FIFTH INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
DECEMBER 15-18, 1997
ADELAIDE, SOUTH AUSTRALIA

TRANSMISSION LOSS: COMPARISONS BETWEEN EXPERIMENTAL DATA AND NORMAL MODE PREDICTIONS BASED ON A SEAFLOOR LITHOLOGY DATABASE

by
A.I. Larsson
Aeronautical and Maritime Research Laboratory
Defence Science and Technology Organisation, Salisbury
PO Box 1500, Salisbury SAust 5108
Email: asl@mod.dsto.gov.au

ABSTRACT

The prediction of underwater acoustics is important to show the capabilities of a theoretical sonar system and improving sonar systems. Unfortunately under water acoustics is complicated and awkward to model, especially the sea floor acoustics. Often many assumptions are made in order to model the acoustics of the sea floor.

Most under water models are covered under four categories, which are Normal mode theory, Ray theory, Parabolic equation and Fast field transform methods, but all require input of ocean floor acoustic properties. Those properties themselves are often poorly known and need to be estimated from geological data.

There are several models which link seafloor geological parameters to acoustic properties - for example Hamilton[1] and Biot[2]. For the Australian region the AUSEABED database Jenkins [3] provides data on the lithology and other geophysical properties of the seafloor, from which acoustic parameters may be estimated Jenkins[4]. Using this resource and a Normal mode model, transmission loss was calculated and compared with in situ measurements of transmission loss. A detailed error analysis is also involved.

1. INTRODUCTION

Transmission Loss formerly known as propagation loss is an important parameter in determining the performance of sonar equipment in the ocean environment. It is also one of the hardest to predict. There are many models used to predict this parameter but often the experimental value and the modelled data are not the same value. Sometimes they agree to within experimental error but rarely do. The most unfortunate aspect is the predictability of the transmission loss in a region where there are no transmission loss measurements. Also the transmission loss changes with sound speed profile of the water column which adds another dimension to the problem.

Consider the scenario of a sound source at depth z_0 and a sound receiver at depth z_1 and distance r from the source. (See Figure 1) At the sea surface (z=0) it is usually assumed the surface is fully reflective though some models assume some loss due to roughness. (See Macaskill [11]) At the sea floor (z=H) lies another boundary condition and another surface roughness parameter. The boundary conditions at z=H are usually continuity of sound pressure and the continuity of stress. These boundary conditions require knowledge of the sea floor. The parameters of the seafloor required are called the geophysical acoustic parameters which are the sea floor's compressional wave speed and attenuation, the shear wave speed and attenuation and density. It is these parameters that are awkward to find and are often guessed or inverted from measured transmission loss data. (See M. Collins, W.Kuperman and Schmidt [8]) Other methods consist of using inversion of reflection amplitude data which are seismic techniques that use low frequency data.
Other techniques are empirical that include Hamilton and Jenkins. Hamilton predicted most of his geophysical acoustic parameters based on mean grain size, which does not take into account the lithology, which means that it does not take into account whether the composition is silicate or carbonate.
Jenkins on the other hand derived his empirical formulas by data linking sediment properties like texture, consolidation and composition from published and unpublished literature. This data spanned a wide sediment texture range that occurs in the Australian maritime region. Unfortunately it is based mainly on surface samples and may not indicate what is below the surface.

