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RESEARCH CENTRE
MEMORANDUM**



**DEVELOPMENT OF A SACLANTCEN MCM
SONAR PERFORMANCE MODEL**

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November 1996

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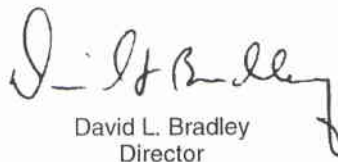
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Development of a SACLANTCEN MCM Sonar Performance Model

P. Caprais and A. Lombardi

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Development of a SACLANTCEN MCM Sonar Performance Model

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Executive Summary: Mine countermeasures performance is influenced by environmental factors such as bottom type, sea state and sound speed profile as well as target characteristics and sonar parameters. Sonar performance models have been developed which may be used operationally to give an indication of performance estimation and to optimize sonar performance according to the prevailing environmental conditions to predict mine hunting systems performance

SACLANTCEN received a copy of SEARAY, an MCM Sonar Performance Model developed at Naval Coastal Systems Center in Panama City. SEARAY is a ray tracing model which determines sound paths in a horizontally stratified water column. It computes signal-to-noise ratio along these paths and plots signal-to-noise ratio contour areas. The model is range independent, it assumes a flat bottom and a single sound speed profile.

SEARAY with additional routines was compared with other models available at SACLANTCEN developed for different applications: MOCASSIN and GSM for anti-submarine warfare and HFEAM for weapon sonars. These four models use different submodels for describing the environment: volume attenuation, surface and bottom backscattering.

The impact of environmental models on sonar system performance has been demonstrated. Modification of the sound speed profile (from isoprofile to a negative gradient profile) or of the bottom type (mud, sand, gravel or rock) causes fluctuations in sonar performance.

Ray tracing and signal-to-noise ratio computations were compared in the four models.

The same inputs gave similar results with MOCASSIN and SEARAY which are reliable, user-friendly and real-time models although GSM and HFEAM offer more options.

The MCM sonar performance model is available to interested parties for use in engineering studies comparing different sonar systems and as a performance estimator. Further work planned includes validation tests and extension of the model to include buried or partly buried mines.

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Development of a SACLANTCEN MCM Sonar Performance Model

P. Caprais and A. Lombardi

Abstract: The report describes the Mine Countermeasures Sonar Performance Model used at SACLANTCEN. This model is based on the environmental model SEARAY and uses ray tracing techniques. It determines sound paths in a horizontally stratified water column, computes signal-to-noise ratio along these paths and draws signal-to-noise contour curves. The model is range independent, and assumes a flat bottom with a single sound speed profile.

Examples of the impact of the environmental parameters on sonar performance are provided. This report includes comparisons between high frequency environmental sub-models (attenuation, bottom or surface reverberation). Comparisons, using simple examples, between SEARAY and other sonar performance models (MOCASSIN, GSM, HFEAM) are also included.

Keywords: environmental acoustic model, sonar performance model, ray tracing, bottom backscattering, model comparison, SEARAY

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1

Introduction

Mine hunting system performance is a function of environmental conditions, target parameters, and sonar parameters.

The environmental conditions include sound speed, water depth, bottom characteristics, bottom location and position, backscattering and sea state. The target parameters are: size, depth and target strength. The most important sonar parameters are frequency, beamwidth, pulse length, sonar depth, tilt angle. The sonar parameters are generally well known during a MCM mission. This is not true for the other parameters. The sound speed profile can be measured. The bottom type is often deduced from nautical charts. Target parameters are usually unknown.

Performance prediction is achieved by using ray tracing techniques and environmental sub-models which describe attenuation in the medium, propagation loss and reverberation. It is often difficult to obtain realistic input parameters for environmental models.

This report will discuss the impact and sensitivity of the environmental, target and sonar parameters and the effects of individual models on system performance compared with SEARAY, a mine countermeasures sonar performance model developed at Naval Coastal Systems Center, Panama City. SEARAY is a ray tracing model which determines sound paths in a horizontally stratified water column. It computes signal-to-noise ratio and draws contour areas. The model is range-independent, assumes a flat bottom and a single sound velocity profile.

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MCM sonar performance models

2.1. SONAR PERFORMANCE MODELS

There are two types of MCM Sonar Performance Model: the environmental type and the mission assessment/mission planning type. The first type of model predicts detection ranges as a function of environmental and sonar parameters. These models enable the user to study the impact of the environment on the performance of an MCM sonar. A derivative of this model computes the best sonar depth and tilt angle for maximizing sonar performance. This option is useful for optimizing the sonar in a real environment. The second type of model is a tool for mission assessment, and planning by providing percentage clearance estimates of an area.

The different types of MCM sonars used as the basis of these models are: side scan sonars, forward looking sonars for detection and classification, hull mounted sonars or variable depth sonars. The frequencies vary from 60 kHz to 800 kHz, the ranges from 25 to 1000 m. This implies that the sub-models used for the environment and the sonars must cover this frequency band.

2.2. ENVIRONMENTAL SONAR PERFORMANCE MODELS

A number of environmental sonar performance models is in use today (Table 1). These models predict detection ranges and detection probabilities. They require sub-models for (Fig. 1). propagation loss, absorption, reverberation, noise, target strength and sonar functions. Real data may be used as input to the sub-models such as sound speed profile, wind speed, tilt angle and sonar depth.

Ray tracing techniques based on sound speed gradient are used by all these models. Signal-to-noise ratio is computed along the acoustic paths according to the following formula:

$$SNR = 10 \log \frac{Signal}{Reverberation + Noise}$$

where :

Signal represents the echo from the target, Reverberation corresponds to volume (VOLR), surface (SURR) and bottom (BOTR) reverberations. Noise is contributed by ambient noise (AMBN), flow noise (FLWN) and system noise or receiver noise (RECN) as displayed in the typical scenario of Fig. 2.

Noise is assumed to be omnidirectional and independent of the projector. Conversely, reverberation comes from the volume insonified by the sonar emission and is proportional to the source level or transmitted power. Figure 3 illustrates both the geometry and the mathematical formulation. Reverberation and signal have the same origin. The sonar emission propagates in the medium then is backscattered by the environment or the target before propagating back to the receiver as emphasized by the signal-flow diagram of Fig. 4.

2.3. MISSION ASSESSMENT/ MISSION PLANNING MODELS

The second type of model is a tool for mission assessment or mission planning. It deals with the detection probability and percentage clearance of an area. For a specific MCM mission, this model will compute these quantities, usually with a relatively straightforward methodology that is illustrated in Fig. 5.

- A = detection width,
- B = detection probability,
- $W = A \cdot B$ = Aggregate detection width

From these characteristics a mission planning tool can compute the track spacing, the number of tracks and the ship speed that are required.

2.4. NATO MCM SONAR PERFORMANCE MODELS

2.4.1. SEARAY

SEARAY [1] and CASTAR [2] were developed at NCSC, Panama City. They are environmental models and use ray tracing techniques. They will be fully discussed in section 4.

2.4.2. CASSANDRA

CASSANDRA [3] is a real time performance and monitoring system. It has been developed by FIAR (Fabbrica Italiana Apparecchiatura Radioelettriche SpA). It has been designed for the SQQ14-IT installed on the Italian Mine Hunter Lerici and Gaeta classes. The principle is very similar to SEARAY and CASTAR. CASSANDRA

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is connected to a probe for recording the sound speed profile and using this input to predict during a mission the best sonar depth and tilt angle. This model uses direct path ray tracing and is range independent (Fig. 6) which is a typical sonar display. This model also provides the mission assessment parameters which are shown in Figs. 7 and 8. No information on the environmental sub-models was made available.

2.4.3. MIJAS

MIJAS [4] is a mine hunting simulation model developed by the MTG (Marinetechnik Gesellschaft) company in Germany in support of the Mine Hunter class 332 sonars and of the Submarine class 212 mine avoidance sonars. Its aim is to study the impact of environmental parameters on MCM sonar performance. MIJAS estimates results of a single mission and computes statistical characteristics over many MCM missions. Its bottom backscattering model is based on bottom type and grazing angle. Both bottom and surface backscattering models are frequency independent. Target strength is computed as a function of pulse length and target diameter. An example of a MIJAS plot is given in Fig. 9.

2.4.4. MPPS

MPPS [5] is a real time performance monitor developed by the Marconi Underwater Systems company in the UK. MPPS stands for Mine hunting Performance Prediction System and was designed for the 193 M and 2093 sonars. MPPS is connected to a sound speed probe and provides tactical recommendations including the choice of the best sonar depth and tilt angle. This model computes percentage of clearance and probability of detection as a function of range, target type and frequency.

2.4.5. HUNTOP

HUNTOP [6] was developed by TNO in Netherlands for the "tripartite" program, based on the DUBM-21 sonars shared by Belgium, France and Netherlands. The objective of HUNTOP is to assess performance for an on-going MCM operation. This model also computes A, B and W. With inputs for area size and percentage of clearance necessary, it calculates the required number of runs and track spacing. HUNTOP was designed as a planning and post-planning analysis tool, not as a real time sonar performance model.

The MCM Sonar Performance Models, available for use in NATO, use direct path ray tracing and are range independent. Table 1 summarizes the model characteristics. Three of the models can use real time SVP measurements: CASTAR, CASSANDRA and MPPS. SACLANTCEN received copies of SEARAY and CASTAR from NCSC and these models were the starting point for this work.

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2.5. ENVIRONMENTAL PARAMETERS

In Sonar Performance Models several environmental sub-models are used for simulating physical phenomena. These sub-models require input parameters for describing the environment. They are summarized below:

- sound propagation (depth, temperature, salinity),
- bottom parameters (depth, bottom type, grain size, porosity),
- surface parameters (sea state, wind speed),
- ambient noise,
- target parameters (type of mine, size, target strength, percentage of burial).

2.6. SONAR PARAMETERS

The main sonar parameters used to calculate performance are:

Technical (sonar) parameters:

- frequency, bandwidth,
- source level, pulse length,
- projector and vertical beam patterns and apertures,
- system noise,
- processing gain,
- receiver operating characteristic curves.

Operational parameters:

- sonar depth,
- tilt angle,
- ship speed.

3

Environmental sub-models

This chapter presents the different environmental sub-models used in the following Sonar Performance Models: MOCASSIN [7], GSM [8], HFEAM [9] and SEARAY. These Sonar Performance Models are discussed in Sections 4 and 5. Table 2 displays the bases for corresponding environmental sub-models.

3.1. VOLUME ATTENUATION - ABSORPTION

The different models used for volume attenuation are:

- Marsh-Schulkin [10],
- François-Garrison [11],
- Thorp [12].

3.1.1. Marsh-Schulkin Model

The Marsh-Schulkin model was developed from sea measurements in the frequency range 2-25 kHz. The model used in SEARAY was modified to fit other data at higher frequencies. This model takes into account the contribution of magnesium sulfate, effects of shear, volume viscosity and pressure dependence.

3.1.2. François-Garrison Model

For the François-Garrison model the absorption coefficient is computed by adding the contribution of boric acid, magnesium sulfate and pure water. The model has a dependency on pH, temperature, salinity, depth and frequency. This model comes from measurements in the high frequency range 10 to 1000 kHz. This model is used in HFEAM. In MOCASSIN a simplified version is used with a standard depth of 10 m and a pH of 8.

3.1.3. Thorp Model

The Thorp attenuation model is an empirical formula solely dependent upon frequency. No other factors are taken into consideration. This model is used in GSM.

3.1.4. Comparison

The models are compared in Figs. 10 and for an expanded frequency scale in Fig. 11. The curves represent one-way absorption in dB/kyd. The Thorp curve gives a fixed value of -40 dB for very high frequencies ($f > 300$ kHz). As this model comes from low frequency measurements it is of limited use in MCM sonar performance modelling.

The two other models agree to within a few dB difference. A more complete comparison between the Marsh-Schulkin, François-Garrison and other models is presented in [13].

For MCM detector sonars the average attenuation coefficient values are:

- 25 dB/kyd at 80 kHz,
- 35 dB/kyd at 100 kHz.

3.2. SURFACE BACKSCATTERING

3.2.1. Definition

The Surface Backscattering coefficient is the ratio between the outgoing energy scattered by the sea surface to the incoming energy for the same direction. The formula that links the surface backscattering coefficient and the received power at the transducer is (see also Fig. 3):

$$P_r = P_t \cdot G_t \cdot 10^{-\alpha r} \cdot r^{-2} \cdot [S_s \cdot r \phi_h \cdot C \tau / 2 \cos(\theta)] \cdot 10^{-\alpha r} \cdot r^{-2} \cdot G_r$$

where,

P_r :	received power	G_t :	transmission gain	G_r :	reception gain
P_t :	transmitted power	S_s :	surface backscattering / m^2		
α :	absorption coefficient	r :	range in m	τ :	pulse length
ϕ_h :	horizontal beamwidth	θ :	tilt angle		
$r \phi_h \cdot C \tau / 2 \cos(\theta)$:	A : insonified area				

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The surface backscattering coefficient is expressed in terms of a unit area. Thus, for the backscattering level the insonified area has to be taken into account. The expression is:

$$\text{SURR} = \text{SL} - 40 \log_{10}(r) - 2 \alpha r + \text{SS} + 10 \log_{10}(A),$$

where SURR = Surface Reverberation at the transducer in dB,

and SL = Source level in dB SS = Surface backscattering coefficient in dB/m²

A = insonified area in m²

At high grazing angles, close to normal incidence, the area is an ellipse defined by the range and the vertical and horizontal beam widths, respectively θ_v and ϕ_h .

$$A = r \phi_h \cdot r \theta_v$$

At medium or small grazing angles this formula which increases with distance squared gives large values for A. The area is then limited by the pulse length. The insonified area has to be computed as the minimum of the two previous expressions:

$$A = \min (r \phi_h \cdot C \tau / (2 \cos(\theta)) , r \phi_h r \theta_v)$$

The limiting grazing angle for the computation of the area is:

$$\cos(\theta) = C \tau / (2 \cdot r \theta_v)$$

The different models used for the surface backscattering coefficient SS are:

- Chapman-Harris [14],
- Urlick-Hoover [15],
- APL-84 [16].

3.2.2. Chapman-Harris Model

The Chapman-Harris model is derived from measurements in the frequency range 400 Hz to 6.4 kHz. It is a function of wind speed, grazing angle and frequency. The model implemented in SEARAY has been modified to fit other data at higher frequencies. Wind speed below 1 kn produces unreliable results at low grazing angles. MOCASSIN uses the same formula with grazing angles set to a minimum level of 2°. Figures. 12 and 13 show the effect of wind speed on surface reverberation from 1 to 5 knots and from 5 to 20 kn. MOCASSIN also has a separate empirical formula for bubbles, 1 m below the surface.

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3.2.3. *Urlick-Hoover Model*

The Urlick-Hoover model was developed from data measured at 60 kHz. This formula is independent of frequency and is based on wind speed and grazing angles. At low grazing angles $<30^\circ$, Urlick attributed scattering to a bubble layer just below the sea surface (Fig. 14).

3.2.4. *APL-84 Model*

The APL-84 model is an adaptation of the Urlick-Hoover model (Fig. 15).

3.2.5. *Comparison*

These models are compared at wind speeds of 5 kn and 20 kn in Figs. 16 and 17. At 5 kn the models do not agree. For a wind speed of 20 kn the models are much closer and certainly more consistent

These models have limitations. The effects of rain, and other effects on impedance variation have not been taken into account.

3.3. *BOTTOM BACKSCATTERING*

3.3.1. *Definition*

Sonar performance is very sensitive to this parameter. The equations for computing surface backscattering are also valid for the bottom backscattering coefficient defined in dB/m^2 . (Fig. 3).

$$\text{BOTR} = \text{SL} - 40 \log_{10}(r) - 2 \alpha r + \text{BS} + 10 \log_{10}(A),$$

where

BOTR = Bottom Reverberation at the transducer in dB,

and

SL = Source level in dB BS = bottom backscattering coefficient in dB/m^2

A = insonified area in m^2

The different models commonly used for bottom backscattering coefficient BS are:

- McKinney-Anderson [17],

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- Lambert's law [18],
- GESMA [19],
- APL-UW [9].

3.3.2. McKinney-Anderson Model

The McKinney-Anderson model was developed from data taken in shallow water at a frequency range of 12 to 290 kHz. Backscattering is a function of bottom type, grazing angle and frequency. The bottom type is divided into four classes 1 for mud, 2 for sand, 3 for gravel, 4 for rock. The bottom type can be any real number between 1 and 4 (1.5 for mud and sand for instance), (Fig. 18).

$$BS = 10 \log (2.53 \cdot C \cdot f^{3.2 - 0.8m} \cdot 10^{2.8m - 12 + 10^{-4.5}})$$

$$\text{where } C = B (\sin(\theta + 0.19))^D$$

$$B = 1 + 125 e^A$$

$$D = m (\cos(\theta))^{16}$$

$$A = -2.64 (m - 1.75)^2 - (50/(m \cdot \tan^2 \theta))$$

$$f = \text{frequency in kHz}$$

$$\theta = \text{grazing angle in radians}$$

$$m = \text{bottom type : 1 for mud, 2 for sand, 3 for gravel, 4 for rock}$$

3.3.3. Lambert's law

Lambert's law computes backscattering as a function of bottom type and grazing angle and is frequency independent (Fig. 19).

$$BS = \mu_0 + 20 \log(\sin(\theta))$$

$$\theta = \text{grazing angle in radians}$$

$$\mu_0 = -29 \text{ for mud} \quad \mu_0 = -22 \text{ for sand}$$

$$\mu_0 = -15 \text{ for gravel and rock.}$$

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3.3.4. GESMA Model

The GESMA model is also based on bottom type, grazing angle and is frequency independent. This model is a synthesis of high frequency models (Fig. 20).

$$BS = \alpha + \beta \log(\theta)$$

θ = grazing angle in degrees

$$\alpha = -60 \quad \beta = 13 \text{ for mud} \quad \alpha = -67 \quad \beta = 28 \text{ for fine sand}$$

$$\alpha = -47 \quad \beta = 21 \text{ for sand} \quad \alpha = -37 \quad \beta = 21 \text{ for gravel}$$

$$\alpha = -16 \quad \beta = 7 \text{ for rock}$$

3.3.5. APL-UW Model

The APL-UW model is based on seafloor sediment grain size and porosity. It is also grazing angle and frequency dependent. This model is an empirical fit to data collected at 20-80 kHz and grazing angles from 5 to 90°. The grain size is expressed in phi values:

$$\phi = -3.32 \log(d), \text{ where } d \text{ is the grain size diameter in mm.}$$

The equation for computing the bottom backscattering coefficient is more complex and is given in the HFEAM manual [9]. Figure 21 shows an example calculation corresponding to medium sand, mean grain size equal to 0.4 mm and 50% porosity.

3.3.6. Comparison

Figures 22 to 25 compare the 4 previous different models for the 4 bottom types for grazing angles from 0 to 90° at 80 kHz. At 80 kHz the wavelength is 18 mm. For mud, mean grain size of 0.01 mm corresponding to fine silt, the backscattering fluctuates from -60 dB at 2° to -30 dB at normal incidence. The variation is from 5 to 10 dB between models.

For fine sand, mean grain size of 0.2 mm, the backscattering fluctuates from -50 dB at 2° to -15, -20 dB at normal incidence. The variation is again around 10 dB. We can notice that at 20°, 3 models (McKinney-Anderson, Gesma and Lambert) agree quite well. For mud and sand at low grazing angles (from 1 to 8°), it seems that the McKinney-Anderson model predicts higher backscattering values. This could be due to multipath interference in the original data.

For gravel, mean grain size of 3 mm, the backscattering fluctuates from -40 dB at 2°, to -15 dB at normal incidence. The GESMA model gives much more backscattering than the others.

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For rock the backscattering fluctuates from - 40, - 30 dB at 2^0 to -15, -5 dB at normal incidence. The variation is quite high with 20 dB difference according to the model.

These models also have limitations. They assume the bottom to be flat, with no features or slope. Mean values of bottom backscattering are computed but they do not take account or calculate statistical distribution, which is also very important.

3.4. TARGET STRENGTH

Target strength is a function of several parameters: target size, frequency, pulse length and aspect.

For a sphere, the target strength is independent of aspect and is a function of the cross-section of the sphere. For a sphere of 1 m diameter, TS = -12 dB.

$$TS = 10 \log(a^2/4) \quad a = \text{radius in m}$$

At high frequency, around 100 kHz, the ratio ka (circumference of the target to wave length) is high and the target strength is stable

$$f = 100 \text{ kHz} \quad \lambda = 1.5 \text{ cm} \quad a = 0.5 \text{ m} \quad ka = 2\pi a/\lambda = 210.$$

At lower frequencies (10 to 50 kHz) and for a smaller target this ratio is much reduced with $ka < 1$.

for $a = 0.1 \text{ m}$

$$TS \approx f = 1 \text{ kHz} \quad \lambda = 1.5 \text{ m} \quad ka = 0.4 \rightarrow -55 \text{ dB}$$

Target strength is also a function of pulse length. It increases until the pulse length is long enough to insonify the whole target. This occurs for a pulse length equal to : $\tau_0 = 2l/c$

where l is the target length, c is the sound speed (assumed to be 1500 m/s).

For the use of pulse lengths longer than τ_0 the echo level from the target will be the same. However, the bottom or surface backscattering will still increase.

