Article, Published Version

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Die Küste

Zur Verfügung gestellt in Kooperation mit/Provided in Cooperation with:
Kuratorium für Forschung im Küsteningenieurwesen (KFKI)

Verfügbar unter/Available at: https://hdl.handle.net/20.500.11970/101532

Vorgeschlagene Zitierweise/Suggested citation:
Schrottke, Kerstin; Abegg, Friedrich (2005): Near Bed Suspended Sediment Dynamics in a Tidal Channel of the German Wadden Sea. In: Die Küste 69. Heide, Holstein: Boyens. S. 353-367.

Die Küste, 69 PROMORPH (2005), 353-367

Near Bed Suspended Sediment Dynamics in a Tidal Channel of the German Wadden Sea

By KERSTIN SCHROTTKE and FRIEDRICH ABEGG

Summary

Research has been undertaken focusing on the sediment transport processes in the water column of tidal channels, but often neglecting the last few decimetres above the seabed, due to limited application of conventional measuring devices within the near-bed zone. This paper introduces a new instrument, called NEBOSS, which has been designed for measuring and sampling sediment suspensions down to 10 cm above the seabed. In an attempt to overcome the spatial limitations of NEBOSS, the echo-sounder system DSLP® of General Acoustics GmbH was simultaneously deployed in the Dithmarschen tidal channel Piep at different tidal phases. It provides data of near-bed acoustic interfaces, defined as suspension layers in a high temporal and spatial resolution. Even complex, tide dependant near-bed sediment processes can be derived from the NEBOSS data with suspended sediment concentrations (SSC) > 1 g/l, a higher ratio of particles > 20 µm and clastic components during flood and ebb tides. Sand transport is not limited to the first decimetre, but also occurs 1 m above the seabed in highly variable amounts, due to turbulent mixing processes. In total, the amount of sand is less than expected, especially close to the seabed under tidal flows with mean velocities up to 57 cm/s. A near-bed suspension layer of an average thickness of 20 cm, as always detected with DSLP, is also reflected in the NEBOSS data, except at slack tides. A tidal signal is visualised with DSLP regarding an increased thickness of the suspension sub-layer closest to the seabed during slack tide.

Zusammenfassung

Sedimenttransportprozesse in Tiderinnen wurden bereits mehrfach untersucht, oft aber ohne die letzten Dezimeter über der Gewässersohle mit einzubeziehen. Grund hierfür ist die eingeschränkte Einsatzmöglichkeit kommerzieller Messgeräte im sohlnahen Bereich. In dieser Arbeit wird das neue Messsystem NEBOSS vorgestellt, das zur Erfassung und Beprobung von Sedimentsuspensionen bis 10 cm über Grund entwickelt worden ist. In einem Versuch, die räumlich limitierte Aussagekraft von NEBOSS zu erweitern, wurde das Echolotsystem DSLP® von General Acoustics GmbH zeitgleich in der Dithmarscher Tiderinne Piep zu unterschiedlichen Tidephasen eingesetzt. Es dient der akustisch basierten Erfassung sohlnaher Sedimentsuspensionen. Mit NEBOSS lassen sich selbst komplexe, tideabhängige Sedimenttransportprozesse 10 cm über Grund mit Suspensionskonzentrationen > 1 g/l, höheren Anteilen von Partikeln > 20 µm und vermehrt klastischen Bestandteilen zu den Flut- und Ebbphasen erkennen. Sand wird nicht nur innerhalb der untersten Dezimeter transportiert, sondern auch 1 m über der Gewässersohle in unterschiedlichen Mengen, was auf turbulente Durchmischungsprozesse zurückführbar ist. Insgesamt ist weniger Sand anzutreffen, als bei den vorherrschenden Tideströmungen mit mittleren Geschwindigkeiten bis zu 57 cm/s erwartet wird. Ein sohlnaher, durchschnittlich 20 cm mächtiger Suspensionshorizont, wie er ausnahmslos mit DSLP zu allen Tidephasen detektiert wird, lässt sich aus den NEBOSS-Daten außerhalb der Stauwasserphasen ebenfalls ableiten. Ein Tidesignal zeigt sich in den DSLP-Daten bezüglich einer Mächtigkeitszunahme des sohlnächsten Suspensionshorizontes zu Stauwasser.

Keywords

Near-Bed Sand Transport, Dithmarschen Bight, North Sea, Field Measurements, Measuring Techniques, SSC, SPM, OBS, NEBOSS, Echo-Sounder DSLP®

Contents

1. Introduction

The extensive tidal flats and channels of the German North Sea wadden coast underlie remarkable morphological changes on various time scales (WIELAND, 2000; ASP NETO, 2004). Intensive utilisation of this coastal zone emphasises the need of reliable forecasts of its morphological evolution in time frames of months, years and decades. This becomes even more important regarding potential changes induced by a rise of the global sea level or an increase in storm activity and intensity. To apply morphodynamic numerical models to achieve this task, a detailed knowledge of the processes, controlling the coastal morphology is strongly required.

Morphological changes of tidal flats and channels are mainly caused by sediment movement due to water motion. Dependent on the hydrodynamic energy input as well as on the particle size, type and shape, these sediments are transported in suspension or as bedload (REINECK and SINGH, 1980; ZANKE, 1982; VAN RIJN, 1993). In the field, it is less obvious where and under which transport mechanism especially sand is moved, particularly in turbid environments. In the literature, the term 'suspended particulate matter (SPM)' is often used as a synonym for all transported particles, disregarding their mode of transportation.

Fine-grained, highly concentrated near-bed suspensions (> 1 g/l, EISMA, 1993) are a well known phenomenon in many tidal estuaries (ROSS and METHA, 1989; SMITH and KIRBY, 1989; SHI et al., 1996; VELEGRAKIS et al., 1997). The dynamics of cohesive sediment suspensions are different from non-cohesive ones and cannot easily be transferred to those sediments found in the investigation area.

