Surveillance du Transport de Charriage dans les Rivières par Inversion Acoustique Passive

Monitoring of Bedload Transport In Rivers by Passive Acoustic Inversion

Mohamad NASR (INRAE, Grenoble, France), **Thomas GEAY** (ONF, Chambéry, France), **Sébastien ZANKER** (EDF Hydro-DTG, Saint-Martin-le-Vinoux, France), **Jules LE GUERN** (GINGER BURGEAP R&D, Grenoble, France), **Adèle JOHANNOT** (INRAE, Grenoble, France), **Alain RECKING** (INRAE, Grenoble, France).

*auteur correspondant

1. Introduction

Difficulties in measuring bedload flux using conventional direct methods have led to the development of indirect surrogate techniques. One of these techniques is based on using hydrophone sensors to measure the self-generated noise (SGN) from colliding bedload particles. Recent field campaigns, on 15 different rivers, measured bedload flux with physical samplers and SGN with a drifted hydrophone (or acoustic mapping) at various positions on the river cross-section ([1] ; [2]). The results of these studies showed that the sediment flux $\bar{q}_s$ $(g\,/s/m)$ can be correlated to the measured cross-sectional average acoustic power $\bar{P}$ (μPa^2) by a unique power law (called global calibration curve) common to all measured rivers. Certainly, the measured SGN is not only dependent on bedload transport, but also on other processes that can explain the uncertainty in the field measurements. For instance, experimental and theoretical studies have shown that SGN measurements are also dependent on the propagation environment which describes how the acoustic signal is dispersed and attenuated as it travels away in the river. The different propagation environments between rivers can cause uncertainties when using the global calibration. A solution for the propagation problem is to use another proxy which is SGN source signal instead of the measured SGN signal. The SGN source signal is the signal generated at the bedload particles impact position (i.e. at the riverbed) before it propagates in the river. Hence the source signal is independent of the propagation environment of the river. In this study, we present the acoustic inversion method to calculate SGN source signals from measurements.

2. Method

The purpose of the inversion problem is to estimate the power spectral density (PSD in $\mu Pa^2 \cdot Hz^{-1}$, the variation of power with frequency) and the spatial distribution of bedload SGN sources in rivers. The riverbed is discretized into M sources distributed on the cross-section. The sources are supposed to be constant along the flow direction. Each source m is defined by its PSD per unit area $\mathscr{s}_m(f)$ $(\mu Pa^2 \cdot Hz^{-1} \cdot m^{-2})$ with m an integer $1 \le m \le M$. For this problem, N acoustic measurements are required at several positions on the river cross-section such that $N \ge M$. These measurements can be conducted following the "acoustic mapping" method with a drifted hydrophone. The parameter $\mathscr{p}_n(f)$ $(\mu Pa^2 \cdot Hz^{-1})$ corresponds to the PSD measured at the n^{th} position with n an integer $1 \le n \le N$. The acoustic measurements is the sum of all acoustic source signals, propagated from each source position to the hydrophone position (Eq. 1a). Where $\mathscr{a}_{m,n}$ is the frequency-dependent attenuation factor which is used to calculate the acoustic power loss for the source signal generated at m^{th} position and propagated to n^{th} measuring position in the river. The attenuation factor $\mathscr{a}_{m,n}$ is dependent on the distance between the source and hydrophone as well as river characteristics such as riverbed slope and roughness. This factor can be inferred from measurements using an acoustic active protocol (Geay et al. 2019). When equation 1a is applied to the whole measuring domain we obtain the formulation as in Eq. 1b.

$$\mathscr{p}_n(f) = \sum_{m=1}^{M} \mathscr{a}_{m,n}(f).\mathscr{s}_m(f) \qquad (1a)$$

$$\begin{pmatrix} \mathscr{p}_1(f) \\ \vdots \\ \mathscr{p}_N(f) \end{pmatrix} = \begin{pmatrix} \mathscr{a}_{1,1}(f) & \cdots & \mathscr{a}_{M,1}(f) \\ \vdots & \ddots & \vdots \\ \mathscr{a}_{1,N}(f) & \cdots & \mathscr{a}_{M,N}(f) \end{pmatrix} \cdot \begin{pmatrix} \mathscr{s}_1(f) \\ \vdots \\ \mathscr{s}_M(f) \end{pmatrix} \qquad (1b)$$

For the inversion problem, we seek the solution of the source vector in Eq. 1b, which allows the best fit of the measured vector. The solution can be calculated using the non-negative least square (NNLS), a constrained least squares problem where the coefficients are not allowed to become negative.

