Comparison of sound speed profile interpolation methods with measured data

Effects on modelled transmission loss

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Abstract

The Bellhop underwater acoustic propagation model was used to investigate the effects of using linear, triangular, and trapezoidal interpolation schemes for incorporating multiple sound speed profiles (SSPs) into range-dependent modelling. Measured and modelled transmission loss (TL) were compared to determine whether there was any clear advantage to using either a series of direct SSP measurements or a series of SSPs interpolated between two or more profiles in a series. Model-measurement differences ranged from -18 dB to $+5$ dB when averaged over the 30-km source-receiver range. Whether using linear, triangular, or trapezoidal interpolation, or direct measurements of SSPs, no consistent change in model performance was observed. Increasing the numbers of intermediate SSPs in a series tended to reduce the modelled TL, regardless of interpolation type.

Résumé

Nous avons utilisé le modèle Bellhop de propagation acoustique sous l'eau pour étudier les effets des méthodes d'interpolation linéaire, triangulaire et trapézoïdale pour intégrer les profils de vitesse de son (PVS) dans la modélisation de la propagation en fonction de la distance. Nous avons comparé les pertes mesurées et modélisées de transmission afin d'établir s'il existait un avantage évident à utiliser une série de PVS mesurés directement plutôt qu'une série de PVS interpolés entre deux profils limites, ou plus, dans une série. Les écarts entre les moyennes sur une distance de 30 km entre la source et le récepteur des résultats des modèles et des mesures tombaient entre -18 dB et +5 dB. Nous n'avons observé aucun changement systématique du rendement du modèle si nous utilisions des interpolations linéaires, triangulaires ou trapézoïdales ou encore les PVS mesurés. L'accroissement du nombre de PVS intermédiaires dans une série tendait à réduire les pertes modélisées, quel que soit le type d'interpolation.

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Executive summary

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Background: Range-dependent model predictions of underwater acoustic propagation rely on a series of input sound speed profiles (SSPs) at different ranges from the acoustic source. In order to avoid computational artifacts associated with sudden changes in SSP, some propagation models interpolate between the input SSPs to calculate the SSP at each range step. The Bellhop underwater acoustic propagation model was used to investigate the effects of using linear, triangular, and trapezoidal interpolation schemes for incorporating multiple sound speed profiles used in range-dependent modelling.

Principal results: Measured and modelled transmission loss (TL) were compared to determine whether there was any clear advantage to using either a series of direct SSP measurements or a series of SSPs interpolated between two endpoint profiles. The number of intermediate profiles in the series was varied in order to investigate the effects of increasing the spatial sampling of SSPs. Whether using linear, triangular, or trapezoidal interpolation, or direct measurements of SSPs, no consistent change in model performance was observed. Increasing the numbers of intermediate SSPs in a series tended to reduce the modelled TL, regardless of interpolation type.

Significance of results: Based on the comparison of modelled and measured TL, there is no benefit to adding the computational burden of triangular or trapezoidal SSP interpolation to existing acoustic propagation models, most of which already implement linear interpolation. Some benefit may be gained from using as many closely-spaced measured SSPs as possible.

Future work: Comparable datasets consisting of densely-sampled CTD casts taken during TL measurements in other ocean areas would be useful in order to determine whether the finding that the interpolation type does not greatly affect TL predictions is more broadly applicable. Since there is no physical justification for introducing calculations such as interpolation that have no relationship to the underlying ocean dynamics, exploring SSP models that take ocean dynamics or water masses into account may be an avenue worthy of further investigation.

Sommaire

Comparison of sound speed profile interpolation methods with measured data

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R & D pour la defense Canada – Atlantique ; janvier 2014.

Contexte : Les prédictions de modèles de la propagation acoustique en fonction de la distance sous l'eau dépendent d'un ensemble d'entrée de profils de vitesse du son (PVS) d'entrée pour différentes distances depuis la source acoustique. Pour éviter que des changements soudains de PVS ne créent des artefacts de calcul, certains modèles de propagation produisent un profil pour chaque incrément de distance, par interpolation des PVS donnés. Nous avons utilisé le modèle Bellhop de propagation acoustique sous l'eau pour étudier les effets des méthodes d'interpolation linéaire, triangulaire et trapézoïdale pour intégrer les PVS dans la modélisation de la propagation en fonction de la distance.

Résultats principaux : Nous avons comparé des pertes mesurées et modélisées de la transmission afin d'établir s'il existait un avantage évident à utiliser une série de PVS mesurés directement plutôt qu'une série de PVS interpolés entre deux profils limites. Nous avons varié le nombre de profils intermédiaires dans la série afin d'étudier l'effet de l'augmentation de l'échantillonnage spatial des PVS. Nous n'avons observé aucun changement systématique du rendement du modèle si nous utilisions des interpolations linéaires, triangulaires ou trapézoïdales ou encore les PVS mesurés. L'accroissement du nombre de PVS intermédiaires dans une série tendait à réduire les pertes modélisées, quel que soit le type d'interpolation.

Importance des résultats : Les comparaisons des pertes de transmission modélisées ou mesurées nous indiquent que le coût de calcul supplémentaire de l'interpolation triangulaire ou trapézoïdale des PVS ne se traduit par aucun avantage par rapport aux modèles existants de propagation acoustique qui utilisent l'interpolation linéaire. On peut tirer certains avantages de l'utilisation du plus grand nombre possible de PVS mesurés très près l'un de l'autre.

Travaux futurs : Des ensembles comparables de données de conductivité, température et profondeur (CTP) recueillies pendant les mesures de pertes de transmission dans d'autres zones océaniques seraient utiles pour déterminer si notre conclusion que le type d'interpolation n'affecte pas grandement la prédiction des pertes de transmission est généralisable. Puisqu'il n'existe pas de justification physique pour l'introduction de calculs comme l'interpolation pour lesquels il n'existe pas de relation avec la dynamique océanique sous-jacente, l'exploration

de modéles de PVS qui tiennent compte de la dynamique des océans ou des masses d’eau pourrait constituer une avenue méritant d’être explorée davantage.

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1 Introduction

ASPIRE (Assessing Sonar Performance in Realistic Environments) was a four-year Applied Research Project (ARP), completed in March 2012. The objective of the project was to determine how to sample the underwater environment in an adaptive and optimal manner to enhance tactical decision-making for anti-submarine warfare (ASW). Project components included collecting environmental data using Rapid Environmental Assessment (REA) techniques, numerical modelling of underwater acoustic propagation including the effects of environmental uncertainty and variability, and integration of sonar performance predictions into an ASW tactical picture to enhance decision-making.

Range-dependent model predictions of underwater acoustic propagation rely on a series of input sound speed profiles (SSPs) at different ranges from the acoustic source. In order to avoid computational artifacts associated with sudden changes in SSP, some propagation models interpolate between the input SSPs to calculate the SSP at each range step. A variety of SSP interpolation schemes exist, not all of which are suitable for entering measured SSPs into propagation models [1]. In addition, when multiple SSPs are available for a range-dependent environment, it is not immediately obvious whether using greater numbers of SSPs will increase model fidelity.

From a physical standpoint, the treatment of SSPs should be guided by the ocean dynamics relevant to a specific environment, in particular, mixing and water mass movement (horizontal or vertical). However, for the moment, we will ignore the non-trivial issue of physical motivation for selecting one interpolation type over another and examine only the tradeoffs in model accuracy and computational complexity that result from the choice of interpolation scheme.

The SSP interpolation schemes investigated in this study will be introduced and explained in Section 2. Section 3 describes the measured SSPs and acoustic transmission loss (TL) data, explains the SSP interpolation scheme implementation, and details the acoustic TL modelling used for comparisons. In Section 4, comparisons are made between measured TL and modelled TL obtained using the different SSP interpolation schemes and varying the numbers of SSPs used. Conclusions and considerations for future work are outlined in Section 5.

2 Theory

Among the most promising interpolation schemes for direct implementation within existing propagation models are linear interpolation, triangular interpolation, and trapezoidal interpolation. This document will be limited to an overview of interpolation types; detailed formulae can be found in [1].

In linear interpolation the sound speed is linearly interpolated between the input speeds at different ranges but at the same depth. Features such as sound channel ducts that strongly affect propagation may be smeared out by the interpolation process [1].

Both triangular and trapezoidal interpolation schemes rely on the identification of SSP features such as the depth of the sound speed minimum. The resulting interpolation preserves the general shape of the SSP feature as a function of range, as it rises or falls in depth. Figure 1a shows two idealized SSPs, each with three features identified: the depth of the sound speed minimum, the depth of sound speed maximum above the minimum, and the depth of the maximum negative gradient between the first two features.

In triangular interpolation, a diagonal line connecting the depths of two features at two different ranges defines two triangles (Figure 1a), and the rate of ascent or descent of the feature along the diagonal line is maintained. For intermediate ranges and depths bounded by the dotted lines and inside the triangles (Regions A, B, and C in Figure 1a), the rate of ascent or descent is proportional to the distance from the diagonal line and can be determined by simple algebra. Linear interpolation is used for ranges and depths outside the triangles (Regions D, E, and F in Figure 1a).

In trapezoidal interpolation the lines connecting the features divide the interpolation region into trapezoidal areas (Regions A, B, C, and D in Figure 1b). For interpolation at a given depth and range point, the rate of descent or ascent is proportional to where the point lies between the two diagonal lines defining the region.

3 Methods

TL measurements acquired in conjunction with multiple SSPs measured along the same straight-line track were used to investigate which type of interpolation is most appropriate for use in range-dependent acoustic TL models. A TL model was run using the series of measured SSPs as well as SSPs calculated at each model range step using different interpolation schemes, and the resulting TL was compared to the measured TL. The number of measured SSPs was also varied in order to investigate the effects of increasing the rate of SSP sampling. The TL and SSP measurements are described in Section 3.1, implementation of the interpolation schemes is described in Section 3.2, and the TL model parameters and calculations are described in Section 3.3.