The Dithmarschen tidal flats are predominantly composed of sand (KÖSTER, 1998). Thus, sand must be transported in reasonable volumes. However, former field measurements of the suspended sediment concentration (SSC) and composition in the water column of the North Sea tidal flats and channels showed that the retrieved amount of sand was either non-existent or negligible (RICKLEFS, 1989, 1998; RICKLEFS and AUSTEN, 1994; POERBANDONO, 2003; JOERDEL et al., 2004). From these results it can be assumed that sand is predominantly transported close to the seabed, as also reported in a study focusing on the transport of sand suspensions and transport on the Middelkerke bank (Southern North Sea). It was shown that up to 73 % of the entire sediment volume in the water column was transported at heights of 0–30 cm above the seabed (Vincent et al., 1998).

The purpose of this field study is the verification of a pronounced near-bed sediment transport in a tidal channel, combined with measurements of water depth and current velocity.

2. Methods

The development of measuring techniques for studying sediment transport in aquatic environments has made remarkable advances during the last decades. Different methods are available including water sampling systems (Hickel, 1984; Christiansen, 1985; Pierce and Nichols, 1986; Van Rjin, 1993; Shi et al., 1996; Kern and Westrich, 1999) and coring devices (Zampol and Waldorf, 1989) for selective measurements of particle concentration and distribution in the water column. Instruments based on optical (Ohm, 1985; Sternberg, 1989; Sternberg et al., 1989; Green and Boon, 1993; van de Kreeke et al., 1997; Fugate and Friedrichs, 2002), acoustical (Hay, 1983; Thorne et al., 1991, 1993; Velegrakis et al., 1997; Vincent et al., 1998; Green et al., 1999, 2000; Webb and Vincent, 1999) and x-ray techniques (Nielsen, 1984) are used for profiling measurements, providing indirect information on particle concentration and distribution.

To simultaneously measure SPM concentration and distribution as well as current velocity in a high temporal resolution even 10 cm above the seabed, a new NEar-Bed Observation and Sampling System, called NEBOSS has been developed (Fig. 1). The essential parts of NEBOSS are two streamlined, isokinetic water-sediment samplers of the type *US-P61 point integrating sediment sampler* (71.1 cm long; 18.6 cm wide) with a sample volume capacity of 0.5 l (van Rijn, 1993). The filling time of a sample bottle varies between seconds and minutes, dependant on the current velocity (in this study: 00:00:31 h – 00:10:30 h). Both samplers are mounted in a tripod frame, which is lowered to the seabed by a supporting vessel crane (Fig. 1). Once the frame is positioned, one sampler is lowered to the seabed with a small electronic underwater winch. The approach of the sampler to the seabed is controlled by a pressure sensor for depth measurements (pressure range 0–2.5 bar, accuracy 1 % of the total measuring range) and an electromechanic bottom detector. Current velocity near the nozzle of the movable sampler is simultaneously registered with a one-axial vane type current meter (sample rate 1Hz, accuracy ± 0.5 cm/s) which is 5 cm in diameter and 1 cm wide. The second sampler is permanently mounted in the frame for sampling 1 m above the seabed (Fig. 1).

Each sampler is equipped with a 12 cm × 2.5 cm large, optical backscatter sensor (OBS) by Seapoint for high temporal resolved (sample rate 1 Hz) turbidity measurements near the nozzle. A source wave length of 880 nm is used and the scattered light is detected from a small water volume within 5 cm of the sensor window. A sensor sensitivity of 10 mV / FTU (Formazine turbidity unit) with a range of 500 FTU was applied in this study. A linear correlation between SSC and OBS intensity is expected, despite sensor limitations of a particle size-dependant response (Fugate and Friedrichs, 2002; Hoitink and Hoekstra, 2005).

All sensors can be deployed both for measurements in discrete water depths and in a vertical profiling mode. The whole system is electronically controlled from the support vessel via cable.

The samples were vacuum filtered through pre-weighed Whatman GF/C glass microfibre filters, retaining particles > 1.2 µm for determining SSC. The amount of particulate organic carbon (POC) was calculated from weight loss after heating to 550 °C for 5 h. The

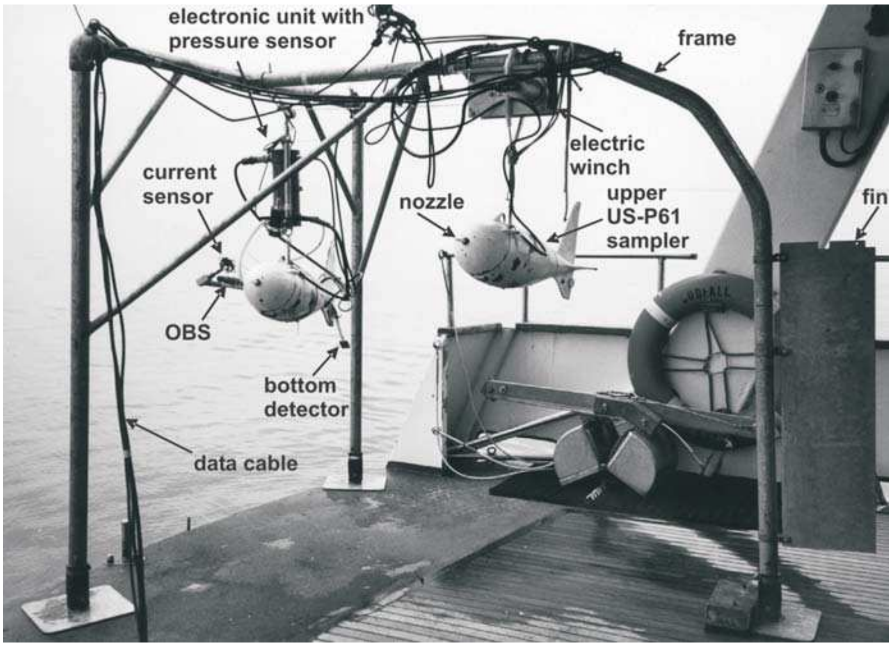

Fig. 1: Deployment of the new near-bed observation and sampling system (NEBOSS) from the RV Südfall

solids of tidal waters often occur in the shape of particle flocs, which are mostly aggregated clays and silts, combined with organic matter (EISMA, 1986, 1993; RICKLEFS, 1989; JOERDEL et al., 2004). To detect and quantify aggregated structures, all samples were analysed twice with a CIS laser particle analyser (REIMERS, 1999). Initially, the samples were analysed as collected in the field. Afterwards, ultrasound and H_2O_2 treatments were carried out to split the flocs and remove organic substances.

