UBERTONE

ultrasonic measurements in liquids

Co-UDlabs

COLLABORATIVE URBAN DRAINAGE RESEARCH LABS COMMUNITIES

Acoustic Scattering from Particles

-

Theory and Scientific Instruments

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About UBERTONE



- Team of doctor and engineers
- Acoustic profilers for scientific research & Sensors for environmental monitoring
- **Velocity** field and **Backscattered echo** (turbidity)
- **Accurate** and **High resolution** measurement
- Fast installation
- From the lab to the field
- **Opaque** liquids
- Wide range of applications : from civil engineering to chocolate manufacturing



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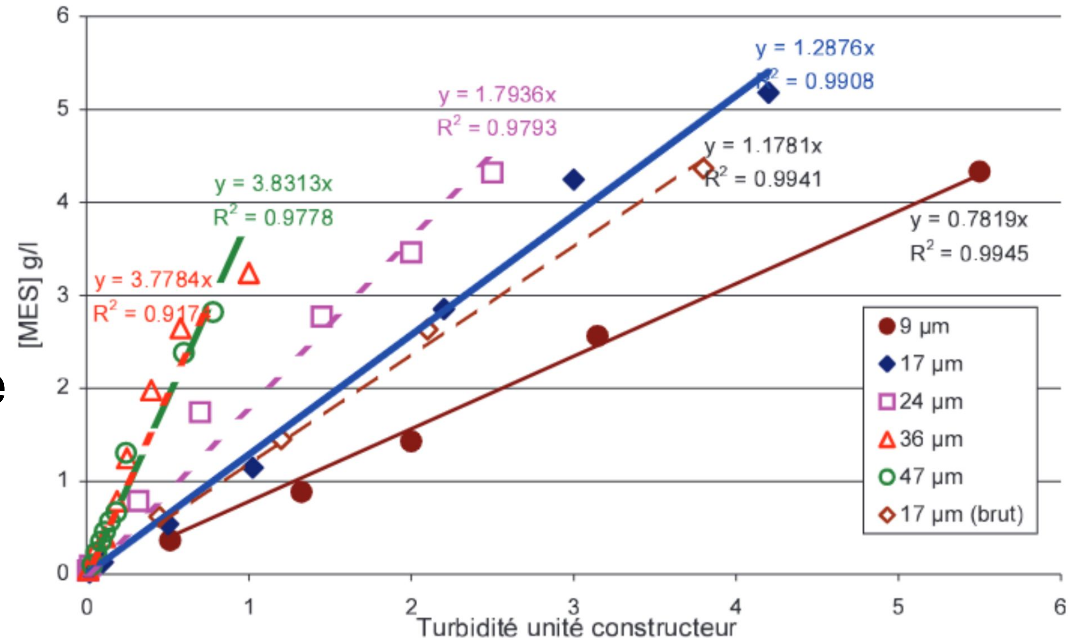
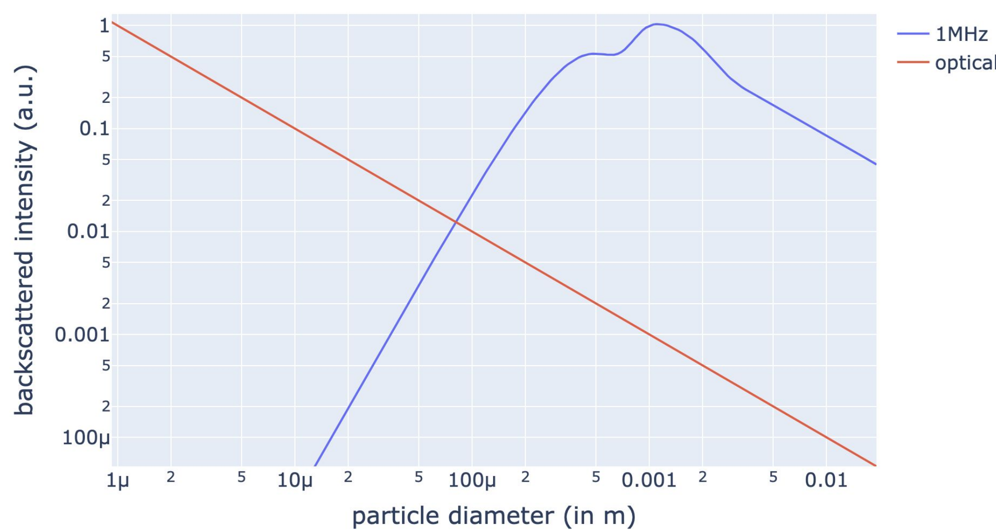
Optical turbidity

- Suspended Sediments : particles of size 1µm -1mm (silt, organic, sand)
- Turbidity meter are sensitive to the particle size

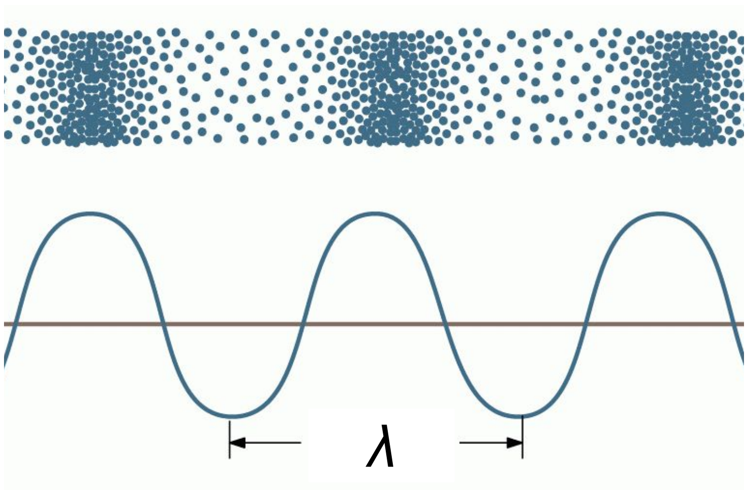


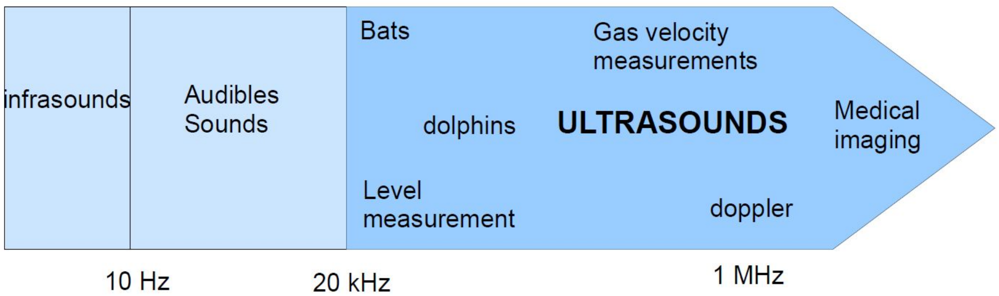
F. Thollet et al. (2013)

