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PC - BASED PROPAGATION AND SONAR PREDICTION MODELS

G. Dreini, C. Isoppo, F.B. Jensen

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SACLANT Undersea Research Centre
Viale San Bartolomeo 400
19138 San Bartolomeo (SP), Italy

tel: +39-187-540.111
fax: +39-187-524.600

e-mail: library@saclantc.nato.int

NORTH ATLANTIC TREATY ORGANIZATION

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David L. Bradley
Director

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Executive Summary: The use of numerical models in ocean acoustics has proliferated over the past two decades, trailing closely advances in computer technology. Earlier models were all ray-based and ran quickly on available main-frame computers. Next came the more accurate but computer-intensive wave models based on normal modes or the parabolic equation (PE) approach. Today these models are the preferred prediction tools in the scientific community, and are also being introduced into operational use. Wave theory models are applied primarily to low-frequency problems, but they still require powerful workstations to provide answers in 'real' time.

The gap in performance between workstations and the much cheaper PC's has been closing in recent years, which means that many modelling tasks can now be performed on a PC without sacrificing the real-time aspect of the endeavor. Hence the requirement for PC prediction software has increased, and many models are now available either commercially or *via* defence research establishments or universities. It was deemed useful to provide an assessment of some of these models as guidance to prospective users. Hence, SACLANTCEN acquired six PC-based prediction models from the US, UK, Germany and the Netherlands.

The validation was done only for propagation loss. Typical North Atlantic and Mediterranean sound speed profiles were selected, and loss predictions were carried out for several source/receiver depths in both deep and shallow water, and at high as well as low frequencies. A total of 13 different propagation situations were considered, with reference solutions obtained from well-tested, workstation-based acoustic models.

The main conclusion of the study is that the choice of prediction model is not important since all models perform well. It is, however, important to know how to run a model correctly, i.e. provide it with the appropriate inputs. Some level of user experience is required to do this. Moreover, better documentation than currently available would definitely improve the quality of the predictions done by inexperienced users.

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PC-based propagation and sonar prediction models

G. Dreini, C. Isoppo and F.B. Jensen

Abstract: Six acoustic models available for use on PC's were tested on a series of typical propagation situations from the North Atlantic and the Mediterranean. The model set includes both early US Navy models (ASTRAL, FACT, RAYMODE) and more recent European models (ALMOST, HODGSON, MOCASSIN). It was found that all models perform well on the selected set of test problems.

Keywords: acoustic models ∘ propagation loss ∘ sonar models

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1
Introduction

The use of numerical models in ocean acoustics has proliferated over the past two decades, trailing closely advances in computer technology. Earlier models were all ray-based and ran quickly on available main-frame computers. Next came the more accurate but computer-intensive wave models based on normal modes or the parabolic equation (PE) approach. Today these models are the preferred prediction tools in the scientific community, and are also being introduced into operational use. Wave theory models are applied primarily to low-frequency problems, but they still require powerful workstations to provide answers in 'real' time.

The gap in performance between workstations and the much cheaper PC's has been closing in recent years, which means that many modelling tasks can now be performed on a PC without sacrificing the real-time aspect of the endeavor. Hence the requirement for PC prediction software has increased, and many models are now available either commercially or *via* defence research establishments or universities.

Over recent years SACLANTCEN has acquired six PC-based prediction models from the US, UK, Germany and the Netherlands (Table 1). In addition, to provide reference solutions, three of the standard SACLANTCEN models [1] were slightly modified and implemented on a PC. This set of nine models is not comprehensive but merely reflects the models available at SACLANTCEN in the 1993–94 time period, when the model evaluation and testing took place. More models will become available on PC's in the future, as hardware limitations on speed and memory are overcome.

2
Overview of models

ASTRAL, FACT, RAYMODE, ALMOST, HODGSON and MOCASSIN (Table 1) are operational-type models that provide quick answers to most propagation problems. PAREQ, SAFARI and SNAP are scientific models which are designed with accuracy in mind and are most effective at lower frequencies (< 1000 Hz). Only the first 6 models will be subjected to the performance evaluation test and only propagation loss predictions will be compared.

A short summary of model characteristics, including input/output options and computational features, is given below.

2.1 ASTRAL

The ASTRAL model [2, 3] is a range-dependent (RD) normal-mode model specifically designed for low-frequency (< 1000 Hz), long-range propagation. Since only range-averaged (over 50–70 km) propagation loss results are available, this model is not suited for convergence zone propagation. This is one of the early models developed for operational use by the US Navy.

The ASTRAL model treats a fully range-dependent environment, i.e., changing water depth, sound-speed profile, and bottom reflection loss as a function of range. Range dependence is treated approximately *via* the adiabatic mode formulation. Surface scattering loss is computed as a function of wave height, whereas bottom loss is dealt with either *via* standard MGS (Marine Geophysical Survey) bottom loss curves or *via* a BLUG-type (Bottom Loss UpGrade) geophysical bottom description.

The ASTRAL model has a simple data file input structure, and the only output available is a plot of transmission loss *vs.* range.

2.2 FACT

The FACT model [4, 5] is a range-independent (RI) ray model designed for applications in both deep and shallow water over a wide range of frequencies. This too is one of the early models developed for operational use by the US Navy.

The FACT model includes losses associated with both surface and bottom reflections. Surface scattering loss is computed as a function of wave height, whereas bottom loss is retrieved from standard MGS (Marine Geophysical Survey) tables. There is a set of built-in bottom loss curves: 9 for high frequencies ($> 1000\,\mathrm{Hz}$) and 9 for low frequencies ($< 1000\,\mathrm{Hz}$), with the latter being frequency dependent curves. In addition, it is possible to read the bottom reflection loss from an external file.

Particular features of this code are the special modules designed to provide quick and accurate answers for propagation in surface ducts and in shallow water.

The FACT model has a simple data file input structure, and the only output available is a plot of transmission loss *vs.* range.

2.3 RAYMODE

The RAYMODE model [6, 7] is a range-independent model that combines the techniques of ray and normal mode solutions. It is designed for applications in both deep and shallow water over a wide range of frequencies. Again, this is one of the early models developed for operational use by the US Navy.

The RAYMODE model includes losses associated with both surface and bottom reflections. Surface scattering loss is computed as a function of wind speed, whereas bottom loss is retrieved from standard MGS (Marine Geophysical Survey) tables. There is a set of built-in bottom loss curves: 9 for high frequencies ($> 1000\,\mathrm{Hz}$) and 9 for low frequencies ($< 1000\,\mathrm{Hz}$), with the latter being frequency dependent curves. In addition, it is possible to read the bottom reflection loss from an external file.

A particular feature of this code is the special module for computing propagation loss in a surface duct.

The RAYMODE model has a simple data file input structure, and the only output available is a plot of transmission loss *vs.* range.

2.4 ALMOST

The ALMOST model [8] is a complete sonar performance prediction model for both active and passive systems. The propagation part is based on range-independent ray tracing, with environmental information retrievable from the ASRAP data base.

The ALMOST model in its current implementation is range independent, but work is in progress to include a range-varying bathymetry. Surface scattering loss is computed as a function of wind speed or sea state, whereas bottom loss is retrieved from standard MGS (Marine Geophysical Survey) tables. There is a set of built-in bottom loss curves: 9 for high frequencies (> 1000 Hz) and 9 for low frequencies (< 1000 Hz), with the latter being frequency dependent. In addition there is the possibility of considering a simple homogeneous bottom and directly specifying the geophysical parameters, i.e., compressional and shear-wave speeds, attenuation of both wave types, and the material density.

A particular feature of this model is the frequency-dependent profile smoothing applied at low frequencies. Moreover, the user can choose to run the model in either 'standard' or 'expert' mode, with the latter providing more flexibility in selecting computational and input parameters.

The ALMOST model has a menu-driven user interface. Outputs consist of:

- Ray diagram.
- Transmission loss *vs.* range.
- Contour of transmission loss *vs.* depth and range.
- Contour of probability-of-detection *vs.* depth and range.

2.5 HODGSON

The HODGSON model [9, 10] is one of the most recent products in the series of commercially available PC-based sonar prediction models. An early version of this range-dependent ray model was developed in the late 1980s, specifically designed for use on a PC. The HODGSON model is still undergoing improvements, but the latest version incorporated in the WADER data base system [10] permits sonar performance predictions on a global scale utilizing the DBDB5 bathymetry data base and the World Ocean Atlas [11].

The HODGSON model treats a fully range-dependent environment, i.e., changing water depth, sound-speed profile, and bottom reflection loss as a function of range. Surface scattering loss is computed as a function of wind speed or sea state, whereas bottom loss is retrieved from standard MGS (Marine Geophysical Survey) tables. There are 12 built-in bottom loss curves: 9 for high frequencies (> 1000 Hz) and 3 for low frequencies (< 1000 Hz), with the latter being frequency dependent. In addition there is the possibility of specifying a constant bottom loss independent of angle.

Particular features of this model are the frequency-dependent profile smoothing applied below 300 Hz, and the possibility of tracing rays both to the left and right of the source. Moreover, the user can choose to run the model in either 'standard' or 'expert' mode, with the latter providing more flexibility in selecting computational and input parameters.

The HODGSON model has a menu-driven user interface. Outputs consist of:

- Contour of sound speed *vs.* depth and range.
- Ray diagram.
- Transmission loss *vs.* depth or range.
- Contour of probability-of-detection *vs.* depth and range.

2.6 MOCASSIN

The MOCASSIN model [12, 13] is a sound propagation and sonar prediction model based on stochastic ray tracing. The model is specifically designed for high-frequency (> 300 Hz), shallow-water applications, with emphasis on the stochastic treatment of scattering due to sound-speed variability along the propagation track.

The MOCASSIN model treats range-varying bathymetry and bottom reflectivity, but allows for only a single deterministic mean sound-speed profile in the water column. The effect of the fine-scale ocean variability is treated *via* a ray diffusion constant, which leads to the concept of stochastic ray tracing. Surface scattering loss is computed as a function of both wave height (for scattered ray direction) and wind speed (for absorption due to bubbles). Bottom loss *vs.* angle is computed as a function of porosity, and there are 9 built-in bottom loss curves. In addition, it is possible to read the bottom reflection loss from an external file.

A particular feature of this model is the frequency-dependent profile smoothing applied at frequencies below 750 Hz. Moreover, reverberation due to backscattering at the sea surface and at the bottom is computed as a function of range.

The MOCASSIN model has a simple data file input structure. Outputs consist of:

- Ray diagram.
- Transmission loss *vs.* range or depth.
- Contour of transmission loss *vs.* depth and range.

- Reverberation level *vs.* range (time).
- Signal excess (against noise and reverberation) *vs.* range.
- Contour of signal excess *vs.* depth and range.

2.7 PAREQ

The PAREQ model [14] is a range-dependent propagation model based on a numerical solution of the parabolic form of the acoustic wave equation. It is designed for research purposes, and hence emphasizes accuracy and generality over computational efficiency. The model is applicable in both deep and shallow water over a wide range of frequencies, but it is computationally slow at higher frequencies. We use this model to benchmark low-frequency, range-dependent propagation problems.

