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LEVEL II

Regional Dependence of Very Low-Frequency Sound Attenuation in the Deep Sound Channel: Correlation with Internal Wave Measurements

A Paper Presented at the Joint Meeting of the Acoustical Society of America and the Acoustical Society of Japan, 27 November—1 December 1978, Honolulu, Hawaii

David G. Browning
Michael J. Fecher
Robert H. Mellen
Surface Ship Sonar Department

Naval Underwater Systems Center
Newport, Rhode Island / New London, Connecticut

Preface

This document was prepared under the sponsorship of the Naval Material Command under NUSC Project No. A65410, "Acoustic Variability Within the Sound Channel," as part of the NUSC Independent Research Program; NAVMAT Program Manager, CAPT D. F. Parrish, and NUSC Principal Investigator, D. G. Browning.

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W. A. Von Winkle

W. A. Von Winkle
Associate Technical Director
for Technology

The authors of this document are located at the New London Laboratory, Naval Underwater Systems Center, New London, Connecticut 06320.

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This document presents the oral and visual presentation entitled "Regional Dependence of Very Low-Frequency Sound Attenuation in the Deep Sound Channel: Correlation with Internal Wave Measurements," presented at the joint meeting of the Acoustical Society of America and the Acoustical Society of Japan, 27 November-1 December 1978, Honolulu, Hawaii.

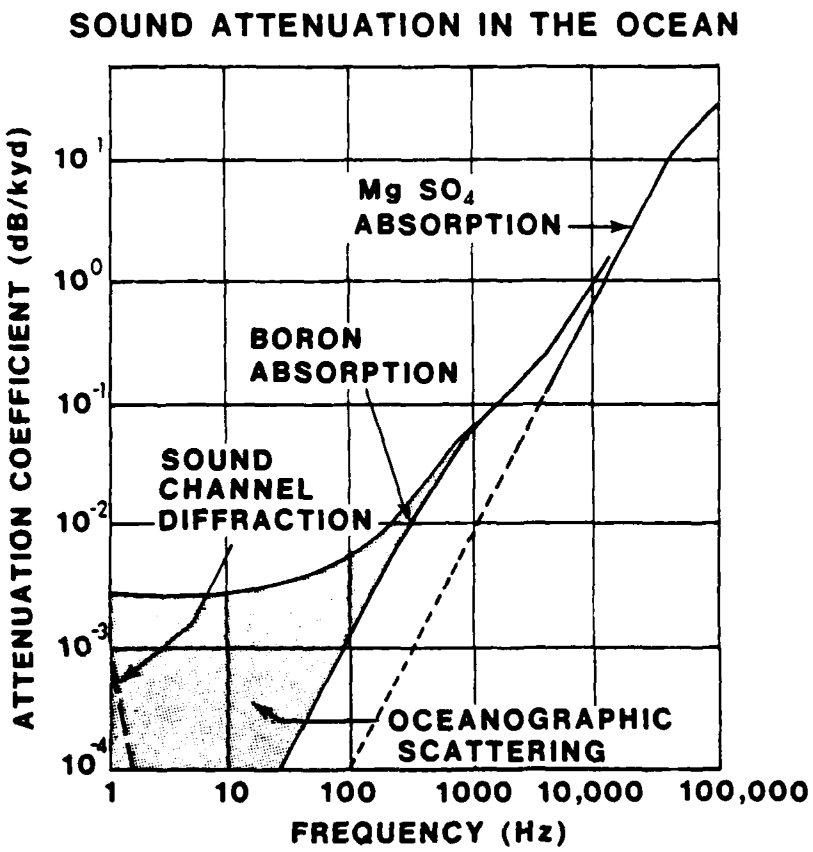
The most promising mechanism for the very low-frequency sound attenuation observed in the deep sound channel is diffusive scattering by internal —

20. (Continued)

waves. Mellen et al. (J. Acoust. Soc. Am., 60, 1053-1056 (1976)) have obtained estimates for the extra attenuation using the Garrett-Munk internal wave model and found consistency with the lower experimental values reported. Kibblewhite et al. (J. Acoust. Soc. Am. 63, 1169-1177 (1978)) have shown a definite regional dependence in the Pacific.

In this paper we compare regional oceanographic measurements with the Garrett-Munk internal wave model and also correlate local acoustic measurements with estimates of the extra attenuation.

