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SEDIMENT TRANSPORT AND MORPHOLOGICAL RESPONSE ON A MACRO-TIDAL SANDY BEACH, MARIAKERKE, BELGIUM

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ABSTRACT

Our knowledge of suspended sediment transport in the nearshore zone is limited. This is due to difficulties in relating hydrodynamics, sediment transport and morphological changes on a meso-scale (weeks-years). The aim of this research is to study the effect of offshore suspended sediment discharge on beach morphology in relation to simultaneous measurements of hydrodynamic conditions. Hydrodynamics and suspended sediment concentrations were measured in the nearshore zone at Mariakerke, Belgium, for two months. Beach topographical profiles were measured three times during this period. Measured suspended sediment concentrations showed a clear spring-neap tidal cycle. They are not related to wave height under calm conditions (wave height < 1.0 m). The sediment concentrations were often higher during flood than during ebb tide. A small shoreward transport of sediment was observed, but the intertidal beach volume increased significantly more during the research period. Although not all morphological changes could be related to offshore sediment discharge, they could be linked to the offshore hydrodynamic conditions. When the wave steepness is small (< 0.02), the intertidal beach volume increases. Peaks in wave steepness result in erosion of the intertidal area.

Keywords: hydrodynamics, intertidal zone, sediment concentration, backscatter intensity

1. INTRODUCTION

Over the last decades suspended sediment transport has increasingly been studied thanks to the improvement of optical and acoustic sensors for measuring suspended sediment concentrations (SSC). These sensors transmit light or sound signals of which a part is reflected by the sediment particles in the water and is recorded by the sensor. Both optical and acoustic sensors have been used for a long time (White, 1998), but because of their reliability optical sensors were often preferred. Recently more effort has been put into the usage of acoustic sensors (Guerrero et al., 2012), because of the capability of some acoustic sensors to make a profile of backscatter intensity.

The use of optical and acoustic sensors on macro-tidal (tidal range > 4 m), sandy coasts allows us to study the amount of sediment discharge in the nearshore area under different hydrodynamic conditions. Thereby it is possible to relate hydrodynamic forcing to morphological response, of which our current knowledge is still very limited. For the Belgian coast, Haerens et al. (2012) defined general storm thresholds for significant erosion and there were some modelling studies simulate storm impact at a short timescale, mostly on the “Sinterklaasstorm” event in December 2013 (Kolokythas, et al., 2016, Lanckriet, et al., 2015). Meso-scale studies to beach accretion are very much lacking though (Maspataud et al., 2009). Some studies have documented small-scale hydrodynamic processes (e.g. Ruessink, et al., 2011) and the contribution of bar motion to beach build up (Walstra, et al., 2012, Masselink, et al., 2008). However, knowledge on the relationship between hydrodynamic conditions and morphological changes on a meso-scale (weeks-years) on a flat intertidal beach is limited.

It appears to be very difficult to relate measured suspended sediment discharge to topographical changes (Cohn et al., 2014). Often sediment discharge rates are found to be in a different order of magnitude or even in a different direction. Masselink et al. (2008), for example, integrated currents and optical backscatter measurements, sand ripple profilers and topographical measurements on a macro-tidal beach in southern France. Their study showed similar trends for the sand transport and topographical measurements, but in a different order of magnitude.

To improve our knowledge of beach build up of flat intertidal beaches, the contribution of offshore suspended sediment discharge should be studied. Thus the aim of this research is to study the effect of offshore suspended sediment discharge on beach morphology in relation to simultaneous measurements of hydrodynamic conditions over several weeks.

2. STUDY SITE

The study site is Mariakerke, Belgium, at the southern edge of the North Sea basin. The Belgian coast is oriented from southwest to northeast. The beach is macro-tidal, with a tidal range varying between 3.5 m at neap and 5 m at spring tide. Currents can reach 1 m/s in the nearshore area (Haerens et al., 2012). The average wave height varies between 0.5 and 1 m and the average wave period is between 3.5 and 4.5 s. Offshore waves are mainly driven by westerly winds, and the incoming waves therefore generate an along-shore drift towards the northeast. Due to the shallow water depth and the relatively short fetch, waves are typically short crested. During storms from the north to the northwest, storm surges can occur with water levels over +5.5 m TAW (Haerens et al., 2012). The significant wave height with a 1 year return period is about 4.5 m. The beach is gently sloping (1-2 %) and the sediment is sandy, with an average grain size of 250 µm (Deronde et al., 2008). From west to east the Belgian beach becomes gradually less natural. At Mariakerke a seawall dike and groins have been build, and sand nourishments have been taking place since 1988 (Houthuys, 2011).

