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# Sonar detection and monitoring of sunken heavy fuel oil on the seafloor

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## Abstract

The oil products transported at sea that have the potential to become suspended in the water column and sink after weathering or mixing with sediment are quite numerous: asphalt, carbon black oil, bunker C, fuel oil n°5 and 6. In many incidents and accidents part of the spilled heavy oil product has actually sunk and has been difficult to track because of the lack of means of detection. To compensate this gap, a comprehensive sonar experiment has been performed through the use of a large seawater tank on the bottom of which several patches of three different heavy fuel oils have been laid on top of a sandy layer. In this facility several kinds of sonar have been tested as for their response according to their frequency, resolution and type (side scan sonar, multibeam/panoramic sonar, 3D acoustic camera).

The results proved to be very valuable according to the acoustic specificity of the products involved. Indeed the acoustic properties are similar to those of the seawater when considering density and sound speed; however the attenuation is much more important and its variation has been measured from 100 kHz to 500 kHz preliminary to the testing. The results of the sonar experiment that have been obtained do confirm the capability of current sonars to detect heavy oil patches over sand seafloors, and should make it possible to select the most adequate survey strategy according to the oil patches dimensions and thickness and to the environmental conditions.

## Introduction

The oil products transported at sea that have the potential to become suspended in the water column and sink after weathering or mixing with sediment are quite numerous: asphalt, carbon black oil, bunker C, fuel oil n°5 and 6. The heavy oils that tend to be non-floating are weathering more slowly and can affect sea resources for long periods and at great distances from the release site. But they will most probably affect areas that are near the surf zone or in river mouth where they can get mixed with sediment, silt or sand, and then be trapped in specific places where the currents are weak enough most of the time except during high tide and storm conditions. In such case they may re-oil the shore line in an unexpected way.

The cleaning operation after the *Erika* spill have lasted for many months and in some cases until two years. These later cases often correspond to coastal sites where sunken oil have

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been found on the seafloor at depths of a few meters. Such sunken patches have re-oiled the nearby shoreline during bad weather and strong current conditions. It is thus of paramount importance to detect and map these oil patches so as to plan an adequate response such as recovery operation.
During the last twenty years there has been several spills involving heavy fuel oil in the world including North-America and Europe. In many of these accidents, part of the heavy fuel has sunk and produced a threat to the environment that has been difficult to evaluate because of the lack of means of detection and monitoring. A number of seafloor mapping systems are commercially available but they have not been used in response to actual oil spills. For this reason a comprehensive acoustic experiment has been performed in Brest through the use of a large seawater tank in the Navy Base (actually a former dry dock for submarines). A small concrete wall (10x5 m large and 30 cm high) was first built on the dry-dock bottom and filled with medium-coarse sand. Three different heavy oils were then laid on top of the sand in patches of two sizes and three thickness'. In fact these oil patches were contained in flexible round skirts of two different diameters with porous mesh bottom so as to avoid air bubbles underneath. But as the fuel oil was laid when still warm enough to easily spread there has been some leakage around the containment through the porous bottom. This has lead to different patterns and not only round patches as initially scheduled. Such irregular patterns are a quite interesting feature that gives good indication as for the ability to detect various sizes of oil patch.
In this facility several sonars have been tested as for their response and ability to map oil patches according to their frequency, resolution and type (side scan sonar, multibeam-panoramic sonar, 3D real-time sonar). In addition to sonar surveys, the heavy fuel oils produced by *Cedre* to simulate the actual stranded fuel oil have been studied by an acoustics laboratory (LMA, Marseille) so as to determine their acoustical properties: density, attenuation and sound speed at frequencies from 150 to 500 kHz. These artificial heavy fuel oils have also been tested and selected as for their "stability" in sea water so as to reduce the risk of real pollution in the testing facility and so as to allow for testing during a long period of several months.
The selected sonars are 5 commonly used sonars (2 sidescan sonars, 2 multibeam echosounders,1 3-D acoustic camera) and 1 prototype front-looking sonar. The "off-the-shelf" sonars are quite representative of the commercial systems but other criteria of selection was their availability during the testing period.

## Testing facilities

After preliminary tests concerning the buoyancy and the long term "stability" of various mixture of fuel oil n°6 with kaolin, *Cedre* decided to select the following products for these acoustic experiments:

- mixture A: 70% fuel oil n°6 + 30% kaolin,
- mixture B: mixture A emulsified with 30% of fresh water,
- mixture C: mixture B with sand similar to the bottom sand layer.

Due to the high viscosity of fuel n°6 the whole process of making the different mixtures had to be done at a sufficiently high temperature. This has implied a strict order to realise these mixtures, (successively A then B then C), so as to keep the production simple enough and to avoid delays that would have lead to a difficult laying in the skirts because of higher viscosity. The natural process of the fuel ageing at the ocean surface after the spill occurred, called weathering, is not quite similar since it is first an emulsification and then possibly a mixing with silt sediment that can lead to the sinking down to the seafloor.

