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Prediction of the bed friction coefficient using either high resolution bathymetric data or granulometry samples

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***Abstract*—Two methods to predict the bed friction coefficient from information related to the bed texture, either bathymetric data or granulometric samples are tested and compared to in situ measurements in coastal environment. For the studied configuration, located near the Somme bay in the eastern English Channel, the method based on granulometry appears as the most efficient in term of accuracy and set up easiness.**

I. Introduction

The Somme estuary, located in France in the eastern English Channel (Fig. 1), endures a severe sedimentation with an increase of the mean bed level about 1.3 cm/year [1]. The sedimentation may result from the asymmetry of the tidal current and the associated residual sediment flux between the flood and the ebb. This phenomenon is probably increased by different hydraulic structures built during the last centuries to domesticate the tide or river dynamics and to gain farmland. More recently, new hydraulic works have been planned to limit the sedimentation, such as flush operation from the Somme channel or an experimental realignment project [2].

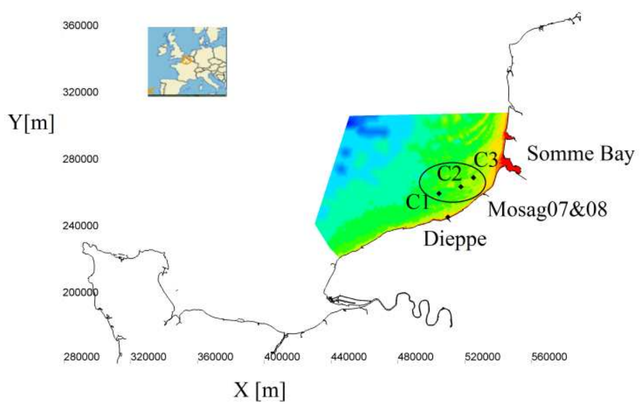


Figure 1. Location of the Somme Bay and extension of the numerical model

To predict the bed morphology evolution and the influence of these hydraulic works, it is necessary to estimate the sedimentation rate feeding the bay from offshore. Field surveys (Mosag07 and Mosag08 on Thalia vessel, Fig. 1), conducted offshore, about 30 km away from the mouth in South West direction [3] (Ferret *et al.*, 2010), lighten the presence of marine sandbanks and dunes ranging from 100 m to 1800 m in wavelength. The presence of bedform, such as dunes, strongly influences the hydrodynamic characteristics and the sediment transport rates. Their influence thus needs to be included into the methodology. The field surveys included high resolution bathymetric data, measurements of tidal currents, wave characteristics and bed material composition.

A 2D numerical model of the Somme estuary is developed. This model comprises a large coastal area (up to 60 km offshore and along shore, Fig. 1) in order to predict the sediment feeding from the sea. In coastal area, the grid can often reach a resolution about 500 to 1000 m. The bedforms are thus not physically represented. Using finer grid may allow to physically represent dunes but it will also require a 3D computation to deal with the 3D flow behaviour induced by dunes. In 2D numerical models, the dune influence is thus generally reckoned through empirical formulae. This kind of formula is generally built from datasets collected on river in equilibrium conditions. Their application to estuarine [4] or coastal environments is still challenging because of: the unsteady behavior of the flow induced by the tide and the waves, and the lack of *in situ* data to validate the predicted value of the roughness.

In the present contribution, different methodologies are tested to predict the bed friction coefficient induced by the dunes from information related to bed texture such as either bathymetric or granulometric data. Numerical results are compared to in situ measurements of tidal levels and flow velocities. Attention is currently paid on the area covered by the Mosag07&08 surveys (Fig. 1).

II. AVAILABLE DATA ON THE STUDIED AREA

A. Studied area

The Somme estuary covers an area about 70 km^2. Flow rate of the Somme River is about 30 m^3/s (yearly average) and is controlled through a lock at Saint Valery sur Somme. The tide is semidiurnal, dominated by M_2 component and its amplitude can reach more than 8 m during spring tide. The bay is covered by a high percentage of tidal flats and salt marshes.

B. Hydrodynamic Data

No tidal gauge is available in the Bay of Somme. The nearest gauge is located at Dieppe (Fig. 1) and data are made available by the "Service Hydrographique et Océanographique de la Marine" (SHOM). Field surveys occurred about 30 km South-West from the bay mouth (Fig. 1) in 2007 and 2008. During these surveys [3,5], tide levels, flow velocities, wave height and period were measured for a neap spring cycle (~15days). ADCP (Acoustic Doppler Current Profiler) measurements occurred at locations C1 - C2 in 2007 (Fig. 1 or zones SW and C respectively on Fig .2) and at C3 in 2008 (Fig. 1 or inside zone E Fig. 2). For each campaign, a neap and a spring event characterized by low wave activities have been selected to compare with the numerical results.

