Hydro-meteo influences on suspended particle size distributions in a coastal turbidity maximum area

Michael Fettweis[1], Matthias Baeye[2], Frederic Francken[1], Dries Van den Eynde[1], Vera Van Lancker[1]

[1]Royal Belgian Institute of Natural Science, Management Unit of the North Sea Mathematical Models, Gulledelle 100, 1200 Brussels, Belgium (*E-mail: m.fettweis@mumm.ac.be)
[2]Ghent University, Renard Centre of Marine Geology, Krijgslaan 281 (S8), 9000 Gent, Belgium

1. Introduction

In the vicinity of Zeebrugge (southern North Sea), almost 200 days of SPM concentration and particle size have been collected using a tripod. The measuring location is situated in an energetic area that is amongst the most turbid in the North Sea. The tripod was positioned at about 1 km from the shore line in a water depth of about 5 m MLLWS. The instruments mounted on the tripod are a SonTek 3 MHz ADP, a SonTek 5 MHz ADV Ocean, a Sea-Bird SBE37 CT system, two OBS, a LISST 100X and two SonTek Hydra systems for data storage and batteries. The cohesive sediment processes associated with storms have been investigated previously (Fettweis et al., 2010); however, no attention was given so far to the flocculation behaviour during such meteorological events. Floc dynamics is strongly influenced by waves due to increased turbulence levels, but also the occurrence of mixed cohesive and non-cohesive sediments plays a significant role. The aim of the presentation is to assess flocculation and particle dynamics during different meteorological events using statistical classification of the data.

2. Methods

Optical (OBS) and acoustic (ADP) devices were used to estimate SPM concentrations. The optical SPM concentration estimates have been used for the ADP calibration. After conversion to decibels, the ADP signal strength was corrected for water sound absorption, sediment absorption and geometric spreading of the acoustic beams (Kim et al., 2004).

The particle size distributions (PSD) from LISST have been classified using two approaches. The first one is based on entropy analysis (see Mikkelsen et al., 2007), where the normalized PSD are classified into groups based on similar distribution characteristics. The entropy analysis was calculated using the Fortran program of Johnston & Semple (1983) extended with the Calinski-Harabasz pseudo F-statistic (see Orpin & Kostylev, 2006; Stewart et al., 2009) to calculate the optimal number of groups. In the second approach the measurements during 380 tidal cycles were assembled in three cases based on the low-pass alongshore velocity component. The averaging procedure consisted of ensemble-averaging the data per case at 10 minutes interval, creating tidal cycles for each parameter. Case I is characterized by mainly tidal forcing and coincides with low-pass alongshore velocities between -0.05 m s^{-1} and 0.05 m s^{-1}. Case II has alongshore sub-tidal currents less than -0.05 m s^{-1} corresponds with a wind-induced velocity component directed to the SW sector. Finally, case III consists of alongshore sub-tidal velocities of more than 0.05 m s^{-1} corresponding with a NE directed wind induced velocity component.

3. Results

The results of SPM concentration (from OBS and ADP) and median particle size are shown in Figure 1 for a measuring period in January-February 2008. During day 31-32.5 a storm occurred with significant wave heights up to 2.7 m. The SPM concentration (OBS) varied between 10 to 1500 mg/l during calm periods, but decreased to less than 100 mg/l during the storm (day 31-32.5). The SPM concentration from ADP is lower, except at the onset of the storm, where we can see a drop in the OBS and a rise in ADP signal. The particle size has a strong tidal signal induced by typical flocculation dynamics during calm periods (D50: 20 to >180 µm) and was characterised by low particle sizes during the storm periods (<60 µm).