Topographic and hydrodynamic measurements were performed at beach section 100 (Figure 1). A frame equipped to measure waves, water level, currents and SSC was placed at -8 m TAW (i.e. relative to the lowest astronomical tide). At the beach the topography of three topographic profiles was measured. These were 150 m apart and stretched from the lowest low water line until the seawall. The frame was in the water for 7 weeks, from 23 September until 14 November 2015. Topographic profiles were measured at the beginning (t_0), the middle (t_1) and the end (t_2) of these 7 weeks. The period between t_0 and t_1 is called period 1 and the period from t_1 until t_2 is called period 2 in this paper. Both periods start and end around spring tide.

Figure 1. Study site and a picture of the measuring frame.

3. DATA COLLECTION

The frame was equipped with an Acoustic Wave And Current profiler (AWAC), an Aquadopp profiler and three Optical Backscatter point Sensors (OBS). The measured parameters are wave height, period and direction, water level, flow velocity and acoustic backscatter profiles and optical backscatter.

The AWAC recorded waves and flow velocity. It was mounted upward looking at 1.4 m above the bed. The cell size of the AWAC was 50 cm and it measured with a frequency of 2 Hz every 2 hours for 20 minutes. The AWAC has four acoustic beams: one vertical and three slanted at 25°. The AWAC uses acoustic surface tracking algorithms to estimate the distance to the water surface using the echo of the vertical beam. Wave direction is calculated by combining the surface tracking algorithms with orbital velocity measurements that are sampled in a cell near the surface. The three slanted beams are used to measure the current profile as the frequency shift of the echo is proportional to the water velocity.

The Aquadopp makes use of the same principles as the AWAC to make profiles of flow velocity. It was mounted looking down at 1.6 m above the bed. It sampled 1 minute every 10 minutes with a sampling frequency of 2 Hz and a cell size of 10 cm. The blanking distance in front of the Aquadopp was 20 cm and the blanking distance near the seabed was 80 cm. The Aquadopp profiler also recorded the backscatter intensity. To convert backscatter to SSC, the signal was first compensated for acoustic spreading (a) and water absorption (b). This was done according to Lohrmann (2001):

a b

$$EL = 0.43Amp + 20\log(R) + 2\alpha_w x \qquad [1]$$

Where Amp is the recorded parameter, R is the range along the acoustic beam and of z/cos(25) in this case, and α_w is the water absorption (1.0637 dB/m here). EL is the range normalized echo level, which can be converted to SSC by calibrating the device with samples with a pre-known SSC.

The three OBS were mounted at 40, 60 and 80 cm above the bed. They recorded optical backscatter with 4 Hz for 10 minutes every hour. OBS use an infra-red light beam to measure turbidity. To calibrate the OBS, sediment samples from near the study site were used. The obtained relation between backscatter and SSC was used to convert the measured backscatter intensities. OBS results have demonstrated to be only reliable for the first 2 weeks, because of biofouling due to the presence of organisms such as algae and barnacles.

Beach topography of the cross-shore profiles was measured with a Real Time Kinematic GPS (RTK-GPS). From these profiles the sediment volume of the intertidal area (from 1.39 to 4.39 m TAW) was calculated with Riemann sums. The profiles were divided into pieces with a width of 10 cm. The measured profile was interpolated to obtain the height at a 10 cm interval. For each 10 cm piece the height was multiplied with the width. The sum of all pieces approximates the total volume.

