MEASUREMENTS OF WIDEBAND ACOUSTIC BACKSCATTER FROM A VARIETY OF SEABEDS AT MINEHUNTING FREQUENCIES

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1. INTRODUCTION

This paper describes results obtained from analysis of acoustic backscatter data gathered using a wideband sonar system in the frequency range 100-200kHz. Data has been gathered from several different seabed types, including well-defined sand ripples, simultaneous supporting environmental measurements were taken including ctd data, stereo photography of the seabed core and grab samples.

The results presented in this paper compare results for short CW pulses and long wideband transmissions, and different insonification areas using different beamwidths. Changes in backscatter were observed as the transducers were trained from across to along the ripple direction.

This work was carried out under a Joint Research Project involving the Fine Scale Acoustics group at SACLANTCEN and the Mine Countermeasures Environmental Acoustics group at DERA (Bincleaves).

2. ACOUSTIC EQUIPMENT

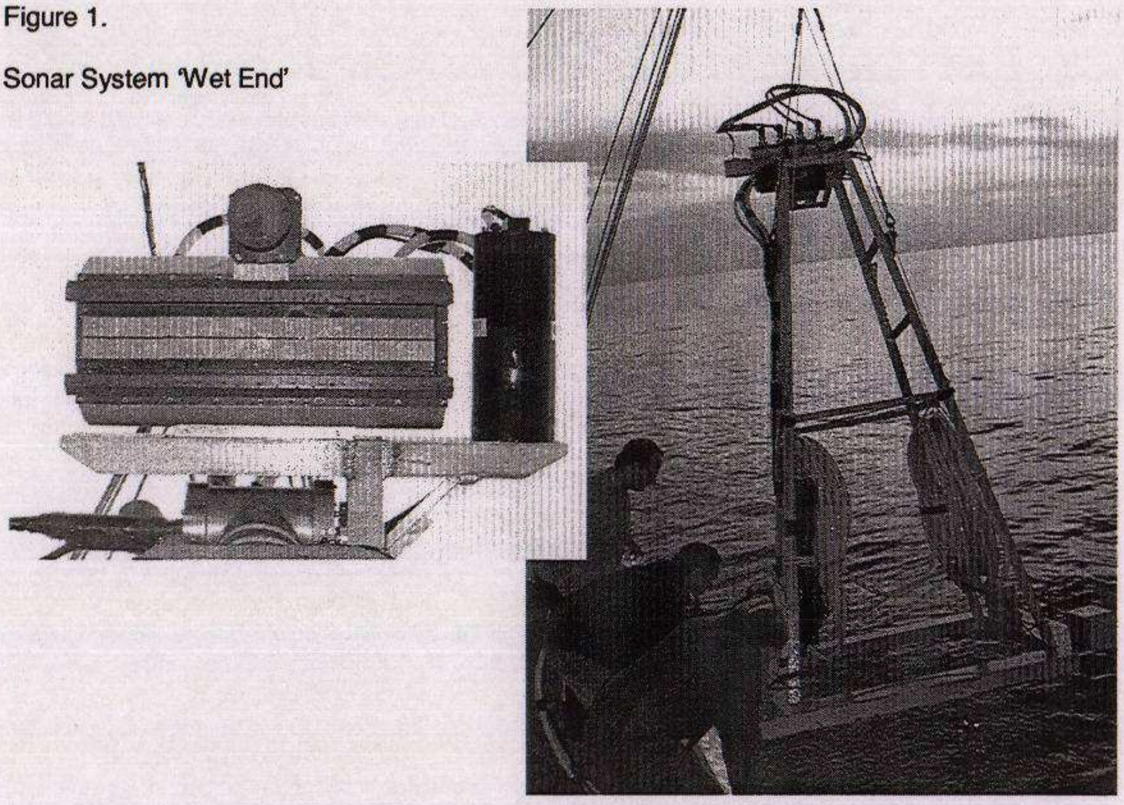
The Sonar System was developed by DERA with transducers manufactured by Fugro UDI (now Sonavision) using technology developed by Strathclyde University and UDI, and supported by DERA. The diced ceramic material make it possible to build arrays of very repeatable elements with a wide usable bandwidth in both transmit and receive.

