Webinar Acoustic Monitoring

Experimental evaluation of hydro-acoustic models and inversion methods in rivers

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as well as
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Contributions

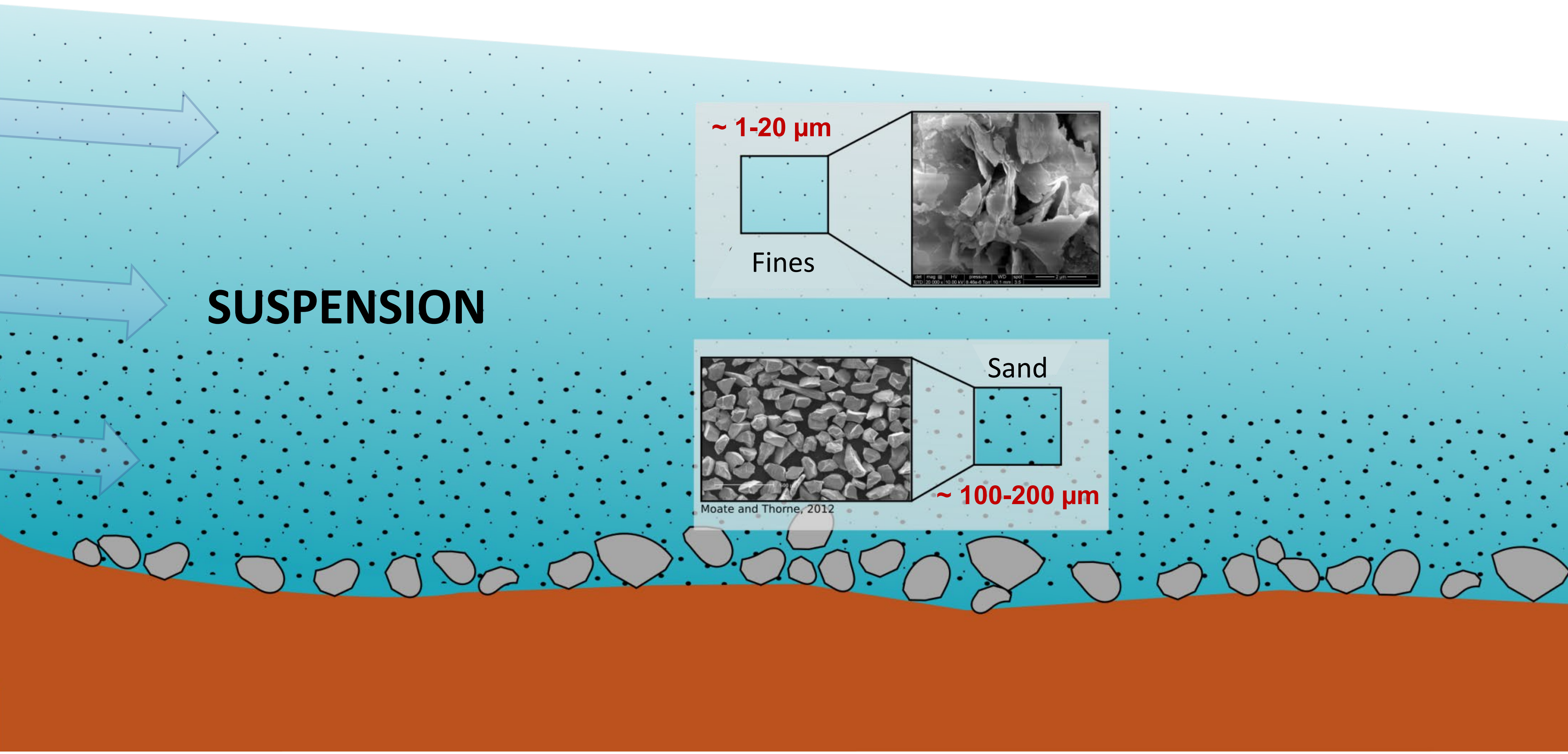
Mainly PhD's work of Adrien Vergne

Co supervised with

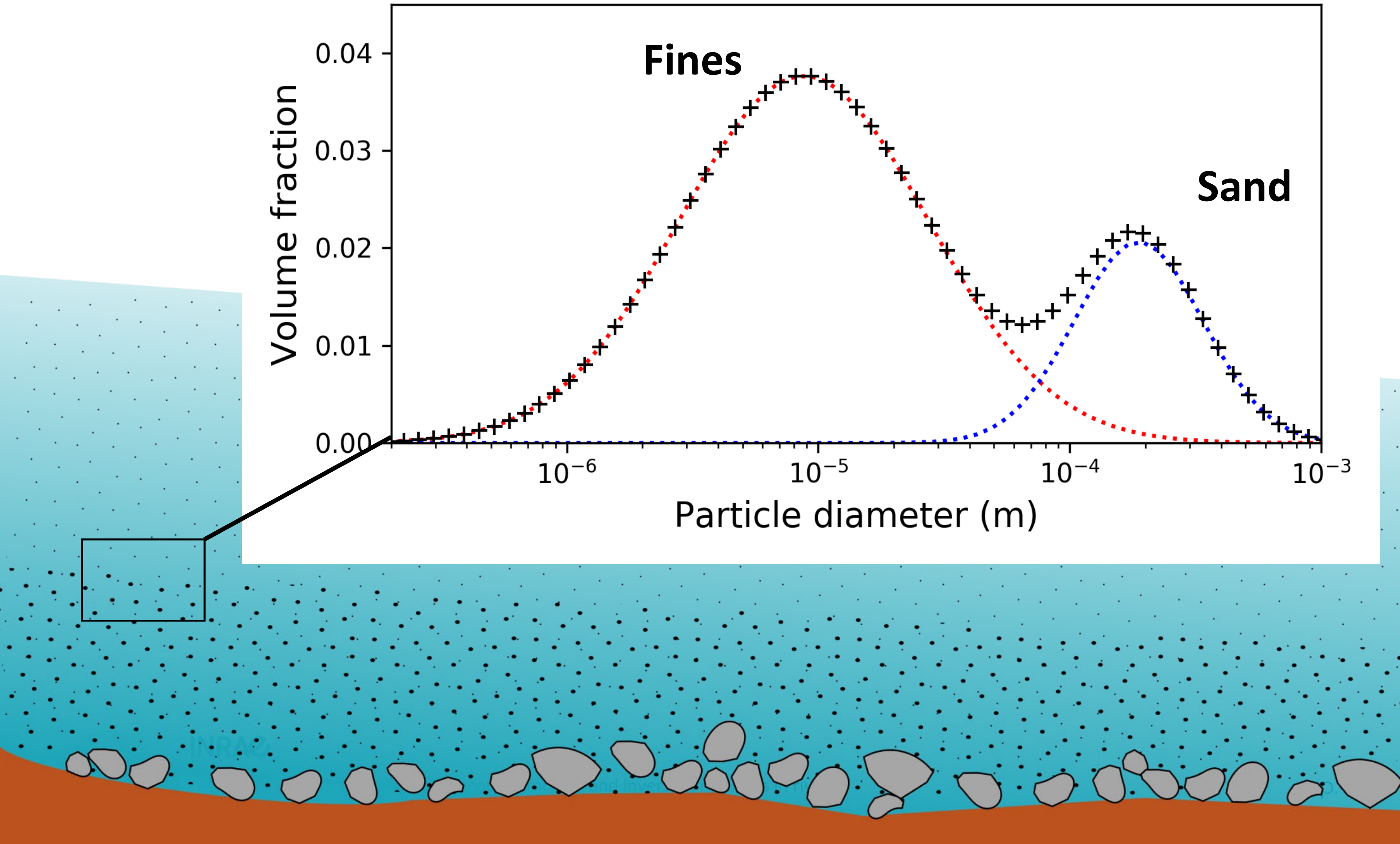
Jérôme Le Coz

Followed by developments of Brahim Moudjed

Suspended sediments in rivers



Bimodal distribution of sediments



Suspended sediments

Flux of suspended sediments in the **Rhône** River : ≈ **16 Mt/year** (Provansal et al., 2014)

Human impacts

- Hydraulic structures
- Change of land-use

Need to quantify suspended sediment fluxes:
both **fines and sand**

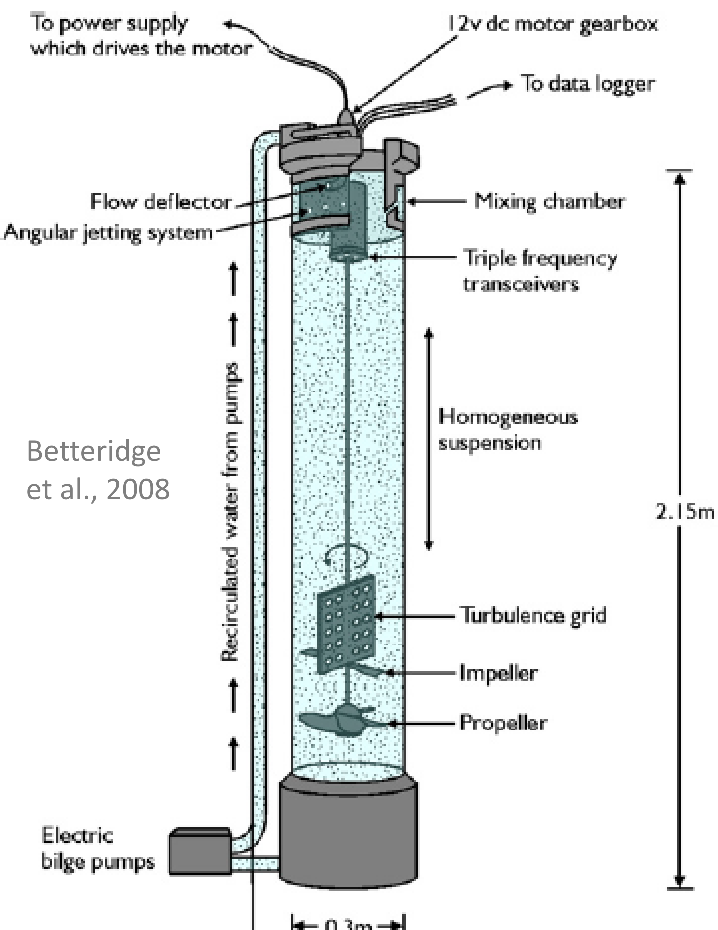
Issues

- Ecosystem habitats
- Flooding (fine sediment accumulation, plants growth …)
- Sedimentation in reservoirs
- Pollutants diffusion (PCB, pesticides, …)
- Erosion (shoreline)