4. CHARACTERIZATION OF HYDRODYNAMICS AND SSC RESPONSE

The hydrodynamic conditions during the research period are presented in Figure 2. Water level variations were very similar for the two periods, with variations of 5.5 m during spring and 3 m during neap tide. The wave conditions, on the other hand, were different for the two periods. The mean significant wave height and period were both 5 % larger for period 2. During period 1 the maximum wave height was 0.98 m, whereas for period 2 it was 1.74 m. The dominant wave direction was from the north during period 1 and from the north and west during period 2.

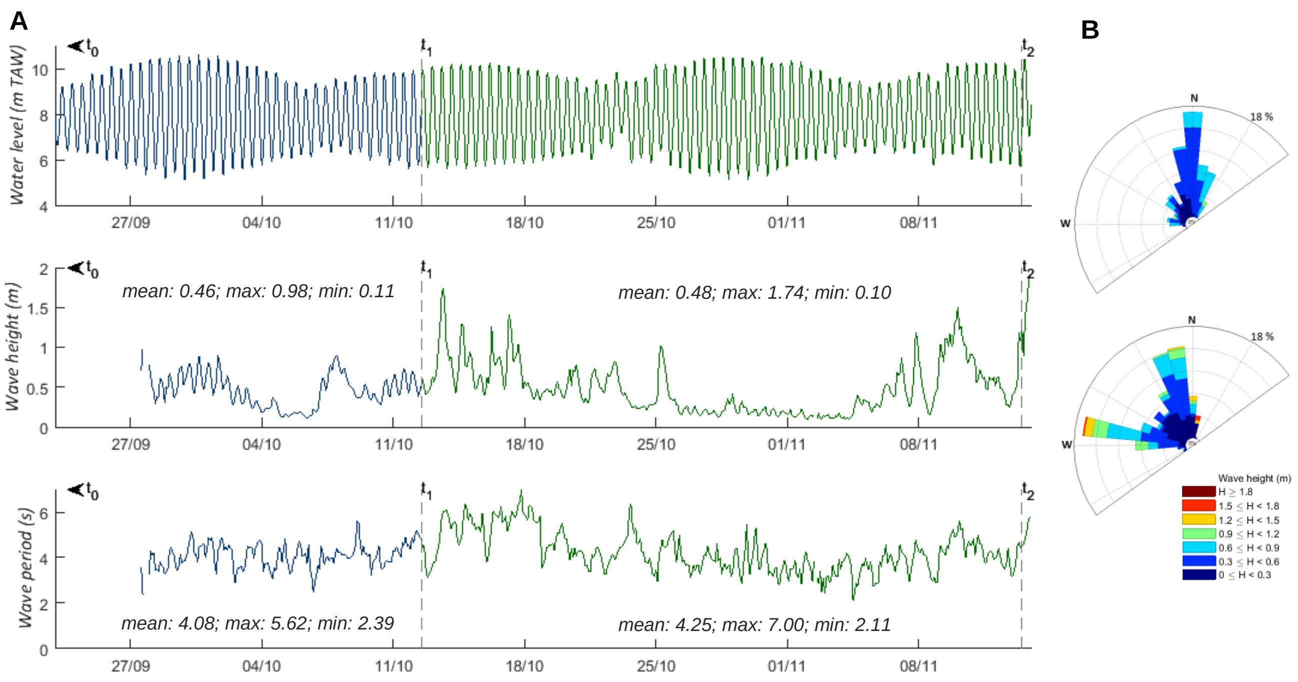

Figure 2. A) Time series of water level (from the Aquadopp), significant wave height and significant wave period (both from the AWAC) with the topographic surveys indicated by dashed lines at t_0, t_1 and t_2; B) wave roses for the two periods (top = period 1, bottom = period 2) at -8 TAW.

