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A comparison of measured time series arrivals with predictions from the Becky and WATTCH models

Sean P. Pecknold
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Defence R&D Canada – Atlantic

Technical Memorandum
DRDC Atlantic TM 2004-250
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Canada

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Abstract

The results of an experiment from DRDC Atlantic sea trial Q283 (the Broadband Adaptive Sonar Experiment 2004) are described. In this experiment, a measurement of the direct arrival strength of a ping from the Vertical Projector 2 (VP2) with the DASM (Directional Acoustic Sensor Module) array was conducted. The purpose of this measurement was to observe any changes in the signal envelope of waveforms transmitted from the VP2. The measurements of the direct path arrival and other arrivals were compared to model predictions for waveform arrival amplitude and times from two models: the WATTCH (WAveform Transmission Through a CHannel) program (used in conjunction with the Generic Sonar Model), and the Becky model. Bottom parameters and source-projector separation were then re-estimated based on the differences between model and data.

Résumé

Le présent rapport décrit les résultats d’une expérience réalisée dans le cadre de l’essai en mer Q283 de RDDC Atlantique (expérience du sonar adaptatif à large bande 2004). Dans cette expérience, on a mesuré l’intensité de réception d’une impulsion s’étant propagée par trajet direct à partir du projecteur vertical 2 (VP2) avec le réseau de DASM (module de détection acoustique à effet directif). Cette mesure visait à déceler tout changement de l’enveloppe du signal émis par le VP2. On a comparé les mesures effectuées relativement au signal transmis par trajet direct et aux signaux transmis par d’autres trajets avec les prévisions d’amplitude et de temps de réception des signaux fournies par deux modèles : le modèle WATTCH (WAveform Transmission Through a CHannel, propagation des formes d'onde dans un canal), utilisé conjointement avec le modèle générique de sonar, et le modèle Becky. Les paramètres du fond et la séparation source-projecteur ont ensuite été réévalués en tenant compte des différences entre les modèles et les données.

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Executive summary

Introduction

The results of an experiment conducted during DRDC Atlantic sea trial Q283 (the Broadband Adaptive Sonar Experiment 2004) are described. This experiment involved a measurement of the direct arrival of a ping from the Vertical Projector 2 (VP2) with the DASM (Directional Acoustic Sensor Module) array. The purpose of this experiment was to determine whether changes in the signal envelope were occurring on the transmission of a waveform from the VP2. Results from the experiment were used to compare model predictions for waveform arrival amplitude and times from the WATTCH (WAveform Transmission Through a CHannel) program (in conjunction with the Generic Sonar Model), with the measured data. The same was done with predictions given by the Becky model. Bottom parameters and source-projector separation were then re-estimated based on the differences between model and data.

Results

The results of the comparison of received data to model predictions suggested that the Becky and WATTCH models could be used to model acoustic propagation in the experimental environment. The comparison also highlighted where the models were sensitive to input data. In addition, the bottom loss parameters of the experimental area were estimated by comparing the model results to the experimental data. This suggested a less reflective bottom than originally thought.

Significance

The validation of the WATTCH model for simulating propagation of broadband waveform transmissions in shallow water environments provides an important tool for modeling acoustic communications and active sonar propagation in littoral waters. Additionally, the combination of projector and towed array used in this experiment is seen to provide a tool for bottom loss parameter estimation. Potentially, given a true omnidirectional source or a complete source beampattern calibration, the measurements described could prove valuable for rapid environmental assessment of bottom loss for a set of grazing angles and for bottom loss model validations.

Further Work

Further comparisons of data with model predictions from Becky and WATTCH are warranted. Although no further work is currently planned, previously acquired experimental data might be used to test the capabilities of the VP2 and DASM arrays to perform direct measurements of bottom loss vs. grazing angle.

Sean P. Pecknold and Dale D. Ellis. 2005. A comparison of measured time series arrivals with predictions from the Becky and WATTCH models. DRDC Atlantic TM 2004-250. Defence R&D Canada – Atlantic.

Sommaire

Introduction

Le présent rapport décrit les résultats d'une expérience réalisée dans le cadre de l'essai en mer Q283 de RDDC Atlantique (expérience du sonar adaptatif à large bande 2004). Dans cette expérience, on a mesuré l'intensité de réception d'une impulsion s'étant propagée par trajet direct à partir du projecteur vertical 2 (VP2) avec le réseau de DASM (module de détection acoustique à effet directif). Cette expérience visait à déterminer si l'enveloppe du signal subissait des changements au cours de la propagation à partir du VP2. On a utilisé les résultats de l'expérience pour comparer les prévisions d'amplitude et de temps de réception des signaux fournies par le modèle WATTCH (WAveform Transmission Through a CHannel, propagation des formes d'onde dans un canal), utilisé conjointement avec le modèle générique de sonar, avec les données mesurées. On a effectué la même comparaison pour les prévisions fournies par le modèle Becky. Les paramètres du fond et la séparation source-projecteur ont ensuite été réévalués en tenant compte des différences entre les modèles et les données.

Résultats

Les résultats de la comparaison des données de réception avec les prévisions fournies par les modèles portent à croire que les modèles Becky et WATTCH pourraient être utilisés pour modéliser la propagation acoustique dans l'environnement expérimental. La comparaison a en outre fait ressortir les conditions dans lesquelles les modèles sont sensibles aux données d'entrée. De plus, on a estimé les paramètres de perte au fond de la zone expérimentale en comparant les résultats des modèles avec les données expérimentales. Cette comparaison semble indiquer que le fond est moins réfléchissant qu'on l'avait cru initialement.

Portée

La validation du modèle WATTCH pour la simulation de la propagation des formes d'ondes à large bande en eaux peu profondes constitue un outil important pour la modélisation des communications acoustiques et de la propagation des signaux du sonar actif dans les eaux littorales. De plus, la combinaison du projecteur et du réseau remorqué utilisée dans l'expérience est considérée comme un outil pour l'estimation du paramètre de perte au fond. Si une source véritablement omnidirectionnelle ou un étalonnage de forme de faisceau de la source en entier était utilisé, les mesures décrites pourraient se révéler utiles pour l'analyse environnementale rapide des pertes au fond pour un ensemble d'angles d'incidence et pour des validations de modèle de pertes au fond.

