ACOUSTIC MEASUREMENTS OF BOUNDARY LAYER FLUX PROFILES OVER A SANDY RIPPLED BED UNDER REGULAR WAVES

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Abstract: *The study of boundary layer sediment transport processes requires contemporaneous measurements of the bedforms, the flow and the sediment movement. Obtaining these three parameters, at the required temporal-spatial resolutions, has been traditionally difficult, especially within a few centimetres of the bed. To circumvent some of these difficulties acoustic techniques have been and are being developed. Here we look at the deployment of an acoustic backscatter system, ABS, an acoustic ripple profiler, ARP, and an acoustic Doppler velocity profiler, ADVP, to measure sediment entrainment processes above a rippled bed under regular waves. High resolution acoustic observations of the suspend sediment concentration, flow and bedforms have been collected. Here we report on some of the initial results obtained from this study.*

Keywords: *Acoustic, backscattering, Doppler, velocity, sediments, ripples, bedforms*

1. INTRODUCTION

Wave induced ripples are a common occurrence on sandy beds in coastal waters. The ripples are formed by the oscillatory action of the fluid due to the waves, which through an initial bed deformation, develops into a rippled bed due to feedback between the flow, the mobile sediments and the evolving bedforms. In many cases they have dimensions directly related to the near bed oscillatory orbital displacement of the fluid particles and as such are known as orbital ripples. In many cases the dimensions of such ripples so formed are of the order of decimetres in length and centimetres in height. Once formed the ripples have a profound impact on the boundary layer physical processes of the hydrodynamics and the sediment mobility. For ripples of low slope, $\eta_r/\lambda_r \leq 0.1$, where η_r is the ripple height and λ_r is the ripple wavelength, the ripples enhance the near bed mixing relative to a plane bed, although the fundamental dynamics are usually considered to be comparable to that of a plane bed. However, if the ripples are relatively steep[1] with $\eta_r/\lambda_r \geq 0.1$, then the dynamics change completely and mixing close to the bed is considered to be dominated by a coherent process involving boundary layer separation and vortex formation. Direct measurements of the hydrodynamics and sediment structures, within this wave boundary layer, above a rippled bed, at field scales are relatively few and it is only recently that detailed observations of the combined hydrodynamic-sediment processes have begun to become available. In this paper we present some measurements of sediment dynamics over a rippled bed collected using recently developed acoustic technologies. The study was carried out in a large scale flume facility in Barcelona, Spain. Combining an acoustic multi-frequency backscatter system, ABS, with an acoustic ripple profiler, ARP, and an dual frequency acoustic Doppler velocity profiler, ADVP, simultaneous collocated measurements of the suspended sediments, bedforms, and flow were collected above a rippled bed. Here we describe the analysis of the data and some provisional results.

2. EXPERIMENTAL ARRANGEMENT AND MEASUREMENTS

The study was carried out in late Autumn 2008, in a large-scale wave flume facility located at the Maritime Engineering Laboratory (LIM) at the Catalonia University of Technology (UPC) CIEM, Barcelona, Spain. The flume dimensions are 100 m long, 3 m wide and 5 m deep. The size of the flume allows hydrodynamic and sediment studies to be carried out at near full scale. Illustrations of the flume are shown in Fig. 1. For the study medium sand was placed in the bottom of the flume to a thickness of 0.5 m. The water depth above the sand was between 1.6 m-1.9 m. The waves used for the work ranged in height, H, between 0.30 m-0.55 m and had a fixed period, T, of 6.5 s. Calculations prior to the experiment indicated that waves with these parameters, for the water depths used, would have sediment processes varying from dynamically plane through to the vortex ripple regime.

Fig.1: Photographs of the Barcelona flume facility.

