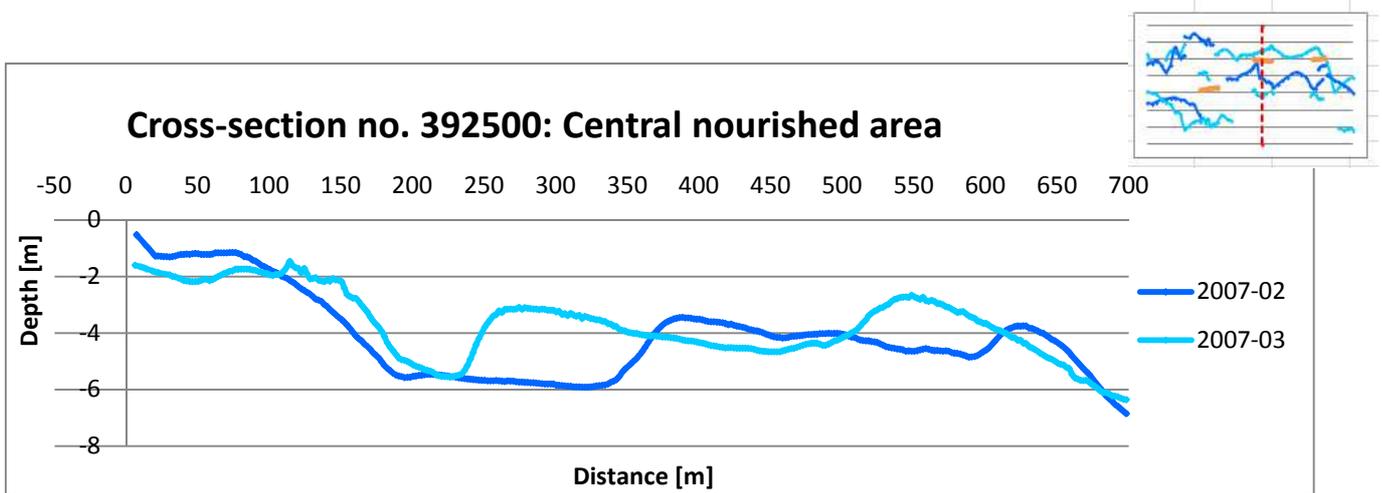


Figure 14: Cross-section of the central nourished area, track no. 392500 (2007.02 - 2007.03)

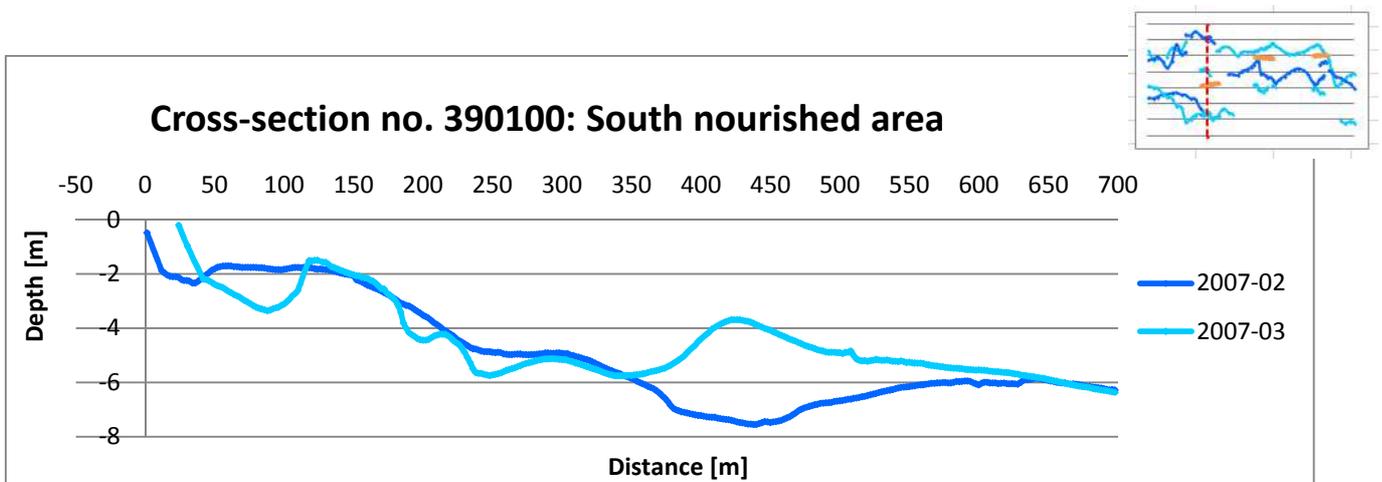


Figure 15: Cross-section of the south nourished area, track no. 390100 (2007.02-2007.03).

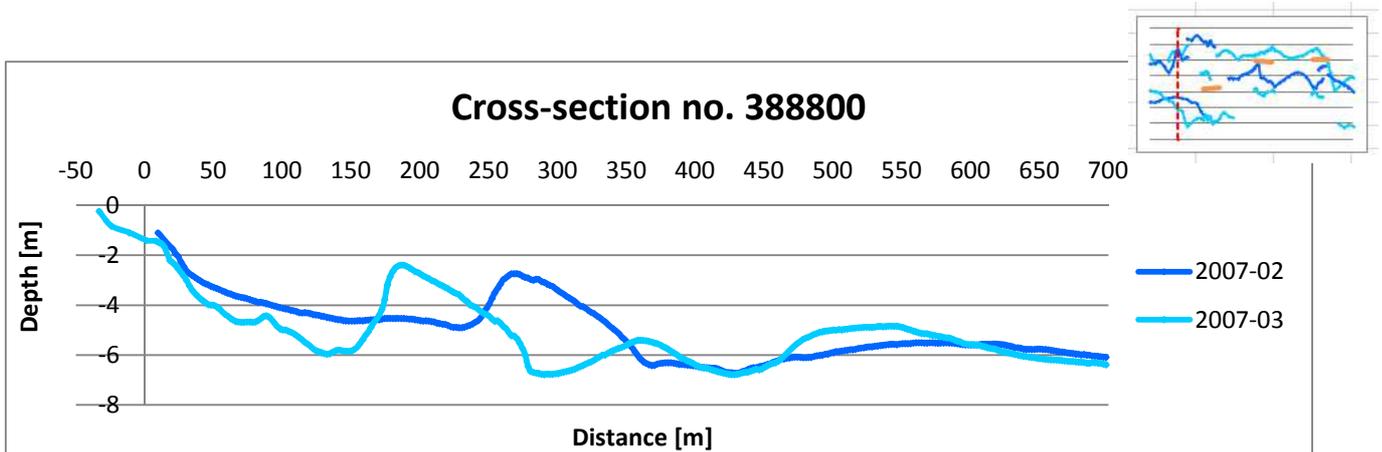


Figure 16: Cross-section to the south of the southern nourished bar. Track no. 388800 (2007.02-2007.03)

Between all nourishments great erosion occurs, Figure 17 and Figure 18. The nourishments are likely a responsible factor for altered hydrodynamics and sedimenttransport dynamics causing the great erosion.

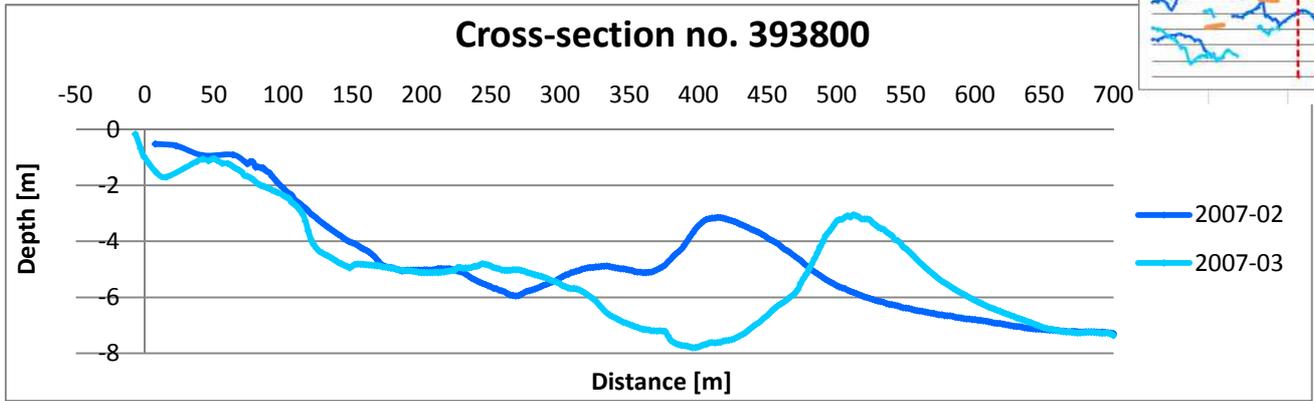


Figure 17: Cross-section between north and central nourishment. Track no. 393800 (2007.02-2007.03)