Previous work in oceanography

Acoustic inversion for sand:

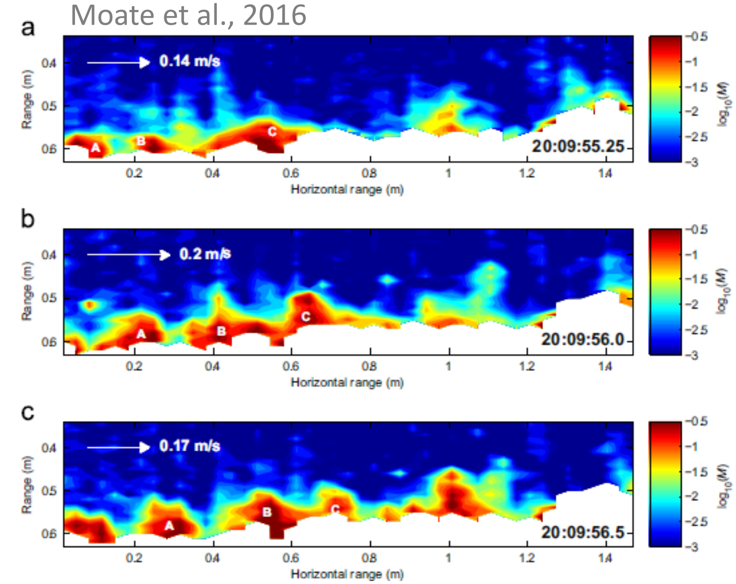
Laboratory experiments: **acoustic models** for suspended sands → Inversion methods are developped



Betteridge et al., 2008

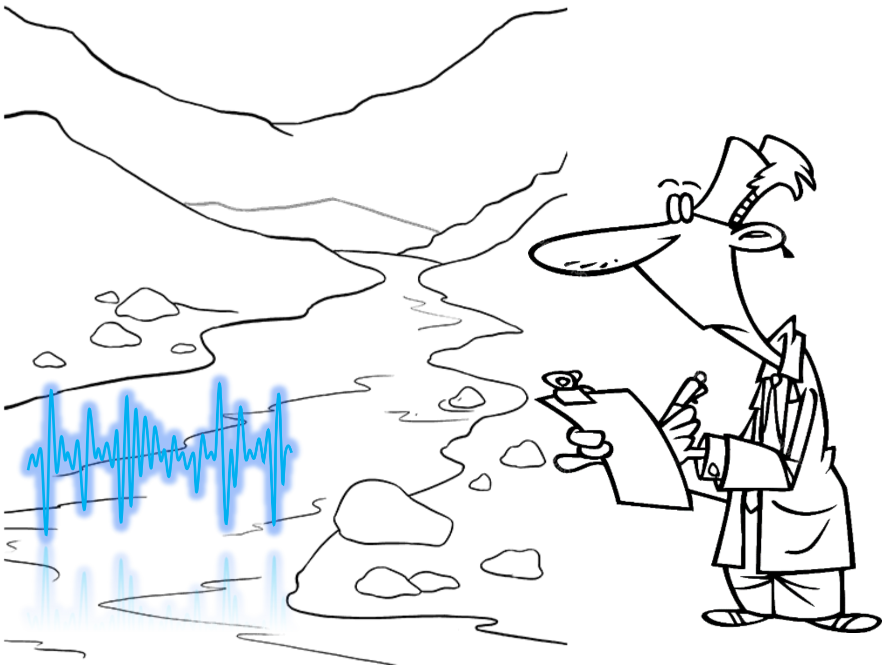
Moate et al., 2016

In situ set-up: concentration vs time and space



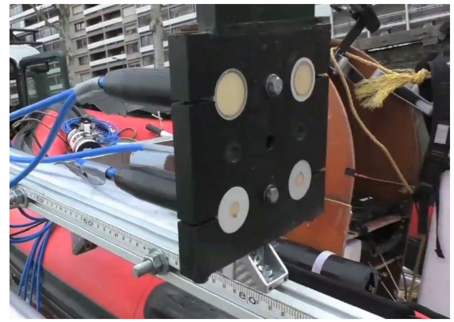
Moate et al., 2016

What about rivers?



Preliminary measurements in rivers

Can we use « ocean models » for rivers?



Measurement of backscatter with an acoustically calibrated multi-frequency ABS

Samples

Acoustic model

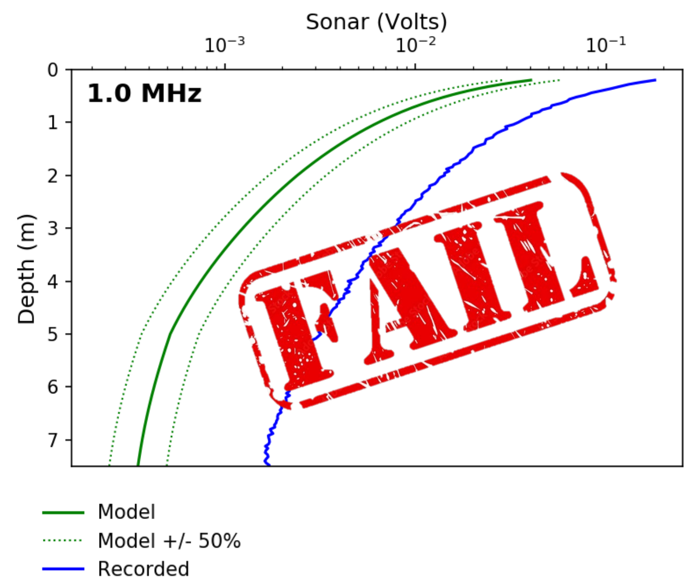
(Thorne et Hurther, 2014)

$$V_{rms} = \frac{\Re\sqrt{s_v}}{\psi r}\, \mathrm{e}^{-2\alpha r}$$

$$\alpha_s = \frac{3M \int_0^\infty a^2(\chi_{sv} + \chi_{ss}) n(a) da}{4\rho_s \int_0^\infty a^3 n(a) da}$$

$$s_v = \frac{3}{16\pi} K^2 M$$

$$K = \left[\frac{\int_0^\infty a^2 f_\infty^2(a) n(a) da}{\rho_s \int_0^\infty a^3 n(a) da} \right]^{1/2}$$

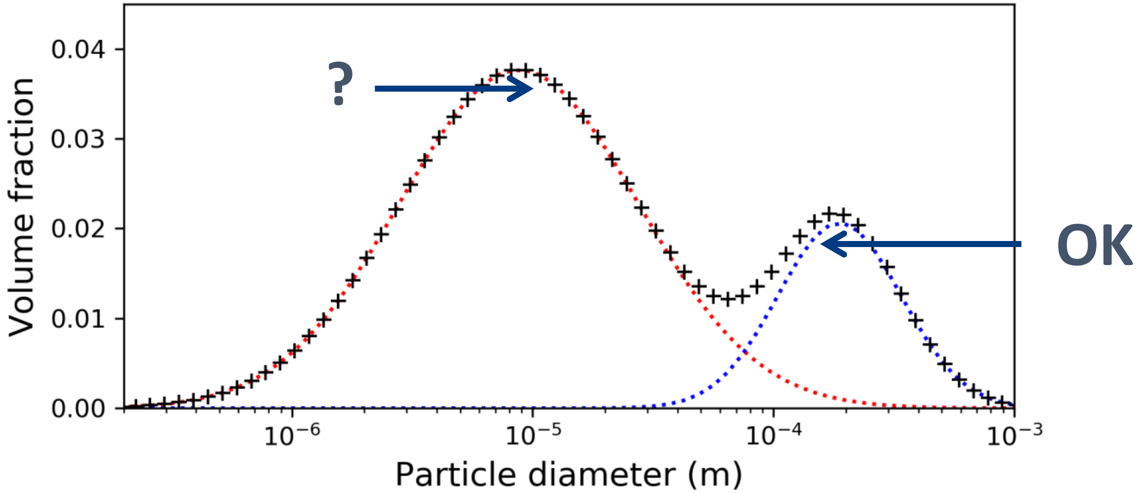


Where does the problem come from?

- Possible answers:
  - Previous models does not apply to **fine sediments**?
  - **Other scatterers** (bubbles, agregates, …) exists?
- **When** can we nevertheless measure suspended sediment concentration in rivers from backscatter?

Acoustic backscatter of fine sediments

In rivers: bimodal distribution



- **Sand** acoustic backscatter is well known.

