High resolution in situ study of multimodal sediment transport processes using Dynamic Sediment Profile Imagery (DySPI).

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Intitulé du sujet de thèse:
Modélisation numérique de la genèse des structures sédimentaires superficielles de la Manche ; application à la modélisation intégrée de l’écosystème.

Olivier BLANPAIN, deuxième année de thèse cofinancée IRSN/IFREMER (depuis le 2 novembre 2005)
Ecole Doctorale Normande Chimie Biologie - Université de Rouen
Robert Lafite (UMR 6143 M2C Rouen) : Directeur de thèse
Philippe Cugier (IFREMER/DYNECO/EB) : Encadrant IFREMER.
Pascal Bailly du Bois (IRSN/DEI/SECRE/LRC) : Encadrant IRSN.
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1 PhD context

Bedload sediments and particulate suspended matters play an important part in abilities and organization of coastal ecosystems in numerous ways:

- They affect trophic web by controlling turbidity which acts on primary production.
- They can fix and carry chemical species (nutrients, pollutants) and radionuclides. Thus, bed sediments can represent alternatively a sink and a source for dissolved and particulate elements by exchange with the water column.
- Bed sediments form a wide range of habitat or spawning habitat for fish and invertebrates.

English Channel seabed is characterized by a wide range of sediment mixture composed from mud to cobbles (Figure 1). Dynamic behaviour of such mixtures depends on the relative ratio of each size class. In order to improve sediment-transport model accuracy, it is essential to take into account particle size distributions.

First developments of a non-uniform non-cohesive sediment model have been realised at IRSN by Cugier (2000). The superficial sediment map of the English Channel (Vaslet et al., 1979) has been digitized (Struski, 1999) and a granulometric curve has been allocated to each sedimentary facies (Bailly du Bois, 2000; Nozière, 2001). Flume studies with sediment mixture (bimodal sand) have been performed in order to test transport formulations and to compare model simulations with observations (Olivier, 2004).

The aim of the PhD is to set up a 2DH sediment transport model (suspended and bed load) in the English Channel, taking into account the sediment sizes heterogeneity. It will be able to simulate heterogeneous sediment covers. This model will allow to predict pathways and sinking zones of radionuclides fixed on particles on the one hand, and to simulate their resuspension events on the other hand. In association with transfer models existing at IRSN, the fate of anthropogenic radionuclides will be assessed in most compartments of the English Channel ecosystem (water, sediments, and aquatic species).
This action will contribute to IRSN mission in order to assess radionuclides dispersion in the environment following chronic or accidental discharges.

Figure 1: Granulometric distribution map of superficial sediment in the English Channel (Vaslet et al., 1979; Struski, 1999; Bailly du Bois, 2000; Nozière, 2001)

2 Introduction

English Channel seabed implies to model mechanical behaviour of mixed particles and especially fine grains in a coarse environment. To deal with this specificity, sediment transport models usually include two numerical methods able to translate dynamical features:

- the active layer concept makes possible to simulate bed armouring phenomenon;
- the hiding / exposure coefficient allows to tune thresholds of movement according to heterogeneity degree of the mixed bed.

The need for *in-situ* data for the adjustment of these numerical computations of physical processes is essential. White (1998) highlighted that despite the numerous available methods, it is still not possible to make detailed or accurate field measurements of bedload, suspension of mixed sizes, or suspension very close to the seabed. The device presented herein, with the addition of appropriate image processing (Keshavarzy and Ball, 1999), provides a way to investigate in details these transport processes at the sediment - water interface.

3 The lack for high resolution bedload process studies

Bedload transport is difficult to measure since sediment movement takes place within a few centimetres of the sea bed. As a result, field studies usually focus on grain and flow parameters governing average transport rates in order to derive and test expressions for bedload transport. Few *in-situ* techniques have been adjusted to estimate average transport processes: 1) *Particle tracking method* which offers a solution to investigate transport pathways of a variety of sediment over wide temporal and spatial...
scales. Black et al. (2007) provides a comprehensive review of the method and highlights its technical limitations, 2) Ripple progression monitoring using a camera based technique (Kachel and Sternberg, 1971), or an echo-sounder based technique (Bell and Thorne, 1997). It can only be applied where hydraulic and sedimentary conditions allow ripple formation, and 3) Bedload traps, which according to Dyer (1986), are of very variable efficiency due to the difficulties of restricting the sampling to the movable layer.

The above methods yield averaged bedload transport hence providing poor resolution of individual or collective grain motion in time and space. On the other hand, two techniques establish a detailed link between boundary layer turbulence and sediment mixture dynamics. These are: 1) Self generating noise measurements due to particles hitting against each other as they move (Thorne et al., 1983/1984). Threshold of movement, size of the moving grain and instantaneous transport rate can be determined. This method is most suitable for coarse grains but presents problems in calibrating the acoustic signal, and 2) Video observations. Williams (1990) used this technique to observe gravel transport. He determined individual transport velocities and distances for 1680 particles whilst he managed to investigate bedload response to momentarily high bed shear stresses.

4 Dynamic Sediment Profile Imagery (DySPI)

DySPI is a new field device which intends to investigate multimodal sediment transport processes with a high resolution. It allows characterization of sediment response to turbulent fluctuations in terms of mode of transport, instantaneous transport rate, threshold of movement, individual grain velocity, transport thickness, sorting processes and armouring.