The flow velocity as measured by the Aquadopp was converted to along- and cross-shore flow velocities. Positive along-shore velocities mean that the currents were directed to the northeast, while for negative velocities they were directed to the southwest. For the cross-shore velocity positive velocities indicate shoreward currents, negative velocities indicate seaward currents. Peaks in along-shore flow velocity were 0.7 m/s, whereas peaks in cross-shore flow velocity were only 0.2 m/s (Figure 3). Flow velocities were 1.3 times higher during flood than during ebb. The along-shore flow velocity generally decreased over depth, whereas the cross-shore flow velocity was often uniform over depth

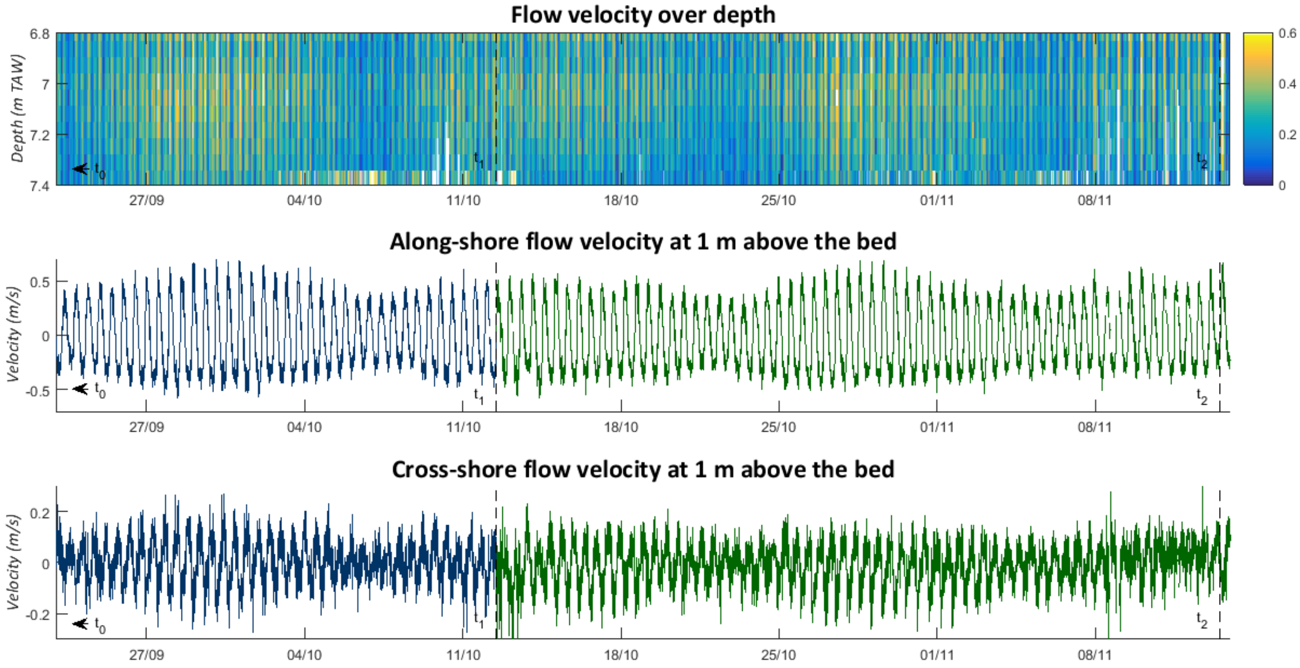

Figure 3. Total, along- and cross-shore flow velocity (m/s). The bed level is 8.2 m below TAW. The topographic surveys are indicated with dashed lines

Time series of the SSC from the Aquadopp are presented in Figure 4. When flow velocities exceeded 0.4 m/s and/or when the wave height exceeded 1.0 m, peaks in SSC of over 6000 mg/l were observed. This was triggered by water bubbles that arose from turbulence. These peaks were removed for further calculations. The average SSC was 1100 mg/l. The average SSC increased from 800 mg/l at -6.8 m TAW to 3800 mg/l at -7.6 m TAW. The average SSC decreased to 2000 mg/l between -7.6 and -7.8 m TAW.

