GLOBAL WARMING, COASTAL EROSION, VORTICES AND SOUND

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1 INTRODUCTION

It is commonly acknowledged that global warming will impact on our coastal environment by an increase in sea level, higher wave conditions and stronger storm surges. However, our capability to predict the impact this may have on the coastal environment is relatively limited and in particular the influence such changes may have on sediment (sand and mud) transport pathways are surprisingly difficult to forecast. This lack of predictability is due in part to our limited understanding of the basic mechanisms that drive sediment transport and it is in this area that acoustics has begun to make a significant contribution. We look back at recent advances in the application of acoustics to sediment transport processes and look forward to future developments.

2 WARMING AND EROSION

It is increasingly accepted that over the next few decades global warming will increasingly impact adversely on coastal environments. The storm surge associated with Hurricane Katrina which devastated New Orleans (figure 1) and the surrounding area, brings into sharp focus the impact global warming may have on our coastlines. In addition to the impact by nature, the coastal shallow waters are utilised as a resource and for recreation, and the management of this environment is a balance of many competing interests. An example of what can happen when developments occurs without a full understanding of the impacts they may have on the coast is shown in figure2.

Figure 1.New Orleans after Katrina

Figure 2. Ariel view of a coastal resort on the Algarve

It can readily be seen that the construction has impacted on the local coastline, causing the requirement for a significant shoreline barrier; such structures are unattractive and may in the long term generate as many problems as they try to solve. Our capability to predict the impact manmade structures may have on the coastal environment is relatively limited and in particular the influences such structures have on sediment pathways is surprisingly difficult to predict. There have been many occasions when coastal developments in one area, have inadvertently led to a degradation of adjacent beaches and coastline. This lack in our capability to predict sediment transport is in part due to a lack of understanding of some of the fundamental processes. It is in this area that acoustics has begun to make a major contribution[1].

3 SOUND AND SEDIMENTS

Sediment transport can be thought of as three interacting components with feedback, this is illustrated by the triad in figure 3. For example, flow separation and vortex generation due to flow

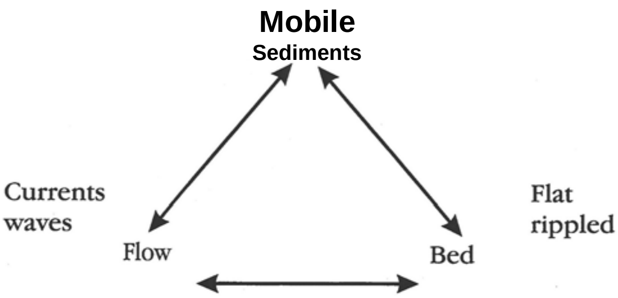

Figure 3. The sediment interacting triad showing the interrelationship between the seabed, wave-currents and the movement of the sediments.

over 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 concept of using acoustics for underwater sediment transport studies is attractive and straightforward, as illustrated by the diagram in figure 4. A pulse of high frequency sound, typically

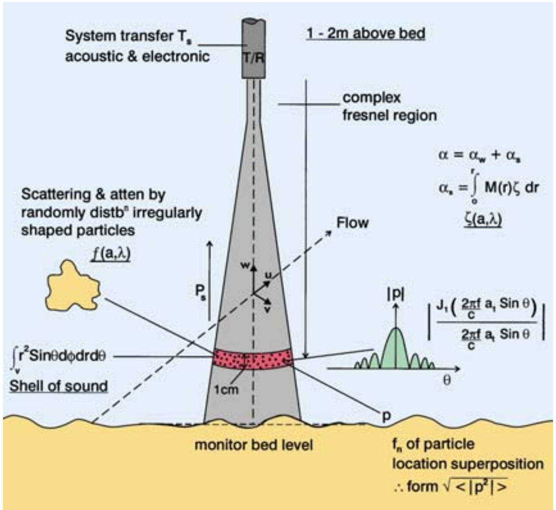

Figure 4. Diagram outlining the use of acoustics for sediment transport studies.

in the range 0.5-5.0 MHz and centimetric 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 travels towards the bed, sediments in suspension backscatter a proportion of the sound and the bed generally returns a strong echo. The former has the potential to provide information on profiles of the suspended sediments[2-4] and the flow[5,6], while the latter provides the time history of the bed location[7,8]. Hence acoustically the three components of the sediments triad can be measured co-located, simultaneously and non-invasively. Acoustics is being developed to obtain such measurements, with sufficient spatial and temporal resolution, to allow the fundamental process of turbulence and wave processes to be probed. No other technique combines all these capabilities.