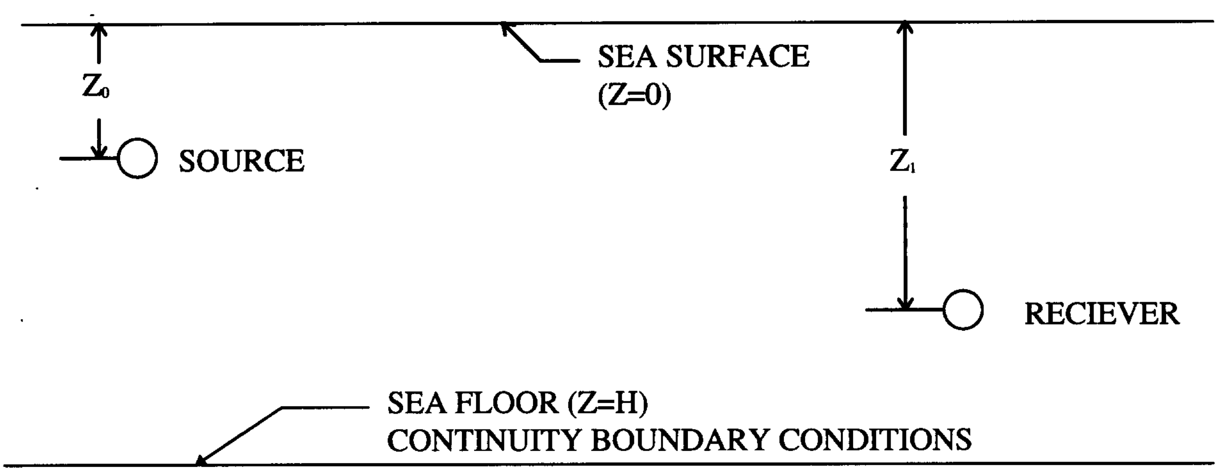

FIGURE 1: SCENARIO

This paper uses Jenkin's database and relations to predict the Geo-acoustic parameters of the sea floor required to predict transmission loss. Using these parameters in the normal mode model SUPERSNAP [16] transmission loss was predicted. Using the modal wave numbers and mode functions from SUPERSNAP in a smoothing process for broad band propagation (see Harrison and Harrison [12]) transmission loss was predicted.
The Harrison smoothed transmission loss (TL), the coherent narrow band TL and the Harrison smoothed TL for a depth 3cm less, was plotted with experimental data and its error bars. These are shown for three different sites and three frequencies in Figures2-11.
The selection of sites was based upon:-

1) where transmission loss experiments had been made
2) the amount of samples in the database near the sites
3) and the consistency of the compressional sound speeds within 10 kilometres of the site.

The details of the propagation model and experiment are given below.

2 THE TRANSMISSION LOSS MODEL

Normal mode models have been around for a long time and these provide a range dependent solution to the acoustic wave equation. Given the scenario in figure 1, and that the boundary conditions and sound speed profile are range independent, the normal mode solution to the Sound pressure P measured at the receiver due to a one Pascal signal given at the source of frequency f, is given as

$$P(r,z_1)=\frac{f\rho_0^2\sqrt{2\pi}}{2}\sum_{n=0}^{M}\frac{u_n(z_0)u_n(z_1)}{\sqrt{k_n r}}\exp(ik_n r)$$

where $u_n(z)$ is the (eigen)mode function and k_n is the eigen or modal wave number of the eigenmode number. Transmission loss is given by 20*log10(P(r,z)) where P is in µPascals. These eigen functions and numbers are effected by the sea floor boundary conditions. Not included in this type of model is surface roughness which is usually modelled as an attenuation. Attenuation in normal modal models is taken into account by a complex k_n which has α_n (attenuation) as the imaginary part of k_n

This formula is used in Supersnap [16], which is a normal modal model. The Jenkin's database is used for the Geoacoustic parameters on the seafloor. These parameters are assumed constant with depth and frequency on the sea floor and the infinite halfspace below the sea floor. Jenkin uses relaxation time to model attenuation (see LeBlanc [9]) and this makes the compressional attenuation frequency dependent. At site 2 the compressional sound speed was modified as the model to give the sound speed assumed 1500 m/s in the water which it was not for this case. All other parameters used, such as the water column sound speed profile and surface roughness were measured at the site during the experiment.

3 EXPERIMENTAL DATA

Several transmission loss experiments have been conducted at many locations in the shallow northern waters of Australia. The data presented here was collected by Marshall Hall Sandra Tavener and J.Carter from the Defence Science and Technology Organisation. The design of the experiment was a similar scenario as shown in Figure 1.

The source was a SUScharge that emits a short time scale broadband signal (spike). The receiver was a hydrophone attached to a calibrated sonobuoy which transmitted via a radio link, the received signal to a ship, where the recording equipment was held

This data was processed by a fast fourier transform and the received spectrum summed into one third octave bands. This one third octave spectrum was converted to micropascals, squared and converted to energy units. This had the energy of the noise subtracted from it and logged to form dB units. The dB energy received had the source strength subtracted from it to form the transmission loss measured.