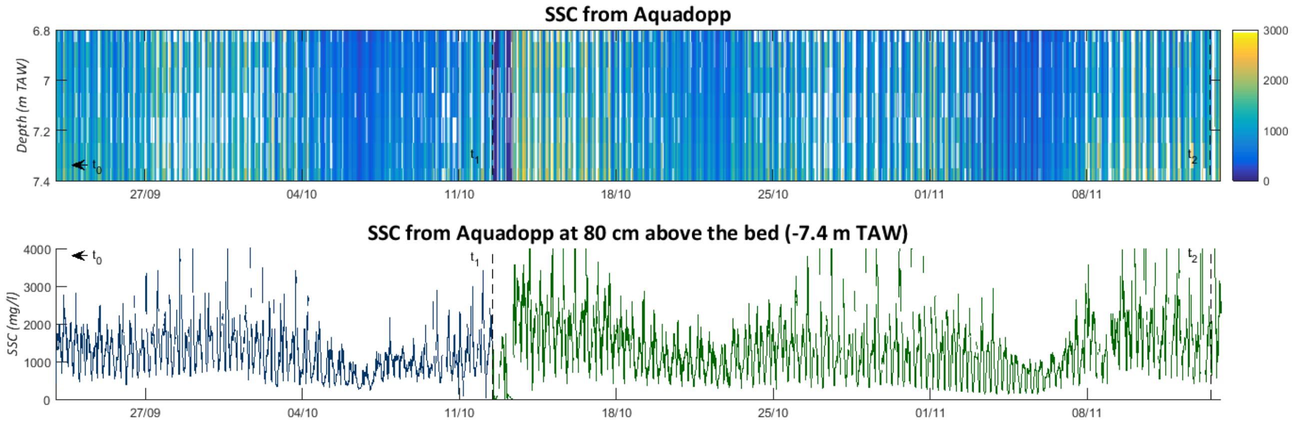

Figure 4. Time series of SSC from the Aquadopp (mg/l) over depth and at 80 cm above the bed. The topographic surveys are indicated with dashed lines

A previous study in a nearby area reported similar SSC for flood and ebb, and spring and neap tide (Fettweis et al., 2010). However, in this study the SSC was 1500 mg/l on average during spring tide compared to 800 mg/l during neap tide. SSC were maximum around maximum flow velocities, with an average of 2000 mg/l during peak velocities, compared to only 800 mg/l during slack tide. The SSC was higher during flood than during ebb tide. This difference was up to 1000 mg/l for spring tide conditions, and almost 0 during neap tide. The difference between this study and previous studies might have been the difference in location or the time when the studies were performed.

In this study no relation between SSC and wave height was found for waves smaller than 1.0 m. For larger waves a relation could not be demonstrated, because of the calm wave conditions during the research period. Previous studies have demonstrated a relation between wave height and SSC when the wave height exceeds 2 m (Fettweis et al., 2010).

5. SEDIMENT TRANSPORT AND MORPHOLOGICAL RESPONSE

Suspended sediment discharge was calculated based on measured SSC and the corresponding flow velocities. The time series of hourly averaged suspended sediment discharge at 80 cm above the bed is presented in Figure 5. Along-shore sediment discharge was much greater than cross-shore discharge, because of the larger along-shore flow velocities. To know the net sediment flux across the -8 m TAW water line, the cross-shore sediment discharge was integrated over time and depth. The cross-shore sediment flux between -6.8 and -7.4 m TAW for period 1 was +15 kg, for period 2 this was +34 kg. On average, this corresponds to +0.4 kg per tidal cycle for period 1 and +0.5 kg for period 2. The positive sign means that sediment was transported towards the shore. Integration over time indicates that the suspended sediment flux on average was negative at -7.2 m TAW. However, it was positive in the rest of the profile. The shoreward sediment discharge was due to the larger flow velocities for flood.

