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Uncertainty of excess density and settling velocity of mud flocs derived from in situ measurements

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Abstract

Direct or indirect measurements of excess density and settling velocity are inherently associated with uncertainties (errors) due to a lack of accuracy of the measuring instruments, inadequate precision of the observations, and the statistical nature of the variables (floc size, primary particle size and primary particle density). When using observations, some understanding of the uncertainties is needed. Based on the theory of error propagation, we have estimated the error of the excess density and the settling velocity of mud flocs using the measurement data of OBS, SPM filtration, LISST 100C, CTD and Sedigraph. The measurements were carried out between 2003 and 2005 in the southern North Sea in the course of eight tidal cycles. The excess density was calculated based on fractal description of mud flocs and using floc and water density data. The water density was derived from CTD measurements and the floc density was calculated using SPM concentration, particle volume concentration, and water and primary particle densities. The settling velocities of flocs were calculated on the basis of their fractal structure following Winterwerp, J. [1998. A simple model for turbulence induced flocculation of cohesive sediments. Journal of Hydraulic Research 36, 309–326].

The results show that the relative standard deviations for excess density, fractal dimension and settling velocity are about 10%, 2.5% and 100%, respectively. These uncertainties should be regarded as lower limits of the real error because the errors due to inaccuracies of the OBS, LISST and Sedigraph have been excluded, as they are unknown. From the results it was found that the statistical error of excess density was dominated by uncertainties of SPM concentration and primary particle density, and for fall velocity by uncertainties of primary particle and floc sizes, respectively. These statistical uncertainties will always be high when dealing with natural flocs or particles and cannot be reduced by increasing the accuracy of the instruments. They should therefore be taken into account when modelling cohesive sediment transport, either by using the calculated standard deviations for settling velocity, or by introducing a floc size (settling velocity) distribution in the transport model.

Keywords: settling velocity; floc density; error propagation; flocs; North Sea

1. Introduction

Knowledge on cohesive sediment transport processes is required to predict the distribution of suspended and deposited cohesive sediments in natural or anthropogenically created environments such as navigation channels and harbours. Settling of mud flocs is controlled by flocculation and hence also determines the transport of cohesive sediments. Flocculation/deflocculation is the process of floc formation and break-up which has a direct impact on settling velocity. The settling velocity is a function of the particle size and excess (also called effective) density, and can be described by Stokes' Law under the assumption that the particle Reynolds number is smaller than one. However, because the Suspended Particulate Matter (SPM) consists of a population of flocs with heterogeneous sizes, densities, and shapes (e.g. Eisma and Kalf, 1987; van Leussen, 1994), the settling velocity of mud flocs in natural environments will vary and, in the case of very large particles, could therefore depart from Stokes' Law. Measuring the floc settling velocity is hampered by technical limitations owing to their size and resistance against shear stresses, properties,

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which may be altered if flocs are taken out of the environment where they were formed. Furthermore, experimental observations are always subject to uncertainties that can be typically attributed to random measurement errors (lack of precision), systematic errors (lack of accuracy), human error, and intrinsic variable stochasticity. Within the field of flocculation of cohesive sediment dynamics, stochastic uncertainty is of primary importance, as recently recognised in the studies of Lee and Matsoukas (2000), Jackson (2005), Khelifa and Hill (2006), and Maggi (2007) who studied the fluctuations of the average and median floc size over time. When using experimental results, some understanding of the uncertainties in such results is also needed.

Two different methods exist for sampling settling velocity: direct and indirect ones. Direct methods are typically carried out in situ (or even in the lab). For this purpose, a number of different techniques have been developed (Owen tube, Griffith tube, LISST-ST, photo cameras, video systems), see, e.g., Dyer et al. (1996) and Eisma et al. (1996). The LISST 100 (Laser In-Situ Scattering and Transmissometer) has become a standard measuring instrument for particle size spectra and volume concentrations for applications in sea and estuarine waters (e.g. Agrawal and Pottsmith, 2000; Gartner et al., 2001; Mikkelsen and Pejrup, 2001; Fugate and Friederichs, 2002; Chang et al., 2006; Fettweis et al., 2006; Curran et al., 2007). However, neither the excess density nor the settling velocity can be directly measured by this instrument; Mikkelsen and Pejrup (2001) have presented an indirect method to calculate the settling velocity based on LISST 100 results together with SPM concentration measurements. The main advantage of this method is that it is convenient to use, but up to now it is not known what the error is of this indirect (or even direct) method is. The objective of our study therefore, is to apply a similar indirect method to calculate the excess density and the settling velocity using measured data of OBS, SPM filtration, LISST 100, CTD, and grain size analysis, and then to estimate the accuracy of excess density and settling velocity. Studies of uncertainties are often limited by calculating the sensitivity of parameters; in our case error propagation theory has been applied on all measured data in order to estimate the total uncertainty on excess density and settling velocity.