For non-spherical objects, target strength is also a function of aspect. It reaches high values when the beam is normal to the axis of the cylinder and can be expressed as:

$$TS = 10 \log(aL^2/2\lambda) \quad \text{where } a = \text{radius of cylinder}$$

$$L = \text{length of cylinder} \quad \lambda = \text{wave length}$$

For an angle of incidence of θ with normal incidence the formulation is [20] :

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$$TS = 10 \log (aL^2/2 \lambda (\sin \beta / \beta)^2 \cos^2 \theta) \quad k=2 \pi / \lambda \quad \beta = k L \sin \theta$$

3.5. RAY TRACING

Ray tracing is based on the change of sound speed with depth, temperature and salinity. The models generally use sound speed profiles stratified in horizontal layers. Each layer is assumed to have a constant sound speed gradient. The sound path shape depends on the sound speed gradient in the layers. If the gradient is null the ray will propagate in a straight line. If the gradient is linear the path will be an arc of a circle the radius of which is a function of that gradient. An example is shown in Fig. 26.

4

Searay

4.1. SEARAY AT SACLANTCEN

SEARAY is an environmental sonar performance model. It models the acoustic environment, uses ray tracing techniques based on SVP gradient in a horizontally stratified water column, determines the sound paths and computes the signal-to-noise ratio along these paths. This model uses direct paths, assumes a flat homogeneous bottom and a single sound speed profile.

SEARAY was originally developed at NCSC Panama City. A new version has been developed at SACLANTCEN [21]. The modifications implemented in the new version are:

- friendly user interface,
- use of ASCII files for the input files,
- saves CPU time by canceling repetitive computations,
- introduction of new environmental sub-models,
- storage of output data in an ASCII file,
- introduction of new plots (signal, reverberation and noise levels),
- computation of the best sonar settings (sonar depth and tilt angle).

SEARAY uses one file for the sound speed profile and a second file for the environmental and sonar parameters. A third file may be used for the bottom backscattering coefficients, bottom type function and grazing angles.

If we now select one environmental acoustic scenario of models studied in Sect. 3 from the possibilities below:

- Marsh-Schulkin, François-Garrison for absorption,
- Chapman-Harris, Urlick-Hoover, APL-84 for surface backscattering,
- McKinney-Anderson, Lambert's law, GESMA, APL-UW for bottom backscattering.

The signal-to-noise ratio is then computed for each angle and for each range increment. The computation process is summarized in Fig. 27.

The different graphical outputs available from SEARAY are:

- ray tracing,
- signal-to-noise ratio contours,
- signal/reverberation/noise as a function of range.

4.2. EXAMPLES OF SEARAY

Examples of SEARAY results are shown in Figs. 28 to 32. The models used are those used in the original version of SEARAY: Marsh-Schulkin for absorption, Chapman-Harris for surface reverberation and McKinney-Anderson for bottom reverberation. The SVP file corresponds to a negative gradient from 1531.9 m/s at 0 m to 1507.5 m/s at 50 m. The main sonar and environmental parameters are given below.

The 80 kHz detector sonar is set at a tilt angle of -1° at 22 m. The target strength has been set to -20 dB as an average target strength value for a mine. The bottom type is mud.

Figure 28 shows the ray tracing. The rays are arbitrarily stopped at a signal to noise level of 6 dB. The rays are curved downward due to the negative sound speed gradient. The vertical beam width is 10° , the angle increment is 0.5° . We can also notice the vertical side lobes.

Figure 29 shows the contour areas for signal to noise ratio of 6, 9 and 12 dB. These values correspond approximately to the levels for target detection by operators. The corresponding ranges are 580, 550 and 450 m. The use of 3 SNR contours gives an indication of the variation of the detection ranges.

Figure 30 shows the evolution of signal level from the target (SIGN), the total noise (TOTN, addition of reverberation and noise) and the signal-to-noise ratio (SNR, difference between signal and total noise).

A more detailed plot of the SNR curve between -10 and 30 dB is plotted on figure 31. The SNR is stable around 9 dB for ranges from 300 to 500 m, at which point it decreases rapidly.

Figure 32 shows the different components of the total noise; first the volume reverberation (VOLN) before the rays hit the bottom, then the bottom reverberation (BOTN) up to 500 m and finally the receiver or system noise (RECN). After 600 m the receiver noise is dominant. As the receiver noise is constant the SNR decreases after 600 m.

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4.3. INFLUENCE OF THE ENVIRONMENTAL PARAMETERS

In this section we will describe the impact of the environmental parameters (sound speed profile, bottom type, target strength) on sonar performance. The environmental parameters used are those from the previous example.

4.3.1. Sound Speed Profile

Figure 33 corresponds to the same sonar and environmental parameters except that the sound speed profile has been set to an isoprofile at 1510 m/s. The sound speed gradient being null, the rays propagate as a straight line. The contour radius for a signal-to-noise ratio of 9 dB is 550 m as for the reference example (Fig. 34).

4.3.2. Bottom Type

Bottom backscattering increases according to bottom type with a corresponding decrease in signal-to-noise ratio according to bottom type. For anSVP with a negative gradient, the impact is quite pronounced.

For a signal-to-noise ratio of 9 dB, the detection range decreases to 300 m for sand, 200 m for gravel and 150 m for rock (Figs. 35 to 37). Bottom type is clearly a major parameter in the performance model.

4.3.3. Target Strength

For a spherical target of 1 m diameter (TS = -12 dB) representing a moored mine, and a cylinder detected in a non favorable aspect ($\theta=40-50$ degrees, TS = -27 dB) representing a mine laid on the bottom were detected at 650m and 250m respectively (Fig. 38 and 39) for a 9 dB SNR demonstrating that large variation in detection range are attributable to target type.

4.4. INFLUENCE OF ENVIRONMENTAL SUB-MODELS

The different Sonar Performance Models GSM, HFEAM, MOCASSIN and SEARAY use different sub-models for describing the environment. These sub-models have been compared in Sect. 3. This section will study the influence of the different sub-models used to describe the same environment.

4.4.1. Absorption Models

The François-Garrison model has been used for absorption (Fig. 40). At 80 kHz the absorption is approximately -25 dB/kyd for François-Garrison, and -23 dB/kyd for Marsh-Schulkin, a 2 dB difference between the models. As detection by operators

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generally occurs from 300 to 700 m, the difference for absorption is approximately 1 dB.

As the reference example is noise limited, the total noise level (noise plus reverberation) is not affected by the choice of the model. Absorption impacts the signal and the signal-to-noise ratio, when the detection range is more than 520 m.

Thus, the choice of absorption model has little impact on sonar performance prediction.

4.4.2. Bottom Backscattering Models

The bottom backscattering comparison is for a sandy bottom.

The detection ranges at 9 dB SNR for the 4 different models are:

- GESMA model (Fig. 41), 500 m
- Lambert's law (Fig. 42), 450 m
- McKinney-Anderson model (Fig. 35), 300 m.
- APL-UW model (Fig. 43), 200 m.

The graphs correspond to an initial tilt angle of -1° . As the rays are curved downward, the angles of arrival at the sea floor are $5-10^\circ$. In Fig. 23 at 10° the bottom backscattering coefficients and their corresponding models are:

- GESMA model, -39 dB.
- Lambert's Law, -37 dB.
- McKinney-Anderson model, -36 dB.
- APL-UW -30 dB.

The previous detection ranges are in agreement with the order of decreasing bottom backscattering coefficients. The shorter range is obtained for maximum backscattering. The deviation of 10 dB between the models gives a difference of 300 m for the detection range.

4.5. INFLUENCE OF SONAR PARAMETERS

A sonar performance model enables also the user to modify the sonar parameters and study their influence on the performance of the system. It is also helpful for designing new sonar systems.

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4.5.1. Frequency

An example of classification sonar is shown in Fig. 44. The frequency is set at 350 kHz, the horizontal receiver beam width to 0.35° , the pulse length to 0.1 ms. The different contour areas give classification ranges between 180 and 220 m.

4.5.2. Pulse Length

As backscattering is a function of pulse length, a pulse length of 0.1 ms instead of 1 ms may decrease the backscattering by 10 dB. If we assume for example a constant target strength independent of pulse length, the signal-to-noise ratio is increased by 10 dB when bottom backscattering is greater than receiver noise.

4.6. INFLUENCE OF OPERATIONAL PARAMETERS - CASTAR

CASTAR stands for Computed Aided Sonar Tactical Recommendations. This model developed at NCSC Panama City is a derivative of SEARAY and runs in real time. It computes sonar depth and tilt angle to maximize detection range. These parameters are operational settings and have to be set prior to an MCM mission.

Figure 45 shows the effect of a strong negative sound speed gradient between 30 and 60 feet. The rays are strongly curved downward and detection range is low indicating that the sonar should be set at another depth.

CASTAR has been inserted into the SACLANTCEN version of SEARAY. Both use the same input files. The user must specify initial and final sonar depths (maximum 50 different depths) and the initial and final tilt angles (maximum 180 different tilt angles). This routine enables the user to consider bottom, moored and/or surface mines.

CASTAR produces 3 types of plots:

- detection range versus tilt angle,
- detection range versus sonar depth,
- detection range versus sonar depth and tilt angle.

Simple calculations are shown in Figs. 46 to 48. The target strength is -20 dB and the signal-to-noise ratio is set to 9 dB. The original sonar depth and tilt angle are respectively 22 m and -1 degree and the corresponding detection range is 550 m (Fig. 29).

The first plot shows that optimal tilt angles are between $+2^\circ$ and $+8^\circ$. The two curves correspond to the minimum and maximum detection for a tilt angle of -1° .

The second plot shows the detection ranges as a function of sonar depth for a tilt angle of -1° . The third plot shows the detection areas for three ranges 550, 650 and

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680. A depth of 22 m and -1° tilt, with a detection range of 550 m clearly fall well within the blue area.

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5

Comparison between several sonar performance models

In this chapter SEARAY will be compared to other Sonar Performance Models which predict detection ranges. These models originate either from anti submarine warfare: MOCASSIN and GSM, or from weapon sonars: HFEAM.

The results of other comparisons between these models are given in [22] and [23].

5.1. MOCASSIN

MOCASSIN (MOnTe CARlo Schall Strahlen INtensitäten) is a sound propagation and sonar range prediction model. It was developed at Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik (FWG) Kiel. MOCASSIN was developed for active ASW sonars operating in shallow waters.

This model allows range dependent bottom depth and bottom type. It also can deal with stochastic sound speed variability. The environmental models are François-Garrison for absorption, Chapman-Harris for surface backscattering and Lambert's law for bottom backscattering. It uses a porosity parameter establishing 9 bottom reflection loss classes. An additional bottom type gives an infinite loss bottom without reflection.

A comparative test of shallow water sound propagation models against data concludes that MOCASSIN should perform well at high frequencies [24].

5.2. GSM

GSM (Generic Sonar Model) was developed at NUWC New London. It was designed to provide sonar systems technologists with a comprehensive modelling capability for evaluating performance.

GSM is commonly used in ASW for computing signal excess for both active and passive sonars. It allows the choice of numerous acoustic environmental sub-models for absorption, backscattering and reflections. GSM is range independent and uses a single sound speed profile. This model computes multipaths and eigenrays. The user is able to compute reverberation levels, signal excess and probability of detection.

5.3. HFEAM

HFEAM (High Frequency Environmental Acoustic Model) was developed at NUWC, Newport. HFEAM is a derivative of GSM that has been extended to weapons sonars (30 kHz), which can be considered to be in the intermediate frequency ranges between anti-submarine sonars (5-10 kHz) and mine sonars (80-200 kHz).

New environmental sub-models have been implemented in HFEAM suitable for weapon frequencies. Also, contour functions have been inserted to provide propagation loss, pressure and signal excess plots *versus* range and depth.

5.4. COMPARISON MODEL (SEARAY)

The same ray tracing techniques are used as in GSM for ASW, HFEAM for weapons and SEARAY for MCM. Ray tracing is a function of sound speed Profile and is independent of frequency. It is quite easy to compare the ray path calculations, except for MOCASSIN where no ray tracing plot is provided.

The main difference between the models is in the environmental acoustic sub-models which are used. This will have impact on the energy level and signal-to-noise ratio computed for each ray. These sub-models have been validated as discussed earlier for different frequency ranges. For example, Thorp is valid for low frequency in ASW and not for MCM where François-Garrison is recommended. The models do not use the same units (of measurement SEARAY refers dB to 1 μ bar, the other models refers to 1 μ pascal. MOCASSIN uses a default pulse length of 1 ms. For these reasons, the computed levels of signal, noise and reverberation have to be corrected for comparison.

The displays generated by the models are listed in Table 3.

5.5. TEST 1 - RAY TRACING

The first test is dedicated to ray tracing comparison between SEARAY and GSM. For GSM the constant gradient ocean sound speed model has been chosen. This procedure is simple and equal to the procedure used in SEARAY. The sound speed profile selected for that test causes a propagation channel between 10 and 20 feet of water depth. No reflections were allowed for GSM. The tilt angle is set to 0°, the vertical beam width to 20° and the angle increment to 0.5°, 40 rays being computed from -10 to +10°. The bottom depth is 35 feet and ray propagation is computed <600 yards.

The ray tracings for SEARAY (Fig. 49) and GSM (Fig. 50) are identical.

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5.6. TEST 2 - SIGNAL TO NOISE RATIO

The aim of this test is to compare propagation loss, signal levels, reverberation levels, signal-to-noise ratio curves and contours computed by the different models from the same inputs.

5.6.1. Test Inputs

The test uses direct path. The sound speed profile is an isoprofile, sound speed being set at 1524 m/s from the surface to a bottom depth of 18 m.

The sonar parameters are:

- frequency 80 kHz,
- bandwidth 4 kHz,
- source level 120 dB (ref μ bar),
- pulse length 1 ms,
- horizontal beamwidth for projector 90° receiver 1.5° ,
- vertical beamwidth for projector and receiver 10° ,
- side lobes levels - 18 dB,
- receiver or system noise - 51 dB (ref μ bar),
- ship speed 2 knots,
- sonar depth 18 m,
- tilt angle 5 m.

The target parameters are:

- target depth 7 m,
- target strength -15 dB.

The environmental parameters:

- flat bottom, depth 18 m,
- bottom type mud,
- wind speed 10 knots.

The standard environmental acoustic models are:

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- François-Garrison for absorption,
- Chapman-Harris for surface backscattering,
- Lambert's law for bottom backscattering.

The François-Garrison model is available in MOCASSIN, HFEAM and SEARAY. For GSM, Fig. 11 shows that at 80 kHz the Thorp model will also give -25 dB/kyd for one-way attenuation.

The Chapman-Harris model is available in SEARAY, GSM and MOCASSIN but not in HFEAM. As this example uses direct path and the tilt angle is set to -5° , surface scattering is not a major parameter.

Lambert's law is available in SEARAY, GSM and MOCASSIN but not in HFEAM. The APL-UW model has been used for HFEAM. Figure 22 shows the deviation between the two bottom backscattering models. Specific detection models or detection thresholds are not used. Emphasis is placed on environmental parameters.

5.6.2. Transmission Loss

One-way transmission loss curves are plotted in Fig. 51. Excluding the first 200 m the results are equal for four sonar performance models. The loss is around 88 dB due to spherical spreading (60 dB for 1 km) and volume attenuation.

$$TL = \alpha \cdot r + 20 \log(r)$$

$$\text{for } r = 1000 \text{ m} \quad 20 \log(r) = 60 \text{ dB} \quad \alpha = 25 \text{ dB/kyd} = 27.5 \text{ dB/km}$$

$$\Rightarrow TL = 87.5 \text{ dB}$$

5.6.3 Signal Reverberation Noise

Figure 52 shows the echo, reverberation and noise levels for the target at 17 m depth computed by MOCASSIN. For MOCASSIN the levels given as dB re 1μ pascal. The signal (echo) level is 130 dB (solid curve) at 100 m, then decreases with range to 51 dB, horizontal dashed line at 650 m. Reverberation (R-ML) (bottom backscattering) reaches 100 dB at 100 m then decreases with range being lower than noise (N-ML) after 350 m.

Similar curves are plotted for SEARAY in Fig. 53. The intersection between the curves are at the same distances, 650 m for signal-receiver noise, 300 m for reverberation-noise. The levels are 100 dB lower due to the dB reference: 1μ bar.

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5.6.4. Signal-To-Noise Ratio Contour

The signal-to-noise ratio computed by the different models is plotted in Fig. 54. From 100 m to 400 m the signal-to-noise ratio is approximately 25-30 dB. The value of 30 dB at 100 m corresponds to the difference between the signal level 130 dB and the reverberation 100 dB. The variability between the different models is around 5 dB.

After 500 m the signal-to-noise ratio decreases linearly with distance. All the models agree and a signal-to-noise ratio of 6 dB is reached at 600 m.

The contour plots (Figs. 55 and 56) represent signal-to-noise ratio regions of 6, 9 and 12 dB versus sonar depth and range. Detection is achieved in the deep part of the water volume, from 9 to 18 m. For SEARAY the ranges are respectively 500, 550 and 600 m for 12, 9 and 6 dB. For MOCASSIN the detection ranges are also 500, 550 and 600 m.

5.7. CONCLUSION

The tests demonstrated agreement in two simple examples between sonar performance models: SEARAY, MOCASSIN, GSM and HFEAM. These comparisons concern mainly the principle of computation of detection ranges by the models, the models using their own subroutines for the environmental sub-models. These comparisons only use direct path propagation over a flat bottom.

The user interfaces of SEARAY and MOCASSIN are similar. They need two input files: one for the sonar and the environmental parameters and another for the sound speed profile. Access to the different options for computations and plots is via a user-friendly menu. They both generate output files. These two models are easy to use and run in real time.

As HFEAM is a derivative of GSM developed for weapon systems, their use is identical. As inputs they need one or two files, one file if the sound speed profile is included. These models allow choice of computation and graph commands. These commands have to be inserted in the input files. Default values for parameters and models are used and it is sometimes difficult for the user to be sure of these values. Though GSM and HFEAM offer more possibilities, the two last points make them less convenient to use than SEARAY and MOCASSIN.

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6

Improvement of MCM sonar performance models

New functions could be implemented for improving SEARAY. Direct path could be replaced with multipaths. It would be necessary to introduce reflection coefficients for symmetric and asymmetric paths.

New bottom description and backscattering models are also necessary incorporate bottom features, presence of ripples and slopes. The use of side scan sonar and two-dimensional images analysis will create improved models.

A stochastic approach to the sonar equation will also improve modelling and explain the performance fluctuation. This use necessitates use of statistical parameters to describe propagation loss, backscattering, target strength and sonar functions [25].

The problem of buried mines is not addressed by the present MCM models. This requires the introduction of bottom penetration, mainly at lower frequencies from 10 to 40 kHz, and leads to new research fields such as:

- attenuation of sound in sediment, [26],
- volume scattering in sediment,
- propagation in sediment at low grazing angles, lower than the limit angle for total reflection, [27],
- value of target strength in the sediment (based on the impedance ratio between target and sediment).

For MCM mission assessment, the computation of the tactical parameters A, B and W as well as detection probabilities based on ROC curves could be added to SEARAY, as in CASSANDRA and HUNTOP.

7

Conclusion

This report describes the use and modifications of SEARAY at SACLANTCEN. SEARAY is an environmental Sonar Performance Model based on ray tracing and computation of signal-to-noise ratio.

The impact of environmental parameters has been studied. The fluctuation of sonar performance can be explained by modification of the environment or the target (sound speed profile, bottom type, target strength). The choice of the environmental sub-models influences the performance predictions. This is mainly true for the bottom backscattering model (GESMA, Lambert's, McKinney-Anderson or APL-UW models). Conversely, the choice of the absorption model has small impact.

SEARAY has been compared to MOCASSIN, GSM and HFEAM in two simple cases. The first test was dedicated to ray tracing, the second to signal to noise ratio computations. These comparisons have given agreement between the Sonar Performance Models.

Two validation tests were conducted by SACLANTCEN on board Italian Mine Hunters equipped with the SQQ-14/IT sonar [28]. The targets used were a cylinder laid on the bottom and three moored spheres. The bottom types were sand and mud. For these two tests the detection ranges predicted by both SEARAY and MOCASSIN were close to the real ranges given by the operators.

New functions could be implemented for improving SEARAY, such as: multipaths, a stochastic approach, new bottom backscattering models and bottom penetration. Also more validations tests have to be conducted on more difficult bottom types with different targets.

