FIELD MEASUREMENTS OF WAVE INDUCED SAND RIPPLES IN THREE DIMENSIONS.

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Abstract: An acoustic profiling system designed to measure sand ripples in three dimensions has been developed and successfully deployed on benthic frames at two sites around the UK coast. The system comprises a mechanically scanning pencil beam acoustic transducer mounted on a two axis stepper motor assembly within a fully enclosed oil-filled housing. A pressure sensor, temperature sensor and conductivity sensor are also integrated with the instrument, ensuring the correct speed of sound is used for deriving distance to the bed from the time of flight of the acoustic pulses. Data recorded at two sites using the 3D-Acoustic Ripple Profiler are presented showing tidally migrating sand waves in the first case, and wave induced sand ripples evolving in response to a passing storm in the second.

Keywords: *ripples, waves, sand*

1. BACKGROUND

Acoustic systems for measuring sea bed topography at high resolution along a line have been in use for a number of years [1][2][3][4][5]. These line-scanning systems are ideal for use in flumes and in other areas where the orientation of the bedforms can be anticipated in advance. However, they give no information about the three dimensional context of the measurements such as the cross-flow uniformity of the bedforms. They are also of limited use in the open ocean where the wave and current forcing may be from any direction, and hence the bedforms and their migration may be oriented in any direction. To address this issue, a system that scans in three dimensions was commissioned, allowing complete three dimensional maps of the sea bed to be generated at high resolution at regular intervals. A number of field deployments of this system have been made and a selection of the results are presented here.

2. INSTRUMENT DESCRIPTION

The brief for the Three Dimensional Acoustic Ripple Profiler (3D-ARP) was drawn up by the authors and developed to order by Marine Electronics Ltd. of Guernsey. It comprises a 1.1MHz pencil beam acoustic transducer mounted on a dual axis stepper motor assembly. All moving parts are enclosed in an oil-filled and pressure balanced acoustically transparent plastic housing, thereby minimising the possibility of corrosion and fouling.

Other integrated sensors include a pressure sensor for depth measurements and +/-20^{o} pitch and roll sensor to remove errors due to non-level mounting. An integrated Falmouth Scientific Inc. conductivity and temperature module allows the accurate determination of the ambient speed of sound – essential in a time of flight applications such as this where the deployment may be in situations with widely varying water temperature and salinity.

During operation the system performs a vertical scan with up to 400 angular steps per 360 degrees typically to a range of 4m. The full backscatter profile at each angular position is stored and once the sweep is completed, the head rotates about the vertical axis by a preset amount ready to perform the next vertical scan. This process is repeated until the complete area beneath the system has been scanned. Onboard processing for detecting the bed echo in the backscatter profiles then obtains the coordinates of the bed in three dimensions for every acoustic pulse in the scan, taking into account the attitude of the instrument and the speed of sound in water at that time. A complete scan of the sea bed takes from 5 to 15 minutes depending on the number of angular steps, i.e. the resolution that has been selected. The resulting coordinate file is stored alongside the raw data file on an internal drive that has recently been upgraded from hard disk to an 8Gbyte compact flash card, reducing the power consumption significantly.

A photograph of the 3D-ARP is shown in Figure 1 mounted on the new STABLE III frame such that the acoustic head will be approximately 1.2m above the sea bed. The 3D-ARP is the yellow tube mounted vertically and has been highlighted by the black oval.

The raw acoustic backscatter data representing a single vertical slice through the water from a full 3D scan of the bed is shown in Figure 2. The location of the bed echo in this profile is marked by a white line. This scan was recorded in a field of migrating sand waves that eventually caused the partial burial of the mini-STABLE frame during the LEACOAST2 project.

Fig.1: A photograph of the 3D-ARP mounted on the new STABLE III frame ready for deployment in the Dee Estuary

