Range-Dependent Geoacoustic Inversion: Results From the Inversion Techniques Workshop

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***Abstract*—Model-based geoacoustic inversion in range-dependent underwater environments is a challenging task constrained by data quality (synthetic or measured) and propagation-model efficiency and accuracy. The Inversion Techniques Workshop (ITW), held in Gulfport, MS, May 15–18, 2001, was organized for the acoustics community to present state-of-the-art numerical geoacoustic inversion capabilities in range-dependent shallow-water environments. The organizers defined five range-dependent test cases (three synthetic and two experimental cases). Two of the synthetic cases were adopted for geoacoustic inversion in this paper. The first test case (TC1) is a monotonic down-slope bathymetry problem and the adiabatic normal-mode model PROSIM was applied for the inversion in this case. The second test case (TC3) is a flat-bottom case with an intrusion. The forward model used in this case was RAMGEO. The global optimization package SAGA was used for geoacoustic inversion of the synthetically generated reference solutions for TC1 and TC3. In general, the geoacoustic inversion results are in good agreement with the true solutions provided by the organizers. The results obtained demonstrate the feasibility of performing geoacoustic inversion in synthetic range-dependent shallow-water environments. However, results show that the propagation model choice in the inversion is strongly dependent on the specific range-dependent environment.**

***Index Terms*—Geoacoustic inversion, PROSIM, RAMGEO, range dependence, SAGA.**

I. Introduction

SOUND propagation in shallow-water regions is strongly dependent on sea-bed properties. In recent years, sea-bed properties have been determined successfully by geoacoustic inversion of acoustic data using search algorithms. In geoacoustic inversion, input bottom properties to acoustic propagation models are altered to obtain the best match between modeled and measured acoustic data. The optimum match defines the "true" bottom properties. Often, the modeling is performed by assuming range-independent environments. Range-independent modeling reduces computation time and makes the geometry simpler. Using a range-independent propagation model to match acoustic data from range-dependent environments results in acoustically averaged bottom properties along the propagation track. A good match at one range does not guarantee a good match at all ranges. Particularly, strongly range-dependent environments requires full range-dependent modeling in order to determine the bottom properties. Geoacoustic inversion for these environments becomes significantly more computationally intensive than range-independent inversion. The choice of a propagation model for the geoacoustic inversion is a tradeoff between computational efficiency and accuracy. For instance, a fast and less-accurate adiabatic normal-mode model, compared to a computationally intensive but accurate coupled normal-mode model is often sufficient for geoacoustic inversion of measured acoustic data. Further, the *a priori* information of the environment is usually the limiting factor in matching model results to experimental data. In the case of sparse environmental information, the match between model and data is not necessarily improving by applying an accurate propagation model.

The Inversion Techniques Workshop (ITW), held in Gulfport, MS, May 15–18, 2001, was organized for the acoustics community to present state-of-the-art numerical geoacoustic inversion capabilities in range-dependent shallow-water environments. This workshop is a natural continuation of the successful Geoacoustic Inversion Workshop held in Vancouver, BC, Canada, in 1997, where only range-independent shallow-water environments were considered [1]. In the ITW, three synthetic test cases were defined with two-dimensional (2-D) range-varying bathymetry and geoacoustic properties [2]. The acoustic data for the synthetic cases were given as complex pressure at selected frequencies and source-receiver geometries. The reference solutions to these test cases were generated by the full-field parabolic-equation (PE) model RAM [3]. A synthetic calibration case with a complete description of the environment and the acoustic reference solution was provided by the organizers. This calibration case (TC0) gave the opportunity to assess consistency in the solutions from different range-dependent propagation models used for the geoacoustic inversion of the synthetic cases. An additional two test cases consisted of field data provided as transmission loss (TL), monostatic and bistatic reverberation with supporting environmental data collected in two different areas. The field data were provided at selected frequencies [2]. The workshop was organized as a "blind test," as no reference solution to the problems was available prior to the workshop.

Two synthetic test cases were chosen from the workshop for geoacoustic inversion: 1) monotonic down-slope (TC1) with unknown bottom properties (in depth and range) and unknown

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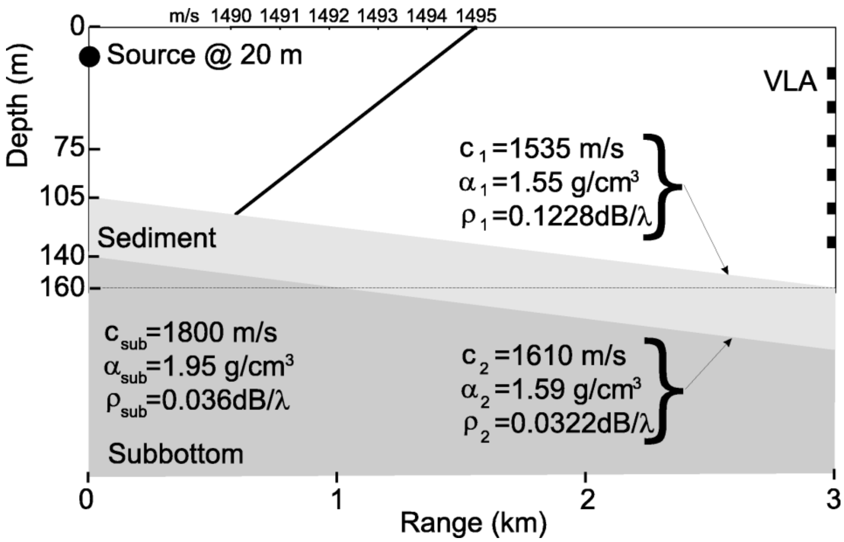

Fig. 1. Schematic of range- and depth-dependent environment for calibration test case TC0.

