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PERFORMANCE ASSESSMENT OF PROPAGATION MODELS IN AESS-6.0

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Performance assessment of propagation models in AESS-6.0

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Executive Summary: The Allied Environmental Support System (AESS) is the standard sonar performance prediction system used by NATO Commands. The system includes environmental databases, acoustic models, system specific data, tactical decision aids, and various support facilities for data manipulation. The AESS is a very powerful tool for optimizing the use of ships and sensors in a complex tactical scenario.

SACLANTCEN was requested to perform an assessment of the six acoustic models (ASTRAL, MOCASSIN, PE, PROLOS, RAYMODE, SUPERSNAP) included in the AESS v6.0, with the aim of providing guidelines for best model choice and identify shortfalls in current model implementations. To this end, a suitable set of test problems was defined covering typical operational scenarios in both deep and shallow water. A full set of AESS propagation-loss predictions was generated for each test scenario, for two sonar frequencies (500 and 3500 Hz) and for several source/receiver combinations. Reference solutions to all test problems were obtained with the GRAB range-dependent ray trace model, which, in turn, has been thoroughly benchmarked against other models from the SACLANTCEN model library.

The validation tests identified several shortcomings in the general model performance. Both implementation problems and inconsistent use of database information were shown to cause large spreads on TL predictions, often 20 dB or more. However, it was also shown that when models are correctly implemented and make consistent use of database information, they all provide similar TL predictions.

With the current shortcomings in the system, users of AESS v6.0 are recommended to only use the ASTRAL model, and to avoid shallow-water scenarios in the Mediterranean due to bathymetry database problems.

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Performance assessment of propagation models in AESS-6.0

C.M. Ferla and F.B. Jensen

Abstract: A set of AESS propagation-loss predictions has been generated for typical operational scenarios in both deep and shallow water, for two sonar frequencies (500 and 3500 Hz) and for several source-receiver combinations. Reference solutions to all test problems were obtained with the GRAB range-dependent ray-trace model, which, in turn, has been thoroughly benchmarked against other acoustic models from the SACLANTCEN model library. The validation of the six acoustic models in the Allied Environmental Support System (ASTRAL, MOCASSIN, PE, PROLOS, RAYMODE, SUPERSNAP) has identified several shortcomings in the general model performance. Both implementation errors and inconsistent use of data base information are shown to be the main causes of observed prediction errors. These deficiencies, however, are all correctable through close collaboration between model developers and AESS system engineers. Detailed conclusions and recommendations are provided.

Keywords: acoustic models ○ propagation loss ○ range dependence ○ sonar models

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Introduction

The Allied Environmental Support System (AESS) [1] is the standard sonar performance prediction system used by NATO Commands. The system includes environmental databases, acoustic models, system specific data, tactical decision aids, and various support facilities for data manipulation. The AESS is a very powerful tool for optimizing the use of ships and sensors in a complex tactical scenario.

SACLANTCEN was recently requested to perform an assessment of the acoustic models included in the AESS v6.0, with the aim of providing guidelines for best model choice and identify shortfalls in current model implementations.

A suitable set of test problems was defined covering typical operational scenarios in both deep and shallow water. A full set of AESS propagation-loss predictions was generated for each test scenario, for two sonar frequencies (500 and 3500 Hz) and for several source/receiver combinations. Reference solutions to all test problems were obtained with the GRAB range-dependent ray trace model, which, in turn, has been thoroughly benchmarked against other models from the SACLANTCEN model library.

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AESS propagation models

A key element of sonar performance predictions is an accurate estimate of the acoustic transmission loss between the sonar and the target. The AESS has a suite of models to do this task, see Table 1. ASTRAL, PE and RAYMODE are US Navy models, whereas MOCASSIN was developed in Germany, PROLOS in Canada, and SUPERSNAP at SACLANTCEN.

In the next columns in Table 1 are listed the model type (mode, parabolic equation, ray), then what type of environment the model handles, range independent (RI) or range dependent (RD), with some models using the adiabatic approximation. Note that only RAYMODE is a range-independent model, i.e. it cannot handle range-varying environmental conditions along the propagation track.

The last column lists the bottom-loss curves used by each model. There are two worldwide databases for bottom loss: BLUG (Bottom Loss UpGrade) and MGS (Marine Geophysical Survey). Since bottom loss is dependent on frequency, different bottom-loss tables will be used at low frequencies (LF) and at high frequencies (HF). Note that RAYMODE has a mixed input, using BLUG at low frequencies and MGS at high frequencies. SUPERSNAP is not linked to either of these two databases but uses a default geo-acoustic model always!

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The GRAB reference model

A model validation and assessment study requires access to high-fidelity "reference" solutions to the full set of test problems. Considering that the current study covers a broad range of operational sonar scenarios from deep to shallow water, with range-varying bathymetry and sound-speed structure, and for frequencies between 500 Hz and 3.5 kHz, there is essentially only one type of model that can provide answers with an acceptable computational effort: a ray-based, range-dependent propagation model.

The Gaussian Ray Bundle (GRAB) model [2] developed recently for use by the US Navy seemed the optimal choice for checking the AESS predictions. GRAB was developed specifically for high-frequency applications in shallow water, but thorough testing showed excellent performance also at frequencies well below 500 Hz, and for deep-water applications in general. Two aspects of this model are unique: first, the use of Gaussian ray bundles, which causes a smoothing of the acoustic field and hence avoids the standard ray artifacts of infinite intensity near caustics; second, a careful treatment of ray reflections at boundaries using the concept of virtual rays. This is important for producing high-fidelity results in shallow water.

In the course of generating reference solutions with GRAB-2.0 for the entire set of test problems, we made several independent checks on the solution accuracy by comparing with other models from the SACLANTCEN model library. Some of these results are included in the Appendix to show that we always obtained close agreement between the GRAB result and solutions from well-tested scientific models. Hence, when we occasionally encountered test problems where the GRAB and AESS transmission-loss predictions were all different, we are confident that the GRAB result is the most accurate.

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Test problem definition

The test scenarios for the AESS propagation model validation should encompass realistic operational conditions, i.e. consider both deep and shallow water scenarios, for both flat and sloping bottom conditions, and for a variety of different bottom-loss situations. Moreover, the test problems should cover a range of sonar frequencies and various sonar/target depths combinations [3].

It was decided to select a few tracks in the Mediterranean and the North Atlantic, using the database information (NSODB) available for bathymetry and bottom loss as inputs to the acoustic models. This approach, as opposed to using purely synthetic test environments, allowed us to check the quality and consistency of the database information, and also to check the consistency in passing the data to the individual propagation models.

4.1 Bathymetry information

In trying to identify suitable tracks in the Mediterranean, it became clear that the bathymetry database has serious problems in the interpolation routine used for generating a smooth bathymetry along a given bearing. As shown in Fig. A1 in the Appendix, the bottom profile has a stair-step structure for a S-N track, with the steps representing exactly the 1' resolution of the database. This rough bathymetry with step changes of 100-200 m is clearly not suited for acoustic modeling purposes. The situation gets worse moving just 1° off the S-N direction (red curve, Fig. A1), where the bottom depth oscillates with excursions of more than 300 m up and down. This problem was found to persist throughout the Mediterranean, and hence it was decided to look for tracks in the Atlantic instead.

Surprisingly the bathymetry interpolation problem was less severe in the North Atlantic. An example is given in Fig. A2 with the smooth black curve being a S-N track and the red curve a track with bearing 10°. There is still a problem with the interpolation off the S-N direction, so we decided to pick the test environments as S-N tracks only, one across the shelf break north of Madeira (Fig. 1) and the other on the shelf itself in shallower water north of Iceland (Fig. 2). Both tracks have a length of 25 km.

4.2 Bottom loss information

Having selected Tracks A and B to represent Atlantic deep-water and shallow-water scenarios, the information on bottom reflection loss (bottom type) was extracted from the NSODB. For the chosen sonar frequencies of 500 and 3500 Hz, the database information on reflection loss versus grazing angle is shown in Figs. 3 and 4. Note that there are two data sets available, the MGS curves and the BLUG curves, and that the two data sets are rather inconsistent. For example, for Track A at 500 Hz (Fig. 3) the MGS curve gives a loss of around 20 dB per bounce, nearly independent of angle, whereas the BLUG curve has low loss at small grazing angles and up to 8 dB per bounce at steeper angles. Clearly, the acoustic prediction in a bottom-interacting situation will be strongly dependent on the choice of bottom loss model. A complicating factor is that some acoustic models use BLUG as the default bottom model and others the MGS curves. Without going into the merits of one set of reflection loss curves versus the other, we just point out that both databases are based on *in situ* reflection loss measurements, and that the BLUG curves are more recent than the MGS curves.

4.3 Test problem summary

To investigate the most important propagation scenarios in shallow and deep water, each track was divided into three cases: (1) a flat bottom with a water depth corresponding to the deepest end of the track, (2) an upslope bottom with propagation from deep to shallow water, and (3) a downslope bottom with propagation from shallow to deep water. For simplicity a single sound-speed profile was used along each track as defined in Tables 2 and 3. In the next section AESS transmission-loss (TL) predictions will be compared with the GRAB reference solutions (using either MGS or BLUG bottom loss curves) for frequencies of 500 Hz and 3.5 kHz and for several source/receiver combinations.

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Test problem results

5.1 Track A: flat bottom

This is a simplified range-independent, deep-water scenario as illustrated in Fig. 5. The water depth is 2260 m; there is a single sound-speed profile for the entire track with a shallow surface duct of 50-m depth (Table 2) and a deeper sound channel centered at 165-m depth. The bottom loss is given by the BLUG and MGS curves in Figs. 3 and 4.

Two source depths are considered, 15 and 100 m, and the associated ray diagrams are shown in Fig. 5. Note that the shallow source transmits energy directly into the surface duct (black rays) and energy via bottom-interacting paths to receivers below the surface duct. Hence for receivers below 50 m, the TL prediction will be strongly dependent on the bottom-loss model used. For the deep source (red rays) there are waterborne ray arrivals at most receiver depths and TL predictions should therefore be less dependent on the choice of bottom-loss model.

The set of AESS model predictions compared to the GRAB reference solutions is given in Figs. 6–11. Each plot is for a different frequency and a particular source/receiver depth combination. The legend on top of each figure groups the models according to the type of bottom-loss model used. For example, in Fig. 6 three models (ASTRAL, PE, RAYMODE) use the BLUG tables and those models should therefore be compared to the GRAB result indicated with the heavy black line. The MOCASSIN model uses the MGS tables and should be compare to the corresponding GRAB result given by the heavy dashed line. As mentioned earlier the SUPERSNAP model uses a default geo-acoustic model which is different from both the BLUG and the MGS curves.

A closer look at the results in Fig. 6 show a spread on TL predictions of 20–30 dB between the various models. There are two main reasons for this: (1) the use of different bottom loss tables, and (2) model implementation errors. The effect of using different bottom-loss tables is already clear by comparing the two GRAB solutions, one using BLUG (heavy black line) and the other using MGS (heavy dashed line). The MGS bottom is much more lossy (Fig. 3) resulting in a TL that, beyond 3 km, is 10–20 dB higher than the prediction using the BLUG curve. Clearly, it would be important for the user to know which of the two bottom models is closest to reality for Track A.

The best result is provided by RAYMODE which is indistinguishable from the GRAB reference. Also ASTRAL is reasonably accurate, even though levels are too high in the range from 2 to 15 km. The PE result is clearly wrong and so is the MOCASSIN result, which should be 20 dB lower and follow the dashed GRAB result for an MGS bottom. Finally, the SUPERSNAP result falls in between the two reference solutions, using a default geoacoustic model. Note that PROLOS did not provide outputs for this test problem.

In summary, only ASTRAL and RAYMODE perform as expected in this case. The other models have implementation errors, which can be explicitly demonstrated by running those same models in a stand-alone implementation available at SACLANTCEN [3]. The result is given in Fig. A3 in the Appendix. Note that MOCASSIN, PE and SUPERSNAP now give results that are all in agreement with the GRAB reference. Hence, we have provided indisputable evidence that these models are not correctly implemented in the AESS.

Turning to the next example given in Fig. 7 for a deeper receiver at 200 m, we see a similar picture as before. Only the PE result is radically different, now showing too high a level at all ranges. It appears that the inconsistent PE results occur only for a shallow source or receiver in deep water, and we presume that it is due to a too coarse sampling of the acoustic field in depth near the sea surface.

Figures 8 and 9 show results for the deep source at 100 m and receivers at 100 and 200 m, respectively. In both cases the ASTRAL and RAYMODE results are very close to the GRAB reference. Also SUPERSNAP gives a similar answer, but this is fortuitous considering the default bottom model used here. The problem is again with PE and MOCASSIN. For the shallow receiver (Fig. 8) the PE prediction follows the GRAB reference, but for the wrong bottom model! The PE answer should agree with the BLUG-bottom result (heavy black line). For this source depth the MOCASSIN result starts off at the right level (GRAB-MGS), but the model fails to reproduce the rise in level between 10 and 15 km indicated by the GRAB reference (heavy dashed line). Again, PE and MOCASSIN are not correctly implemented in AESS-6.0.

We finally show two high-frequency results in Figs. 10 and 11. At 3.5 kHz in deep water only the three ray-based models can be selected. Note that RAYMODE in this frequency range is linked to the MGS bottom tables. For the shallow source in Fig. 10 both ASTRAL and RAYMODE are in close agreement with the GRAB references. The MOCASSIN solution is much too high (30 dB) and should follow the RAYMODE result. Again, we can explicitely show that these three models give consistent answers when run correctly. In Fig. A4 is shown an inter-model comparison for stand-alone versions of MOCASSIN and RAYMODE, and now there is perfect agreement with the GRAB reference. For the deep source in Fig. 11, we see good performance by ASTRAL and RAYMODE, whereas MOCASSIN starts off correctly but fails to reproduce the sharply rising level beyond a range of 12 km.

Model performance summary: Track A – flat.

- ASTRAL and RAYMODE provide most accurate TL predictions.
- PE and MOCASSIN are not correctly implemented and should be avoided.
- PROLOS fails entirely on this test problem.
- SUPERSNAP is not linked to any of the standard bottom loss tables but uses a default bottom instead. Unreliable for bottom-interacting scenarios.

5.2 *Track A: upslope bottom*

We now introduce the correct bathymetry along Track A with propagation from deep to shallow water, see Fig. 12. There is still a single sound-speed profile along the entire track (Table 2), and bottom losses are given by the BLUG and MGS curves in Figs. 3 and 4. This range-dependent environment provides an added degree of complexity for validation of the TL models in AESS-6.0.

Two source depths are considered, 15 and 150 m, and the associated ray diagrams are shown in Fig. 12. Note that the effect of the sloping bottom on long-range propagation is felt only for the shallow source and for receivers below the surface duct. By comparing Figs. 5 and 12 we see that the number of ray reflections off the sloping bottom increases towards the shallow end of the track, which, in turn, results in higher transmission losses.

The set of AESS model predictions compared to the GRAB reference solutions is given in Figs. 13–16. First, note that PROLOS surprisingly provided results for this environment, but not for the flat-bottom case! Second, note that the GRAB reference solutions for the shallow source exhibit a sharp fall off in level beyond the 17–18 km range. This is the increased bottom loss resulting from the shoaling bathymetry near the end of the track.