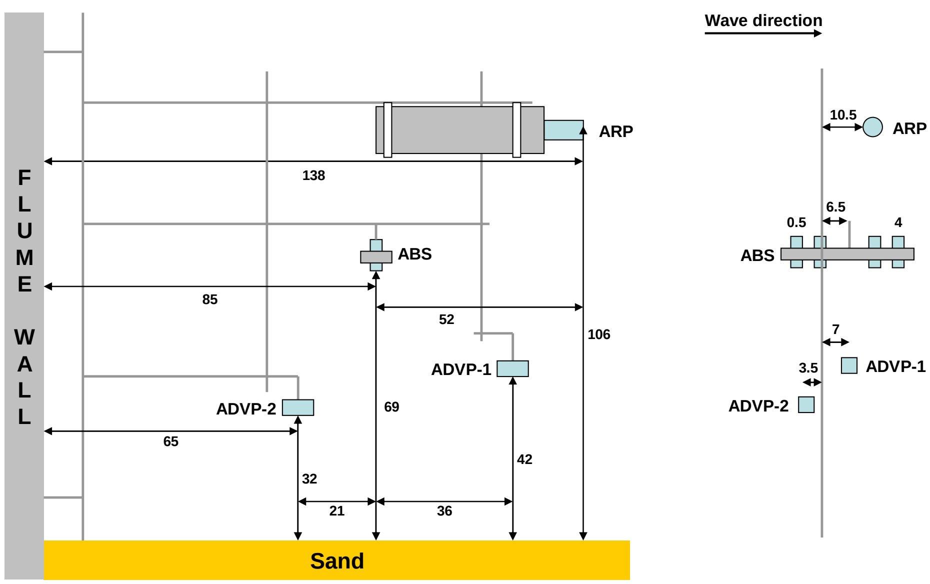

Fig.2: Schematic showing the layout of the Acoustic Ripple Profiler, ARP, Acoustic Backscatter System, ABS and the two Acoustic Doppler Velocity Profilers, ADVP.

The experimental set up is shown above in Fig. 2. Suspended sediment concentration profiles were obtained using the ABS. The system operated at 0.5, 1.0, 2.0 and 4.0 MHz. During the study the pulse repetition frequency was set at 64 Hz. The pulse length and range sampling were selected to provide 0.005 m vertical range resolution with 200 samples, thereby covering a range of 1.0 m. To measure the bedforms the ARP, based on a rotary narrow beam scanner, was used to measure the height of the sand surface over a transect of 4 m. Transects were collected each minute during the data collection periods, which were typically between 15 min – 30 min. To obtain the vertical and horizontal velocity components dual frequency ADVP's were used. These operated at 1.25 MHz and 2.0 MHz. From the phase and magnitude of the backscattered signal these respectively provided 12.5 Hz velocity and concentration profiles, at two locations above the bed, with 0.003 m vertical resolution.

3. DATA ANALYSIS

Suspended sediment measurements. The objective of the study was to measure collocated velocity and suspended concentration above known bedforms to assess the processes of sediment entrainment. To this end the ABS was calibrated using a suspensions of spheres[2] and suspended concentration profiles obtained based on an inversion[3] using a median suspended particle size of d_s=200 μm, which was 80% of the median bed size. The results from the acoustic inversion are shown in Fig. 3. The suspended sediment concentration is seen to steadily increase in magnitude as H is increased, with typical profiles[4,5] which rapidly reduce close to the bed followed by slower reduction with increasing height above the bed.

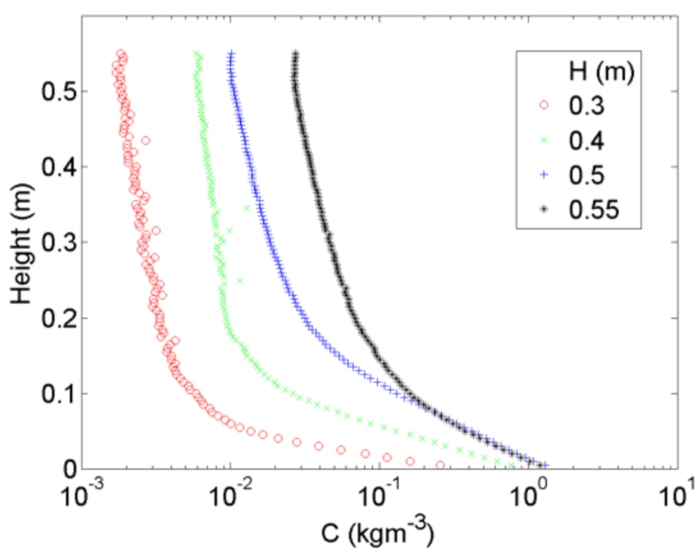

Fig.3: ABS measurements of suspended sediments concentration with height above the bed for increasing values of wave height.