Recherches futures

Il y a lieu d'effectuer d'autres comparaisons des données avec les prévisions des modèles Becky et WATTCH. Même si on ne prévoit pas effectuer d'autres recherches pour le moment, les données expérimentales déjà acquises pourraient être utilisées pour évaluer les capacités du VP2 et des réseaux de DASM aux fins de la mesure directe des pertes au fond en fonction de l'angle d'incidence.

Sean P. Pecknold et Dale D. Ellis. 2005. *A comparison of measured time series arrivals with predictions from the Becky and WATTCH models* (Comparaison des valeurs mesurées de l'intensité de réception sous forme de séries chronologiques avec les prévisions des modèles Becky et WATTCH). RDDC Atlantique TM 2004-250. R & D pour la défense Canada - Atlantique.

Table of contents

List of figures

List of tables

Acknowledgements

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1. Introduction

1.1 Broadband pulse propagation modeling

There are a number of situations in which it is desirable to model broadband time series propagation of a signal through an underwater environment. In particular, both for underwater communications and sonar performance estimates, the ability to accurately model multiple arrivals and signal distortion caused by the environment can be important. DRDC Atlantic has developed a coherent pulse-propagation model, the WATTCH (WAveform Transmission Through a CHannel) model [1]. It is designed to propagate an arbitrary waveform time series through a potentially range-dependent environment. Figure 1 gives an overview of the WATTCH model concept.

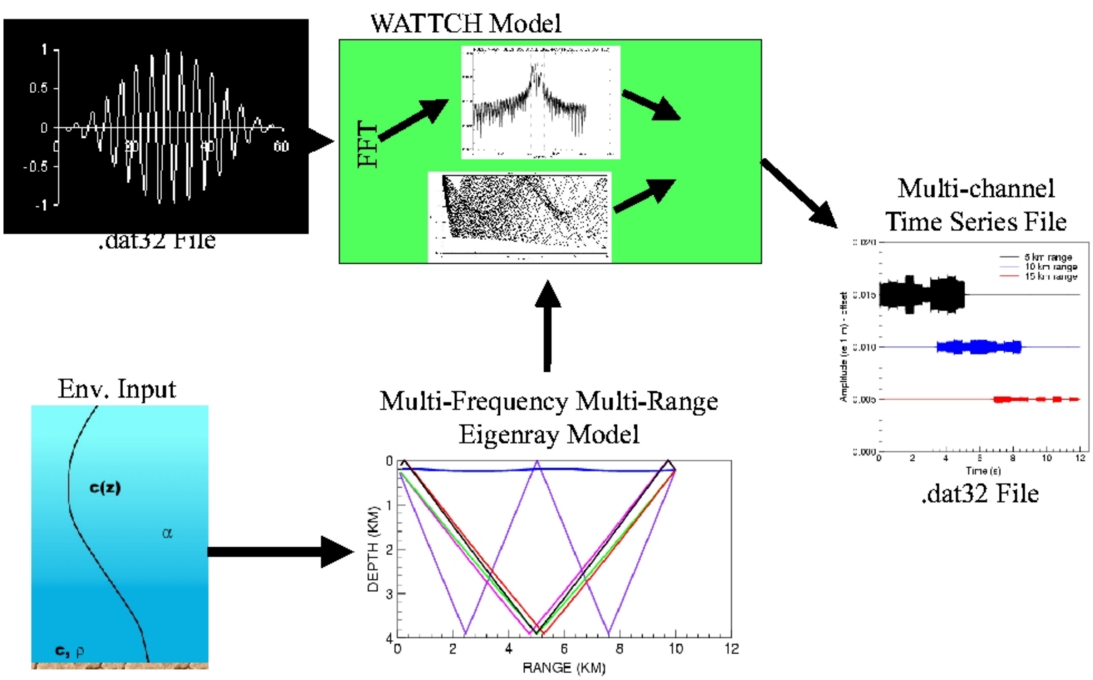

Figure 1. *WATTCH model concept.*

A broadband pulse-propagation model is essentially a convolution of the broadband pulse time series with the environmental transfer function. The choice of propagation model used to calculate this environmental transfer function is largely dependent on the modeling regime required. In the examples presented, we are interested in near one kilohertz-range frequencies in moderately shallow to deep environments. Westwood [2] claimed that a ray-theory based model could contain all of the relevant physics for the problem of interest. This approach is also less computationally demanding than either a direct computation in the time domain or alternative propagation models such as OASES [3](a fast-field model).

WATTCH is a frequency- and phase-dependent program that accepts as input a transmitted acoustic waveform and a set of propagation data. These data can include source angle, time of travel, phase changes due to boundary interactions, and propagation loss for a range of frequencies through the bandwidth of the transmitted waveform. The program that generates the model predictions described below uses a multipath expansion model, the US Generic Sonar Model (GSM) [4] to calculate eigenrays for a particular environment. GSM itself is a range-independent model, but the WATTCH model can accept information from range-dependent models as well, including CASS/GRAB [5] and Bellhop [6]. WATTCH performs an FFT on the acoustic waveform, then, using eigenray data interpolated through the frequency range for FFT magnitudes and phases, integrates the data to calculate the acoustic magnitude and phase at the receiver. In essence, it combines the eigenrays generated by GSM with a given waveform and determines what the receiver would see, producing a timeseries of the resulting pulse or waveform. The WATTCH model has been compared to OASES [7,8] (in a range-independent environment), showing good agreement with greatly reduced computation time.

The Becky model, which will be used for comparison, is a simplified time-domain ray-path model. It calculates the amplitude and time-of-arrival of rays between a source and a receiver in a simplified range- and frequency-independent environment. It is constrained to an isovelocity water column over a bottom halfspace, and no surface reflection losses or phase changes are included. Although the model is greatly simplified, it should provide a good first estimate in benign water conditions for a narrowband signal.

1.2 The TIAPS system

The data used for comparison with the WATTCH and Becky models were collected during DRDC Atlantic sea trial Q283, also called BASE04 (Broadband Adaptive Sonar Experiment 2004), a joint trial with the NATO Undersea Research Centre. The data were collected using the TIAPS (Towed Integrated Active Passive Sonar) system, located on DRDC research vessel *C.F.A.V. Quest*. The TIAPS system is comprised of two major elements: the dry end, or signal processing and display suite; and the wet end, or sources and sensors (shown in Figure 2).