Regional Dependence of Very Low-Frequency Sound Attenuation in the Deep Sound Channel: Correlation with Internal Wave Measurements



Slide 1

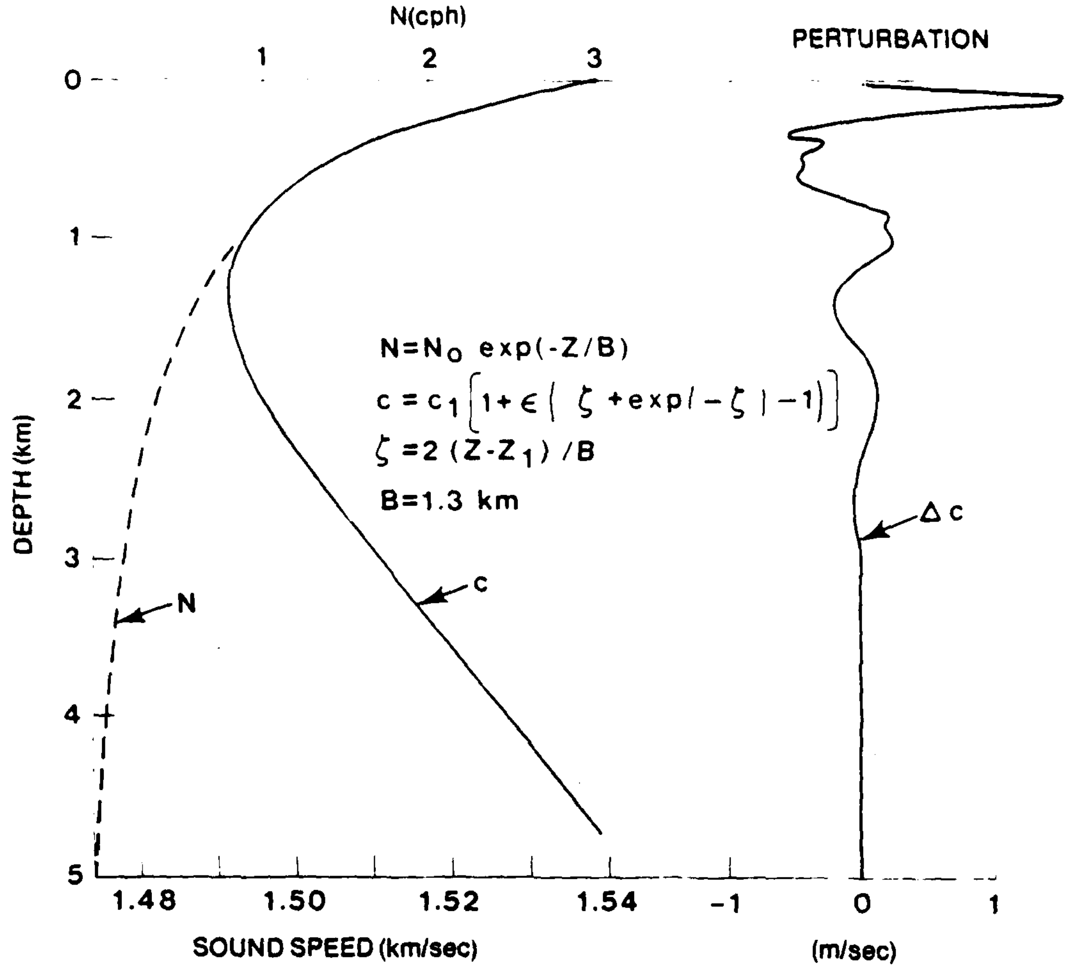
At most frequencies, measurements of the attenution of sound in the sea can be explained by chemical absorption mechanisms. For very low frequencies, typically below 100 Hz, the measured attenuation is consistently higher than expected from absoprtion alone.

This excess attenuation, generally attributed to diffusive scattering loss from oceanographic inhomogeneities, ranges from 4 to 50×10^{-4} dB/km depending upon the geographic location of the experiment.

Mellen, Browning, and Goodman* have estimated the attenuation coefficient for an idealized deep sound channel perturbed by internal waves based on the Garrett-Munk formulation. The result, 5×10^{-4} dB/km, is consistent with the lower experimental values.

The following discussion will show that improved predictions of low frequency attenuation coefficients can be obtained using internal wave theory if regional deviations from the ideal ocean are considered.

*"Diffisuion Loss in a Stratified Sound Channel, *Journal of the Acoustical Society of America*, vol. 60, no. 5, November 1976.



