MORPHOLOGIC CHANGE DETECTION IN THE WADDEN SEA FROM LIDAR DATA

Alexander Brzank, Christian Heipke, Jens Goepfert

Institute of Photogrammetry and GeoInformation, Leibniz University of Hanover, Germany
- (brzank, heipke, goepfert)@ipi.uni-hannover.de

Commission VIII, WG VIII/6

ABSTRACT:

Morphologic change detection in the Wadden Sea is an important task in the context of coast protection. Commonly, lidar data is used to calculate a Digital Terrain Model (DTM). In order to detect and evaluate morphologic changes of the surface, a difference model is determined from the DTM of two epochs. Erosion and accumulation refer to significant positive and negative differences. Usually, erosion and accumulation processes are not independent of each other but occur due to shifts of tidal channels. The analysis of these shifts and the change of the trenches are rather difficult to evaluate if only the difference model is available. Within this paper, a new method to detect and analyse morphologic changes in the Wadden Sea is presented. The idea is based on the extraction of the bank lines of the tidal channels in both epochs. The four bank lines of a trench represent its skeleton and can be used for deriving geometrical parameters such as the channel bed width. Based on the extracted bank lines and the parameters of both epochs the changes of the tidal channels can be determined and evaluated. In order to demonstrate the capability of the proposed change detection method, a representative area of the Wadden Sea, which was captured by lidar in 2005 and 2007, is evaluated. It is shown that neighbouring erosion and accumulation processes are often caused by shifts and changes in size of a tidal channel. With the help of the extracted bank lines and the geometrical parameters these changes can be detected and evaluated in an elegant way.

1. INTRODUCTION

The Wadden Sea is a unique habitat in the North Sea located next to the coast of Denmark, Germany and the Netherlands. This area, formed by the tide, is flooded two times a day, which has led to a unique flora and fauna (Reineck, 1982).

The surface of the Wadden Sea is characterised by tidal channels. These are oblong depressions of various size and depth. While small tidal channels have widths of a few meters and depths of less than one meter, larger depressions reach widths of more than 100m and depths of more than 10m. Commonly, neighbouring tidal channels are linked to each other, which results in a tidal channel net (Henke, 1999).

The impact of the moving seawater results in various accumulation and erosion processes within the Wadden Sea. The size and position of such surface changes are of great interest especially for coast protection purposes. In order to determine and evaluate accumulation and erosion processes, highly precise height data of the relevant epochs are required. Lidar is commonly used to acquire the corresponding height data. This method offers important advantages. It allows obtaining 3D points of the surface with high density as well as high accuracy (Baltsavias, 1999). Moreover, the method is capable to collect data of large areas in a short time, which enables to neglect morphologic changes of the surface within one measurement campaign. However, lidar is not able to penetrate water (Zissis, 1993). Due to the fact that water still remains in tidal trenches and depressions even during low tide, water points are part of the captured lidar data. In order to calculate a Digital Terrain Model (DTM), which describes the mudflat surface accurately, water points have to be detected and removed, and additional correct height data (e.g., bathymetric data) have to be introduced (Brzank and Heipke, 2007).

For change detection purposes, a DTM is calculated for at least two different epochs. Subsequently, a difference model is determined by subtracting the two corresponding DTMs. Large absolute differences indicate significant morphologic changes while the algebraic sign hints at accumulation or erosion of material. Although the calculation is simple, the interpretation requires time and deep knowledge about the area, because every difference relates to a certain location but not necessarily to the same object. Hence, if a tidal channel changed its position, accumulation will be detected at the old location while erosion occurs on the current position. An easier and more accurate evaluation of morphologic changes of tidal channels is possible, if the geometry of these objects is derived and integrated in the analysis.

In this paper, we present a new method to detect and evaluate morphologic changes of the Wadden Sea based on the extraction of structure lines of tidal channels from lidar. First, the extraction algorithm is briefly described. Then, several parameters, which can be used for evaluating morphologic changes of tidal channels, are introduced. Subsequently, it is shown, how they can be derived from the structure lines and how morphologic changes can be verified. Based on a meaningful example, the suggested new algorithm of change detection in the Wadden Sea is demonstrated.

