

# Passive acoustic monitoring of large gravel bed rivers

Geay T.<sup>1</sup>, P.Belleudy<sup>1</sup>, J.Laronne<sup>1,2</sup>, C.Gervaise<sup>3</sup>, H.Habersack<sup>4</sup>, J.Aigner<sup>4</sup>

<sup>1</sup>LTHE, Université de Grenoble, France

<sup>2</sup>Ben Gurion Univ. of the Negev, Beer Sheva, Israël

<sup>3</sup>GIPSA Lab, Grenoble, France

<sup>4</sup>Univ. of Bodenkultur, Wien, Austria

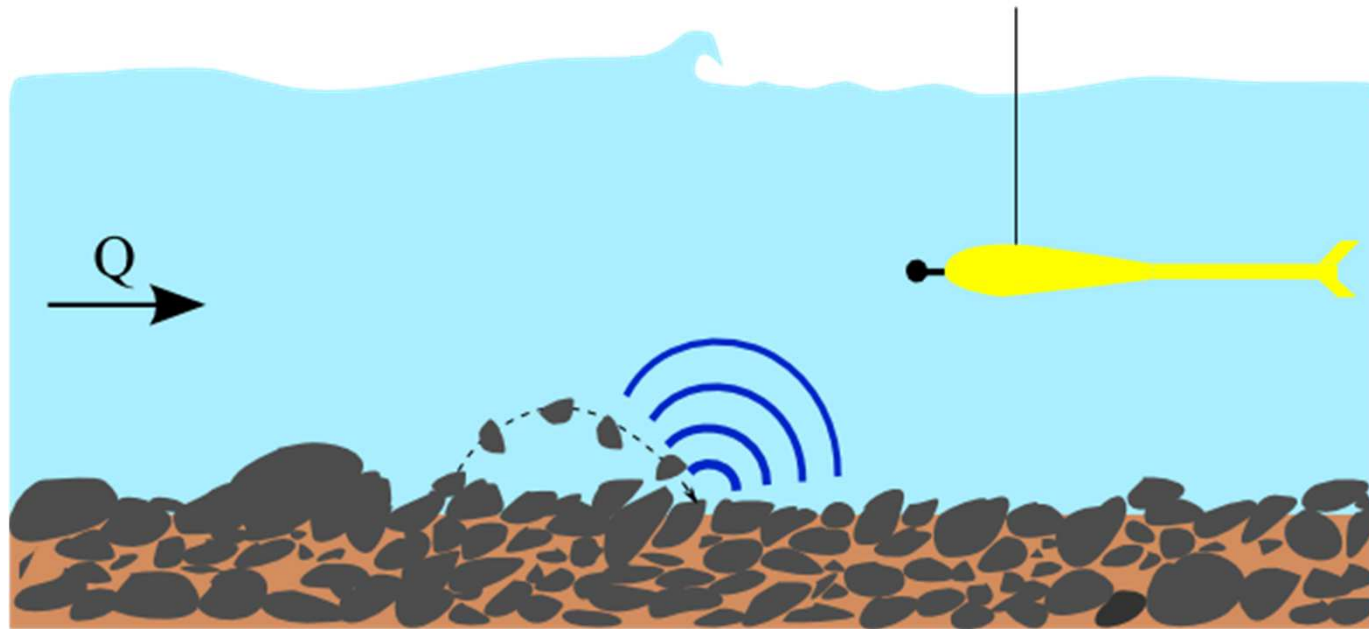


This research is  
supported by the  
project **GESTRANS**  
(ANR-09-RISK-004)



# Passive acoustic monitoring

**Self Generated Noise (SGN)**  
**Acoustic pressure, using a hydrophone**



# Plan

- **Comparative measurements in natural streams**
  - Rhine River
  - Drau River
- **River acoustics**
  - Observations in a large gravel bed river
  - Interpretations
- **Conclusion & perspectives**



# Comparative measurements

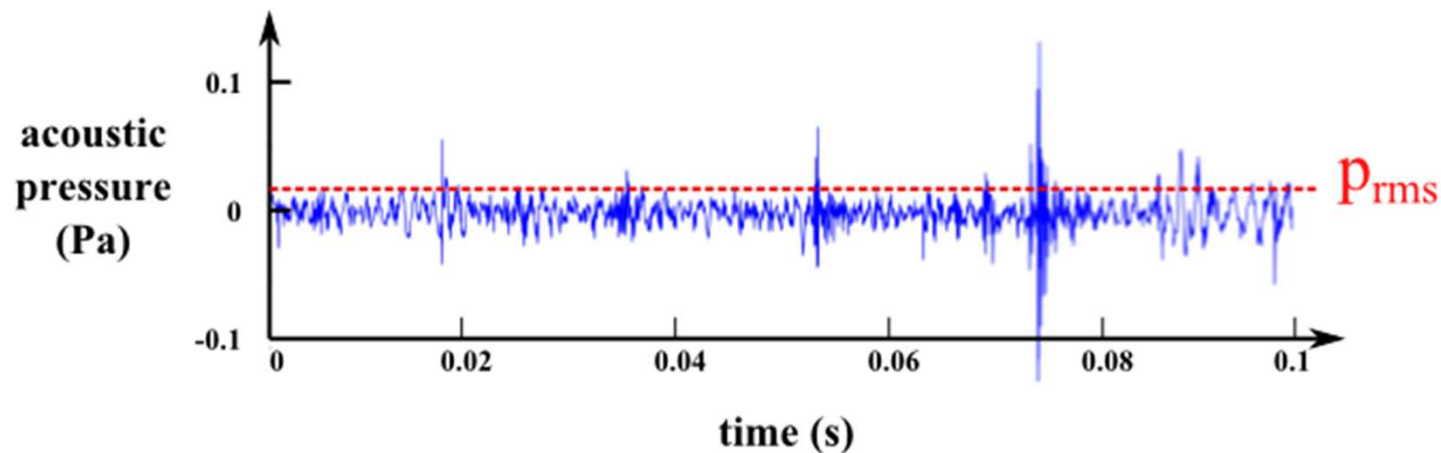
- Hydrophone vs. Underwater camera  
(*Thorne, 1986; Barton, 2003*)
- Hydrophone vs. geophones

# Laboratory & marine studies

- **Acoustic** intensities have been related to **bedload fluxes** [*Johnson and Muir; Thorne 1985, 1986; Rouse, 1994; Voulgaris et al., 1995*] :

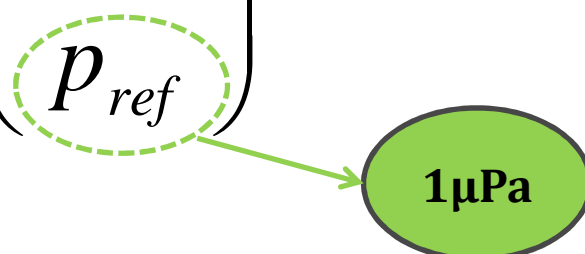
$$P_{rms} = \beta I_b^\gamma$$

Bedload flux ( $\text{kg m}^{-1} \text{s}^{-1}$ )



# Method

- **Digital signal** → pre-processing to filter extraneous noises (in time and frequency plans)
- **Sound Pressure Level (SPL in dB re 1μPa):**

$$SPL = 20 \log \left( \frac{p_{rms}}{p_{ref}} \right)$$


reference pressure

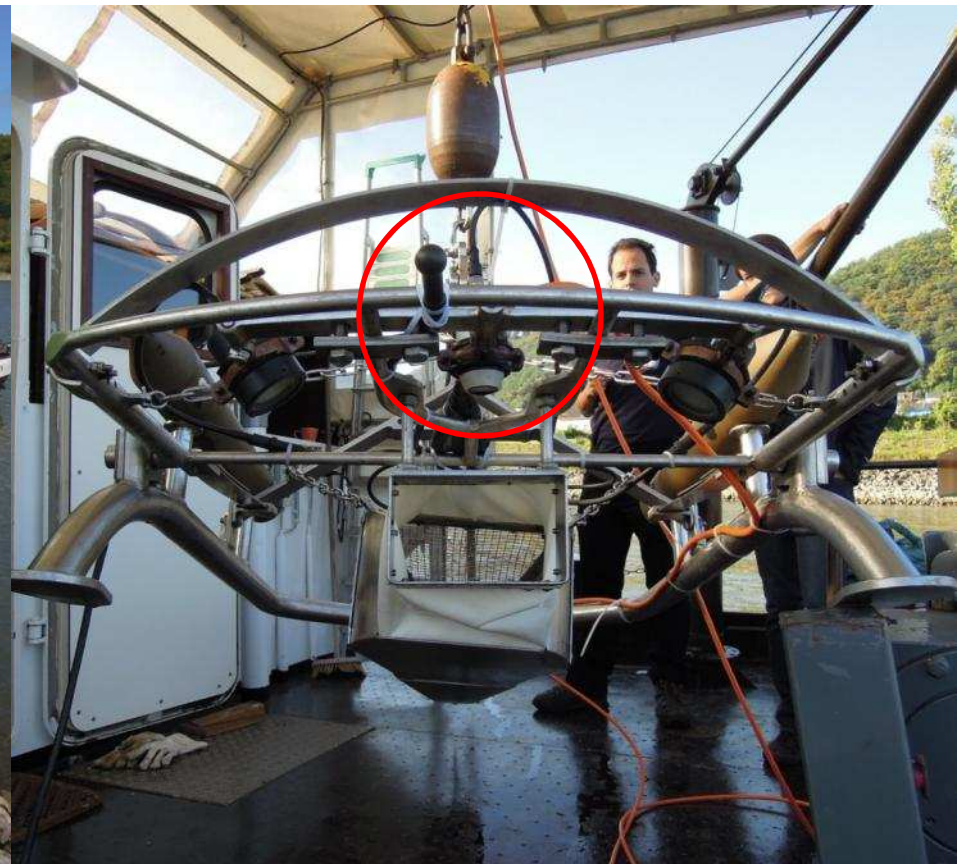
# Rhine River

bfg Bundesanstalt für  
Gewässerkunde

- Operational bedload monitoring
- Hydrophone & underwater camera

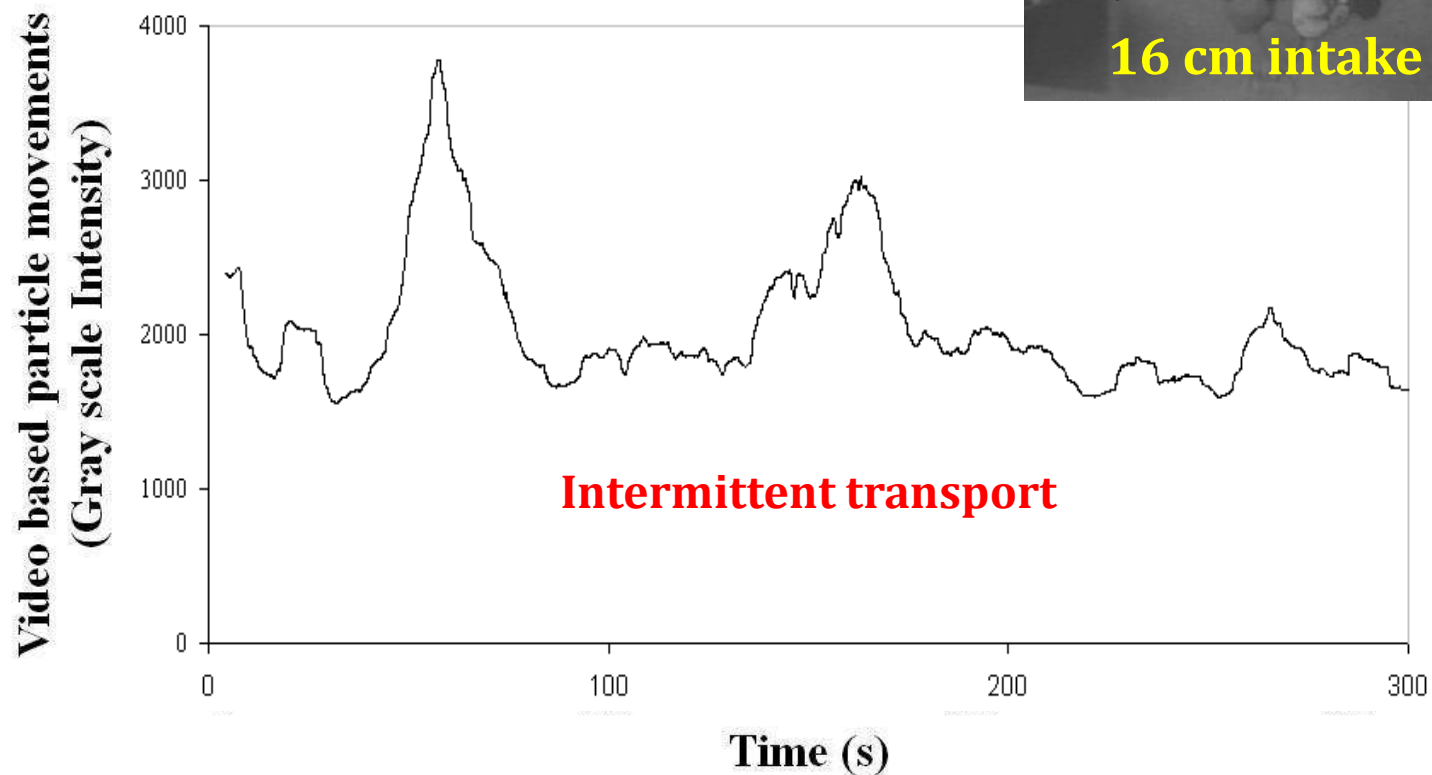


Zurich 04th Sep. 2013



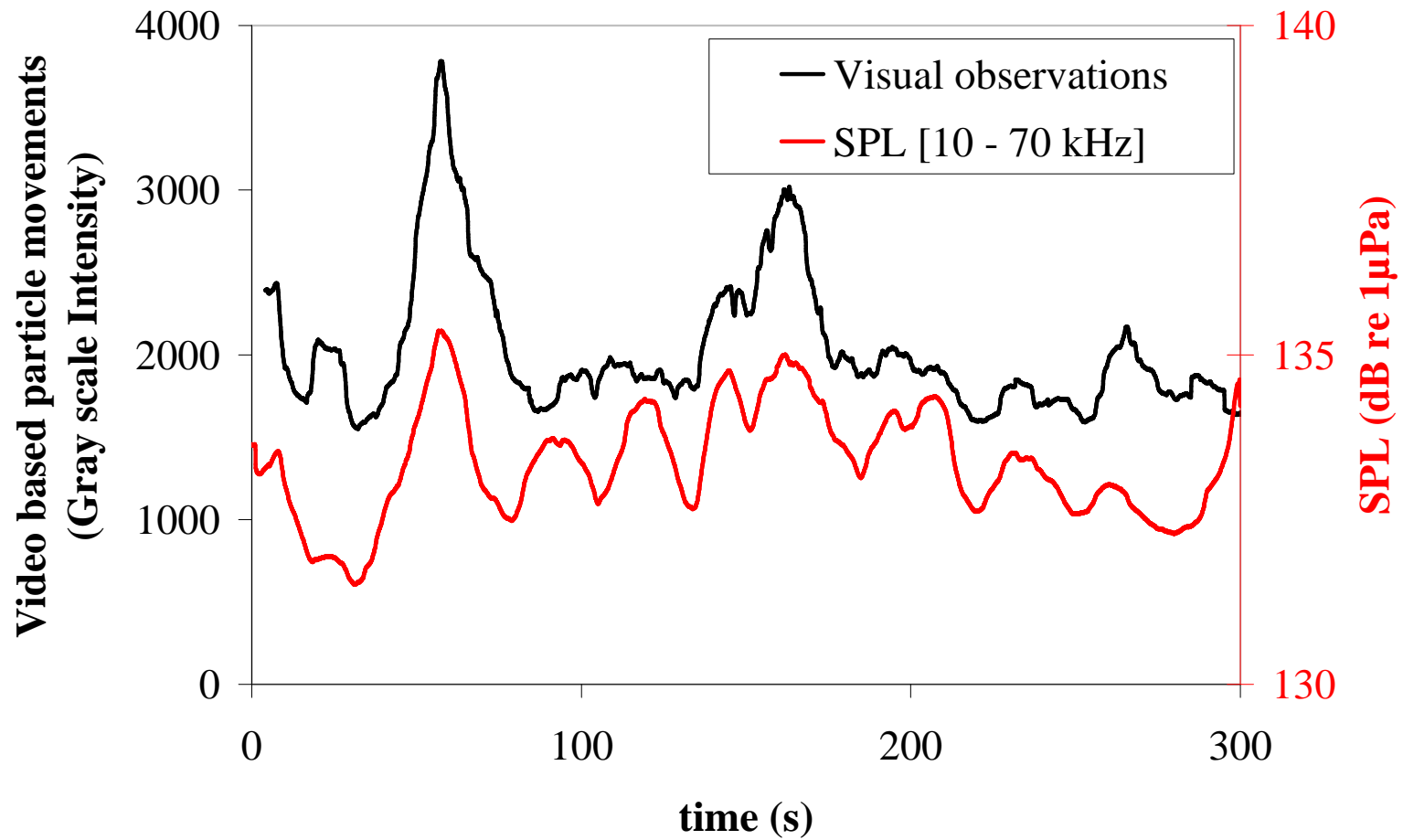
# Rhine River

- Low flow ( $v_{\text{water}} < 1\text{m/s}$ )





# Rhine River



# Rhine River

- Detection of **initiation of motion in a large gravel bed river** (at a local scale);

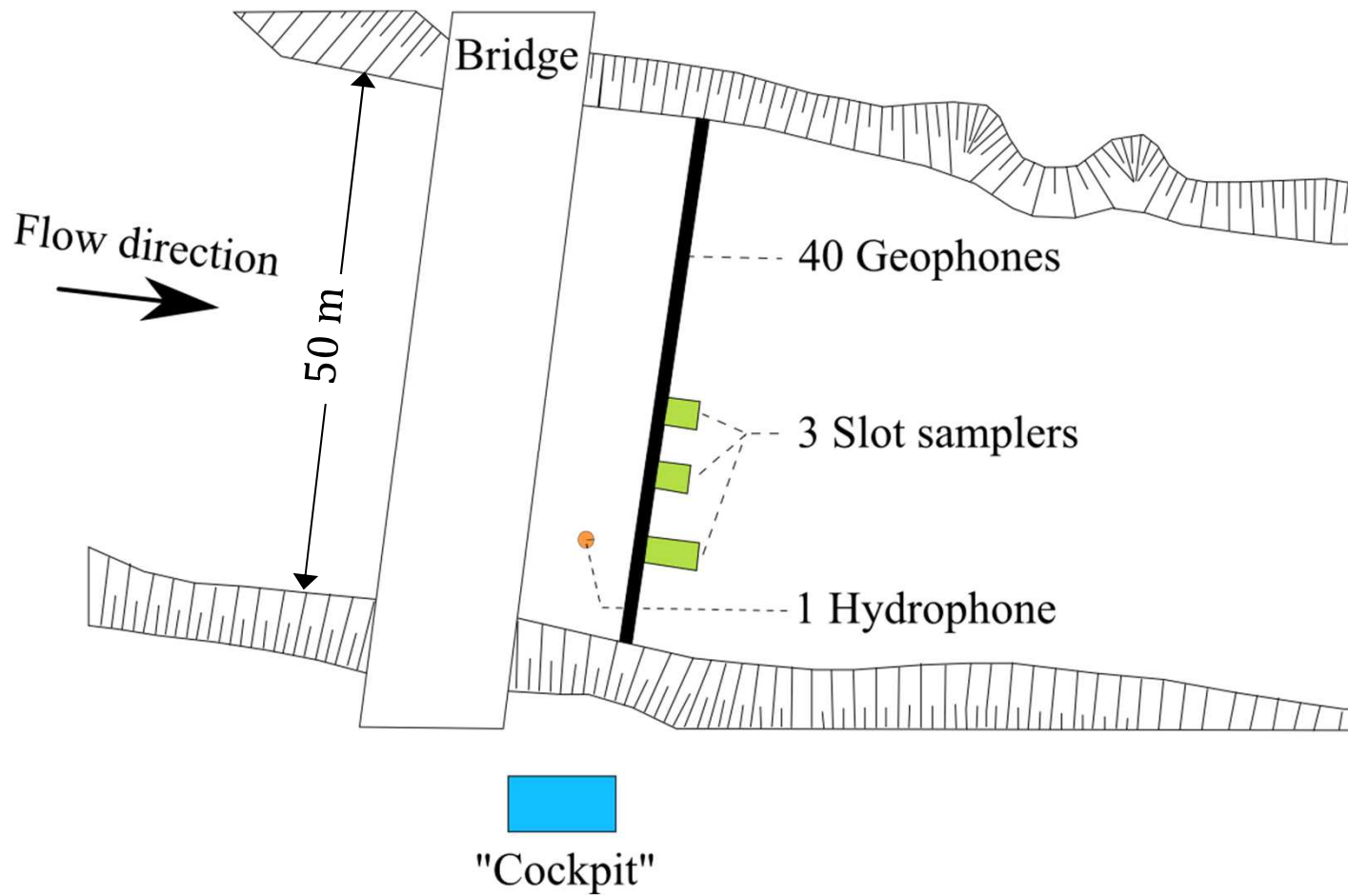
→ Hydrophone response at higher bedload fluxes in flood is yet to be determined.