3.1 Measured data

The TL experiment took place on 3 Nov 2009 in the Emerald Basin during sea trial Q325 with Canadian Forces Auxiliary Vessel (CFAV) Quest. The bathymetry consisted of a

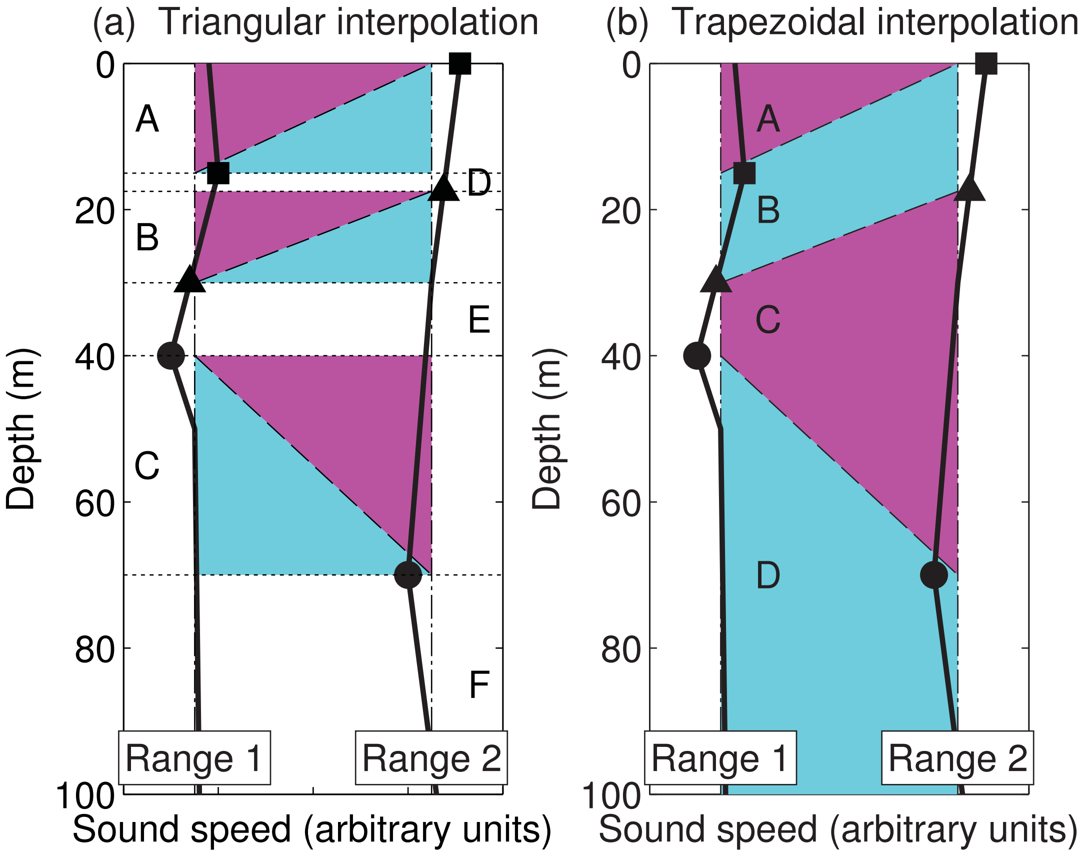

Figure 1: *Types of interpolation. The sound speed minimum (circle), maximum above the minimum (square), and depth of maximum negative gradient between the first two features (triangle) are indicated on each profile. (a) Triangular interpolation: the depths at which the features are found define the diagonals of the triangles. Dotted lines indicate the extent of regions with triangular (A, B, C) and linear (D, E, F) interpolation. (b) Trapezoidal interpolation: the depths at which the features are found define the non-parallel sides of the trapezoidal regions A, B, C, and D.*

sloping, soft bottom at 260 m depth rising to 95 m depth along a 30-km track[1].

A sequence of two continuous wave (CW) tones (1200 Hz and 3000 Hz) and two frequency-modulated (FM) sweeps (1100-1300 Hz and 2900-3100 Hz) was transmitted from a towed source and recorded on stationary receivers at two different depths (52 m and 72 m). The depth of the towed source was logged with an electronic data logger and varied from 56 m to 66 m. The detailed processing required to produce the TL measurements is described in two reports [2, 3].

During the TL experiment, a total of 40 SSPs were acquired by a conductivity-temperature-depth (CTD) sensor deployed from a Moving Vessel Profiler (MVP). The range interval between SSPs ranged from 0.04 km to 1.15 km, with a mean value of 0.74 km. Obtaining SSPs from CTD measurements is straightforward: the temperature T, salinity S, and depth z measured by the CTD were used to estimate SSPs [4, p. 85]:

$$\begin{aligned} c(T,S,z) = {} & 1449.2+4.6T-0.055T^2+0.0029T^3 \\ & +(1.34-0.01T)(S-35)+0.016z \end{aligned} \tag{1}$$

Since the CTD acquires data both on the upward and downward parts of the cast, the values for T and S were averaged into 2-m depth bins combining both the upward and downward data for each profile.

3.2 Interpolation

Figure 2 is a plot of the SSPs along the track, including bathymetry (thick black line), receiver locations (red triangles), and source depth (red line). The true range for each measured SSP was rounded to the nearest range step used in the modelling (50 m).

The SSP interpolation was first performed by using the first and last measured SSPs as endpoints of the interpolation. In order to explore the effects of having additional intermediate profiles available, increasing numbers of SSPs between the two endpoints were included as additional interpolation points, as detailed in Table 1. Linear, triangular, or trapezoidal interpolation as described by McCammon [1] was used to calculate the remaining SSPs.

The SSP features used for triangular and trapezoidal interpolation were the same features described in Figure 1: the depth of the sound speed minimum, the depth of the sound speed maximum above the minimum, and the depth of the maximum negative gradient between the first two features.

In addition to interpolated SSPs, the measured SSPs were used directly as inputs to Bellhop. The result was four different sets of SSPs used as inputs to the model: (1) measured

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[1] The track endpoints were (43.88° N, 62.88° W) and (43.64° N, 62.60° W)

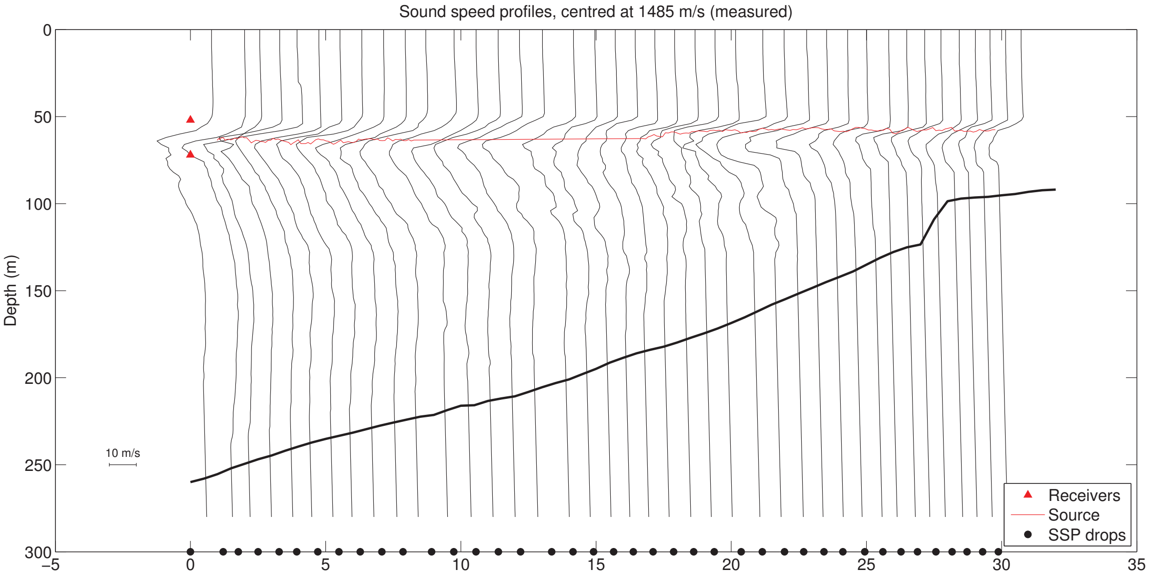

Figure 2: *SSPs acquired using a CTD during the TL experiment, including bathymetry (thick black line), receiver locations (red triangles), and source depth (red line). Drop locations are indicated as black circles.*

Model Run	Number of profiles	Profile indices
1	2	1 40
2	3	1 20 40
3	5	1 10 20 30 40
4	9	1 5 10 15 20 25 30 35 40
5	17	1 3 5 8 10 13 15 18 20 23 25 28 30 33 35 38 40
6	40	all (1–40)

Table 1: *Numbers of profiles used in each model run.*

SSPs with no interpolation, (2) linear interpolation, (3) triangular interpolation, and (4) trapezoidal interpolation.

Each figure in the Appendix (Figures A.1 through A.6) contains plots of all four SSP types for a given set of intermediate profiles listed in Table 1. For example, using only profiles #1 and #40, the measured SSP (Figure A.1a) is plotted along with SSPs obtained by linear interpolation (Figure A.1b), triangular interpolation (Figure A.1c), and trapezoidal interpolation (Figure A.1d). The three interpolation methods yield results that appear visually to be very similar.

3.3 Transmission loss modelling

The acoustic transmission loss modelling was performed using BellhopDRDC [5, 6], a customized version of the well-known Bellhop transmission loss model [7]. The reciprocity principle allows the measured TL to be compared with the modelled TL by using the logged source depths as the modelled receiver depths, and the logged receiver depths as the model source depths. In order to reduce confusion, the remaining discussion will refer to the TL model setup (shallow or deep *sources*) rather than the experiment setup (shallow or deep *receivers*).

In order to compare with the 1100-1300 Hz FM sweep, the model was run in incoherent mode at a frequency of 1200 Hz, using the true receiver depths as source depths. The range-dependent bathymetry used in the model was extracted from the Non-Acoustic Data Acquisition System (NADAS) file, which logged the bottom depth as measured aboard CFAV Quest. A range-independent bottom type (clayey silt) was used in order to isolate the effect of the SSPs on TL.

