SOUNDING OUT SEDIMENT TRANSPORT; DEVELOPMENTS OVER THE PAST TWO DECADES

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1 INTRODUCTION

The transport of sediments can be considered as arising from dynamic feedback interactions between the seabed, the hydrodynamics and the sediment movement (1-2). For example, flow separation and vortex generation due to flow over steep ripples on the seabed influences the suspension of sediment. Further, the shape of the ripples contributes to the overall flow resistance and the flow structure in the boundary layer. Yet the ripples themselves are a product of the local sediment transport. The term ‘sediment triad’ (3) has been coined to describe these interactions with feedback and it is illustrated schematically in figure 1.

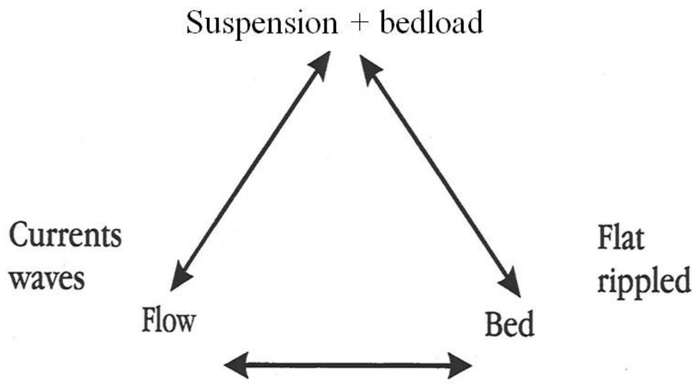

Figure 1. The sediment interacting triad showing the dynamic interrelationships between the seabed, wave-currents and the movement of the sediments.

2 APPLICATION OF SOUND

Sound is a powerful tool for sediment transport measurements, which can be used both to develop understanding of processes and assess transport models (4). It uniquely provides non-intrusive, collocated, high spatial-temporal resolution profiles of the flow, mobile sediments and bedforms. Therefore in recent years acoustics has been developed to measure the dynamically interacting sediment triad. The concept of using acoustics for sediment transport studies is attractive and straightforward, as illustrated in figure 2. A pulse of sound, typically in the range 0.5-5.0 MHz and millimetric in length, is transmitted from a downward pointing directional sound source, usually mounted about a metre above the bed and the backscattered signal is gated into range bins and digitised. As the sound pulse travel towards the bed, sediments in suspension backscatter a proportion of the sound and the bed generally returns a strong echo. The former provides profiles of the suspended sediments and the flow, while the latter gives the time history of the bedforms. Acoustics has/is being developed to obtain such measurements, with sufficient spatial and temporal resolution, to allow the fundamental process of turbulence and intra-wave processes to be probed, while at the same time being non-intrusive (5-7). No other technique combines all these capabilities.

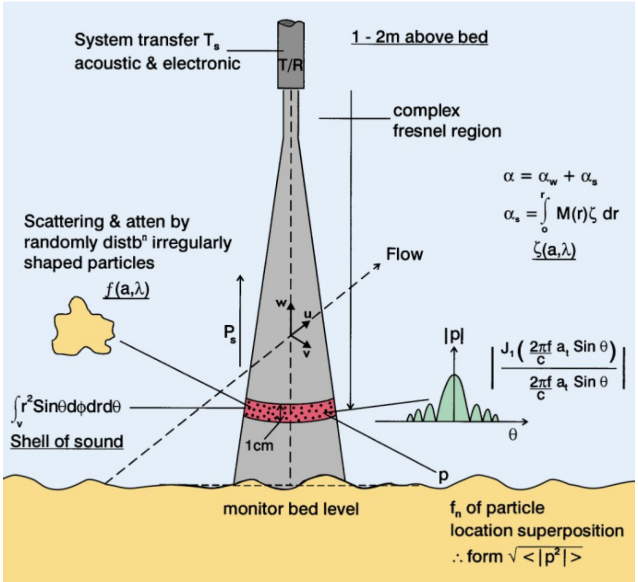

Figure 2. Diagram outlining the use of acoustics for sediment transport studies.

3 A CASE STUDY

To illustrate this application of acoustics, the problem of understanding sand transport over a rippled bed under waves is described. As shown schematically in figure 3, for waves propagating over a steeply rippled bed, vortex generation and shedding at flow reversal is considered to provide a mechanism capable of lifting sand into suspension to significant heights above the bed (8).