The single element transmitter and multi-element receiver were fixed to a pan and tilt head on top of a tower that was positioned on the seabed to give a very stable measurement platform.

The Arrays were calibrated at DERA Bincleaves, and levels checked in the field against reference hydrophones and calibrated targets. The wet end of the system is shown in Figure 1 with the tower about to be deployed.

Figure 1.

Sonar System 'Wet End'



3. SITES AND SEABEDS

The Tower, the Trials Vessel and much of the supporting equipment was provided by the SACLANT team, as were the trials sites as described in Table 1.

Table 1.

Site (Date)	Water depth(m)	Seabed Type
ELBA Posidonia Procchio Bay(1997)	12.5	Large areas of Posidonia (sea grass),
ELBA Sand Procchio Bay(1997)	10.5	Flat bottom with extended well-defined sand ripple fields (a=5cm, λ=25cm)
TELLARO La Spezia Bay (1998,1999)	14	Sand with silt seabed, some poorly defined ripples
VENERE AZZURA La Spezia Bay (1998,1999)	10	Mixed fine sand and silt seabed
PORT VENERE La Spezia Bay (1998,1999)	12	Mud seabed with shells
PTA della MARIELLA La Spezia Bay (1999)	19	Mud seabed with shells and organisms.

4. ACOUSTIC DATA

Data from up to 64 receive elements was stored to files using a C40 system interfaced to a PC with large amounts of hard disc space. The raw data was sampled at 570kHz (or 800kHz 32 channels) so no processing or basebanding was required prior to storage. Transmit pulses were short 50μsec CW pulses or 5msec LFM pulses with either a 20kHz, 40kHz, 60kHz, or 80kHz frequency sweep, centred around 140kHZ or 150kHz. Other CW spot frequencies in the pass band where also used.

The first stage of analysis was to beamform the data using a frequency domain beamformer and at the same time applying a matched filter using recorded transmit replica pulses to give envelope values. The same data was used to study different receive beamwidths, and results from the narrower beams averaged over the whole receive sector. Figure 2 shows two of examples of beamformed data from the silt and sand Venere Azzura site (a) and from the sand ripples off Elba. Figure 2

Figure 2(a)

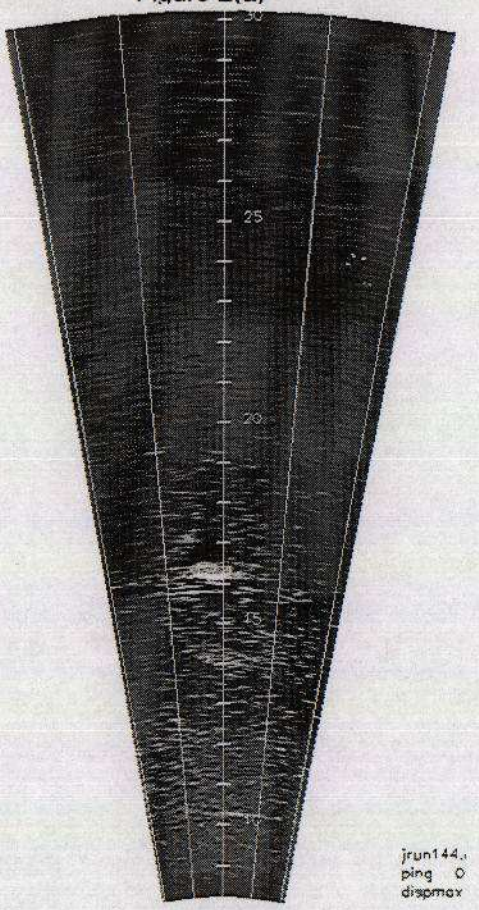
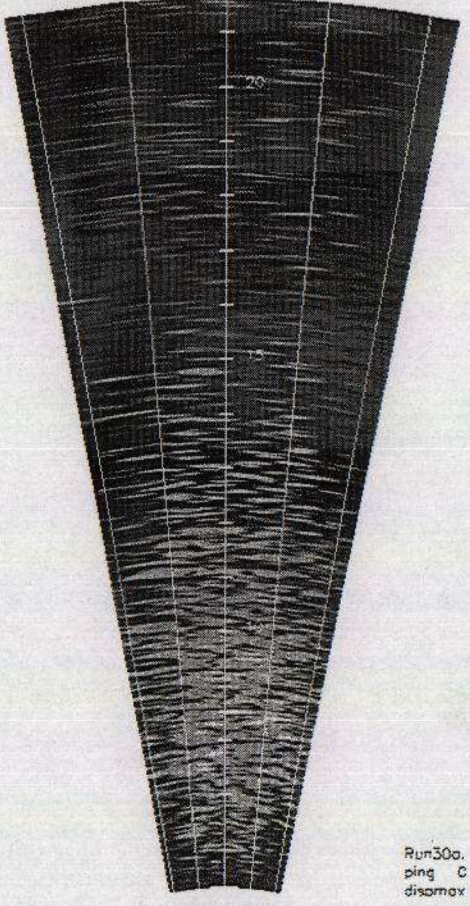