Bellhop has a native linear interpolation mode that can be enabled or disabled; however, TL results using uninterpolated SSPs with the native interpolation enabled are not identical to TL results using linearly interpolated SSPs with the native interpolation disabled. Even after an extensive troubleshooting effort, the source of the discrepancy was not determined. Therefore, in order to retain complete control of the interpolation, the native linear interpolation was disabled, and interpolated SSPs were provided for Bellhop at each 50-m range step. The measured SSPs were provided at the nearest range step that corresponded to one of the 50-m model range steps. The result was a total of 48 model runs (6 sets of profiles × 4 SSP types × 2 source depths).

4 Results and Discussion

Appendix B contains full field plots of modelled TL for each of the 24 modelling scenarios (Figures B.1 through B.6). Modelled TL was interpolated at the ranges and depths corre-

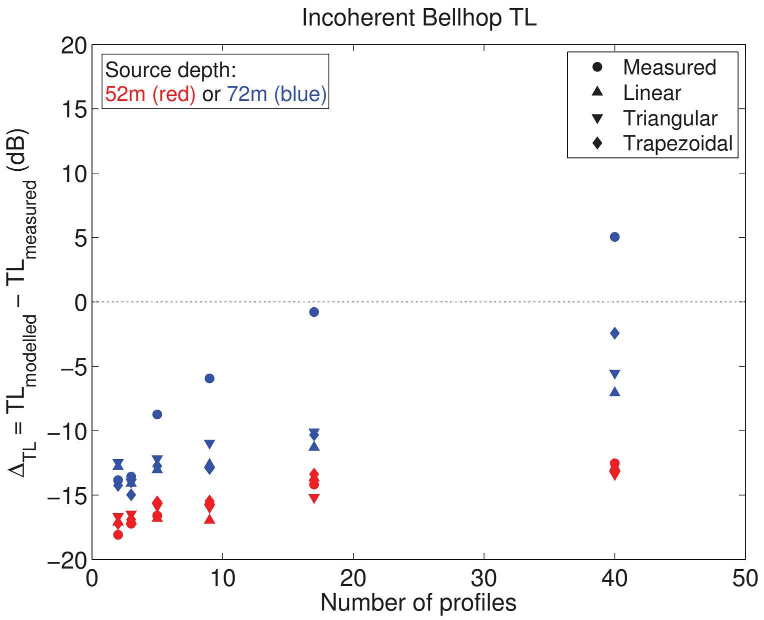

Figure 3: *Mean values of $\Delta_{TL} = TL_{modelled} - TL_{measured}$, averaged over all source-receiver ranges. Symbol colour indicates source depth, and symbol shape indicates whether measured or interpolated SSPs were used in the TL model.*

sponding to the logged source position for each experiment, and compared with measured TL at the corresponding range and depth point.

The difference between modelled and measured TL

$$\Delta_{TL} = TL_{modelled} - TL_{measured} \tag{2}$$

was calculated as a function of range for all 48 model runs, and then averaged for all source-receiver ranges along the entire track to give a sense of overall model-measurement agreement for each SSP type used in the modelling.

Figure 3 is a plot of the average value of Δ_{TL} as a function of the number of profiles used. The plot symbols indicate which group of SSPs was used: measured SSPs (circles), linear interpolation (up-triangles), triangular interpolation (down-triangles), or trapezoidal interpolation (diamonds). Symbol colour indicates source depth: 52 m (red) or 72 m (blue).

The results for the three different interpolations types are closely clustered together. Agreement between measured and modelled TL was generally poor, with Δ_{TL} ranging from -18 dB to $+5$ dB. Only 3 of the model runs agreed with measurements within ± 5 dB: measured SSPs using 17 and 40 profiles, and trapezoidal interpolation using 40 profiles, all for the 72-m source depth.

For the 52-m source depth (red symbols in Figure 3), model-measurement agreement improved with increasing number of profiles used in the interpolation. However the model underestimated TL by 12 to 18 dB, and the average values of Δ_{TL} were within 1–2 dB of each other for a given number of profiles regardless of SSP types used.

For the 72-m source depth and interpolated SSPs (blue triangles and diamonds in Figure 3), the average values of Δ_{TL} for the interpolated SSPs were within 1–2 dB of each other. The measured SSPs for the 72-m source depth (blue circles) consistently resulted in TLs that were 5–7 dB greater than the TL obtained with interpolated SSPs.

Increasing the number of profiles increased the modelled TL, and the effect was most drastic for the measured SSPs and the 72-m source depth. There was very little difference in model-measurement agreement with the different interpolation type used.

Better model-measurement agreement for the deeper source suggests that the specific features of the SSPs at depths between the source (52 m or 72 m) and receiver (56 m to 66 m) may be responsible for the agreement. Examination of Figure 2 reveals a strong gradient that changes from profile to profile between 50–60 m depth, while the gradient below 60 m changes less drastically between adjacent profiles.

5 Conclusions

Three different methods (linear, triangular, and trapezoidal) of interpolating in range between measured SSPs were investigated for use in range-dependent ocean acoustic propagation modelling. Measured TL was compared with modelled TL that was calculated using Bellhop, with inputs of either measured or interpolated SSPs based on 40 SSPs that were acquired along the TL track. The number of SSPs used for interpolation was varied to investigate the effects of changing spatial sampling of SSPs along the track.

For any given modelling scenario, different interpolation types resulted in modelled TL that was consistent within 1–2 dB. However the difference between modelled and measured TL ranged from -18 to $+5$ dB, and only 3 out of 48 modelling scenarios resulted in a range-averaged accuracy of less than 5 dB. The three model runs with the best agreement resulted from using many (17 or 40) directly-measured SSPs and 40 SSPs with trapezoidal interpolation, suggesting that closely-spaced measurements may be preferable to sparsely-spaced measurements, regardless of interpolation type between SSPs.

In general, none of the SSP interpolation types resulted in consistently more accurate TL predictions; therefore, there is no benefit to adding the computational burden of triangular or trapezoidal SSP interpolation to existing acoustic propagation models. Comparable datasets consisting of densely-sampled CTD casts taken during TL measurements in other ocean areas would be useful in order to determine whether the finding that the interpolation type does not greatly affect TL predictions is more broadly applicable.

It bears repeating that there is no physical justification for introducing calculations such as interpolation that have no relationship to the underlying ocean dynamics. On the other hand, using SSP models that take ocean dynamics or water masses into account (e.g., the Integrated Command Anti-submarine warfare Prediction System (ICAPS) model [8] or empirical orthogonal functions [9]) may be an avenue worthy of further investigation.

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Annex A: Measured and interpolated SSPs

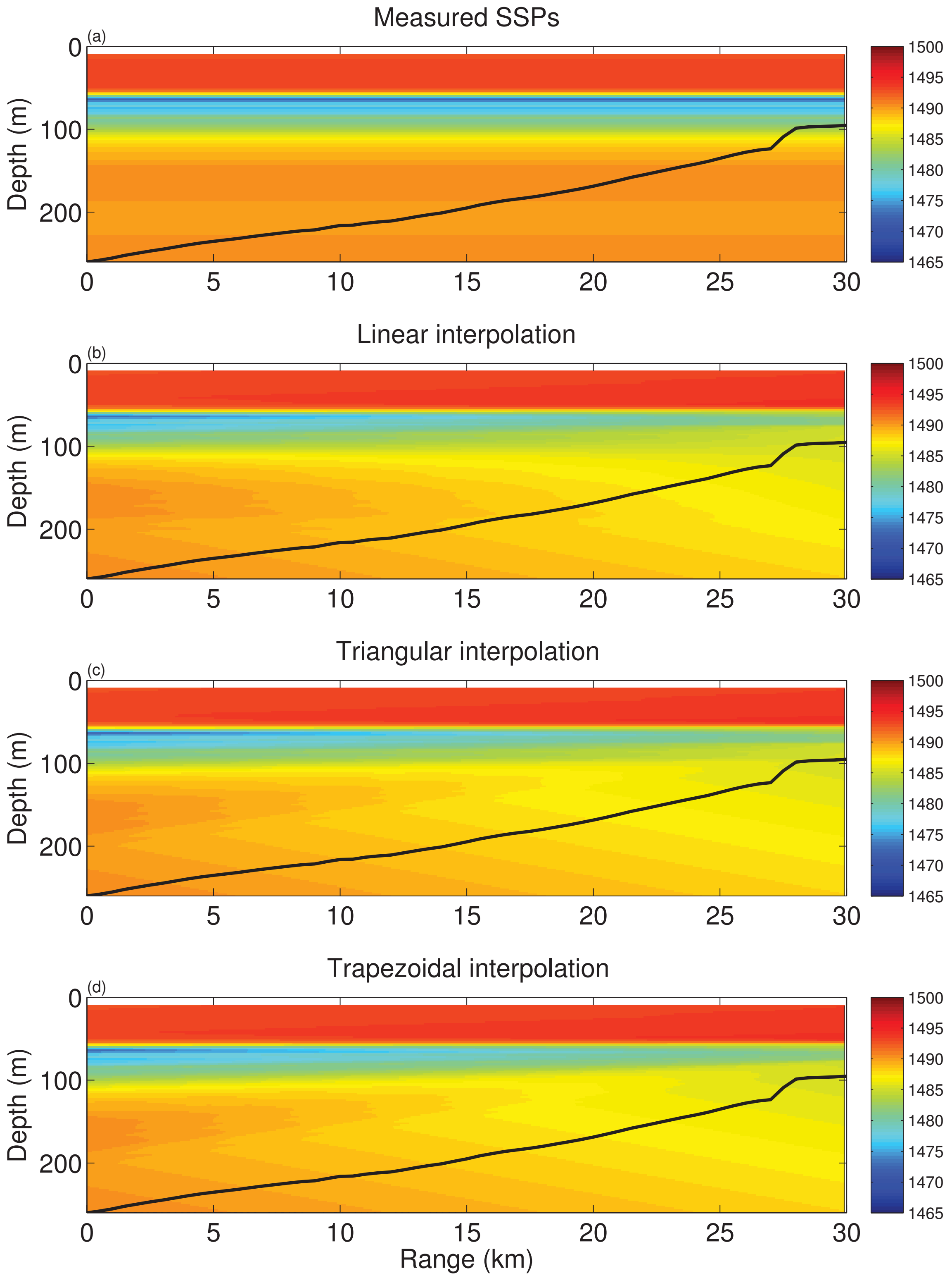

Figure A.1: *SSPs: (a) measured, (b) linear interpolation, (c) triangular interpolation, (d) trapezoidal interpolation, using 2 profiles (at endpoints).*