C. Bathymetry Data and Bedform Information

High resolution bathymetric data (1 sampling point/3m) were collected offshore during surveys MOSAG07& MOSAG08 (Fig. 1). In the intertidal part of the Bay of Somme, Light Detection and Ranging (LiDAR) data (1 sampling point/1m) have been acquired in February 2013 by the CLAREC operational team (M2C Lab, University of Caen). Elsewhere bathymetric data collected by the SHOM are used. The bathymetric data have been analysed to extract information about the bed form height and wavelength using ParamDunes software developed by the SHOM [5]. From the analysis of Moasag07&08 data, 4 different zones of bedforms are defined (North West NW, South West SW, Center C, and East E; [5]). Similarly, 2 additional zones are defined [6] from the LiDAR data (Small Dunes SD and Medium Dunes MD).

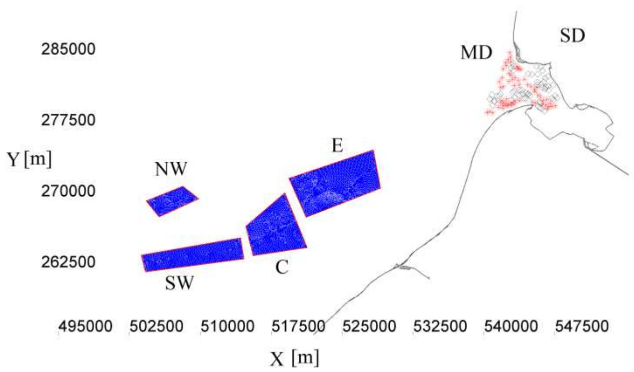


Figure 2. Bed form zones

For each zones, the averaged values of the bed form height and wavelength are summarized in Table I. Bed form height can reach up to 9 m in the NW zone and the values decrease down to 0.25 m in the tidal flat area at the mouth (SD).

TABLE I. BED FORM GEOMETRY [5,6]

Zones	*Dune height H (m)*	*Dune wavelength L (m)*	*Equivalent bed roughness k_s (m)*
NW	9.00	900	1.53
SW	6.50	530	1.32
C	4.25	375	0.80
E	6.00	425	1.37
SD	0.25	2.8	0.17
MD	0.6	7.5	0.40

D. Granulometric data

About 700 bed material samples are available in the area covered by the numerical model (Fig. 3). M2C Rouen collected 290 in the studied area (MOSAG07&08, Fig. 1) between 2005 - 2008 and 240 samples near the bay mouth between 2009 and 2013. Other samples come from the SHOM database.

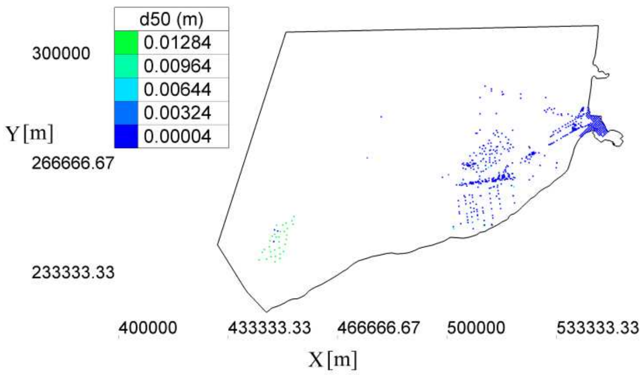


Figure 3. Location of the bed material samples

Moving from South West (SW, Fig. 2) to East (E, Fig. 2), the bed material becomes progressively finer: d_{50} about 1 mm around C1 (zone SW, Fig. 2), within 0.6 ~ 0.7 mm around C2 (zone C, Fig 2) and within 0.2 ~ 0.3 mm around C3 (zone E, Fig. 2).

III. MODEL SET UP

The unstructured grid is formed of 36349 nodes. Distance between nodes is ranging from 5 km (offshore) to 3 m in some channels inside the bay. The numerical domain is extending along the seaside from Etretat to Le Touquet and contains two bays: the Somme and the Authie estuaries (Figs 1&3).