The results in Fig. 13 for a source at 15 m and a receiver at 200 m show a spread on TL predictions of 40–50 dB, with the PE result being the most optimistic and the PROLOS result the most pessimistic. The best result is provided by RAYMODE which is very close to the GRAB reference out to a range of 18 km. However, there is no sign of the rapid level drop-off near the end of the track as predicted by GRAB, and for a good reason: RAYMODE is a range-*independent* model that ignores environmental changes along the propagation track! Hence this model should not be applied to this scenario.

ASTRAL is a range-dependent model and agrees quite well with the GRAB reference solution. However, this model uses a geometry consisting of a fixed receiver at 200 m and a moving source at 15 m (passive sonar geometry). Most other models[1], including GRAB, operate with a fixed source at 15 m and a moving receiver at 200 m (active sonar geometry). In a range-dependent environment these geometrical choices will affect the shape of the TL curve. To be consistent we may invoke the principle of reciprocity and interchange source and receiver depth for the ASTRAL model. If this is done, i.e. SD=200 m and RD=15 m, we get a slightly improved result for ASTRAL as shown in Fig. A5 in the Appendix. More evidence to support this point will be presented for the following test problems.

Returning to Fig. 13, none of the other model predictions are of acceptable accuracy. The MOCASSIN result should be 20 dB lower and follow the dashed GRAB result for an MGS bottom. Moreover, there is no level drop-off in shallow water. Only the SUPERSNAP result shows a rapidly dropping level beyond 20 km, but the overall level is determined by the default geo-acoustic model which is not consistent with neither BLUG nor MGS. To press the point that PE, PROLOS, MOCASSIN and SUPERSNAP have implementation errors, we show in Fig. A5 results obtained from stand-alone versions of some of these models. The consistency with GRAB is excellent; all models show a rapid level drop-off beyond a range of 17–18 km.

Turning to the next example in Fig. 14 for a source and receiver near the sound channel axis, we have excellent agreement between all models, except MOCASSIN. Note that the acoustics here is particularly simple with sound being channeled to long ranges without boundary interaction, see ray diagram in Fig. 12.

We finally show two 3.5-kHz results in Figs. 15 and 16. Note that RAYMODE in this frequency range is linked to the MGS bottom tables. For the shallow source in Fig. 15 both ASTRAL and RAYMODE are in close agreement with the GRAB references out to a range of 18 km. However, as mentioned previously only ASTRAL includes range-dependent effects, but this model should be run with an inverted source/receiver geometry. RAYMODE being inherently range-*independent* should not be applied to this type of scenario. The MOCASSIN solution is much too high (30 dB) and should follow the GRAB-MGS result. For the simple channel propagation situation in Fig. 16, we have excellent performance by all models, except MOCASSIN.

Model performance summary: Track A – upslope.

- ASTRAL provides quite accurate TL predictions with moving receiver geometry.
- RAYMODE is a range-independent model and should not be applied to this type of scenario.
- PE, PROLOS and MOCASSIN are not correctly implemented and should be avoided.
- SUPERSNAP is not linked to any of the standard bottom loss tables but uses a default bottom instead. Unreliable for bottom-interacting scenarios.

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[1] PE also uses the passive sonar geometry.

5.3 *Track A: downslope bottom*

For completeness we next consider the opposite propagation direction with transmission from shallow to deep water along Track A, see Fig. 17. This scenario is acoustically simpler than the upslope case because there is less bottom interaction.

The AESS-6.0 model predictions compared to the GRAB reference solutions are given in Figs. 18–21. For a source at 15 m and a receiver at 200 m (Fig. 18) all curves group around the GRAB-BLUG reference solution. However, MOCASSIN should have been 15 dB lower and followed the GRAB-MGS result. That the SUPERSNAP prediction looks good in this case is fortuitous considering that it uses its own geo-acoustic model.

For the deeper source in Fig. 19 we have excellent results from ASTRAL, PE and SUPERSNAP. RAYMODE provides too high a level, presumably due to a range-dependent propagation effect not handled by this model. PROLOS and MOCASSIN have poor prediction accuracy.

The 3.5-kHz results in Figs. 20 and 21 show that only ASTRAL provides accurate TL predictions. The ASTRAL result could even be improved in Fig. 20 by inverting source and receiver so as to duplicate the propagation geometry assumed by GRAB.

Model performance summary: Track A – downslope.

- ASTRAL provides accurate TL predictions.
- RAYMODE is a range-independent model and should not be applied to this type of scenario.
- PE performs well on this test case, but fails in other situations.
- PROLOS and MOCASSIN are not correctly implemented and should be avoided.
- SUPERSNAP is not linked to any of the standard bottom loss tables but uses a default bottom instead. Unreliable for bottom-interacting scenarios.

5.4 *Track B: flat bottom*

This is a simplified constant-depth, shallow-water scenario as illustrated in Fig. 22. The water depth is 500 m; there is a single sound-speed profile for the entire track with a surface duct of 10-m depth (Table 3) and a weak sound channel centered at 80 m. The bottom loss is given by the BLUG and MGS curves in Figs. 3 and 4. Note that this track straddles two MGS provinces, with low loss to the south (MGS 2) and much higher loss to the north (MGS 6).

Two source depths are considered, 15 and 100 m, and the associated ray diagrams are shown in Fig. 22. Note that rays leaving the shallow source all interact with both surface and bottom, which will cause TL prediction to be strongly dependent on the bottom-loss model used (typical shallow-water scenario). For the deep source (red rays) there are waterborne ray arrivals, but only near the channel axis.

The AESS model predictions compared to the GRAB reference solutions are given in Figs. 23–26. Each plot is for a different frequency and a particular source/receiver depth combination. The legend on top of each figure groups the models according to the type of bottom-loss model used. For example, in Fig. 23, three models (ASTRAL, PE, RAYMODE) use the BLUG tables and those models should therefore be compared to the GRAB results indicated with the heavy black line. The MOCASSIN model uses the MGS tables and should be compared to the corresponding GRAB result given by the heavy dashed line. The SUPERSNAP model uses a default geo-acoustic model which is different from both the BLUG and the MGS curves.

A closer look at the results in Fig. 23 show a spread on TL predictions in excess of 50 dB between the various models at long ranges. There are two main reasons for this: (1) the use of different bottom loss tables, and (2) model implementation errors. The effect of using different bottom-loss tables is already clear by comparing the two GRAB solutions, one using BLUG (heavy black line) and the other using MGS (heavy dashed line). The MGS bottom is much more lossy (Fig. 3) resulting in a TL that, beyond 7 km, is 10–20 dB higher than the prediction using the BLUG curve. Clearly, it would be important for the user to know which of the two models is closest to reality for Track B.

The best results are provided by ASTRAL and RAYMODE which are both very close to the GRAB reference. The PE result has clearly too little loss and ends up with a level that is around 15 dB too high compared to GRAB. The SUPERSNAP result is much better, but this is fortuitous considering its use of a default geo-acoustic model. Finally, MOCASSIN performs quite well in this situation even though it is consistently 5–10 dB lower than the GRAB-MGS reference. Note that PROLOS did not provide outputs for this test problem.

Turning to the example for the deep source in Fig. 24, we see that all models perform well, except MOCASSIN. For this source/receiver combination sound is traveling in the channel without bottom interaction, and hence the two GRAB results are identical.

We finally show some 3.5-kHz results in Figs. 25 and 26. For the shallow source in Fig. 25 only MOCASSIN is in close agreement with the GRAB reference! The ASTRAL and PE answers are both too high, and so is the RAYMODE prediction which should follow the GRAB-MGS solution. Again, we can explicitely show that all models give consistent answers when run correctly. In Fig. A6 is shown an inter-model comparison for stand-alone versions of ASTRAL, MOCASSIN, PE, RAYMODE and SUPERSNAP, and now there is excellent agreement with the GRAB reference, except for SUPERSNAP which overestimates the loss. This is a known limitation in that model associated with high-loss environments (shallow water, lossy bottom, high frequency). The improved ASTRAL prediction was obtained for the moving receiver geometry. Finally, for the deep source in Fig. 26, we see good performance by all models, except MOCASSIN.

Model performance summary: Track B – flat.

- ASTRAL and RAYMODE provide most accurate TL predictions.
- PE and MOCASSIN are not correctly implemented and should be avoided.
- PROLOS fails entirely on this test problem.
- SUPERSNAP is not linked to any of the standard bottom loss tables but uses a default bottom instead. Unreliable for bottom-interacting scenarios.

5.5 Track B: upslope bottom

The correct bathymetry along Track B is introduced next (Fig. 3) with propagation from deep to shallow water, see Fig. 27. There is still a single sound-speed profile along the entire track (Table 3), and bottom losses are given by the BLUG and MGS curves in Figs. 3 and 4. This range-dependent environment provides an added degree of complexity for validation of the TL models in AESS-6.0.

Two source depths are considered, 15 and 100 m, and the associated ray diagrams are shown in Fig. 27. Note that the effect of the sloping bathymetry on long-range propagation in an increased number of ray reflections off the bottom towards the shallow end of the track. This, in turn, results in higher transmission losses compared to the flat-bottom scenario studied previously.

The AESS model predictions compared to the GRAB reference solutions are given in Figs. 28–31. Note that the GRAB reference solutions for the shallow source exhibit a sharp fall off in level beyond 7–10 km. This is the increased bottom loss resulting from the shoaling bathymetry near the middle of the track.

The results in Fig. 28 for a source at 15 m and a receiver at 50 m show a spread on TL predictions of more than 50 dB at long ranges. What is most worrisome is that only one model (MOCASSIN) give an answer that is vaguely similar to the GRAB reference. Only RAYMODE is expected to fail here since this model is range-independent and hence ignores the change in water depth with range. The reason that the other models fail is either implementation errors or, as is the case for ASTRAL and PE, the issue of correctly specifying the source/receiver geometry. We again illustrate this through an inter-model comparison using stand-alone versions of the AESS models. As shown in Fig. A7 for a source at 15 m and a receiver at 150 m the various TL predictions are in excellent agreement. It is also more evident here than in previous examples that we need to interchange source and receiver in the ASTRAL and PE models to obtain agreement with the GRAB reference.

Turning to the next example in Fig. 29 for a source near the sound channel axis, only PROLOS and MOCASSIN give very poor predictions. ASTRAL does predict too much loss at long ranges, but this is easily fixed by interchanging source and receiver in the input.

We finally show two 3.5-kHz results in Figs. 30 and 31. For the shallow source in Fig. 30 none of the AESS results come close to the GRAB references! However, we know from previous examples that ASTRAL should be run with an inverted source/receiver geometry to match the GRAB reference. The other models (excluding RAYMODE) would also do fine if implemented correctly. For the deeper source in Fig. 31, we have best performance by ASTRAL and SUPERSNAP.

Model performance summary: Track B – upslope.

- ASTRAL provides quite accurate TL predictions with moving receiver geometry.
- RAYMODE is a range-independent model and should not be applied to this type of scenario.
- PE, PROLOS and MOCASSIN are not correctly implemented and should be avoided.
- SUPERSNAP is not linked to any of the standard bottom loss tables but uses a default bottom instead. Unreliable for bottom-interacting scenarios.

5.6 Track B: downslope bottom

For completeness we also consider the opposite propagation direction with transmission from shallow to deeper water along Track B, see Fig. 32. This scenario is acoustically simpler than the upslope case because there is less bottom interaction.

The AESS-6.0 model predictions compared to the GRAB reference solutions are given in Figs. 33–36. For a source at 15 m and a receiver at 150 m (Fig. 33) none of the model predictions are close to the GRAB reference. Again we illustrate through an inter-model comparison that stand-alone versions of the AESS models perform much better. The result is given in Fig. A8 in the Appendix.

For the deeper source in Fig. 34 we have excellent results from ASTRAL, RAYMODE, PE and SUPERSNAP. Only PROLOS and MOCASSIN fail in this situation. Finally, the 3.5-kHz results in Figs. 35 and 36 show that only ASTRAL provides accurate TL predictions. The ASTRAL result could even be improved by inverting source and receiver so as to duplicate the propagation geometry assumed by GRAB.

Model performance summary: Track B – downslope.

- ASTRAL provides accurate TL predictions with moving receiver geometry.
- RAYMODE is a range-independent model and should not be applied to this type of scenario.
- PE, PROLOS and MOCASSIN are not correctly implemented and should be avoided.
- SUPERSNAP is not linked to any of the standard bottom loss tables but uses a default bottom instead. Unreliable for bottom-interacting scenarios.

6

Conclusions and recommendations

The validation of six acoustic models in AESS-6.0 (ASTRAL, MOCASSIN, PE, PROLOS, RAYMODE, SUPERSNAP) on a series of test problems has identified several shortcomings in the general model performance. Both implementation problems and inconsistent use of database information were shown to cause large spreads on TL predictions, often 20 dB or more. The main implementation and database issues that emerged from this study are summarized below:

1. Bathymetry database unusable in the Mediterranean. The bottom profile always appears spiky or stair-step like with rapid depth excursions of several hundred meters.
2. Inconsistent use of bottom-loss information. There are 2 sets of bottom-loss curves, BLUG and MGS, and we have seen that predicted TL levels are very sensitive to which model is picked for bottom-interacting scenarios. Some models use BLUG, other models MGS, but it is outside the users control. It is suggested that all models be linked to both databases, and that the default be BLUG (newer).
3. ASTRAL is overall the most reliable model, but contrary to the other models, it uses a moving source instead of a moving receiver geometry. Hence, for consistency with the other models, including GRAB, source and receiver should be inverted in the input to ASTRAL.
4. MOCASSIN is not implemented correctly. This model performed poorly on most of the test problems, but it was shown that a stand-alone version provided good prediction accuracy. The implementation problems are associated with some default parameter selections in the model.
5. PE is not implemented correctly. Again the problems are associated with the choice of some default numerical parameters. The fully coherent PE answers should be smoothed to display mean levels in accordance with the other models. As for ASTRAL also PE uses an inverted source/receiver geometry.
6. PROLOS is not implemented correctly. This model should give prediction accuracy similar to that of SUPERSNAP.
7. RAYMODE is a range-*independent* model, and it should not be applied to range-varying environments. Moreover, it uses BLUG tables for low frequencies and MGS tables for high frequencies, which is inconsistent.
8. SUPERSNAP uses an area-independent geo-acoustic bottom. This model should be linked to the BLUG and MGS tables to give answers that are consistent with other acoustic models.

The above database and model deficiencies are all correctable through close collaboration between model developers and AESS system engineers.[2] In this report it was shown that when models are correctly implemented and make consistent use of database information, they all provide similar TL predictions. Hence, in future AESS releases the choice of acoustic model should not be important. Some models run faster or provide more detail of the acoustic field, but average TL levels should all agree to within a few decibels.

Recommendations: For users of AESS v6.0 select ASTRAL which is linked to the BLUG bottom-loss tables, but interchange source and receiver. Avoid shallow-water scenarios in the Mediterranean due to bathymetry database problems.

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[2] The detailed findings of this report were presented to the AESS custodian [1] during a meeting held at SACLANTCEN on 23–25 March 1999. Technical solutions to the various problems were discussed with the intent to have most of the corrections implemented before the next release of the software.

References

[1] "Allied Environmental Support System (AESS): Operator's course; Trainee's guide," Integrated Performance Decisions, Inc., Middletown, RI (1996).

[2] H. Weinberg and R.E. Keenan, "Gaussian ray bundles for modeling high-frequency propagation loss under shallow-water conditions," Naval Undersea Warfare Center, TR-10568 (1996), and J. Acoust. Soc. Amer. **100**, 1421–1431 (1996).