Slide 2

For long-range diffusion loss in a stratified sound channel, we consider a plane acoustic wave propagating through random lenticular sound speed inhomogeneities that have large-scale dimensions compared with the acoustic wavelength. In particular, an exponential buoyancy frequency profile N (dashed line) and the resulting canonical sound speed profile C are assumed. Typical values are shown. B is the vertical scale of the sound channel. Internal wave displacements produce inhomogeneities by perturbing the sound speed profile, as suggested on the right-hand side.

TRANSVERSE DIFFUSION CONSTANT AT SOUND CHANNEL AXIS

$$D_1 \approx 4\mu_1^2 j_* n_1 \left(\frac{n_1}{\omega_i}\right)$$

ATTENUATION COEFFICIENT FOR DIFFUSIVE SCATTERING

$$\boxed{\alpha_1 = \frac{13\,D_1}{\theta_0^2 B}\ \mathrm{dB/km}}$$

---

where,

μ_1^2 = variance of refractive index $\cong \overline{\left(\frac{\Delta c}{c}\right)^2}$

θ_o = initial angle of bottom-limited array

B = scale size of sound channel

n_1 = (scaled) buoyancy frequency

ω_i = (scaled) inertial frequency

j_* = internal wave mode scale number, typically = 3

Slide 3

Then, for small ray angles, the vertical transverse diffusion constant and the attenuation coefficient are evaluated at the sound channel axis, as indicated by subscript 1, μ^2 is the variance of refractive index, and θ_0 is the initial angle for the bottom-grazing ray.

Values of μ^2, B, n, and θ_0 have been inferred from two sets of oceanographic data collected at mid-latitudes in the North Atlantic. Resulting attenuation coefficients will be compared with the acoustically-derived coefficients.

GENERAL (1) $$\mu^2(z) \equiv \overline{\left[\frac{\Delta c(z)}{C}\right]^2} = \overline{\left[\frac{\partial_z C_p(z)}{C}\right]^2}\ \zeta^2(z)$$

INTERNAL WAVE - CANONICAL MODEL

(2) $$\zeta^2(z) = \zeta^2_o \frac{No}{N(z)}, \quad \zeta(z) = \text{rms IW displacement } z = o = 7.3\ m$$

(3) $$\frac{\partial z\ C_p(z)}{C} = \eta(z)\ N^2(z)/g$$
$$\approx \eta o\ No^2/g\ [\exp(-2z/B)]$$
$$\text{where } \eta o = 24.5 \approx \eta(z)$$