- Scattering : wavelength – particle size
- Optical Turbidity meter : 400 to 900 nm
- Acoustic waves : > 50 µm



Acoustic Wave





- Acoustic **frequency** f_0 [Hz]
- Sound speed *c* [m/s]
- Impédance acoustic *Z* [Ray]

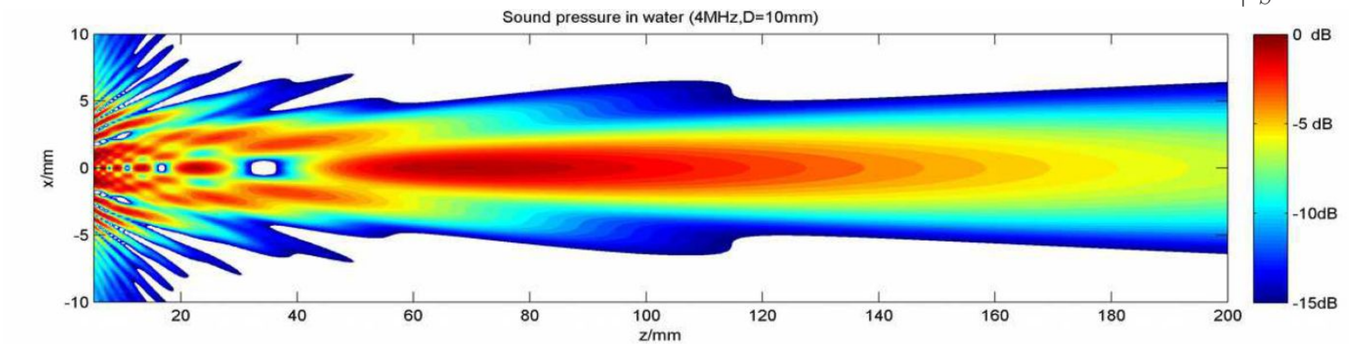
$$Z = \sqrt{\frac{\rho}{\kappa}} = \rho c$$

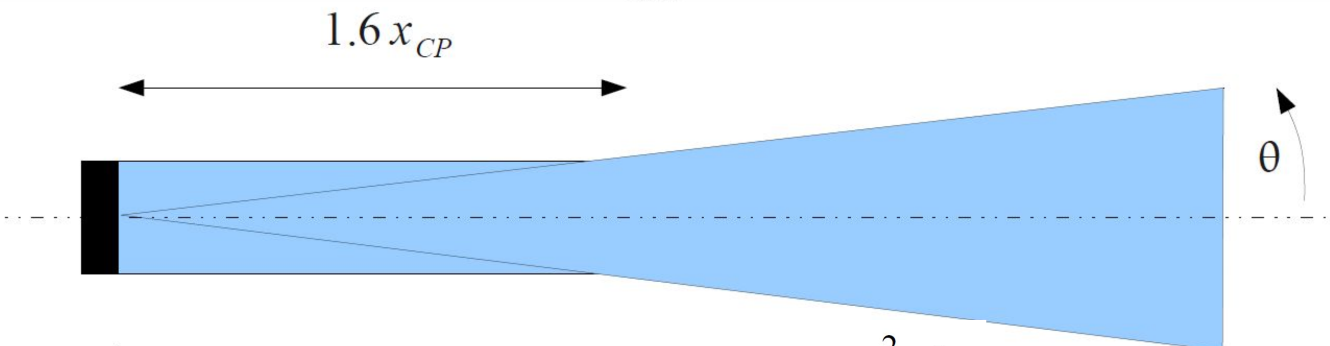
- **Wave length** *λ* [m] (wave number *k*)
  → optimal scattering

$$\lambda = \frac{2\pi}{k} = \frac{c}{f_0}$$

Acoustic Beam

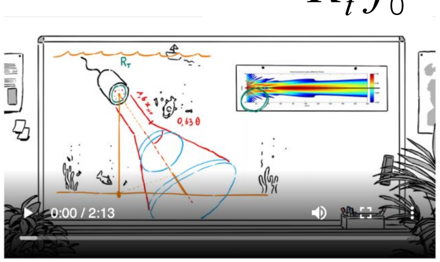
- Transmission/Reception by a **transducer** $f_r(x,y,z) = \left| \iint_S \frac{\exp(-jkd_{0x})}{d_{0x}} \cos(\overrightarrow{x}, \overrightarrow{d_{0x}}) dS \right|$





- **Near field** length x_{cp} [m] : $x_{CP} = \frac{R_t^2 f_0}{c}$
- Aperture half angle θ [rad] : $\theta = \frac{0.61\, c}{R_t f_0}$

