USING A PERSONAL WATERCRAFT FOR MONITORING BATHYMETRIC CHANGES AT STORM SCALE

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Abstract

Monitoring and understanding coastal processes is important for the Netherlands since the most densely populated areas are situated directly behind the coastal defense. Traditionally, bathymetric changes are monitored at annual intervals, although nowadays it is understood that most dramatic changes are related to high-energy events like storms. To monitor their impact it is important to have access to a flexible surveying platform that is directly operational after the storm. For this reason, Delft University of Technology has developed a PWC (Personal Watercraft) based surveying system. The objective of the present study is to monitor bathymetric changes on the shoreface of the straight sandy Holland coast on the temporal and spatial scale of storm impact. In this paper the PWC as a surveying platform is evaluated and it is demonstrated that both the theoretical and practical error assessment indicate a depth accuracy in the order of 1 decimeter, depending on wave conditions. Moreover, the depth maps resulting from the surveys show that observed morphological changes are in agreement with the expected behaviour considering literature of Van Rijn [1997]. The results on measurement accuracy and on observed coastal changes at storm scale demonstrate the potential of a flexible surveying platform such as a PWC.

1. Introduction

In the Netherlands the most densely populated areas are situated directly behind the coastal defense and partly below the mean sea level. The coastal stretch of the Holland coast is approximately 124 km long and consists mainly of sandy beaches and multiple barred nearshore zones [Short, 1991]. The sandy coastal system protects the hinterland and is renowned to suffer from structural erosion. It is therefore vital to understand the physical system of the sandy Dutch coast at high level to mitigate upcoming sea level rise. Current national coastal policy is to maintain the coastline position seaward of its 1990 position. This is achieved by applying a total amount of approximately $15x10^6$ m^3 of sand per year in nourishments on the beach and shoreface. How this nourished sand is redistributed over the surrounding coast in time remains a question.
A way to improve understanding of the coastal processes is by monitoring changes in bathymetry. Traditionally, changes along the Dutch coast are monitored only on yearly intervals by the Ministry of Public Works and Transport (JARKUS measurements). The intervals of these yearly measurements, however, are longer in time and larger in space than many morphological processes, especially close to the coast [Plant, 2002]. Moreover, nowadays it is understood that most dramatic changes are related to high-energy events like storms [van Rijn and Walstra, 2002]. To monitor their impact it is important to have access to a flexible surveying platform that is directly operational after a storm. Intervals between measurements on storm scale are in the order of weeks or even days, rather than years. For this reason, Delft University of Technology has developed a Personal Watercraft (PWC) based surveying system baptized *NEMO*, based on the system presented by MacMahan [2001].

The objective of the present study is to monitor bathymetric changes on the shoreface of the straight sandy Holland coast on the temporal and spatial scale of storm impact. A pre-defined area is monitored just before and after storm events to assess the impact of a North Sea storm on the coastal system. The accuracy of a PWC based survey system is explored and compared with the bathymetric changes over a storm cycle at the Dutch coast, yielding an evaluation of the applicability of a PWC based system to measure storm induced morphological changes. MacMahan [2001] and Morris [2000] present a similar analysis of a different PWC based surveying system. This paper also deals with the resulting bathymetric changes in the coastal system.
The outline of the paper is as follows: First a description is given of the project location and the PWC as a survey platform is introduced. Secondly, the methodology with respect to the acquisition and processing of data is shown in section 2. An analysis of the error in the measurements is given in section 3, whereas section 4 shows how the PWC can be applied to detect morphological changes at storm scale. Finally section 5 lists the conclusions and (practical) recommendations.

2. Survey campaign and data handling

2.1 Project location

Surveys were performed just before and after storm events on the shoreface near Ter Heijde, on the Holland coast between the Port of Rotterdam and The Hague (figure 1) at approximately *N52°02' 45'', E4°10' 40" (WGS84 coordinates)*. An area of 1200m longshore and 800m cross-shore was pre-defined as the project area. In the survey area a longshore subtidal bar is aligned parallel to the shore. The bar is situated between 500m and 600m seaward from the coastline and its crest lies around –4m NAP (Normaal Amsterdams Peil, the Dutch height datum, 0m NAP = mean sea level). The subtidal bar mainly results from sand nourishments in the project area carried out in 2001 and 2005.

