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A. Vergne, Céline Berni, J. Le Coz. Acoustic measurement of suspended sediments in rivers: potential impact of air micro-bubbles?. Underwater Acoustics Conference and Exhibition 2017, Sep 2017, Skiathos, Greece. pp.749-754. hal-01768427

HAL Id: hal-01768427

<https://hal.science/hal-01768427>

Submitted on 17 Apr 2018

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ACOUSTIC MEASUREMENT OF SUSPENDED SEDIMENTS IN RIVERS: POTENTIAL IMPACT OF AIR MICRO-BUBBLES?

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Abstract: *Following the success of Acoustic Doppler Current Profiler (ADCP) technology for measuring river discharge, there has been a growing interest in the last decade in extracting information on river suspended sediment fluxes from acoustic backscatter (ABS) data. Despite the efforts to find a relationship between suspended sediment concentration (SSC) and ABS, an inversion technique applicable to vertical river ABS profiles is still missing. The theoretical and empirical bases of such techniques have been originally developed for ocean bottom suspended sediment monitoring. As a first step in our attempt to adapt these models to rivers, we measured the acoustic response of a usual glass beads suspension in a tank. Unsurprisingly, the acoustic model agrees quite well with the measurements as soon as the effect of air micro-bubbles is limited. Typical river sediment suspensions are expected to produce weak ABS signal, especially at common ADCP frequencies, due to small particle sizes (Rayleigh regime) and relatively low concentrations. In such conditions, the impact of air micro-bubbles – generally neglected at the bottom of the ocean – could be relevant in rivers. As a second step, we deployed an ABS profiler in the Rhône River (France) in very clear water conditions (SSC < 10 mg/l). The recorded acoustic intensities were higher than expected, suggesting that other scatterers may participate to the recorded echo. This preliminary work calls for further investigations to assess the potential impact of non-sediment scatterers on the acoustic signal when trying to link SSC with ABS in rivers.*

Keywords: *Suspended Sediments, Rivers, Acoustic Backscatter Profiler*

1. INTRODUCTION

The wide development of Acoustic Doppler Current Profiler (ADCP) technology for measuring river discharge has led to a growing interest in monitoring rivers with acoustics. One of the most promising applications could be the remote sensing of suspended sediment concentration (SSC) from acoustic backscatter (ABS) systems, which already gave great results in marine environments. Despite the efforts to link ABS with SSC in rivers, a valid acoustic model as well as a robust inversion technique for vertical ABS profiles are still missing. Our first objective is to investigate whether existing ABS models are suitable for rivers or not. To test our instrument as well as our algorithms, we measured the ABS signal of a usual suspension of glass spheres in a tank. It made us more aware of the strong effect of air micro-bubbles when trying to measure small particles backscatter at relatively low concentrations. With this potential impact in mind, we measured the ABS signal in the Rhône River (France) in very low suspended sediment conditions (SSC < 10 mg/l). We found unexpectedly strong ABS signal at lower frequencies, suggesting that other scatterers may participate to the recorded echo.

2. ACOUSTIC BACKSCATTER DIRECT MODEL

The theory of sound backscattering by an incoherent suspension of particles has been well described for years and recently summarized by Thorne and Hurther [1]. In the monostatic configuration, the sonar equation can be written as:

$$V_{rms} = \frac{k_s k_t}{\psi r} M^{1/2} e^{-2\alpha r} \quad (1)$$

where V_{rms} is the root mean square of the recorded voltage averaged over a large number of measurements, r is the range from the instrument, ψ a near field correction, k_t a constant depending on the instrument, k_s a term depending on the acoustic properties of the sediments, M the mass concentration and α the attenuation coefficient. In this equation, two terms depending on the sediment properties – k_s and α – are particularly challenging to assess, and respectively depend on the so called intrinsic form function f and intrinsic normalized total extinction cross section χ . In the following, we used SSC and grain-size distribution data taken from water samples to compute k_s and α , using Thorne and Meral [2] and Urlick [3] widely-used formulas for f and χ ; making the assumption of non-cohesive inorganic sand-like particles. Our objective was to compare the outputs of this basic and widespread ABS model to our measurements.

