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Flocculation in a nutrient-rich coastal area (southern North Sea): Measurements and modeling

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Introduction

The Belgian and southern Dutch coastal waters are an effective trap for fine-grained cohesive sediments. Most of these suspended sediments originate from the English Channel transported into the North Sea through the Dove Strait. Continuous dredging and dumping activities in the Belgian coastal water and harbors add about 10 millions tons of dry matter annually, from which 70% is silt and clay (Fettweis et al., 2006). These are the main sources of recent fine grained sediments in the southern North Sea (Fig.1).

Natural Suspended Particulate Matter (SPM) comprises many different substances with concentrations that are generally site specific and time varying. The SPM can be divided by inorganic and organic fractions. The inorganic fraction mainly consists of clay minerals, carbonates, quartz and other silicates. The organic fraction of the SPM is prevalently made of a variety of micro-organisms, their metabolic products, detritus, and fecal pellets (e.g. Mehta, 1989; Droppo et al., 1997; Grossart et al., 2003; Bhaskar et al., 2005). Settling of mud flocs is controlled by flocculation and hence also determines the transport of cohesive sediments. Flocculation 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 density and varies strongly in natural environments because SPM consists of a population of flocs with densities, heterogeneous sizes, shapes and constituents (e.g. Eisma and Kalf, 1987; van Leussen, 1994).

A flocculation model (BFLOC) proposed by Maggi (2009) taking the coupling effects between the mineral and micro-organism dynamics was calibrated using two sets of in situ data collected in the Belgian North Sea (Fettweis et al., 2006). The model has shown significant influence of micro-organism and organic matter on the particle size and the variation of particle size with turbulence.

The aim of this poster is to show the results of calibration of the model against a larger set of SPM measurements from different location on the Belgian continental shelf, extended with turbulence shear rate modeled with COHERENS-3D. Flocs observed from the time series through out a complete tidal cycle during several years and seasons are analyzed and compared with various variables measured at the same time, i.e. SPM, POC. Sensitivity tests are carried out for understanding the influences of each parameter. Modeled floc sizes with the tuned parameters during tidal cycles have shown good agreement for some sets of data. The possible causes of those model results not fitted with the measurements are also discussed.

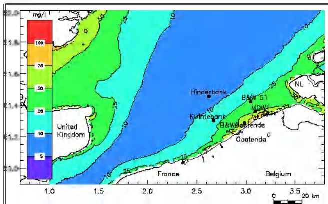


Fig. 1 SPM distribution in the North Sea

Fig. 2 (a,left) Instrument setup aboard; (b,right) Bottom sediment sample.

Data and analysis

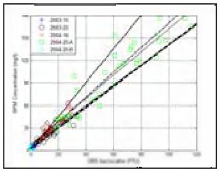
Data collected during 2003 and 2004 (see Table 1) on the Belgian continental shelf are discussed here (see figure 1 for the sites). These are ship board measurements for a complete tidal cycle (13 hours) which consist of in situ observations of SPM using OBS and floc sizes with LISST 100 optical sensors (figure 2). Water samples were taken for lab experiments on SPM for OBS-SPM calibration and the POC/PON for organic fractions in the SPM . Continuous filtration of the water was also carried out for analyzing the primary particles. Velocities were measured by current meter or shipboard ADCP.

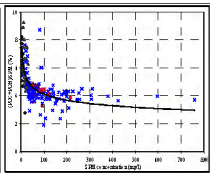
The currents, surface elevation and turbulent kinetic energy have been computed for these measuring periods using a 3D hydrodynamic operational model for the Belgian continental shelf (OPTOS-BCS). The turbulence closure scheme used in OPTOS-BCS describes the turbulent energy dissipation as the product of a velocity and a length scale Mellor and Yamada (1974).

Parameters were first analyzed in order to find their correlations. OBS backscatter data are compared with sampled SPM have shown strong correlation (see Table 2 and Figure 3), and used for calibrating the SPM time series observed from OBS. The biomass concentrations are calculated using the sampled POC/PON fraction of the SPM. Higher organic fractions can be observed with lower SPM concentrations (Fiure 4). The relation between Kolmogrov micro-scale(λ) and current velocity is also obtained for computing the turbulent shear rates in the BFLOC model (Figure 5).

Table 1 Tidal cycle measurements, further the linear regression coefficients between the OBS signal and the SPM concentration from filtrations are shown (TM= coastal turbidity maximum)

Nr.	Data	Location	Area	SPM=A+B×OBS	
				A	B
2003-15	11-12/06/2003	Kwinebank	Offshore	0.31	2.253
2003-25	09-10/10/2003	Kwinebank	Offshore	1.30	1.472
2004-16	15-16/07/2004	B&W Oostende	TM	5.60	1.643
2004-25-A	08-09/11/2004	MOW1	TM	7.95	1.542
2004-25-B	09-10/11/2004	Hinderbank	Offshore	3.06	1.953





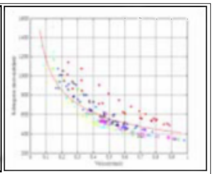


Fig. 3 OBS-SPM Calibration. Fig. 4 Organic fractions in SPM. Fig. 5 Current-Turbulence.

