Image Cover Sheet

CLASSIFICATION	SYSTEM NUMBER 517164
UNCLASSIFIED	

TITLE

Boundary 2001 REA: Model-data comparison at the Stratform and Scotian Shelf sites using GSM and manual fits to the reverberation data

System Number:

Patron Number:

Requester:

Notes: Paper #17 contained in Parent Sysnum #517147

DSIS Use only:

Deliver to: CL

This page is left blank

This page is left blank

#516164 (17)

Boundary 2001 REA: Model-Data Comparisons at the Strataform and Scotian Shelf Sites using GSM and Manual Fits to the Reverberation Data

Dale D Ellis[†] and John R Preston[*]
[†]*Defence Research Establishment Atlantic, Dartmouth, Nova Scotia, Canada*
[*]*Applied Research Laboratory, the Pennsylvania State University, State College, PA, USA*

Abstract
During the Boundary 2001 experiment, long-range reverberation data were collected on several SACLANTCEN towed horizontal line arrays This report uses some of that data, and compares it with model predictions from the Generic Sonar Model To achieve the agreement, the bottom loss and scattering functions were manually adjusted to produce a reasonable fit to the data All the work was conducted at sea during the trial period, so the results can be considered the output from a REA (Rapid Environmental Assessment) exercise, similar to the approach used by Ellis *et al* [SACLANTCEN Report SR-280, 2000] in the NATO REA exercises Rapid Response The estimates can now be compared with other results from the experiment, namely direct scattering measurements, and more sophisticated inversion techniques such as simulated annealing

Introduction

Boundary 2001 was the second sea trial in a three-year Joint Research Program between Canada, the United States, and SACLANT Undersea Research Centre (SACLANTCEN). The purpose of the program is to make direct measurements of the boundary interactions – scattering and bottom loss in particular – that affect low-frequency reverberation in shallow water. A further aspect of the analysis is the comparison of the direct measurements with the estimates of bottom loss and scattering extracted from model-data comparisons between reverberation data and model predictions. Our contribution is the latter part.

Most of the work will be presented elsewhere by other authors This paper describes the model-data comparisons and bottom estimates obtained at sea during the sea trial from 10 May to 2 June 2001. This is very much a REA (Rapid Environmental Assessment) approach, with procedures very similar to those done during the Rapid Response series of experiments [1, 2], and the Boundary 2000 experiment. A manual inversion procedure, using simple bottom loss and backscattering parameters together with the Generic Sonar Model (GSM) [3], was used [4]. Better fits to the data can be obtained [5, 6], using a more complicated bottom model and a simulated annealing approach, this was not attempted at sea.

As in previous experiments, the data were gathered on horizontal line arrays towed behind the NATO Research Vessel *Alliance*. Generally a five-sided "petal" pattern was used, to resolve the left-right ambiguity of the array Details of the procedure are given in Ref. 4. The main receivers were the SACLANTCEN 256-m LF (low-frequency)

Prakla array and the 32-element 5.6-m MF (mid-frequency) array; these were deployed as a dual tow The sources were 0 8-kg SUS charges During Boundary 2001, three petal-patterns were run, two on the Stratform region off the United States New Jersey coast, and one on the Canadian Scotian Shelf between Halifax and Sable Island. This report describes some model-data comparisons for three petal patterns. As mentioned before, all the data analysis and model predictions were performed at sea, so the latter site, done in the last few days of the trial, had very little time devoted to modelling it. Other data were taken using the SACLANTCEN Atlas source and cardioid array, but not analysed at sea.

Petal-pattern P02 (Strataform Site C1.5)

The water depth for petal pattern P01 was too shallow to deploy the 90-m SUS charges, so only the Atlas source and MF array were used, these data were not available at sea for modelling Petal pattern P02 was run on 15 May, centered at N 39° 16.0' W72° 43 0' in about 118 m of water The headings on the legs of the petal pattern are 139°, 002°, 220° (rerun at 036°), 070°, and 289°; the compass on the Prakla (LF) array was not working, so the heading estimates are from records of the ship heading The Prakla array was initially deployed at a depth of 15 m (5 turns on the winch), rose to 5 m on the initial leg 3, then was lowered to 30 m (10 turns) for the remaining legs The MF array was deployed with 19 turns, later 38 turns, its depth was close to that of the LF array Two 90-m SUS charges were dropped on each leg, for the first charge the gains on the LF array were initially 18 dB, and changed to 36 dB after about 10 s; for the second SUS the gain was initially 0 dB, then changed to 36 dB. On the MF array the gains were 12 and 24 dB respectively for the first SUS, and 0 dB and 24 dB on the second SUS The sea state was about Beaufort 4 during the experiment.