3. LABORATORY MEASUREMENTS

3.1. Instrumentation

Prior to field experiment, we measured the ABS response of a usual suspension of glass beads in a 1 m³ experimental tank (Fig. 1). Two submerged pumps were placed at the bottom of the tank in order to create turbulences and generate sediment suspension. A multi-frequency ABS profiler Aquascat 1000R was deployed horizontally in the tank, using 4 transducers at 0.3, 0.5, 1.0 and 5.0 MHz. Unfortunately, 0.3MHz data were not useable because of unexpected backward reflections and strong background noise. The ABS profiler had been previously calibrated following Betteridge et al. [4] procedure. The temperature was regularly recorded and water samples were taken within the tank using a peristaltic pump connected to a Ø5 mm pipe. Mass concentration was measured by filtering the samples, and a Cilas 1190 laser grain-sizer was used for evaluating the particle size distribution.

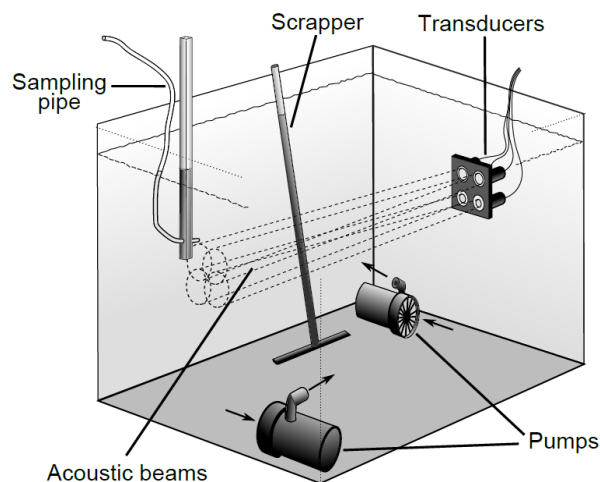


Fig.1: Experimental tank diagram. The scrapper is used for moving the sediments from the bottom of the tank in order to raise the sediment concentration when necessary.

The tank was filled with fresh water and left 24h for degassing before recording the background noise at rest. We then switched on the pumps and recorded a low ABS signal due to air micro-bubbles produced by surface stirring. We waited for this signal being stabilized and added 500g of glass beads of typical diameter 40-80µm in the tank. Backscatter profiles were recorded at a rate of 10 Hz during typically 2 minutes in order to collect more than 1000 profiles and compute their root mean square. Water samples were also regularly taken.

Injection of dry sediments from the free surface was expected to add air micro-bubbles in the tank. We let the system run for 24h, which led most the sediments fall at bottom of the tank. To remove them and raise the concentration again, we used a long scrapper that was immersed in the tank since the beginning of the experiment (Fig. 1). ABS profiles were recorded and water samples taken again.

3.2. Measurements and results

We used the concentration and grain size data obtained from the water samples to feed the widespread acoustic model briefly presented above and compute theoretical ABS profiles. We assumed that the concentration and grain size were constant along the acoustic beams, as extensive water sampling in the tank showed that the suspension was fairly stable in space. However, as the concentration was dropping over time, we compared the measurements to a min. / max. span corresponding respectively to the water sample taken right after / before a given acoustic recording period.

Fig. 2 shows the comparison between simulated and recorded ABS profiles for two suspensions with similar characteristics of grain size and concentration (≈ 0.4 g/l). In case 1, glass beads were added from the free surface a few minutes before recording the backscatter. This is expected to add a lot of air micro-bubbles in the tank, and the recorded ABS intensities are much stronger than the simulated ones at lower frequencies (0.5 and 1.0 MHz). The recorded profile at 5.0 MHz is however weaker than the simulation. In case 2, the suspension was created by moving the sediments from the bottom of the tank with a long scrapper, which is expected to produce less micro-bubbles. The recorded ABS intensities are weaker and agree much better with the simulations at 0.5 and 1.0 MHz. Conversely, the 5.0 MHz recorded profile is stronger than in case 1. As air micro-bubbles attenuation coefficient is stronger at high-frequencies, one can make the assumption that a drop in air micro-bubble concentration could lead to a reduction in attenuation and a rise in ABS intensities at high frequencies.

