Hydro-acoustic sediment flux profiling in highly turbulent particle flows

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[1] Advances in flow-controlled sediment transport physics and modelling still suffer from the lack of high-resolution flow measurement technologies. This is particularly true in high geophysical Reynolds number flows driven by energetic gravity currents in rivers or by surface gravity waves in the coastal marine environment. Over the past years, a novel hydroacoustic measurement instrument: the Acoustic Concentration and Velocity Profiler (ACVP) was developed and had improved the understanding of sediment transport processes. The present study is devoted to confirm the validity of this multi-bistatic and multi-frequency instrument by interpreting data from a laboratory flume exposed to under well-known sheet flow conditions. **Citation:** Hurther *et al.*, 2011; Thorne and Hurther, 2014.

1. Introduction

[2] In a time of climate change, environmental issues including sedimentary and fishing resources management or shoreline recession are becoming impacted by extreme events. In a long run, flood, waves and, storms on coastal regions are controlling morphological evolution of the sea bed. To hold it as much as possible, sedimentary transport models are becoming improved.

[3] Nowadays, sedimentary transport prediction is too much empirical. Transport models are not clear or accurate enough to be used alone. Sediment measurements are currently doing one by one frequency. To obtain the sediment grains size, the novel multi-frequency system Acoustic Concentration and Velocity Profiler (ACVP) is studied [Hurter *et al.*, 2011]. Characterisation of its performances and comparison between mono and multi-frequency instruments were made in the same flow conditions. It allows coherent observations for hydroacoustic intensity, normal velocity and, Reynolds shear stress profiles.

2. Method

[4] The ACVP is a multi-bistatic instrument [Hurter *et al.*, 2011] which combined multi-bistatic Acoustic Doppler Velocity Profiler [Hurther *et al.*, 2001] and multi-frequency Acoustic Backscattering Systems [Thorne *et al.*, 2002; Hurter *et al.*, 2011; Thorne *et al.*, 2014] technologies. It is composed of one emitter and two separate receptors (Figure 1). The emitter sends one acoustic pulse to propagate in the vertical direction. When the emitted pressure wave is backscattered by inhomogeneities (bubbles, sediments…), it is captured by the receptors.

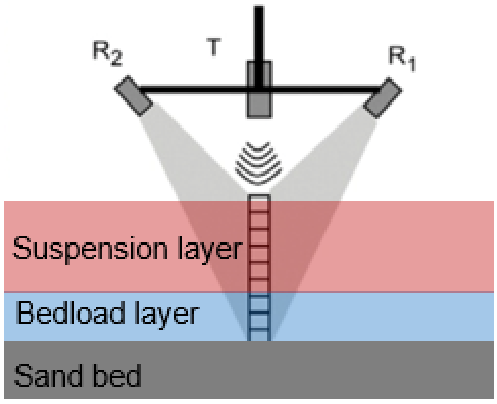

Figure 1. Multi-bistatic ACVP instrument.

[5] ACVP measurements are direct, non-intrusive and, collocated. This method permits to obtain 1D2C – vertical with two components – profiles of sea bed interfaces. Flow normal velocities are estimated by Doppler effect whereas concentration is deduced from hydroacoustic intensity. Mono-frequency method uses sediment grains size to determine concentration, but multi-frequency method could at the same time, gives the concentration and the sediment grains size. It permits to estimate the sediment flux.

[6] The ACVP transducers are piezoelectric and wide band. Depending of the electric signal sends to the emitter, it emits an acoustic pulse at one specific frequency. Theoretically, transducers

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could emit at the frequencies included in the range [500 kHz – 2.5 MHz] with a central frequency equals to 1 MHz. The experiment is governed by a free surface flume (Figure 2) with a $5°/_{00}$ slope and a uniform rugosity on the bed. The walls friction of the flume is negligible regarding to the bed one. The flow is composed of clear water – negligible viscous effect without sediment – and a stationary, uniform, fluvial and turbulent flow with a Froude number strictly inferior to 1 (rectangular flume) and a Reynolds number approximately equals to 10^5.

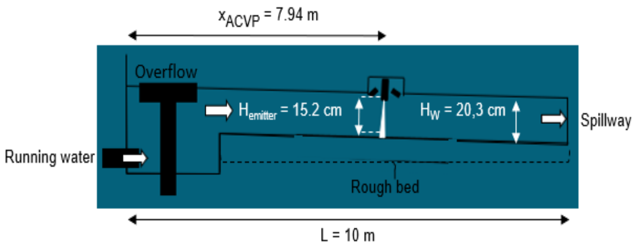

Figure 2. Schematic representation of a free surface flume with variable slope (LEGI – Grenoble, France).