Figure 1 shows the XBTs near site P02 on the day of the experiment. The XBTs seem to be spatially dependent, and more dependent on the water depth than on temporal variability A more extensive survey of the XBTs was conducted by Baldasserini [7]

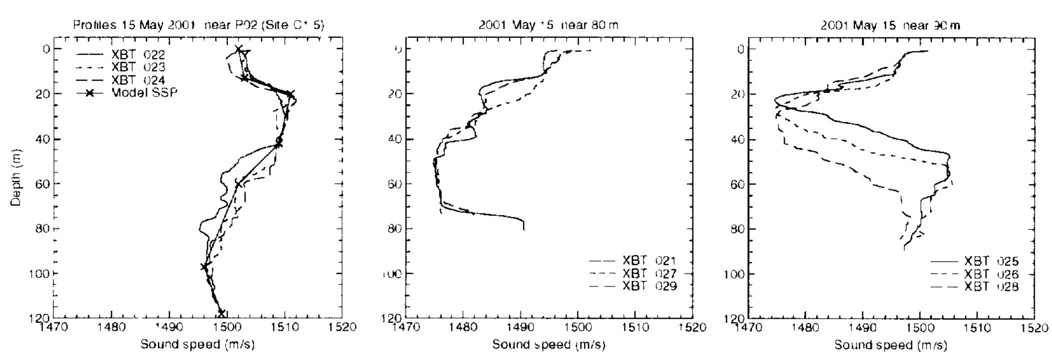

Figure 1 On the left, sound speed profiles, and simplified profile used for modelling The other two figures show profiles at two shallower water depths

Figure 2 shows the reverberation on the broadside beams from each leg at 350 Hz (maximum array aperture and resolution) Some of the spikes around 10 seconds are related to the gain change (18 to 36 dB). The reverberation traces from all 5 headings are remarkably consistent, except near 30-50 seconds, where shelf-break features seem to be causing enhanced reverberation

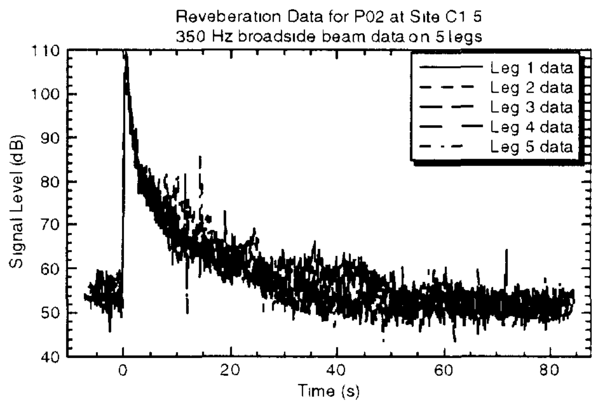

Figure 2 Broadside beam data in 350 Hz band, on all 5 legs of petal pattern P02.

For modelling, a half-space model was chosen for the bottom loss, after adjusting the parameters to fit the 630 Hz data, the acoustic parameters were chosen to be sound speed 1650 m/s, density (relative to water) 1 7, and attenuation 0 5 dB/m-kHz The reflection loss is shown in Fig 3a Reasonably good fits to the data were obtained using the Generic Sonar Model, and varying the strength of the Lambert scattering coefficient for the various frequencies Figure 3b shows a typical scattering function used in the modelling, in this shallow-water environment, the steep-angle facet strength and width are not determined by the data, and are program defaults. For computational efficiency, the monostatic mode of GSM was used, with source and receiver at the array depth of 30 m

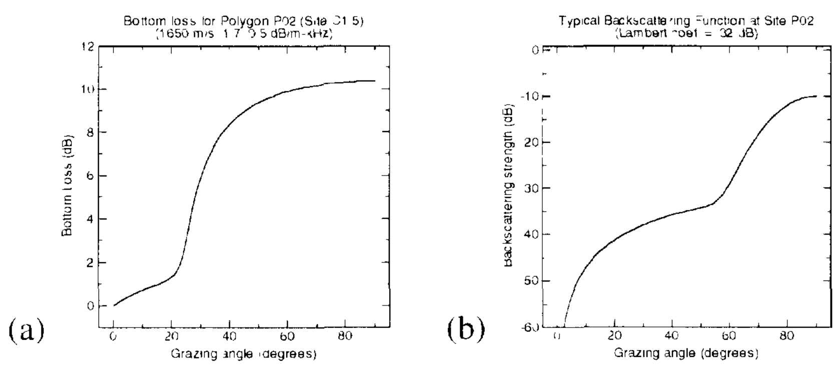

Figure 3. (a) Bottom reflection loss curve, corresponding to the geoacoustic halfspace; (b) typical backscattering function, with a Lambert scattering coefficient of −32 dB, the steep-angle dependence is due to our default values, and not determined from the data.