The distance r was measured by noting the time of detonation of the Suscharge and recording the time of arrival of the first major Signal. This was divided by the average sound speed of the water column. This technique for range would roughly give an error of 50 metres but it gives no direction of the propagation the signal would come from and this would change with time as the buoy drifts. The usual depth z was assumed for the hydrophone as the buoy. The source depth was assumed to be the usual depth but this was checked by the bubble pulse emitted by the source. See Laurence,Prenc and Hill for more details [20].

An experimental error analysis of the trial results is described below.

3.1 EXPERIMENTAL ERROR ANALYSIS

The received pressure signal at the hydrophone was converted to electronic millivolts and the measured millivolts was transmitted by radio waves to a receiver antenna. This receiver then passed the signal electronically to a recording tape and a digitiser which stored the data on a computer Hard disk. The frequency response of the system without the hydrophone was measured as a straight line to within 0.2 dB for 70% of the cases. Then the sensitivity of the hydrophone, sonobuoy and receiver system was calibrated in water and measure as gradient of straight lines and the deviations was 0.8 dB for 80% of cases. This was quoted from an email message ref [15]. I took this to mean that the error of the mean of the measurement to be 1 dB for any frequency due to the calibration of the hydrophone to the receiver on the ship. The rest of the system on the ship was calibrated in the non dB scale by a 1 Volt sin wave which had an error of ±0.05 Volt. This gave an approximate error of ± 0.45 dB.

Another error is the error due to the digitiser which cuts the signal into finite values. This was given in terms of least significant bit and approximated to 0.6 dB. The error due to the source level of a SUScharge is given in Chapman [5] to be 1dB since we used his source level results. This gives the error of the mean of the transmission loss is 3.05 dB.

The remaining error to consider for the Transmission loss, is the deviation due to the noise present. The distribution of ambient noise varies but a paper by Neilsen and Thomas [14] looked at several noise sources within the ocean and concluded that most noise sources were non-Guassian and non-stationary. However it also said, especially for arctic conditions and shrimp, that the noise could be modelled as a mixture process of a Guassian background component and a random number of narrow-band components each with unknown phase and amplitude. I have assumed that the Guassian background noise will dominate on a first estimate basis. Unfortunately the data for background noise was not available at this present time for Hall's trial. An estimate of the background noise comes from the Cato [13]. Cato for the site the estimate of 80 dB for 100 Hz, 65dB for 2500Hz and 60 dB for 5000Hz was used

The pressure distribution for a known signal in Guassian noise has been well known for years and in books like Minkoff [19] proves it is the Rician Distribution with the parameters of signal strength and noise strength as being the only influence.. Source strengths for the SUScharge in one third octave bands come from Chapman for low frequencies and Gaspin and Shuler [6] for high frequencies. The number of samples in the averaging over the one third octave frequency range is based on about one Hertz per sample. These values were used to calculate the variance of the ambient noise estimate and thus variance in the signal level due to fluctuating guassian noise. The error in the transmission loss due to the noise was taken at the 99% probability level. This turned out to be very small due to the high signal to noise ratio.

The shear of current can affect the depth of the hydrophone. If a shear current of 5 knots was applied to the hydrophone and not to the surface canister, then the hydrophone with roughly a drag coefficient of 0.4 would be raised by approximately 3 centimetres. Thus the second

Harrison smoothed curve of transmission loss to show the variation of the transmission loss with a small deviation in receiver depth.

4.1 COMPARISON

A comparison of the Geoacoustic parameters from the Ocean Science Institute's Data base predictions of the Ocean floor acoustic properties placed in SUPERSNAP and used to predict transmission loss for the sound speed given on the day with other measured parameters. This transmission loss was plotted against measured transmission loss with error bars for several sites at three different frequencies. Only results from two sites are shown. The frequencies were 100 Hz, 2500 Hz and 5000 Hz. The comparison at low frequencies for all sites was poor as expected as the low frequencies penetrate deeper into the sea floor and are affected by sub-surface structure. The high frequencies have tendency to penetrate less and are affected by near surface acoustic properties.

