BOTTOM REVERBERATION MEASUREMENTS IN DEEP AND SHALLOW WATER

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1. INTRODUCTION

1.1 Reverberation can significantly affect the performance of active sonar. For both deep and shallow water environments the seabed is often the dominant source of reverberation. The ability to predict and model seabed reverberation for different locations and frequencies is therefore highly desirable for the design and operation of active sonar systems.

1.2 Bottom scattering is usually modelled as varying with grazing angle Θ according to Lambert's rule:

$$S_b \text{ (in dB)} = K + 20 \log \sin\Theta$$

Measurements of seabed scattering at search sonar frequencies have usually shown wide variations with little correlation between scatter strength and bottom type and there is little guidance currently available as to the value for the K parameter, nor is there general agreement as to how universally applicable Lambert's rule is.

1.3 The Defence Research Agency is conducting a trials programme to measure reverberation in different areas with the aim of gaining a better understanding of reverberation mechanisms leading to improved prediction models. This programme includes measurements in both deep and shallow water.

1.4 In this paper two sets of measurements are described, one in deep water in 1990, and the other in shallow water earlier this year. These measurements give some insight into the variability of reverberation within restricted geographical areas. Measurements from the deep water area, from the edge of the Biscay Abyssal Plain, have been analysed to show the variation of scatter strength with grazing angle and frequency and show differences between different sets of data. The shallow water data come from an area outside Vestfjord, Norway. These are being analysed using a method which is intended to highlight the geographic variability and assist in identifying the causes of this variability. Only preliminary results are available from this trial. This work is sponsored by the Ministry of Defence.

2. DEEP WATER EXPERIMENT

2.1 Measurements of reverberation from an area near the edge of the Biscay Abyssal Plain were obtained during October 1990. Data were obtained during three runs within a 60x60nm box as shown in figure 1. During each run 1lb TNT charges were used as sources and measurements of reverberation made with a towed array receiver. Each run comprised a straight track at constant speed with fixed detonation and receiver depths and with the charges dropped at fixed intervals. Results presented here are from sets of ten charges detonated at 5 minute intervals with a tow speed of 5 knots. The delay required for the charge to reach the detonation depth meant that the detonation point was sufficiently close to the receiver array for the geometry to be considered to be horizontally monostatic. The detonation and receiver depths differed to ensure the survival of the latter.

2.2 A typical return from a charge received at a hydrophone of the towed array is shown in figure 2. It shows the direct-path arrival followed by successive bottom-bounce arrivals (fathometer returns)[1]. Analysis of reverberation data was restricted to the time period between the first and second fathometer returns; during this period reverberation arrives along a single path (excluding surface images) and estimates of scatter strength can be obtained. Reverberation arriving following the second fathometer return arrives at the receiver by more than one path and is therefore not suitable for estimating bottom scatter strength. This limits measurements of scatter strength in this environment to grazing angles in excess of around 30 degrees. Scatter strength was determined from hydrophone rather than beam data to avoid the need to correct for beam pattern effects.

2.3 Scatter strengths were determined by correcting for propagation losses. These were determined from straight line paths assuming spherical spreading - a reasonable assumption for the ray angles being analysed. Allowance was made for sound arriving along surface-reflected paths. A correction for refraction was included when determining grazing angles at the bottom. No adjustments were made to allow for any bottom slope - the assumption was that the seabed was effectively flat for each run.

2.4 Uncertainties due to fluctuations in propagation and scattering were reduced by averaging results over 10 charges within a run.

2.5 Frequency dependence was determined by analysing returns within third-octave bands centred on 400, 500, 630, 800, and 1000 Hz.

3. DEEP WATER RESULTS

3.1 Results were obtained from three runs, one in a flat part of the centre of the trials area with a water depth of 4720m (run 2002); one in a flat part near the southern edge of the area with a water depth of 4750m (run 1801), and the third in the south-eastern corner of the area with water depth 4700m but where the bottom sloped upwards to the south-east with a slope of about 3° (run 2203).

3.2 Figures 3 and 4 show the variation of scatter strength with grazing angle at 400 Hz and 1000 Hz respectively for each of the three runs. Also shown on these figures are curves corresponding to Lambert's Rule for various values of K. Scatter strengths were found to vary by up to 7 dB between runs. Although all results show a general increase of scatter strength with grazing angles broadly in line with that suggested by Lambert's Rule, some divergences from Lambert's Rule are apparent, particularly at lower grazing angles. It is notable that there is about a 5dB difference in scatter strength between the runs in the two flat areas (runs 2002 and 1801) and that these runs show the greatest divergence from Lambert's Rule. The data from the run with a sloping bottom - the run which might be expected to show the least similarity to Lambert's Rule - instead provides the best fit.