4 VORTEX RIPPLES AND THE HUGE FLUME

To illustrate an application of acoustics to sediment transport, the problem of understanding entrainment processes, over a rippled bed, under waves, has been studied. 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. The process of vortex generation and sediment entrainment into the water is shown schematically in Figure 5.

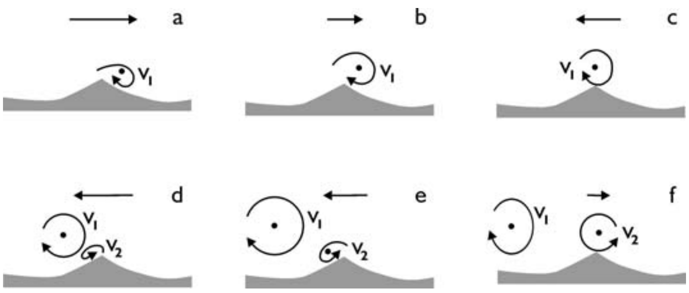

Figure 5. Schematic of lee slope vortex entrainment of sediment over a rippled sandy bed. The horizontal arrow at the top of each figure represents the near-bed velocity.

Figure 5a shows the growth of a vortex, v_1, occurring around the time of maximum wave velocity on the lee slope of the ripple. This vortex is trapped near the bed and becomes sediment laden rich. As the wave velocity decreases and the flow reverses, figures 5b-5d, the sediment loaded vortex becomes detached from the bed, gets carried over the crest carrying the sand high up into the water. At the same time, figure 5d, a vortex v_2 is formed on the lee slope on the opposite side of the ripple due to the reversed flow. As shown in figures 5d-5f, v_2 grows, entrains sediment, becomes detached and moves over the crest at the next flow reversal carrying sediments into suspension. The main feature of this mechanism is that sediment is carried up into the water twice per wave cycle at flow reversal; this is the main prediction of the vortex model.

To investigate experimentally the concept of vortex entrainment of sediments, an experiment was conducted in the large flume shown in figure 6. The Deltaflume, Deltares|Delft Hydraulics, the Netherlands, is one of the largest flumes in the world. It is 230 m in length, 5 m in width and 7 m deep and it allows the waves and sediment transport to be studied at full scale. A huge 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 medium 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 tripod platform was developed; STABLE II; Sediment Transport And Boundary Layer Equipment. This is shown in figure 6b.

Figure 6. (a) Photograph of the flume used to collect the measurements. (b) The instrumented tripod platform, STABLE II, used to make the acoustic measurements. (c) A wave propagating down the flume.

5 SOUNDING OUT VORTICES

To investigate vortex entrainment, it was a priori necessary to establish if the surface waves were generating ripples on the bed in the flume. Using a sector scanner on the platform to collect images of the bed, figure 7, and a pencil beam ripple profiler to measure the temporal variation of a 3m

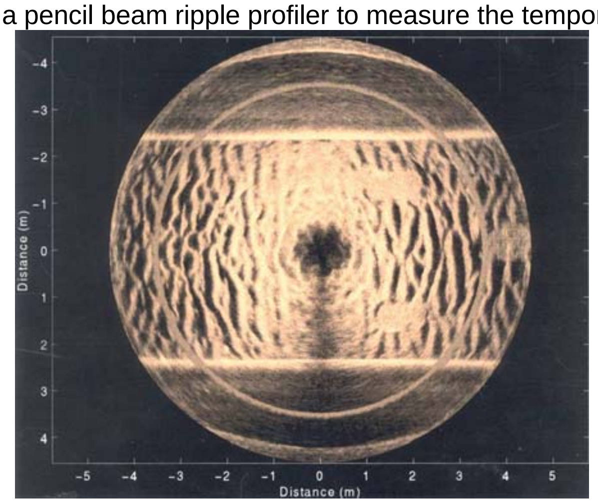

Figure 7. High resolution acoustic sector scanning image of the bed.