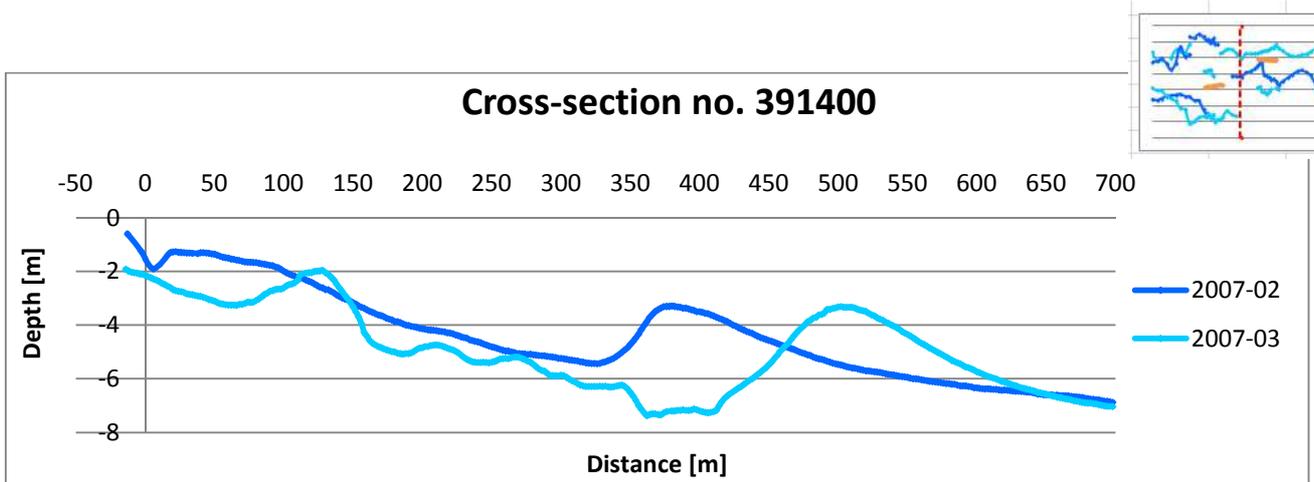


Figure 18: Cross-section between central and south nourishment. Track no. 391400 (2007.02-2007.03)

Taking a look on the bar top heights, it can be seen despite the offshore shifting of the northern bar system that the bar top heights have not been decreasing detectably, Figure 19. Large amounts of sediment are therefore stored in the bar system. The northern bar system and the nourishment actions are believed to have caused starvation at the southern outer bar degrading the bar system.

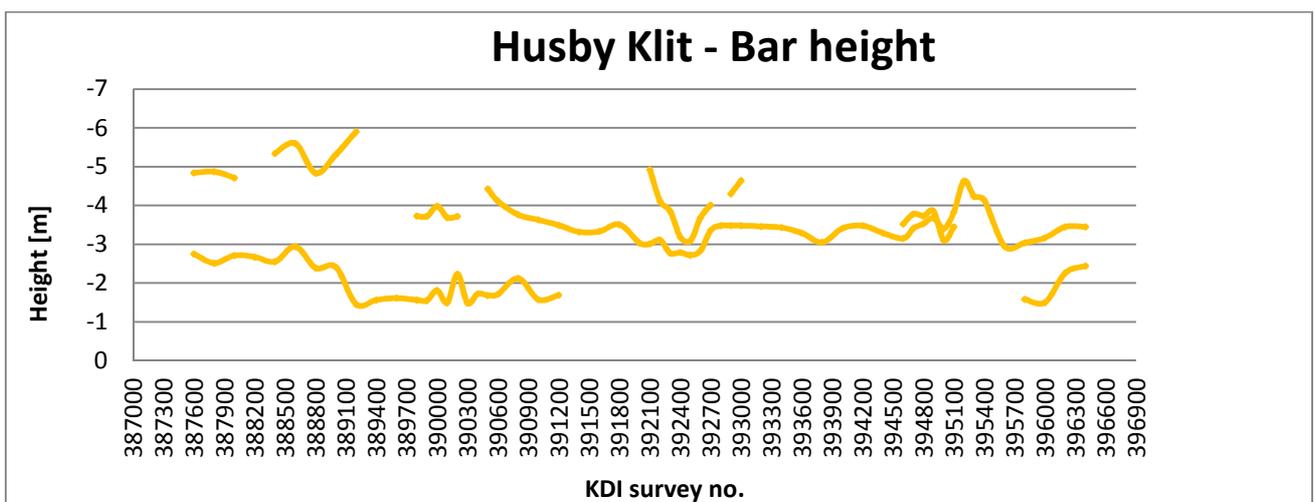


Figure 19: Bar top heights, 2007.03

Since the 2007.03 survey was carried out a winter period with additional storm surges has passed, *Figure 2*. The largest changes can be observed when studying the southern bar system and the area between the north and central nourishments. The southern bars have migrated rapidly onshore, *Figure 20*.

A slight northward migration of the outer bar can be detected while the inner bars migrate towards the south rearranging sediment degrading the northern end of the southern bar system. It is notable that the south nourished bar is no longer detectable as a confined bar. It is expected that the sediment has been rearranged offshore and been contributing considerably to the southward development of the northern bar system, *Figure 21*.

The northern outer bar system is re-curling. For most areas onshore migration can be detected expect between the north and central nourishment, where offshore bar migration has occurred. The northern initiated inner bars continue to migrate onshore but fails to appear in the bar analysis as they do no longer fulfill the 1m criteria, *Figure 22*. Note 2008.01 has a long survey period.

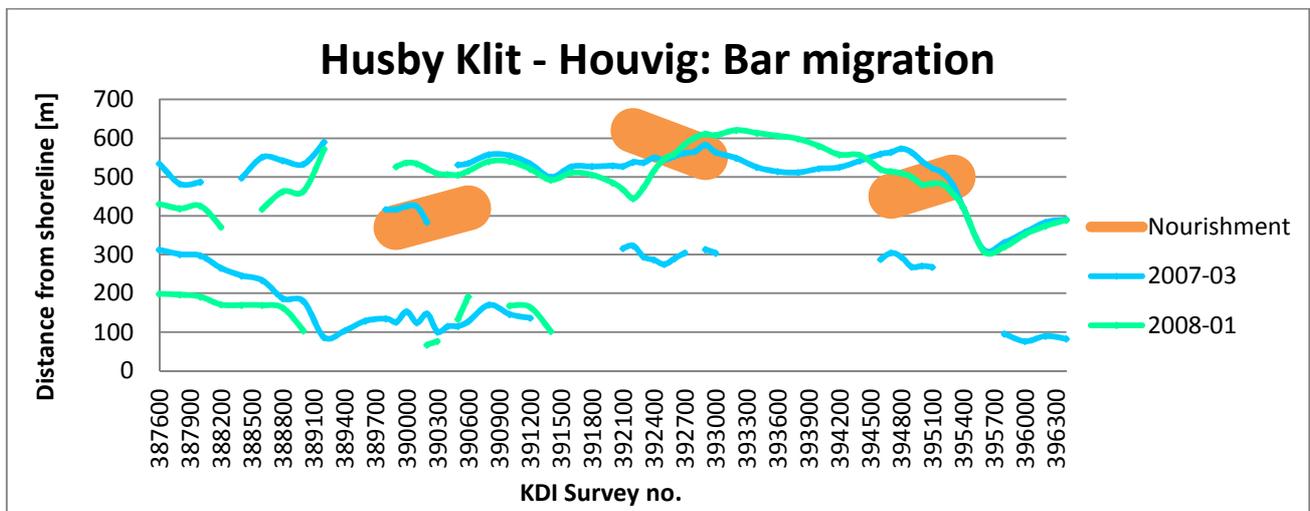


Figure 20: Bar positions, 2007.03 – 2008.01. South bar [left]. Central bar [middle]. North bar [right]

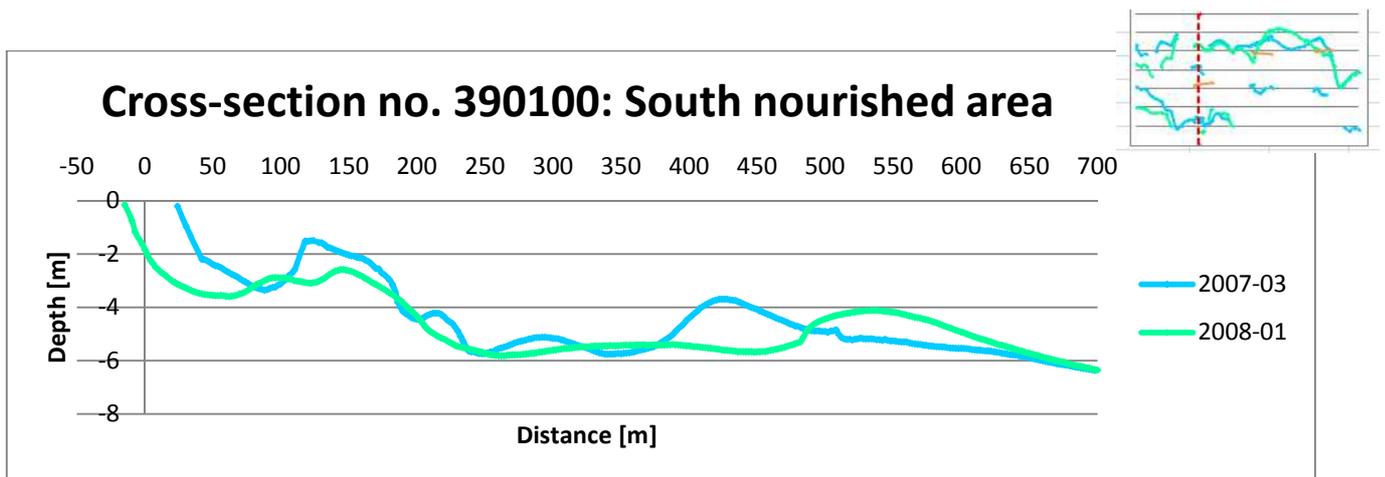


Figure 21: Cross-section of the south nourished area, track no. 390100 (2007.03-2008.01)

