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MODELLING MULTIBEAM REVERBERATION WITH AN NX2D MODEL

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Abstract: The SWAMI (Shallow Water Active-sonar Modelling Initiative) toolset in use at DRDC Atlantic contains modules to produce predictions of transmission loss, reverberation, signal excess, and probability of detection. The toolset includes a capability to consider many source and receiver configurations from omnidirectional to line-arrays (horizontal and vertical) to volumetric arrays. The environment can vary both azimuthally and radially (Nx2D). This paper presents measurements made through a Joint Research Project with the NATO Undersea Research Centre called BASE 04 (Broadband Active Sonar Enhancement 2004). The towed-array reverberation data and associated model predictions using the SWAMI reverberation model are presented.

1. INTRODUCTION

Figure 1 shows a chart of the Malta Plateau where data were collected on June 1st, 2004 by the Canadian research ship, *CFAV Quest*, as part of a joint research project with the NATO Undersea Research Center. A Low-Frequency Active (LFA) source [1,2] was used in conjunction with the receiver array DASM (Directional Acoustic Sensor Module) [3] to record reverberation time series. The DASM array provides both improved reverberation suppression and target discrimination as compared with an array of omnidirectional hydrophones. The DRDC Atlantic system and data collection are presented elsewhere [4].

The SWAMI (Shallow Water Active-sonar Modelling Initiative) toolset [5,6] is under continual development at DRDC Atlantic. Originally based on normal mode theory, it has been extended to include Gaussian Ray Bundle [7] and Gaussian Beam [8] approaches for modelling the acoustic propagation. The toolset includes components to simulate array directivities, transmission loss, reverberation, signal excess, and probability of detection.

The remainder of this paper will focus on a description of the SWAMI reverberation model, environmental data, acoustic data, and model predictions.

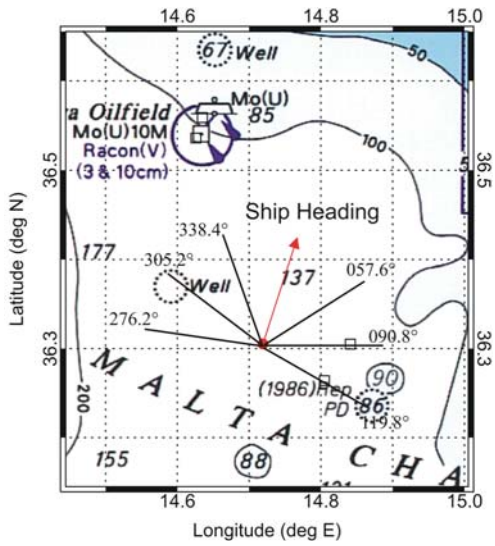

Fig.1 Malta Plateau environment. Black lines are the radials used for the model calculations. The red line represents the array heading.

2. REVERBERATION MODEL

The SWAMI reverberation model consists of an Nx2D technique where a full beam set is calculated in parallel [5]. The reverberation time series for a given beam consists of the summation of the contributions from each of the N radials. The N radials form an environmental model consisting of N range-varying descriptions of the ocean and seabed. The beams represent the output of the signal processing (beamformer). In the example presented here, the radial angles align with the beam steering angles. The model has been documented in detail in previous works [5,6]. The only difference between the previous references and the current application is the addition of the GRAB model [7] as a means to predict the propagation loss between the source, scatterer, and receiver.

3. EXPERIMENT

The data were collected on June 1st, 2004, at approximately 12:26UTC with the ship at 36°18.317' N, 14°43.154' E. The ship's course and speed were 018.0°T and 2.5 m/s, respectively.

The DASM receiver array consists of 94 directional sensors with 0.5 m spacing [4]. One hundred and twenty beams were formed with equal spacing in the cosine domain assuming a sound speed of 1500 m/s. The receiver was towed at a depth of approximately 66 m. Only three beams will be considered in detail. The source consisted of a vertical pair of Free Flooding Ring projectors [1,2]. The source transmitted a 1.25 s Hyperbolic Frequency Modulated (HFM) waveform with 50 Hz bandwidth centred at 1125 Hz with a source level of 217 dB re 1μPa @ 1m.

Figure 2 shows a reverberation map associated with the ping. This image represents the output of the matched filter (replica correlator) without decimation. The black arrow represents the ship position and heading. Broadband interfering targets dominate beams steered at 108°T (Broadside), 144°T, 252°T, 288°T (broadside), and 344°T. Reverberation from the Ragusa Ridge is shown as a high scattering feature to the east side of the ship.