Figure 1: Project location along the central Netherlands coast

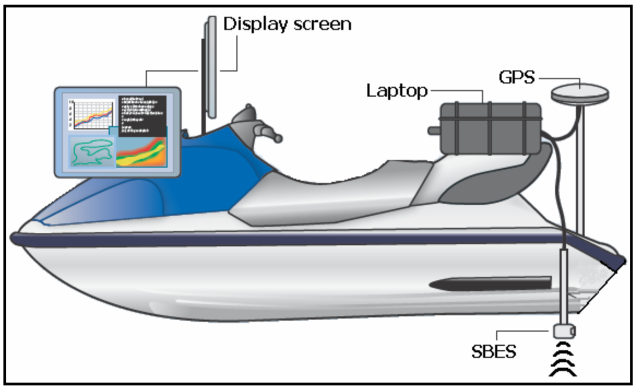

Figure 2: Personal Watercraft including survey equipment (by Dean Alberga)

2.2 The PWC based survey system

Bathymetric changes were monitored using a PWC as a survey platform. The use of this type of survey platform has several advantages over more conventional survey vessels:
1) The PWC has a large power-to-weight ratio, providing great acceleration for surveying safely in the surf zone. 2) It has the ability to sail in very shallow water (depth<1m) due to

pump-drive propulsion. 3) It is relatively light and can thus be launched from places that may not be accessible for other surveying platforms.
As the crew is flexible, decisions about a survey can be taken up to hours before the real survey. This is advantageous in situations depending on environmental conditions as well as for monitoring short-term morphological changes.

Measuring instruments are mounted on a Yamaha VX Jetski (figure 2). The water depth below the PWC is measured using a *Hydrobox* Single Beam Echo Sounder (SBES) at a sampling rate of 10 Hz. Positioning (in all directions) is done using a *Septentrio* GPS receiver. The GPS receiver is set to Real Time Kinematic (RTK-GPS) mode; with reference observations received every second via a mobile Internet connection from a nearby base station in Hoek van Holland (7 km distance). SBES and GPS measurements are logged on a laptop using *HYPACK* hydrographic acquisition software. The PWC is equipped with a display screen to provide real-time information to the navigator, showing planned survey tracks as well as current position and instrument status.

2.3 Bathymetric surveys

The aim of the monitoring campaign was to assess the applicability of the PWC to monitor nearshore bathymetric changes on storm scale. The measurements have taken place from September 15 until December 12, 2008. Within this four-month period the environmental conditions were followed closely and surveys were performed whenever possible before and after storm periods. Details and conditions during 5 surveys are listed in table 1.

Table 1: Details and conditions during surveys on the shoreface near Ter Heijde

Survey	**1**	**2**	**3**	**4**	**5**
Date in 2008	16/09	23/10	31/10	01/12	12/12
Offshore wave height, H_s (m)	0.5	1.5	0.8	0.7	1.5
Mean wave period, T_p (s)	3.6	4.2	4.0	4.2	4.2
Wind speed	2 Bft	3-4 Bft	2-3 Bft	1-2 Bft	3-4 Bft
Wind direction	NE	S	ENE	N	S
Water temperature (℃)	18	14	13	9	7
Speed of sound (m/s)	1508	1496	1492	1478	1470
Mutual track distance (m)	30	50	55	45	250
Surveying time	3h 5’	3h 50’	3h 10’	2h 5’	2h 35’

Note: During survey 5 the JARKUS transects (track distance: 250m) were monitored.

