Aria of the Dutch North Sea

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2.1 OVERVIEW OF PROPAGATION METHODS AND THEIR PERFORMANCE: PROPAGATION LOSS MODEL COMPARISONS ON SELECTED SCENARIOS FROM THE WESTON MEMORIAL WORKSHOP

This section is a modified version of "H.Ö. Sertlek and M.A. Ainslie, Propagation loss model comparisons on selected scenarios from the Weston Memorial Workshop, Proc. 1st International Conference on Underwater Acoustic (UAC), 441-448, Corfu, Greece, 2013"

Abstract: *The accurate and stable calculation of underwater acoustic propagation is needed for applications such as sonar performance prediction, noise mapping and acoustic communication. In this work, some widely used acoustic propagation models, based on different methods such as normal mode, ray tracing, parabolic equation and flux theory are tested on the scenarios specified for the Weston Memorial Workshop, held at the University of Cambridge in 2010. Incoherent, coherent and depth-averaged propagation losses are generated for range independent and range-dependent scenarios. The effects of each method's characteristic parameters (such as number of rays, stair-step size, Weston's approximations, range and depth resolution etc.) on propagation loss are investigated. Propagation loss results and run times of each model are compared at the different frequencies, ranges and receiver depths. An automated script has been developed to carry out systematic convergence tests from a single input file. Using this script, comparisons are made of propagation loss results generated by different methods. These comparisons provide insight to the optimal choice of running parameters and performance of each model.*

2.1.1 Introduction

Accurate estimation of propagation loss (PL) plays an important role in underwater acoustic simulations. An unstable and inaccurate propagation loss result may lead to undesirable errors in sonar performance simulations, environmental risk assessments etc. The propagation loss calculations should therefore be compared with available benchmark results. Test problems from the 2010 Weston Memorial workshop [Ainslie,2010b; Zampolli et al,2010] are considered. These are based on the test problems for the 2006 and 2008 Reverberation Modelling Workshops at the University of Texas at Austin [Thorsos and Perkins,2007]. In this section, some of these test cases are solved with different methods for different bathymetries, smooth sea surface and uniform sound speed. The detailed descriptions of each available algorithm have been investigated. The critical characteristic parameters of the methods used (such as number of rays, stair-step sizes, spatial resolution etc.) are analysed systematically by using convergence tests. Then, an automatic comparison script has been used in order to minimize user errors for the comparisons and estimate running parameters for an arbitrary problem. This program compares the propagation loss (PL) versus range, depth and frequency which is calculated by various methods such as Normal Mode, Ray Tracing, Parabolic Equation and Weston's approach for the calculation of average intensity. The different running parameters are used and the sensitivity and stability of each method is tested. Well-known propagation models that are available in the Ocean Acoustic Library (OALIB) are used [oalib.hlsresearch.com]. The details of these test cases will be given in the next sections. the scenario naming convention follows [Ainslie et al,2013].

2.1.2 Used Methods

There is no single standard method to estimate PL. Different methods can be preferred depending on the frequency range, problem size or calculation time. One may even need to develop a new propagation algorithm to solve the specific problem. In order to investigate the accuracy of any PL model, some benchmark tests can be done for the calibration of the model. In this section, the PL calculations with different methods such as normal modes, ray tracing, parabolic equation and Weston's approximations are investigated. The use of the model with the inappropriate options may lead to errors. The possible effect of these options on PL accuracy is investigated in the following sections.

Normal Mode Theory

The normal mode method can provide a full wave solution which may be used as a benchmark test. It is based on the solution of the Helmholtz equation by the separation of variables technique. A stair-step approximation of bathymetry is used for range-dependent problems. Selection of step size can affect the accuracy [de Groot-Hedlin,2004; Jensen and Ferla,1990]. In Figure 1, a comparison of incoherent PL with different step sizes is shown for Case 4 (see Fig. 5). These figures were generated with the adiabatic approximation option of Krakenc. It can be seen from this comparison that the effect of stair step size also depends on frequency and on other environmental changes. For high frequencies, the selection of stair-steps size can be more critical. The fluctuations in Figure 1 are related to the different mode cut-off frequencies for different water depths. In this section, minimum step length is selected as 20 m (after convergence tests) for all normal mode calculations. Normal mode comparisons are achieved by the well-known normal mode algorithm Kraken[Porter,1990] and another normal mode solution based on an analytical estimation of eigenvalues [Sertlek and Aksoy, 2010].