2. BANK LINE EXTRACTION

The used extraction algorithm allows determining the corresponding lower and upper structure lines of one bank of a tidal channel. The method consists of two parts. The first one delivers a 2D approximation of the centre line which is situated in between both corresponding structure lines by digital edge detection. The second part deals with the piecewise

reconstruction of the surface in the vicinity of both structure lines. For that purpose two versions of the hyperbolic tangent function are designated (see Figure 1). Depending on the horizontal propagation of the centre line one variant is chosen automatically for each patch. The parameters of each function are estimated by a least squares adjustment. Subsequently, one point of the upper and lower bank can be derived for each patch. Corresponding points of one line are linked together by a spline interpolation. A detailed description of the method can be found in Brzank et al. (2008).
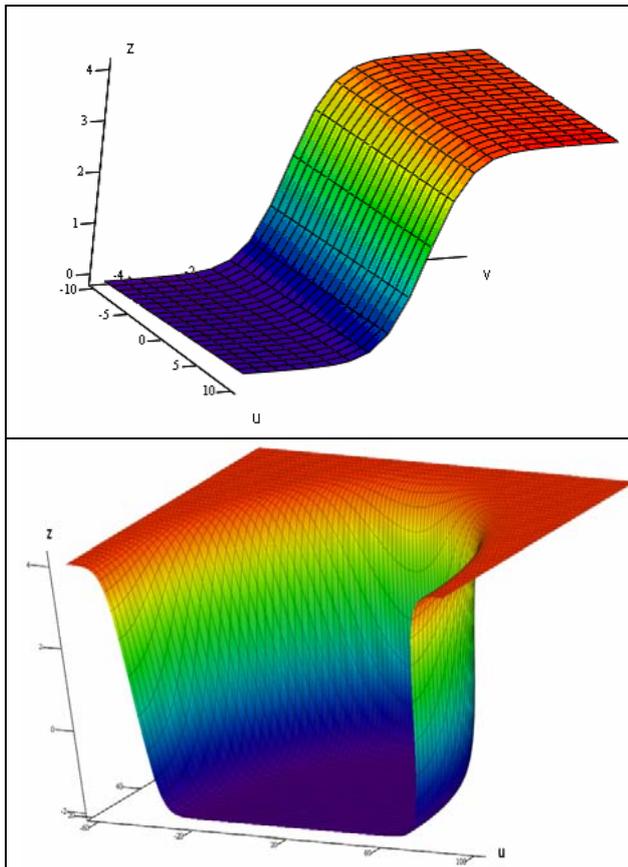
Figure 1. Variants of hyperbolic tangent function for piecewise surface reconstruction of a channel side – "straight" version (up) and "circular" version (down)

3. CHANGE DETECTION OF TIDAL CHANNELS

3.1 Geometrical parameters of a tidal channel

Based on the outlined algorithm the upper and lower bank line of each side of a tidal channel can be derived. All four lines are essential elements of a tidal channel and can be interpreted as its skeleton. Therefore, they are used to represent the depression in a simple model as well as to analyse its size and position. Important parameters of a tidal channel, which can be derived from the structure lines, and their description are listed in Table 1.

parameter	description
channel length	average horizontal length of all four lines
channel width	horizontal distance between corresponding points of the upper bank lines
channel bed width	horizontal distance between corresponding points of the lower bank lines
left bank width	horizontal distance between corresponding points of the upper and lower left bank lines
right bank width	horizontal distance between corresponding points of the upper and lower right bank lines
left bank depth	vertical distance between corresponding points of the upper and lower left bank lines
right bank depth	vertical distance between corresponding points of the upper and lower right bank lines