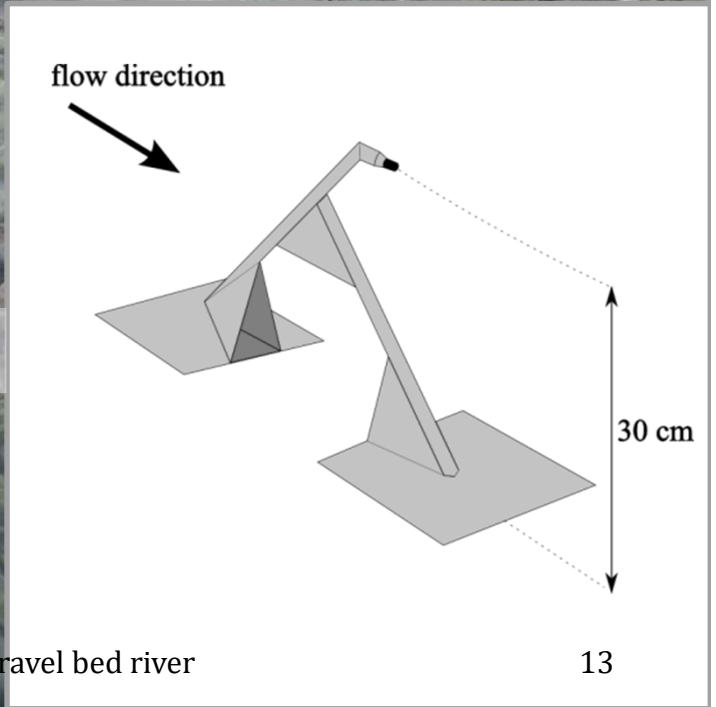
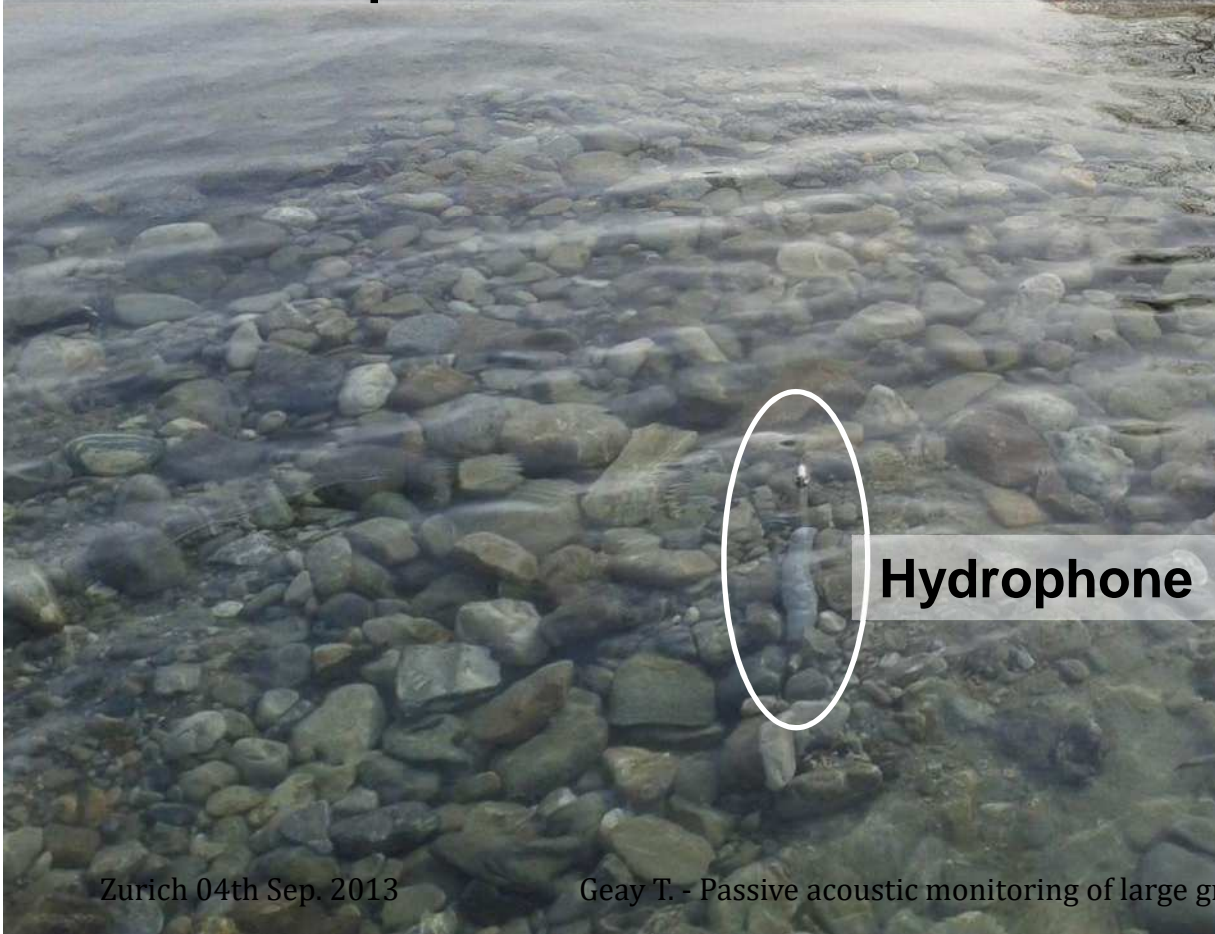
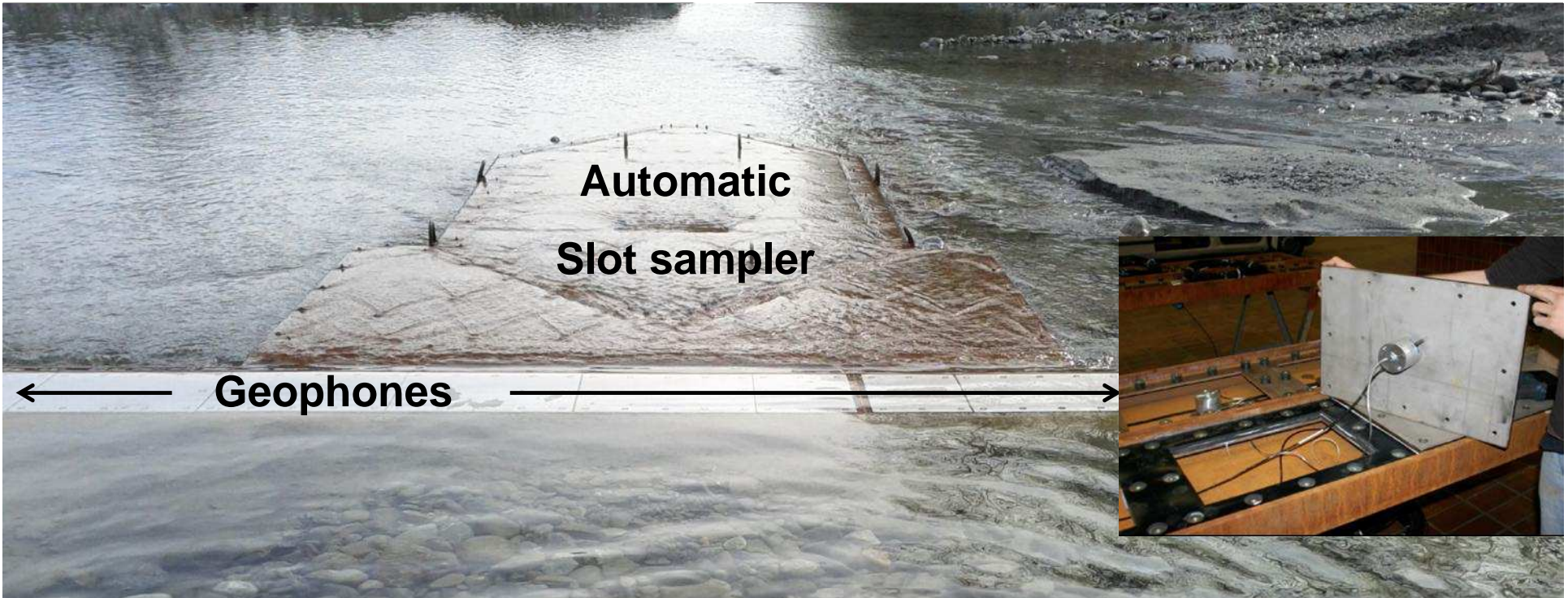
# Drau River (Austria)

- Highly equipped cross-section  
(H.Habersack research team, BOKU, Vienna)
- Hydrophone monitoring system



# Drau River

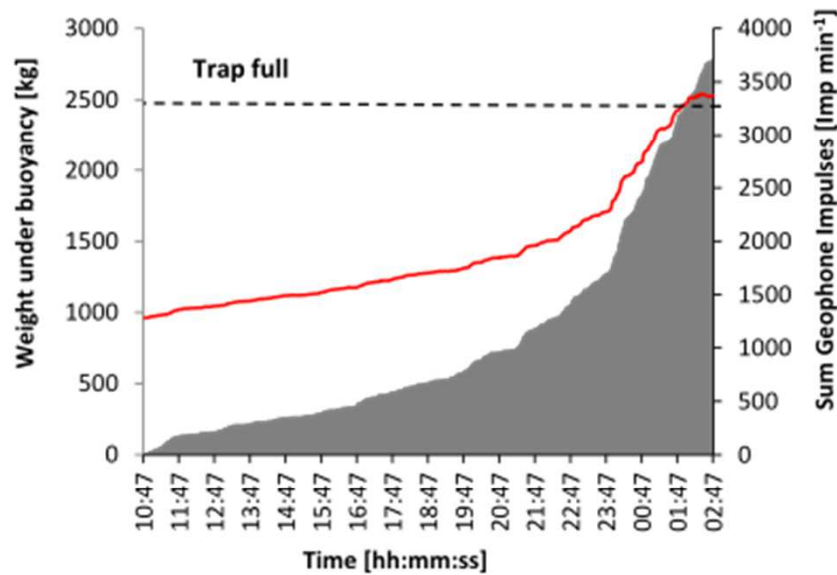




# Calibration of Geophone-Signal

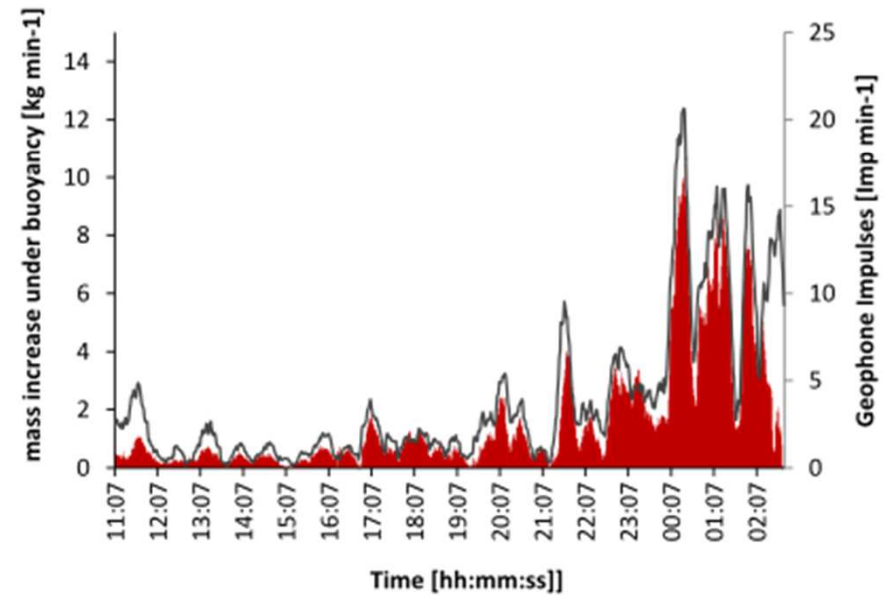
(Habersack et al.; (in prep.) Integrated Bedload Transport Monitoring at the Drau - Isel system.)