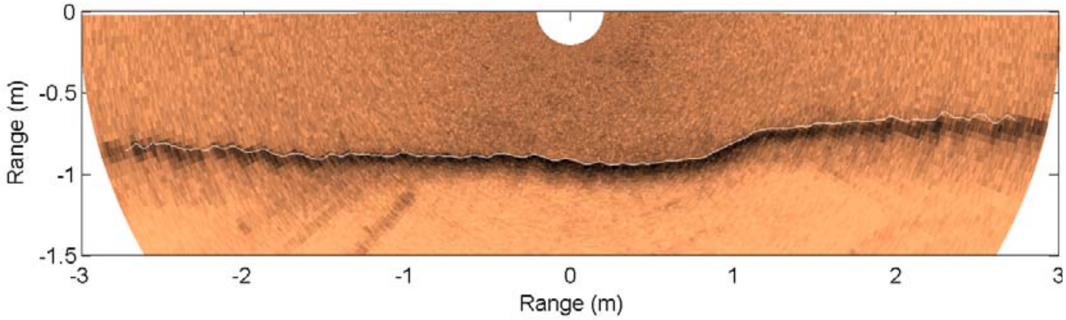

Fig.2: A single vertical acoustic backscatter slice through the water as recorded by the 3D-ARP. Darker colours correspond to stronger backscatter and the detected position of the bed is shown as the white line..

3. RESULTS

Several deployments of the 3D-ARP have now been completed and a selection of results are shown in the following pages. To date, three deployments have taken place in a 15m deep tidal channel in the Dee Estuary between the Wirral peninsular and North Wales where sand waves are known to exist. These data have shown tidally migrating sand waves and some wave induced ripples at high water when waves are able to reach the deployment site.