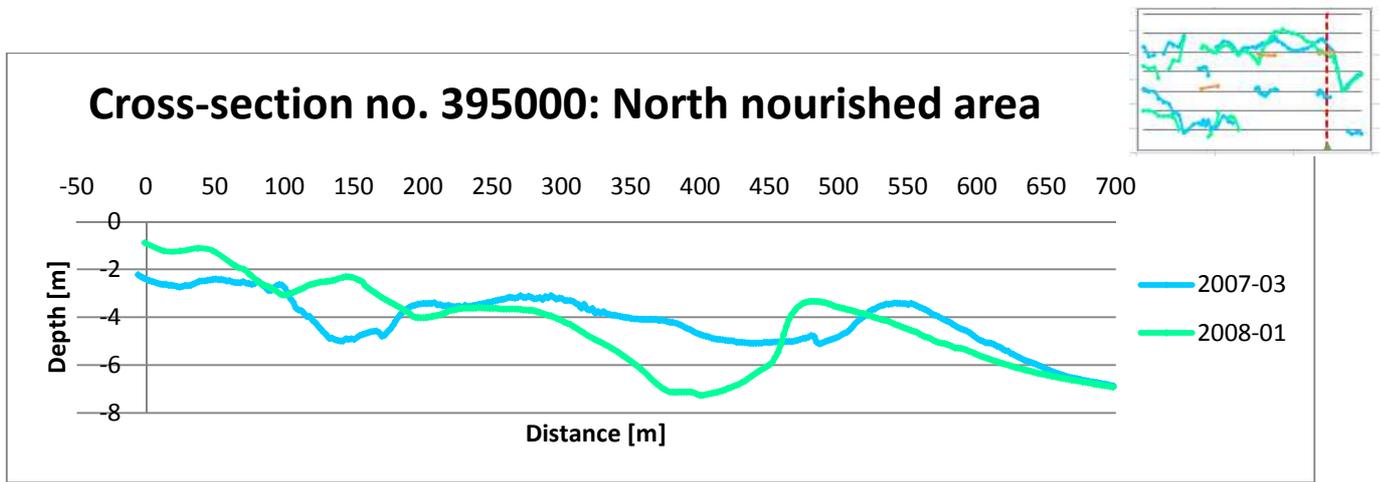


Figure 22: Cross-section of the north nourished area, track no. 395000 (2007.03-2008-.01)

After the 2008.01 survey a short period has gone by with no storm surges. Moderate conditions have caused both onshore and offshore migration of bars. The northern central bar is fairly still positioned. However the central curved part of the northern bar system has generally migrated offshore, where the terminal ends have migrated onshore, *Figure 23*. A breach in the northern bar can be detected. However it should be noted that no field data exist for this area and it is therefore believed that the bar is still there and no degradation has occurred.

Former initiated inner bars in the north and central part can again be detected as sediment is building up. The central inner bar has however migrated offshore while the north inner bar has migrated onshore since, *Figure 24 and Figure 25*. The beach width does also vary accordingly. The outer bar position is believed to be of influence on the bar development and migration pattern observed.

The southern outer bar system continues to weaken while the inner bars develop and migrate onshore, *Figure 23*. Smaller detached bars appear as they are fulfilling the 1m bar criteria.

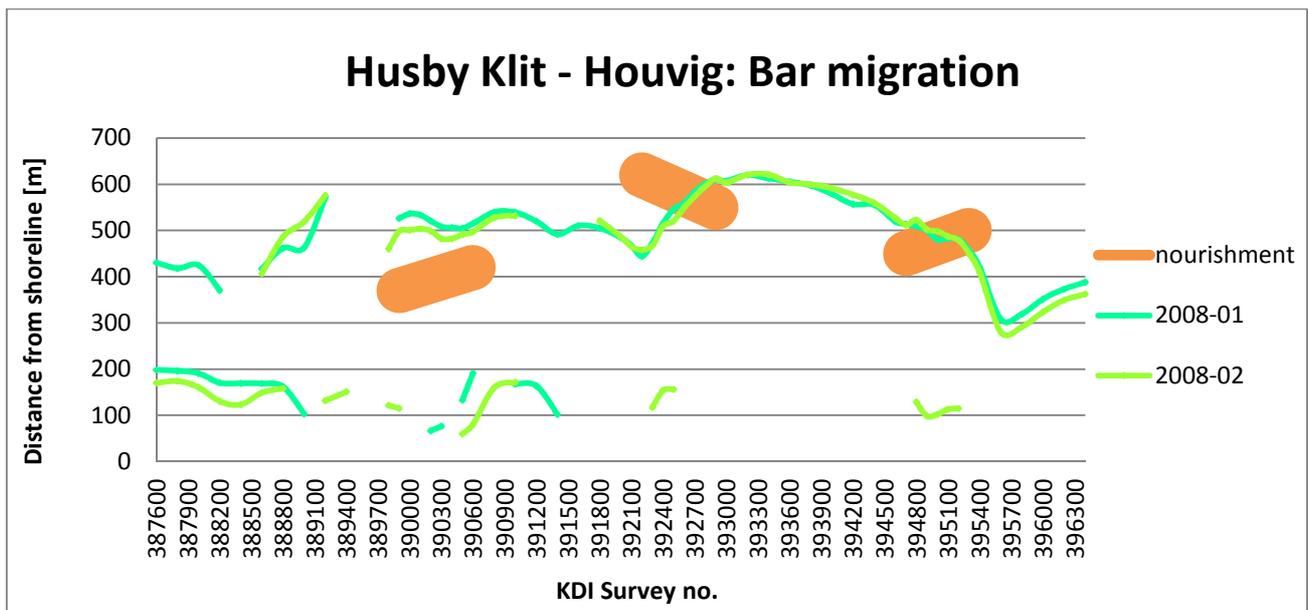


Figure 23: Bar positions, 2008.01 – 2008.02. South bar [left]. Central bar [middle]. North bar [right]

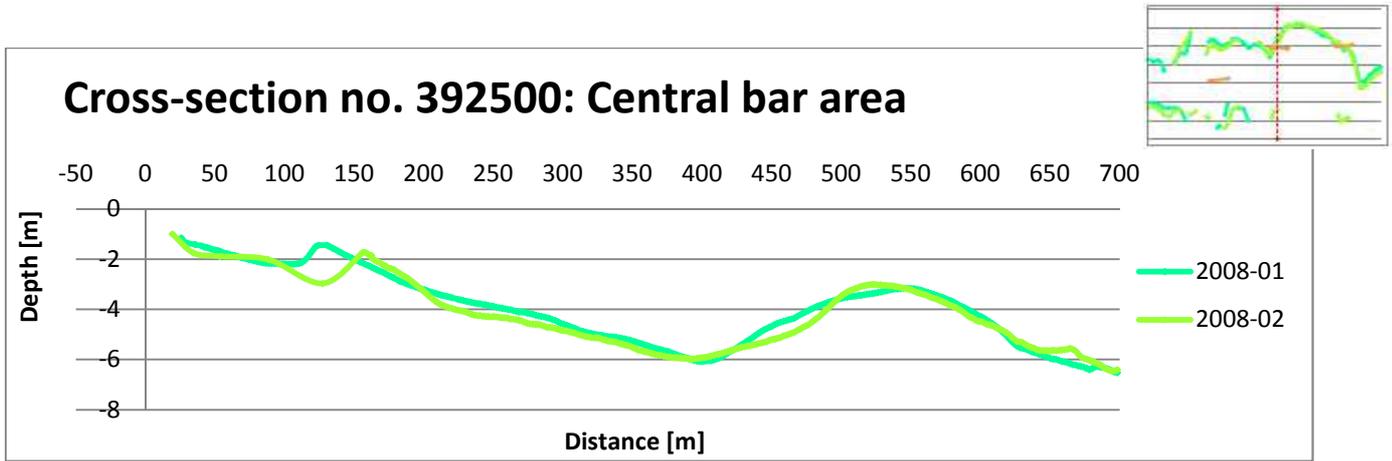


Figure 24: Cross-section of the central bar, track no. 392500 (2008.01-2008.02)

