Introduction

Despite significant advancements, over the last decade, by the academic sector in the acquisition of 3D, Very High Resolution (decimetre), sub-surface imaging (e.g. Bull et al., 2005; Muller et al., 2009; von Deimling et al., 2015) the technology developed has not been regularly adopted by the industry sector for either pre-installation, principally UXO and object detection, nor post-installation infrastructure (e.g. cable or pipeline) burial depth characterisation. This asymmetry in use by the two sectors has primarily been driven by a perception that such devices had restricted use to both very low energy protected environments (e.g. harbour basins, lakes or the upper parts of estuaries) and finer grained, muddy, substrates. There has also been a valid concern that such instruments are capable of acquiring good resolution volumes but on time frames for both acquisition and processing that are not applicable to the commercial sector (e.g. months versus days).

Here we present results from a 3D Chirp survey (Vardy et al., 2011) taken on the UK shelf in water depths ranging from -5.5 to -25 mLAT, in sands to gravelly sands, with a requirement to consistently penetrate to depths below seabed of up to 10 m, to identify objects > 0.25m, to provide their depth of burial, dimensions and absolute position to an accuracy of ± 0.1 m. This research survey was undertaken ahead of a windfarm installation and focused upon proposed turbine locations, inter-array cable sites and the investigation of pre-identified (magnetometer) UXO targets.

Method

The survey was undertaken using the 3D Chirp system developed by the University of Southampton and Kongsberg GeoAcoustics Ltd. (Vardy et al., 2011). The acoustic source was a swept frequency 1.5 - 13.0 kHz $\sin^2$ 8th sweep (Gutowski et al., 2004). The system is composed of 60 hydrophone groups (each group containing four individual hydrophones to further enhance signal-to-noise ratio) spread across a frame 2 x 2.5 m, with a receiver spacing of 25 cm. The source and receiver elements are positioned using a combination of Real Time Kinematic GPS technology and inertial motion unit. This samples the reflected wavefield at 12.5 cm intervals and positions each source and receiver pair to an accuracy of X= ±0.46 cm, Y= ±0.70 cm, and Z= ±1.82 cm (Vardy et al., 2011).

To fully sample the reflected wavefields in 3D, these hydrophones are not confined to a single line, rather they form a 2D grid. Thereby these multiple hydrophones receive the signals about 360^{o} of azimuth to enable effective 3D migration. The data was processed as follows: (1) Normal Move-Out (NMO) corrected stacked volumes in 0.25 m bins; and (2) fully 3D diffraction stacked migrated volumes, which have been geometrically corrected and produce the optimal imagery and resolution of the sub-surface. The completed volumes have been depth converted using a two-layer velocity model (water column 1480 ms^{-1}; unconsolidated fine grained sediments 1650 ms^{-1} based on Richardson & Briggs, 1996 empirical equations for coarse sand). The completed volumes can be sliced at an interval of 4.5 cm in the vertical. An independent test of the system was achieved through picking the first seabed peak of 28 traces from a single bin from one of the stacked volume (Figure 1). This provided a seabed surface with a standard deviation in depth of ±3.7 cm.

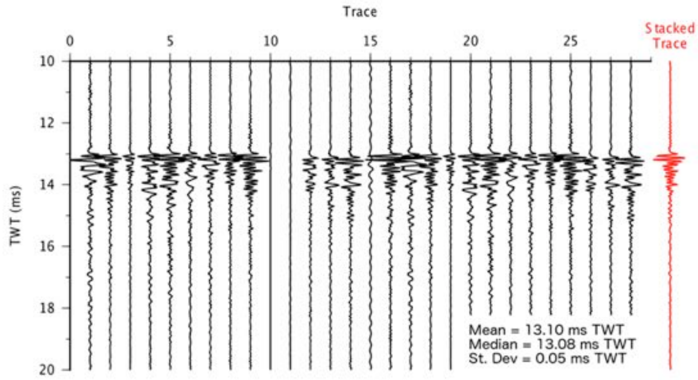

Figure 1 *A plot of 28 traces from a single 25 cm bin from one of the monopile volumes. The standard deviation of 0.05 ms TWT for the first peak represents a z precision of ±3.7 cm using a water velocity of 1480 ms*$^{-1}$.

