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AcouSed: a software for acoustic inversion to compute concentrations of suspended sediments in rivers.

B. Moudjed, C. Berni, J. Le Coz, B. Camenen

INRAE - UR RiverLy, Lyon Villeurbanne, France

ABSTRACT: Down-looking multi-frequency Acoustic Backscattering Systems (ABS) have been deployed at the surface of rivers for several years, to measure the suspended solids throughout the water column. The acoustic backscatter signal is processed using multi-frequency inversion method to compute suspended sediments concentrations. This method involves both water sample calibration and models to determine the acoustic properties of suspended particles. This document presents a software, named *AcouSed*, developed to make complex theoretical acoustic inversion methods accessible. Acoustic backscatter signal is visualized and preprocessed in the software. Both, concentration and particle size distribution of water sampling are also plotted and used to calibrate the acoustic signal. *AcouSed* was designed so that the user can control inversion method options and plot results.

1 INTRODUCTION

Investigating and understanding sediment suspension within rivers is an important question due to many reasons for river management (hydroelectric facilities, biodiversity, quality of water, etc.). The use of samplers for sediment flux measurements remains the reference although it is time-consuming, often difficult to deploy during floods, and provides a very limited and discrete description of concentration throughout the cross-section. In the past decades, Acoustic Doppler Current Profilers (ADCPs) and Acoustic Backscatter Systems (ABSs) have been deployed in rivers to extract information on Suspended Sediment Concentration (SSC) from acoustic backscatter signal (Topping *et al*., 2007, Moore *et al*., 2012, Landers *et al*., 2016, Haught *et al*., 2017). These instruments provide measurements at a much higher spatial and temporal resolution than traditional water sampling. However, the measurement is indirect as it requires a complex and uncertain inversion of the backscatter signal into concentration, which requires as many calibration data (samples) as possible.

It is now well known that Particle Size Distributions (PSD) observed in rivers are often bimodal (Wright *et al*., 2010). The first mode is usually composed of fine silt and clay particles, and is often fairly homogeneous in concentration throughout the river cross-section. The second mode is made of fine to coarse sand particles and it usually presents strong lateral and vertical gradients, with concentration increasing towards the bed. Sonar technology (ADCP and ABS) could potentially provide information on both of these modes.

Based on studies in both acoustic oceanography (acoustic response of a suspension of sand particles) and rivers, Vergne *et al*. (2020) investigated the less known question of acoustic response of suspended sediments in rivers. Suspension of fine sediments must have an impact on recorded backscatter signal. An acoustic inversion method was then successfully developed to evaluate SSC of fines and sand within the river cross-section.

This work confirms the capacity of hydro-acoustic technology for providing spatial information on river suspensions. An open-source software, named *AcouSed* (for Acoustic backscattering for concentration of suspended Sediments in Rivers) is developed to apply this method more easily so it can be shared with a broad public. More generally, *AcouSed* focuses in making these methods convenient to use for those who are not acoustics experts, for sediment studies and research in rivers, estuaries and coastal areas. It allows to read and visualise raw data from different ABS instruments, to pre-process the acoustic signal and sample data (PSD and concentration) and apply "in an easy way" an implemented inversion method applicable to the measurement conditions.

2 ACOUSTIC INVERSION METHOD

As depicted in Figure 1, acoustic signal recorded from ABS in the river cross section is processed using a multi-frequency inversion method. Water samples are simultaneously collected in order to calibrate the backscattered signal on one vertical. It is assumed that signal backscatter is mainly due to sands and acoustic attenuation is dominated by fine sediments. Sediment calibration consists in estimating the attenuation due to fine sediments as the acoustic theory is not reliable for the platelike particles found in rivers (Vergne *et al*., 2021). A sand concentrated sample is taken as the "target sample", and for which, concentration and PSD are known. The acoustic attenuation of fine sediments, α_S is computed along the backscattered signal path, from the target sample up to the acoustic sensor. The sediments acoustic attenuation constant, ζ (see Figure 1), is evaluated by dividing α_S by the concentration profile of fine sediments integrated along the acoustic path. The backscattered signal is, by this way, corrected with the path through the fine sediments. The calibration vertical is chosen with sufficient sand in the target sample so that backscatter signal can be measured at the surface. The calibration constant, k_t, is directly linked to the ABS and measurement parameters. The backscatter dimensionless parameter, X, is directly calculated from concentration and PSD of the target sand sample. These parameters are used to evaluate the Volume Backscatter Index (*VBI* in Figure 1) in the model. The backscatter acoustic signal is then inverted, through *VBI*, to compute the separate *SSC* of sand and fine sediments. Details of the method are provided in Vergne *et al*. (2020), section 4.3: Acoustic inversion at site 2 (High SSC). This method can be applied, in the same manner, deploying the ABS instrument either throughout the river cross section (2D spatial variation) or in one position (temporal variation).