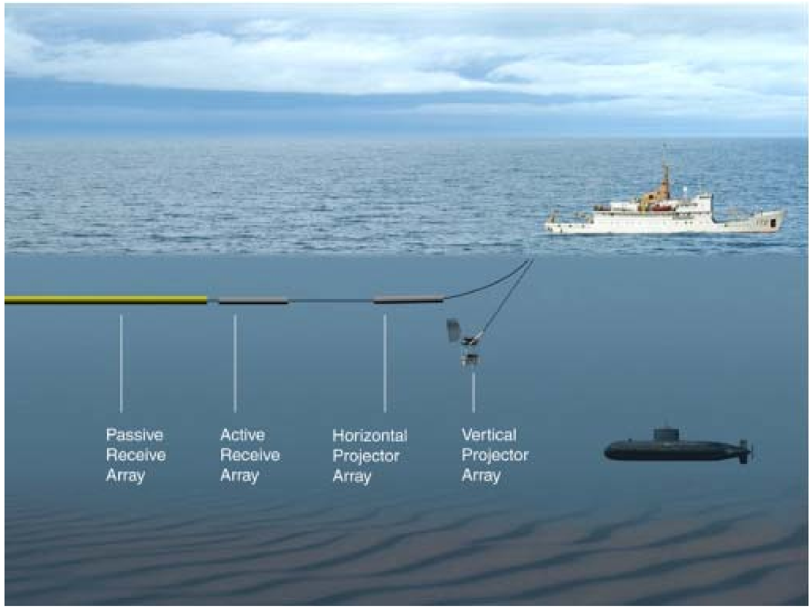

Figure 2. *TIAPS system (wet-end).*

The TIAPS wet end includes the VP2 (Vertical Projector 2), a variable-depth array consisting of two free-flooding ring projectors with good source level at frequencies near 1 kHz, and DASM, the Directional Acoustic Sensor Module, an active receive array of 96 elements. Each element is made up of one omnidirectional sensor and one roll-resolved directional sensor. The array is designed to receive signals in the 500 Hz to 1500 Hz range. The datasets used in the following sections are taken from the omnidirectional DASM sensors.

The TIAPS system also includes both a passive receive array and a horizontal projector array. Neither of these arrays were used in this experiment.

2. Experiment description

During DRDC Atlantic sea trial Q283 an experiment was performed that was intended to test the envelope of the VP2 (Vertical Projector 2) output signal to ensure that it was not clipping or being amplitude modulated. This test was performed by pinging six times from the VP2 and measuring the received levels on the DASM (Directional Acoustic Sensor Module). This took place at approximately 17:30 Z on June 3, 2004, in the Mediterranean Sea, in water depths between 268 m and 270 m. The weather was clear and the sea state was 1. The VP2 and DASM arrays were being towed at 5 knots by *C.F.A.V. Quest*.

Two types of pings were transmitted: the first type (used for the first three pings) was a 50 ms LFM (linear frequency modulation) from 1200-1300 Hz with default 10% Tukey shading. The second (used for the last three pings) was a 0.5 s LFM from 1050-1450 Hz, again with default 10% Tukey shading. The VP2 depth at this time was 93.2 m, with a transmit power of -24 dB from max (first three pings) and -36 dB from max (last three pings). The likely position of the VP2 is offset by about 35 m aft, based on tow angle information at 5 knots [9]. The measurements of receive level were performed using two of the omni-directional channels of the DASM array, with nominal sensitivity inclusive of pre-amp of -165 dB/V. The channels used corresponded to a) channel 44 of the recorded DRDC .DAT32 format data file [10], i.e. acoustic channel 12 of VCI (Virtual Channel Identifier) 102, and b) channel 224, the last omnidirectional acoustic channel of VCI 104. The physical positions of these channels are a) 80 m from the forward end of the array, and b) 35 m from the forward end. The cable scope was 223.8 m, at a depth of 91.3 m. The experimental configuration, along with a schematic of the direct path and surface paths, is shown in Figure 3.

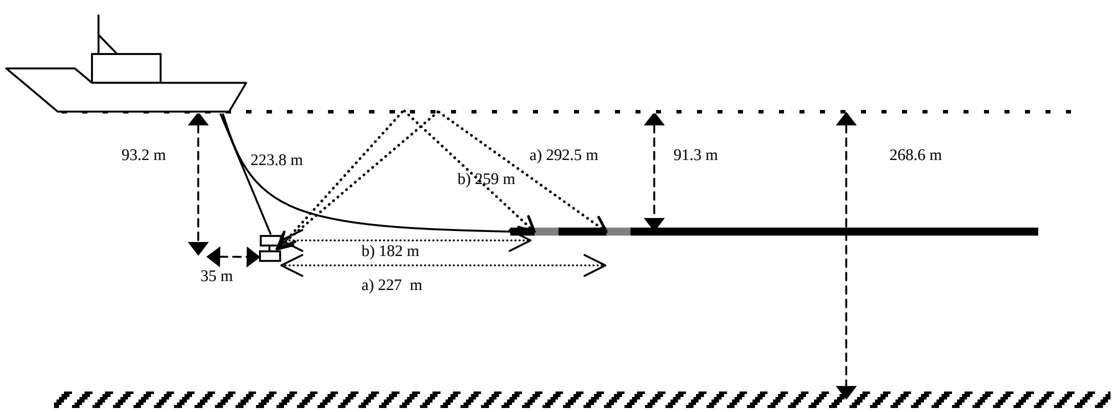

Figure 3. *Experimental configuration.*

The difference measured between time of arrival for the pings on the far channel and recorded ping generation times is 0.15 s, with 0.12 s being the difference between ping generation time and received time on the near channel. This corresponds to distances of 182 m for the near channel and 227 m for the far channel. It is expected that the shape of the tow cable would be characterized by a parabola (assuming constant force caused by drag along the length of the cable) or a catenary (assuming that most of the drag is caused by the array). The array itself is close to neutrally buoyant. For a parabola, the distance between the projector and the first receiver would be 157 m; a catenary gives a distance of 190 m, therefore the distance of 182 m is consistent.