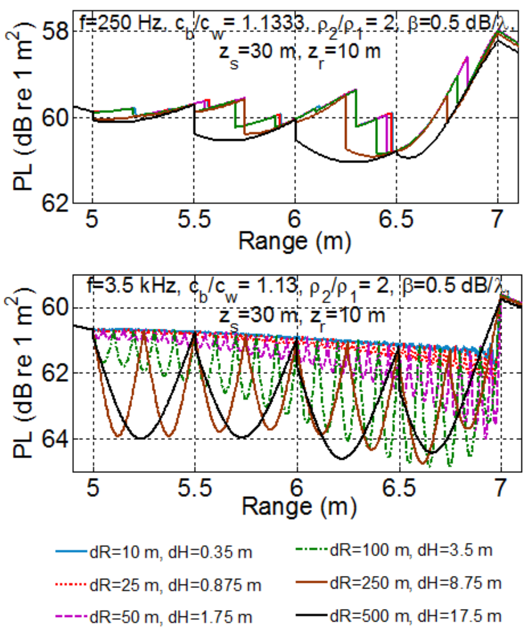

Figure 1. Propagation loss vs range for Case 4

(Effect of stair-step sizes on PL for 250 Hz and 3.5 kHz)

Ray Theory

Ray based models are widely used in many underwater acoustic applications. A ray tracing algorithm traces a sound ray for each launch angle by using physical concepts. It is based on a high frequency approximation. For this reason, ray theory results may be inaccurate in shallow water and especially near the cut-off frequency of the waveguide. However, it can be a useful method where the running times are critical. Bellhop is a well-known ray tracing program [oalib.hlsresearch.com]. It can provide propagation loss, ray paths, arrival times, eigenrays etc. Different tracing options can be selected in Bellhop. In this work, the geometric ray option is used. The required number of rays depends on the range and geometry. A sufficient number of rays can be selected by convergence testing. Especially for long range problems, a large number of rays may be required. The effect of rays on the accuracy of incoherent PL for Case 9 (see Figure 7) is shown in Figure 2.

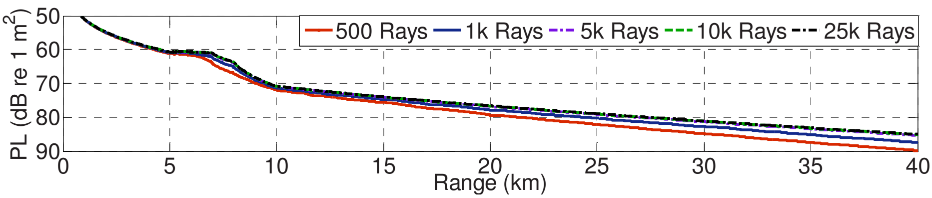

Figure 2. Propagation loss vs range for Case 9:

Effect of number of rays for depth-averaged PL (f=3.5 kHz)

Parabolic Equation Method

The parabolic equation (PE) method is used in many different fields of wave propagation such as electromagnetism, optics, seismology and underwater acoustics. RAM is a well-known PE program [Collins,1999]. It can solve range-dependent ocean acoustics problems with the split-step Padé algorithm [Collins,1993]. It is based on the paraxial approximation for the wave equation, providing a one-way solution to the wave-equation. It is especially used for range-dependent propagation problems. The accuracy of a parabolic equation solution depends on its starter field, number of Padé terms, false bottom, the grid size (the choice of which depends on frequency). Selection of range and depth step sampling size is important in PE calculations. Using smaller steps may reduce the fluctuations in the calculated fields, but increases the computation time [Robertson,1999]. In Figure 3, the effect of depth sampling size is shown for coherent PL. An optimum value of grid size should be selected. Beside the selection of grid sampling size, selection of the sediment layer thickness (which must be artificially truncated at a user-specified depth [Jensen et al,1994]) can be important for low frequencies.

