AQUATEC GROUP

Using acoustics to observe suspended sediment concentration

Aquatec House, Stroudley Road, Basingstoke, RG29 1EL, UK
inquiry@aquatecgroup.com

Introduction

Measuring suspended sediment concentration is important for a wide range of applications and disciplines, from operational dredge monitoring or civil engineering activities, to understanding natural environments, as well as fundamental research into sediment transport processes.

There are many methods of measuring suspended sediment, each with their strengths and weaknesses. Alternatives to acoustics include optical backscatter instruments (turbidity loggers), Secchi disks and water samplers combined with laboratory analysis. Acoustic instruments have clear advantages over alternatives: a non-invasive approach, minimal impact of biofouling on sensors, profiles rather than single point measurements, and the fact that in situ samples are not always needed.

This article explores the acoustic approach in more detail, looking at the science behind the concept as well as the features of the commercially available AQUA*scat* instrument.

Basic Principles

Optical backscatter is a common approach to observing suspended particles including sediment. In its simplest form, acoustic instruments use the same fundamental principles – i.e. measuring a signal scattered from material suspended in water. Optical instruments use light to measure turbidity (the clarity of the water) and acoustic instruments use sound. The fact that sound travels more slowly in water (i.e. its travel time can easily be measured) means it is possible to observe profiles, rather than a single point.

Acoustic instruments use transducers at different set frequencies to transmit sound into the water. The sound travels through the water and is scattered by sediment in suspension. The scattered signal is then picked up by the transducer (Figure 1). The amount of scattering depends on both the size of the sediment and the frequency of sound. If the speed of sound is known, the returned signal can be analysed to give a profile of signal intensity against distance from the transducer (Smerdon & Thorne, 2008).

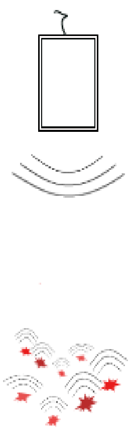


Figure 1: Acoustic backscatter principle

Acoustic Backscatter Method

Some of the earliest work on acoustic backscatter in this context took place in the 1980s, with the description of monitoring instruments that measured the backscatter from suspended sediment (Young *et al*., 1982; Hay, 1983). A method was developed for a single frequency device that transmitted a pulse of sound into the water and then analysed the returned signal (Libicki *et al*., 1989).

The 1990s brought a series of theoretical studies that used idealised glass spheres in suspension to derive general equations (Thorne *et al*., 1993). The result was a form function for a suspension of regularly shaped scatterers that described backscattering as a function of frequency and particle size. Subsequent work showed that similar results were achieved when applying the general principle to irregularly shaped scatterers, as would be found in marine sediments (summarised in Smerdon & Thorne, 2008).

Experimental work also demonstrated a method of determining particle size from the backscattered signal using multiple frequencies (Hay & Sheng, 1992). The method used the dependence of the backscatter form function on the wave number and mean particle size. Testing with three different frequencies (1, 2.25 and 5 MHz) showed that once the relative sensitivities were known, the calibration was site independent (summarised in Smerdon & Thorne, 2008).

A general relationship between the measured backscatter signal (P) and the mass concentration (M) was found (Thorne and Hanes, 2002):

$$P = \frac{k_s k_t}{r\psi}\sqrt{M} \cdot e^{-2r\alpha}$$

Where r is the range, α is the signal attenuation, k_t is a system constant derived in calibration, ψ corrects for beam characteristics and k_s is given below:

$$k_s = \left(\frac{F_m}{\sqrt{a_s \rho_s}}\right)$$

Where F_m is the form function (a function of size and frequency), a_s is the mean particle radius and ρ is the sediment density.

The development of experimental, research and commercial acoustic instrumentation has allowed research to expand beyond theoretical and idealised particles into natural waters and sediment, cohesive sediment and flocs.

Multi-Frequency Approach

The magnitude of the backscattered signal is dependent not only on the suspended load, but also on the size of the scattering particles. If a single frequency of sound is used, it is not possible to determine the load without knowledge of the mean particle size as the response for a fixed load varies with particle size (Figure 2). In situ samples or independent analysis would be required.