The PSD have been classified in an optimal number of 6 groups using entropy analysis. The averaged PSDs per group are shown in Figure 2 together with the corresponding temporal distribution of the groups during the deployment. The different groups indicate a transition between uni-modal (with rising tail in the lowest size classes) and bi or multimodal distribution. Class 1 corresponds with the PSD during maximum flood currents; class 2 is associated with the storm. Classes 4, 5 and 6 occur during slack waters or during ebb currents and are typically multimodal. The PSD grouping according to long-shore currents is shown in figure 3. Bimodal distributions are typically associated with case I and III and are more obvious during high energy condition (spring tide). Rising tails in the lowest size bins of the LISST occur in class 1 (Figure 2) and during peak flood velocity (most obvious for case II spring tide).

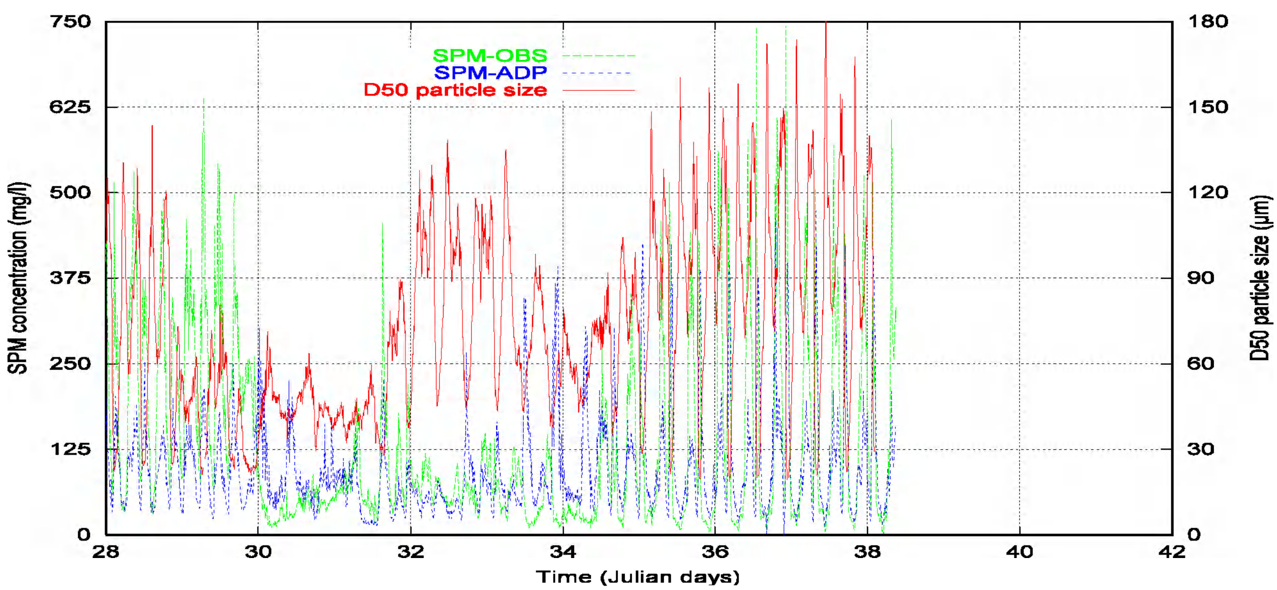

Figure 1: Temporal variability of SPM concentration at 2 m above bed from OBS (green) and ADP (blue), and median particle size as measured by the LISST (red line) from 27 January to 12 February 2008. A storm occurred between day 31 to 32.5. Significant wave heights were up to 2.7 m.