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	SEARAY US NCSC	CASTAR US NCSC	CASSANDRA ITALY FIAR	MPPS UK MARCONI	MIJAS GERMANY MTG	HUNTOP NL TNO
MAXIMUM RANGE	X		X	X	X	
BEST SONAR PARAMETERS		X	X	X	X	
DETECTION PROBABILITY			X	X		X
MISSION ASSESSMENT PLANNING				X	X	X
<i>SVP real time</i>		*	*	*		
<i>range-independent direct path</i>	*	*	*	*	*	

Table 1 NATO MCM Sonar Performance Models

	SEARAY	GSM	MOCASSIN	HFEAM
ABSORPTION	MARSH SCHULKIN	THORP	FRANCOIS GARRISON	FRANCOIS GARRISON
SURFACE SCATTERING	CHAPMAN HARRIS	CHAPMAN HARRIS	CHAPMAN HARRIS	URICK HOOVER APL 84
BOTTOM SCATTERING	McKINNEY ANDERSON	LAMBERT	LAMBERT	APL-UW

Table 2 Environmental Sub-Models

	SEARAY	GSM	MOC	HFEAM
RAY TRACE EIGEN RAYS	X	X X		X X
P-LOSS vs Range vs Range & Depth		X	X X	X X
SURFACE, BOTTOM BACKSCATTERING vs Range vs Time	X	X	X	X
SIGNAL vs Range	X		X	
SIGNAL EXCESS vs Range vs Time vs Range & Depth	X X	X	 X	 X X

Table 3 Plots from Performance Models

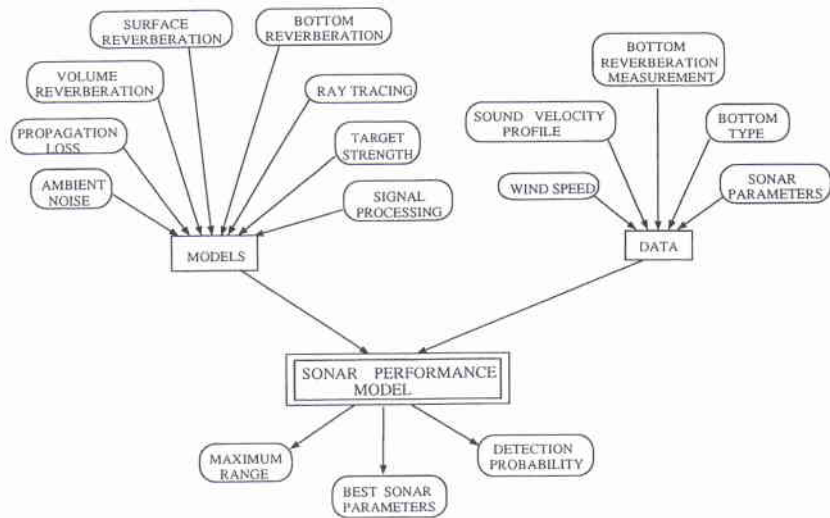


Figure 1 MCM Sonar Performance Model

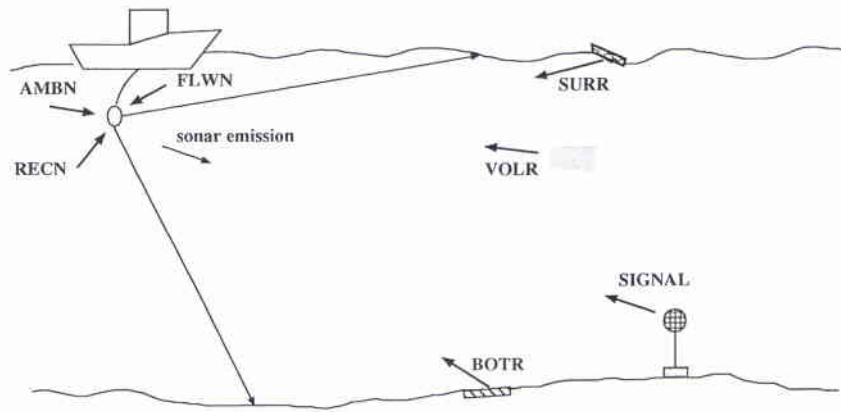


Figure 2 Signal/Reverberation/Noise – typical scenario

P_r : received power	α : absorption coefficient	ϕ_h : horizontal beamwidth	T_s : Target Strength
P_t : transmitted power	r : range	θ_v : vertical beamwidth	V_s : Volume Backscattering
G_t : transmission gain	C : celerity	θ : tilt angle	B_s : Bottom Backscattering
G_r : reception gain	τ : pulse length		

Signal

$$P_r = P_t \cdot G_t \cdot \frac{10^{-\alpha r}}{r^2} \cdot [T_s] \cdot \frac{10^{-\alpha r}}{r^2} \cdot G_r$$

Volume

$$P_r = P_t \cdot G_t \cdot \frac{10^{-\alpha r}}{r^2} \cdot [V_s \cdot r \phi_h \cdot r \theta_v \cdot \frac{C \cdot \tau}{2}] \cdot \frac{10^{-\alpha r}}{r^2} \cdot G_r$$

insonified volume

Bottom

$$P_r = P_t \cdot G_t \cdot \frac{10^{-\alpha r}}{r^2} \cdot [B_s \cdot r \phi_h \cdot \frac{C \cdot \tau}{2 \cos \theta}] \cdot \frac{10^{-\alpha r}}{r^2} \cdot G_r$$

insonified area

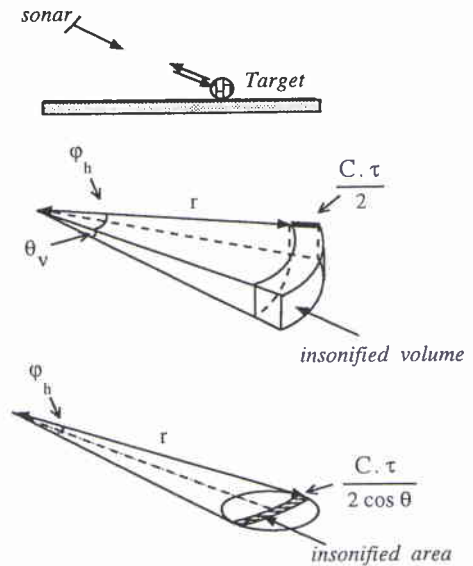


Figure 3 Signal/Reverberation geometry and formulation

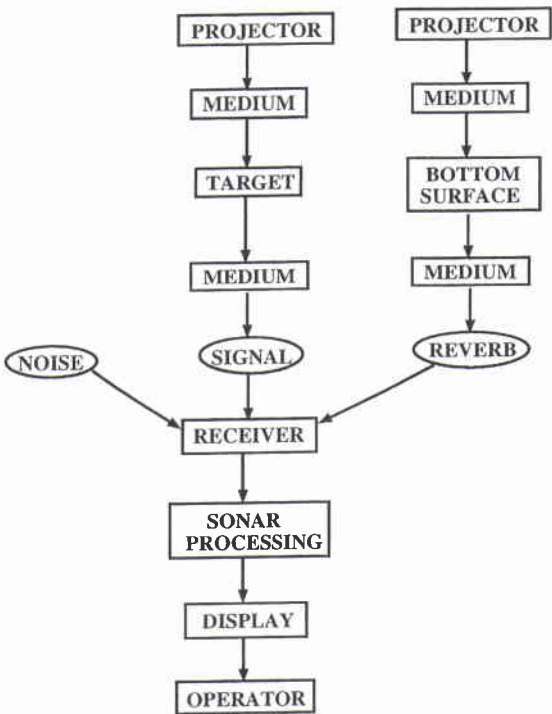


Figure 4 Signal/Reverberation/ Noise flow diagram

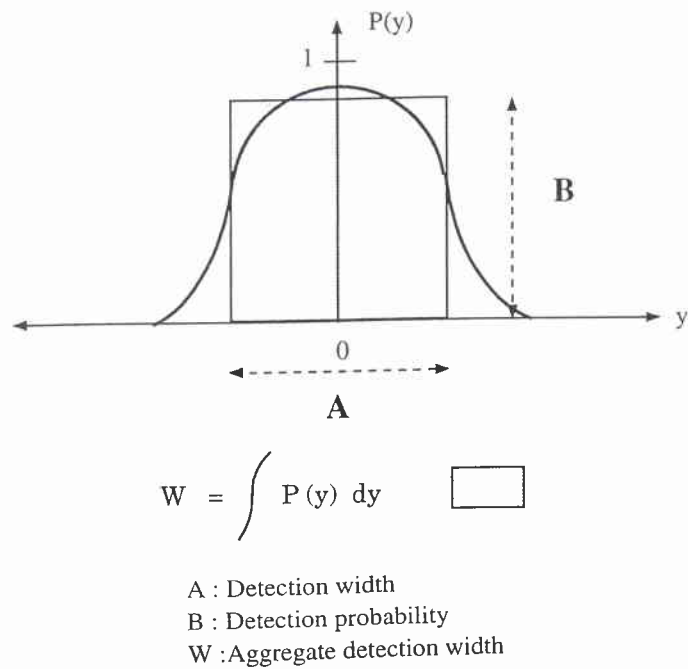


Figure 5 Detection Widths

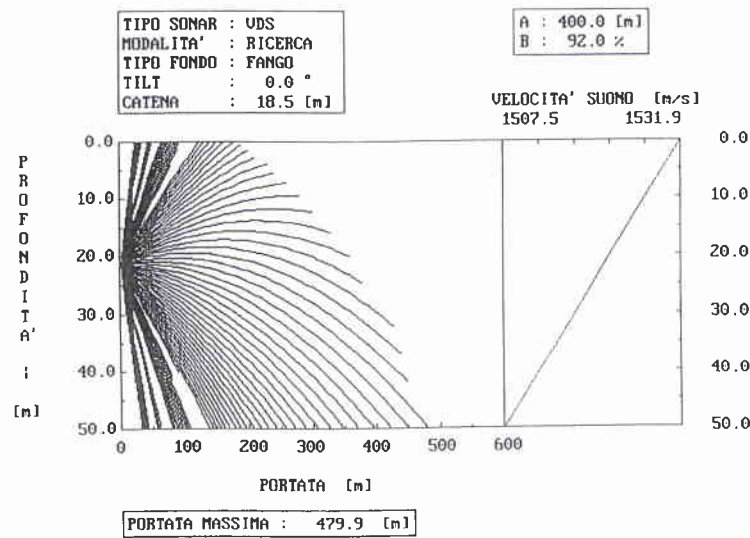


Figure 6 CASSANDRA ray tracing, muddy bottoms

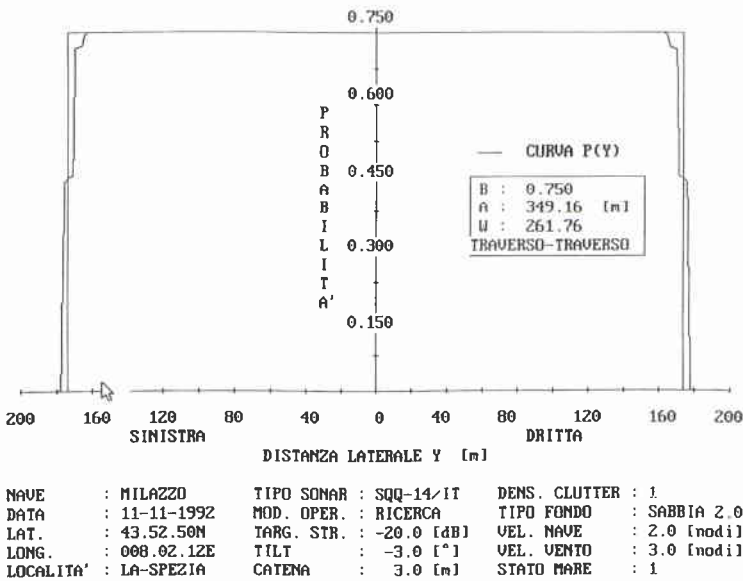


Figure 7 CASSANDRA mission assessment parameters (A)

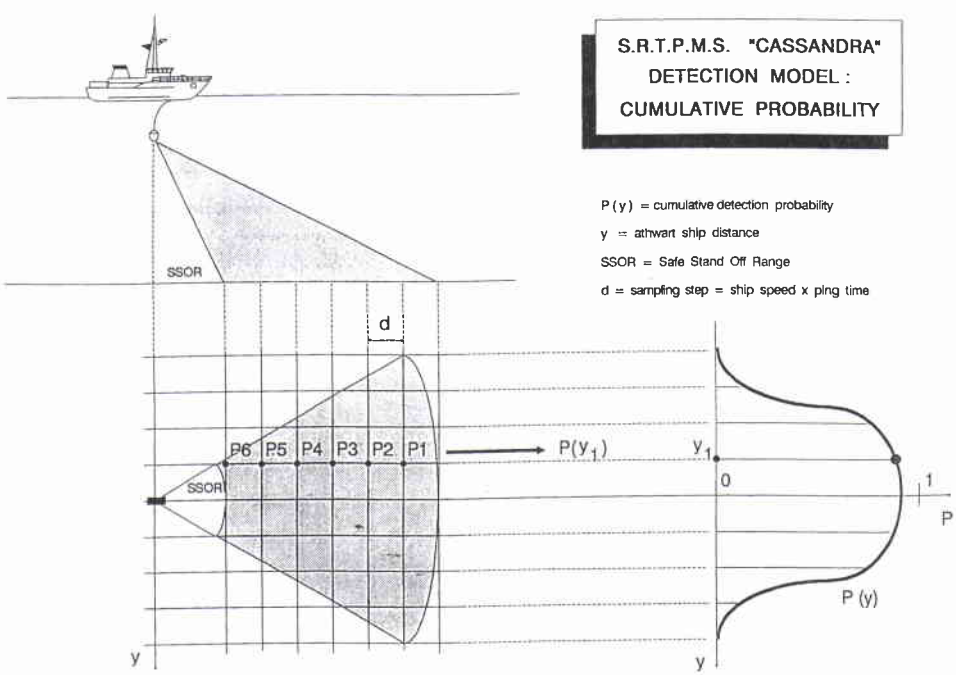


Figure 8 CASSANDRA mission assessment parameters (B)

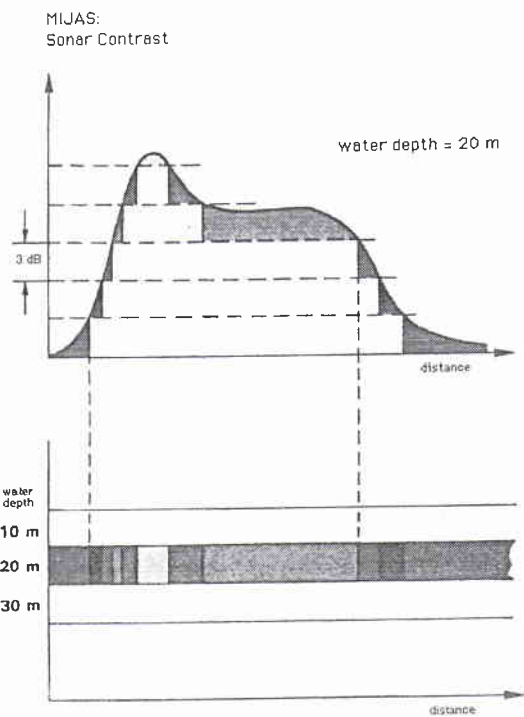


Figure 9 MIJAS sonar contrast

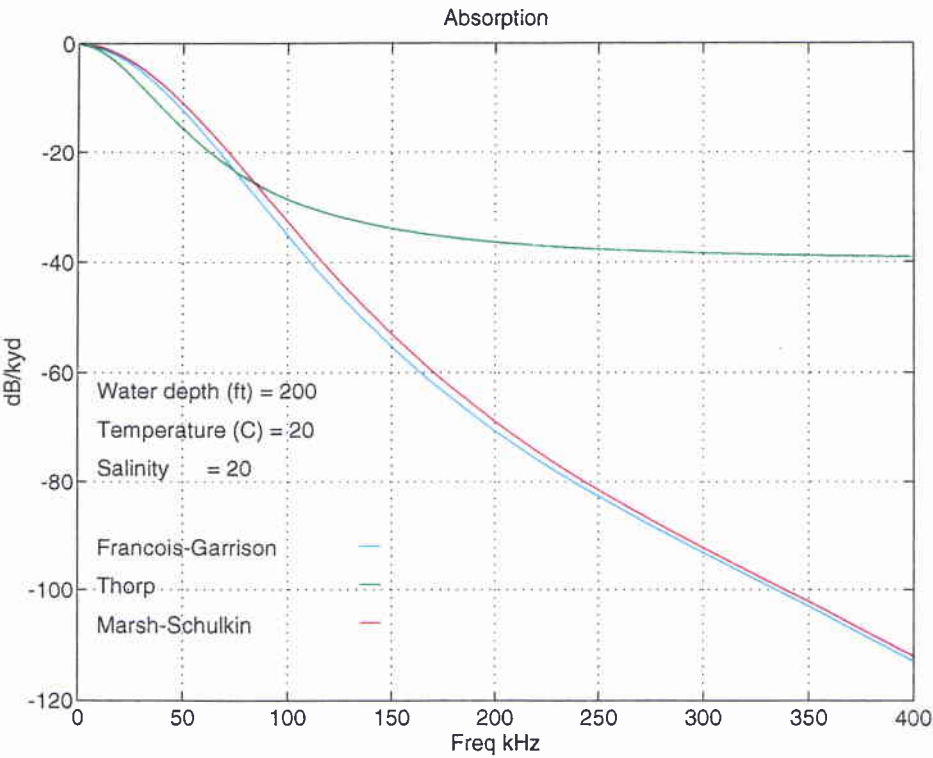


Figure 10 Comparison of Marsh-Schulkin, François-Garrison and Thorp models

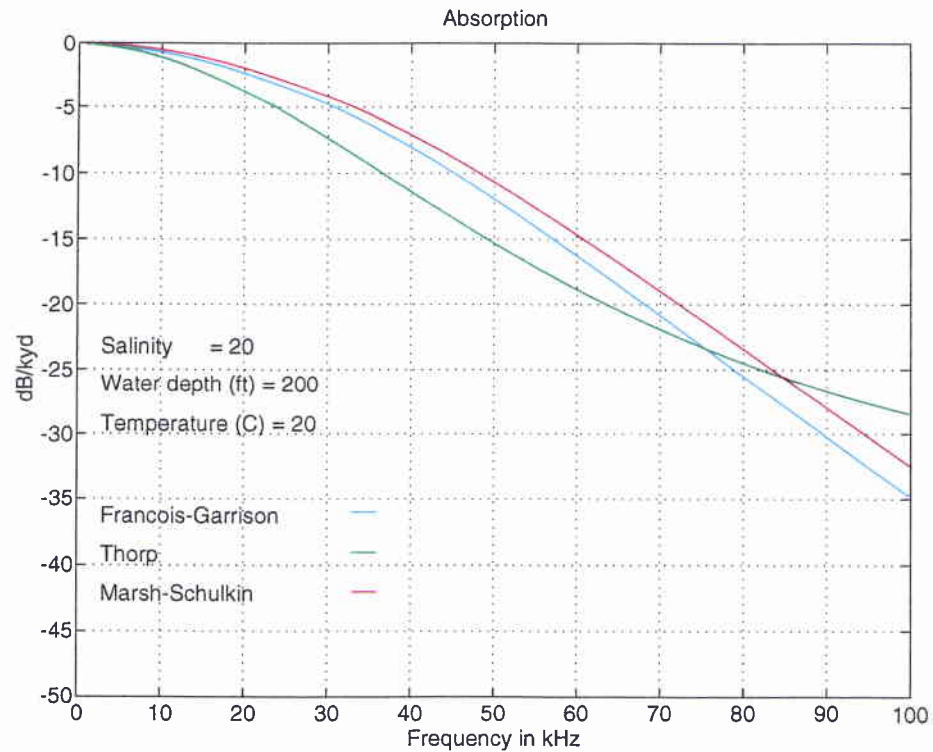


Figure 11 Comparison of Marsh-Schulkin, François-Garrison and Thorp models

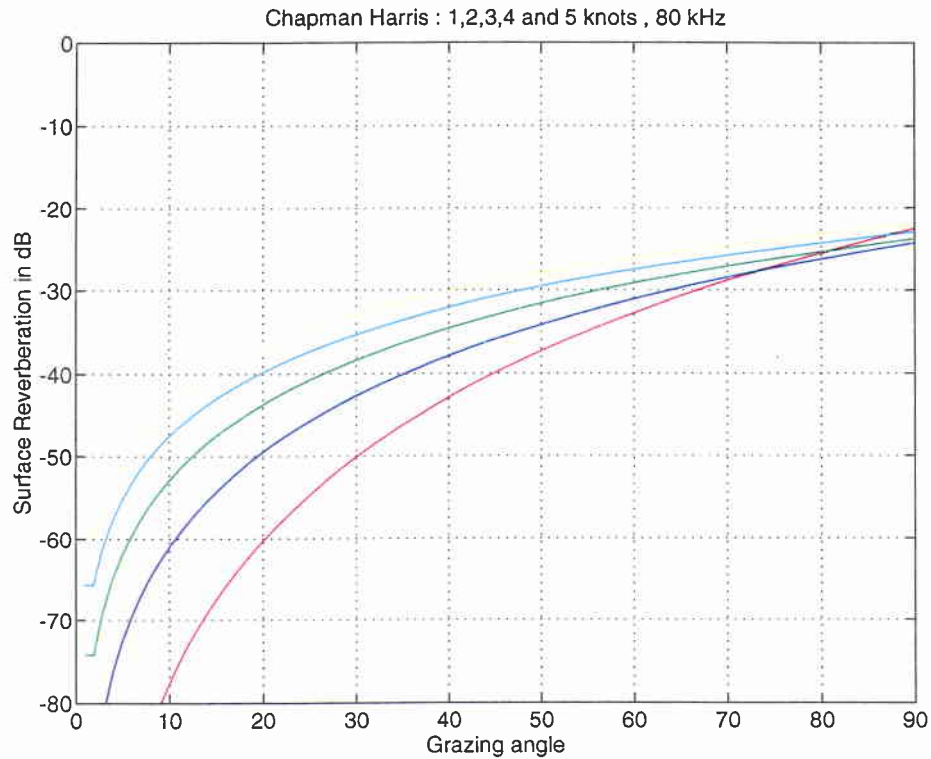


Figure 12 Chapman-Harris model: effect of wind speed at 1 to 5 kn on surface reverberation