To overcome the spatial limitation of NEBOSS while deploying it at one location at a time, the echo-sounder system DSLP (Detection of Sediment Layers and Properties) by General Acoustics GmbH was simultaneously used (EDEN et al., 2005). This device has been developed for a high spatial and temporal resolved, precise detection of interfaces in a complex stratification of suspensions and sediments (EDEN et al., 1999, 2000, 2001). The resolution is in the range of millimetres, the system accuracy amounts ± 1.5 mm. The DSLP device was used stationary and in a profiling mode, applying frequencies of 12.5, 110 and 200 kHz. Geographical positioning was performed by a high presision DGPS with a land based reference station.

A 1200 kHz broadband Acoustic Doppler Current Profiler (ADCP) of RD Instruments© was deployed to measure current velocity and direction in a profiling mode with a depth cell size of 25 cm. Information on the amount of SPM is given by the strength of the retrieved backscatter signal (DEINES, 1999). Tidal data from the Büsum gauge was provided by the regional office of the Federal Administration for Waterways and Navigation.

3. Regional Setting

The data presented in this study are based on surveys carried out from October 2000 to November 2001 in the tidal channel Piep under different tidal phases (always between neap and spring tide), and wind speeds of about ≤ 4 m/s (Fig. 2). The Piep is located in the tidal flat area of the Dithmarschen Bight (Fig. 2). The channel system is the main pathway for the semidiurnal exchange of tidal water masses between the open sea and the Dithmarschen Bight with mean flow velocities of up to 2 m/s and a mean tidal range of 3.2 m. In the Piep, the cross-sectional averaged current velocities vary between highest mean values of 0.87 m/s (neap) and 1.03 m/s (spring) during flood tide and 0.91 m/s (neap) and 1.05 m/s (spring) during ebb tide (ASP NETO, 2004). Ebb-dominated flows prevail in summer and during neap tides, whereas flood currents dominate in winter and during spring tides. A lateral asymmetry of the tidal flow is controlled by the Coriolis force (ASP NETO, 2004).

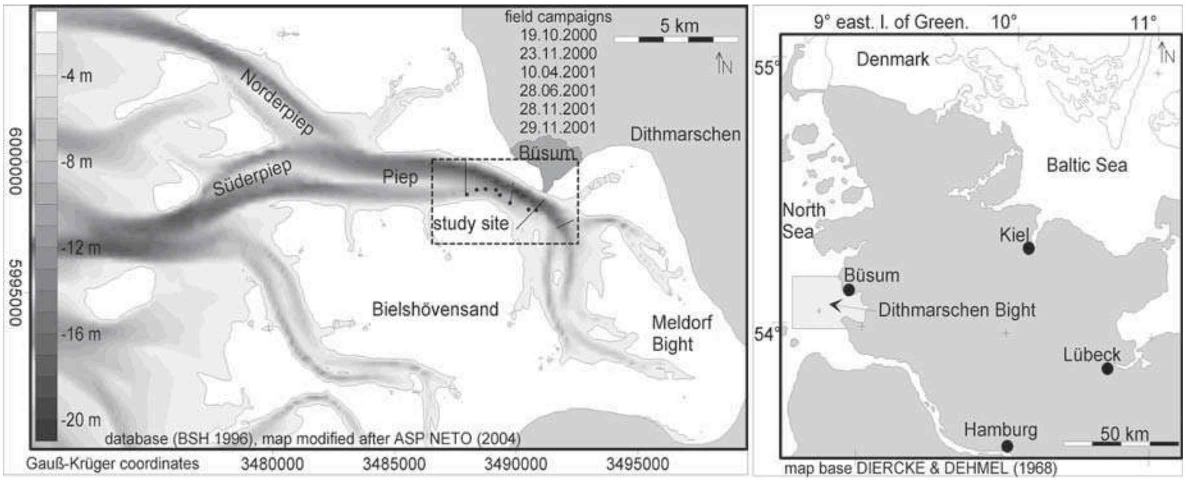

Fig. 2: Bathymetric map of the Dithmarschen Bight (North Sea, Germany), showing the study site (positions of stationary measurements are marked with dots; cross profiles with lines)

The average salinity in the water column is about 25 ppt, with tidal fluctuations of up to 2.5 ppt. The mean water temperature varies between 6 °C in winter and 18 °C in summer, with tidal variations of about 1°C. These values are based on measurements in summer (28 June 2001) and winter (28 November 2001). Fresh-water discharge can be expected on an irregular basis from sluices gates.

The tidal flats are intersected by the Piep channel, in parts reaching depths > 21 m below sea level, where consolidated clays of early Holocene origin occasionally outcrop (ASP NETO, 2004). These clays are present in the deepest section and at the steep northern slope of the Piep channel (Fig. 2). Often, its subsurface is dissected leaving a prominent pattern of ridges and grooves. The southern slope is only gently inclining toward the Bielshövensand and its rippled surface is composed of very fine to medium sand (POERBANDONO and MAYERLE, in this volume). The maximum depth-averaged SSC in the water column of the Piep down to 1 m above the seabed is about 0.5 g/l (POERBANDONO and MAYERLE, in this volume). The median size of suspended particles is in a range of 6 µm – 86 µm (untreated) and 4 µm –19 µm (aggregates dissolved), respectively (POERBANDONO, 2003).

4. Results

4.1 NEBOSS Measurements

The signal intensities of the OBS linearly correlate with SSC in the water column at the 95 % significance level (Fig. 3a–b). The correlation coefficients from the data sets 10 cm above the seabed increase up to $R^2 = 0.97$ ($\alpha = 0.05$; $n = 6$) when focusing on single surveys.