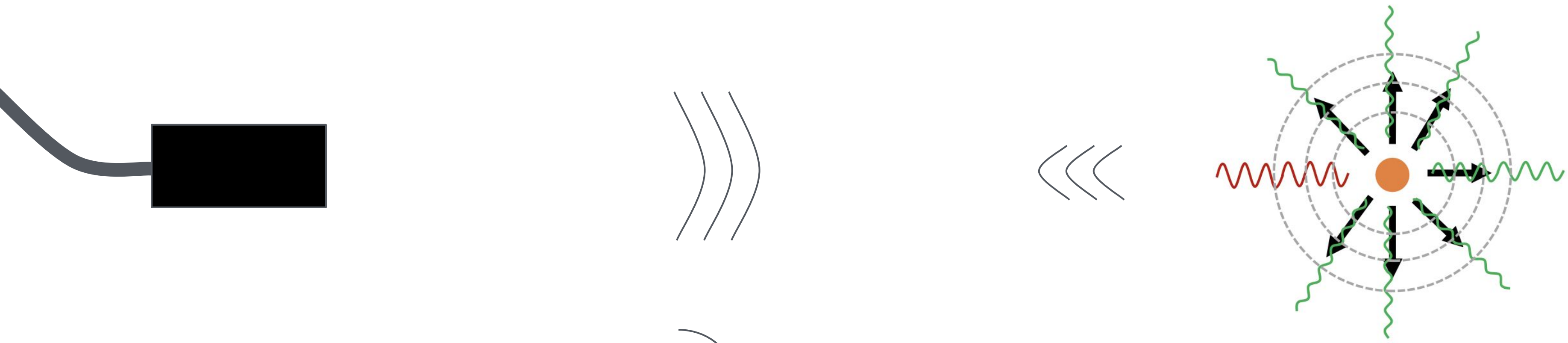
R_t *the active surface radius [m]*
f_0 *the emission frequency [Hz]*
c *the sound speed [m/s]*



What does the acoustic beam look like? How does it impact the measuring cell's geometry ?

Thanks to this video, you will understand how to define a model of your transducer's beam and estimate your profiles cell sizes.

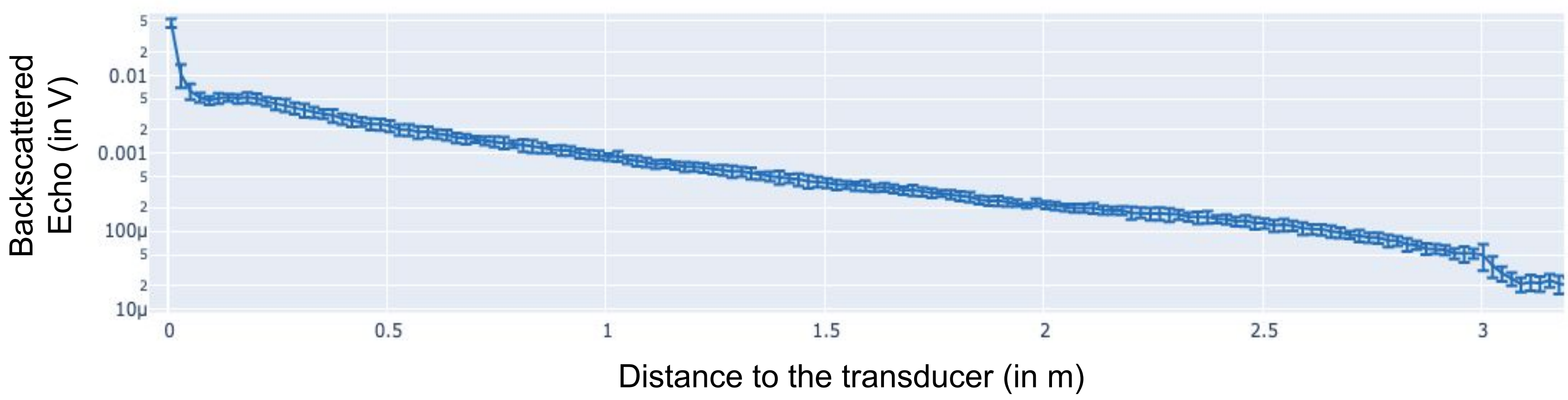
Acoustic Scattering



- More particles
- Larger particles

⇒ increase of the backscattered **echo** and the **attenuation**

- Sampling delay → backscattered echo profile



Acoustic Backscattering

- Backscattered acoustic amplitude given by the **sonar equation**

$$V_{rms} = \frac{k_s k_t}{r\psi} M^{1/2} e^{-2\alpha r}$$

r: distance (m)
k_t: instrumental constant
k_s: particle retrodiffusion properties
ψ: near field correction
M: sediment concentration
α: attenuation

- Influence of the sediment in the backscattering

$$k_s = \frac{\langle f \rangle}{\left(\rho_s \langle a_s \rangle\right)^{1/2}}$$

f: form function
ρ_s: particle density
a_s: particle radius

- … and in the attenuation

$$\alpha = \alpha_w + \alpha_s = \alpha_w + \frac{3}{4}\frac{\chi_m}{\rho_s \langle a_s \rangle} M$$

χ_m: normalized total scattering cross section

\+ viscous attenuation

Thorne PD & Hardcastle PJ (1997)