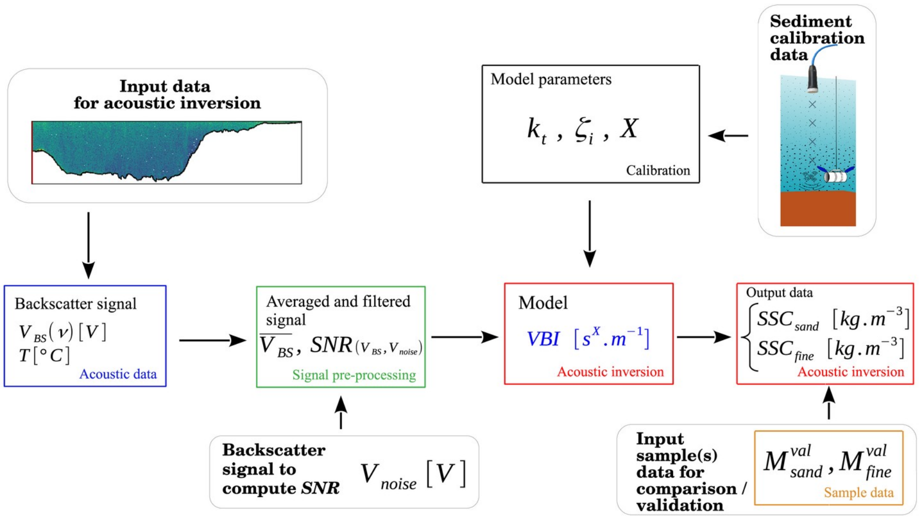

Figure 1. Acoustic inversion method from Vergne et al. (2020). Tabs of *AcouSed* software are illustrated through squares with right angles. Squares with curved corners correspond to input data needed in *AcouSed* to compute and validate the model. Acoustic backscattered signals V_{BS} and V_{noise} are used to calculate *SNR* (Signal to Noise Ratio) and to pre-process V_{BS}. Volume Backscatter Index (*VBI*) is computed from both, preprocessed V_{BS}, and parameters such k_t (the calibration constant of ABS), ζ (the sediment acoustic attenuation constant) and X (the dimensionless exponent). SSC_{sand} and SSC_{fine} are respectively sand and fine sample concentrations used to compare concentrations calculation (M^{val}_{sand} and M^{val}_{fine}).

3 *ACOUSED* SOFTWARE ARCHITECTURE

AcouSed was designed using *PyQt*, a package from *Python* programming language, and is an open source software (compatible with *Windows*, *macOs* and *Linux*) meant to be shared with a broad public (https://gitlab.irstea.fr/brahim/acoused). In its latest version, *AcouSed* is divided in seven tabs including Acoustic data, Signal pre-processing, Sample data, Calibration, Acoustic Inversion, Note and User manual. The data from two commercially-available ABS models: the *AQUAscat* (from *Aquatec*) and the *UBSediFlow* (from *Ubertone*), are supported by the software. The graphical interface, in particular for inversion tab, was developed from the inversion method for high concentration explained in Vergne *et al*. (2020). The acoustic signal data recorded at the Isère-Rhône confluence (France), during upstream dam flushing in January 2018 (high sediment concentrations of around 10 g/L), was used to develop *AcouSed*.