2.4 Data processing

The data processing consists of a number of actions that are performed to process raw data from the instruments into the bottom topography. Both the GPS receiver and the SBES separately log data in their specific temporal and spatial reference system. To obtain the bottom topography both signals are combined in the following steps:

1. Transform GPS data into the Dutch reference & coordinate system RD-NAP.
2. Correct the SBES depth values for latency, the speed of sound in water and the offset between transducer and GPS antenna.
3. Remove outliers and spikes in the SBES data using a moving average filter
4. Couple and match the GPS signal to the SBES signal by temporal interpolation
5. Calculate the depth for specified locations
6. Smoothen the sea floor observations using a moving average filter

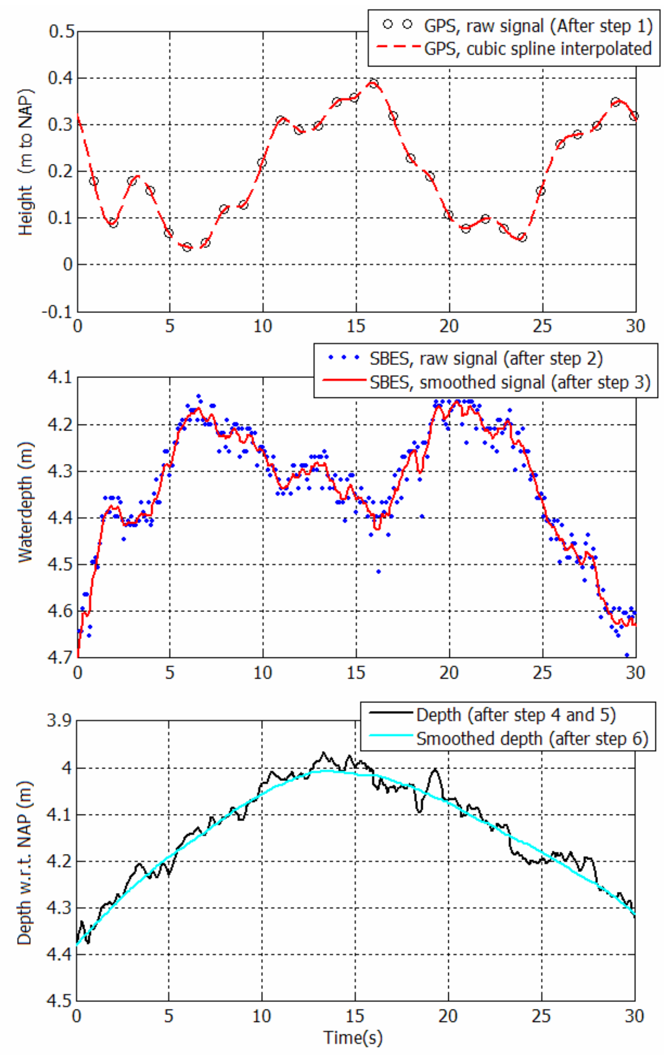

Figure 3: PWC platform elevation (top), Echosounder depth values (middle) and resulting seafloor topography (down)

To visualize these processing steps a sample of the signal from survey 4 is depicted in figure 3. During the 30s sample interval the PWC sailed +/- 80m shoreward over the subtidal bar. The circles and dots indicate the raw signal from the GPS and the SBES respectively. When considering the spline-interpolated GPS signal (top figure) an elevation of up to 0.4m can be observed. This indicates a heave motion of the PWC overtaking a wave while sailing shoreward. The opposite pattern is present in the SBES signal because the SBES transducer is lifted by the wave. By combining both signals the shape of the sea floor is reconstructed. The top of the bar at 4m below NAP is visible in the depth signal (down). The final step is smoothing of the sea floor. Smoothing the calculated depth (step 6) by using a moving average filter is done for later analysis: In section 3.4 the difference between the calculated and smoothed depth is investigated. Note that the smoothed line may be a more realistic representation of the sea floor because it filters errors due to platform motion (see section 3.1). However, a systematic bias is introduced by filtering this signal and features on the sea floor like ripples are filtered out.

3. Error analysis of the PWC based survey system

The error in the measured signal obtained with the PWC is evaluated in two essentially different ways. First, a theoretical breakdown of the error budget is given by analyzing its components and by determining how systematic and random errors at the component level propagate to the final depth measurements (a priori). The second evaluation consists of a practical analysis of two different surveys (under calm and rough conditions) of the same piece of coast in the autumn of 2008 (a posteriori). Focus is here on the vertical error; the horizontal error is only mentioned briefly. The components contributing to the theoretical error can be split into three different types of errors. First of all the random error in the signal (R), secondly the systematic bias (S) and thirdly the uncertainty of the depth value as a result of bathymetric depth interpolation. The first two error contributions are treated in this section; the third contribution is dealt with in section 4.1.