To convert the ADVP backscattered signals to suspended sediment concentration, the same inversion was performed on their backscatter data and the results matched to the ABS concentration profiles. Comparison of the ABS and ADVP results are shown in Fig.

4. The results from the ABS and the ADVP are deemed sufficiently comparable that the veracity of the ADVP concentration measurements is considered high.

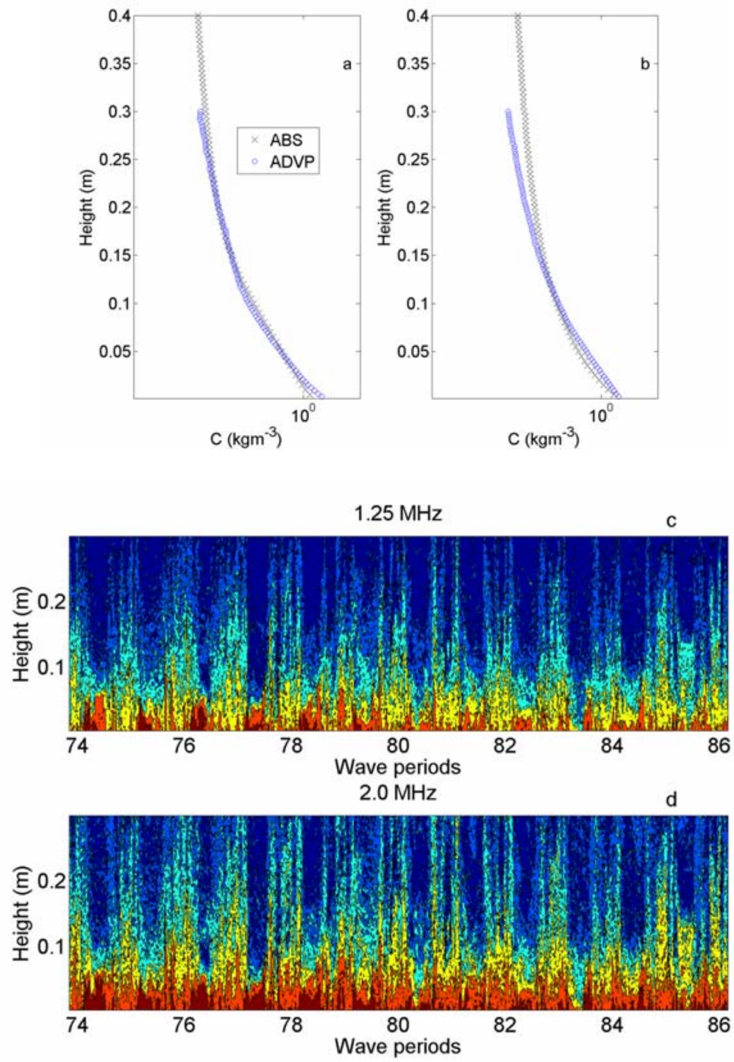

Fig.4: a) b) Comparision of suspended sediment concentration profiles from the ABS and the ADVP c) d) Comparison of the intra-wave suspended sediment concentrations at the two ADVP frequencies

Bedform measurements. As mentioned earlier, bedforms have a profound impact on sediment entrainment and transport[6], due the changing flow and sediment dynamics as the bedforms develop. Examples of the bedforms from the study are shown in Fig. 5. This shows the development of a 4 m transect over time. For low wave conditions, H=0.3 m, the average ripple height and wavelength were respectively η_r=0.009 m and λ_r=0.11 m, this results in a slope of η_r/λ_r=0.08. Ripples of these dimensions and slope are considered to increase the bed roughness, ie enhance near bed turbulence, however, the dynamics is considered to be nominally similar to those of a plane bed. For the second case shown in Fig. 5b, H=0.55 m, the values for the ripples were η_r=0.03 m,λ_r=0.26 m and η_r/λ_r=0.12.