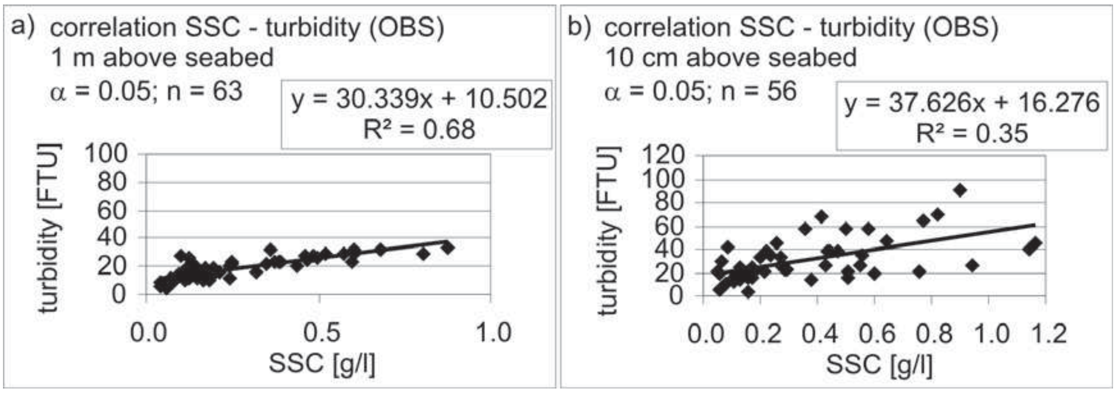

Fig. 3a–b: Linear regressions, relating (a) OBS turbidity to SSC at 1 m and (b) 10 cm above the seabed, based on data sets from all surveys

An increase of the OBS intensity und thus the SSC trough the water column towards the seabed was repeatedly registered at the study site, a good example being shown in figure 4. Highest values of 28 FTU (> 0.3 g/l) in this case occur close to the seabed. Simultaneously, the current velocity decreases from ~ 100 cm/s near the water surface to 40 cm/s near-bed (Fig. 4).

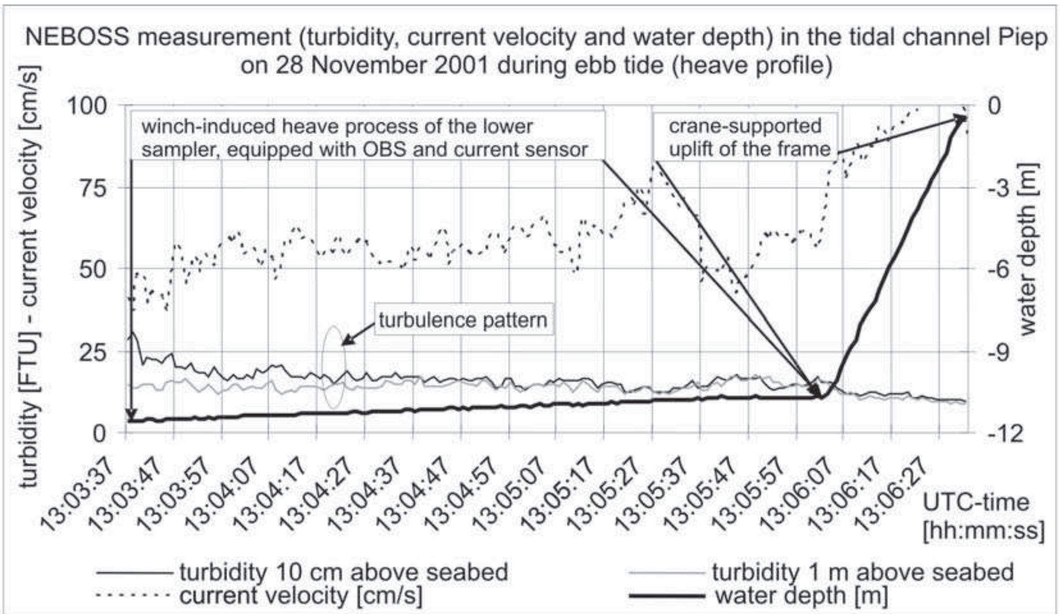

Fig. 4: Turbidity and current measurements in the tidal channel Piep on 28 November 2001 during ebb tide (heave profile)

During high-water slack tide, a slight downward increase of the OBS intensity is visible with highest values of 15 FTU, corresponding to 0.15 g/l (Fig. 5). Also, there is no distinct differentiation between the signal strength 10 cm and 1 m above the seabed. The near-bed current velocity is < 10 cm/s.

Regarding data from both OBS in further detail, there is a considerable variability of the signal intensity over short time intervals of only a few seconds visible (Fig. 4, 5). This is linked to small-scale variations of the current velocity, representing ongoing turbulent mixing processes. They are even more noticeable during ebb tide with higher hydrodynamic energy input (Fig. 4). Thus, SPM is turbulently moved up- and downwards the lower water column. As a result, the SSC at 10 cm and 1m above the seabed is occasionally similar for a few seconds (Fig. 4).