Various model-data comparisons are shown in Figs. 4 and 5, for several beams at 630 Hz, and for the broadside beam at 160, 350, 630, and 1400 Hz. With the constant geoacoustic half-space, there seems to be an increase in the scattering with frequency, see Table 1 There is also an indication that the bottom loss should be higher at lower frequencies and less at higher frequencies. With a half-space model, that would require a lower sound speed, (or higher attenuation) at low frequencies, this is not what one might expect It may be that there is is a more reflective (higher sound speed) layer near the surface, and lower sound speed below The details of an optimum solution are beyond the "manual inversion" approach, and best left to direct measurements [8] or simuated annealing [6] to determine a set of parameters that fit the data.

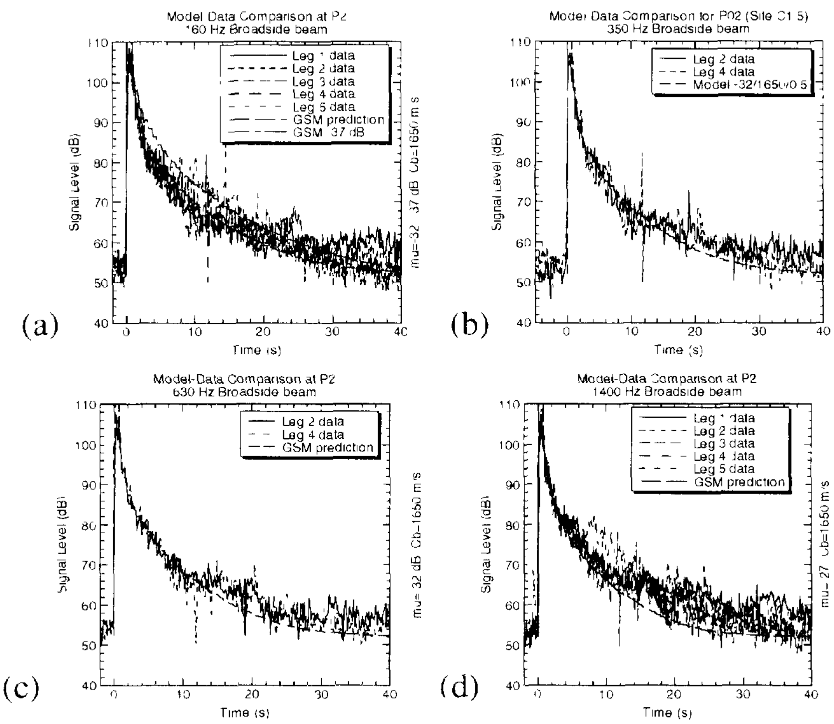

Figure 4 Model data comparisons at various frequencies for the broadside beam. (a) 160 Hz, (b) 350 Hz; (c) 630 Hz, (d) 1400 Hz The geoacoustic model was determined with the 630 Hz data, and for the other frequencies only the scattering strength was adjusted. Note that for 160 Hz, other bottom loss fits were tried

To get a feeling for the overall quality of the predictions over all beams, the model-data differences at 350 Hz are plotted in Fig 6, and overlain on the bathymetry The fits at short times (ranges) are reasonably good (0 dB, the blue-"orange" colour transition) To the right aft of the array heading (black arrow), note the high scattering starting just beyond the shelf break, it also appears on the ambiguous beam. These range-dependent features are not treated in the flat-bottomed model that we are using