(4) $$N(z) = No \exp(-z/B), \quad No = 3 \text{ cph}, B = 1 \text{ km}$$

(5) $$\mu^2_c(z) = \mu^2_o \exp(-3Z/B) \approx 2.4 \times 10^{-7} \exp(-3Z/B)$$

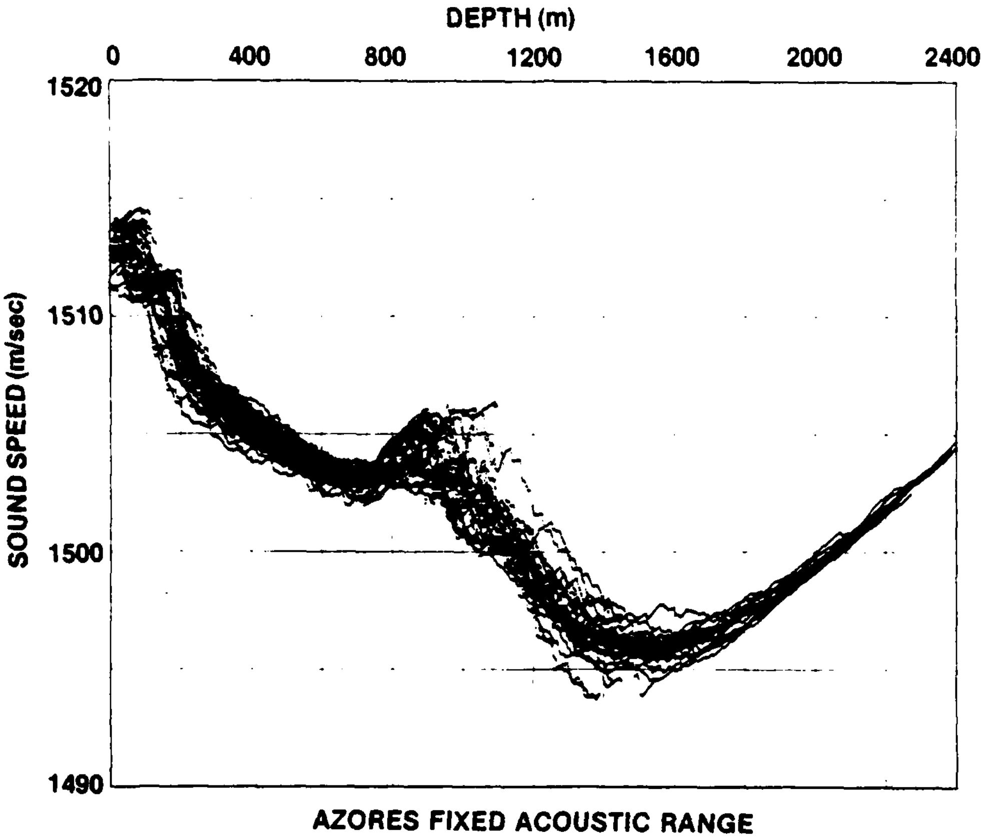
INTERNAL WAVE - NON-CANONICAL

(6) $$\mu^2_{nc}(z) = \frac{\langle[\partial_z C_p(z)]^2\rangle}{C^2}\ \langle\zeta^2_d\rangle\ \frac{N_d}{\langle N(z)\rangle}$$

Slide 4

But first we recall that mean-square fluctuations in sound speed (μ^2) are related to vertical perturbations by equation 1. Here, zeta is the rms displacement amplitude, and $\partial_z C_p$ is the potential sound speed gradient. Variations in internal wave amplitude with depth can be scaled according to the buoyancy profile (as in equation 2). The potential sound speed gradient is also related to N by equation 3. Assuming idealized exponential stratification (equation 4) then yields equation 5, a canonical model wherein μ^2 decays exponentially with depth.

Equation 6 is non-canonical in that exponential stratification is not assumed. Instead, the internal waves perturb the actual sound speed profile; wave amplitude is scaled to the existing buoyancy profile and a measured rms displacement at depth d. One set of measurements used to evaluate equation 6 was conducted in the Azores Fixed Acoustic Range.

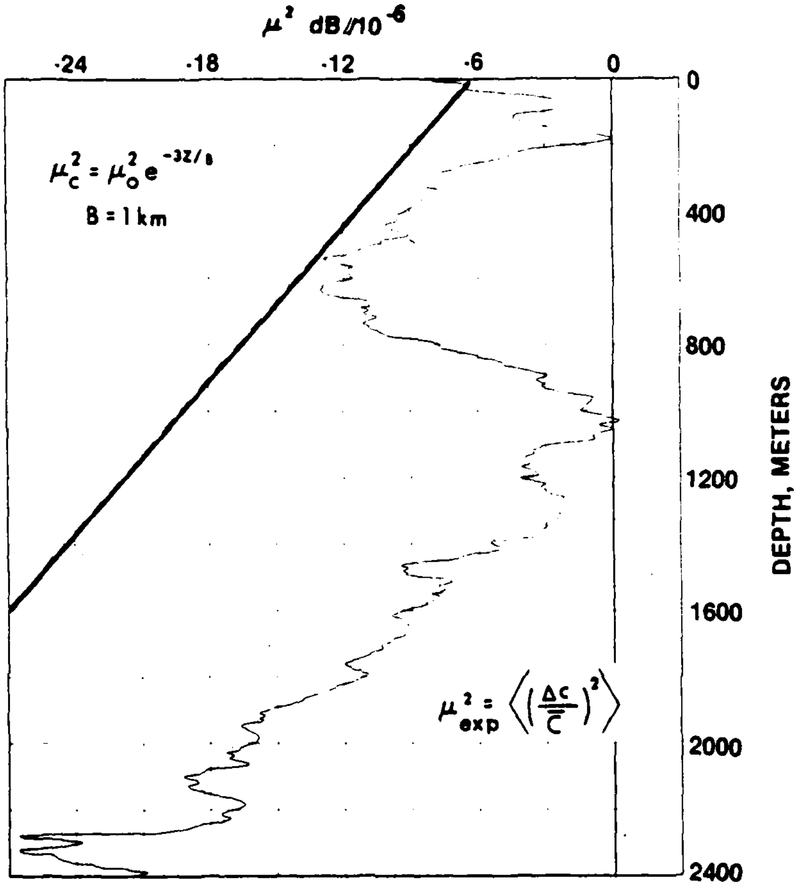


Slide 5

This is a composite of 46 sound speed profiles collected in the Azores Range. Three similar data sets were collected concurrently with profiling systems onboard other ships. Each data set shows the same spread in sound velocities, and the intrusion of the Mediterranean water at 900 meters.