Case Study Example

A seven day research survey was undertaken in February 2016, across a range of water depths (-5.5 to -25 mLAT) and up to 15 km offshore (and 18 km from the installed RTK base station) in order to test the capability of the 3D chirp system to survey a range of sites associated with a proposed windfarm. Significant wave heights ranged from 0.3 – 1.1 m with a mean of 0.65 m (Sea States 1-3). The 3D Chirp system acquired excellent quality data throughout, the only restriction on the use of the system during this period being the deployment and retrieval of the mat which had to be restricted to sea states of < 3. During this period the surveyed sites included four monopiles covering areas between 15 and 30 m in diameter; 4 km of inter-array cables; and four UXO target sites covering an area of 15 m diameter. From these areas a total of 561 discrete objects were identified, for which dimensions of 535 (95%) could be calculated. Individual targets had dimensions ranging from 0.25 m to several metres and ranged in burial depth from 0.13m to 5.42 m (although stratigraphical reflectors were identified to a depth of 10 m). This abstract will focus on the results from the monopile site.

Example 1: Monopile Site Survey

For the proposed monopile locations survey areas of 15 m diameter required surveying (being extended to 30 m where the extensive sub-surface targets were identified). Each location took 3.5 hours to survey (with additional data added during turns associated with adjacent inter-array cables) and the data was both stacked at 0.25 m bin size (processing time < survey time) and diffraction stack migrated at 0.125 m (processing time = survey time). For the stacked data typical fold ranged from 30 to 60 traces per bin, providing excellent signal to noise ratio. Within the designated area, coverage of > 99% (with at least one cleaned trace per bin) was achieved (Figure 2).

The stacked and migrated volumes are shown in Figure 3, a 3D auto-picked bathymetry surface, binned at 25 cm, in Figure 4 and a depth-slice taken at -2.9 m below seabed shown in Figure 5. The data from this locality includes traces taken over three different days with a tidal variation of over 3 metres and significant wave heights during surveying of up to 0.75 m. The stacked and migrated volumes show a laterally consistent seabed at -6.5 mLAT with an irregular seabed but within a vertical variation of < 0.35 m (Figure 3). The consistency of this seabed return is another indicator of the consistency of the z-static corrections being undertaken by the system.

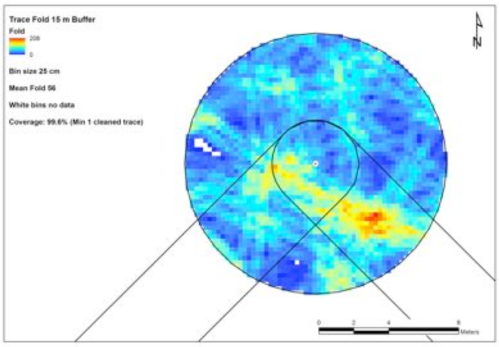

Figure 2 *A trace fold coverage plot for a turbine location, this is based on the stacked data binned at 0.25 m. For this locality mean fold was 56 and coverage was 99.6% for the 15 m diameter survey area.*

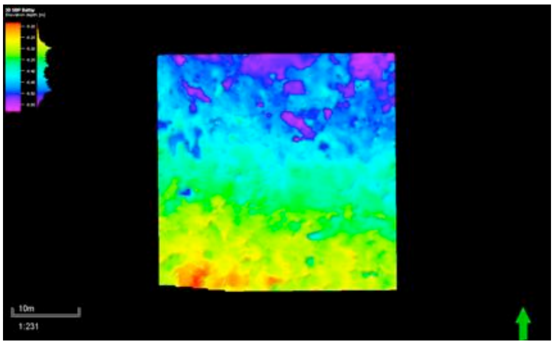

Figure 3 *Auto-picked seabed from the 3D stacked volume for the monopile location showing localised small scale irregularities in the seabed surface.*