2. Methods

2.1. Regional settings

The measurements described here have been carried out in the southern North Sea, more specifically in the Belgian nearshore zone (Fig. 1). The area is characterised by depths between 5 and 35 m, a mean tidal range at Zeebrugge of 4.3 m (2.8 m) at spring (neap) tide and by maximum current velocities of more than 1 m/s. The winds are mainly from the southwest and the highest waves occur during north-westerly winds. The area is of interest due to the occurrence of a highly turbid coastal zone. The SPM concentration measurements indicate variation between a minimum of 20–70 mg/l and a maximum of 100–1000 mg/l; lower values (<10 mg/l) have been measured in the offshore area. The source of the SPM is mainly the inflowing water entering the area through the Dover Strait (Fettweis et al., 2007b). The SPM concentration measurements indicated variations between approximately 50 and 1000 mg/l; lower values (<10 mg/l) were measured offshore.

2.2. Tidal measurements

The field data were collected from the R/V Belgica during eight tidal cycles between February 2003 until July 2005; the vessel was moored to maintain the position during the tidal cycle (see Table 1 and Fig. 1). The measurements were carried out in the coastal turbidity maximum (MOW1, B&W Oostende) and further offshore (Kwintebank, Hinderbank).

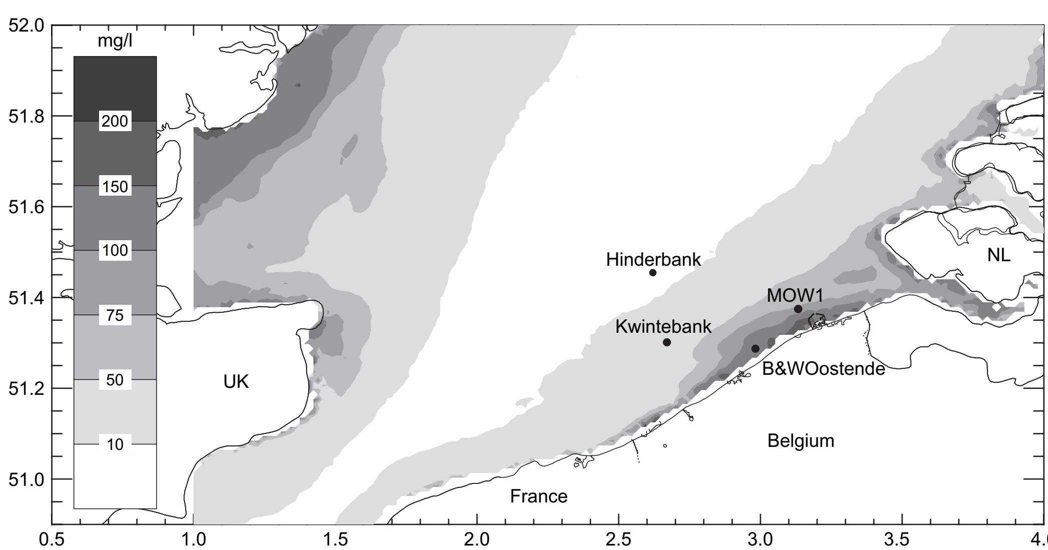

Fig. 1. Yearly averages of vertically averaged SPM concentration in the southern North Sea derived from 362 SeaWiFS images (1997–2004) (Fettweis et al., 2007b). Also shown are the locations of the tidal measurement stations. The coordinates are latitudes (°N) and longitudes (°E).