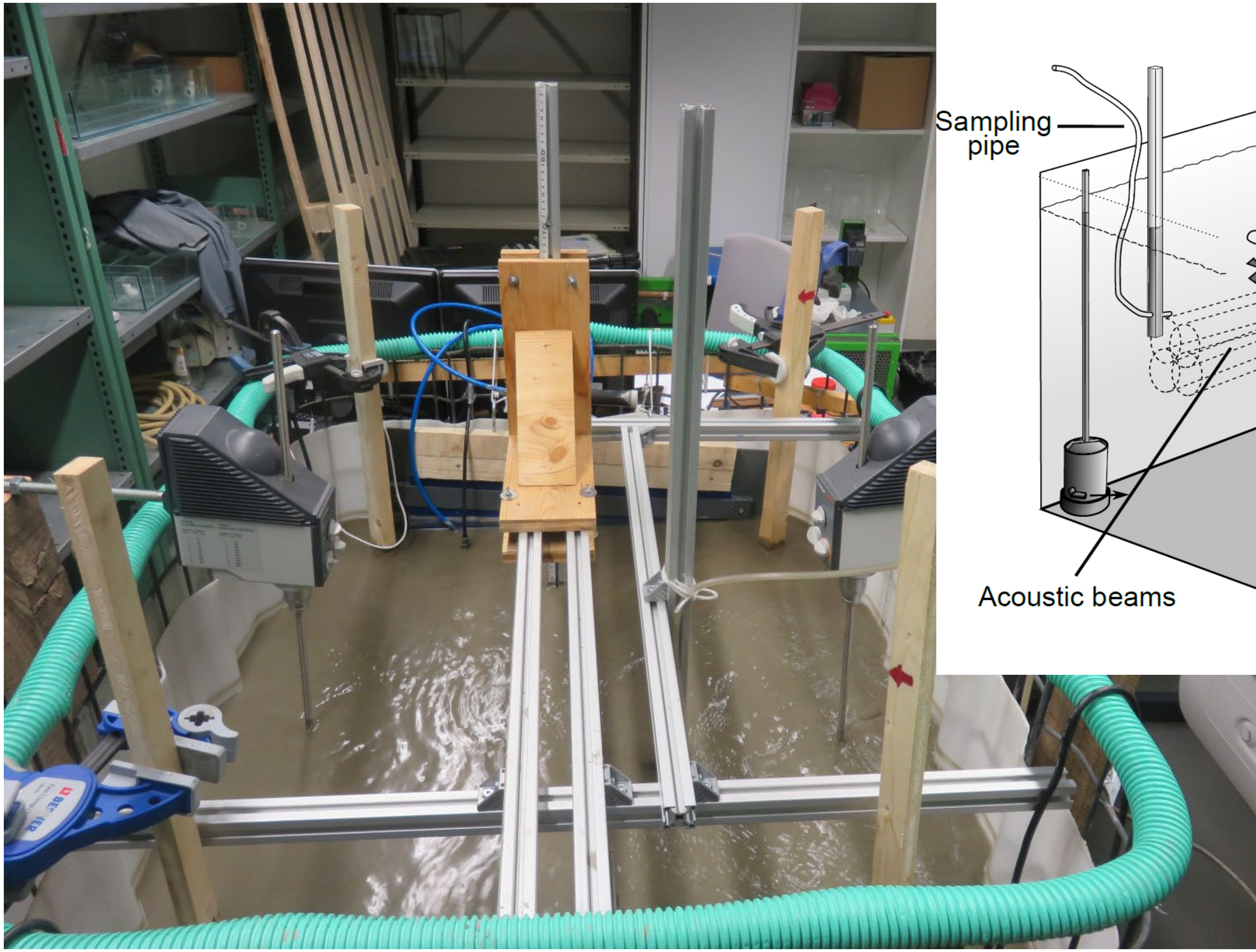
(Sheng et Hay, 1988 ; Hay, 1991 ; Hay et Sheng, 1992 ; Thorne et al., 1993, Thorne et Buckingham, 2004 ; Thorne et Meral, 2008 ; Moate et Thorne, 2012)

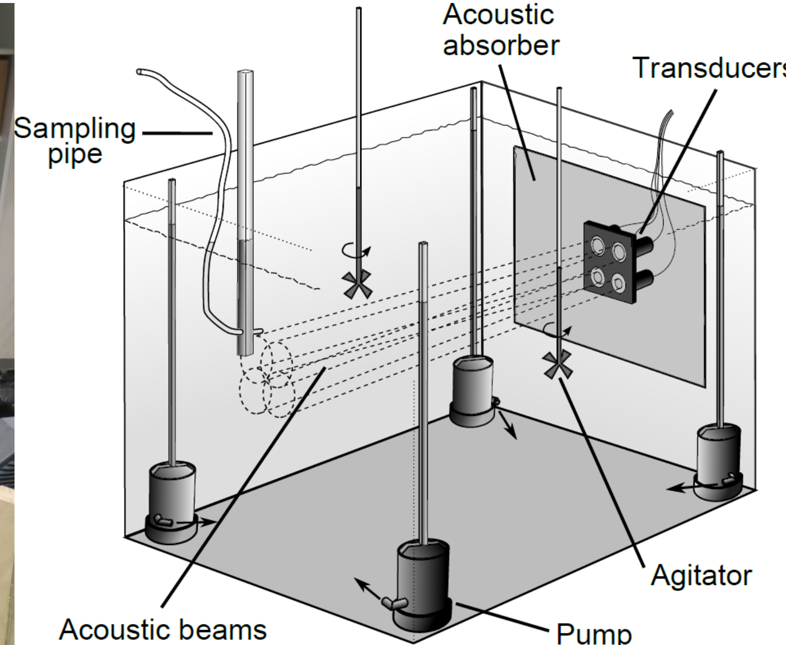
- But only a few studies were dedicated to **fine sediment** backscatter (Urick, 1948 ; Richards et al., 2003)

→ Laboratory experiments with river fine sediments

Experimental set-up

Homogeneous suspension of fine sediments (stable with time)





Experimental set-up

Acoustic measures: attenuation (α_s) and backscatter (s_v)

Experimental set-up

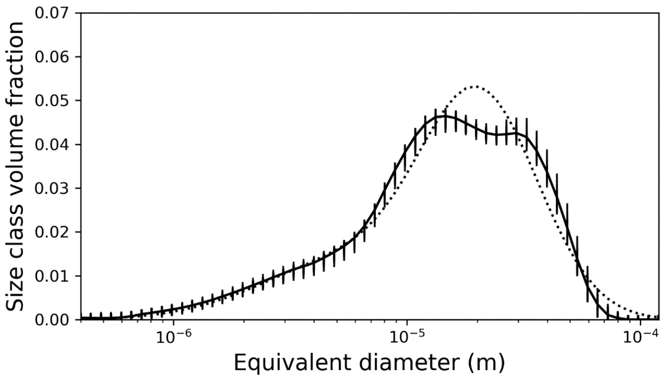
Samples : **concentration** **(filtration)** and **grain size distribution** **(laser)** measurements

Does previous models apply to fine sediments?

concentration

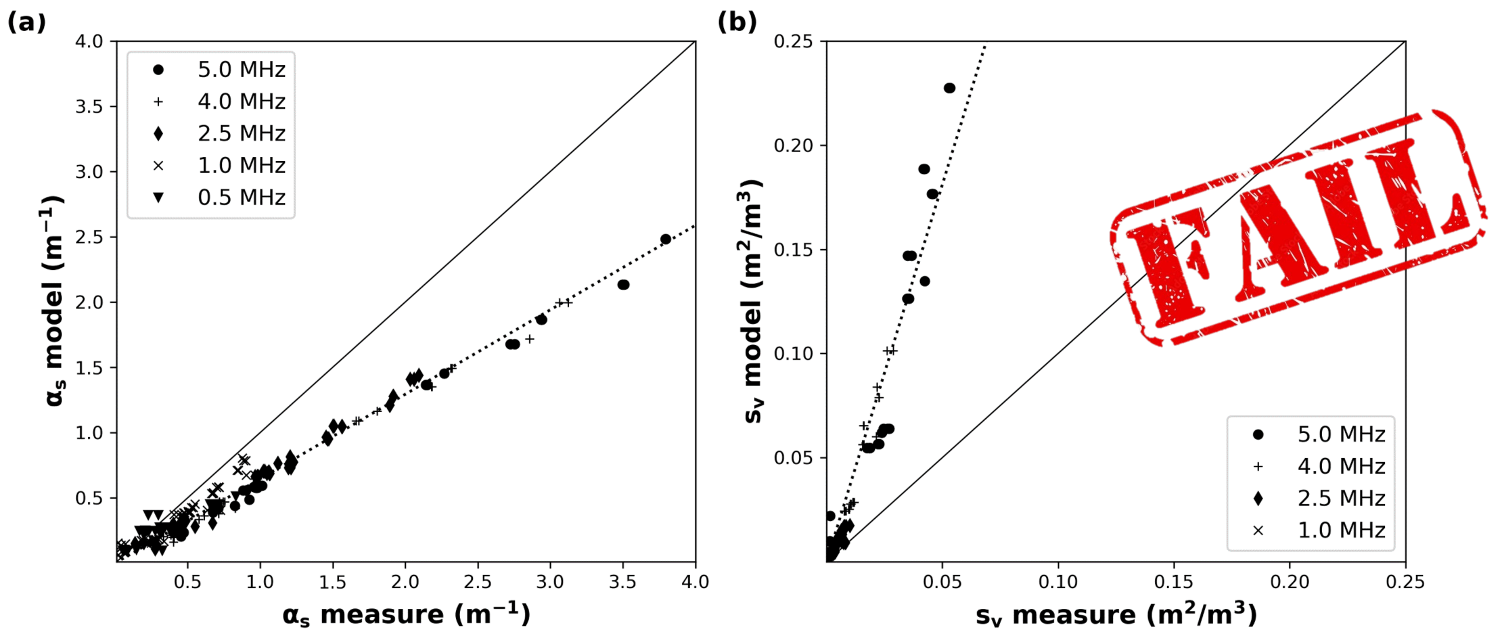
+

GSD



→ Acoustic model

- attenuation $\boldsymbol{\alpha_s}$ (Urick, 1948)
- backscatter $\boldsymbol{s_v}$ (Moate et Thorne, 2012)

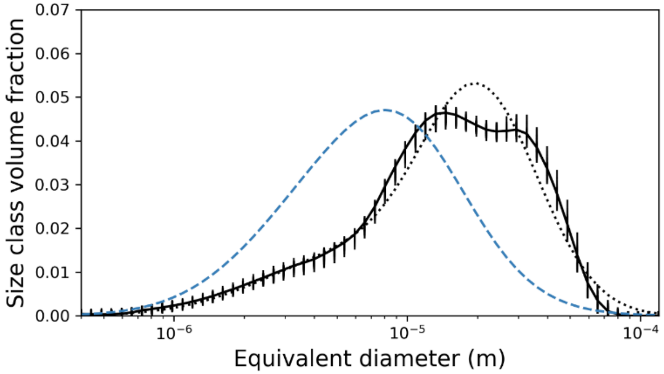


Does previous models apply to fine sediments?