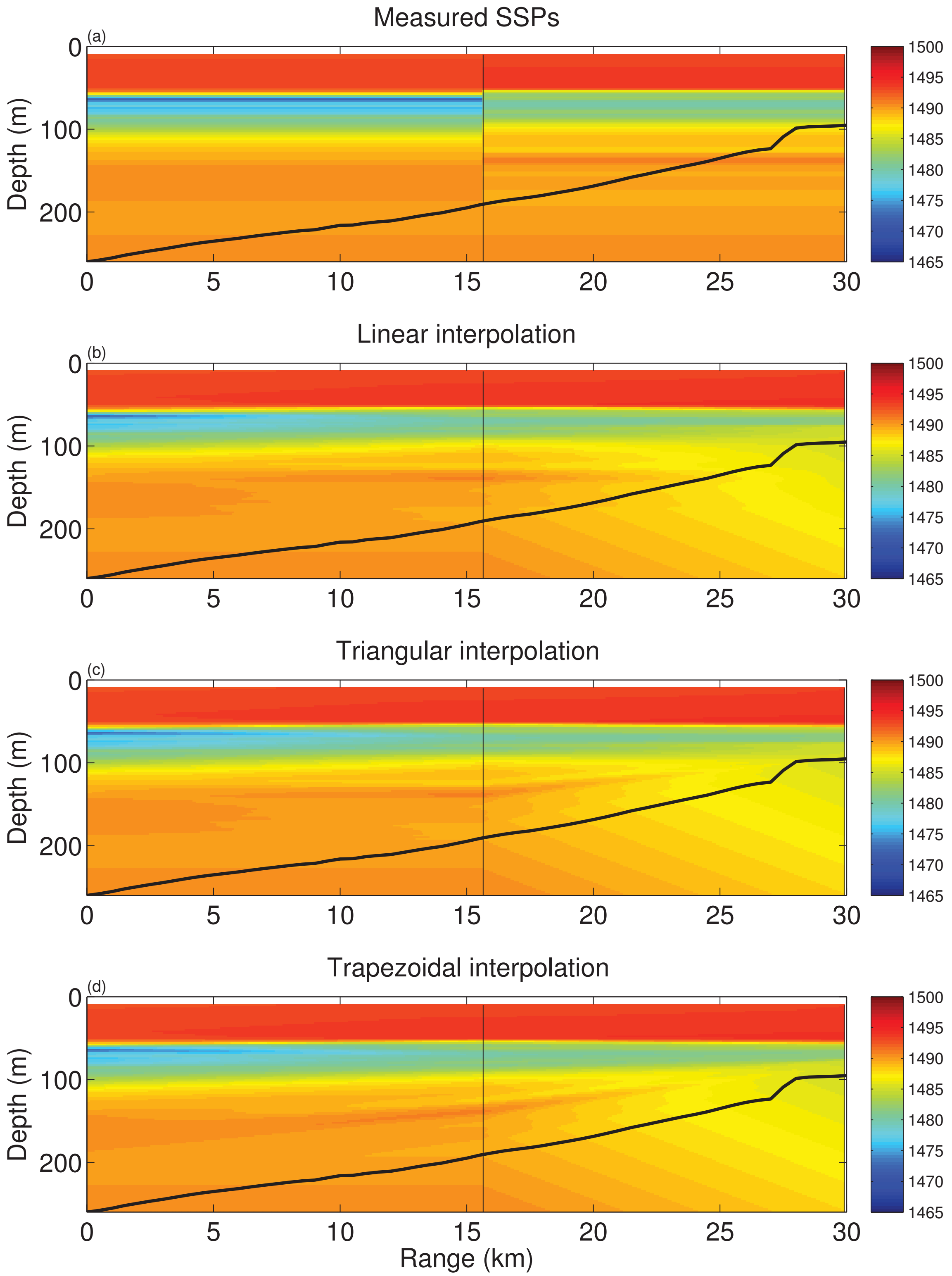

Figure A.2: *SSPs: (a) measured, (b) linear interpolation, (c) triangular interpolation, (d) trapezoidal interpolation, using 3 profiles (at endpoints and black lines).*

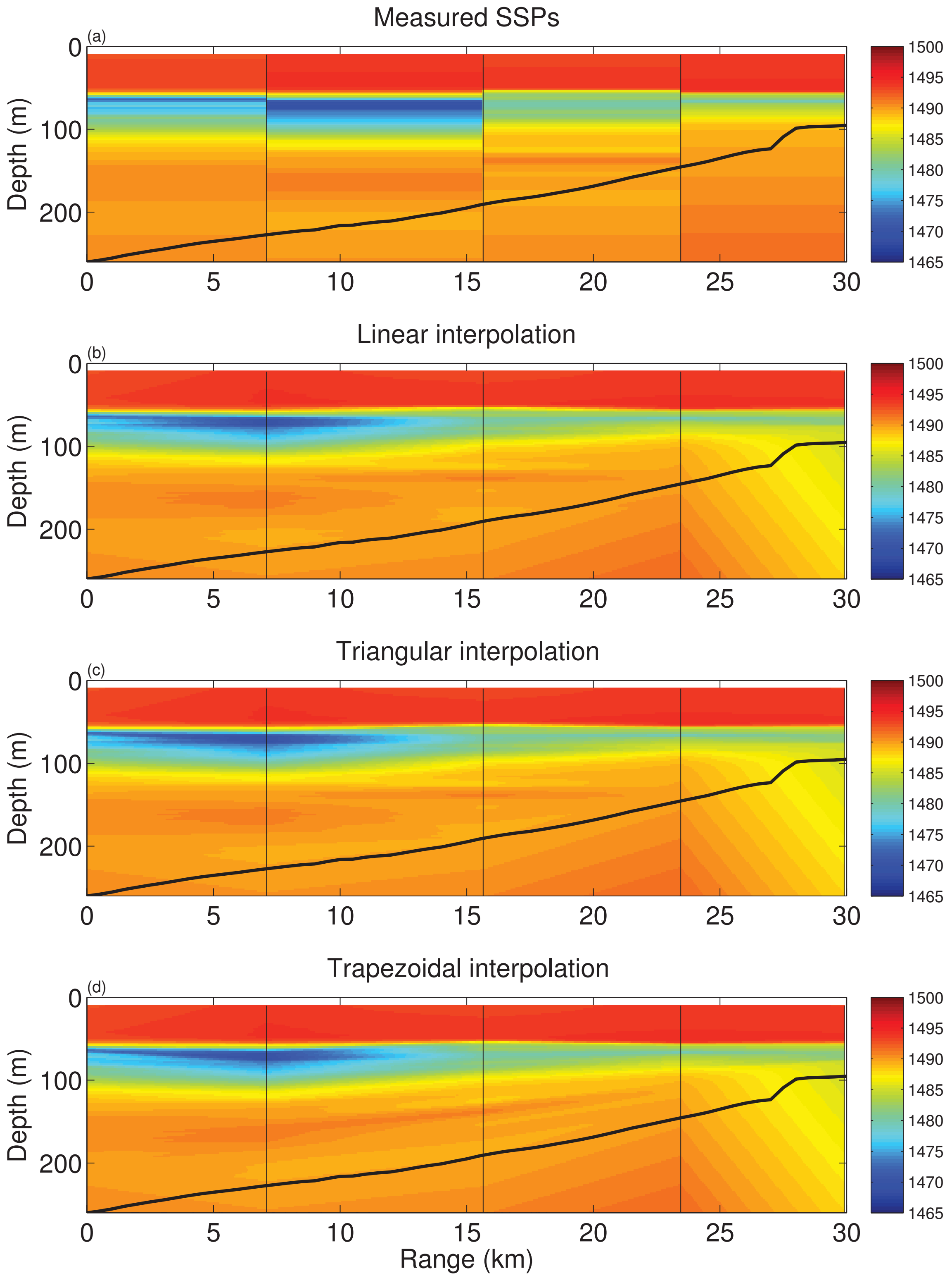

Figure A.3: *SSPs: (a) measured, (b) linear interpolation, (c) triangular interpolation, (d) trapezoidal interpolation, using 5 profiles (at endpoints and black lines).*

