Low frequency acoustic backscatter from the seabed

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Introduction

A simple model for backscatter from inhomogeneities within the seabed is described. The model predictions are compared with some recent (Hines et al 1992) experimental measurements obtained from the Sohm Abyssal Plain.

Scattering model

Scattering from within the volume of the seabed is deemed to be caused by fluctuations in the local properties of the seabed. For instance the porosity, upon which the density and sound velocity depend, fluctuates about a mean value. These fluctuations may be described by a standard deviation and a correlation length. The way in which seabeds are formed suggests that the statistical nature of the property fluctuations will be directionally dependent. The correlation lengths in the vertical and horizontal senses are expected to be quite different.

The backscatter due to volume scatter within the seabed in practice has to be cast in terms of an equivalent interface backscatter coefficient. This is done as follows.

Consider a target, which in water would have a unit target strength, to have a target strength when buried in the seabed and observed from the water of

$$M_T = \frac{I_w \left(R / R_{ref}\right)^2}{I_{ii}}$$

where I_{w} is the intensity scattered by the target and received in water at a range of R from the water/seabed interface. I_{ii} is the intensity incident on the water/seabed interface. If the ratio n of the sound speed in water to in the seabed is unity and the ratio of seabed to water density m is also unity then the target strength becomes unity providing the seabed attenuation is negligible.

If the volume backscatter strength of the seabed is M_V, then the equivalent surface backscatter strength of the seabed may be written as

$$M_s = \int M_T M_V dz$$

Expression for target strength

The expression given by Brekhovskikh (1) has been used to calculate the effect of a refracting interface on the pressure p of a spherically spreading wave and the required intensities obtained using the general expression

$$\bar{I} = \frac{1}{2\rho\omega} \mathrm{Imag}\left(p^{*}\nabla p\right)$$

where ρ is the density and ω is the angular frequency

Thus an expression for the target strength is obtained as

$$M_T = \frac{\left|T_{01}(\theta)\right|^4 \Re(k_1)}{m^2 \left|k_1\right| \left|A\right|^2} \exp\left(\Re\left(ik_1 \cos(\theta_1) z\right)\right)$$

Here subscript 1 refer to the seabed. T_{01} is the plane wave transmission coefficient from water to the seabed and z is the depth below the water/seabed interface and k is the wavenumber and θ is the angle measured from the normal to the interface. For all expected values of seabed attenuation $\Re(k_1) \approx |k_1|$. The parameter A introduces the ratio of receiver height h above the seabed to the effective depth z below the interface from which the scattering comes.

$$A = \left(1 + \frac{z\cos\theta}{nh\cos\theta_1}\right)\left(1 + \frac{z\cos^3\theta}{nh\cos^3\theta_1}\right)$$

A is only significantly different from unity in a small range of angles around the critical angle in which the field in the seabed is composed of contributions from both a refracted wave and a lateral wave. At angles of incidence outside this region and beyond critical, A is equal to unity and the field in the seabed is dominated by the lateral wave .

Expression for equivalent surface backscatter coefficient

In full knowledge that in a small angular range in the vicinity of the critical angle the expression will be incorrect, $|A|$ will be taken as unity and the 'far-field' equivalent surface backscatter coefficient becomes

$$M_S = \frac{|T_{01}(\theta)|^4 M_V(\theta_1)}{4m^2 \Re(ik_1 \cos\theta_1)}$$

Volume backscatter coefficient

Following a similar derivation given by Chernov(2) , the intensity scattered to the far field of a small volume dV of the scattering medium due to an incident intensity I_i is given by

$$I_S = \frac{k^4 V I_i}{4\pi R^2} S \int_V B(\bar{\tau}) \exp(i2\bar{k} \bullet \bar{\tau}) dV$$

The fluctuations considered here to cause the scatter are in the porosity of the medium and the parameter B describes their spatial autocorrelation. The parameter S describes the magnitude of the effect and is given by

$$S = \overline{\Delta\phi}^2 \left(\frac{1}{c_0} \frac{\partial c}{\partial \phi} + \frac{1}{\rho} \frac{\partial \rho}{\partial \phi} \right)^2$$

where ϕ is the porosity $\overline{\Delta\phi^2}$ is its variance and ρ is the density and c the sound speed.

The volume backscatter coefficient may be written as

$$M_V = \frac{I_S R^2}{V I_i} = 2\pi k^4 S G(2k)$$

where G is the power spectrum of the porosity fluctuations.