concentration

+

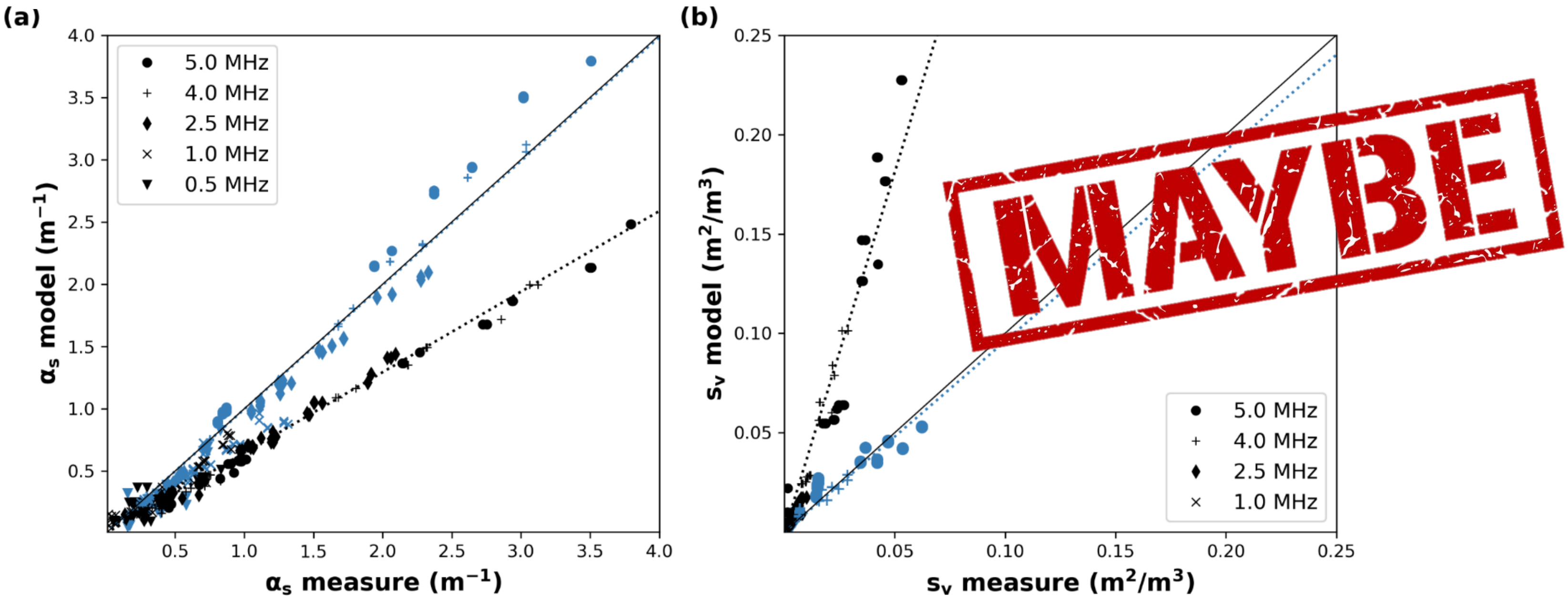
GSD



→ Acoustic model

attenuation α_s (Urick, 1948)

backscatter s_v (Moate et Thorne, 2012)

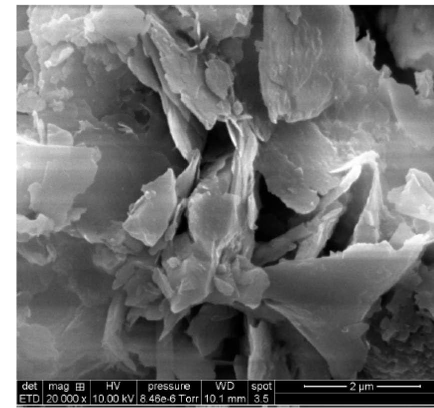


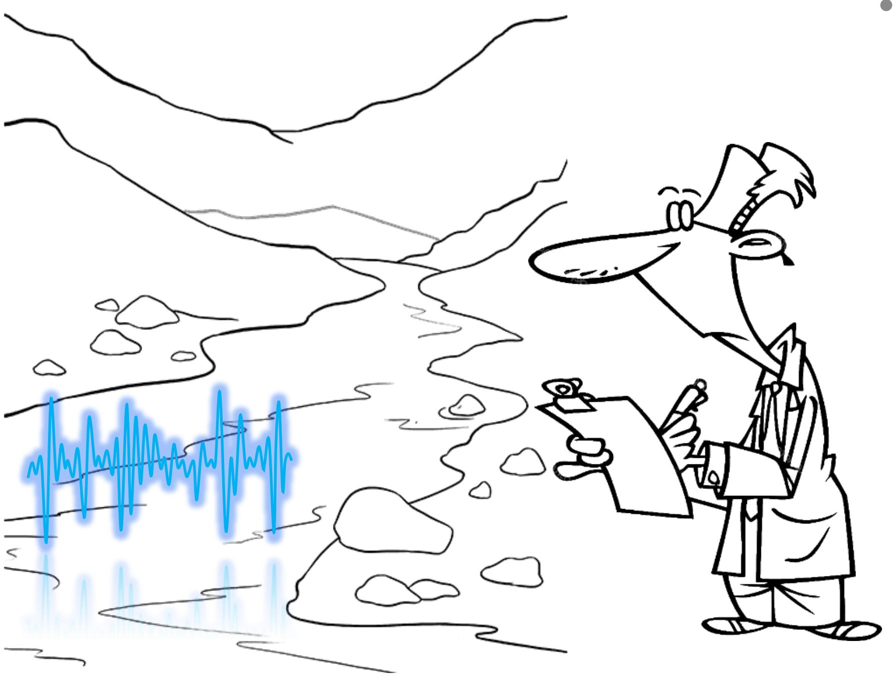
What about rivers?

Acoustic backscatter in rivers is significantly different from what acoustic models predicts

It can be partly due to fine sediment response

- Difficulties in applying spherical models
- What is the representative diameter ?
  - Adjusting it, we can get concentration from acoustic signal

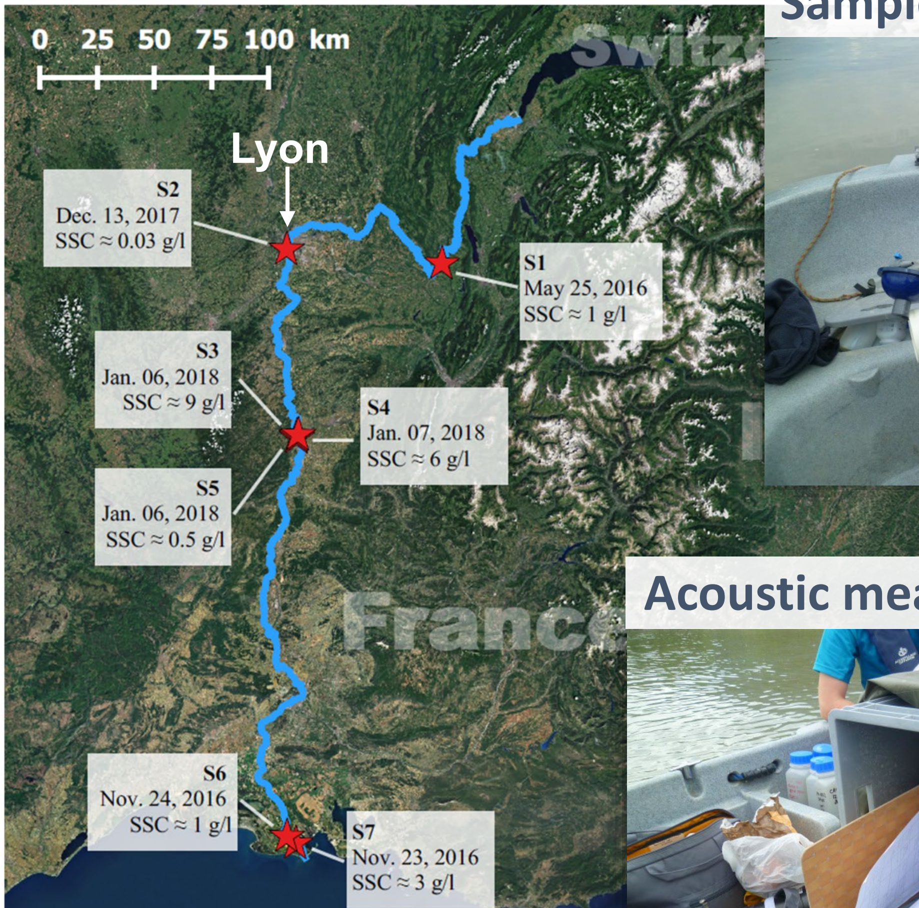




[Vergne A., Berni C., Le Coz J., et F. Tencé. Acoustic backscatter and attenuation due to riverine sediments: experimental evaluation of models and inversion methods. *Water Resources Research*, 2021]

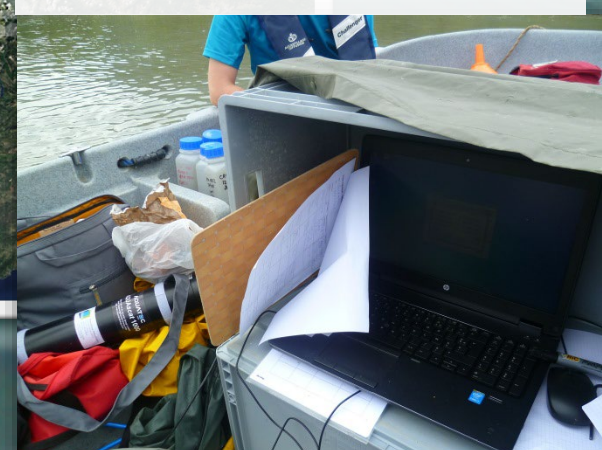
Can it explain all?

