LONG-TERM MULTIBEAM MEASUREMENTS AROUND A TIDAL TURBINE TEST SITE IN ORKNEY, SCOTLAND

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1 INTRODUCTION

Marine Renewable Energy (MRE) extraction in the UK has until now focused on offshore wind turbines, with targets of 34 GW by 2020. Wave and tidal energy follow this trend, with targets of 1-2 GW[1]. By 2050, most accessible MRE sources will be exploited or close to being fully exploited[2]. However, little is known of the general effects of installation and operation. Impacts on the surrounding ecosystems have been predicted as varying from benign to adverse[3,4]. Experience gained over the years, and around the world, has been summarised in recent reviews, which all highlight the need for more generic modes of assessment[5-7]. MRE developers have also stressed the need for an improved understanding of the baseline environment[8], measuring common impacts with easily adaptable technologies.

The NERC/DEFRA project FLOWBEC-4D (*FLOw, Water column and Benthic ECology 4-D*: http://noc.ac.uk/project/flowbec) started investigating these effects at MRE test sites in Orkney (European Marine Energy Centre: http://www.emec.org.uk) and in Cornwall (Wave Hub: http://www.wavehub.co.uk) in September 2011, with its first field deployment at EMEC in summer 2012[8,9]. FLOWBEC-4D combines long-term measurements from a remote-sensing sonar platform [8], bird observations[9], shore-based X-band radar surveys of wave and current data[10] and detailed modeling of the flow and water column. It aims at quantifying the impacts of MRE devices on marine life (e.g. fish, mammals and seabirds) as well as the surrounding environments using remote sensing. This article describes the self-contained multibeam sonar platform designed and built at Bath to image the water column and seabed around MRE devices for as long as 2 weeks at a time. Section 2 explains the concept and building of the instrument. Section 3 presents the results from the 2012 survey in Orkney. Section 4 presents preliminary analyses of the wealth of measurements collected during this first deployment (> 4.5 GB/day for the multibeam instrument alone). Finally, Section 5 summarises the results so far and presents the next steps in MRE acoustic monitoring.

2 MULTIBEAM IMAGING

2.1 Concept

The size and design of MRE structures varies widely[11]. To maximise energy extraction, they are located in very dynamic environments: strong and continuous currents, high-amplitude waves and sometimes both currents and waves, usually in areas also showing significant tidal variations. For example, spring tides in the Fall of Warness (Orkney) regularly reach 8 knots and maximum wave heights at Billia Croo (Orkney) are documented to reach 17 m. Monitoring devices must at the same time be close enough to the MRE structures to measure variations on the seabed and in the water column in their immediate surroundings, and be far enough to avoid any physical risk of affecting MRE extraction or damaging the structures themselves. Finally, any monitoring device needs to be deployed and left for a significant period of time (e.g. tidal cycle). These requirements make an ideal case for acoustic echosounders, and this was the option chosen for the FLOWBEC-4D project.

Multibeam echosounders provide the advantage of a wide cover, a calibrated response and the provision of both range/bearing and scattering strength information for any target either on the seabed or in the water column. They have been used with great advantage for the mapping of marine habitats[12,13]. “Traditional” mapping uses a moving platform and the multibeam sonar images the seabed, and sometimes the water column, below the survey vessel. However, for monitoring the environment around MRE devices, the multibeam sonar is fixed to a frame on the seabed, imaging the water column, any moving acoustic targets and changes in the seabed around fixed structures like MRE devices (if within the field of view). Single-beam echosounders provide a much narrower cover, also with a calibrated response, and can be used to provide additional information, e.g. species identification[14].