[1] The time scale origin is arbitrary and does not correspond to the instant of detonation.

3.3 The collection of discrete sets of data at different locations does not enable causes of differences in observed reverberation levels to be identified easily. There are no apparent differences between the environment for runs 2202 and 1801 that might account for the difference in reverberation levels between these runs nor has it been possible to identify the reason for it.
3.4 Figure 5 shows the variation of scatter strength with frequency. There appears to be a tendency for scattering strength to reduce as frequency decreases, but this variation is no greater than $f^{0.5}$.

4. SHALLOW WATER EXPERIMENT

4.1 A further sea trial was conducted in May 1994 on the continental shelf outside Vestfjord in Norway in an area 20nm long by 10nm wide with water approximately 400m deep shown in figure 6. The objective of this trial was to determine whether differences in reverberation level could be observed that correlated with bathymetric features or with variations in bottom type. The area had slightly deeper water along the central axis and towards the northwest. The bottom sediment was mud and sand with sediment depth varying from 0 to 150m within the area. Measurements were obtained along several tracks through the area.

4.2 Measurements were made using a towed sound source and a 32-element towed array receiver. Both were deployed to similar depths with the receiver about 200m behind the source. Measurements were made at 930 Hz using a 1 second pulse with 10 Hz bandwidth. The choice of bandwidth was determined as a compromise between the need to ensure a high reverberation to ambient noise ratio within the band and the need to reduce the high variability inherent with single-frequency measurements.

5. PRELIMINARY SHALLOW WATER RESULTS

5.1 Accurate determination of scatter strength is difficult in shallow water environments because of the large number of multipaths and uncertainties in propagation loss because of bottom interactions. No attempt has so far been made to determine absolute values of scatter strength. Attention has been concentrated instead on determining the variability of reverberation levels within the area. A novel analysis and display method was used. This produced a map of the geographical variation of reverberation within a single beam as the ship moved along each track, in effect using the system as a sidescan sonar.

5.2 A typical reverberation plot is shown in figure 7. This shows reverberation levels in the broadside beam along a single pass through the trials area. The different grey levels show reverberation decreasing with distance from the ship's track with the central gap corresponding to the area close to the ship's track blanked out by the pulse transmission. The plot is symmetrical about the ship's track because of the left-right ambiguity of the towed array. Along-track resolution is determined by the beamwidth and pulse repetition rate. Each elemental reverberant area often contributed to returns from successive pulses and the reverberation level associated with each pixel is the average over all pulses to which it contributed. This provides enhanced along-track resolution and assists in reducing the effect of random fluctuations.

5.3 This type of display of raw reverberation level is unsuitable for analysing geographic variability of scatter strength as the rapid reduction of reverberation with range masks any more subtle changes. A better indication of variations in reverberation level can be determined by subtracting an average reverberation decay curve from the raw reverberation levels. The resulting scan for one track is shown in figure 8. This shows variations of up to 6dB within the swath[2].

5.3 The analysis method used offers the ability to monitor variations in reverberation level over an extended area. The good resolution of the system in beamwidth and range should assist in determining where changes in reverberation occur and identify whether they can be associated with bottom features. Echo-sounder traces were taken throughout the areas and it is hoped that a reasonable assessment of bottom bathymetry can be made. At the current early stage of analysis it has not been possible to identify whether the observed variability is be due to random effects, propagation loss changes, or to changes in bathymetry or bottom type.

5.4 There is some evidence that reverberation returns from different tracks have different average decay curves and that greater variability may be apparent when results from different tracks are compared. The magnitude of track-to-track variability seems to be only of the order of a very few dB. This low variability appears slightly surprising given the variability observed in the deep water area and suggests that bathymetry features and variations in sediment depth may not be particularly significant in this shallow water environment.

5.5 A further line of analysis that will be adopted is to look at scans from different beam directions. By considering different beams, returns from similar areas can be compared for different propagation paths and arrival directions. This may assist in identifying the effect of bottom slopes.

5.6 The analysis method used for shallow water should also be applicable for analysis of deep water data although in this case it may be necessary to restrict its application to regions between fathometer returns. This is because differences in the time of arrival in fathometer returns due to changes in water depth are likely to swamp the expected smaller differences in the subsequent reverberation. Analysis of deep water data by this method may give some insight into the cause of variability in deep water reverberation measurements.