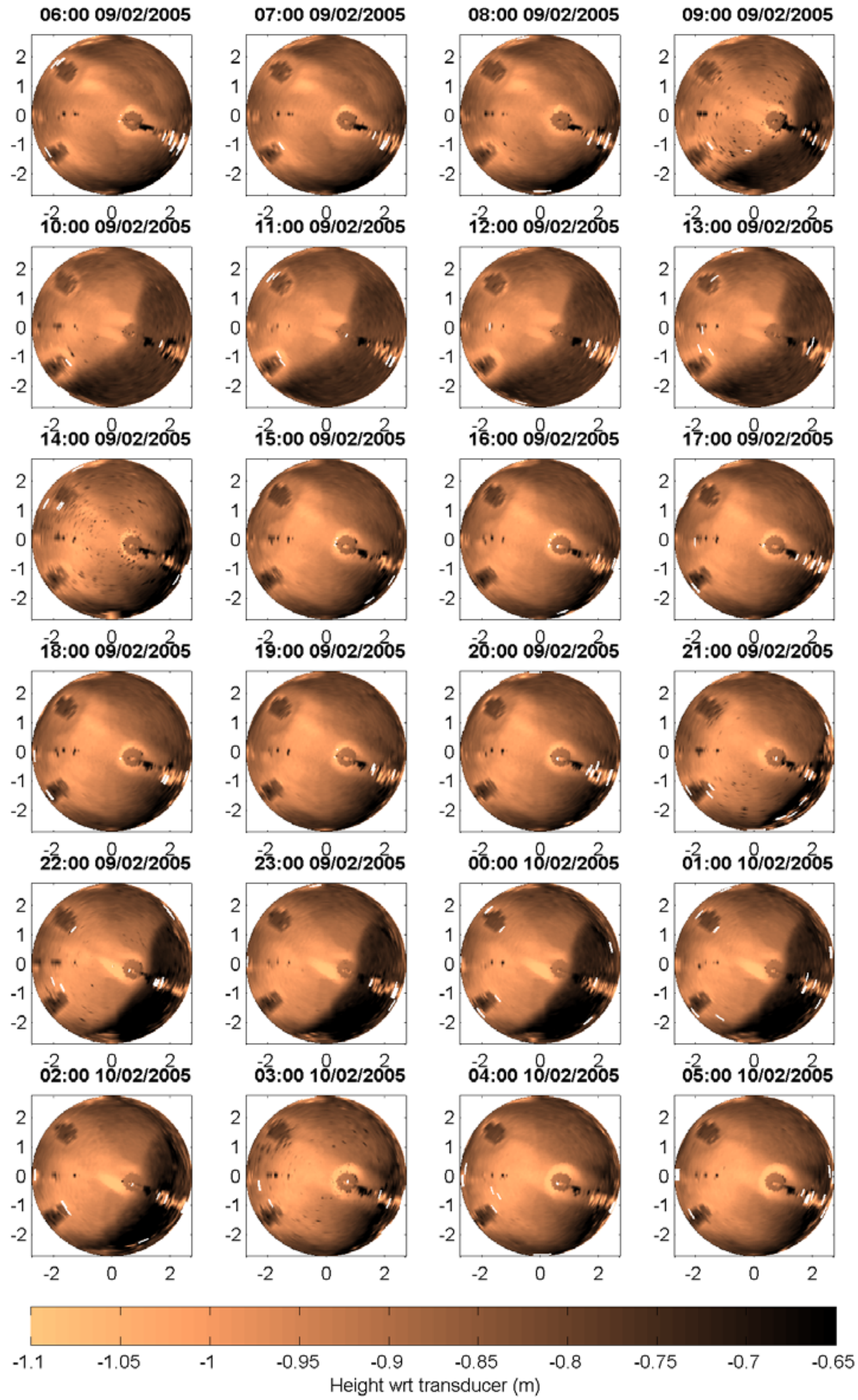

Fig.3: A 24 hour sequence of 3D-ARP data recorded in a field of migrating sand waves in a tidal channel in the Dee Estuary. A sand wave can clearly be identified moving in from the right and then back out again to the left in phase with the tide. The three 0.5m diameter circular feet of the STABLE II tripod can be seen in the plots. The length scales on each plot are in metres.

Figure 3 shows a series of these data spanning a 24 hour period illustrating a migrating sand wave over a period of 1 day at 1 hour intervals. The sand wave migrates back and forth in response to strong tidal currents in the 12m (to Admiralty Chart Datum) deep channel. The colour scale represents height relative to the instrument; hence all height values are negative as the bed is always below the instrument. The three 0.5m diameter circular lead feet of the STABLE II frame show up clearly in the data, surrounded by noticeable scour pits.

The sensor data associated with the time period covered by Figure 3 are shown in Figure 4. These data were recorded at the start of each record using the on-board sensors, and show depth, water temperature, salinity, pitch and roll. The sound velocity was calculated from the temperature and salinity readings. A clear tidal signal can be seen not only in the depth data but also in the temperature and salinity, and hence the sound velocity. This is not surprising as the tidal channel in which the instrument tripod was deployed is one of the main tidal channels of the Dee Estuary, into which flows the fresh water of the River Dee. It is thought that the jump in the roll data may be due to the instrument frame changing attitude as a result of scour round the feet.

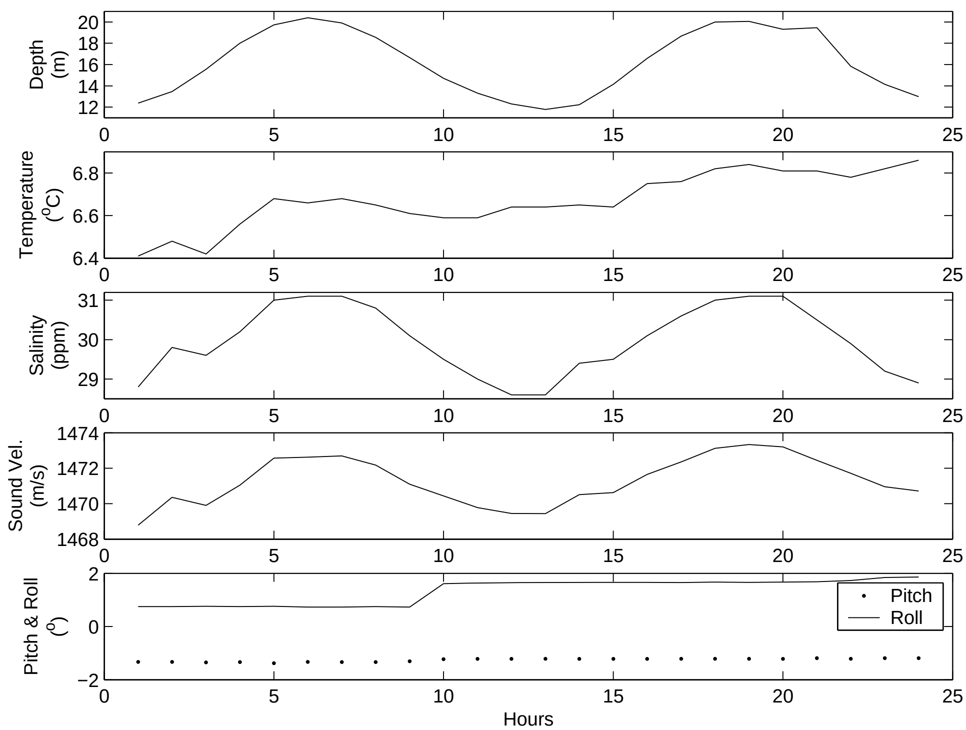

Fig.4: The on-board sensor data associated with the 24 hours of data illustrated in Figure 3.