Form of the autocorrelation function

As discussed below, a tractable model for the autocorrelation function is one that decays exponentially in the horizontal and has the form of an exponentially damped sinusoid in the vertical. For such a model, the volume scatter coefficient becomes

$$M_V = \frac{|k_1|^4 S}{2\pi} \frac{b^2}{\left(1+4|k_1|^2 b^2 \sin^2\theta_1\right)^{3/2}} (F_+ + F_-)$$

where $F_\pm = \frac{a}{\left(1+a^2\left(e \pm 2|k_1|\cos\theta_1\right)^2\right)}$

Here, b is the horizontal correlation length , e is 2π divided by the spatial period of the sinusoid and a is the exponential damping constant of the vertical autocorrelation function.

Surface roughness

In order to make comparisons with measured data, the contribution to the backscatter of the surface roughness must be acknowledged. Kuo's (9) first order perturbation theory yields a surface roughness backscatter coefficient of

$$M_{SK} = 10\log\left(4k^4 \cos^4\theta |Y(\theta)|^2 W(2k\sin\theta)\right)$$

where $Y(\theta) = \frac{(m-1)^2 \sin^2\theta + m^2 - n^2}{\left\{m\cos\theta + \sqrt{(n^2 - \sin^2\theta)}\right\}^2}$

W is the two dimensional isotropic power spectral density function of the seabed roughness. Mourad (10) described the surface relief as

$$W(2k\sin\theta) = \frac{w_2}{(h_0 2k\sin\theta)^\gamma}$$

where h_0 is 0.01m . w_2 is the spectral strength of the interface roughness in units of m^4 and is an experimentally obtained quantity as is the exponent γ .

Seabed data

The backscatter coefficient is proportional to the parameter S . The angular and frequency dependence of the backscatter coefficient is greatly influenced by the correlation structure of the seabed property fluctuations .

The amount of data available in the literature from which the required parameters can be estimated is sparse. Data provided by Hamilton(3) allows the gradient of the sound speed and density with porosity to be estimated for various environments. Baldwin(4) presents data from which the variance of the porosity fluctuations is 0.004. Analysis of core data is available (Baldwin(4), Winokur and Bohn (5) and Mayer (6)) . However, the analysis of the cores is presented at no greater resolution than 20cm. which is insufficient for the present requirements. Recently Mayer(7) in a private communication has provided high resolution saturated bulk density data from sites in the Pacific with a vertical resolution of 1cm. The autocorrelation function of this data lends strong support for modelling it as an exponentially damped sinusoid.

Experimental measurements of the low frequency backscatter coefficients from the ocean bottom which is well qualified and documented is rare. Recently Hines et al (8) have published detailed backscatter coefficient measurements in the Sohm Abyssal Plain. The data consists of measurements at four essentially smooth sites over the frequency range 800Hz to 2400Hz at grazing angles down to 4 degrees.
Sites A,B and C are essentially flat whilst Site D is described as undulating. Seabed data (Hines(8)) employed in the model predictions is listed in the Table (1) together with the correlation lengths and roughness parameters used .

The measured values of backscatter coefficient together with model predictions are shown in Figures 1,2,3 and 4. The parameters used are listed in Table(1). The model results for Site D include the effects of surface roughness, as calculated using Kuo's model

Conclusion

The model predictions provide backscatter coefficients which are in good accord with the data both as regards absolute level and grazing angle dependence. The sensitive role played by the correlation structure of the seabed on a centimetric scale is demonstrated. Experimental measurements of this aspect of the seabed is the subject of a current research programme.

References

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	Site A	Site B	Site C	Site D
water density kg m^3	1000	1000	1000	1000
water speed m/s	1541	1541	1541	1541
attenuation dB per λ	0.34	0.30	0.35	0.38
porosity variance	0.001	0.002	0.005	0.001
seabed sound speed m/s	1580	1690	1660	1700
seabed density kg m^3	1640	1900	1900	2120
vertical correlation length m	0.75	0.2	0.05	0.5
ratio of horizontal to vertical correlation length	1	1	2.5	2
period of sinusoid m	3	4	0.5	4
frequency Hz	2000	2000	2000	2000
exponent				3.25
spectral strength m^4				$5.0\ 10^{-11}$

$$\frac{\partial c}{\partial \phi} = -570 \ \ m/s \quad \text{and} \quad \frac{\partial \rho}{\partial \phi} = -1440 \ \ kg\,m^{-3}$$

Table(1) Values of parameters used in the model.