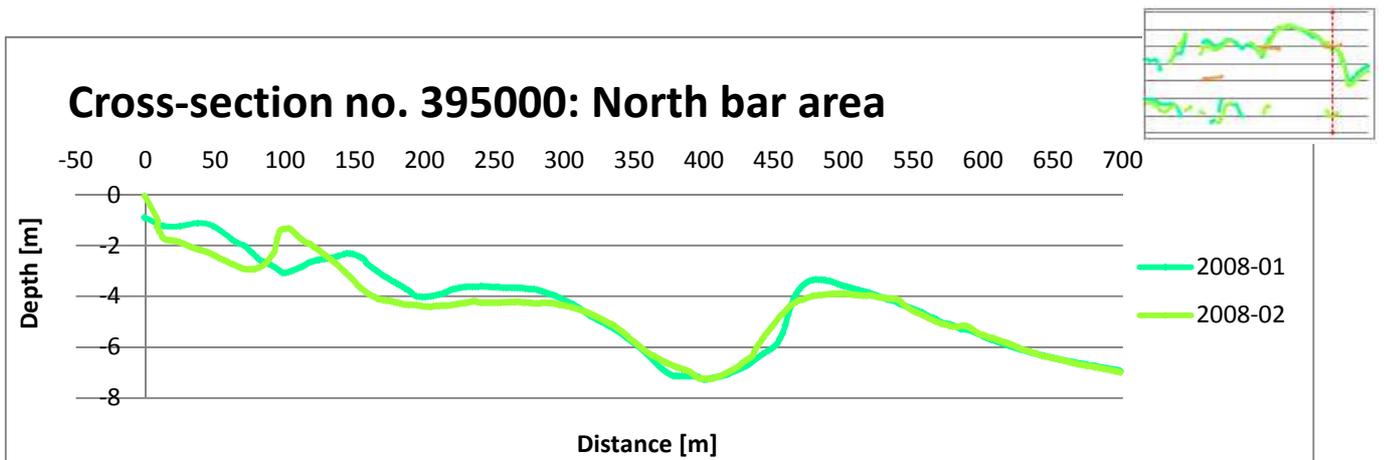


Figure 25: Cross-section of the north bar, track no. 395000 (2008.01-2008.02)

In 2009.01 inner bars have started to form and prolong in the northern part, *Figure 26*. It is evident that a continuously build-up occur. The sheltered conditions and continuously sediment supply favor repeatedly bar initiation and build-up. The inner bars to the south have slowly migrated slightly offshore while. It is notable how the southern outer bar continues to degrade and vanishing. The degradation is expected to be a result of strong southwesterly waves (*Figure 2*) and that the northern bar growth continue to cause sediment starvation degrading the southern outer bar system.

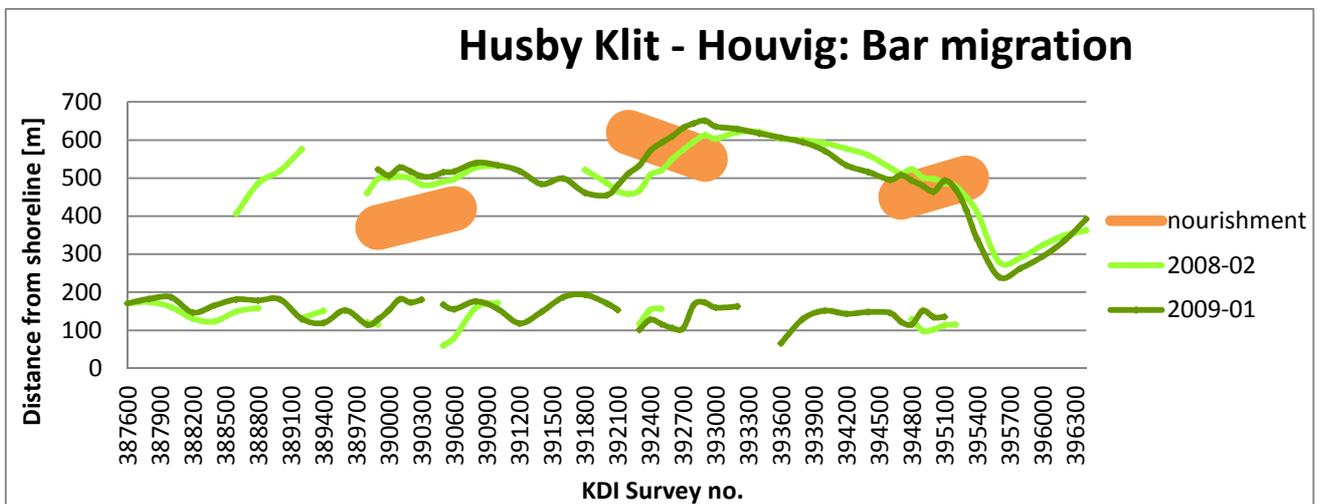


Figure 26: Bar positions, 2008.02 – 2009.01. South bar [left]. Central bar [middle]. North bar [right]

Taking a look on the last survey campaign the northern outer bar continues to migrate towards the south and slightly onshore. The inner bars have merged and migrated slightly offshore. The southern outer bar system continue to weaken. Only single elevated areas are present, *Figure 27*.

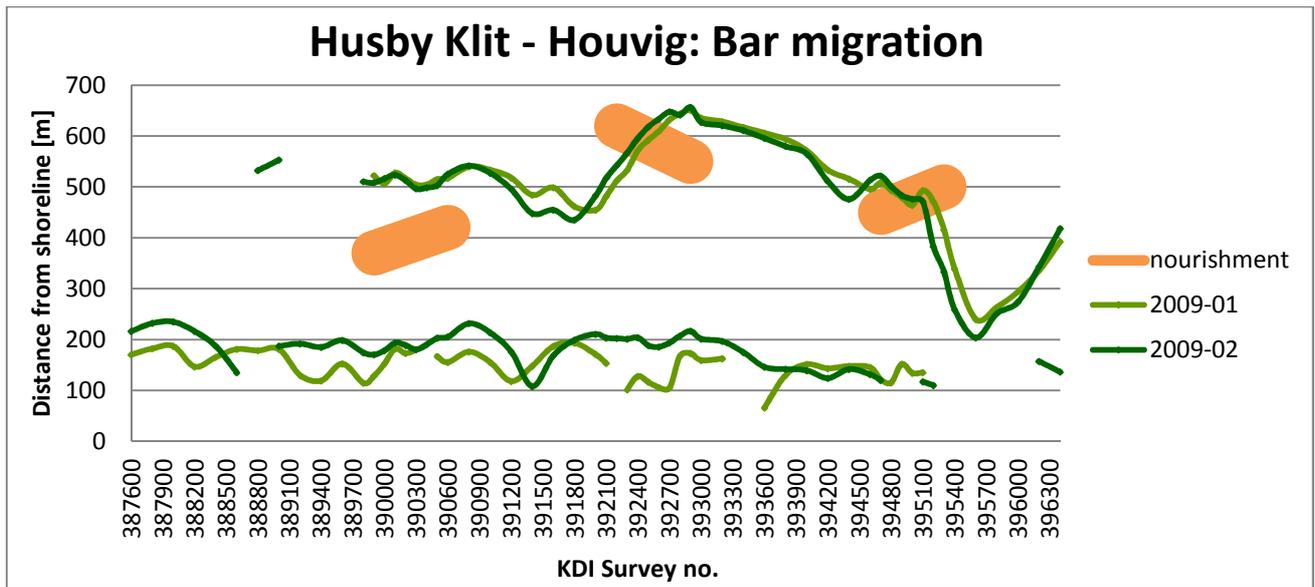


Figure 27: Bar positions, 2009.01 – 2009.02. South bar [left]. Central bar [middle]. North bar [right]

Studying the temporal bar top behaviour at the seven selected profiles, both onshore and offshore bar migration can be observed, *Figure 28-41*. No direct trends can be identified. To the north a slight onshore migration can be observed, *Figure 28-29*. Consequently a result of southward migrating bedforms.