[3] G. Dreini, C. Isoppo and F.B. Jensen, "PC-based propagation and sonar prediction models," SACLANTCEN Report SR-240, 1995.

TABLES
and
FIGURES

Table 1 *List of AESS propagation models.*

Model name	Model type	RD/RI	Bottom type
ASTRAL	mode	RD(adiab)	BLUG
PE	parab. eq.	RD	BLUG
RAYMODE	ray/mode	RI	BLUG (LF) MGS (HF)
MOCASSIN	ray	RD(bathy)	MGS
PROLOS	mode	RD(adiab)	BLUG
SUPERSNAP	mode	RD(adiab)	geo-acoustic
GRAB (reference)	ray	RD	MGS/BLUG

Table 2 *Sound speed profile for Track A.*

Depth (m)	Sound speed (m/s)
0	1526.0
25	1527.0
50	1528.0
70	1518.0
95	1511.0
165	1509.0
210	1510.0
270	1510.8
300	1511.0
400	1511.6
500	1513.1
600	1514.5
700	1516.4
800	1517.3
900	1518.7
1000	1520.4
1100	1522.1
1200	1523.7
1300	1525.4
1400	1527.2
1500	1528.9
1750	1533.1
2000	1537.4
2260	1541.7

Table 3 *Sound speed profile for Track B.*

Depth (m)	Sound speed (m/s)
0	1538.6
10	1539.3
15	1535.6
20	1531.9
60	1514.3
80	1509.6
200	1510.9
500	1514.6

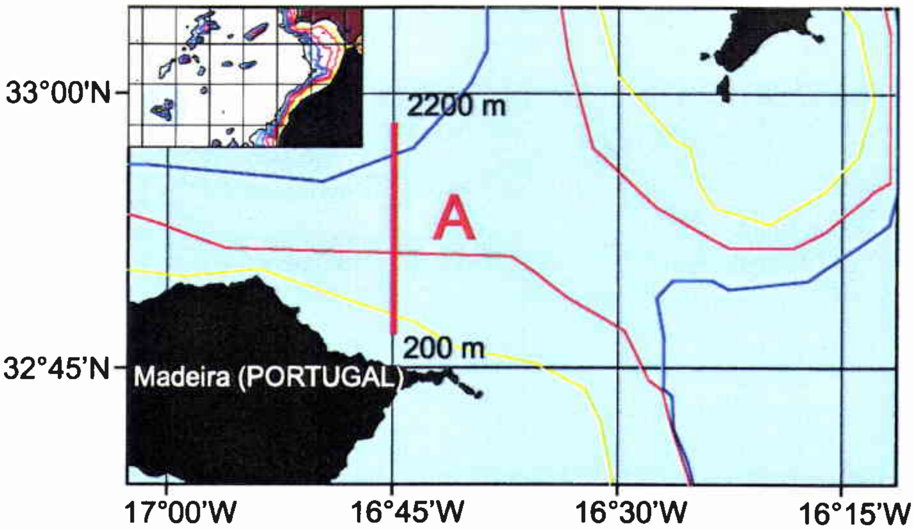

Figure 1 *Track A: Range-dependent deep-water track north of Madeira with end-point coordinates 32°46.5'N, 16°45'W and 32°58.3'N, 16°45'W.*

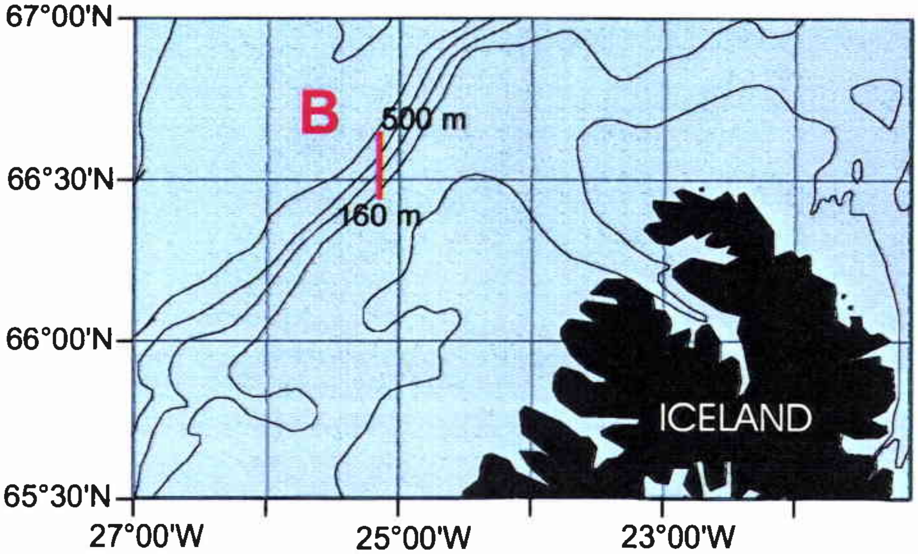

Figure 2 *Track B: Range-dependent shallow-water track north of Iceland with end-point coordinates 66°26.1'N, 25°9.5'W and 66°38.5'N, 25°9.5'W.*

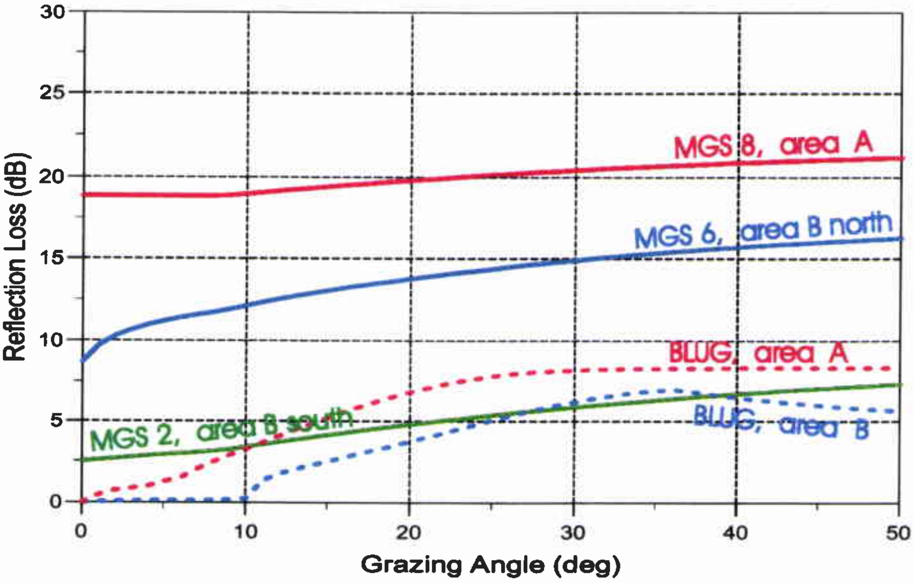

Figure 3 *Low-frequency (500 Hz) MGS and BLUG bottom-loss curves.*

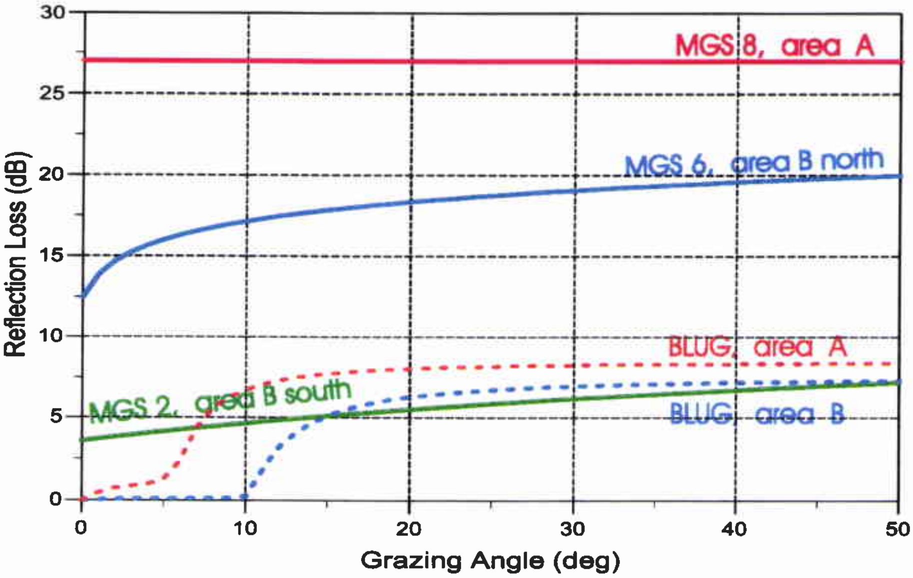

Figure 4 *High-frequency (3500 Hz) MGS and BLUG bottom-loss curves.*

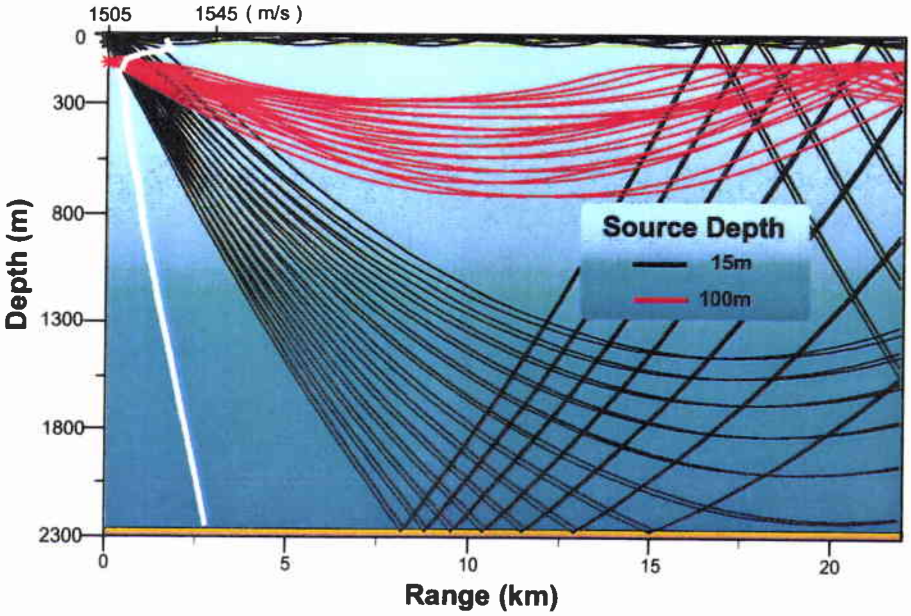

Figure 5 *Track A – flat: Ray diagrams for two different source depths.*

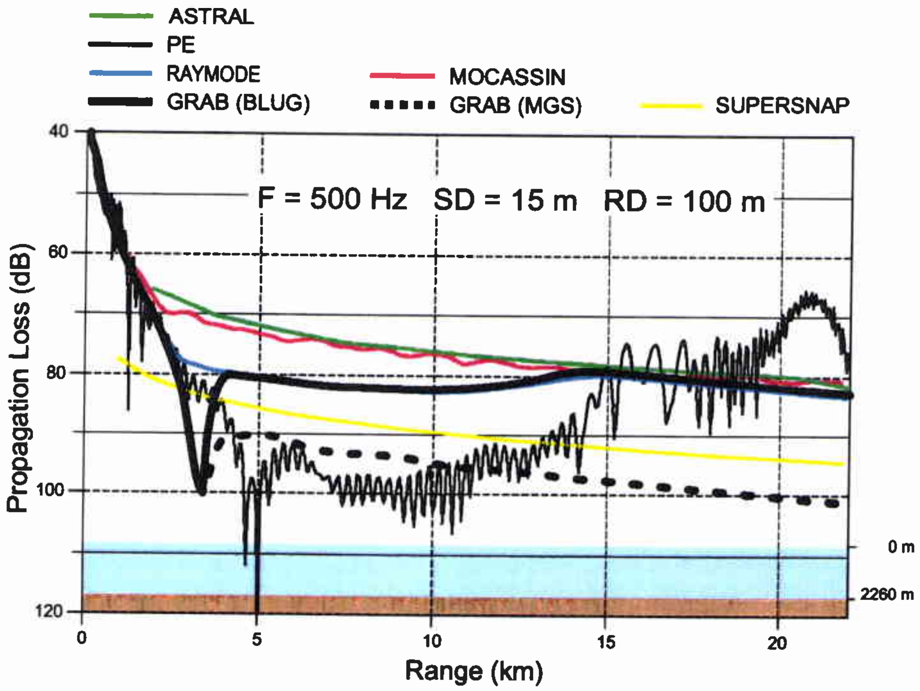

Figure 6 *Track A – flat: Model predictions at 500 Hz for source at 15 m and receiver at 100 m.*

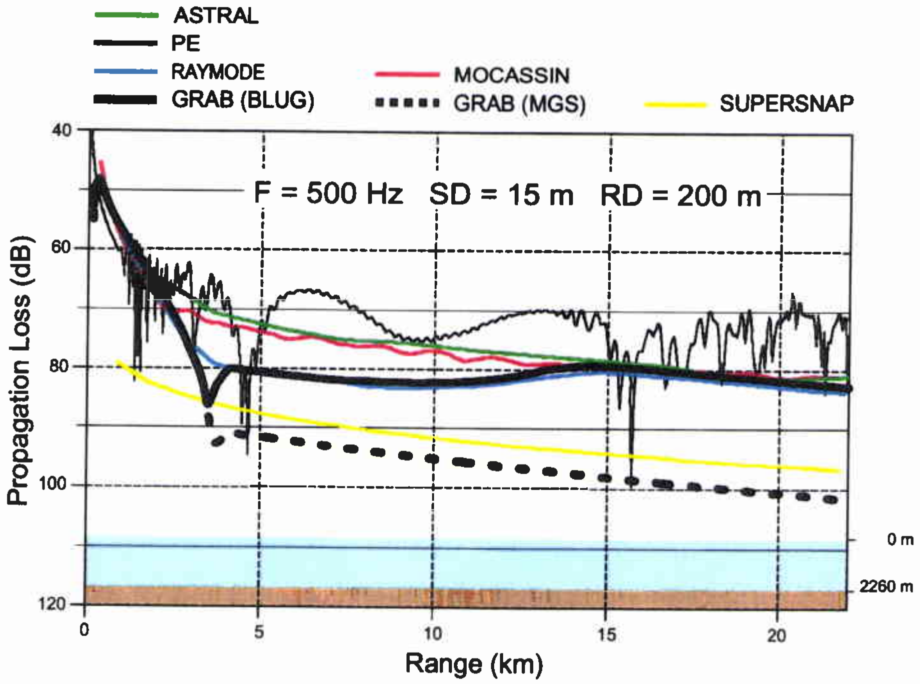

Figure 7 *Track A – flat: Model predictions at 500 Hz for source at 15 m and receiver at 200 m.*