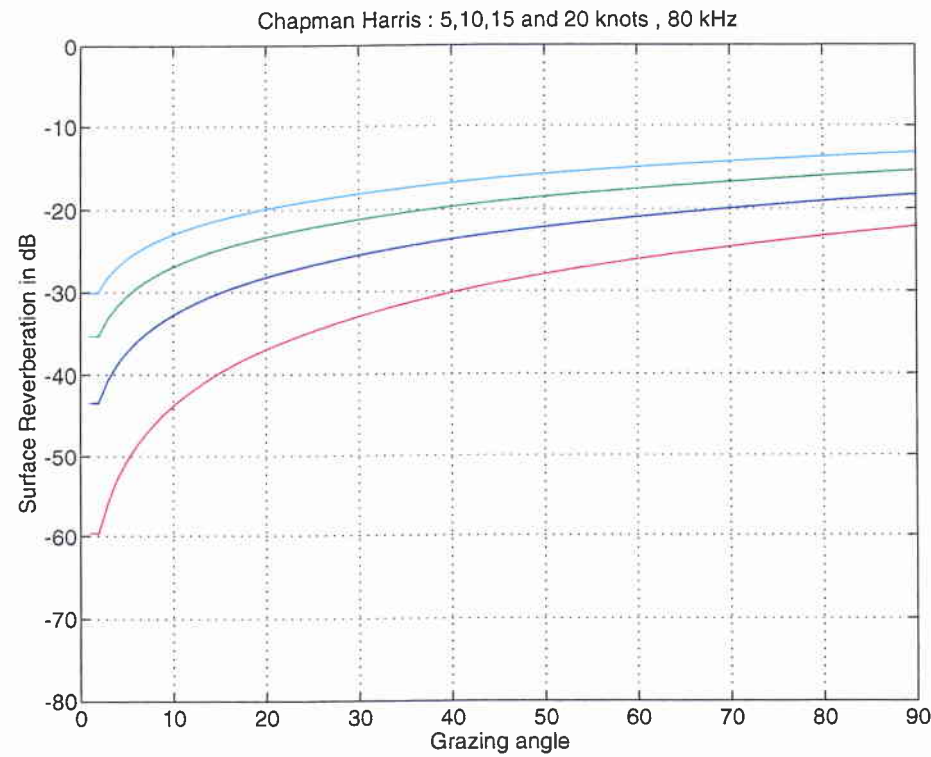


Figure 13 Chapman-Harris model: effect of wind speed at 5 to 20kn on surface reverberation

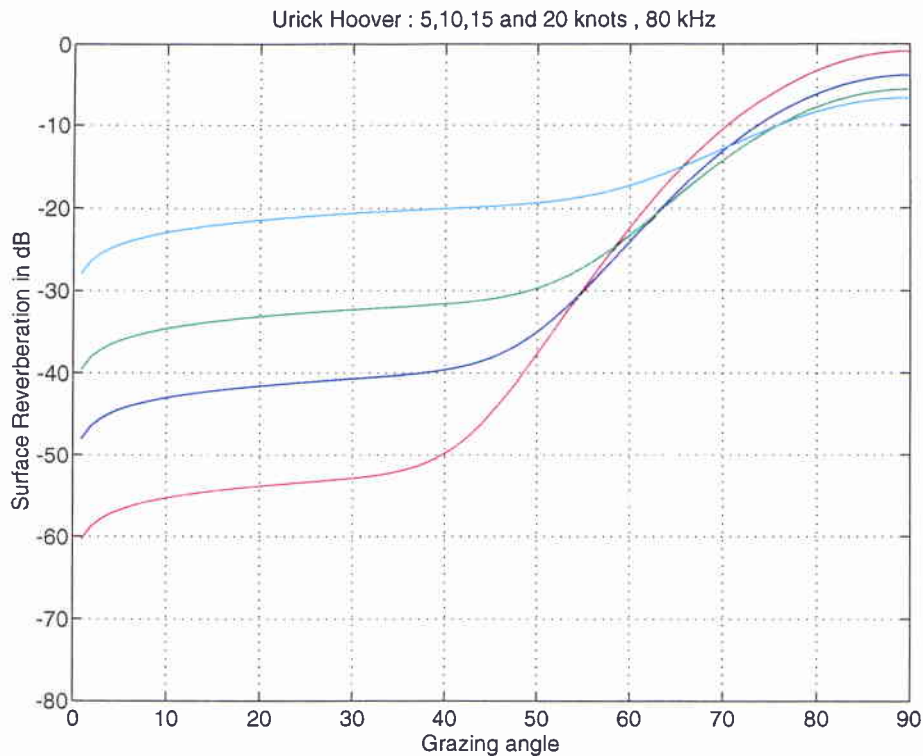


Figure 14 *Urlick-Hoover model: effect of wind speed and grazing angle on surface reverberation*

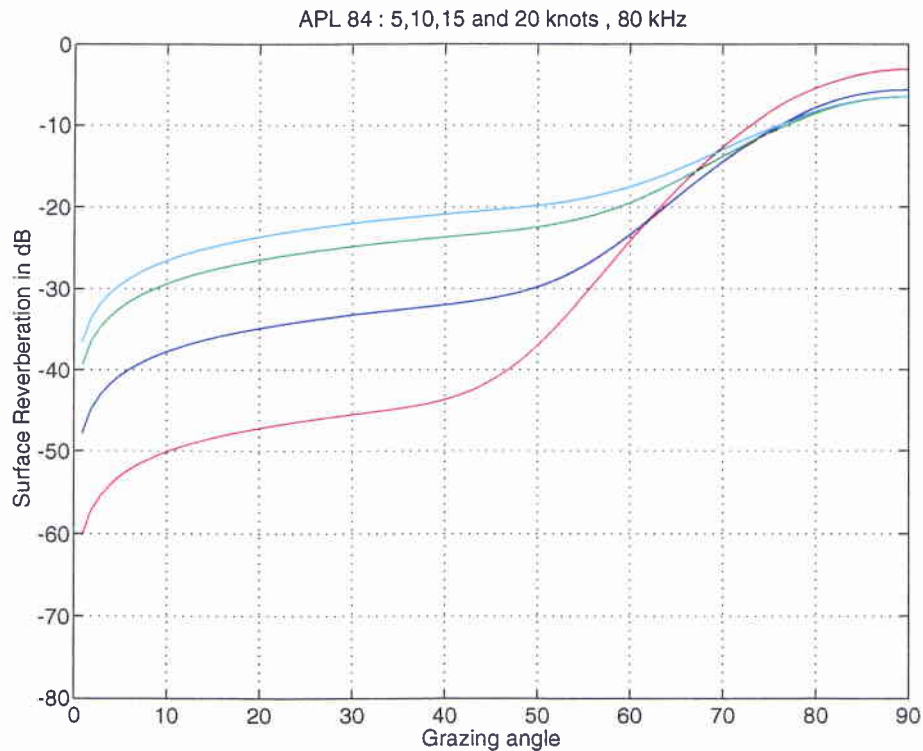


Figure 15 *APL-84 model: effect of wind speed and grazing angle on surface reverberation*

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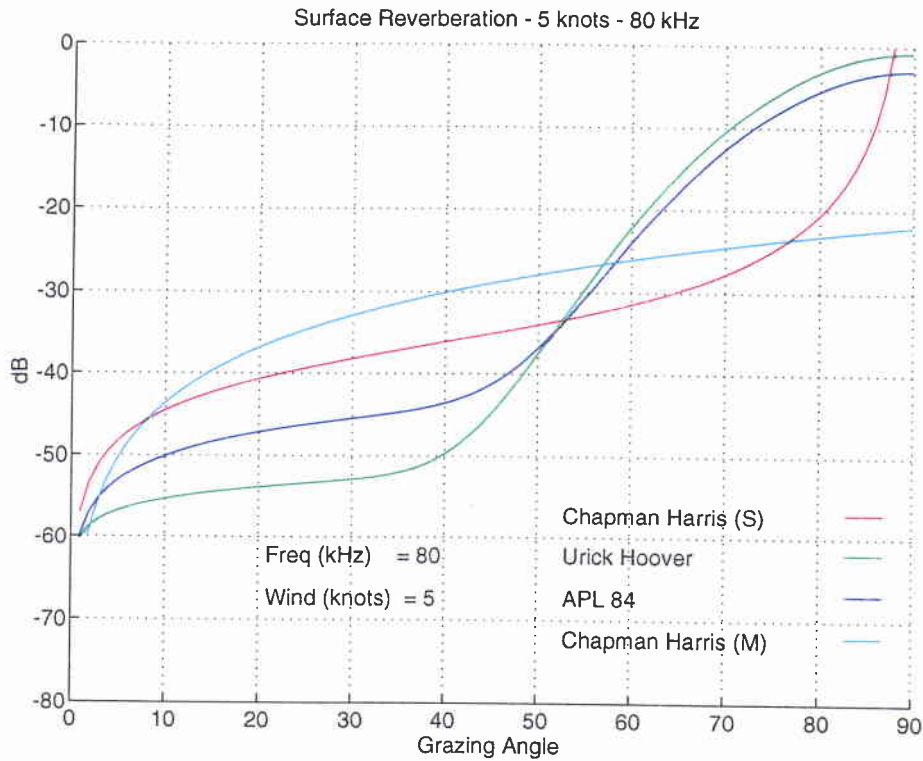


Figure 16 Effect of 5kn wind speed/grazing angle on surface reverberation, comparison of four models

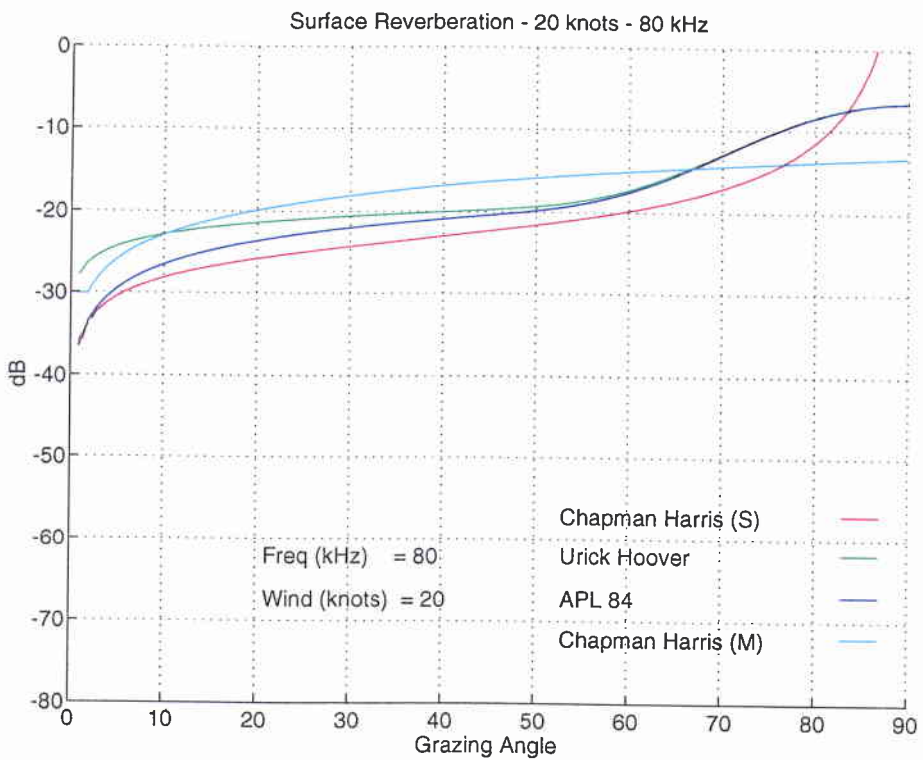


Figure 17 Effect of 20kn wind speed/grazing angle on surface reverberation, comparison of four models

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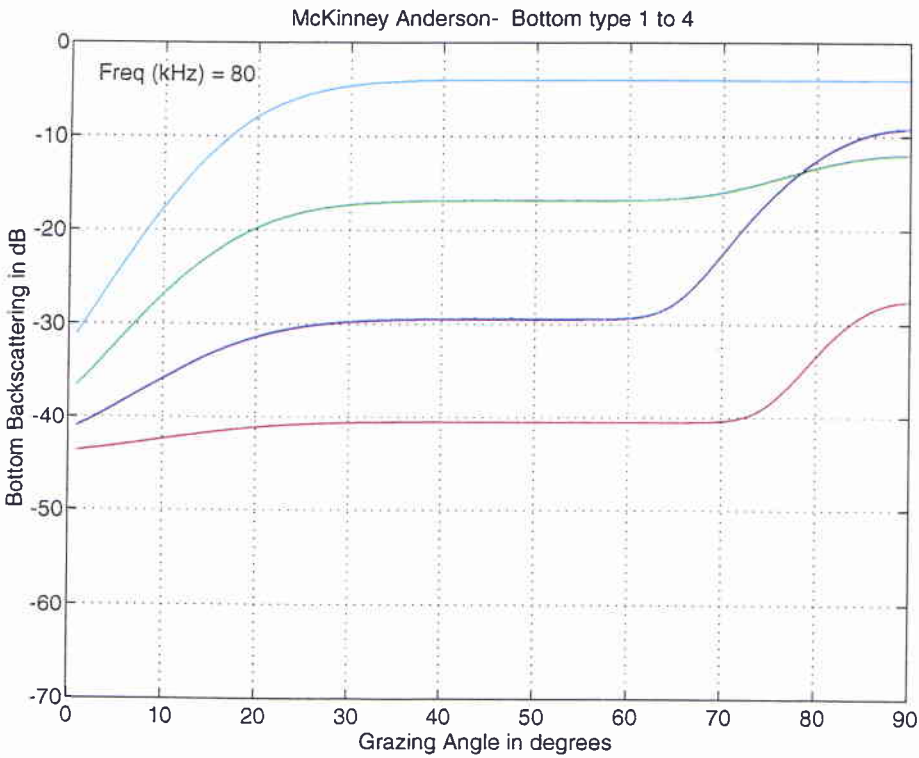


Figure 18 *McKinney-Anderson model, backscattering for (1) mud, (2) sand, (3) gravel, (4) rock*

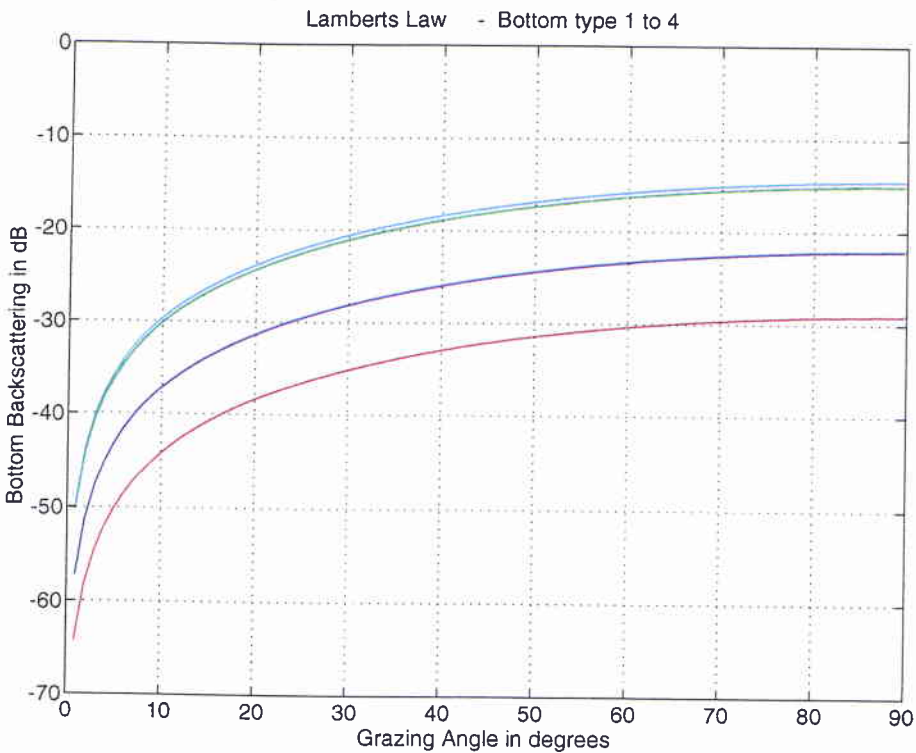


Figure 19 *Lambert's Law, backscattering as a function of bottom type and grazing angle*

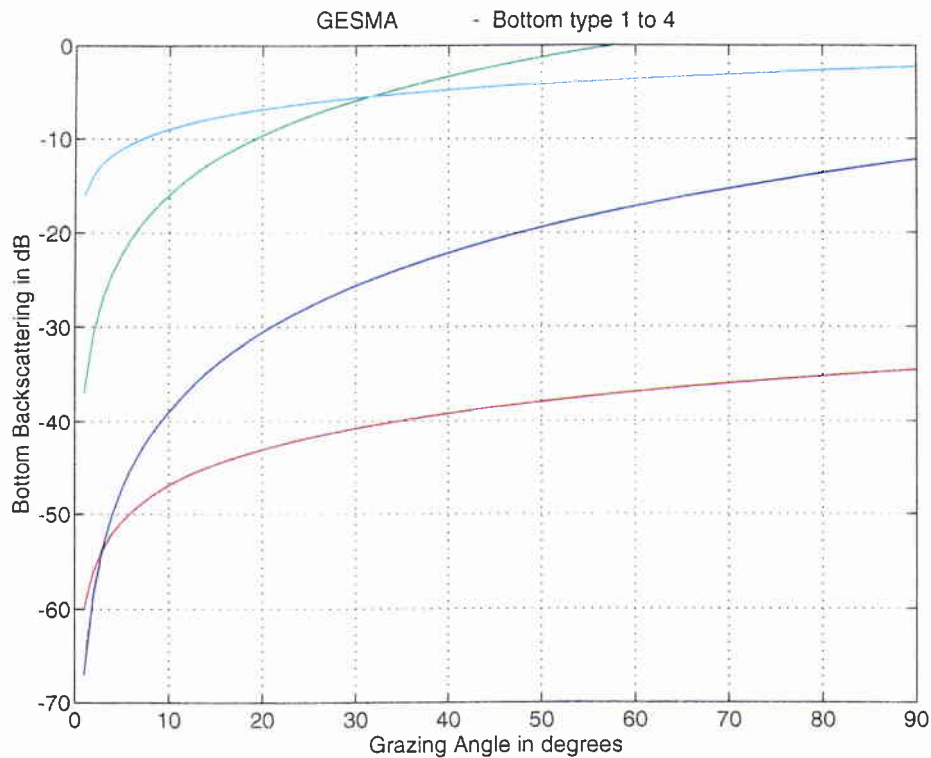


Figure 20 GESMA model, backscattering as a function of bottom type and grazing angle

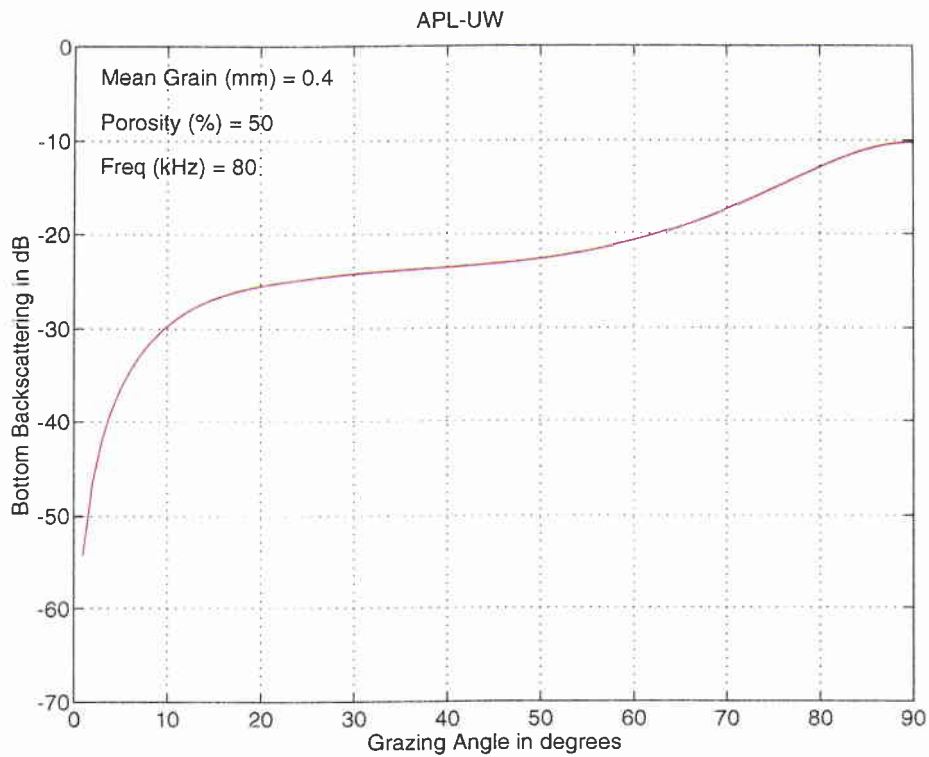


Figure 21 APL-UW model, backscattering as a function of grain size and porosity, grazing angle and frequency