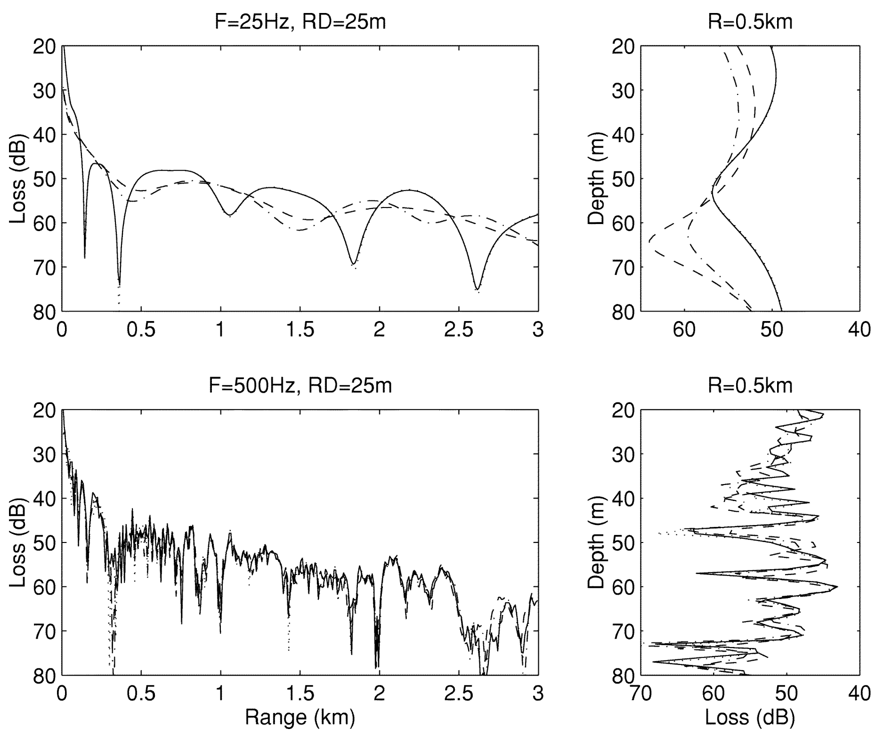

Fig. 2. Comparison between different range-dependent propagation-model results for the calibration test case TC0 at 25-m receiver depth and 0.5-km range and frequency of 25 (upper panels) and 500 Hz (lower panels). Solid curve: Reference solution; dotted curve: RAMGEO; dashed curve: C-SNAP; dotted–dashed curve: PROSIM.

water depth and 2) flat bottom (TC3) with an unknown intrusion in the sediment and an unknown water depth. The sound speed in the water column for all the test cases is given by

$$c_w(z) = 1495 - 0.04z \tag{1}$$

where z is depth in meters from the sea surface and measured positive downward. The density and attenuation in the water is 1.0 $\mathrm{g/cm^3}$ and 0.0 dB/λ, respectively. The source depth (SD) is fixed at 20 m for all the test cases. The reference solution is given as complex pressure received on two horizontal arrays at receiver depths (RD) of 25 and 85 m in 5-m range steps from 5 m to 5.0 km and on vertical arrays at depths from 20 to 80 m in 1-m increments located at ranges (R) of 0.5 to 5.0 km in 0.5-km increments. The maximum range for the TC0 is 3.0 km and the maximum range for TC1 and TC3 is 5.0 km. The complex pressure is calculated at frequencies from 25 to 199 Hz in 1-Hz increments and from 200 to 500 Hz in 5-Hz increments [2].

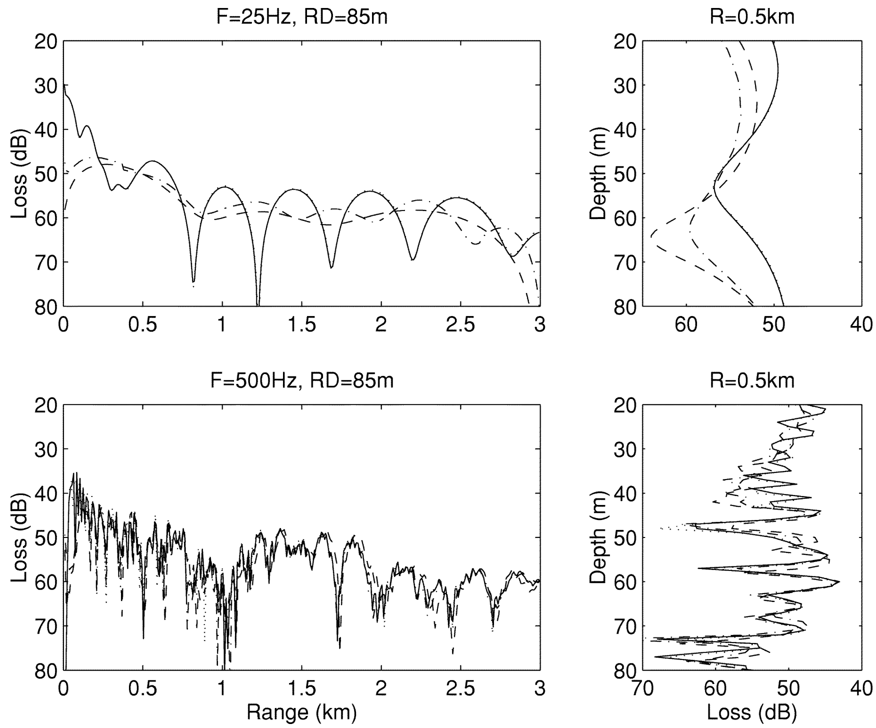

Fig. 3. Comparison between different range-dependent propagation-model results for the calibration test case TC0 at 85-m receiver depth and 3.0-km range and frequency of 25 (upper panels) and 500 Hz (lower panels). Solid curve: reference solution; dotted curve: RAMGEO; dashed curve: C-SNAP; dotted–dashed curve: PROSIM.