The PAREQ model treats a fully range-dependent environment, i.e., changing water depth, sound-speed profile, and geo-acoustics properties as a function of range. Surface scattering loss is computed as a function of the *rms* wave height, whereas bottom effects are dealt with entirely *via* geophysical inputs. A two-layer fluid bottom is considered: (1) a sediment layer having an arbitrary sound-speed profile but constant attenuation and density with depth, (2) a homogeneous subbottom with constant sound speed, attenuation and density.

A particular feature of this model is the automatic interpolation of all environmental inputs in range. Moreover, reverberation due to backscattering at the sea surface and at the bottom is computed as a function of range.

The PAREQ model has a simple data file input structure. Outputs consist of:

- Contour of sound speed *vs.* depth and range.
- Transmission loss *vs.* range or depth.
- Contour of transmission loss *vs.* depth and range.
- Reverberation level *vs.* range (time).

2.8 SAFARI

The SAFARI model [15] is a range-independent propagation model based on a spectral integral solution of the acoustic wave equation. It is designed for research purposes, and hence emphasizes accuracy and generality over computational efficiency. The model is applicable in both deep and shallow water over a wide range of frequencies, but it is computationally slow at higher frequencies. We use this model to benchmark range-independent propagation problems that involve fluid or elastic bottoms.

The SAFARI model is a full-spectrum solution for horizontally stratified fluid/elastic media. All wave types (including shear and interface waves) are propagated and their losses accounted for. Surface scattering loss is computed as a function of the *rms* wave height, whereas bottom effects are dealt with entirely *via* geophysical inputs. A multi-layered elastic bottom is considered with each layer being characterized by two wave speeds (compressional and shear waves), the associated attenuations and a density.

A particular feature of this code is the availability of a module for computing the plane-wave reflection coefficient at the bottom, and of a module for computing pulse propagation results *via* Fourier synthesis of single-frequency solutions.

The SAFARI model has a simple data file input structure. Outputs consist of:

- Reflection loss and phase *vs.* grazing angle.
- Contour of reflection loss *vs.* grazing angle and frequency.
- Transmission loss *vs.* range or depth.
- Contour of transmission loss *vs.* depth and range.
- Range and depth-stacked pulses.

2.9 SNAP

The SNAP/C-SNAP model [16, 17] is a range-dependent normal-mode model. It is designed for research purposes, and hence emphasizes accuracy and generality over computational efficiency. The model is applicable in both deep and shallow water over a wide range of frequencies, but it is computationally slow at higher frequencies and in deeper water. We use this model primarily for low-frequency shallow-water problems.

The SNAP model treats a fully range-dependent environment, i.e., changing water depth, sound-speed profile, and geo-acoustics properties as a function of range. Surface scattering loss is computed as a function of the *rms* wave height, whereas bottom effects are dealt with entirely *via* geophysical inputs. A two-layer bottom is considered: (1) a fluid sediment layer having an arbitrary sound-speed profile but constant attenuation and density with depth, (2) a homogeneous elastic subbottom with constant wave speeds, attenuations and density.

A particular feature of this model is the robustness of the numerical algorithm which guarantees meaningful solutions to most problems. Moreover, reverberation due to backscattering at the sea surface and at the bottom is computed as a function of range.

The SNAP model has a simple data file input structure. Outputs consist of:

- Mode function plots.
- Transmission loss *vs.* range or depth.
- Contour of transmission loss *vs.* depth and range.
- Reverberation level *vs.* range (time).

3
Test problems

The selection of a small set of test problems that allows us to check out the principal features of a whole suite of propagation models is an extremely difficult task. Such test problems would, as a minimum, involve both deep and shallow-water propagation (refraction *vs.* reflection effects), at high and low-frequency (ray *vs.* wave-theory solution), in range-independent and range-dependent environments (1D *vs.* 2D variability). Moreover, the effect of profile type and source/receiver depths should be carefully investigated. Clearly, much more time could be spent on designing the optimal set of test problems than actually performing the model comparisons and writing the summary report.

We decided to not attempt to generate elaborate test problems, but to take some standard data files already available on the computer for the North Atlantic and the Mediterranean. Next we chose two different frequencies (one low and one high) and a few source/receiver depths (both shallow and deep). Hence the test problems were chosen quite arbitrarily and may not constitute a severe test for any of the models. On the other hand, the problem set presented here is a reasonable minimum set, which still involves 13 different propagation situations to be investigated for each of the six models.

One of the major difficulties encountered in doing transmission-loss comparisons for a set of different PC models was to make sure that each model solved the intended environmental situation. Not only was it necessary to carefully check the use of default choices of various input parameters (e.g. source/receiver beamwidths), but it turned out to be a non-trivial task to ensure that the bottom loss for a given problem was treated similarly in all models. This difficulty arises because the various models use different bottom description, such as MGS bottom loss curves, BLUG geophysical bottoms, generic geophysical bottoms, *etc.* (Sect. 2). An MGS(4)-type bottom was selected as a standard, but we then had to generate an equivalent geophysical bottom for use in some of the models.

The final issue in terms of model testing is the generation of reliable reference solutions. We used four models with which we have considerable experience and whose reliability is generally recognized in the community. Low-frequency reference solutions were generated by either SNAP [16, 17] or PAREQ [14], and high-frequency solutions by MPE (Multi-Path Expansion)[18, 19] or GRASS [20].

The performance of the PC models on four different test problems is summarized in Table 2. The first column provides a generic description of the four test problems. Case 1 is a deep-water (DW) problem with a double-duct profile characteristic of the eastern North Atlantic. Case 2 is a deep-water (DW) problem with a single-duct profile characteristic of the Mediterranean. Case 3 is a flat-bottom, shallow water (SW) problem with a profile characteristic of the Mediterranean in the summer. Finally, Case 4 is a range-dependent version of Case 3, with the water depth changing from 500 to 150 m over a range of 10 km. The next column lists the source frequencies, which always comprise one low (50 or 100 Hz) and one high frequency (3.6 kHz). Column 3 provides information on the source/receiver depths considered. Finally, the performance of each model on a given test problem is indicated (subjectively) by a number of asterisks. Not all models are applicable to every test problem (N/A = Not Applicable). As to the execution time on a standard 66-MHz PC, this turned out not to be an issue, since the six models were all designed with computational efficiency in mind.

3.1 CASE 1: Deep water, double duct[1]

As shown in Fig. 1, the water depth is 4500 m and we consider propagation to a range of 200 km over an MGS(4)-type bottom. For a shallow source at 15 m, we have convergence-zone propagation at higher frequencies as indicated by the ray diagram.

Comparison of modelling results at 50 Hz are given in Figs. 2 and 3 (RD = 15 and 1000 m, respectively). Note that the reference solution produced by SNAP shows that no convergence zones are present at this frequency. Several of the ray models (FACT, HODGSON, MOCASSIN, RAYMODE) erroneously retain this high-frequency feature in the solution. Only ALMOST and ASTRAL produce entirely satisfactory answers. For the deep receiver (1000 m) in Fig. 3, all six models are seen to produce excellent results.

Comparison of modelling results at 3.6 kHz are given in Figs. 4 and 5 for receivers at 15 and 1000 m, respectively. Here the reference solutions generated by MPE show a clear convergence-zone structure with a spacing of approximately 60 km. All models generally perform well for both receiver depths. However, HODGSON predicts levels which are too high in the second CZ in Fig. 4, and ALMOST entirely misses the second peak in the first CZ in Fig. 5. ASTRAL is not applicable to these high-frequency problems due to smoothing of results in range.

[1] The HODGSON model originally had problems with this test case for both source and receiver at 15-m depth. However, a minor change in the code produced the improved predictions shown here [21].

3.2 CASE 2: Deep water, single duct

As shown in Fig. 6, the water depth is 2000 m and we consider propagation to a range of 60 km over an MGS(4)-type bottom. The ray diagrams for the two different source depths show the qualitatively different propagation structures. Thus the deep source gives rise to ducted propagation, whereas the shallow source gives rise to CZ propagation with a spacing of 35–40 km.

Comparison of modelling results at 50 Hz are given in Figs. 7 and 8 (RD = 25 and 250 m, respectively). All six models are here seen to produce excellent results compared with the SNAP reference solution.

Turning next to the high-frequency (3.6 kHz) results given in Figs. 9–11, we notice a few minor problems with some of the models compared with the reference solution produced by MPE. In Fig. 9 the MOCASSIN result shows a 'noisy' behaviour at longer ranges (> 40 km), whereas the other four models perform very well. For the deeper receiver in Fig. 10 we obtain good results from ALMOST and MOCASSIN, whereas the remaining three models show minor problems. Finally, for the shallow source (90 m) in Fig. 11, all models perform well.

3.3 CASE 3: Shallow water, flat bottom

As shown in Fig. 12, the water depth is 500 m and we consider propagation to a range of 20 km over an MGS(4)-type bottom. For a source at 30-m depth, we have continued interaction of sound with the bottom, as shown by the ray diagram.

Comparison of modelling results at 100 Hz is given in Fig. 13. All six models are seen to produce excellent results compared with the PAREQ reference solution.

Also the comparison of results at 3.6 kHz (Fig. 14) is seen to be good for most models compared with the GRASS reference solution. Only ALMOST seems to invoke too much smoothing, hence missing the characteristic step structure in range.

3.4 CASE 4: Shallow water, sloping bottom

As shown in Fig. 15, the water depth is here changing from 500 to 150 m over the first 10 km. We consider propagation to a range of 20 km over an MGS(4)-type bottom. For a source at 30-m depth, we have continued interaction of sound with the bottom, as shown by the ray diagram. This type of shallow-water problem is a severe test of ray-based acoustic models, particularly at lower frequencies.

Comparison of modelling results at 100 Hz is given in Fig. 16. Both models applicable to this range-dependent problem (HODGSON and MOCASSIN) are seen to overestimate bottom loss in the shallow part beyond 10 km. The relatively good result obtained with MOCASSIN at this frequency is fortuitous, and both models generally predict too much loss, even at frequencies of several hundred hertz. An additional complication is that the two models do not use the same bottom-loss table. Whereas the standard MGS(4) table was used in MOCASSIN, we had to use a slightly different bottom-loss table (LF2) in HODGSON, leading to higher loss predictions on the shelf. [The HODGSON model would have performed better if the correct bottom-loss table could have been used.] In summary, we are here dealing with a strongly bottom-interacting, low-frequency propagation scenario which is not well handled by any of the ray models.

The comparison of results at 3.6 kHz (Fig. 17) is seen to give excellent results for both models compared with the GRASS reference solution.

4
Summary and conclusions

The model performance is summarized in Table 2. Generally, all models perform well when care is taken to run them correctly. ALMOST, ASTRAL, FACT and RAYMODE show fair-to-good performance for all test problems to which these models are applicable. HODGSON and MOCASSIN show the same overall performance except for the 100-Hz shallow-water result (Case 4) where both models predict too high transmission loss. It should be noted that MOCASSIN was specifically designed for use at frequencies above 300 Hz, and hence could be expected to fail on low-frequency, shallow-water problems. The HODGSON model clearly has similar applicational restrictions.

It appears that the choice of prediction model is not important since they all perform well. It is, however, important to know how to run a model correctly, i.e. provide it with the appropriate inputs. Some level of user experience is required to do this. Better documentation would definitely improve the quality of the predictions done by inexperienced users.