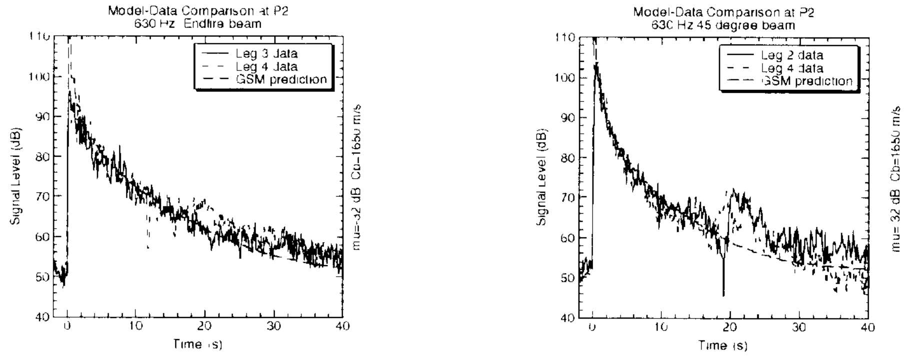

Figure 5 Model data comparison at 630 Hz, for aft endfire beam and beam 45 degrees from aft endfire.

Frequency (Hz)	Lambert Coefficient (dB)
160 Hz	–37
350 Hz	–32
630 Hz	–32
1400 Hz	–27

Table 1 Summary of scattering strengths from manual fit in petal pattern P02.

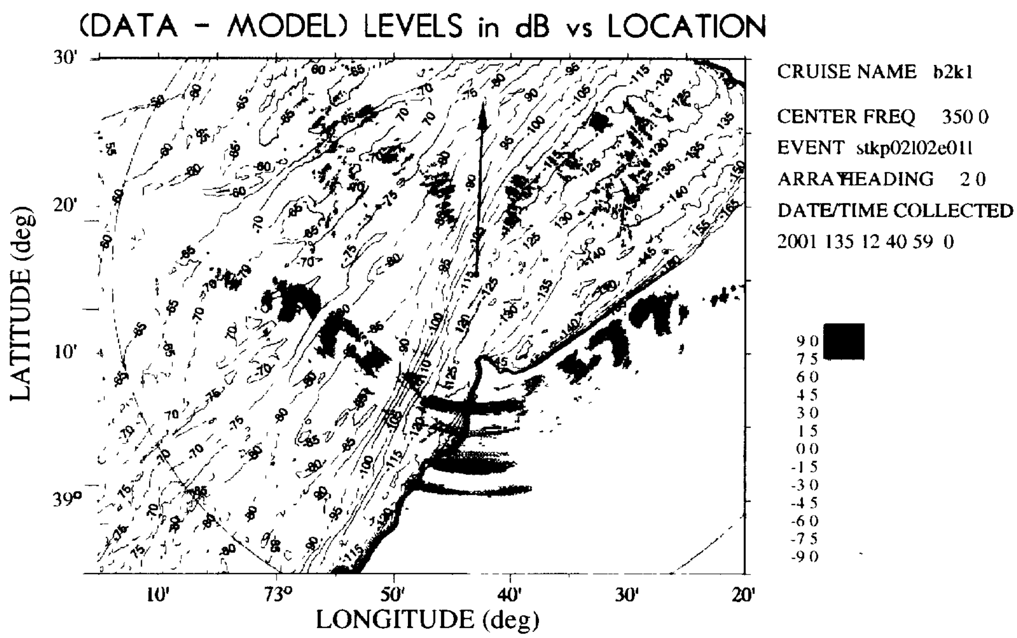

Figure 6. Polar plot of model-data differences at 350 Hz.

Petal Pattern P03 (Stratform Site C3)

Another petal pattern P03 was run on 17 May 2001 at Site C3, centered at N 39° 18' W 72° 31', in about 140 m of water The ship's headings on the legs of the petal pattern were 152°, 199°, 054°, and 276°, only 4 legs were completed On Leg 1 the LF array had a number of noisy hydrophones, on Legs 2, 3 and 4 the data quality was better The LF array and MF arrays were deployed at about 70 m, with cable scopes of 26 and 97 turns respectively The SUS nominal depth was 90 m, so an average depth of 80 m was used for modelling with the monostatic version of GSM

The sound speed profile was nearly isovelocity, with some structure shallower than 60 m. Figure 7 shows two measured sound speed profiles, and the simplified composite used for modelling