II. Inversion Procedure

The general seismo-acoustic inversion package, SAGA, [4] was used for geoacoustic inversion of the synthetically generated acoustic data in TC1 and TC3. SAGA is a global optimization package based on a direct Monte Carlo (random) search and genetic algorithms. The package can be used to infer geometry in underwater scenarios (source/target localization) and geoacoustic properties of the sea bed. The determination of the underwater environmental properties in SAGA is performed by a systematic change of input parameters for numerical propagation models, where the results from the modeling are compared with observed data, i.e. measured or synthetic data. The measure of the mismatch between model and data (objective function) depends on the observed data, but SAGA includes a suite of objective functions allowing for inversion of a wide range of observed data. The objective functions are derived from an approach based on maximum-likelihood and additive Gaussian noise models [5].

In the inversion of TC1 and TC3, only vertical array data are considered. The objective function in this case was chosen as the Bartlett processor, which correlates the complex pressure received across the vertical array coherently for multiple ranges and frequencies. The objective function maximized in SAGA by searching for optimum environmental inputs to the propagation model is given by

$$B = \frac{1}{N_R}\frac{1}{N_F}\sum_{k=1}^{N_R}\sum_{j=1}^{N_F}\frac{\left|\sum_{i=1}^{N_D} p_{ijk}^{*} q_{ijk}\right|^2}{\sum_{i=1}^{N_D}|p_{ijk}|^2\sum_{i=1}^{N_D}|q_{ijk}|^2} \qquad (2)$$

where N_D is the number of depths, N_F is the number of frequencies, and N_R is the number of range points. The complex pressure vectors from observations (synthetic reference or measured data) and modeling are given by p_{ijk} and q_{ijk} and $(^*)$ denotes complex conjugate. The objective function is normalized by the total energy in the observed and modeled acoustic fields to values between 0 and 1. The value of the objective function is 1 for two identical acoustic fields and the function value is 0 for orthogonal acoustic fields.

The environmental input data for the numerical models that result in the best match between modeled and observed data [maximum of (2)] is the final result from the inversion. SAGA has been applied successfully to single and multifrequency acoustic data received on vertical or horizontal hydrophone arrays, coherent and incoherent TL, and reverberation and reflection coefficients from the bottom. The result of the inversion can be analyzed in terms of *a posteriori* probability distributions, which give an estimate of the importance and uniqueness of each of the environmental parameters searched for. Thus, the uncertainty in the solution can be assessed by using these probability distributions [6].

Two different propagation models were used to determine the water depth and geoacoustic properties in TC1 and TC3: the adiabatic normal-mode model PROSIM [7] and the wide-angle PE model RAMGEO [3]. PROSIM is a range-dependent version of the real-wavenumber ORCA model [8]. The RAMGEO model is derived from the RAM model [3], allowing sediment layers to follow the variations in the bathymetry, i.e. constant sediment thickness in environments with range-varying bathymetry.

RAMGEO is a well-established wide-angle PE model and is often considered as an efficient benchmark model because of these features [9], [10]. This PE model is probably the easiest accessible range-dependent propagation model to the acoustics community that is sufficiently accurate to solve TC3.

The results from the geoacoustic inversion of the reference solutions presented in the following sections were obtained prior the ITW, i.e. no further inversions were carried out after the workshop to refine the solutions. The bottom properties used for generating the reference solutions were released at the workshop [2]. The central processing unit (CPU) times for the geoacoustic inversions refer to a dual-processor Compaq AlphaServer DS20E.

TABLE I
BARTLETT VALUE FOR TEST CASE TC0

	RAMGEO	PROSIM	C-SNAP
R=0.5 km			
F=25 Hz	1.000	0.890	0.929
F=500 Hz	0.999	0.840	0.945
R=3 km			
F=25 Hz	1.000	0.960	0.927
F=500 Hz	1.000	0.902	0.989
RD=25 m			
F=25 Hz	1.000	0.810	0.830
F=500 Hz	1.000	0.922	0.926
RD=85 m			
F=25 Hz	1.000	0.450	0.470
F=500 Hz	0.992	0.700	0.740

III. CALIBRATION CASE TC0

The calibration test case is applied to the propagation models used in the geoacoustic inversion. The purpose of this intermodel comparison is to check model consistency, i.e. the reference solution is generated on a particular workstation, the same propagation model is operated by different researchers, and range-dependent models based on different algorithms than the model used for generating the reference solution are applied. The "true" solution to synthetically generated geoacoustic inversion problems cannot be achieved if significant differences in the modeling results are present. However, the solution from less-accurate propagation models may be sufficient in the inversion of measured data. The complexity of running different numerical models by different researchers for the same underwater acoustic environment was illustrated by the SWAM'99 workshop [11]. The results from SWAM'99 show 10 s of decibel difference in TL, obtained by using accurate range-dependent models from various participants. The TC0 environment defined for ITW and used for intermodel comparison is shown in Fig. 1.

The propagation models used to calculate the acoustic field for the environment in Fig. 1 are RAM, RAMGEO, PROSIM, and C-SNAP [12]. The modeling results are compared with the reference solution provided by the organizers. The coupled normal-mode model C-SNAP is applied to assess the importance of the continuous spectrum and mode coupling against the PE model RAMGEO and the adiabatic normal-mode model PROSIM. The acoustic field is calculated at a frequency of 25 and 500 Hz. The TL from the models is compared at depths of 25 and 85 m out to a range of 3.0 km and across depths from 20 to 80 m at ranges of 0.5 and 3.0 km (see Figs. 2 and 3).

An average value of density and attenuation (1.57 $\mathrm{g/cm^3}$ and 0.0775 dB/λ, respectively) in the sediment layer has been used in the C-SNAP calculations, as this model does not support gradients of density and attenuation. The gradients are included in the RAMGEO and PROSIM computations. It should be noted that it was necessary to compile and run RAMGEO in double precision to obtain convergence of the solution at 25 Hz.