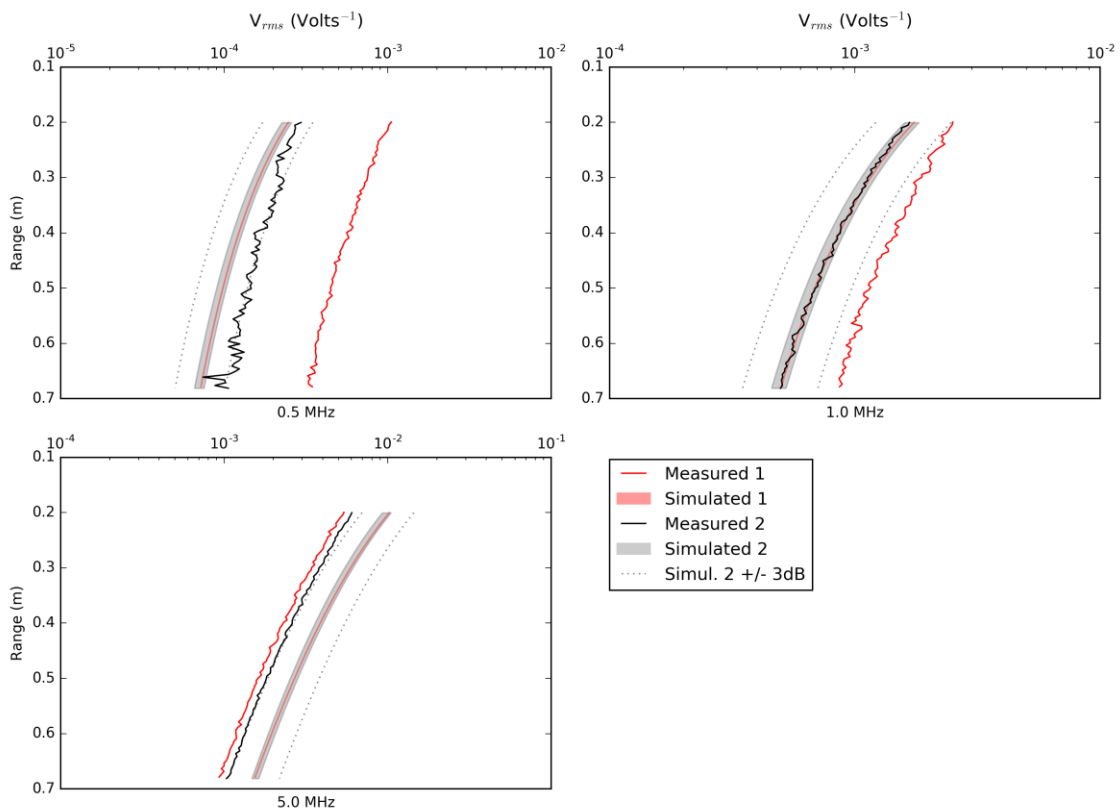


Fig.2: Comparison between simulated and recorded ABS profiles for two similar suspensions: 1- dry sediment injection from the water surface; 2 - sediment mixing from the bottom of the tank.

4. FIELD EXPERIMENT IN CLEAR WATER CONDITIONS

4.1. Study site and instrumentation

We deployed our ABS profiler in the Rhône River (France) in clear water conditions on January 17th 2017. The study site was located in Lyon, 130m downstream a bridge and 1700m downstream a weir. The instrument was mounted on a boat with 4 down-looking transducers at 0.5, 1.0, 4.0 and 5.0 MHz. During the measurements, the ship was kept as static as possible with the help of a GPS. Vertical ABS profiles were recorded during typically 3 minutes in order to collect around 2000 profiles and account for the variability of both the particle flux and the ABS signal. Background noise was recorded prior to the measurements, and we did not observe any interference from the boat engine or any other electronic devices. Right after ABS profiling, water samples were collected at several depths using a 2 liters Niskin bottle.

4.2. Measurements and results

We used the same procedure as presented above to compute the theoretical ABS profiles and compare them to the recorded ones. As well as in the tank experiment case 1 (strong air micro-bubbles signal), Fig. 3 shows that the recorded echo in the river is stronger than the simulation at lower frequencies (0.5 and 1.0 Mhz) and weaker at higher frequencies (4.0 and 5.0 MHz). It suggests that the classic ABS model we used for the simulations is not taken all the backscatter and attenuation into account.

