Acoustic turbidity as online monitoring tool for rivers and sewer networks

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This paper focuses on the use of acoustic turbidity as an online monitoring tool. Some experimental results on river and sewer network are shown. The river data analysis demonstrates the great potential of the acoustic measurements in sediment transport studies. The sewer data shows different application as suspended sediments concentration or water height measurements. A comparison of the acoustical data to the most usual methods used for the total suspended solids concentration evaluation, namely sampling and optical turbidity is also done.

Keywords: Acoustic, turbidity, suspended solids.

1 INTRODUCTION

The demand for better characterization of water quality in its natural environment or in sewer systems has increased with the evolution of the water policy laws. An online or at least regular survey of the water networks is needed. Thus, the implementation of network survey devices is a growing practice. Erosion, transport, and deposition of sediments are primary and growing environmental, engineering, and agricultural issues around the world. Environmental impacts of sedimentation are various, going from mechanical obstruction to contamination by pollutants attached to and transported by sediments.

To monitor the pollutant load, an essential parameter is the Suspended Solids Concentration (SSC). Unfortunately only few monitoring techniques provide real time data. Currently, the suspended sediment concentration in water is either measured through sampling and laboratory measurement, or optical methods (nephelometric and optical backscatter sensors) [1]. The major drawback of the first method is the time delay between the sampling and the measurement which forbids any real time retroaction on the water regulation. On the other side, the optical measurements might provide values of the total suspended solids concentration after adequate calibration.

Due to the importance of flow velocities in the pollutant load behaviour, monitored water ways are often equipped with Acoustic Doppler Velocimeters (ADV) or Acoustic Doppler Current Profilers (ADCP). In addition to velocities, these devices also monitor the acoustic backscattered signal amplitude, or directly the acoustic turbidity, which is proportional to the Total Suspended Solids Concentration (TSS). A comparison of the acoustical data to the most usual methods used for the SSC concentration evaluation, namely sampling and optical turbidity will be done.

2 ACOUSTIC MEASUREMENT

2.1 Pulsed measurement principle

All ADVs and ADCPs work on the Doppler principle. At the beginning of a measurement cycle, an ultrasonic burst of a given frequency and duration is emitted into the medium. At the end of the emission, the instrument switches into the reception mode. The emitted signal travels along the beam axis and each encountered particle partly backscatters the acoustic wave as shown in Figure 1. If the particle is moving in the medium, a frequency shift is observed in the backscattered wave (so-called Doppler shift). This assumes that the velocity of the suspended particles is equal to the flow velocity. This working principle allows the precise knowledge of the position in the flow of a given velocity or backscattered signal amplitude at a given time stamp.

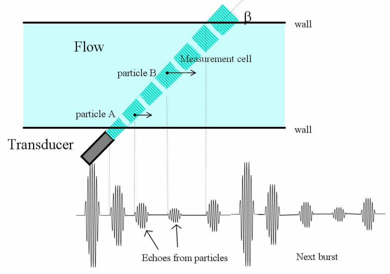

Figure 1: Pulsed Doppler principle: initial pulse and echoes from particles.

In the same time, due to thermal conduction and viscosity effects, the intensity of the ultrasonic wave propagating in a homogeneous medium decreases. In particle laden flows, an additional attenuation due to the scattering and the absorption by the particles themselves contribute to the intensity decay.

2.2 Acoustic turbidity

On the theoretical point of view, for an acoustic profiler, the recorded root-mean-square of the backscattered voltage can be written at range *r* as follows [2]:

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

where

$$\alpha = \alpha_w + \alpha_s = \alpha_w + \frac{3}{4\rho_s r}\int_0^r \frac{\chi_m}{\langle a_s \rangle} M(r')dr'$$

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

V_{rms} is an average value over a large number of backscattered receptions. k_t is an acquisition system constant for a given instrument working at a given frequency. ψ stands for the near field correction, M is the particle concentration, α_w is the attenuation due to the water absorption and α_s is the particle attenuation mainly due to scattering for non cohesive particles insonified at megahertz frequencies ultrasound. As shown, α_s is related to the normalized total scattering cross-section χ_m of the particle. k_s represents the particle backscattering properties, with $\langle f \rangle$ the averaged form function which describes the backscattering characteristics of the particles, ρ_s the particle density, $\langle a_s \rangle$ the mean particle radius.

Given equation (1), the exact expression of the acoustic turbidity would be:

$$T = \frac{V_{rms} r\psi}{k_t} e^{\alpha_w r} = k_s M^{1/2} e^{-2\alpha_s r} \quad (2)$$

In equation (2), the right part only depends on the particle characteristics. Thus, the backscattered signal directly includes information about the particles encountered in the explored medium. With adequate analysis, different elements concerning the nature and the concentration of the particles can be extrapolated. If the particles in the medium are well known, in terms of shape, size and density, their acoustic characteristics can be determined. If the content of the flow is unknown, only a qualitative interpretation can be made as the relative behaviour of the TSS concentration for example.

Anyhow, if comparison data are available, the acoustic turbidity can be linked to the SSC after adequate calibration or give more precise concentration values by using the data inversions techniques mentioned in [3].

