

# ACOUSTIC BACKSCATTER MODEL FOR A MIXTURE OF SAND AND SHELL SEDIMENTS

Guillaume Fromant, Université Littoral Côtes d'Opale, [guillaume.fromant@univ-littoral.fr](mailto:guillaume.fromant@univ-littoral.fr)

France Floc'h, University of Brest, Geo-Ocean UMR6538, [France.floch@univ-brest.fr](mailto:France.floch@univ-brest.fr)

Oriana Yon-Campaner, University of Brest, Geo-Ocean UMR6538, [oriana.yon--campaner@etudiant.univ-brest.fr](mailto:oriana.yon--campaner@etudiant.univ-brest.fr)

Nicolas Le Dantec, University of Brest, Geo-Ocean UMR6538, [Nicolas.ledantec@univ-brest.fr](mailto:Nicolas.ledantec@univ-brest.fr)

Emmanuel Augereau, University of Brest, Geo-Ocean UMR6538, [emmanuel.augereau@univ-brest.fr](mailto:emmanuel.augereau@univ-brest.fr)

Marion Jaud, University of Brest, Geo-Ocean UMR6538, [marion.jaud@univ-brest.fr](mailto:marion.jaud@univ-brest.fr)

## INTRODUCTION

Assessing sediment stocks and transfers has become a key issue in recent decades. While the contribution of acoustic methods has led to a better understanding of sediment dynamics, through the measurement of waves and currents, the idea of using them to quantify the sediment fluxes is in full development. However, the use of these methods requires precise knowledge of the scattering properties of the suspended particulate matter present in the water column (also called the form function), as a function of the particle properties (size, shape, density...) and the instrument frequency. Analytical models (also called backscattering model) do exist for simple shapes, but their complexity increases when it comes to real suspensions, preventing accurate inversion of the acoustic intensity into suspended sediment concentration (Stanton & Chu, 2000). Therefore, heuristic or semi-analytical models have been developed to overcome these limitations. But this approach has mainly been steered towards the case of homogeneous mineral (sand - Thorne & Hanes, 2002) or organic (zooplankton - Holliday & Pieper, 1995; Stant & Chu, 2000) suspensions. However, in situ sediments in the marine domains are often made of mixed biological and geological origins. This study proposes for the first time a heuristic formulation describing the backscattering properties of a mixture of coarse sand and shell sediments. Different proportions are considered. The method is validated against unsorted in situ samples.

## METHOD

In order to design a new backscattering model, the DEXMES facility (*Dispositif Expérimental de quantification des Matières En Suspension*) is used (Tran et al., 2021) has been used. This 1 m<sup>3</sup> tank was designed to generate homogeneous (in the sense of the concentration) sediment suspensions and host multiple sensors running simultaneously (acoustical, optical and sampling facility). The upper part is a cylindrical tank with an inner diameter of 0.96 m and 1.4 m high. In order to break up the large vortexes and mitigate the vortex-induced bubbles, four evenly-spaced baffles are attached to the inner side of the tank (Fig. 1). The bottom part of the DEXMES device is a convex, elliptical-shaped Plexiglas bed. An impeller with a diameter of 0.36 m placed approximately 1 m below the water surface generates a turbulent flow in the tank. The speed of the impeller, ranging from 0 to 235 rpm, is regulated by a controller box. However, for this experiment, considering mixed coarse shelly particles and sand, it was not possible to obtain an homogeneous suspension. Therefore, a known mass or volume of sand-shell mixtures was introduced in the water tank through a hopper. The resulting sediment jet can be assumed

circular in an horizontal plane, with a gaussian distribution (Hay, 1991). The acoustic backscatter of this jet is measured horizontally (Fig. 1). Knowing the total mass of the sample, and integrating the backscatter signal over time (during the whole period of sediment fall) allow to convert the backscatter in term of mass. Considering 4 frequencies and samples with different mixture ratios and equivalent radius lead to the construction of the backscatter model. More precisely, the sediment profiler gives access to the root-mean-square backscatter amplitude  $V_{rms}$  which then relates to the mass concentration by equation (1).

$$V_{rms}^2 = MA_j A_s e^{-4\alpha} \quad (1)$$

With  $M$ , the mass concentration,  $A_j$  the constant defined by the equipment and containing information related to the insonified volume and the attenuation parameter of water and particles,  $A_s$  the parameter containing the form function, and  $\alpha$  the attenuation due to sediments. In equation (1), only the parameter containing the sum of the particle scattering properties  $A_s$  is unknown. We further assume that the form function of all the insonified scatterers is an ensemble average of the form function of a mixed sand-shell particle, integrated over the size distribution of the particle cloud (Hardcastle and Thorne, 1997). To determine  $A_s$ , we use equation (2):

$$A_s = \frac{3}{4\rho_s} \frac{\langle a^2 f^2 \rangle}{\langle a^3 \rangle} \quad (2)$$

With,  $\rho_s$  the particle density,  $f$  the form function of the mixture,  $a$  the radius of the particles, and the  $\langle . \rangle$  denoting the ensemble averaging over the particle size distribution.