[7] In these flow conditions, we chose a constant but different gain (adjusting with the bandwidth of transducers) for each frequency. This arbitrary but simpler decision is composed of two main experimental risks for mono and multi-frequency ACVP instruments. On the one hand, the signal could be saturated at the bed because of the high acoustic impedance contrast. It corresponds to a decrease of the hydroacoustic intensity with the distance from transducers. On the other hand, hydroacoustic intensity is impacted by the transducers sensitivity. The experimental part was followed by an adaptation of computer programs to process raw data, analyse and, interpret hydroacoustic intensities, normal velocities and Reynolds shear stress along the water column.

3. Results

[8] The high frequencies hydroacoustic intensity profiles included in the range [1.388 MHz – 2.5 MHz] are relevant but the hydroacoustic intensity is too low to be well received by the receptors. Its deficient reception impacts the normal velocities and Reynolds shear stress graphs. Thus, to determine the mono and multi-frequency instruments correlation, we compared the low frequencies profiles.

[9] For each frequency, at mono or multi-frequency configuration, the graphical shape stays the same (Figure 3). The first peak corresponds to the flume rough bed whereas the second one is the emitter.

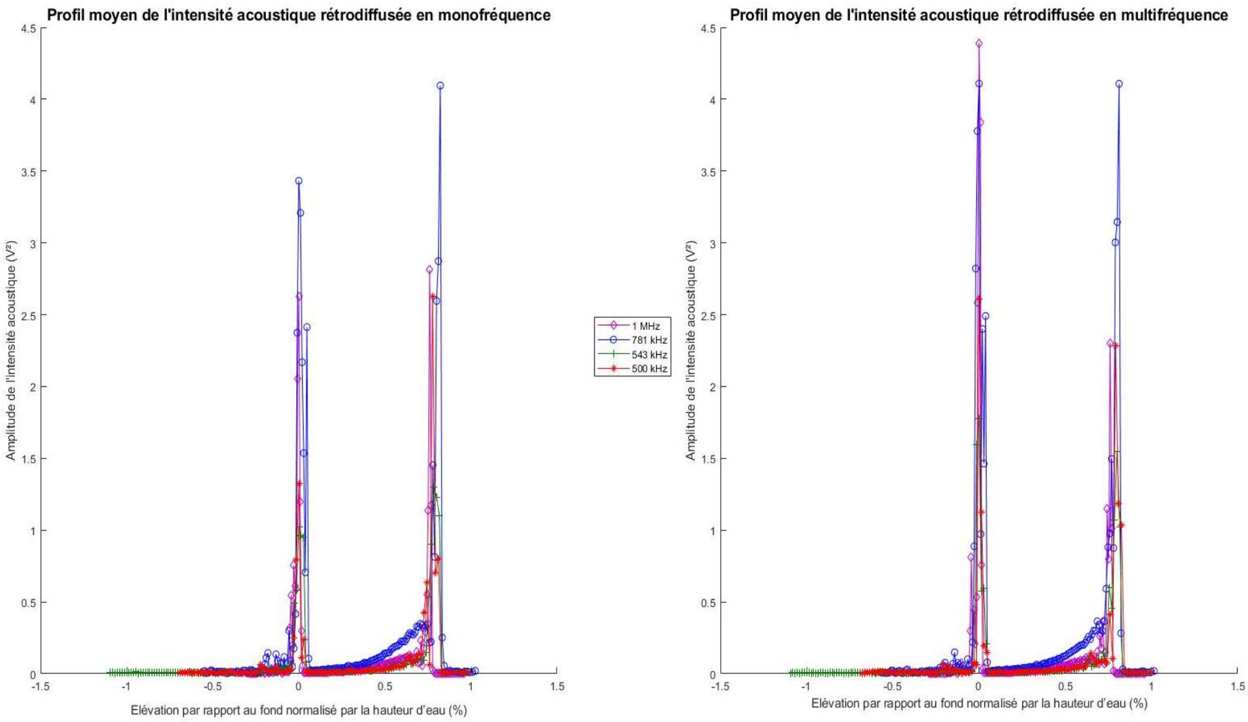

Figure 3. Backscattered mean hydroacoustic intensity profiles for mono and multi-frequency ACVP configurations at low frequency (1 MHz – 781 kHz – 543 kHz – 500 kHz).

[10] At the same frequency range, the low normal velocities (Figure 4.a & b) permit to deduce the flow limit conditions where the velocity equals zero. It will be later used to estimate the Reynolds shear stress. By applying the least square method to mono and multi-frequency measurements, we find a similar order of magnitude between its trendlines slope and intercept (Figure 4.c & d). The equation (1) from Von Kármán constant is checked. It involves that mean velocity of a turbulent flow taken at one specific point is proportional to the boundary of the fluid region.

$$u = \frac{u_*}{\kappa} \ln \frac{z}{z_0} \qquad (1)$$

where u refers to the mean flow velocity at height z, u_* to the friction velocity (or shear velocity), κ = 0.41 is the Von Kármán constant, z the height above the boundary and, $z_0 \neq 0$ the roughness height (or roughness length).