3.1 A priori analysis of random errors

R1: GPS accuracy

The positioning method used for the surveys is Real Time Kinematic GPS (RTK-GPS). This method requires simultaneous observations at two locations. On one side the base station (i.e. Hoek van Holland reference station at 7 km distance). On the other side the rover with a mobile antenna on the PWC. The vertical baseline accuracy can be expected to be 2cm+2ppm (parts-per-million of distance between base station and rover) [Geomatics, 2008]. Hence the expected theoretical standard deviation for the vertical GPS position is 0.034m.

R2: Platform motion (heave)

The RTK-GPS records the heave motion of the PWC once per second. To match the 10 Hz depth values of the SBES, the GPS positions are interpolated using cubic spline interpolation. This interpolation method however tends to underestimate the extremes in the positioning data. Consequently the GPS may deviate slightly from the real heave motion or it may not record the full range of vertical motion. The corresponding random error contribution is expected to be of order 0.01m.

R3: Platform motion (pitch and roll)

The GPS and SBES are rigidly fixed on the PWC, therefore roll and pitch motions will cause errors in the measurements (figure 4). Mainly short wind induced waves above 1.5m cause substantial platform motion (e.g. during survey 5).

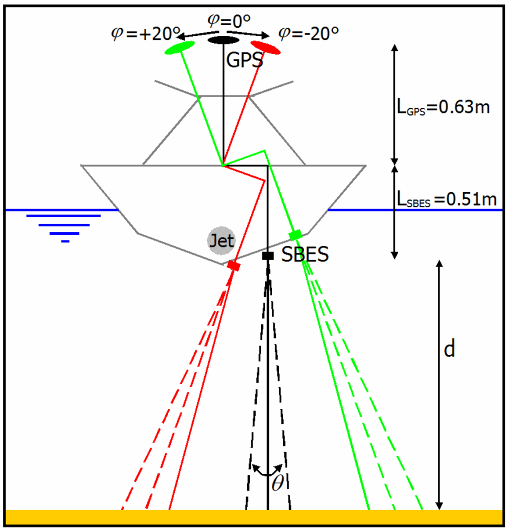

Figure 4: Schematic rear view of the PWC together with the SBES and GPS under three different roll angles (φ= +20°, φ =0°, φ = -20°)

The vertical error consists of two contributions: The first is an overestimation of the water depth when the pitch or roll angle exceeds half the opening angle of the SBES beam (equation 1). The second contribution is due to the mounting distance between GPS antenna and SBES transducer, causing a changing (vertical) offset between the GPS and SBES when the platform tilts (equation 2). The error calculation corresponds to an assumed flat bottom.

$$\Delta d_{SBES} = \begin{cases} 0 & \text{for } \varphi \le 0.5\theta \\ d(1/\cos(\varphi - 0.5\theta) - 1) & \text{otherwise} \end{cases} \quad (1)$$

$$\Delta d_{offset} = \sin\varphi \cdot L_{GPS} + \sin\varphi \cdot L_{SBES} \quad (2)$$

Where: φ = Roll or pitch angle of the PWC
θ = Beam width of the emitted SBES pulse, $\theta = 8°$

The total vertical error due to platform motion is calculated by adding the separate contributions (equation 3).

$$V_{Total.error} = \Delta d_{SBES} + \Delta d_{offset} \tag{3}$$

The pitch and roll motions depend on the sea state and affect the vertical error. Accuracy decreases when conditions become rougher. Table 2 gives an indication of the difference in error contribution for two representative sea states, calm and rough.

Table 2: Vertical error due to roll or pitch motions

At water depth →	*1m*	*5m*	*9m*
12° roll / pitch (rough sea)	0.09m	0.12m	0.18m
6° roll / pitch (calm sea)	0.04m	0.04m	0.05m

R4: Echo sounder
Theoretically the Single Beam Echo Sounder has a vertical accuracy of 0.01m [Hydrobox, 2008].