The near surface sediments are characterised by a dense cluster of point-hyperbolae between 0.8 and 1.5 m below the seabed. These targets migrate to a series of small < 0.25 m discrete reflectors and are associated with a horizon of coarse gravels. Interestingly just above the strong reflector there is a second discrete horizon of sub-metre (XY) targets which are identified over a depth range of < 10 cm. These are regarded as a localised changed in the substrate rather than foreign objects although there is no clear change in the single core from the location.

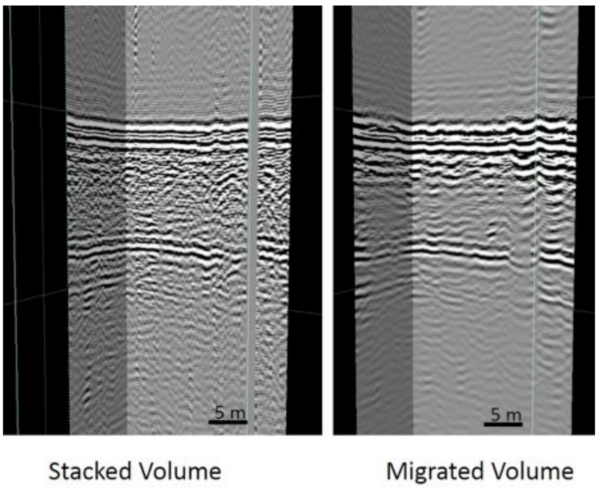

Figure 4 *Equivalent stacked and migrated volumes from the example monopile site. The strong reflector is at 3 m below the seabed.*

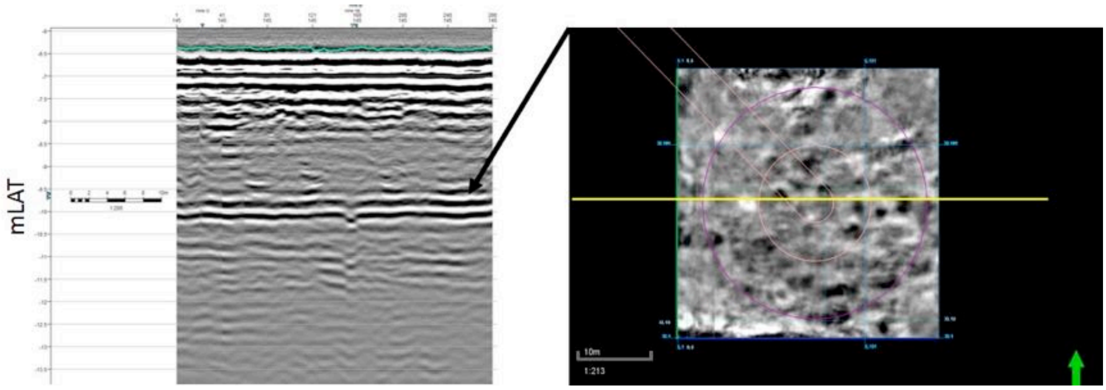

Figure 5 A time slice taken -2.9 m beneath the seabed and showing a clear cluster of < 1 m targets stratigraphically located associated with a major reflector at -3 m. These were more clearly imaged in the

Conclusions

The data presented here shows the capability of very high resolution 3D systems, in this case the 3D Chirp, to acquire high quality volumes in open ocean conditions, in a range of water depths, up to 18 km from the RTK base station and in a wide range of substrates. Almost 100% coverage with high average folds can be acquired in 3-4 hours, processed in near real time and interpreted for both point target identification and sediment stratigraphy. Similar quality volumes were also obtained for the purpose of verification of UXO targets identified from alternative geophysical techniques and from very narrow corridor (5 m) cable array sections.

Acknowledgements

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