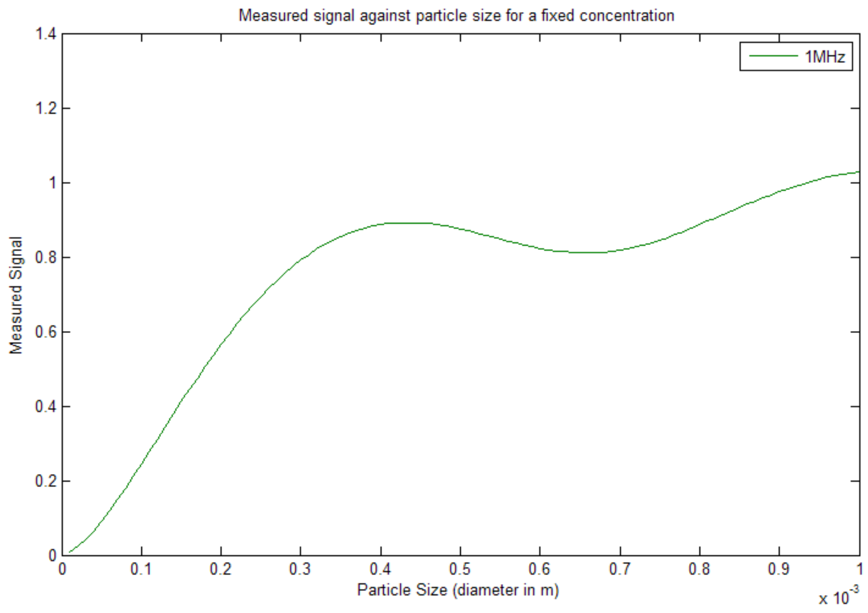


Figure 2: Scattered signal from different mean particle sizes for a single frequency and fixed concentration

The returned signal from the same group of scatterers will be different if different frequencies are used. This size dependent response can be used to determine the mean particle size (Figure 3).

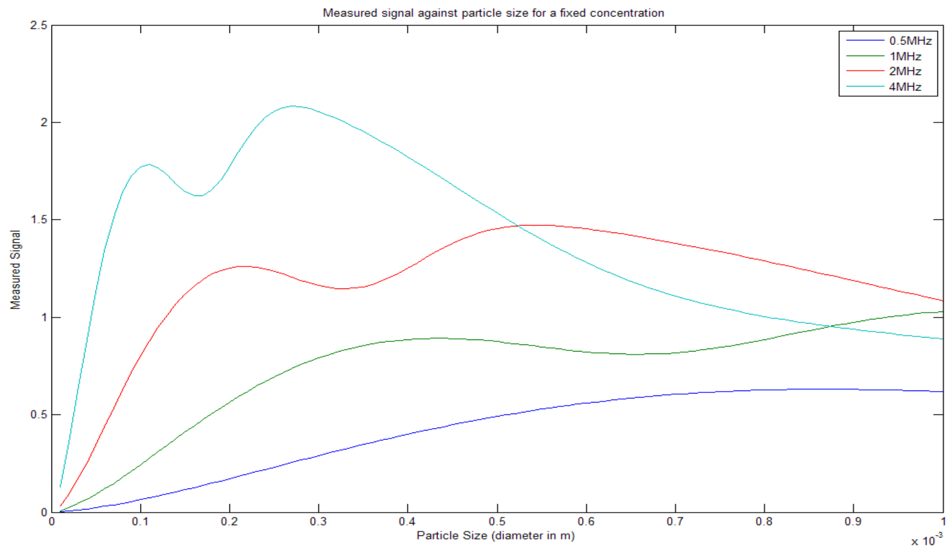


Figure 3: Scattered signal using multiple frequencies

To take advantage of the multi-frequency approach, a minimum of 2 different frequencies must be used, with the sound being transmitted in the same direction. The selection of those frequencies, typically between 300 kHz and 5 MHz, requires careful consideration: higher frequencies give higher spatial resolution (a function of transducer bandwidth) and the ability to detect finer particles, but at the cost of range, which is reduced due to higher attenuation. The lower frequencies give a longer range, but lower spatial resolution and the ability to preferentially detect the larger particles. An added benefit of the multi-frequency approach is the combination of a range of frequencies, thus getting the benefits of the higher and lower frequencies (Aquatec Group, 2014).

In fact, the ‘real’ range is a function not only of the sound frequency but also the amount of suspended material (increased material gives increased backscatter but also increased attenuation, which reduces backscatter further away from the transducer) and the particle size (smaller particles attenuate less but scatter less) (Aquatec Group, 2014).

AQUAscat 1000 – Commercial Acoustic Profilers

Aquatec launched the first commercial acoustic suspended sediment profiler in 2002 and has released new models and software in the subsequent 15 years. The AQUA*scat* 1000 range of instruments (Figure 4) use the acoustic backscatter principles and multi-frequency approach described above. The instruments all feature between 2 and 4 transducers, with frequencies ranging from 300 kHz to 5 MHz, resolution of 2.5 mm to 4 cm, and profiling ranges from 64 cm to 10 m. The instruments are designed for field and lab use, with built in batteries, subsea housing (on field models) and integral memory.

Figure 4: AQUA*scat* 1000 research model

AQUA*scat* instruments transmit sound and measure the returned signal at 2 to 4 different frequencies, one per transducer. The data is analysed to first calculate the mean particle size for each individual bin (size between 2.5 mm and 4 cm) and then secondly the suspended sediment concentration using the derived particle size. The use of multiple frequencies means the mean particle size can be calculated from the returned signals alone (one method is shown in Figure 5), although in situ samples can help guide the process and provide a ground-truth.