R5: Shape of the seafloor
On a sloping bottom the point of first return of the echo sounder may not be the point directly below the survey platform. The beam width of the SBES is very small (8º angle) and the maximum bottom slope in the area of interest is only 2.5º (at the land side of the subtidal bar). From geometry it can be derived that the vertical error contribution is of order 0.01m.

3.2 A priori analysis of systematic bias

S1: Speed of sound in water
In order to calculate the depth below the echo sounder, the speed of sound in water has to be defined. This value depends on the depth, salinity and temperature of the water column below the transducer. It is calculated by means of the empirical relation of MacKenzie [1981]:

$$\begin{aligned} c_{Mackenzie}(d,S,T) \; = \; & 1448.96 + 4.591T - 5.304\cdot 10^{-2}T^{2} + 2.374\cdot 10^{-4}T^{3} + \\ & 1.340\cdot(S-35) + 1.630\cdot 10^{-2}d + 1.675\cdot 10^{-7}d^{2} - 1.025\cdot 10^{-2}T(S-35) - 7.139\cdot 10^{-13}Td^{3} \end{aligned} \tag{4}$$

In this relation d is the water depth in meter (m), S is the salinity in parts per thousand (ppt) and T is the water temperature in degrees Celsius (°C). The error due to the difference in water depth in the range 1-10m is negligible. The salinity in the survey area is measured by Rijkswaterstaat and is assumed constant with a value of 28.5ppt during all surveys. The temperature (see table 1) is defined for every survey based on measurements by Rijkswaterstaat performed close to the survey area. Both the salinity and temperature vary in time and in space (e.g. due to the presence of a nearby river outflow). A deviation from their real value causes a systematic bias in the depth calculation. A sensitivity analysis shows that the systematic error is of order 0.01m per meter water depth (see table 3).

S2: SBES / GPS offset
The vertical distance between the GPS antenna and the SBES transducer is 1.14m. When the GPS and the SBES are mounted on the PWC, their vertical distance may change slightly from survey to survey. The maximum expected vertical bias in the measurements is 0.01m.

3.3 Overview of theoretical vertical errors

All errors mentioned in the previous section are summarized in table 3; a distinction is made between random errors and systematic errors. The largest vertical random error contribution is the platform motion and the largest systematic bias is due to the speed of sound in water.

Table 3: Overview of theoretical errors

R: Maximum random errors		Vertical random error (theoretical)		
R1	**GPS accuracy**	0.034m		
R2	**Heave**	0.01m		
	At water depth →	*1m*	*5m*	*9m*
R3	**12° pitch / roll (rough sea)**	0.09m	0.12m	0.18m
	6° pitch / roll (calm sea)	0.04m	0.04m	0.05m
R4	**Echo sounder**	0.01m		
R5	**Seafloor shape**	0.01m		
S: Maximum systematic bias		**Vertical systematic bias (theoretical)**		
	At water depth →	*1m*	*5m*	*9m*
S1	**Speed of sound**	0.01m	0.05m	0.09m
S2	**GPS/SBES offset**	0.01m		

3.4 A posteriori analysis of the random error

Field data is analyzed and the empirically calculated random error is estimated. The standard deviation of the calculated depth relative to the smoothed depth is calculated (equation 5). The noise in the measured signal is not constant over the entire survey area. Therefore the noise for seaward/landward sailing, in varying water depths and for rough/calm surveys is compared (table 4). The overall average standard deviation of the noise is: $\sigma_{all\ data}$ = 8.1cm.

$$Noise = depth_{calculated} - depth_{smoothed} \quad (5)$$

Table 4: Standard deviation of the noise in the recorded signal.

	$\sigma_{all\ data}$ (cm)	$\sigma_{landward}$ (cm)	$\sigma_{seaward}$ (cm)	$\sigma_{shallow}$ (cm)	σ_{medium} (cm)	σ_{deep} (cm)
Average of all surveys →	**8.1**	**4.3**	**7.6**	**9.7**	**6.4**	**8.5**
Survey 4 (calm)	5.5	2.4	5.3	7.6	4.3	5.4
Survey 5 (rough)	10.5	5.7	8.4	12.1	7.2	12.2

Note for table 4: "*All data*" refers to a complete survey (including the turning and manoeuvring of the PWC), "*landward*" refers to tracks that have been sailed towards land, "*seaward*" refers to tracks that have been sailed towards sea. "*Shallow*" = 0 to –3.5m NAP, "*Medium*" = –3.5 to –6m NAP, "*Deep*" = –6 to –10m NAP.