References

[1] Schneider, H.G., Acoustic models at SACLANTCEN, SM-285. La Spezia, Italy, SACLANT Undersea Research Centre, 1995.

[2] Spofford, C.W., The ASTRAL model. Volume I: Technical description, SAI-79-742-WA. McLean, VA, Science Applications, Inc., 1979.

[3] Blumen, L.S. and Spofford, C.W., The ASTRAL model. Volume II: Software implementation, SAI-79-743-WA. McLean, VA, Science Applications, Inc., 1979.

[4] Spofford, C.W., The FACT model, MC-109. Washington, DC, Acoustic Environmental Support Detachment, Office of Naval Research, 1974.

[5] Jacobs, G., FACT-9H: Version description document, TN-133T. NSTL Station, MS, Naval Ocean Research and Development Activity, 1982.

[6] Leibiger, G.A., A combined ray theory – normal mode approach to long-range low-frequency propagation loss prediction, TM-PA3/0109/71. New London, CT, Naval Underwater Systems Center, 1971.

[7] Yarger, D.F., The user's guide for the passive RAYMODE propagation loss program, TM-821061. New London, CT, Naval Underwater Systems Center, 1982.

[8] Schippers, P., Operational manual for the acoustic range prediction model ALMOST 4.2 and 4.3, both including the modules PROPLOSS, REACT, REPAS and RAYTRACE, FEL-92-A434. The Hague, The Netherlands, TNO Physics and Electronics Laboratory, 1993.

[9] Nicell, P., User guide to the Hodgson(C) model, MS-DOS version 3.2, 9/M/068. Greenford, England, Dowty Maritime Ltd., 1991.

[10] Hodgson, J. and Hodgson, D., WADER user manual. Bude, England, Ocean Acoustics Developments Ltd., 1993.

[11] Levitus, S. *et al.*, World Ocean Atlas (NOAA Atlas NEBDIS), CD-ROM data sets. Washington, DC, US Department of Commerce, 1994.

[12] Schneider, H.G., Excess sound propagation loss in a stochastic environment. *Journal of the Acoustical Society of America* **64**, 1977: 871–877.

[13] Schneider, H.G., MOCASSIN: Sound propagation and sonar range prediction model for shallow water environments, TR-1990/9. Kiel, Germany, Forschungsanstalt der Bundeswehr für Wasserschall- und Geophysik, 1990.

[14] Jensen, F.B. and Martinelli M.G., The SACLANTCEN parabolic equation model (PAREQ). La Spezia, Italy, SACLANT Undersea Research Centre, 1985.

[15] Schmidt, H., SAFARI: Seismo-acoustic fast field algorithm for range-independent environments, SR-113. La Spezia, Italy, SACLANT Undersea Research Centre, 1988. [AD A 200 581]

[16] Jensen, F.B. and Ferla, C.M., SNAP: The SACLANTCEN normal-mode acoustic propagation model, SM-121. La Spezia, Italy, SACLANT Undersea Research Centre, 1979. [AD A 067 256]

[17] Ferla C.M., Porter, M.B., and Jensen, F.B., C-SNAP: Coupled SACLANTCEN normal mode acoustic propagation loss model, SM-274. La Spezia, Italy, SACLANT Undersea Research Centre, 1994.

[18] Weinberg, H., Application of ray theory to acoustic propagation in horizontally stratified oceans. *Journal of the Acoustical Society of America* **58**, 1975: 97–109.

[19] Weinberg, H., Generic sonar model, TD-5971D. New London, CT, Naval Underwater Systems Center, 1985.

[20] Cornyn, J.J., GRASS: A digital-computer ray-tracing and transmission-loss prediction system, NRL 7621 (Vol. 1: Overall description) and NRL 7642 (Vol. 2: User's manual). Washington, DC, Naval Research Laboratory, 1973.

[21] Hodgson, J., Private communication, May 1995.

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Tables

and

Figures

Table 1: PC-models at SACLANTCEN.

Model name	Theory	RI/RD	Sonar model	Database	User interface	Custodian
PC-ASTRAL	mode	RD(adiab)	N	N	N	APtek[1]
PC-FACT	ray	RI	N	N	N	APtek
PC-RAYMODE	ray/mode	RI	N	N	N	APtek
ALMOST	ray	RI	Y	Y	Y	TNO[2]
HODGSON	ray	RD	Y	Y	Y	Dowty[3]
MOCASSIN	ray	RD(bathy)	Y	N	N	FWG[4]
PAREQ	PE	RD	N	N	N	SACLANTCEN
SAFARI	spectral	RI	N	N	N	SACLANTCEN
SNAP	mode	RD	N	N	N	SACLANTCEN

1. Applied Technology Inst., 6253 Hidden Clearing, Columbia, MD 21045, USA
2. TNO Physics and Electronics Lab., P.O. Box 96864, 2509 JG The Hague, The Netherlands
3. Dowty Maritime, Bridport Road, Greenford, Middlesex, UB6 8UA, England
4. FWG, Klausdorfer Weg 2-24, 24148 Kiel, Germany

Table 2: PC-model performance on four test problems.

Test Problem	F [Hz]	SD/RD [m]	ALMOST	ASTRAL	FACT	HODGSON	MOCASSIN	RAYMODE
Case 1 - DW	50	15/15	***	***	**	**	**	**
Double duct	50	15/1000	***	***	***	***	***	***
	3600	15/15	***	N/A	***	**	***	***
	3600	15/1000	**	N/A	***	***	***	***
Case 2 - DW	50	500/25	***	***	***	***	***	***
Single duct	50	500/250	***	***	***	***	***	***
	3600	500/25	***	N/A	***	***	**	***
	3600	500/250	***	N/A	**	**	***	**
	3600	90/250	***	N/A	***	***	***	***
Case 3 - SW	100	30/50	***	***	***	***	***	***
Flat bottom	3600	30/50	**	N/A	***	***	***	***
Case 4 - SW	100	30/50	N/A	N/A	N/A	*	**	N/A
Sloping bottom	3600	30/50	N/A	N/A	N/A	***	***	N/A

Legend: *** Good performance
** Fair performance
* Poor performance

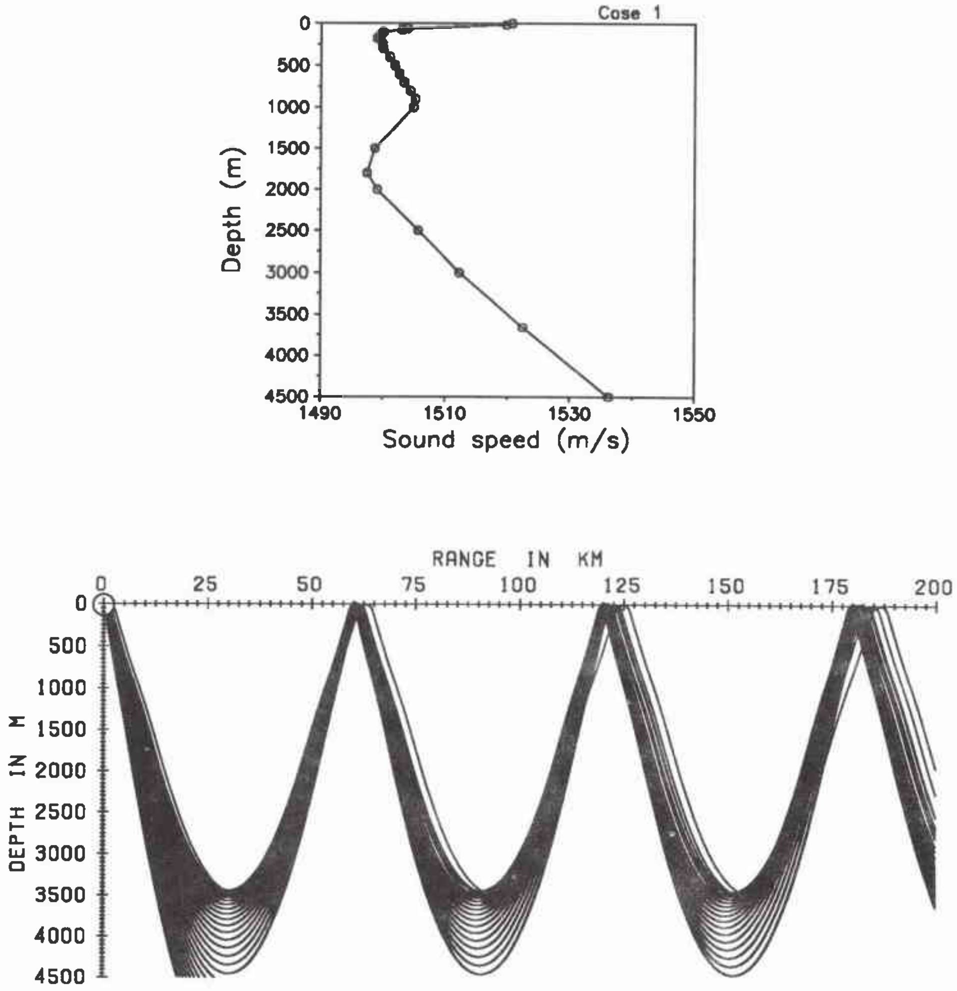

Figure 1 *CASE 1: Sound-speed profile and ray diagram for a source at 15-m depth.*