2.3 Instrumentation

All the following measurements were done with UB-Flow profilers from Ubertone, France. They are equipped with two wideband transducers emitting with a given tilt regarding to the instrument's base. Technical details are given in Table 1. The river measurements were done with an UB-Flow F156 and the wastewater treatment plant ones with the more recent UB-Flow F315 flowmeter. They have an excellent sensitivity (down to -107dBm) that allows measurements in many conditions, even in low scattering liquids. A compact submersible enclosure integrates the hardware, a web interface and a logger, making the device easy to install.

Reference		Transducer 1	Transducer 2
UB-Flow F156	Min. Frequency (MHz)	0.938	3.75
	Max. Frequency (MHz)	2.08	7.54
	Tilt (°)	75	55
UB-Flow F315	Min. Frequency (MHz)	0.800	2.08
	Max. Frequency (MHz)	1.94	4.25
	Tilt (°)	65	97

Table 1. Technical details of Ubertone profilers.

3 ACOUSTIC MEASUREMENT

3.1 River survey

Measurements have been conducted with an UB-Flow F156 on the Couesnon River in the bay of Mont Saint-Michel, France. This river is flushed on a daily basis in order to remove the sediments around the island. The profiler has been installed above the river bad, looking downwards in order to observe the velocity profile near the Couesnon bed with a frequency of 6.25 MHz. The results obtained at the beginning of the flush are displayed in Figure 2.

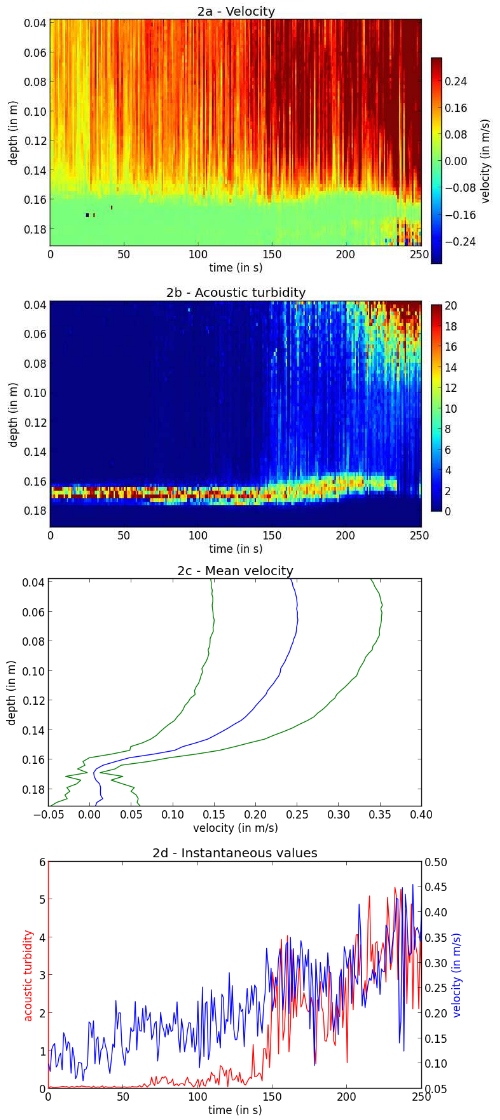

Figure 2: Evolution of the velocity and the acoustic turbidity during the flush of the Couesnon river; *a*. Velocity value as a function of measurement depth and time; *b*. Evolution of acoustic turbidity with depth and time; *c*. Mean velocity and standard deviation as a function of depth; *d*. Simultaneous evolution of acoustic turbidity and velocity as a function of time.

Figure 2.*a*. shows the evolution of the velocity monitored at 1.5 MHz, with time: a clear increase of the velocity and coherent structures can be observed. Figure 2.*b*. shows the evolution of the acoustic turbidity over the same time as in 2.*a*. At a distance of ~0.17 m from the instrument, the moving of the river-bed peak shows a river bed form evolution through time. One can also observe the progressive increase of the turbidity values due to the suspension of particles, especially at the end of the time laps. Figure 2.*c*. shows the standard deviation on the mean velocity which is directly linked to turbulence. Its large value suggests a turbulent flow. The last Figure, 2.*d*., shows the combined temporal evolution of the velocity and the acoustic turbidity in a measurement cell located 50 mm above the river bed. Sediments are clearly suspended after a velocity threshold. As can be seen, the instrument allows the accurate observation of the velocity profile near the stream bed. The instantaneous velocity profile gives access to the shear stress as well as to the turbulent intensity contributing to sediment transport. Moreover, the combined measurement of the acoustic turbidity profile allows to follow, in real-time, the evolution of the suspended sediment concentration.

3.2 Wastewater treatment plant

Another measurement campaign was done in the entry chamber of the wastewater treatment plant of Greater Nancy (250 000 p.e.). The instrument, a UB-Flow F315, was located close to one of the inflows. It was fixed on a floating arm and was looking at the chamber bottom.