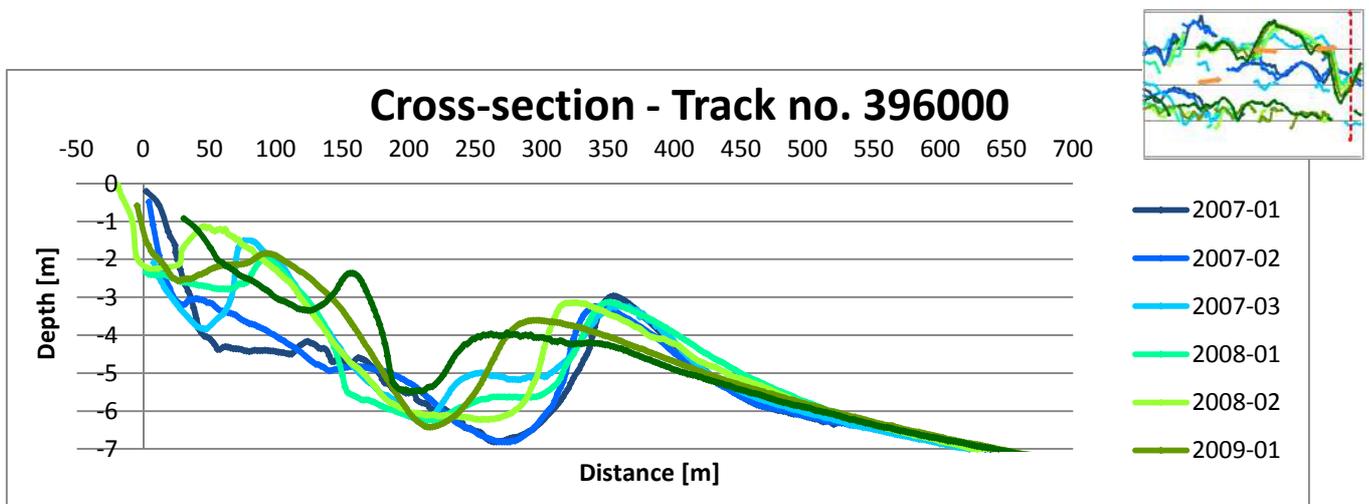


Figure 28: Cross-section at track 396000 - located to the north of the northern nourishment

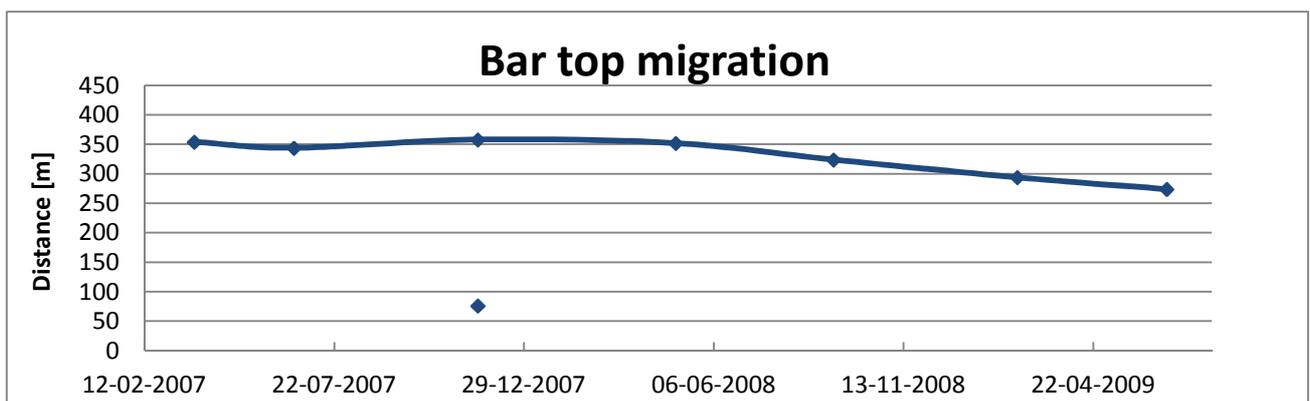


Figure 29: Bar top position and cross-section at track 396000 - located to the north of the northern nourishment

The cross-sectional profile through the northern bar show both onshore and offshore bar movement, *Figure 3131*

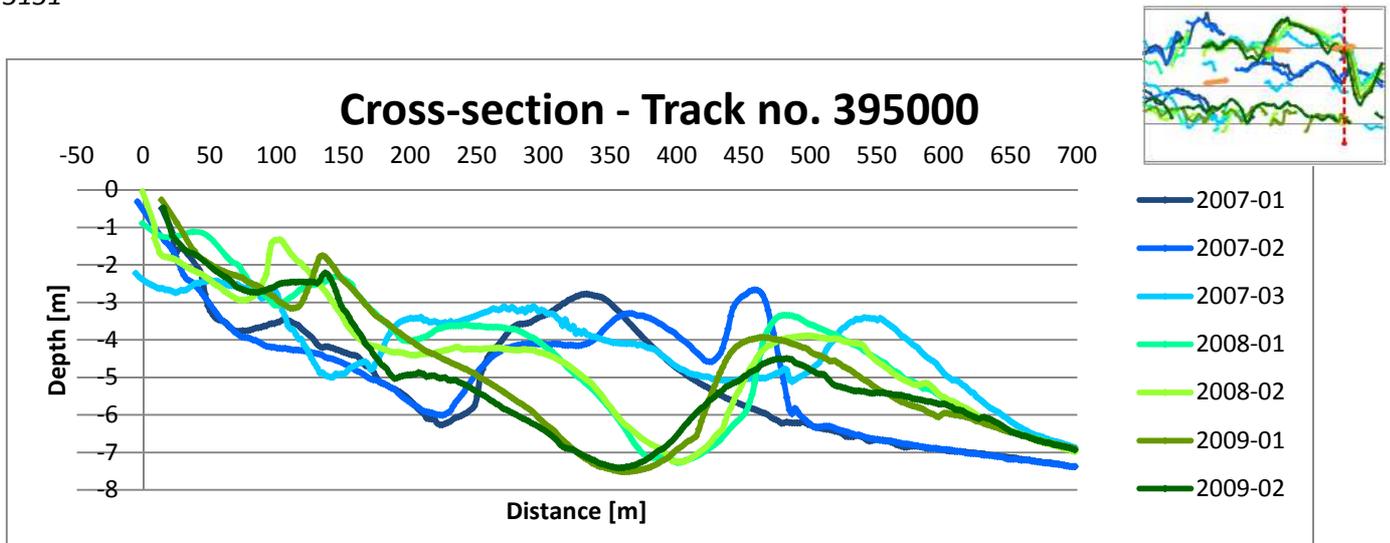


Figure 30: Cross-section at track 395000 - located through the northern nourishment

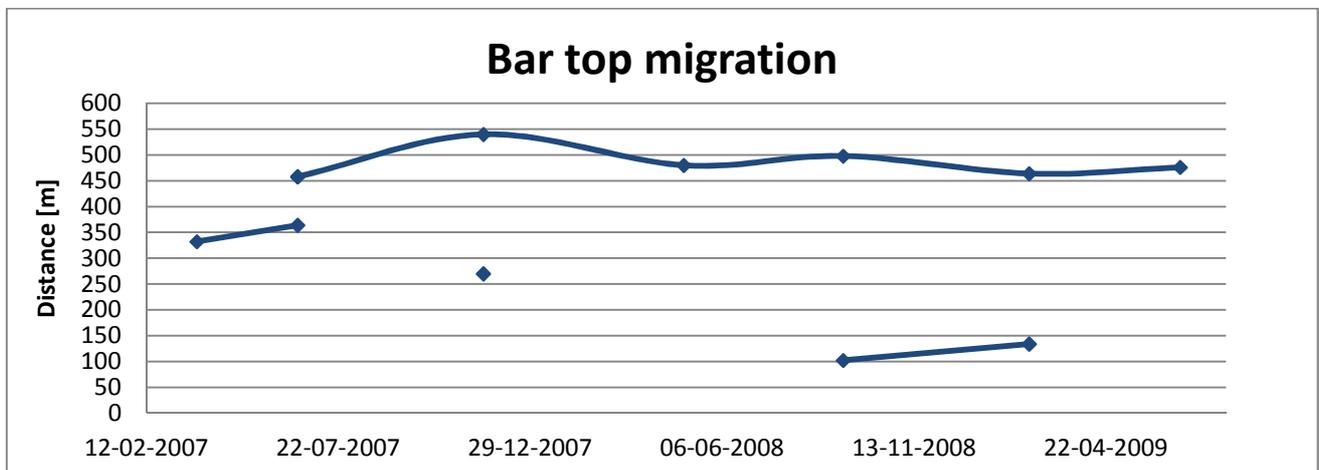


Figure 31: Bar top position registered at track 395000 - located through the northern nourishment

Between the north and central nourishment great erosion has occurred, *Figure 32*. The initial bar has migrated offshore and a new inner bar has developed, *Figure 32-33*.