Acoustic Turbidity

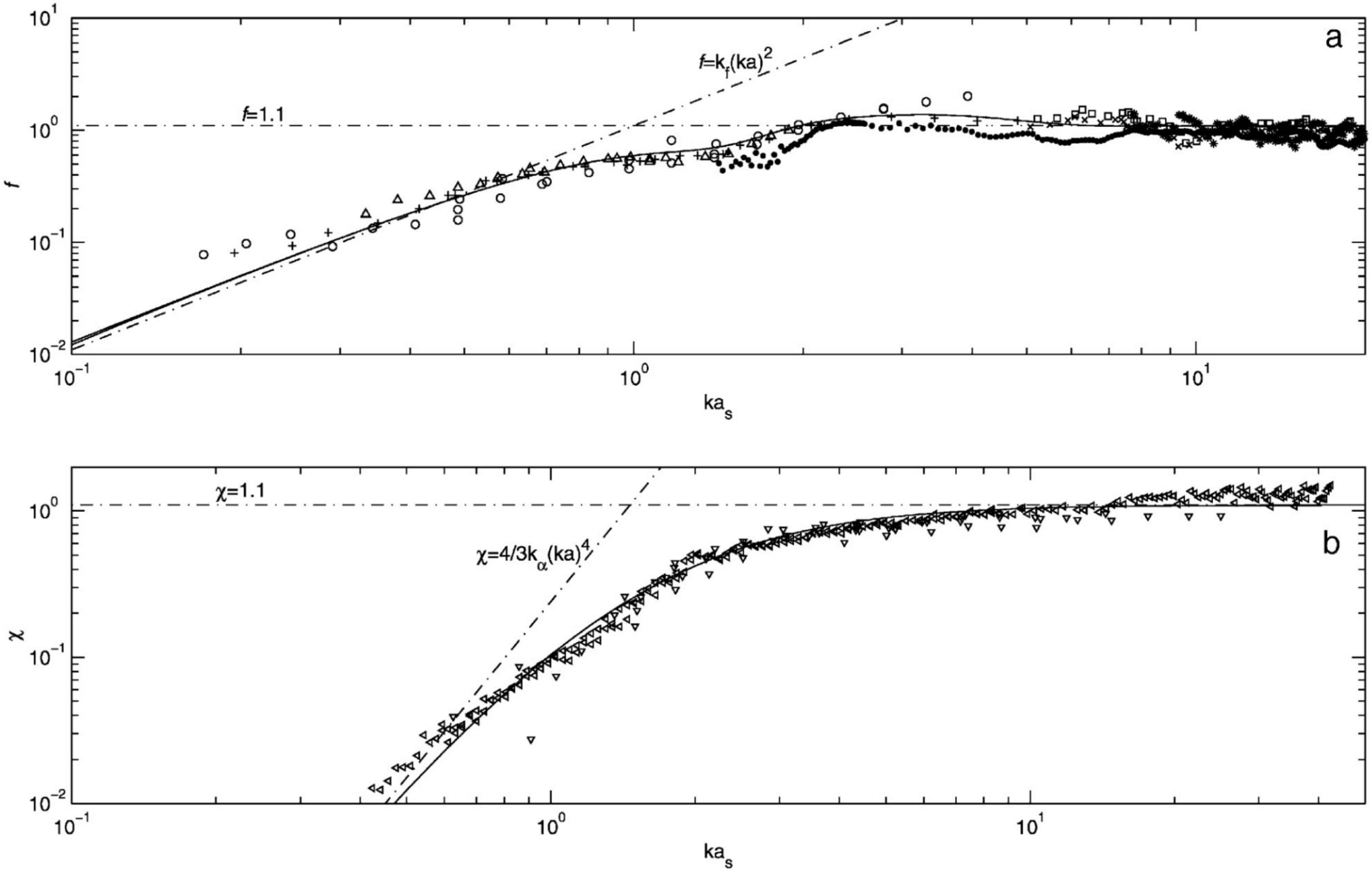
$$T_r = \frac{v_r^2}{v_e^2 \cdot \Delta t_p \cdot G_t(z)} \left(\frac{z}{R_t} \right)^2$$

v_r : received voltage,
v_e : emitted voltage,
Δt_p : pulse duration
$G_t(z)$: electro-mechanic gain,
z : distance to the transducer,
R_t : transducteur radius.

- Independent from the instrument
- Reflects the attenuation of sound in the medium and the ability of particles to scatter the ultrasonic wave at a given frequency f_0

Backscattering Model

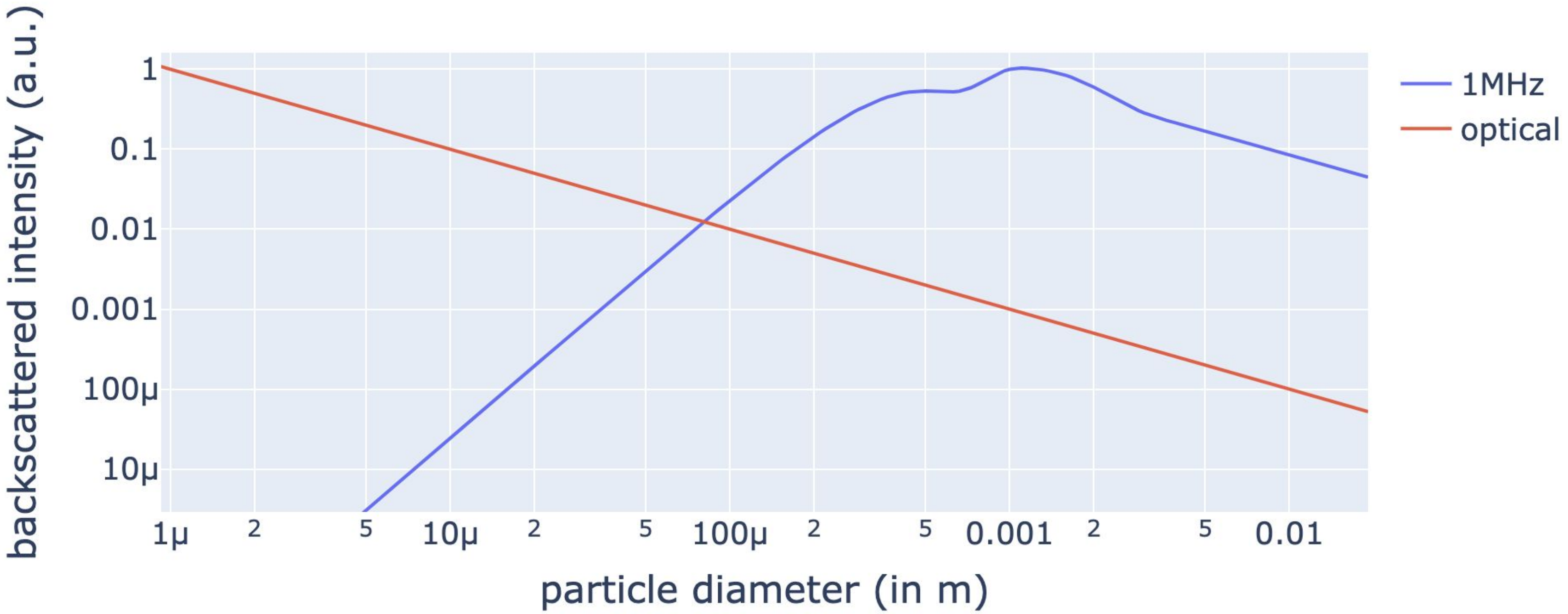
- form function and normalised total scattering cross-section