The current release V6P2 of TELEMAC-2D is used to solve shallow water equations. Nikuradse formulation is chosen to impose the bed friction coefficient. Constant flow rates are imposed for the Somme and Authie rivers. The treatment of the offshore boundary condition is discussed in the next section.

IV. SENSITIVITY TO THE TIDAL MODEL

In estuarine configuration, it is necessary to provide the tide level and velocities on offshore boundary. The imposed values are calculated from harmonic constants provided by global or regional tidal model. Influence of the harmonic constants on the accuracy of computed water levels has been pointed out by Huybrechts et al. [4] on the Gironde estuary in France. Simulations based on harmonic constants from Janin and Blanchard [7], SHOM and NEA atlases (North East Atlantic solution, [8]) have been compared. For the Gironde estuary, best results were obtained using NEA atlases. Similar comparison has also been performed by Pham and Lyard [9] on the Paimpol and Bréhal site (Brittany France). In their study, they have compared simulations based on harmonic constants from Janin and Blanchard [7], NEA atlases and regional tidal solution form Oregon State University (European Shelf database "ES"). NEA atlases allow to integrate 46 harmonic components whereas ES atlases give 11 harmonic constants (M2, S2, N2, K2, K1, O1, P1, Q1, M4, MS4, and MN4). For the Paimpol and Bréhal site, NEA and ES atlases provide similar accuracy for the water levels whereas less difference is observed between measured velocity and computed velocities based on the ES solution [9]. The comparison between the NEA and ES solutions is continued here and is currently based on a quantitative criterion: the Relative Mean Absolute Error "RMAE" [10]. The RMAE is given by (1):

$$RMAE = \frac{\langle |Y_c - X_c| \rangle}{\langle |X_c| \rangle} \quad (1)$$

where X_c (x_1, …., x_N) is a set of observations and Y_c the model predictions. The mean value noted <> is defined by (2).

$$\langle |X| \rangle = \frac{1}{N} \sum_{i=1}^{N} |x_i| \quad (2)$$

The quality criteria associated with RMAE criteria is reminded in Table II [10]. The spring event of 2007 is selected to perform the comparison and two different values of the bed roughness are imposed k_s= 0.5 and 1 m. Scores of the different simulations are summed up in Table III.

TABLE II. QUALITY CRITERION

	RMAE
Excellent	<0.2
Good	0.2-0.4
Reasonable	0.4-0.7
Poor	0.7-1.0
Bad	>1.0

TABLE III. RMAE SCORES FOR ES AND NEA SOLUTIONS

	Velocity C1	*Velocity C2*	*Water level C2*	*Average*
ES k_s=0.5 m	0.16	0.22	0.07	0.15
ES k_s=1 m	0.16	0.24	0.07	0.16
NEA k_s=0.5 m	0.16	0.17	0.21	0.18
NEA k_s=1m	0.12	0.15	0.23	0.17

ES solution appears as the most accurate for the water level whereas NEA solutions provide better predictions for velocities. Results obtained with ES k_s=0.5 m and NEA k_s=1 m are illustrated on Figs 4 and 5.

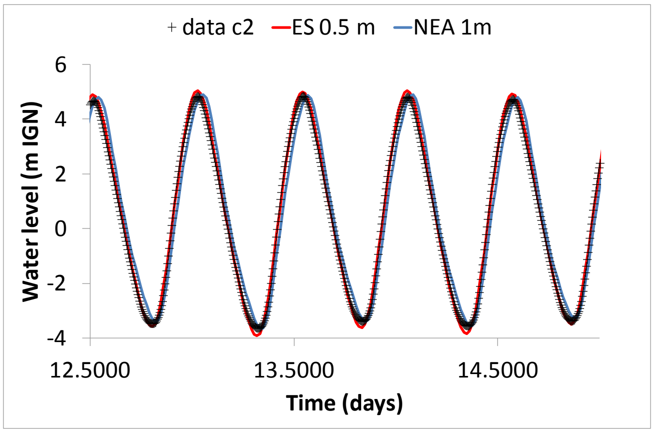
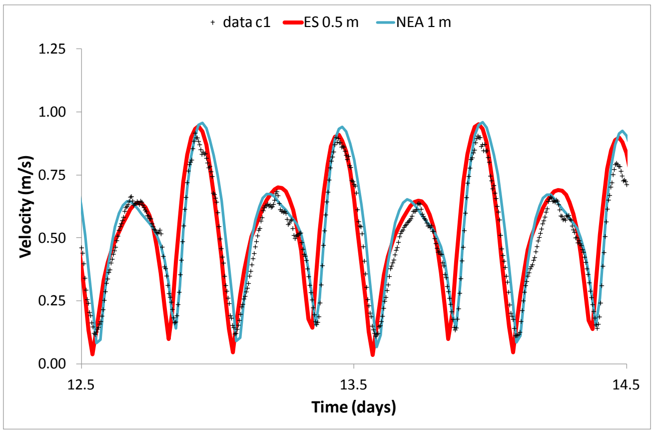


