A Coastal Deployment of a Commercial Multiple Frequency Acoustic Backscatter Sediment Profiler

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ABSTRACT

Introduction

Recently, an Aquatec AQUA*scat* 1000 multiple frequency acoustic backscatter suspended sediment profiler was deployed from 10th October 2006 to 29th November 2006 and from 4th December 2006 to 18th January 2007, at Sea Palling in Norfolk, on the North Sea coast, as part of the LEACOAST2 EPSRC shore parallel breakwater study. The objective of the study is to evaluate the effects of shore parallel breakwaters in tidal environments on coastal morphology. The instrument deployments are intended to provide validation and calibration data for new numerical process models. Sediment traps and two other acoustic backscatter instruments were also deployed to obtain site samples and comparative data.

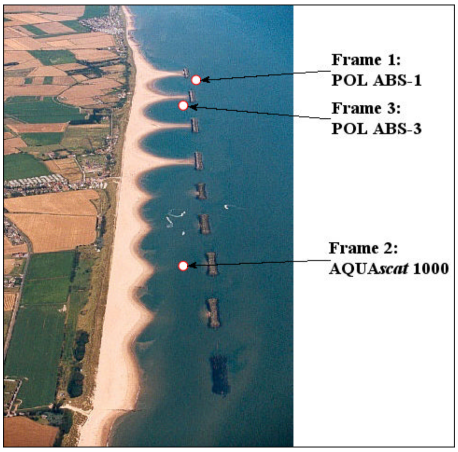

Figure 1: Positions of ABS systems

The AQUA*scat* 1000 and two further acoustic backscatter systems built by Proudman Oceanographic Laboratory (POL) were each deployed on the sea bed on multi-instrument tripod frames in the locations shown in Figure 1.

Acoustic Backscatter Principle

Young *et al.* (1982) and Hay (1983) first described monitoring instruments that measured acoustic backscatter from suspended sediment, and Libicki *et al.* (1989) developed a detailed theoretical approach for the interpretation of acoustic backscatter data from a single frequency device. The technique involves transmitting a pulse of high frequency, directional, acoustic energy, typically in the range 0.5 to 5 MHz into the suspension, and analyzing the received signal to obtain a time series of scattered signal strength. Knowledge of the sound speed in the water allows the data to be converted into a profile of signal intensity versus range from the transmitting element. Scattered signal strength is related to the amount of material in suspension, and there has been considerable research effort to describe this relationship and thus to derive suspended load from backscatter strength.

In a series of theoretical studies of backscatter characteristics from suspended glass spheres, Thorne *et al* (1993) developed a general form function for a suspension of regular shaped scatterers, which was tested against laboratory experiments. The form function describes the backscattering characteristics of the scatterers as a function of incident frequency and mean particle radius. Later work by Thorne *et al* (1995) on irregularly shaped scatterers showed the general principles applied to regularly shaped scatterers with moderate size distribution is similar to a first order approximation to that of irregularly shaped scatterers, such as would be found in marine sediment. Thorne and Hanes (2002) summarised the relationship between a measured backscatter signal P and mass concentration M as follows:

$$M=\left(\frac{\mathrm{Pr}\psi}{K_sK_t}\right)^2\cdot e^{4r\alpha} \qquad (1)$$

where r is range from the transducer, ψ corrects for the acoustic transducer beam characteristics in the near field, α describes signal attenuation due to the suspended sediment and water absorption, K_t is a system constant, derived during calibration, and K_s is given by:

$$K_s = \left(\frac{F_m}{\sqrt{a_s \rho_s}} \right) \tag{2}$$

where F_m is the sediment form function, a_s is the mean sediment radius and ρ_s is the sediment density.

Hay and Sheng (1992) described and tested a method of particle size determination using multi-frequency acoustic backscatter. The principle is to use the dependence of the backscatter form function for suspended particles with ka_s, where k is the wave number equal to $2\pi f/c$, and c is speed of sound. Using frequencies of 1 MHz, 2.25 MHz and 5 MHz, Hay and Sheng were able to estimate particle sizes in the range 50 µm to 170 µm to between 10% and 20%. They also noted that once the relative sensitivities of the three frequencies had been established, the calibration of the system was site independent.

AQUA*scat* 1000 Acoustic Backscatter Instrument

In 1992, Aquatec manufactured a data acquisition system for a three frequency acoustic backscatter probe, similar to that described in Pearson and Thomas (1991). Over the coming decade they continued to manufacture various research instruments based on these principles for institutions studying bottom boundary layer processes around the world. In 2001, when the original technology became obsolete, Aquatec designed a new instrument using the latest available techniques, and the first AQUA*scat* was produced. The AQUA*scat* 1000, launched in 2006 is the latest evolution of the technology. The instrument is controlled by a digital signal processor (DSP), which also carries out signal processing and analysis. A programmable logic array is used for high frequency signal generation and filtering. Up to four transducers are driven through a multiplexer from amplified, digitally generated signals. The same transducers are used to receive the backscattered response, which is amplified using a linear amplifier with programmable gain and high speed, broadband data acquisition. The digitised signal is then mixed digitally down to I and Q components in the bandwidth of interest – for example 75 kHz for approximately 1 cm spatial sampling with a nominal 1500 m/s speed of sound. This approach to signal acquisition and processing results in both a stable, measurable gain and low noise, both of which aid in calibration. Data is stored on Compact Flash, and may be accessed at the end of a deployment or in real time by high speed USB communications.