Effect of sailing direction on the random error contribution

Platform motions are stronger while sailing in seaward direction compared to landward sailing. Consequently the standard deviation of sailing seawards, $\sigma_{seaward}$ (7.6cm) is larger than $\sigma_{landward}$ (4.3cm), see table 4. Hence their difference $\sigma_{seaward}$ - $\sigma_{landward}$ = 3.3cm is fully due to wave motion. It cannot be proved here that the remaining $\sigma_{landward}$ (4.3cm) is also fully due to wave motion. Part of this value will be due to wave motion and some part will consist of small-scale features on the seafloor that are smoothed by the filter. Still it is concluded that sailing in landward direction results in a smaller error contribution than seaward sailing.

Effect of water depth on the random error contribution

Another notable aspect derived from table 4 is the fact that the standard deviation in medium water depth (6.4cm) is smaller than in deep (8.5cm) or shallow water (9.7cm). Turning of the PWC and outliers in the SBES signal occur mainly near shore and in deeper water [Van Son, 2009]. Filtering those errors will improve the shallow and deep-water measurement up to the level of the medium depth standard deviation (6.4cm), thereby reducing the random error.

Effect of survey conditions on the random error contribution

Calm sailing conditions: during survey 4 conditions were calm: H_s = 0.7m with some weak offshore wind (1-2 Bft). For this day the total theoretical error is calculated, assuming that roll and pitch motions remained below +6° and -6°. The vertical error corresponding to this value is 0.04m, derived from equation 3. The assumption of the degree of pitch and roll is based on some available motion sensor data for a comparable, but somewhat calmer day in January: H_s = 0.3m and weak offshore wind (2 Bft.). The motion sensor sample shows that the roll and pitch motions remained within +4° and -4° that day.

Rough sailing conditions: during survey 5 conditions were rather rough: H_s = 1.5m with onshore wind (3-4 Bft). No motion sensor data is available for this rough day. A tilt angle of 20° will almost make the PWC roll over; such large motions were not encountered. A value of +/-12° is assumed for these conditions. The vertical error corresponding to this value is 0.12m, derived from equation 3.

3.5 Theoretical errors versus empirical errors

A survey under calm and one under rough conditions at sea (survey 4 and 5 from table 1) are compared with respect to measurement errors in 5m water depth. The theoretical random errors are summed using the propagation law of error; the systematic bias is added separately (equation 6).

$$\varepsilon_{total} = \sqrt{\varepsilon_a^2 + \varepsilon_b^2 + \ldots + \varepsilon_z^2} + \varepsilon_{sys} \quad (6)$$

$\varepsilon_{a...z}$ = theoretical random error contributions

ε_{sys} = theoretical systematic bias contributions

The only error component that varies between calm and rough conditions is the contribution due to roll and pitch motions. Table 5 shows a comparison of the total theoretical and empirical vertical random error. The random errors are all of order 0.1m, being somewhat higher for rough wave conditions and somewhat lower for calm seas. It is thus demonstrated that both the theoretical and practical error assessment indicate a depth accuracy in the order of 1 decimeter, depending on wave conditions.

Table 5: Comparison of theoretical and empirical error in the vertical seafloor position

Wave conditions	Total vertical random error (theoretical, from table 3)	Vertical random error (empirical, from table 4)
Calm (survey 4)	0.062m (R1-5) ⟷	0.055m
Rough (survey 5)	0.129m (R1-5) ⟷	0.105m

3.6 Accuracy in the horizontal plane
The total horizontal position accuracy is of order 0.5m [Van Son, 2009]. The main error contribution in horizontal positioning is the horizontal offset between the SBES and the GPS on the PWC. This causes a horizontal error with a maximum of 0.25m, varying with the sailing direction. Furthermore the horizontal GPS positioning error is of order 0.1m.