In general, there is a reasonable agreement in the mean TL between the range-dependent models at all depths, ranges, and frequencies. The solution obtained by RAMGEO is in excellent agreement with the reference solution. The mode models clearly have difficulties at 25 Hz compared to the PE solutions, which is attributed to the excitation of the continuous spectrum included in the PE model. The discrepancy between the mode models is caused by mode coupling handled by C-SNAP, but excluded in the adiabatic model PROSIM. At 500 Hz, the agreement between the PE and mode models is improved significantly. At higher frequencies, more propagating modes are excited in the water column and there are a sufficient number of modes that carry the majority of the energy, which makes the adiabatic solution acceptable. The increase in mode numbers in the down-slope propagation has only a minor effect on the total acoustic field received down-range. In these cases, the continuous spectrum and mode coupling becomes less important. The same conclusions were drawn for various propagation models applied to a variety of range-dependent shallow-water environments in [9] and [10].

The value of the objective function used in the geoacoustic inversion (2) depends solely on the phase difference between the observed and modeled acoustic field. Therefore, the objective function is insensitive to a constant offset in TL levels and phase obtained by the various models. The normalized Bartlett value between the reference solution and the results from the applied models are given in Table I.

The Bartlett value for $\mathrm{R} = 0.5$ and 3.0 km is calculated by (2) coherently in depth [N_F and N_R equal 1 and $N_D = 61$ in (2)]. For $\mathrm{RD} = 25$ and 85 m, (2) has been applied coherently in range by interchanging the summation over depth and range [N_F and N_D equal 1 and $N_R = 1000$ in (2)]. A good convergence of model results was obtained by refining environmental discretization and computational grid. Ideally, the Bartlett value should become 1, correlating the RAMGEO result with the reference solution. The fact that the value is not exactly 1 indicates slight differences in the RAM and RAMGEO models, differences in the environmental and computational discretization used in generating the reference solution and the results shown here, and that different workstations have been used to generate the solutions. The mode models show a worse match with the reference solution than the RAMGEO results and C-SNAP has a slightly better performance than PROSIM, as expected.

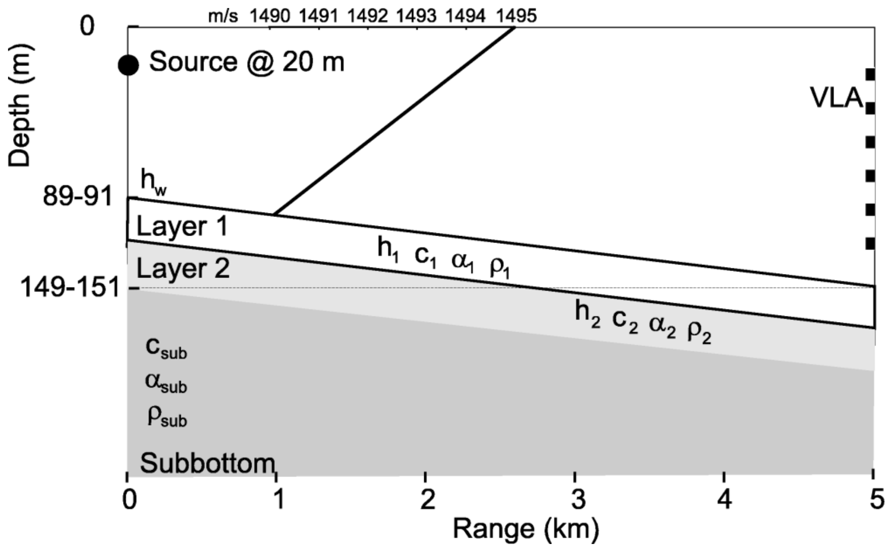

Fig. 4. Schematic of range- and depth-dependent environment for test case TC1.