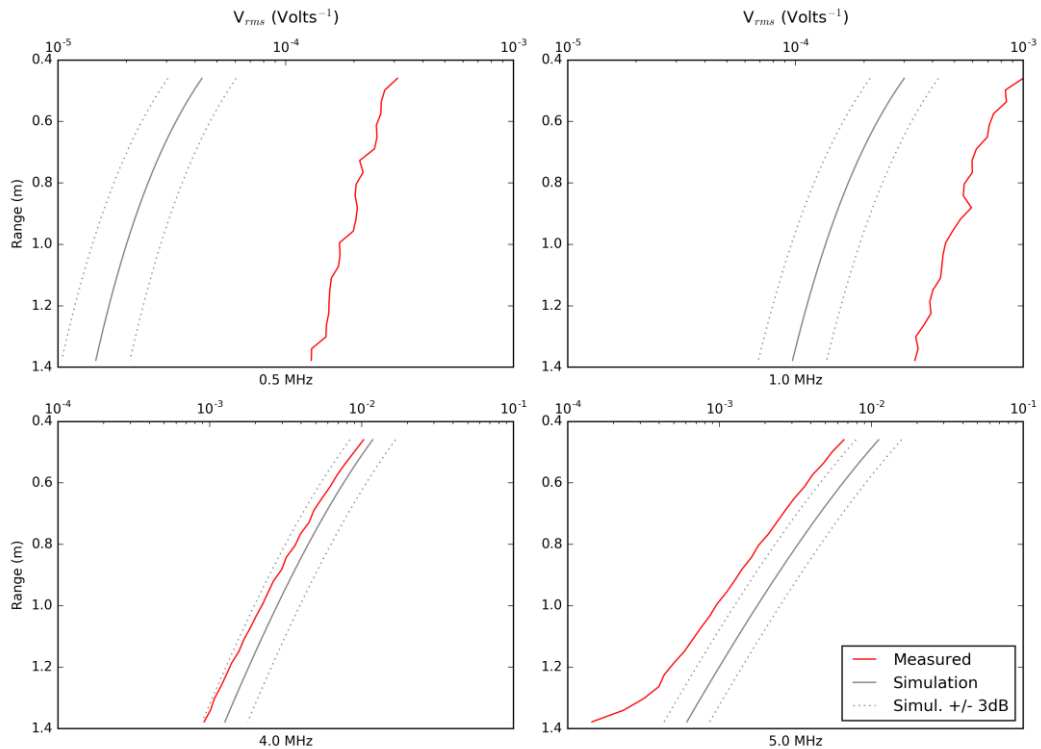


Fig.3: Comparison between simulated and recorded ABS profiles in the Rhône River in clear water conditions.

5. DISCUSSION

As reported in the literature [4], particular attention should be paid to air micro-bubbles when measuring ABS of suspended sediments in the laboratory. Any injection of external bodies from the water surface as well as the surface stirring itself can produce air micro-bubbles that may remain in suspension for minutes to hours. Bubbles have a strong target strength, leading to stronger backscatter at low frequencies (0.5, 1.0 MHz) and stronger attenuation at high frequencies (5.0 Mhz).

In a river, weirs, surface stirring, vegetation, etc. are likely to produce micro-bubbles as well. In addition, river suspended sediments are generally smaller than marine sand particles. When using typical ADCP frequencies in the range 0.5 – 1.5 MHz, the product of the wave number by the particle radius is likely to be much smaller than 1; pushing the backscatter deep into the Rayleigh regime, which will result in weak ABS signal. In these conditions, the impact of other scatterers like air micro-bubbles may increase.

We made some ABS measurements in the Rhône river in very low sediment load conditions. As observed in the lab experiment case 1 (strong air micro-bubbles effect), the recorded signal in the river was stronger than expected at lower frequencies (0.5, 1.0 MHz) and weaker at higher ones (4.0 and 5.0 MHz). However, unlike in the lab, air micro-bubbles are not the only factor that could explain the discrepancies between the measurements and the simulations. Inappropriate models for sediment form factor / extinction cross section, strong uncertainties in natural sediment size distribution measurement, flocculation and micro-organisms could also impact the ABS signal. All these hypotheses will need more investigation in the objective of building an effective ABS model, suitable for river applications.

6. ACKNOWLEDGEMENTS

This work was supported by the Compagnie National du Rhône. The authors would also like to thank the members of Irstea metrology team who helped for the experiments.

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