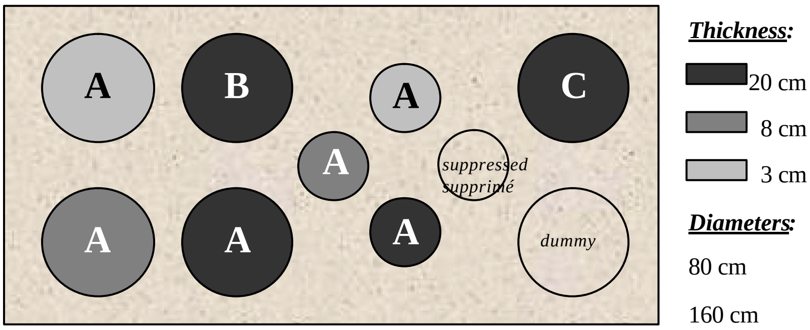


*Figure. 1 Lay out of the various oil patches on the sand floor over the dry-dock bottom.*

*Figure 2: (left) The ten patches on the sand floor, before oil filling and water flooding. (right) Filling of an oil patch.*

The sonar head was mounted onto a deployment trolley fully equipped with a dual-axis motorization, a small control cabin and the necessary electric power. The trolley could be moved over the sand tank at slow speed and the operating depth was adjustable; for each one of the surveys, the sonar head was kept approximately 5 m above the oil patches.

The surveys with swath systems were conducted following lines parallel to the sand tank width; these lines were at varying distances from the sand tank edge in the longitudinal axis.
With the multibeam sounders and front looking sonars, the survey was conducted along lines parallel to the sand tank length.