SITE 2

Figures 2-4 show the transmission loss for three frequencies at site 2 which has a compressional sound speed of 1557 m/s. This seafloor is nearly transparent to an acoustic wave which should produce a high transmission loss. In figure 5 at 100Hz there is only one mode so the Harrison smoothing does not work because of an approximation in the number of modes. The cut off frequency is about 50 Hz. The coherent transmission loss should be taken as the modelled data. This transmission loss agrees reasonably with the experimental transmission but is not with in its error bars. The higher the frequency, the poorer the agreement. This is due to the transparent nature of the seafloor. The acoustic wave at higher frequencies is finding the seafloor interface nearly transparent and is reflecting off some sub-surface layer. This is causing a lower transmission loss than if the whole seafloor half space was homogeneous. This prediction is badly out but with a surface sample showing it is transparent to acoustic waves it should be expected.

SITE 4

Figures 5-7 show the transmission loss at one site for three frequencies This site had the data base give it a value of 1767 m/s for compressional sound speed. Figure 5 shows the 100 Hz transmission loss and the comparison shows poor agreement as expected. The database estimate is only a surface sample and low frequencies are affected by deeper sedimentary layers than just the surface. These results show very little fluctuations in the transmission loss. The higher frequencies of 2500 Hz Figure 6 and Figure 7, 5000 Hz ,the modelled data compares well. In fact at the 5000 Hz the modelled data is within experimental error. This site did have very different mean grain size but the database class the sound speed of all the samples as having a sound speed of 1767m/s.

5 CONCLUSION

The poor results at low frequencies show that surface samples are not enough information to give good Geoacoustic parameters for all frequencies. It is important to know what is below, specially at low frequencies or when the sea floor surface sample indicates that it is transparent.

The surface values do give an indication of what to expect. The reasonably reflective surface samples gave reasonable comparisons to the experimental values at high frequencies but often not within the error bars. Completely transparent samples gave poor comparisons. Roughness is a key factor not taken into account in this comparison.

The noise model to give the variation in transmission loss could be done better with a better understanding of the pressure distribution of the ambient noise.
Site 4 had varying mean grain sizes from 0.2 -2 phi and using the composition of the sea floor a single compressional sound speed was given in the data base. This value gave a good comparison in Transmission loss modelling to that of the experimental data.

Future work

1) Investigate other methods
2) Correlate OSI data to inversion process acoustic parameters to form a relational database.
3) Investigate means of finding substructures in the Sea floor This is work is to be with Australian Geological Survey Organisation

6. REFERENCES

[1] Hamilton (1980) "*Geoacoustic Modelling of the Sea Floor*", J.A.S.A. **68**, 1313-1340

[2] Biot (1962) "*Generalised Theory of Acoustic Propagation in Porous Media*" J.A.S.A **34** 1254-1264

[3] Jenkins, C.J. (1997). "*AUSEABED version 7 Seafloor Database and GIS of the Australian EEZ: Structure, Content and Function*". Univ. Sydney Ocean Sci. Inst. Rep., **61**. [With Digital Database].

[4] Jenkins, C.J. (1997) "*Relationships between Geological/Geophysical and Acoustic Properties in the Australian Seafloor*". Univ. Sydney Ocean Sci. Inst. Rep. **73**

[5] Chapman, N.R.. (1985) "*Measurement of the waveform parameters of shallow explosive charges*" J.A.S.A. **78** pp 672-681

[6] Gaspin, J.B. and Shuler, V.K. (1971). "*Source levels of shallow underwater explosions*" (NOLTR-71-160,50p). White Oak, MD: Naval Ordnance Laboratory.

[8] Collins, M.D., Kuperman W.A. and Schmidt H. " *Nonlinear inversion for ocean-bottom properties*" J.A.S.A. **92** (5) November 1992 pp2770-2783

[9] LeBlanc, L.R., Pand, S. and Schock, S.G. "*Sonar attenuation for classification of marine sediments.*" J.A.S.A.**91**, p 116-126.