These fluctuations in sound speed were used to calculate μ^2 directly.

CANONICAL MODEL VS. MEASUREMENTS (AZORES)

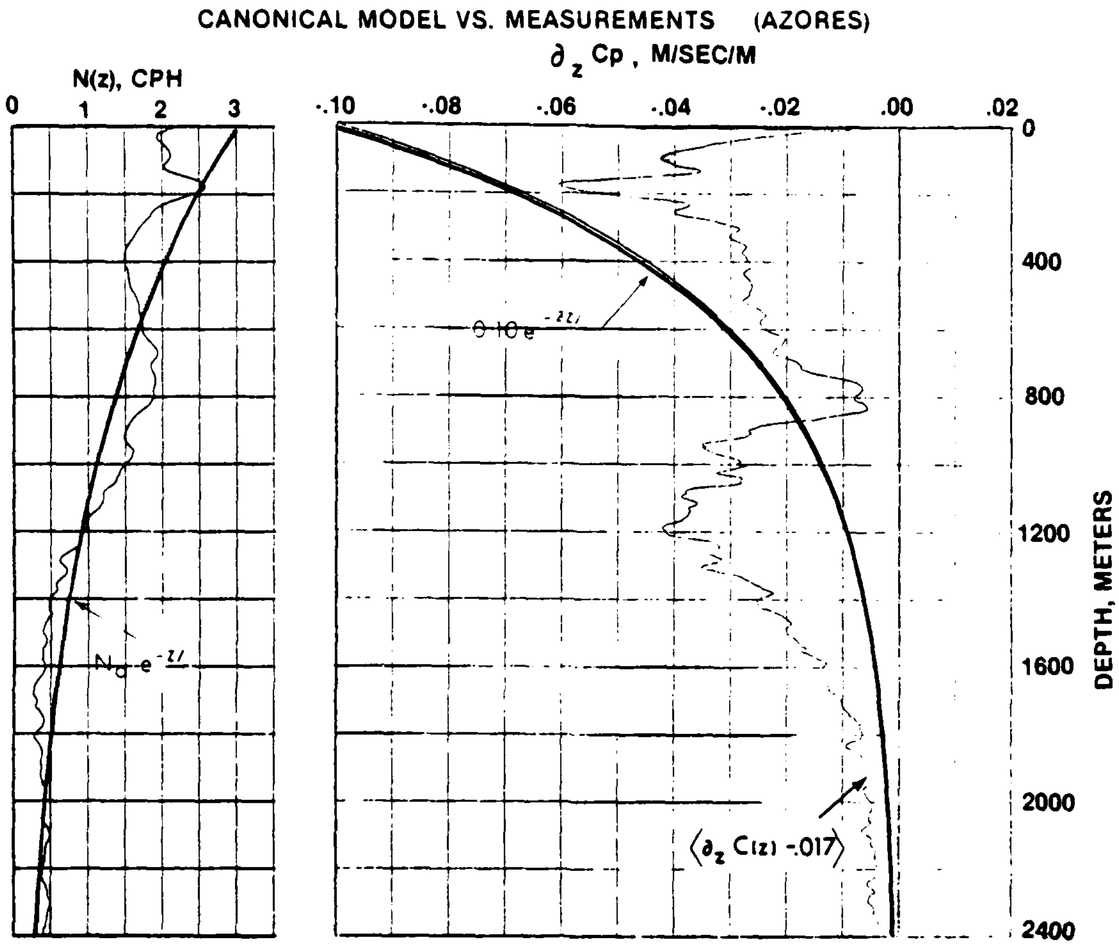


Slide 6

Here μ^2 has been scaled as dB relative to 10^{-6}. The thick solid line is the canonical internal wave model. Above 600 meters and below 1000 meters, the measured values agree with the canonical decay rate.

However, at the deep sound axis (~1500 meters), the observed μ^2 is at least 17 dB larger than given by the canonical equation.