Figure 2(b)



The calibrated target used to check calibrations appears in Figure 2(a) just to the right of the 10m marker rather than the more obvious target at 16m.

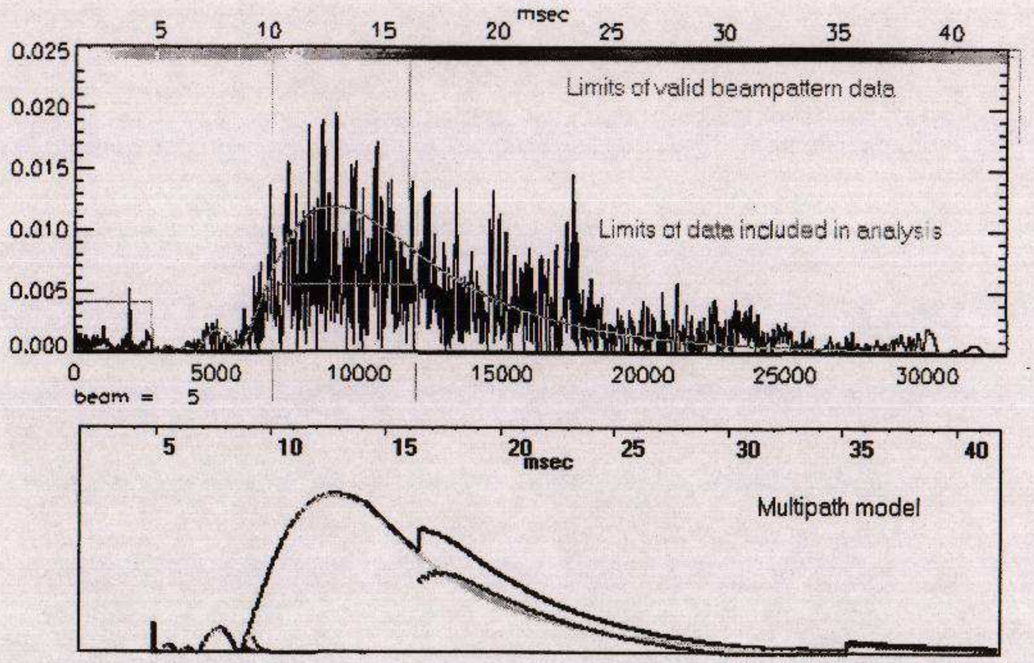
The orientation of the sonar was recorded however correction was required for slight local slopes of the seabed, which did not show up on the initial site survey. This was overcome by comparing the nulls in a-scan data with a model curve using the same beampattern data. The geometry is then adjusted slightly if necessary to ensure the nulls match up before continuing with analysis. An example of this is shown in Figure 3a, as are the limits within which data is accepted as valid.