The “Acoustic data” tab is illustrated in Figure 2. It is organized with 5 group boxes including Download, Measurements information, Display options, Raw acoustic data 2D field and Profiles. The Acoustic backscatter raw signal (V_{BS} in Figure 1) is imported from two file formats: “*.aqa” for *AQUAscat* or “*.udt” for *UBSediFlow* according to the user choice. Data conversion from time to space (distance from one bank) will be implemented using either a constant velocity (the total distance divided by the duration of the record) or downloading the GPS file if available. When an acoustic file is downloaded, measurements information and the graphs are automatically created or updated. The limits of the recorded signal, for all the process up to inversion, can be defined in time (if GPS box is not filled) or in space (if GPS data are entered). A river bed detection algorithm is also implemented. The maximum backscatter value is detected along the first vertical between two depth values fixed by the user. The search area is then moved, at the next vertical, by plus or minus a value defined by the user. The process is repeated up to the last vertical to draw the river bed line.

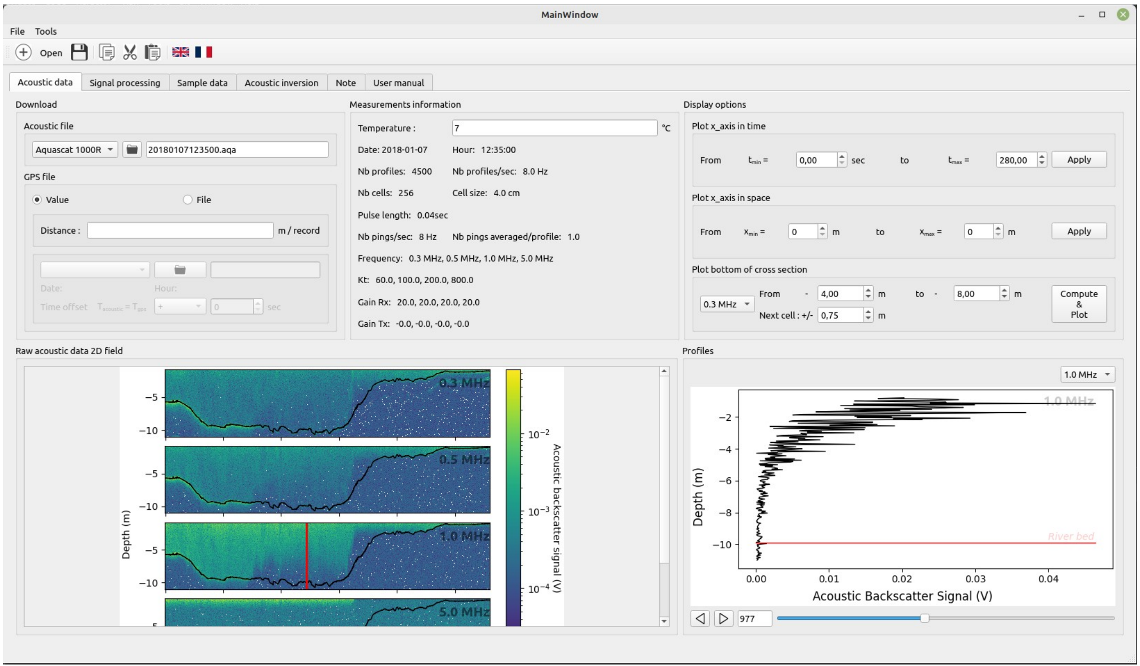

Figure 2. “Acoustic data” tab for acoustic backscatter signal input data. River stream bed is plotted for each frequency with black solid line on backscattered signal 2D fields (bottom left) where vertical red solid line illustrate profile position. Profile (bottom right) is plotted for one frequency, selected with combo box at the top right corner of the figure area. The horizontal red solid line represents the river bed.

Noise data must be defined in “Signal pre-processing” tab (Figure 3), either downloading a file or from the profile tail (see Vergne *et al*. 2020) or with entering a value. All the graphs are plotted automatically as soon as a noise data file is uploaded (or constant value or profile tail value is defined): noise 2D field, *SNR* (Signal-to-Noise Ratio) 2D field, pre-processed V_{BS} with *SNR* criterion, and averaged profile. *SNR* filter means that any value of the signal is removed if the *SNR* is lower than a value. Rayleigh criterion filter can also be used to “despike” the signal (details of the filter are provided in Appendix A of Vergne *et al.* 2020). Average is applied for all cells, between a number of cells along the horizontal and around the considered cell.