3. Example of SGN source inversion

In this section, we present an example SGN source inversion carried out on the Giffre river located in French Alps. On this river, SGN measurements were carried out with the drifted hydrophone method (acoustic mapping). Figure 1a shows the measured acoustic power profile (in μPa^2) calculated by frequency integration of the median measured PSD above 2 kHz for each drift. Using this measured acoustic profile and the active test results conducted on the measuring site, the bedload SGN source has been inversed and the results of inversed acoustic power (in $\mu Pa^2/m^2$) are presented in Figure 1b. In addition, bedload flux has been sampled from the bridge using a handheld Elwha sampler at various cross-sectional positions and the measured bedload flux is presented in Figure 1c. To compare these three previous profiles, we present the relative profiles in Figure 1d. The comparison shows a better synchronization of the bedload flux profile with the inversed power profile than the measured power profile. This is particularly evident when considering the peaks and the sharp transition to low transport at the side of the section. This can be explained by the fact that the acoustic measurements are attenuated signals and are not only due to the locally generated noise but also to the noise propagated from all the sources in the river. On the other hand, SGN

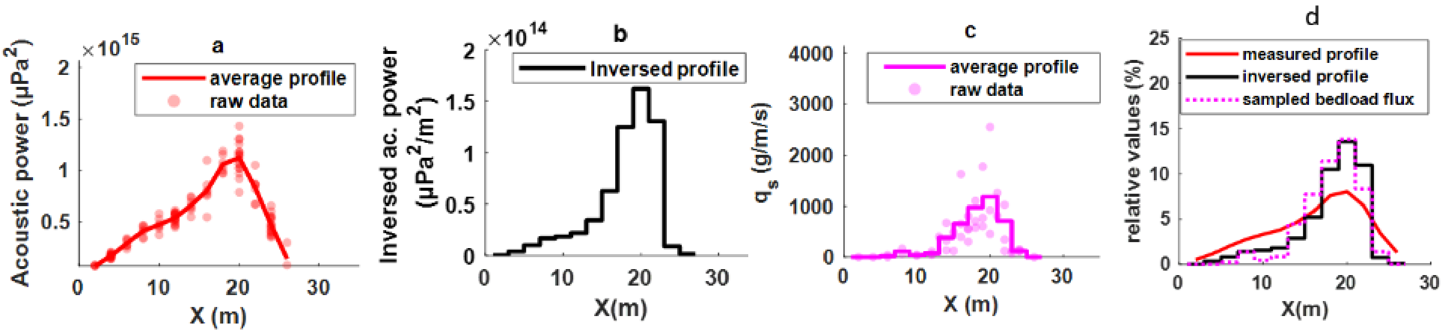

Figure 1 Results on the Giffre River for a) measured acoustic power by acoustic mapping, b) inversed SGN source profile, c) sampled bedload flux, d) relative profile of the profiles in a, b and c

source is dependent on the local bedload flux values.

4. Conclusion and perspectives

In this study, we presented an inversion model to locate the SGN sources and calculate their acoustic power using acoustic mapping measurements. Testing the inversion model on field data showed that the inversed SGN source can locate bedload transport zones and better describes bedload flux than the measured acoustic signal. Following the encouraging results in addition to our theoretical understanding of the SGN in rivers, it is a matter of interest to investigate using the SGN sources signal to monitor bedload flux. Using the dataset of the global calibration curve (Eq. 2a) presented [2], and after inversing the whole data set we obtain another global calibration curve (Eq. 2b) based on inversed average cross-sectional acoustic power $\overline{P^*}$ (in $\mu Pa^2/m^2$).

$\bar{q}_s = 4.2 \times 10^{-9}\bar{P}^{0.76};\ R^2 = 0.72$ (2a) $\qquad \bar{q}_s = 3.7 \times 10^{-7}\overline{P^*}^{0.67};\ R^2 = 0.74$ (2b)

Comparing the correlation coefficient (R^2) of both calibration curves shows that the inversion model didn't contribute to a significant improvement of the data fit. However, the main difference between these two calibration curves relies on the estimation of bedload flux. Regardless that the theory of SGN supports that using the inversed global calibration curve should improve bedload flux monitoring, however, a definitive conclusion on the improvement carried out by using the inversed global calibration curve requires field validations. In addition to bedload flux monitoring, additional investigation can be implemented on the effect of using inversed SGN source signal to estimate bedload particles grain-size distribution (GSD). Finally, developing a bidimensional (2D) inversion model allows the characterization of the spatial variability of bedload transport over the measured zone. The latest information can be useful for diverse applications such as calibrating bedload transport models.

5. REFERENCES

[1] Geay T, Zanker S, Misset C, Recking A. 2020. Passive Acoustic Measurement of Bedload Transport: Toward a Global Calibration Curve? J Geophys Res Earth Surf. 125(8):e2019JF005242. doi:10.1029/2019JF005242.

Nasr M, Johannot A, Geay T, Zanker S, Le Guern J, Recking A. 2023. Passive Acoustic Monitoring of Bedload with Drifted Hydrophone. J Hydraulic Eng.