A typical instrument is pictured in Figure 2. All the electronics described above, and a battery pack for short deployments, are incorporated within the 1000 m depth rated aluminium housing. The instrument shown includes four narrow-beam acoustic transducers at frequencies between 0.5 MHz and 5 MHz, all arranged close to the instrument axis – unlike Doppler current profilers, which have divergent beams. This means that all transducers observe the same volume of water. The configuration used in the deployment described in this paper allows the transducers to be connected to the main instrument via individual cables, so they may be arranged in any orientation, and for this deployment they were arranged facing vertically down towards the bed.

Figure 2: AQUAscat 1000S Instrument

Calibration

The key to successful use of acoustic backscatter for measurement of suspended sediment is an effective method of calibration. During the developmental stages of this type of instrument, there has been a strong emphasis on building calibration tanks that have a homogeneous suspension over a relatively long depth profile. Such tanks have been described by Thorne and Hanes (2002). Aquatec have designed and built a similar sediment tower shown in Figure 3.

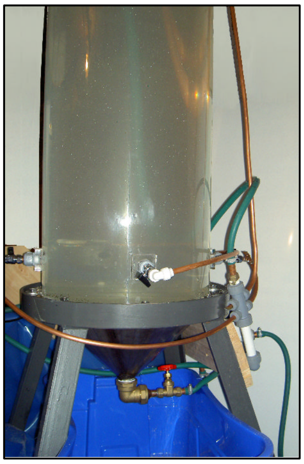

Figure 3: Sediment Tower

The tower is 0.4 m diameter and 2.1 m deep, with a conical bottom to prevent deposition of sediment. The sediment suspension is pumped from the bottom and re-injected at two elevations. A mechanical stirrer is used to ensure mixing at the injection points. Calibrations were carried out with suspensions of glass spheres at a quarter phi size interval. Typically calibrations were carried out at three sizes for each of the instrument's frequencies.

The purpose of calibration is to establish the system constant K_t described in equation (1) for each of the instrument's transducers (Betteridge *et al*, 2008). This is achieved by taking 10,000 samples of vertical backscatter profile in the sediment tower to minimise the effects of acoustic scattering variability. Pump samples were taken at a 0.6 m to establish actual concentration. The plots in Figure 4 illustrate the stages in the calibration process.

In plot a), measured signals are corrected for the effects of spreading loss and attenuation that are a function of range from the transducer. The apparent increase of signal with range on the 4 MHz trace occurs when the recorded signal drops to the system noise floor. In plot b), K_t is calculated assuming the tank has a constant mass concentration based on the pump samples. The 4 MHz value steps to zero near 1.4 m range as values beyond this range have been discarded because the recorded signal value was too low. In plot c), using the frequency least affected by sediment-related attenuation (in this case the blue 1 MHz trace) the actual concentration profile is calculated. In plot d), K_t is recalculated for each frequency using the actual concentration profile.