Table 1. Geometrical parameters of a tidal channel

3.2 Evaluation of change detection of a tidal channel

The bank lines of a tidal channel are determined with the previously introduced extraction algorithm for at least two epochs based on lidar data sets. Subsequently, the derived lines can be used for evaluating morphological changes of the tidal channel. Generally, several approaches are suitable. A simple and effective method is the comparison of corresponding bank lines of different epochs. For that purpose, the distance of points of one epoch to the line of the other epoch is computed (see Figure 2). As a result, every referred line point can be characterised by a 3D shift vector. With the help of two empirically defined horizontal and vertical shift values the points can be classified as "no change", "probable change", or "change". This separation allows the detection of those regions of the line, which have been changed from one epoch to the next.
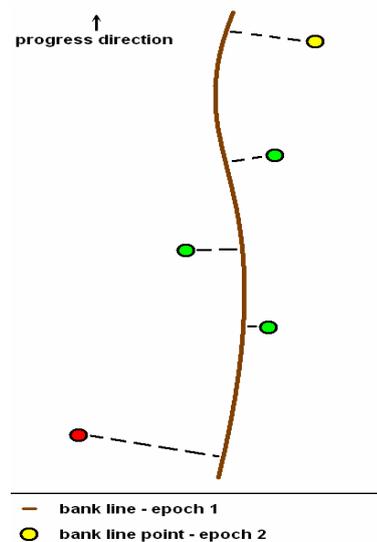

Figure 2. Comparison of corresponding bank lines of different epochs by computing the distance of points of epoch 2 to the line of epoch 1. The different colours of the line points label the decision: "no change" – green, "probable change" – yellow, and "change" – red.

A more global comparison is possible, based on calculating the average shift vector and its standard deviations in the directions X, Y and Z. Subsequently, it can be checked, whether the average shifts in each direction are significant or not. Another suitable strategy is based on the comparison of the geometrical parameters. For both epochs the mean values and their assigned standard deviations are calculated. Then, every parameter is assessed for significant changes by applying a two sided Student's t-test. Equation 1 displays the used test statistic t_f.

$$t_f = \frac{\overline{x}_{Epoch\_1} - \overline{x}_{Epoch\_2}}{\sqrt{s_{\overline{x}\,Epoch\_1}^2 + s_{\overline{x}\,Epoch\_2}^2}} = \frac{d}{s_d} \quad (1)$$

where

$\overline{x}$ = average value of parameter **x** of a certain epoch

$s_{\overline{x}}$ = standard deviation of the average value of parameter **x** of a certain epoch

t_f = test statistic

4. EXAMPLES

The estuary of the river "Weser" into the North Sea is of great interest for the Water and Shipping Agency of Bremerhaven, Germany. Half of the area is mapped every year with lidar. While the east side of the estuary (approximately 344km^2) is covered every even year, the west side (approximately 258km^2) is obtained every odd year, enabling change detection for a certain region every two years. Within this paper lidar data of the years 2005 and 2007 of the west side are used to detect and evaluate morphologic changes. Table 2 lists the parameter of both flights.

flight parameters	2005	2007
company	Toposys, Germany	Toposys, Germany
scanner system	Falcon II	Harrier 56
flight height [m]	1200	400
dates of operation	18.08. -21.09.2005	16.05. -21.05.2007
point density [points/m^2]	4	5

Table 2. Flight parameters of examples

From the lidar data a representative area of 2km*4km was chosen. It contains two main tidal channels, each with a width of several 100m. The width decreases with reducing distance towards the coast line situated in the south of the scene. Several smaller tidal trenches are in the area as well.

A Digital Height Model (DHM) was calculated from the last echo lidar data set of each epoch. Because the last echo point cloud includes also water points the DHM does not correspond to the DTM. Nevertheless, the DHM can be used for evaluation purposes by considering only regions above the water level. Based on the experience of the agency, all heights above -1.3m sea level are treated as mudflat. Figure 3 displays the research