[11] Macaskill C., "*Acoustic Scattering from the Sea surface*" , Acoustics Australia **20**(3) p99-101,(1992)

[12] Harrison, C.H. and Harrison J.A. "*A simple relationship between frequency and range averages for broadband sonar*", J.A.S.A. **97**(2) February 1995 p1314-1317

[13] Cato, D. "*The Biological Contribution to the Ambient Noise in waters near Australia*", Acoustics Australia **20** (3) p76- 80 December 1992

[14] Nielson, P.A. and Thomas J.B. "*A comparison of parametric and nonparametric detector performance levels in underwater noise*" J.A.S.A **87** (1) January 1990 p225-236

[15] Taverner, S. *Private Communication* 1997

[16] Jensen F. B. and Ferla M.C. "*SNAP: the SACLANTCEN Nornal -Mode Acoustic Propagation Model*" SACLANTCEN Memorandam SM-121 (1979)

[17] Hall M.V., Tavener, S. and Carter J. "*Shallow Water Transmission Experiments in the Timor and Arafura Sea*" Technical Report MRL-TR- (to be published)

[18] Hall M.V. and Tavener, S " *Measurements and Modelling of Acoustic Transmission loss in the Timor Sea and the Northwest Australian Continental Shelf* " Technical Report MRL-TR (to be published)

[19] Minkoff J., "*Signals, Noise, and Active Sensors : Radar, Sonar, Laser Radar*" John Wiley and Sons, Inc U.S.A. 1992

[20] Lawrence M.W., Bell M.J. and Prenc S. "*Acoustic Propagation by Bottom Bounce Mode to the North East of Australia* " AR-008-549 1994