- different for sand, silt, flocs …

From the Backscattered Echo to the Concentration and the Particle Size

- Size range µm to mm → theoretically frequency GHz (!) to MHz



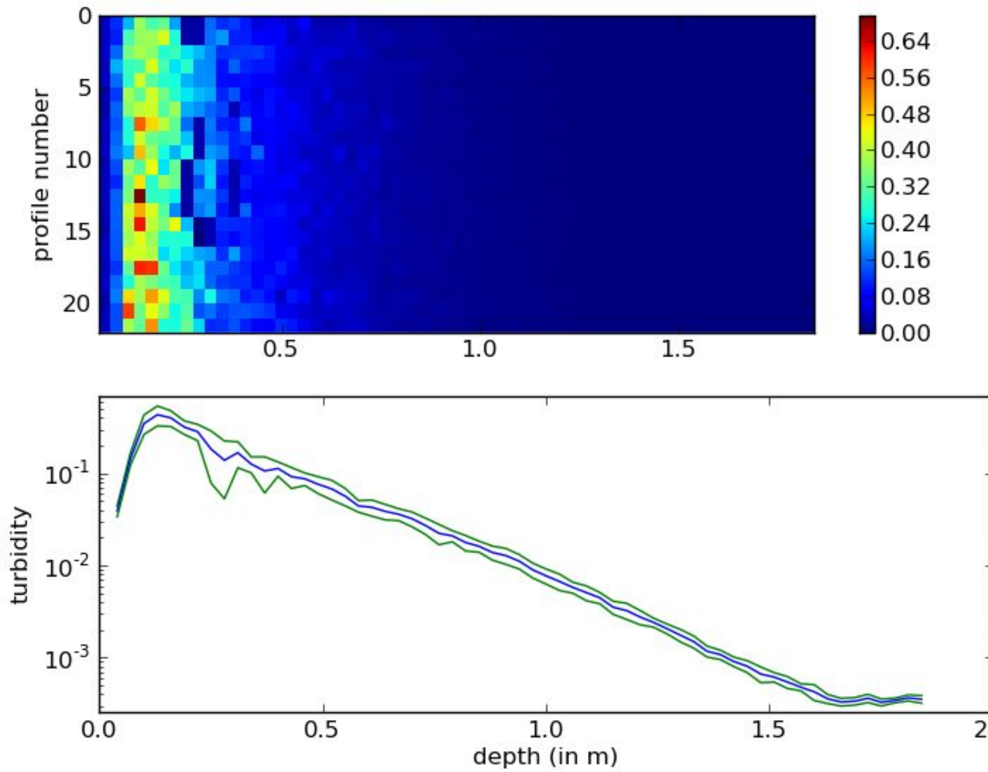
- Importance of wide transducer bandwidth → frequency scanning
- Importance of accurate amplification with variable gain

- Inversion methods (dual frequency …)

Acoustic Turbidity at High Concentration

- Aeration Tank (**~6 g/l**)
- Theoretical relation between acoustic turbidity ratio and concentration (**homogeneous medium**) :

$$T_r = \beta_v C \exp(-4\alpha_v C r)$$



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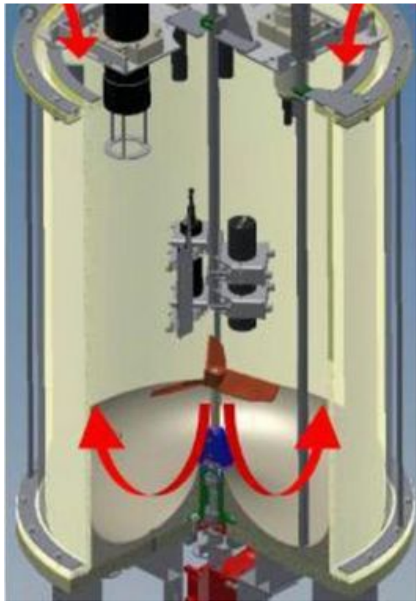
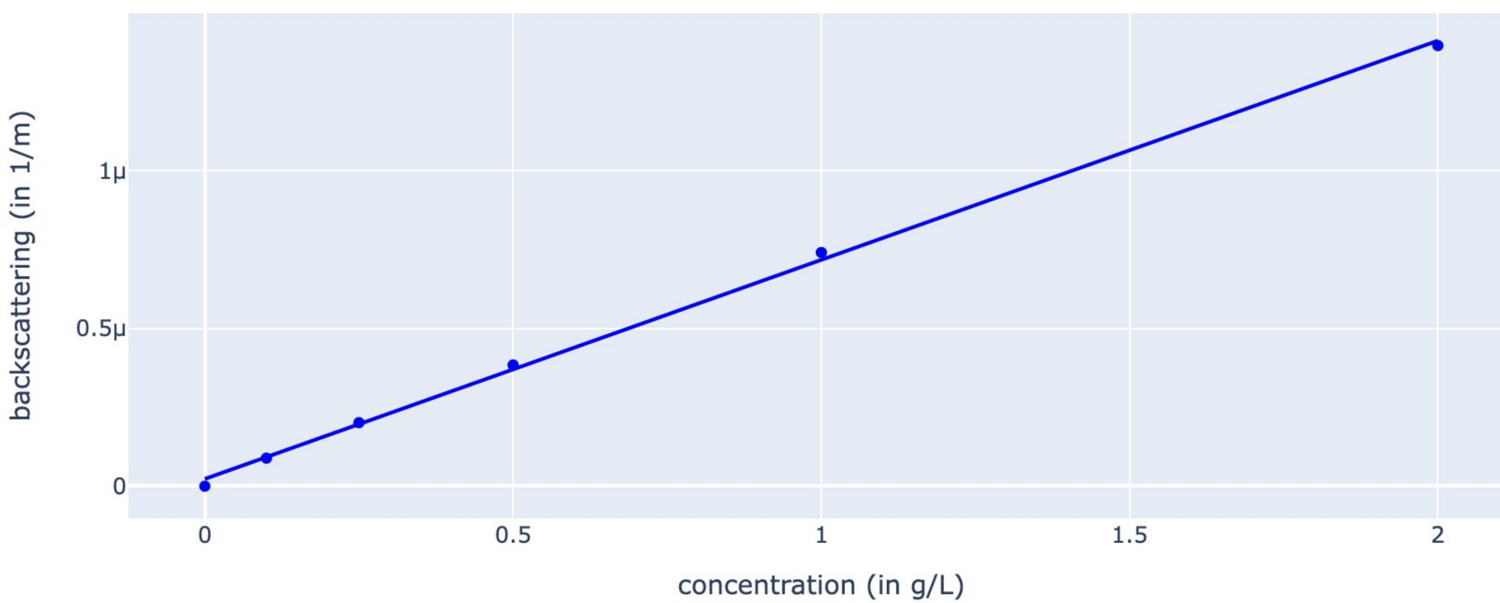
Sand Suspension in the Lab