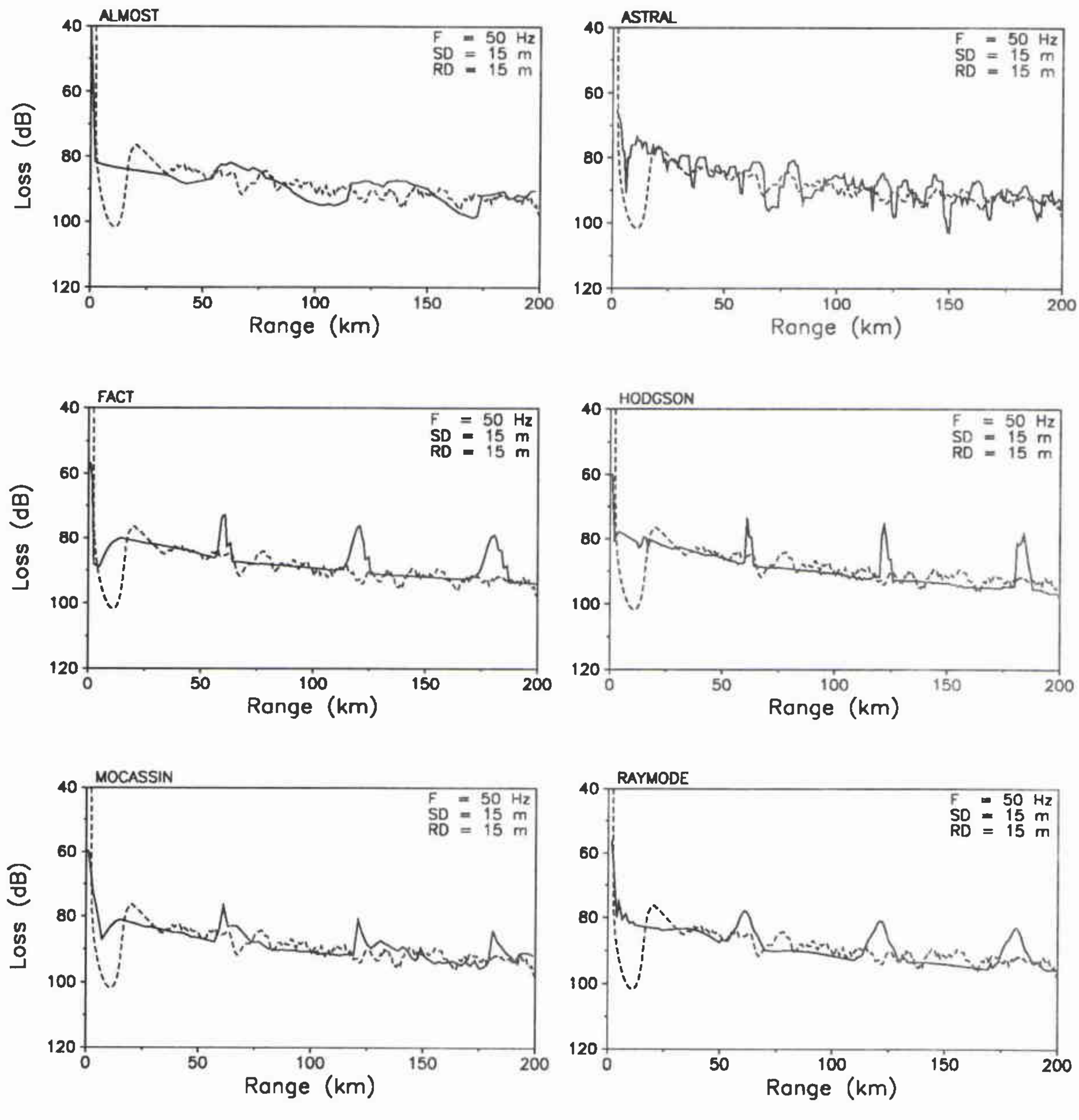

Figure 2 *CASE 1: Comparison of 50-Hz modelling results for both source and receiver at 15-m depth. The reference solution (dashed line) was generated by* SNAP *[16].*

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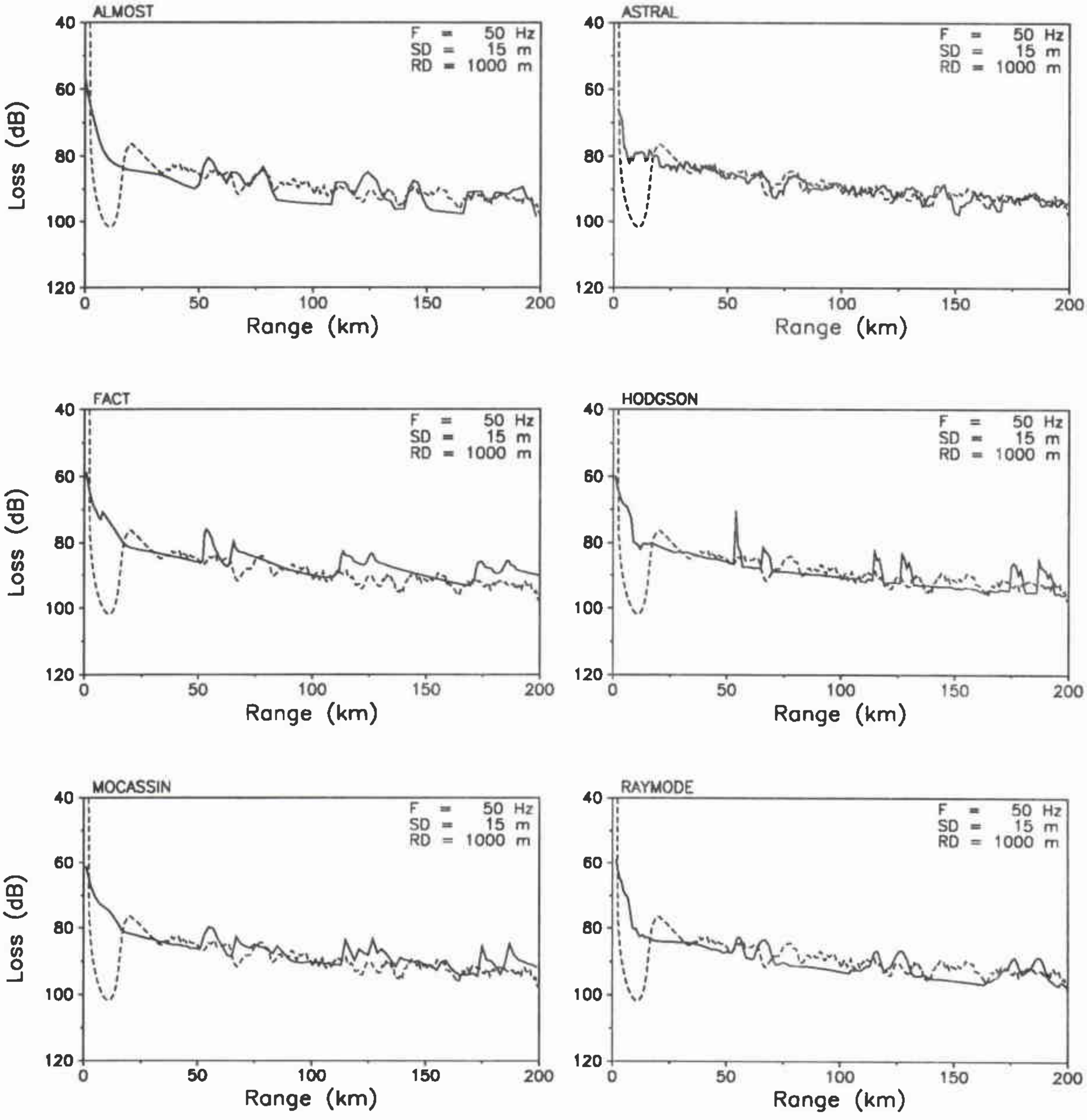


Figure 3 *CASE 1: Comparison of 50-Hz modelling results for a source at 15 m and a receiver at 1000 m. The reference solution (dashed line) was generated by* SNAP *[16].*

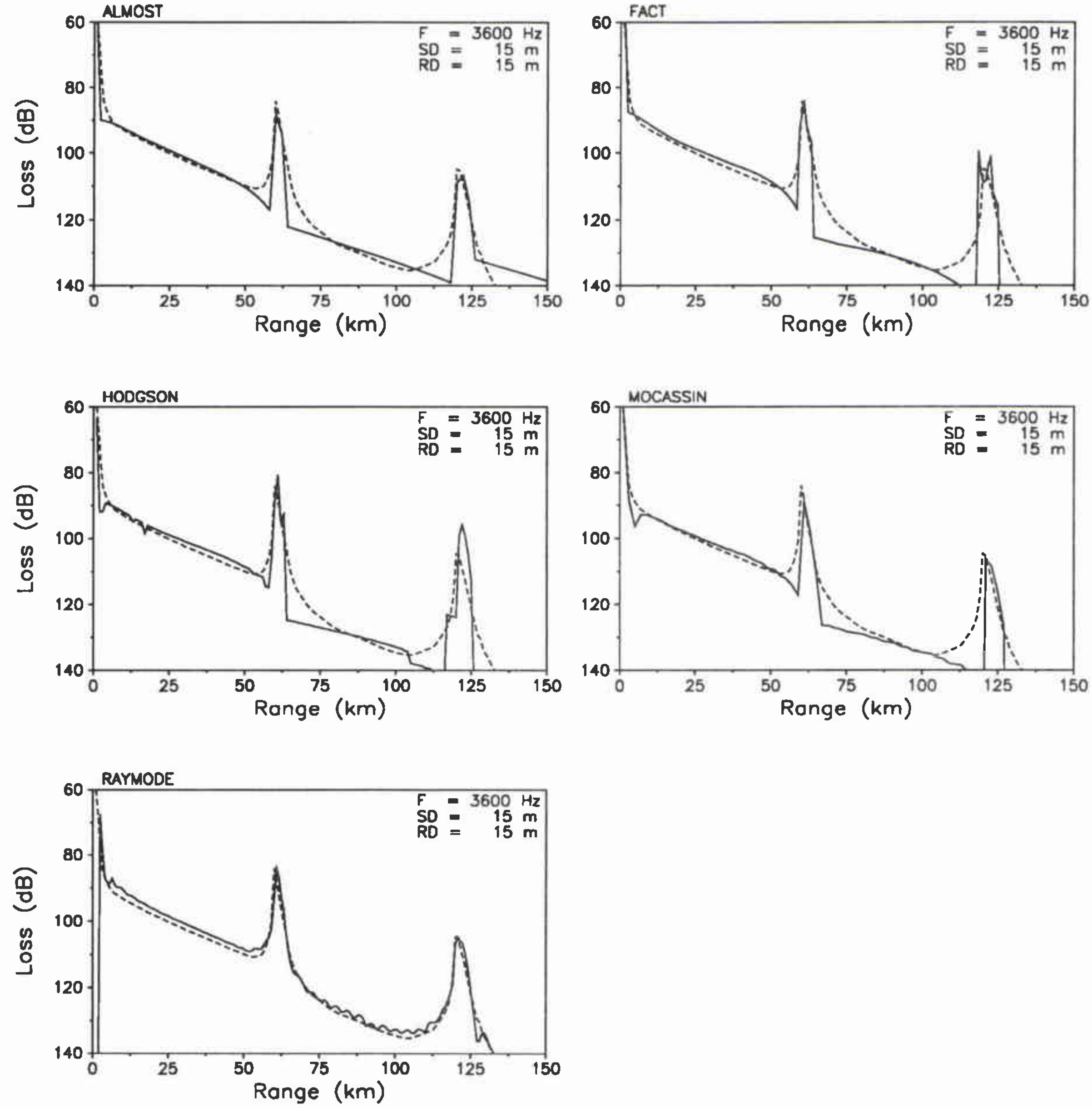


Figure 4 *CASE 1: Comparison of 3.6-kHz modelling results for both source and receiver at 15-m depth. The reference solution (dashed line) was generated by* MPE *[19].*