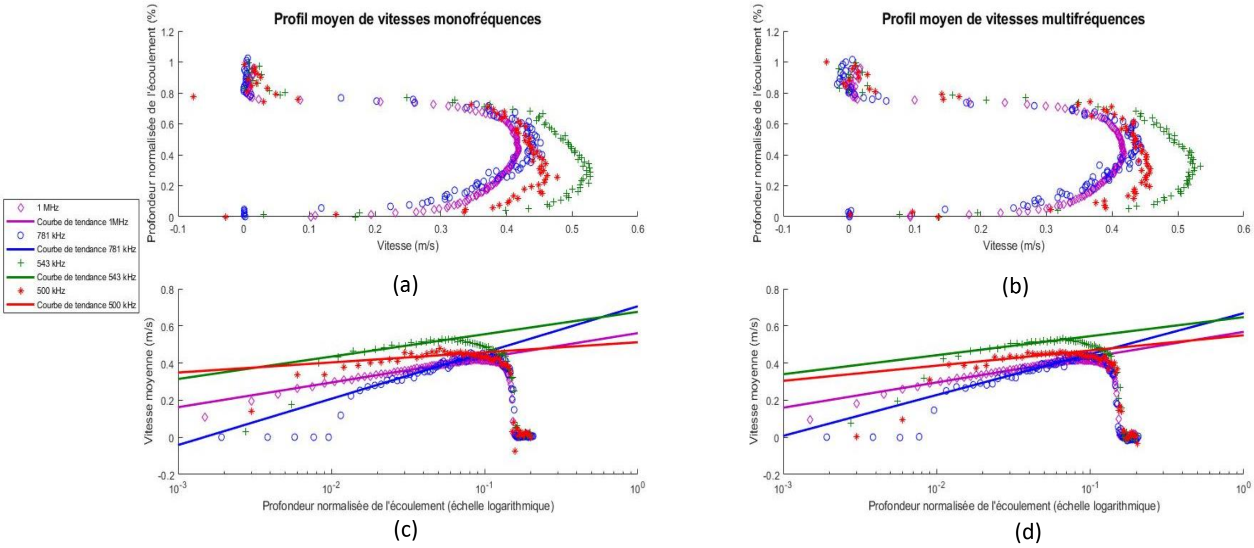

Figure 4. Mean velocities profiles for mono and multi-frequency ACVP configurations at low frequency (1 MHz – 781 kHz – 543 kHz – 500 kHz).

[11] The comparison between mono and multi-frequency radial velocity is linear (Figure 5) with a low frequency coefficient of determination $R^2 = 0.9625$. It confirms the mono and multi-frequency methods similarities. The multi-frequency ACVP could be used as we already use the mono-frequency one.

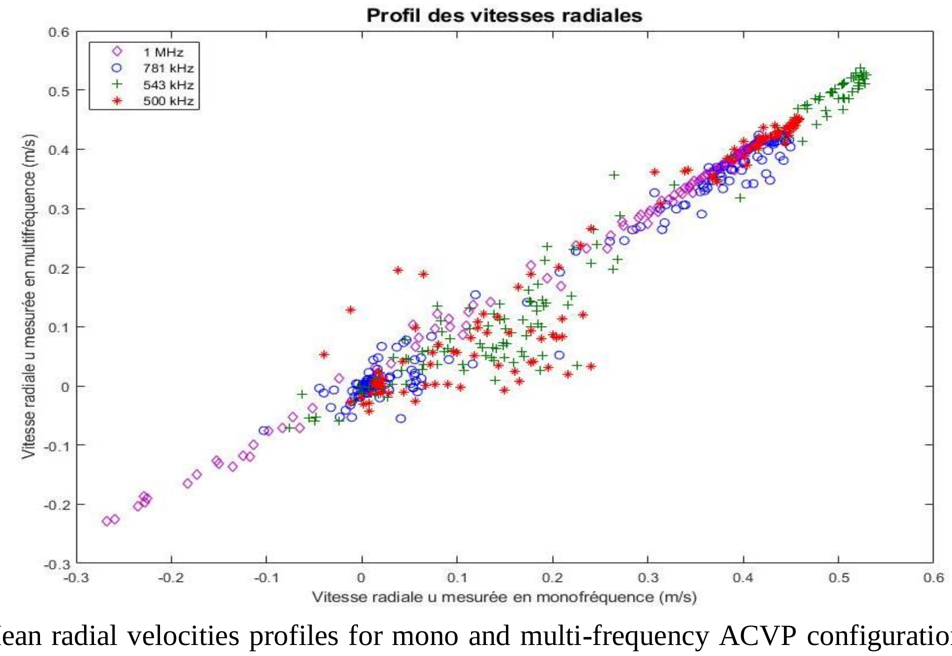

Figure 5. Mean radial velocities profiles for mono and multi-frequency ACVP configurations at low frequency (1 MHz – 781 kHz – 543 kHz – 500 kHz).