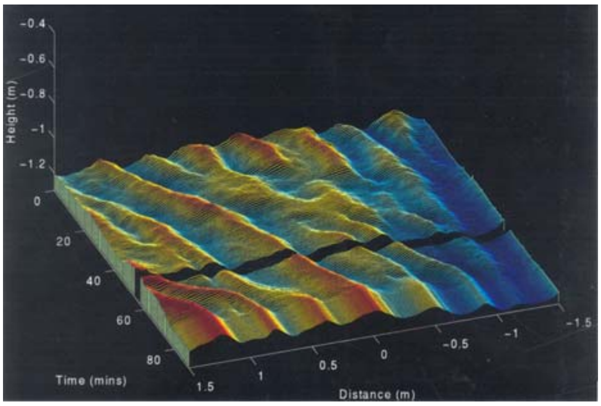

Figure 8. Acoustic ripple profiler measurements of the sand ripples on the bed.

transect of the bed, figure 8, 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.

To obtain measurements of the flow, auxiliary current meters were used in conjunction with an acoustic coherent Doppler velocity profiler. An example of the measurements from the velocity profiler is shown in figure 9.

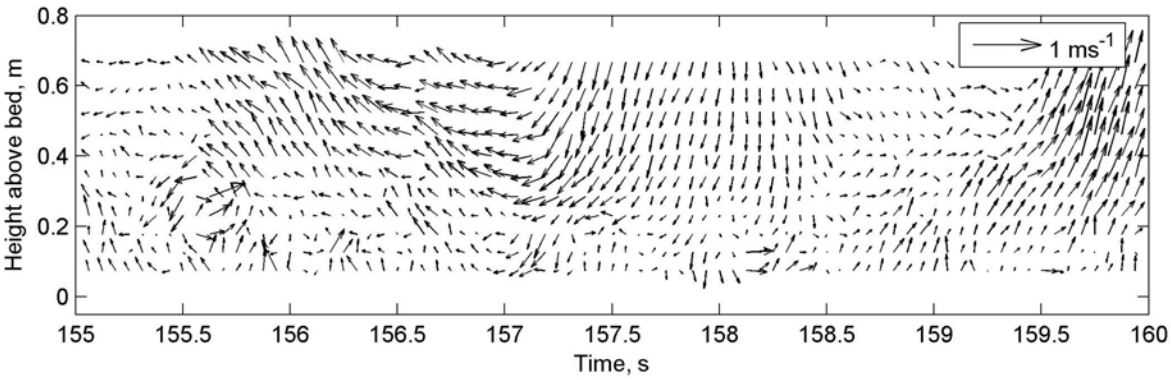

Figure 9. Measurements of the vertical and along wave horizontal flow velocity obtained using an acoustic coherent Doppler velocity profiler.

The data shown covers 5s in the bottom 0.8 m above the bed and illustrates the detailed images of the flow that can be obtained using the acoustic approach. No other technique provides such detailed profile measurements.

To obtain the third component of the sediment transport triad, 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[9,10].