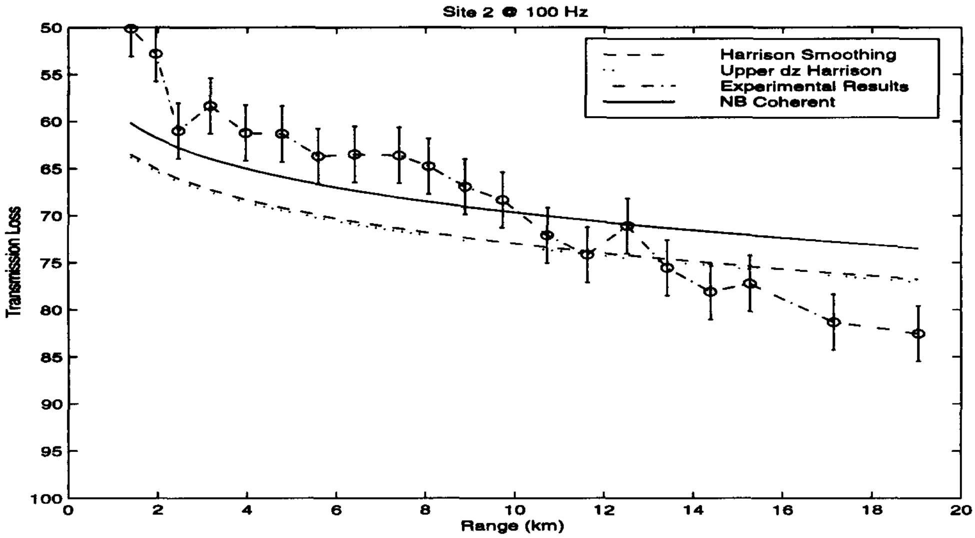

Figure 2: Transmission Loss for Site 2 at 100Hz

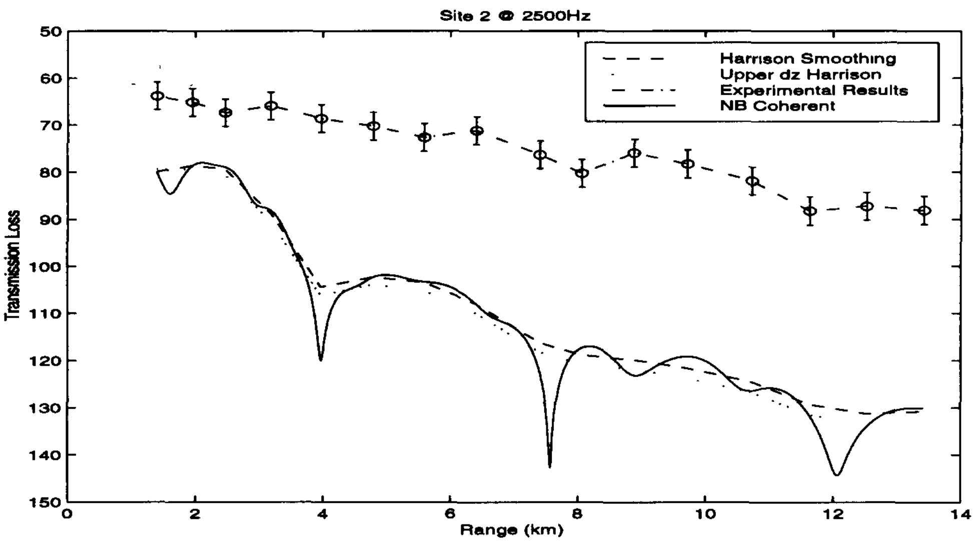

Figure 3: Transmission Loss for Site 2 at 2500Hz

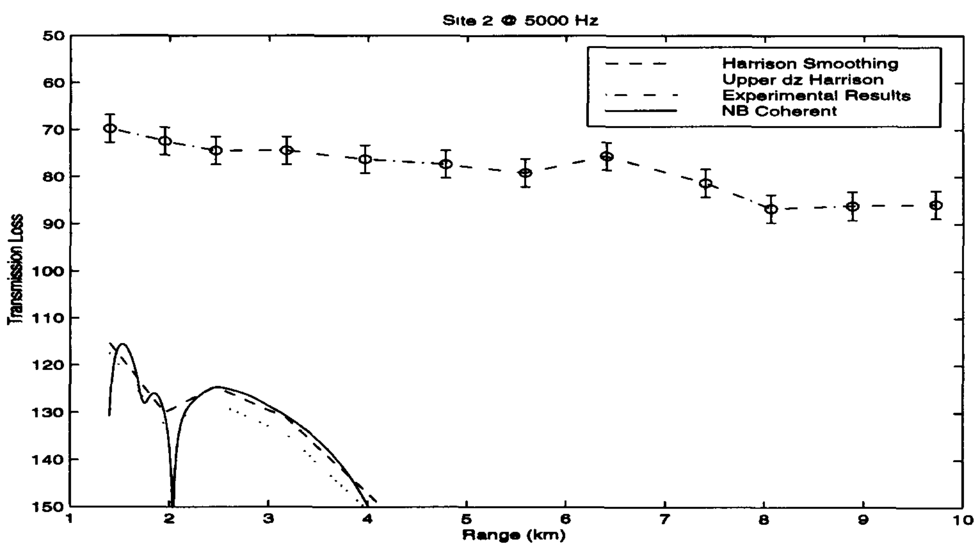

Figure 4: Transmission Loss for Site 2 at 5000Hz