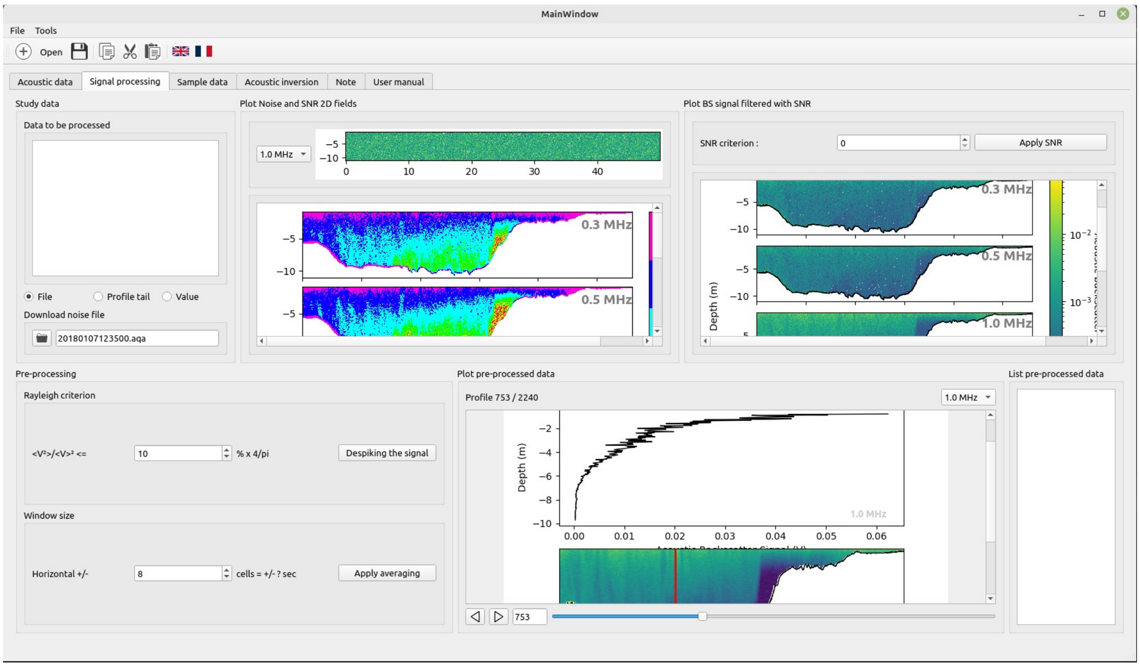

Figure 3. “Signal pre-processing” tab (under development). Noise data, *SNR* and filtered raw backscatter signal are plotted in the top half. Pre-processed profile and 2D field are plotted in the bottom half, for one frequency, selected with the combo box at the top right corner of the figure area. The vertical red solid line represents the position of the profile.

The results from water samples collected on site are uploaded in the “Sample data” tab (Figure 4) in Excel (*.xls) or Libre Office Calc (*.ods) formats in two separated files: one for sand and one for fine sediments. They both include the same information: time, distance from bank, depth, total concentration, D50 diameter, diameter of cumulative PSD (volume fraction, in percent, of the particles in the sample, with a diameter less than or equal to the considered diameter). This tab only allows to plot and visualize the position, total concentration and PSD of samples. *AcouSed* can then be used as a PSD viewer tool.

For the present paper, “Calibration” and “Acoustic inversion” are presented as a single tab (Figure 5). Sample data are selected for sediment calibration and acoustic parameters are shown. Here the same acoustic file is used for the calibration and the inversion. Final results are plotted and comparison between measured concentration (M_{sand}^{val} and M_{fine}^{val} in Figure 1) and computed concentration (SSC_{sand} and SSC_{fine} in Figure 1) is provide on the tab.

4 DISCUSSIONS

Acoustic parameters provided in Figure 1 (k_t, ζ_i and X) can be calculated using the sand sediments concentration (target sample) and the fine sediments concentration profile. Parameter ζ_i measured the capacity of fine sediment to attenuate the acoustic backscatter signal, from the target sample position (as close as possible to the bottom) to the acoustic sensor (at the surface). Sufficient level of sand concentration is needed so that the attenuated signal can be measured in the surface. Nonetheless, in some cases and for practical reasons, sand target sample can’t be collected in suitable conditions. Position is not closed enough to the river bed. Sand concentration is to low. Furthermore, depending on ABS used, the calibration parameter k_t may not be well known. Based on these limitations, values of calibration and model parameters are computed and including in “spin boxes widgets”. So that, they can be adjusted by the user to have realistic value of acoustic sediment attenuation and thus, obtain a better fit of inversion method. Another way to adjust parameters will be to use calibration file from other similar measurement, in terms of concentration and PSD. To conclude, new measurement campaigns are planned in 2024 to used inversion method with new data and compared results between ABS.