- DEXMES facility
- Sand 100µm
- **UB-SediFlow** (**ABS** 0.3 to 6 MHz)

→ linear relationship between **backscattering** and **concentration**
→ different for each frequency



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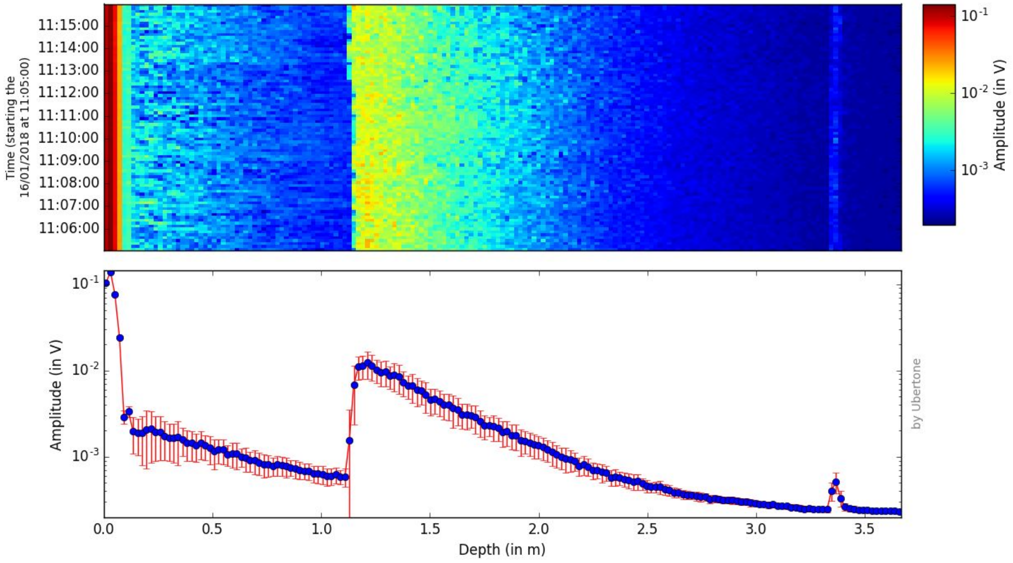
Sludge Analysis and Level Detection

- Clarifier Tank
- Echo amplitude profile
- Different slopes in the **two phases**



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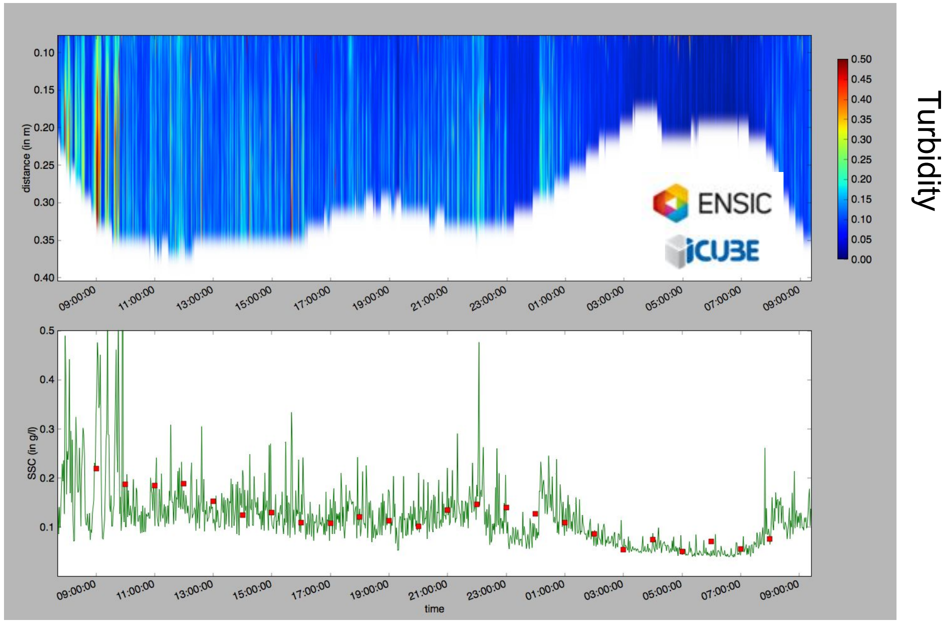
Suspended sediment concentration from acoustic turbidity profile