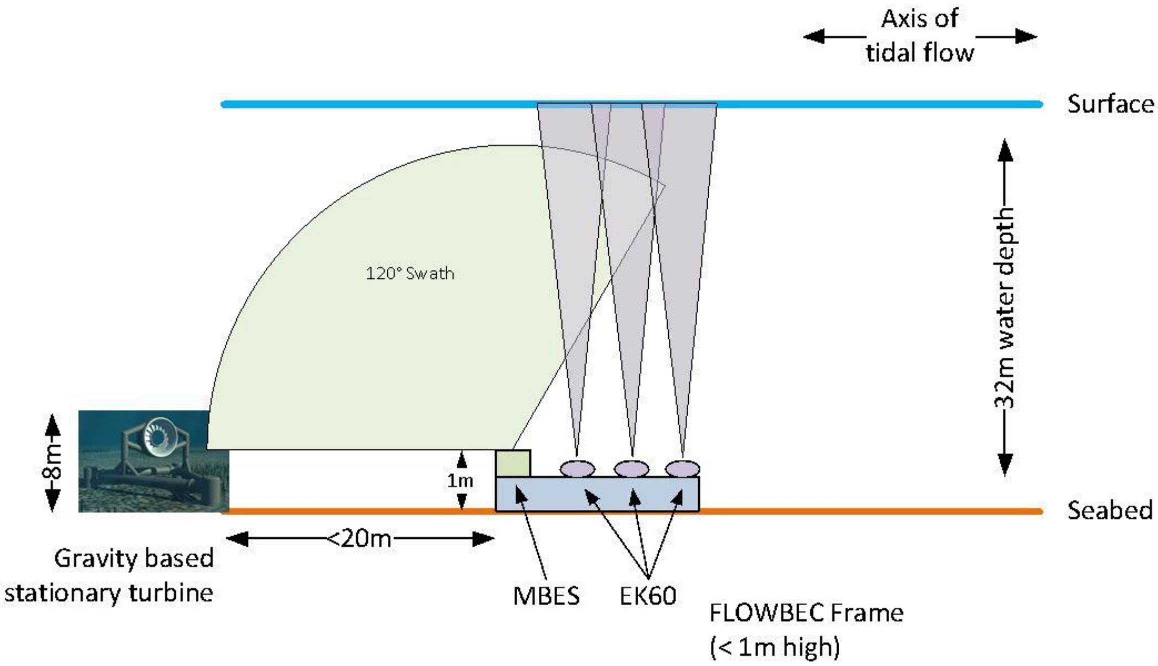

Figure 1. General setup of the FLOWBEC-4D acoustic imaging platform[8]. Left: tidal turbine similar to the test turbine monitored in 2012 (image from http://www.openhydro.com/images.html). The acoustic platform is placed relatively close, ensuring the turbine and its immediate surroundings are well within the field of view of the multibeam sonar. This sonar is slightly tilted, oriented along the axis of the tidal flow (in this case, but its orientation can be adapted to suit other sites too). It overlaps slightly with the multi-frequency single-beam echosounders used for fish identification.

The FLOWBEC acoustic imaging platform integrates the Imagenex 837 Delta T multibeam sonar and the Simrad EK60 multi-frequency sounder[8] (Figure 1). The Imagenex was selected for its low cost, ease of use (direct ping scheduling[15] and access to raw measurements), its low power consumption, and previous experience by the Bath team in other challenging environments (e.g. in the Arctic[16]). Working at 260 kHz, the Imagenex sonar images a wide swath of 120° by 20°, with 120, 240 or 480 beams and at rates of up to 20 pings/second. Its operating range varies from 0.5 to 100 m and can be adapted in real-time during operation. This sonar measures the backscattering strengths (in dB) of all targets, relative to a source level of 190 dB re. 1 μPa @ 1 m (Patterson, pers. comm., 2012). Pulse lengths vary with the range setting (e.g. 0.3 ms at 50 m range). The range setting will also affect the resolution of targets, nominally expected to be 0.2% of the range. This would correspond to 10 cm along the line of sight at 50 m range, and resolutions of 0.2 – 0.5 m across-swath. The Imagenex multibeam sonar is aligned in the direction of the tidal flow, pointing upwards and slightly tilted to cover the immediate surroundings of the MRE structure within its field of view, enabling clear imaging of any interaction of marine life with the structure and within its wake (varying with the direction of the waves or the tidal flow). Next to it, and slightly overlapping with its field of view, a Simrad EK60 multi-frequency sounder, operated by Marine Scotland Science and the University of Aberdeen, covers the region immediately adjacent. Its 38 kHz echosounder has a 12° conical beam and the other echosounders (120 and 200 kHz) have 7° conical beams. Comparison of scattering strengths at the different frequencies enables fish species identification, and this sounder has also been used successfully to look at diving sea birds[14].