6. SUMMARY AND FUTURE DEVELOPMENTS

6.1 Both the deep and shallow water results show positional variation in reverberation levels. In the deep water case this variability is some what surprising with results for adjacent areas with no apparent significant environmental differences showing variation of scatter strength of the order of 5dB. Measured scattering strengths and their variation with grazing angle are broadly compatible with those expected from Lambert's Rule, but some divergence from Lambert's Rule is apparent at grazing angles between 30 and 45 degrees for some runs. Some slight variation of scatter strength with frequency is apparent.

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[2] This figure is not to the same scale as figure 7 in order to assist reproduction, with only 6dB between lightest (highest) and darkest areas.

6.2 In shallow water, where variability might be expected to be higher, results of preliminary analysis suggests that variability may be no higher than that observed in deep water. The method of analysis should permit comparisons to be made between reverberation variability, bathymetric features, and changes in bottom type although no attempt has yet been made to do this.

6.3 As part of its ongoing trials programme, DRA will be obtaining data from additional areas during forthcoming trials. It is hoped that data sets will be collected that will permit the left-right towed array ambiguity to be resolved and that this may further assist in identifying the causes of changes in reverberation level.

6.4 The analysis method should be applicable to deep water data and it is hoped to apply it both to existing data and to data from forthcoming trials.

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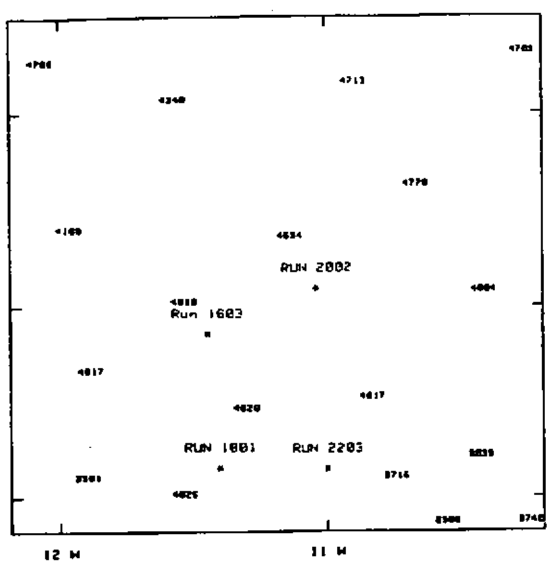

Figure 1: Deep water trials area

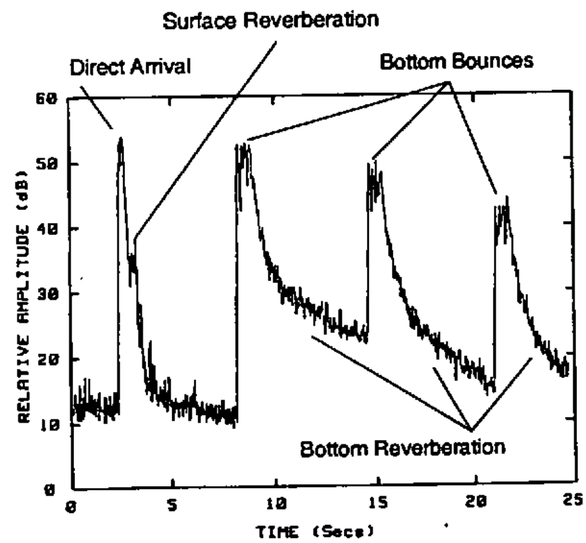

Figure 2: Typical deep water reverberation return

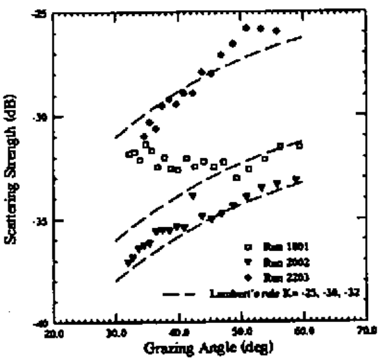

Figure 3: Variation of deep water bottom backscatter strength with grazing angle - 400Hz

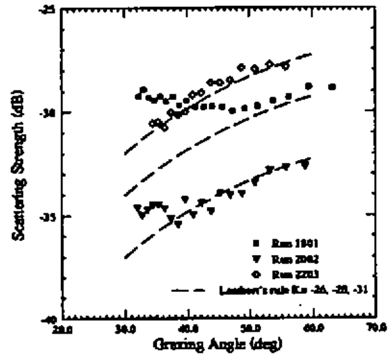

Figure 4: Variation of deep water bottom backscatter strength with grazing angle - 1000Hz