5 CONCLUSION

We present a new open-source software named *AcouSed* which aims at making complex acoustic inversion methods accessible to non-expert in acoustics. So far, it is adapted for *AQUAscat* and *UBSediFlow* ABS instruments and includes a sample PSD viewer. It is meant to be shared with a broad public through a simple executable file compatible with *Windows*, *macOs* and *Linux*. The new version is designed so that acoustic data for calibration and inversion can be different. A number of future developments are planned such as, in the short term, register a study, implement new inversion method (for low concentration) or, in the longer term, include other ABS instruments and GPS positioning for georeferencing and mapping the results.

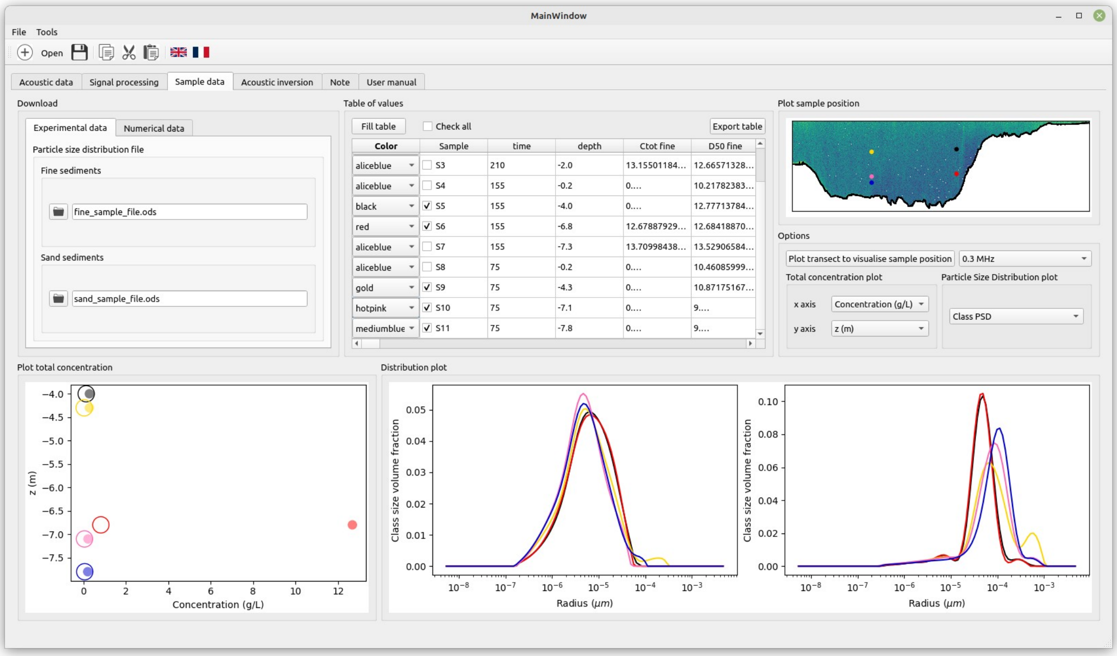

Figure 4. "Sample data" tab for sample input data. Fine and sand sediments are downloaded separately and data is concatenated in the central table. Checkboxes allow to select samples to plot in terms of position on the recorded signal 2D field (top right), concentration (bottom left) and particle size distributions (bottom right) of fine (left) and sand (right) sediments. Large empty circles and small filled circles represent fine and sand sediments, respectively, on concentrations plot.