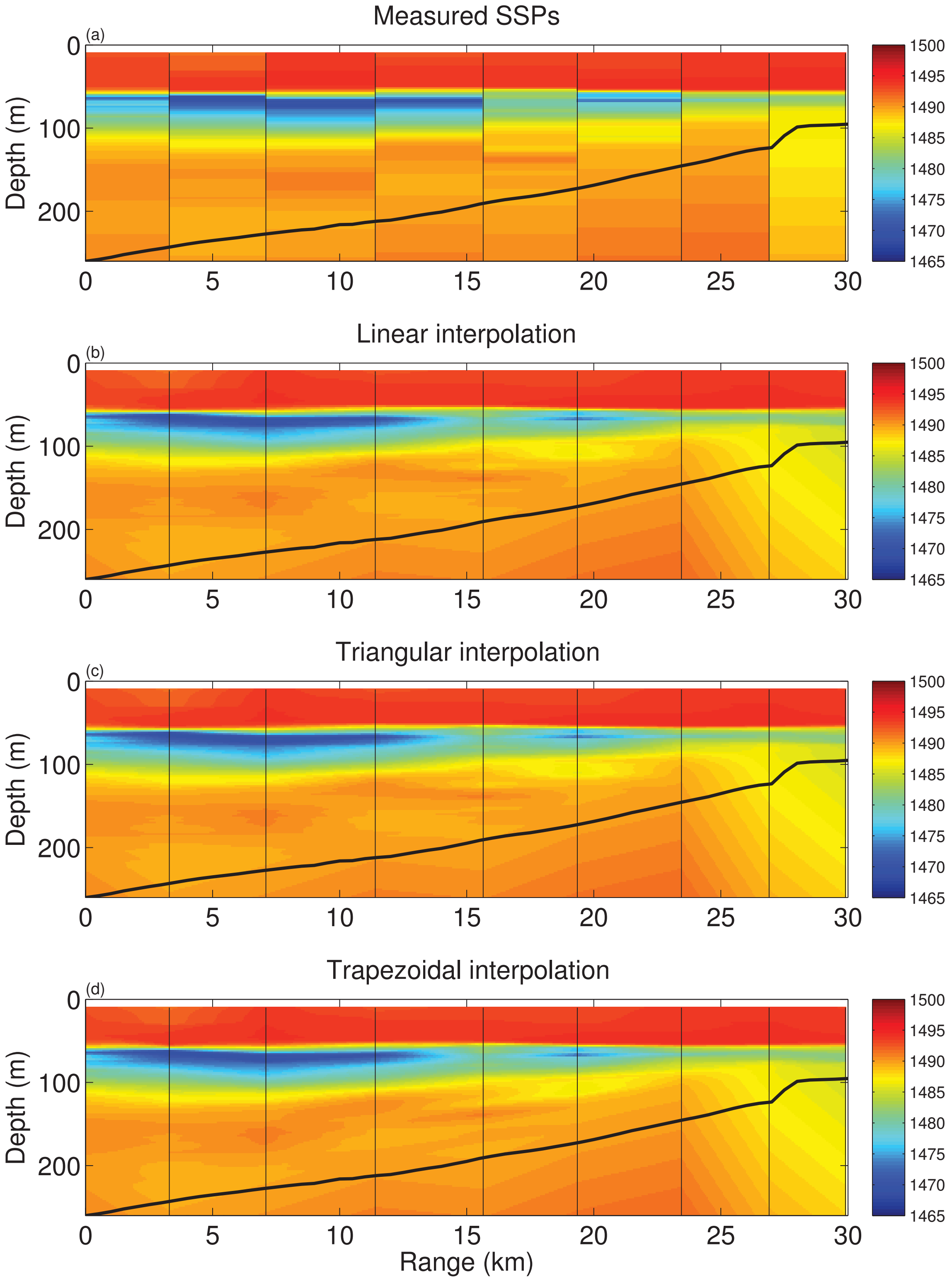

Figure A.4: *SSPs: (a) measured, (b) linear interpolation, (c) triangular interpolation, (d) trapezoidal interpolation, using 9 profiles (at endpoints and black lines).*

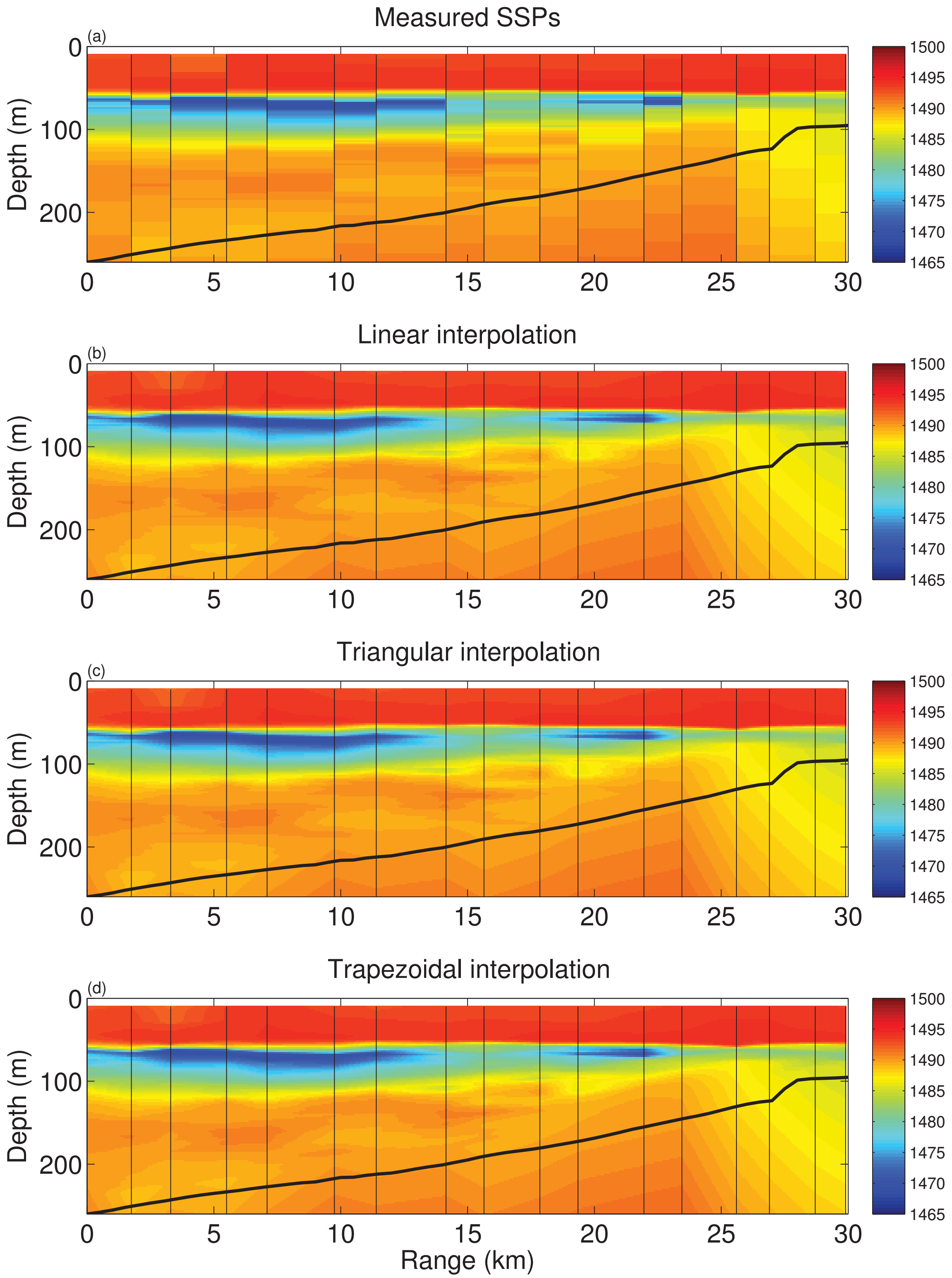

Figure A.5: *SSPs: (a) measured, (b) linear interpolation, (c) triangular interpolation, (d) trapezoidal interpolation, using 17 profiles (at endpoints and black lines).*

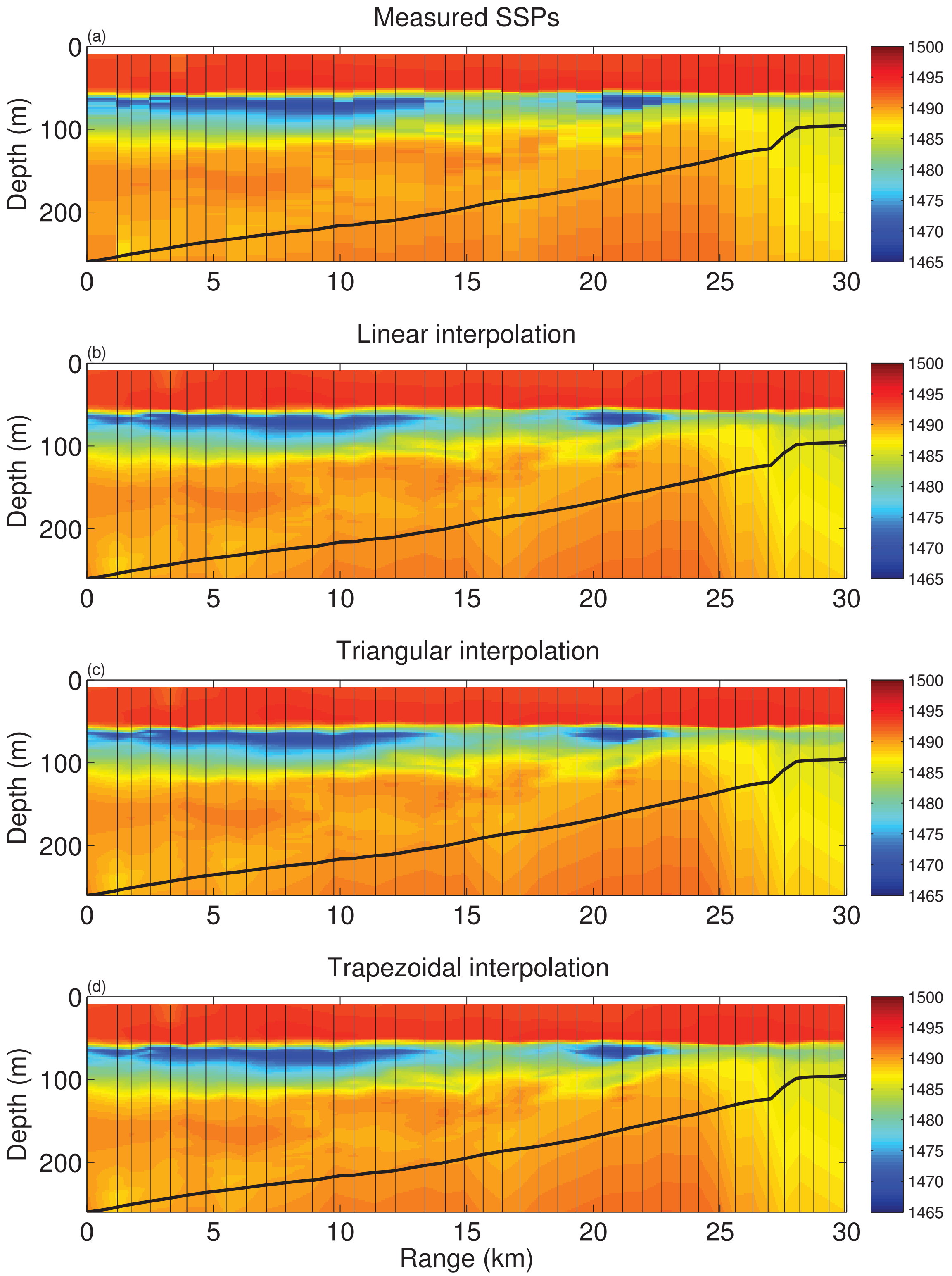

Figure A.6: *SSPs: (a) measured, (b) linear interpolation, (c) triangular interpolation, (d) trapezoidal interpolation, using 40 profiles (at endpoints and black lines).*