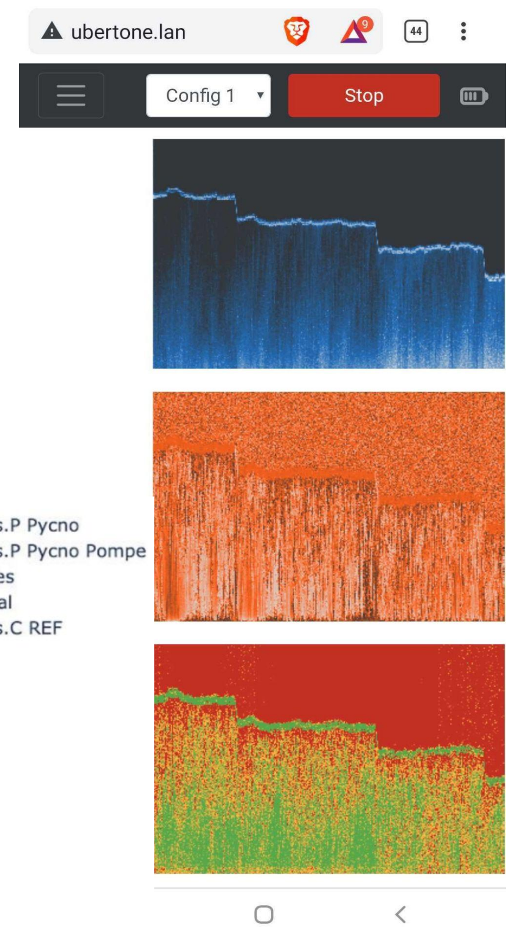
- **Continuous** concentration measurement based on calibrated acoustic turbidity
- **Wide frequency** range (1.0 to 3.7 MHz)
- One day life in sewer (high activity in the morning ; still by night) :

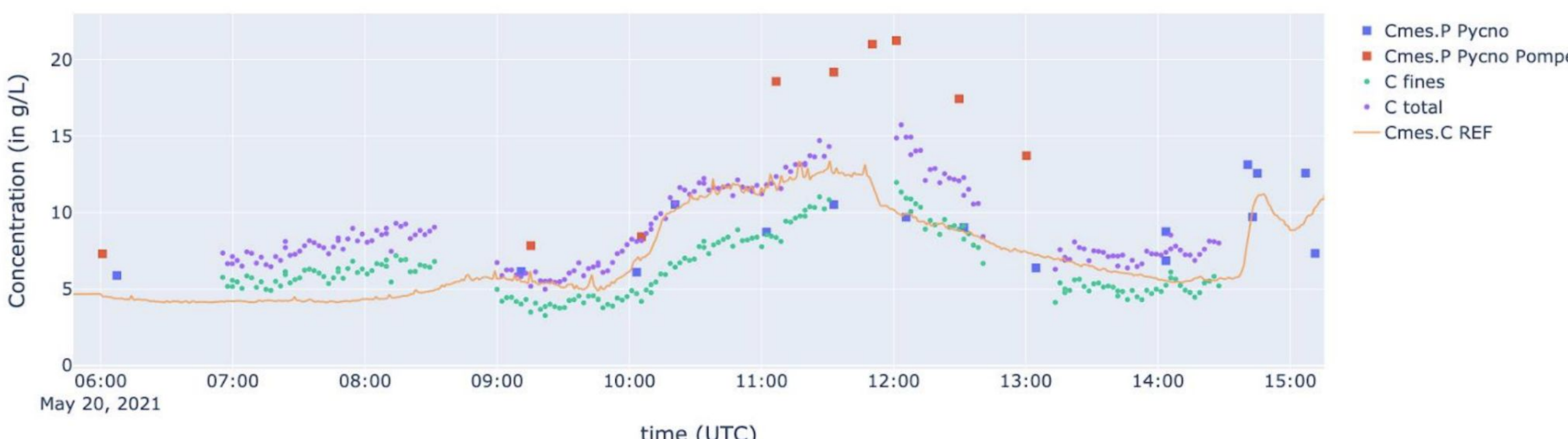


Pallarès A, et al. (2016). Long-term acoustic and optical turbidity monitoring in a sewer, *IWA World Water Congress & Exhibition 2016, Brisbane, Australia*.

Field SSC profiling

- Rhône river, France
- Up to 15 g/L
- **UB-SediFlow** (**ABS**)
- Dam flushing event (APAVER)