2.2 Design and Integration

In view of the intended first deployment at a tidal site in Orkney, additional requirements meant the acoustic imaging platform had to withstand very strong currents (up to 8 knots), and it had to be deployed at slack tide, i.e. within a 20-minute time frame, left on the bottom for the duration of a tidal cycle (14 days) and ready to be re-deployed within 24 hours to capture the next tidal cycle. These constraints were integrated in the overall design. The acoustic instruments were mounted on a stainless steel frame of dimensions 3.2 m × 2.9 m × 1 m, with an overall weight of 3,400 kg in air and 2,500 kg in water. This frame supported 4 transducers and associated controllers, an inclination sensor and 10 battery housings, and was designed to withstand the strong currents expected at this site and future deployment areas.

Power is supplied to the multibeam system by a bank of five 220-Ah sealed lead acid batteries connected in parallel and housed in stainless steel housings mounted on the base of the frame. These batteries can be recharged *in situ* using high-current connectors and vent plugs to follow the 24-hour service period between deployments. A similar (larger) battery bank supplies the EK60 system. The batteries are suitably rated for the overall power consumption for a 2-week deployment, with a safety factor for later expansion and appropriate temperature de-ratings. A low-voltage cutout protects the batteries against deep-discharge and the voltage and current are continually monitored by the controller. A fused distribution panel supplies DC-DC converters which provide the various voltages required throughout.

A VIA ARTiGO A1100 x86 computer with a 120-GB solid-state disk controls operation of the multibeam and records all data. This controller was selected for its small form factor, very low power consumption and flexibility of development. The accompanying EK60 is configured to transmit at a rate of 1 ping per second and a synchronising pulse is transmitted to the multibeam control computer and read by a National Instruments USB-6008 data acquisition board. Custom NI LabVIEW code is used to read this pulse and interface with a specially compiled version of the Imagenex 837 Delta T control software. A series of 8 multibeam pings spaced at 90-ms intervals are scheduled in the remaining fraction of a second before control is returned to the EK60. This ping scheduling is design to minimize the risk of any direct acoustic interference between the two sonars. The clocks are regularly synchronised between the two controllers to allow the data from the two sonar devices and inclination sensor to be registered in post-processing. Aside from the TTL ping synchronisation line, inter-device communication is performed using Ethernet and all components are selected for their low power consumption. Data download and diagnostics are possible without opening the pressure vessel, using either a wired Ethernet connection or a Wi-Fi connection to each controller.

3 FIELD TRIALS

This system was successfully tested in summer 2012 at the European Marine Energy Centre (EMEC) test site for tidal energy in the Fall of Warness (Orkney, Scotland), and the first results were presented a few days after recovery at the Institute of Acoustics/European Conference on Underwater Acoustics[8]. Funded by the European Union, EMEC is using the strong tides around the Orkney Islands to host the world’s largest test bed for MRE devices, and as such is an ideal proving ground for any new technologies.

The FLOWBEC-4D frame was deployed in winds of 10 mph, with gusts at 20 mph, using a hydraulic release, approximately 20 m from the OpenHydro Stationary Turbine on the seabed in a water depth of 32 m. Acoustic inclination feedback was used throughout deployment to check for correct siting of the frame on the seabed before the frame was released. The frame was then left to run autonomously for 14 days and successfully recovered on 27 June 2012. Both deployment and recovery were limited to a 20-minute window imposed by the slack tide. The inclination of the mounting frame was continually logged throughout the 14-day deployment to ensure the frame has not moved in the high currents. Other parameters like water depth, pitch, roll and heading were recorded several times per second throughout the two weeks. Imagenex multibeam data was acquired at a sampling rate of 8 Hz, synchronised with the EK60 echosounder. Figure 2 shows a typical screenshot of the raw multibeam data. The maximum range was set at 50 m, and backscatter strengths are colored by intensity levels, from black (near-zero) and dark blue (lowest), to red (highest). The sea surface is clearly visible as a horizontal line with varying high intensities, associated with sea-surface turbulence and the angles at which the individual waves are imaged. The turbine (highlighted) is clearly visible too, with very high backscatter strengths. Other reflectors are visible behind the turbine, but have not been formally identified (yet). Variations with time are visible at the seabed, behind and around the turbine, and most noticeably at the sea surface, depending on tides and surface wind. Algorithms have been written to detect and remove interference from the EK60 for periods when synchronisation was intermittently lost between the two systems. Figure 2 also shows individual targets, circled in red. In previous and later acoustic snapshots, they are seen to come from the surface at an angle, dive down to the same depth and surface again. This behaviour is consistent with their tentative identification as diving sea-birds. In the course of the deployment, many other targets are visible in the water column, with varying backscatter strengths, sizes and behaviours.