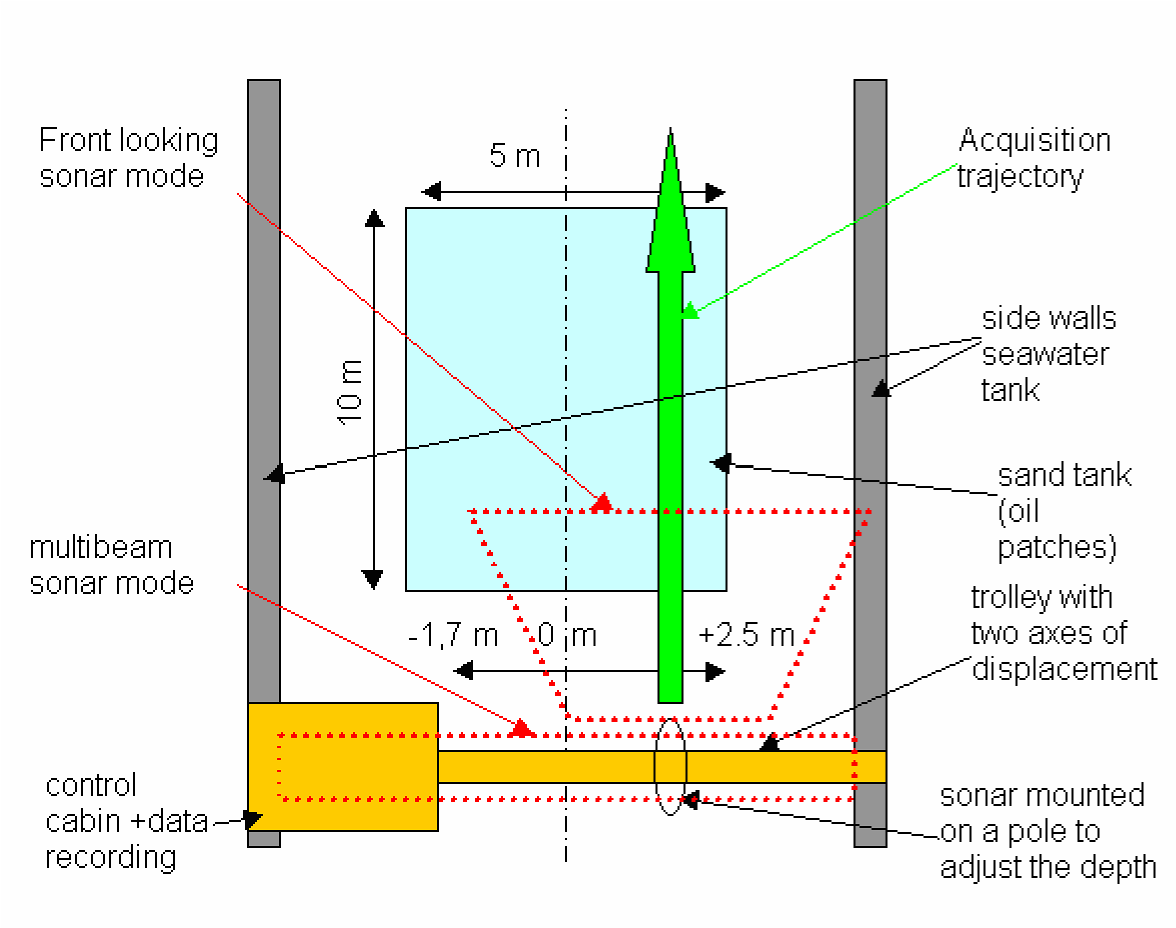


*Figure 3: Sketch of the sonar deployment geometry over the sand tank*

## Acoustical measurements of the oil fuel

Samples of the fuel oil used in the experiment were measured by L.M.A. in order to get the relevant acoustical parameters (density, velocity, absorption coefficient). The two samples measured were found to have densities respectively 1280 and 1109 kg/m$^3$, and velocities respectively 1492-1520 m/s and 1500-1515 m/s (varying with frequency inside the range 140-500 kHz). Hence the acoustical impedance contrast with water is expected to be quite low. The absorption coefficient values were found to be respectively around 1,0 and 0,6 dB/wavelength, hence quite high values (about 10 times what is typically expected in soft sediments with similar impedance). Oil fuel is then essentially characterised by its high acoustical attenuation.

Other measurements were also conducted in order to get the reflection and backscattering coefficients of the water-oil interface, and of the oil containment net itself. On the one hand the measurements on oil reflectivity were not very conclusive due to the too small thickness of the oil patches available in laboratory; on the other hand, the acoustical influence of the containment net was found to be reasonably negligible.

## Characteristics of the operated sonars

The main characteristics of the six systems tested are given in Table 1: namely the sonar type (sidescan sonar, multibeam echosounder, front-looking sonar, 3D acoustic camera), the nominal frequency, the across track resolution (given by the transmitted pulse length), the along track resolution at a 50 m range (given by the along track angular aperture, for swath sonars), the number of beams and their across track width (for multibeams), the total angular aperture, and the maximum swath width. All of these characteristics are nominal values, taken from the technico-commercial documentation available from the suppliers.

| | Type | Nominal Frequency (kHz) | Acrosstrack resol. (cm) | Alongtrack aperture (°) res.(cm)@50 m | Beam number & width (°) | Total apert. (°) | Max. swath (m) |
|---|---|---|---|---|---|---|---|
| Reson Seabat 8101 | MBES | 240 | 1,25 | 1.5 / 130 | 101 / 1,5° | 150° | 600 |
| Reson Seabat 8101 | FLS | 240 | 1,25 | 1.5 / 130 | 101 / 1,5° | 60° | / |
| Edgetech DF-1000 | SSS | 100 / 400 | 7,5 / 0,75 | 1.2° / 100<br>0.5° / 40 | / | / | 500 / 200 |
| Klein 5500B | SSS | 455 | 3,75 | 0.15° / 12 | / | / | 300 |
| Reson Seabat 8125 | MBES | 455 | 1,6 | 1° / 80 | 240 / 0,5° | 120° | 200 |
| COSMOS | FLS | 100 | 30 | / | 32 / 1,5° | H:25° - V:75° | / |
| EchoScope 1600 | 3DAC | 100-300-600 | 1 | 2.5°-1.3°-0.6° | 4096 | 90°-50°-25° | / |

*Table 1. Main characteristics of the tested sonars, based upon their respective commercial documentation. MBES=multibeam echosounder; SSS=sidescan sonar; FLS=front-looking sonar; 3DAC = three-dimensional acoustic camera*

## Sidescan Sonar images

**Klein 5500B:** this high-resolution sonar was operated along a series of 11 measurement lines, at various sonar-target distances. The image presented here (Fig.4) corresponds to a range of 5.2 m between the sonar and the closest sand tank edge. The sonar data was projected over a horizontal grid, the bin size of which was taken relatively high (10 cm) in order to allow comparisons with other systems (multibeams); indeed it must be emphasised that the actual resolution of individual sonar images by Klein 5500 systems is clearly much better than the one in Fig.4. The resulting image gives a very good contrast between the sand and the oil patches. Data recorded at longer ranges were often smeared by unwanted reflections from the water surface, and hence were found to be of less quality.

