The limits of spatial resolution achievable using a 30kHz multibeam sonar: model predictions and field results.

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I. Abstract

A Simrad EM300 multibeam sonar was used to attempt to resolve small (~5m high) targets in 450m of water. The targets had previously been surveyed using a deeply towed 59 kHz sidescan sonar. Using multi-sector active yaw, pitch and roll compensation, together with dynamically altering angular sectors, the sonar is capable of maintaining sounding densities of as tight as 10m spacing in these water depths. This is significantly smaller than the largest dimension of the projected beam footprints (16-64m).

The observed data suggest that the targets are intermittently resolved. The field results compare well to the output of a numerical model which reproduces the imaging geometry. Possible variations in the imaging geometry are implemented in the model, comparing equiangular and equidistant beam spacings, differing angular sectors and all the different combinations of transmit and receive beam widths that are available for this model of sonar.

While amplitude detection is significantly aliased by targets smaller than the across track beam footprint, under conditions where the signal to noise ratio is favorable, phase detection can be used to reduce the minimum size of target observed to about the scale of the across track beam width. Thus having the beam spacing at the scale is justifiable. The phase distortion due to smaller targets, however, is generally averaged out.

II. Introduction

Multibeam sonars are increasingly used to provide information about the shorter wavelength seafloor morphology [1], previously invisible with single beam methods, or only inferred through the use of towed sidescans. As the seabed gets deeper it becomes more difficult to resolve short wavelength seabed targets from the surface. This results mainly from the growing size of the projected beam footprint, the growing inter-beam spacing and the difficulty of guaranteeing a uniform sounding density from a moving platform [2]. While deeply towed sidescan sonars can provide the resolution, they require much lower speeds and, if absolute positioning is required, complimentary acoustic positioning systems are needed.

In order to get around some of the limitations of surface mounted multibeams, the Simrad EM300 [3] was developed with narrower than normal beam widths, higher soundings densities and active motion compensation.

This paper reports of a series of experiments where an EM300 (1x2) was used to resurvey an area in 450m of water that had previously been examined using a deeply towed 59kHz SMS960 sidescan sonar [4]. Of particular interest was the ability to resolve small (<10m high) targets that are known to exist. These include reported 5m size concrete blocks which lie in ~5m deep broad (30-80m wide) depressions. Model results are compared with the observations to try and realistically assess the limits of the spatial resolution achieved from the surface mounted system.

III. The Instrument

The Simrad EM300 [5] is a 30 kHz multibeam echo sounder that uses a single Mills Cross array geometry. It is available in a variety of transmit and receive array lengths corresponding to 1, 2 or 4 degree beam dimensions in either axis (as tested the system had a 1 degree transmit beam and receive beams that were 2 degrees at nadir). Swath widths between 60 and 150 degrees are selectable at 2-degree intervals with either 111 (shallower modes) or 135 beams formed. For all sectors, a choice of equiangular (EA) or equidistant (EDBS) beam spacing is available.

The swath width may be set either to a fixed angular sector, or to a fixed maximum swath width. In the second case the angular sector is then adjusted accordingly (in 2 degree steps) to maintain the desired swath width.

Beams are stabilised for roll, pitch and yaw. This is done through the use of 9 (or 3 in shallower modes) discrete transmit sectors that are fired within a few milliseconds of each other [5]. Each sector uses a slightly different frequency (offset by about 500Hz). The end result is a near uniform sounding density irrespective of instantaneous ship orientation (Fig. 1)

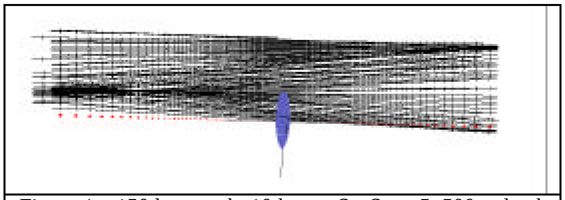

Figure 1a: 150deg swath, 10 knots, SeaState 5, 500m depth Simulation without multi-sector yaw stabilisation