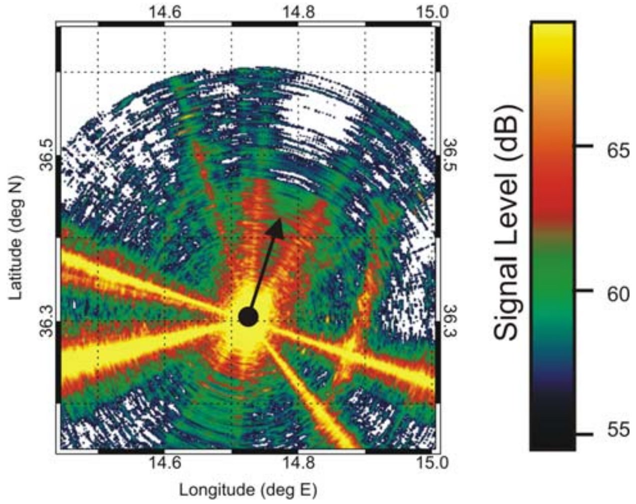

Fig.2 Reverberation map.

3.1 Environment

Three beam steering directions were selected, and bathymetry data were examined to obtain 60 km long profiles centred on the DASM and radiating at 057.6°T, 090.8°T, and 119.8°T from the central point. The conjugate beams in the case of an omni-only array would be at 338.4°T, 305.2°T, and 276.2°T (Figure 1). Six radials were chosen to align with the beam steering and conjugate directions. The bathymetric profiles were estimated from available data [9] with a spatial resolution of 500 m. Although the environmental database does not give depths below 400 m (Figure 3(a)), this is not a concern because the areas with shallower depths dominated the reverberation.

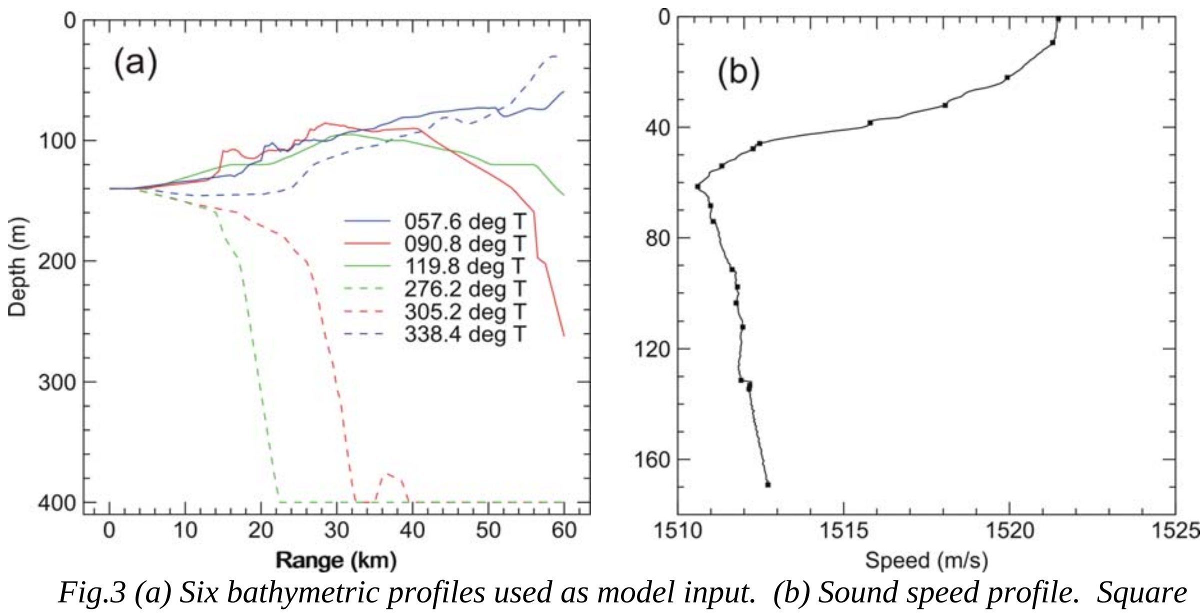

Fig.3 (a) Six bathymetric profiles used as model input. (b) Sound speed profile. Square boxes indicate the decimated profile used as a model input.

The sound speed profile calculated from an eXpendable BathyThermograph measurement near the time and location of the data was selected to be representative of the oceanographic conditions (Figure 3(b)). A subset of 21 values, containing the sound-speed inflection points, was extracted from the profile to provide the sound-speed profile to be used in modelling. The decimated profile was extended using a constant gradient to the seabed for deeper locations. The use of a single sound-speed profile is likely to be a source of error as there is significant variability in the area [10].