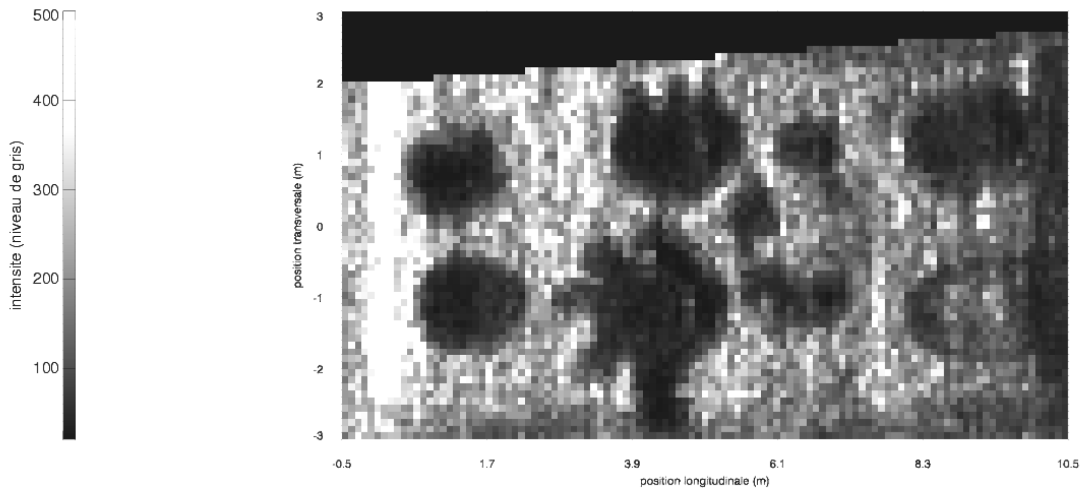


*Figure 4: Reflectivity map obtained with sidescan sonar Klein 5500*

**DF1000 :** This bi-frequency sidescan sonar was operated in the same geometry as Klein-5500. The two images presented here were obtained at 400 and 100 kHz, for a 6.6 m range between the sonar and the closest wall of the sand tank ; this geometrical configuration gave the best results. The high-frequency image is very well defined and contrasted, and provides an excellent detection of the oil patches. On the other hand, the 100-kHz image is poorly contrasted, and is smeared by many echoes from the water surface.

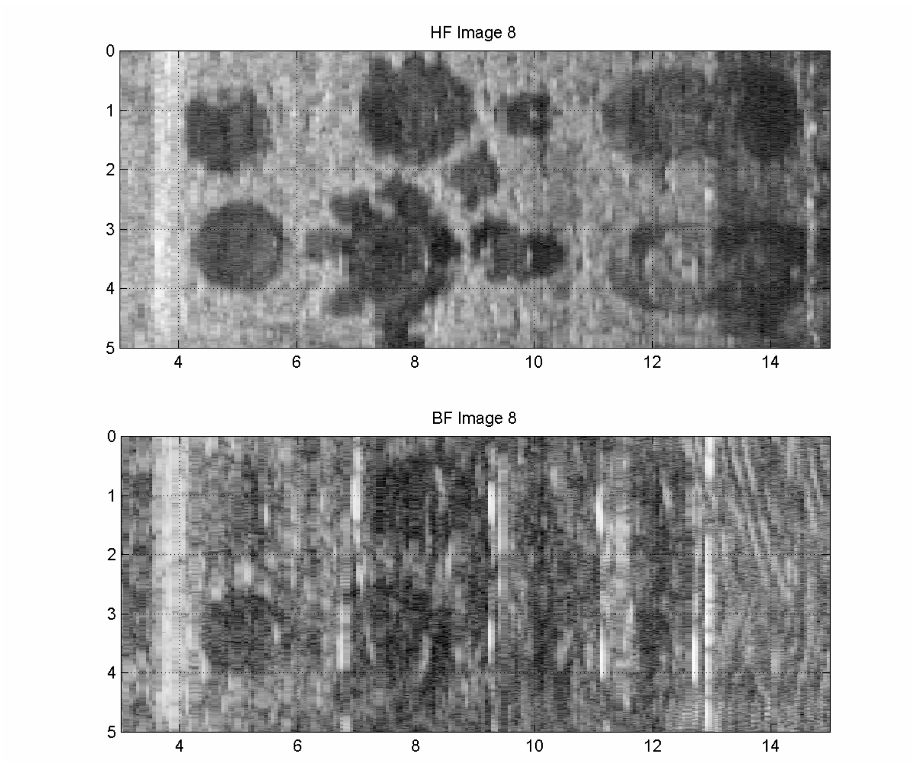


*Figure 5: Sonar image obtained with Edgetech DF-1000 at 400 kHz (upper) and 100 kHz (lower.*

**Seabat 8101, multibeam echosounder mode**: This 240-kHz sonar was operated successively along three lines parallel to the sand tank length, at various distances from the longitudinal axis. Each obtained map of backscattered echo intensities (e.g. Fig. 6) gives a nice image of the sand floor with oil patches clearly visible (contrast around 10 dB). Finally the three maps were averaged over a 0.1-m grid of the horizontal plane, providing an excellent reflectivity image (Fig. 7).