Bedload Trap Measurement, Dellach - Drau (30.07.2009) – Cumulative Curve



■ Cumulative curve of impulses  
 — Cumulative curve of weight

Bedload Trap Measurement, Dellach - Drau (30.07.2009) – Load Curve



■ Load curve mass increase  
 — Load curve geophone Impulses

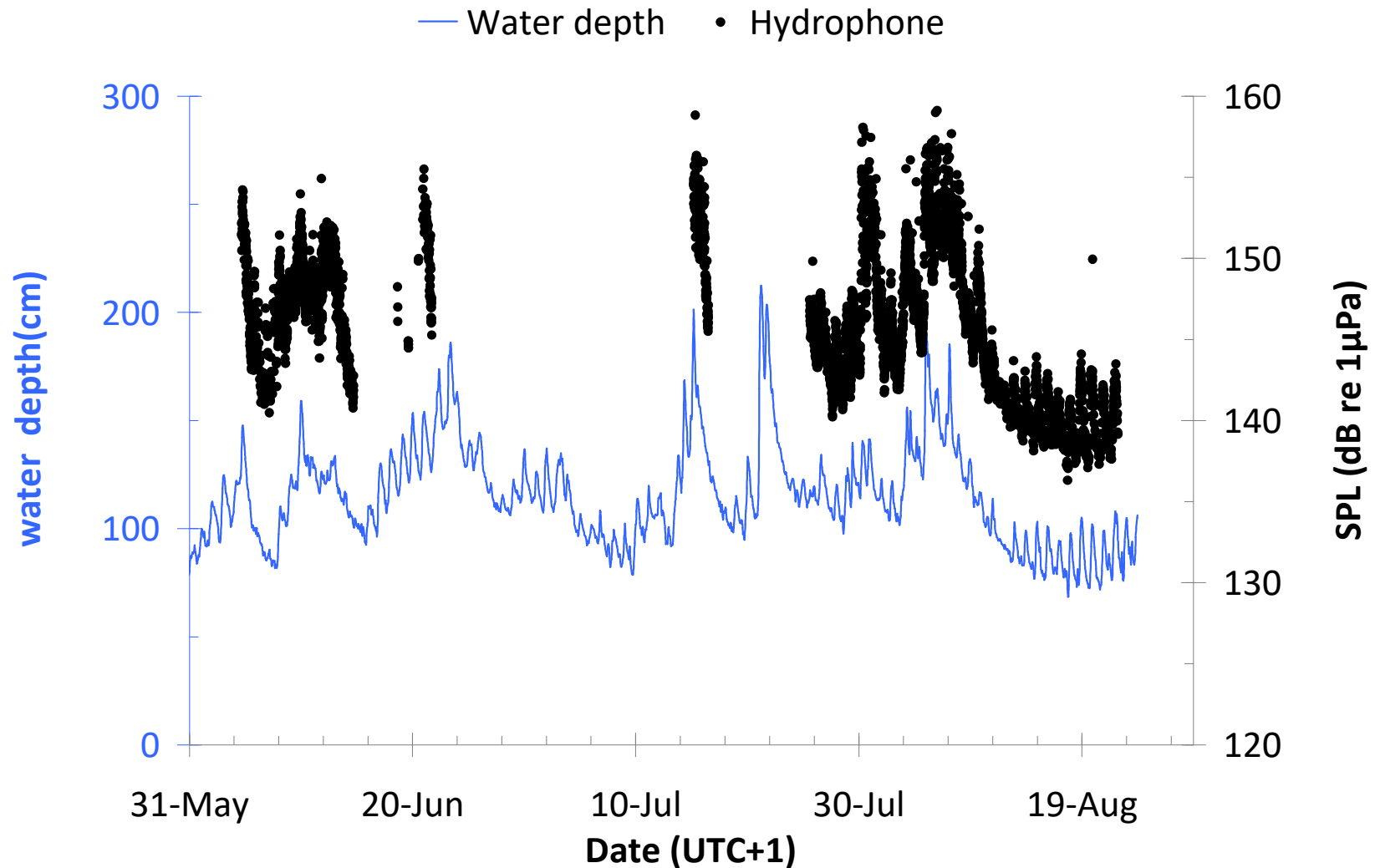
# Drau River

- **Acoustic Data:**

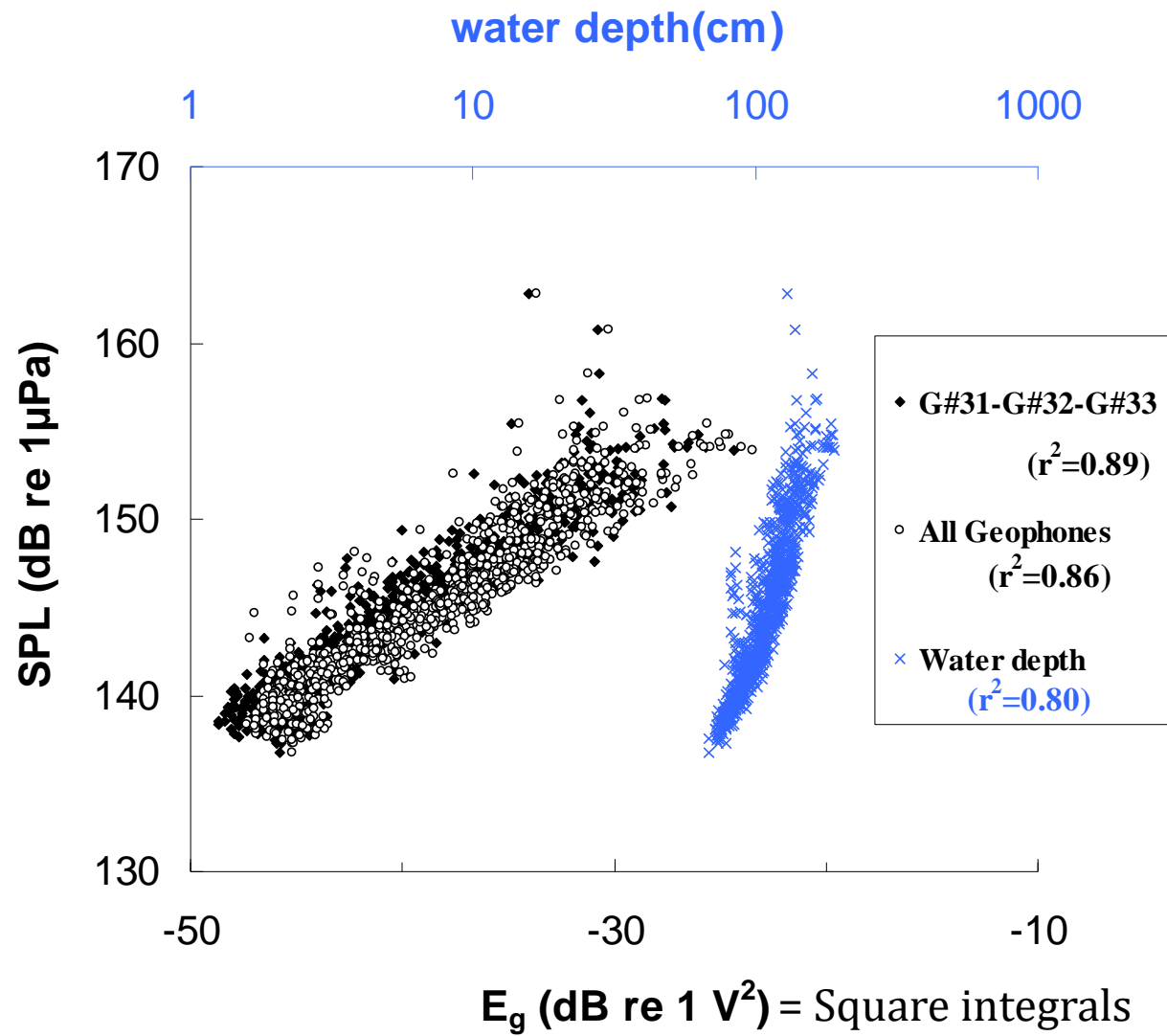
- **Sampling rate:** 1 min duration once every 10 min ;
- **Raw data** (Wave files, 500 kHz);

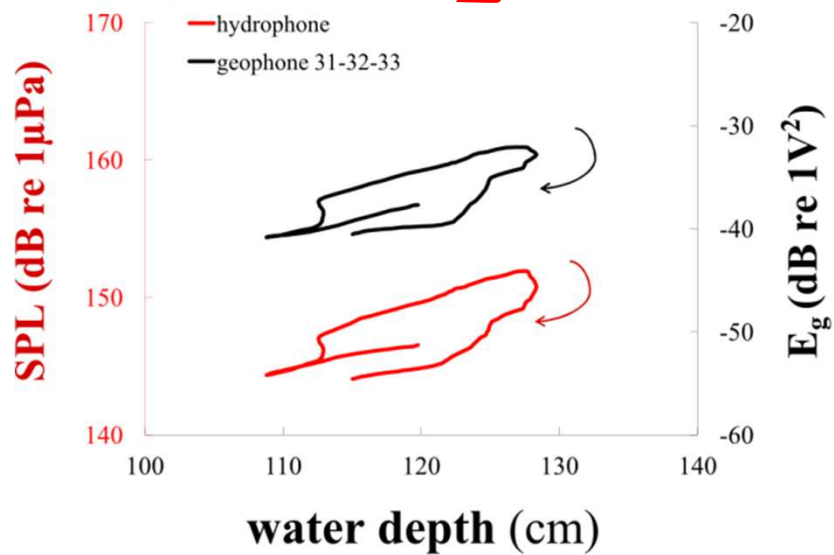
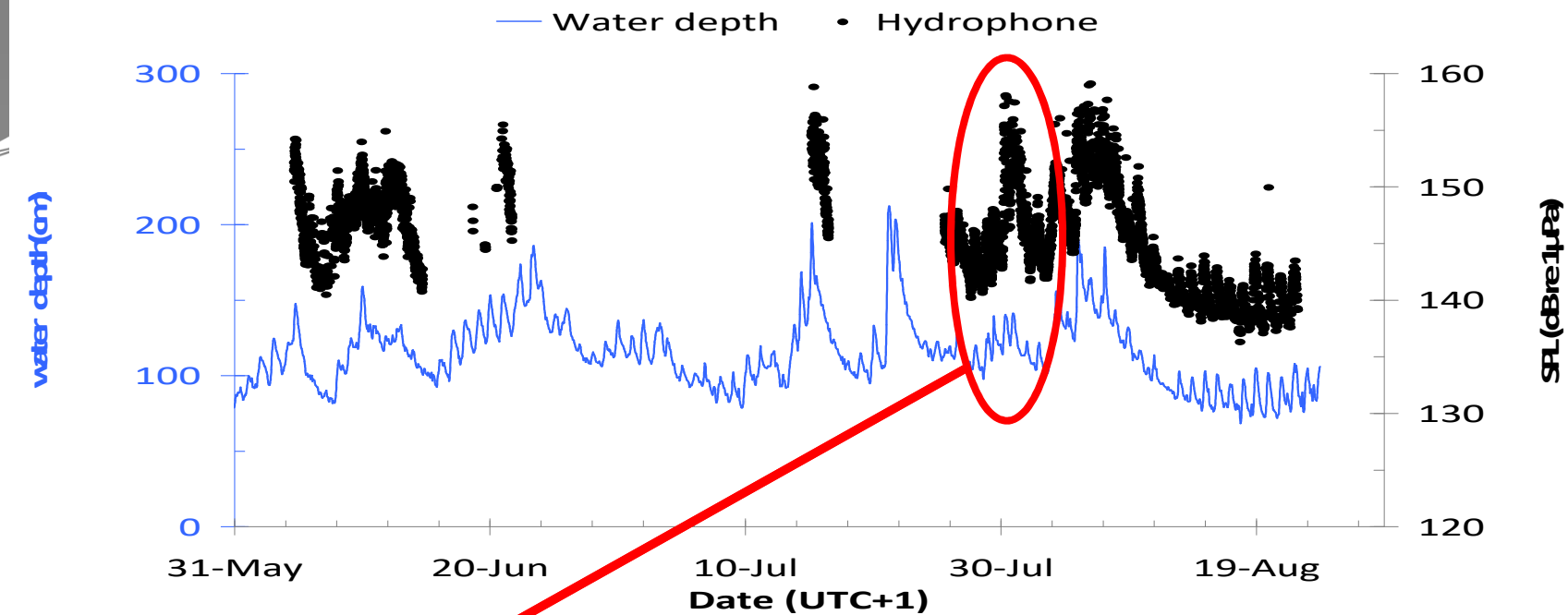
**→ To be compared to a continuous monitoring of the geophones and water-level**

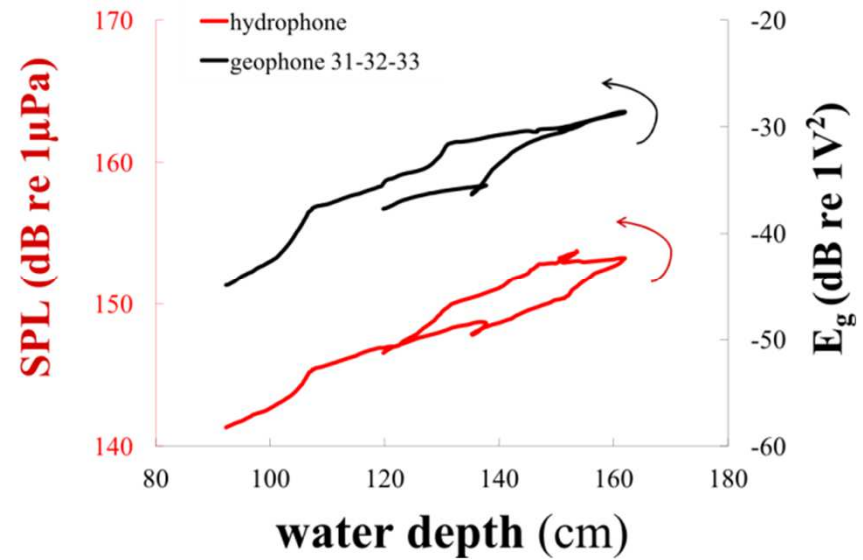
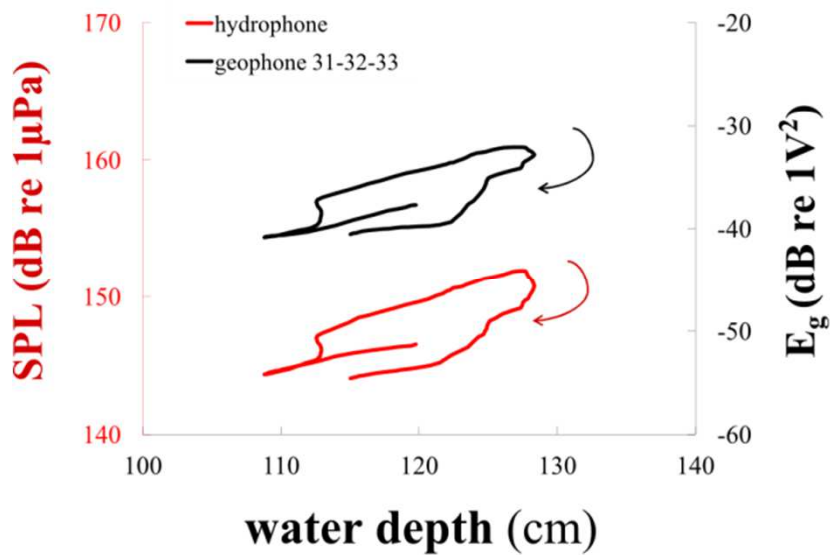
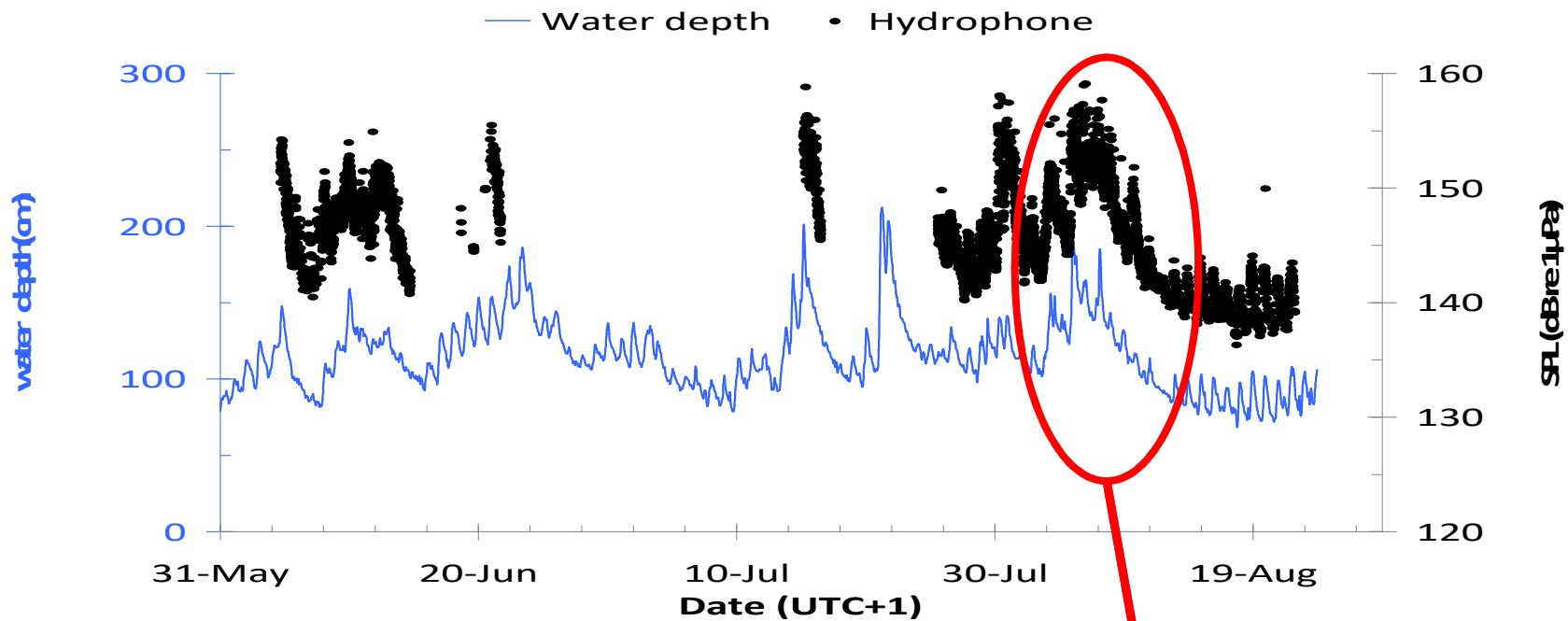
# Drau River 50 days of acoustic data











# Drau River

- Temporal variation of hydrophone and geophone are highly correlated; geophone response is highly correlated with physical bedload sampling;
- Potential of the hydrophone for **bedload monitoring** in large gravel bed rivers

# Plan

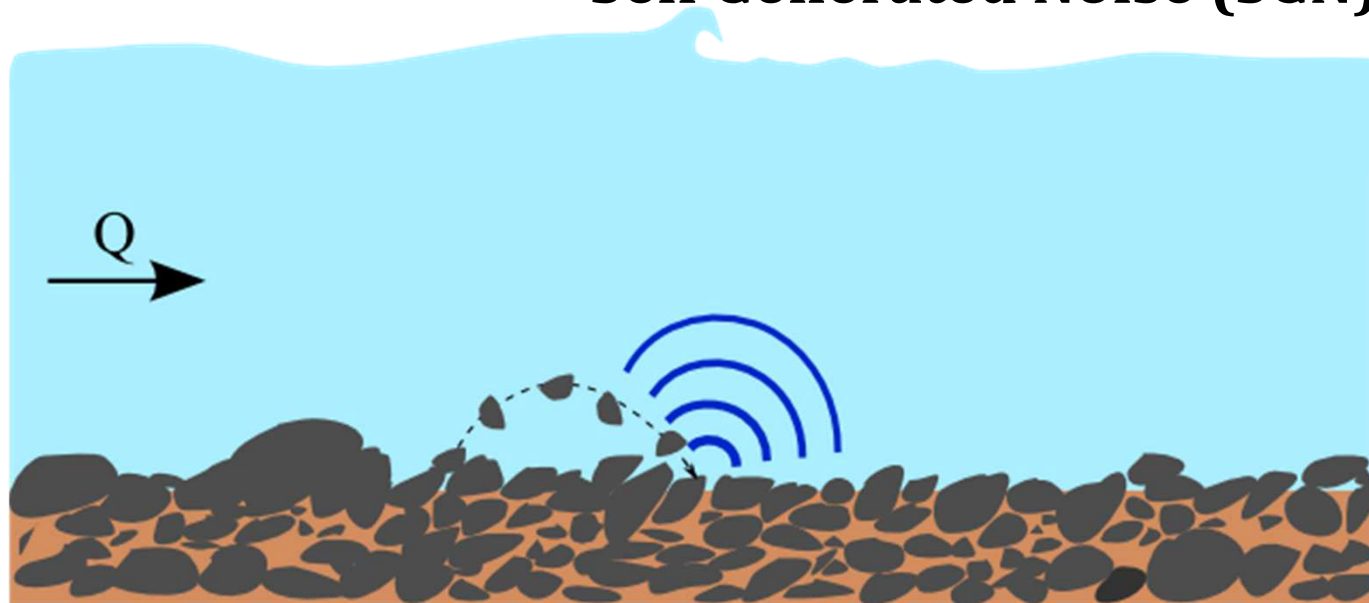
- **Comparative measurements** in natural streams
  - Rhine River
  - Drau River
- **River acoustics**
  - Observations in a large gravel bed river
  - Interpretations
- **Conclusion & perspectives**