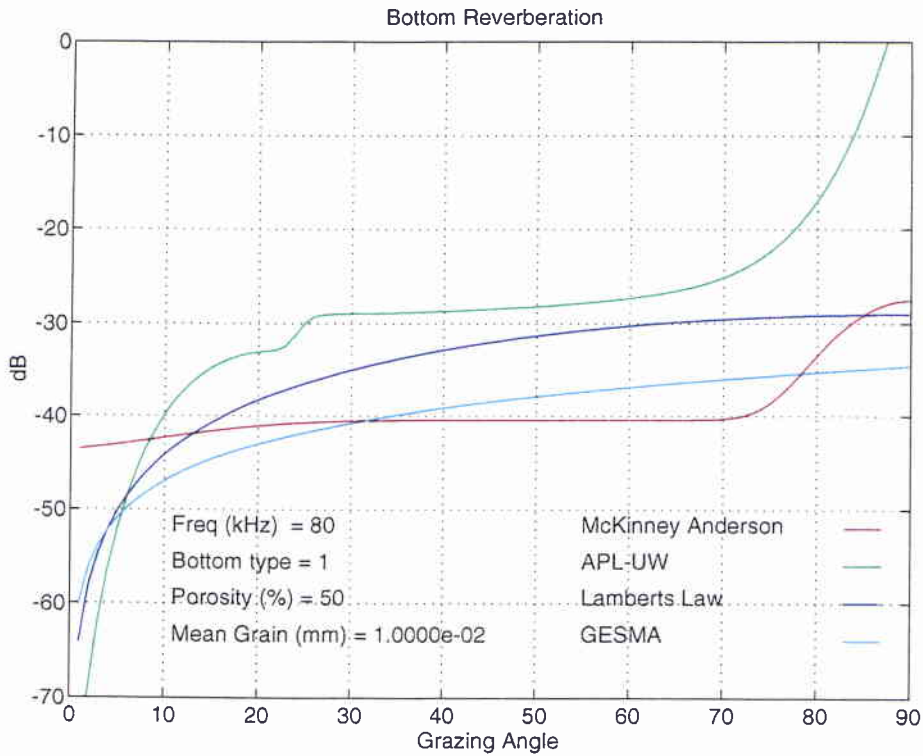


Figure 22 Comparison of four models: backscattering as a function of bottom type and grazing angle

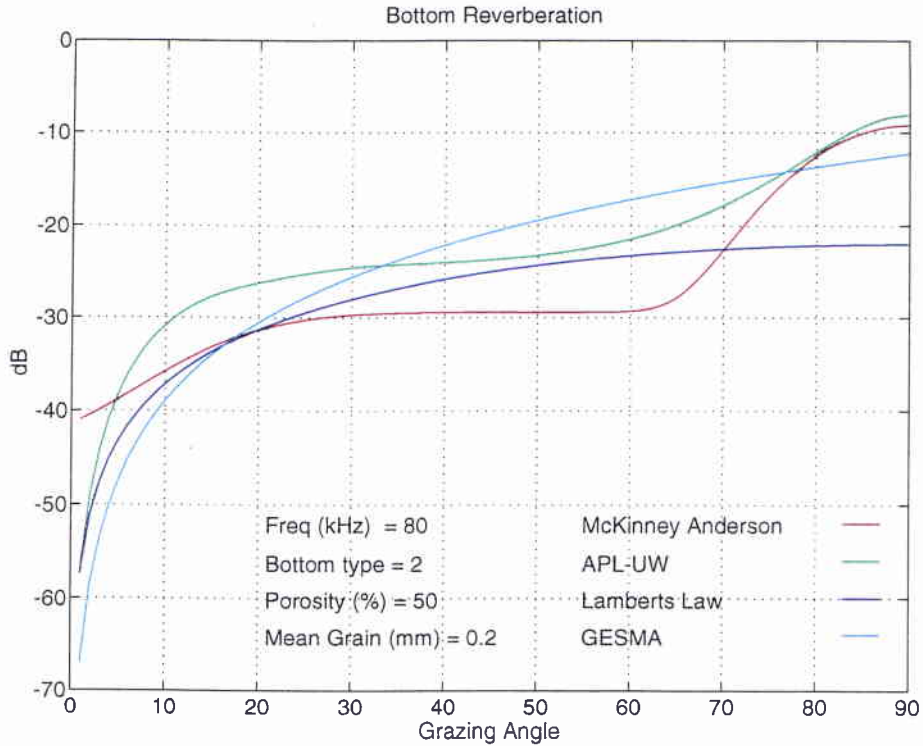


Figure 23 Comparison of four models: backscattering as a function of bottom type and grazing angle

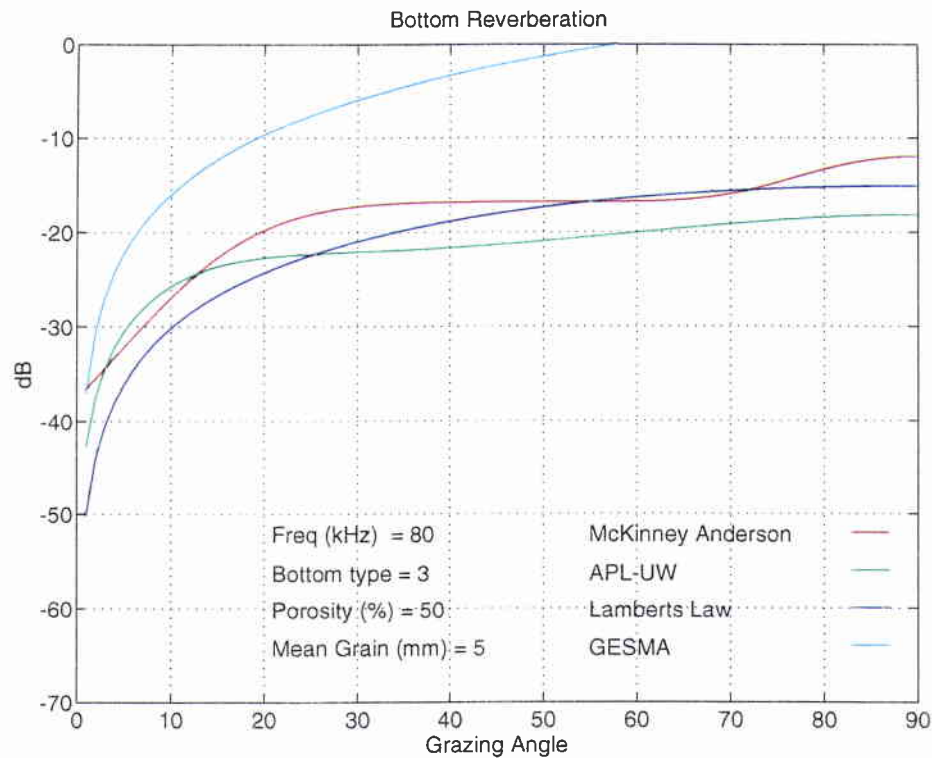


Figure 24 Comparison of four models: backscattering as a function of bottom type and grazing angle

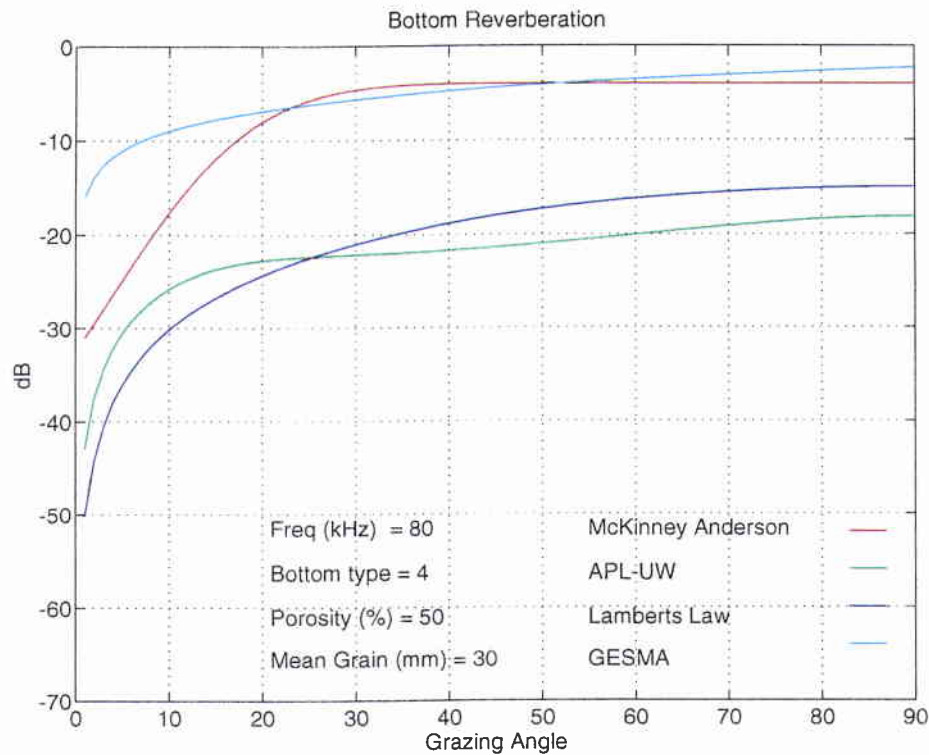
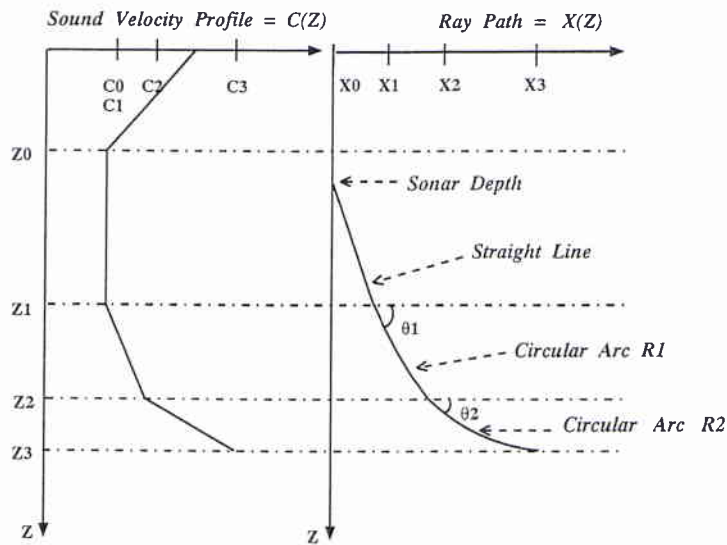


Figure 25 Comparison of four models: backscattering as a function of bottom type and grazing angle



From Z0 to Z1 : $C1 = C0 \rightarrow$ SVP gradient = 0 $\rightarrow$ straight line

From Z1 to Z2 : $C2 > C1 \rightarrow$ SVP gradient $> 0 \rightarrow$ arc of circle curved upward

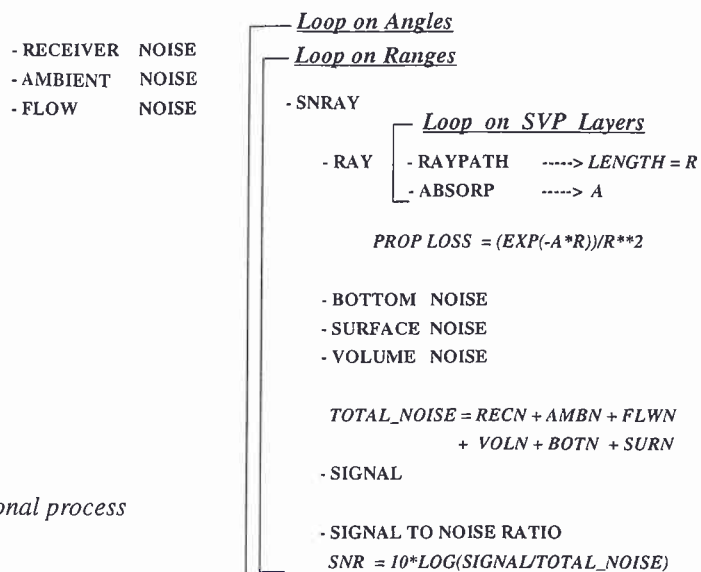
$$\text{SVP gradient : } G1 = (C2 - C1)/(Z2 - Z1)$$

$$\text{radius : } R1 = C1/(G1 * \cos(\theta1)) = \text{radius of the circle from which the arc is taken}$$

$$\text{horizontal distance in the layer : } X2 - X1 = R1 * (\sin(\theta1) - \sin(\theta2))$$

Figure 26 Ray tracing example

Figure 27 SEARAY, computational process



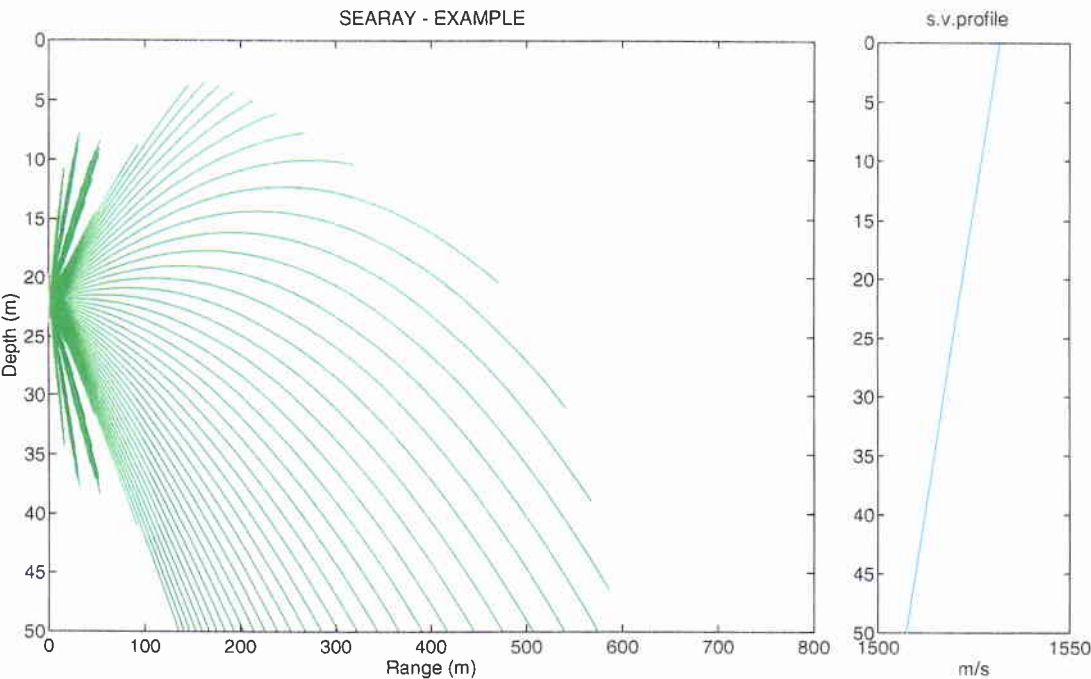


Figure 28 SEARAY, ray tracing

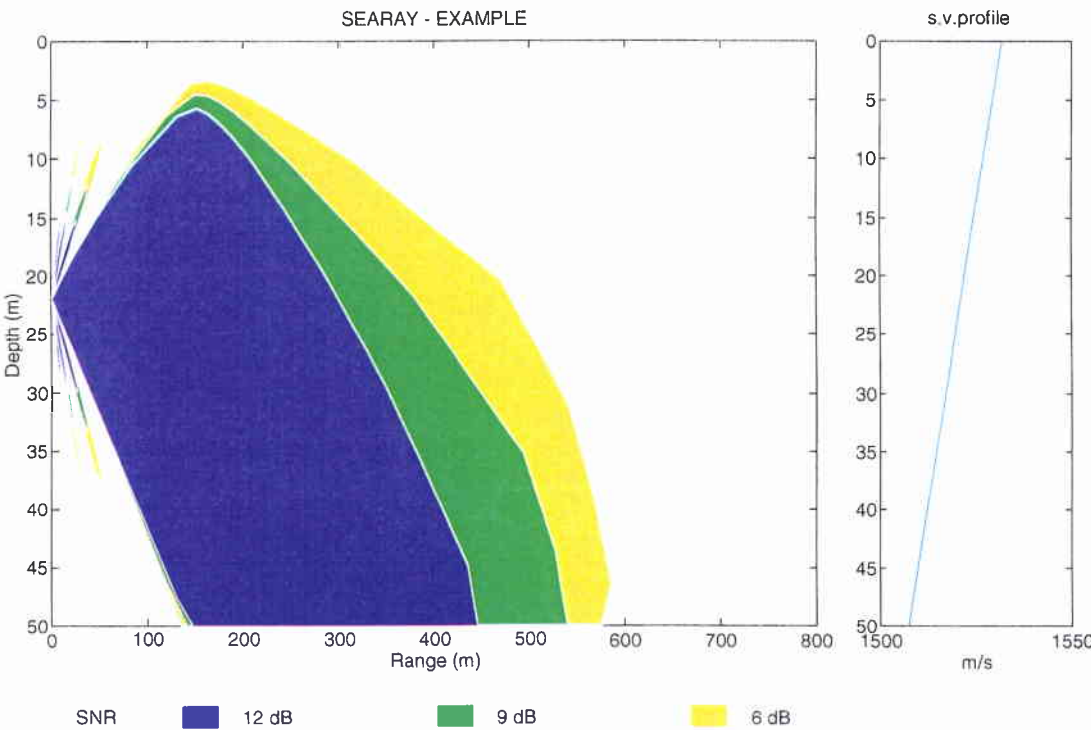


Figure 29 SEARAY, contour areas

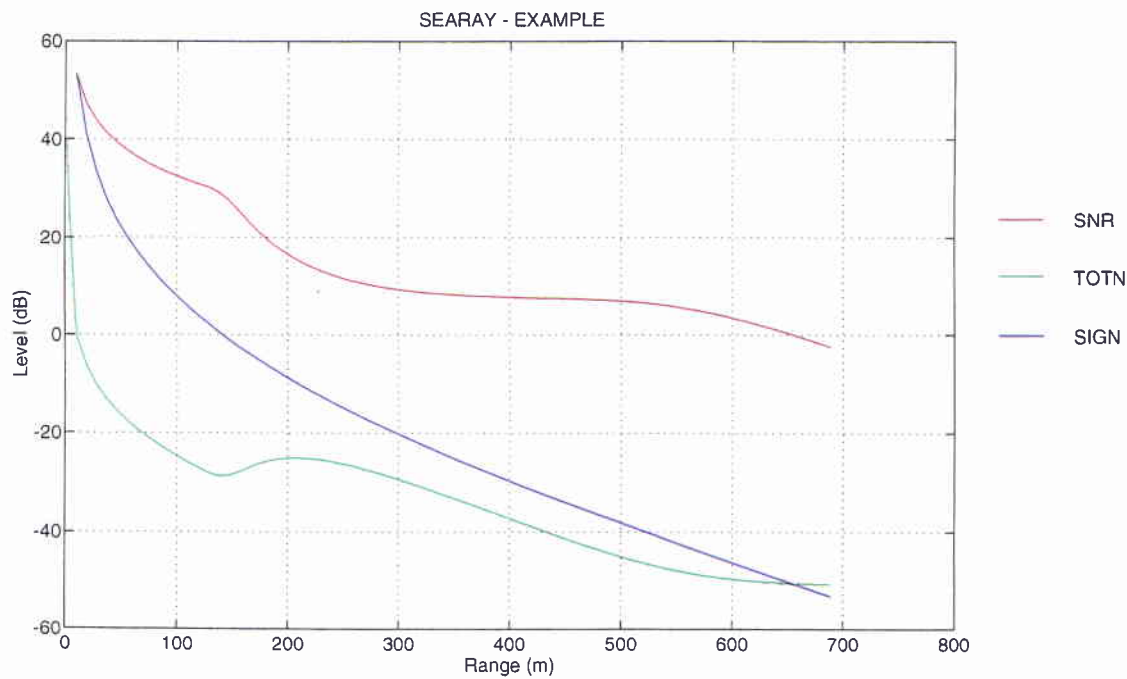


Figure 30 SEARAY, range dependence of signal level, total noise and signal-to-noise ratio