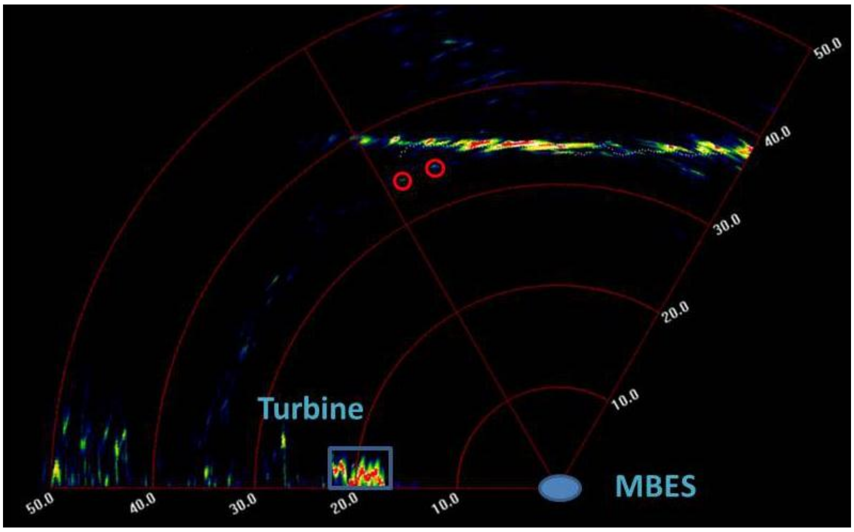

Figure 2. Raw data as acquired by the Imagenex multibeam. The range was set to 50 m, encompassing the sea surface (visible as a horizontal line close to 40-m range), the turbine (highlighted at approximately 20-m range, as expected from deployment conditions), the seabed on approximately 20-25 m each side of the turbine, and a sizeable portion of the water column. Two individual targets (circled in red) are visible here and tentatively identified as diving sea-birds (see text for details).

The acoustic data was not acquired in isolation. Its sea-surface footprint of approximately 70 x 15 m covered the underwater area around the test turbine with a decimetric resolution. Shore-based radar measurements[10] covered the same area, but above the water surface, extending further and wider, to a maximum range of 4.8 km and with a resolution of 7.5 m. They provided surface velocities of currents/tides with resolution < 0.1 m/s large-scale information about wave heights and patterns, and also allowed identification of surface "targets" like marine mammals or passing vessels and airborne "targets" like birds. Bird activities and identification were assured by two birdwatchers, covering different angular sectors around the turbine[9]. These complementary datasets therefore provided a complete understanding of the environment around the turbine, from above water using bird observations and shore-based radar, and underwater using the acoustic frame. Their time of operation encompassed the frame deployment, and provided background measurements before and after the deployment too.

4 ACOUSTIC ANALYSES

4.1 General Processing

The large amount of multibeam backscatter measurements acquired during this first deployment has been processed with a suite of custom playback and analysis software written in LabVIEW and MATLAB. Radiometric corrections are used to assess the quality of individual frames (acquired at a sampling rate of 8 Hz). Frames affected by EK60 noise, visible as a strong, radial echo at mid-range, are discarded at the moment, and future refinements will include masking of only the specific ranges and angles associated to the EK60 noise. Initial analyses are focusing on three regions: the seabed and turbine, the water column and the sea surface (Figure 3). Acoustic returns from the turbine, the seabed immediately surrounding it and, to some extent, the far-range returns from behind the turbine are correlated with tide speed and direction. Water-column returns, including around the turbine, are used as general measures of acoustic intensity as a function of time, tide speed and direction, surface conditions and biological activity. Initial work is focusing on quantification/detection, but will later fully use the EK60 and radar data, correlated with shore-based bird identifications. Finally, the sea surface can be delineated using a combination of image processing, tide height and readings from the pressure sensor on the FLOWBEC-4D frame. The envelope, based on surface roughness, can be compared later to radar observations of the roughness seen from above, over a larger footprint and with a lower resolution. The current stage of processing identifies different types of variations with time and other factors, which need to be cautiously analysed and related to concurrent radar and visual observations.