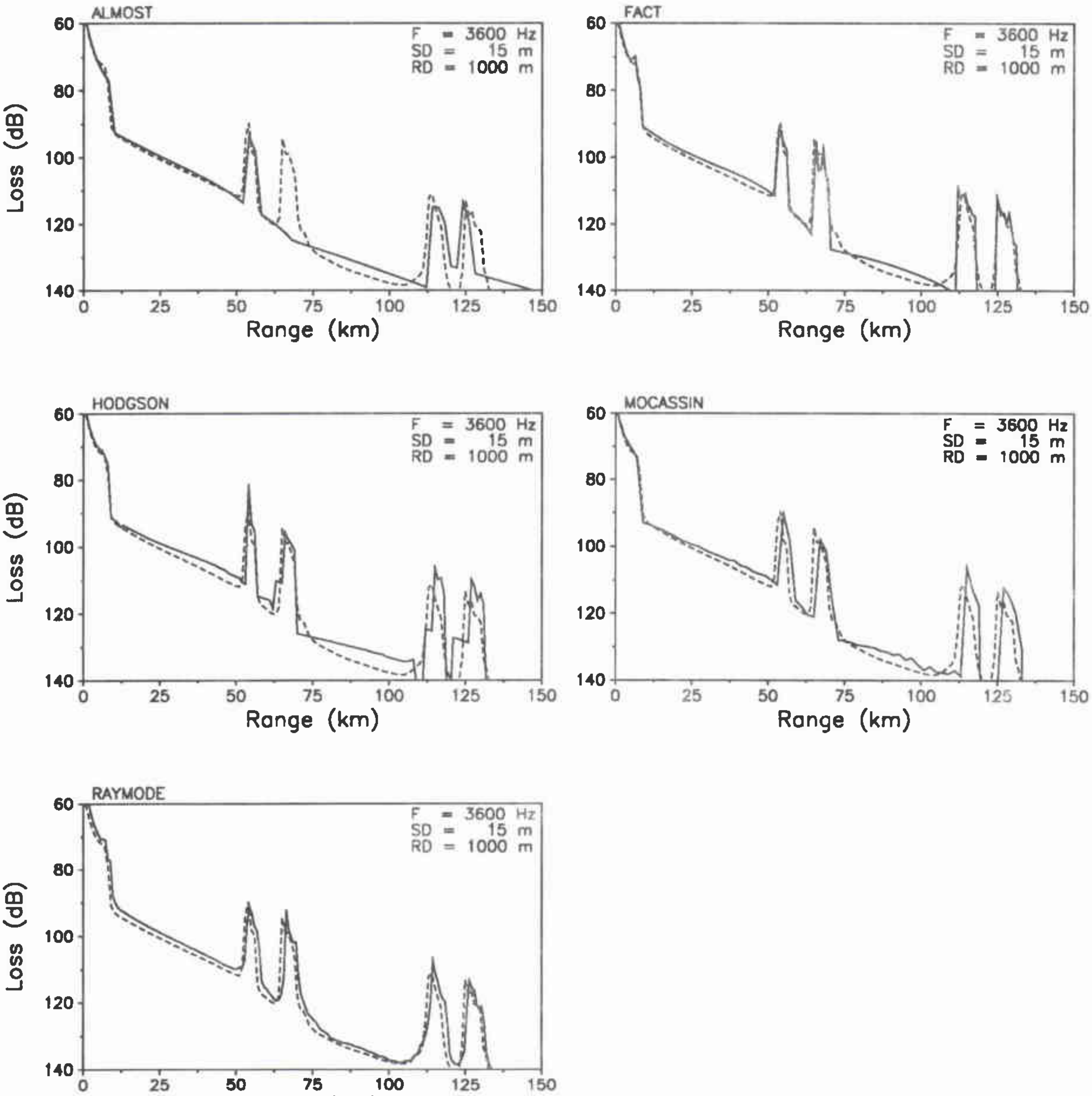


Figure 5 *CASE 1: Comparison of 3.6-kHz modelling results for a source at 15 m and a receiver at 1000 m. The reference solution (dashed line) was generated by* MPE *[19].*

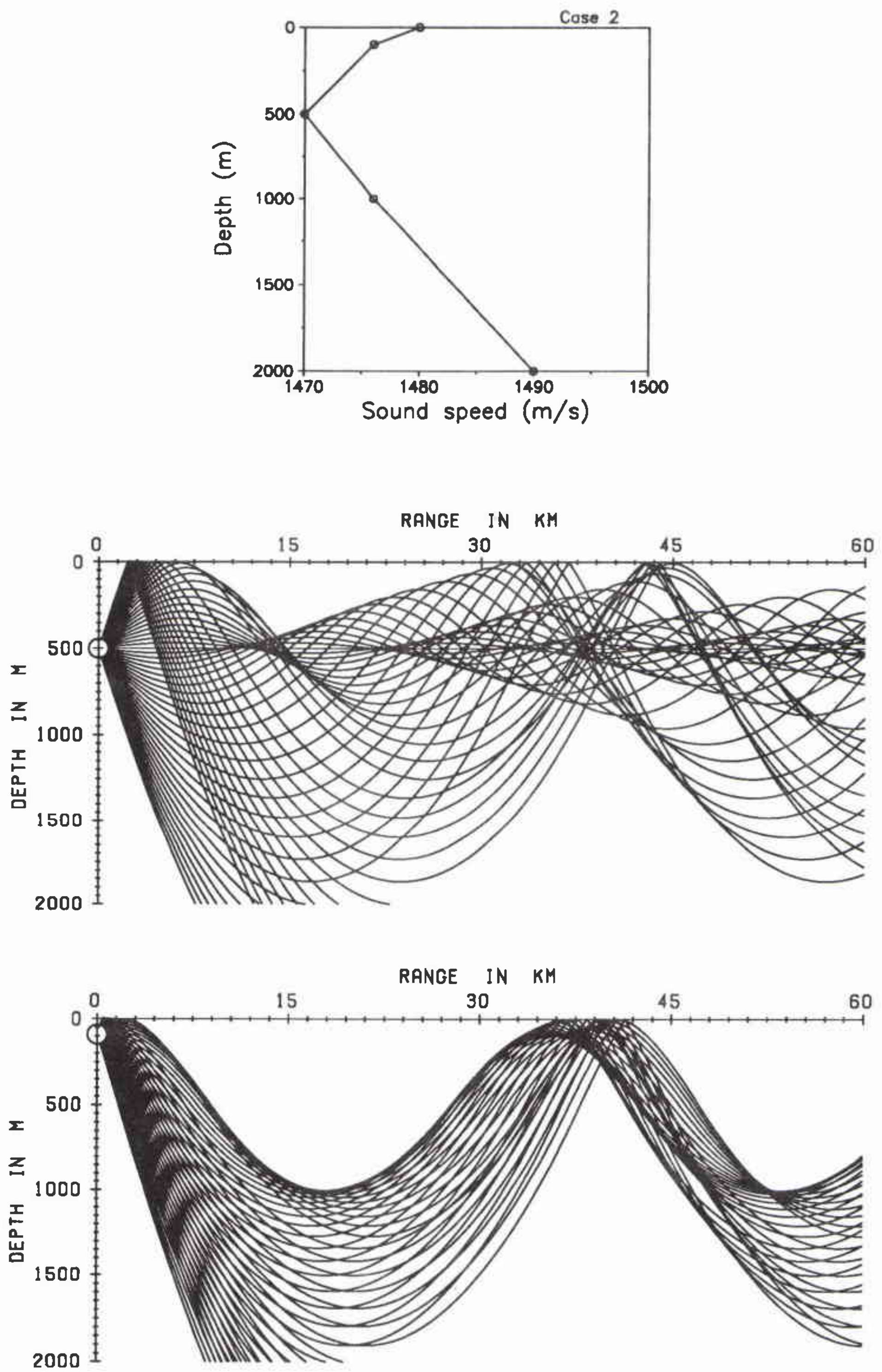


Figure 6 *CASE 2: Sound-speed profile and ray diagrams for a source at 500 m and a source at 90 m.*

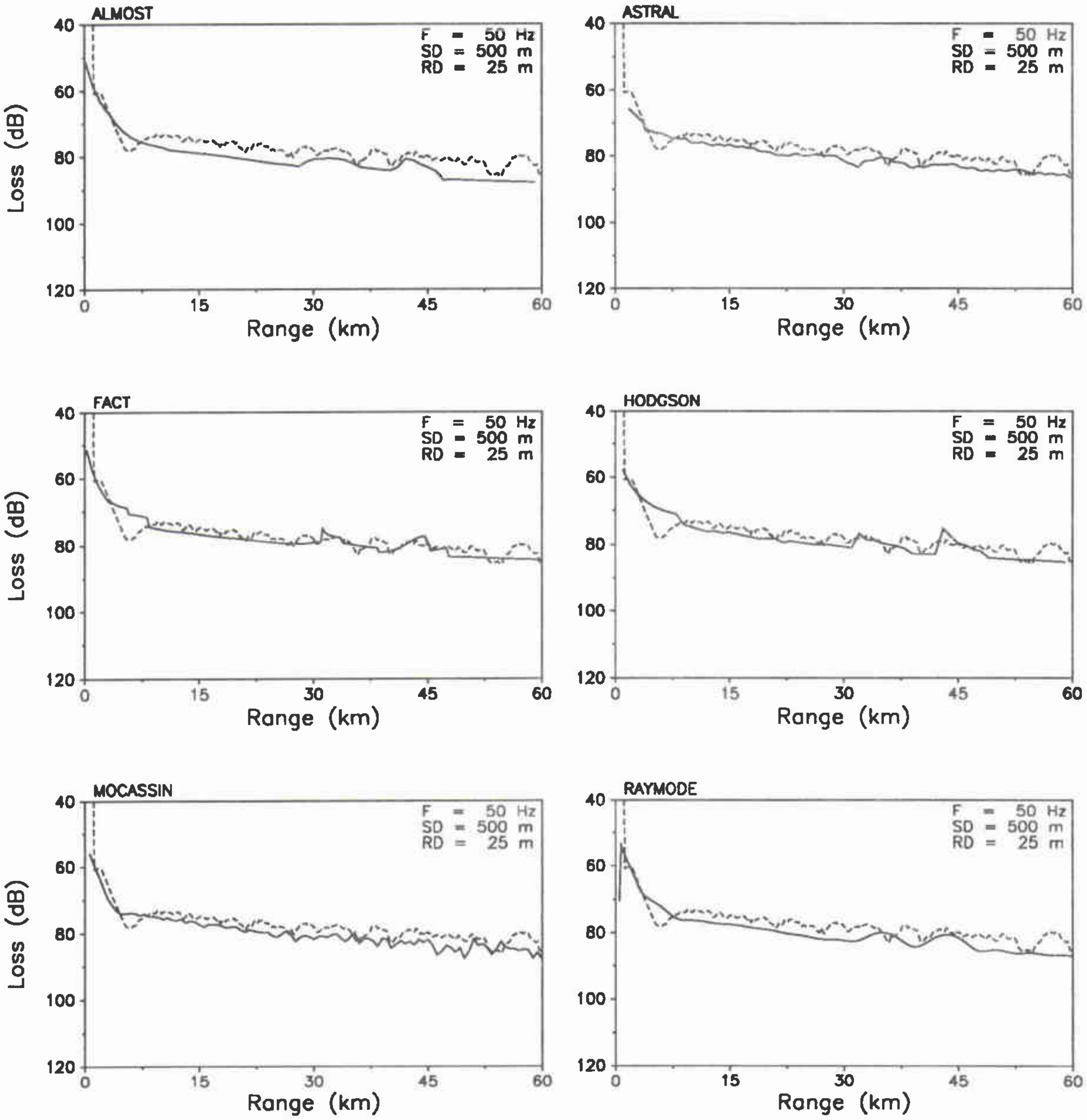


Figure 7 *CASE 2: Comparison of 50-Hz modelling results for a source at 500 m and a receiver at 25 m. The reference solution (dashed line) was generated by* SNAP *[16].*