Where wider vertical beamwidths have been used in these shallow water measurements (specifically the data collected off Elba) particular care must be taken to avoid multipath returns corrupting the results. An example of the a-scan from an isovelocity multipath model is shown in Figure 3b, and the anticipated model seabed reverberation curve is overplotted on the upper a-scan. The beampattern corrections used in the analysis are calculated theoretically for the specific experimental geometries and frequencies, the theoretical values have been compared with and checked against available calibration measurements.

Figure 3

(a)

(b)



5. RESULTS

As can be seen from Figure 2 above, this sonar system has been used at ranges of about 10-40 metres to study small areas that have been well characterised. Typical resolution cell size is of the order of about 25cm in azimuth (at 15m range) and 4cm in range. With this resolution the beamformed images corrected for geometry, beampattern effects and transmission loss show seabed features and scattering hot spots that are contributing to the average scattering strength values.

The images shown in Figure 4 are from data collected at the Venere Azzura site, 4(a) is raw beamformed data including the effects of the sonar presented as a sector plot, and the 4(b) is the same data converted to show scattering strength values and showing a distinct band of higher scattering strength across the middle of this supposedly homogeneous area. It has not yet been possible to identify what has caused this from the supporting environmental measurements made at this site. Figure 4(c) is also converted to show scattering strength values and gives an indication of the spatial variability usually seen in these results whilst ping to ping results are generally extremely stable (except when fish swim past). The scale down the middle Figures 4(b) and 4(c) indicate the grazing angle and the colour scale the scattering strength.

FIGURE 4 4a Raw Data 4b Scattering strength 4c Scattering strength

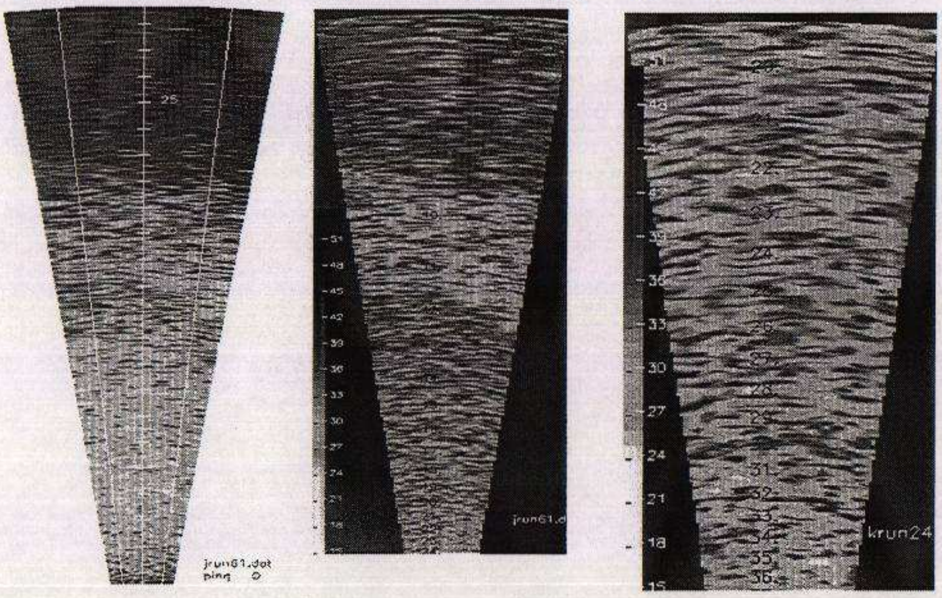
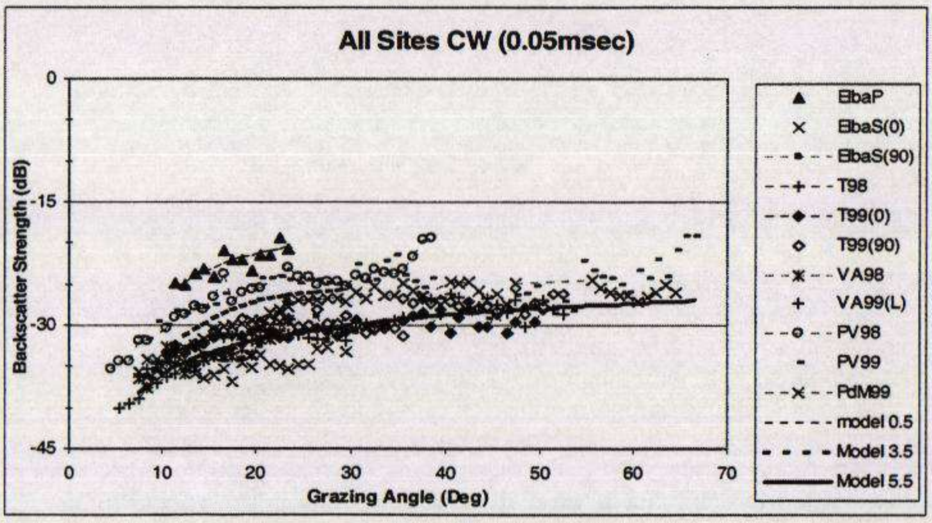