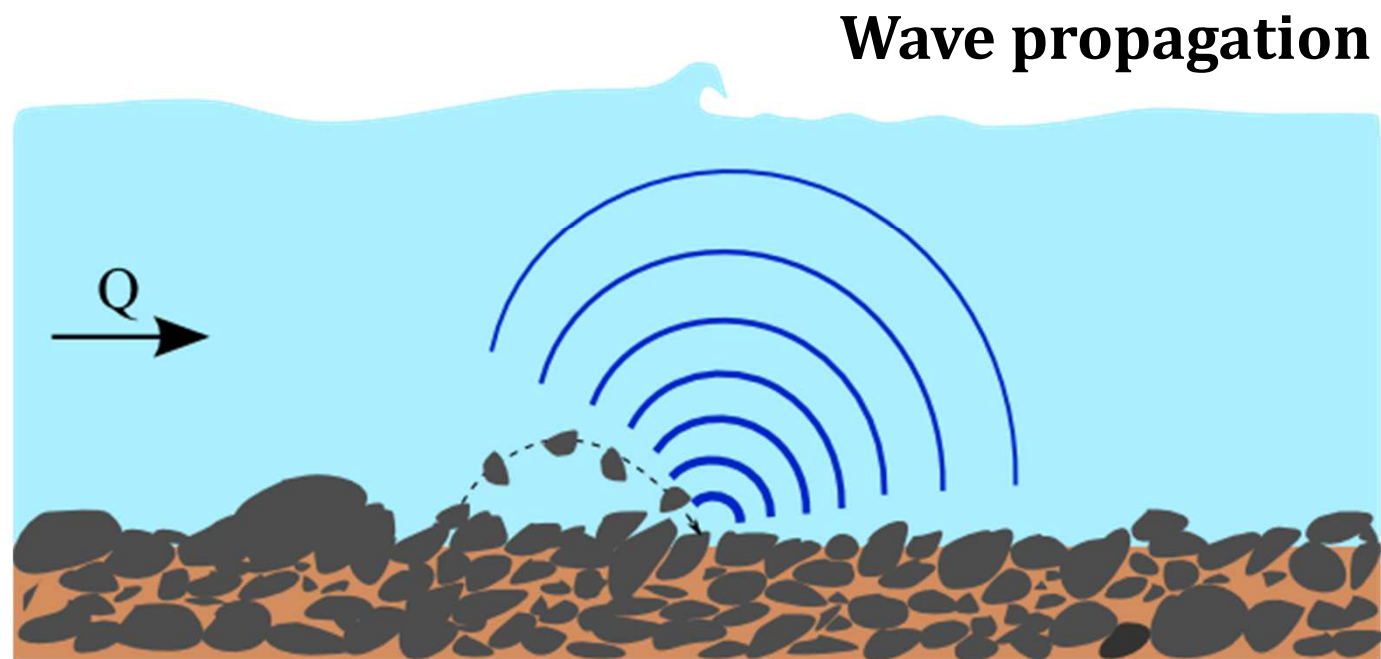
# River acoustics

# Passive acoustic monitoring

## Self Generated Noise (SGN)



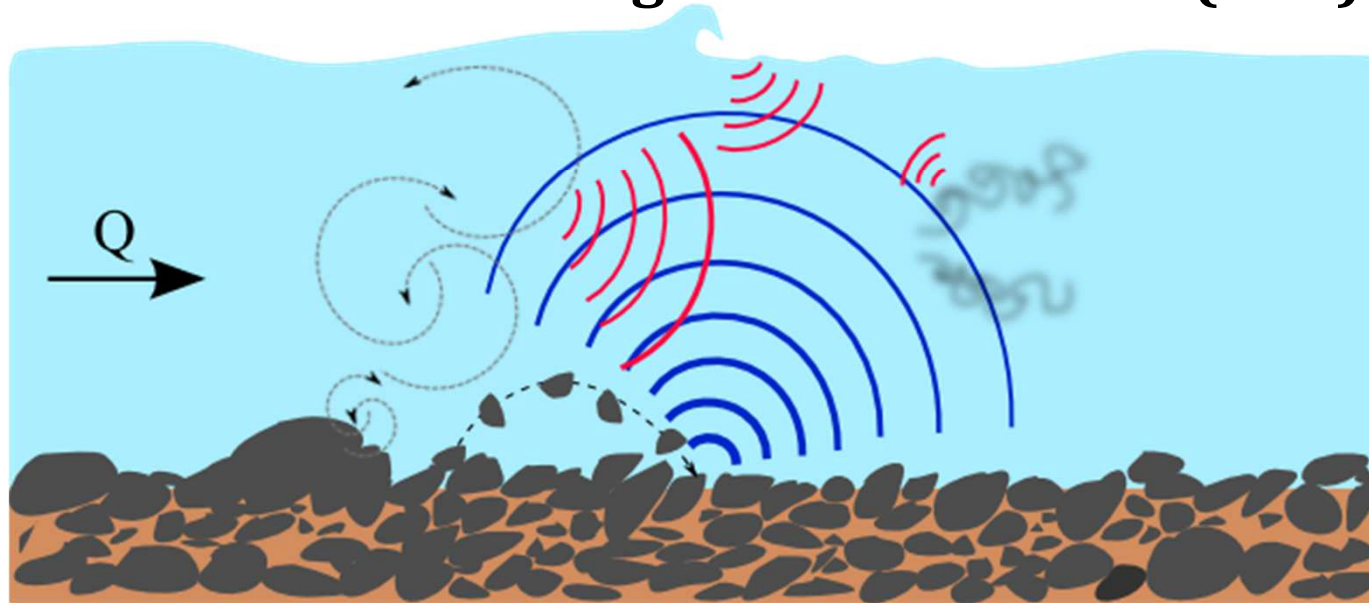
# Passive acoustic monitoring





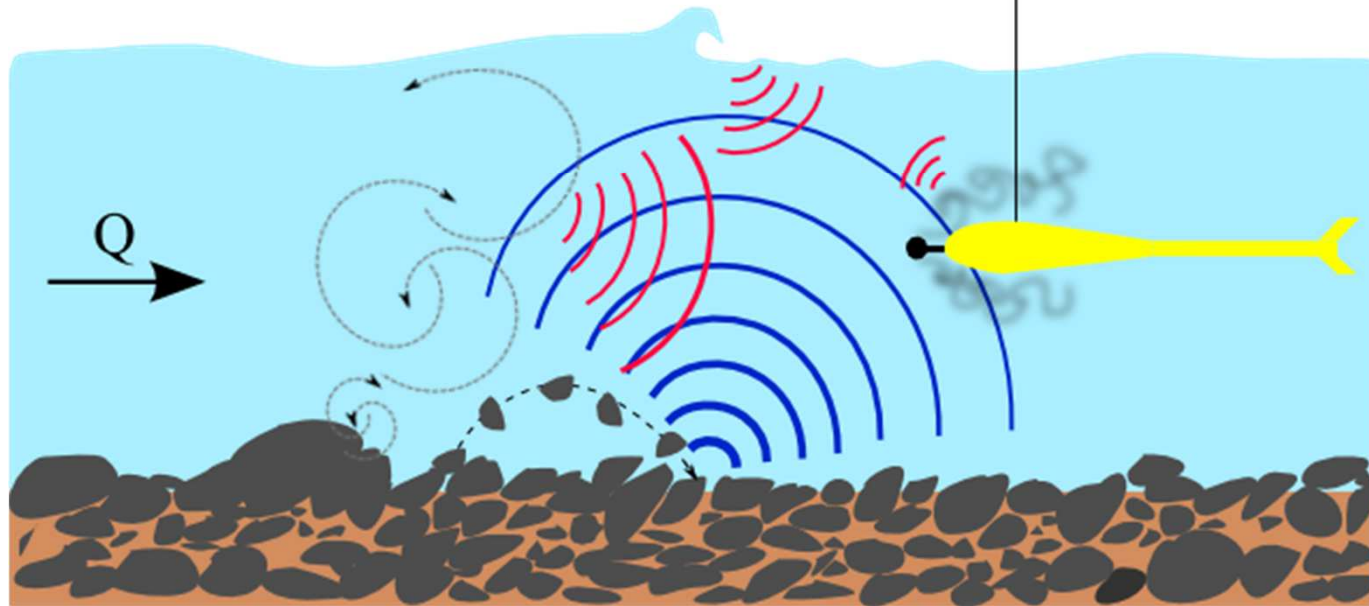
# Passive acoustic monitoring

## Signal to Noise Ratio (SNR)

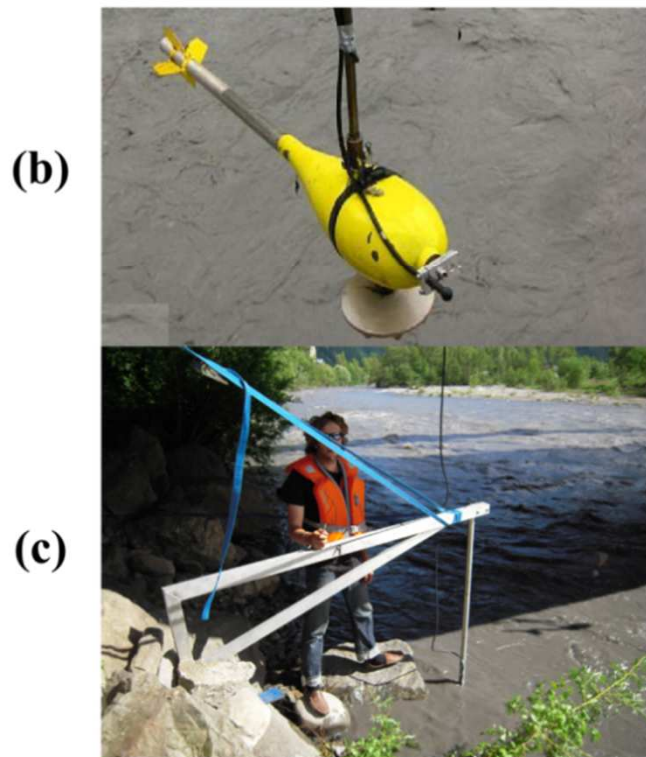
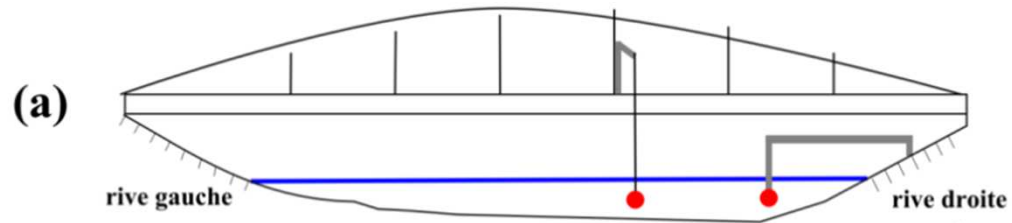


