Développement de la mesure acoustique passive du charriage en rivière

Development of an acoustic method for bedload transport measurement in rivers

(Thèse en co-financement EDF DTG)

Abstract

This thesis aims to consolidate and validate passive acoustic measurement of bedload transport in rivers, by hydrophone. It is part of a dynamic initiated for several years between different actors in the Grenoble area: EDF DTG, Ige, Gipsa-Lab, Irstea. This research is now starting to produce very encouraging results, suggesting a future operational use. However, work is still needed, and the objectives of the thesis will be to (1) validate a model of acoustic noise transformation in transport rate (2) better understand the contribution of the different fractions transported and in particular sand, (3) propose a methodology for using this tool in banks for continuous measurement.

Résumé

Cette thèse a pour objectif de consolider et valider la mesure acoustique passive du charriage en rivière, par hydrophone. Elle s'inscrit dans une dynamique engagée depuis plusieurs années entre différents acteurs de la place grenobloise : EDF-DTG, IGE, Gipsa-Lab, Irstea. Cette recherche commence aujourd'hui à produire des résultats très encourageants laissant entrevoir une utilisation opérationnelle prochaine. Des travaux sont néanmoins encore nécessaires, et les objectifs de la thèse seront de (1) valider un modèle de transformation du bruit acoustique en flux transporté (2) mieux comprendre la contribution des différentes fractions transportées et en particulier du sable, (3) proposer une méthodologie d'utilisation de cet outil en berge pour une mesure en continu.

Context and challenges

The measurement of river bedload is a complex exercise that is still the subject of much research today. While direct sampler sampling techniques have been developed for more than a century, they now reach limits that can hardly be exceeded (heavy technical and implementation costs, non-quantifiable measurement biases related to the very intrusive method, inability to measure at large flows). At the same time, new methods have been developed in recent years that take advantage of technological advances and the wide variety of materials available in commerce; Among these methods, three deserve special attention if one refers to the growing number of publications that refer to them (about 30 A-ranking publications in the last five years): geophone measurement; hydrophone measurement; and seismic measurement.

These methods have in common that they seek to connect the waves emitted by pebbles that collide in the transported layer and the transported flows. The geophone method measures the acoustic waves that propagate when the stones hit a plate previously placed on the bed of the stream. The seismic method measures the waves emitted in the ground. The hydrophone method measures the waves that propagate in the water; we will talk about passive acoustic measurement to differentiate it from geophones. Seismic and passive acoustic methods are inexpensive (unlike geophones that most often require the construction of a civil engineering across the watercourse), easily implemented, non-intrusive, with no flow limitation, and can be deployed on site for long periods. This thesis is particularly interested in the acoustic method by hydrophone.

The stakes are important. They concern the validation of the many models that our community is developing elsewhere. The hydrophone technique also offers great prospects for flood monitoring, risk management and hydraulic developments. Industrial prospects are also being considered, as these tools, which are easy to implement, may be of interest to many stakeholders in watercourse management.

This thesis is the culmination of a collaborative process initiated several years ago between Irstea, GIPSA-Lab, IGE and EDF, which has already produced more than encouraging results (Geay et al 2018, Zanker et al 2018).

Subject consistency with other strategic documents:

This subject is consistent with the objectives set out in the Irstea guidelines (Hydrosystems and Natural Hazards Axis of the Water and DSS Department "Natural, Health and Environmental Risks") which encourage the development of innovative approaches and tools for facing the challenge of increasing hazard in a context of global change. Measurement will be at the heart of future adaptation strategies, whether it is for an understanding of the dynamics of change or for simply setting up real-time monitoring and warning systems. The hydrophone project is fully in line with this dynamic.