Using the acoustic backscattering some of the most detailed measurements of sediment transport recorded over a rippled bed at full scale were captured. These measurements from the Delta Flume are shown in figure 10. The images shown were constructed over a 20 min period as a ripple passed beneath the backscatter system. The suspended concentrations at different locations on the ripple, at the same (four) velocity instants during the wave cycle, were combined to generate the respective images. The length and direction of the arrows in the figure gives the magnitude and direction of the wave velocity. Comparison of figure 10 with figure 5 shows substantial similarities. In figure 10a there can be observed the development of a high concentration event at high flow velocity above the lee slope of the ripple, v_1. In figure 10b as the flow reduces in strength, the near-bed sediment-laden parcel of fluid travels up the lee slope of the ripple towards the crest. As the flow reverses this sediment laden fluid parcel, v_1, travels over the crest and expands. As the reverse flow increases in strength, figure 10d, the parcel v_1 begins to lift away from the bed and a new sediment-laden lee vortex, v_2, is initiated.

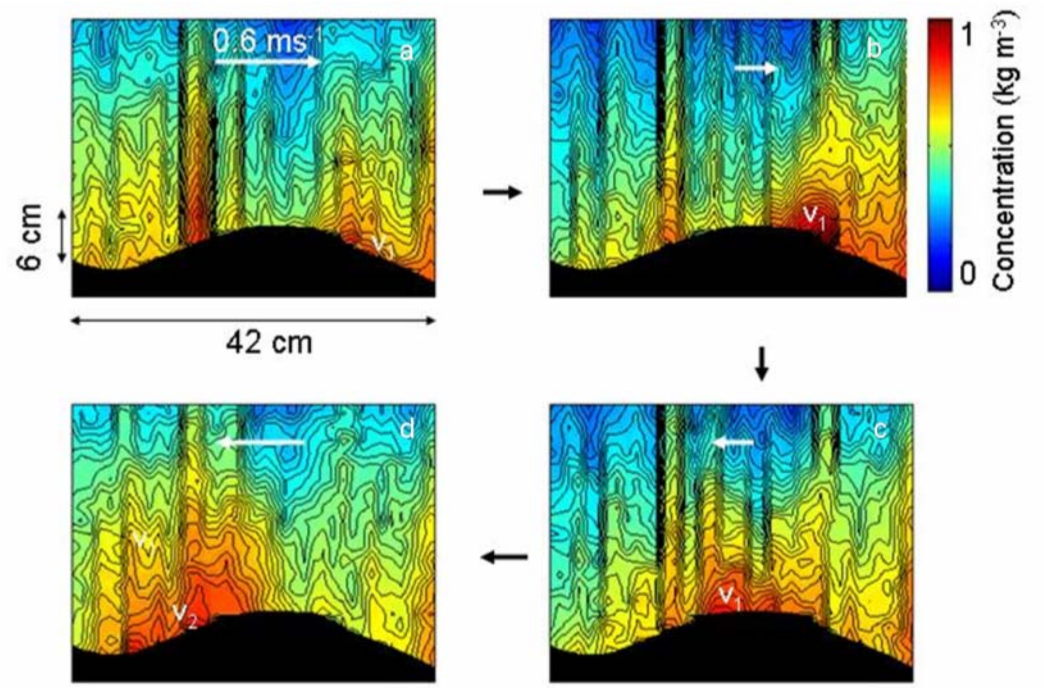

Figure 10. Acoustic imaging of suspended sand entrainment over a rippled bed due to waves, at four phases of the wave cycle. The length of the white arrow in each plot gives the magnitude and direction of the near-bed wave velocity.

These acoustic observations have been used to assess a recently developed model of sediment transport over vortex ripples. In order to capture the essential features of this data within a relatively simple 1DV (one-dimensional in the vertical) model, the data has first been horizontally averaged over one ripple wavelength for each phase instant during the wave cycle. The resulting pattern of measured sediment suspension contours is shown in the right panel of figure 11, while the upper panel shows the oscillating velocity field measured at a height of 0.3 m above the bed. The measured concentration contours presented in figure 11 show two high concentration peaks near the bed that propagate rapidly upwards through a layer of thickness corresponding to several ripple heights. The first, and strongest, of these peaks occurs slightly ahead of flow reversal, while the second weaker, and more dispersed peak is centred on flow reversal. The difference in the strengths of the two peaks reflects the greater positive velocity that can be seen to occur beneath the wave crest (time=0 s) than beneath the wave trough (time=2.5 s). Between the two concentration peaks the sediment settles rapidly to the bed. The underlying mechanism of sediment entrainment by vortices shed at or near flow reversal is clearly evident in the spatially-averaged measurements shown in figure 11.