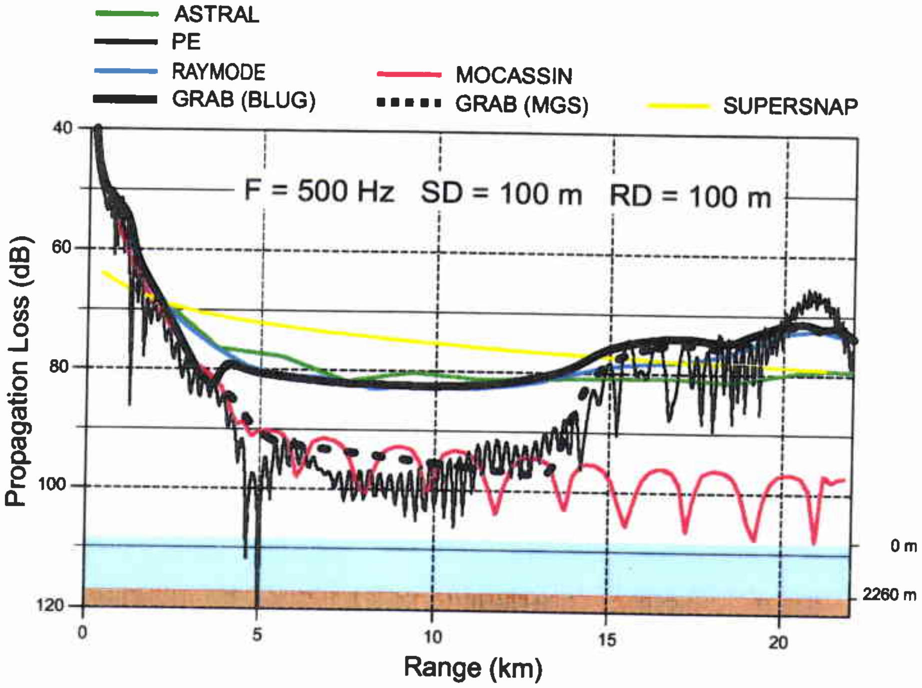

Figure 8 *Track A – flat: Model predictions at 500 Hz for source at 100 m and receiver at 100 m.*

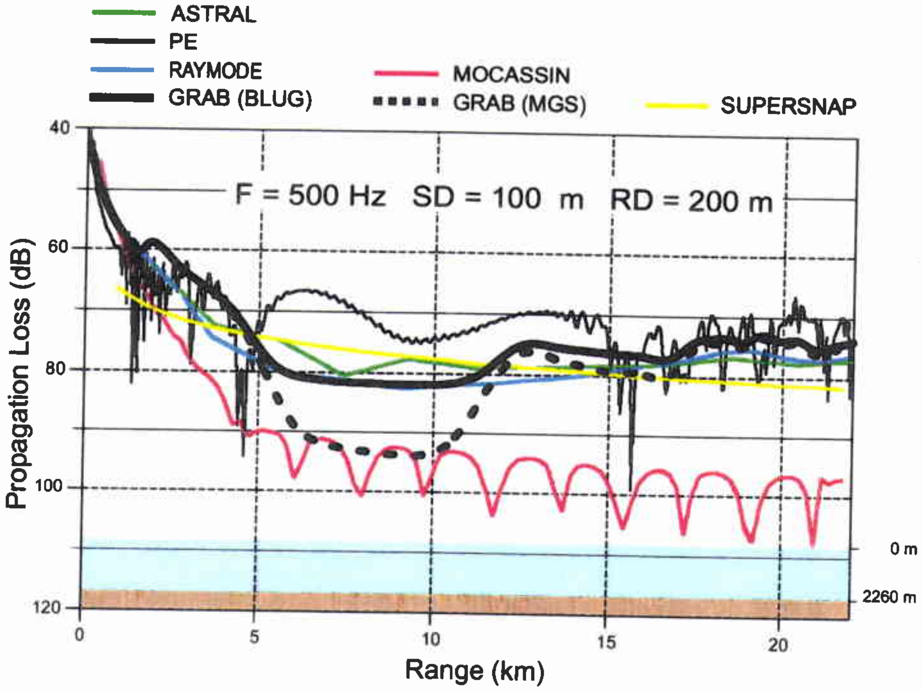

Figure 9 *Track A – flat: Model predictions at 500 Hz for source at 100 m and receiver at 200 m.*

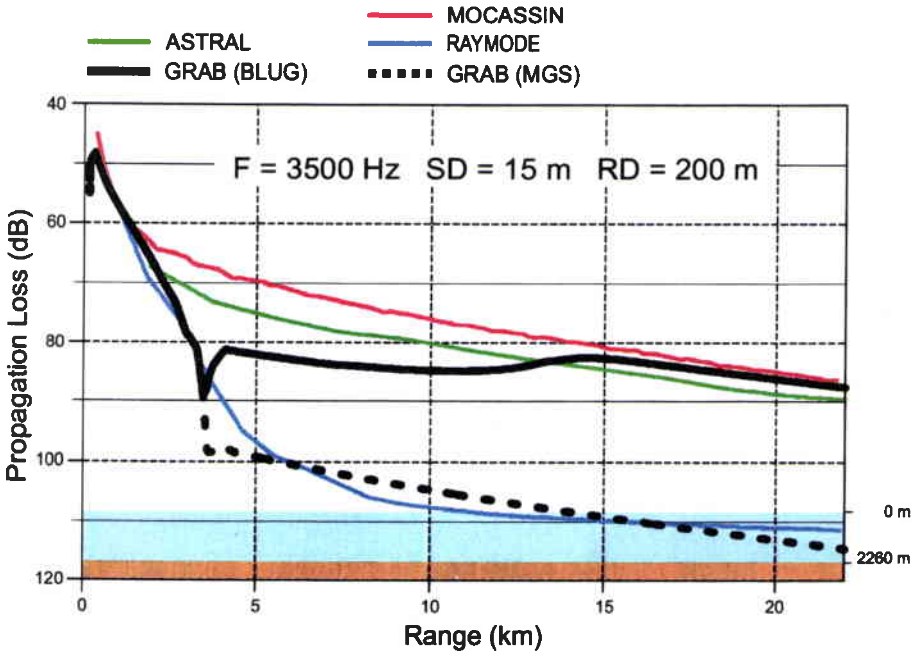

Figure 10 *Track A – flat: Model predictions at 3500 Hz for source at 15 m and receiver at 200 m.*

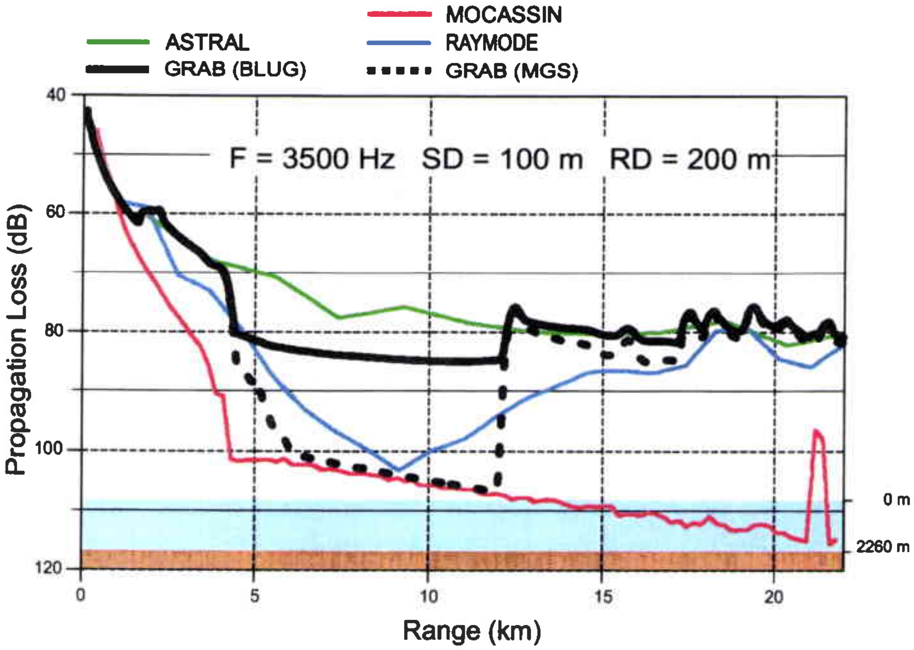

Figure 11 *Track A – flat: Model predictions at 3500 Hz for source at 100 m and receiver at 200 m.*

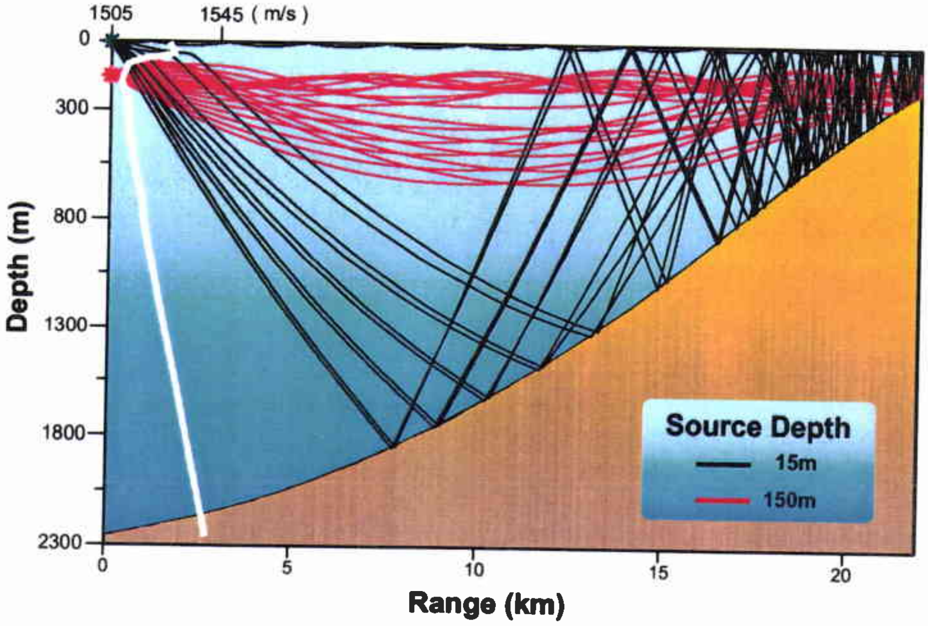

Figure 12 *Track A – upslope: Ray diagrams for two different source depths.*

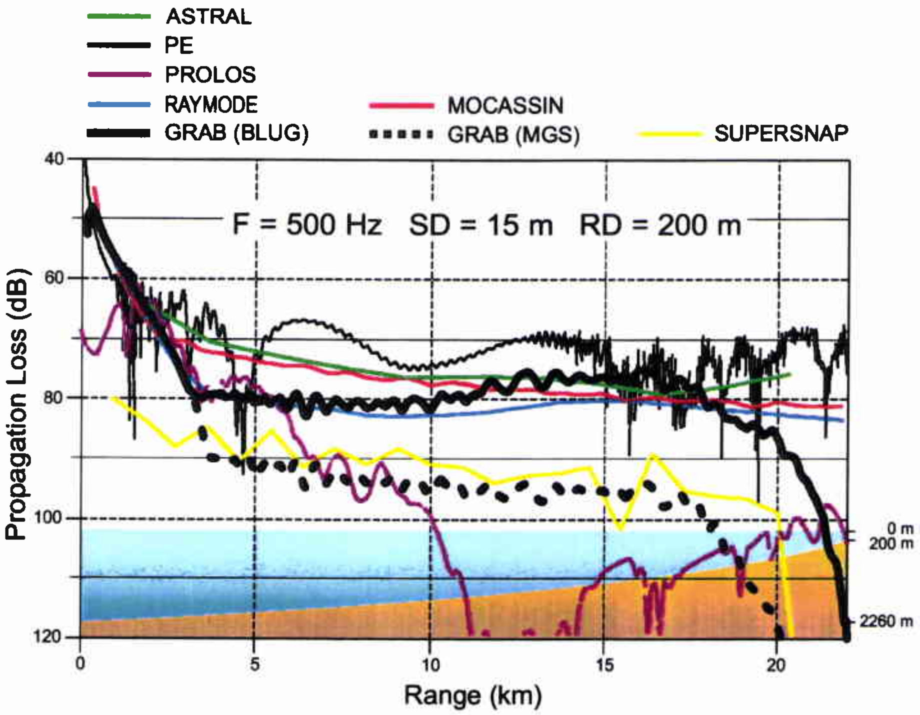

Figure 13 *Track A – upslope: Model predictions at 500 Hz for source at 15 m and receiver at 200 m.*

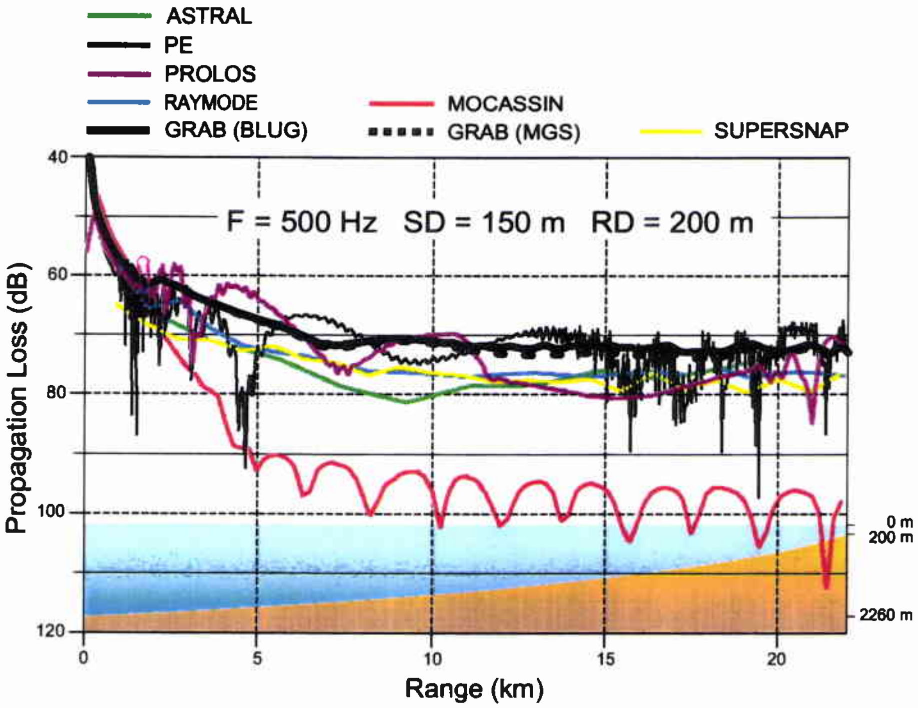

Figure 14 *Track A – upslope: Model predictions at 500 Hz for source at 150 m and receiver at 200 m.*

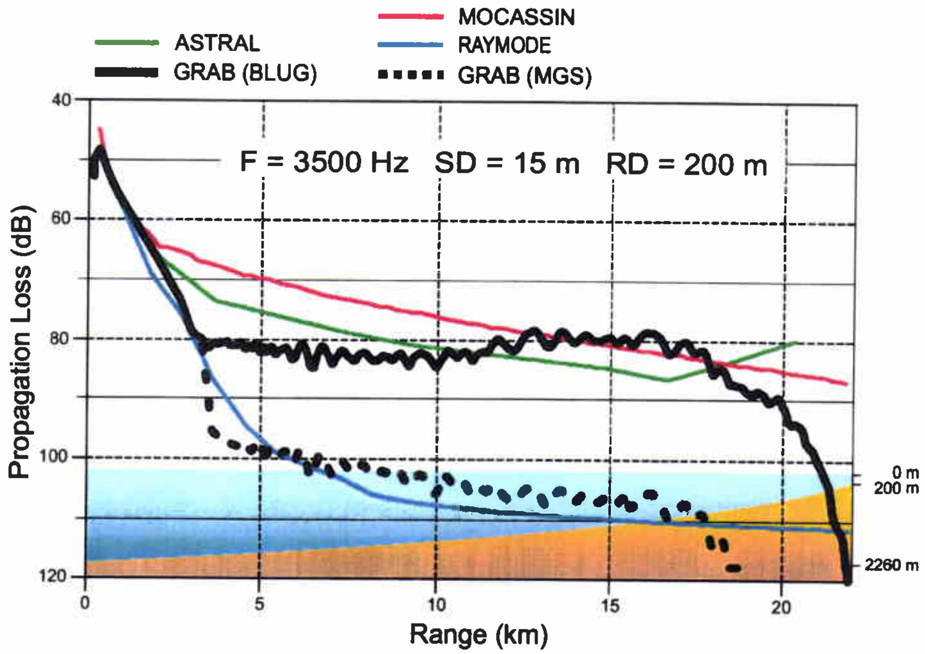

Figure 15 *Track A – upslope: Model predictions at 3500 Hz for source at 15 m and receiver at 200 m.*