State of the art

The first traces of acoustic measurement in the scientific literature date back to 1936 (Reitz, 1936) and Grenoble was not left out since a hydrophone was built in 1942 (Braudeau, 1951). Later there are some attempts to relate acoustic power to the mass of sediment transported (Bedeus and Ivicsics 1963, Jonys 1976). In the 1980s, laboratory measurements (Thorne, 1985, 1986) and theoretical studies (Thorne, 1988) provided some theoretical bases still used today. It will nevertheless be necessary to wait until the 2000s to see resurgence of an interest for the measurement hydrophone (Belleudy 2001), with in particular the thesis of Thomas Geay (2013). It is now established that acoustics is a good proxy for the measurement of the flow carried (Geay et al 2017).

From a theoretical point of view, the work of Thorne (1985, 1986, 1988) has shown that the spectrum of the acoustic signal is related to the size of the grains transported. Two parameters were used: (1) the frequency peak fpeak and (2) the central peak fc, expressed in Hz. Fpeak corresponds to the maximum of the spectral density of power (PSD in μPa2 / Hz). fc represents the frequency center of the PSD. For uniform sediments it has been shown that these significant frequencies are almost inversely proportional to the size of the D grains:

$$f_{peak} = \frac{224}{D^{0.9}} \quad (1)$$

$$f_c = \frac{209}{D^{0.88}} \quad (2)$$

These equations have been used in several studies to try to estimate the size of particles transported from passive acoustic measurements (Bassett et al., 2013, Marineau et al., 2016, Mason et al., 2007). But if the detection of thrust in the acoustic signal has been demonstrated by all these works, the ability to go back to transported flows remained a challenge. This is why we have been engaged since 2015, in the framework of an EDF / Irstea / GIPSA-Lab / IGE collaboration, of a vast validation campaign consisting in comparing the acoustic measurement with direct measurements to the sampler (Elwha or Toutle). A dozen streams have been sampled in the Alps and the Pyrenees and the first results presented in the following figure show a clear relationship between the flow and the acoustic signal (Geay et al 2018, Zanker et al 2018).

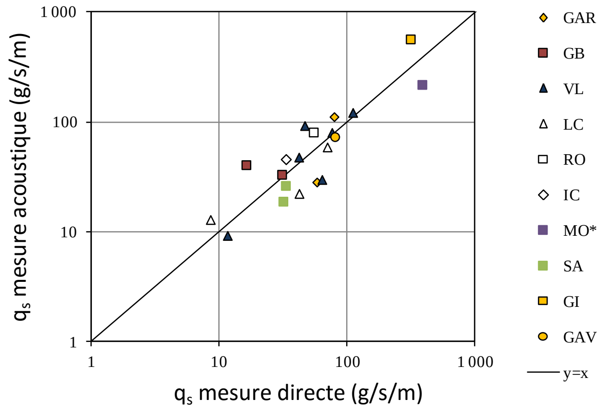

Figure 1 : Résultats des premiers tests de validation de la mesure acoustique par comparaison avec la mesure directe du charriage

Work plan:

This thesis will have for objectives:
- Consolidate the current results with new measures
- To better understand the contribution of the various fractions of the sedimentary mixture, and in particular of the sandy fraction
- To validate the continuous measurement in banks (not requiring the presence of an operator)
Each of these objectives will result in a scientific publication.

Consolidation

Fit of figure1 is :

$$qs = 1.5\ 10^{-7} P^{0.65} \quad (3)$$

The results with this equation, shown in Figure 1, indicate a flow prediction in an error envelope of 2 to 3, which by far is much better than most transport equations whose error can reach several orders of magnitude. It is also interesting to remember that this relationship was built from 16 samples covering a wide range of slopes (0.05 to 1.5%), grain size (D84 between 5 and 300 mm), width (8 to 100 m), and water level (0.4 to 2.8m). This "universal" side of the relationship, was a good surprise and brings out beautiful perspectives for the acoustic measurement. But the method must still be validated, and these results need to be reinforced, from a theoretical point of view, by a better consideration of the physics of the propagation of acoustic waves in the river.
New sampling points will be produced in the watercourses already studied, but also in new

watercourses to be defined. The direct measurement of the thrusting will be carried out with the Elwha-type Helley-Smith sampler (Figure 2). The advantage of this type of sampler is that it can be handled by two operators, without machinery, from a bridge. Therefore it allows rapid interventions on site in case of flood (a major difficulty of the measure is to be able to intervene during floods that sometimes occur over a short period of time, especially in the Alps). It will be possible to carry out, more occasionally, measurements to the Toutle sampler, bigger and handled from a crane truck.