Figure 5, shows the backscatter strength averaged values against grazing angle for each of the sites at 140kHz (all sites except Elba) or 150kHz (Elba sites) . APL-UW9407 model curves for 'Coarse Sand and gravel' (model 0.5), Very Fine sand (model 3.5) and Silt/Sand/Clay (model 5.5) are plotted for comparison. [1]

FIGURE 5.



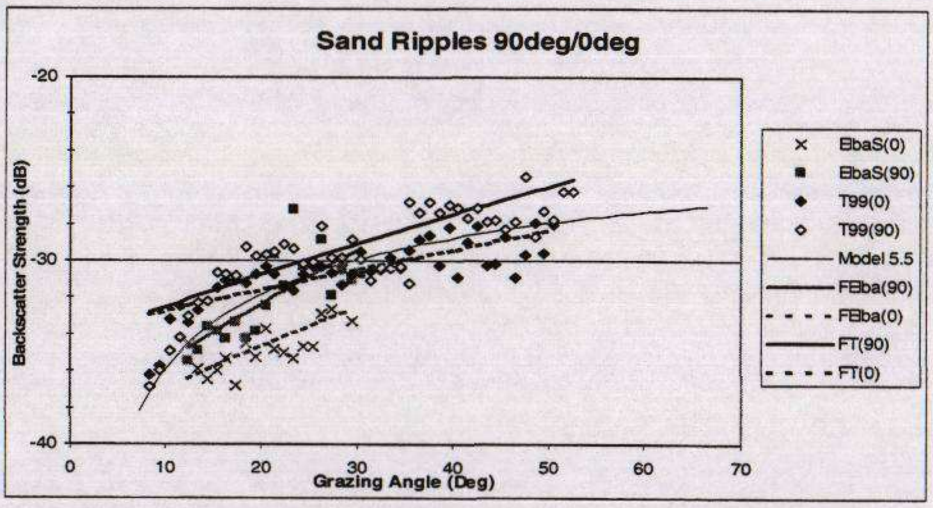
The beamformed data was converted to provide backscatter strength values before being averaged in pulse length (50µsec) and over a number of independent beams within the available sector. This scattering strength data was then sorted into bins covering a 1° spread of grazing angle, it is the mean value of the results in each of these bins which has been plotted here. The model parameters used for this comparison were generic values for the seabed materials described, when the results of the analysis of the samples from each of the sites become available the parameters may have to be modified and the comparisons re-examined. These results would seem to indicate that this model might not be appropriate at these frequencies.

The Posidonia (sea grass) has very high and extremely variable backscatter strength and, as the weed is constantly moving with wave and tide, the results show a lot of fluctuation and variability.

The two 'mud' (PV and PdM) sites exhibit higher backscatter strength than the sand sites, possibly indicating a higher 'shell content than originally thought, or a high gas content due to marine organisms, again the results of the core sample analysis may suggest that different model parameters should be used. For grazing angles higher than about 30 degrees the results become more variable, but even accounting for the very small areas due to the short ranges (near field problems were avoided by using a restricted array length at these ranges), there would appear to be a slight drop in the backscatter strength values.