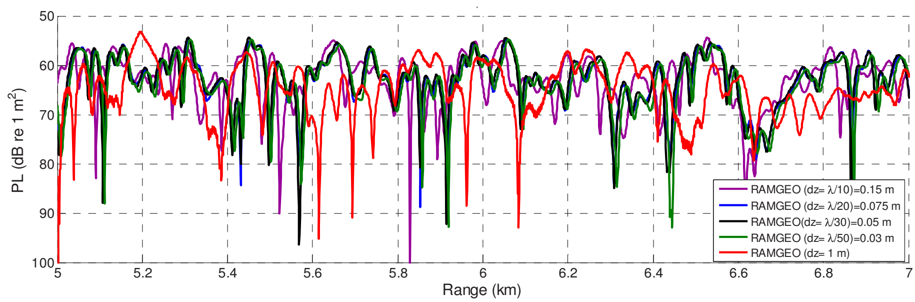

Figure 3. PL vs range for Case 1: effect of depth sampling sizes for 1 kHz at 1 m above sea bottom

Weston's Approximations

According to Weston's paper, propagation loss for range dependent media can be calculated using the effective depth concept [Weston,1971 ; Weston,1976]. For an arbitrary bathymetry, the depth profile can be divided into small segments. Then, variation of depth for each segment can be simplified in order to calculate the effective depth integral analytically. It can provide an analytical estimation of PL for range-dependent and lossy waveguides. The estimated PL is depth-averaged.

2.1.3 Comparisons

PL versus range (up to 40 km) comparisons are obtained for coherent, incoherent and depth-averaged (averaged over receiver depth) calculation of PL. However, only depth averaged results are shown for sake of simplicity. The depth averaged PL was computed over incoherent field except RAM's results. This exception was made because RAM only generates coherent field. The characteristic parameters of each method (such as depth and range sampling size, number of rays etc.) are obtained by convergence tests. In all test cases, the sound speed in water is 1500 m/s. The sound speed in sediment is 1700 m/s and bottom absorption loss is 0.5 dB/wavelength [0.294 dB/ (m kHz)]. The Thorp model [Jensen et al,1994] is used for the volume absorption.The first scenario ("Case 1" [Ainslie et al,2013]) is a flat waveguide with 100 m depth. The model is run for 250 Hz, 1 kHz and 3.5 kHz for a fixed source depth at 30 m. PL versus range comparisons are shown for Case 1 in Figure 4. There is a good agreement between the solutions until 20 km. However, the RAM solution is different at longer ranges. This difference depends on the choice of spatial resolution. The RAM version used in these tests is based on single precision. Altough the choice of small spatial sampling size increases the agreement with normal mode results until around 20 km, floating point errors may arise at longer ranges.