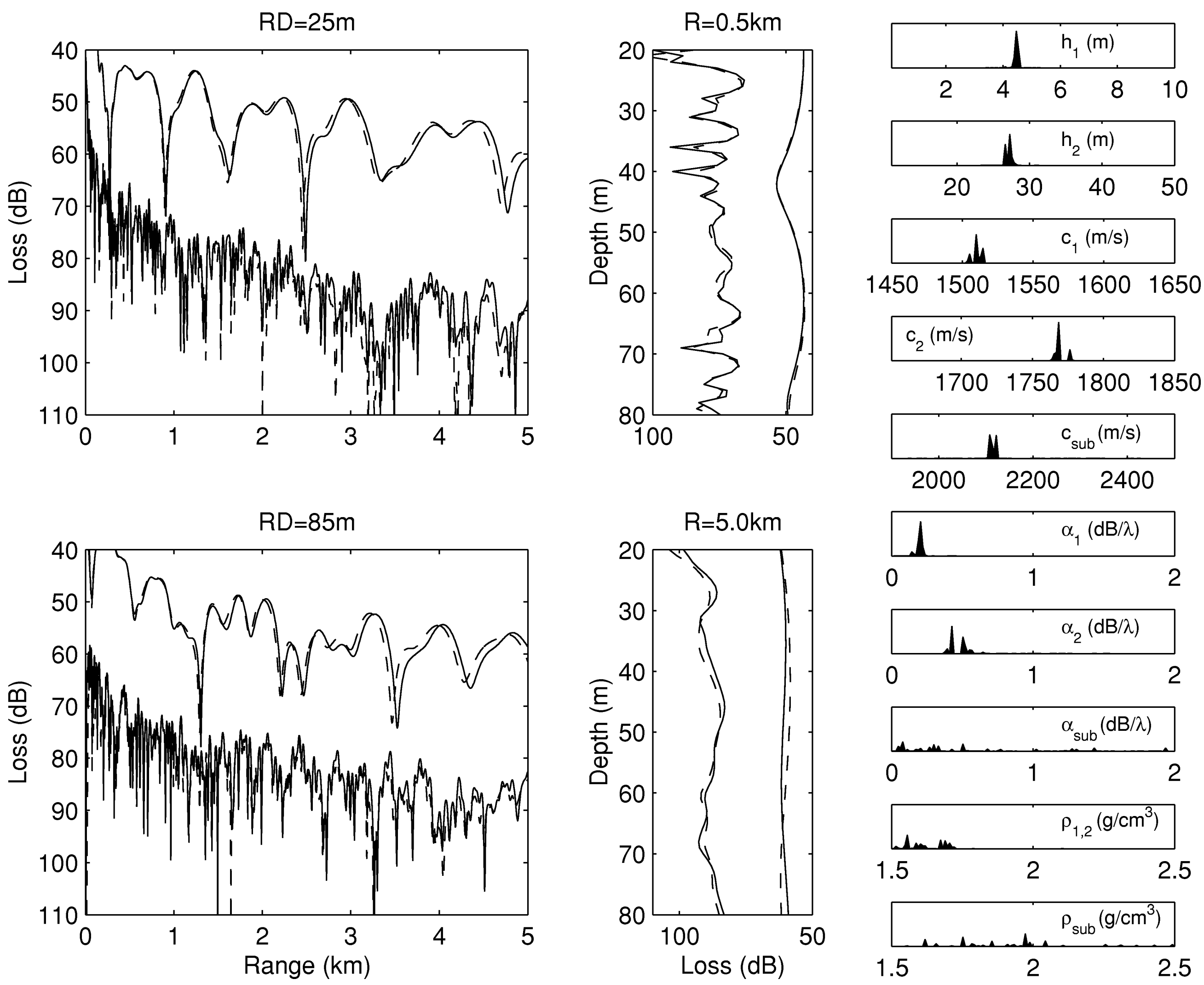

Fig. 5. Comparison between reference solution (solid line) and RAMGEO (dashed line) with inverted bottom properties at a receiver depth of 25 m and range of 0.5 km (upper left and mid panels) and at a receiver depth of 85 m and range of 5.0 km (lower left and mid panels). The TL is calculated at two frequencies: 25 (upper and right curves in the TL versus range) and 500 Hz with the 500-Hz results offset by 25-dB higher loss. The right panel shows the probability distributions for the inverted bottom properties.

IV. Test Case TC1

This test case is defined as an environment with a monotonic down-slope bathymetry out to a range of 5.0 km. The water depth is provided as an interval between 89–91 m at zero range and 149–151 m at 5 km ($\sim 0.7^{\circ}$ down-slope). The layering structure and range dependence of the bottom properties are unknown. The environment is denoted as weakly range dependent and it is assumed that the broad-band adiabatic normal-mode model PROSIM is sufficiently accurate for geoacoustic inversion of this environment. The description of the bottom structure is based on SAGA "trial runs" with a continuous monitoring of the objective function value and sensitivity to changes of the individual bottom parameters. Only a certain degree of details in the bottom properties can be extracted from the acoustic reference solution provided by the workshop organizers. The complexity of the bottom description is increased from an infinite half-space to several sediment layers overlying an infinite half-space searching for thickness, sound speed, density, and attenuation for each layer. The bottom discretization based on these SAGA trial runs was found to be a two-layer sediment overlying an infinite half-space to be used in the final geoacoustic inversion (Fig. 4).

The bottom properties are assumed to be range independent and the search parameters are depth-independent sound speed, density, and attenuation in each layer. The density is assumed to be the same for the two sediment layers. The geoacoustic inversion was performed by using the reference complex pressure over depth at the ranges of 0.5 and 5.0 km (independent SAGA inversion for each range). The geoacoustic inversion result was the bottom parameters corresponding to the best match between the reference solution and the PROSIM result from 40 000 forward-modeling runs (2000 iterations and 20 populations in the genetic algorithm). The sloping bottom was approximated by a range-independent sector every 100 m and the complex pressure was calculated in the frequency band from 30 to 500 Hz in 10-Hz increments (48 frequency components). The match of TL between the reference solution and the geoacoustic inversion result for selected source–receiver combinations and frequencies is shown in Fig. 5.

The probability distributions of the search parameters (Fig. 5) show uniqueness in the inversion except for the attenuation in the sub-bottom and the density in sediment and sub-bottom. The geoacoustic properties determined from TC1 (both 0.5- and 5-km vertical array inversion) using the adiabatic PROSIM model is given in Table II, together with the search interval of the individual inversion parameters.

The sediment and sub-bottom density found by inversion of the 0.5-km data was used in the inversion of the 5.0-km data. There is a slight difference in the solution for the inverted bottom properties, depending on the propagation range of the acoustic field. The discrepancy between the solutions is most likely due to the propagation model applied in the inversion.

1) PROSIM does not include the continuous spectrum, which may be important in calculating the acoustic field at close range (0.5 km).
2) The adiabatic approximation is less accurate for down-slope than for up-slope propagation [10].

The water depths in parenthesis are determined by the exhaustive search using RAMGEO with the bottom properties found in the PROSIM inversion. The water depth found by the two propagation models is consistent.

There is a reasonable agreement between the determined sound speed, density, and attenuation profiles and the true geoacoustic profiles, although the accuracy of the applied propagation model is limited. The sound speed, density, and attenuation profiles found in the inversion of TC1 represent average-like properties within each layer, compared to the true profiles [2].