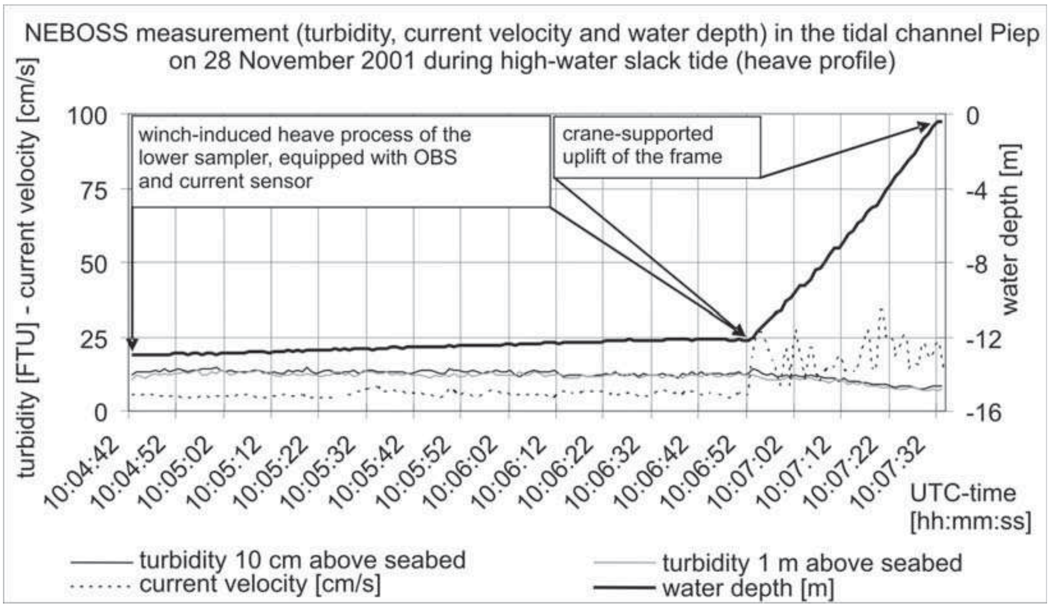

Fig. 5: Turbidity and current measurements in the tidal channel Piep on 28 November 2001 during high-water slack tide (heave profile)

Tide dependant variations of the near-bed SPM dynamics, even in a channel section with complex tidal current patterns, can be derived from the NEBOSS and selected ADCP data (Fig. 6a–e). The stationary measurements represent the near-bed current and sediment situation on 29 November 2001 (4 days before spring tide) eastwards of the Bielshövensand in 10 m water depth over a tidal cycle at 30 minutes time intervals. NEBOSS and ADCP current velocity and backscatter data linearly correlate at the 95 % significance level ($\alpha = 0.05$, $n = 24$; $R^2 = 0.82$). Similar results are given for the OBS intensity and ADCP backscatter ($\alpha = 0.05$, $n = 24$; $R^2 = 0.70$).

In the example shown here, the flood current decreases evenly towards slack water, whereas an irregular decrease of the ebb current velocity occurs with a second peak right after flow reversal (Fig. 6a–b). This reversal is not synchronous with low-water slack tide. Tide dependant changes of the hydrodynamics are also reflected by temporal variations of the SSC at 10 cm and 1 m above the seabed, with higher values occurring exclusively during flood and ebb tide (Fig. 6a–b). A time offset of about 30 minutes emerges between peak current velocity and SSC (6a–b). Highest SSC > 1 g/l appears only close to the seabed, although a considerable amount of SPM up to 0.6 g/l is also found at the higher elevation for a few times (Fig. 6b).

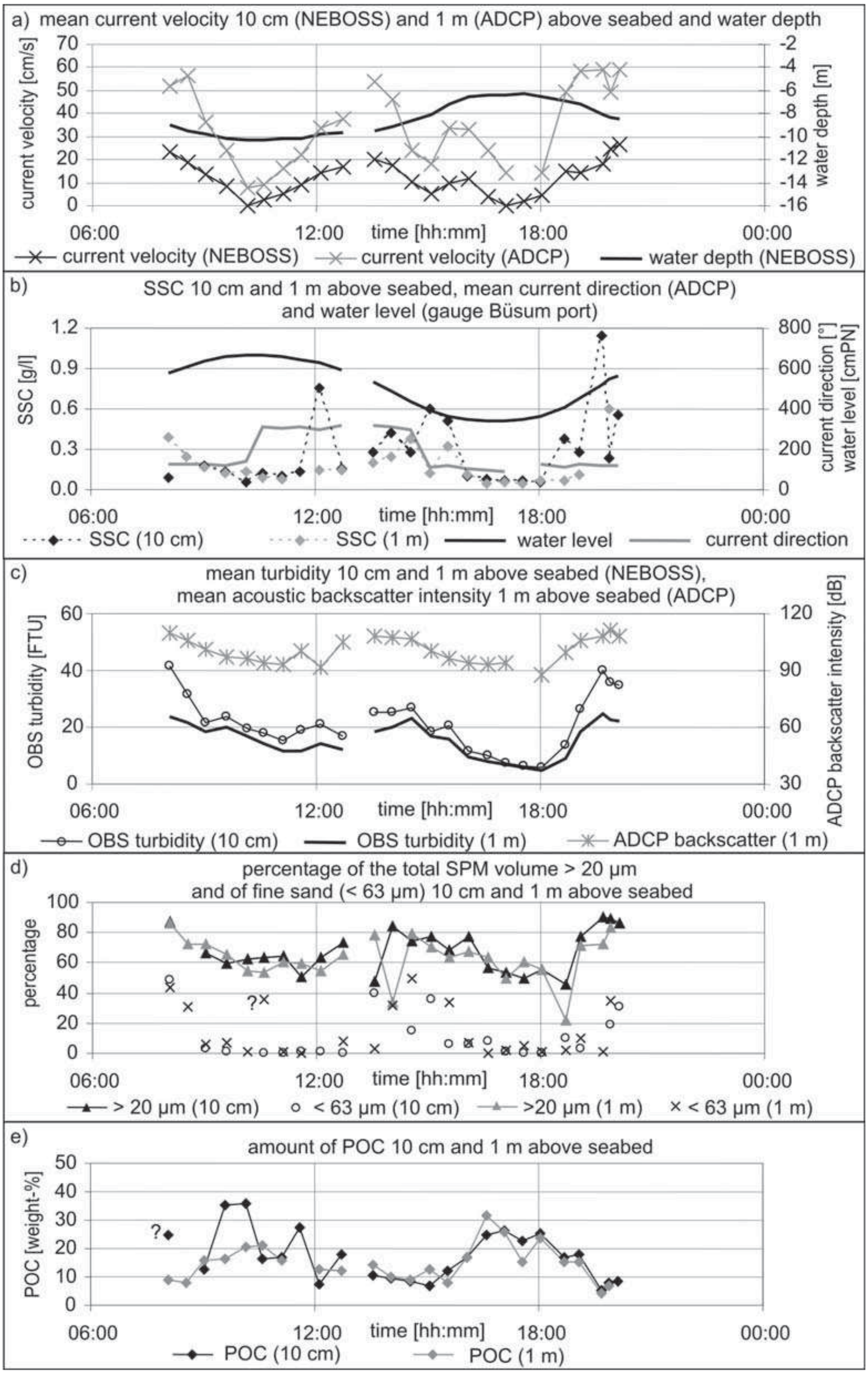

Fig. 6a–e: Stationary NEBOSS and ADCP measurements on 29 November 2001 over a tidal cycle