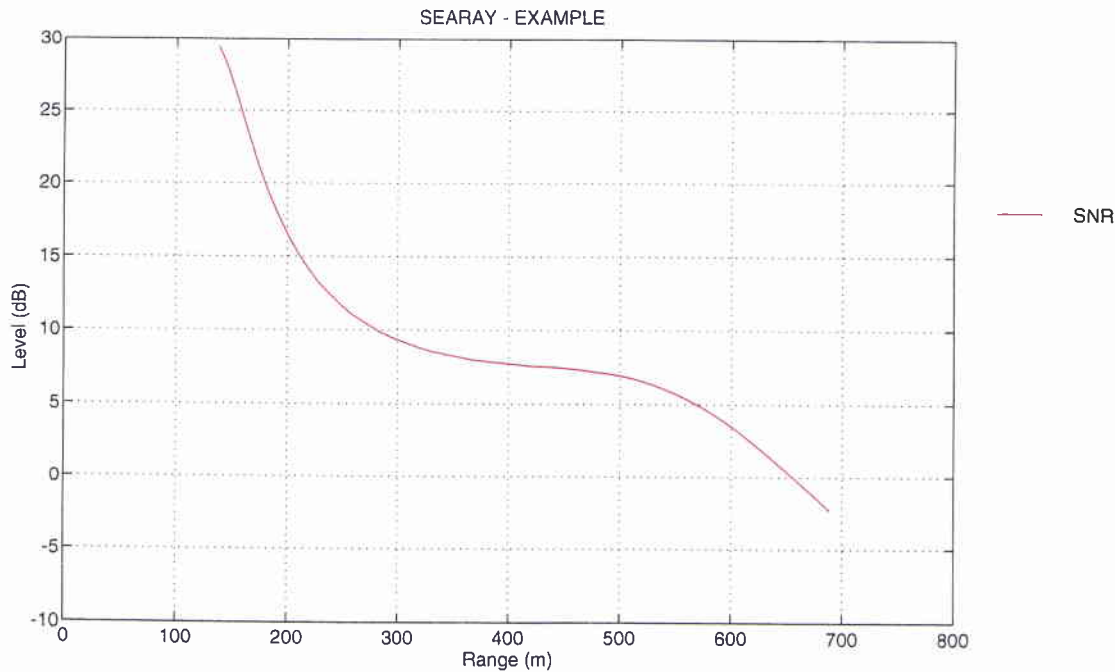


Figure 31 SEARAY, expanded scale signal-to-noise ratio versus range

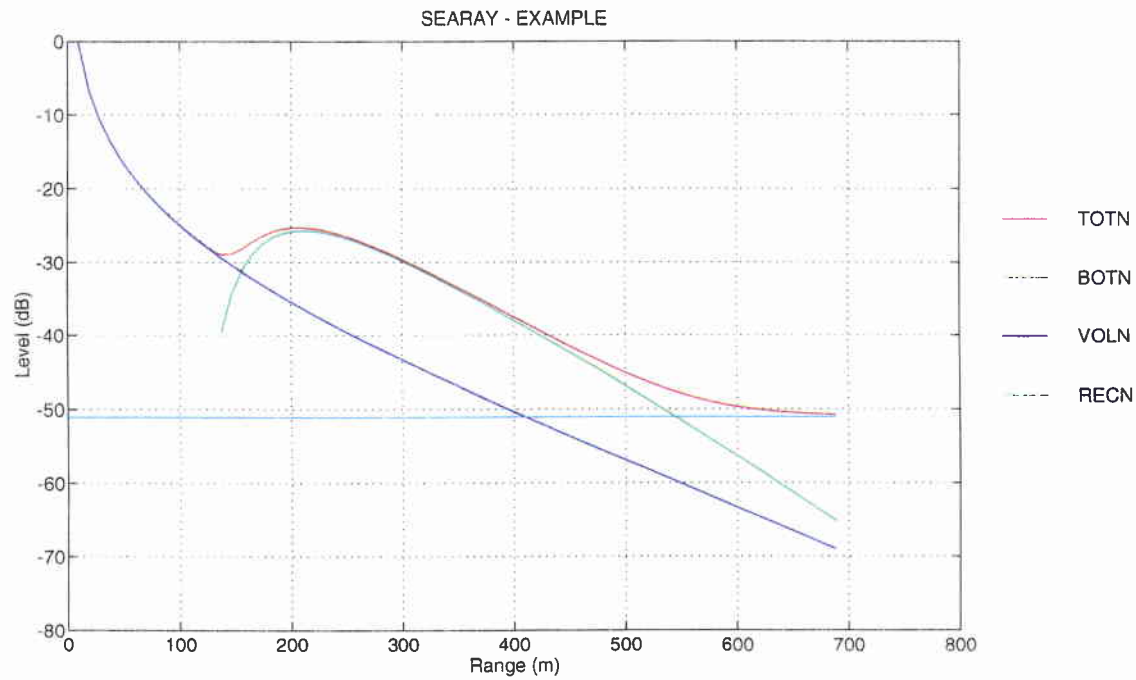


Figure 32 SEARAY, range dependence of total noise components

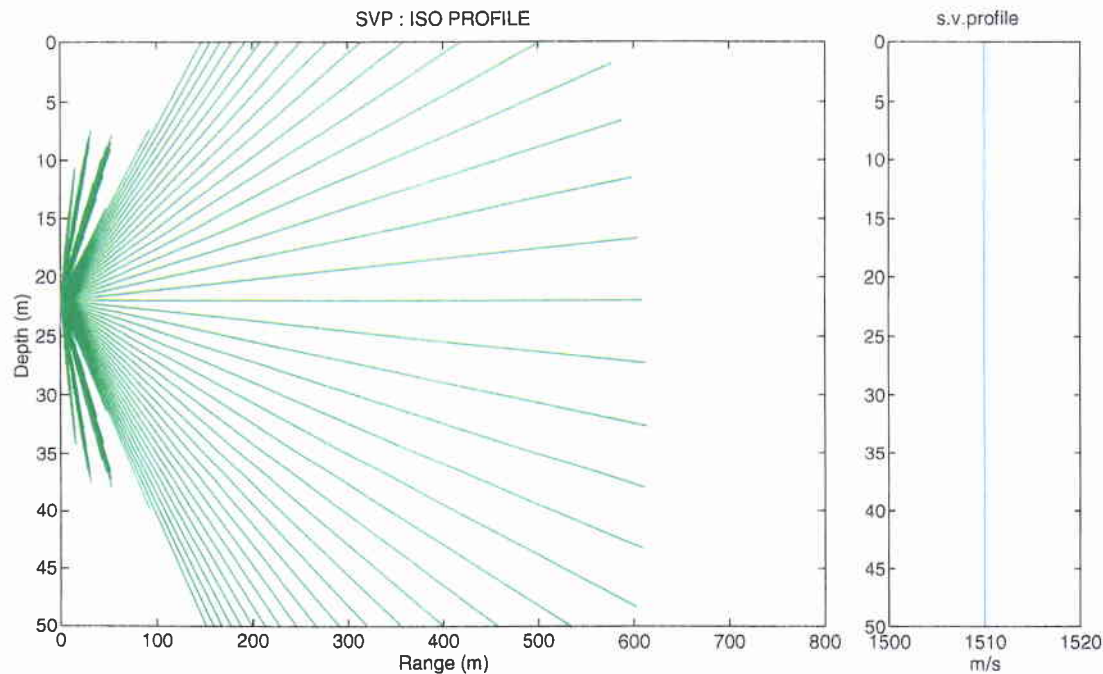


Figure 33 Isovelocity propagation

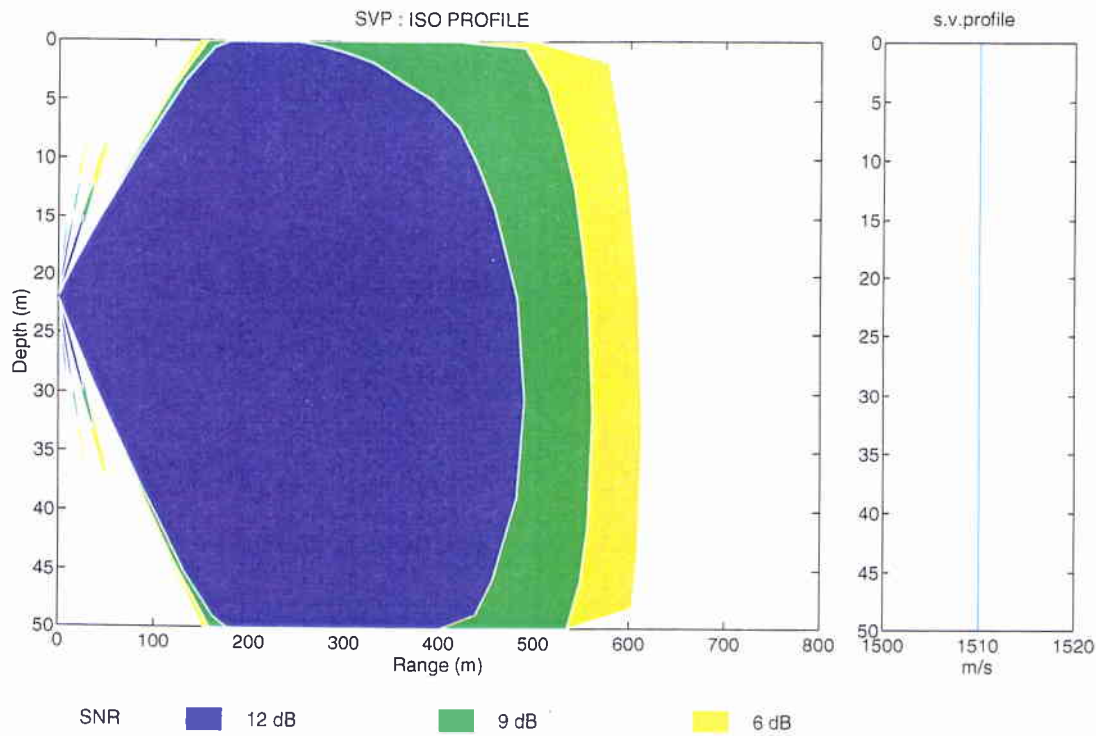


Figure 34 SNR contours for isovelocity profile

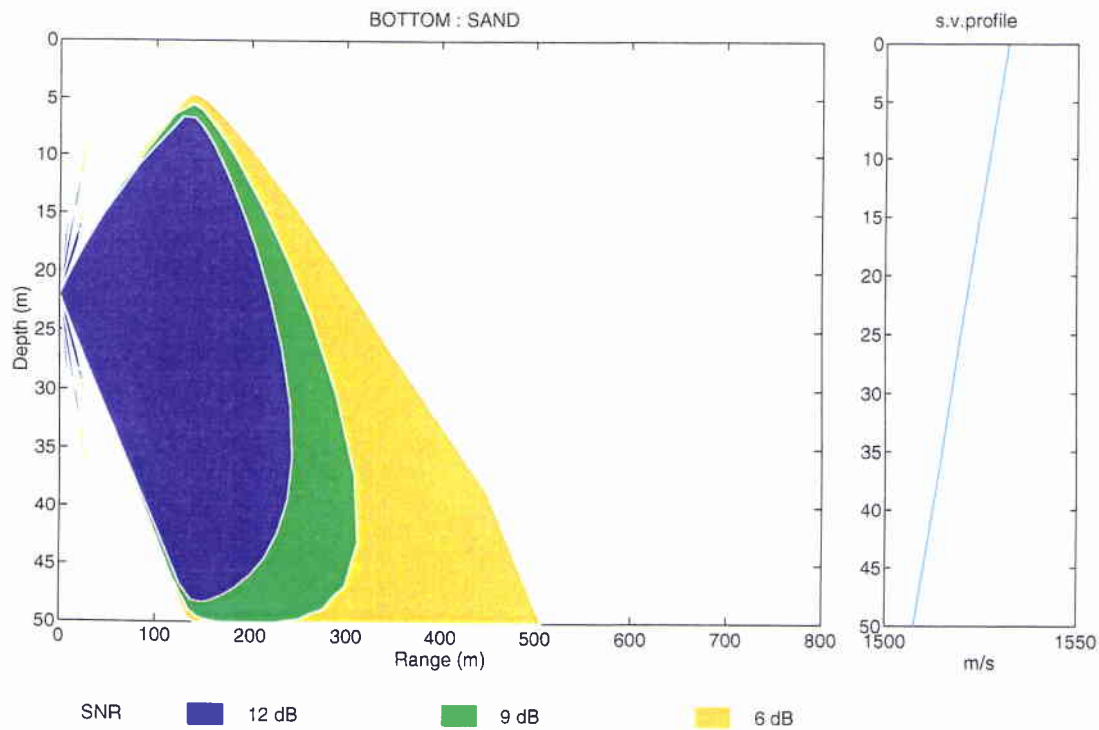


Figure 35 SNR contours: sand

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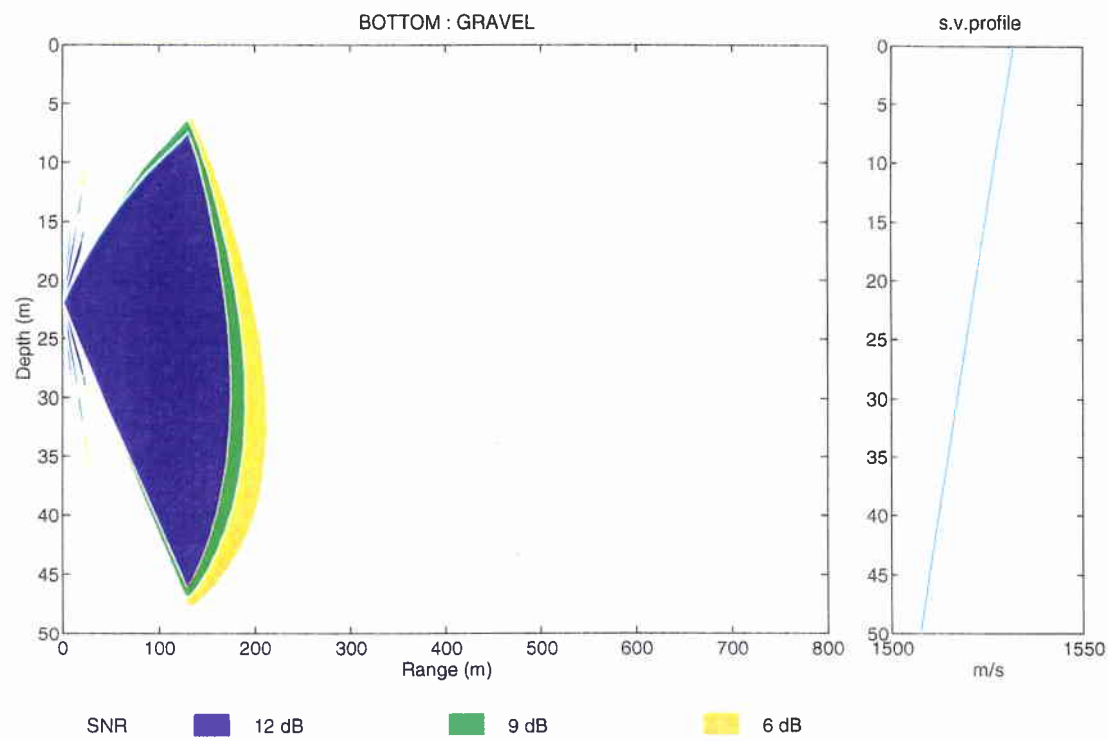


Figure 36 SNR contours: gravel

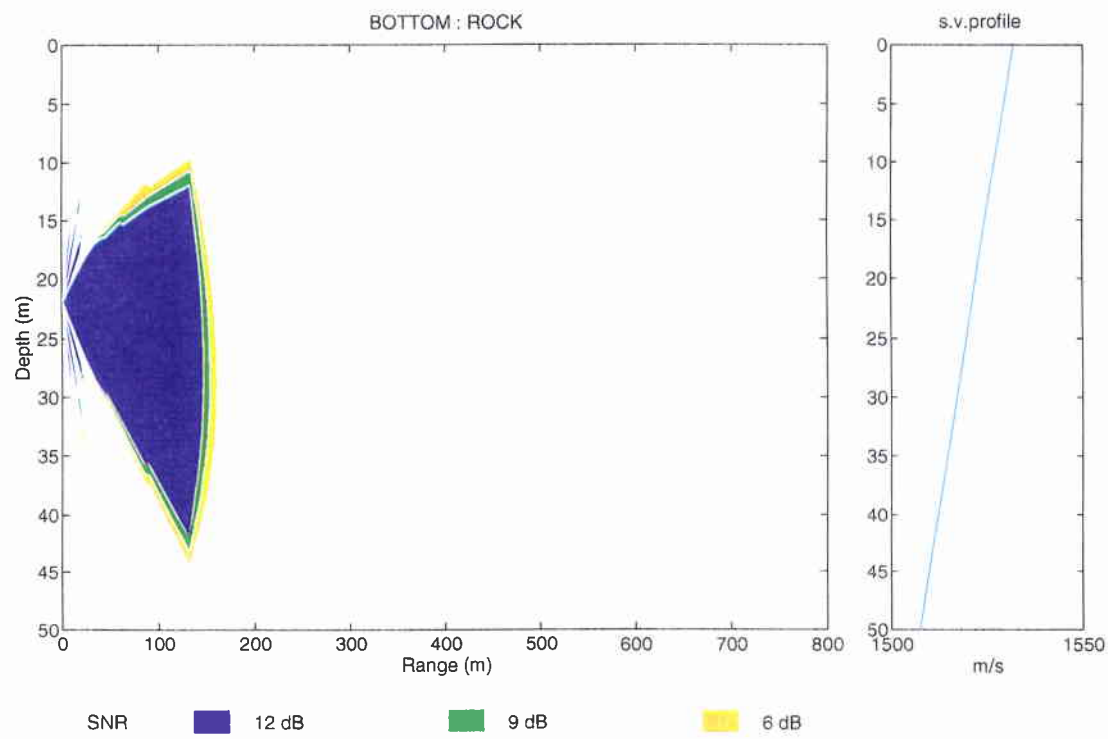


Figure 37 SNR contours: rock

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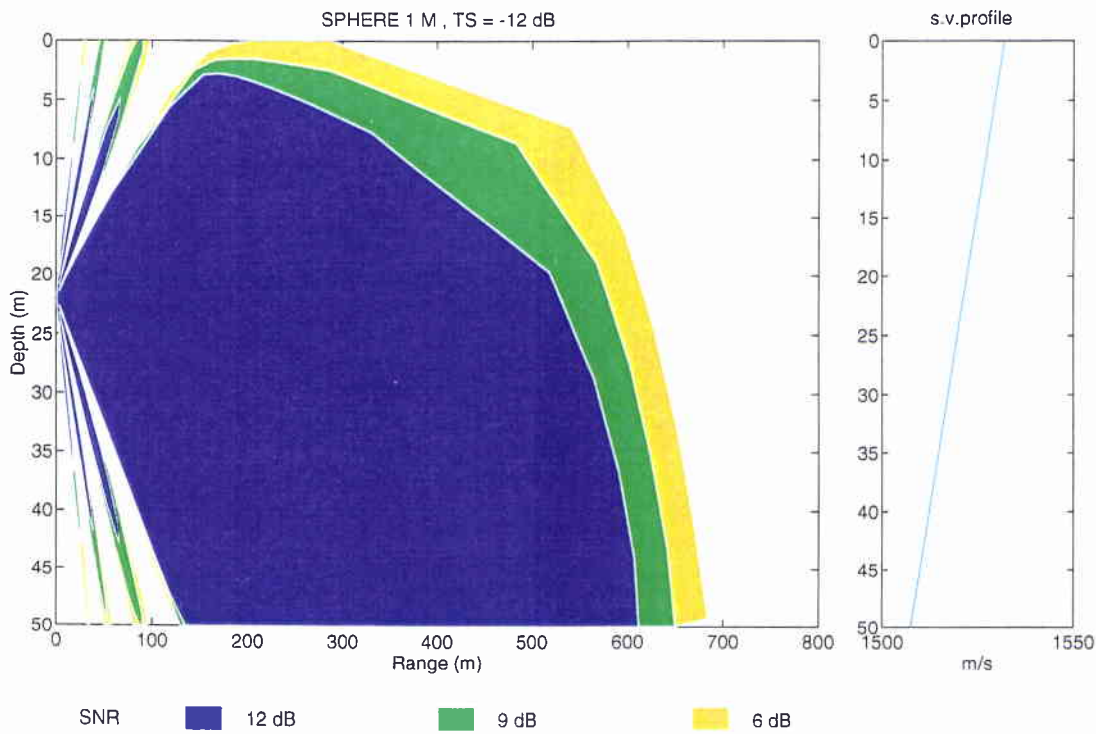


Figure 38 SNR contours for a 1m sphere target:

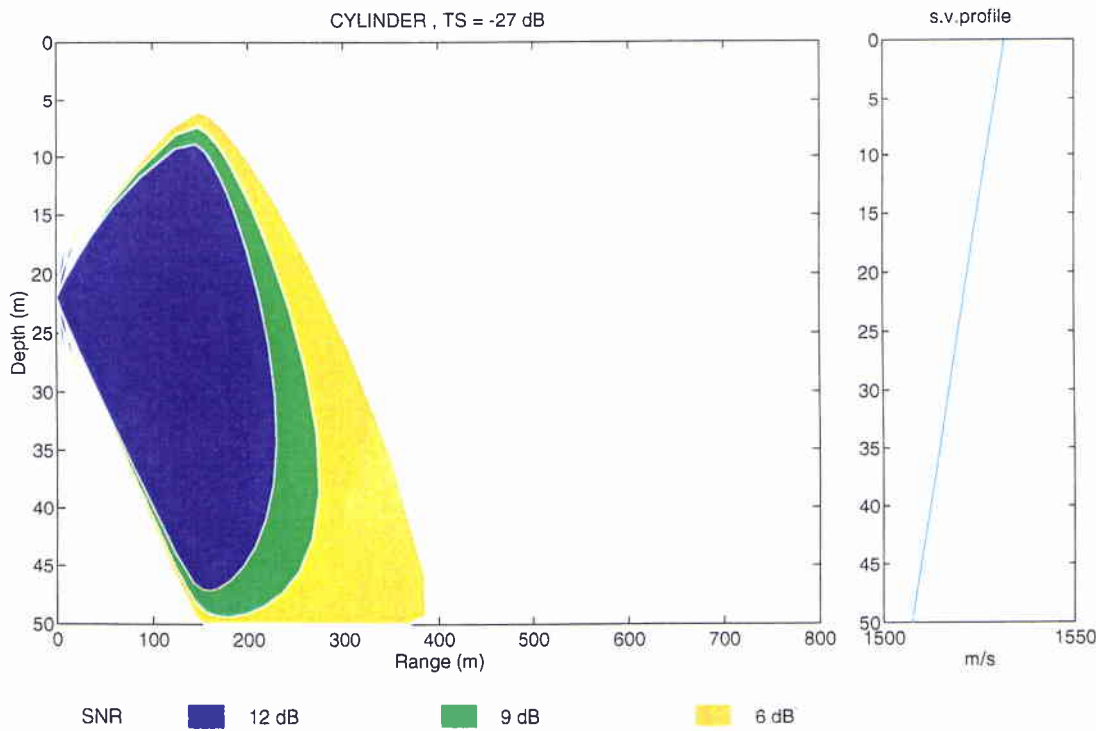


Figure 39 SNR contours for a cylinder viewed at off-axis aspect

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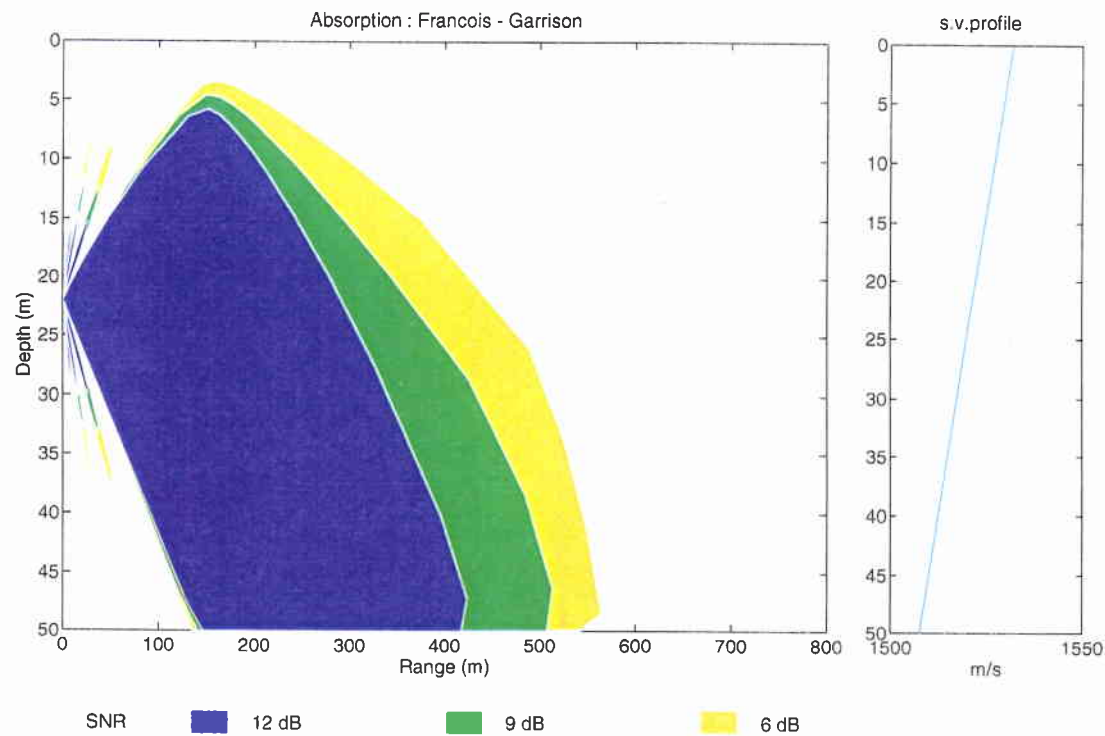