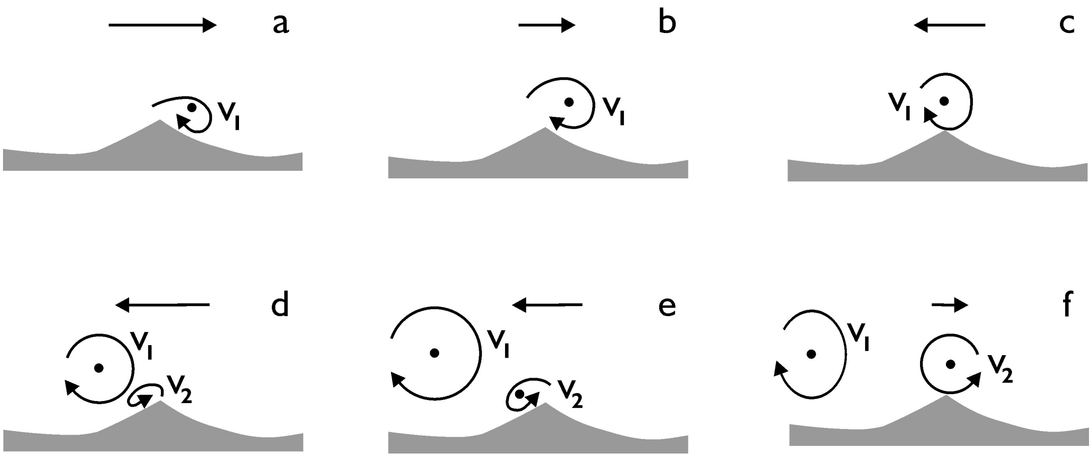

Figure 3. Schematic of vortex entrainment of sediment over a rippled sandy bed. The horizontal arrow at the top of each figure represents the near-bed velocity.

Figure 3a shows the growth of a vortex, V_1, occurring around the time of maximum wave velocity. This vortex is trapped near the bed and becomes sediment laden rich. As the wave velocity decreases and the flow reverses, figures 3b-3d, the sediment loaded vortex becomes detached from the bed and gets carried over the crest lifting sand high up into the water. At the same time, figure 3d, a vortex V_2 is formed on the opposite side of the ripple due to the reversed flow. As shown in figures 3d-3f, V_2 grows, entrains sediment, becomes detached and moves over the crest at the next flow reversal carrying sediments into suspension. The main prediction of the vortex concept is that sediment is carried up into the water column twice per wave cycle at flow reversal.

To investigate experimentally the concept of vortex entrainment of sediments, an experiment was conducted in a large wave flume (http://www.deltares.nl/en/facility/107939/delta-flume). The flume, one of the largest in the world, is 230 m in length, 5 m in width and 7 m deep, allowed the waves and sediment transport to be studied at full scale. A paddle at one end of the flume generated waves, which propagated along the flume over a sandy bed and dissipated on a beach at the opposite end. The bed comprised of coarse sand which was located in a layer of thickness 0.5 m and length 30 m, approximately halfway along the flume. To make the acoustic and other auxiliary measurements an instrumented platform was deployed in the flume. Measurements were made of the bedforms, flow and suspended sediments; the interacting sediment triad.

To investigate the vortex entrainment model it was a priori necessary to establish if the surface waves were generating ripples on the bed in the flume. Using an acoustic sector scanner to collect images of the bed, figure 4a and a pencil beam acoustic ripple profiler to measure the variation of a 3m transect of the bed, figure 4b, it was clear that ripples were being formed on the bed. To obtain flow separation and hence vortex formation requires ripples with slopes of the order of 15^{o} or greater, analysis of the observations showed this was the case (9).