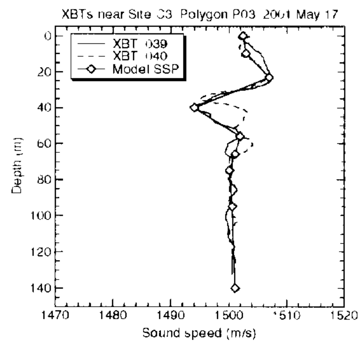

Figure 7 Measured sound speed profiles for P03, and composite used for modelling

Figure 8 illustrates the manual approach to obtain a match with the data from the broadside beam for petal pattern P03. Leg 1 was chosen since the broadside beam has the least interaction with scattering features on the shelf edge The geoacoustic model for petal pattern P02 was the starting point, but falls below the data in the 5 to 20 s region Two lower loss models were tried, one with a lower absorption coefficient 0.1 dB/m-kHz, and another with a higher sound speed, 1700 m/s. The first is clearly far off, and the second, although it improves things at short times, does not provide a good fit to the rate of decay of the reverberation. Increasing the Lambert coefficient to –30 dB from –32 dB seems to provide a better fit Perhaps even more loss is called for to match the decay and provide a match beyond 20 seconds; the last two curves increase the loss by almost an identical amount, decreasing the bottom sound speed to 1630 m/s, or increasing the attenuation to 0 7 dB/m-kHz Our best fit is essentially the same geoacoustic model as for P02, but with the attenuation increased from 0 5 to 0 6 dB-m/kHz.

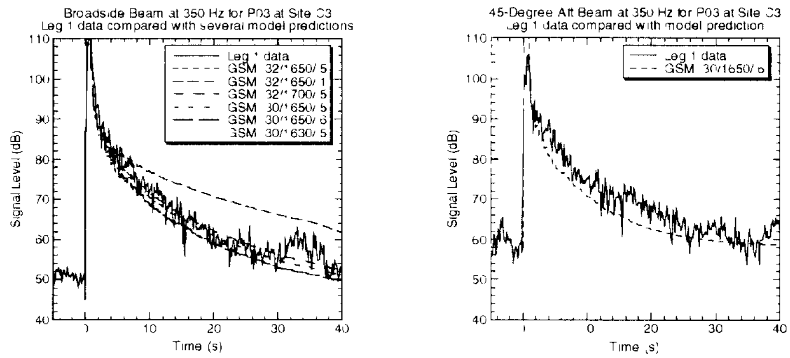

Figure 8 (a) Broadside beam data for petal pattern P03 compared with successive iterations of the manual procedure, (b) data from P02 for beam pointed 45°aft of broadside, compared with model prediction

Petal pattern P04 (Scotian Shelf)

Petal pattern P04 was conducted (mainly) on 29 May 2001 in the vicinity of Site C4, centered at N 44° 11 0' W 61° 8 5', on the Scotian Shelf, in about 80 water depth The legs were at nominal headings of 153°, 018°, 219°, 084°, and 112°, (the final leg was run on 31 May, with both monostatic and bistatic sources) There were problems with the SUS charges, and foggy weather, so a number of the SUS drops were delayed and did not occur near the centre of the petal pattern The DREA Research Vessel *Quest* dropped some SUS charges for bistatic measurements, and, to help align the LF array for monostatic measurements, provided a 2-s beacon ping at 1380 Hz, 157.6 dB re 1 µPa at 1m

Figure 9 shows four sound speed profiles in the area, and a composite profile used in the modelling The water depth used for modelling near Site C4 was 78 m The SUS charges had a nominal detonation depth of 18 m, and the arrays were towed near 30 m depth, the source depth used in GSM was 21 m.

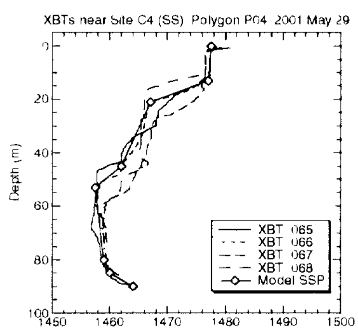

Figure 9. Sound speed profiles on Scotian Shelf, and composite profile used for GSM model predictions

Figure 10 shows some data from the broadside beam for two legs at 350 Hz There were one or more seismic survey vessels in the area, booming loudly around 37 Hz and spilling over into much of the other spectrum, Leg 3 was particularly affected

Figure 10 also shows an initial modelling attempt for the Site The "Strataform" P02 bottom parameters seem to provide a reasonable fit to the data. The Lambert scattering coefficient is –32 dB, but due to the lower water sound speed at the bottom (1464 m/s vs 1499 m/s), the seabed sound speed is reduced to about 1610 m/s, the relative density (1 7) and seabed attenuation (0 5 dB/m-kHz) are not significantly changed A slightly higher bottom loss (attenuation coefficient 0 6 dB/m-kHz) seemed to give a better slope to the reverberation time series. Other beams and frequencies need to be run to determine a better estimate of the bottom loss and scattering

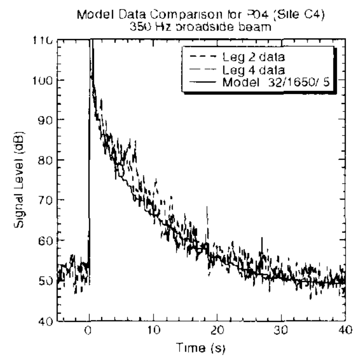

Figure 10. Initial data and model runs for Scotian Shelf, for broadside beam at 350 Hz.

