Behavior of supended sediment flocs in tidal basins

A case study from the backbarrier area of Spiekeroog Island, German North Sea

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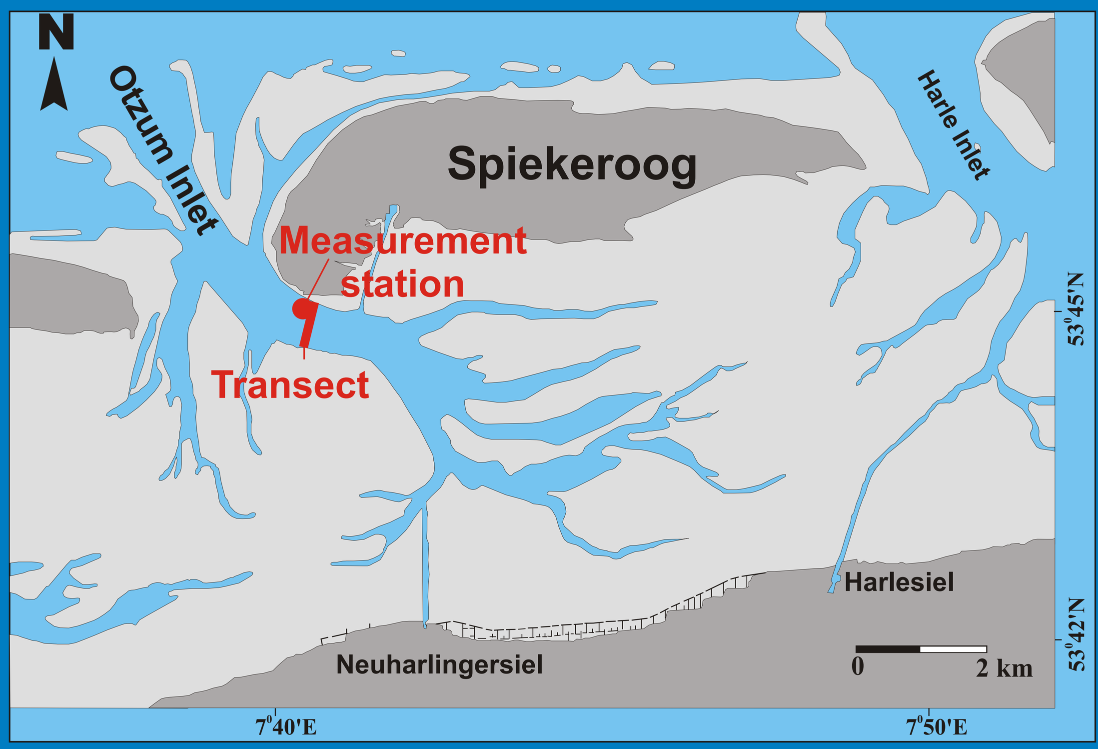
Introduction

The Wadden Sea is a complex ecosystem in the transition zone from land to sea. This ecosystem consists in the area of the East Frisian Islands of various environments ranging from salt marshes at the foot of the dyke as landward margin, over a network of tidal flats and tidal creeks to barrier islands, which form the seaward margin of the Wadden Sea (FLEMMING, B.W. & DAVIS, R.A. JR., 1994). Permanent fluctuation between draining and flooding characterises and even more establishes this coastal environment. Driving forces in this area are tides. These tidal currents do not only exchange large volumes of water with the open sea and are thus forming the local morphology they transport large volumes of needful and harmful substances in solution into and out of the Wadden Sea. The here presented subproject "Hydrodynamics and Suspended Matter Budget" is dealing with another way of exchanging large amounts of material: the transport of suspended matter. We survey the net transport of suspended matter in the hydrodynamic context in order to understand the different processes involved in suspended matter transport.



Study area

The East Frisian Wadden Sea is characterised by a line of seven major barrier islands at the seaward margin and backbarrier tidal flats (for a general overview of the area see e.g. WOLFF, J.-O. & FLEMMING, B.W., 2003). Investigations are carried out in the backbarrier tidal basin of Spiekeroog Island, German North Sea (Fig. 1). The Spiekeroog tidal basin covers an area of about 75 km². The tidal setting is semidiurnal with a tidal range of approximately 2.6 to 2.8 m (FLEMMING, B.W. & DAVIS, R.A. JR., 1994). Most of the water exchange is carried out through the Otzum Inlet situated west of the island. Exchange over the tidal watershed with neighbouring tidal basins occurs mainly due to wind forcing, but is generally much smaller and is therefore omitted in this study.