Following the established procedure already well established by the Edf / Irstea teams, joint and simultaneous HS / Hydrophone measurements will be produced at various points of the section and then averaged. Each point will be associated with a hydraulic condition (water level measured by local sounding, speed measured by radar or LSPIV, flow rate when a gauging exists). These measurement campaigns will benefit from synergies with other ongoing projects (see below), which will ensure both the feasibility and the quality of the data collected.

Figure 2 : a) Le préleveur Elwha b) l'hydrophone monté sur un radeau

Contribution of fractions size

Improving the quality of the measurement will require a better understanding of the contribution of each size involved in the transported mixture. In particular doubts exist about the real contribution of the sandy fraction, which could contribute to the variability of the measurement (the sand can be a source of noise, but at the same time could be a source of attenuation of the propagation in the medium). This question is all the more important because in some rivers this fraction is far from being negligible, and is therefore of great interest to the works managers. Several actions will be considered to study this question. First, special attention will be paid to measuring sand during field campaigns. Appropriate sampling strategies will be put in place on the water column (the sand can be transported by suspension and on the bottom). Sand-specific samplers will be used (P72, Delft Bottle or Nile), but we will also try to innovate with techniques better adapted to alpine rivers, for example by using a column of pumped samplers associated with pressure sensors. differential, arranged on a rod manipulated from a bridge according to the protocol established and validated for the Elwa sampler.

We also envisage field measurements under controlled conditions. This will consist in making releases of sedimentary mixtures, of known composition, upstream of the measurement section. This will require finding stable bed sections (pavement), where the noise generated by the injected sediments will not be drowned in the noise generated by the load naturally carried by the stream (we already have several candidate streams).

These field measurements will be coupled with measurements in the laboratory. Simple experiments will consist in measuring releases of mixtures of varied composition, without water. Water experiments will be carried out at Irstea, as far as the ability to listen to the microphones in a closed environment and in the presence of pumps. An alternative will be to do tests in an external laboratory (for example a thesis in progress with Dieter Rickenmann at WSL is to test the geophones on a channel of tens of meters outside, we could easily associate an acoustic measurement with these experiments).

These experimental approaches will of course be conducted in conjunction with a theoretical analysis. Various developments have recently been proposed, notably in the context of Teodor Petrut's thesis (Petrut et al 2018, Geay et al 2018a). These methods can be tested and improved.

Continuous meausrement

For the moment acoustic data "exploitable" were measured with a microphone attached to a raft and driven by an operator from a bridge (Figure 3a). The principle consists in measuring by drifting the raft, which minimizes the effects of turbulence (interactions of the raft with the waves) on the surface. This is a "local" measure which, in principle, captures the noise generated as close as possible, ie to the right of the measuring point. The advantage is that the propagation effects in the environment are considerably reduced and the signal is easily exploitable. The disadvantage is that it requires an operator and does not allow continuous monitoring.

The second option is to install a fixed hydrophone on the bank (Figure 3b). This solution enables continuous measurement without the presence of an operator, and is therefore an essential issue from an operational point of view.

Figure 3 : a) Hydrophone mobile sur radeau (mesure locale) et b) Hydrophone fixe en berge (mesure intégrée)

Several hydrophones in banks have been installed by EDF (Vénéon ...) and chronicles are already available. The data produced is encouraging (Figure 4) but has not been exploited to date. The objective of the thesis will be to establish the conditions of use of the signals acquired in the bank.