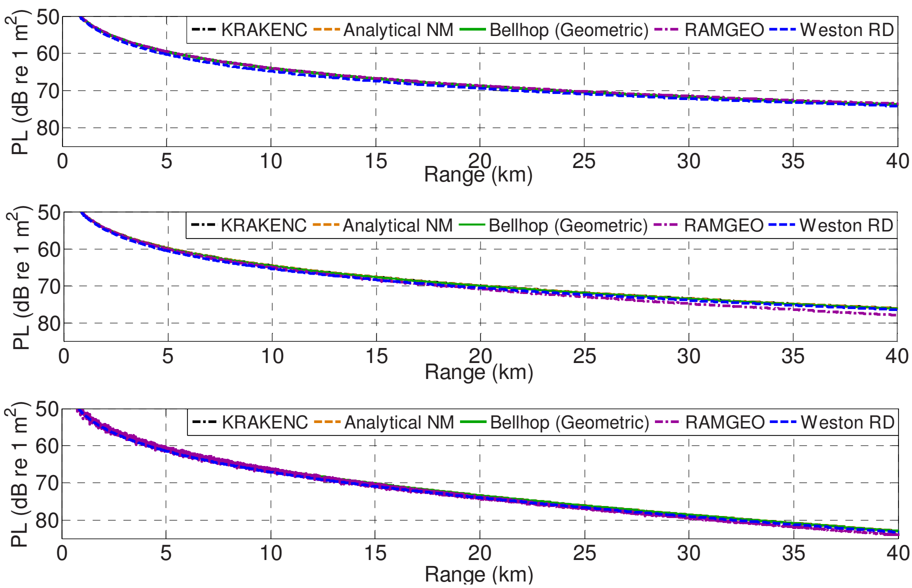

Figure 4. Depth-averaged (over receiver depth) PL vs range for Case 1 (f=250 Hz (top), f=1 kHz (middle), f=3.5 kHz (bottom)). Source depth = 30 m.

The second scenario is "Case 4" [Ainslie et al,2013]. It has 100 m water depth up to 5 km. Then, it features an upslope from 5 km to 7 km up to water depth 30 m (see Figure 5). The bathymetry and depth-averaged (over receiver depth) PL comparisons are shown for Case 4 in Figure 6.

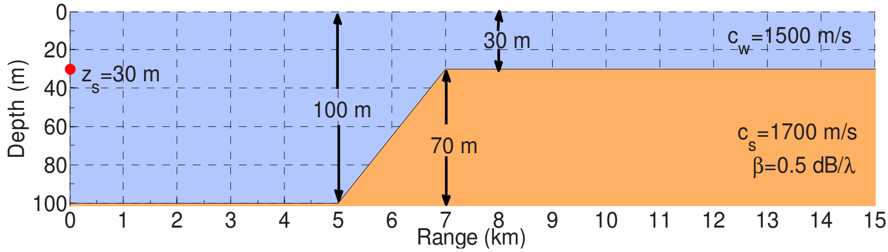

Figure 5. The bathymetry of Case 4

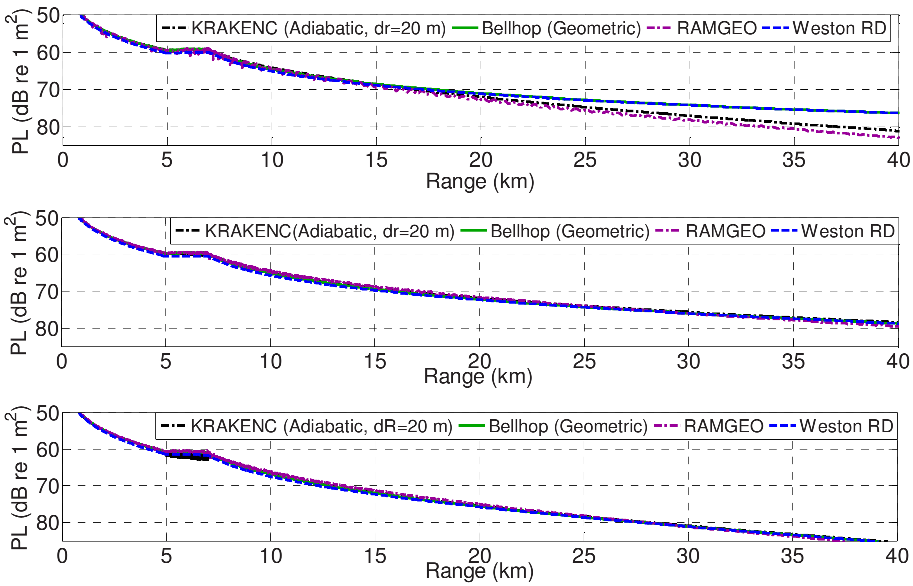

Figure 6. Depth-averaged (over receiver depth) PL vs range for Case 4. (f=250 Hz (top), f=1 kHz (middle), f=3.5 kHz (bottom)). Source depth = 30 m.