Further deployments have been made as part of the LEACOAST2 project studying sediment and hydrodynamics around shore parallel breakwaters at Sea Palling in the south east of England. During the pilot study the instrument tripod onto which the 3D-ARP was mounted was deployed offshore of the breakwaters in an area exposed to both waves and currents. A photograph of this somewhat smaller instrument tripod, now known as ‘Mini STABLE’ can be seen in Figure 5.

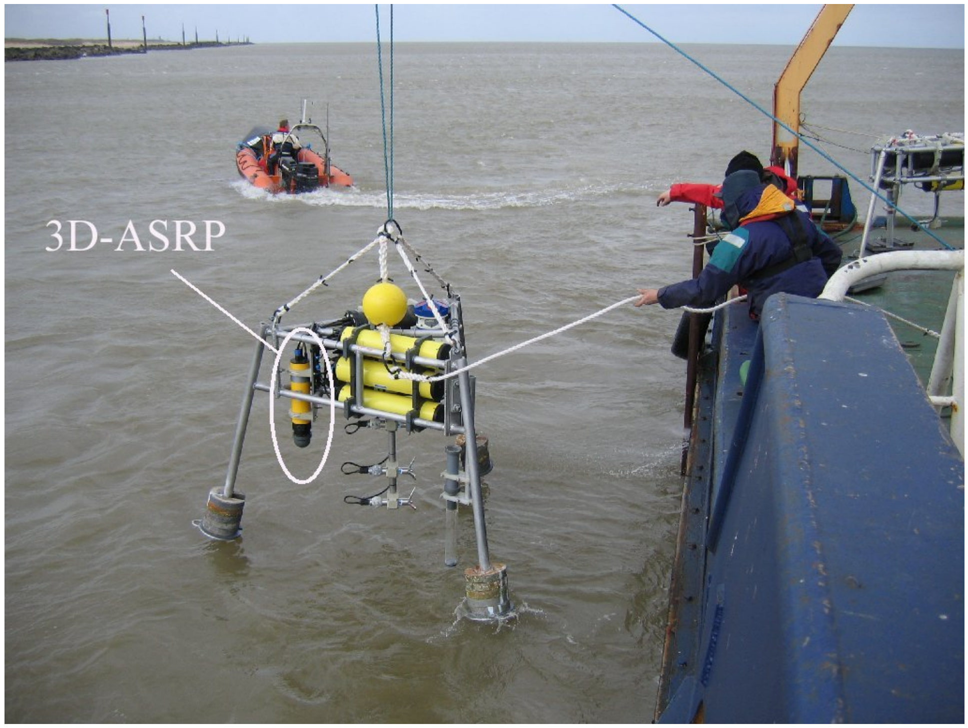

Fig.3: A photograph of the 3D-ARP mounted on the mini-STABLE frame about to be deployed outside the breakwaters at Sea Palling. Some of the shore-parallel breakwaters can be seen in the top left of the photo.

During the pilot deployment during March-April 2006, it was found that the small feet and heavy load of the instruments caused the frame to sink into the sand by approximately 60cm, leading to the 3D-ARP being only 45cm above the bed – considerably lower than intended. The effect of this on the data is to reduce the grazing angle of the acoustic beam, particularly at the longer ranges, causing more shadowing of the bed by the bedforms and reducing the ability of the instrument to accurately determine the proper bed topography. This can be seen as increased noise in the plots in Figure 6 compared to those in Figure 3, particularly in the troughs of the bedforms which are in the acoustic shadow of the bedform peaks at the longer ranges. The design of the feet was subsequently modified to reduce the problem of frame sinkage, although the modifications cannot prevent burial by migrating bedforms.

Several wave events originating from different directions occurred during the deployment and a selection of bedforms are illustrated by the plots in Figure 6, recorded at various times during one of those wave events in early April 2006. The bedforms can be seen to change significantly in both size and orientation in response to a combination of waves and tidal currents. Initially the bedforms are produced in response to swell waves from the north, producing large ripples approximately oriented across the images. Towards the end of the wave event, the waves were dominated by short period, locally generated wind waves from the south east, leading to a set of smaller amplitude, shorter wavelength ripples, oriented at approximately 90 degrees to the original ones. These quite different ripples formed on top of the existing larger and longer bedforms, almost obliterating them by the time of the last plot in Figure 6.

