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Implications of bio-flocculation on fine estuarine particle transport

1. Introduction

Background

The settling velocity of suspended particulate matter (SPM) is a crucial parameter for predicting SPM transport and morphological development in coastal environments, such as estuaries. While settling velocities of non-cohesive particles (for instance quartz) can be determined from their size and density, this becomes more difficult for fine cohesive particles which tend to change in size and density through undergoing dynamic flocculation processes.
Previous studies have characterized flocculation as an ephemeral process governed by SPM concentration, turbulence, organic matter and EPS suggesting strong variations over space and time. Extracellular polymeric exopolymers produced by phytoplankton and bacterioplankton. Because of their "stickiness" EPS can facilitate aggregation of suspended particles and existing flocs resulting in mixed bio-flocs consisting of biotic and abiotic components, which makes them important agents for bio-geochemical cycling and alters settling and transport of SPM.

Aim

To investigate the imapct of EPS induced floccualtion on estuarine SPM transport by (1) conducting laboratory experiments measuring EPS induced flocculation and settling dynamics and by (2) testing the impact of EPS altered settling velocities on SPM transport in a 1D estuarine transport model.

2. Methodology

Laboratory experiment

The laboratory experiment takes place in a rotational flume where particle size distributions can be measured online, at different concentrations of SPM, EPS and at various shear rates using a laser diffraction based particle size analyser (LISST-200X)(Fig.1). Two types of experiments were conducted (a) an equilibrium floc size experiment and (b) an idealized tide experiment. (a) The equilibrium flocsize was determind by a consecutive reduction in shear rate (G) from 100 s^{-1} to 1 s^{-1} with an interval sufficient for flocs to reach their equilibrium size (120 min)(Fig.2a). (b) During the equilibrium tide experiment an idealized tidal cycle based on field measurements in the Scheldt estuary was simulated by interchanging periods of high and low shear rate representing flood/ebb and high/low water slack respectively, following the approach of (Verney 2011)(Fig.2b).

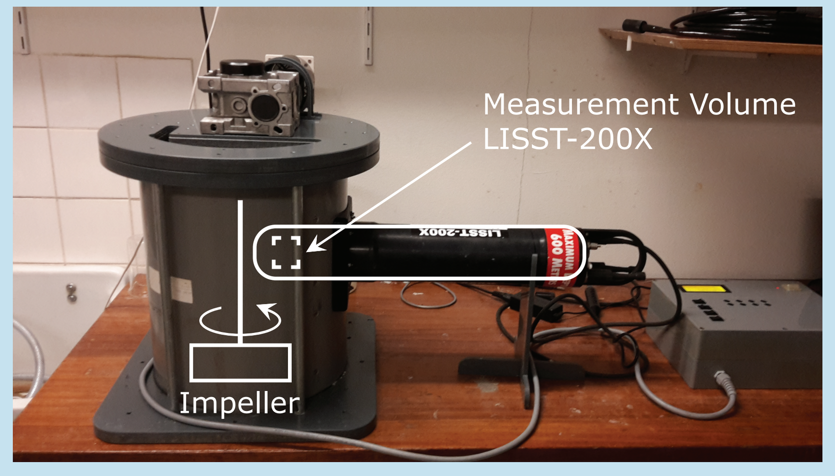


Figure 1: Experimental setup of the rotational flume, the engine on the flume lid as able to create specific shear rates over time by adjusting the rotational speed of the impeller. Particle size distribution measurements were collected online using a LISST-200X.