The expectation for ripples with these dimensions and slope is that flow separation would occur and the sediment dynamics be related to the process of vortex entrainment.

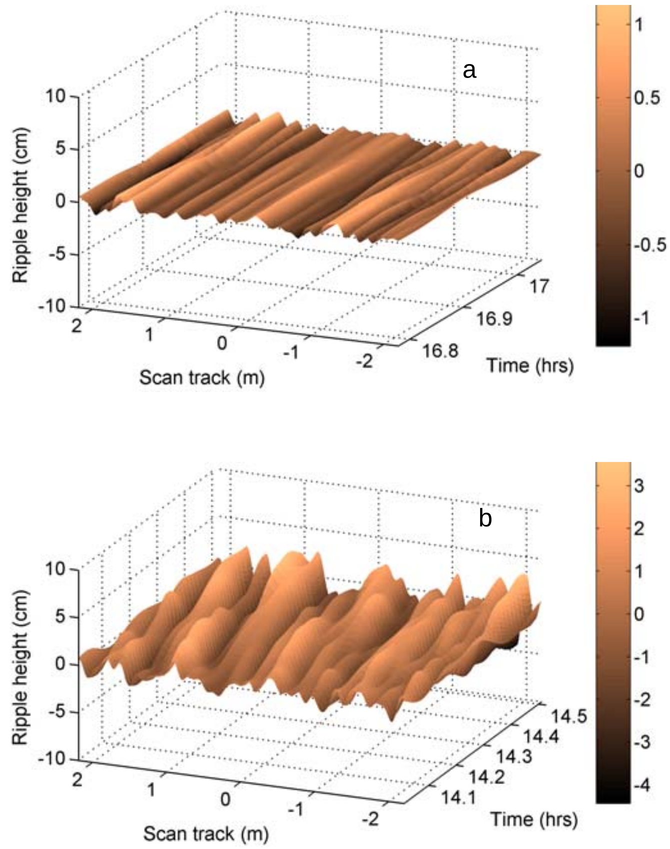

Fig.5: Measurements of bedforms for a) H=0.3 m and b) H=0.55 m.

Combined measurements of the flow and suspended sediments. As shown in the ‘Suspended sediments’ section the amplitude of the ADVP backscattered signal can be used to obtain suspended concentration. However, the rate of change of phase of the same signal can also be utilised for flow measurements [7-10]. This technique can provide high spatial-temporal detailed velocity profiles in the bottom boundary layer. Therefore using the ADVP, collocated combined profile measurements of the velocity components and the suspended sediment concentration were obtained. Provisional results are shown in Fig. 6. In Fig. 6a, the horizontal flow component, u, is superimposed on the instantaneous flow vectors in the uw plane, where w is the vertical velocity component. In Fig. 6b, the corresponding concentration field is given; this was simultaneously obtained from same ADVP signal. It can be seen that the event of the near bottom maximum in suspended sediment concentration coincides with a strong upward surge in the velocity field. The data are presently being analysed in order to understand the physical processes which gave rise to the type of results shown in Fig. 6, although it is already evident that such detailed combined velocity and concentration observations will provide new insight into bottom boundary sediment dynamics.