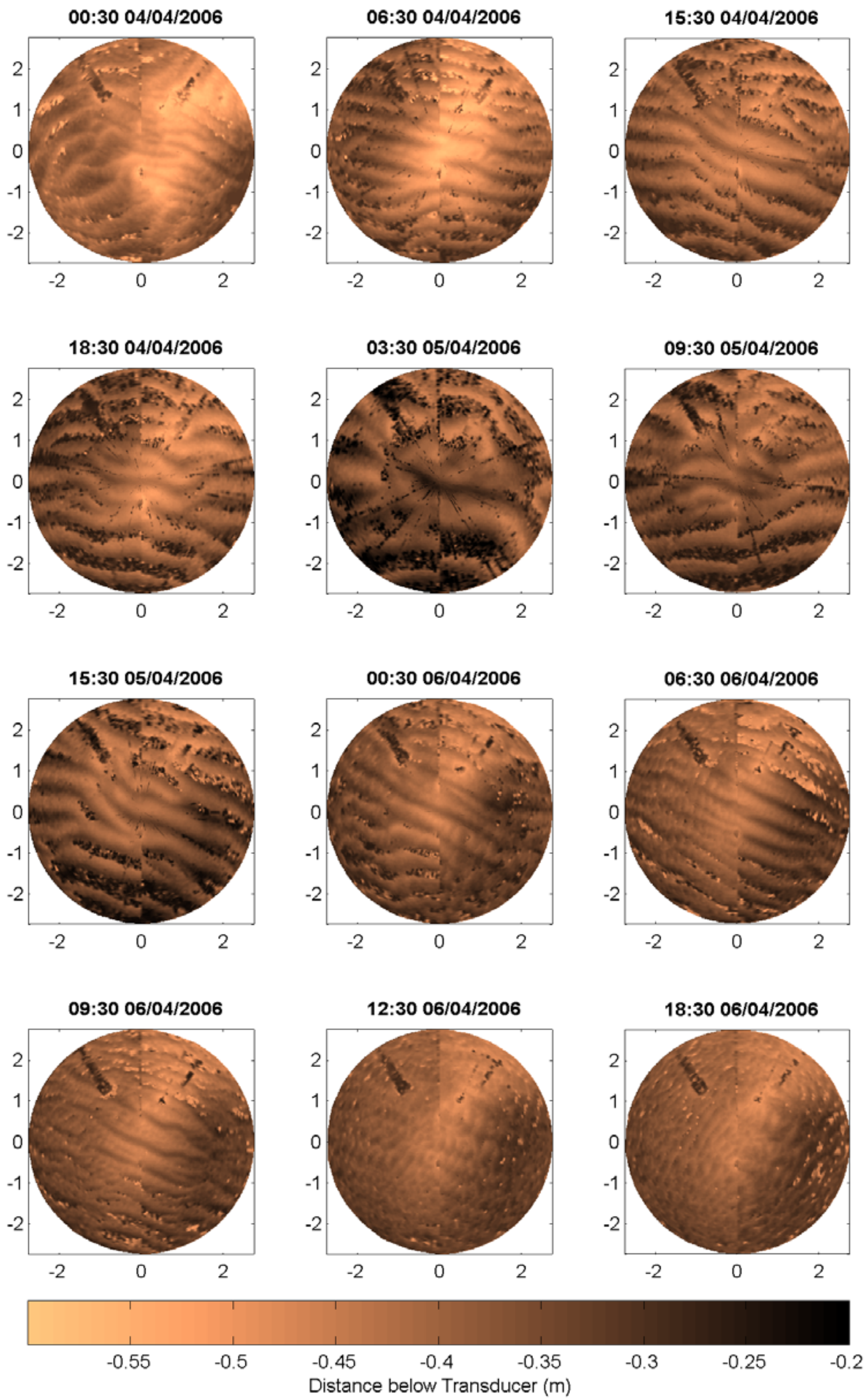

Fig.6: A selection of 3D-ARP scans recorded during a wave event at Sea Palling in March 2006 as part of the LEACOAST2 project. Various size and orientations of bedforms can be seen as the wave direction, size and period evolve during the passage of the storm.

4. SUMMARY

A dual axis, mechanically scanning acoustic bed profiler has been developed and deployed in a number of locations. It includes sensors to determine the ambient speed of sound as well as sensors for monitoring depth and instrument attitude. The data collected so far have demonstrated the usefulness of the instrument for monitoring evolving and migrating bedforms in three dimensions at high resolution. This will allow the quantification of bed-load transport due to bedform migration in field situations where the orientation of the bedforms and their migration direction is arbitrary.

5. ACKNOWLEDGEMENTS

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