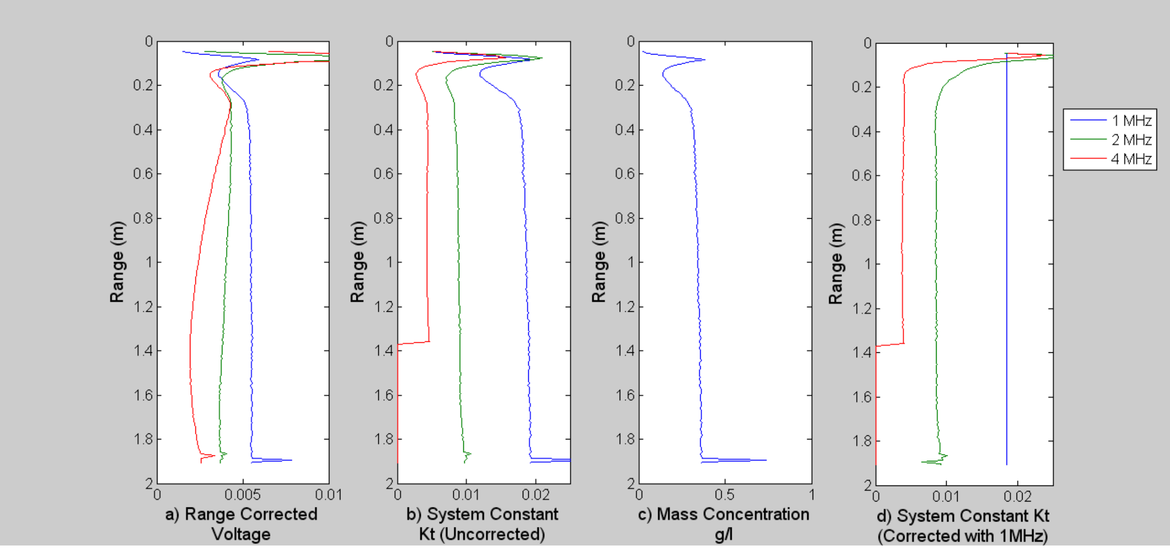

Figure 4: Calibration Process

Results

The AQUA*scat* 1000 was configured with fixed gain. It records to 16-bit digital resolution and has an operational range of approximately 80 dB. The system worked at 1.0 MHz, 2.0 MHz and 4.0 MHz, with a pulse repetition frequency of 128 Hz, averaged internally over 32 profiles to give 4 Hz stored profiles, with 0.01 m range bins over a range of 1.28 m. Each burst contained 5280 profiles (22 minutes of data) and from these profiles the mean linear voltage averaged over the burst has been calculated.

For the analyses presented in this paper, mean particle size has been determined from sediment traps from earlier deployments and from the convergence of acoustic concentrations at the three frequencies. Because no independent suspended sediment samples were obtained, then for consistency, the same d_{50} of 300 µm was used for the analysis of the ABS data on each of the three instruments. The linearized voltages were used with the previously measured K_t to obtain suspended sediment concentration profiles at each of the three frequencies. A similar process was applied to the POL ABS instruments. Figure 5 overleaf shows on the left a time series of calculated suspended sediment concentration at a single elevation of 0.075 m above the bed for each of the three instruments (blue line) with the standard deviation (green line) derived from the three frequencies used. The use of acoustics allows accurate detection of the bed so that concentration can be measured relative to the bed position.

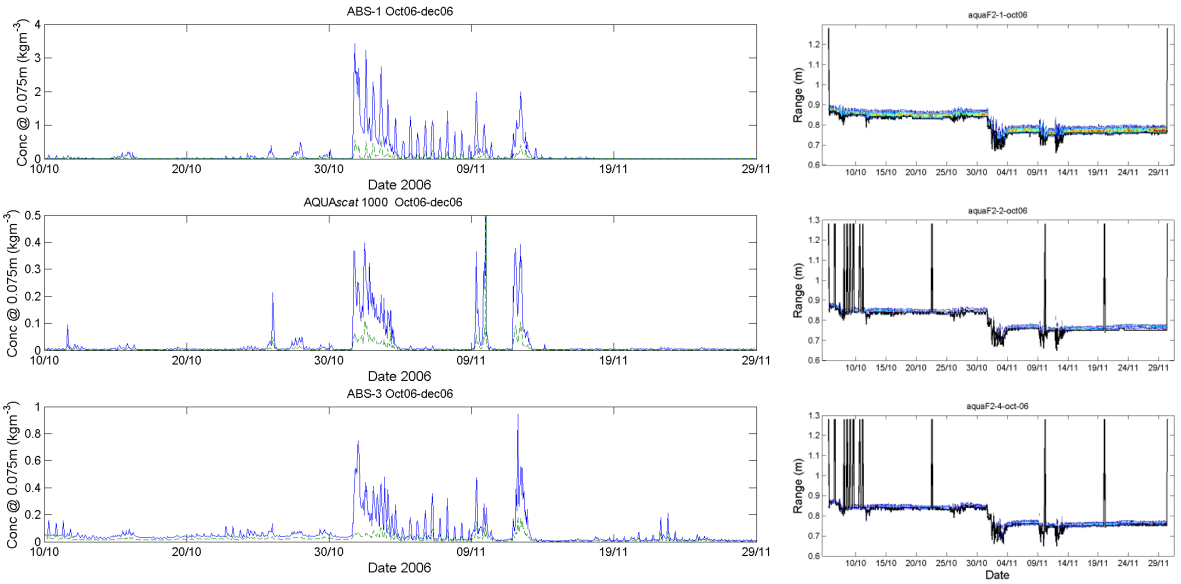

Figure 5: Left - Suspended sediment concentration at 0.075 m above the bed for POL ABS-1 on frame 1, the AQUAscat 1000 ABS on frame 2 and POL ABS-3 on frame 3. Right - bed range from each AQUAscat transducer

Discussion and Further Work

In the results presented here, we have carried out acoustic backscatter inversions using an assumed mean particle size based on knowledge from previous physical measurements. The AQUA*scat* 1000 was shown to function without problems throughout the deployment, and has recorded data that has similar temporal characteristics to acoustic data recorded elsewhere at the site. Acoustic detection of the moving bed position means that suspension profiles can be related to elevation above the bed. This initial analysis allows us to identify areas of particular interest, which can then be selected for a full multi-frequency inversion, which will provide a more detailed description of particle size distribution.

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