4. Bathymetric changes at storm scale

The subtidal shore-parallel sand bar (resulting from sand nourishments, figure 5) is an interesting morphological feature within the survey area. Understanding its behaviour under storm conditions is of interest for those in charge of taking measures against coastal problems. In the previous section we have shown that the error in the vertical depth measurements is of order 0.1m. In this section the bathymetric maps show how the sandbar migrated approximately 30m offshore in a storm month, while during fair weather conditions onshore bar migration of order 5-10m is observed.

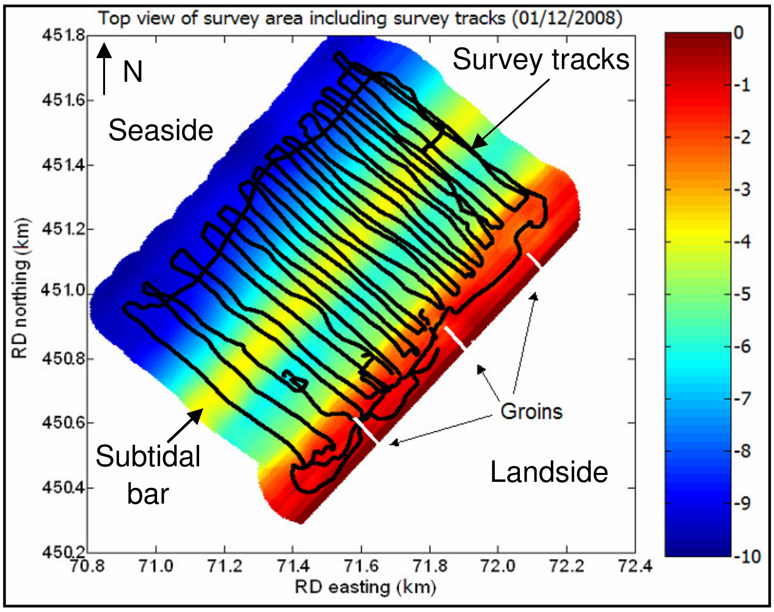

Figure 5: Top view of bathymetric of survey area including survey tracks. Warm and cold colors indicate shallow and deep water respectively.

4.1 Uncertainty as a result of bathymetric depth interpolation
Navigation information is available for the navigator on the display screen. However, the surveyed tracks of different surveys in this campaign do not cover exactly the same line. To enable the comparison of results from different campaigns, the measured depth values are interpolated towards a rectangular grid. This introduces an additional uncertainty. In the present study the survey data is interpolated using the Ordinary Kriging technique [Wackernagel, 2003]. Besides an interpolated depth value, Ordinary Kriging also provides the standard deviation of the interpolation, which is an estimate of the accuracy of the interpolation based on the distance to nearby observations. During all surveys a maximum distance between survey tracks of 60m has been maintained (see table 1). For the resulting bathymetric map the standard deviation of the interpolated depth values remains below 15cm. Good coverage of the area is thus obtained when tracks are sailed within approximately 60m from each other. When the distance between sailed tracks exceeds 60m, then the standard deviation and the uncertainty will grow rapidly.

4.2 Morphodynamic behaviour on storm time scale

Wave conditions in the autumn of 2008 on the North Sea have been recorded at an offshore buoy (Europlatform Buoy, situated 60 km West of the survey area in 30m water depth). Three periods between surveys are compared, two periods of calms and one stormy period. Cross-sections of the subtidal bar as monitored in four different surveys are shown in figure 6. The resulting morphological behaviour of the subtidal bar is described in table 6. During storm conditions intense wave breaking on the bar causes sediment to move offshore. On the other hand, fair-weather waves and swell return the sediment shoreward [Van Rijn, 1997]. The morphological changes at Ter Heijde show this pattern:

- First of all *onshore* bar migration is observed in the calm weather periods (between 16/09/'08 and 31/10/'08). Erosion takes place on the seaside of the subtidal bar and sedimentation on its landside, which causes the bar to migrate onshore.
- Secondly *offshore* bar migration is observed in the stormy period (between 31/10/'08 and 01/12/'08). Longshore uniform sedimentation takes place on the seaside of the bar and erosion on the landside.