4.1 Apparatus and deployment

DySPI is an advancement of an about thirty year’s old device called Sediment Profile Imagery (SPI). SPI is a remote sensing technique for mapping superficial sediment properties along with observing and quantifying animal sediment interactions in aquatic systems (Rhoads and Young, 1970). A remotely operated camera is used to obtain profile photographs of the sediment-water interface. SPI is an effective technique for the assessment of benthic habitat quality. A multi-parameter organism-sediment index (OSI) is calculated on the basis of physical, chemical and biological parameters derive from sediment profile images (Rhoads and Germano, 1986; Nilsson and Rosenberg, 1997). OSI has been defined to interpret images, and to reduce them to a univariate factor.

DySPI enlarge the scope of SPI by allowing bedload processes to be studied with video imagery. Indeed, thanks to its streamlined shape, the sediment-water interface remains undisturbed during the penetration and the main flow is not modified during video acquisition.

An inverted periscope is placed at the middle of a half hull-shaped walking beam (Figure 2). The periscope consists of an optical mirror mounted at a 45° angle into a box with 2 Perspex face plates. The Perspex box is filled with clear water and sugar to prevent corrosion of the mirror and to obtain the same light diffraction as the sea water. A high definition digital video camera (resolution of 1080x1920, 50 half frames per second) is housed on the rotation axis on top of the mirror. The field of view is centred in order to see both the sediment vertical section reflected by the mirror and the sea floor directly. It is noted that the finest grain size to consider is determined by the camcorder resolution. Because video frames are taken through the periscope box, turbidity of the ambient water does not affect image quality. Light is provided alternatively by a spotlight to illuminate the entire area of interest and by a light pencil to see a specific volume of water. The periscope is horizontally sliced through the sediment thanks to a motorised
winch that ensures the penetration is slow enough to minimise disturbance of the sediment-water interface. The penetration depth can be adjusted to a maximum of 10 cm inside the sedimentary layers. A drag anchor is mounted on the DySPI frame to ensure it is trimmed right in the current direction when it descends through the water column. Thus, the periscope vertical face plate is parallel to the current without any disturbance from obstacles upstream.

![Figure 2: DySPI and autonomous sensors on the benthic frame](image)

4.2 Video measurements

An appropriate image processing allowed the determination of moving area ratio, size of the largest particle in motion, instantaneous transport rate and interface evolution. A spatial calibration of the video has been done at each deployment by diving operators: a millimetric grid was placed horizontally over the bed of sediment and vertically in the area illuminated by the light pencil. For the entire set of images, a typical value for pixel resolution is about 125μm/pixel. The software ImageJ (developed at the National Institutes of Health, USA) is used in combination with Fortran routines to handle the digital images. Captured pictures are converted in black and white. Pixels are represented by 8 bit integers, ranging in intensity value from 0 to 255. Sediment vertical section view and direct view are processed in a different way:

- Parameters obtained from the direct view are: 1) proportion of the moving grain surface and, 2) size of the largest particles to move. A region of interest (ROI) is set based on an analysis of the brightness distribution. In order to remove non-moving background particles, a difference image is obtained by the subtraction of two images. Thresholding is applied to the resulting image. After analysis of the histogram for the ROI, only pixels with a brightness variation over 20% are considered as moving pixels. Resulting image shows both grains that appear on the last image and grain that disappear from the previous one (Figure 3). The “AnalyseParticles” function of ImageJ is used to circumscribe and calculate the area of each particle (in pixel). Thus, with the video calibration, proportion of moving surface and size of the largest moving particle can be evaluated.
Figure 3: Difference images obtained after processing of the direct view part of video

- Parameter obtained from the vertical section is the deposition / erosion rate. Brightness and contrast are adjusted to enhance the sediment water interface. Then, this one is hand labelled with ImageJ. Interface position in pixel is obtained by selecting label coordinates with a Fortran routine. Then, the interface evolution can be plotted (Figure 4) and deposition/erosion rate measured.

Figure 4: Water-sediment interface evolution

4.3 Application during SEDHETE field campaign

DySPI has been launched at several stations during spring tide in the Normand-Breton Gulf. Deployment duration did not exceed a tide cycle. Mooring locations were chosen with bidirectional currents (according to MARS hydrodynamic model) to make study of sediment structure reorganization following turn of tide accessible. Before deployment, Shipeck garb samples, video observations and side scan sonar investigation ensured that seabed was homogeneous around the landing point: flat bed geometry with sediment characterised by a mixture of size with coarse grains being dominant. DySPI has been associated with several autonomous optical (OBS, particle size analyser, fluorometre) and acoustic sensors (ADV, ADCP) on a benthic tetrapod (Figure 2) in order to monitor boundary layer characteristics simultaneously with video observations. Thus, observed grains dynamics have been linked with high resolution time series of velocity, pressure, SPM, fluorescence and particle size.
5 Discussion and conclusions

The device presented herein, with the addition of appropriate image processing, provides a way to investigate in details transport processes at the sediment - water interface. Threshold of movement, size of the moving grain, moving area ratio, transport thickness and sorting processes can be studied in addition to usual SPI parameters (Kennedy, 2006). Furthermore, if DySPI is moored at a bidirectional current location, study of sediment structure reorganization following turn of tide is made accessible. This new apparatus enables in-situ sediment processes investigation in a large range of hydro-sedimentary conditions which are monitored as accurately as during flume experiments.

Data collected from SEDHETE field campaign will allow to characterise mechanical behaviour of mixed particles. Sediment transport formulation, active layer thickness and hiding / exposure coefficient will be tested in the model and chosen to fit the observations. Then, movement of the sedimentary cover in the English Channel will be simulated taking into account specificities of mixed size facieses.

References