TABLE II
Geometry and Geoacoustics From PROSIM for TC1

	R=0.5 km	R=5.0 km	Search interval
Bartlett value	0.962	0.960	
Layer 1			
h_1 (m)	4.5	4.3	0.1–10.0
c_1 (m/s)	1509.8	1511.4	1450–1650
α_1 (dB/λ)	0.2	0.1	0.0–2.0
ρ_1 (g/cm^3)	1.7	-	1.5–2.5
Layer 2			
h_2 (m)	22.8	20.8	1.0–50.0
c_2 (m/s)	1768.5	1730.9	1651–1850
α_2 (dB/λ)	0.4	0.7	0.0–2.0
ρ_2 (g/cm^3)	1.7	-	1.5–2.5
Sub-bottom			
c_{sub} (m/s)	2112.6	2169.3	1900–2500
α_{sub} (dB/λ)	1.4	0.3	0.0–2.5
ρ_{sub} (g/cm^3)	2.0	-	1.5–2.5
Water depth			
h_w 0.0 km (m)	90.5		88.0–92.0
h_w 0.5 km (m)	95.3		94.0–98.0
h_w 0.0 km (m)		90.2 (89.7)	88.0–92.0
h_w 5.0 km (m)		150.0 (150.0)	148.0–151.0
CPU-time (h)	4.2	28.0	

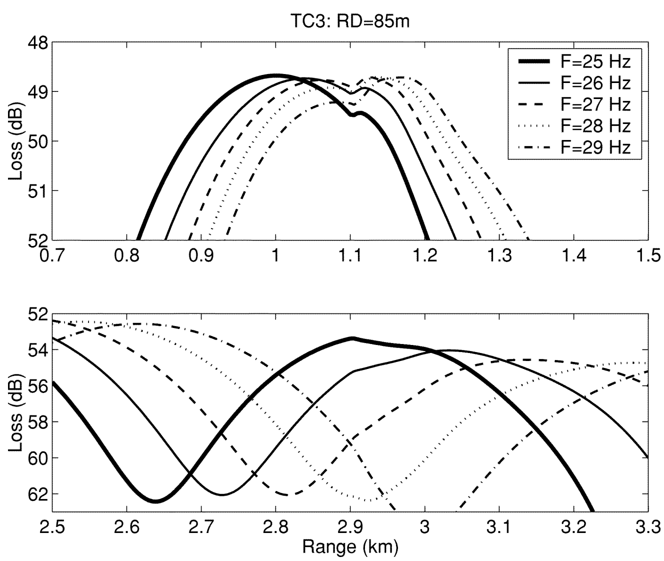

Fig. 6. Transmission loss (reference solution) at two-range intervals, receiver depth 85 m and selected frequencies for test case TC3.

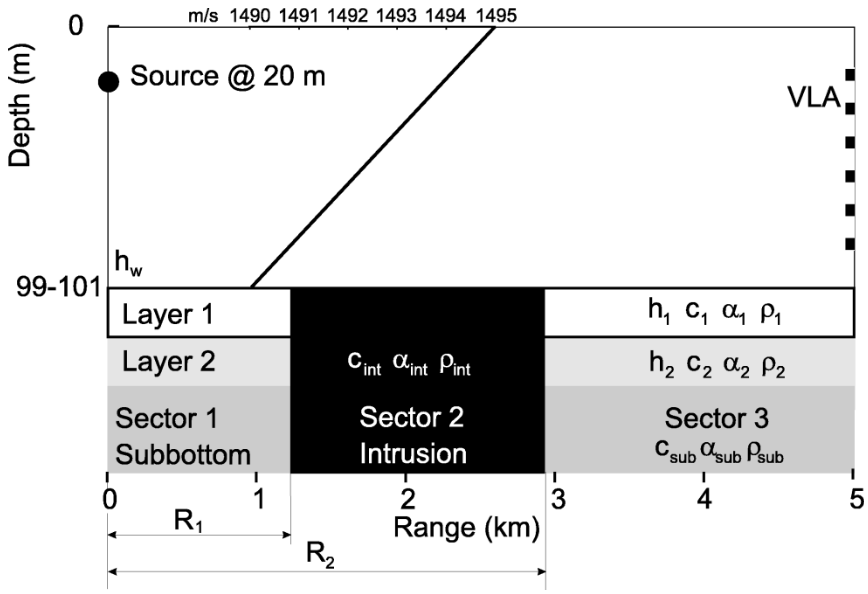

Fig. 7. Schematic of range- and depth-dependent environment for test case TC3.