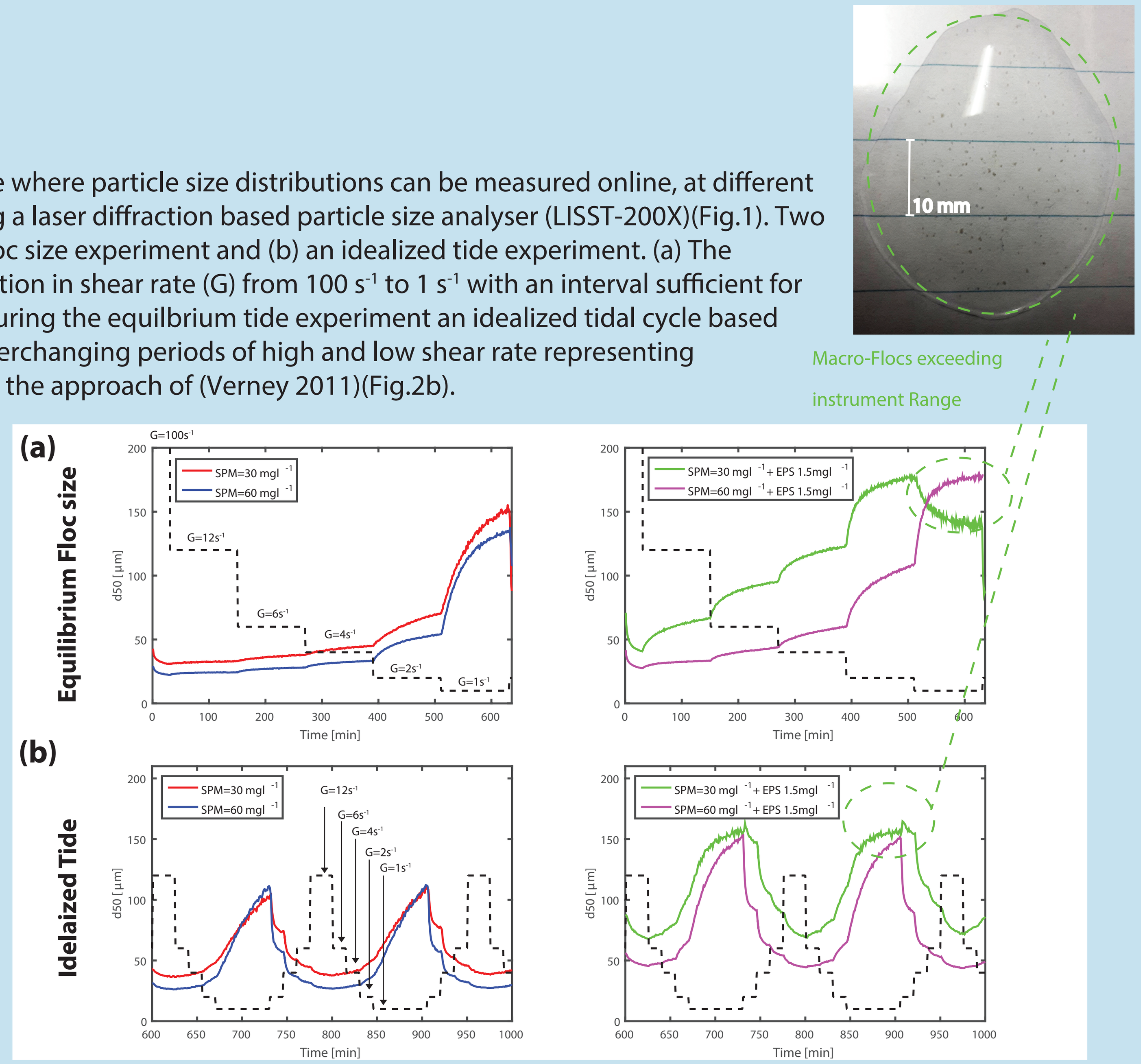


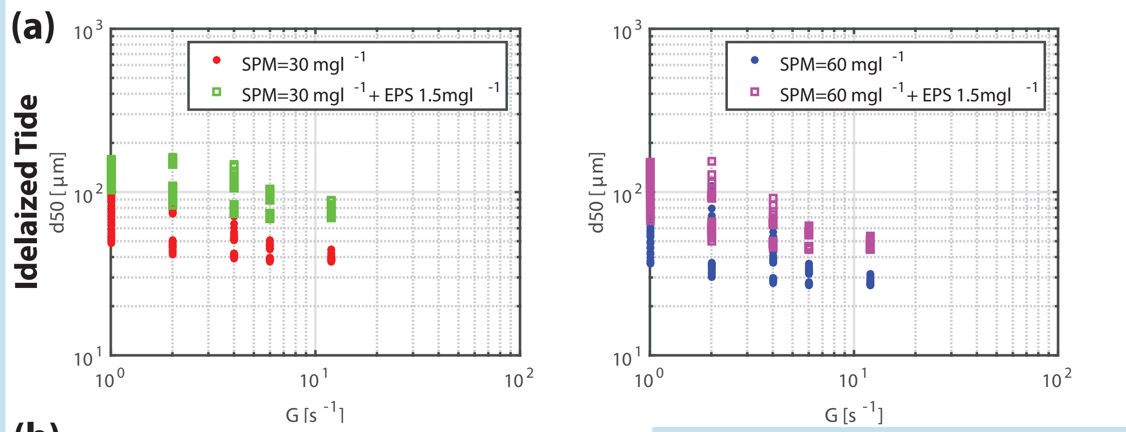
Figure 2 : Showing the experimental setup and results of the equilibirum floc size(a) and idealized tide(b) flume experiments. Used SPM was sampled from the watercolumn of the Scheldt estuary(11/2017). Experiments were conducted with SPM concentrations of 30 mgl^{-1} and 60 mgl^{-1} in deminearilzed water representing lower to medium range SPM concentrations present in the Scheldt estuary. EPS was simulated by adding Guargum, a charge neutral high molecular weight ploysaccharide. The Guargum concentration(1.5 mgl^{-1}) was based on EPS values found in other estuaries during spring blooms(Morelle 2017, Annane 2011). The dashed lines represent the shear rate(G) present in the rotational flume.