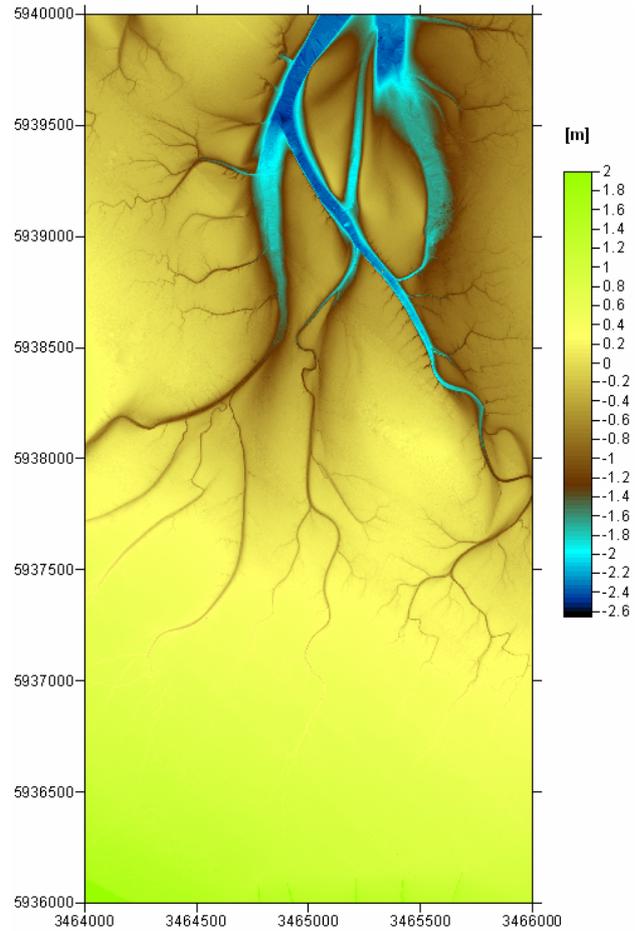area of the year 2005 of the chosen region colour, coded with respect to the height.

Figure 3. Digital Height Model (Gauss-Krueger coordinate system) of the area of interest of the year 2005 derived from lidar data.

4.1 Classical change detection

In the first step of the morphological change detection in the area of interest between both epochs the difference model was calculated from the DHM of 2007 and 2005. Figure 4 displays the result. The blue colour indicates accumulation while the red colour labels erosion. It can clearly be seen that the important morphological changes occur in the vicinity of both main tidal channels. In the north part of the area material eroded on the west side of these trenches, while the east side accumulated new material. In the southern part of the left channel the situation is reversed. The erosion–accumulation–relationship can be explained by a shift of both trenches to the west for the northern part and a shift to the east for the southern part of the left channel. This trend can also be observed for smaller channels within the scene. However, the horizontal and vertical size of erosion and accumulation processes or equivalently the shift of trenches reduced with decreasing distance towards the coast line. Besides vertical differences caused by morphologic changes systematic height shifts are visible in the difference model. They pass through the area from north west to south east identically with the flight direction in both campaigns. The reason is not evaluated further. However, it is likely that systematic height failure occured on the edges of the flight strip as detected by the water agency in older measurements.
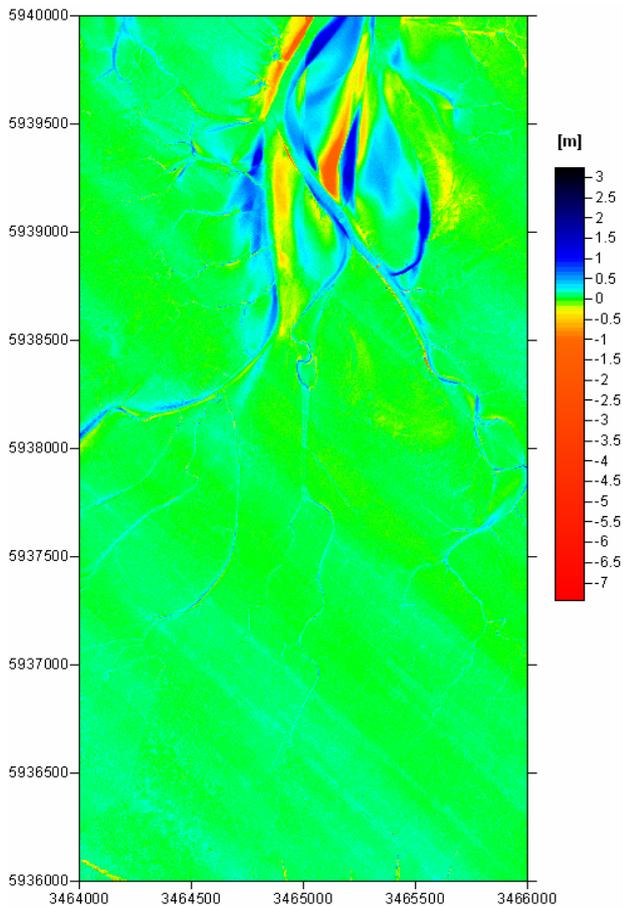
Figure 4. Difference Model of the area of interest – DHM 2007 minus DHM 2005. The blue colour indicates accumulation while the red colour labels erosion.