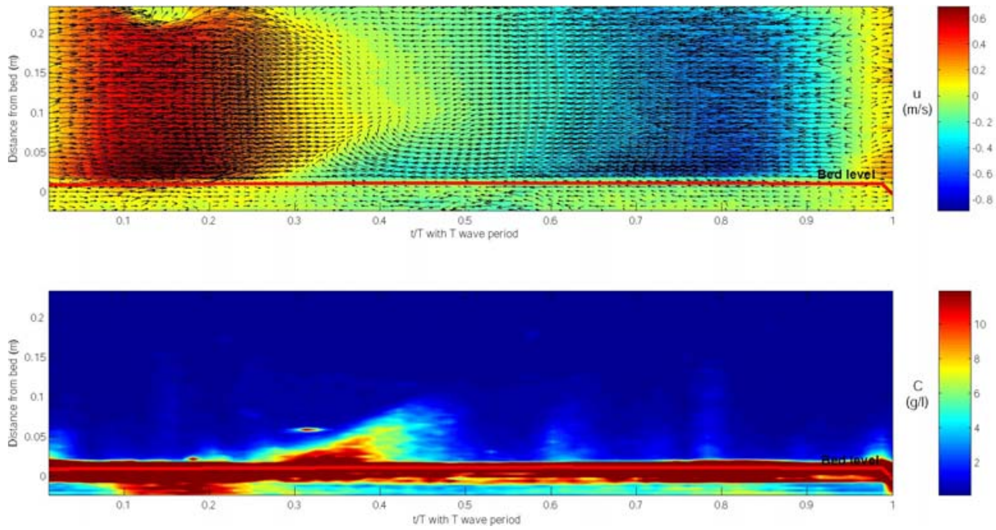

Fig.6: Collocated simultaneous intra-wave measurements of ; a) the velocity field, b) the concentration field, obtained using an ADVP.

4. CONCLUSIONS

The aim of the paper has been to provide a description of the application of acoustics to the study of sediment entrainment over sandy rippled beds. An overview of the facility, instrumentation and data collected has been presented. Detailed analysis of the boundary layer measurements, aimed at furthering understanding of the mechanisms of sediment entrainment is ongoing. Here we have presented some early results from this analysis. It is expected that the detailed contemporaneous observations of flow and suspended sediments collected with the ADVP, coupled with the bedform measurements, will provide a data set which will both assess and aid the development of theoretical models describing sediment transport over complex bedforms.

5. ACKNOWLEDGEMENTS

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REFERENCES

[1] Sleath J. F. A. 1982. The suspension of sand by waves. J. of Hydraulic Research, 20, 5, 439-452.

[2] Betteridge K. F. E., Thorne P. D. and Cooke R. D. 2008. Calibrating multi-frequency acoustic backscatter systems for studying near-bed suspended sediment transport processes. Continental Shelf Research, 28, 227-235.
[3] Thorne P.D. and Hanes, D. M. 2002. A review of acoustic measurement of small scale sediment processes. Continental Shelf Research. 22, 603-632.
[4] Crawford, A.M., Hay, A.E. 1993. Determining suspended sand size and concentration from multifrequency acoustic backscatter. J. Acoust. Soc. Am. 94(6), 3312-3324.
[5] Thorne, P. D. Williams, J. J. and Davies, A. G. 2002. Suspended sediments under waves measured in a large scale flume facility. J. Geophys Res. Vol 107, No C8, 4.1-4.16.
[6] Thorne, P. D., A. G. Davies, and P. S. Bell (2009), Observations and analysis of sediment diffusivity profiles over sandy rippled beds under waves, J. Geophys. Res., 114, C02023, doi:10.1029/2008JC004944.
[7] Zedel, L. and A.E. Hay, 2002. A Three Component Bistatic Coherent Doppler Velocity Profiler: Error Sensitivity and System Accuracy. IEEE J. Ocean. Eng. 27, 717-725.
[8] Hurther, D. and Lemmin, U., 1998. A constant beam width transducer for 3-D acoustic Doppler profile measurements in open channels. *Meas. Sci. Techno.*, **9**, 1706-1714.
[9] Hurther, D. and Lemmin, U., 2008. Improved turbulence profiling with field adapted Acoustic Doppler Velocimeters using a bi-frequency Doppler noise suppression method. J. Atmos. and Oceanic Technology. 25 (2), 452-463.
[10] Betteridge, K.F.E, Bell, P. S, Thorne P. D.and. Williams J.J. 2006. Evaluation of a triple axis Coherent Doppler Velocity Profiler for measuring near-bed flow: A field study. J of Atmos and Oceanic technology. 2006 Vol 23, 90-106.