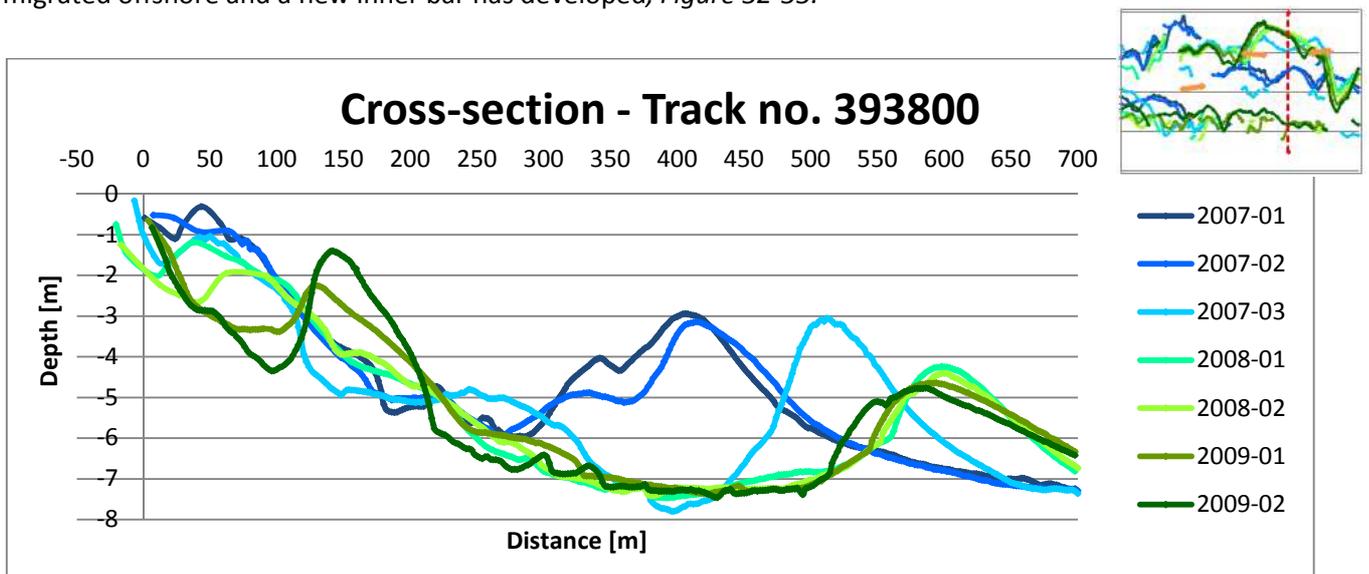


Figure 32: Cross-section at track 395000 - located between the north and central nourishment

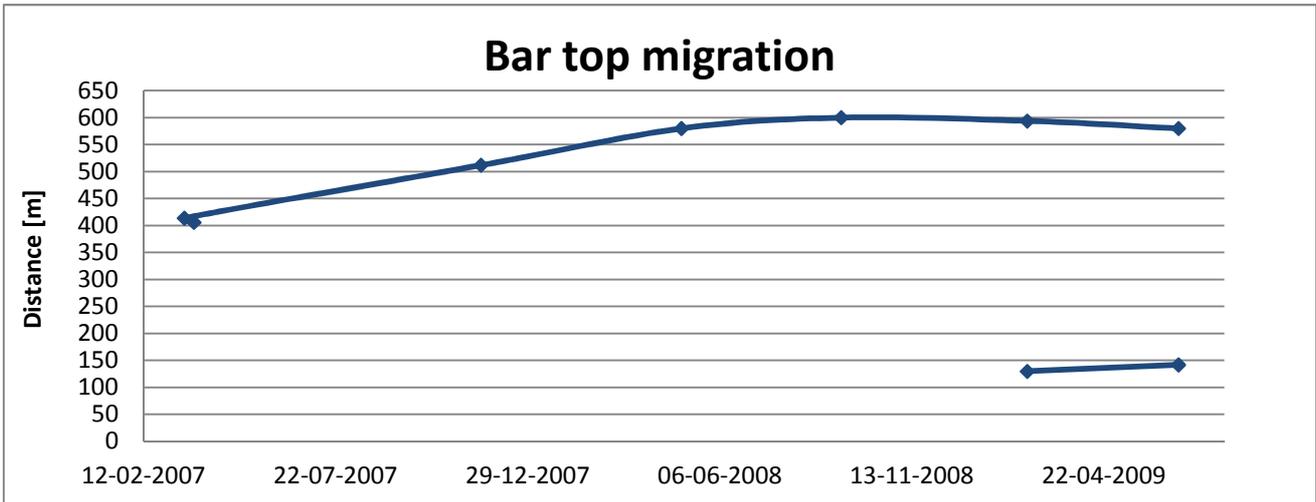


Figure 33: Bar top position registered at track 395000 - located between the north and central nourishment

The central bar has continuously moved offshore, only with different speed. As a large outer offshore bar is established, inner bars are initiated, Figure 34-35.

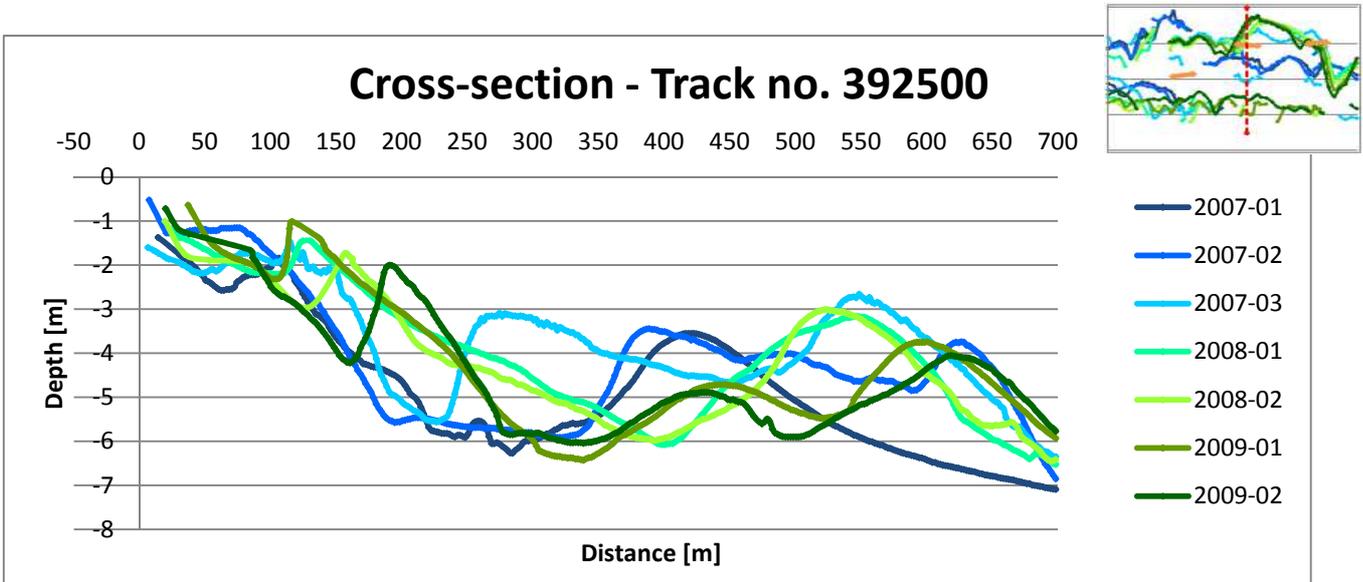


Figure 34: Cross-section at track 395000 - located through of the central nourishment

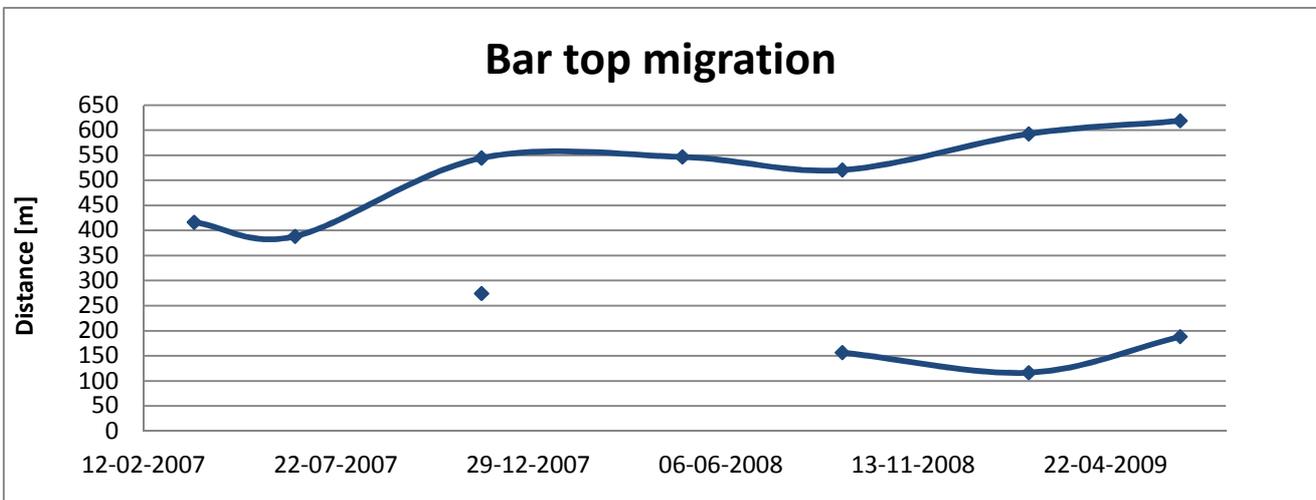


Figure 35: Bar top position registered at track 392500 - located through the central nourishment

The area between the central and south nourished bars has heavy been eroded. Offshore migration is detected in the years 2007-2008 whereas onshore migration is predominantly in 2009, *Figure 36-37*.