The sound speed profile, as measured by an XBT with assumed salinity of 35 ppt, for the time and position of the experiment is shown in Figure 4. The sound speed at source and receiver depth was 1515 m/s. The path difference between direct path and surface bounce for channel 224 is about 77 m, or 51 ms. The path difference for channel 44 is 66 m, or 44 ms.

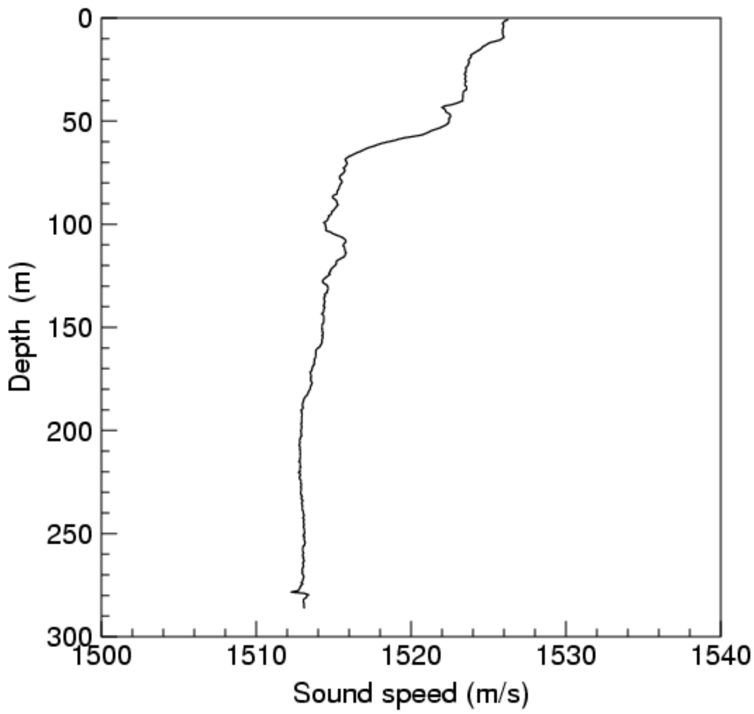

Figure 4. *Sound speed profile.*

3. Analysis

3.1 VP2 output signal envelope

Figures 5 and 6 show examples of the time series data collected, with amplitude in volts plotted against time in seconds from the beginning of the file. Figure 5 shows a 50 ms ping transmitted at 17:32:41 at 24 dB below maximum power, measured on the DASM acoustic channel number 44. Figure 6 shows the 0.5 s ping transmitted at 17:34:18, measured on channel 224 and transmitted at 36 dB below maximum power.

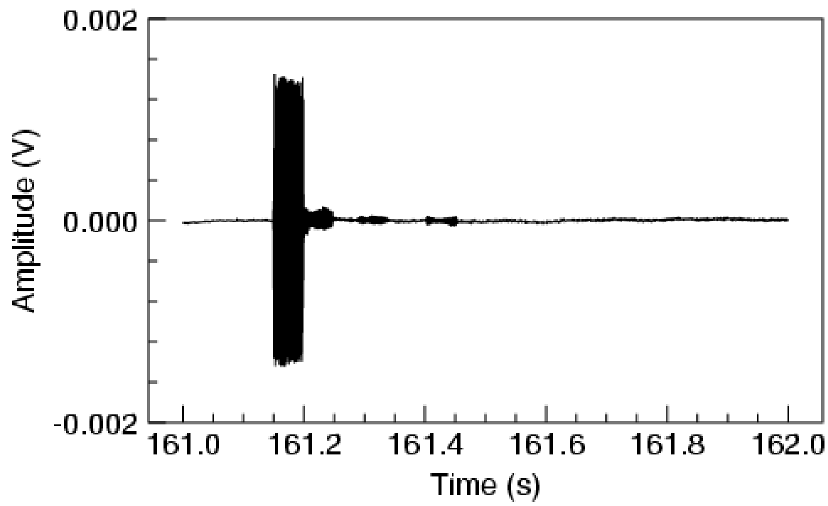

Figure 5. *Received time series for 50 ms ping transmitted at 17:32:41, channel 44.*

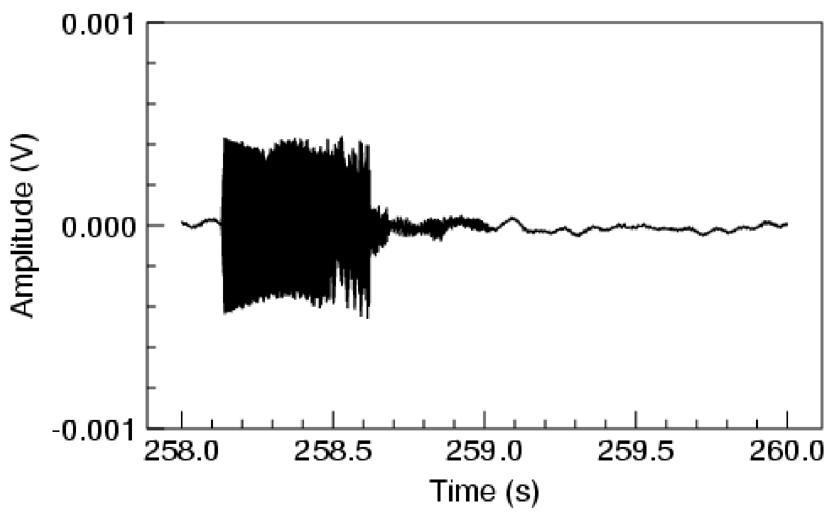

Figure 6. *Received time series for 0.5 s ping transmitted at 17:34:18, channel 224.*

The receive levels were within the dynamic range of the DASM array and no clipping was evidenced in any of the pings.