3. Main findings

Our observations confirm earlier observations of shear-induced flocculation, i.e. periods of high shear lead to floc destruction (smaller d50) whereas periods of low shear lead to floc growth (higher d50). The comparison of the idealized tide and equlibrium floc size experiment revealed that durig the idealized tidal cycle flocs did not reach the shear and concentration dependent equilibrium floc size (Fig.2,3a).
The addition of EPS lead to increased equilibrium floc sizes and increased floccualtion rates (Fig.2,3a).

Our experiment further revealed that higher SPM concentrations induce smaller equilibrium floc sizes, which became even more pronounced after EPS was added (Fig.2,3a). During our experiments we could further oberve a hysteresis effect on floc-growth and -breakup relaled to increasing or reducing turbulence, which was also previously found in the field (Fig.3a).

To evaluate the impact of EPS on SPM transport we calculated settling velocities using the approach of (Winterwerp 1998 and Strom 2011), showing that EPS is able to double the settling velocities which during our experiment was concentration independent (Fig.3b).



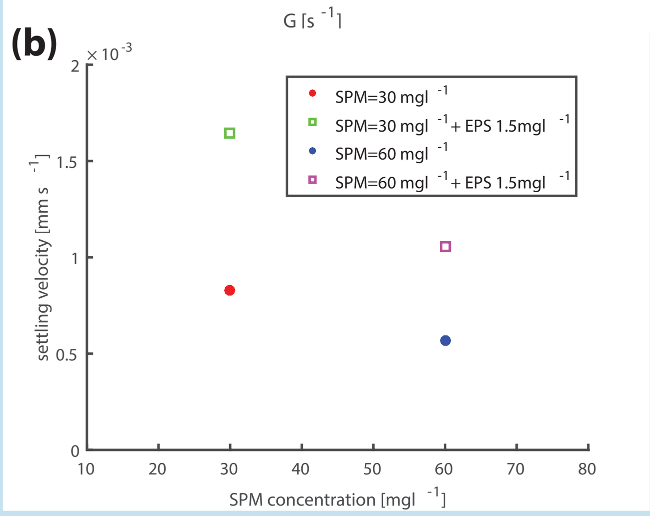
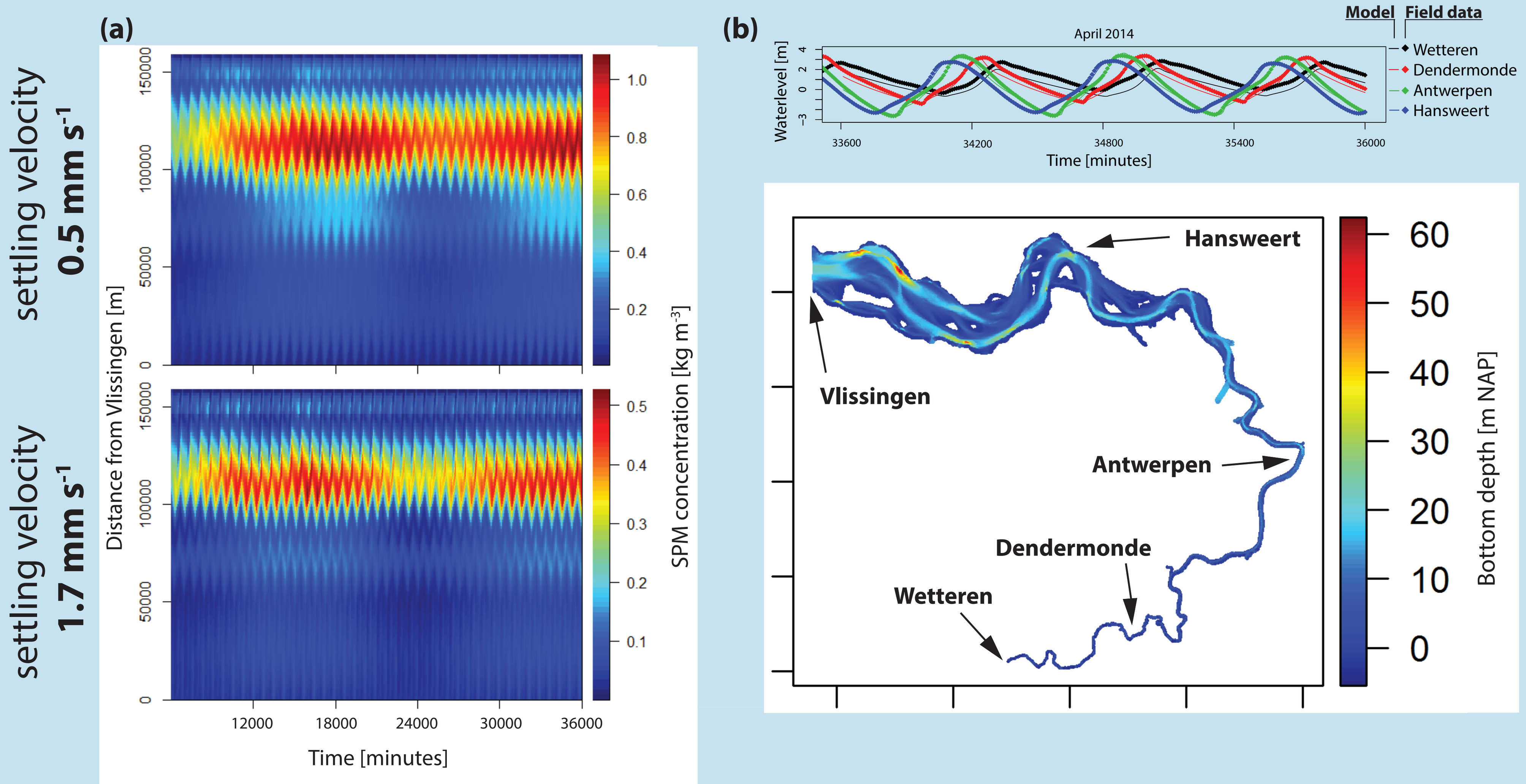