# Passive acoustic monitoring

Received signal =  
bedload SGN + **propagation** + **ambient noise**

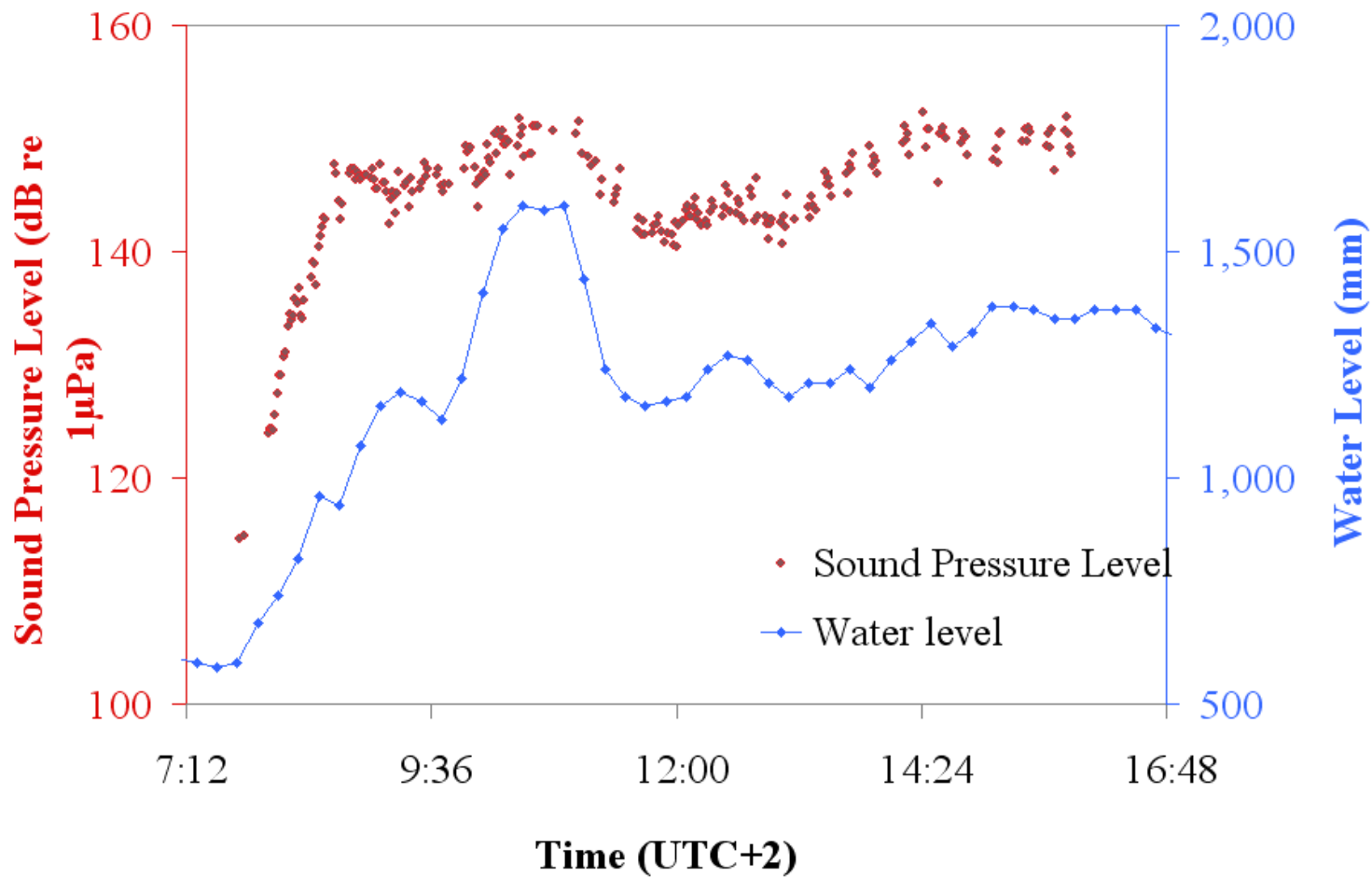


# Arc en Maurienne River

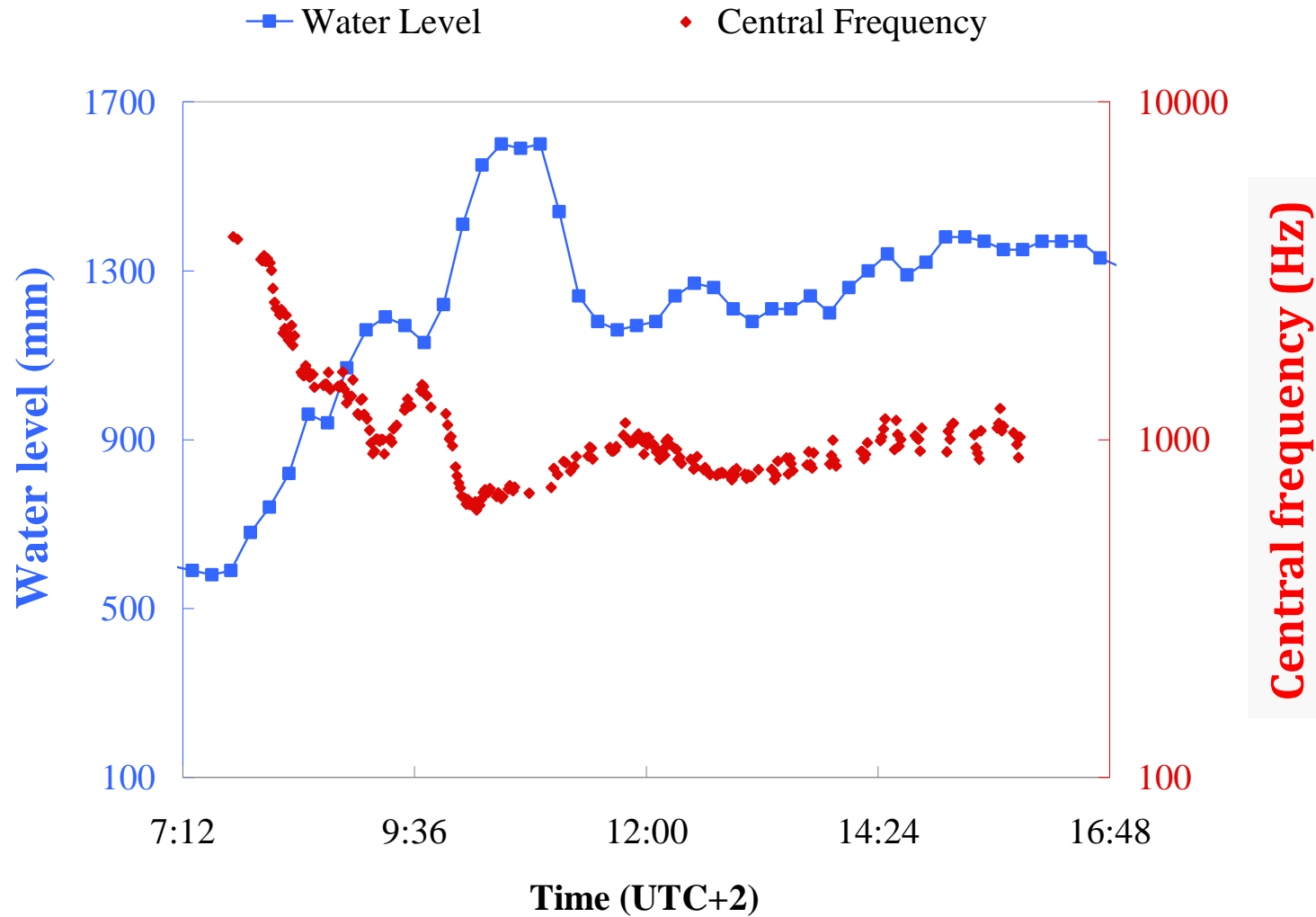


Flushing operations: surface velocity up to 3 m/s

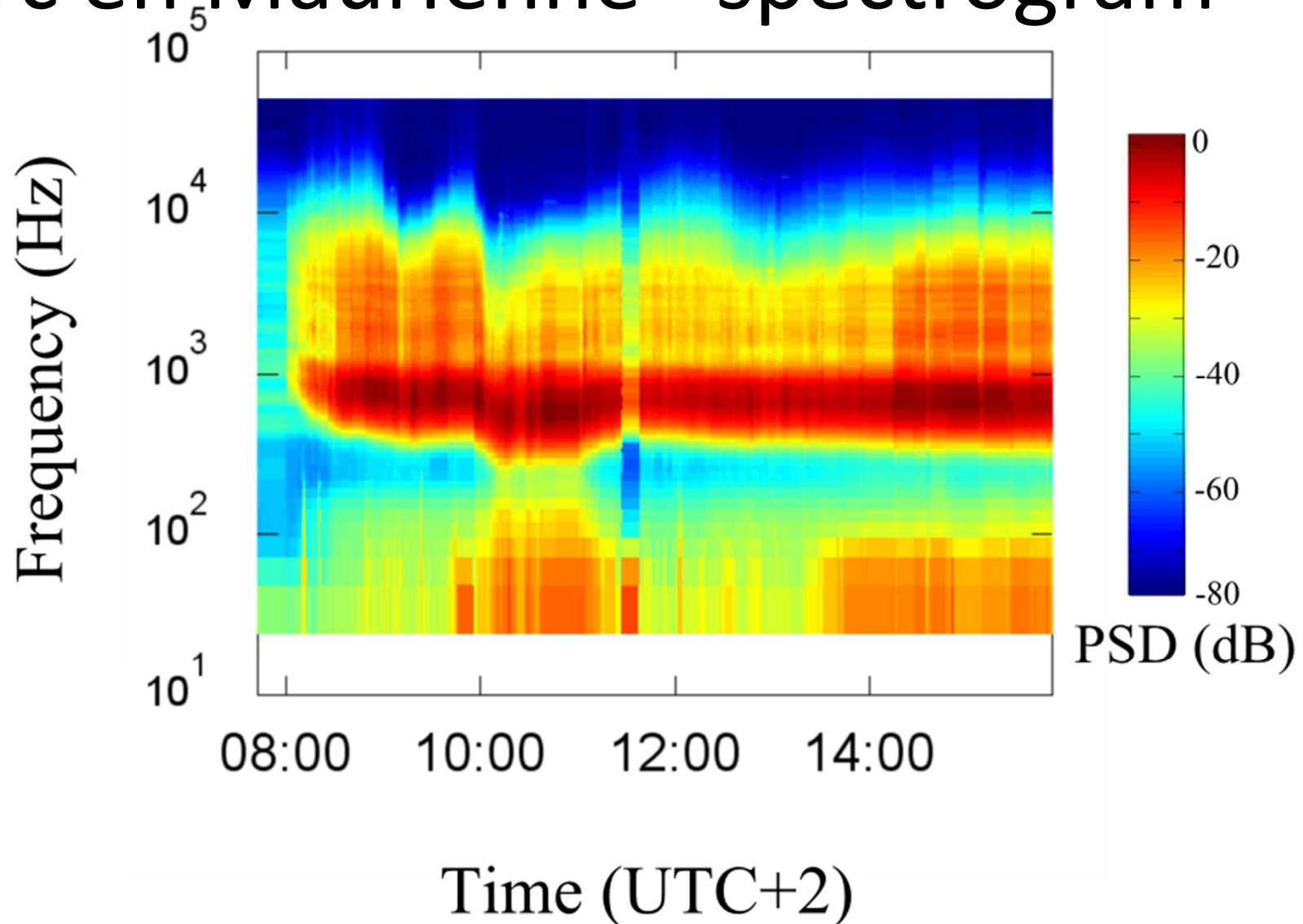
# Arc en Maurienne River



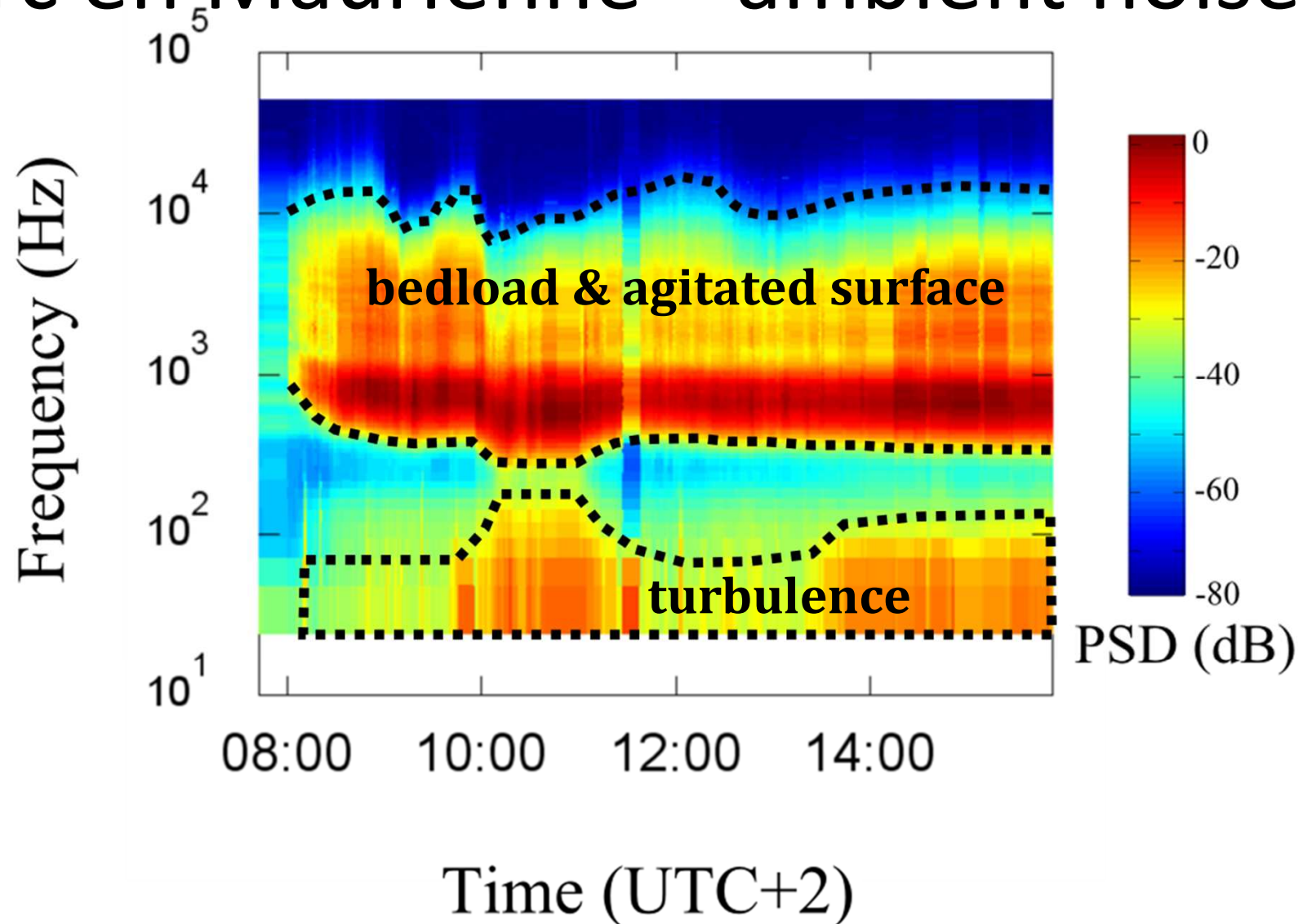
# Arc en Maurienne River



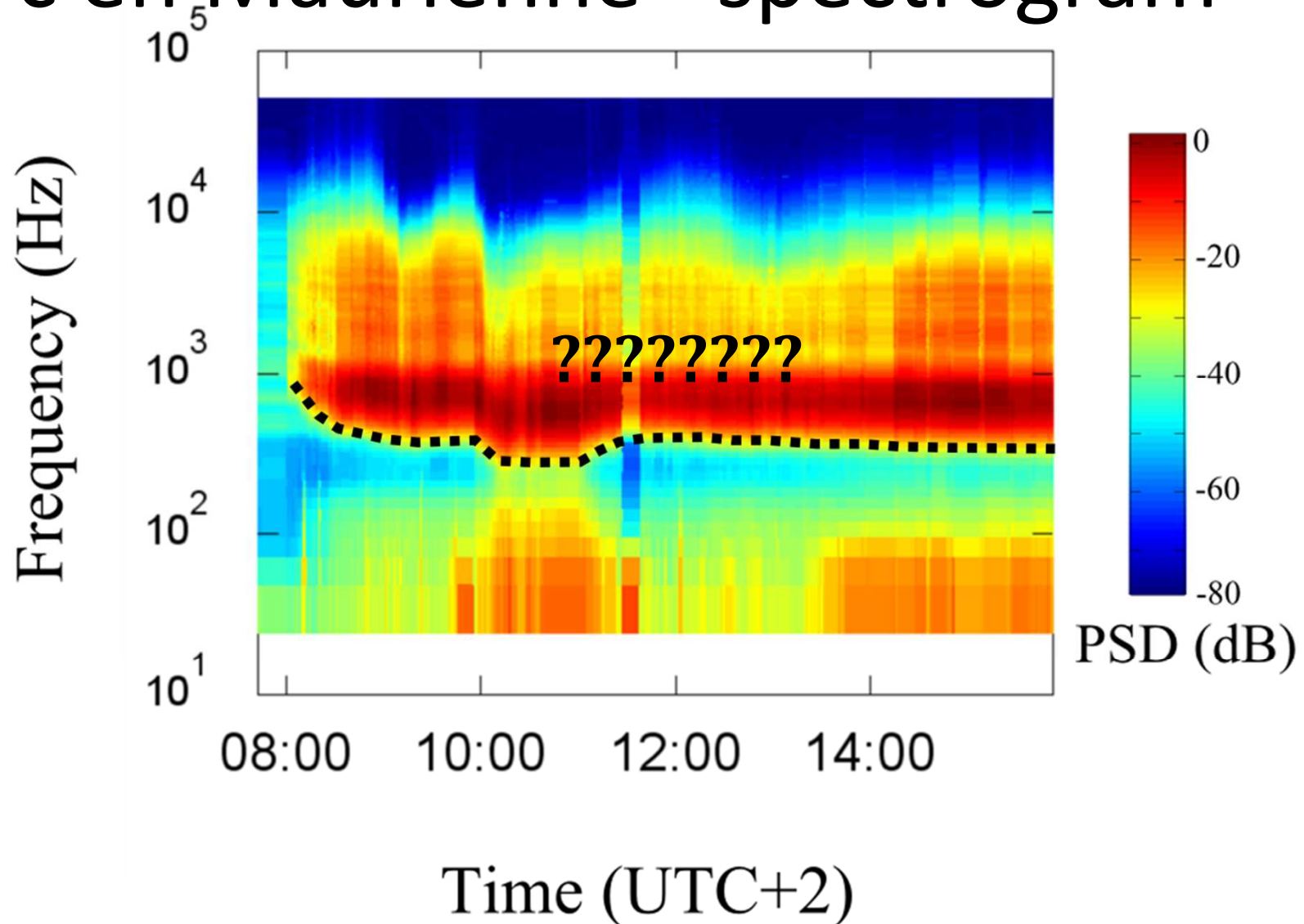
# Arc en Maurienne - spectrogram



# Arc en Maurienne – ambient noise

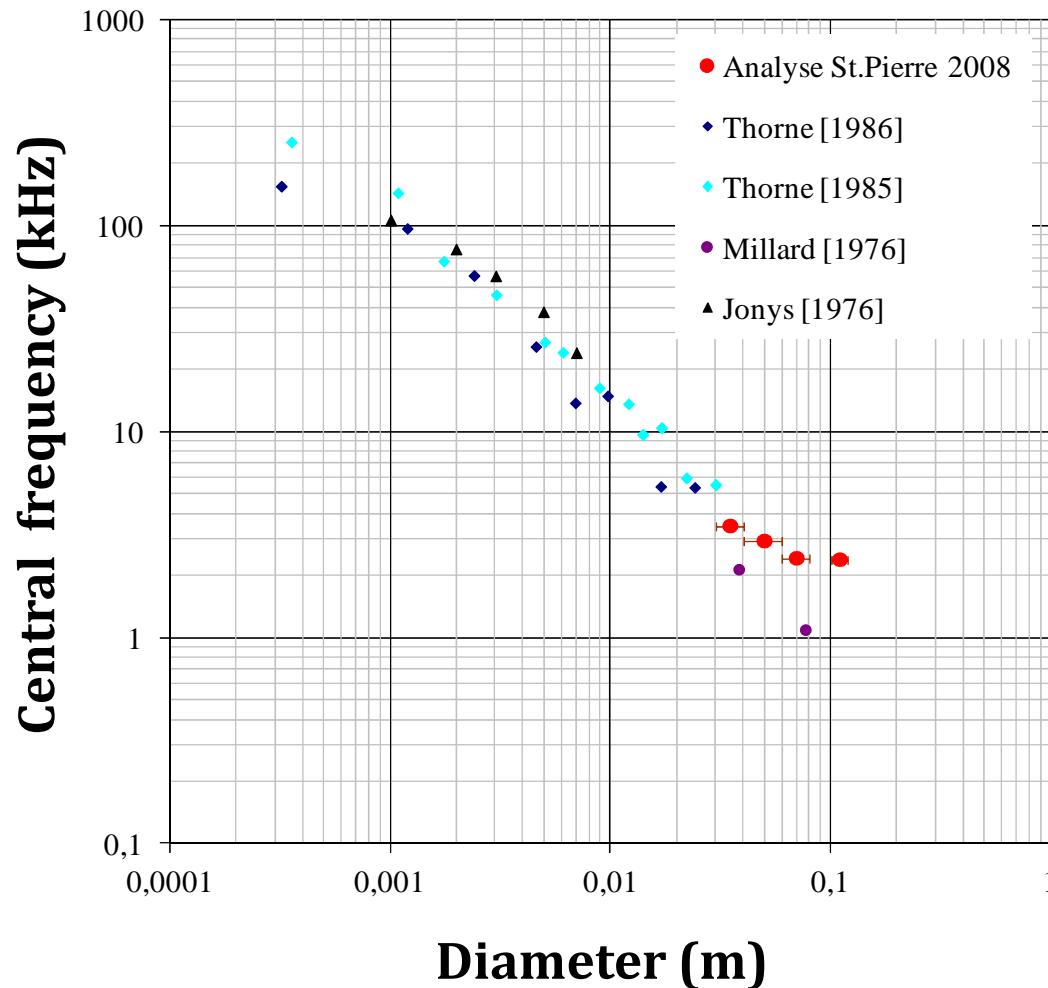


# Arc en Maurienne - spectrogram



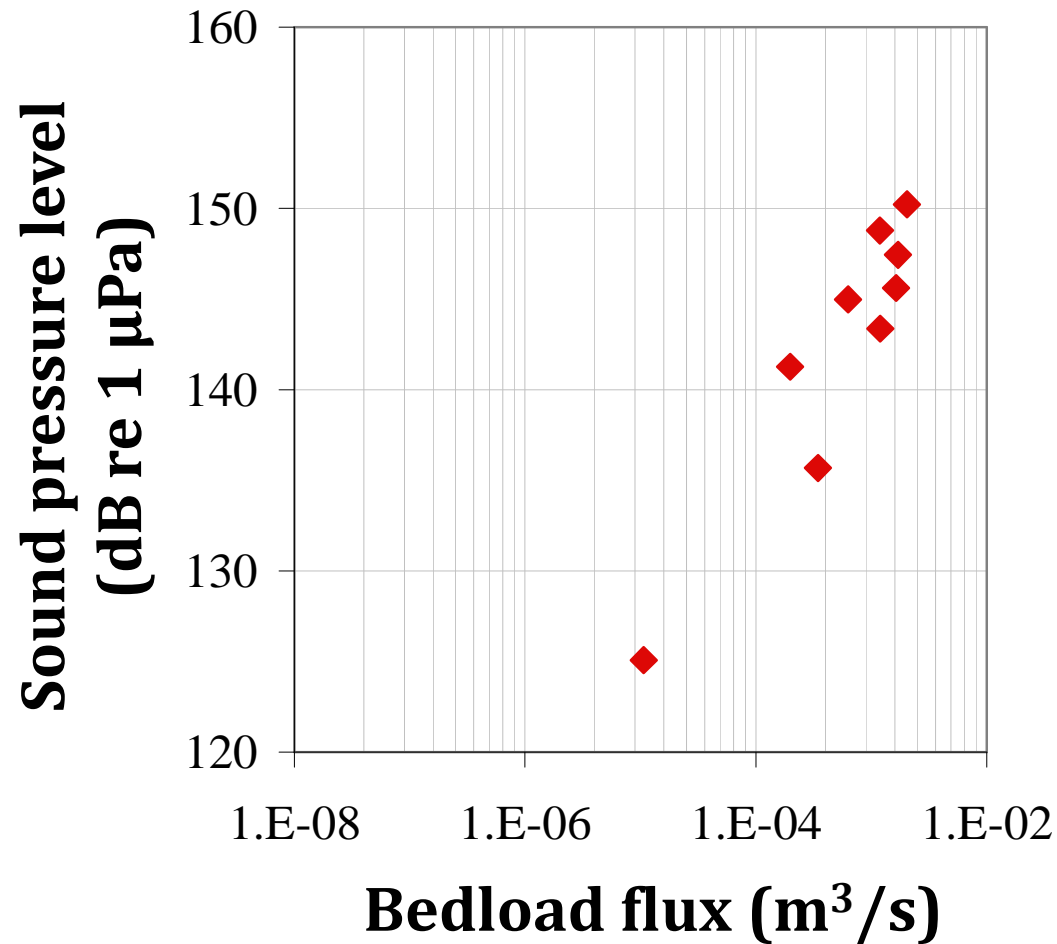


# Frequency & diameters



# Helley-Smith Sampling

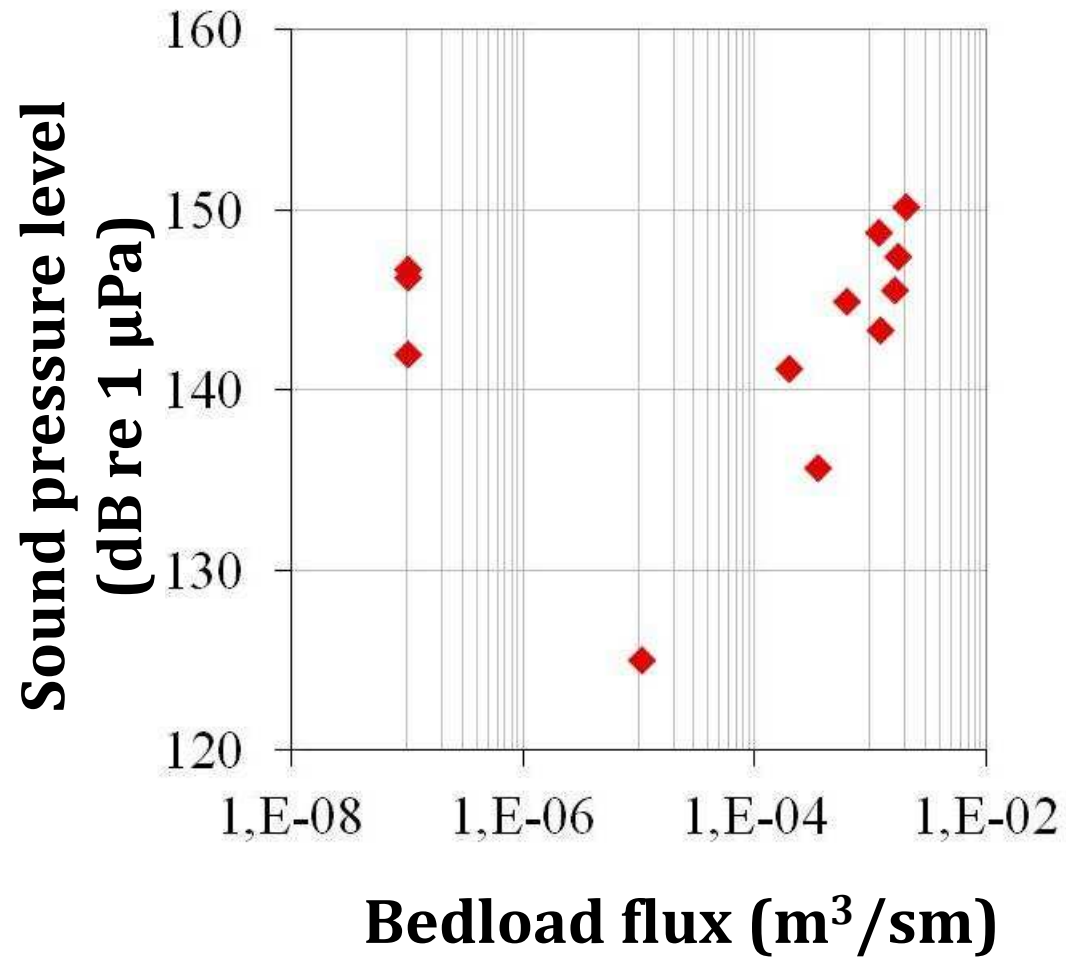
(Camenen, 2010)