Fig. 1: Study area Spiekeroog tidal basin. Locations of the permanent measurement station and ADCP transects

Methods

Field measurements are carried out in the inner part of the Otzum Inlet covering nearly all the water and material exchange. For the hydrodynamic and suspended sediment survey we combine acoustical and optical instrumentation. Tidal currents are surveyed over the entire water column using "Acoustic Doppler Current Profiler" (ADCP). The instrument is mounted on a boat to cover complete main tidal channel transects during tidal cycles (Fig. 1). Suspended sediment concentrations are calculated based on the ADCP's backscatter signal (SANTAMARINA CUNEO, P. & FLEMMING, B.W., 2000).

A "Laser In-Situ Scattering and Transmissiometry" (LISST) system is used for surveying the suspended sediment at an anchor station 50 m southwest of the measurement station successively at several water depths. By means of optical diffraction in-situ floc sizes are estimated. Suspended sediment concentration is calculated based on optical transmission (AGRAWAL, Y.C. & POTTSMITH, H.C., 2000). A pump centrifuge system is used to obtain suspended sediment samples for analysing grain size distributions and suspension concentrations. This direct approach to suspended sediment concentration is used to calibrate the acoustical and optical methods.

Additionally floc sizes are recorded using a photogrammetric system by the subproject "Ecology of Suspended Particles". Comparison of the photogrammetric and LISST methods for estimating in-situ floc sizes will be presented soon.

References

AGRAWAL, Y.C. & POTTSMITH, H.C. (2000) Instruments for particle size and settling velocity observations in sediment transport. Mar. Geol. **168**, 89-114.

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SANTAMARINA CUNEO, P. & FLEMMING, B.W. (2000) Quantifying concentration and flux of suspended particulate matter through a tidal inlet of the East Frisian Wadden Sea by acoustic doppler current profiling. In: Flemming, B.W., Delafontaine, M.T. & Liebezeit, G. (eds.): Muddy Coast Dynamics and Ressource Management. Elsevier Science B.V., 39-51.

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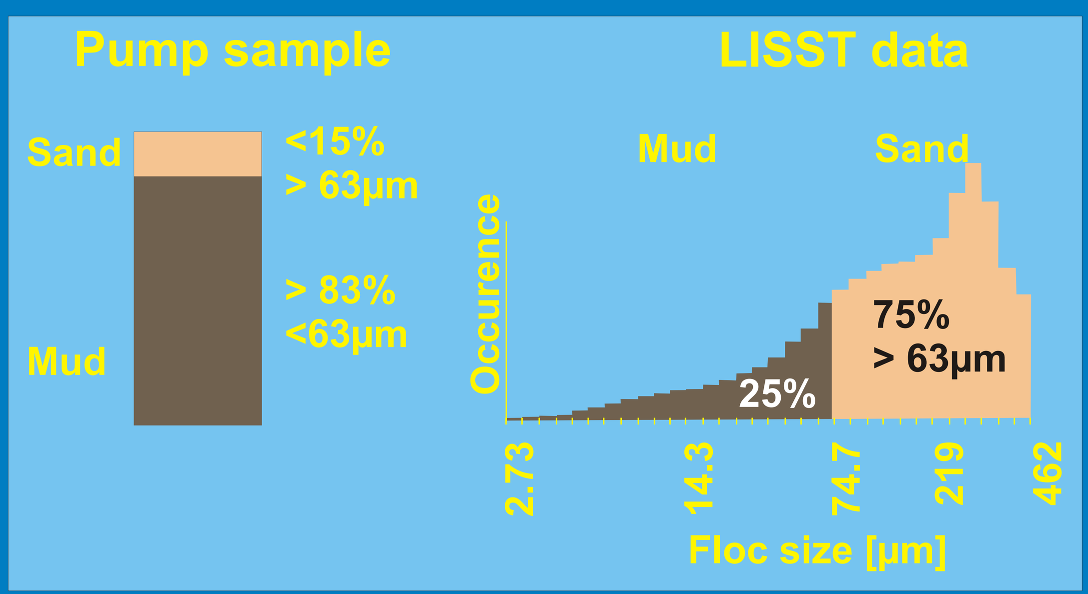

Fig. 2: Comparison of particle sizes: on the left single grain sizes of pump samples. In-situ floc sizes obtained by the LISST shown on the right (Size resolution of the LISST 2.5 to 500 µm).