Using a recently developed 1DV model, which applies a strongly time varying eddy viscosity, the processes of vortex shedding were modelled[11]. The resulting concentration contours in the present case are shown in the left panel of figure 11. The essential two-peak structure of the eddy shedding process can be seen to be represented rather well, with the initial concentration peak being dominant. The decay rate of the concentration peaks as they go upwards is also represented quite well, though a phase lag develops with height that is not seen to the same extent in the data. Essentially the detailed acoustic observations of sediment entrainment under waves over ripples of moderate steepness, have begun to establish a new type of 1DV modelling, thereby allowing the model to go on to be used for practical prediction purposes in the rippled regime, which is the bed form regime of most importance over wide offshore areas in the coastal seas.

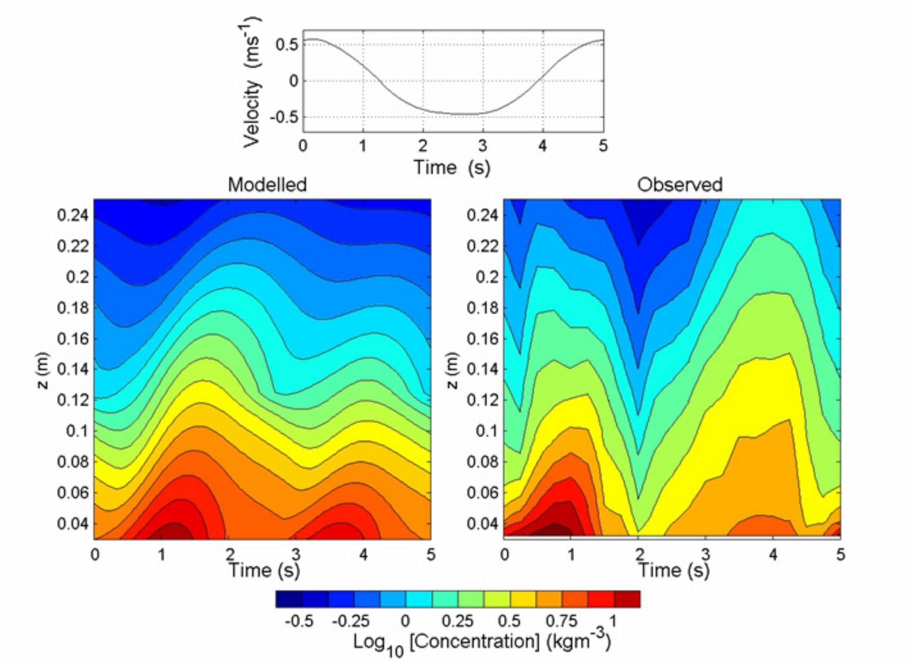

Figure 11. Acoustic measurements and modelling of suspended sediments with height z above a rippled bed under a 5 s period wave.

6 REFLECTIONS

Over the past two decades the application of acoustics to the measurement of near bed sediment transport processes has moved on from a qualitative tool, to being able to quantitatively measure detailed flow, suspended sediments and bedforms. The aim of the paper has been to illustrate the application and use of acoustics in the study of sediment transport under waves over a rippled bed. Intra-wave, intra-ripple measurements of suspended sediments were obtained and these were used to investigate the concept of vortex entrainment over a steeply rippled bed. The observations indicate the vortex mechanism was occurring. By averaging the data over the ripple, the ripple averaged suspended concentration, with the phase of the wave, was formed. These 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. And this is only the beginning; 3-D ripple profilers are now available, multi-frequency coherent Doppler profilers are beginning to be used, multi-beam system will probably come into play and integration of systems to directly measure sediment flux and bed forms is just around the corner.

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