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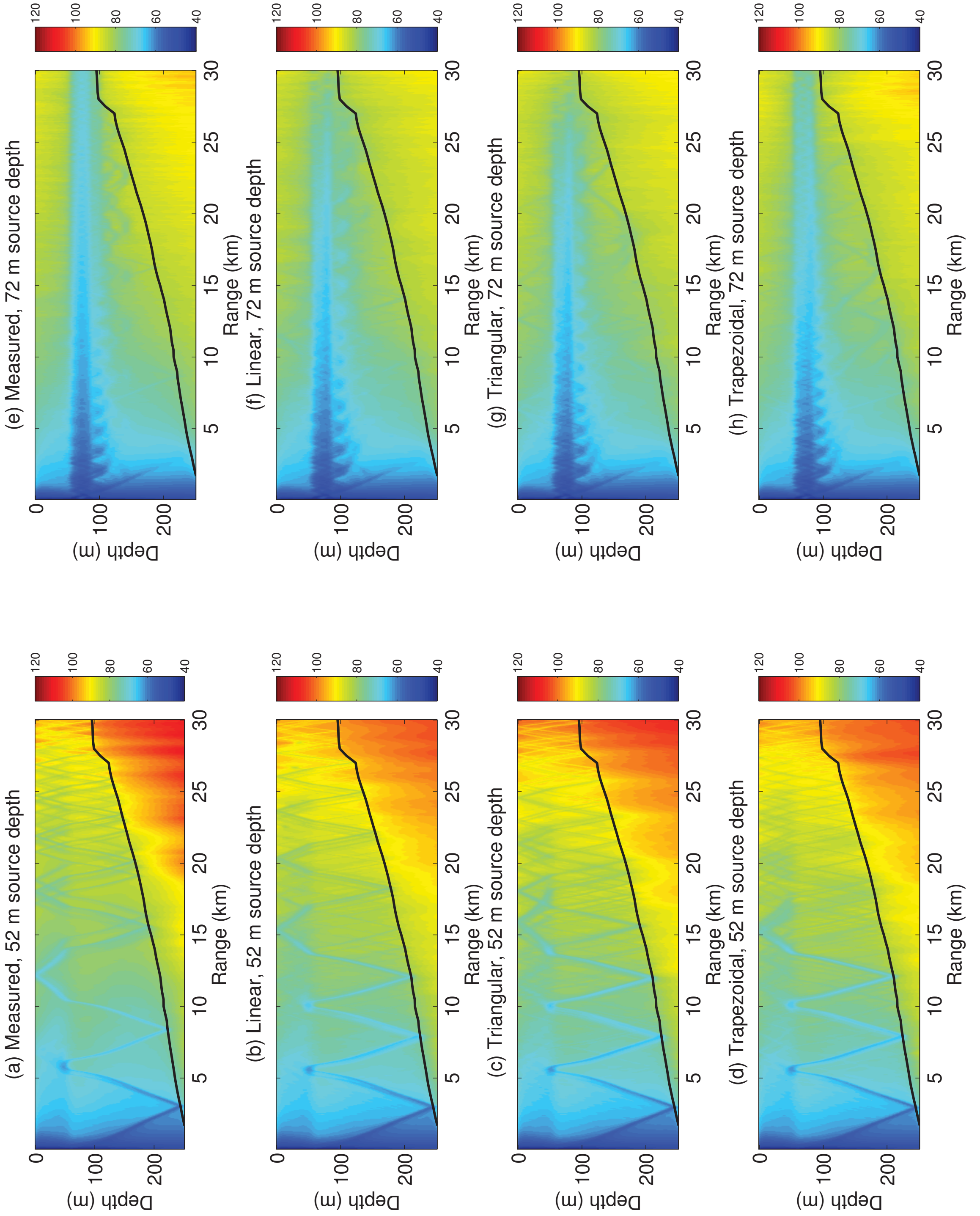
Annex B: Full field transmission loss plots



(a) Measured, 52 m source depth

(b) Linear, 52 m source depth

(c) Triangular, 52 m source depth

(d) Trapezoidal, 52 m source depth

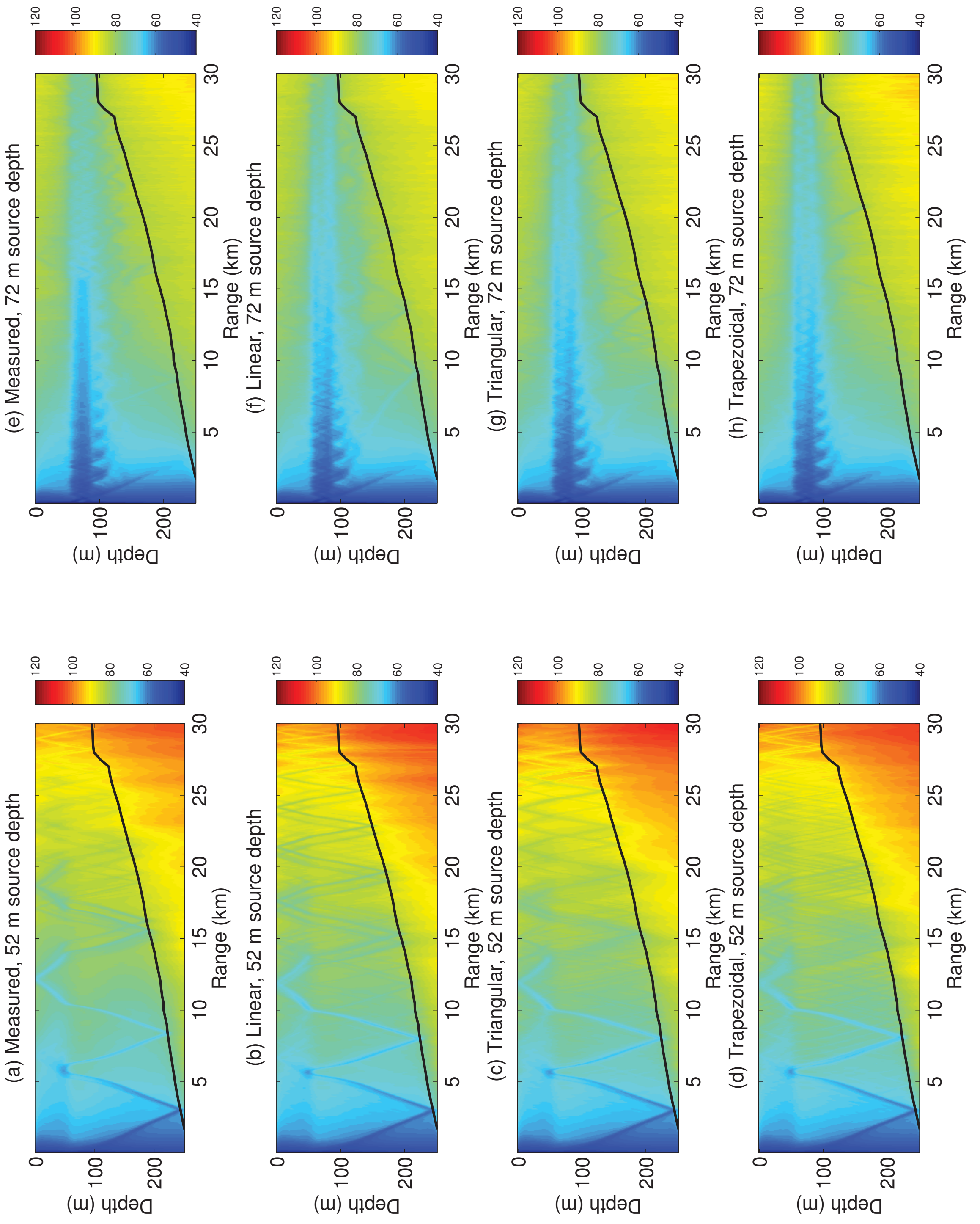
(e) Measured, 72 m source depth

(f) Linear, 72 m source depth

(g) Triangular, 72 m source depth

(h) Trapezoidal, 72 m source depth

Figure B.1: *Modelled TL with 2 profiles used for SSP interpolation (note image rotation). Left column, 52 m source depth, right column, 72 m source depth. First row, measured SSPs; second row, linear interpolation; third row, triangular interpolation; fourth row, trapezoidal interpolation.*