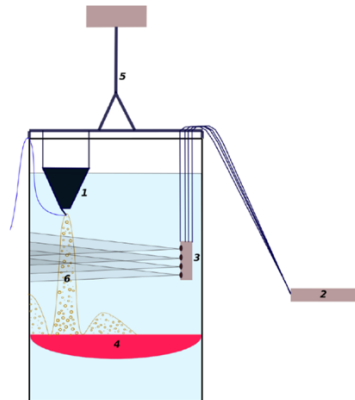


Figure 1 - DEXMES device schematic view and protocol used for the present study: the sample is placed in the hopper (1) and then released in the water tank. The multifrequency sediment profiler (2) Aquascat® 1000R records 4 backscatter signals from 4 transducers (3) of frequencies (0.5, 1, 2 and 4 MHz) placed vertically in the

water tank. The sediments (6) fall in the recovery device (4). Everything is taken out of the water tank with the winch (5).

With prior knowledge of the distribution width (ratio of standard deviation to mean radius) of the particles contained in theinsonified volume and the proportion of sand/shell within the particle cloud, it is possible to find the values of  $f$  for as a function of size, frequency, and the proportion of shell within the mixture, by solving  $A_s$ .

Samples from two study sites are used. Sediments are sorted in 7 size classes from 250 to 1000  $\mu\text{m}$ . The shelly part is defined with the carbonates ratio estimated from a loss by ignition method. Ratio from 4 to 53% are found. Crushed oyster shells are used as the shell reference: a ratio of 92% of carbonates is found, 6 size classes are sorted from 315 to 1000  $\mu\text{m}$ . Therefore 13 runs are carried out and repeated three times.

Table 1 - Corresponding Runs and sizes for in-situ samples Fig. 2 with carbonates ratio

Run	1	2	3	4	5	6	7
Size	250	315	400	500	630	800	1000
ratio	24%	33%	49%	53%	4%	8%	18%

Table 2 - Corresponding Runs and sizes (in  $\mu\text{m}$ ) for crushed oyster shell samples Fig. 3

Run	8	9	10	11	12	13
Size	1000	800	630	500	400	315

## RESULTS & DISCUSSION

Preliminary results of ensemble averaged form functions are presented on Fig. 2 for in-situ samples of mixture of shelly and sandy sediment and on Fig. 3 for pure crushed oyster shell. The Thorne & Hannes (2002) model is considered as a reference backscatter model for a homogeneous (irregularly shape) sand suspension with a  $\frac{1}{4}\Phi$  distribution. The form function magnitudes are in good agreement with Thorne and Hanes (2002) model, with increasing values below  $ka=1$ , reaching a plateau afterwards. The form function for the pure oyster shells are well below the sand mixture values as expected due to their lower density ( $\sim 1400 \text{ kg.m}^3$ ) compared to the sand ( $\rho_s = 2600 \text{ kg.m}^3$ ). The next step of this work consists in accounting for the sand/shell proportions within the different runs, as well as their size distributions, to derive a generalized heuristic formulation describing the scattering properties of a mixture of sand and shells in different proportions and size distributions.

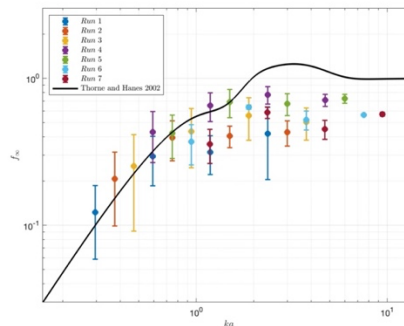


Figure 2 - Ensemble averaged form function  $\langle f \rangle$  versus  $ka$  with  $k$  the wave number (deduced from the transducer frequency) and  $a$  the equivalent radius for in-situ samples (Table 1).

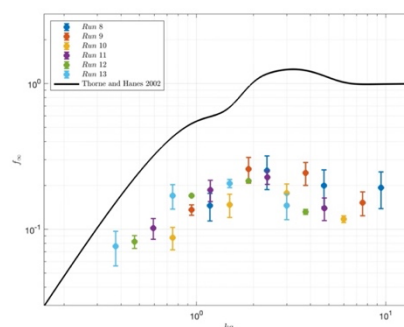


Figure 3 - Ensemble averaged form function  $f$  versus  $ka$  with  $k$  the wave number (deduced from the transducer frequency) and  $a$  the equivalent radius for crushed oyster shell samples (Table 2).

## ACKNOWLEDGEMENTS

This work was supported by Geosciences Ocean lab (UMR6538), EC2CO DEXMES, UBO, LabexMER (ANR-10-LABX-19), ISblue project, Interdisciplinary graduate school for the blue planet (ANR-17-EURE-0015), WEST (ANR-20-CE01-0009 WEST), Ifremer and CPER from Brittany Council.

## REFERENCES

- Thorne & Hanes (2002). A review of acoustic measurement of small-scale sediment processes. *Continental shelf research*, 22(4), 603-632.
- Tran, Bocher, Jacquet, Pearson, Floc'h, Dantec, Dorval, Fromant, Vergne, Jourdin, Crave, Lintanf, Verney (2021, September): DEXMES: A novel cylindrical device for SPM experiments. In INTERCOH (International Conference on Cohesive Sediment Transport).
- Hay (1991) Sound scattering from a particle-laden, turbulent jet. *The Journal of the Acoustical Society of America* 90.4: 2055-2074.
- Holliday & Pieper (1995) Bioacoustical oceanography at high frequencies. *ICES Journal of marine Science* 52.3-4: 279-296.