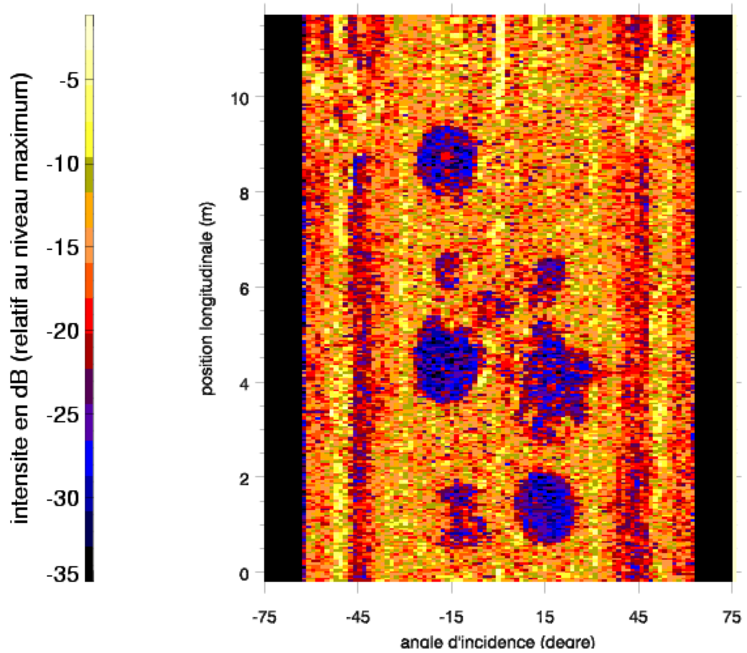


*Figure 6. Echo intensity level obtained with the Seabat 8101 multibeam echosounder operated along a line exactly in the middle of the sand tank.*

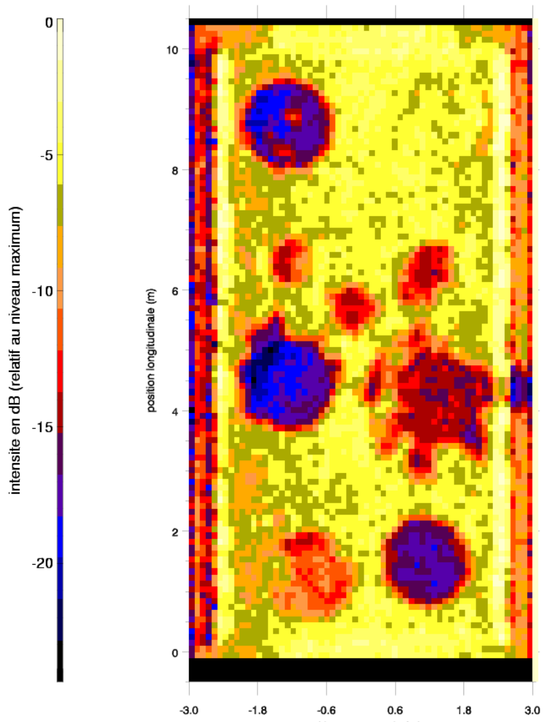


*Figure 7. Backscattered level, averaged from the three acquisition lines for Seabat 8101.*

**Seabat 8125 :** This high-frequency (455 kHz) and high-resolution (1° x 0.5°) echosounder was operated on the same three tracks as Seabat 8101, parallel to the sand tank length. Compared to the Seabat 8101 results, as expected the image resolution is bettered, while the interpretation is different in terms of reflectivity measurement. On one hand, the echoes are more sensitive to the sand microroughness, due to the higher frequency and resolution ; on the other hand, echoes from oil patch with various thickness are less differentiated, since the high-frequency signal echo is due to the water-oil interface rather than the oil patch volume and underlying sand.