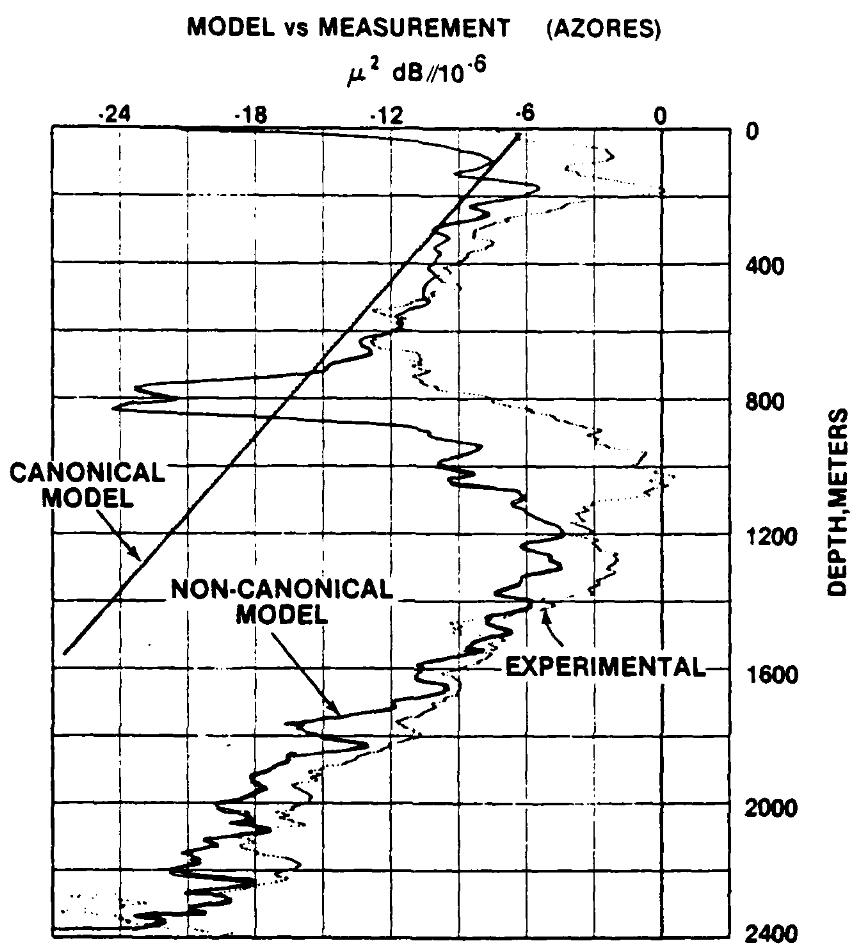
To infer whether these observed values can be attributed to internal waves in the real ocean, μ^2 was calculated using the non-canonical model, that is, without assuming exponential stratification. Inputs to the model are now examined.



Slide 7

A comparison of the canonical profiles of buoyancy frequency and potential sound speed gradient (thick solid lines) is made with averages obtained from STD casts. Significant differences occur, primarily in response to the Mediterranean Water instrusion.

In addition, a 17-meter rms internal wave amplitude was estimated from two thermistor arrays moored at 375 meters in the Azores Range. This compares with a 9-meter canonical amplitude for the same depth. Results of the non-canonical model are now shown.