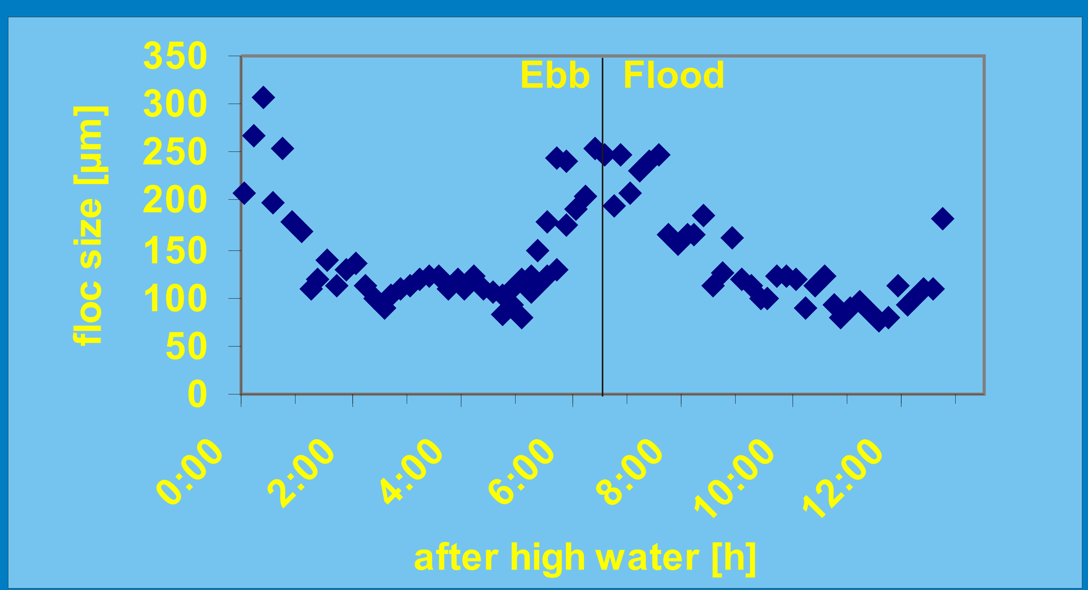

Fig. 3: Variation of in-situ floc sizes measured over an entire tidal cycle. Maximum floc sizes occur about half an hour after slack water.

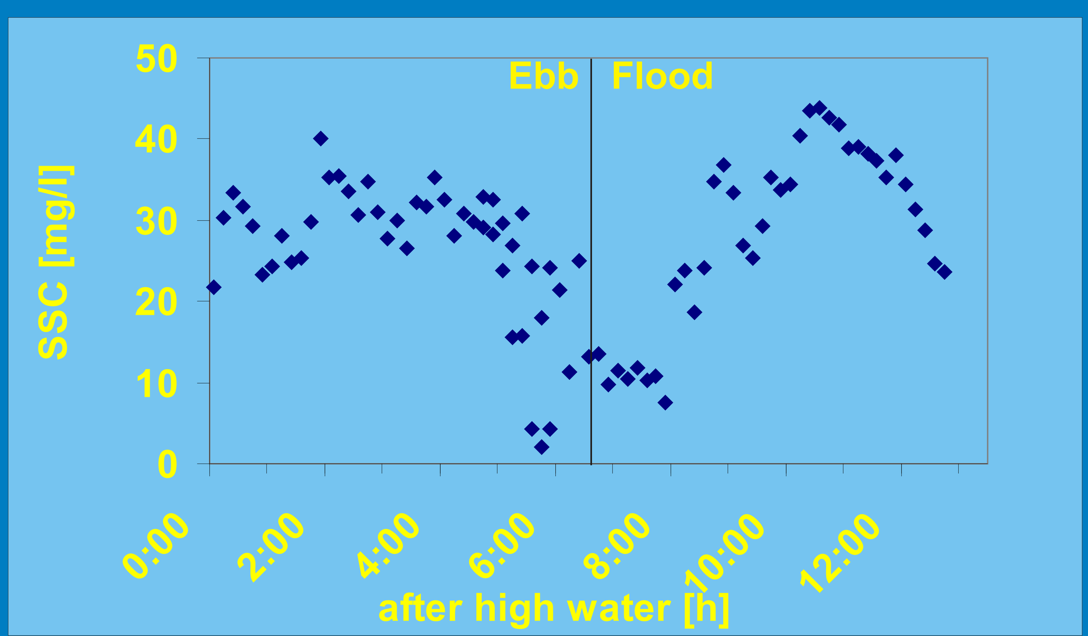

Fig. 4: Variation of suspended sediment concentration (SSC) over an entire tidal cycle. Minima are present around slack water. The Concentration is higher during flood phase due to resuspension of previously deposited sediment.