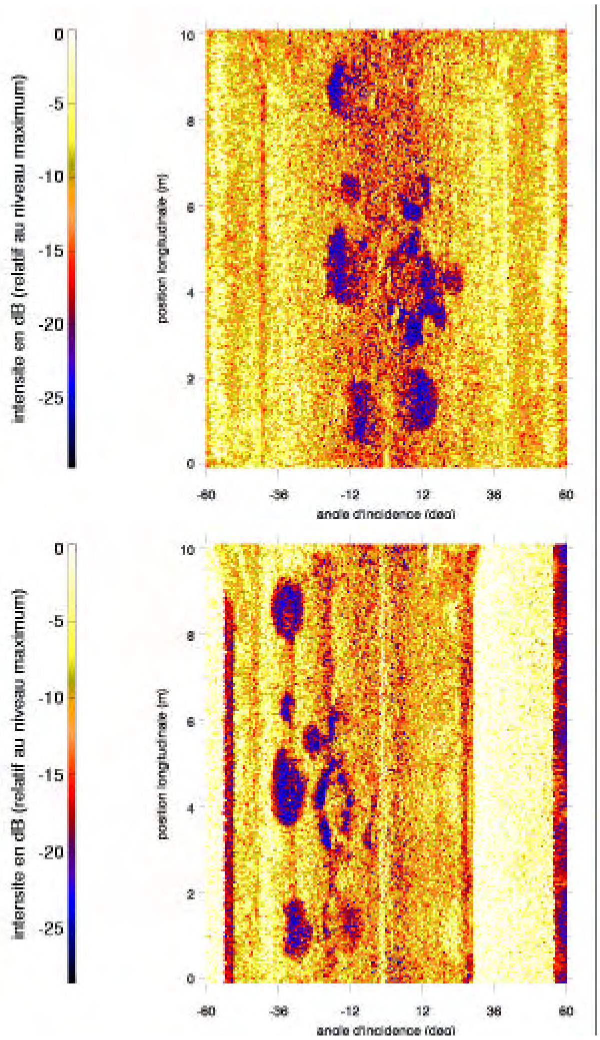


*Figure 8. Reflectivity map recorded with Reson Seabat 8125, with an offset of 0 m (left) and 2.5 m (right) from the sand tank longitudinal axis.*

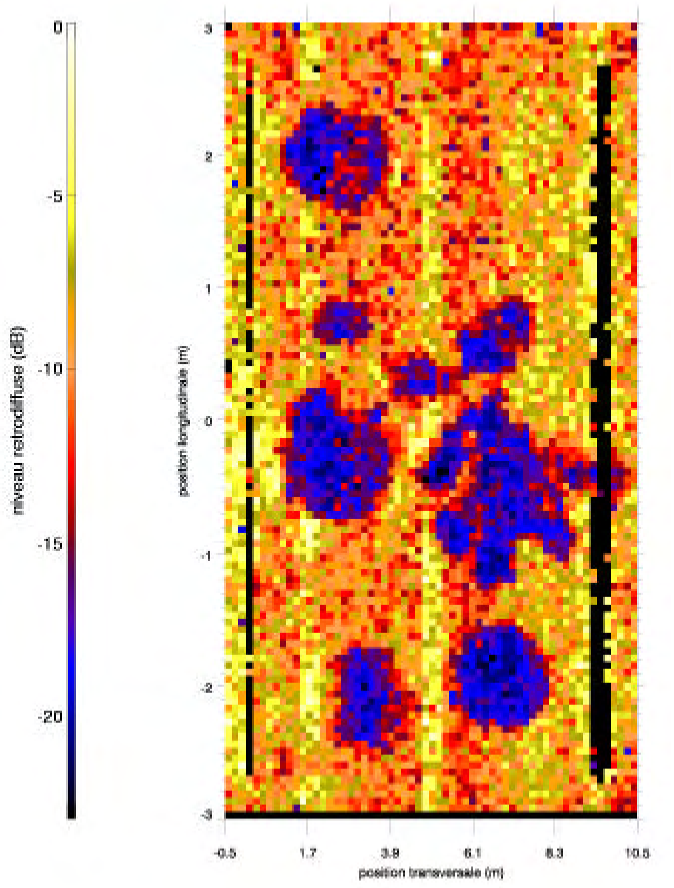


*Figure 9. Backscattered level, averaged from the three acquisition lines for Seabat 8125.*

## Front-looking Sonar images

**Seabat 8101, front-looking mode**: The 240-kHz echosounder was operated along the longitudinal axis of the sand tank. Four images, extracted from the whole sequence, are presented here, making clear the various targets appearing each in turn.