Back to the field



Samples

Acoustic measurements



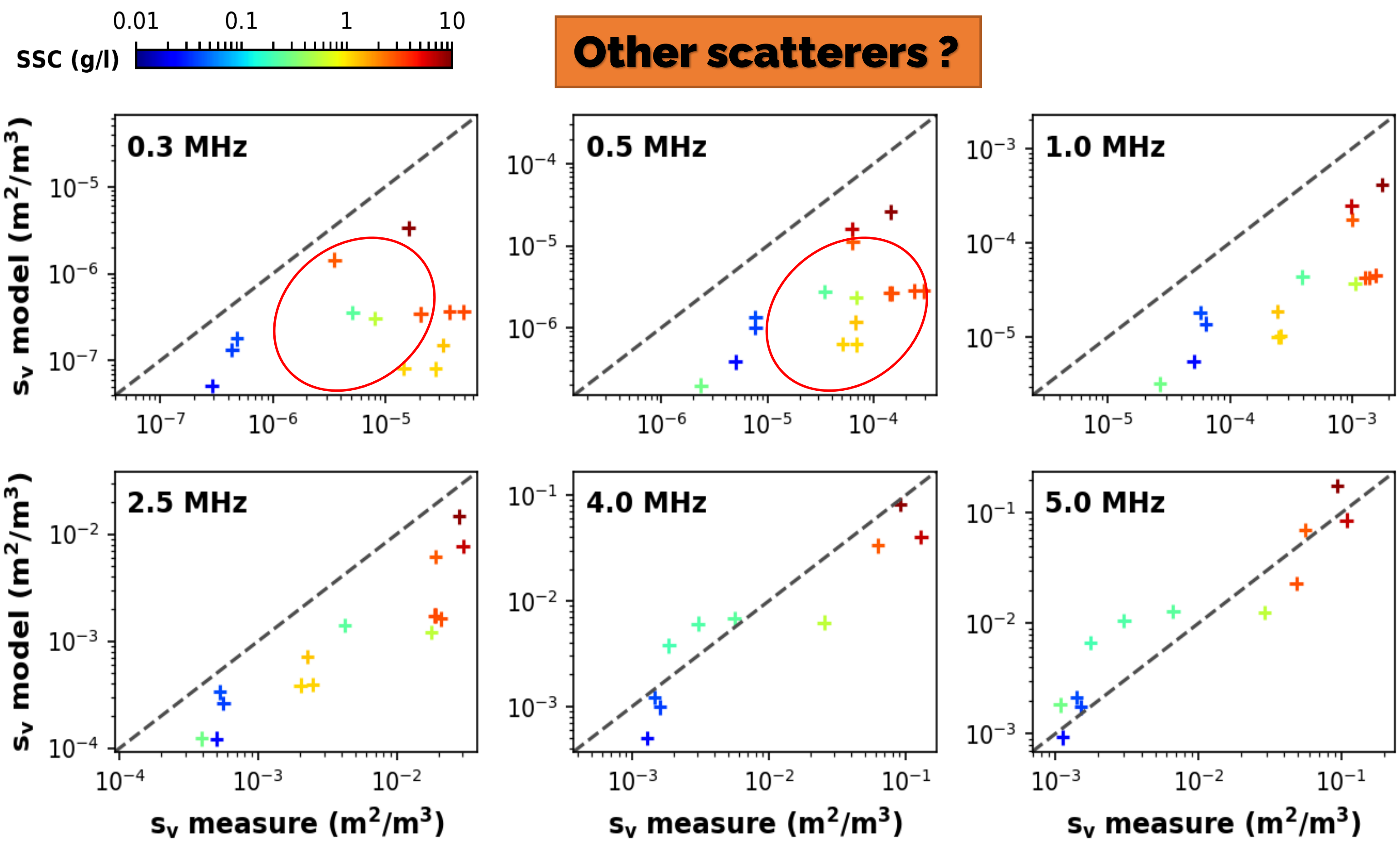
Near surface backscatter

Comparison s_v measured (near surface) **vs. s_v model** (surface sample) (Moate et Torne, 2012)

- s_v model **lower** than measured for freq. ≤ 2,5 MHz : error = **up to 100!**

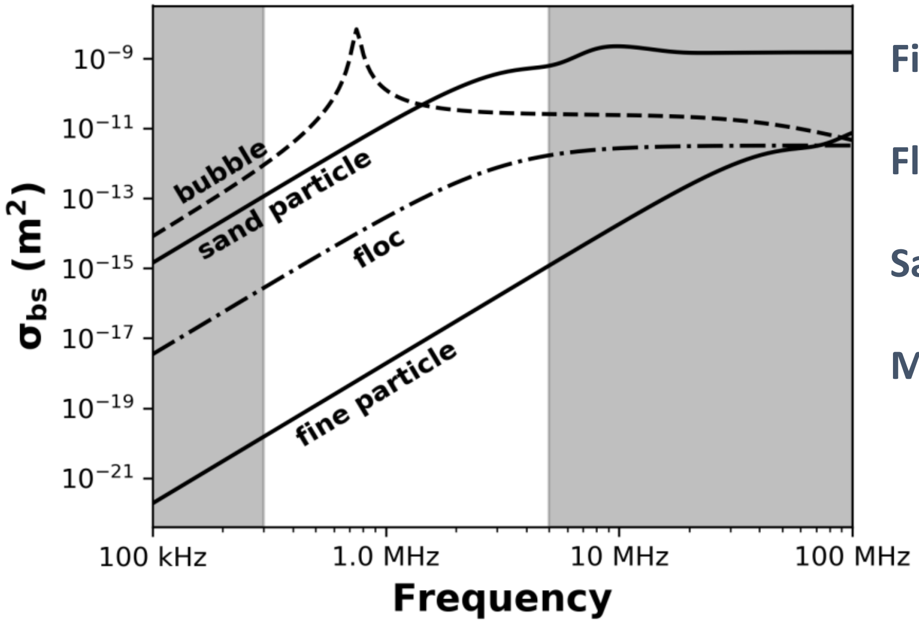
field difference >> lab difference

Other scatterers ?



Backscatter in rivers

- There should be other scatterers in rivers than sediments.
- It could be:
  - **Aggregates?**
  - Turbulence?
  - **Air micro-bubbles?**
  - Micro-organisms?
- Some backscatter estimates vs frequency



Fine particle : 10 µm
(Thorne et Meral, 2008)

Floc : 140 µm
(Thorne et al., 2014)

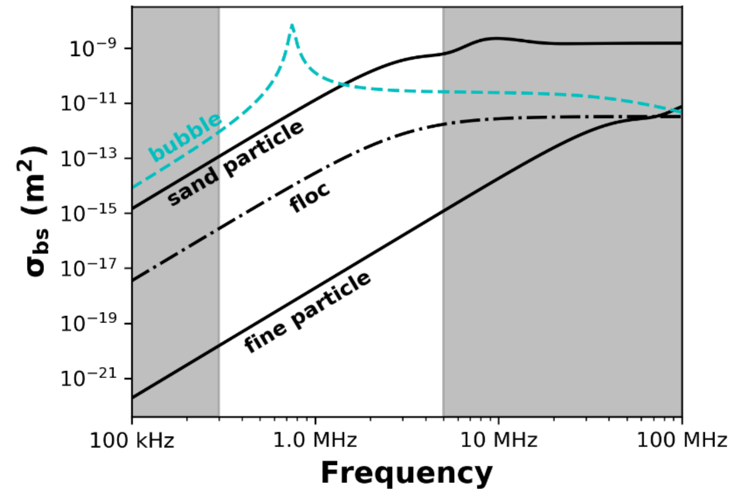
Sand : 140 µm
(Thorne et Meral, 2008)

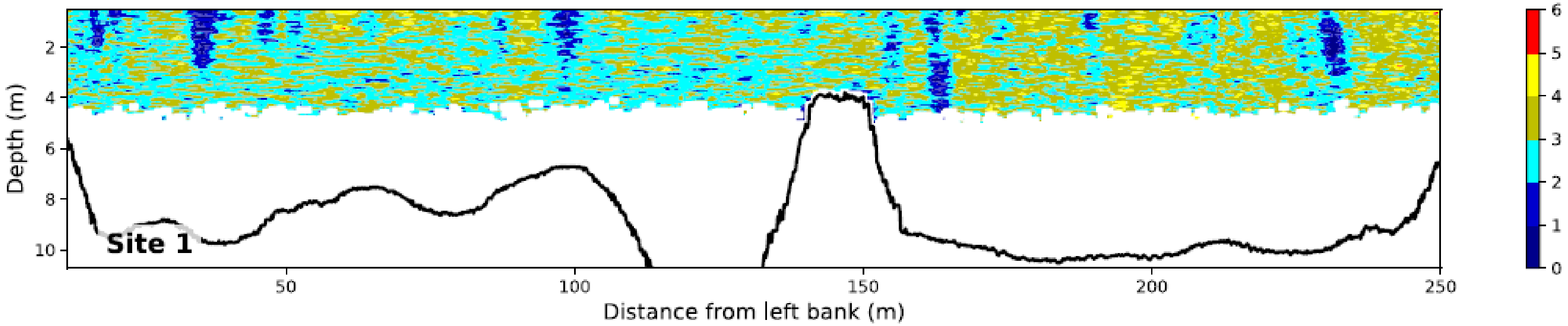
Micro-bubble : 10 µm
(Medwin et Clay, 1998)

Air micro-bubbles

Can it be dominant?

- Different behaviors of bubbles vs sediment as a function of frequency.
- X such as $s_v \propto f^X$
- Sediments: $X \approx 4$





- Vertical patches with $X \approx 0$
  - Bubbles

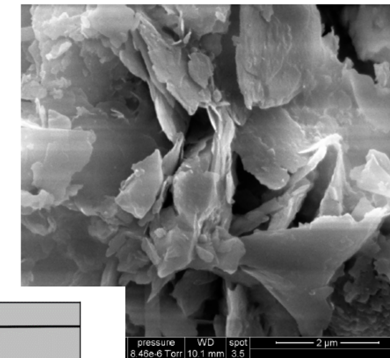
[Vergne, A., LeCoz, J., Berni, C. & Pierrefeu, G. (2020). Using a down-looking multifrequency acoustic backscatter system (ABS) for measuring suspended sediments in rivers. *Water Resources Research*, *56*]

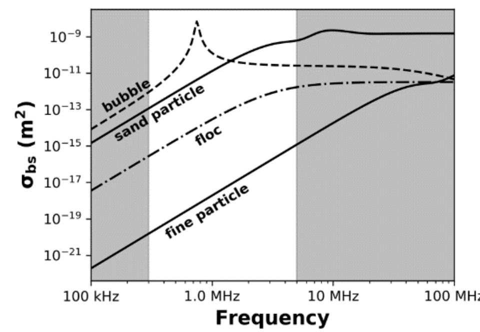
What about rivers?

