Survey results obtained in a complex geological environment with Midwater Stationary Cable
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Summary
A survey with a novel acquisition technique was acquired in a complex environment. A classical processing flow was applied in order to obtain 3D stacks. Fine resolution and low frequency content are obtained. The seabed interface is clear and the images are homogeneously consistent. Future work is discussed to exploit the potential of the technique.

Introduction
A new marine acquisition technique was recently introduced consisting of independent seismic cables (named MSC for Midwater Stationary Cable) controlled by unmanned autonomous vessels (named RAV for Recording Autonomous Vessel). The first test results in the Med Sea obtained with a low power source were presented in Haumonté et al. (2016). The scope of this paper is to present test results of a survey performed in a different area, and shot obtained with a conventional seismic source.

Survey Background
The survey actually consisted in two small surveys. The marine spread included:
- 2 MSCs controlled by 4 RAVs (one RAV at each end of both MSCs);
- A master vessel (DP-Cirrus) with a control room to perform launch and recovery, to supervise the overall operations, to monitor the system and to perform real-time QC of the data;
- A source vessel (Ocean Europe).

Acquisition Parameters
The two MSCs were maintained parallel during the survey with a constant spacing between them. Each MSC embeds 4C station every 25m. Two small surveys are acquired at two different locations with conventional seismic source of standard size. Survey A consisted in shooting lines orthogonal to the cables. Survey B used parallel shooting.

Figure 1 and figure 2 display the post-plot shooting lines, the pre-plot seismic coverage, and the post-plot seismic coverage, respectively for survey A and for survey B. Since the shot lines are executed as planned and the MSC positions are accurately controlled (spread center within tens of meters and feathering smaller than a few degrees), the post-plot fold maps are in line with the pre-plot coverages. It can be observed that survey B is not complete: this is due to time shortage (limited time window on site).

Figure 1: Survey A: from left to right: actual shooting lines, pre-plot coverage and post-plot coverage
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Acquired seismic data

Throughout the survey recorded data was collected in real-time for QC in the control room. Continuous seismic records were split into shot records by using time break instants. Three-component geophone data was rotated by using inclinometer information so as to recover vertical, inline and crossline components of the particle velocity wave. Figure 3 and Figure 4 display 4C receiver gathers for two shooting lines respectively in survey A (crossline shooting) and in survey B (inline shooting). The upper line represents the hydrophone gather obtained with a low-cut filter at 2Hz. The three bottom lines represent from top to bottom the inline geophone obtained with an FK filter at 1500m/s, the vertical geophone and the crossline geophone obtained with a 10Hz low cut filter.

It is noteworthy to highlight that the seismic reflections and refractions are coherently visible on all four components. Note that both surveys were not acquired at the same location. Seismic energy can be observed for the three directions because the complex geological (hilly seabed, cliffs, and slanted reflectors) creates events that may possibly come from any 3D angle. In the left part, the inline geophone receives low amounts of signal since the shooting line is perpendicular to the cable. Conversely, in the right part, the crossline geophone receives limited signal since the shooting is parallel to the cable. In the latter case, it is interesting to observe that the useful content recorded by the inline geophone is strong. In both surveys the vertical geophone efficiently captures the signal coming from the subsurface.
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Figure 4: 4-C receiver gather in survey B. Top to bottom: hydrophone, inline, vertical, and crossline geophones.

Processed data

Acquisition data have been processed to produce a 3D stack and a post-stack migrated 3D volume for each survey. Only the hydrophone and the vertical component after rotation are used in this initial run. A classical processing flow is followed with PZ summation, spherical divergence correction, spike deconvolution, velocity scan, NMO, multiple attenuation, stack, and Kirchhoff migration. Interestingly zero offset data is used to build a reliable velocity model and direct arrivals are exploited to estimate source wavelet signature when the shooting vessel crisscrosses above the cable. Thanks to the inherent low acquisition noise of the method and the good coupling of the 4C sensors in the water (as it is an homogeneous medium), the deghosting operation is straightforward and yields an ideal flat receiver spectrum. Figures 5 and 6 display sections of the 3D processed stack corresponding to a shooting line of respectively survey A and survey B (with a different time scale). The white line represents the seabed interface. Remarkably the images are consistent around the seabed surface: there is no amplitude anomaly or impedance mismatch. No stripe is visible: the resolution is fine and homogenous across the image, i.e. along the depth and x-axis. Frequency content is broad with useful signal down to 2 to 3 Hz.

Future work

Early encouraging results are obtained with a simple and straightforward processing flow run over a two-cable acquisition dataset. The MSC technology has more potential and significant improvements are possible in future work. The current processing flow only used hydrophone and vertical geophone data while strong energy is observed in the crossline and inline components. Exploiting the unused components will improve the image by immediately bringing more information. Using the 3D velocity measurement unlocks vector processing algorithms. For instance PZ summation could be angle-dependent as suggested in Bale (1998) by rotating along a radial direction. Additionally, pre-stack 3D migration and depth imaging solution such as travel time tomography will improve the image in this complex bathymetry and subsurface area. On the acquisition side the sensor responses could be advantageously modified to even further enhance the low frequency content. Finally, using more cables yields a full-offset full-azimuth high-fold acquisition geometry which is unanimously the best solution for imaging and illuminating complex reservoirs. Besides, advanced imaging such as full azimuth angle domain techniques as described in e.g. Huang et al. (2011) could be optimally exploited.

Conclusion

The survey was successful since the system was able to efficiently produce seismic data in a few days with a high productivity rate. The system demonstrated its proficiency to maneuver and to autonomously keep the array at the desired position in a complex environment around islands, obstacles, in shallow water and in changing sea current profiles. The new method was able to deliver high quality data with low noise, a flat spectrum and a low frequency content. Seismic signals are readily visible on all four components up to 10 seconds of record and the technology allows recording from zero offset to long offset. The acquisition method was able to deliver quality data in both a deep water and a shallow water environment. Data is easy to process through a classical processing flow. Many significant improvements seem possible by exploiting the potential of this new acquisition technique. This could be achieved by processing all four components, developing more advanced processing techniques, or taking advantage of the full-azimuth full-offset benefits directly obtained with more cables.
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Figure 5: Processed stack for survey A (orthogonal shooting) - 2D shooting line section

Figure 6: Processed stack for survey B (parallel shooting) - 2D shooting line section
EDITED REFERENCES
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REFERENCES