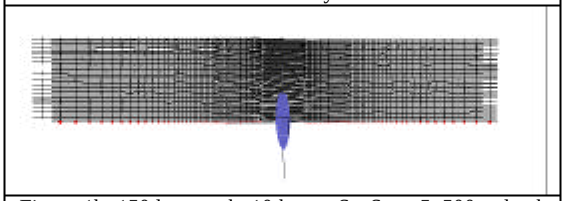

Figure 1b: 150deg swath, 10 knots, SeaState 5, 500m depth Simulation with multi-sector yaw tabilisation

IV Sounding Density and Distribution

As the sonar always uses the same number of beams irrespective of the angular sector employed, the available across track beam spacing is highly variable (Fig. 2). Similarly, with the change in maximum slant range that comes with changing angular sector, the along track beam density for a given depth is also highly variable. And depending on the beam spacing model used (equiangular or equidistant) the beam density may vary across the swath. In all cases, because of the active motion compensation, the ping to ping alignment remains very stable, so that orientation does not significantly impact on the sounding pattern.

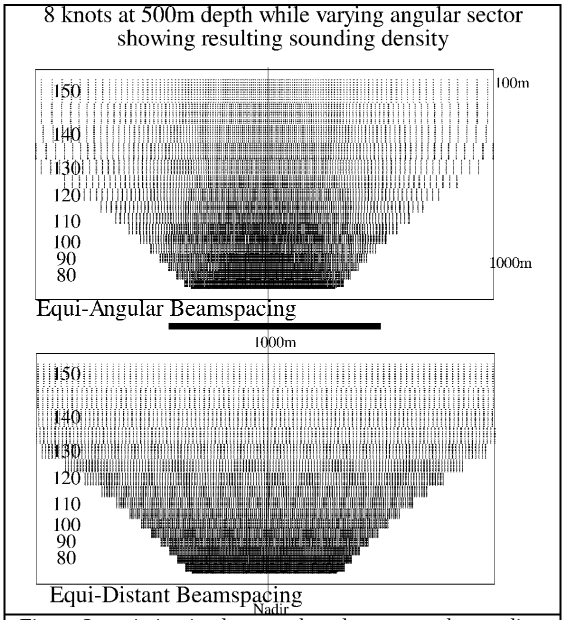

Figure 2: variation in along track and across track sounding density due to changing angular sector and beam spacing methodologies.

As one goes deeper with a given angular sector, naturally the beam spacing opens up (Fig. 3). However, if a fixed swath width is set, as one goes deeper, the angular sector closes down, thus maintaining a uniform across track beam spacing (Fig. 3). Whilst the along track beam spacing does grow, it does so more slowly than a fixed angular sector as the maximum slant range no long grows linearly with depth.

A traditional problem when surveying highly incised continental margins has been that both the sounding density and swath width vary strongly with the topography. To ensure 100% coverage, line spacing is set by the swath width achieved on the shoallest points in a line. This has the unwanted effect that in the deeper sections (such as canyon axes) the sounding density splays out and produces redundant overlap with adjacent lines (Fig. 4a).