3.2 Model comparison

3.2.1 Becky

A comparison can now be made between the received data and two model predictions. The first model predictions are made using the Becky model [11]. The Becky model is a simple time-domain ray-path model. It assumes an isovelocity water column (sound speed 1515 m/s, as measured) over a bottom half-space, with no surface loss. To generate the predictions in this case, the model was altered to allow for the inclusion of a transmit beam pattern. The VP2 beam pattern used is based on a 1250 Hz signal with an approximate empirical fit based on calibration data as shown in [9]: calibration data was not tabulated, but was estimated from the graphs. Figure 7 shows the pattern from the empirical fit for two frequencies, using the formula:

$$b(\lambda,\theta) = 2\left(0.2306\cos\left(-1.32\pi\frac{\sin\theta}{\lambda}\right) + 0.1664\cos\left(0.02\pi\frac{\sin\theta}{\lambda}\right) + 0.103\cos\left(0.82\pi\frac{\sin\theta}{\lambda}\right)\right)$$

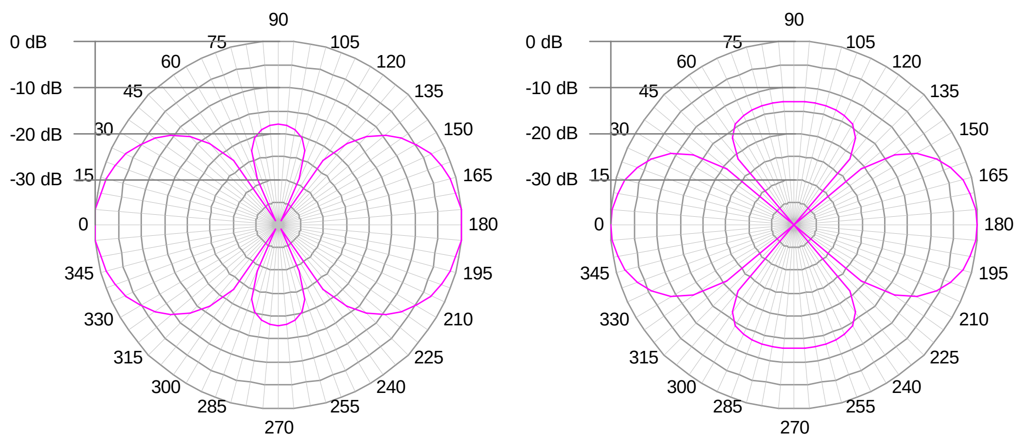

Figure 7. *Beam pattern used for VP2: 1 kHz (left), 1.25 kHz (right).*

Figures 8 and 9 show a comparison of the measured data with the Becky prediction, for two source-receiver separations, 182 m (Fig.8) and 227 m (Fig.9). Both predictions are based on the 50 ms pulse length described above, with a depth of 268.6 m. The model prediction is scaled in amplitude according to the actual receive levels. The bottom loss corresponds to a bottom half-space of 1650 m/s, relative density of 1.9, and attenuation of 0.8 dB/m-kHz. The model includes two bottom bounces.

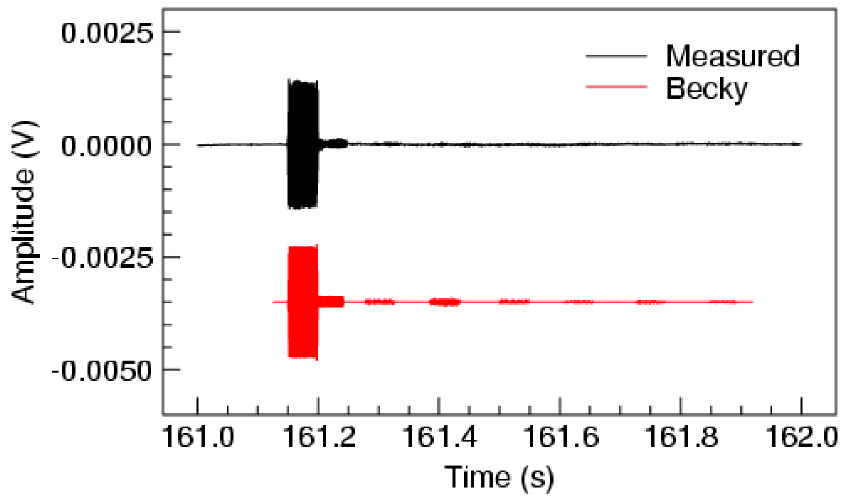

Figure 8. *50 ms ping transmitted at 17:32:41, channel 44 (far), with modeled output from Becky.*

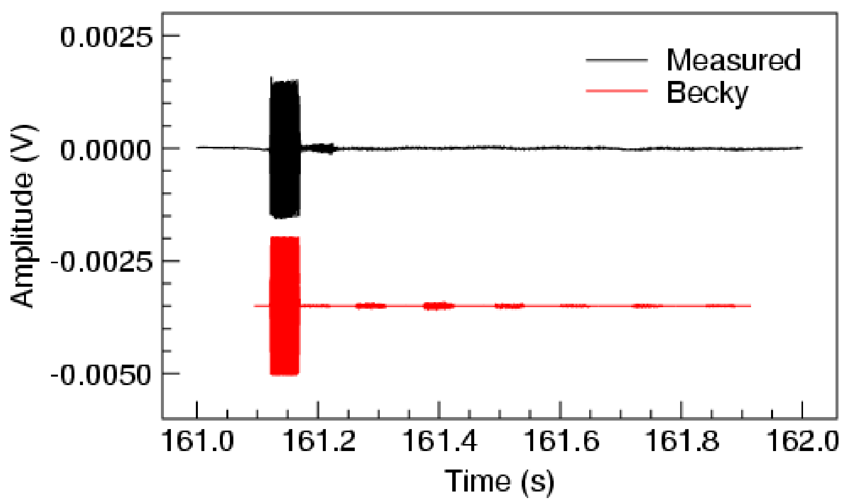

Figure 9. *50 ms ping transmitted at 17:32:41, channel 224 (near), with modeled output from Becky.*