Table 2 Parameters used for sensitivity test

Date Set: 2004-16, 2004-25-A (*ref* 2003-22 from Maggi (2009))

No.	Parameter		Original value (ρ)	20% of the value (σ)	Min (ρ-3σ)	Max (ρ+3σ)
1	ka'	[−]	0.189	0.0378	0.0756	0.3024
2	kb'	$[-]\times10^{-6}$	11.41	2.2820	4.5640	18.2560
3	η_{max}	$[s^{-1}]\times10^{-6}$	6.586	1.3172	2.6344	10.5376
4	K_m	$[M]\times10^{-6}$	1.159	0.2318	0.4636	1.8544
5	β	[−]	0.226	0.0452	0.0904	0.3616

Date Set: 2003-15, 2003-25, 2004-25-B (*ref* 2004-04-05 from Maggi (2009))

No.	Parameter		Original value (ρ)	20% of the value (σ)	Min (ρ-3σ)	Max (ρ+3σ)
1	ka'	[−]	0.156	0.0312	0.0624	0.2496
2	kb'	$[-]\times10^{-6}$	4.261	0.8522	1.7044	6.8176
3	η_{max}	$[s^{-1}]\times10^{-6}$	6.126	1.2252	2.4504	9.8016
4	K_m	$[M]\times10^{-6}$	1.968	0.3936	0.7572	3.1488
5	β	[−]	0.285	0.0570	0.1140	0.4560

Table 3 RMSE between the BFLOC model results and the measured floc sizes using calibrated parameters.

r	*ref* Michael Fettweis, 2008			Tuned parameter	RMSE(μm)		
	SPM ± stdv	D_f±stdv	d±stdv		Original	Tuned	O−T
003-15	4.5±1.1	160±38	2.06±0.02	$kb' = 2.025\times10^{-6}$	85.059	68.516	16.543
003-25	27±12	75±20	2.08±0.04	$ka' = 0.148$	16.222	16.156	0.066
004-16	32±14	81±22	3.23±0.06	$kb' = 9.934\times10^{-6}$	24.481	23.414	1.067
004-25-A	89±54	88±25	1.72±0.03	$ka' = 0.076$, $kb' = 18.202\times10^{-6}$	65.363	26.988	38.375
004-25-B	3.6±1.3	115±34	3.25±0.03	$kb' = 1.938\times10^{-6}$	58.316	39.188	19.128

Results of the Biological Flocculation Model

Maggi (2009) presented a flocculation model where a coupling between the mineral and micro-organism dynamics was implemented. The model was calibrated using two sets of in situ measurements of SPM concentration, turbulent shear rate and average floc size collected in the Belgian North Sea (Fettweis et al., 2006). Using the coefficients tuned by Maggi (2009), the model described the particle sizes well comparing with the observations. The significant influence of biomass on the particle size can clearly observed. A sensitivity test has been carried out for the 5 parameters used in the BFLOC model, i.e. the aggregation parameter; breakup parameter; the biomass growth rate; half-saturation concentration and carrying capacity coefficient. A similar Monte Carlo analysis was carried out to characterize the parameters. We applied five independent normally-distributed probability density functions to the parameters with the averages obtained from standard deviation equal to 20% of each parameters (σ) according to the parameters of Maggi (2009). The range of parameter values was limited to ±3 times the standard deviation in 300 replicate test (see Table 2). Root mean square errors (RMSE) of each test set are calculated. The best parameters for each measurement are listed in Table 3.

The RMSE can be improved from 65.363μm down to 26.988μm for the measurement 2004-25-A. There are no significant improvements but well fitted with the observations for the sets 2003-25 and 2004-16 (Figure 6a). The worst predictions are for the 2003-15 (Fig 6b) and 2004-25-B, though RMSE could decrease (See Table3). The floc sizes of these two data sets are mostly biger than 100μm (160±38μm, 115±34μm). The floc sizes of these two measurements are not well distributed from the LISST records (see Figure 7). This may due to the real particles are mostly larger than 500μm which were exceeded the valid LISST record range. And, thus caused the modeled results based on the biological flocculation depart from the observations. Further study will be required, e.g. correction of the floc size distribution patterns will be necessary for verifying the influences.

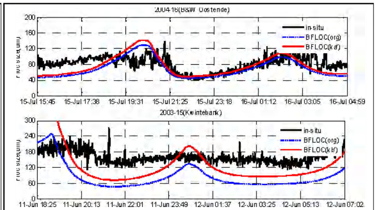


Fig. 6 Modeled time series from (a, up) the better fitted results; (b,low) not fitted results.

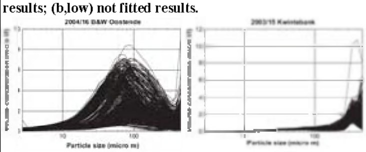


Fig. 7 Particle (floc) size distribution of the SPM measured by the LISST as function of volume concentration

Conclusions

Five data sets of SPM measurements in Belgian coastal area are further studied and the floc dynamics are modeled after Maggi (2009). Data sets with fine particles are well modeled using calibrated parameters. Two sets of measurements were not well predicted by the flocculation model are investigated. This may cause by the uncertainties of the LISST records since the particles are exceeding the valid instrument ranges. Further study on this issue will be necessary.

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