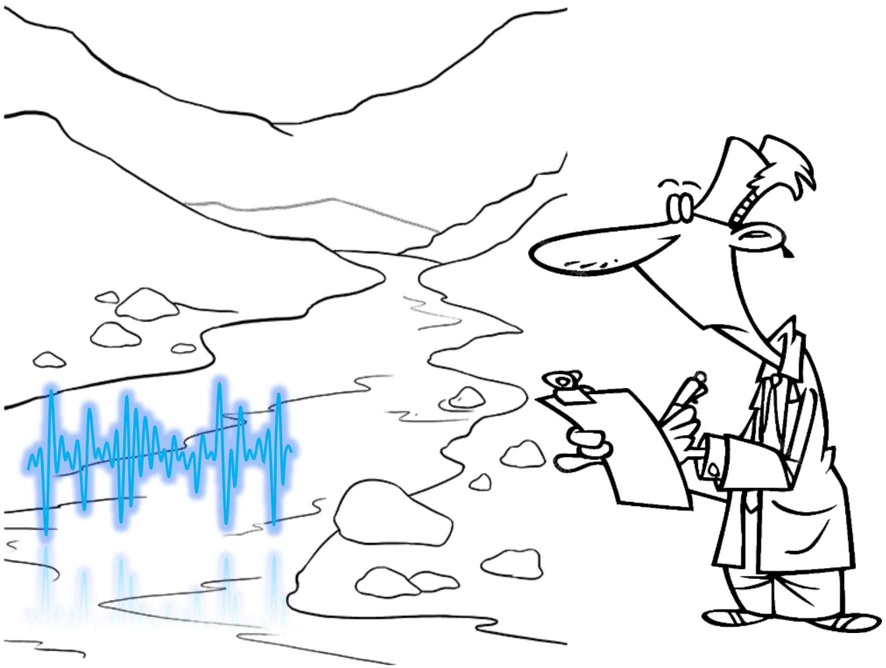
Acoustic backscatter in rivers is significantly different from what acoustic models predicts

It can due to

- Fine sediment response
- Other scatterers (bubbles, flocs, …)







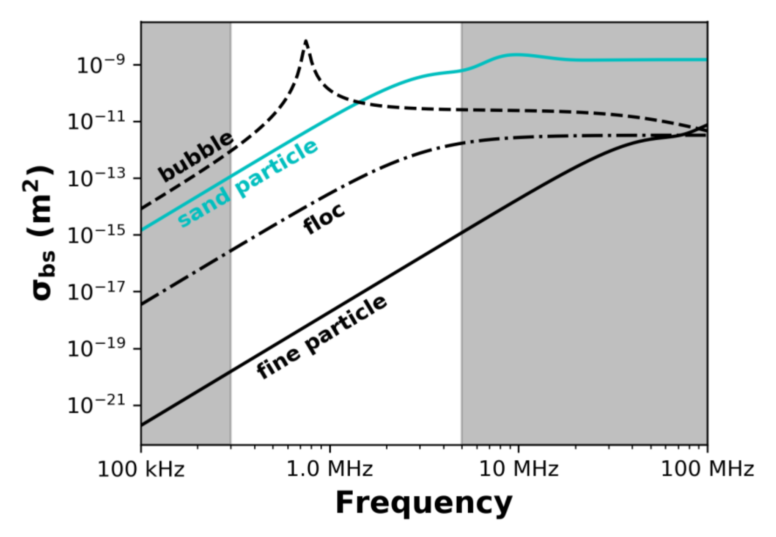
Can we still use acoustic for concentration measurements ?

Inversion can work

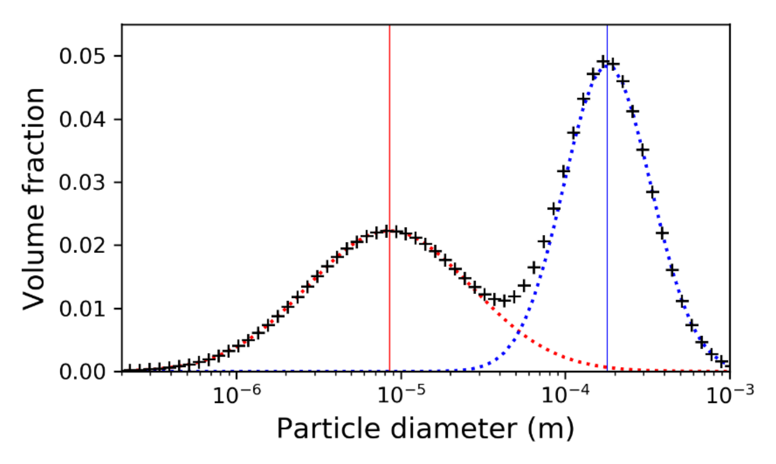
when everything is fine…

Assumptions:

- Enough **sand**: it dominates **scatter**
- Enough **fines**: it dominates **attenuation**

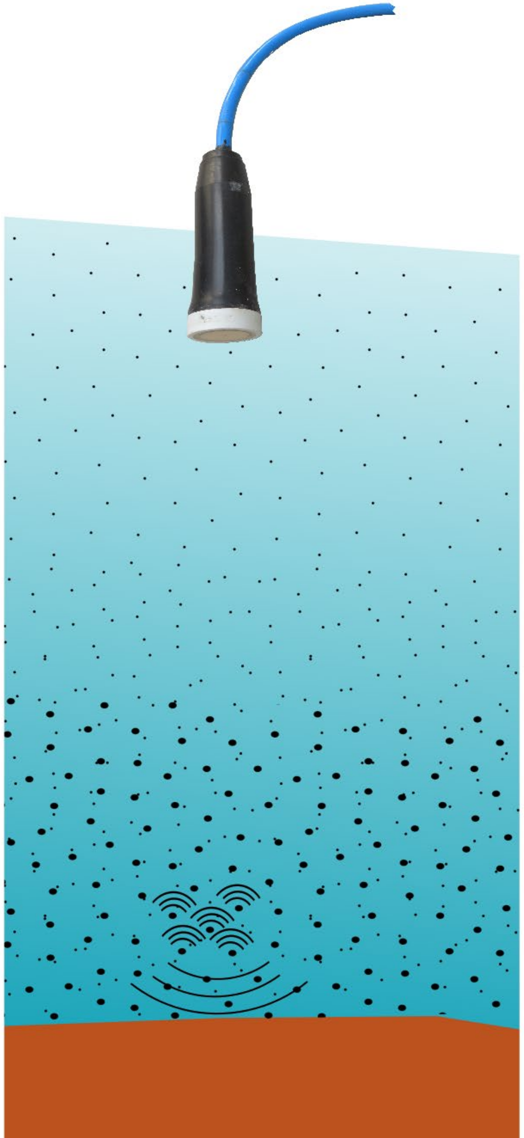


- **Fines GSD** is **homogeneous** in the section
- **Sand GSD** is **homogeneous** in the section
- Both **sand** and **fine concentrations** can **vary** within the section



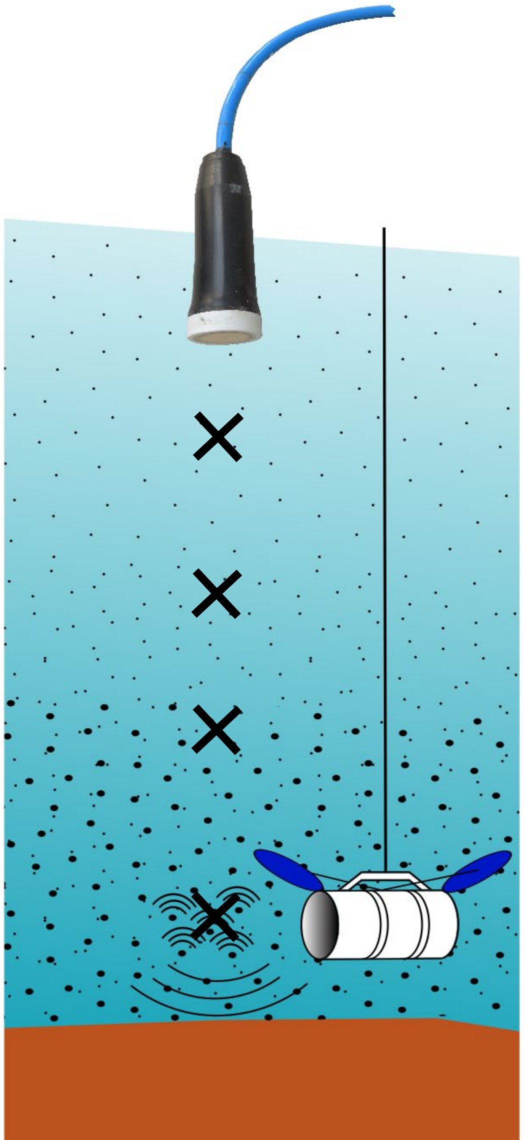
Method

What do we need?



Method

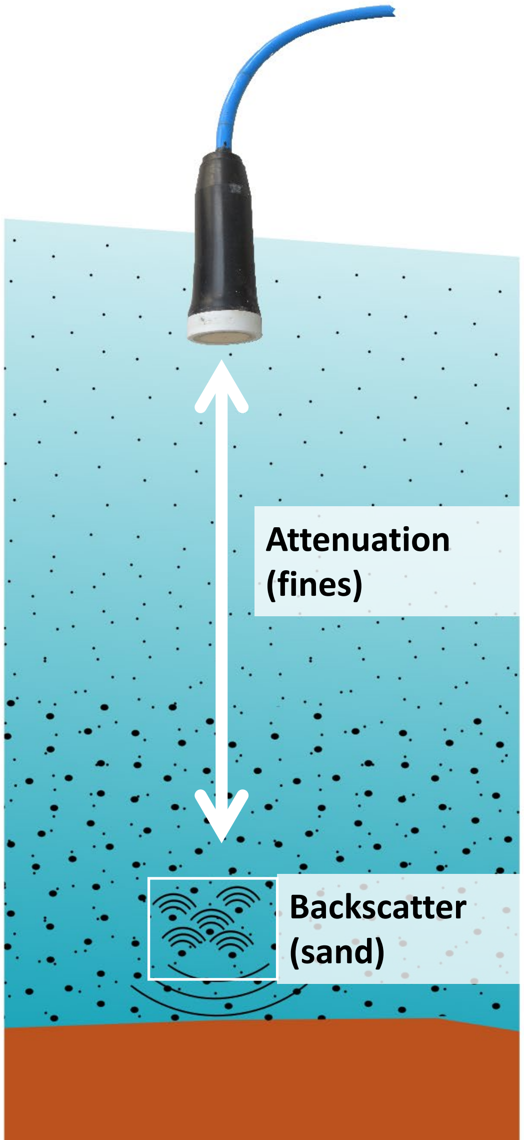
What do we need?



- **Near bed** samples with a large concentration of **sand (+ samples above it)**

Method

What do we need?