During slack water, the SSC decreases to ≤ 0.15 g/l at both depths, with slightly higher values during high-water slack tide (Fig. 6b). SSC exceeding values of 0.15 g/l are encountered in up to 50 % and 34 % of all measurements at 10 cm and 1 m above the seabed, respectively.

The mean OBS and ADCP backscatter signal intensities also show less SPM during slack water (Fig. 6a–c). Both sensors similarly reflect the SPM situation 1 m above the seabed, despite different measuring positions from the vessel. Comparing them with the time-variation curve of the lower OBS, higher values are restricted to the near-bed, in particular during maximum flood flow (Fig. 6c). However, there is not much difference visible between both depths during slack water, especially during low-water slack tide. The particle size and composition of the SPM change closely related to the tides (Fig. 6d–e). The percentage of particles > 20 μm is comparatively higher during flood and ebb flows as during slack water. A downward coarsening of suspended particles is not distinguishable in the shown case (Fig. 6d). On average, 25 % of the SPM volume appears flocculated. Suspended sand only turns up under higher flow conditions, but is not restricted to peak flows. Whereas the amount of sand up to 40 % is similarly high at both depths during flood tide, more fluctuations occur during ebb tide (Fig. 6d). A predominant sand transport close to the seabed cannot be derived from the data. Furthermore, the amount of sand, as in the example shown here, was not regularly found during all measuring campaigns, even under stronger currents.

Contrary to the time-variation curve of the clastic components found in suspension during flood and ebb currents, there is a higher ratio of POC during slack water (Fig. 6e). During high-water slack tide POC values > 25 % of the total SPM weight only occur close to the seabed, whereas during all other tidal phases the POC amount is similar at both depths.

4.2 DSLP Measurements

One result obtained from all DSLP measurements is the distinct increase of signal intensity a few decimetres above the seabed. The presence of a near-bed suspension layer of 20 cm on average is derived, based on the acoustic detection criteria for suspensions, which is defined as an abrupt change of the signal characteristics due to a significant or erratic increase of the particle density (Fig. 7).

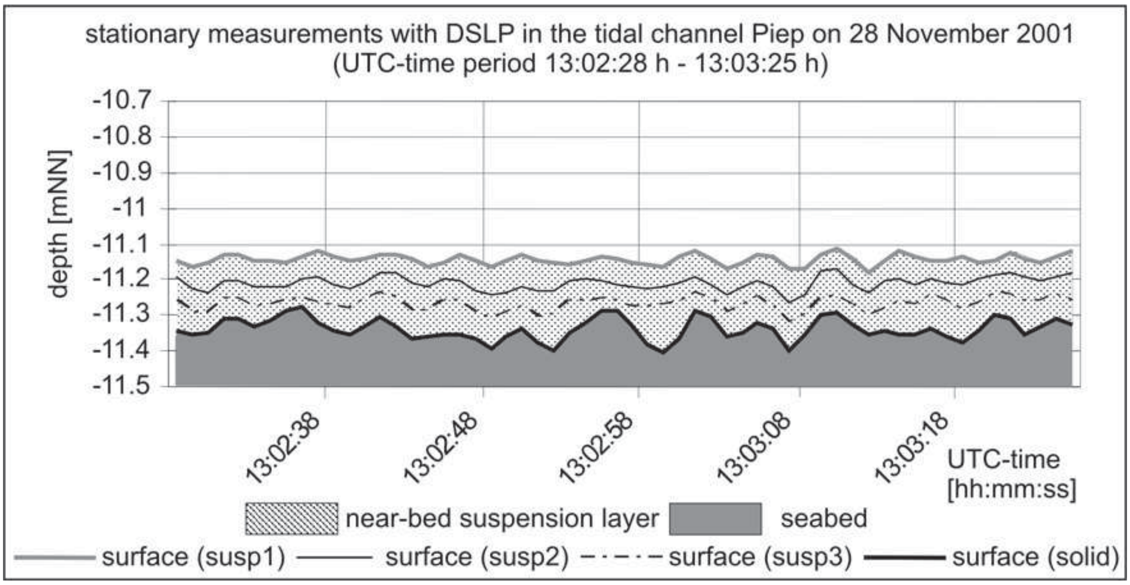

Fig. 7: Stationary measurements with DSLP on 28 November 2001, showing a roughly 20 cm thick, stratified near-bed suspension layer. The vertical sub-division is based on a downward increase of acoustic attenuation (susp1 – susp3)

The relatively low signal intensity (linear and weakly nonlinear acoustic signal characteristics) returning from the above water column is equated with SSC < 0.3 g/l (based on NEBOSS data). This near-bed suspension layer can be further vertically subdivided, based on a downward increase of the acoustic attenuation (Fig. 7). The layer boundaries are defined at 5 % (susp1 – susp2) and 50 % (susp2 – susp3) of the total acoustic attenuation of the near-bed suspension layer. These sub-layers were present at all measuring sites and during all tides. Short-term variations of the layer thickness indicate turbulent mixing processes, as also seen in the OBS data (Fig. 4–5). The mean layer thickness varied in a range of 1–3 cm during the stationary measurements (Fig. 8). A linear relationship between the mean near-bed current velocity and the thickness of lowermost layer susp3 ($\alpha = 0.05$; $n = 24$; $R^2 = 0.399$) exists in the example shown here, with a vertical increase of the layer thickness congruently with a decrease of the current velocity. The mean layer thickness of susp1 differs between both slack tides with higher values during high-water slack, as illustrated in figure 8. These findings are comparable to the mean OBS and ADCP data (Fig. 6c).