The monostatic reverberation model (MONOGO) used SWAMI beam patterns, GRAB eigenrays, the sound-speed profile (Figure 3(b)), the bathymetric profiles (Figure 3(a)), and scattering parameters to calculate the reverberation for a specific beam-steering angle. The constant bottom scattering strength, based on Lambert's law scattering with –27 dB/m^2, was used for simplicity and is not a limitation of the model. The generation of the eigenrays using GRAB assumed Bechmann-Spezzichino surface loss with wind speed of 7.5 m/s and an MGS [11] bottom loss province of 6. Though the model allows range-dependent bottom loss, a constant was used for simplicity. This will be further discussed in context of the data.

3.2 Results

Figures 4(a) and 4(b) represent the two beams on either side of broadside, with steering directions of 090.8°T and 119.8°T. The broadside beams have not been included since they were dominated by interfering noise from transiting vessels (see Figure 2). The time series "Measurement" curves represent a moving 0.1 s average of the output of the beamformer, rather than the matched filter shown in Figure 2.

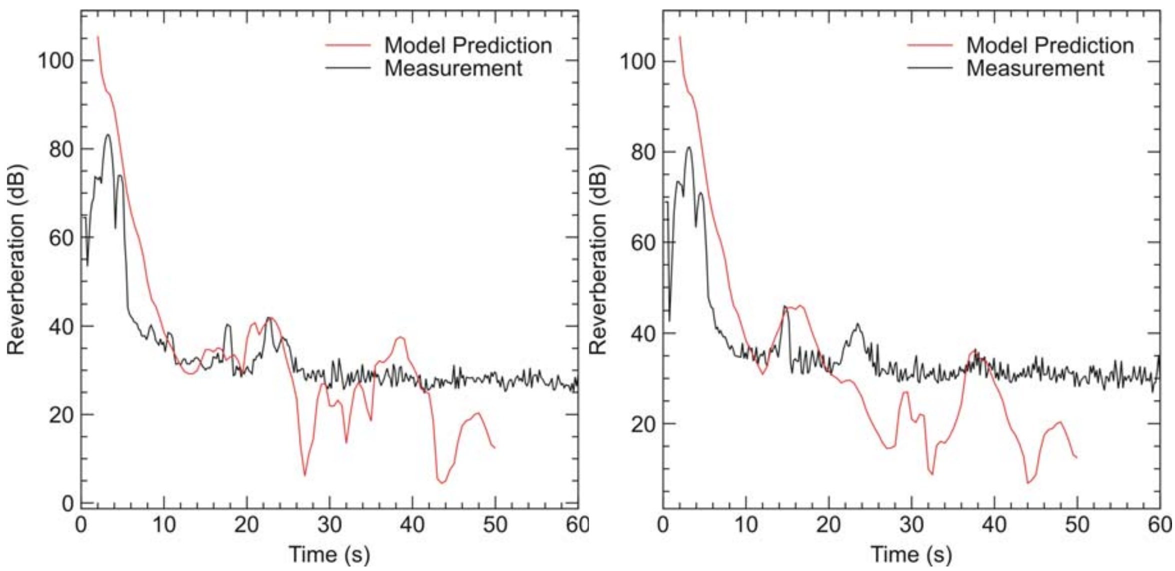

Fig.4 (a) Model and data comparison from beam steered at 090.8°T. (b) Model and data comparison from beam steered at 119.8°T.

Even with a simple model of the environment, the reverberation model predictions show reasonable agreement with the data at most ranges, however some features in the model prediction do not present themselves in the data. At short ranges, the modelled reverberation decays at a similar rate to the data. In Figure 4(a), the relatively constant ambient noise floor dominates the majority of the time beyond 25 s, Though the computational model includes a provision for ambient noise, it has not been included in generating these figures. Bottom properties and surficial sediment thickness in the area vary from high loss to medium loss depending on position [12,13]. Allowing the bottom loss and scattering strength to vary in regional patches may address the discrepancies between the model and measurement.

Figure 5 shows the model and data comparison for a beam near the endfire direction. Again, the general trends are consistent between the data and prediction. In this case, the predicted reverberation levels are higher (> 10 dB at some ranges) than the observed noise floor. Although lowering the scattering strength for the entire study region would decrease the reverberation level below the noise, the other parameters used in the environmental model (constant bottom loss, small number of radials, etc.) could also be reconsidered.