Results

Suspended matter in coastal waters within the North Sea comprises mainly of mineral particles. Total organic matter content lies within 6 to 11% of the suspended matter. This contribution varies seasonally reaching higher organic content in spring and early summer due to higher primary production.

Comparing pump samples and LISST data shows that 85% of the single grains are smaller than 63 µm compared to only 25% of the in-situ particles contributing to the mud size (Fig. 2). Suspended sediment is thus mainly transported in complex, highly changeable flocs. These consist of single grains as well as smaller flocs.

Flocculation is resulting in different orders. Flocs of higher order are generally less dense and more fragile. Thus floc sizes vary according to the tidal cycle (Fig. 3). Maximum floc sizes are reached half an hour after slack water.

Tidal variations of suspended sediment concentration are shown in Fig. 4. Minima in concentration occur after slack water. Analysing Figs. 3 & 4 shows differences between flood and ebb phases. During flood the concentration is higher and floc sizes are generally smaller than during ebb. This seems to be forced by resuspension of previously deposited sediment and disruption of flocs due to slop over of waves on tidal flats.

Integrating ADCP data into the analysis (Fig. 5 & 6) documents that floc sizes are mainly controlled by a combination of current velocity and suspended sediment concentration. Suspended sediment concentration increases proportionally with increasing current velocity (Fig. 7). The maximum floc size is limited by current velocity and shear stress in the bottom boundary layer (Fig. 7). A higher concentration of suspended sediment on the other hand aids faster flocculation and thus larger floc sizes.

Background photo shows in-situ suspended sediment flocs made by M. Lunau (2002) in the Spiekeroog backbarrier area.

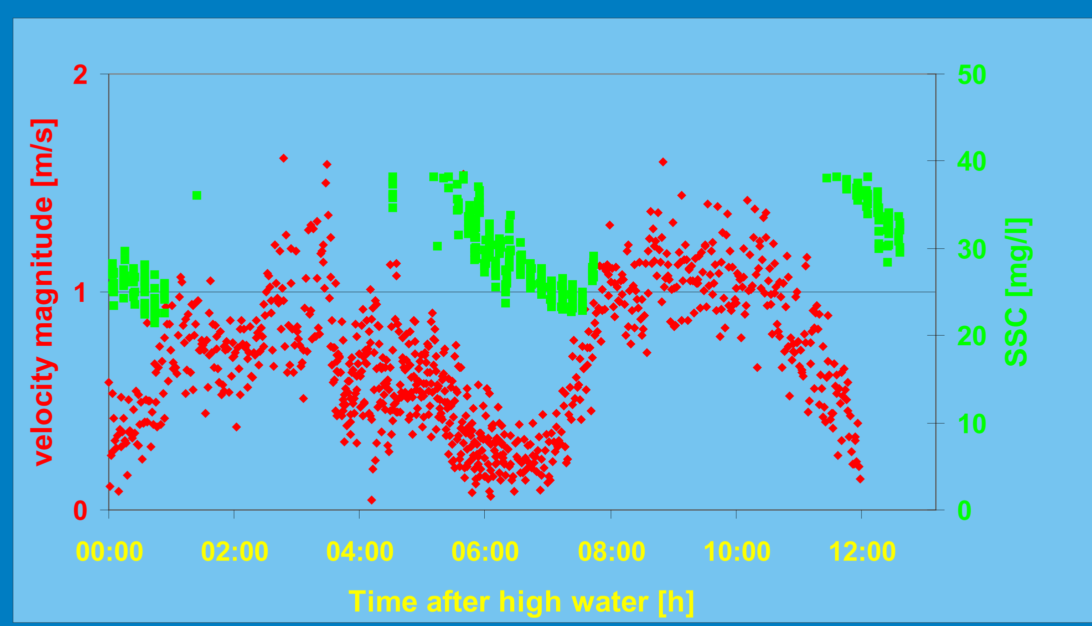

Fig. 5: This diagram combines estimates of parallel measurements by ADCP and LISST over an entire tidal cycle:
The velocity magnitude obtained by the ADCP is plotted in red. The green data come from suspended sediment concentrations (SSC) derived from the LISST. A causal relationship between current velocity and SSC seems to be obvious.