For 250 Hz, Weston approximations and Bellhop result seem different after 20 km. This difference is related to propagation in the single mode region [Weston,1971; Weston,1976]. This error can be addressed by replacing the flux integral with a discrete mode sum in this region at long ranges.

The last scenario, "Case 9", has 100 m water depth up to 5 km, followed by an upslope region from 5 km to 7 km up to water depth 30 m comparable to "Case 4". A shallow water region (depth 30 m) is then followed by a downslope region from 8 km to 10 km down to water depth 100 m, and uniform depth thereafter (see Figure 7).

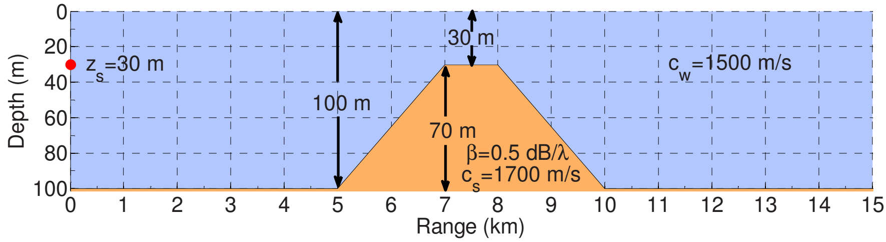

Figure 7. The bathymetry of Case 9

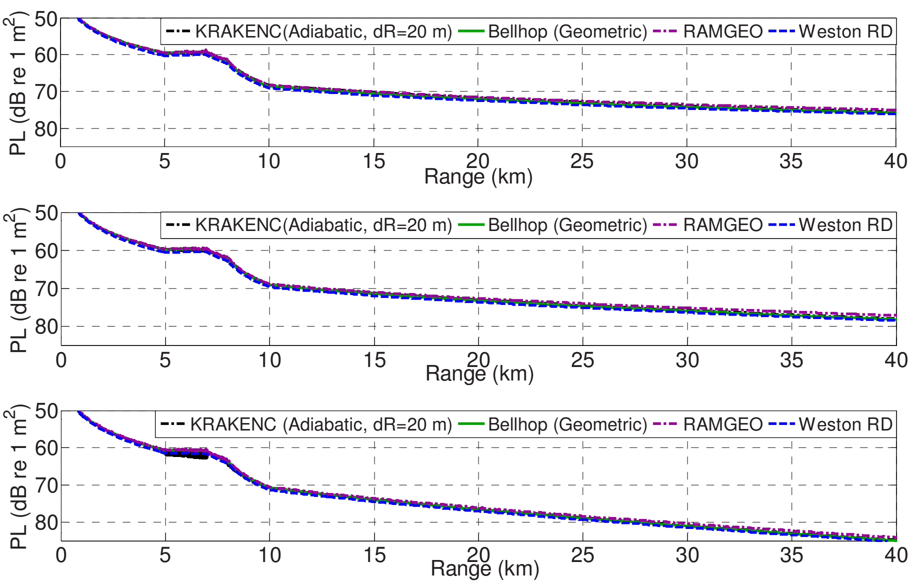

Figure 8. Depth-averaged (over receiver depth) PL vs range for Case9. (f=250 Hz (top), f=1 kHz (middle), f=3.5 kHz (bottom)). Source depth = 30 m.

Weston's range dependent approach has a good agreement with other models. All models have a good agreement between depth-averaged PL results. However, coherent PL comparisons might be different due to the sensitivity of environmental parameters and used different approaches for range dependency.

2.1.4 Conclusion

An automated script has been used to make the comparisons between selected methods with provided bathymetry, frequency, receiver and source depths with incoherent, coherent and depth-averaged options. Each method is based on different assumptions and numerical algorithms. Thus, the characteristic parameters of these methods should be selected with convenient convergence tests or comparisons with other models in the validity range of each model. Otherwise, it may lead inaccurate results especially for long range problems and range-dependent bathymetries. The comparison results can provide an insight into the possible differences between these methods.