The observed migration in the project area in relation to the environmental conditions show that the observations agree with the notions of Van Rijn, [1997].

Table 6: Sea state and bar migration during periods between surveys

Period (in 2008)	**16/09 – 23/10**	**23/10 – 31/10**	**31/10 – 1/12**
Sea state	Relatively calm	Calm	Stormy
Main wave direction	Northwest	Northwest	Northwest
Bar migration	7m onshore ←	< 5m onshore ←	30m offshore →

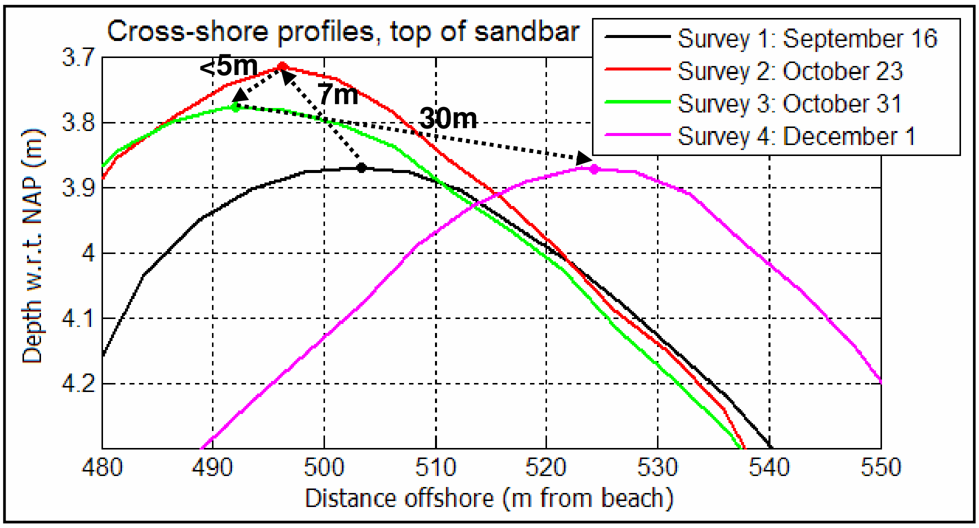

Figure 6: Migration of the subtidal bar due to storm impact and calm periods.

5. Conclusions and recommendations

Both the theoretical and practical error assessment indicate a vertical depth accuracy in the order of 0.1m, depending on wave conditions. For calm seas (H_s<1m) the accuracy becomes less than 0.1m. For rough seas (1m<H_s<2m) measurements become less accurate (>0.1m). The horizontal accuracy is of order 0.5m. The bathymetric maps resulting from the surveys show how a shore-parallel bar, situated 500m from the beach migrated approximately 30m offshore in a storm month, while during fair weather conditions onshore bar migration in the order of 5m is observed. The error budget is therefore acceptable for this monitoring purpose. It is concluded that morphological changes on storm scale are of a higher order of magnitude than the error in the measurements. This demonstrates the potential of the PWC as a surveying platform for coastal engineering purposes. This outcome offers the opportunity to combine measurements with a numerical model as shown in Van Son [2009].

Installing a motion sensor (IMU) and filtering outliers from the dataset could reduce the random errors in the measurements. An IMU may not be a very practical solution since the amount of data that needs to be processed will increase considerably. This improvement is not desirable when morphological changes of this scale are monitored and when the sea state is not too rough. Further, the speed of sound in water can be measured more accurately by performing bar-checks or by taking water samples and by registering the water temperature during surveys.
For future surveys some recommendations can be made based on the experience from Ter Heijde. First of all it is advised to monitor the same surveyed lines on different days. The uncertainty due to depth interpolation will then be limited. Secondly recordings of tracks sailed in landward direction are more accurate; hence under rough circumstances the seaward sailed tracks could be sailed quickly without recording any data.
Finally the accuracy of measurements can be related to the sea state. The demand for information of a measurement could be taken into account in deciding whether or not it is worth surveying during certain conditions, or that one should wait for a calmer sea state.

Acknowledgements

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