(a) Measured, 52 m source depth

(b) Linear, 52 m source depth

(c) Triangular, 52 m source depth

(d) Trapezoidal, 52 m source depth

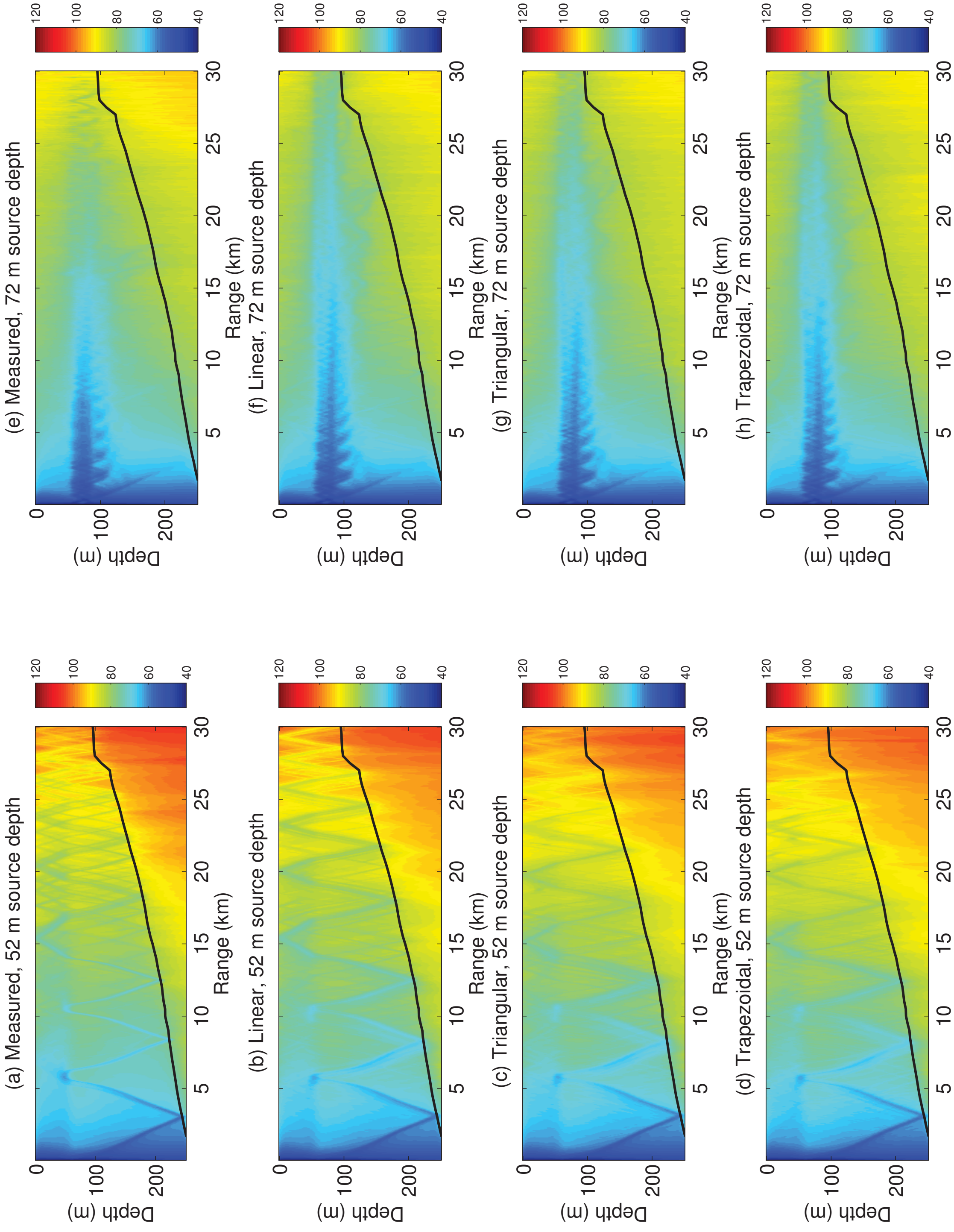
(e) Measured, 72 m source depth

(f) Linear, 72 m source depth

(g) Triangular, 72 m source depth

(h) Trapezoidal, 72 m source depth

Figure B.2: *Modelled TL with 3 profiles used for SSP interpolation (note image rotation). Left column, 52 m source depth, right column, 72 m source depth. First row, measured SSPs; second row, linear interpolation; third row, triangular interpolation; fourth row, trapezoidal interpolation.*


(a) Measured, 52 m source depth

(b) Linear, 52 m source depth

(c) Triangular, 52 m source depth

(d) Trapezoidal, 52 m source depth

(e) Measured, 72 m source depth

(f) Linear, 72 m source depth

(g) Triangular, 72 m source depth

(h) Trapezoidal, 72 m source depth

Figure B.3: *Modelled TL with 5 profiles used for SSP interpolation (note image rotation). Left column, 52 m source depth, right column, 72 m source depth. First row, measured SSPs; second row, linear interpolation; third row, triangular interpolation; fourth row, trapezoidal interpolation.*

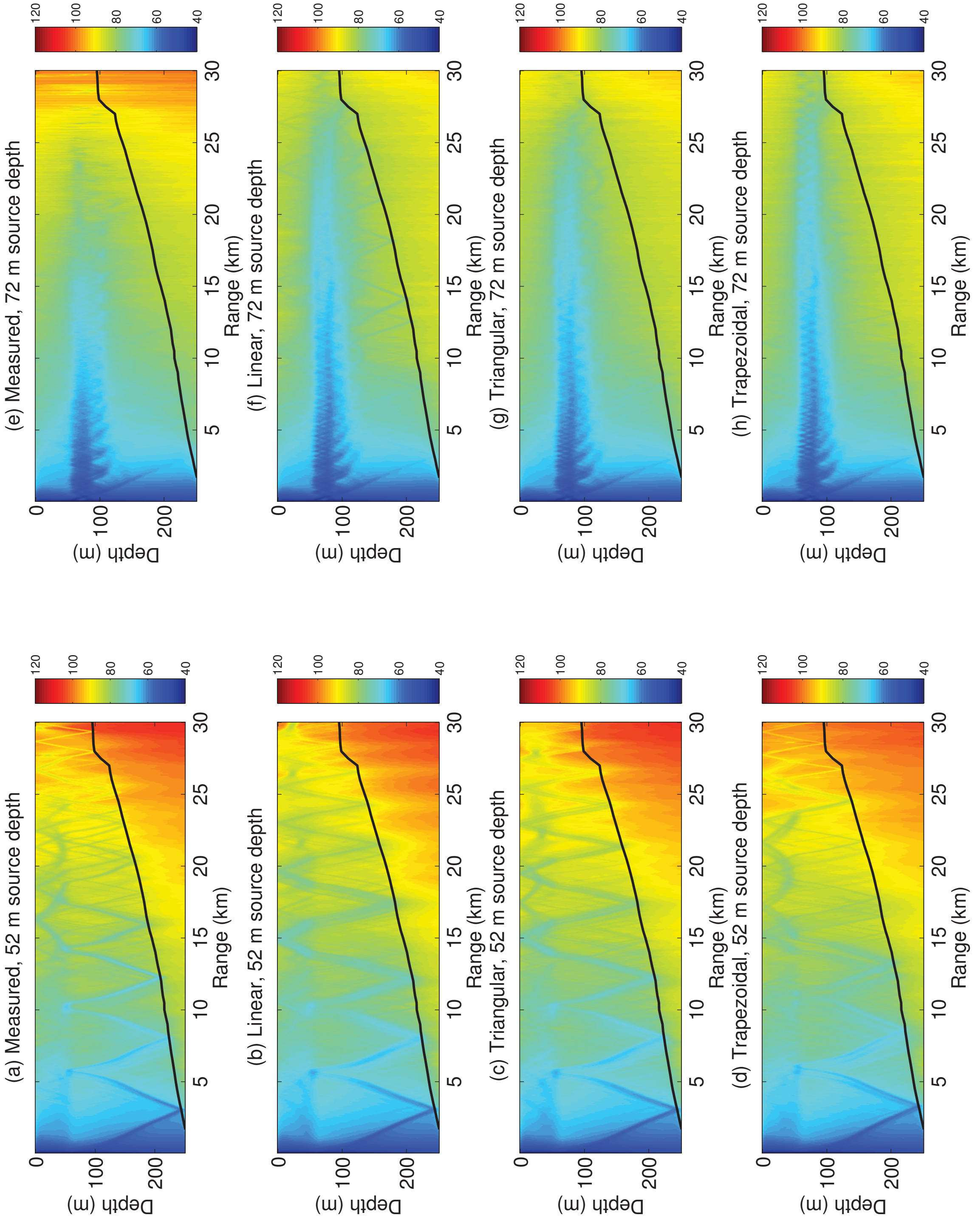
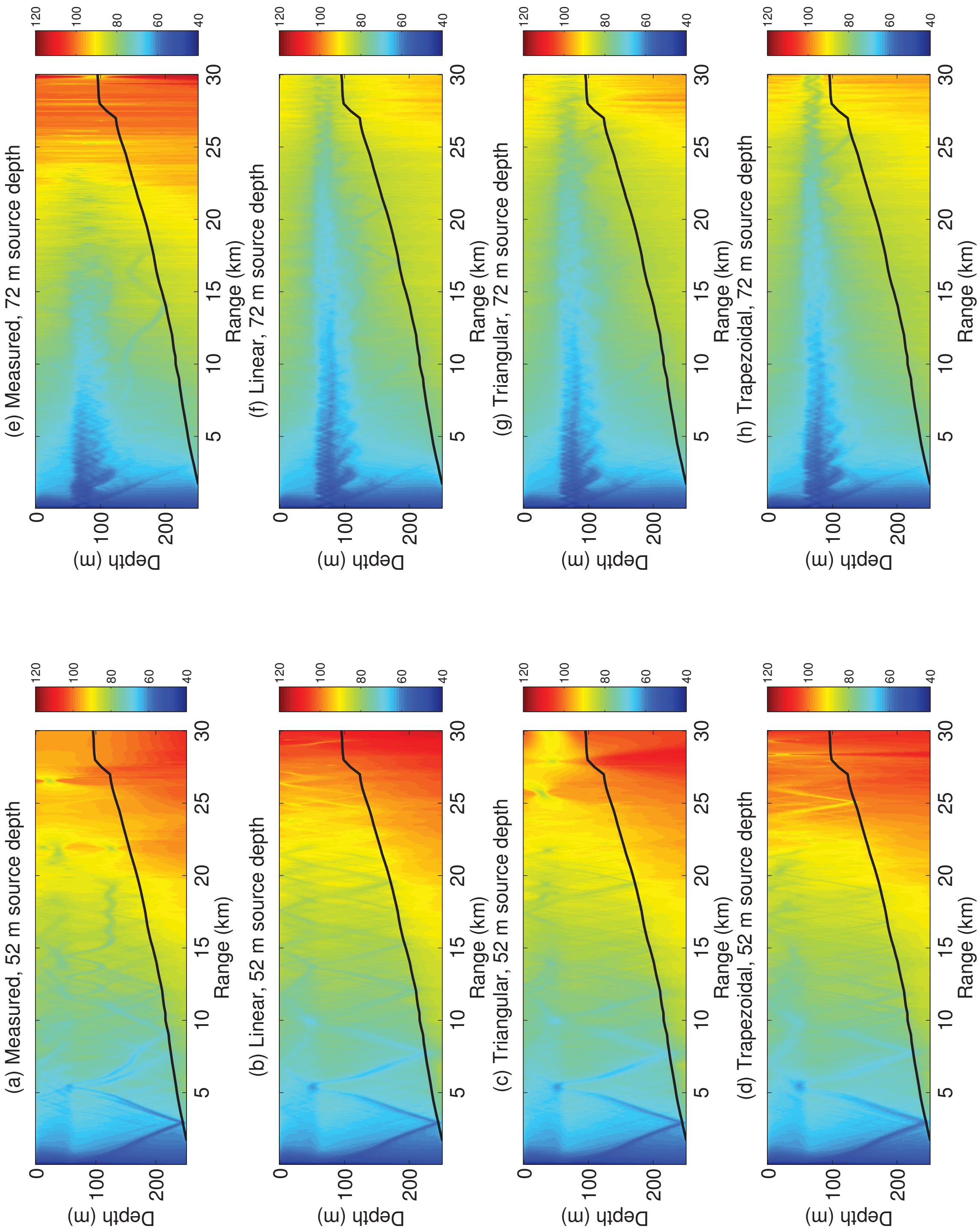