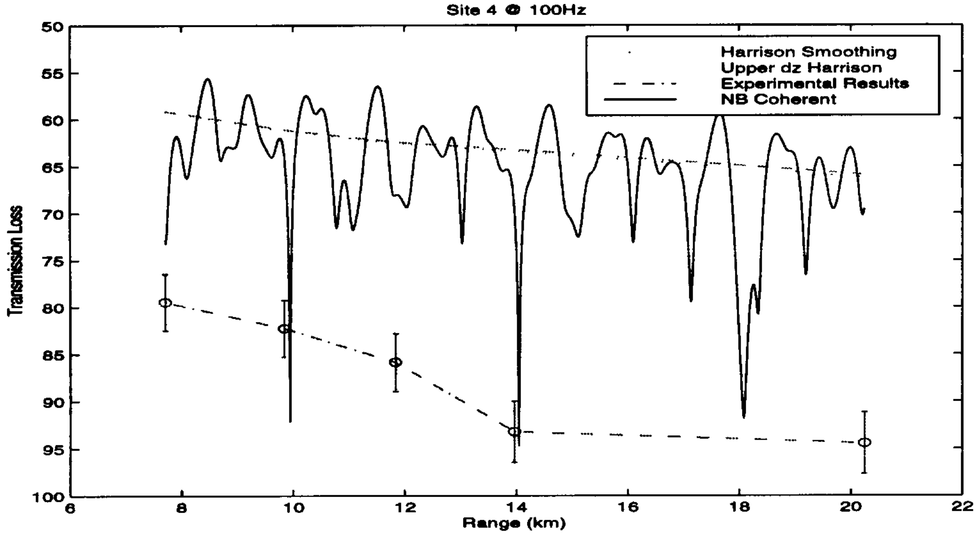

Figure 5: Transmission Loss for Site 4 at 100Hz

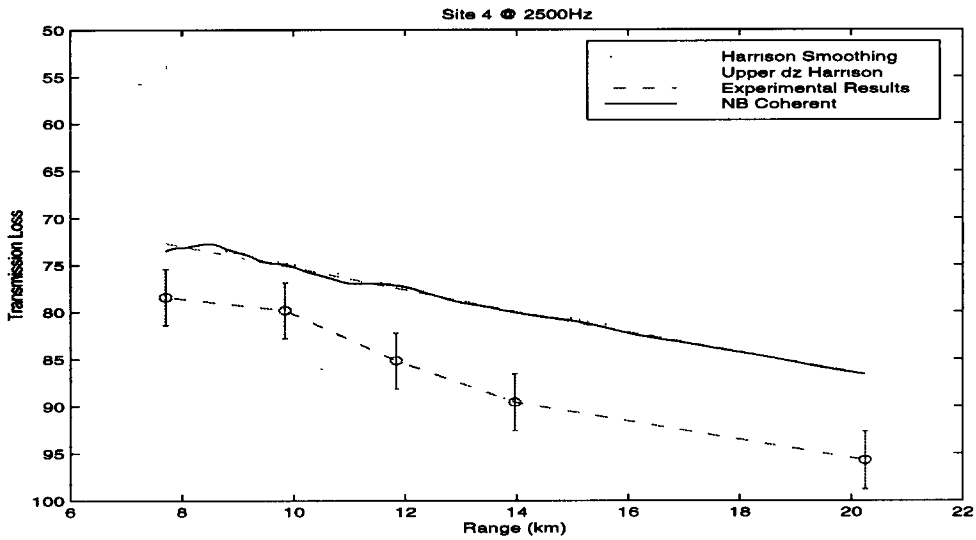

Figure 6: Transmission Loss for Site 4 at 2500Hz

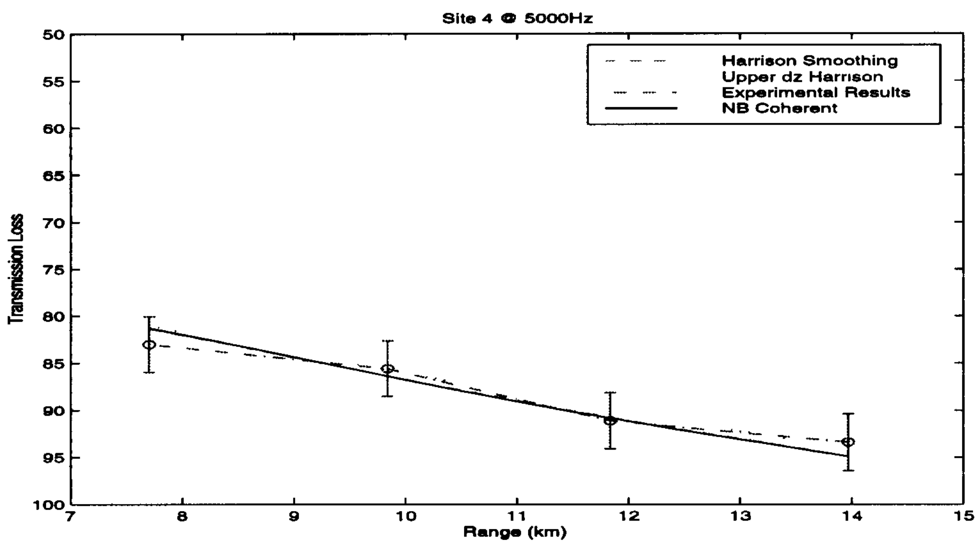

Figure 7: Transmission Loss for Site 4 at 5000Hz