4.2 Change detection by bank line extraction

In order to simplify the bank line extraction we concentrate on the end of the left main channel. Because its height is above -1.3m in this region, no echo sounding is needed and the extraction is based only on lidar data. Figure 5 displays the channel part. The relation of accumulation and erosion indicates primarily a shift of the trench to the south east direction.
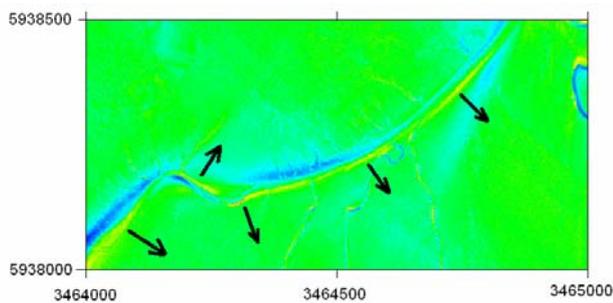

Figure 5. Difference Model of the selected tidal channel – DHM 2007 minus DHM 2005. The blue colour indicates accumulation while the red colour labels erosion. The dark arrows display the assumed shift of the channel.

The bank lines were determined for both epochs based on the introduced algorithm (see Brzank et al., 2008). Figure 6 displays the extracted lines.
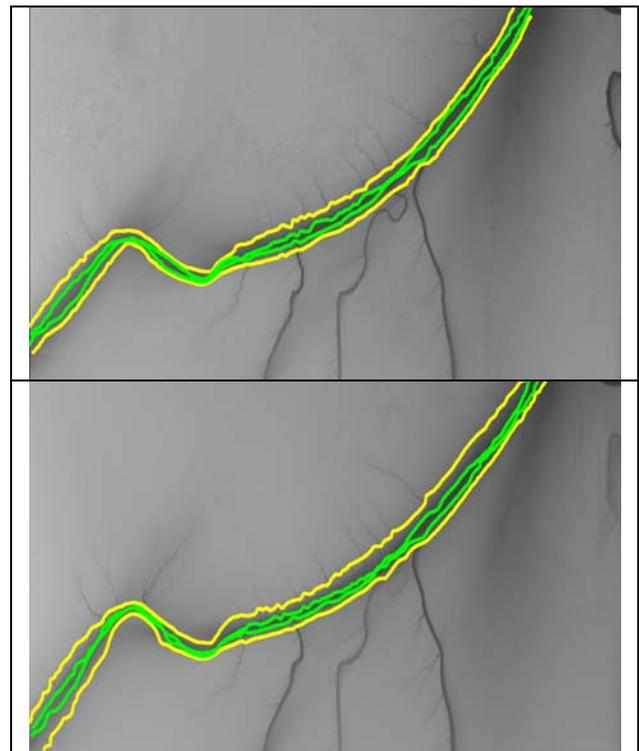

Figure 6. Extracted bank lines of the selected tidal channel – 2005 (up), 2007 (down). The yellow colour indicates the upper bank lines while the green colour labels the lower bank lines.

Subsequently, the geometrical parameter values (see Table 1) as well as their standard deviations were calculated. Then, the Student's t-test was performed to evaluate whether the parameter changes are significant. Table 3 lists the results.

parameter		2005 $\bar{x}$ / $s_{\bar{x}}$ [m]	2007 $\bar{x}$ / $s_{\bar{x}}$ [m]
channel length	*	1042.07 / 5.86	1079.92 / 8.06
channel width	*	29.38 / 0.22	33.97 / 0.31
channel bed width	*	9.61 / 0.15	7.12 / 0.14
bank width – north	*	11.15 / 0.13	16.55 / 0.19
bank width – south	*	8.45 / 0.09	9.93 / 0.15
bank depth – north	*	0.51 / 0.01	0.57 / 0.01
bank depth – south	*	0.45 / 0.01	0.49 / 0.01

Table 3. Geometrical parameters of the chosen tidal channel for epochs 2005 and 2007. The "*" marks a parameter which has significantly changed with a prior fixed probability error of 5%.