The sand (Elba) and mixed sand/silt sites (T,VA) all show a similar level of backscatter strength but perhaps rather lower than might have been predicted by the model using any of the generic sand parameters. More interestingly a closer examination of the data would seem to indicate a difference in backscatter strength depending on the orientation of the sand wave direction to the acoustic axis. Figure 6 shows some of the results for the Elba and Tellaro sites at the two different orientations along with a curve fit to each of the data sets.

Figure 6

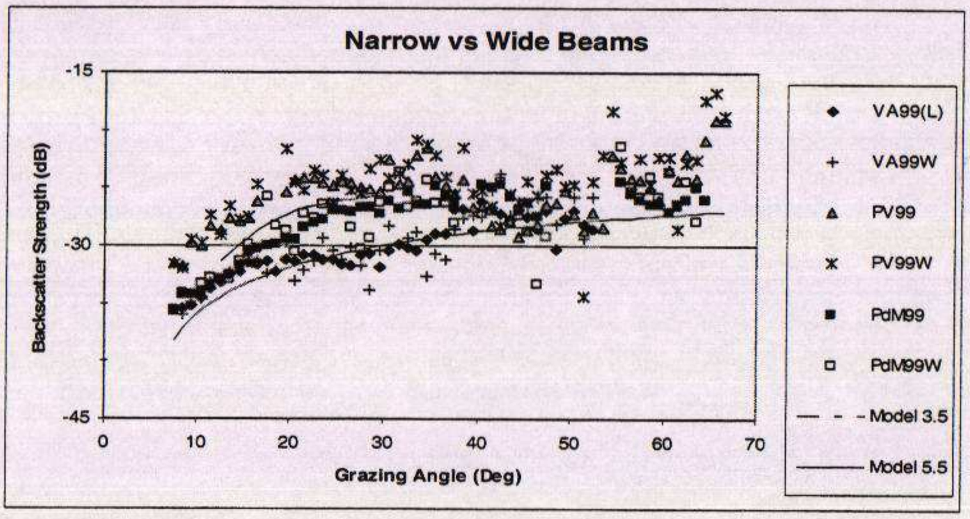


At the Elba site the sand ripples were well defined and have been measured using analysis of stereo photographs taken at the time **[2]**. These data sets are the same as those described in the comparison with an extension to the composite roughness model to take account of the reoughness spectrum **[3]**. The difference in Backscatter strength was seen to be about 2.5dB for the CW (50usec) measurements, a similar difference was seen for LFM measurements made using the same bandwidth (20kHz) and a longer (12.8msec) pulse length and also over a limited range for 60kHz and 5msec. Unlike the sand ripples at Elba, the sand ripples at the Tellaro site were poorly defined, and due to water conditions the same quality of stereo photographic analysis has not been available. There still appears to be a similar difference in backscatter strength for the different orientations with this difference appearing to increase with grazing angle.

The variation in backscatter strength due to the orientation of the sand ripples is of the same order as those observed for the changes in seabed type shown in Figure 5. This suggests that fine scale bottom topography is as significant as fine differences in bottom material for model predictions at high frequency and with high resolution sonar.
All the results shown so far have been calculated using narrow beams (1or 2 deg) for each experimental geometry, and averaging as many independent beams as possible in the available sector. To examine the affect of varying the insonified patch size the same data sets were also analysed using a single wide beam covering the same sector as the multiple narrow beams. This would give a more realistic resolution cell shape, rather than increasing the patch size by increasing pulse length if the results are to be compared with those for longer ranges. Figure 7 shows a comparison of the results for wide and narrow beams over exactly the same data set for three of the