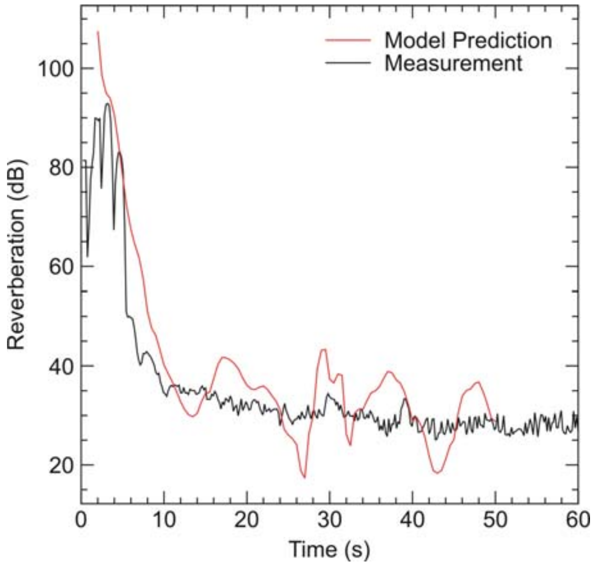

Fig.5 Model and data comparison from beam steered at 057.6°T.

4. CONCLUSION

This paper has shown the agreement between SWAMI reverberation model predictions and measured reverberation time series with a 6-radial environmental model. Near the endfire direction, the model predicts more structure and higher levels than observed. The beams near broadside show reasonable agreement. In both cases, introducing a beam-dependent ambient noise estimate and a more complex environmental model may improve the model-data comparison.

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REFERENCES

[1] Barry, P.J., Hutton, J.S., and Franklin, J.B. Dual Free Flooding Ring Towed Projector Array, DREA Technical Memorandum TM 92/214, 1992.

[2] Bonin, Y.R., Gallaher, A.B., Purcell, C., and Hardie, D.J.W. Comparing Predictive Methods for a Ring Projector, in *Proc. Inst. of Acoustics*, 17(3): 44-53, 1995.

[3] Theriault, J.A. and Hood, J. Using Directional Sensors to Enhance the Performance of the Towed Receiver Array of Active Sonar, in *Proc. of UDT Hawaii 2004*, Waikiki, Hawaii, October 2004.

[4] Theriault, J.A., Hood, J., Hazen, D.G. and Beslin, O. Comparison of Arrays of Directional versus Omnidirectional sensors using BASE ’04 Data, in *Proc. of the Eighth European Conference on Underwater Acoustics, ECUA 2006*, Carvoeiro, Portugal, June 2006.

[5] Ellis, D.D. and Theriault, J.A. Model-Data Comparisons of Shallow-Water Reverberation in Range-Dependent Environments, in *Proc. of the Fifth European Conference on Underwater Acoustics, ECUA 2000*, Lyon, France, July 2000.

[6] Theriault, J.A. and Ellis, D.D. Shallow-Water Low-Frequency Sonar Modelling Issues, in *Proc. Oceans '97*, Halifax, Canada, October 1997.

[7] Keenan, R.E. An Introduction to GRAB Eigenrays and CASS Reverberation and Signal Excess, in *Proc. Oceans 2000*, Vol. 2. 1065-1070. Providence, RI. US, September 2000.

[8] Porter M.B. and Bucker H.P. Gaussian Beam Tracing for Computing Ocean Acoustic Fields, J. Acoust. Soc. Am., 82(4), 1349-1359, 1987.

[9] Data courtesy K. LePage, Private Communication.

[10] Pecknold, S.P., Hines, P.C., Ellis, D.D., Dosso, S., McCammon, D. and Giles, P. Effect of Environmental Variability on Transmission Loss During The Base '04 Experiment, in *Proc. of the Eighth European Conference on Underwater Acoustics, ECUA 2006.* Carvoeiro, Portugal, 12-15 June 2006.

[11] Yarger, D. F. The Users Guide for the RAYMODE Propagation Loss Program. NUSC Technical Memorandum 222-10-76. Naval Undersea Systems Center, New London, Conn. US 1976.

[12] Osler J. and Algan O. A High Resolution Seismic Sequence Analysis of the Malta Plateau, SACLANTCEN Report SR-311. SACLANTCEN, La Spezia, Italy, 2000.

[13] Turgut A., Gauss R. and Osler J. Measurements of Velocity Dispersion in Marine Sediments During the Boundary '04 Malta Plateau Experiment, in *Proc. MTS/IEEE Oceans Conf. 2005*, Washington, D.C., USA, September 2005.