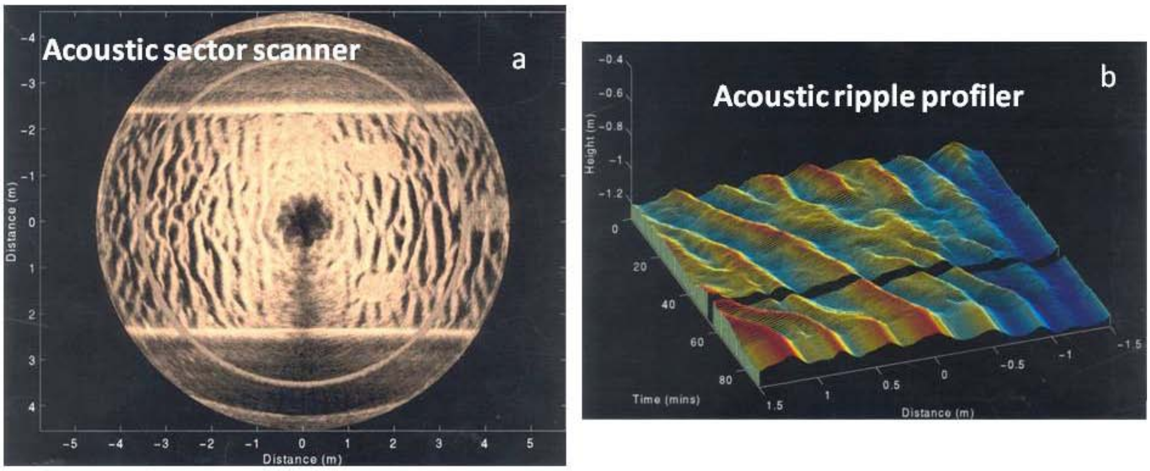

Figure. 4. a) High resolution sector scanning image and b) ripple profiler transect measurements of the bedforms.

To obtain measurements of the flow and suspended sediments simultaneously Acoustic Doppler Velocity Profilers, ADVP, (10-11) and Acoustic Concentration Velocity Profilers (12), have been developed to enable processes such as vortex entrainment to be investigated. An example of the measurements from these instruments is shown below in figure 5.

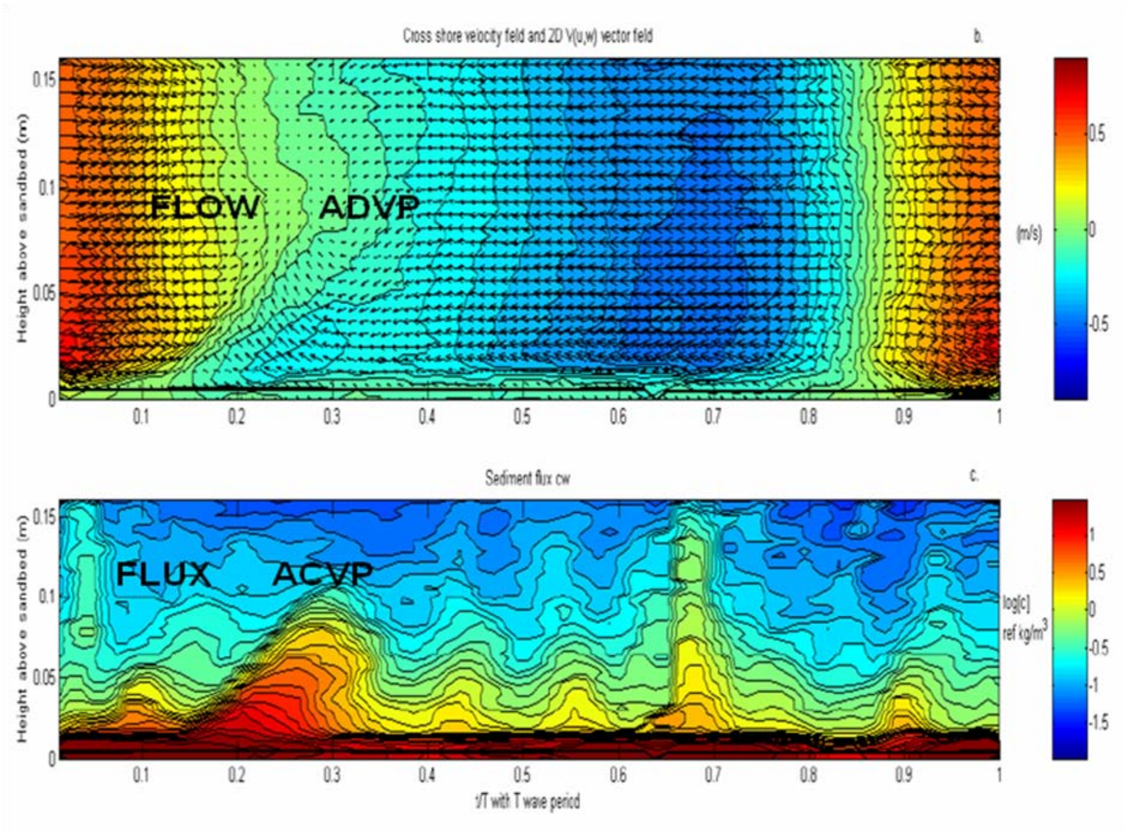

Figure 5. Measurements of the vertical and along wave horizontal flow velocity and concentration using an Acoustic Doppler Velocity Profiler, ADVP and an Acoustic Concentration Velocity Profiler ACVP.