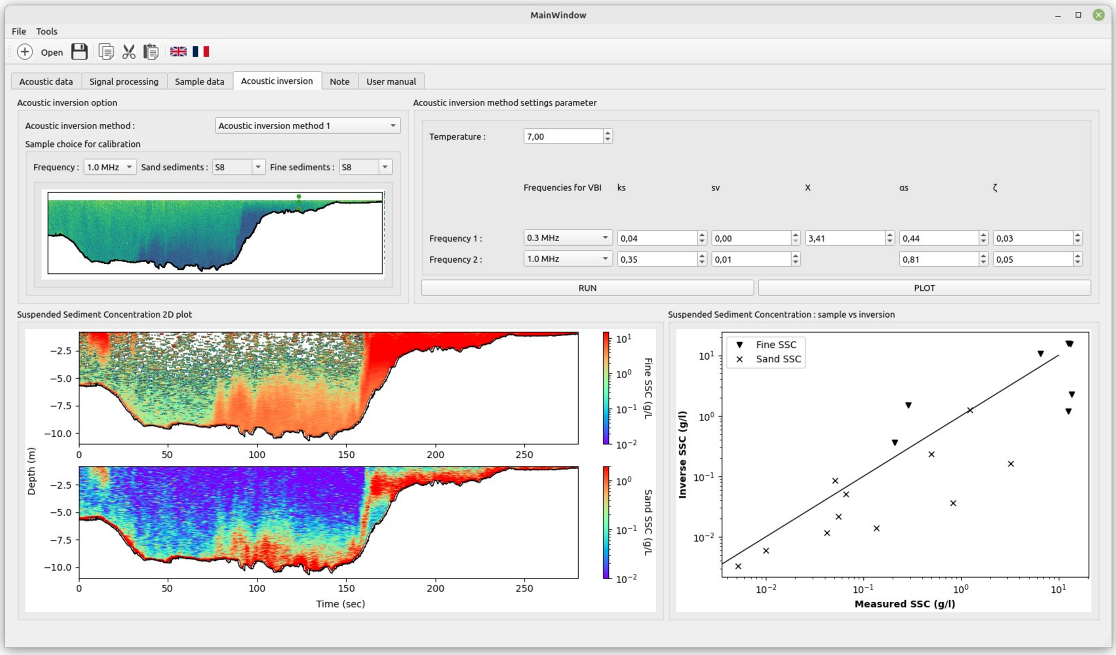

Figure 5. "Acoustic inversion tab". Samples choice for sediment calibration are plotted at the top left. SSC of sand and fine sediments are drawn at the bottom left. Inverted SSC are plotted according to the measured SSC at the bottom right. Black solid line correspond to the ideal case where inverted and measured concentrations are equal.

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REFERENCES

Haught, D., Venditti, J. G., and Wright, S. A., 2017. Calculation of in situ acoustic sediment attenuation using off-the-shelf horizontal ADCPs in low concentration settings. *Water Resour. Res.*, 53:5017-5037.

Landers, M. N., Straub, T. D., Wood, M. S. & Domanski. M. M., 2016. Sediment acoustic index method for computing continuous suspended-sediment concentrations. USGS Techniques and Methods, book 3, chap. C5. URL http://dx.doi.org/10.3133/tm3C5.

Moore, A., Le Coz, J., Hurther, D., & Paquier, A, 2012. On the application of horizontal ADCPs to suspended sediment transport surveys in rivers. *Cont. Shelf Res.*, 46:50-63.

Topping, J., Wright, S. A., Melis, T. S., & Rubin, D. M., 2007. High-resolution measurements of suspended-sediment concentration and grain size in the Colorado River in Grand Canyon using a multi-frequency acoustic system. *Proceedings of the 10th International Symposium on River Sedimentation*, Russia, Moscow.

Vergne, A., Le Coz, J., Berni, C., & Pierrefeu, G., 2020. Using a Down-Looking Mutlifrequency ABS for Measuring Suspended Sediments in Rivers. *Water Resources Research,* 56(2).

Vergne, A., Berni, C., Le Coz, J., & Tencé, F., 2021. Acoustic Backscatter and Attenuation Due to River Fine Sediments: Experimental Evaluation of Models and Inversion Methods. *Water Resources Research*, 57(9).

Wright, S. A., Topping, D. J. & Williams, C. A., 2010. Discriminating silt-and-clay from suspended-sand in rivers using side-looking acoustic profilers. *Proceedings of the 2nd Joint Federal Interagency Sedimentation Conference*, USA, Las Vegas.