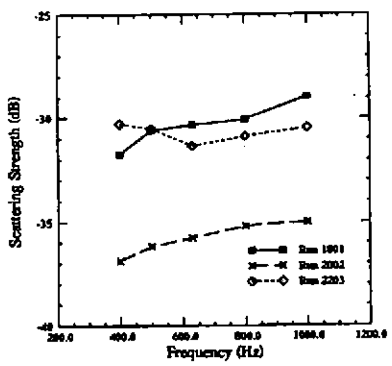

Figure 5: Frequency dependence of deep water bottom backscatter

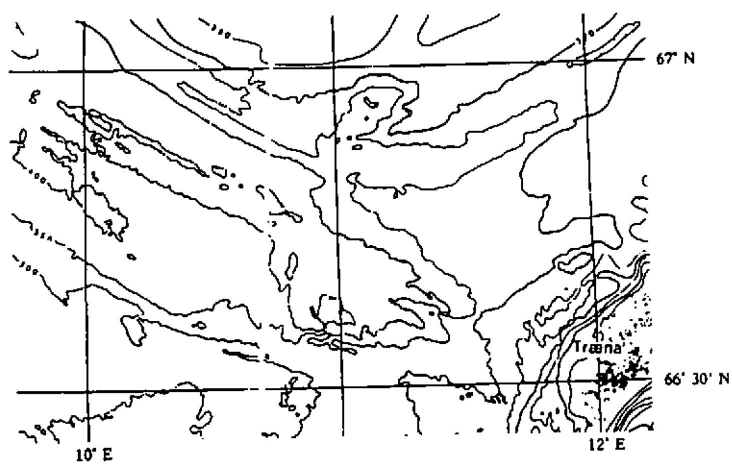

Figure 6: Shallow water trials area

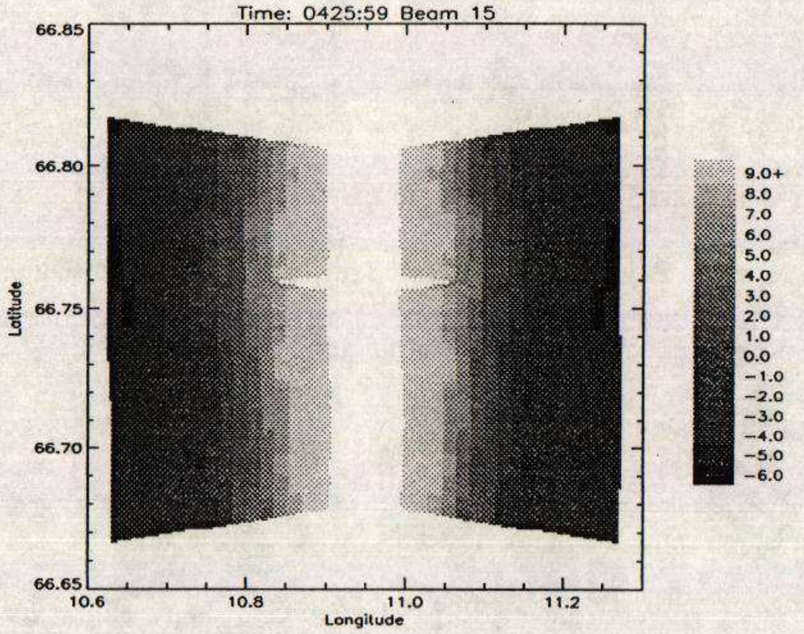

Figure 7: Shallow water reverberation levels

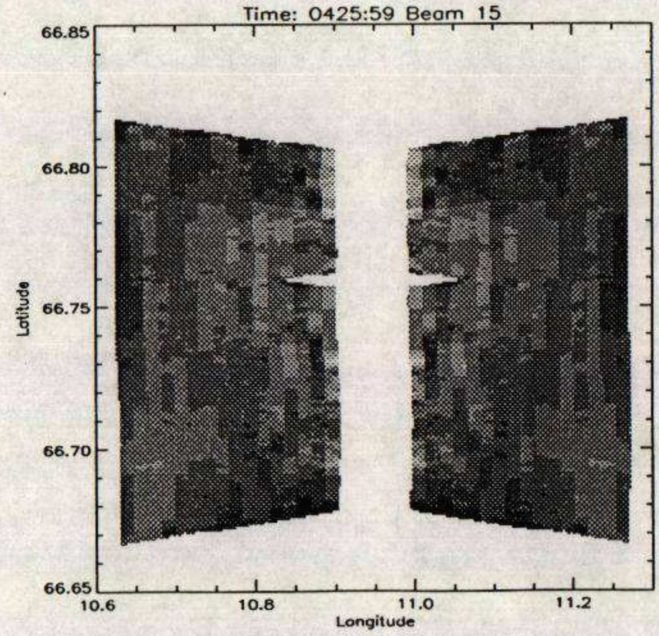

Figure 8: Variations in shallow water reverberation

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