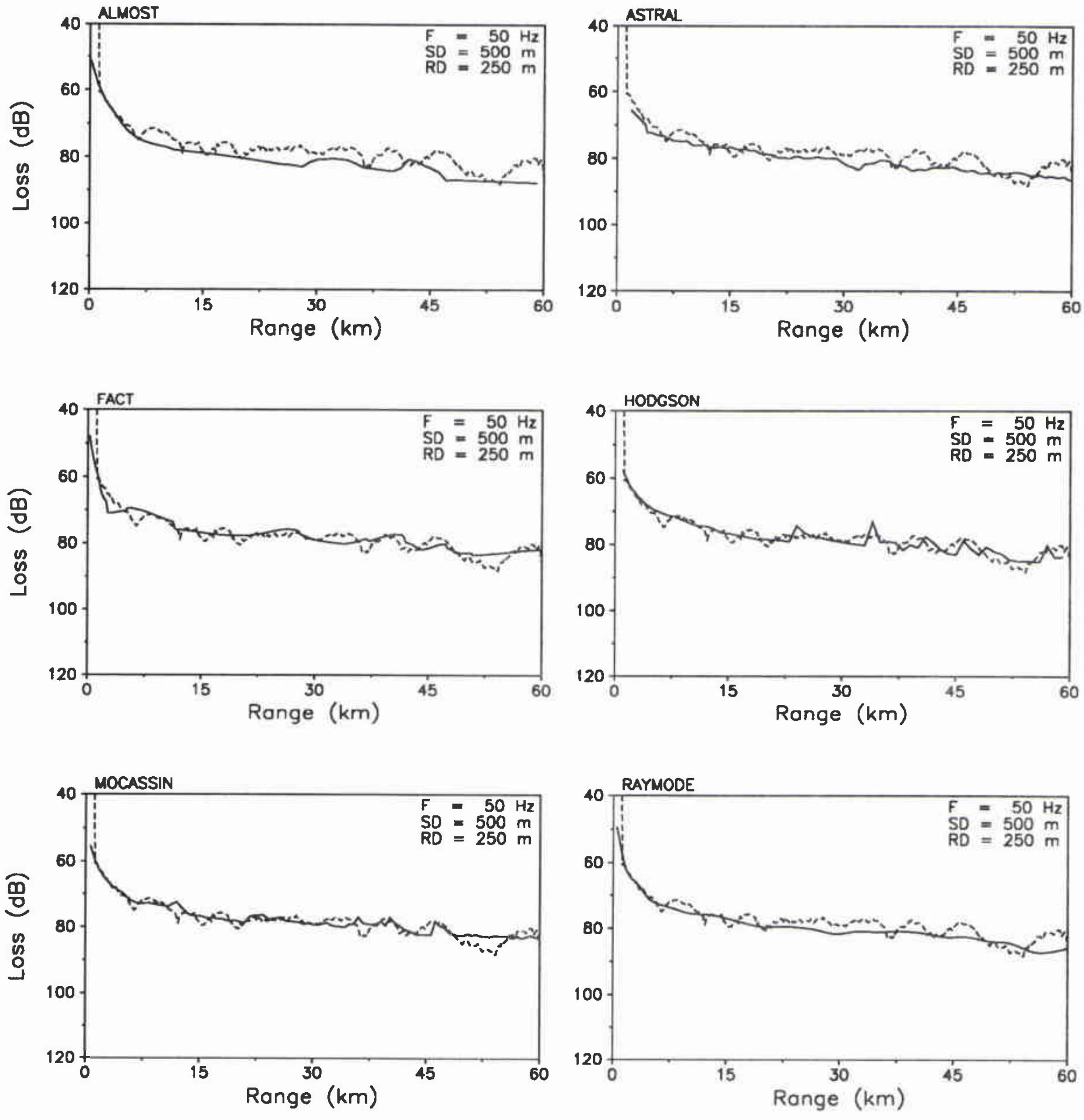


Figure 8 *CASE 2: Comparison of 50-Hz modelling results for a source at 500 m and a receiver at 250 m. The reference solution (dashed line) was generated by* SNAP *[16].*

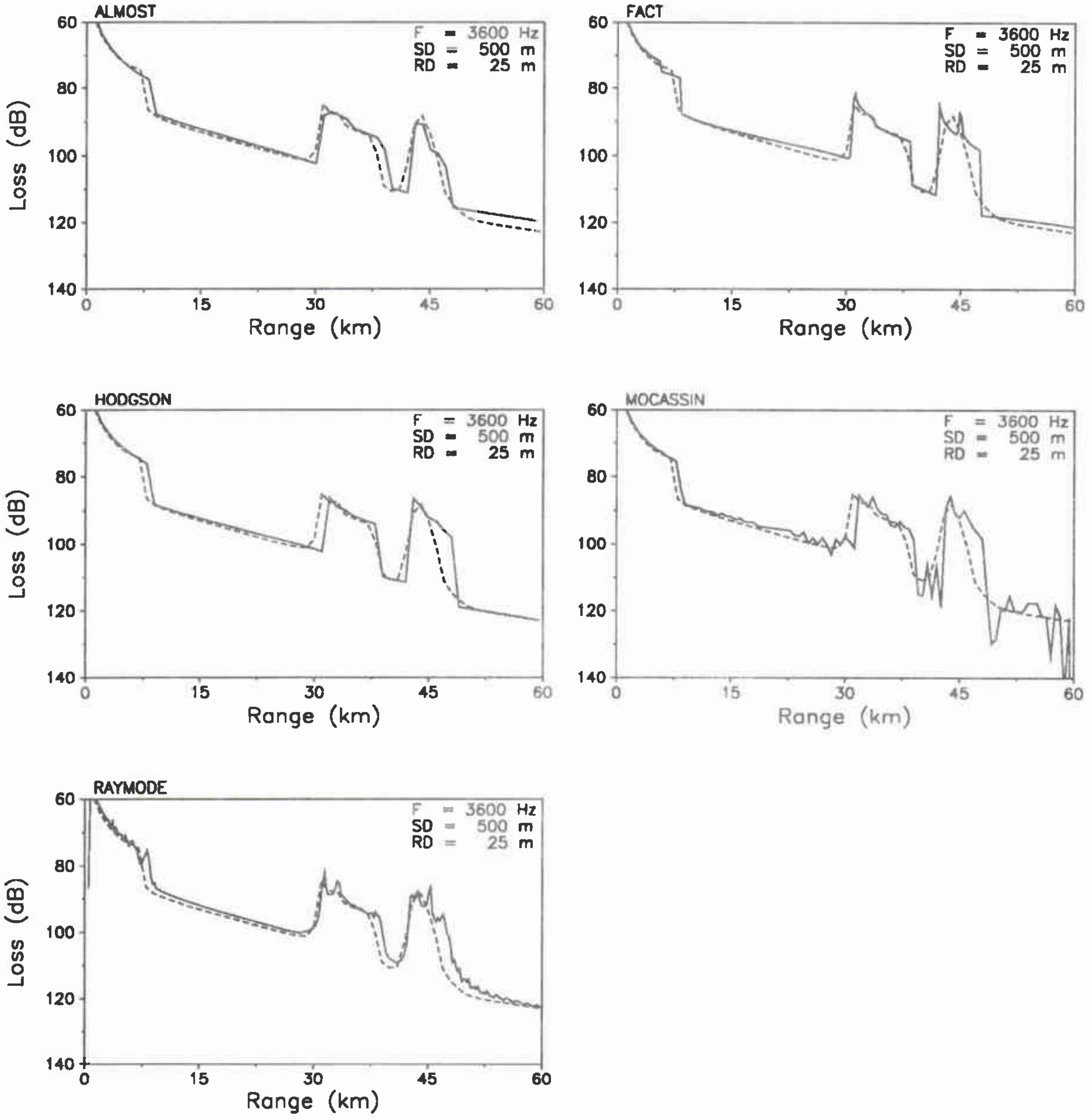


Figure 9 *CASE 2: Comparison of 3.6-kHz modelling results for a source at 500 m and a receiver at 25 m. The reference solution (dashed line) was generated by* MPE *[19].*

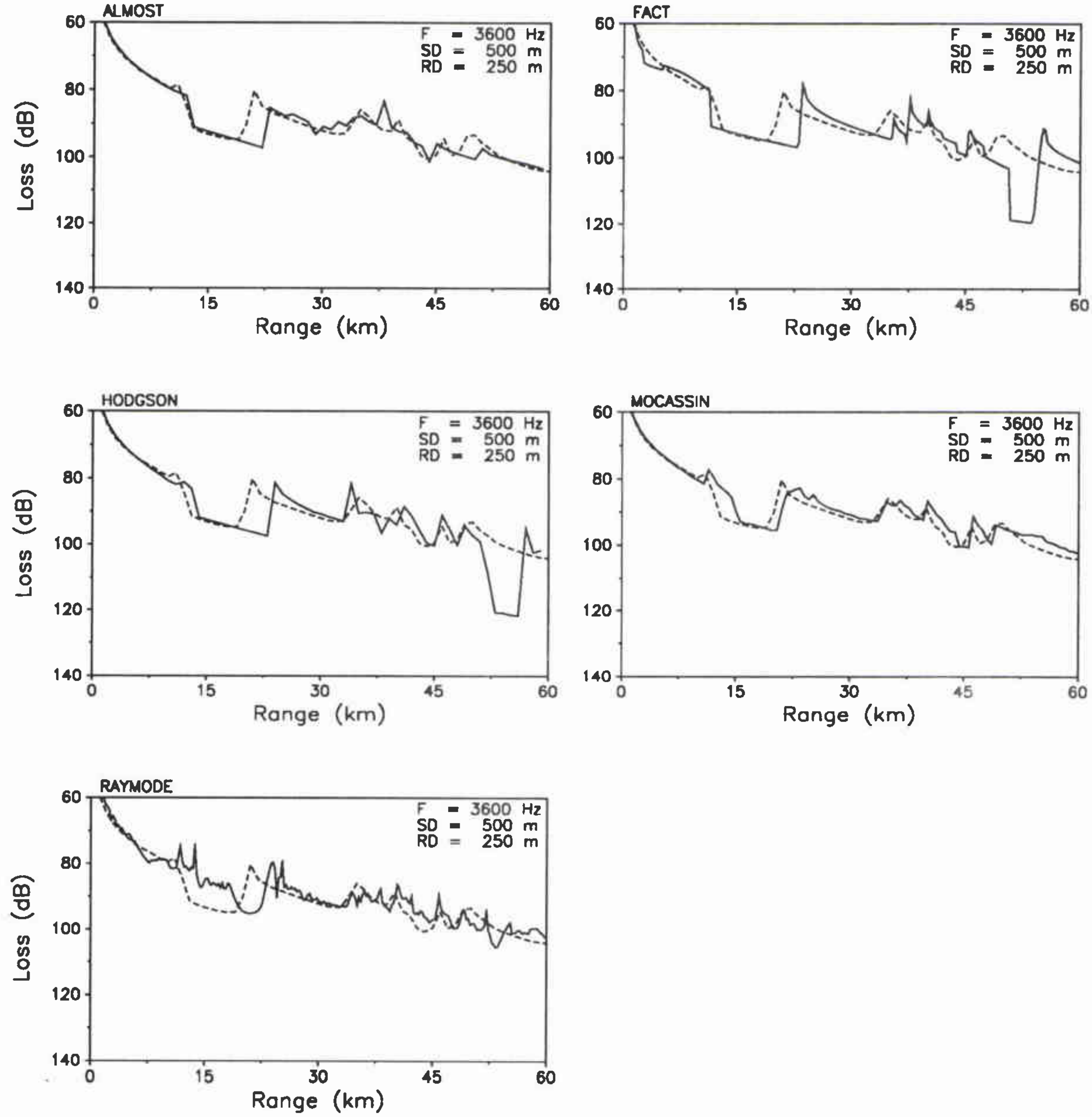


Figure 10 *CASE 2: Comparison of 3.6-kHz modelling results for a source at 500 m and a receiver at 250 m. The reference solution (dashed line) was generated by* MPE *[19].*