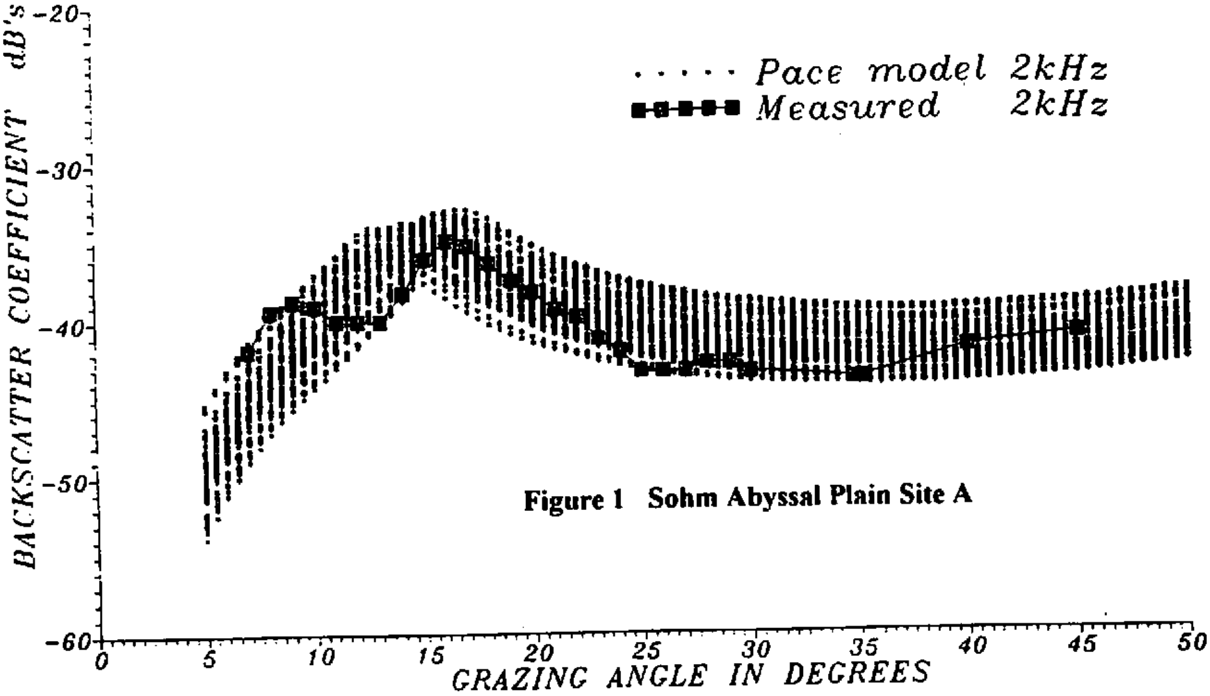

Figure 1 Sohm Abyssal Plain Site A

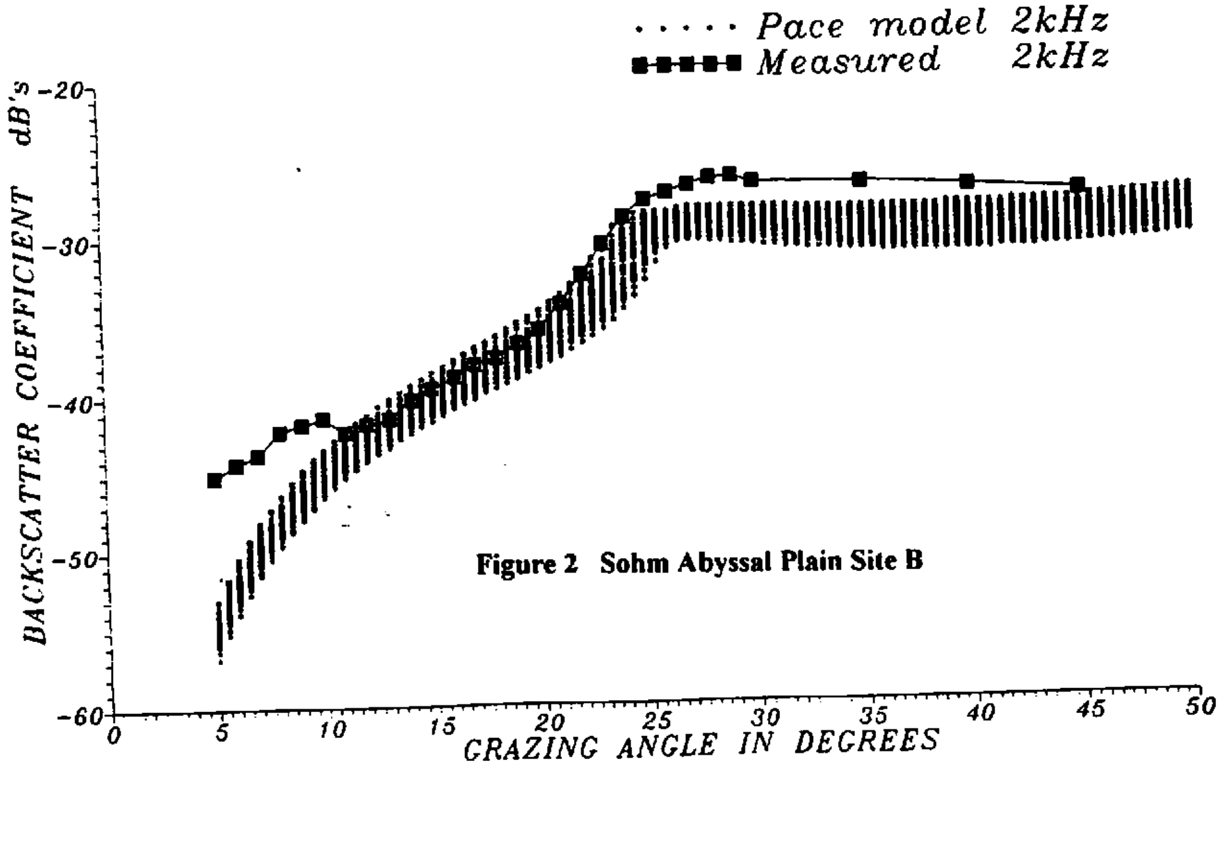

Figure 2 Sohm Abyssal Plain Site B

Comparison of the Pace model with experimenal measurements from the Sohm Abyssal Plain (Hines et al (1992)). The central values of model parameters used are given in Table(1). The effect of indicated fractional changes is indicated. (attenuation ±10%,density ±5%, vertical correlation length ±25%, ratio of vertical to horizontal correlation lengths ±25%, sound speed ±1%)