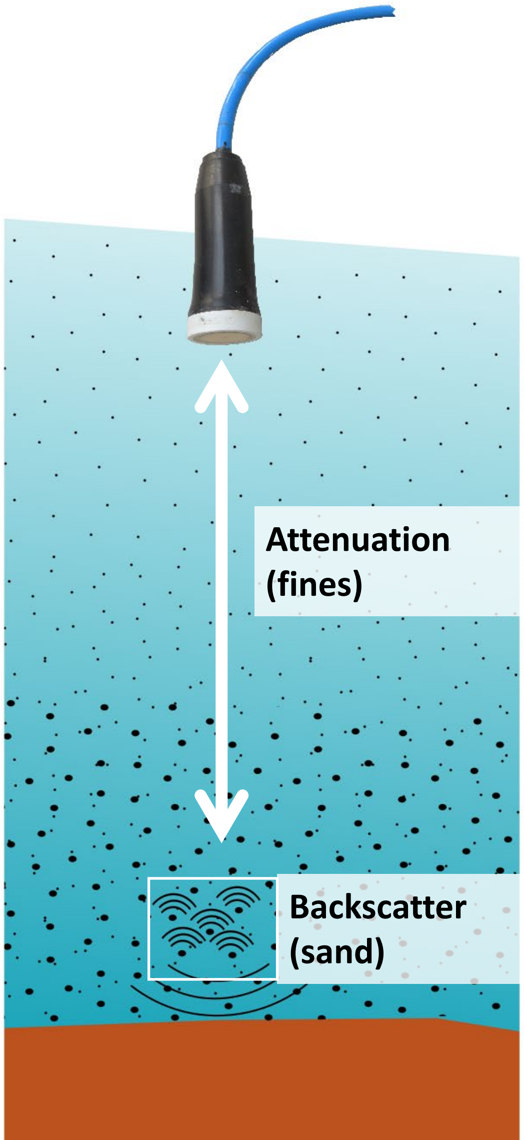
- **Near bed** samples with a large concentration of **sand (+ samples above it)**
- s_v model for the near bed sample (sand dominates)
- **Attenuation** coefficient **ζ = α_s / M** estimates (assuming fine GSD constant → ζ constant)
- Apply **bi-frequency inversion method** from Hurther et al. (2011)

→ **estimate of sand concentration** everywhere in the section

→ Attenuation in the section, and then **fines concentration**

Method

What do we need?



- **Near bed** samples with a large concentration of **sand** **(+ samples above it)**
- s_v model for the near bed sample (sand dominates)

$$k_s = \left[\frac{\int_0^\infty a^2 f_\infty^2(a) n(a) da}{\int_0^\infty a^3 n(a) da}\right]^{1/2} \quad s_v = \frac{3}{16\,\pi} k_s^2 M_s$$

- **Attenuation** coefficient **ζ = α_s / M** estimates (assuming fine GSD constant → ζ constant)

$$\zeta = \alpha_s / \left[\left(\frac{1}{r_s}\right)\int_0^{r_s} M_f(r) dr\right]$$

- Apply **bi-frequency inversion method** from Hurther et al. (2011)

$$J = \frac{3\,\overline{V^2} r^2}{16\pi k_t^2} \quad s_v = VBI \times f^X = J\, e^{4r(\alpha_s + \alpha_w)} \quad X = \frac{\log_e\left(\frac{s_{v,1}}{s_{v,2}}\right)}{\log_e\left(\frac{f_1}{f_2}\right)}$$

$$\log_e(VBI \times f^X) = \log_e(J\, e^{4r\alpha_w}) + 4\zeta \int_0^r M_f dr$$

$$\log_e(VBI) = \frac{\zeta_2 \log_e(J_1\, e^{4r\alpha_{w,1}}/f_1^X) - \zeta_1 \log_e(J_2\, e^{4r\alpha_{w,2}}/f_2^X)}{\zeta_2 - \zeta_1}$$

→ **estimate of sand concentration** everywhere in the section

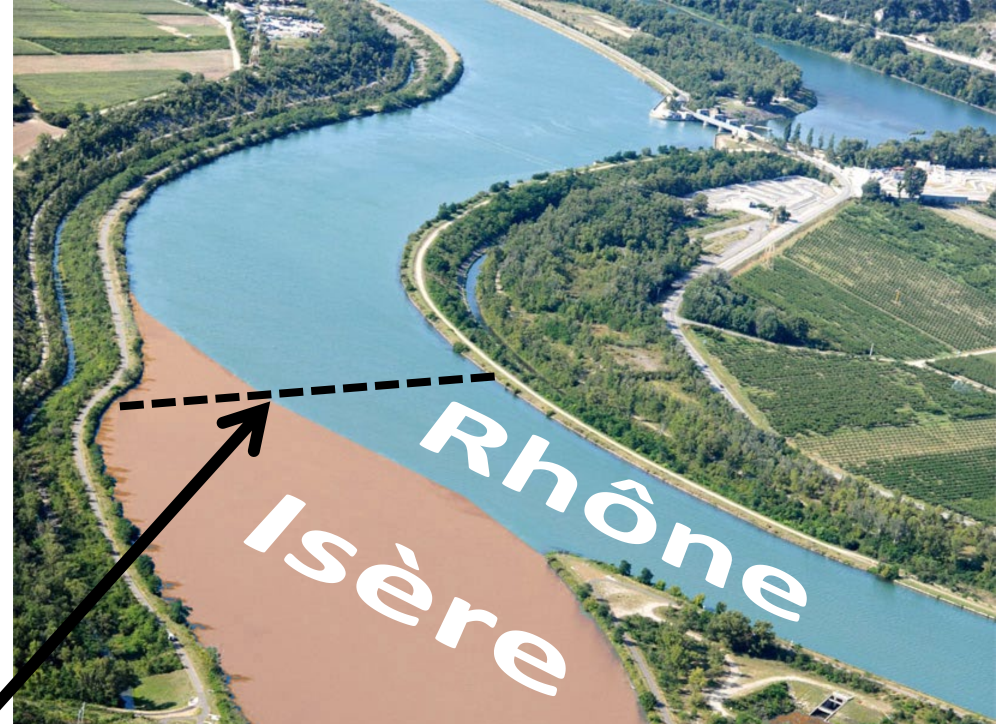
$$M_s = \frac{16\pi \times VBI \times f^X}{3k_s^2}$$

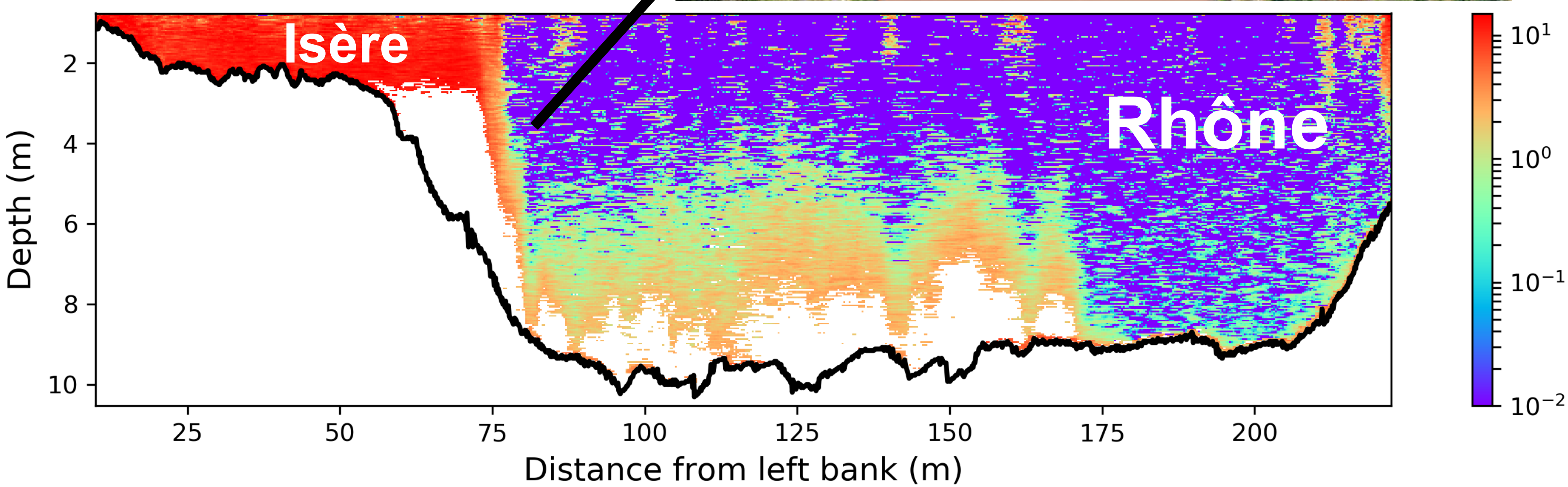
→ Attenuation in the section, and then **fines concentration**

$$M_f = \frac{1}{\zeta} \times \left[\log_e\left(\frac{VBI \times f^X}{J}\right) - \alpha_w\right]$$