Figure 40 SNR contours using the François-Garrison model for absorption

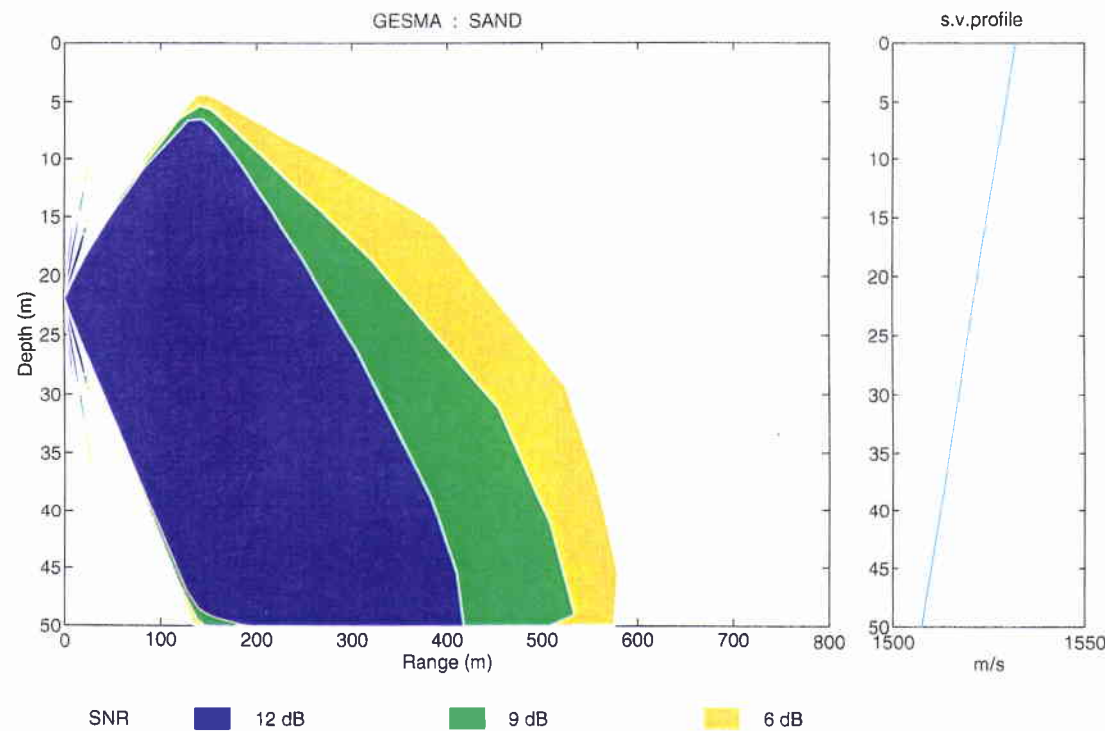


Figure 41 SNR contours using a GESMA model for bottom backscattering – sand bottom

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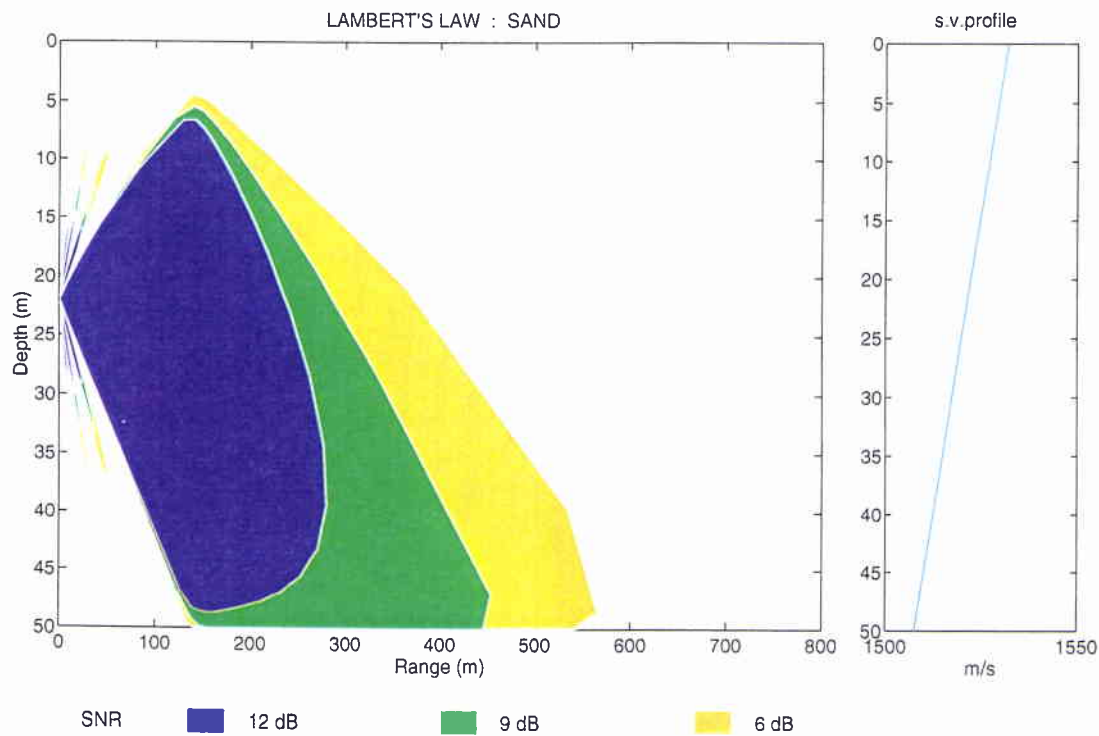


Figure 42 SNR contours using Lambert's Law for bottom backscattering – sand bottom

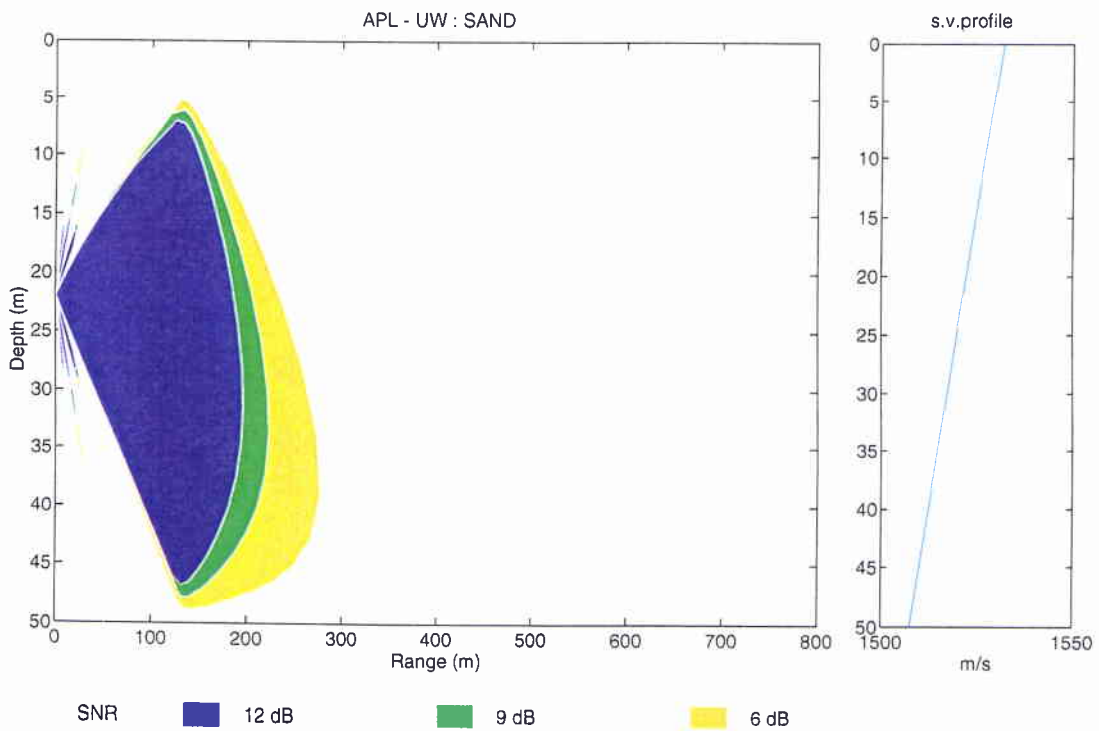


Figure 43 SNR contours using APL-UW model for bottom backscattering – sand bottom

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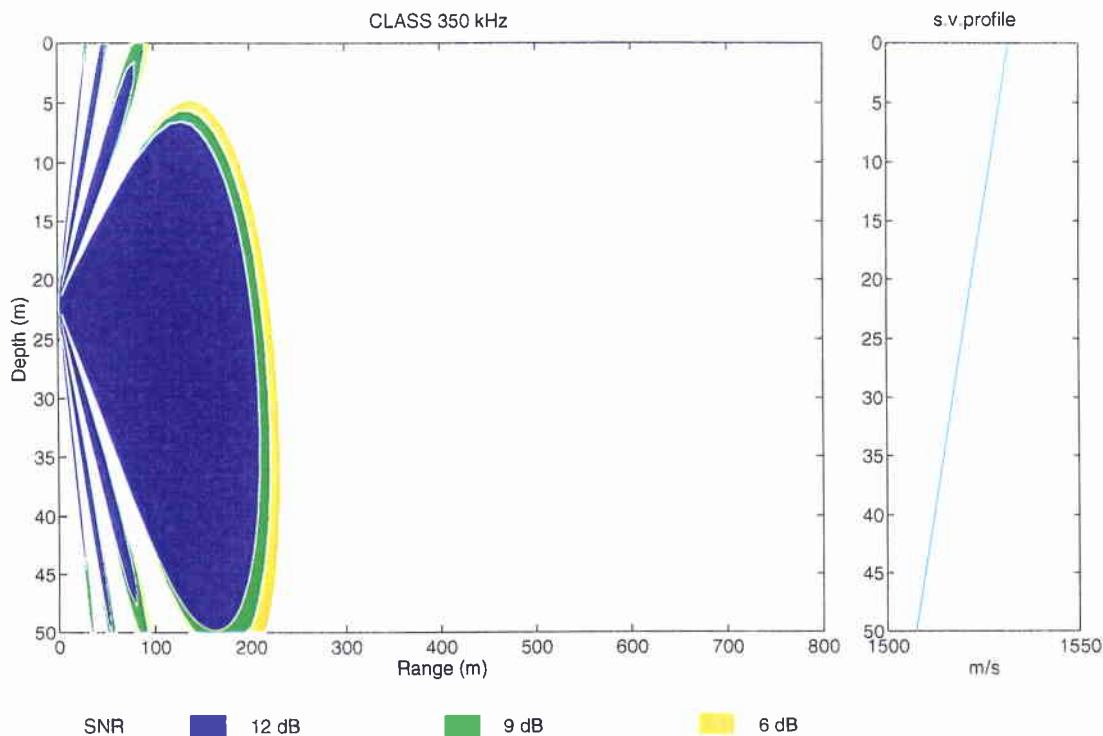


Figure 44 SNR contours for classification (350 kHz)

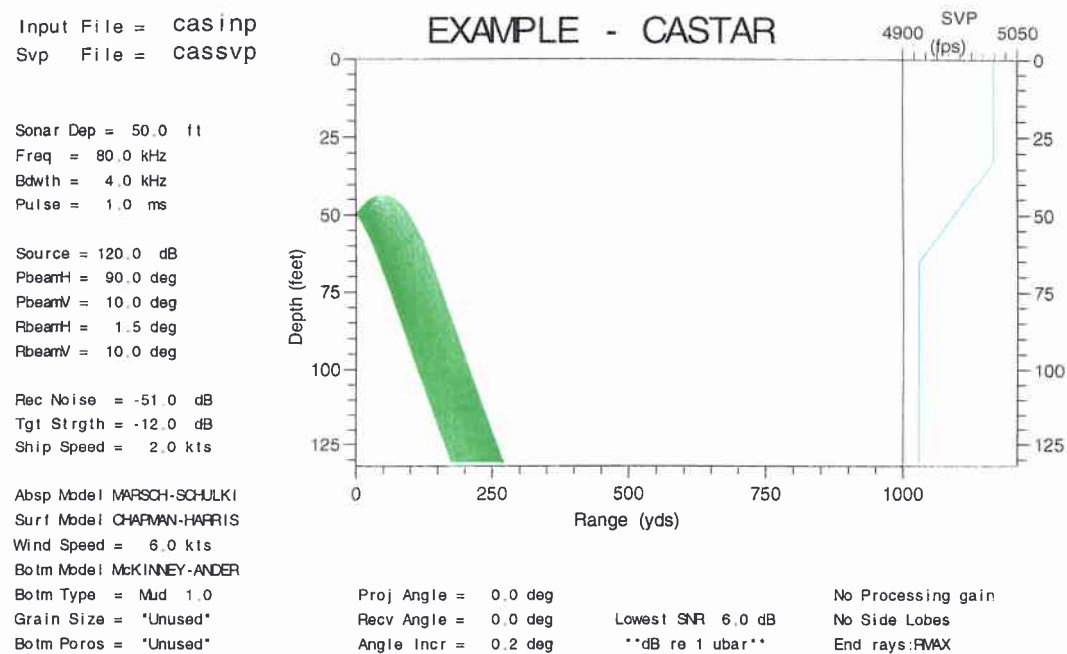


Figure 45 CASTAR sample display showing effect of strong sound speed gradient

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Input File = itninp
Svp File = itnsvp

Freq = 80.0 kHz
Bdwth = 4.0 kHz
Pulse = 1.0 ms

Source = 120.0 dB
PbeamH = 90.0 deg
PbeamV = 10.0 deg
RbeamH = 1.5 deg
RbeamV = 10.0 deg

Rec Noise = -51.0 dB
Tgt Strgth = -20.0 dB
Ship Speed = 2.0 kts

Absp Model MARSCH-SCHULKI
Surf Model CHARMAN-HARRIS
Wind Speed = 5.0 kts
Botm Model McKINNEY-ANDER
Botm Type = Mud 1.0
Grain Size = 'Unused'
Botm Poros = 'Unused'

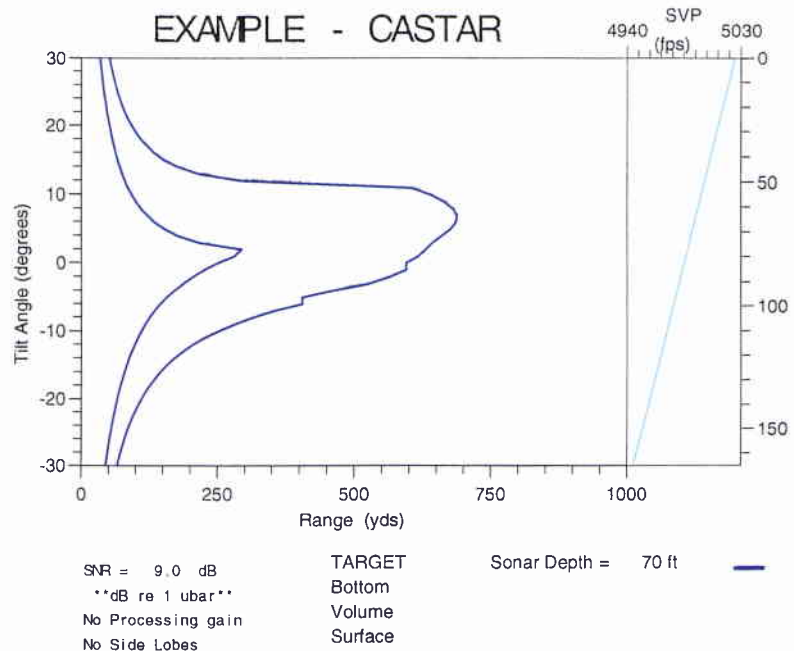


Figure 46 CASTAR: detection range versus tilt angle

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Svp File = itnsvp

Freq = 80.0 kHz
Bdwth = 4.0 kHz
Pulse = 1.0 ms

Source = 120.0 dB
PbeamH = 90.0 deg
PbeamV = 10.0 deg
RbeamH = 1.5 deg
RbeamV = 10.0 deg

Rec Noise = -51.0 dB
Tgt Strgth = -20.0 dB
Ship Speed = 2.0 kts

Absp Model MARSCH-SCHULKI
Surf Model CHARMAN-HARRIS
Wind Speed = 5.0 kts
Botm Model McKINNEY-ANDER
Botm Type = Mud 1.0
Grain Size = 'Unused'
Botm Poros = 'Unused'

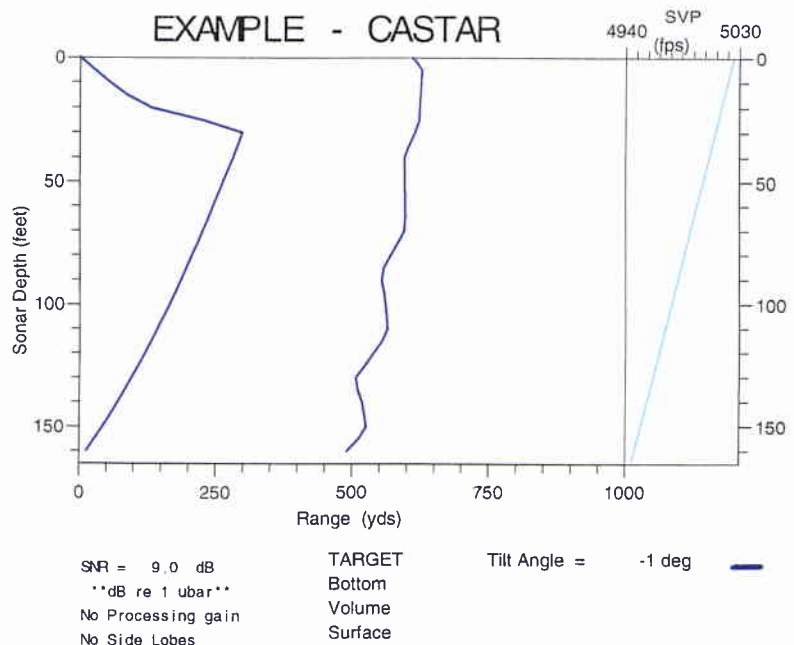


Figure 47 CASTAR: detection range versus sonar depth

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Svp File = itnsvp

Freq = 80.0 kHz
Bdwh = 4.0 kHz
Pulse = 1.0 ms

Source = 120.0 dB
PbeamH = 90.0 deg
PbeamV = 10.0 deg
RbeamH = 1.5 deg
RbeamV = 10.0 deg

Rec Noise = -51.0 dB
Tgt Strgth = -20.0 dB
Ship Speed = 2.0 kts

Abstp Model MARSCH-SCHULKI
Surf Model CHARMAN-HARRIS
Wind Speed = 5.0 kts
Botm Model McKINNEY-ANDER
Botm Type = Mud 1.0
Grain Size = "Unused"
Botm Poros = "Unused"