All parameter changes are significant. The tidal channel has increased in length by more than 37m. Furthermore, the channel became broader by over 4m while the channel bed width decreased from 9.81m in 2005 to 7.12m in 2007. In consequence, both bank widths increased significantly, in case of the northern bank by more than 5m. The depth of the tidal channel has grown slightly as the bank depth of both banks increased by a few cm.
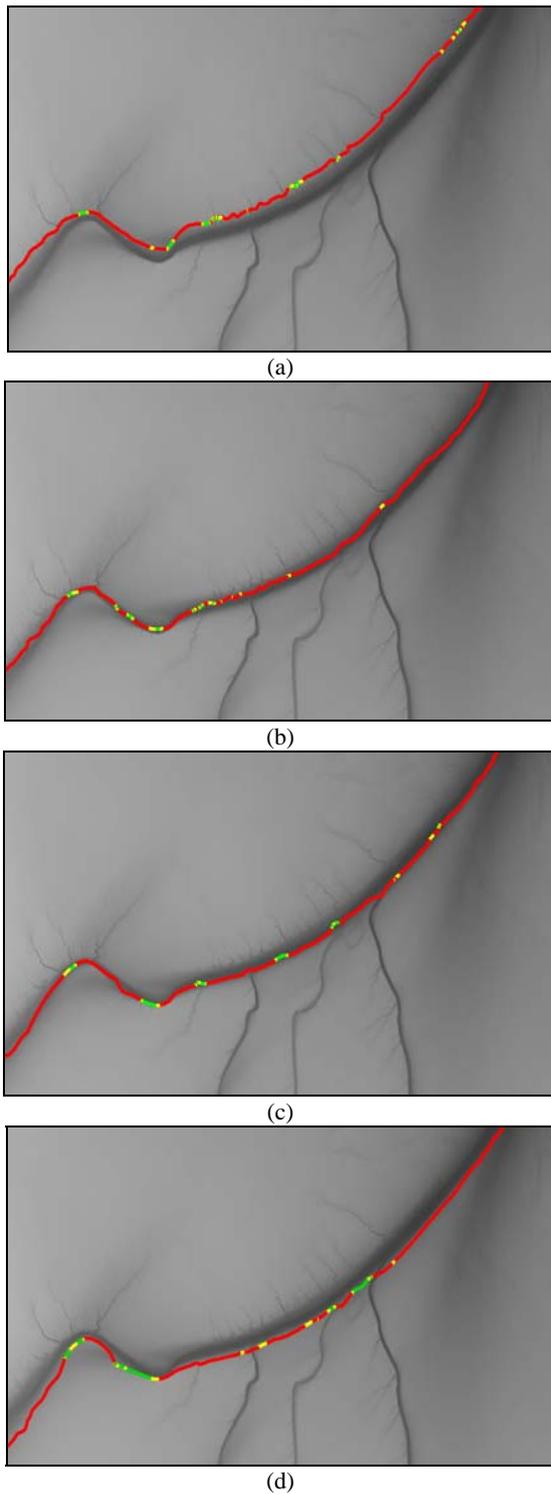
(a)

(b)

(c)

(d)

Figure 7. Comparison of corresponding bank lines. The epoch 2005 is used as reference. The bank line points of epoch 2007 are displayed in the figure (a: upper north, b: lower north, c: lower south, d: upper south). The green colour labels points with a horizontal distance smaller than 1m. They are treated as "no change". The yellow colour indicates points with a horizontal distance in between 1m and 2m. They are treated as "probable change". The red colour marks points with a horizontal distance larger than 2m. They are treated as "change". The displayed DTM in the background originates from the epoch 2007.