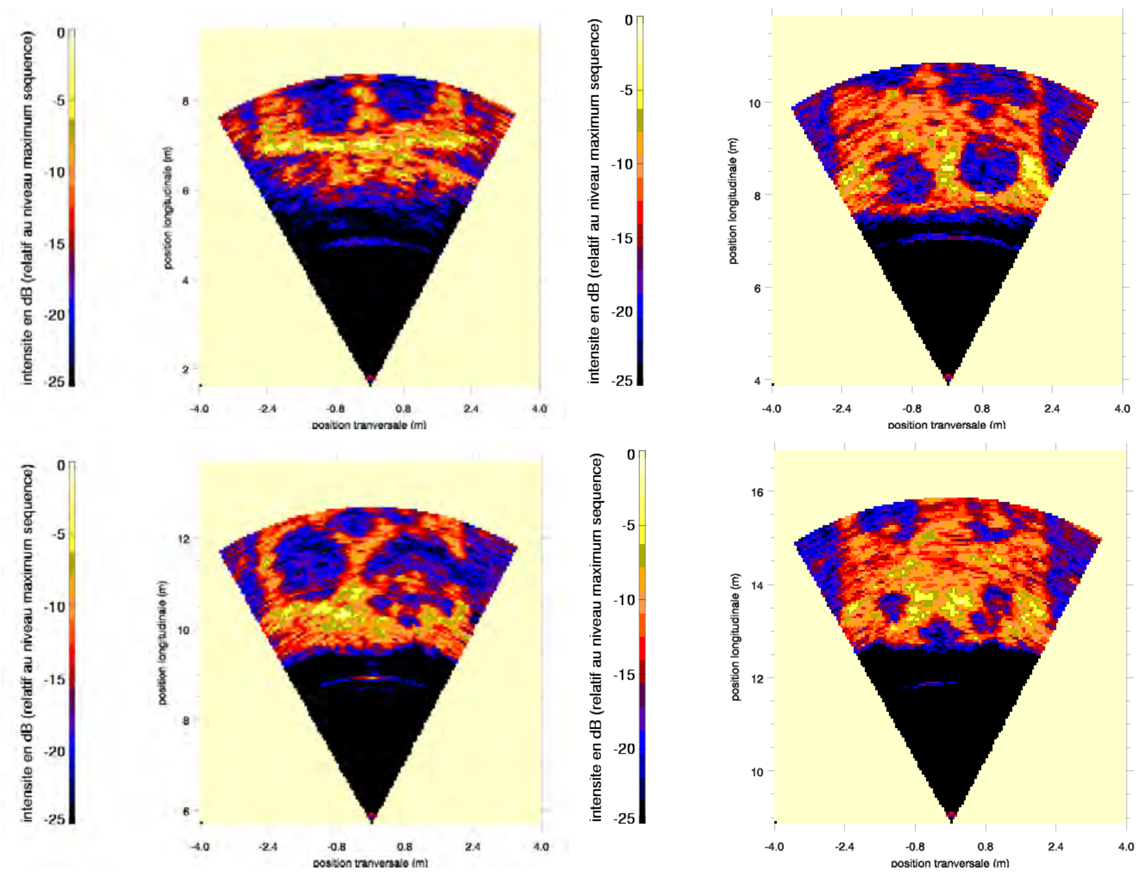


*Figure 10. Successive images obtained with the Seabat 8101 sonar operated in front-looking mode. The oil patches appear as the sonar proceeds along the sand tank axis.*

**COSMOS** : the prototype sonar developed by LMP (Université de Paris 6) was operated along 13 longitudinal and 24 transversal tracks. The main interest of this sonar for such a study is its capability to provide images corresponding to various incidence angles, while it is still possible to build global response by integrating successive views over a wide angular sector. These interesting properties are illustrated in Fig.11, while it is clear Unfortunately the sonar beamwidth and its quite low operating frequency (around 100 kHz) are not well-adapted to high-resolution imaging, and the image resolution is far less good than the sidescan sonar results. As a result of the angle sector analysis capability, Fig.11 shows the backscattering strength obtained as a function of angle at 100 kHz: it is given here as the difference between the sand and oil echo levels, i.e. the echo contrast practically observable upon oil patches.

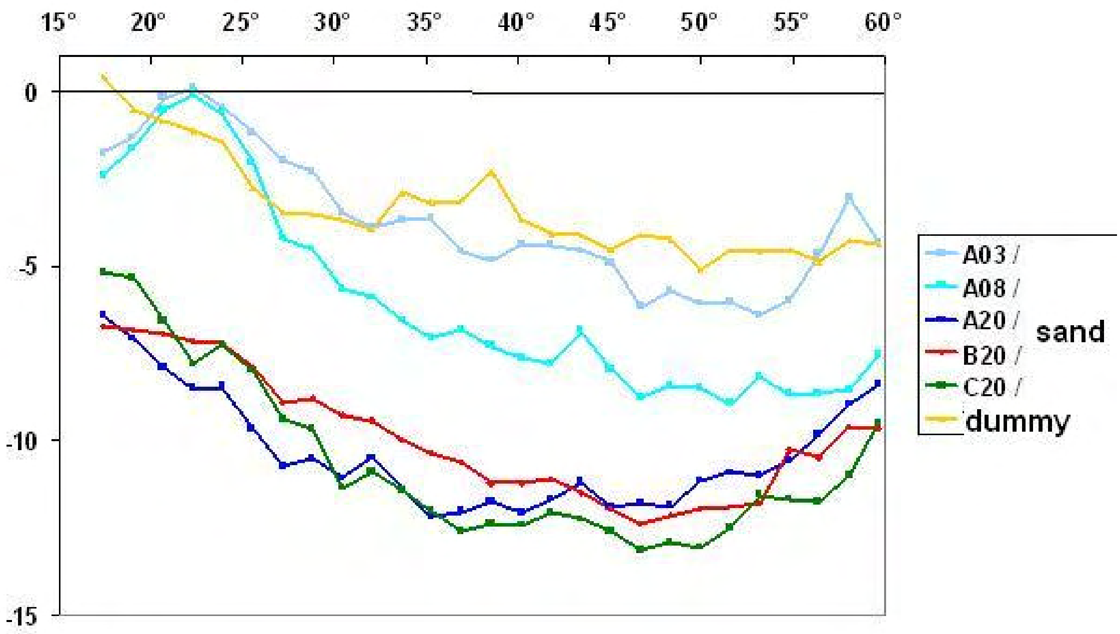


*Figure 11: Backscattering strength contrast (referenced to the sand response) of the various oil patches as a function of incident angle, measured by the front-looking multibeam interferometric system COSMOS. (cf fig.1 for the meaning of A03…C20)*