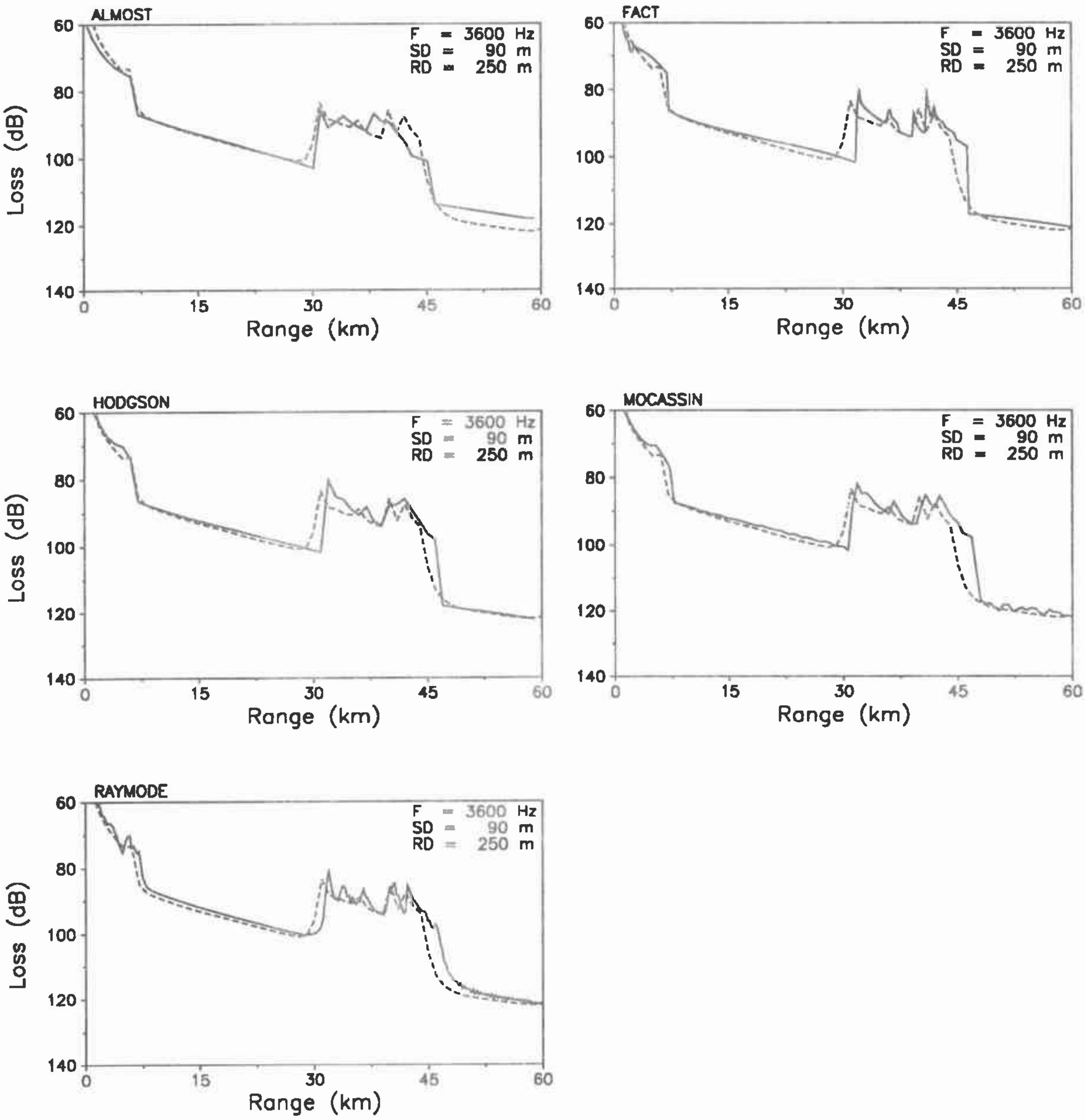
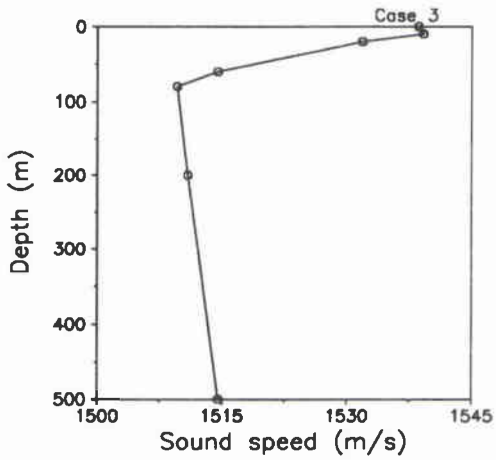


Figure 11 *CASE 2: Comparison of 3.6-kHz modelling results for a source at 90 m and a receiver at 250 m. The reference solution (dashed line) was generated by* MPE *[19].*



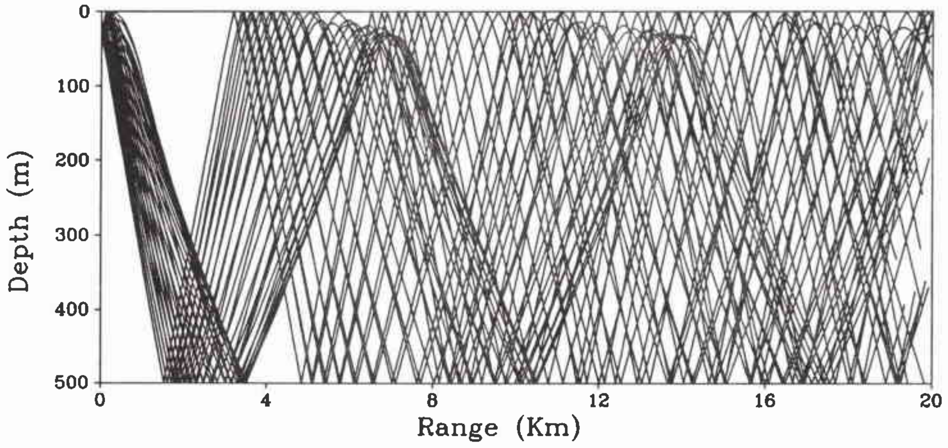


Figure 12 *CASE 3: Sound-speed profile and ray diagram for a source at 30-m depth.*

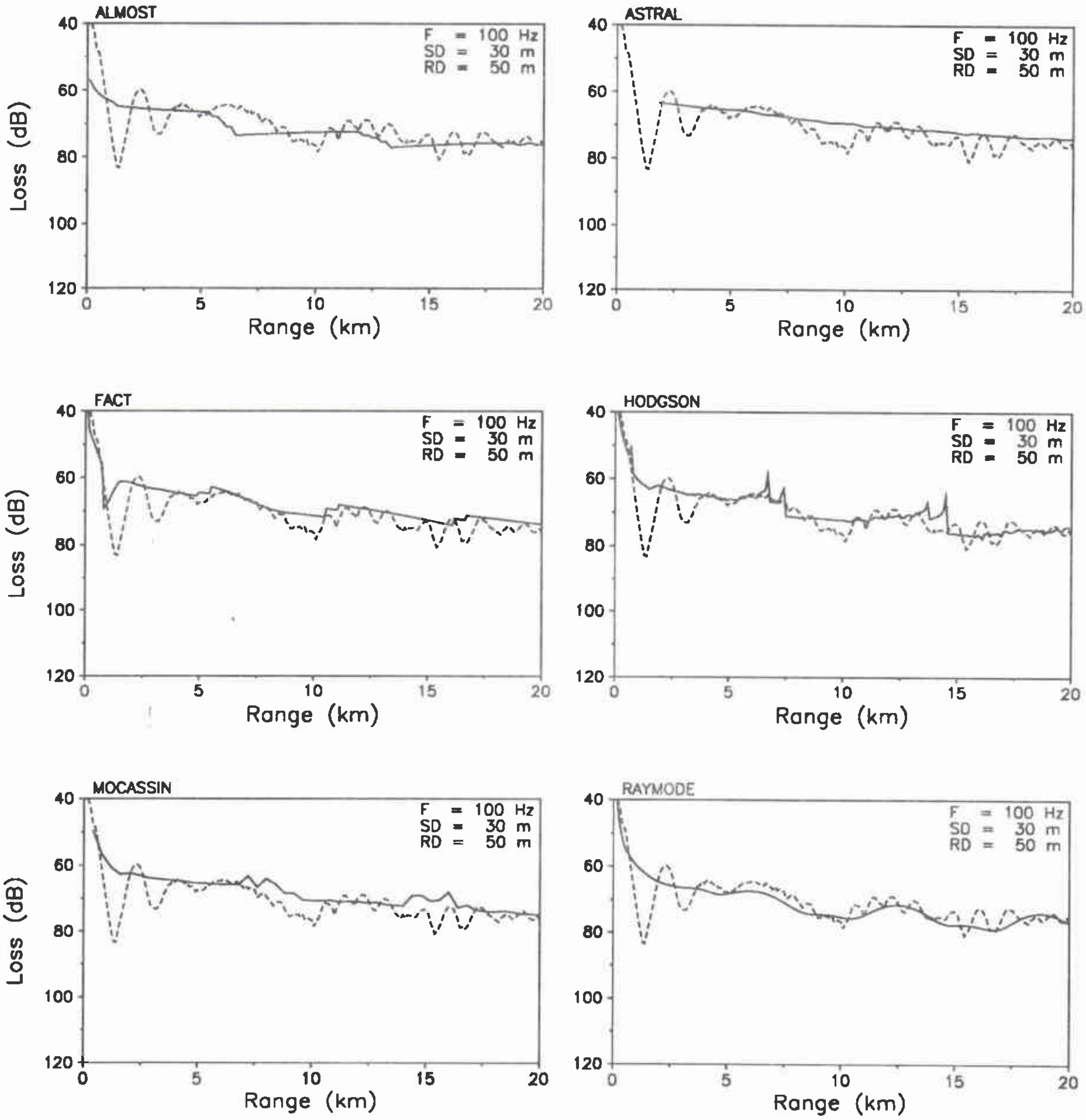


Figure 13 *CASE 3: Comparison of 100-Hz modelling results for a source at 30 m and a receiver at 50 m. The reference solution (dashed line) was generated by* PAREQ *[14].*