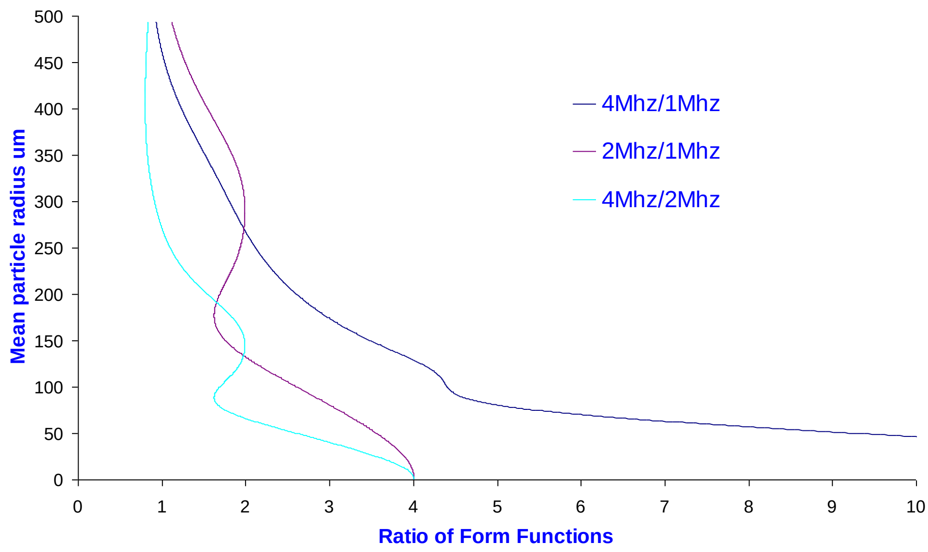
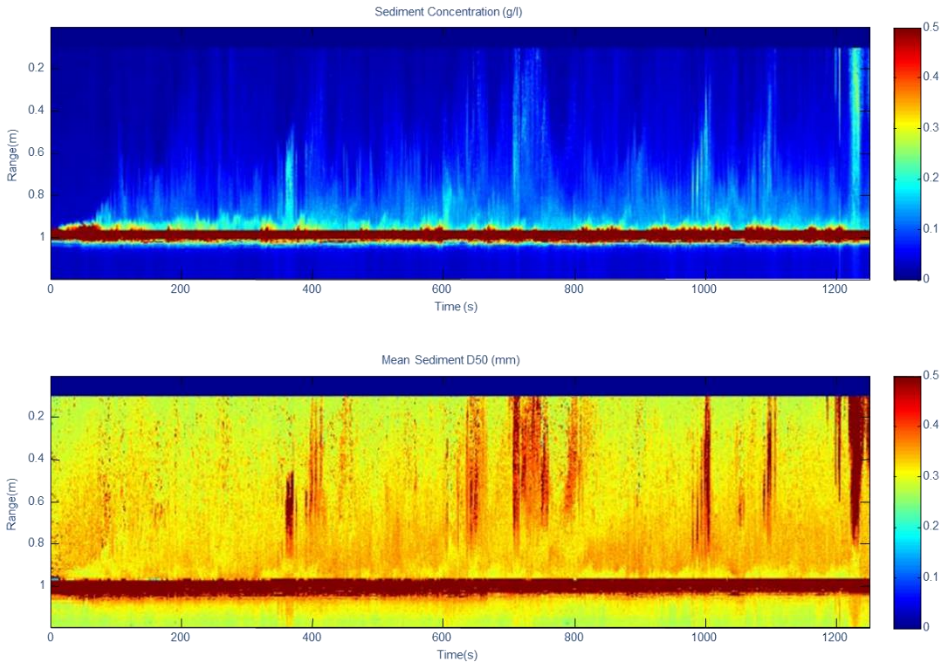


Figure 5: A method of calculating mean particle size – ratio of form functions

The AQUA*scat* instruments have averaging capabilities, which helps with an important feature of acoustic backscatter from sediment – its statistical nature. The amplitude of the backscattered signal changes as the particles move randomly and is Rayleigh distributed. It is therefore important to gather lots of profiles and average to improve accuracy. Only in very few scenarios (water with no sediment or limited attenuation) is it not recommended to gather data faster (up to 128Hz) and average.

The AQUA*scat* instruments have been used across the world for a wide range of sediment research, and can provide information that other forms of sediment monitoring instrumentation cannot (Figure 6).

Figure 6: Example AQUA*scat* post processed data



Summary

The acoustic backscatter method and multi-frequency approach provide a methodology to observe profiles of mean particle size and suspended sediment concentration. The AQUA*scat* acoustic suspended sediment profilers are well-established commercially available multi-frequency instruments that use the described principles.

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