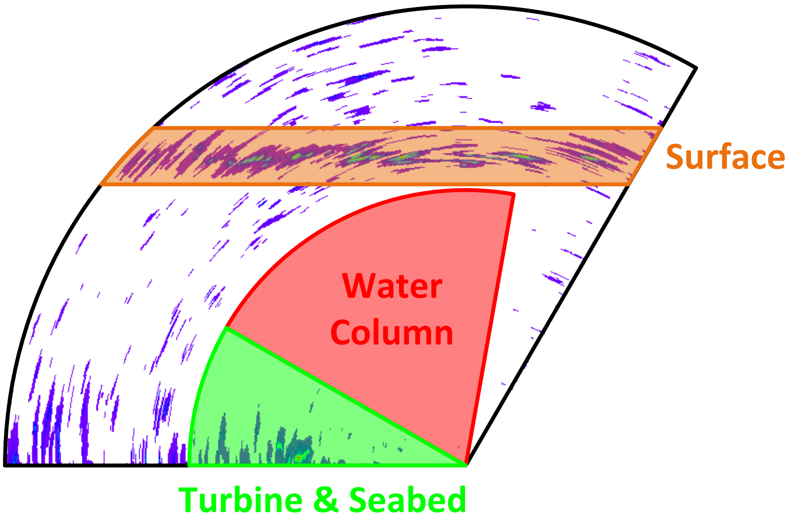

Figure 3. Several areas have been delineated, corresponding to the turbine and seabed, the water column and the sea surface. Their variations with time, tide speed and direction, surface conditions and shore-based wildlife observations are analysed in combination with the neighboring EK60 acoustic measurements.

4.2 Variations with Tides and Other Parameters

Figure 4 shows a typical plot of water column intensity as a function of time, for example for a 12-hour period. These variations can then be compared with bird observations, EK60 data, radar observations, water speed and direction. They can also be correlated with actual detection of biological activity in the water column, combined with identification from EK60 measurements (fish) and radar/visual observations (seabirds, mammals). These variations need thorough analyses in close cooperation with biologists and oceanographers, and already provide a wealth of information.

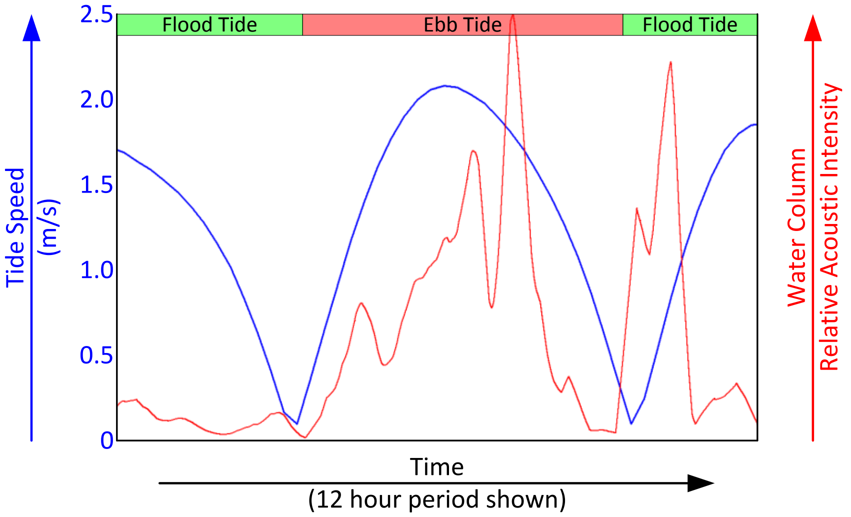

Figure 4. Example of acoustic variations in the area conservatively delineated as “water column” in Figure 3. These variations can be correlated with tide speed and direction, as well as all other concurrent surface observations (visual observers, radar) and oceanographic/biologic models

4.3 Animal Tracking

This first field deployment was timed to coincide with the local bird-breeding season, which peaked in June 2012. The two sonars ensonify upwards and parallel to the strong (8 knots) tidal flow. Tracking of individual targets within the water column is possible using the Imagenex measurements. Figure 5 shows acoustic returns over a 7-second period (i.e. 49 acoustic frames after quality checks). The returns are coloured according to the time over which they have been observed during this 7-second window: targets observed in the most recent ping are coloured red, and other targets are coloured according to the frame in which they were observed. The turbine and seabed around it are in red, as they have been observed consistently throughout the frames. One can note an individual target, moving at a height of approximately 8.5 m above the seabed, tracked over a distance of 10 metres. The tide at this time was flowing from right to left (blue arrow in Figure 5), at an angle of 15° from the imaging axis of the sonar. This explains why the target enters and leaves the multibeam’s field of view. For smaller targets, changes in target orientations might also make them more difficult to detect consistently from frame to frame. Across-track resolution of targets is in general not possible, but given the tracked speed of this individual (1.4 m/s) and the 15¨ off-axis tide velocity (1.65 m/s), it is highly probable that this individual was moving with the tidal flow.