Figure 3 shows two plots. The upper one corresponds to the time evolution of the acoustic turbidity at 3.125 MHz. The second one shows the SSC concentration, obtained either by sampling (red squares), optical turbidity (blue squares) and by acoustic turbidity after calibration, for a cell situated 190 mm away from the transducer (green line). The acoustic data are instantaneous and obtained every 1.5 second.

To get these comparative data, water samples were taken on a hourly basis at the level of the buoy. These water samples were analyzed. After the sampling, the water was filtered on a 1 µm filter and the TSS concentration was calculated from the solid depot on the filter after evaporation. Also, the optical turbidity of these samples was measured with a HACH turbidimeter. The TSS values obtained by weighting were linked to both turbidities, optical and acoustic, by a simple linear fit [4].

The time evolution of the instantaneous values of the acoustic turbidity, upper part of Figure 3, and the figure below, show that the SSC is very unstable and varies significantly with time, especially at the beginning of the measurement. So this site seems to be highly turbulent in the morning hours. However, the measurements done during the night are less noisy, more stationary. This can be explained by the decrease of the flow and the turbulence.

On second figure, Figure 3, bottom, a good agreement can be seen between the SSC given by sampling, acoustic or optical turbidity. Variations are quite equivalent whatever the measurement method is.

However, at the beginning of the measurement period (between 8 and 10 am) several concentration peaks are observed through ultrasound. At the same time, a significant gap between the optical turbidity values and the TSS measured by sampling is observed. This is very likely related to an increase in the particle size as optical turbidity is insensitive to larger particles. This hypothesis is confirmed by the acoustic turbidity measurements done on lower frequency at 1.5 MHz which shows a clear increase of the turbidity values in the same time period.

The comparison of the acoustic SSC data to the results obtained by sampling shows that the sampling data are much more stable. As the sampling process takes several minutes, we suppose a time smoothing effect. One could also imagine that an additionnal smoothing is obtained because of the filtering of large particles and flocks.

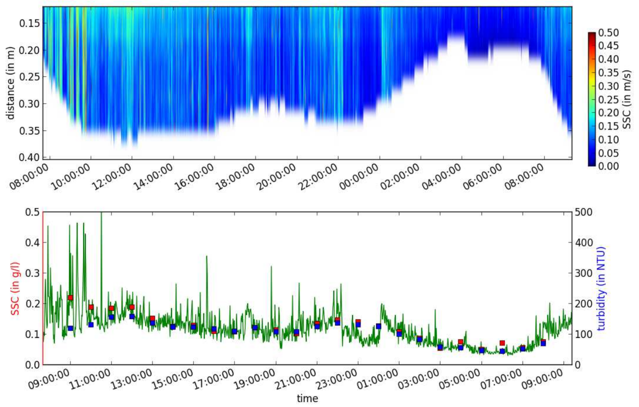

Figure 3: Time evolution of acoustic turbidity (up) and SSC with various techniques (down).

Figure 4 shows the water height obtained on a five days recording. The daily water cycle can clearly be identified. The data from the two transducers were compared and show excellent agreement. Also, as the attenuation of the beam increases with frequency, the lower frequency has a greater range. The water height was also measured by a standard acoustic water level sensor represented by the so-called “Standard” plot on Figure 4. A systematic bias of about 20 cm is observed compared to the profiler data measured at 1.974 MHz. This is totally coherent with the fact that a sediment layer of about 20-30 cm exists at the bottom of the chamber. The profiler was aware of the presence of these sediments at the bottom of the flow. Thus ultrasonic velocity profiler gives more accurate values of the water height especially for load calculations.

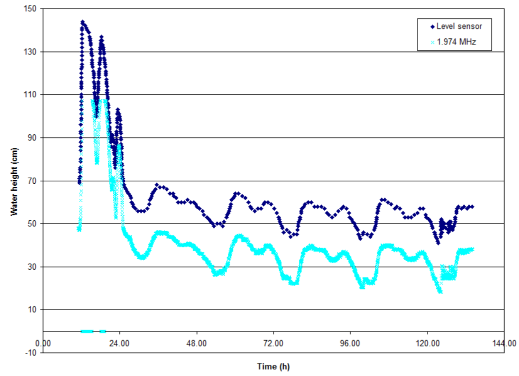

Figure 4: Water height as a function of time and technique.

4 CONCLUSION

The experimental results show that the TSS concentration could easily be monitored through acoustic turbidity. As the optical methods, the acoustic turbidity is sensitive to the suspended solid matrix and the origin of the solid phase content. However multi-frequency measurements are indicators for the possible particle size evolution and reduce the possible systematic errors. Thus, without complicated data inversion, using only the velocity and acoustic turbidity values given by the instrument, coherent data interpretation can be made.

As sensitive to the nature and the size of the particle, the acoustic turbidity could also be a storm event indicator upstream of a river. Two levels of use of acoustic devices could be distinguished. A macroscopic use of the acoustic data could be identified as river or sewer network gauging. A finer analysis, corresponding to a microscopic use, could be associated to sediment transport analysis. Anyhow, with a good knowledge of the theoretical fundamentals, acoustic profiling is a powerful and promising technique.

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