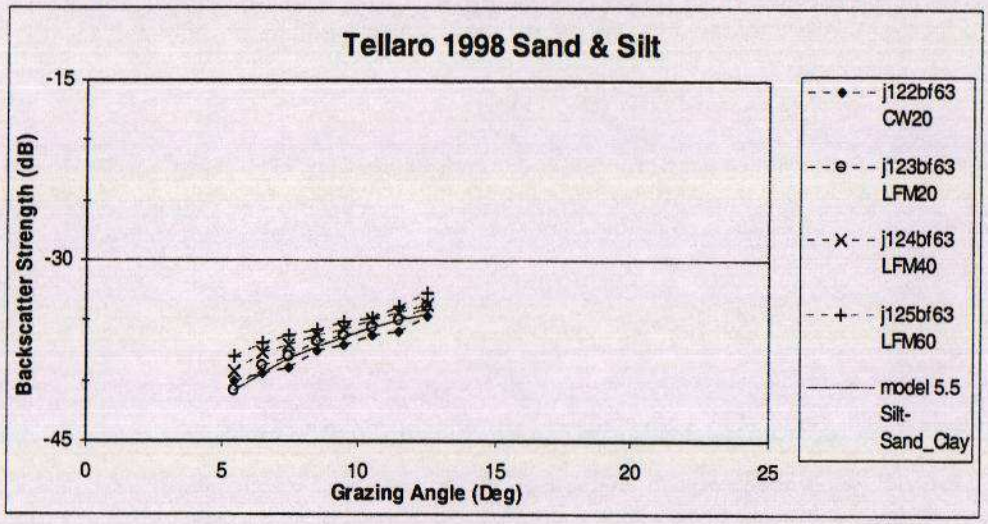
sites. In each set the solid points represent the multiple narrow beam data.Typically the curve fit through the points would be very similar for either set of results but the wide beam results tend to show more spread and variability.

Figure 7.



Comparisons have also been made between the CW results and those for different bandwidth LFM pulses. By processing the beamformed data with a matched filter, pulse compression has been applied where the BT (Bandwidth x Pulse Length) product is greater than 1. Images for the higher bandwidths show high definition detail, and in cases where an obvious shadow is present (eg Figure 2a) a possible filling in of the shadow region.Figure 8 shows an example of the comparison of backscatter strength results from these different bandwidths showing typically very similar values.

Figure 8.



No obvious sand ripples were visible at this site at the time of these measurements hence no orientation is given, and in practice the range resolution used with this system during these measurements was less than the wavelengths of any sand ripples measured. A calibrated target sphere was available in this data set and the measured increase in peak target signal to reverberation was within 0.8dB of the expected value for the 20 kHz LFM. The measured echo levels from this target sphere are being used to carry out further calibration checks on these results before inferring any trend in the backscatter strength levels due to increased bandwidth in LFM transmissions.

6. FUTURE WORK

The results presented in this paper only show a small part of what is available from a large data set of detailed and accurate high frequency wideband acoustic measurements with good supporting ground truth data. Statistical analysis of the same data is currently being carried out, as is analysis of CW data collected at other frequencies in the band, mainly for the purpose of validating the backscatter and other models used in sonar performance prediction modelling.

For some of the measurement sites data has also been collected (simultaneously with the backscatter data) using hydrophones placed both in and above the sediment in the seabed patch being studied acoustically. This was done in order to get an understanding of the acoustic penetration at these high frequencies in support of the work on more detailed acoustic modelling. To facilitate these measurements it was possible to vary the height of the array from the seabed, and hence the grazing angle (or vertical angle at which the acoustic axis intercepted the seabed) could be changed whilst keeping the patch of seabed the same (specifically the patch with the hydrophone). These data sets are also being analysed and compared with model predictions. In addition some data sets have been collected for fluctuation studies using picket fence type transmit pulses. As a result of these initial measurements it is hoped that more detailed measurement methods can be developed for both these areas.

7. CONCLUSIONS

The results shown here will be used to compare with APL-UW 9407 model backscatter strength curves generated using the ground truth data from the seabed samples at these sites once this data is available. The aim is for a better understanding of the physics at these higher frequencies and for validated backscatter strength models for use in sonar performance prediction models. Further measurements are required if the model is to cover all minehunting frequencies.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

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