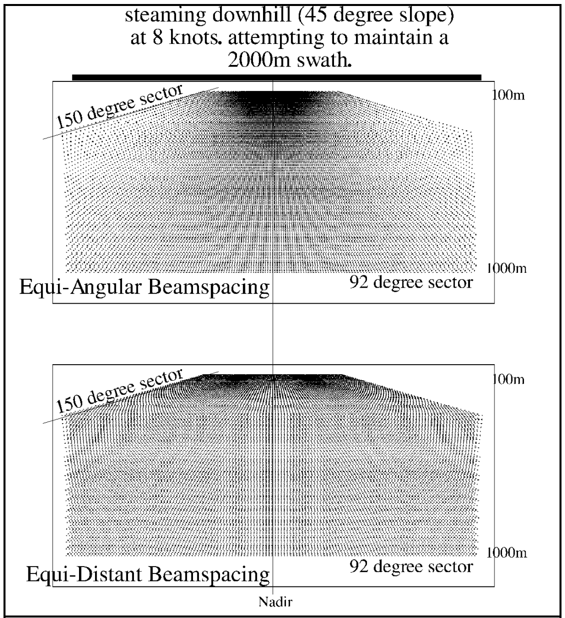

Figure 3: variation in sounding density steaming downslope, whilst maintaining constant swath width.

With the fixed swath width mode, the beam density is maintained across track and redundant data is avoided (Fig. 4b).

The main result of the dynamically varying angular sector strategies is that, very dense beam spacings may be retained, even in deeper water. In doing so however, in general the beam spacing is considerably finer than the individual beam footprints. Can we then resolve features that have wavelengths shorter than the beam footprint? Previous studies suggest that with amplitude detection methods, this is unlikely (topographic and/or textural variations below the beam footprint tend only to alias the sounding solution [6]).

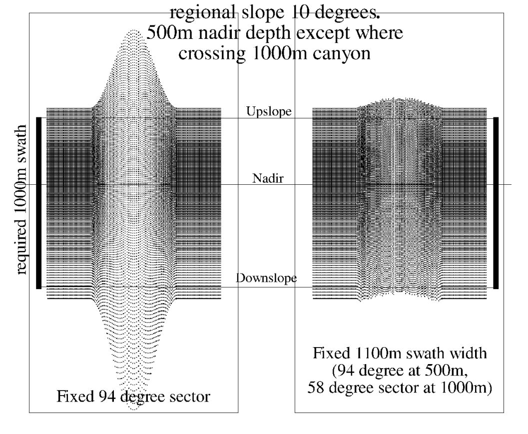

Figure 4: Effect when traversing margin normal features. Note that the uniform swath width is not centred at nadir. Redundant data is avoided and sounding density is maintained in the deeper section .

With split aperture phase methods however, this may be possible. To test this we present a series of field observations where the sonar was deployed over targets that are close to the beam spacing in horizontal dimension, but considerably smaller than the beam footprint. These results are then compared with the predictions from a numerical model [6].

V. Field Examples

The targets considered lie at ~450m in a dumpsite in Mamala Bay, Oahu [4]. The targets are believed to be large blocks of building debris, up to 5m is size. Around these blocks are ring like depressions about 5m deep and 50 to 80m wide. The targets were previously located in 1993 using a 59kHz sidescan towed, 80m above the bottom, using an 800m swath [4]. The targets show up as high backscatter features that cast clear shadows in the sidescan (Fig. 5E). The ring-like depressions, however were not seen in the deep-towed sidescan and only recognised from the EM300 surveys (Fig. 5C,D).

The EM300 surveys were conducted in February 1998 in about seastate 2-3 at 8 knots. The data presented in Figure 5 (A-D) were collected using equiangular mode, 100-120 degree angular sector data in "Medium" mode (3 sectors, 2.0ms pulse length, 135 beams).

The EM300 always recognised the circular depressions and in a few of the cases, recorded positive anomalies in their centres.