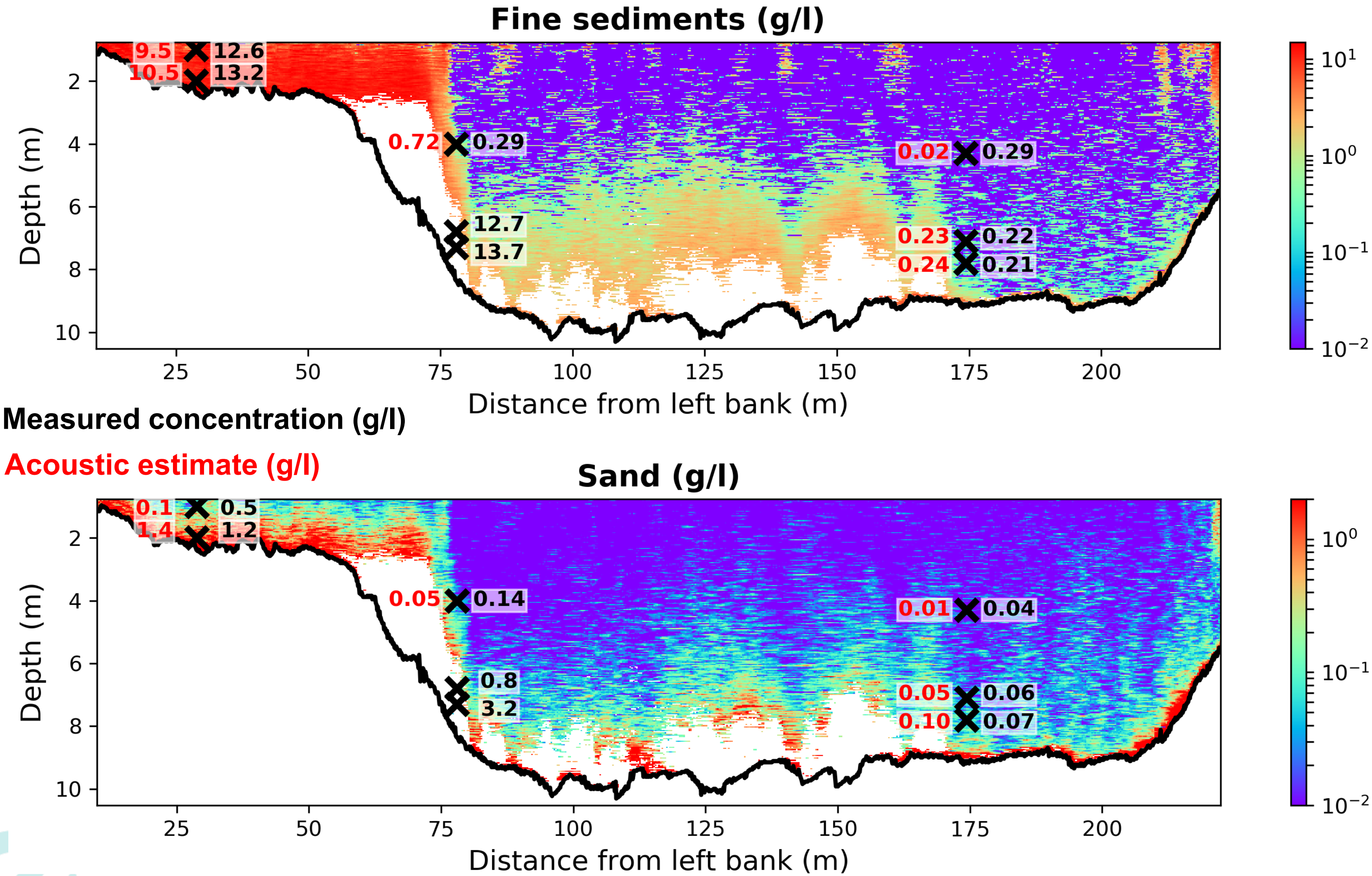
Field study

Results


Rhône
Isère


Isère
Rhône
Depth (m)
2
4
6
8
10
25
50
75
100
125
150
175
200
Distance from left bank (m)
10^{1}
10^{0}
10^{-1}
10^{-2}

Results



Fine sediments (g/l)
9.5
12.6
10.5
13.2
0.72
0.29
0.02
0.29
12.7
13.7
0.23
0.22
0.24
0.21
Depth (m)
Distance from left bank (m)
Measured concentration (g/l)
Acoustic estimate (g/l)
Sand (g/l)
0.1
0.5
1.4
1.2
0.05
0.14
0.01
0.04
0.8
3.2
0.05
0.06
0.10
0.07
Depth (m)
Distance from left bank (m)

Inversion can work

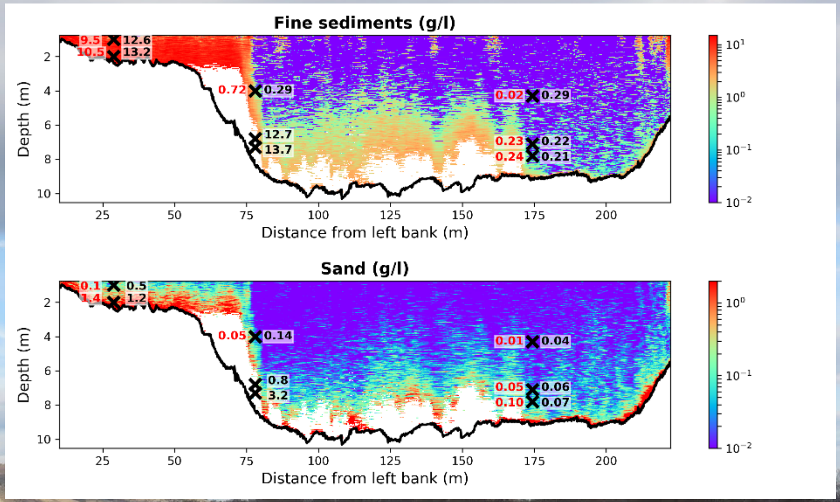
when everything is fine…

Assumptions:

- Enough **sand**: it dominates **scatter**
- Enough **fines**: it dominates **attenuation**
- **Fines GSD** is **homogeneous** in the section
- **Sand GSD** is **homogeneous** in the section
- Both **sand** and **fine concentrations** can **vary** within the section

Data:

- Calibration samples
- **Multi-frequency** calibrated ABS



But it might be not so easy…

$$s_v = \frac{3}{16\,\pi} k_s^2 M_s \qquad s_v = VBI \times f^X = J\, e^{4r(\alpha_s + \alpha_w)}$$

$$k_s = \left[\frac{\int_0^\infty a^2 f_\infty^2(a) n(a) da}{\int_0^\infty a^3 n(a) da}\right]^{1/2} \qquad \zeta = \alpha_s / \left[\left(\frac{1}{r_s}\right) \int_0^{r_s} M_f(r) dr\right]$$

$$X = \frac{\log_e\left(\frac{s_{v,1}}{s_{v,2}}\right)}{\log_e\left(\frac{f_1}{f_2}\right)} \qquad J = \frac{3\,\overline{V^2} r^2}{16\pi k_t^2} \qquad M_s = \frac{16\pi \times VBI \times f^X}{3 k_s^2}$$

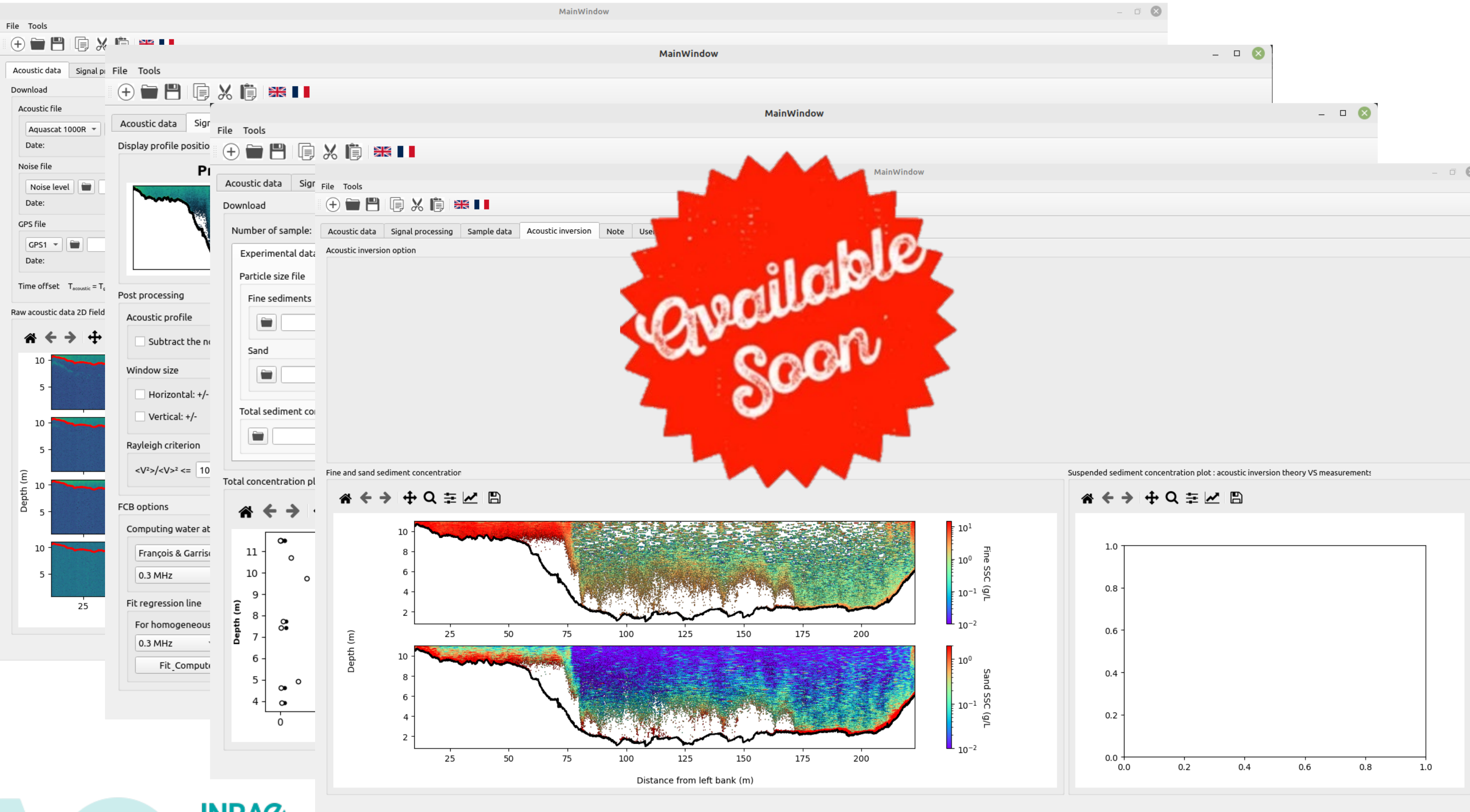
On going work

A software to help with the inversion

- 4 main tabs
  - Acoustic data
    - Preview of the raw data + SNR
    - Help in sample positioning
  - Signal Processing
    - Filtering / averaging / visualisation of a single profile
    - FCB computation (backscatter corrected from water attenuation)
  - Sample data
    - Visualisation of concentration and GSD of samples
    - Selection of samples for calibration
  - Acoustic inversion
    - Visualisation of distribution of concentrations in the section.

On going work

A software to help with the inversion



INRAE

Thank you for listening

Vergne A., Berni C., Le Coz J., et F. Tencé. Acoustic backscatter and attenuation due to riverine sediments: experimental evaluation of models and inversion methods. Water Resources Research, 2021.

Vergne, A., LeCoz, J., Berni, C. & Pierrefeu, G. Using a down-looking multifrequency acoustic backscatter system (ABS) for measuring suspended sediments in rivers. Water Resources Research, 56, 2020.

A. Vergne, C. Berni and J. Le Coz. Sound scattering in rivers: limitations of the solid particle theory. Water Resources Research, Under Review.

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