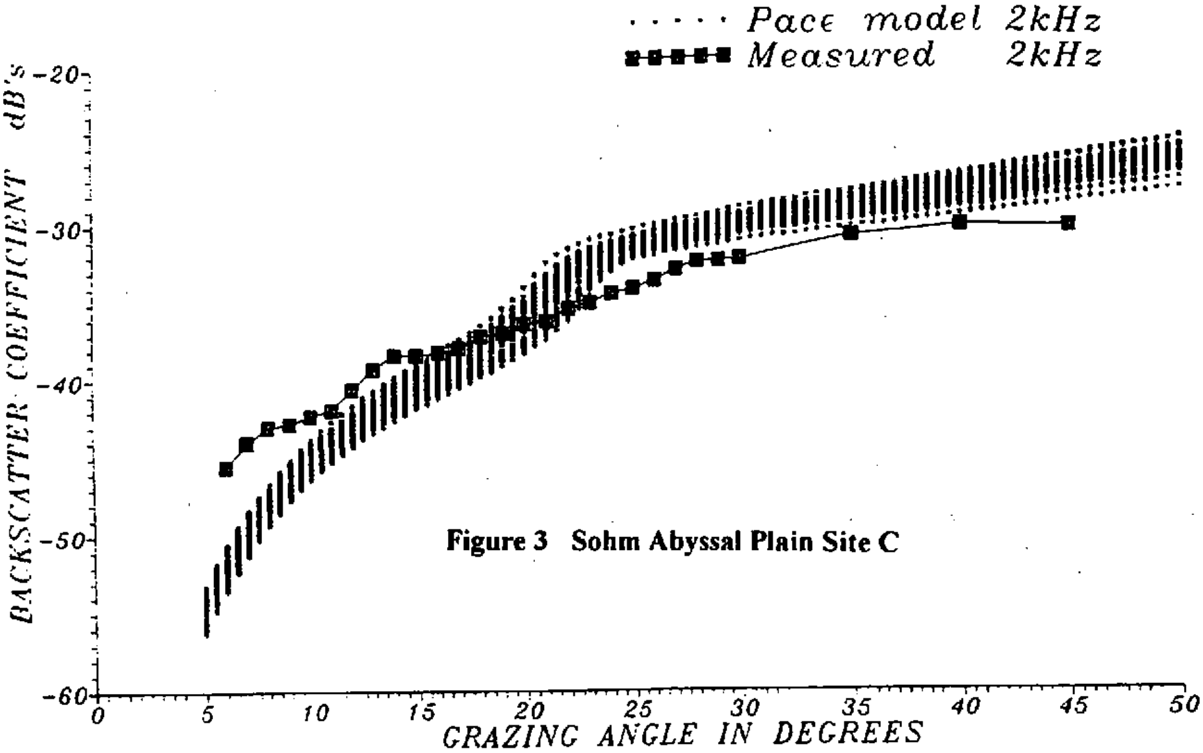

Figure 3 Sohm Abyssal Plain Site C

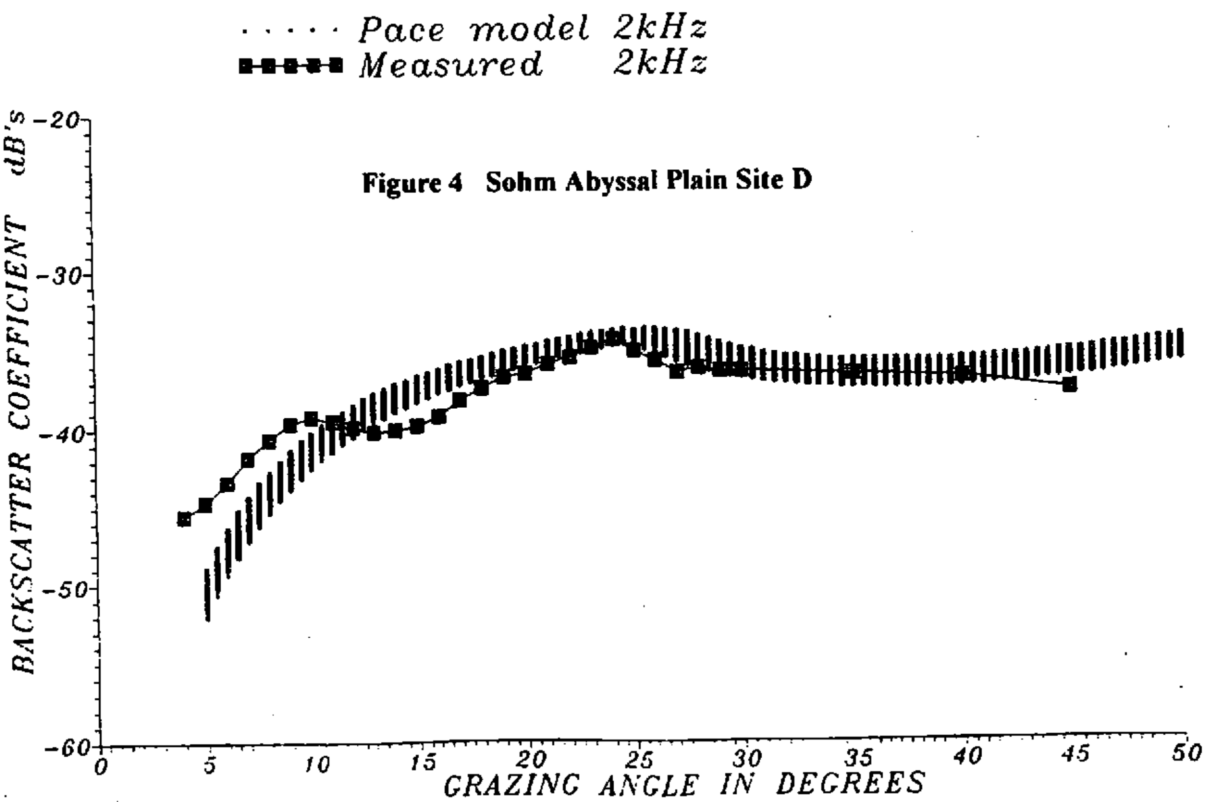

Figure 4 Sohm Abyssal Plain Site D

Comparison of the Pace model with experimenal measurements from the Sohm Abyssal Plain (Hines et al (1992)). The central values of model parameters used are given in Table(1). The effect of indicated fractional changes is indicated. (attenuation ±10%,density ±5%, vertical correlation length ±25%, ratio of vertical to horizontal correlation lengths ±25%, sound speed ±1%)