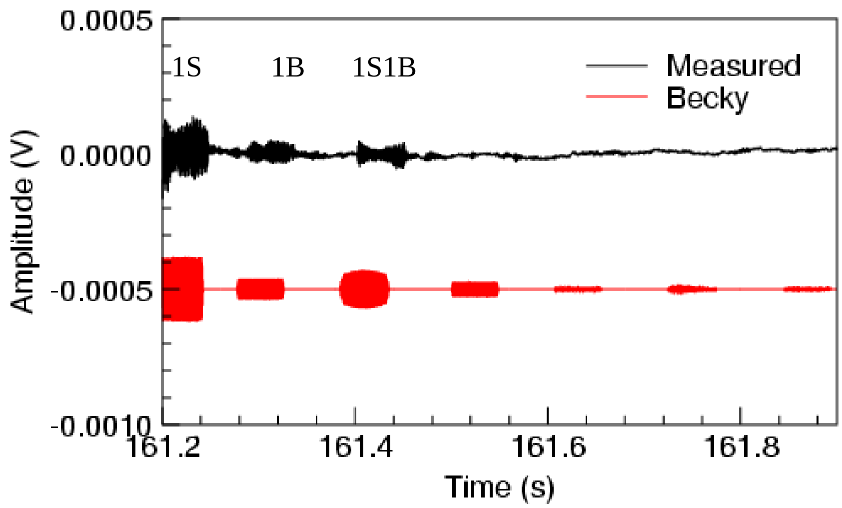

Figure 10. *50 ms ping transmitted at 17:32:41, channel 44 (far), with modeled output from Becky: non-direct arrivals.*

Figure 10 zooms in on the later arrivals for the data and model found in Figure 8. The model prediction appears to be advanced relative to the data. The arrival time for the first surface reflection, measured by the end of the arrival, is 10 to 15 ms advanced in the model, as is the first bottom bounce. The third arrival (surface-bottom) is about 25 to 30 ms advanced in the model as compared to the data. Also, the later arrivals are significantly stronger in the modeled data as compared to the measured data, particularly in the case of the nearer channel (Figure 9). Figure 9 also shows that the model prediction has a significantly weaker first surface reflection than the data shows. This is due to the modeled surface reflection angle being located within the null of the modeled VP2 projector, and is indicative of some error in modeling the VP2 beampattern or the possibility that the VP2 tow body was not strictly vertical.

3.2.2 WATTCH

The second model used for predictions is the WATTCH model; the acoustic eigenrays required by WATTCH were calculated using the MULTIP model of GSM [4], a multipath expansion propagation model. The sub-models used for describing the environmental parameters were Bechmann-Spezzichino for surface reflection coefficient, with a wind speed of 2 m/s, and Rayleigh for bottom reflection coefficient. The same parameters were used here as for the Becky model run, i.e. a bottom half-space with density 1.9 and sound speed 1650 m/s. No attenuation is included in this model, which should not be an issue, as the grazing angles are above the critical angle (approximately 23.3º).

The beam pattern for the VP2 projector used in the WATTCH model here is an approximate fit to the pattern measured in [9], as shown in Figure 6, through the frequencies of the ping. The output prediction from WATTCH for the pings shown in Figures 5 and 6 (i.e. the 50 ms and 0.5 s ping for two source-receiver separations) is plotted in Figures 11 and 12, together with the measured data. The WATTCH output has been shifted to match the start time of the measured data and has been offset to plot on the same figure (the output amplitude has not been altered, but is based on an input amplitude calculated from the VP2 source level).

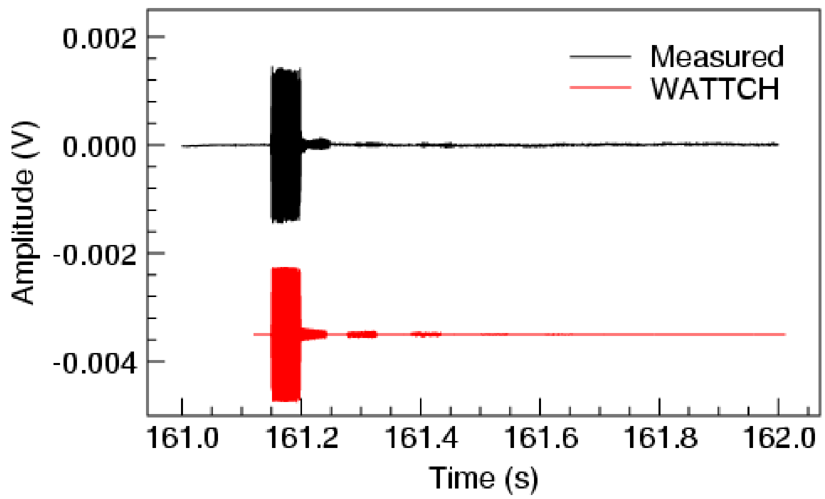

Figure 11. *50 ms ping transmitted at 17:32:41, channel 44 (far), with modeled output from WATTCH.*

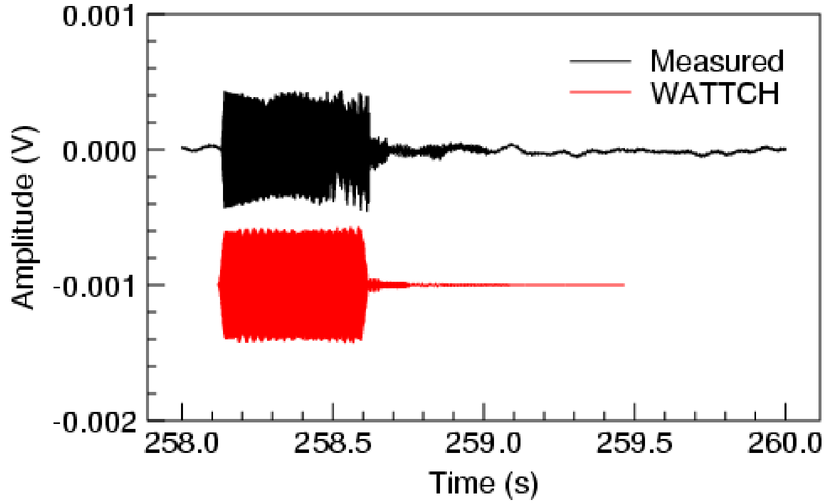

Figure 12. *0.5 s ping transmitted at 17:34:18, channel 224 (near), with modeled output from WATTCH.*

Figures 11 and 12 seem to indicate that the amplitude of the direct path as modeled by WATTCH/GSM is fairly close to correct. In Figure 11, the 50 ms ping as predicted by the model is approximately 0.7 dB less than the data indicates. The interference between the direct path and first surface bounce in Figure 12 as modeled by WATTCH is somewhat more coherent than supported by the data, suggesting that the GSM eigenray model is not modeling all the complexities of the environment, particularly any phase changes that may be occurring.