https://www.ubertone.com/news-220921_IAHREurope2022.html

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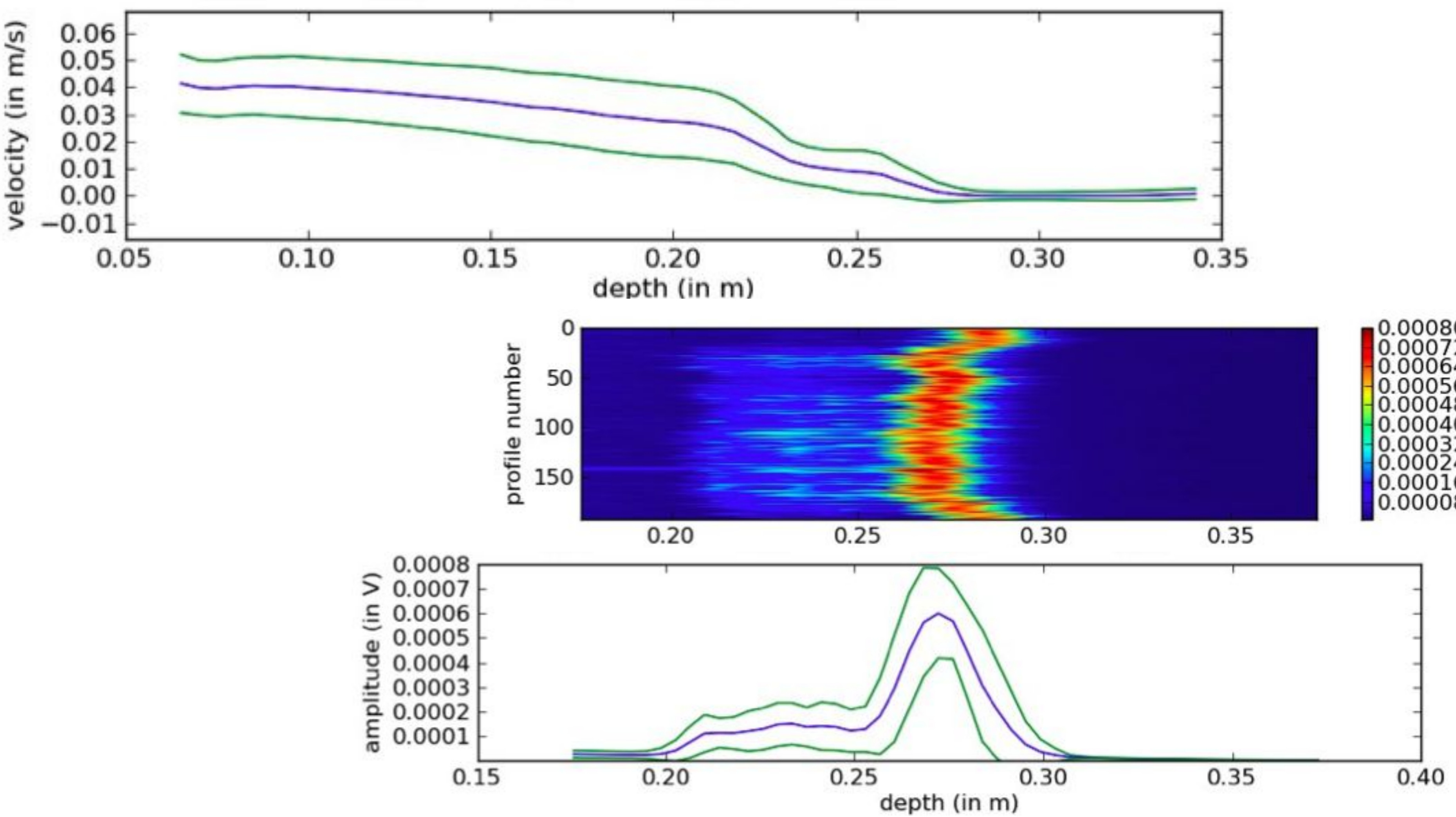
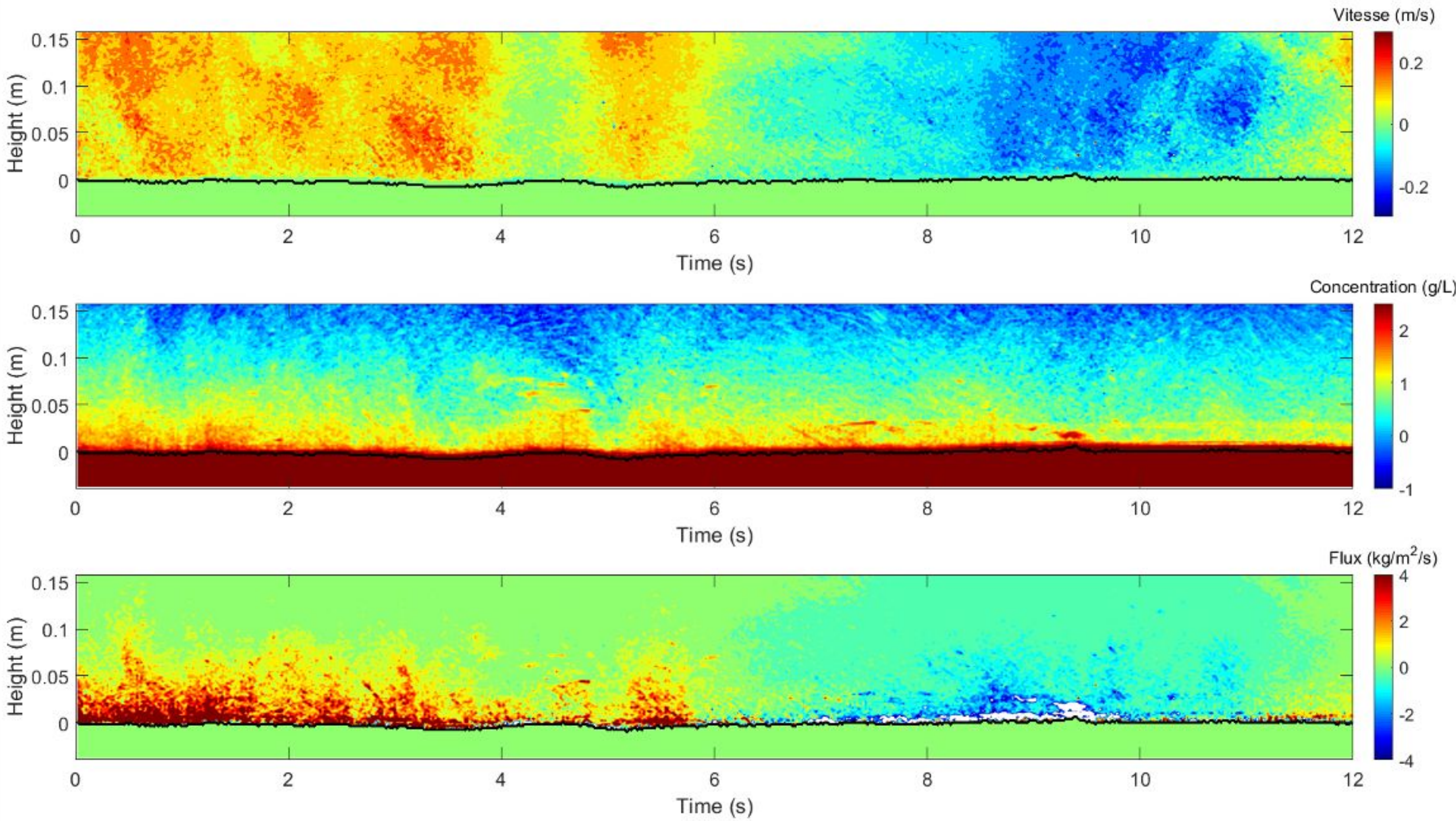
Moving bed in sewer



Sediment Transport on Beach



Fritsch N, et al. (2023).Sediment Dynamics Under Real Waves, *Coastal Sediments, New Orlean, US*.

https://ubertone.com/news-221013_3C_prototype_on_beach-advp.html

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Take Home

- **Acoustic backscattering** allows to monitor the **Suspended Sediment** concentration
- Use of a **wide frequency** range allows to resolve the particle size distribution
- The backscattered **echo profile** gives access to the field of concentration (gradient …)

Thank you for your attention

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comment, question, request ?

→ info@ubertone.fr or contact.ubertone.com