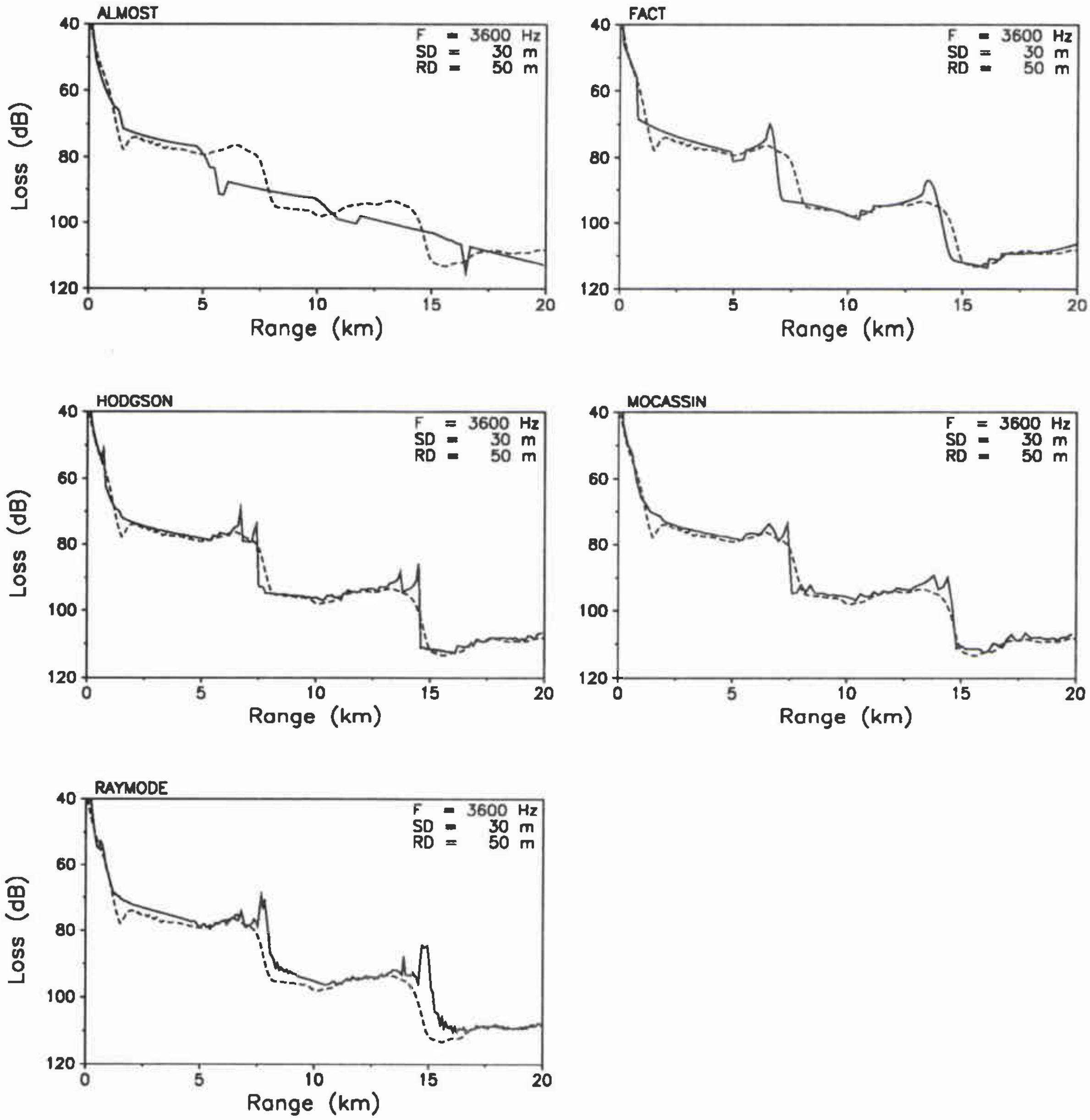


Figure 14 *CASE 3: Comparison of 3.6-kHz modelling results for a source at 30 m and a receiver at 50 m. The reference solution (dashed line) was generated by* GRASS *[20].*

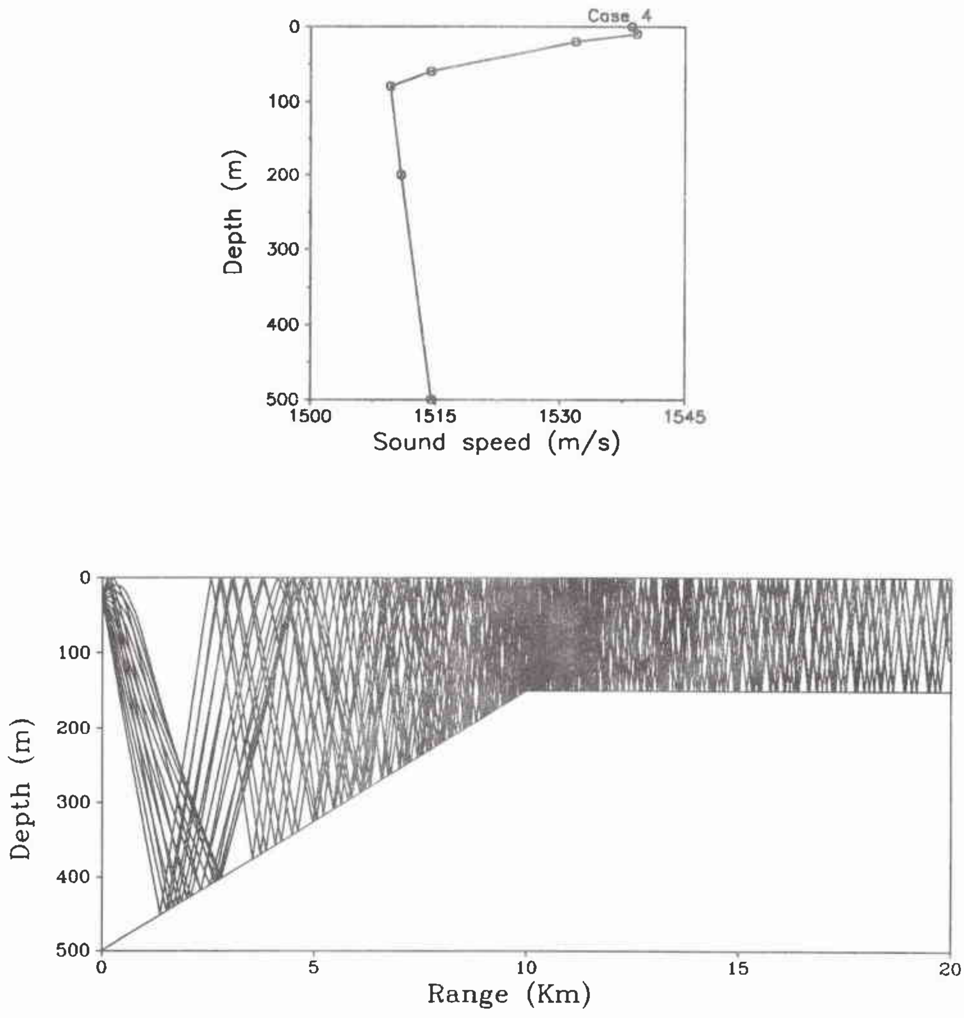


Figure 15 *CASE 4: Sound-speed profile and ray diagram for a source at 30-m depth.*

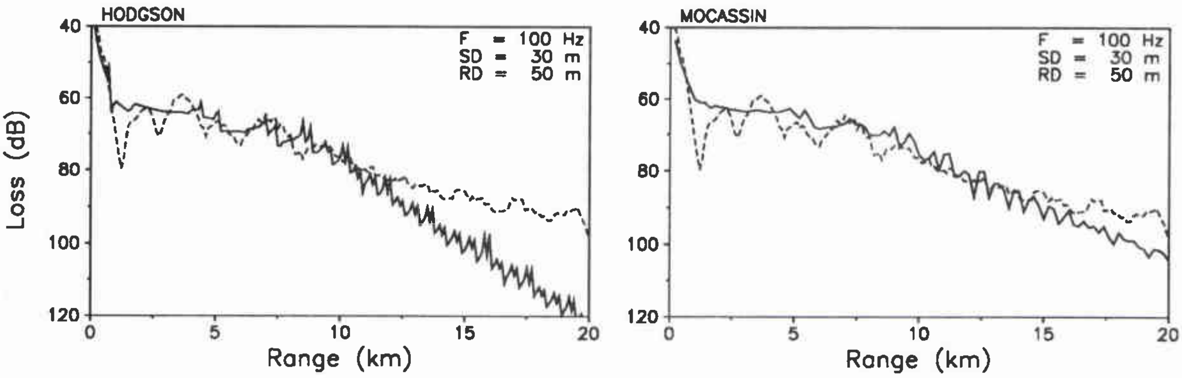


Figure 16 *CASE 4: Comparison of 100-Hz modelling results for a source at 30 m and a receiver at 50 m. The reference solution (dashed line) was generated by* PAREQ *[14].*

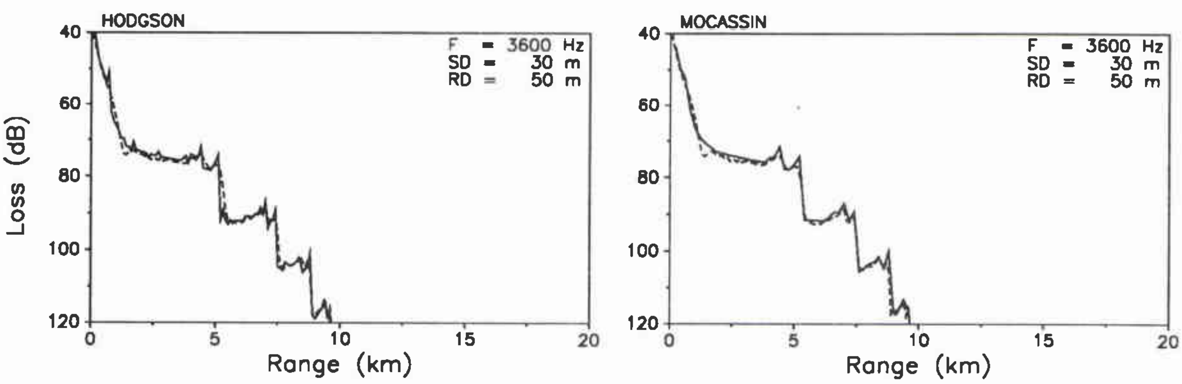


Figure 17 *CASE 4: Comparison of 3.6-kHz modelling results for a source at 30 m and a receiver at 50 m. The reference solution (dashed line) was generated by* GRASS *[20].*

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Author(s)

G. Dreini, C. Isoppo and F.B. Jensen

Title

PC-based propagation and sonar prediction models

Abstract

Six acoustic models available for use on PC's were tested on a series of typical propagation situations from the North Atlantic and the Mediterranean. The model set includes both early US Navy models (ASTRAL, FACT, RAYMODE) and more recent European models (ALMOST, HODGSON, MOCASSIN). It was found that all models perform well on the selected set of test problems.

Keywords

acoustic models – propagation loss – sonar models

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North Atlantic Treaty Organization
SACLANT Undersea Research Centre
Viale San Bartolomeo 400, 19138 La Spezia,
Italy

[From N. America: SACLANTCEN CMR-426 (New York) APO AE 09613]

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