In the next evaluation step the corresponding bank lines of both epochs were compared. The channel lines of the epoch 2005 were used as reference while the distance of the corresponding line points of epoch 2007 to the line of 2005.was computed. Subsequently, the points were classified into the groups "no change", "probable change" and "change" depending on their horizontal distance to the reference. The classification thresholds (smaller 1m – "no change", 1m to 2m – "probable change", and larger 2m – "change") were chosen empirically with respect to previously performed accuracy checks of the extraction method. Figure 7 shows the results of all four line comparisons. It can be seen that for most parts of the tidal channel the bank lines have considerably changed in position. The red regions of the bank lines correspond to a high degree with the erosion-accumulation-relations as already pointed out in the Figure 5.

Finally, the mean shift vectors and their standard deviations were derived. Table 4 lists the results. All four lines have moved in south east direction. While the mean shift of the upper north bank line is within one meter, the lower north line is shifted by almost 6m. This explains the remarkable bank width increase of the north side of the channel from 11.15m in 2005 to 16.55m in 2007. The channel also was lifted slightly upwards by a few cm. All shifts are significant with respect to the a priori selected probability error of 5%.

compared lines		mean shift vector [m]	standard deviation of mean shift vector [m]
upper north	* * *	$\begin{pmatrix} 0.71 \\ -0.30 \\ 0.19 \end{pmatrix}$	$\begin{pmatrix} 0.14 \\ 0.15 \\ 0.01 \end{pmatrix}$
lower north	* * *	$\begin{pmatrix} 3.89 \\ -4.46 \\ 0.13 \end{pmatrix}$	$\begin{pmatrix} 0.13 \\ 0.14 \\ 0.01 \end{pmatrix}$
upper south	* * *	$\begin{pmatrix} 3.80 \\ -4.09 \\ 0.14 \end{pmatrix}$	$\begin{pmatrix} 0.16 \\ 0.20 \\ 0.01 \end{pmatrix}$
lower south	* * *	$\begin{pmatrix} 3.16 \\ -3.08 \\ 0.09 \end{pmatrix}$	$\begin{pmatrix} 0.11 \\ 0.16 \\ 0.01 \end{pmatrix}$

Table 4. Comparison of corresponding bank lines of 2005 and 2007 of the selected tidal channel – mean shift vectors and their standard deviations. The "*" marks a shift which is significantly different from 0 with a prior fixed probability error of 5%.

5. CONCLUSION AND OUTLOOK

In this paper it was shown that the evaluation of morphologic change detection in the Wadden Sea based on a difference model can be performed fast. However, the analysis is rather complex. The newly proposed way allows the evaluation of size and position changes of tidal channels, which are elementary objects of the mudflat surface. The extracted skeleton and the derived parameters enable a multiplicity of analysis strategies. Related erosion-accumulation-processes can be explained by the movement of tidal channels.

Future work will focus on creating a full 3D model of the trench based on the extracted bank lines. This will allow even more evaluation possibilities of new parameters such as cross section surface and volume. Furthermore, it will be analysed if morphologic changes, which have been evaluated from several epochs, can be extrapolated in the future to detect and point out prospective spots with respect to coast protection and shipping security.

REFERENCES

Baltsavias, E. 1999. Airborne laser scanning: basic relations and formulas. *ISPRS Journal of Photogrammetry and Remote Sensing*, 54(2-3), pp. 199-214.

Brzank, A., Heipke, C. 2007. Supervised classification of water regions from lidar data in the Wadden Sea using a fuzzy logic concept. In *International Archives of Photogrammetry and Remote Sensing and Spatial Information Sciences*, Espoo, Finland, Vol. XXXVI/3, pp. 90-95.

Brzank, A., Heipke, C., Goepfert, J., Soergel, U. 2008. Aspects of generating precise digital terrain models in the Wadden Sea from lidar − water classification and structure line extraction. *ISPRS Journal of Photogrammetry and Remote Sensing*, accepted for publication.

Henke, S. 1999. Umweltatlas Wattenmeer − Wattenmeer zwischen Elb- und Emsmündung, Band 2.Ulmer Verlag, Stuttgart, 200p.

Reineck, H.-E. 1982. Das Watt. Verlag von Waldemar Kramer, Frankfurt am Main, 185p.

Zissis, G. J. 1993. The Infrared and Elctro-Optical Systems Handbook. Vol. 1, Sources of Radiation. Enviromental Research Institute of Michigan, 373p.