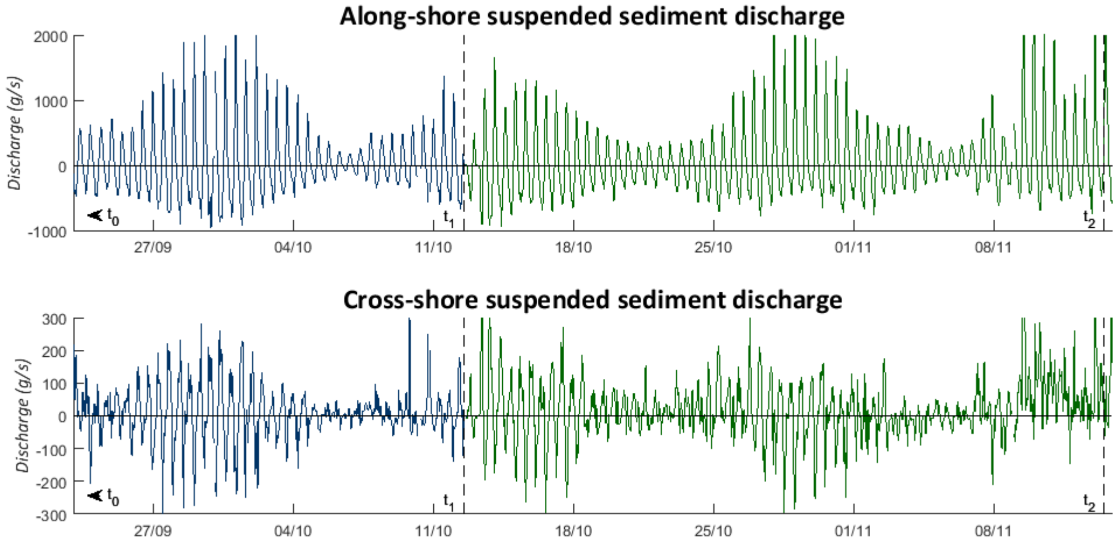

Figure 5. Time series of hourly averaged along-shore and cross-shore of suspended sediment discharge at 80 cm above the bed. The topographic surveys are indicated with dashed lines

Both volume and width of the intertidal areas for the three beach sections were calculated and presented along with the surveyed topographical profiles in Figure 6. The three profiles showed the same trends, but there are small differences in the magnitude of the changes. During period 1 the sediment volume increased 2.4 m^3 and the bed level raised 3 cm on average. During period 2 the beach build up on average 5.5 m^3. This was due to a widening of the intertidal zone, where the bed level actually lowered 1 cm.