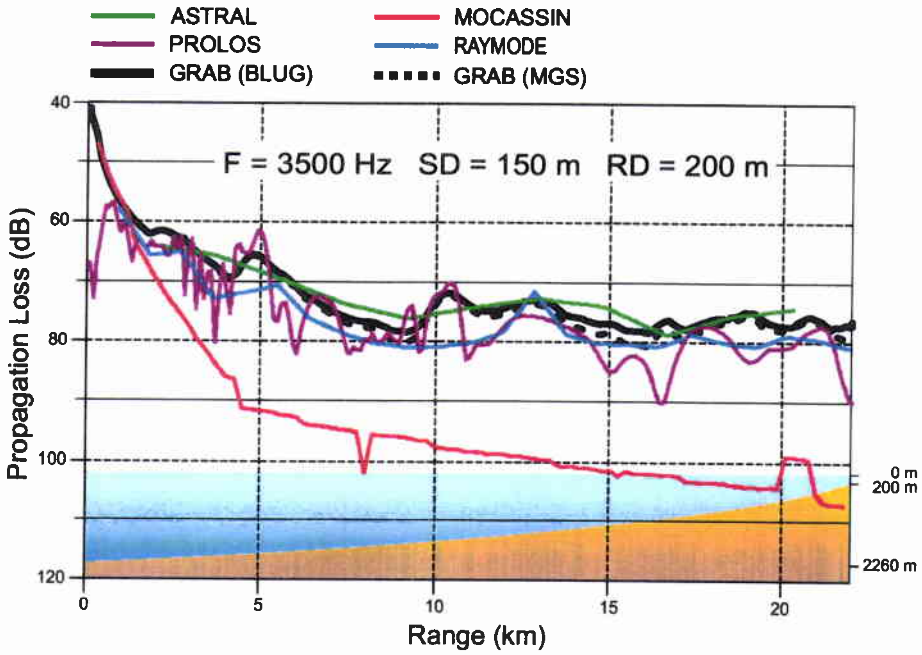

Figure 16 *Track A – upslope: Model predictions at 3500 Hz for source at 150 m and receiver at 200 m.*

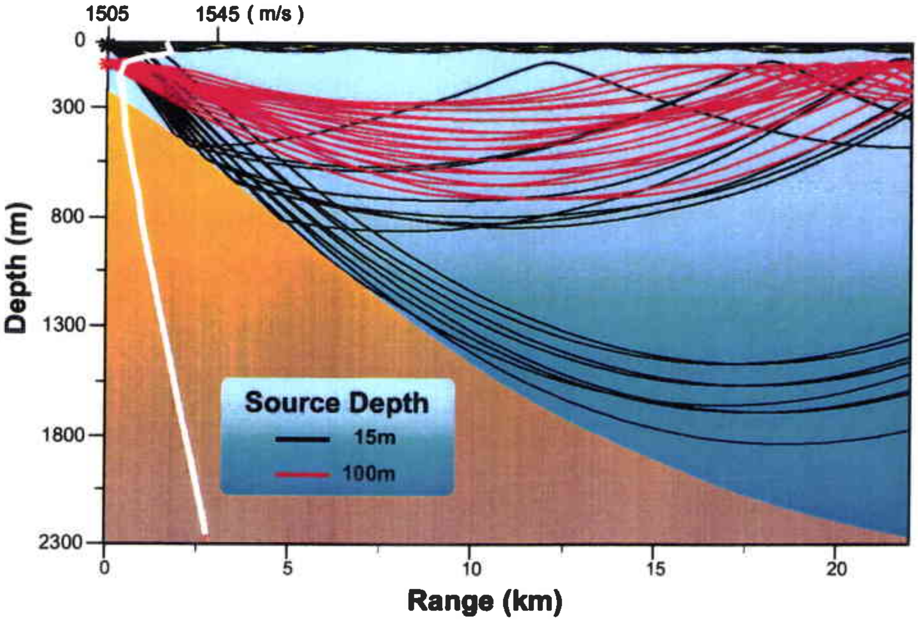

Figure 17 *Track A – downslope: Ray diagrams for two different source depths.*

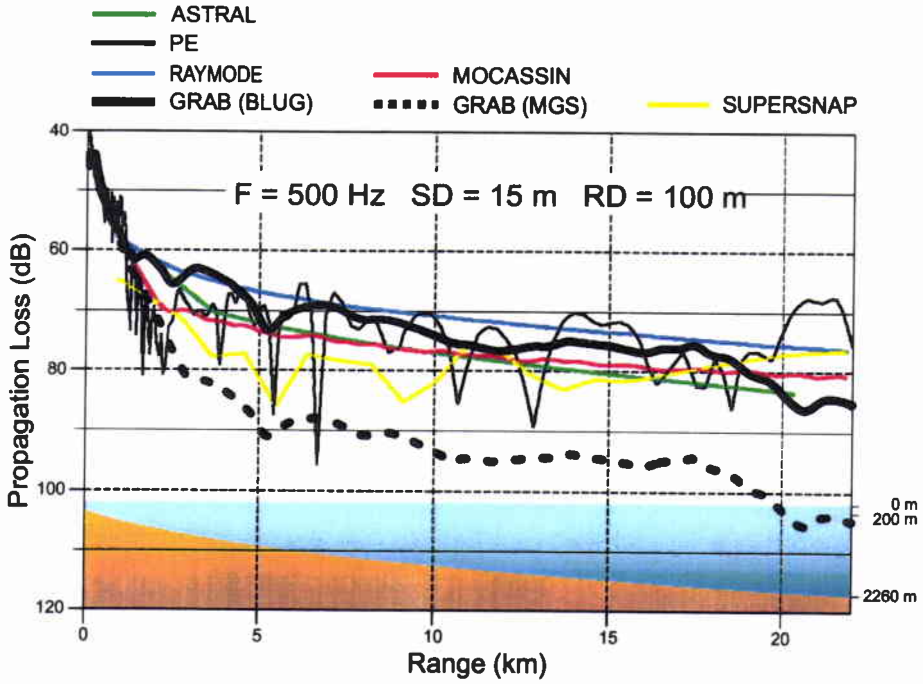

Figure 18 *Track A – downslope: Model predictions at 500 Hz for source at 15 m and receiver at 100 m.*

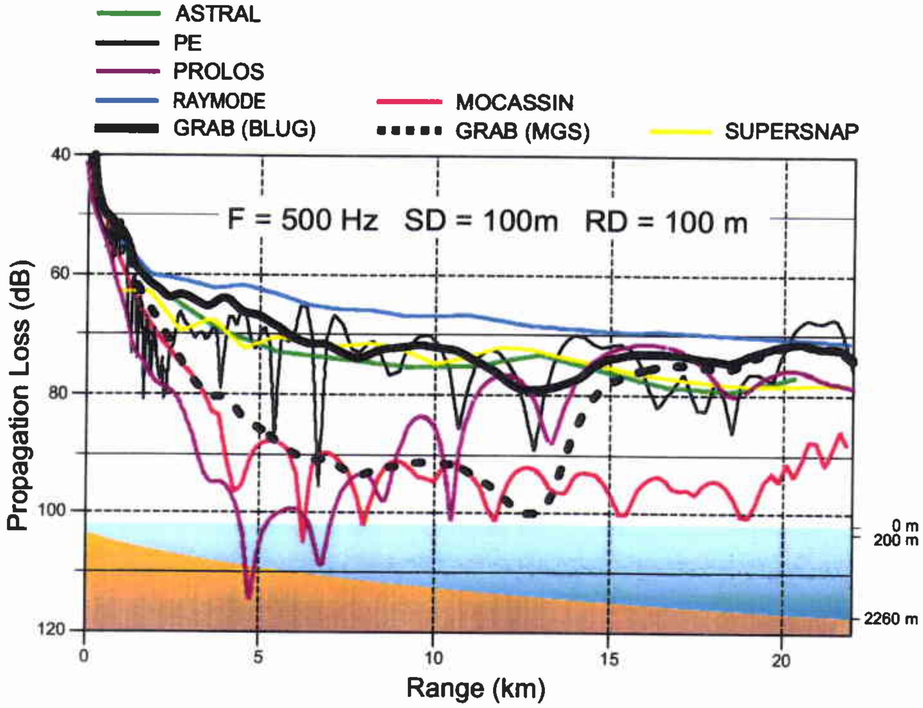

Figure 19 *Track A – downslope: Model predictions at 500 Hz for source at 100 m and receiver at 100 m.*

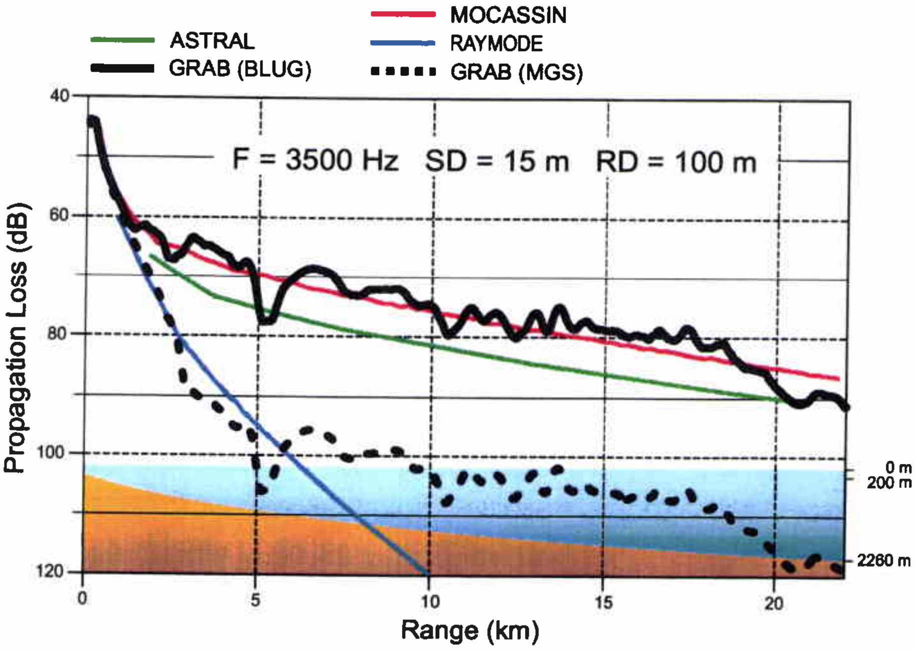

Figure 20 *Track A – downslope: Model predictions at 3500 Hz for source at 15 m and receiver at 100 m.*

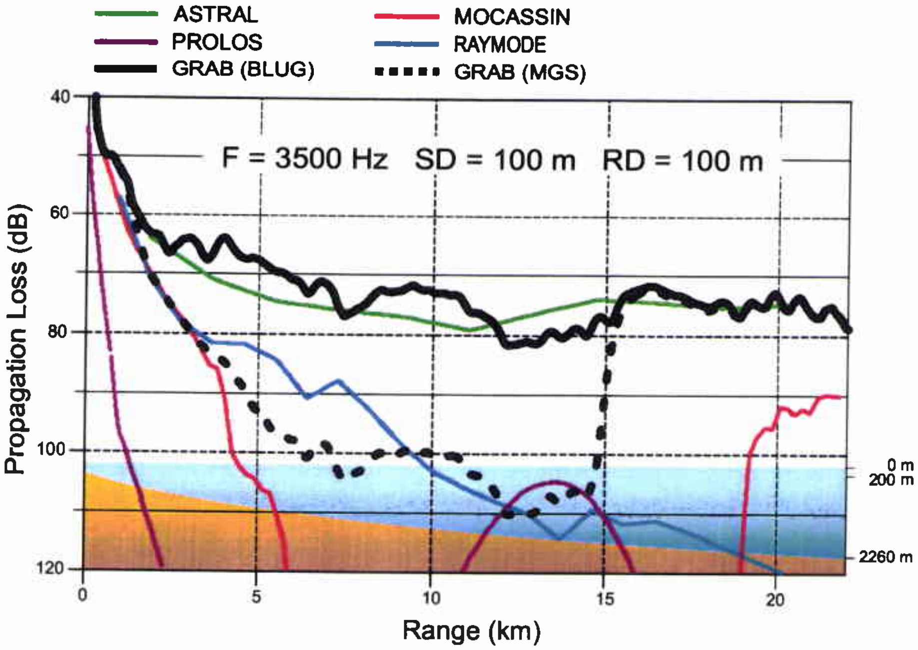

Figure 21 *Track A – downslope: Model predictions at 3500 Hz for source at 100 m and receiver at 100 m.*