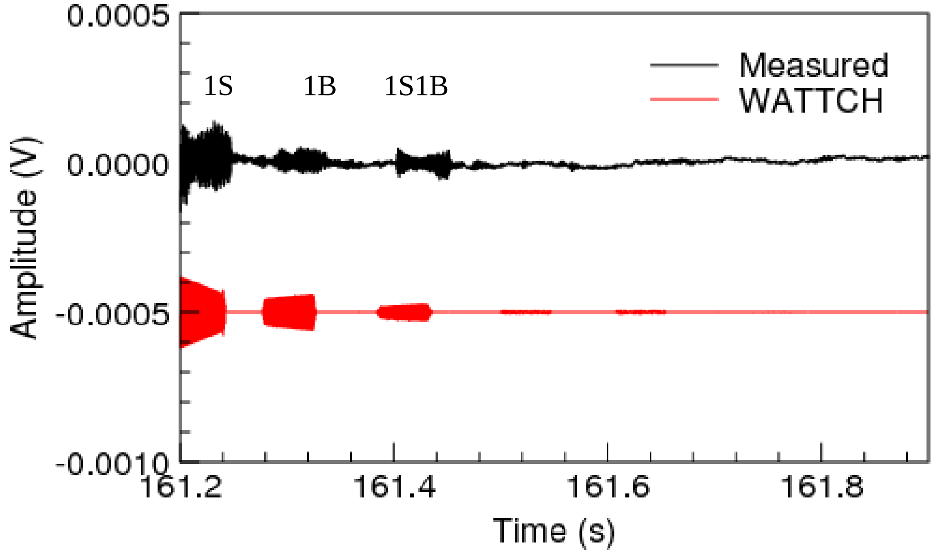

Figure 13. *50 ms ping transmitted at 17:32:41, channel 44 (far), with modeled output from WATTCH: non-direct arrivals.*

Figure 13, which is a magnification of the non-direct arrivals of Figure 11, shows that the modeled arrival times for the surface reflection and first bottom bounce are approximately 10 ms advanced from the data. This was also found in the Becky model predictions (Fig. 10), and may be caused by an overestimate of the horizontal distance between projector and receiver, i.e. the ping generator time recorded may be out of sync with the timestamp of the recorded data. In this case, a 10 ms difference (implying a 15 m horizontal change in distance) would change the path differences of the arrivals relative to each other sufficiently to resolve the model-data discrepancy. The difference is not likely to be caused by errors in measuring depth or sound speed, as the relative size of the error would need to be quite large, e.g. 110 m/s for sound speed or 20 m of water depth for the size of the time difference.

Additionally, in Figure 13 the relative amplitudes of the surface reflection and bottom bounce paths are different. This may be due to an overestimate of the bottom reflection coefficient, as the 1S (single surface reflection) arrivals seem to be approximately equal in amplitude. An alternative explanation is that the VP2 beam pattern used is inaccurate, or potentially that the VP2 tow is causing a deviation of the projector from vertical, as noted in the discussion of the results of the Becky model. The differences between the Becky model prediction and the WATTCH model for the far channel (where the beampattern null does not interfere to as great a degree) show that the initial bottom bounce as modeled by WATTCH is stronger and that later arrivals are stronger in the Becky model (compare Figures 10 and 13).

3.3 Parameter estimation

Working under the assumption that the WATTCH/GSM model is accurate, it can be used to obtain a better estimate of the less well known environmental and experimental parameters. It is evident that the model prediction for the first bottom bounce is significantly stronger than the measured bounce. If one could fully account for the VP2 beampattern, this difference should be due primarily to the ocean bottom (given the fairly good agreement between the isovelocity Becky model and the data, the water column properties are not likely to be an issue in this case). This setup would therefore allow direct measurements of bottom loss at multiple grazing angles, i.e. rapid environmental assessment of an area's bottom loss parameters. Alternatively, it would enable the validation of a particular bottom loss model and determination of the correct parameters for that model.

It is interesting to proceed under the assumption that the bottom reflection coefficient is fully determining the model-data differences. For each 50 ms ping, we can determine the ratio between the first bottom bounce arrival as measured and as modeled for the near channel and the far channel, i.e. for two source angles (here 62.68º and 57.21º). Comparing the modeled data to the measured data, we find that the bottom reflection is too large from the model by 2.3 dB for the near channel and 2.1 dB for the far channel. Table 1 shows the calculated bottom loss and the measured bottom loss (based on spherical spreading for propagation loss). We can then use these two measurements to determine the two parameters in the Rayleigh bottom reflection model used in WATTCH/GSM, i.e. bottom density and sound speed.

Table 1. *Measured and calculated bottom loss.*

	Bottom density	Bottom sound speed	Bottom loss (dB)	
			Ch. 44	Ch. 224
Data	-	-	11	11
Initial model prediction	1.9	1650 m/s	8.7	8.9
Improved model prediction	1.77	1520 m/s	11	11

Solving the Rayleigh bottom loss equations for the bottom sound speed and density results in a density of 1.77 and a sound speed of 1520 m/s. Given our lack of knowledge of the complexity of the seabed and our transmit beam pattern, as well as the fact that we are only using two data points, this is not a reliable estimate of the bottom parameters even assuming that a two-parameter Rayleigh model is appropriate. However, the factor of about 2.5 dB difference between measured and modeled data does indicate that we are overestimating the reflectivity of the bottom in our model.

Thus, it is interesting to rerun the WATTCH model using these parameters. Additionally, the modeled horizontal separation will be decreased by 15 m to better match the arrival times of the indirect paths. The results of the WATTCH model prediction for these changes are now shown in Figure 14 and 15, with Figure 16 zooming in on the indirect paths for the far channel. The modeled results for the far channel now show good agreement with the data in time of arrival and amplitude for direct path and bottom bounce arrivals, with the only significant difference being that the modeled surface bounce is slightly lower amplitude than the data. For the near channel, the overall amplitude for all paths is 1 to 2 dB higher than the data indicates.