**EchoScope 1600**: This multi-frequency 3D real time acoustic camera, developed by CodaOctopus Omnitech in Norway, was operated in such a way to obtain: echo strength analysis when scanning frequency (100-900 kHz); echo strength analysis as a function of angle; survey of the sand tank in order to build 3D elevation and reflectivity maps. Although this version is not designed for providing as high-quality images as sidescan sonars, the EchoScope gave very interesting results in volume imaging of the targets and reflectivity mapping (see fig.12). It has the capability to provide large snapshots of the seafloor and to allow for making in situ mosaicing. It is a tool that is efficient for a quick ROV survey of polluted areas. The three frequencies allow to adjust the best trade off between maximum range and resolution according to the local conditions for the security of the survey system.

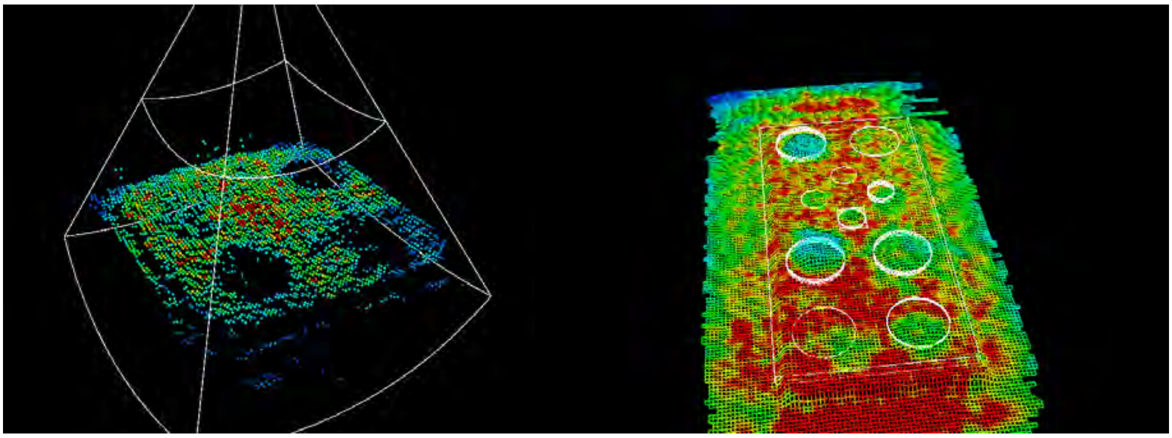

*Figure 12: Typical snapshot obtained with Echoscope 3D-Camera (left); averaged reflectivity measurement over the targets (right; note the difference between the nominal and the actual location of some oil patches)*

## Summary of the main results

The results derived from the analysis of all the data recorded during these experiments are the following:

- High frequency sonar systems (200-500 kHz), commonly used at sea (side scan sonar, multibeam sonar, front-looking 3D acoustics camera) enable to detect oil patches laying on a sand sediment floor because of the low reflectivity of the oil patches due to their high attenuation property. However the contrast depends on the altitude over the sea floor, the system type and the geometry of the beams.
- The contrast that was obtained in comparison with the surrounding sand, for any sonar type and all three pollutant type (A/B/C), is in the order of 10-15 dB within the frequency range of 240-460 kHz for the three thickness (3/8/20 cm). Around 100 kHz the contrast is never more than 5 dB and logically varies with the thickness (the thinner the oil patch, the least contrast).
- Near the vertical (+/- 10°) and when the frequency is increased from 240 kHz to 455 kHz the contrast derived from the multibeam sonar is significantly decreasing although in this case the bathymetry data clearly gives the thickness of the patches although they are not visible on the acoustic image.
- The side scan sonar systems are working away from the vertical (30° to 80°) and in such conditions the oil-sand contrast is rather high (around 15 dB). As they should be operated at a constant altitude above the seafloor, these systems should provide good surveillance on wide swaths, although at nadir the resolution of their images is very poor.

Actually sides scan sonar could be deployed for mapping large areas so as to quickly assess where there could be oil pollution. Then in case of possible detected oil patches a more precise survey could be undertaken with the use of multibeam, front-looking sonar or 3D acoustic camera installed on board a vessel or an underwater vehicle equipped with a precise positioning system. The definitive confirmation could be derived from sampling or more probably from close video shots by the use of an underwater vehicle. This strategy will probably be tested on actually polluted areas in the near future so as to have an operational validation.

**Acknowledgement**

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