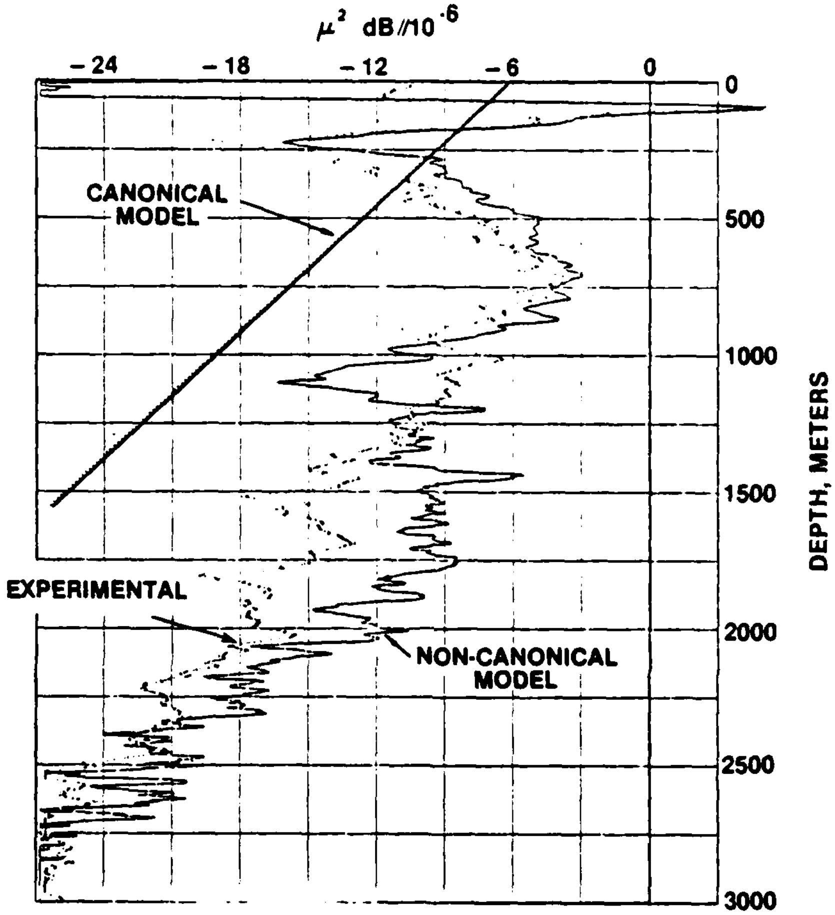


Slide 8

Here, the non-canonical model is the internal wave μ^2 calculated using the actual ocean conditions. The canonical and the experimental curves are the are the canonical and directly-measured μ^2 profiles shown previously. Agreement between the non-canonical and experimental curves, particularly at the sound channel axis, suggests that the experimental μ^2 values result primarily from internal waves.

Furthermore, concurrent measurements in the Azores Range using towed, moored, and dropped sensors, plus intensive sound propagation experiments were also consistent with internal wave fluctuation statistics and with the high observed μ^2 levels.

MODEL VS. MEASUREMENT (MID-ATLANTIC RIDGE)



Slide 9

A similar set of sound speed profiles was collected at a second location, near the mid-Atlantic Ridge (~540 nautical miles SW of AFAR). The resulting direct, canonical, and non-canonical versions of μ^2 are shown. Again, use of the actual, rather than the idealized sound speed profile, can account for the large observed μ^2 values. The net result of these calculations is now shown.

COMPARISON OF VERY LOW FREQUENCY ATTENUATION COEFFICIENTS FOR DEEP SOUND CHANNEL, MID-LATITUDES, N. ATLANTIC

METHOD	ATTENUATION COEFFICIENT, α_1
CANONICAL MODEL	0.5×10^{-3} dB/km
NON-CANONICAL MODEL	
AZORES RANGE	1.4
MID-ATLANTIC RIDGE	1.8
ATTENUATION MEASUREMENTS	1.3

Slide 10

Here the theoretical attenuation coefficient resulting from internal waves has been evaluated at the channel axis for both the Azores and the mid-Atlantic Ridge experiment. Also shown are attenuation coefficients based on the canonical model and on historial attenuation experiments in the North Atlantic. Slide 11 (not shown during the presentation) summarizes various parameter values used in the analysis. The predicted and measured coefficients agree closely when regional ocean conditions are used.

		GM 75	AZORES	M-AR
Z_1	(m)	1	1.5	1.3
N_1	(cph)	1.1	0.4	0.8
latitude		33°	36°50'	28°18'
n_1		0.37	0.13	0.27
n_1/w_i		24	8	20
μ_1^2		1.2×10^{-8}	1.5×10^{-7}	6.0×10^{-8}
j*		3	3	3
B	(km)	1	0.8	1.2
θ_o^2 ǂ		.033	.022	.023
D_1		1.28×10^{-6}	1.87×10^{-6}	3.93×10^{-6}
α_1	(dB/km)	5.0×10^{-4}	1.4×10^{-3}	1.8×10^{-3}

ǂ all θ_o^2 values standardized to a mean bottom depth of 3 km for N. Atlantic

EXPERIMENTAL α_1 FOR MID-LATITUDES IN N. ATLANTIC: 1.3×10^{-3} dB/km

Slide 11

In conclusion, we have presented evidence that appears to link the observed regional dependency of very-low frequency loss in the deep sound channel with an internal wave scattering mechanism. We are currently applying this methodology to data obtained in other areas.

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