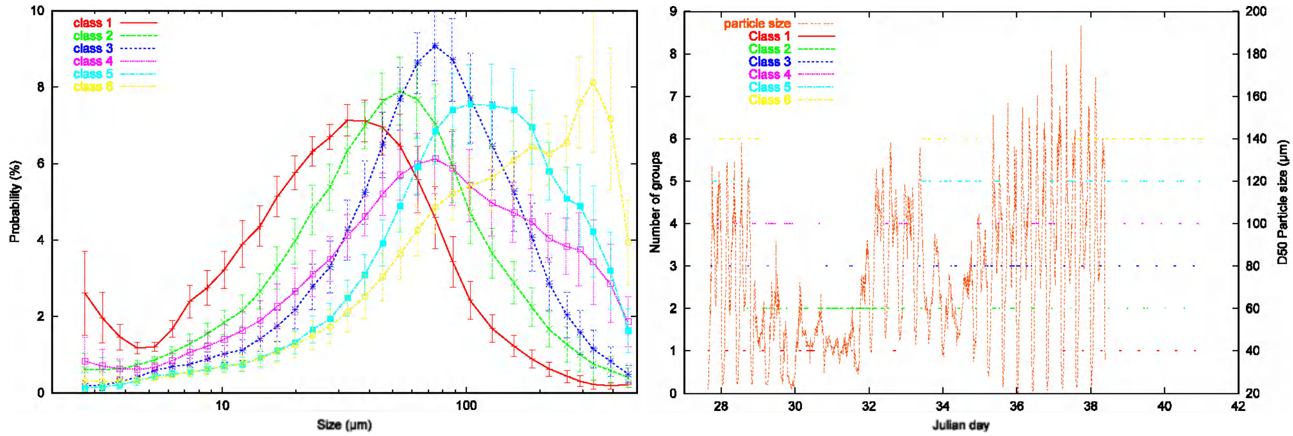

Figure 2: Results obtained by grouping the particle size distribution using the entropy analysis. The averaged PSD together with the standard deviation are presented left and the temporal variation of the median particle size and group occurrence (horizontal lines) right.

4. Discussion

The particle size data during tide dominated conditions showed distinct multi-modal behaviour that is well known in literature (e.g. Manning et al., 2006; Mikkelsen et al., 2007, Verney et al., 2009). Multi-modal flocculation occurs due to differences in particle bindings between primary and secondary bindings, resulting in more resisting microflocs and fragile macroflocs. The macroflocs were constant in size (350 µm), in contrast with microfloc sizes, where the D50 varied between 30 µm up to 150 µm. The microfloc population was characterized by a gradual shift of the PSD towards bigger size classes occurred and by the occurrence of two microfloc populations coinciding (D50 of 90 µm and 150 µm). The latter is possibly caused by the heterogeneity of components within the SPM. Analysis of SPM from the same area showed a significant amounThe flocs are dominated by microflocs with rising tail in the lower size classes during maximum flood velocity, suggesting partially disruption of microflocs into primary particles. It was therefore astounding to see that during storm conditions, when turbulence is even higher due to wave action, no primary particles were detected by the LISST. The PSD was log-normally distributed, uni-modal and remained almost constant (40 µm), see Class 2 (Figure 2). The storm was characterized by lower SPM concentration (OBS) suggesting possibly that the flocs where transported away from the measuring location by wind induced currents and replaced by sand resuspended by wave action. The latter would also explain the absence of a rising tail as observed during flood. The ADP (2 mab, Figure 1) confirm that sand was resuspended, the ADP signal closer to the bed gave SPM concentration of up to 2 g/l. The very low OBS signal during the storm is, however, probably significantly caused by the sensitivity of OBS to varying particle sizes, as the OBS was not calibrated for sand but mud. Limitations associated with optical and acoustic instruments have been addressed in literature (Bunt et al., 1999; Fugate and Friedrichs, 2002; Voulgaris and Meyers 2004; Hamilton et al., 1998; Thorne et al., 1991).Situations when changing suspended-sediment size can produce apparent variations in SPM concentration have been reported by Downing (2006) and include co-mingling of flows carrying different sediments.t of carbonates (40%), organic matter (10%), besides mineral particles (Fettweis, 2008). Microflocs are partially disrupted into primary particles during peak flood velocity. The data confirm that the floc size is primarily a function of turbulence and available residence time (Winterwerp, 1998). Macroflocs are formed during slack water, when turbulence is low, but also during the ebb, when currents are significant, but less than during flood. The latter suggests that in order to form macro-flocs a critical level of turbulence exist, during which flocculation is enhanced.