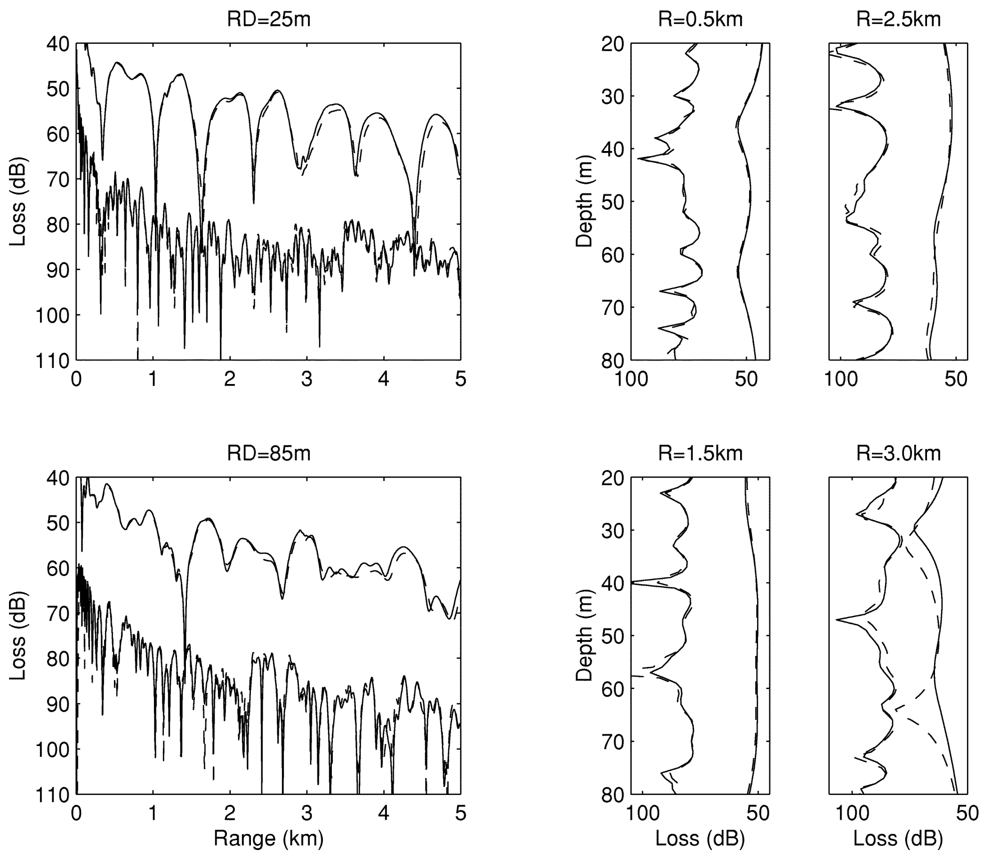

Fig. 8. Comparison between reference solution (solid line) and RAMGEO (dashed line) with inverted bottom properties at a receiver depth of 25 m and a range of 0.5 and 2.5 km (upper panels), and at a receiver depth of 85 m and range of 1.5 and 3.0 km (lower panels). The TL is calculated at two frequencies: 25 (upper and right curves in the TL versus range) and 500 Hz with the 500-Hz results offset by 25-dB higher loss.

V. Test Case TC3

Test case TC3 is characterized by a flat bathymetry with a water depth between 99 and 101 m. The bottom properties are range dependent, caused by an intrusion with unknown position, size, and shape. It is possible to identify ranges where abrupt changes in the TL appear by simply inspecting the reference solution. These abrupt changes in the TL in range are particularly clear at the receiver depth of $\mathrm{RD} = 85$ m and at lower frequencies (Fig. 6). At ranges around 1.1 and 2.9 km, a clear distortion of the otherwise smooth varying TL in range appears and the distortion indicates abrupt changes in the bottom properties at these ranges. The distortion of the TL at higher frequencies

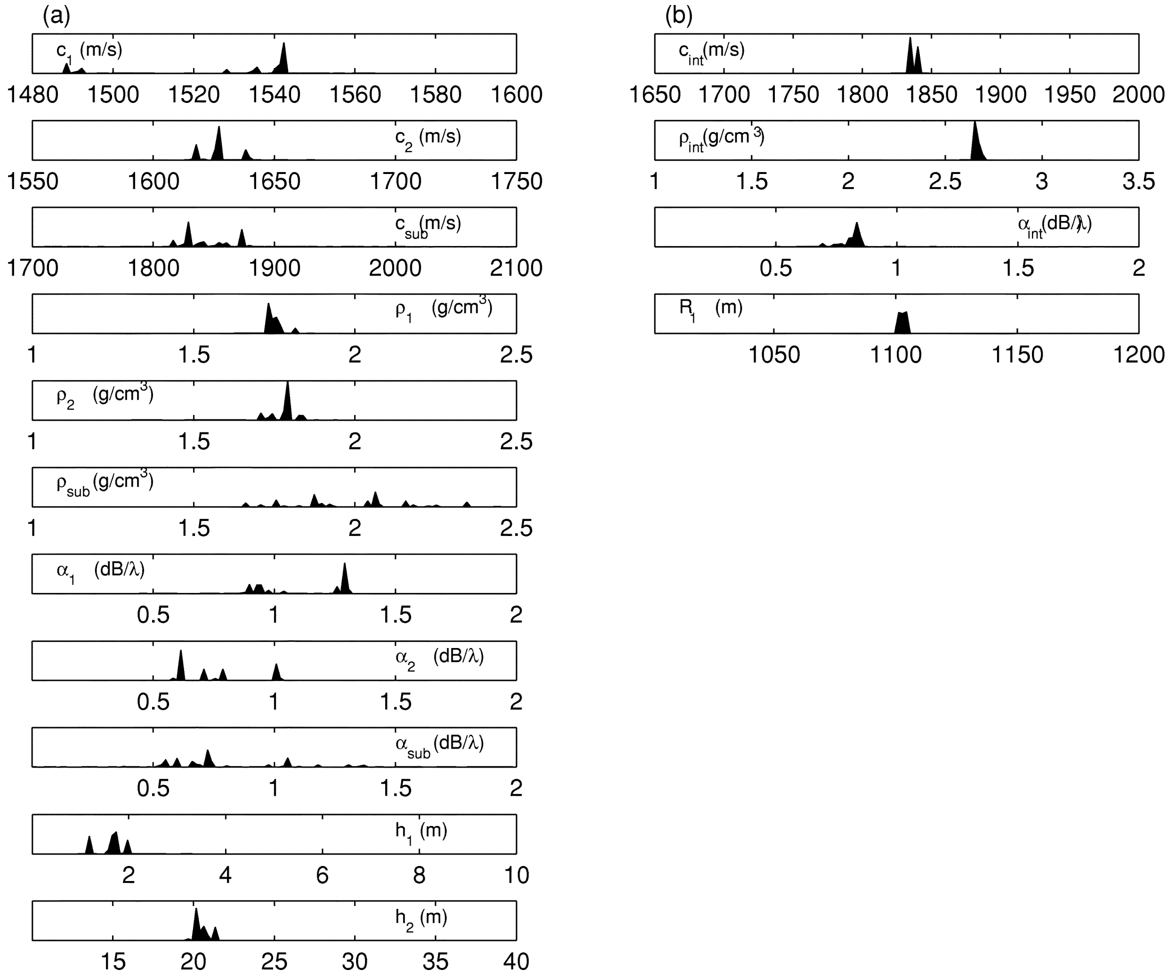

Fig. 9. The *a posteriori* probability distributions of the inverted bottom properties for (a) sector 1 and (b) sector 2.

is not obvious as the changes in the TL by the range-dependent bottom is masked by the strong interference of the acoustic field at these frequencies. Further processing of the reference solution also indicates abrupt changes in the acoustic field at the ranges mentioned above [13]. However, the exact ranges of the changes in bottom properties are unknown.