Figure 4. Sensitivity to the tidal model and bed friction coefficient. Influence on the water levels (T=0 correspond to July 20th at 0h TU)

In term of tidal amplitude (Fig. 4), both solutions are in good agreement with the measured data. NEA solution presents a slight delay in phase (10-15 min) compared to the measurements. NEA solution better captures the time evolutions of the velocity during the flood, low and high tides. However, peaks of ebb velocities (at C1 and C2, Fig. 5) are not in phase compared to the ADCP measurements and ES solution. A time lag is now observed for the computed velocities based on ES solutions especially during low or high tides.



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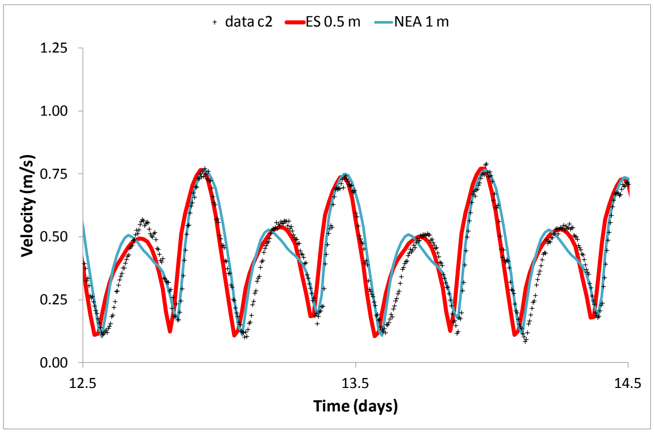


5B

Figure 5. Sensitivity to the tidal model and the bed friction coefficient. Influence on the velocity levels at C1 (5A) and C2 (5B) (T=0 corresponds to July 20th at 0h TU)

In average (Table III), ES solution reaches the lowest value of the RMAE and it is thus further kept in this contribution.

V. Bed Friction Prediction using Batyhmetric Data

van Rijn formula [11] is used to predict the equivalent bed roughness k_s which is decomposed into grain roughness k'_s and roughness induced by bedforms k''_s (3).

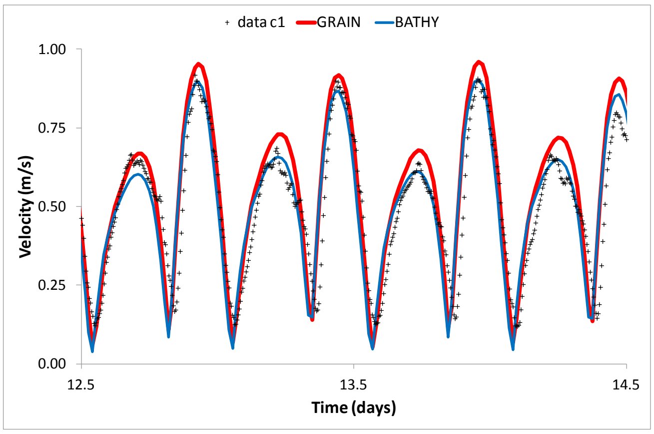
$$k_s = k_s^{'} + k_s^{''} \tag{3}$$

In this section, it is assumed that the dunes are dominant and the roughness induced by bedforms k''_s is only evaluated from information related to the dune geometry (2, [11]).

$$k''_s = 1.1\gamma_d H\left(1 - e^{-25H/L}\right) \tag{4}$$

where H is the dune height, L the bedform wavelength and $\gamma_d = 0.7$ for field dune (= 1 for dune observed in flume).

For each zones of Fig. 2, a bed roughness can be computed from (2) (Table I). High resolution bathymetric data are available for some parts of the numerical domain. Data available for the whole domain have a lower space resolution and information on the bedform geometry cannot be extracted. An averaged bed roughness height (k_s = 1 m) is thus provided in the zones not covered by high resolution bathymetric data.