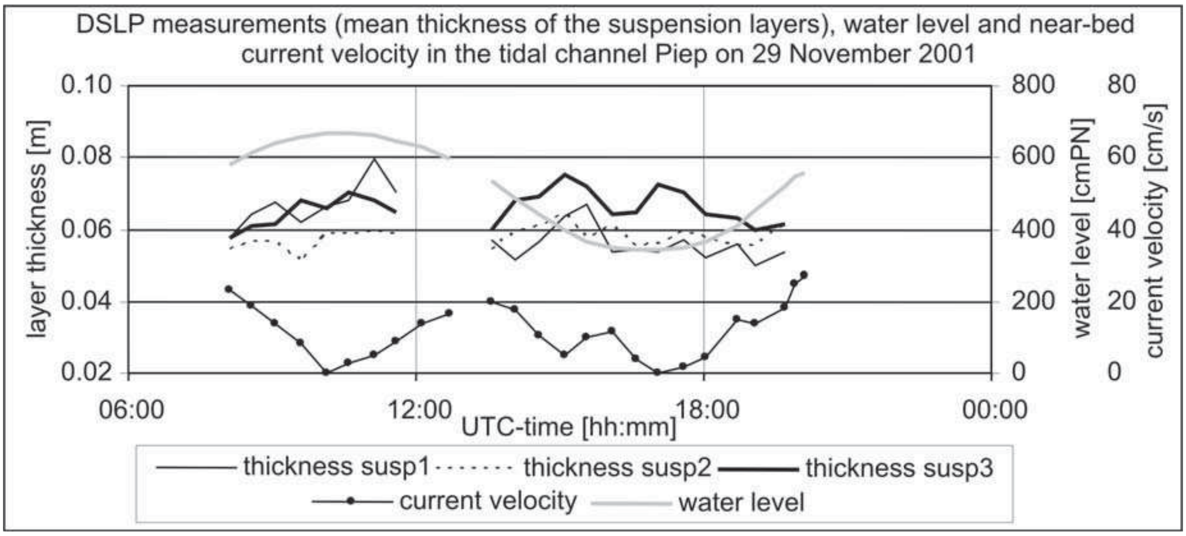

Fig. 8: Mean thickness of the near-bed suspension sub-layers (DSLP), and mean current velocity (NEBOSS) in the tidal channel Piep on 29 November 2001 during a tidal cycle

The differences in mean thickness of the detected near-bed suspension layer were small during stationary measurements, but remarkable variations repeatedly occurred, regarding profiles across the tidal channel Piep (Fig. 9). Furthermore, a thinner near-bed suspension layer was found at the sandy channel section near the Bielshövensand as in the deeper part of the channel or at its northern flank, where clays partly outcrop (chapter 3). This spatial distribution was not restricted to slack water. In addition, a stratified suspension layer was measured at each cross section.

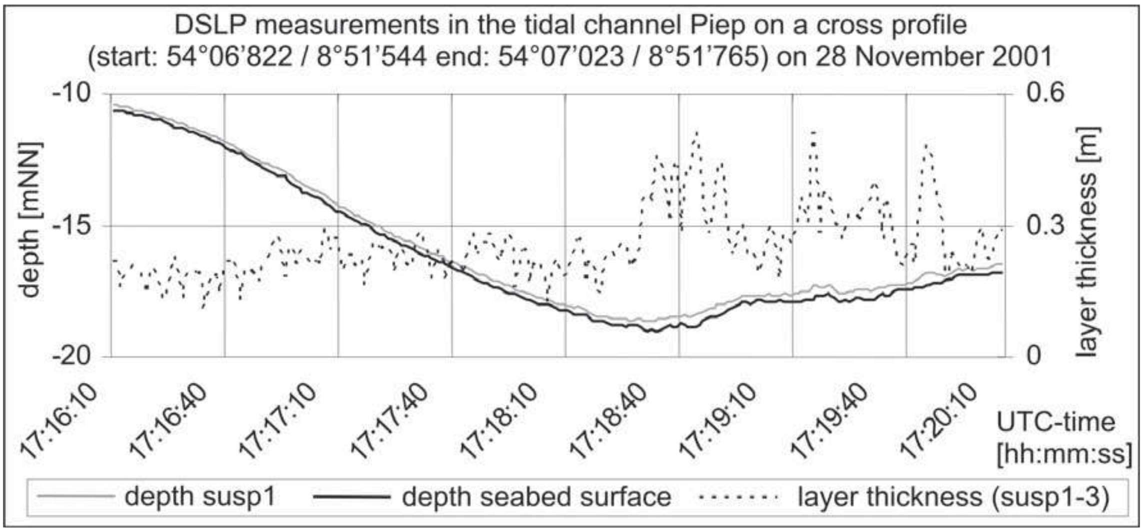

Fig. 9: Bathymetry and mean thickness of the near-bed suspension layer in the Piep on 28 November 2001 over a cross profile, based on DSLP measurements

5. Discussion

The near-bed sediment dynamics in the Piep is controlled by the semidiurnal tide, as demonstrated with the NEBOSS data. Influences by waves during the measurements can be excluded. It has been shown that the SSC increase at both considered depths corresponding to higher current velocities during flood and ebb tides (mid lunar cycle) with values > 1 g/l at 10 cm above the seabed. Isochronal, the composition of the SPM shifts towards coarser fractions and the amount of clastic components rises in relation to the organic matter. These findings reveal that the near-bed SSC is considerably higher as estimated from extrapolations of calibrated optical beam transmissometer profiles in the Piep with SSC values up to 0.25 g/l (POERBANDONO, 2003).