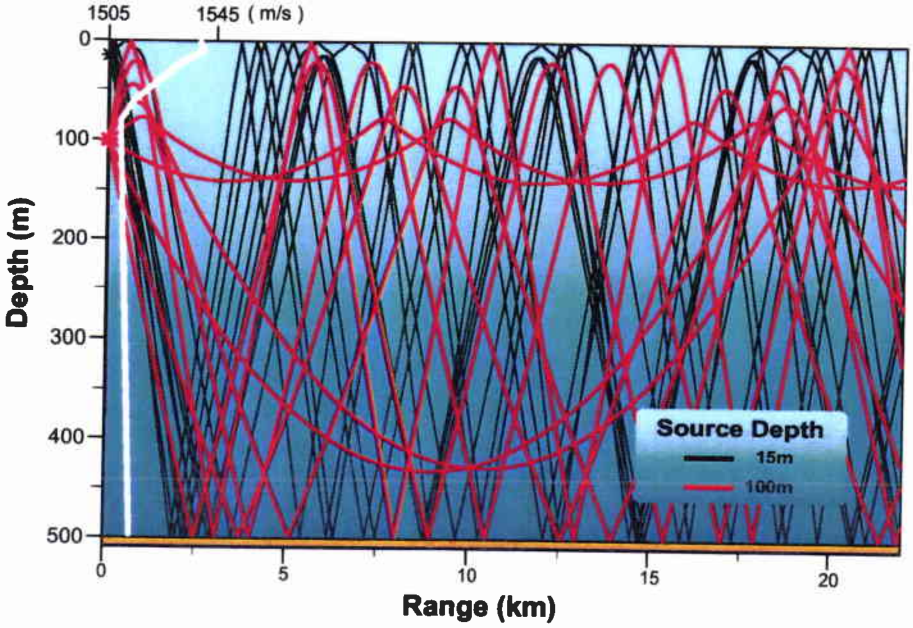

Figure 22 *Track B – flat: Ray diagrams for two different source depths.*

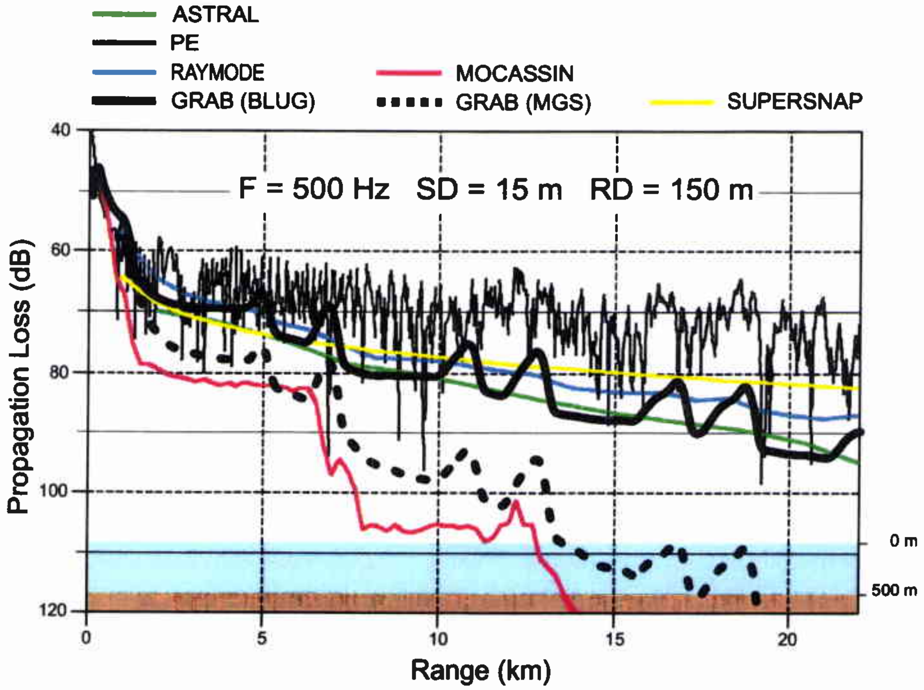

Figure 23 *Track B – flat: Model predictions at 500 Hz for source at 15 m and receiver at 150 m.*

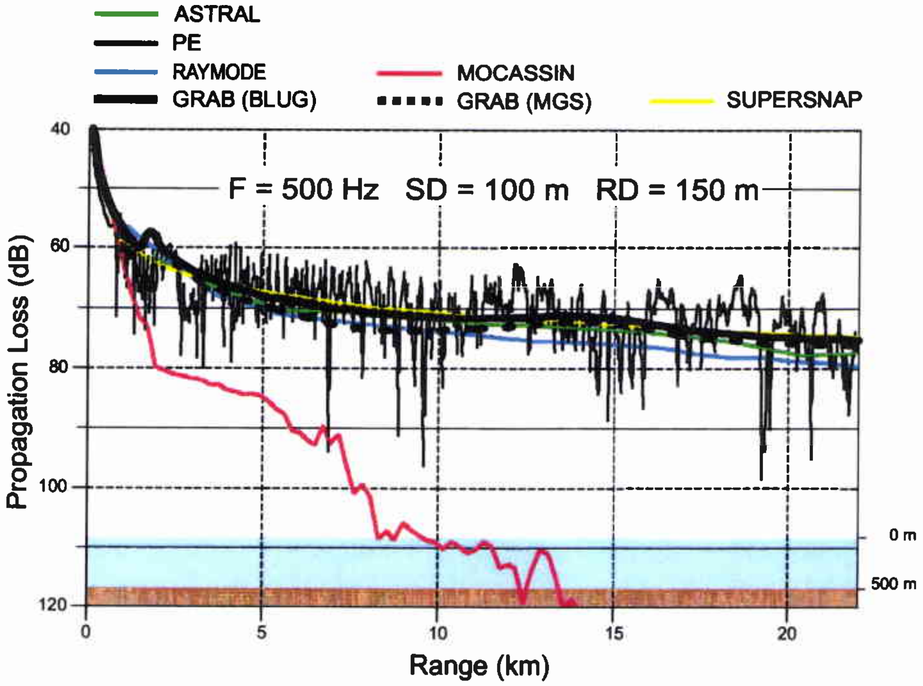

Figure 24 *Track B – flat: Model predictions at 500 Hz for source at 100 m and receiver at 150 m.*

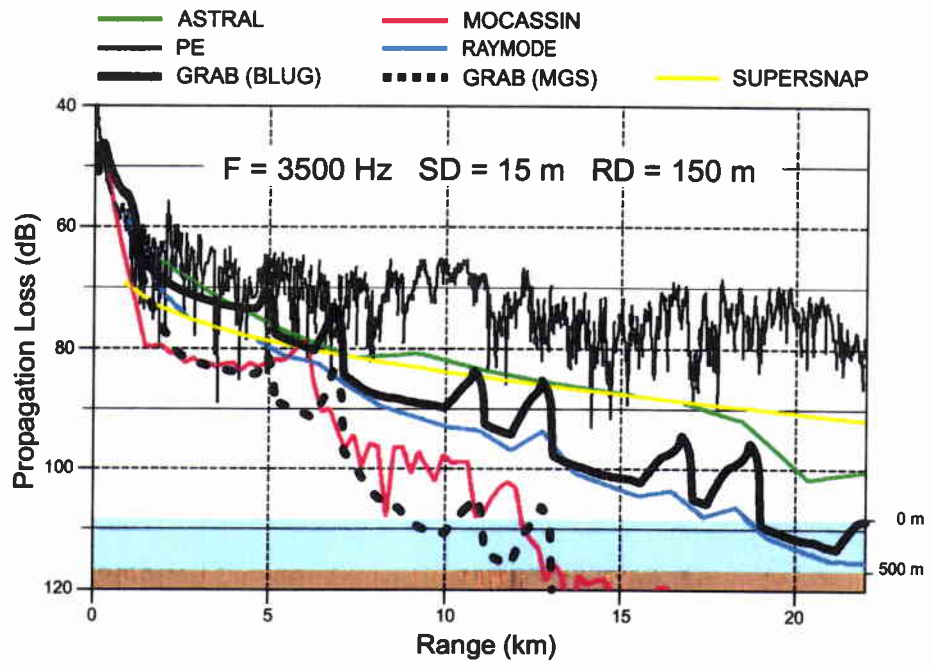

Figure 25 *Track B – flat: Model predictions at 3500 Hz for source at 15 m and receiver at 150 m.*

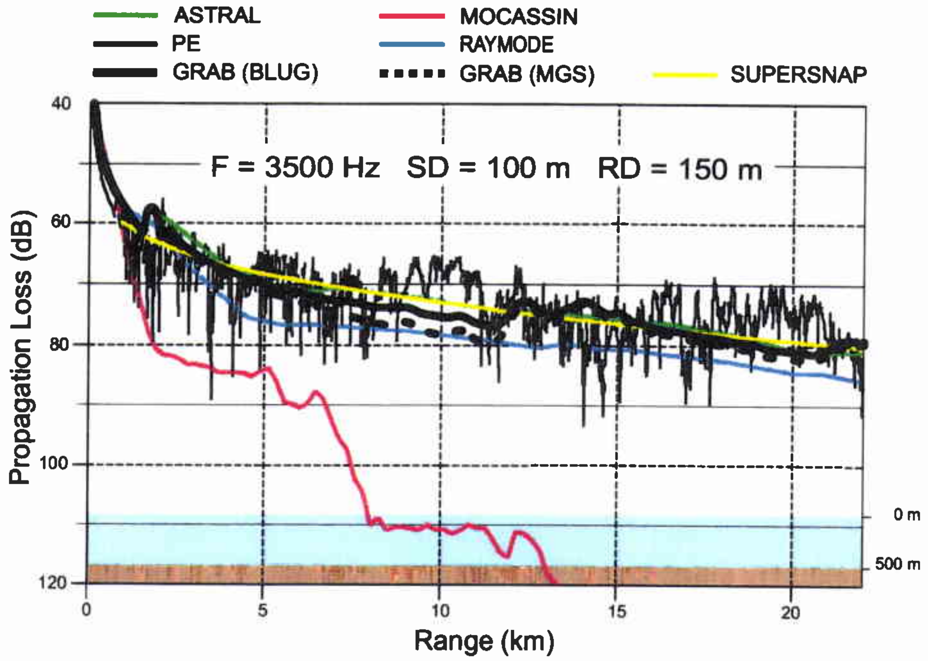

Figure 26 *Track B – flat: Model predictions at 3500 Hz for source at 100 m and receiver at 150 m.*

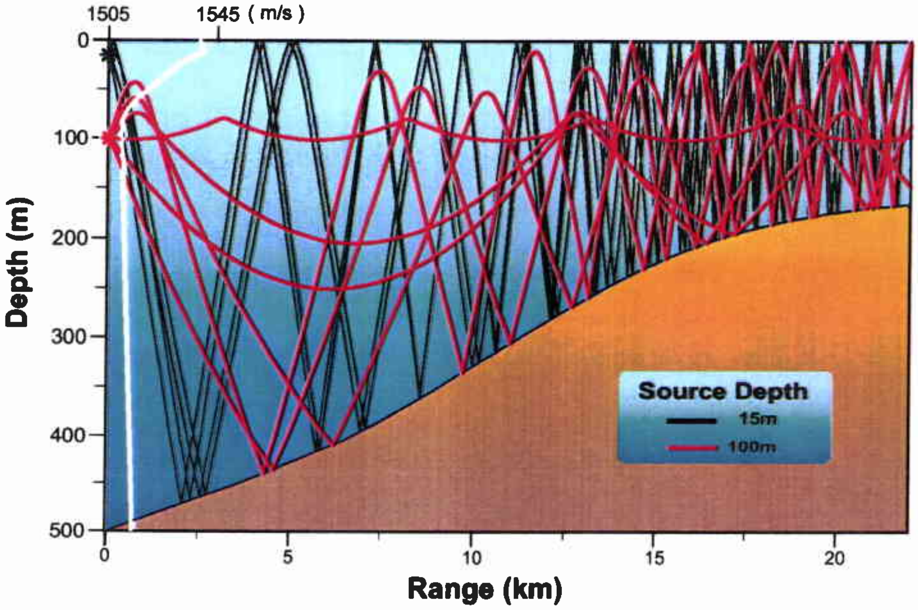

Figure 27 *Track B – upslope: Ray diagrams for two different source depths.*

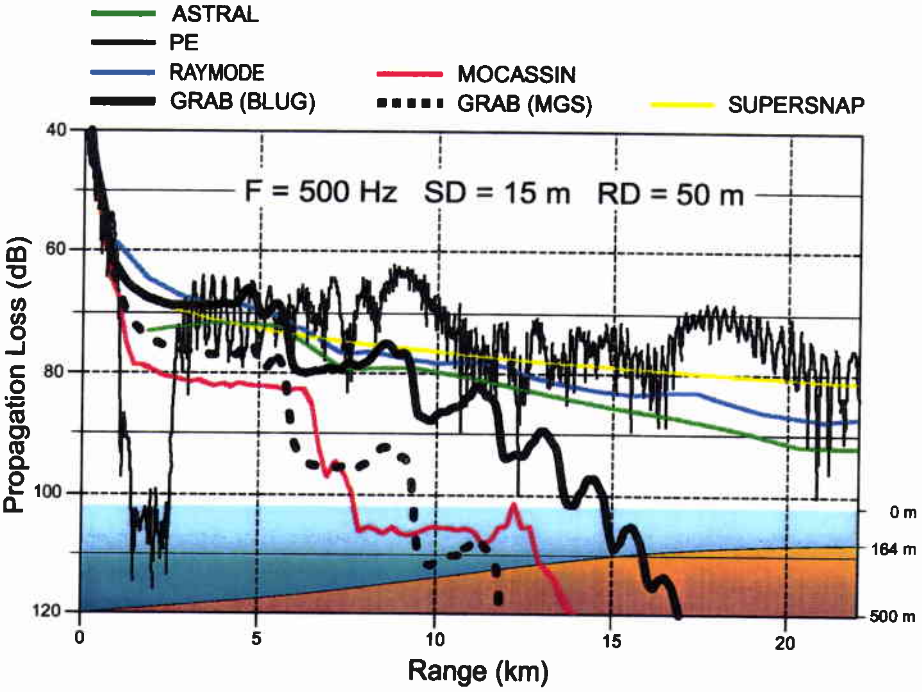

Figure 28 *Track B – upslope: Model predictions at 500 Hz for source at 15 m and receiver at 50 m.*

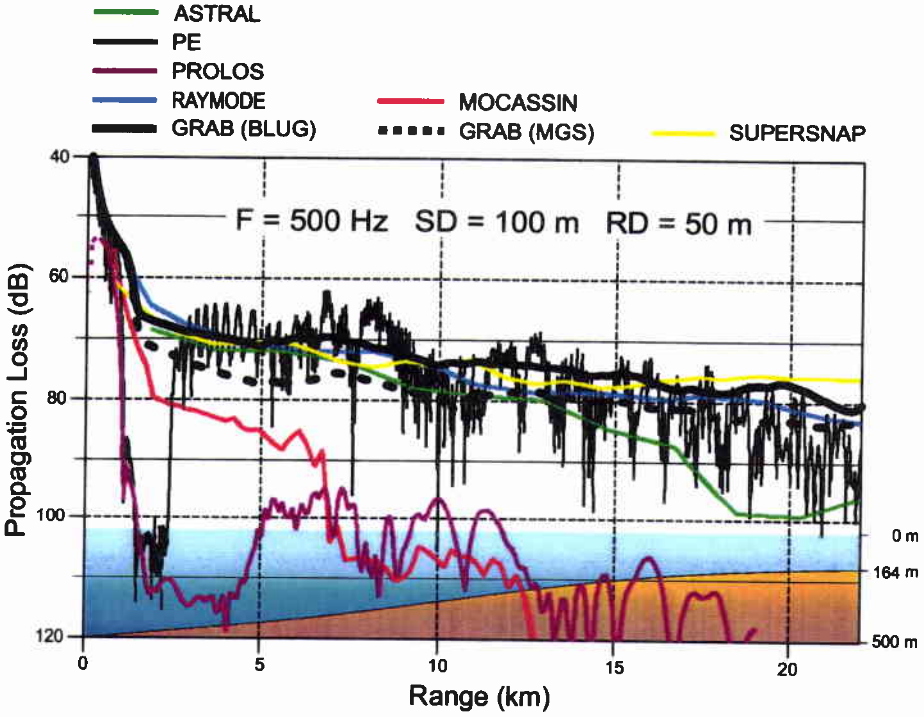

Figure 29 *Track B – upslope: Model predictions at 500 Hz for source at 100 m and receiver at 50 m.*