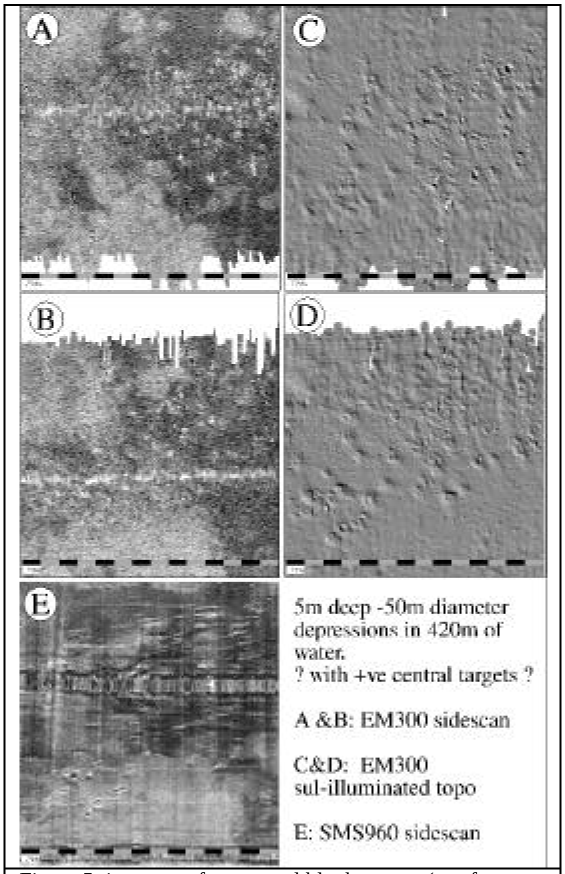

Figure 5: imagery of suspected block targets (sun from top right in C and D). Are is 568m wide by 622m high.

VI. Model Results

The numerical model used (synSwath [6]) projects a beam pattern formed from user-specified transmit and receive array parameters onto a user -defined seafloor model. The seafloor model consists of a grid, (in this case with node spacing of 1m) for which the elevation and backscatter angular response (texture) for every node may be assigned separately. For each node the mean backscattered intensity and phase is calculated based on the energy transmitted in that direction, the local seafloor slope and texture. The complex sum of these nodal contributions for each time slice are combined with a speckle and noise simulator to produce intensity and phase time series for each beam. Amplitude and phase detections are then attempted for each beam projected.

The amplitude detection method used is a simple centre of mass calculation based on logarithmic intensities above the mean noise level. The phase detection method used is multi stage. A phase detection is only attempted if more that 5 coherent samples are available. An initial estimate of the zero phase crossing is made using a window based on that used for the amplitude detection. If the residuals from this linear regression are low enough, the window is iteratively shortened about the previous estimate of the zero phase crossing. Thus, if the signal to noise is adequate and the phase trend is simple the window will come down to as little as 5 samples about the zero crossing. Thus under ideal conditions, the phase estimate should be based on data just from the central section of the beam (considerably smaller in area that the total beam footprint that is used in the amplitude detection).

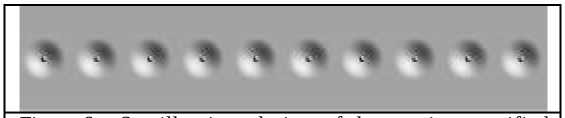

Figure 6a: Sun-illuminated view of the terrain ensonified (1000m long by 200m wide). Source lies to the centre left, elevated 500m above the surface. Each 5m deep, 80m wide depression has a 5m high, 10m wide knoll at its centre.

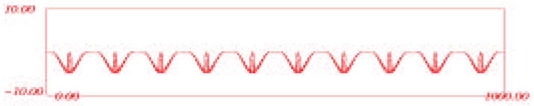

Figure 6b: 2D topographic profiles, extracted from along the ensonified axis of the terrain model.

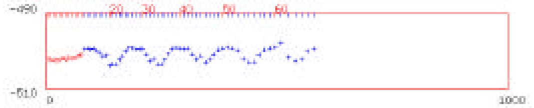

Figure 6c: EA100 1x2 (green amplitude, blue phase)