*B.Camenen* research team

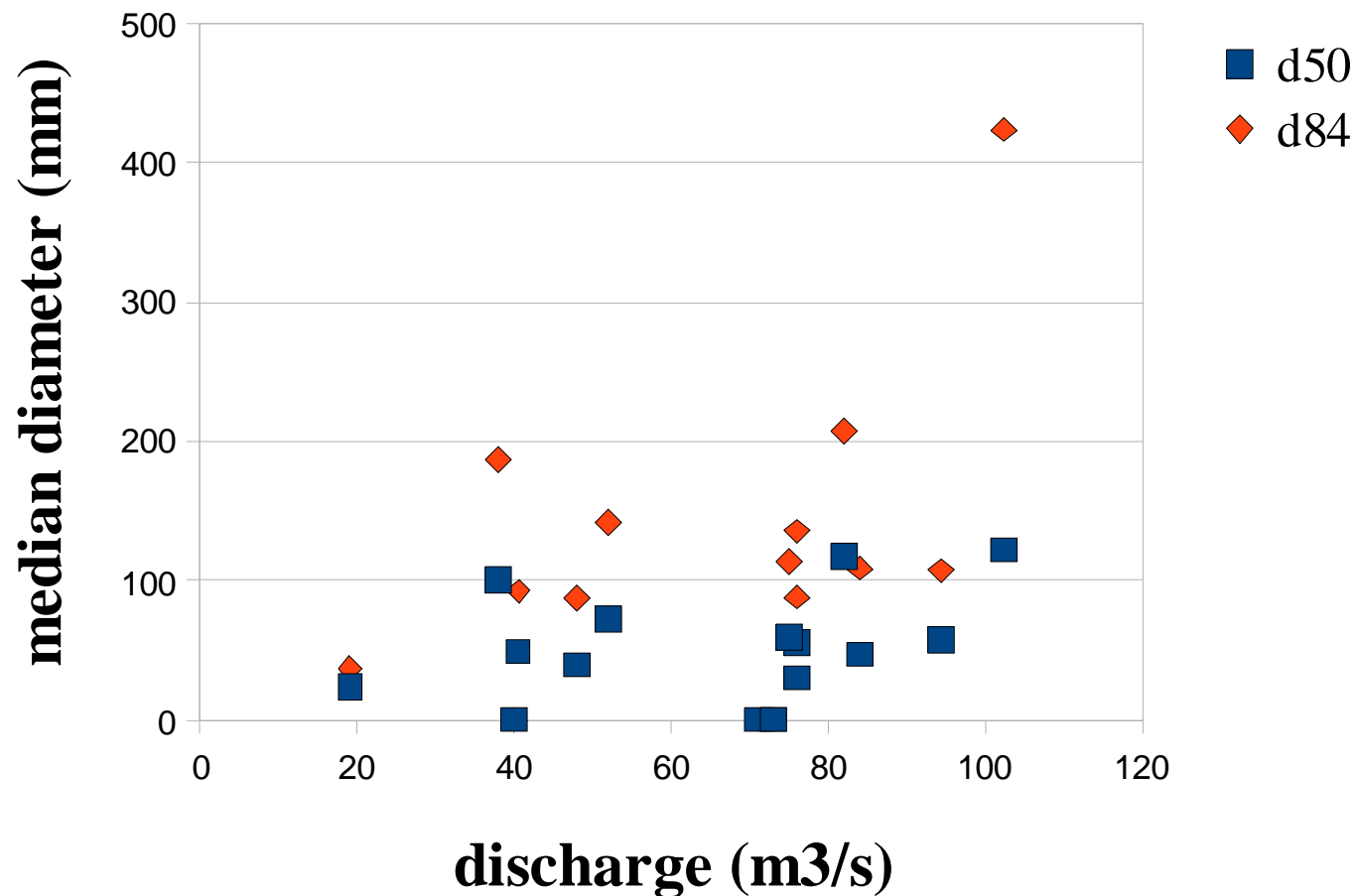
# Helley-Smith Sampling

(Camenen, 2010)



# Grain Size Distribution

(Helley-Smith sampling)



# River acoustics

- **Propagation effects:**

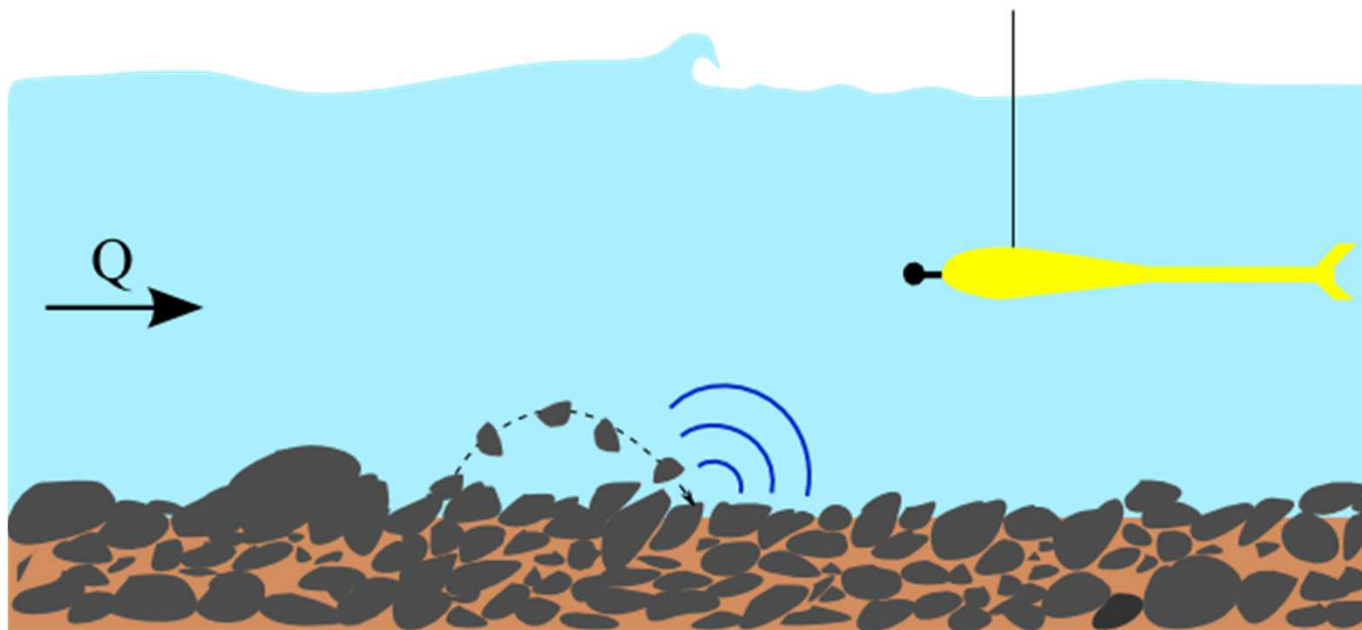
- Geometric dispersion (environment geometry and boundary conditions)
- Attenuation & absorption by water and suspended sediments
- Interferences
- ...

→ **frequency** dependent

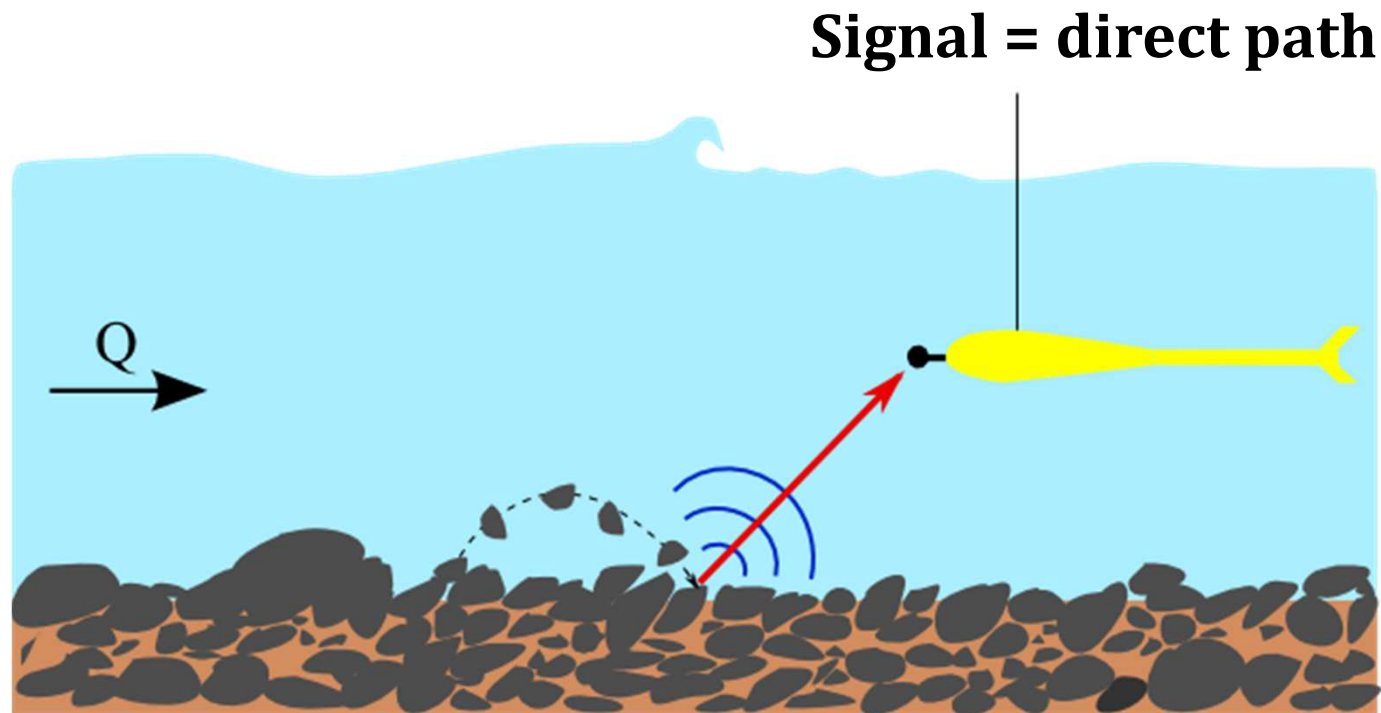
(Ratio wavelength & problem dimensions)

-

# Acoustic wave guide

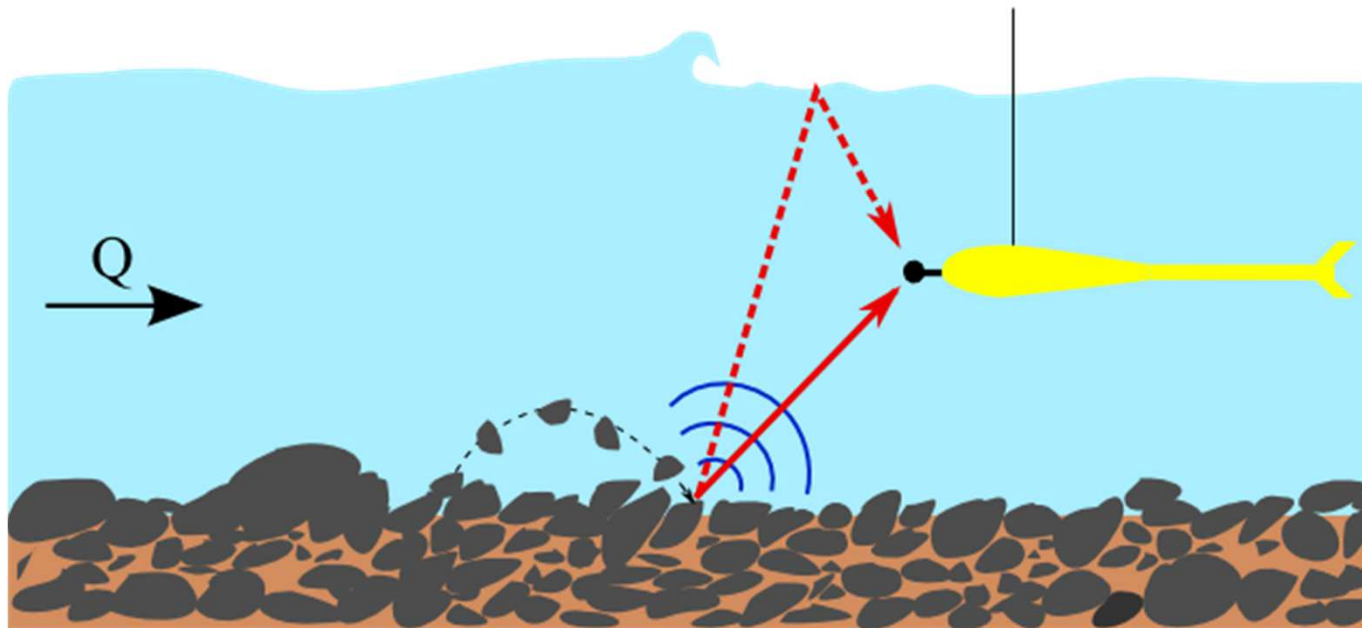


# Acoustic wave guide



# Acoustic wave guide

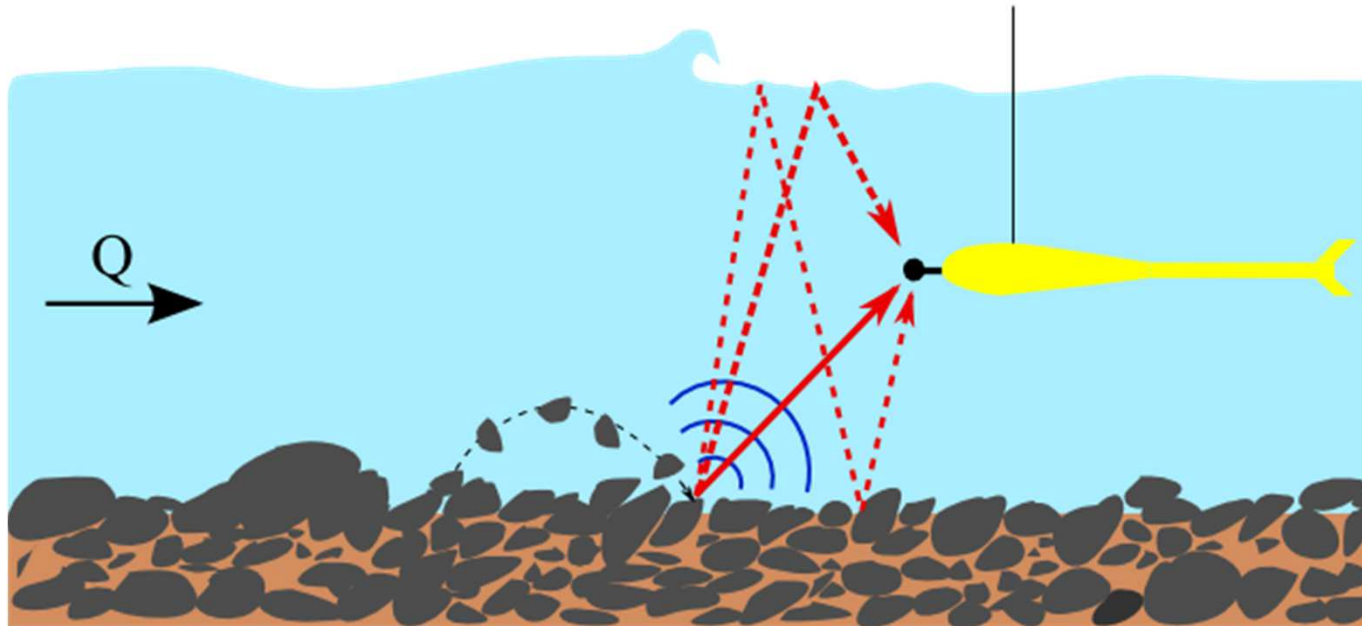
**Signal = direct + surface reflected**



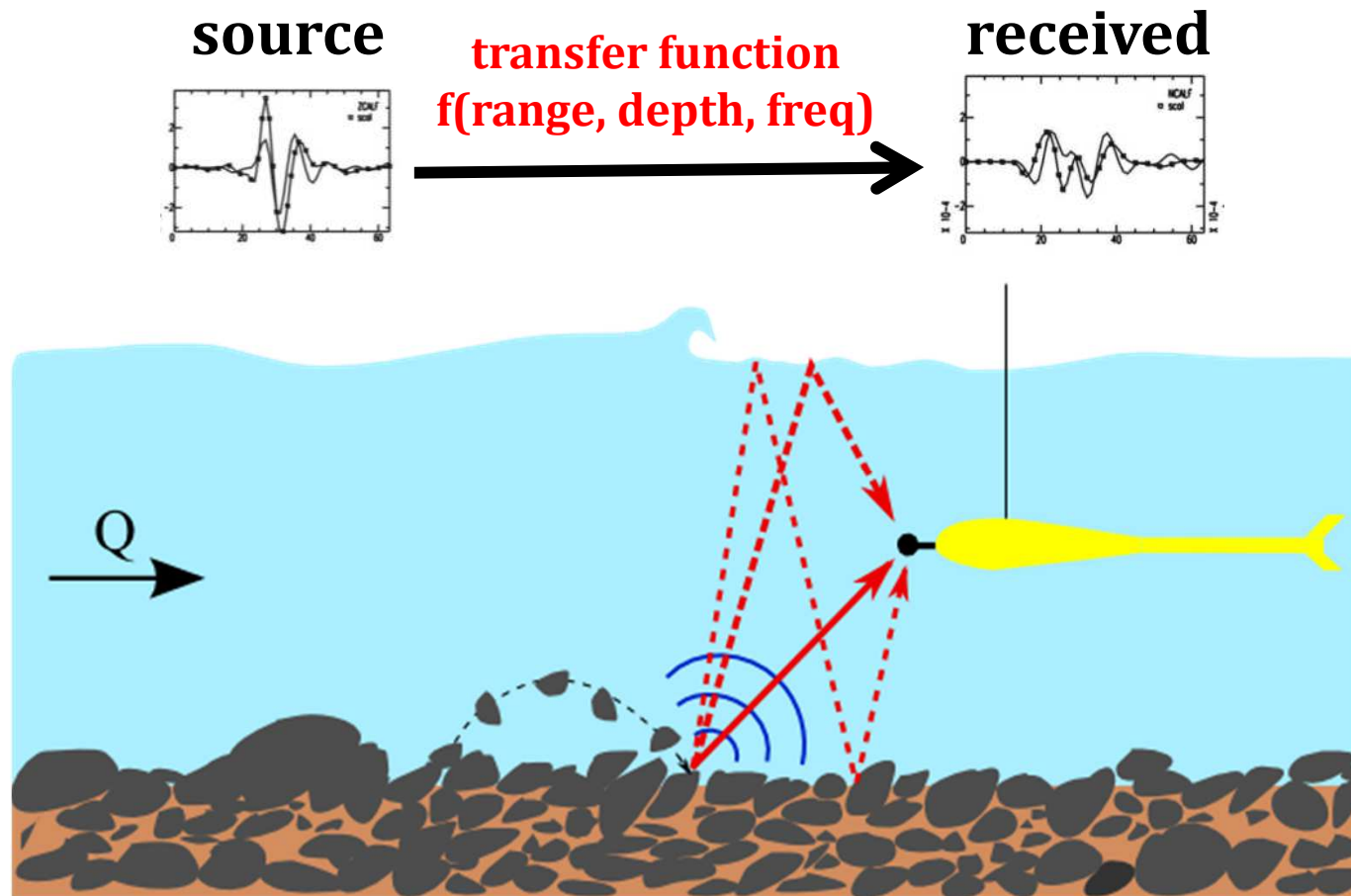


# Acoustic wave guide

**Signal = direct + surface reflected + bottom reflected**

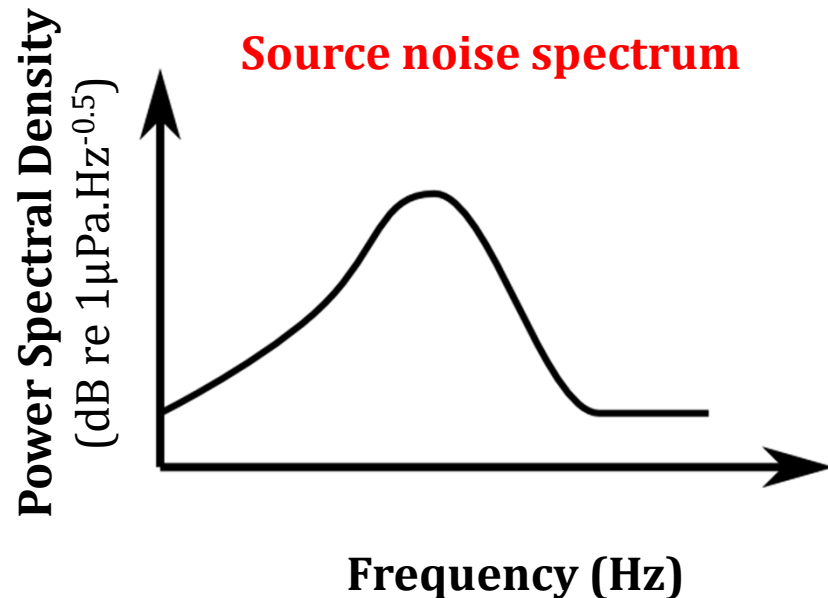
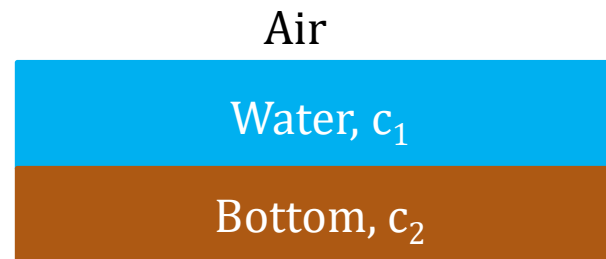