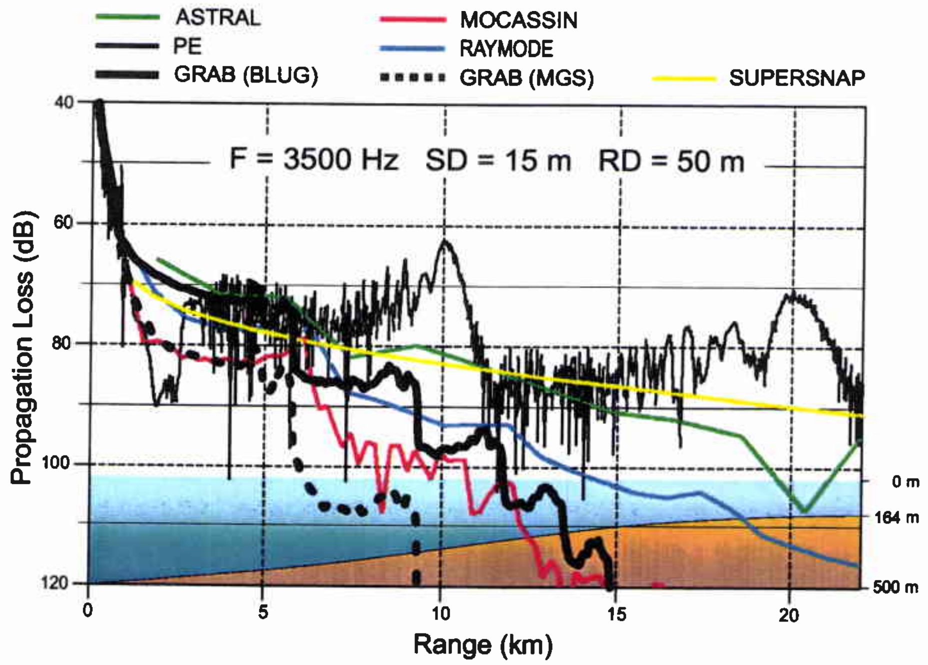

Figure 30 *Track B – upslope: Model predictions at 3500 Hz for source at 15 m and receiver at 50 m.*

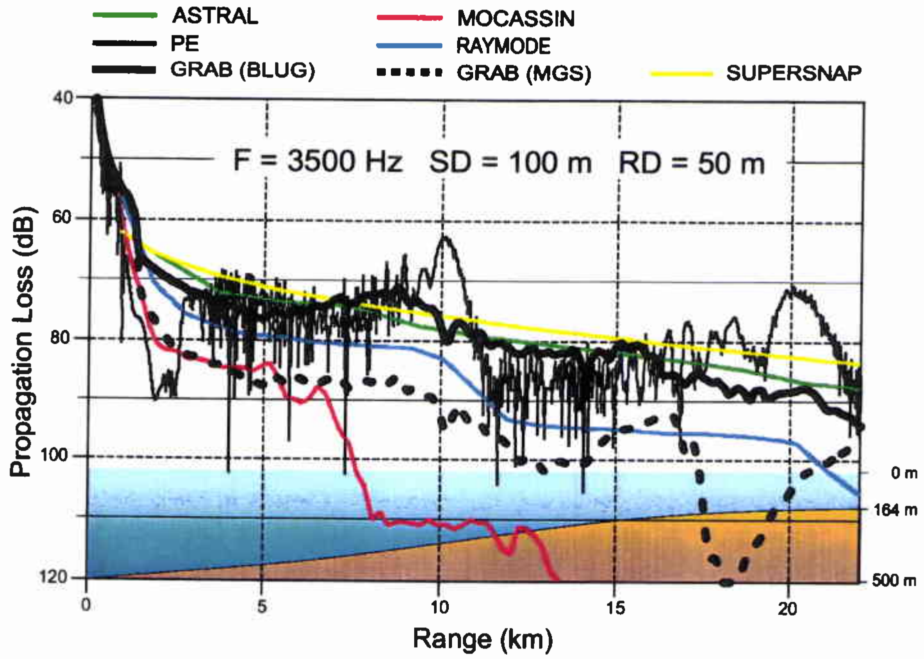

Figure 31 *Track B – upslope: Model predictions at 3500 Hz for source at 100 m and receiver at 50 m.*

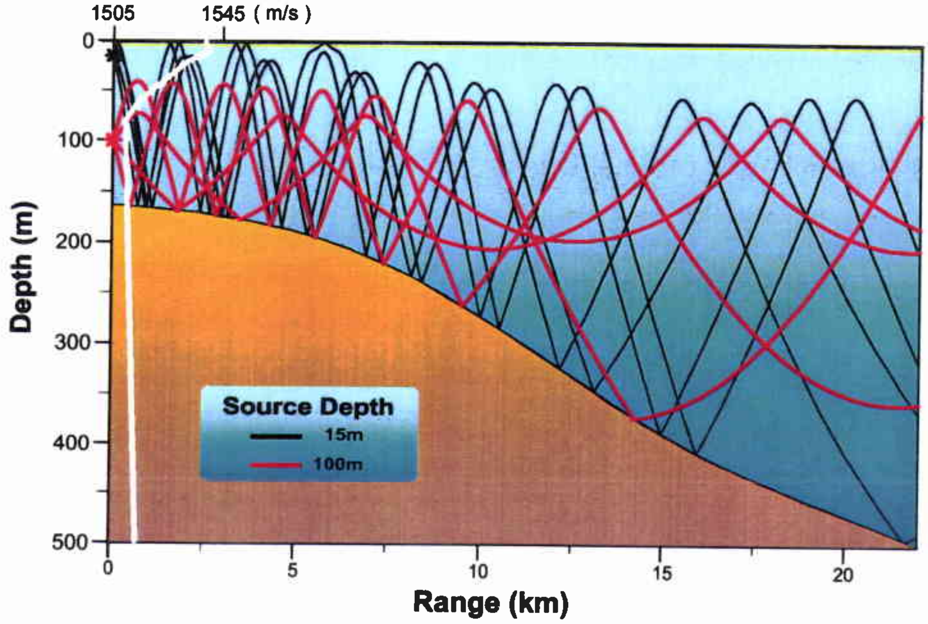

Figure 32 *Track B – downslope: Ray diagrams for two different source depths.*

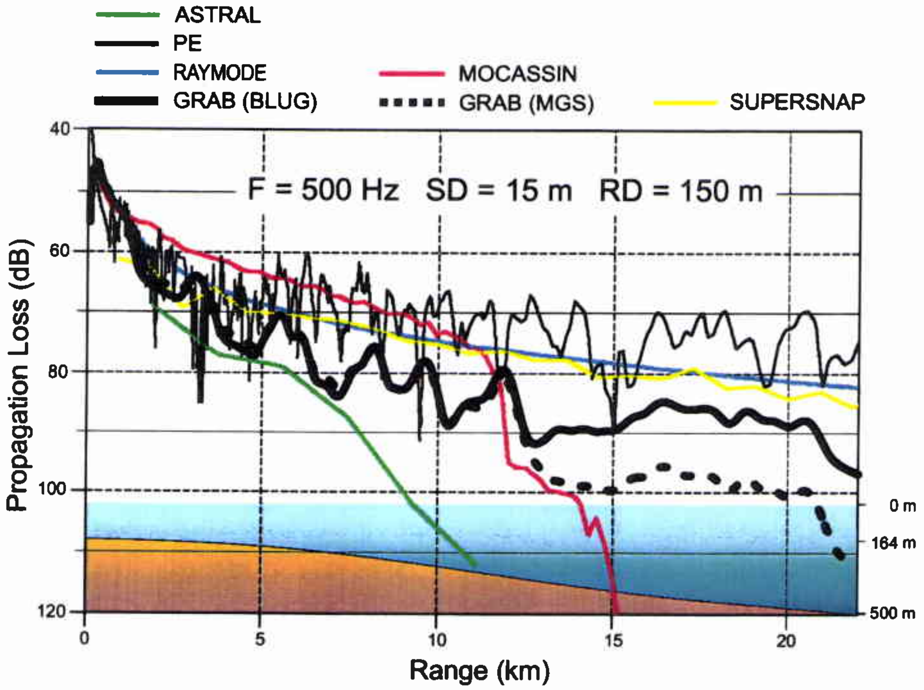

Figure 33 *Track B – downslope: Model predictions at 500 Hz for source at 15 m and receiver at 150 m.*

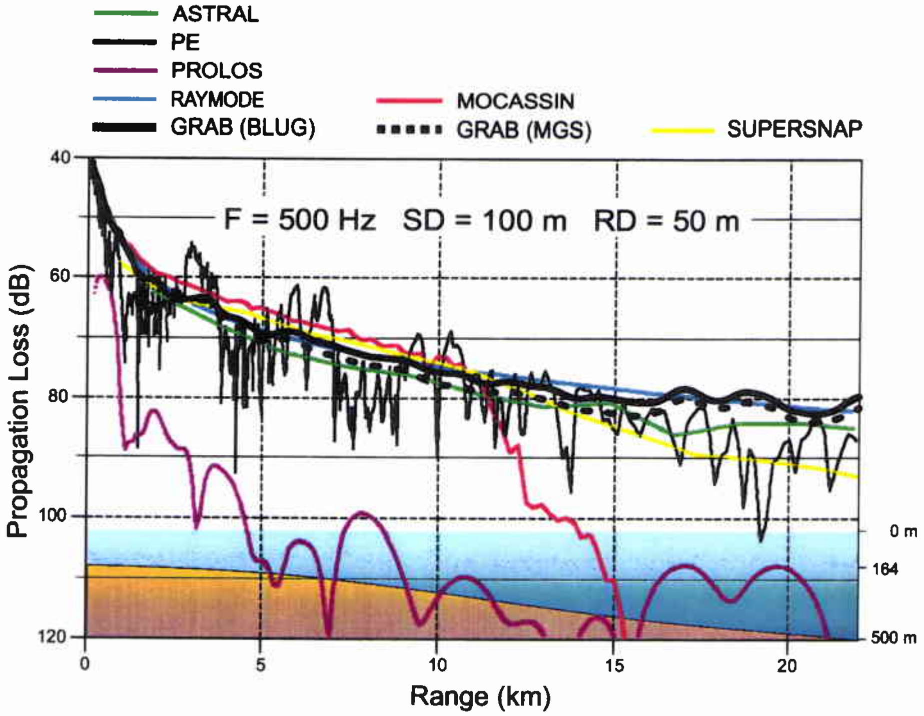

Figure 34 *Track B – downslope: Model predictions at 500 Hz for source at 100 m and receiver at 50 m.*

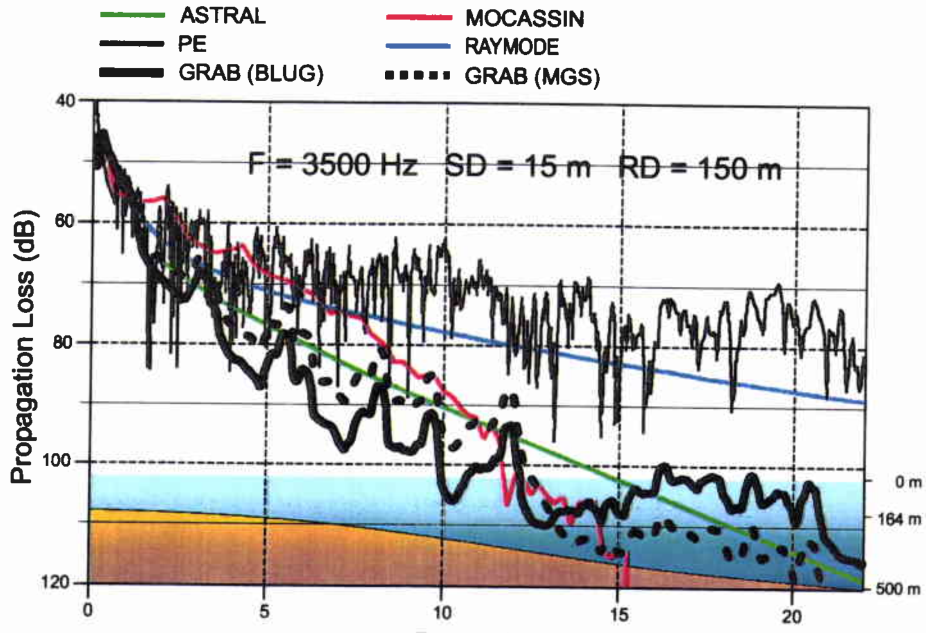

Figure 35 *Track B – downslope: Model predictions at 3500 Hz for source at 15 m and receiver at 150 m.*

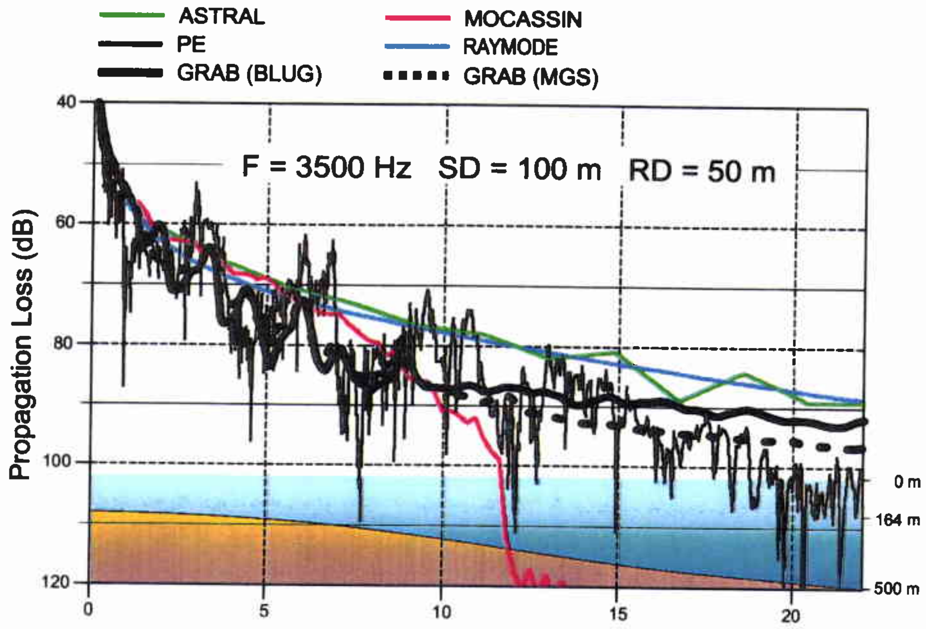

Figure 36 *Track B – downslope: Model predictions at 3500 Hz for source at 100 m and receiver at 50 m.*

Appendix

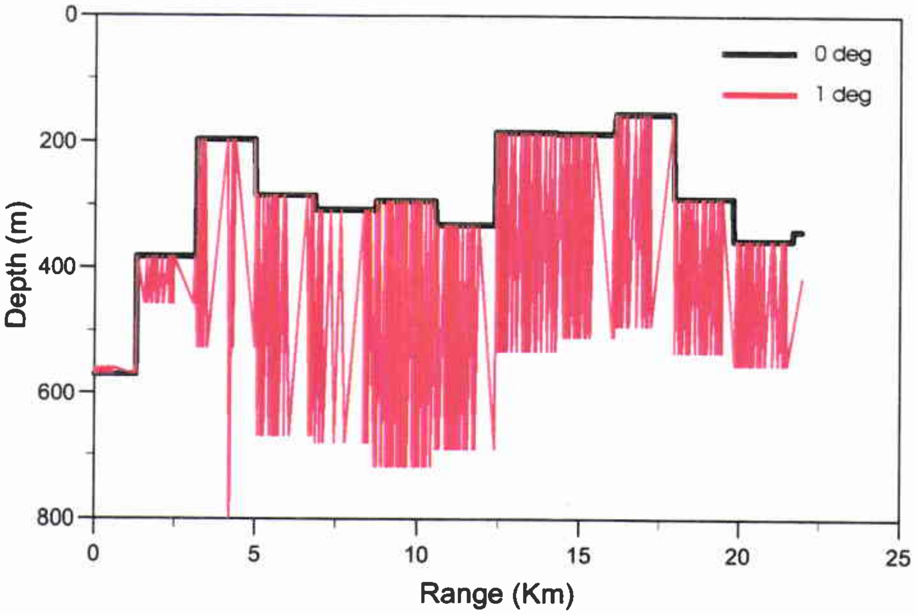

Figure A1 *Bathymetry extractions from the AESS database for two bearings in the Mediterranean starting at location 36°20.8'N, 22°79.7'E. Both the stair-step structure and the rapidly oscillating red curve are unreal and unsuited for acoustic modeling purposes.*