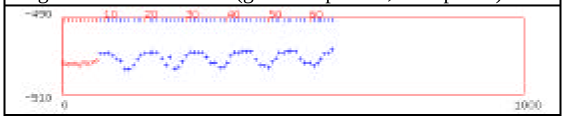

Figure 6d: EDBS100 1x2

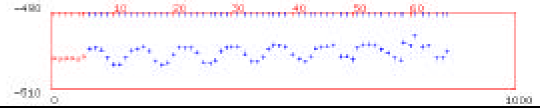

Figure 6e: EA120 1x2

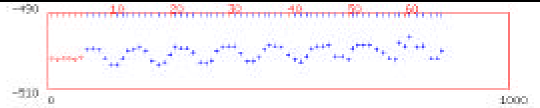

Figure 6f: EDBS120 1x2

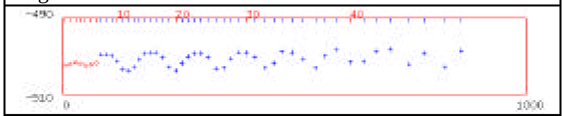

Figure 6g: EA140 1x2

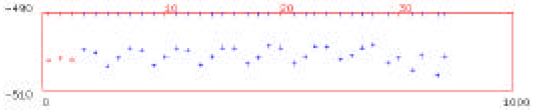

Figure 6h: EDBS140 1x2

The model results presented in figure 6 examine a single ping along the axis of a series of synthetic targets (Fig. 6a and b) designed to reproduce the dumpsite targets.

In all cases (Figs. 6c-h), the broad depressions are identified although the definition of the lows clearly degrades as the beam spacing opens up. The only hint of the targets occurs at the densest beam spacing (EA or EDBS100). With a 140-degree sector, a clear compromise in data quality between inner and outer swath data quality has to be made between using EA or EDBS.

Although not plotted here, the amplitude estimates where phase detection was finally used tend to show up as radial arcs trending up and out from the inward faces of each depression. This phenomena was observed in the real data and generated apparent positive topographic anomalies where nothing actually exists (as determined from overlapping swaths).

To quantify the effect of the transmit and receive beamwidths, for the EDBS 100 case, the same model was run for all the available combinations (Fig. 7).

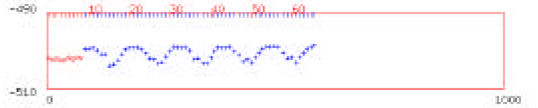

Figure 7a: EDBS100 1x1

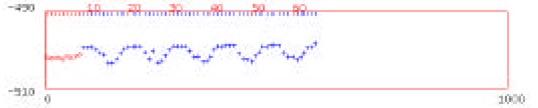

Figure 7b: EDBS100 1x2

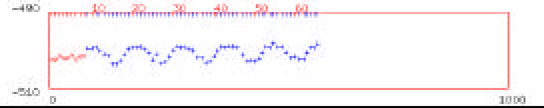

Figure 7c: EDBS100 1x4

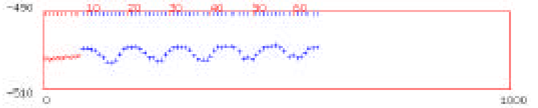

Figure 7d EDBS100 2x2

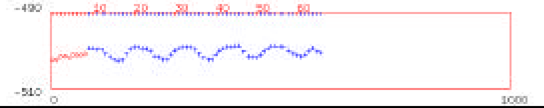

Figure 7e: EDBS100 2x4

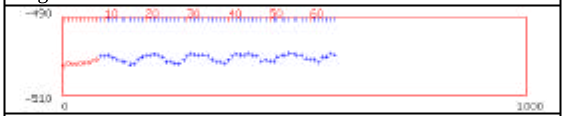

Figure 7f: EDBS100 4x4

Interestingly, because the phase detection is utilising only a narrow subset of the across track beam width, there is little noticeable difference in the delineation of the broad depressions with changes in the size of the receive beam width. Where the broad receive beam has the most detrimental effect would be for the amplitude detections.

To illustrate the contribution of the broad depressions and shorter wavelength targets one needs to examine in detail the amplitude and phase sweeps for those beams that intersect the small positive targets (Fig 8 and 9c). These can be compared with equivalent solutions for a flat seafloor (Fig. 8 and 9a) or the seafloor with the broad depressions alone (Fig. 8 and 9b) or a seafloor where the targets are replaced with transverse ridges (Fig. 8 and 9d).