Summary

The polar plots, e g Fig 6, provide information about the anisotropy of the reverberation At short times, these sites (by design) show much less anisotropy than any of the previous sites we have visited for REA analysis [1, 8]

The mean reverberation, and model predictions, were remarkably similar at all sites A similar bottom model and scattering seemed to provide a reasonable fit at all sites, see Table 2 for 350 Hz As indicated in Table 1, Site P02 indicated a frequency dependence of the scattering strength The frequency analysis was not done for the other sites

Site	**Relative Density**	**Sound Speed**	**Attenuation Coefficient**	**Lambert Coefficient**
P02 / Site C1 5	1.7	1650 m/s	0 5 dB/m-kHz	–32 dB
P03 / Site C3	1.7	1650	0 6	–30
P04 / Site C4	1 7	1610	0.5	–32

Table 2. Summary of extracted properties at 350 Hz

Due to our data processing parameters and limited dynamic range of the measurement system, a measure of the high-angle bottom properties was not possible in these shallow water sites.

We found the manual inversion procedure more difficult at the Boundary 2001 sites compared to previous sites, perhaps because of the relatively shallow water. It may be that the reverberation data do not contain much information about the bottom properties other than a low-angle "dB per degree" for the bottom loss, and a simple measure of the scattering, such as the Lambert coefficient.

All the work was conducted at sea during the trial period, so the results can be considered the output from a REA (Rapid Environmental Assessment) exercise similar to the approach used in Rapid Response [4]. They can now be compared with other results from the experiment, namely direct scattering measurements (such as Ref. 9), and more sophisticated inversion techniques such as simulated annealing (Ref. 6).

Acknowledgements

We are most appreciative of the crew of the NATO Research Vessel *Alliance*, and the dedicated personnel from SACLANTCEN.

The Generic Sonar Model from the US Naval Underwater Warfare Centre is instrumental to our work.

This work was supported in part by ONR Code 32, Grant N00014-97-1-1034.

References

[1] J. R. Preston and D. D. Ellis, "Summary of bottom reverberation findings and model/data comparisons during three rapid environmental assessment trials," in CDROM *Collected Papers from the Joint Meeting "Berlin 99"*, Deutsche Gesellschaft für Akustik (DEGA), eds., Universität Oldenburg, Physik/Akustik, Oldenburg, Germany, 1999, Paper 2aUWb3, 4 pp.

[2] D. D. Ellis and J. R. Preston, "Extracting sea-bottom information from reverberation data," in CDROM *Collected Papers from the Joint Meeting "Berlin 99"*, Deutsche Gesellschaft fur Akustik (DEGA), eds., Universität Oldenburg, Physik/Akustik, Oldenburg, Germany, 1999, Paper 2aUWb10, 4 pp.

[3] H. Weinberg, "The Generic Sonar Model," Naval Underwater Systems Center, New London, CT, USA, Technical Document 5971D, June 1985.

[4] D D. Ellis, J. R. Preston, R. Hollett, and J. Sellschopp, "Analysis of Towed Array Reverberation Data from 160 to 4000 Hz During Rapid Response 97," SACLANTCEN Report SR-280, July 2000.

[5] J. R. Preston, "Automated Bottom Parameter Extraction from Reverberation Data with Examples from LWAD and HEP Data," Applied Research Laboratory, TM 00-169, 25 October 2000.

[6] J. R. Preston, "Bottom parameter extraction from long range reverberation measurements," to appear in Proceedings of Oceans 2001, Honolulu, Hawaii, USA, November 2001.

[7] G. Baldasserini, SACLANTCEN, informal communication, May 2001.

[8] C. W. Holland *et al.*, draft SACLANTCEN report, to appear in 2002.

[9] C. W. Holland, "Shallow Water Coupled Scattering and Reflection Measurements," SACLANTCEN Report SR-344, 2001.