[12] By using the flow normal velocities, we deduce the Reynolds shear stress. This classical hydraulic parameter increases with the force applied by the flow to the bed.

$$\tau = -\rho\overline{u'w'} \qquad (2)$$

where ρ = 997 kg.m^{-3} is the water density, $u' = u - \bar{u}$ and $w' = w - \bar{w}$ are the turbulent normal velocities fluctuations with mean profiles $\bar{u}$ and $\bar{w}$. The mean Reynolds shear stress profiles were drawn for each frequency with mono and multi-frequency methods. Nevertheless, the only pertinent graphs – with a linear progression (2) – are obtained with the frequencies 1 MHz et 781 kHz (Figure 6). By increasing the profile duration, it would be easier to observe the Reynolds shear stress convergence.

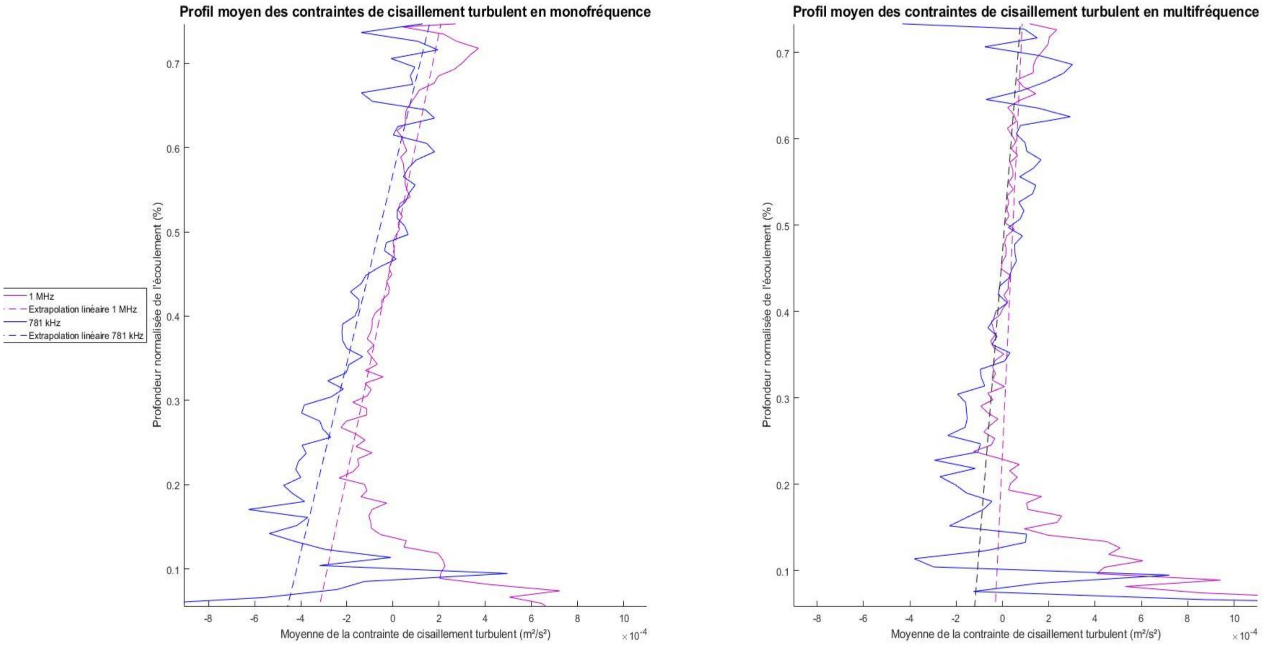

Figure 6. Reynolds shear stress profiles for mono and multi-frequency ACVP configurations at low frequency 1 MHz and 781 kHz.

4. Discussion and conclusion

[13] The obtained mono and multi-frequency measurements are coherent for the frequency range [500 kHz – 1 MHz]. To extend this study to more frequencies, the electronical part of the ACVP instrument – especially the bandwidth – would be improved. The multi-frequency inversion method uses many frequencies and hydroacoustic intensities. It permits to determine the sediment concentration – such as the mono-frequency method – but also the sediment grains size (Thorne *et al.*, 2002). This area of active research is becoming more and more performing by giving environmental perspectives.

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