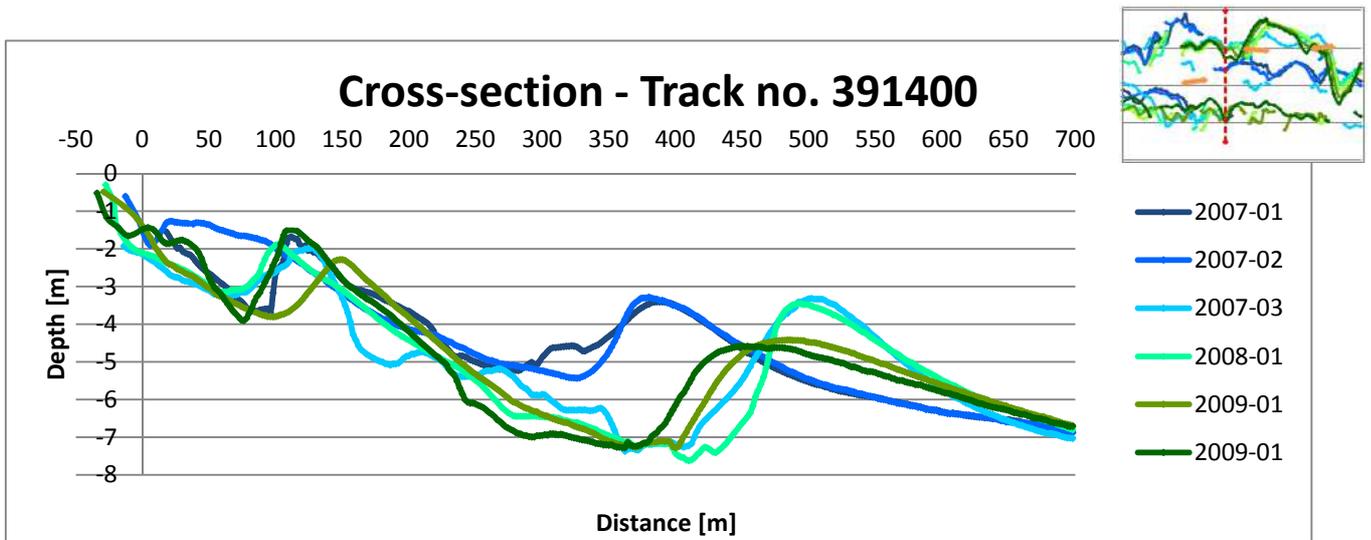


Figure 36: Cross-section at track 391400 - located between the central and south nourishment

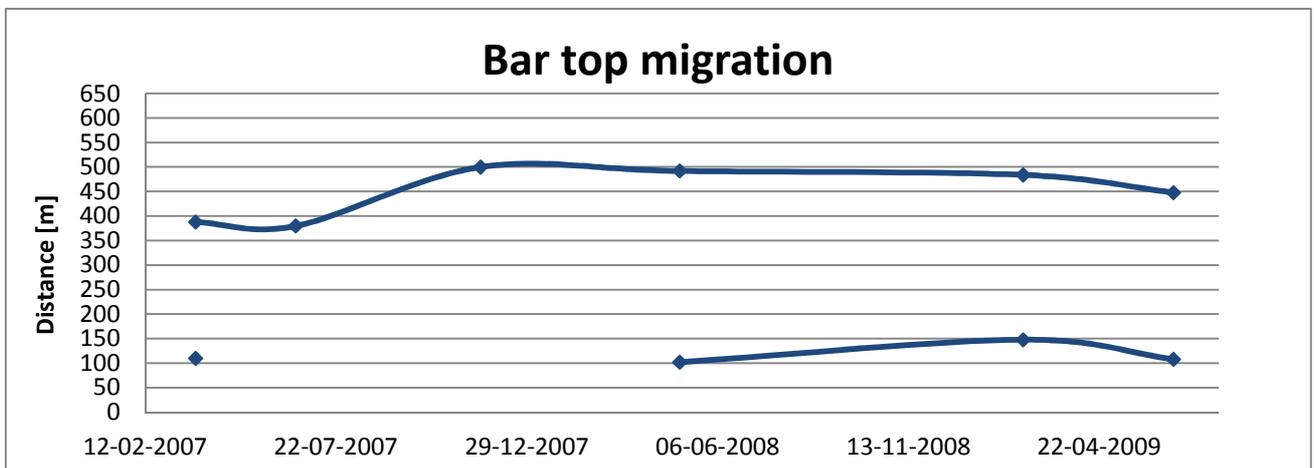


Figure 37: Bar top position registered at track 391400 - located between the central and south nourishment

As a result of the nourishment actions closer proximity to shore a new bar evolved on the onshore side of initial bar. Offshore migration is observed after 2008, *Figure 38-39*.

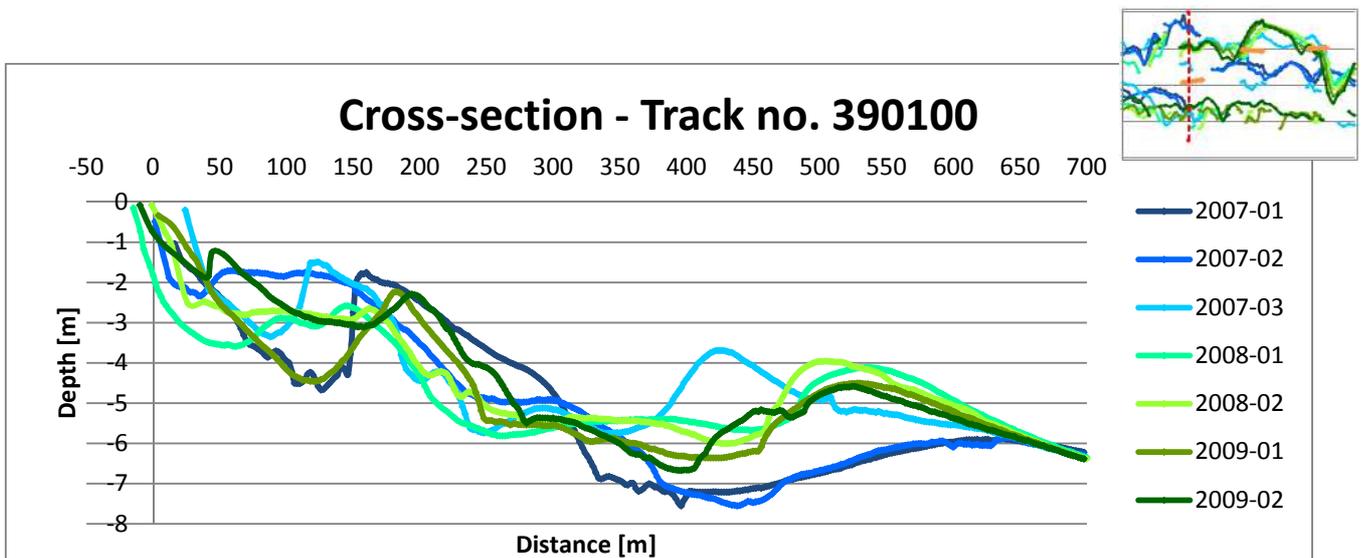


Figure 38: Cross-section at track 390100 - located through the southern nourishment

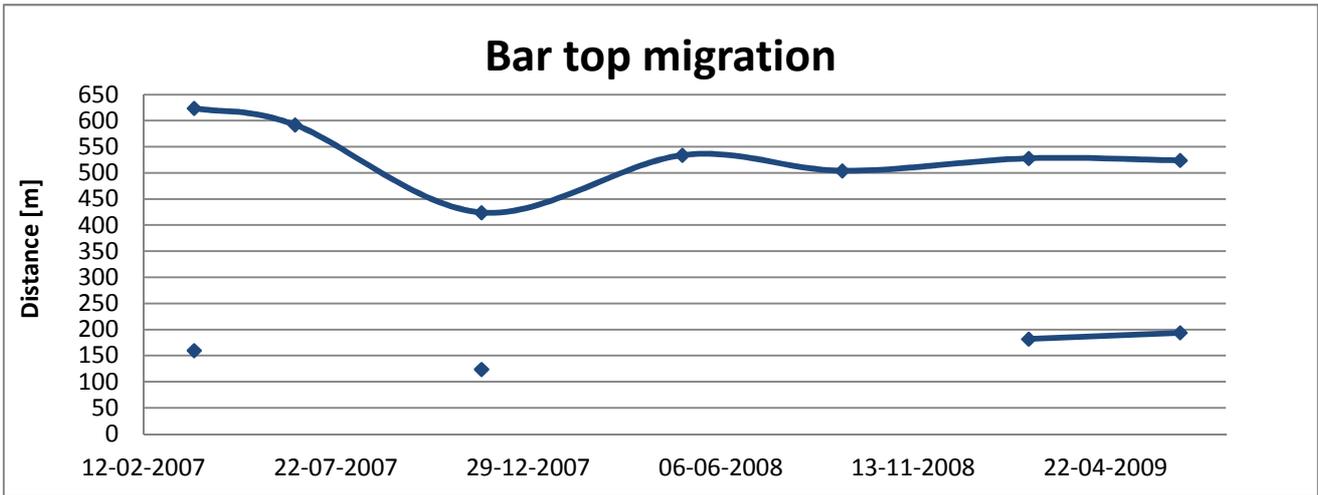


Figure 39: Bar top position registered at track 390100 - located through the southern nourishment

To the south of the nourishment area a general erosion has occurred until 2009 where profile build up occurred, Figure 40-41