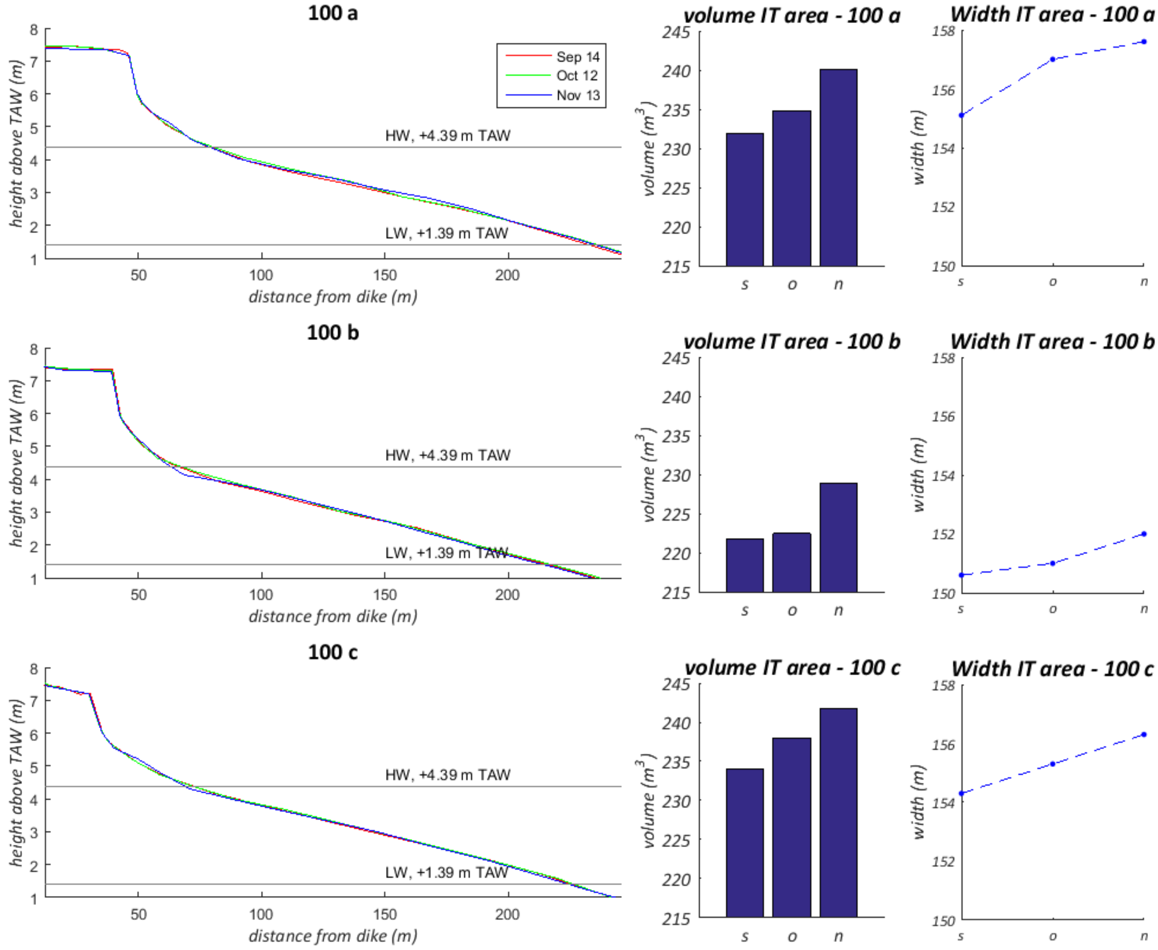

Figure 6.Topographic profiles of the beach, and morphological changes of the intertidal (IT) area at the three sections.

The beach width increased approximately 2 m over the two months and the total volume increased with approximately 8 m^3. Assuming a sediment density of 1400 kg/m^3, 11,200 kg of sediment would be needed to explain this volume change. However, the total sediment flux calculated from the Aquadopp measurements was less than this volume. Although the order of magnitude is different, the sediment discharge and morphological changes showed the same trend. For period 1, 15 kg of sediment was transported towards the shore and during that period the measured volume of the intertidal area increased with 3360 kg. During period 2, 34 kg of sediment was likely to be transported to the shore and the increase in volume of the intertidal area was 7700 kg.

Even with similar trends, offshore sediment discharge can only explain a small part of the growth of the intertidal area. This means that sediment must have been brought to the intertidal zone in other ways. An assessment was done for aeolian transport and it was found that this cannot explain the growth of the intertidal beach, because the supratidal beach volume increased as well. Thus the accretion in the intertidal zone is most likely due to shoreward sediment transport closer to the shore by shoaling or breaking waves. Previous studies have demonstrated that closer to the shore, in the intertidal zone, the amount of along-shore sediment transport can be large, resulting in significant morphological changes (Sedrati and Anthony, 2007).

According to Masselink et al. (2003), onshore sediment transport in the nearshore area occurs when the wave steepness (H/L) is smaller than 0.02. For both periods the average wave steepness was 0.012. For period 1 peaks in wave steepness were up to 0.024, whereas for period 2 they were 0.032. The larger peaks in wave steepness during period 2 most probably have brought sediment lower into the intertidal area. This could explain the lowering of the bed level and the widening of the intertidal area during this period.

6. CONCLUSIONS

The observed SSC showed a clear positive relation with tidal conditions, with higher SSC for flood than for ebb and for spring than for neap tide. The wave conditions during the research period were calm, with most often wave heights smaller than 1 m. For these calm conditions no relation between SSC and wave height was found, but such a relation is expected for larger waves.

Due to the flood dominance of both the flow velocity and the SSC, suspended sediment was transported shoreward. It was also found that the intertidal beach volume increased during the research period. However, the increase in intertidal beach volume was significantly more than the volume of sediment that was transported shoreward. Probably only a small part of the sediment supplied to the beach originates from offshore and most sediment was brought to the beach from closer to the shore. Although the increase in beach volume could not be explained by offshore sediment supply, the morphological changes could be linked to the observed hydrodynamic conditions. When the wave steepness was small (< 0.02), waves transported sediment shoreward. During period 2 peaks in wave steepness resulted in the transport of sediment lower into the intertidal area.

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