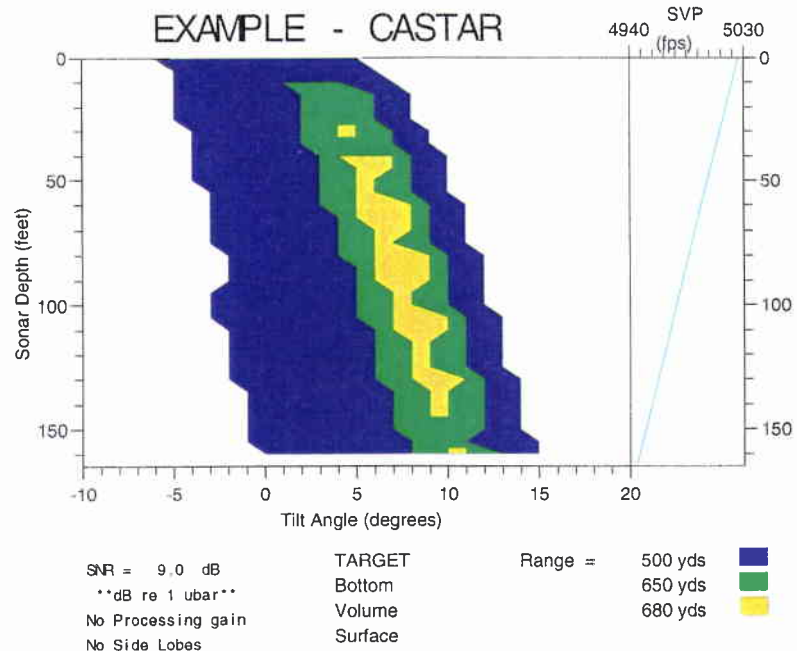


Figure 48 CASTAR: detection range contours of 500, 650 and 680 yds versus sonar depth and tilt angle

Input File = gsminp
Svp File = gmsvp

Sonar Dep = 15.0 ft
Freq = 80.0 kHz
Bdwh = 10.0 kHz
Pulse = 1.0 ms

Source = 120.0 dB
PbeamH = 90.0 deg
PbeamV = 20.0 deg
RbeamH = 1.5 deg
RbeamV = 20.0 deg

Rec Noise = -51.0 dB
Tgt Strgth = -15.0 dB
Ship Speed = 2.0 kts

Abstp Model FRANCOIS-GARRI
Surf Model CHARMAN-HARRIS
Wind Speed = 10.0 kts
Botm Model McKINNEY-ANDER
Botm Type = Mud 1.0
Grain Size = "Unused"
Botm Poros = "Unused"

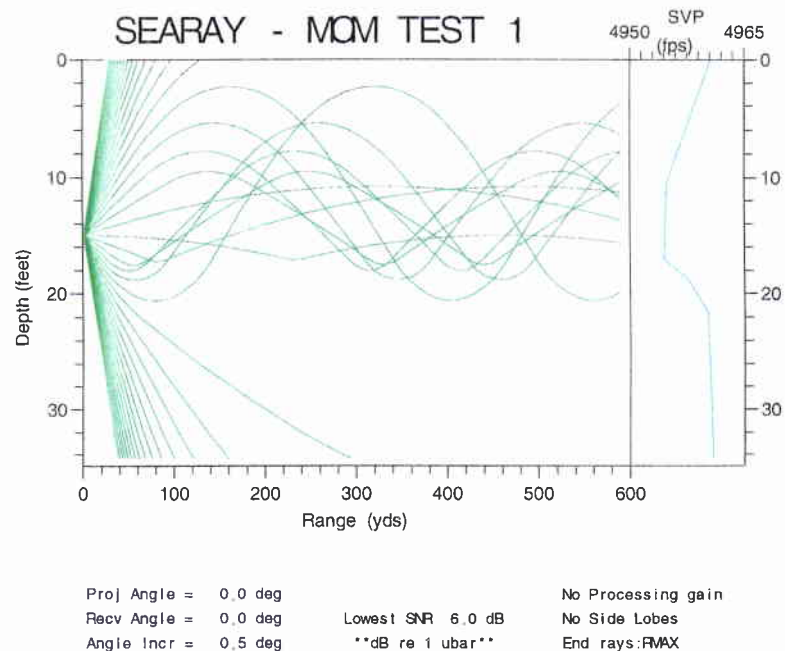


Figure 49 SEARAY: ray tracing

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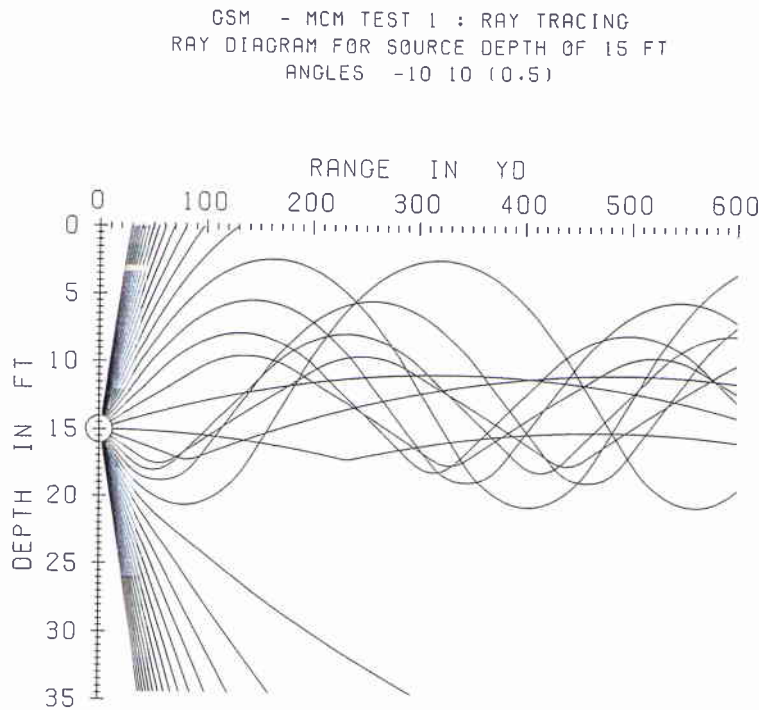


Figure 50 GSM: ray tracing

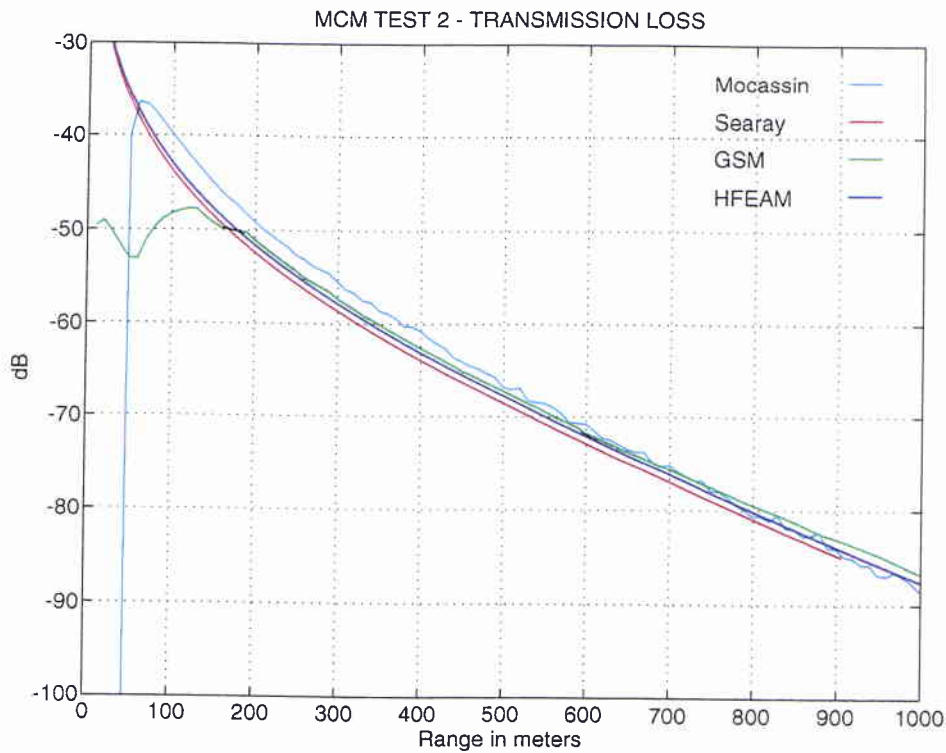


Figure 51 Transmission loss

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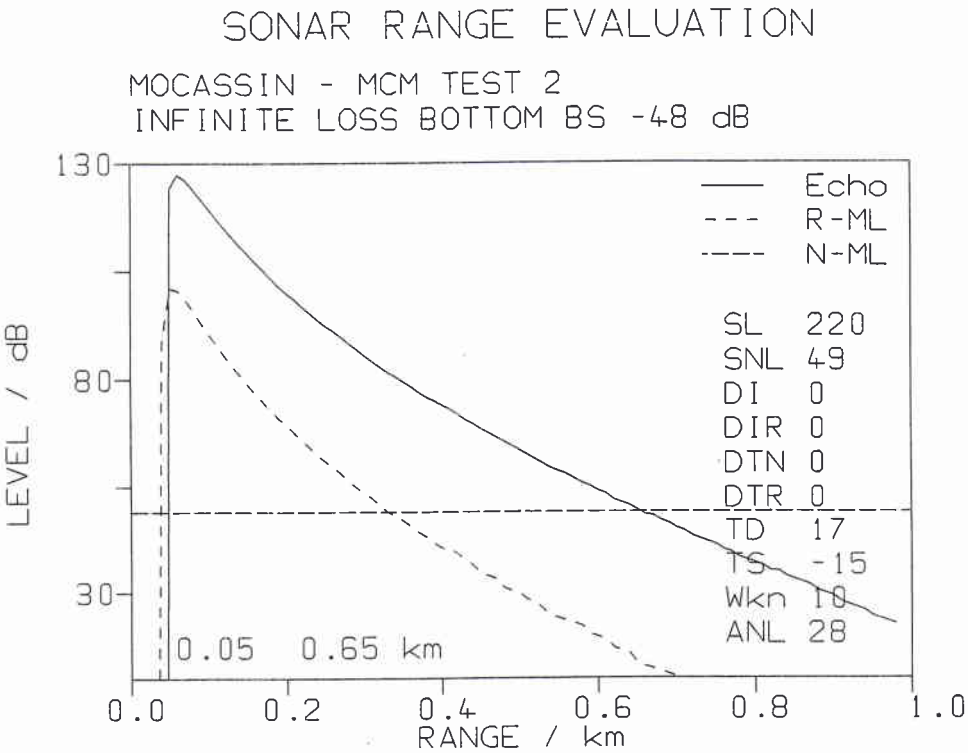


Figure 52 MOCASSIN: echo, reverberation and noise levels

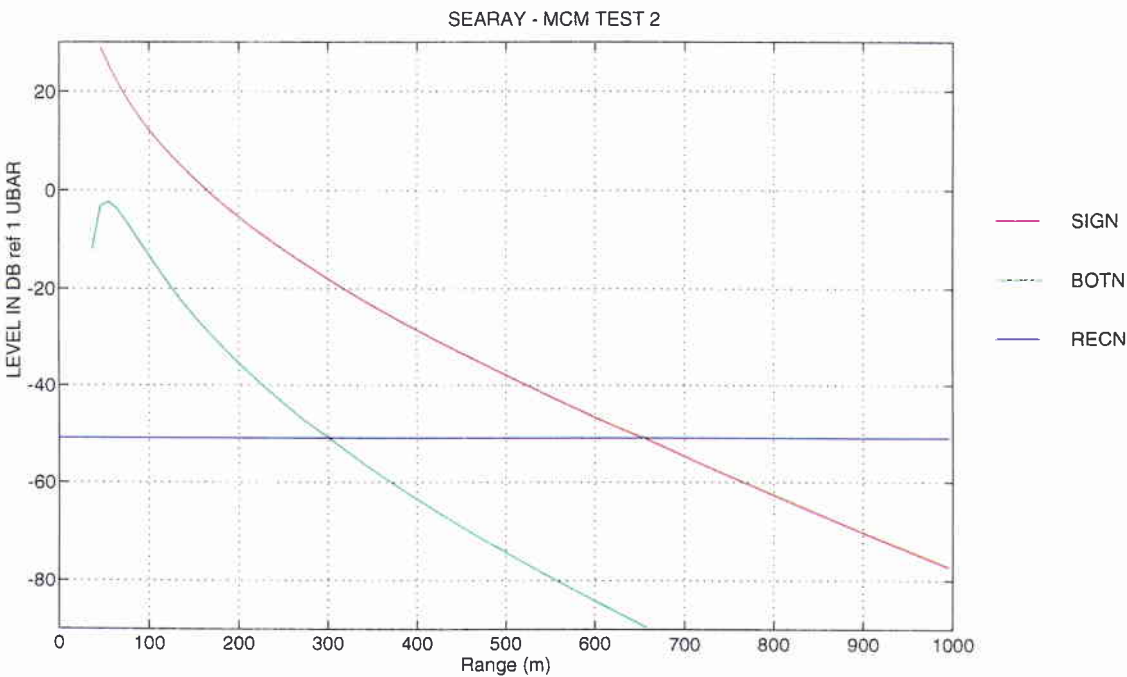


Figure 53 SEARAY: echo, reverberation and noise levels

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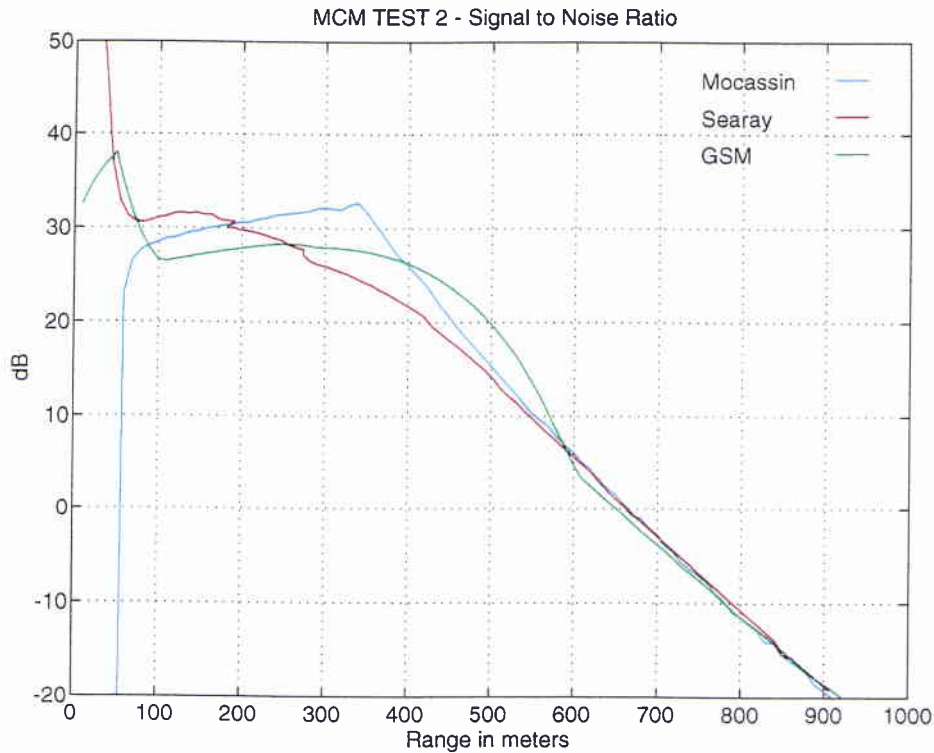


Figure 54 MOCASSIN, SEARAY, GSM signal-to-noise ratio

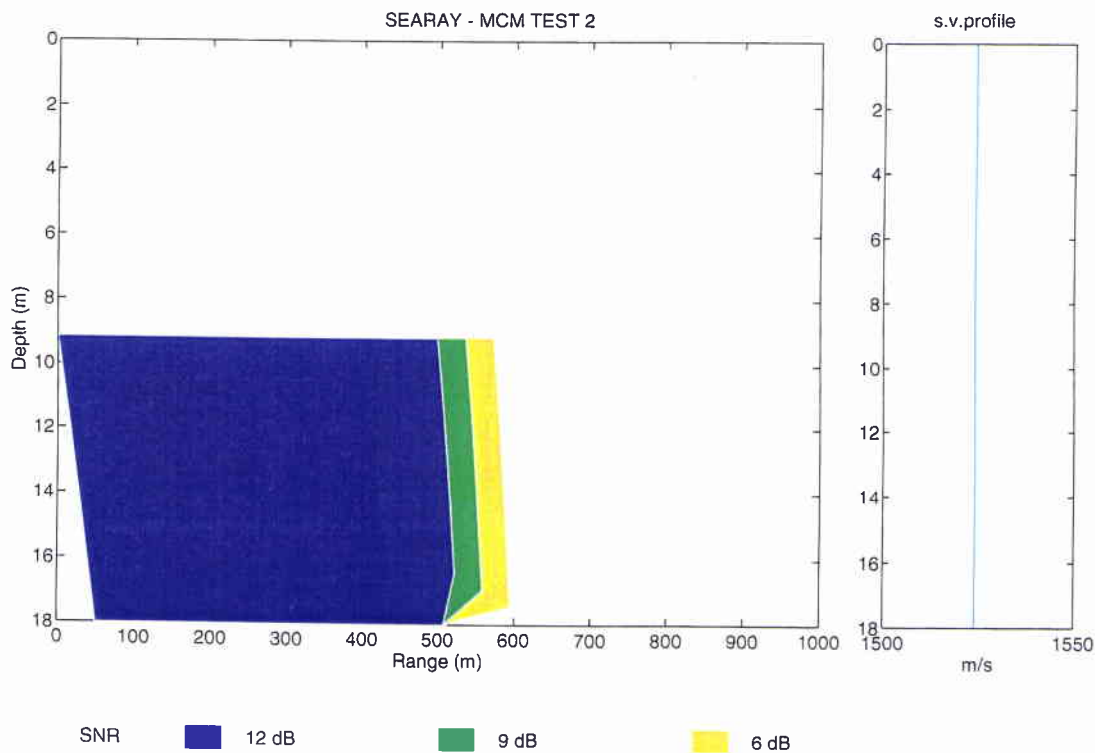


Figure 55 SEARAY: signal-to noise ratio

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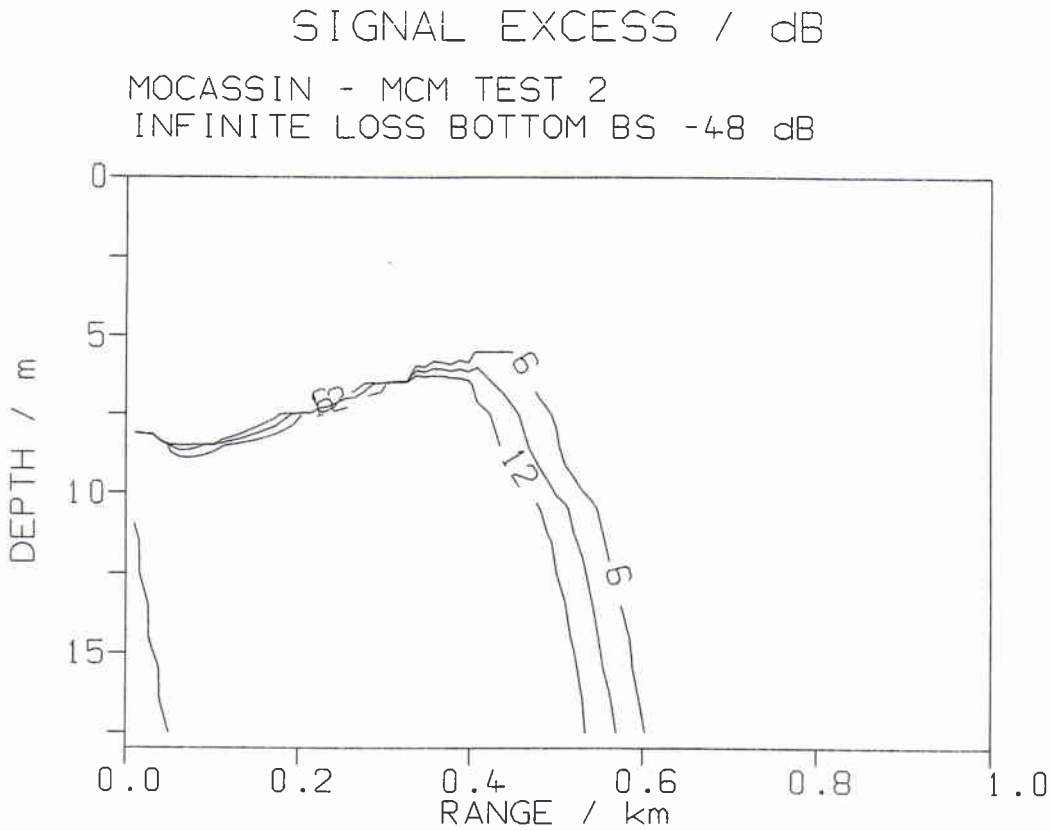


Figure 56 MOCASSIN: signal-to-noise ratio

Document Data Sheet

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Document Serial No. SM-315	Date of Issue November 1996	Total Pages 64 pp.
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Title Development of a SACLANTCEN MCM Sonar Performance Model		
Abstract The report describes the Mine Countermeasures Sonar Performance Model used at SACLANTCEN. This model is based on the environmental model SEARAY and uses ray tracing techniques. It determines sound paths in a horizontally stratified water column, computes signal-to-noise ratio along these paths and draws signal-to-noise contour curves. The model is range independent, and assumes a flat bottom with a single sound speed profile. Examples of the impact of the environmental parameters on sonar performance are provided. This report includes comparisons between high frequency environmental sub-models (attenuation, bottom or surface reverberation). Comparisons, using simple examples, between SEARAY and other sonar performance models (MOCASSIN, GSM, HFEAM) are also included.		
Keywords environmental acoustic model, sonar performance model, ray tracing, bottom backscattering, model comparison, SEARAY		
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