Considerable amounts of sand up to 69 % of the SPM volume were only found when mean near-bed current velocities exceeded > 10 cm/s. However, flow magnitude and amount of sand do not correlate at the 95 % significance level. At the same time, hardly any differences between sand trapped 10 cm and 1 m above the seabed were found. Turbulent mixing processes, as derived from the OBS data, lead to up- and downward directed transport of sand and thus prevent a downward particle coarsening. The time offset between maximum flow velocity and SSC can be ascribed to the processes of lag effects in resuspension and settling of SPM (DYER, 1986).

Overall, higher amounts of suspended sand were expected to appear close to the seabed congruently with higher SSC. The hypothesis, that the main pathway of sand is focused on the near-bed horizon has basically been proven to be true. Consequently, the amount of sand trapped in the lower sampler was expected to be constantly high during mean current velocities up to 57 cm/s above a sandy seabed, also according to the Shields criterion (SOULSBY, 1997). In a study on near-bed sand transport (0.26 m and 2.36 m above the seabed) in an inlet throat at the Dutch Frisian coast under low wave activity, a threshold velocity between 20 and 30 cm/s was detected (HIBMA and VAN DE KREEKE, 2001). Near-bed suspended sand concentrations of up to 0.2 g/l were obtained with an acoustic device. Despite different regional settings, the values were in the same range as in the Piep. Moreover, higher values were not restricted to the near-bed elevation (HIBMA and VAN DE KREEKE, 2001). Similar values were reported from a sandy tidal site in the outer Thames estuary (WHITEHOUSE, 1995). There, the amount of sand 5 cm above the seabed (based on pump samples) rose up to 0.27 g/l under currents velocities of 0.4 m/s, which were measured at 1 m elevation.

Investigations of SPM composition within the water column of the tidal channel Piep showed that there was hardly any sand in suspension (POERBANDONO and MAYERLE, 2005), matching the results of former investigations (RICKLEFS, 1989, 1998; RICKLEFS and AUSTEN, 1994). An uplift of sand into the water column by local eddies even to the surface as described by JACKSON (1976) can not be derived from the actual data sets of the Piep channel. These comparisons lead to the implication that sand is more likely to be mobilised during higher hydrodynamic input e.g. during simultaneous spring tide and storm conditions or that a larger amount of sand is transported as bedload even below the lowermost measuring depth of NEBOSS.

Slack tides in the Piep clearly illustrate reduced near-bed sediment transport as expected (EISMA, 1993). Then, the SSC drops down to 0.15 g/l at both depths which can be defined as background concentration and coincides with a size decrease of clastic particles and a higher ratio of organic matter. These values are similar (0.15 g/l – 0.22 g/l) to near-bed SPM values found in the Chesapeake Bay (USA) during slack water (FUGATE and FRIEDRICHS, 2002).

A near-bed suspension layer of 20 cm in thickness on average as present during flood and ebb tides was also detected with DSLP during slack water, but not with NEBOSS. A response to tidal variations can only be seen in the increased thickness of the lowermost suspension sub-layer during slack water. This can be explained with particle accumulation induced by settling processes. Similar results were reported from a tidal channel in New Zealand, where settling sand intermittently formed a 2 cm thick deposit during slack water (GREEN et al., 2000).

The evaluation of the DSLP results is more difficult, considering the presence of a few decimetres thick near-bed suspension layer, irrespective of the tide. Short-term fluctuation of the layer thickness can be ascribed to turbulent mixing processes, although with much smaller amplitudes as derived from NEBOSS. A sudden distinct volume expansion of the near-bed suspension layer (‘burst’) of up to 1 m above the seabed was not detected by the DSLP at any time. A remarkable change in layer thickness only occurred spatially with increasing values in the deeper part of the channel where clays outcrop, producing a prominent relief. This cause extra turbulence due to increased bed roughness. However, the spatial distribution and volume expansion of a near-bed suspension remained constant over the tidal cycle.

6. Conclusions

In this study, it has been shown that the new measuring device NEBOSS is capable of identifying tide dependant near-bed sediment transport processes, such as turbulent movement of SPM, particularly during flood and ebb tides. Even complex flow patterns and resulting complex near-bed sediment transport processes can be visualised with NEBOSS. The hypothesis, that sand is transported close to the seabed can be seen to be true. However, higher amounts of sand have been expected to be trapped at the lower elevation. In this case, further measurements are needed with samplings even closer to the seabed while surveys include periods of higher hydrodynamic energy input.

By means of NEBOSS and DSLP, a near-bed suspension layer of about 20 cm in thickness were detected during flood and ebb tides, which indicates a prominent near-bed sediment transport. However, differing results were found when it comes to the tide dependant decrease of this layer during slack water. Other discrepancies occurred, regarding the SSC > 0.3 g/l which was repeatedly registered 1 m above the seabed with NEBOSS. This does not match the thickness of the near-bed suspension layer detected with the DSLP.

Sediment transport processes a few centimetres above the seabed as indicated by DSLP can not be resolved with NEBOSS due to its limitation in the lowermost measuring depth. The results indicate, that tide dependant SSC is equal or lower than 10 cm above the seabed (0.15 g/l – 1.2 g/l) than closely above it (1–2 cm). However, the acoustic signal characteristics of DSLP within the lowermost centimetres above the seabed cannot be verified with SSC data or other particle characteristics such as particle size and composition in this study. Indications are that different near-bed sediment transport mechanisms occur at both depth ranges.

7. Acknowledgements

The work presented in this paper was part of an interdisciplinary project funded by the Federal Ministry of Education and Research (funding number 03 F 0262 B). The authors express their sincere thanks to Dr. K. Ricklefs, who initiated and coordinated the project. We would also like to thank our project partners of General Acoustics for their much appreciated cooperation throughout the project. The assistance of G. Bojens and B. Meier in the development and deployment of the NEBOSS device is also gratefully acknowledged. We would also like to thank the captain and crew of the RV SÜDFALL of the Research and Technology Centre Westcoast of Kiel University for their valuable assistance in the measuring campaigns.

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