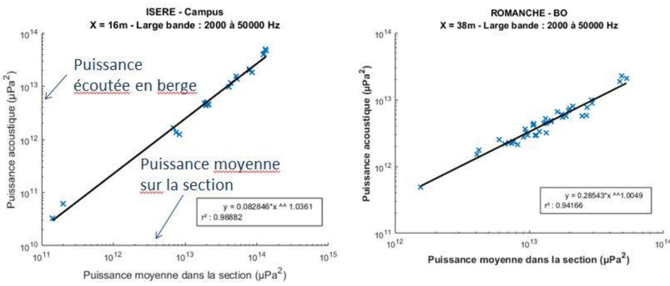

Figure 4 : comparaison de mesures acoustiques en berge et ponctuelles moyennées sur la section, pour l'Isère et la Romanche

Hydrometric bank station monitoring will consist in establishing a solid gauging curve at a preferred site. The construction of this curve is comparable to the establishment of calibration curves for the continuous monitoring of river flow. Regular solid gaugings will have to be performed (by mobile hydrophone and / or sampling) in order to show the feasibility of calibrating a measurement of the solid flow in the bank and thus to provide a first estimate of the continuous solid transport flow by hydrophone.

Planning :

From this year (year 0), we will recruit a master student who will work on acoustic modeling in the river. The aim will be to take existing models (Petrut 2017, Geay et al 2018) and test the limits in different configurations. Ideally this student could continue in thesis.

The thesis will begin in year 1 with a bibliographic study coupled with field campaigns to complete the existing dataset. The bibliographic study will allow the student to appropriate the concepts, in particular on wave propagation physics and river acoustics applications. This year will also be used for first simple tests to drop into the laboratory and to test different sand sampling methods (protocol, material). The doctoral student will also have to think about the experimental protocols of year 2.

The year 2 will be dedicated to specific experiments (lab or field) for the study of the contribution of the granulometric components and for the measurement in bank. The experimental approach will be coupled to a theoretical analysis of these signals (noise models generated by thrusting and propagation effects, inversion algorithms for estimating thrust load parameters -granulometry, flux- from acoustic observations.). This second year will also be devoted to writing a first article on the validation of the acoustic method.

Year 3 will be a year dedicated to the finalization of the thesis, with the analysis of the data produced, the production of articles, and the writing of the manuscript (which can be on articles).

Collaborations:

The thesis will benefit from a strong synergy with other ongoing projects, in particular with the project SEISMORIV (in which Irstea is engaged with the IGE) which shares the same objectives as the thesis, since it aims to validate the seismic measurement. thrusting. This project already benefits from a post-doc in progress (with Maarten Bakker who joined Irstea Grenoble in September 2018) and a thesis will begin in the next months (recruitment in progress). A synergy will also occur naturally with the work done by Alexandre Hauet at EDF DTG on the aDcp fond fond (the idea being to try to calculate the flow carried from the adcp signal of the bed). Finally, a synergy is also expected with the ANR DEAR piloted by Irstea Lyon, which provides for numerous measurement campaigns on different rivers. Other cooperation is also in progress with the Universities of Tours (measures on the Loire) and Strasbourg (measures on the Moselle), and also with the Cerege which recently launched research actions on passive acoustic measurement of thrusting.

Valorisation :

Organisation :

The supervision of the thesis will be ensured by a team already invested for several years on this subject: Sébastien Zanker (EDF), Thomas Geay (Gipsa-Lab / Burgeap), Alain Recking (Irstea)

The doctoral student will be welcomed in the STRIM team of Irstea, under the direction of Alain RECKING (HDR).

The candidate must have a background in mechanics of continuous environments (Engineer or Master), have a good level of English, have provisions for computer programming, and be motivated for the field work.

A thesis committee will be set up. The group will be joined by Florent Gimbert (IGE), who works on the seismic measurement of thrusting, Benoit Camenen (Irstea Lyon) who is involved in the measurement of sands on different rivers, Oldrich Navratil (Lyon2

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