# Acoustic wave guide



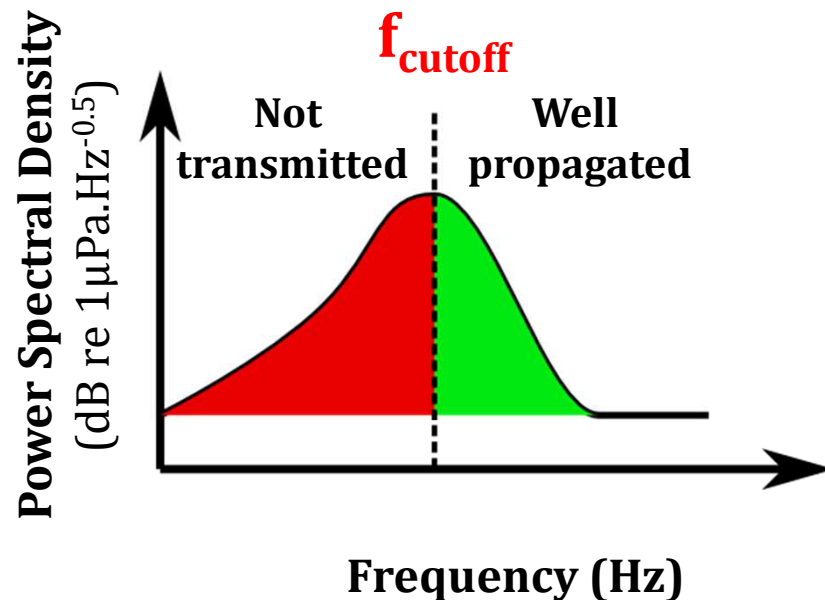
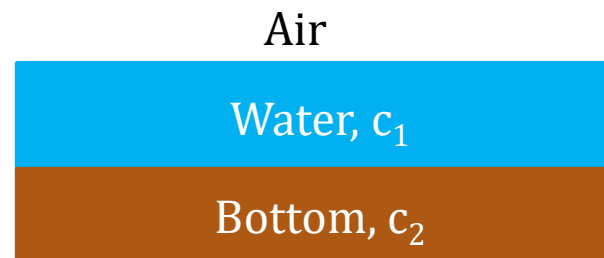
# Acoustic wave guide

- Pekeris waveguide:



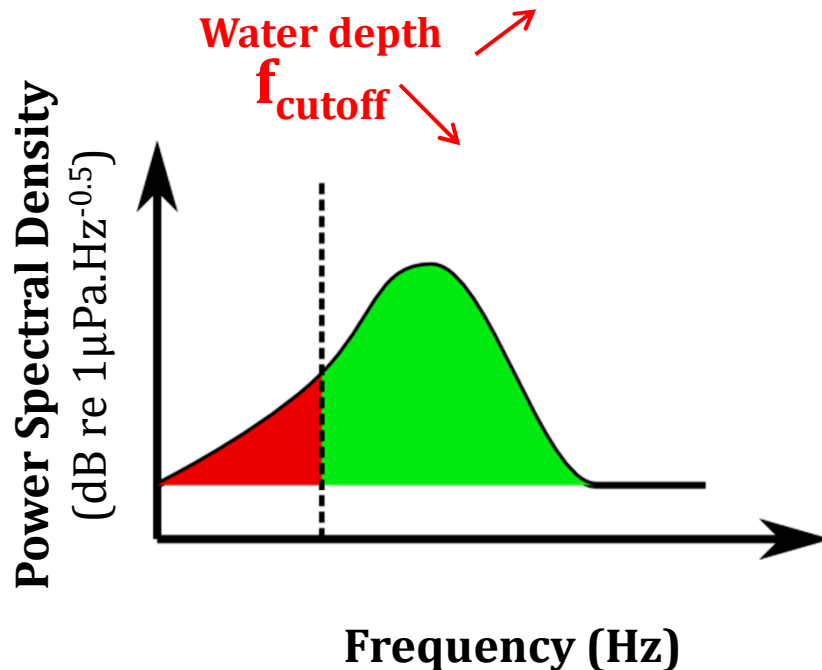
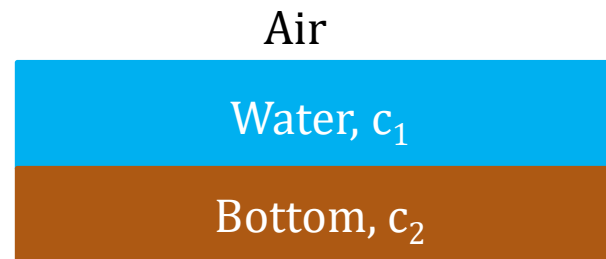
# Acoustic wave guide

- Pekeris waveguide:



# Acoustic wave guide

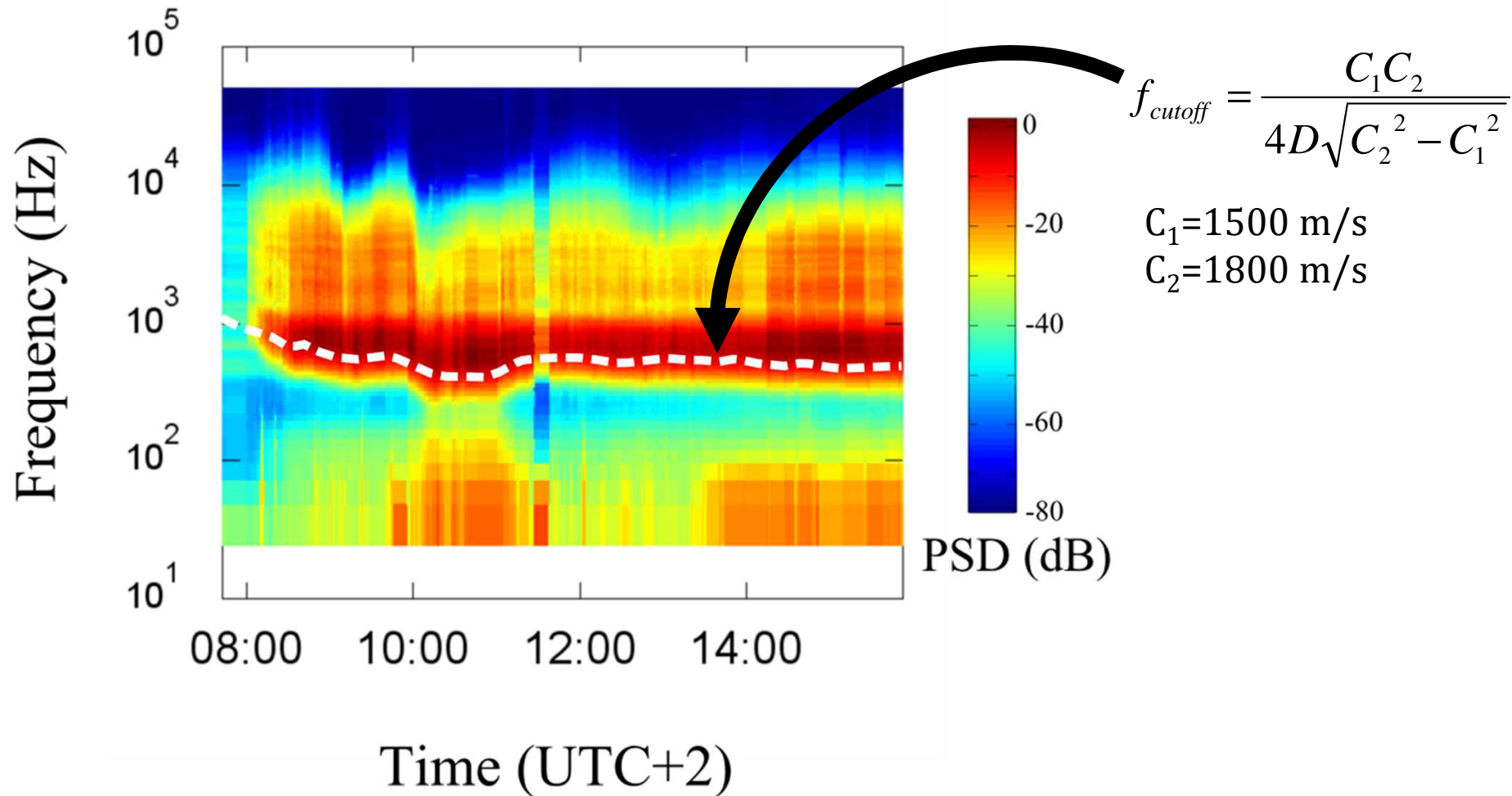
- Pekeris waveguide:



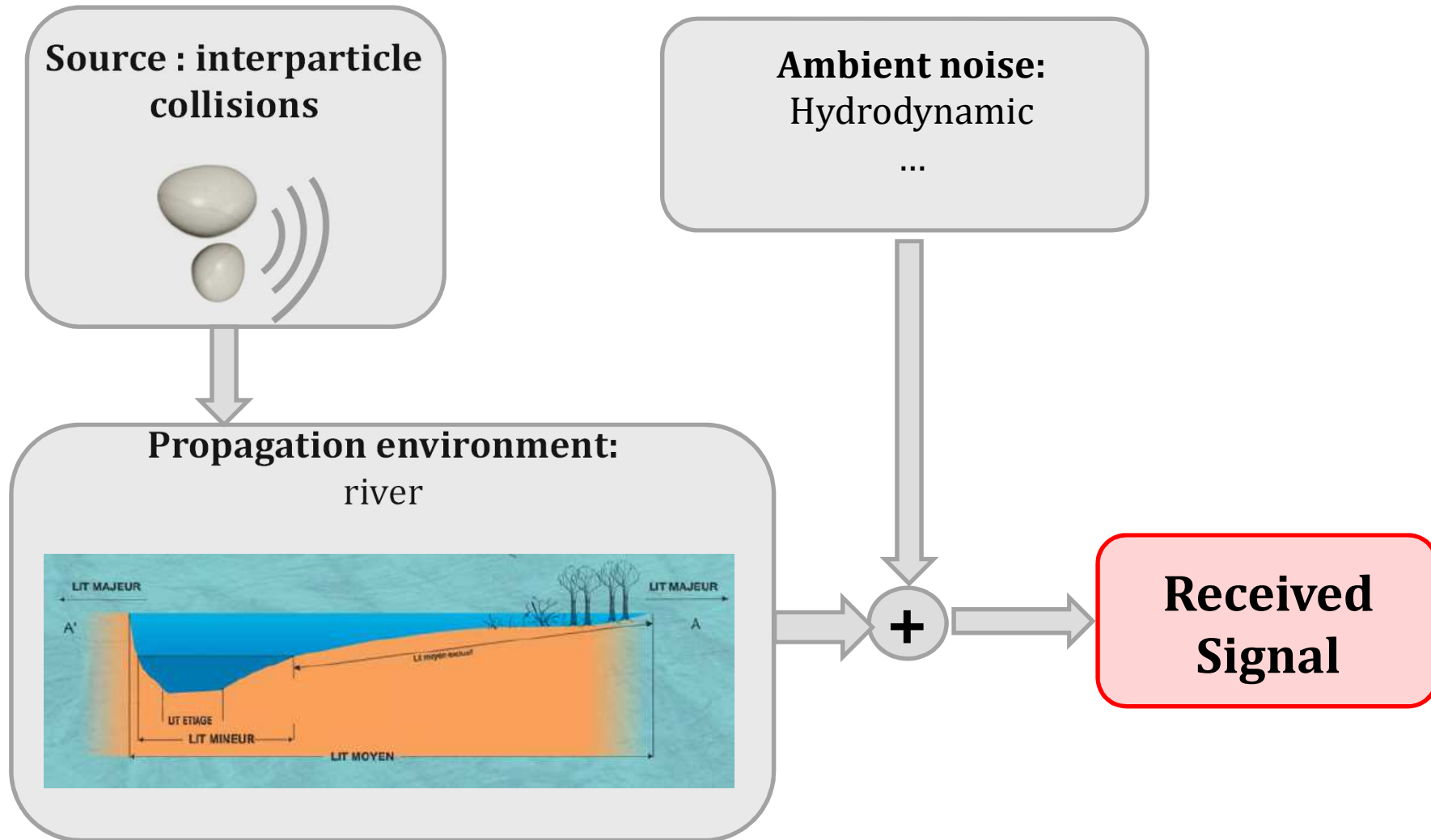
$$f_{cutoff} = \frac{C_1 C_2}{4D \sqrt{C_2^2 - C_1^2}}$$

$c_1$ , sound speed in water (m/s)  
 $c_2$ , sound speed in sediment (m/s)  
 $D$ , water depth (m)

# Acoustic wave guide



# Signal transformations



# Suitability (hydrophone)

- *Continuous sampling & high temporal resolution*
- *Sediment type: gravel and larger*
- *Stream type : **large** gravel bed river*
- *Integrative measurement*
- *Not disruptive to flow field*

-----

- *Easy to deploy (but not everywhere)*
- *Low cost*
- *Potential use as calibration standard: probably not*



# Perspectives

- Improve signal descriptors (signal processing)
- More calibration relative to the noise generated by interparticle collisions (Laboratory experiments)
- Active acoustic methods to investigate river acoustics in the middle frequency range (1-100 kHz)



**Thanks for your listening**



This research is supported by the project **GESTRANS** (ANR-09-RISK-004)

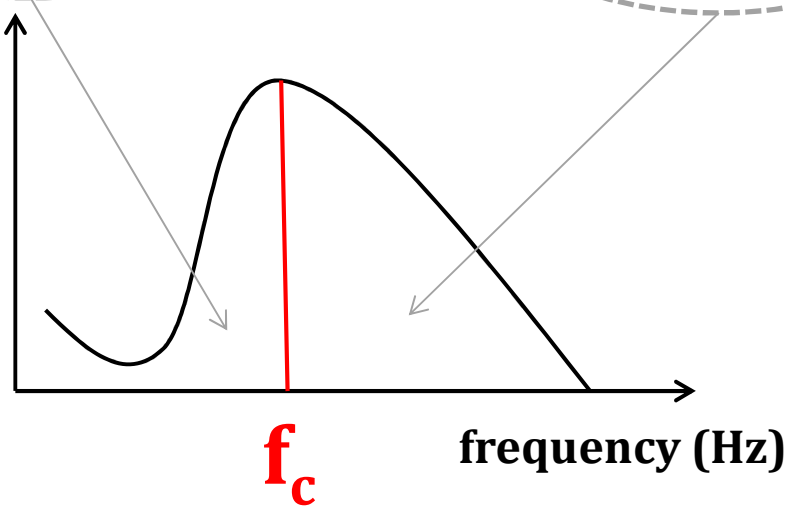




# Central frequency (Hz)

$$\int_{-\infty}^{f_c} P(f)df = \int_{f_c}^{+\infty} P(f)df$$

Power Spectral Density  
( $\mu\text{PaHz}^{-1/2}$ )