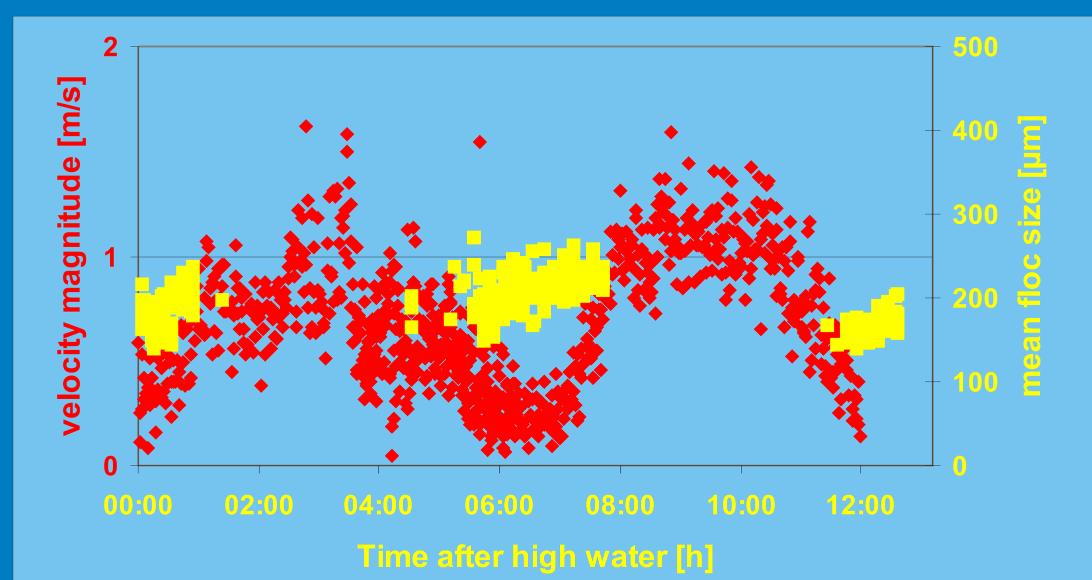

Fig. 6: Here we plotted the velocity magnitude obtained by the ADCP (red) versus mean in-situ floc sizes derived from the LISST (yellow). Again a causal relationship between current velocity and floc size seems to be obvious.

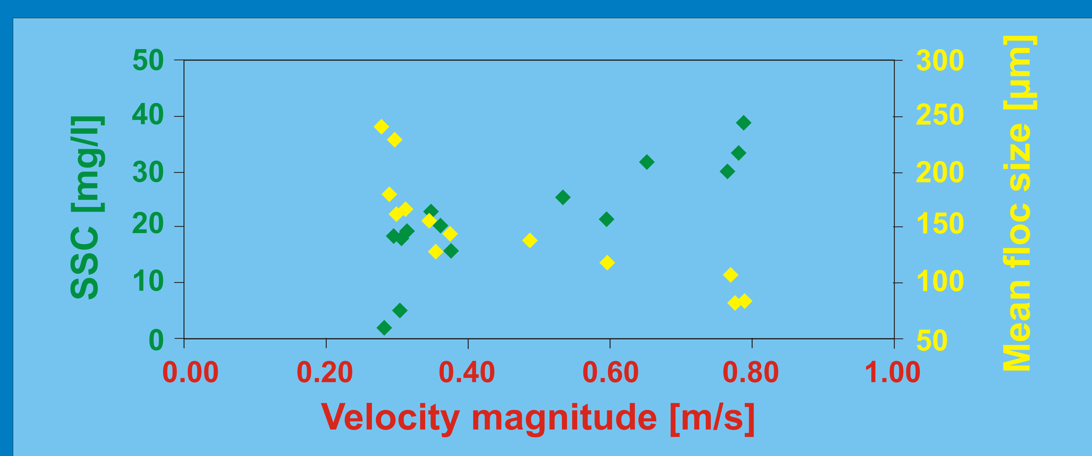

Fig. 7: This combined diagram of suspended sediment concentration (green) and mean in-situ floc size (yellow) obtained by the LISST versus velocity magnitude measured by the ADCP shows the relations between these hydrodynamic parameters:
Proportional for velocity - SSC
Inverse proportional for velocity - floc-size.

Outlook

It is planned to mount an ADCP on the measurement station for surveying tidal currents and suspended sediment permanently and independent of weather conditions. Furthermore this instrument is capable of estimating the wave field. Thus we will be able to analyse suspended sediment transport processes including the influence of waves also during storm events. Additionally we plan to expand measurements onto tidal flats near the landward margin. There we will obtain information about deposition and resuspension processes.

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