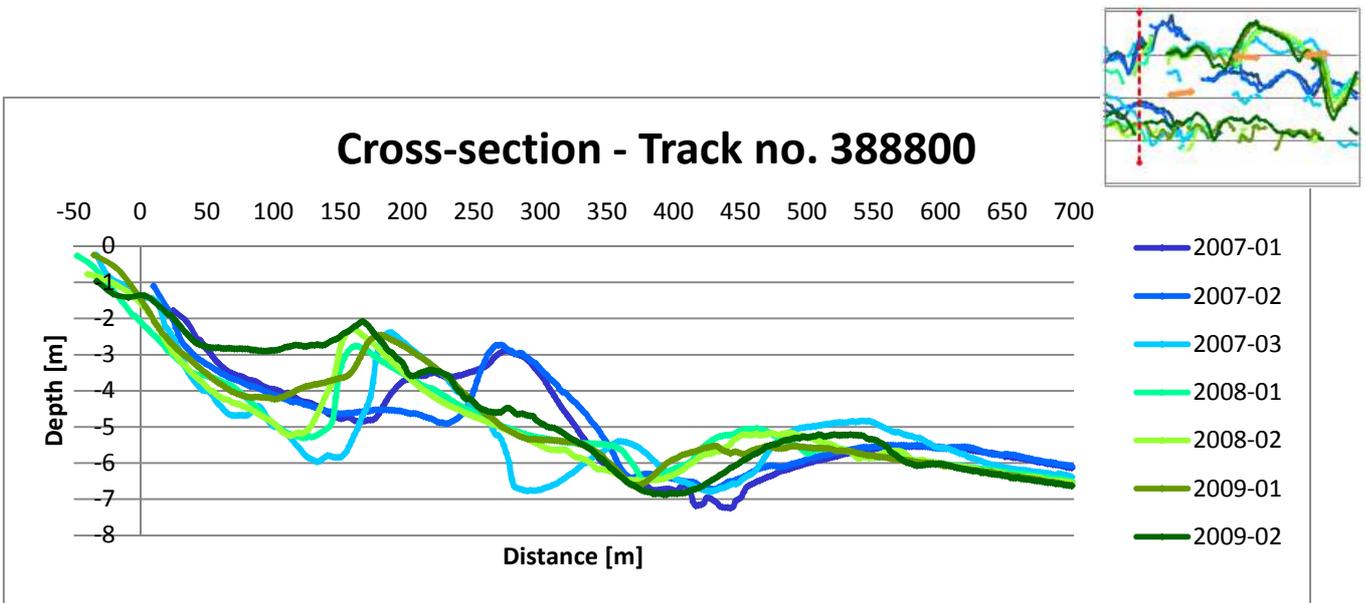


Figure 40: Cross-section at track 390100 - located to the south of the south nourishment

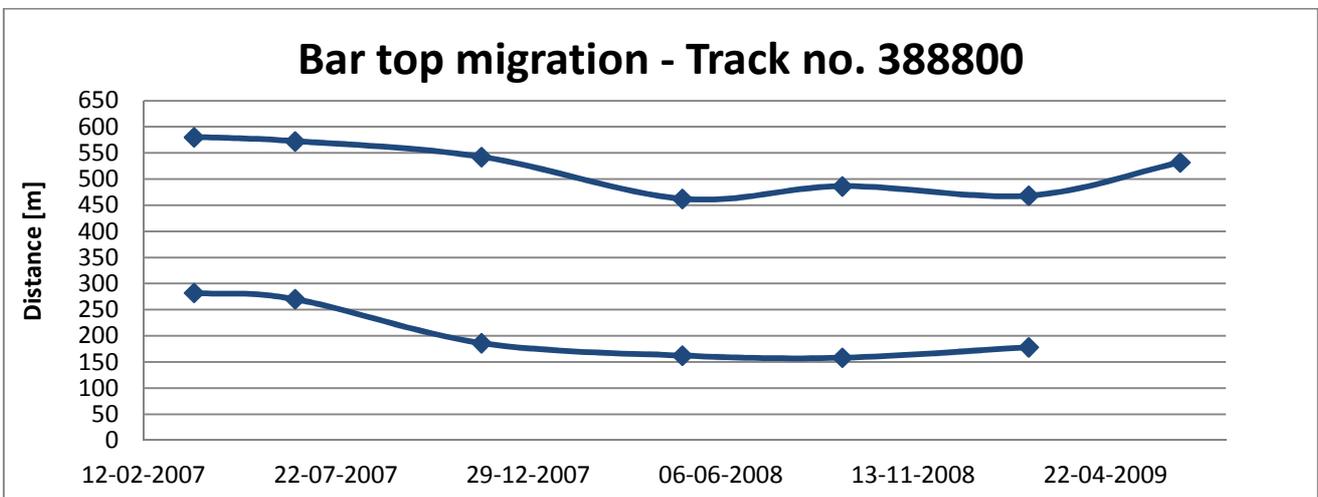


Figure 41: Bar top position registered at track 390100 - located to the south of the south nourishment

The bar system at Husby vary between the presences of one or two bars. New bars continue to develop and old degrade and eventually disappear. Bars can be detected to a distance of 700m from the coast to a depth of 6m. The existence of an outer northern bar system is strong where as the southern bar system is degrading. The growth of the northern bar system has lead to sediment starvation, degrading the southern bar system. The north and central nourishments have enabled a strong outer bar system, building-up existing bar system. The northern bar system prolong towards the south and continuous migration and growth of the northern bar system is expected. The heights of the bars vary significantly along each bar stretch, *Figure 42*. The existence of an outer bar system influence the presence of an inner bar system and is expected to increase the ability to maintain an inner bar system, provided a continuous sediment supply. Nourishment and extreme weather events interfere with the natural processes, affecting the morphological response and the equilibrium states. The nourished material does not stay put but does however help stabilizing and initiating new bars. Nourishment actions do therefore influence the morphology and bar behaviour.

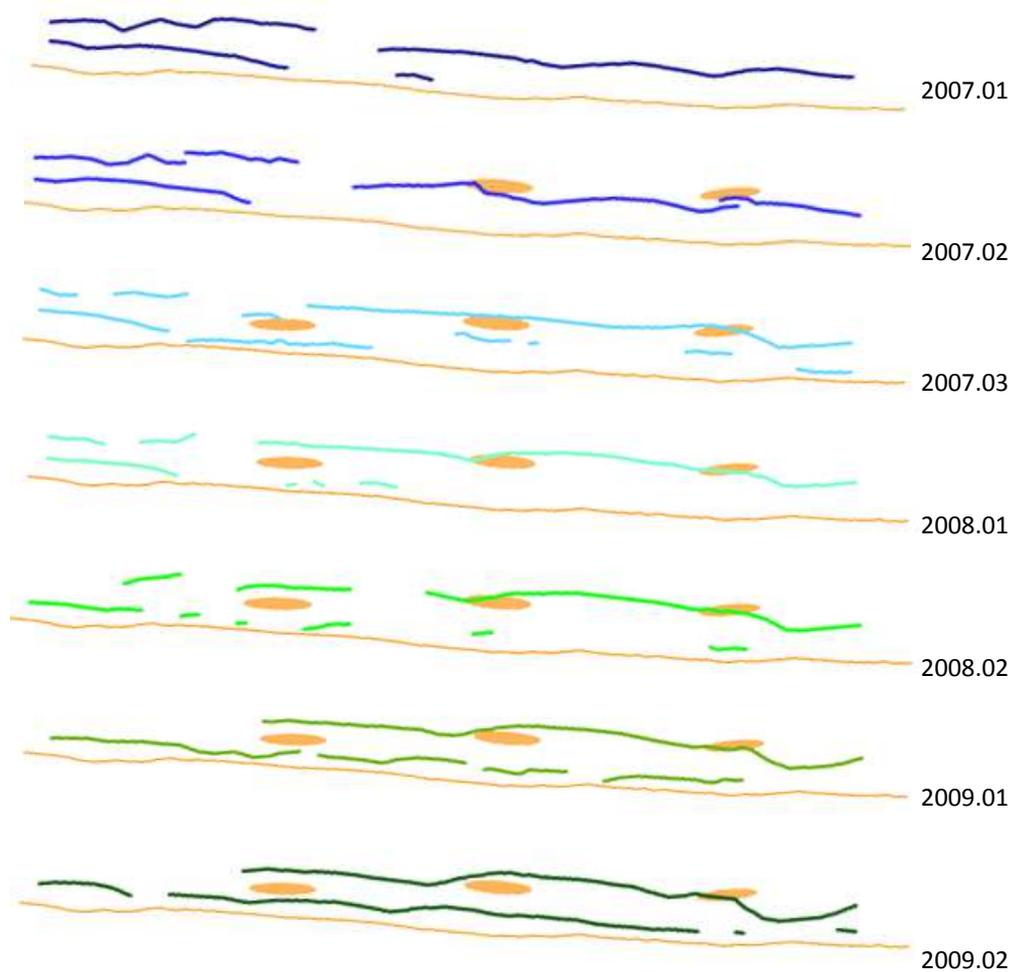


Figure 42: Bar behaviour