To obtain the third component of the sediment transport triad in the large scale flume, the suspended sediments, a three frequency acoustic backscatter system was used. Profiles of the suspended sediments were collected with a temporal resolution of 0.25 s and with a vertical spatial resolution of 0.01 m over the bottom 1.24 m above the bed. These measurements were synchronised with the wave velocity data, so that patterns in the suspended sediment concentration could be directly related to the near bed oscillatory flow generated by the waves. Figure 6 shows acoustic measurements and a sediment processes model output (13), of the variation of the suspended sediments due to the passage of waves over the ripples shown in figure 4. Focusing on the observed acoustic concentrations it can readily be seen that there are two periods of intense suspended sediment activity, at nominally 1 s and 4 s, in the wave cycle. From the wave velocity plot it can be seen that the suspended sediment events lie close to the times of flow reversal. Apart from flow reversal, there are only low levels of suspended sediment concentration. These observations are consistent with the vortex entrainment description given in figure 3 and support the model in figure 6, which is based upon the generation of vortices as the primary mechanism for lifting sediment into suspension**.** These acoustic measurements represent some of the most detailed data collected to date on the interacting feedback sediment triad.

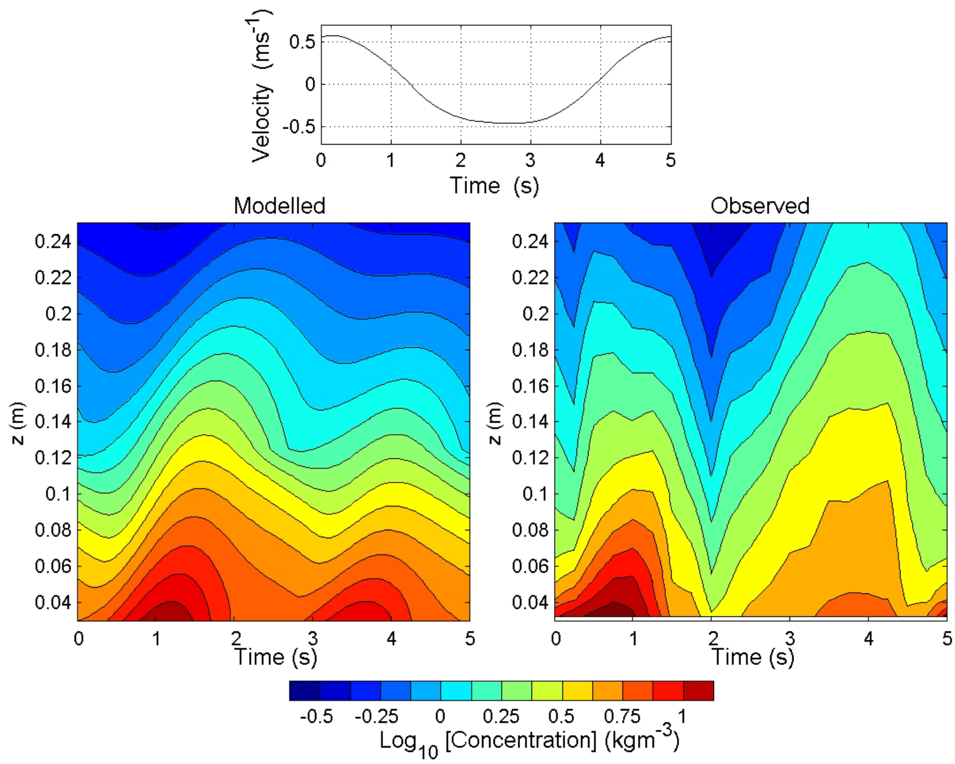

Figure 6. Measurement and modelling of suspended sediments with height z above a rippled bed under a 5 s period wave.

4 CONCLUSIONS

Over the past two decades the application of acoustics to the measurements of near bed sediment transport processes has moved on from a qualitative tool, to being able to quantitatively measure detailed bedforms, flow and suspended sediments. The measurements can now be obtained with sufficient detail and accuracy, that emerging sediment transport models are being benchmarked against the acoustic observations, which are providing some of the most detailed measurements on sediment transport processes that have been obtained to date (14). Looking towards the future the expansion of acoustic velocity and concentration profile measurements, from one dimensional in the vertical, 1DV, to two dimensional in the vertical and horizontal, 2DHV (15), to study spatial structures would provide a significant step forward in our measuring capability for sediment transport studies. Further the quantitative use of sound for measuring sediment processes has been primarily limited to non-cohesive sediments, eg sands, however, much of the world's sediments are composed of cohesive muds, clay and silts and new suspension scattering models (16,17) are required to use acoustics in these environments. There is therefore much more to be done in the application of acoustics to sediment transport processes.

5 REFERENCES

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