# Suspended load

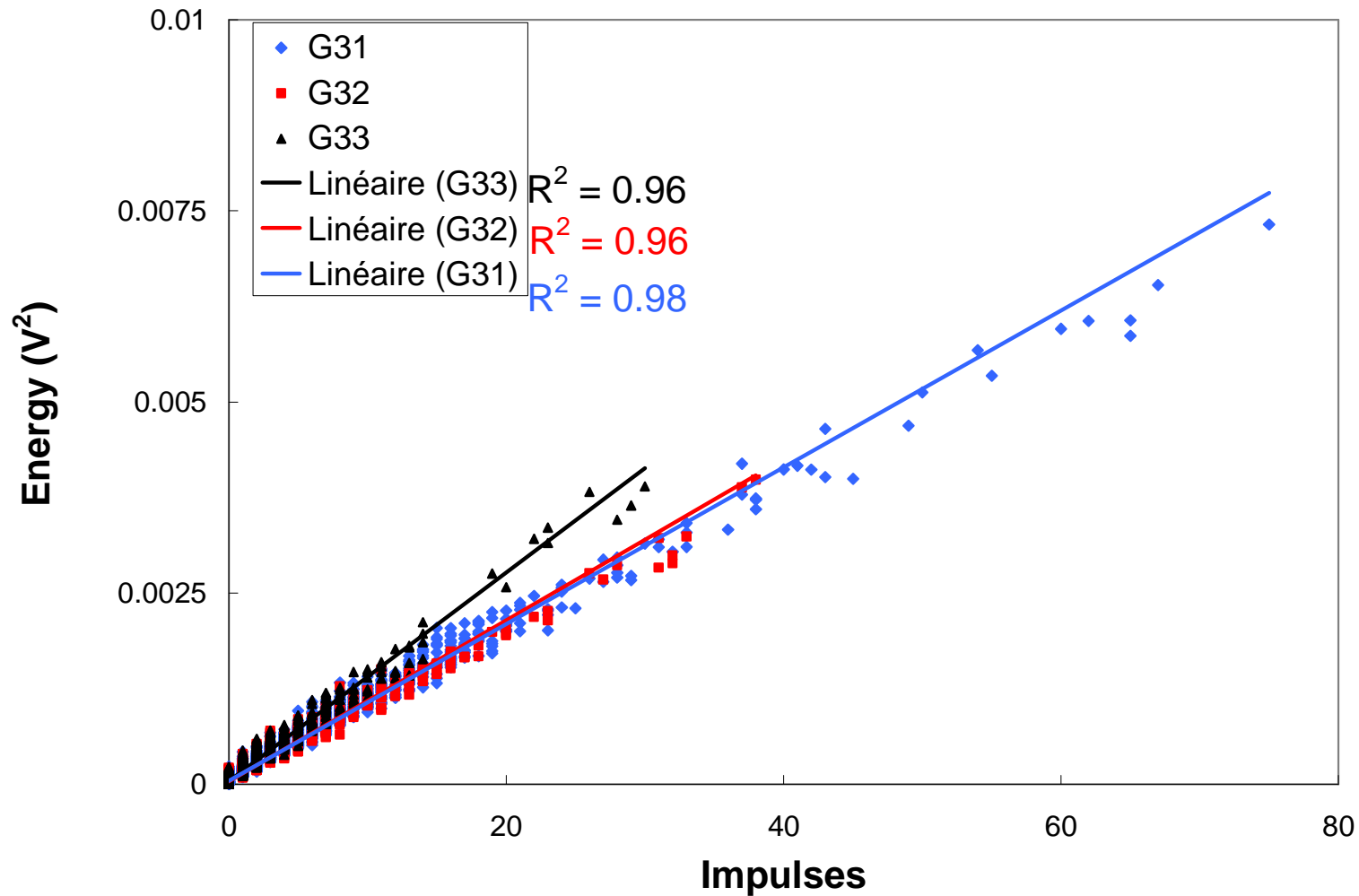
Attenuation coefficient computed using:

- *Thorne & Meral (2008)* , diffraction component
- *Urlick (1948)*, viscous component

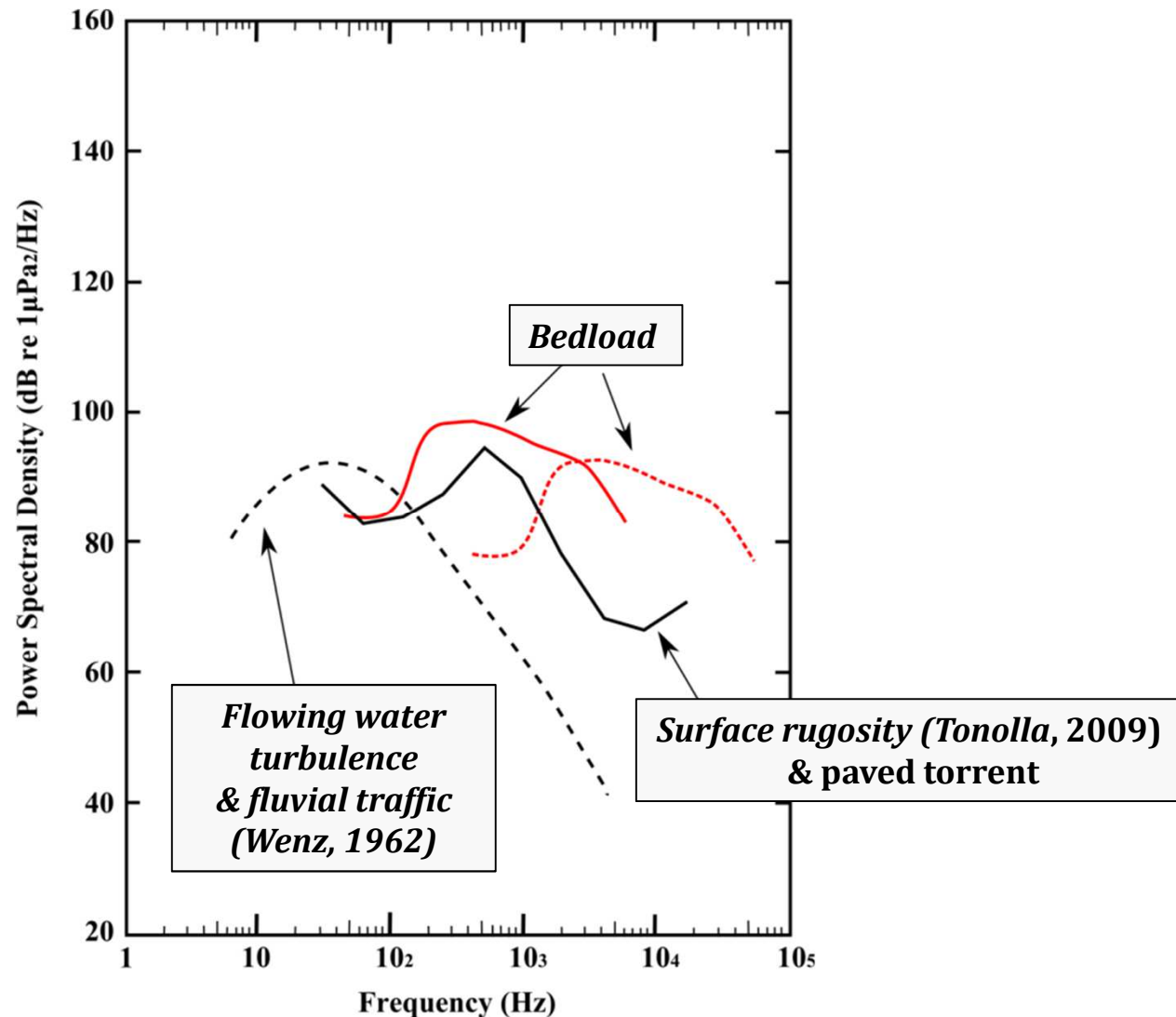
	Fréquences (kHz)			
	0.1 kHz	1 kHz	10 kHz	100 kHz
$\alpha_{scat}$ (dB/m)	$3,1 \cdot 10^{-16}$	$3,1 \cdot 10^{-12}$	$3,1 \cdot 10^{-8}$	$3,1 \cdot 10^{-4}$
$\alpha_{visc}$ (dB/m)	$1,0 \cdot 10^{-3}$	$5,4 \cdot 10^{-3}$	$1,9 \cdot 10^{-2}$	$6,3 \cdot 10^{-2}$

Table 6.2 : Composantes d'atténuation calculées selon (6.19) et (6.21) pour une concentration de 10 g/L, une densité de sédiment de  $2000 \text{ kg/m}^3$  et une viscosité cinématique de  $1,20 \cdot 10^{-6} \text{ m}^2\text{s}^{-1}$ .

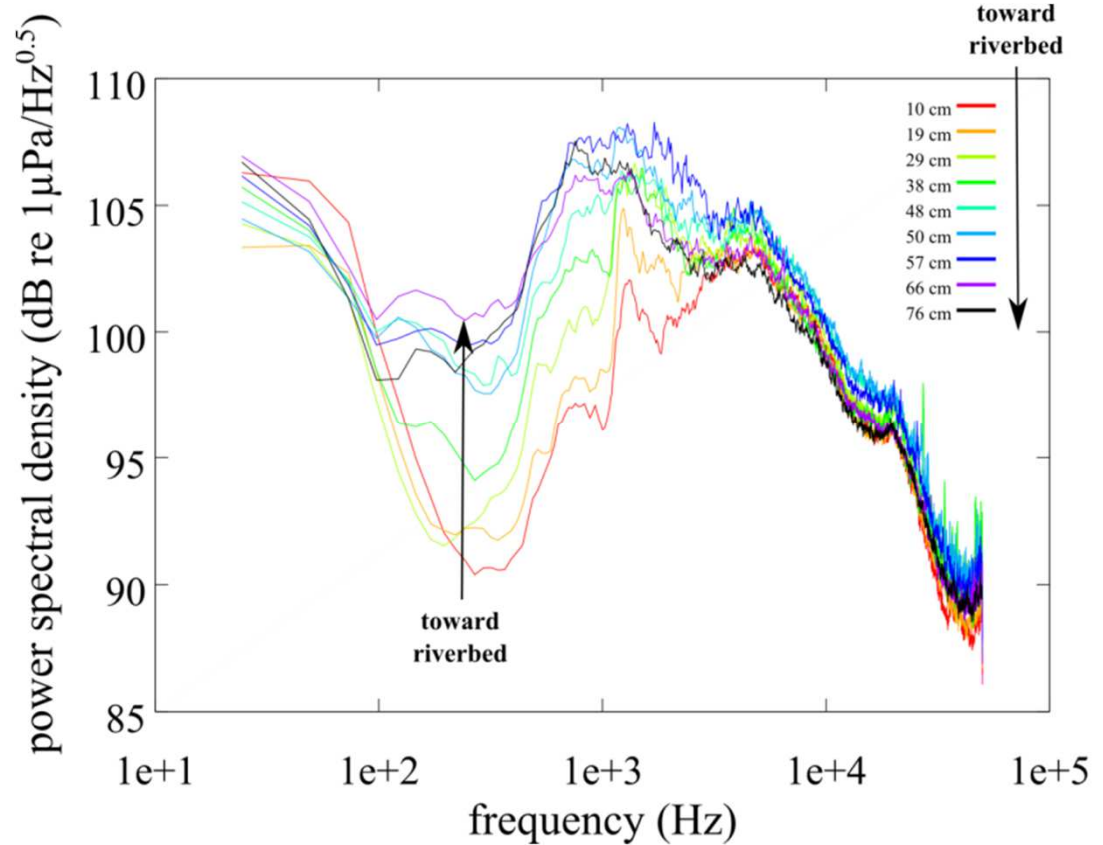
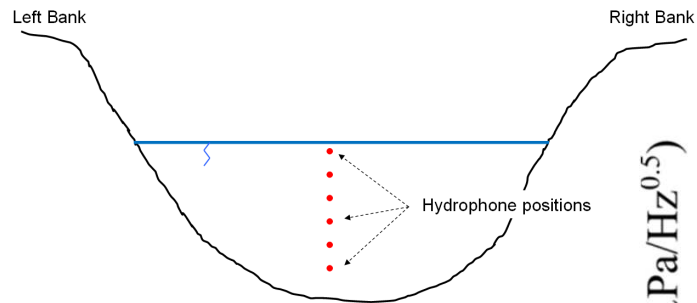
# Impulses & squared integrals



# Wenz Diagram, River version

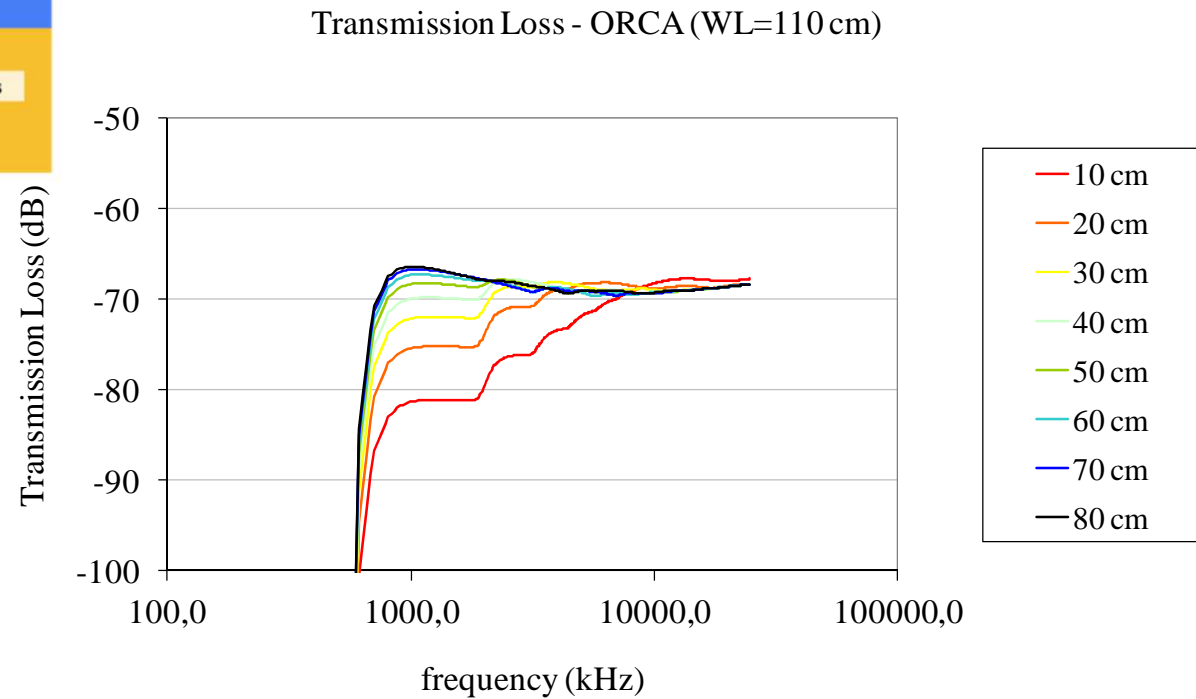
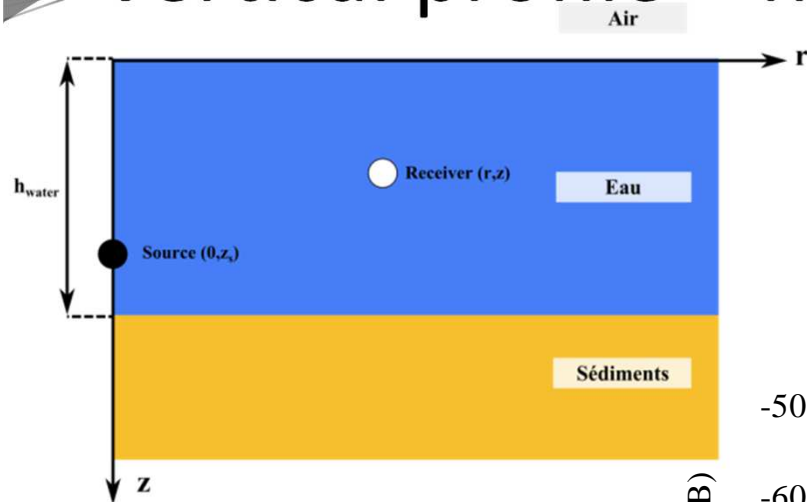


# Acoustic pressure, vertical profile

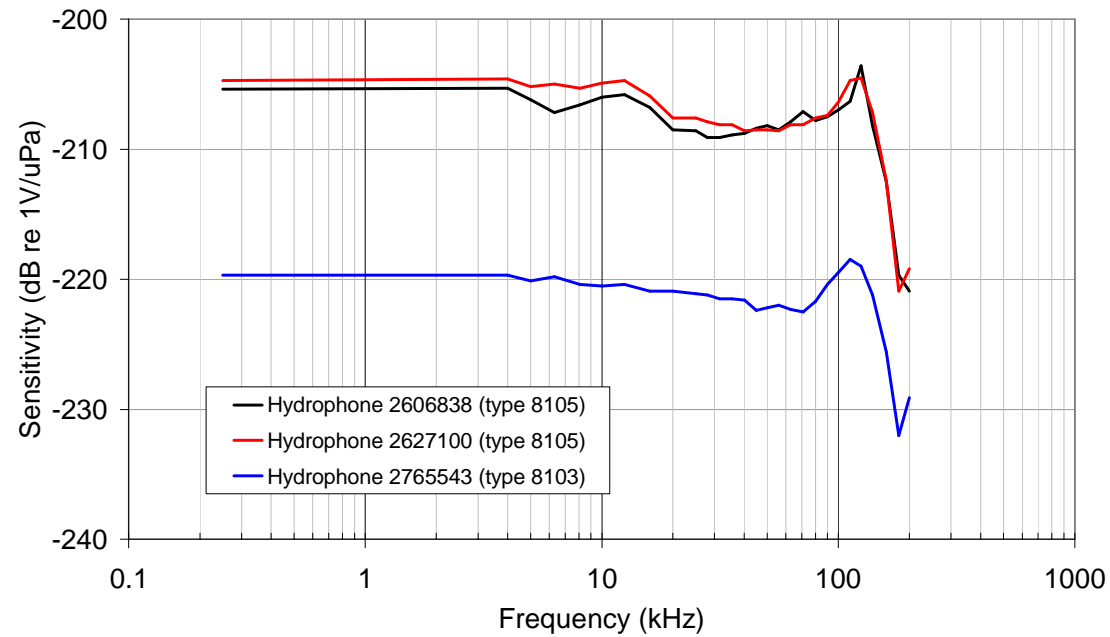




# Vertical profile – Modal propagation model

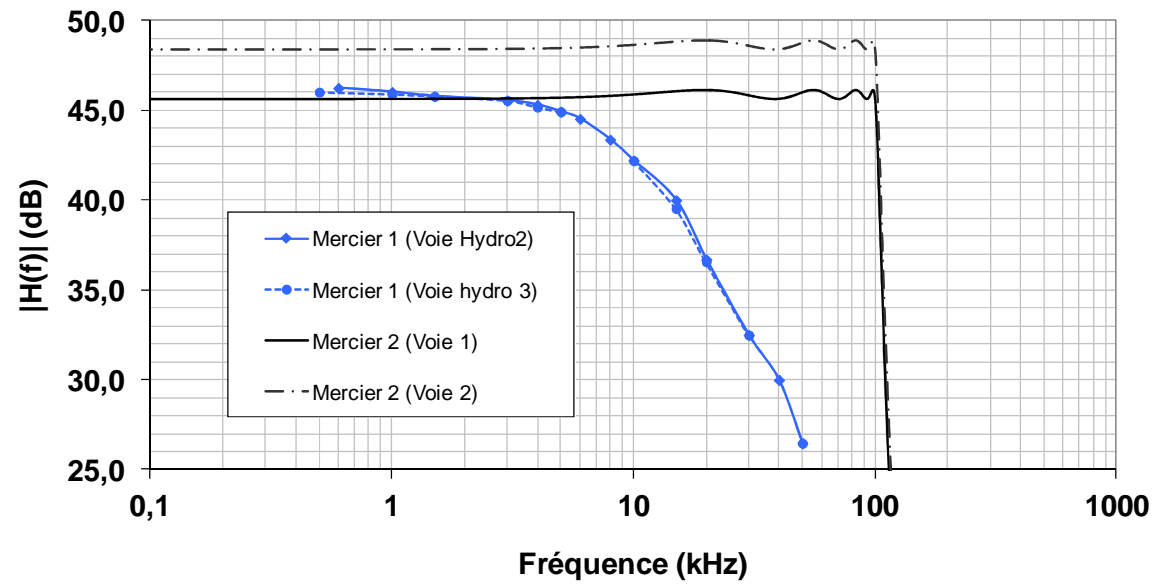


# Sensors



# Pre-amp

Diagramme de Bode



# Doppler

$$f_{received} = \pm f_{source} \frac{c}{c + v_0}$$

Sound celerity, 1500 m/s

Particle velocity, 1-5 m/s