The discretization of the environment for TC3 (Fig. 7) is based on the behavior of the TL shown in Fig. 6 and initial SAGA trial runs. The bottom properties are divided into three range-independent sectors. The first and third sector are assumed to have similar properties with a two-layer sediment overlying an infinite half-space. The second sector simulates the intrusion assuming an infinite half-space with the interface between sectors 1 and 2 appearing after 1.0-km range and the interface between sectors 2 and 3 before 3.0-km range. The reference acoustic data are available from two vertical array locations within the first sector and the data from both of these arrays were used simultaneously in inferring water depth and bottom properties for sector 1. Hereafter, acoustic reference data from three vertical arrays located within sector 2 were used simultaneously to invert for the bottom properties and the range of the intrusion boundary. The computation time required for the inversion of sector 2 using RAMGEO was decreased by propagating the acoustic field in sector 1 with known bottom properties out to a range of 1.0 km only once. The subsequent model runs in the search for the bottom properties in sector 2 reuse and propagate the acoustic field from the 1-km range. The location of the other boundary of the intrusion was determined by the acoustic field from the remaining five vertical arrays located in sector 3. A search for the range to the intrusion boundary was performed using the same bottom properties in this sector, as determined in sector 1.

The inversion results were obtained from 40 000 forward-modeling runs (2000 iterations and 20 populations in the genetic algorithm) for each sector including the six frequencies: 50, 150, 250, 350, 450, and 500 Hz. The run parameters for RAMGEO were as follows: Depth grid spacing of 0.1 m, range grid spacing of 5.0 m, maximum depth to false bottom was 300 m with a linear increase of the attenuation from 1 to 10 dB/λ for the last 100 m, and the number of Padé terms was 5. Comparison between the TL reference solution and the geoacoustic inversion result for selected source–receiver combinations and frequencies is shown in Fig. 8. The TL obtained by the inversion result is in good agreement with the reference solution. The agreement becomes worse at longer ranges, which may be due to the procedure by marching the inversion result out in range.

TABLE III
GEOMETRY AND GEOACOUSTICS FROM RAMGEO FOR TC3

	Sector 1 (and 3)	Search interval
Bartlett value	0.991	
Layer 1		
h_1 (m)	1.7	0.1–10.0
c_1 (m/s)	1541.4	1480–1600
α_1 (dB/λ)	1.3	0.0–2.0
ρ_1 (g/cm^3)	1.7	1.0–2.5
Layer 2		
h_2 (m)	18.6	1.0–30.0
c_2 (m/s)	1627.2	1550–1750
α_2 (dB/λ)	0.7	0.0–2.0
ρ_2 (g/cm^3)	1.8	1.0–2.5
Sub-bottom		
c_{sub} (m/s)	1838.6	1700–2100
α_{sub} (dB/λ)	0.7	0.0–2.0
ρ_{sub} (g/cm^3)	2.0	1.0–2.5
Sector length		
R_1 (m)	1105.	1001–1200
Water depth		
h_w (m)	100.9	99–101
CPU-time (h)	8.8	
	Sector 2	**Search interval**
Bartlett value	0.987	
Intrusion		
c_{int} (m/s)	1834.7	1650–2000
α_{int} (dB/λ)	0.8	0.0–2.0
ρ_{int} (g/cm^3)	2.7	1.0–3.5
Sector length		
R_2 (m)	2820.0	2800–2995
CPU-time (h)	13.2	

An error in the inverted environmental parameters for sector 1 may accumulate in range and this error affects the inversion results for sectors 2 and 3.

The *a posteriori* probability distributions of the inverted bottom parameters for sectors 1 and 2 are shown in Figs. 9(a) and (b), respectively. The probability distributions have a peak at the optimum value of the individual inversion parameters for both sectors, except for density and attenuation for the infinite half-space in sector 1 (not shown). This behavior of the probability distributions indicates uniqueness in the inversion results for both sectors.

The inversion results for sector 1 and 2, together with the search interval used in the inversion, are given in Table III. The results found by inversion of TC3 are in reasonable agreement with the true geoacoustic parameters. The geoacoustic profiles found here represent average-like properties within each layer, compared to the true profiles as for the inversion of TC1 [2]. The adiabatic PROSIM model was also applied to this test case and good inversion results were obtained for the first sector. However, the search for bottom properties in sector 2 failed completely. This failure is most likely due to a strong mode coupling caused by the abrupt change in bottom properties or an inaccurate interpolation of eigenvalues and mode functions at the intrusion boundaries.

VI. CONCLUSION

Test cases TC1 and TC3 defined for the ITW were selected in this paper for range-dependent geoacoustic inversion. The results from inversion of these synthetic generated reference solutions demonstrate the feasibility of extracting bottom properties from synthetic acoustic data in range-dependent environments. The results presented were obtained before the true solution was known, i.e. no "after-workshop" inversion runs with *a priori* knowledge of the right environment. In general, good agreement between the inverted bottom properties and the true solution was achieved using the inversion package SAGA.

The choice of range-dependent propagation model depends strongly on the "expected" properties of the range-dependent environment. In TC1, both the high-fidelity RAMGEO and the fast-adiabatic PROSIM are applicable. The environment in TC1 is characterized as weakly range-dependent, which allows the use of the less-accurate adiabatic model. This is not the case in TC3, where the adiabatic approach fails as the intrusion in the bottom causes significant mode coupling. The PE model was applied with confidence in this case. However, the efficient adiabatic model is more suitable for practical applications, whereas the PE model, in most cases, requires prohibitively long computation times.

The comparison of efficiency between the two propagation models in geoacoustic inversion depends on the actual range-dependent environment, to what accuracy the bottom properties have to be determined, optimum number of frequencies in the modeling, and convergence criteria applied in the modeling.

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