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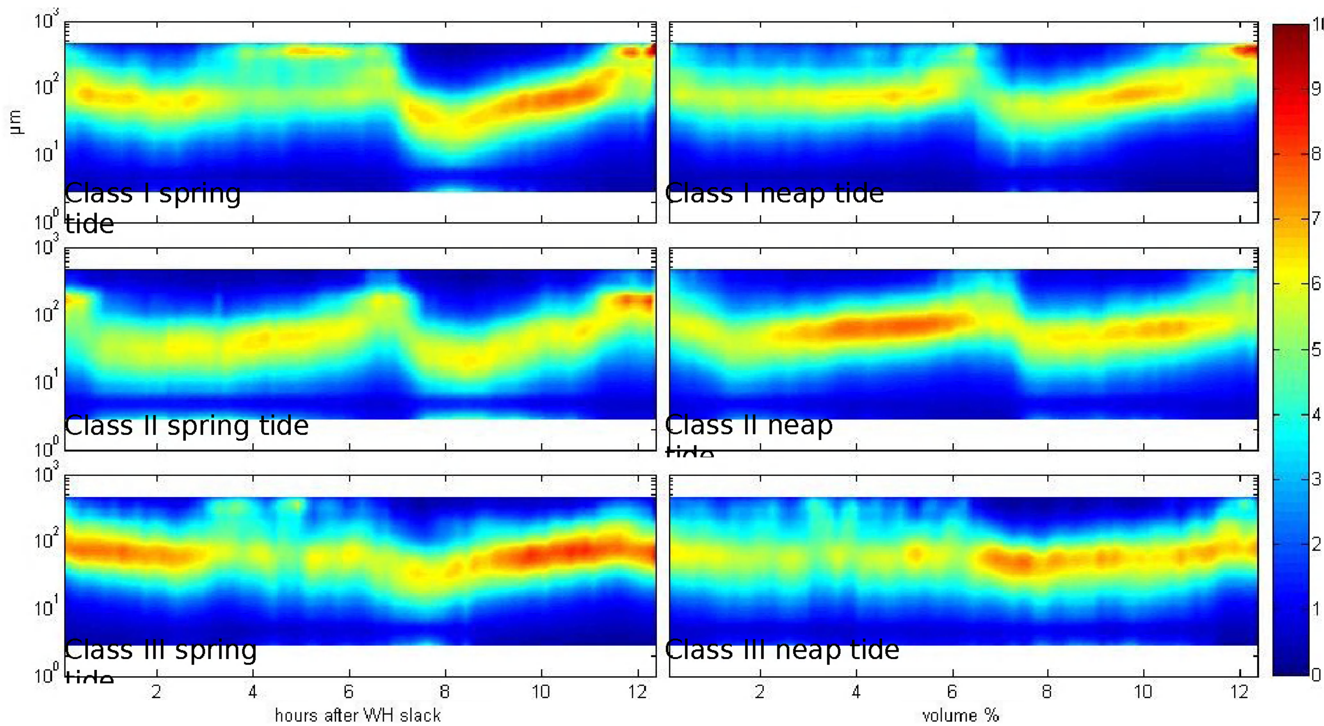

Figure 3: Volume concentration during a tidal cycle as a function of particle size (µm) and time (0-6.5 hour: ebb; 6.5-12.5 hour: flood). The data are grouped according to long-shore residual current direction and spring-neap tides. The color scale indicates volume concentration (0-10 µl/l). Remark the occurrence of bimodal distributions during ebb (spring tide class I and spring and neap tide III) as well as during slack water.

4. Conclusions

The presented data have shown that flocculation is very dynamic during periods with mainly tidal forcing showing the occurrence of primary particles, microflocs of different sizes and constant size macroflocs. During storm conditions flocs seemed to disappear by advection. The PSD measured by the LISST was uni-modal suggesting that flocs were replaced by sand in suspension.

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