Figure 3: (a) Showing shear dependent floc sizes during the idealized tide experiment for a (left) SPM concentration of 30mgl^{-1} and (right) SPM concentration of 60 mgl^{-1}. (b) shows the EPS induced change in tide averaged settling velocity during the idealized tide experiment.

Model

We applied a new 1D tidally resolved hydraulic model to the 150km long Scheldt estuary coupled with a simple SPM model using the newly developed packagae sw1D (Soetart 2015) in the R model environment. We forced the model with a waterlevel timeseries at the lower boundary(Vlissingen) from April 2014 and an averaged discharge and SPM concentration of the same period at the upper bouandry.

Figure 4:
(a)
SPM concentrations across the estuary for different settling velocities based on our laboratory experiments over the simulated period
(b)
(top)
modeled waterlevel data compared to field measurements at 4 measurement locations
(bottom)
overview over the model domain.



The simple 1D model simulation is able to reproduce measured water levels (Fig.4b) and the location of the turbidity maximum zone at about 120 km from Vlissingen which agrees with previous field observations (vanDamme 2005). Testing different EPS induced tide averaged settling velocities (based on the idealized tide experiment) with the 1D model showed differences in estuarine SPM transport. Where higher settling velocities result in lower SPM concentrations and vice versa (Fig.4a).

Although the conceptual diagram of (Dyer 1989) also predicts smaller floc sizes at higher concentrations, this is an unexpected result. The concentrations where this plays a role are usually thought to be much higher. Also, classical models developed for estuarine flocculation do not typically take this into accountm which requires further investigations.

Future steps will incorporate experimental results, linking SPM, EPS and tide induced shear with dynamics in flocculation and settling velocities. This link will be explored within a tidal cycle and over the algae growth season (controling EPS) within the estuary.

4. Conclusions

- Higher SPM concentration leads to smaller equilibrium floc sizes verifying the conceptual idea from (Dyer 1989)

- In a tidal setting flocs do not reach their equlibrium floc size

- EPS increases the equilibirum floc size and the flocculation rate

- EPS has a major impact on settling velocites (addtion of 1.5 mgl^{-1} resulted in a doubeling of settling velocities)

- Estuarine SPM concentrations are highly influenced by the presence of EPS which alters settling velocities and is a potentially important factor to improve predictions in spatio-temporal SPM transport

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