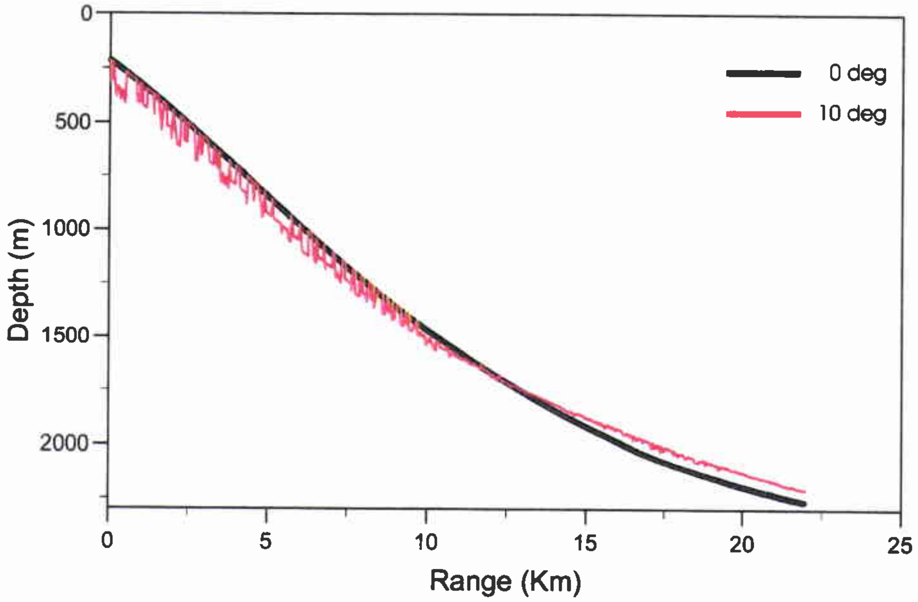

Figure A2 *Bathymetry extractions from the AESS database for two bearings in the Atlantic starting at location 32°46.5'N, 16°45.0'W. The smooth bottom profile coincides with Track A.*

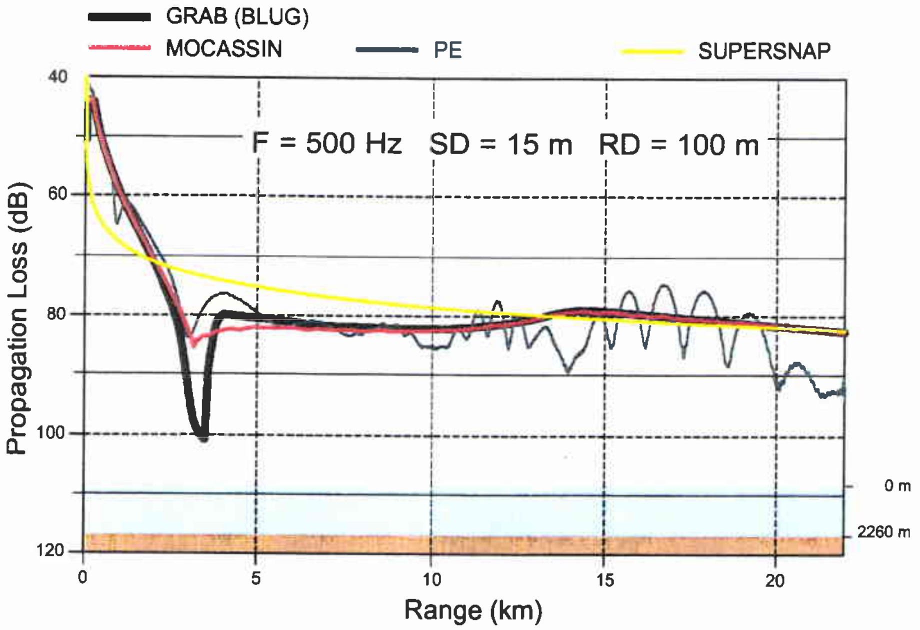

Figure A3 *Track A – flat: Inter-model comparison at 500 Hz for source at 15 m and receiver at 100 m.*

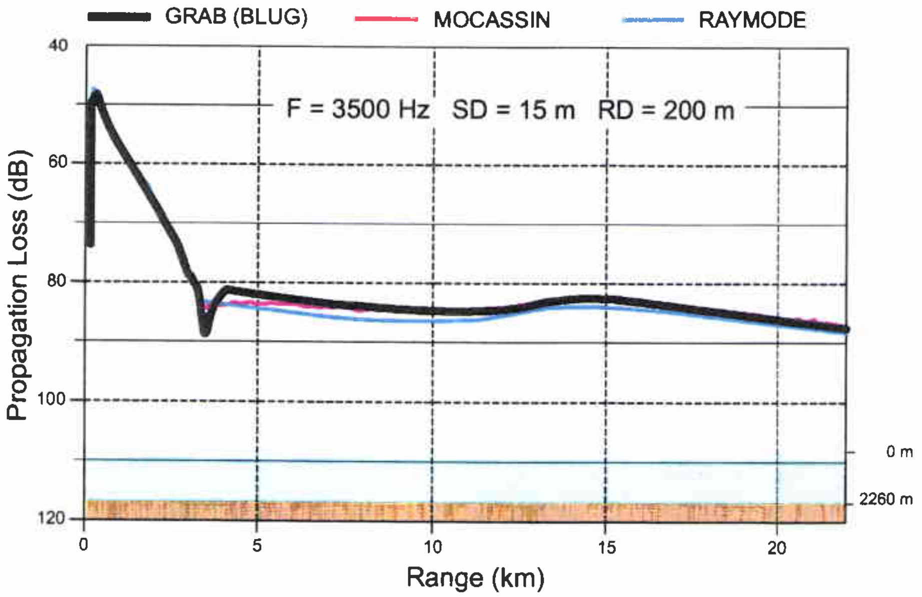

Figure A4 *Track A – flat: Inter-model comparison at 3500 Hz for source at 15 m and receiver at 200 m.*

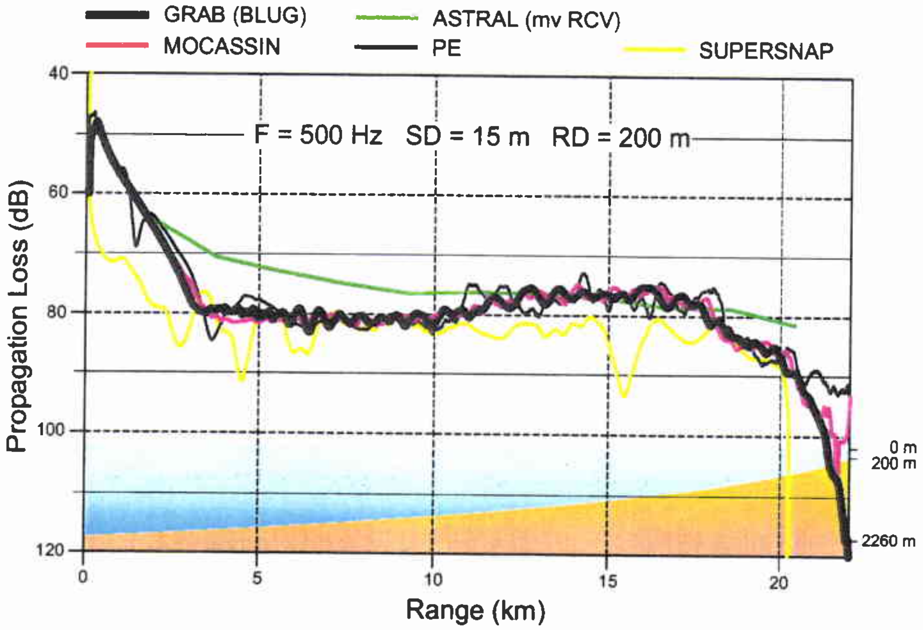

Figure A5 *Track A – upslope: Inter-model comparison at 500 Hz for source at 15 m and receiver at 200 m.*

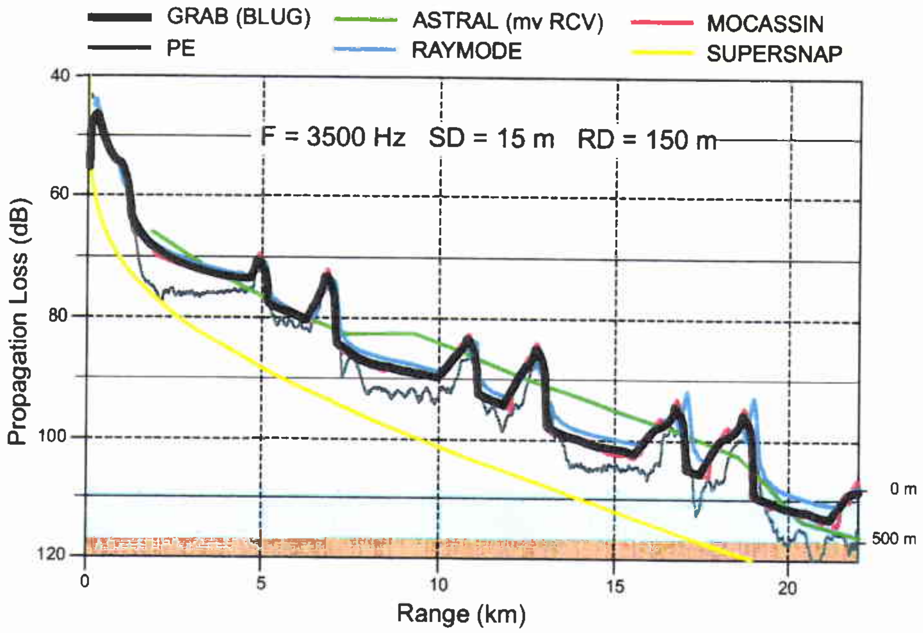

Figure A6 *Track B – flat: Inter-model comparison at 3500 Hz for source at 15 m and receiver at 150 m.*

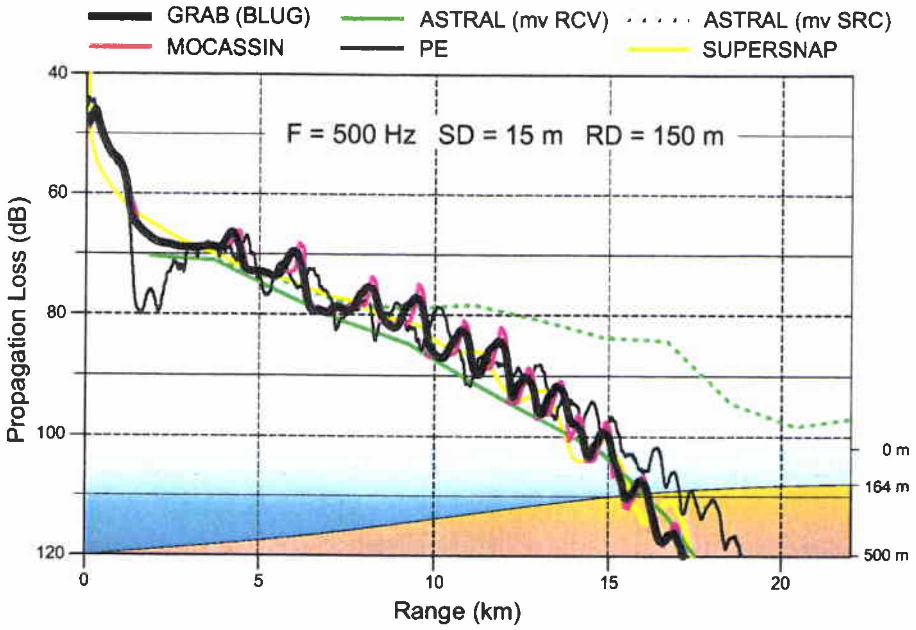

Figure A7 *Track B – upslope: Inter-model comparison at 500 Hz for source at 15 m and receiver at 150 m.*

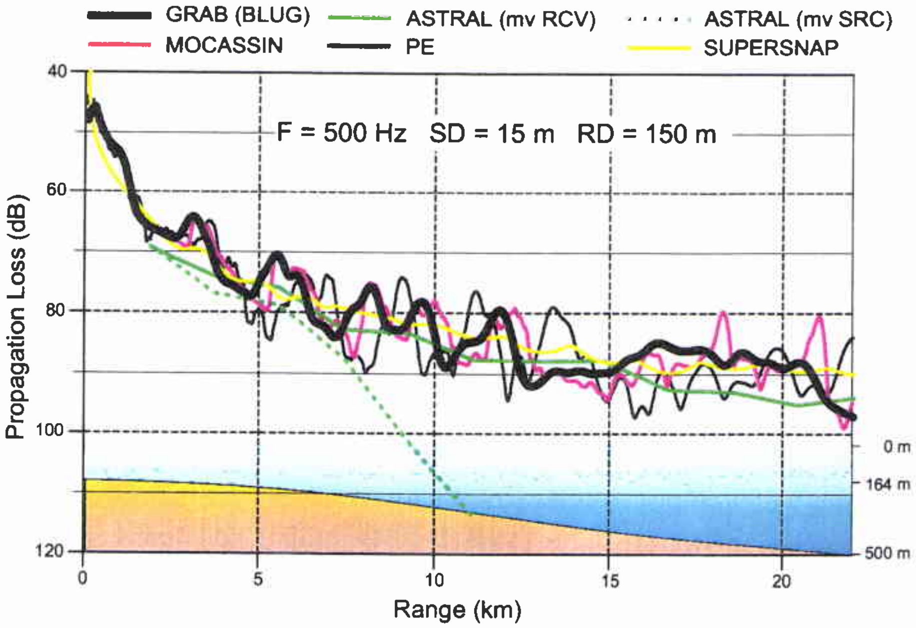

Figure A8 *Track B – downslope: Inter-model comparison at 500 Hz for source at 15 m and receiver at 150 m.*

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Title
Performance assessment of propagation models in AESS-6.0

Abstract

A set of AESS propagation loss predictions has been generated for typical operational scenarios in both deep and shallow water, for two sonar frequencies (500 and 3500 Hz) and for several source-receiver combinations. Reference solutions to all test problems were obtained with the GRAB range-dependent ray-trace model, which, in turn, has been thoroughly benchmarked against other acoustic models from the SACLANTCEN model library. The validation of the six acoustic models in the Allied Environmental Support Systems (ASTRAL, MOCASSIN, PE, PROLOS, RAYMODE, SUPERSNAP) has identified several shortcomings in the general model performance. Both implementation errors and inconsistent use of data base information are shown to be the main causes of observed prediction errors. These deficiencies, however, are all correctable through close collaboration between model developers and AESS system engineers. Detailed conclusions and recommendations are provided.

Keywords

Acoustic models - propagation loss - range dependence - sonar models

Issuing Organization

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