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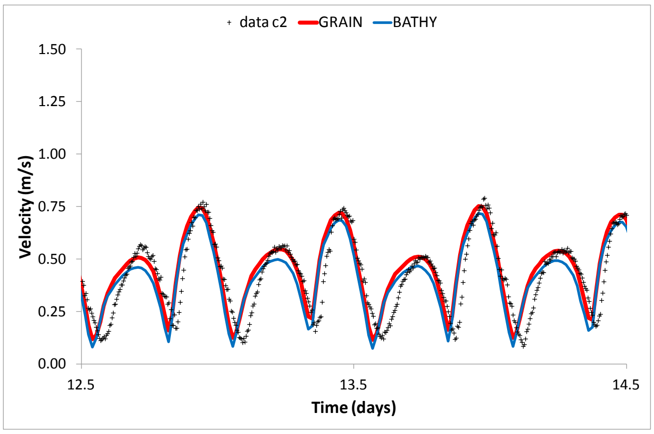


6B

Figure 6. Bed roughness predicted from bathymetric data (BATHY) and granulometric samples (GRAIN). Comparison of velocity levels at C1 (6A) and C2 (6B) for the spring event of 2007 (T=0 corresponds to July 20th at 0h TU).

A map of bed roughness is generated for TELEMAC-2D. The bed friction coefficient is steady but variable in space. Fig. 6 A-B shows the time evolutions of the computed velocities (BATHY curves) for C1-C2 stations. For C2, the velocity signal has been too much damped by the friction coefficient whereas better agreement is observed for C1.

VI. Bed Friction Prediction using Granulometric Data

More recently, van Rijn [12] proposed a new version of its equation for the total equivalent bed roughness (3). The bedform roughness k"$_s$ is decomposed into roughness due to the ripples k_r, megaripples k_{mr} and dunes k_d (5)

$$k_s^{"} = \sqrt{k_r^2 + k_{mr}^2 + k_d^2} \quad (5)$$

The value of the roughness for each bedform component depends on the flow characteristics (depth h and flow velocity U) and the median diameter d_{50} (6).

$$k_s = fct\ (U, d_{50}, h) \quad (6)$$

From the granulometric data (Fig. 3), a map of the median diameter can be generated and a value of the d_{50} can be associated to each node. The map of the median diameter is entered as formatted data file into SISYPHE. TELEMAC is calling SISYPHE at each time step and SISYPHE is returning to TELEMAC the value of the bed roughness (neither bed load, suspension load or bed evolution are calculated by SISYPHE). The bed friction coefficient is now unsteady (tide variation) and variable in space. Computed ttime evolutions of the velocities for C1 and C2 (GRAIN curves) are plotted on Figs. 6 for the spring event of 2007. Velocity amplitudes are correctly reproduced for C2 whereas more differences are noticed during ebb peaks for C1.

VII. Synthesis on the Different Methodologies

Two methodologies to supply the values of the bed friction coefficient have been tested in this contribution: predicted space variable bed friction from bathymetric data (BATHY) and predicted time and space variable bed from granulometry data (GRAIN). The different values of the predicted roughness at the locations of C1 and C2 are summed up in Table IV.

TABLE IV. Values of the bed roughness at C1 and C2

Bed roughness (m)	*C1*	*C2*
Constant value	0.5	0.5
BATHY	1.32	0.80
GRAIN	0.4	0.32

In Table IV, time averaged values are given for GRAIN method. Fig. 8 illustrates how the bed roughness is evolving according to the tide variation. Values are higher during the flood than the ebb and they are minima during low or high tides.

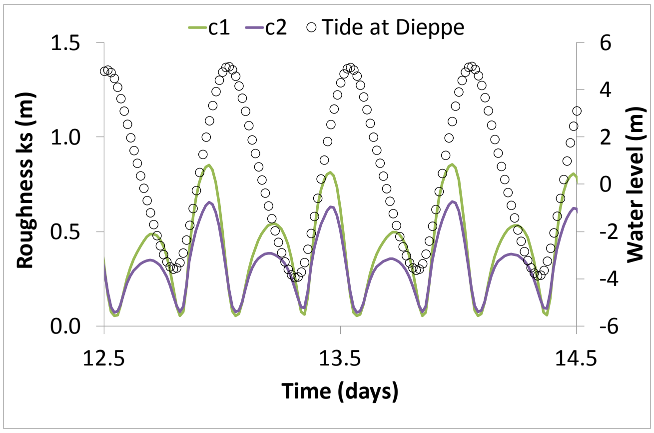


Figure 7. Time evolution of the bed roughness during tidal cycle (T=0 correspond to July 20th at 0h TU).