Figure B.4: *Modelled TL with 9 profiles used for SSP interpolation (note image rotation). Left column, 52 m source depth, right column, 72 m source depth. First row, measured SSPs; second row, linear interpolation; third row, triangular interpolation; fourth row, trapezoidal interpolation.*


(a) Measured, 52 m source depth

(b) Linear, 52 m source depth

(c) Triangular, 52 m source depth

(d) Trapezoidal, 52 m source depth

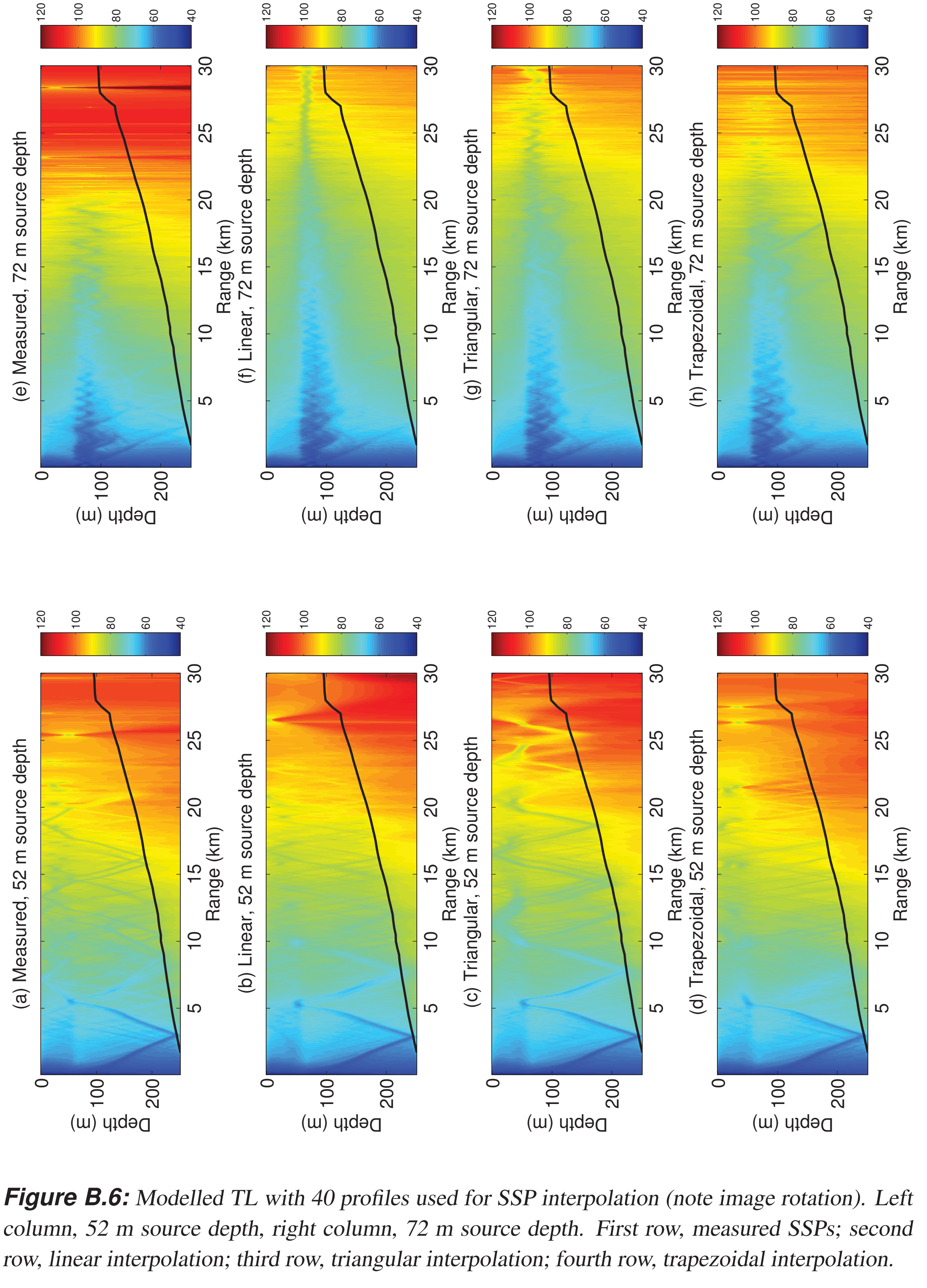
(e) Measured, 72 m source depth

(f) Linear, 72 m source depth

(g) Triangular, 72 m source depth

(h) Trapezoidal, 72 m source depth

Figure B.5: *Modelled TL with 17 profiles used for SSP interpolation (note image rotation). Left column, 52 m source depth, right column, 72 m source depth. First row, measured SSPs; second row, linear interpolation; third row, triangular interpolation; fourth row, trapezoidal interpolation.*



(a) Measured, 52 m source depth

(b) Linear, 52 m source depth

(c) Triangular, 52 m source depth

(d) Trapezoidal, 52 m source depth

(e) Measured, 72 m source depth

(f) Linear, 72 m source depth

(g) Triangular, 72 m source depth

(h) Trapezoidal, 72 m source depth

Figure B.6: *Modelled TL with 40 profiles used for SSP interpolation (note image rotation). Left column, 52 m source depth, right column, 72 m source depth. First row, measured SSPs; second row, linear interpolation; third row, triangular interpolation; fourth row, trapezoidal interpolation.*

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Annex C: Bellhop model settings

Bellhop Option	**Value**
Frequency	1200 Hz
Number of receiver depths	51
Range step	50 m
Maximum range	30 km
Wind speed	5.8 kn
Surface loss model	Beckmann-Spezzichino
Run mode	Coherent
Bathymetry interpolation mode	Linear
Sea water absorption	Thorpe
Step size	default
Number of rays	default
Start angle	default
Stop angle	default
Kill-after-bounce	5000
Smoothing	off

Table C.1: *Parameters for Bellhop* `runinput.inp` *file.*

Bottom Option	**Value**
Bottom treatment option	geoacoustic fluid layers
Range	0.0 km
Layer 1 sound speed	1550 m/s
Layer 1 density	1.5 g/cm^3
Layer 1 attenuation	0.5 dB/(m kHz)
Layer 1 depth	100 m
Layer 2 sound speed	1550 m/s
Layer 2 density	1.5 g/cm^3
Layer 2 attenuation	0.5 dB/(m kHz)

Table C.2: *Parameters for Bellhop* `bottomloss.inp` *file. Two identical layers were used to satisfy Bellhop's minimum requirements for bottom parameters.*

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Annex D: List of Abbreviations

ARP	Applied Research Project
ASPIRE	Assessing Sonar Performance in Realistic Environments
ASW	Anti-Submarine Warfare
CFAV	Canadian Forces Auxiliary Vessel
CTD	Conductivity, Temperature, and Depth
CW	Continuous Wave
dB	decibel
DRDC	Defence Research and Development Canada
FM	Frequency-Modulated
ICAPS	Integrated Command Anti-submarine warfare Prediction System
NADAS	Non-Acoustic Data Acquisition System
MVP	Moving Vessel Profiler
REA	Rapid Environmental Assessment
SSP	Sound Speed Profile
TL	Transmission Loss

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The Bellhop underwater acoustic propagation model was used to investigate the effects of using linear, triangular, and trapezoidal interpolation schemes for incorporating multiple sound speed profiles (SSPs) into range-dependent modelling. Measured and modelled transmission loss (TL) were compared to determine whether there was any clear advantage to using either a series of direct SSP measurements or a series of SSPs interpolated between two or more profiles in a series. Model-measurement differences ranged from -18 dB to $+5$ dB when averaged over the 30-km source-receiver range. Whether using linear, triangular, or trapezoidal interpolation, or direct measurements of SSPs, no consistent change in model performance was observed. Increasing the numbers of intermediate SSPs in a series tended to reduce the modelled TL, regardless of interpolation type.

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transmission loss
sound speed profiles
propagation model
interpolation
Bellhop
ASPIRE