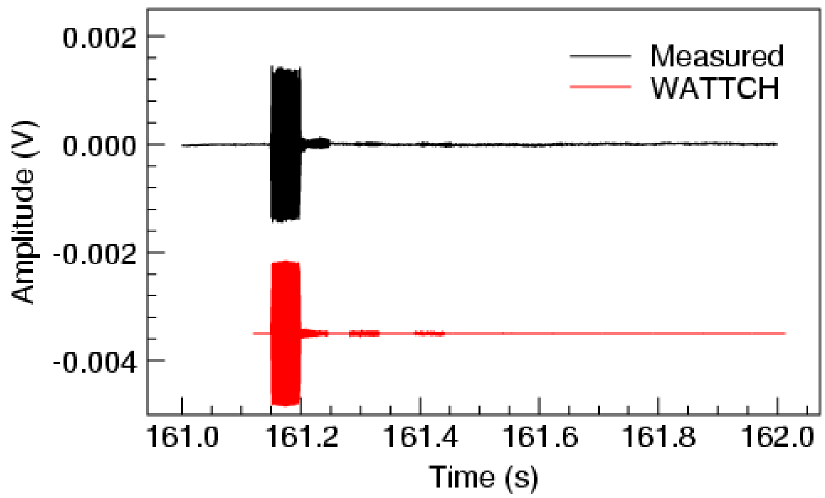

Figure 14. *50 ms ping transmitted at 17:32:41, channel 44 (far), with modeled output from WATTCH, using revised bottom loss and tow parameters.*

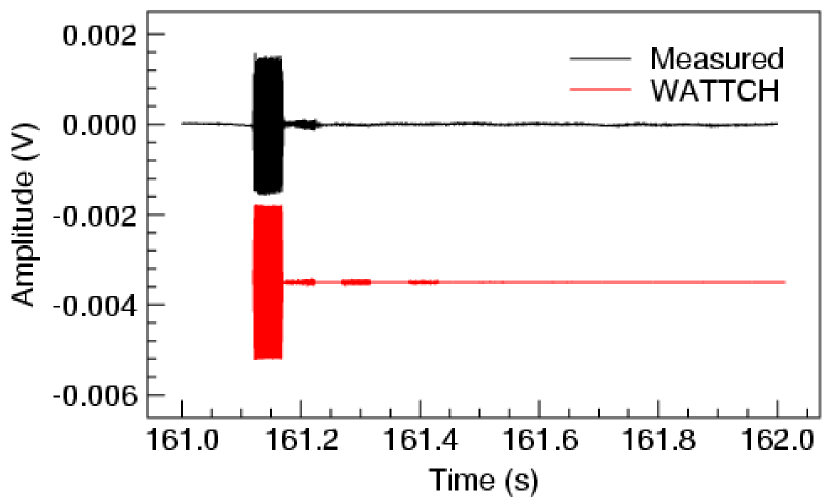

Figure 15. *50 ms ping transmitted at 17:32:41, channel 224 (near), with modeled output from WATTCH, using revised bottom loss and tow parameters.*

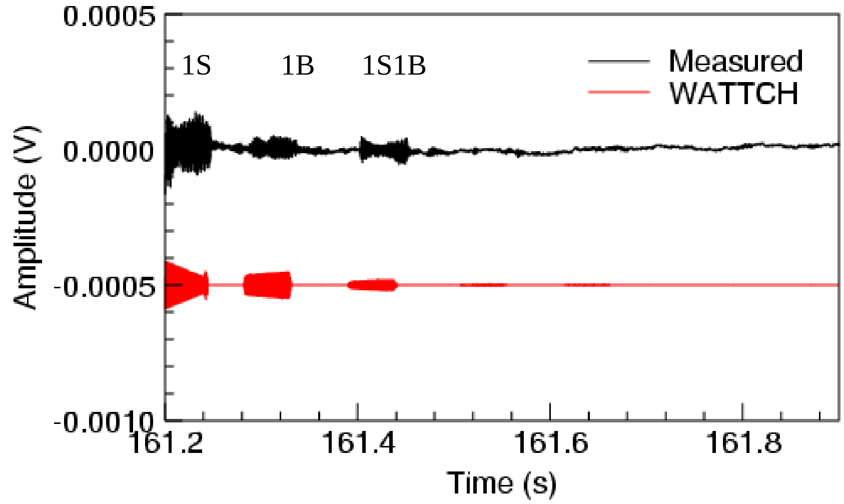

Figure 16. *50 ms ping transmitted at 17:32:41, channel 44 (far), with modeled output from WATTCH, using revised bottom loss and tow parameters: non-direct arrivals.*

4. Concluding Remarks

The results of the comparison of received data to model predictions suggested that the Becky and WATTCH models could be used to model acoustic propagation in the experimental environment. The comparison of the data to the Becky model prediction suggests that even a fairly simple model can provide reasonable agreement in some environments. This provides good validation for the use of these models for shallow-water broadband pulse propagation modeling, such as would be required for determining optimum characteristics for an underwater communications system.

A quantitative analysis of the model results and comparison to the data pointed to areas where the measurements were not necessarily accurate, primarily with regards to the VP2 beam pattern or tow body orientation, as well as the horizontal separation of the source and projector and the exact bottom loss properties. It was found that the initial bottom loss parameters used in the model predictions did not give as good a fit to the data as was found using a lower bottom density and sound speed. Given an omnidirectional projector, direct measurements of bottom loss vs. grazing angle could be performed, or alternatively bottom loss model validation and parameter finding could be accomplished. This demonstrates that, particularly with an appropriate tow depth, the TIAPS system could be used for rapid environmental assessment, in this case of bottom reflection loss strengths.

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List of symbols/abbreviations/acronyms/initialisms

BASE04	Broadband Adaptive Sonar Experiment 2004
DASM	Directional Acoustic Sensor Module
GSM	Generic Sonar Model
VCI	Virtual Channel Identifier
VP2	Vertical Projector 2
WATTCH	Waveform Transmission Through a Channel
XBT	Expendable bathythermograph

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Time series modelling

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