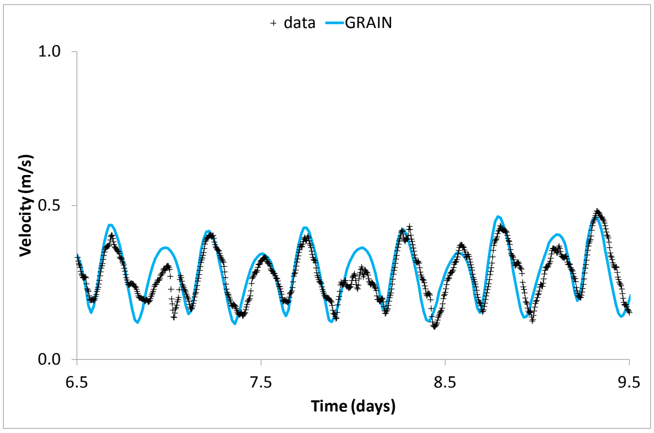
Between the different methodologies, the value of the roughness varies within 0.4 to 1.32 m at C1 and within 0.32 to 0.8 m at C2 whereas the median diameter varies respectively between 1 mm to 0.6 mm from C1 to C2. RMAE scores are given in Table V.

TABLE V. RMAE scores for BATHY and GRAIN approaches

RMAE	*Velocity C1*	*Velocity C2*	*Water level C2*	*Average*
BATHY	0.16	0.25	0.07	0.16
GRAIN	0.17	0.21	0.07	0.15

The accuracies of both approaches according to RMAE criteria are relatively similar. In practice, both these predicted values can serve as first set of friction value if a finer calibration is desired. However, both methods need to specify information relative to the bed texture (bed form geometry or sediment composition). The method based on high resolution bathymetric survey is more time- and money-consuming. It requires expensive sensors as well as a long treatment and analysis of the data (through ParamDune) especially for wide domain. The method based on granulometry is cheaper and easier to set up. When high resolution bathymetric data are missing, the BATHY becomes more difficult to apply whereas GRAIN can be applied even with a low resolution of bed material samples. In regards of the comparison with the measured data (Figs. 6 and Table V), GRAIN appears slightly more efficient (combination of accuracy and set-up easiness) and this method is thus currently recommended.

The efficiency of GRAIN approach can be further illustrated on the time series of the flow velocities at location C3 during neap and spring tides in 2008.



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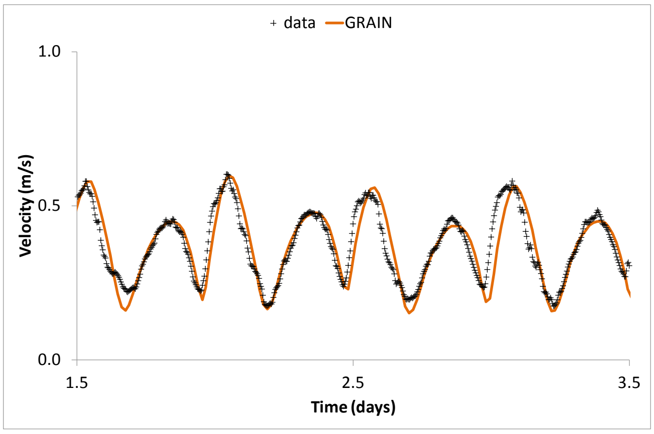

8B

Figure 8. Verification of the MT2 efficiency on the neap (9A) and spring tides (9C) in 2008. Comparison between measured data and computation "GRAIN" (T=0 correspond to July 21st 0h TU).

VIII. PERSPECTIVES

In this contribution, it has been implicitly assumed that the data relative to the bed texture are not evolving according to the tidal cycles. In a near future, it would be interesting to couple this methodology with graded sediment transport to analyse how the model can predict the sediment mixing during the tidal cycle and how this mixing can influence the bed roughness value. During the Mosag07&08 field surveys, higher wave activities have been noticed during a couple of days (waves up to 3 m high). A coupling with TOMAWAC to analyse the influence of the wave is forecast. New field surveys are also currently occurring near the bay mouth on tidal flat covered on small dunes (zones AD, SD, Fig 2). The present methodology will be also further tested on this new dataset.

ACKNOWLEDGEMENT

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