Measures of relative target intensities, together with swim speed and characteristics (such as directionality, minimum and maximum depths attained, diving behaviour if applicable) can be combined with the EK60 multi-frequency recognition tools (for fish) and shore-based radar and visual observations (for birds and for surfacing mammals). This can then be achieved for all individual targets identified through the two weeks of deployment, and general behaviours, densities and other patterns can be summarised for types of animals, depending on conditions and on proximity to the turbine, and fed into more general biological models.

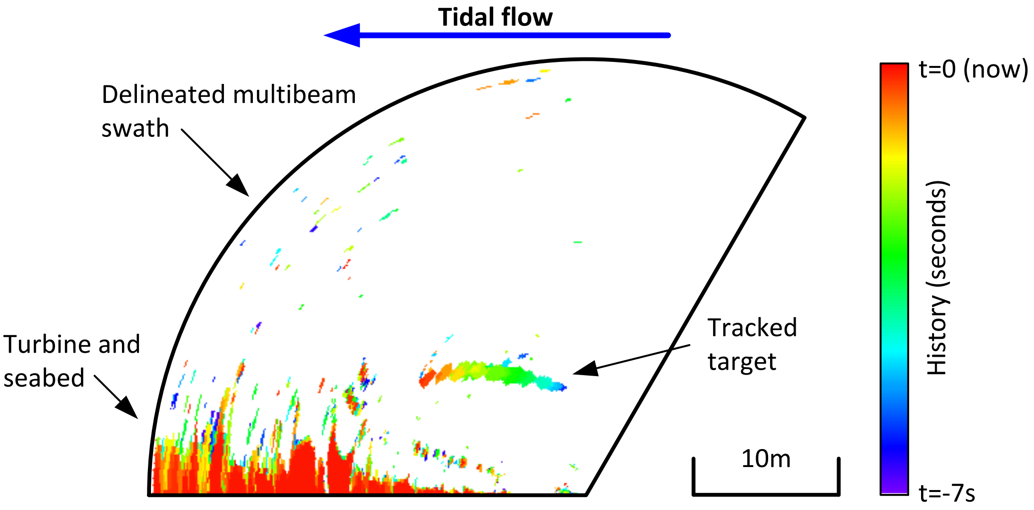

Figure 5. Example of animal tracking, for a single individual swimming with the tidal flow. This particular target can be tracked over 10 m, and its behaviour correlated with identifications from shore-based data or concurrent EK60 measurements.

5 CONCLUSIONS – NEXT STEPS

The development and installation of Marine Renewable Energy structures is proceeding at an ever-increasing pace, around UK shores and elsewhere around the world, at all depths and in all environments. Little is known of the general environmental and biological impacts of installing and operating MRE devices, and the NERC/DEFRA project FLOWBEC-4D is currently quantifying these effects at selected test sites, using above-water measurements like shore-based radar and visual observations, and underwater measurements from sonars. The Imagenex 837 Delta T was selected for its low cost, ease of use and versatility. It has been integrated into a subsea platform, alongside an EK60 multi-frequency single-beam echosounder. The first survey took place in June 2012 at a tidal test site in Orkney (Scotland), next to an OpenHydro test turbine and has been a success.

The Imagenex multibeam sonar provides high-resolution range and backscatter measurements of the seabed and mid-water environment around the turbine, up to the sea surface, at decimetric resolutions and sampling 8 times a second for several weeks. Current work is focusing on technical improvements to the integrated sonars (e.g. optimization of the ping scheduling), refinements to the processing suite, and the identification and tracking of fish, marine mammals and diving seabirds, in conjunction with the other measurements available. The next series of long-term deployments will start in May 2013, investigating a tidal test site and a wave energy test site, also at EMEC in Orkney. The quantification of animal interaction with MRE devices, above water and below water, is of direct use to ecologists and ecosystem modelers. With short installation times (20 minutes), short turn-around between successive deployments (< 24 hours) and highly mobile, the FLOWBEC-4D frame and the acoustic sensors can be adapted to a large variety of other MRE devices around the world, potentially at any depth.

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