Figure 8: intensity and phase time series of 8 adjacent beams (16-23) for EA100. Red vertical lines indicate chosen detection point for each method. Red horizontal line in phase window indicates length of regression window used.

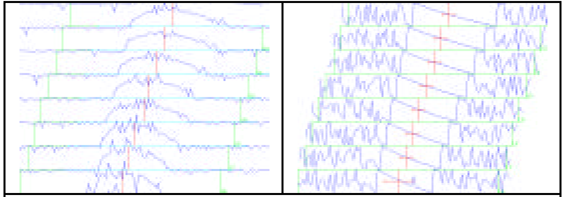

Figure 8a: flat seafloor (130m slant range window)

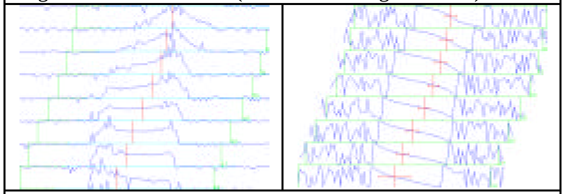

Figure 8b: depressions only

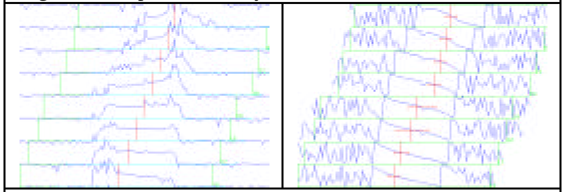

Figure 8c depressions with 5m radius hemispherical targets

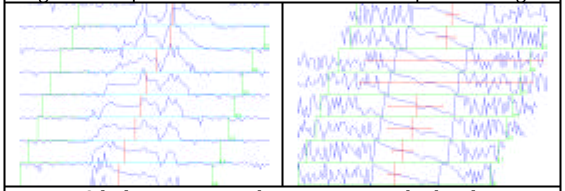

Figure 8d: depressions with transverse 5m high ridge.

The broad depressions significantly distort the amplitude time series and introduce long wavelength curvature to the phase sweeps. Both the hemispherical and cylindrical targets introduce a short distortion into the phase sweep. Because, however, the hemisphere (Fig 9c) (unlike the transverse ridge (Fig. 9d)), occupies only about 30% of the along track beamwidth, its influence is diluted. The across track beam width dimension is thus a limiting factor in target recognition.

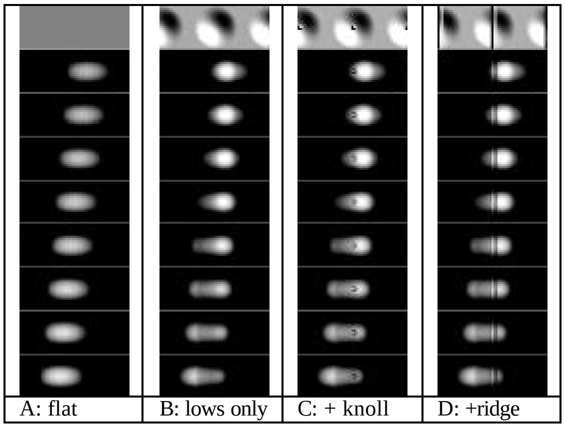

Figure 9: top is sun-illuminated view of seafloor ensonified (200 by 60m). lower 8 scenes show illumination patterns of main lobe of beams 16-23 (from bottom to top respectively).

VII. Conclusions

The combination of narrow beam widths, higher sounding densities and active motion compensation help the EM300 better resolve short wavelength seabed targets. This resolution however, is critically dependent on the proper implementation of the phase detection method which allows feature detection at scales smaller than the across track beam footprint. The along track beamwidth however, remains a limitation and thus narrower (and stabilised) transmit beams are a particular advantage..

Acknowledgements

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