Estimates of the Influence of Seafloor Type on Vertical Directionality of Surface-Generated Ambient Noise in Shallow Oceans

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ABSTRACT

The level and vertical directionality of ambient noise in shallow oceans may each be influenced by the acoustic reflectivity properties of the seafloor. Components of ambient noise interacting with the seafloor at small grazing angles may be either strongly reflected or absorbed, depending on seafloor density, sound speed and attenuation, and the speed of shear waves in the seafloor. The nature of the seafloor reflectivity near normal incidence is almost entirely determined by the product of the sound speed and density for the seafloor material. In a brief study, estimates are made of the vertical directivity of the ambient noise generated by dipole surface sources, with consideration to the influence from reflections from several, quite different, seafloor types. This work includes the derivation of several simple expressions for resultant noise intensity and their comparison with numerical integrations. As these expressions are in terms of the geoacoustic properties of the seafloor, it suggests that prediction of ambient noise characteristics may be viable.

1 INTRODUCTION

The basic assumption used to estimate ambient noise intensity is that there is a uniform, but randomised, spread of surface dipole sources in an isovelocity ocean. The noise contributions from all sources are then summed at a receiver, assuming incoherent addition. With no reflection of sound at the seafloor, the noise intensity received over the grazing angles (in radians) $\beta_{\min}$ to $\beta_{\max}$ may be shown to be

$$N = 2\pi\, I_d \int_{\beta_{\min}}^{\beta_{\max}} \sin\beta \cos\beta \, d\beta \ \ \text{watts}/\text{m}^2 . \tag{1}$$

Integrating over angles zero to $\pi/2$ radians, Equation (1) is equivalent to $N = 2\pi\, I_d \int_0^1 \sin\beta \left[d\left(\sin\beta\right)\right] \text{watts}/\text{m}^2$, a form used by Desharnais and Chapman (Desharnais and Chapman, 1999). Easily seen from this form, is that half the received noise intensity is from angles $\pi/6$ to $\pi/3$ radians, a quarter from 0 to $\pi/6$ radians, a quarter from $\pi/3$ to $\pi/2$ radians, and these values are independent of receiver depth.

All noise components reflected from each of the seafloor and surface may now be added assuming incoherent addition. With $\left|R(\beta)\right|$ the pressure reflection amplitude at the seafloor, and no losses at the surface, adding all multiple reflections of noise intensity over angles $\beta_{\min}$ to $\beta_{\max}$ and $-\beta_{\min}$ to $-\beta_{\max}$ gives a total as

$$N \approx 2\pi\, I_d \int_{\beta_{\min}}^{\beta_{\max}} \frac{\sin\beta \cos\beta \left\{1 + \left|R(\beta)\right|^2\right\} d\beta}{\left\{1 - \left|R(\beta)\right|^2\right\}} \ \ \text{watts}/\text{m}^2 . \tag{2}$$

The integral in Equation (2) is, of course, carried out over +ve angles $\beta_{\min}$ to $\beta_{\max}$, only

2 NOISE CONTRIBUTIONS FROM ZONES OF VERTICAL ANGLE

Values of $\left|R(\beta)\right|$ vs grazing angle for seafloors commonly show distinct zones: a "near-vertical" zone from about $\beta = \pi/3$ to $\pi/2$ where $\left|R(\beta)\right|$ is nearly constant at $R(\pi/2) = \left(\rho_b\, c_b - \rho_w\, c_w\right)/\left(\rho_b\, c_b + \rho_w\, c_w\right)$ and dependent on seafloor and water sound speed and densities only; a "near-horizontal" zone from about $\beta = 0$ to $\pi/12$ for which $\left|R(\beta)\right| \approx 1 - 2X_0\beta$, where X_0 is the real part of the seafloor surface impedance at small angles.

From Equation (2), the contributions to noise intensity from the near-vertical zone, over angles β from $\pi/3$ to $\pi/2$ and $-\pi/3$ to $-\pi/2$, may be approximated as

$$N_{nv} \approx \frac{\pi I_d}{4}\left\{1+\left|R\left(\tfrac{\pi}{2}\right)\right|^2\right\}\Big/\left\{1-\left|R\left(\tfrac{\pi}{2}\right)\right|^2\right\}\text{watts/m}^2. \tag{3}$$

Also, from Equation (2), making appropriate simplifications for seafloors that are ***not*** highly absorptive, the noise intensity contributions from the near-horizontal zone, over angles β from $\pi/12$ to $-\pi/12$, are

$$N_{nh} \approx I_d\left[40\pi\beta_{\max}\big/\left[F\left(\ln 10\right)\right]-\pi\left(\beta_{\max}\right)^2\big/2\right]\ \text{watts/m}^2 \tag{4}$$

for $\beta_{\max}=\pi/12$, where the substitution $X_0 \approx (\ln 10)F/40$ is made. The "bottom loss parameter", F dB/radian, is the same as the Weston α parameter (Weston, 1971), and represents the slope of the seafloor Bottom Loss (in dB) vs grazing angle curve for small angles. Clearly, Equation (4) gives the expectation that the noise intensity from the near-horizontal zone, in watts/m^2, is approximately proportional to the inverse of the value F. For a seafloor that ***is*** highly absorptive, Equation (4) applies for the smaller grazing angles, 0.0 to about $\beta_{\min}=20\big/\left[3(\ln 10)F\right]$, but another expression for noise intensity must be used for angles $\beta_{\min}$ to $\beta_{\max}=\pi/12$. Excluded for brevity, this alternative expression varies more rapidly than inversely with F.

2.1 Noise Intensity Determined by Derived Expressions

Using goeacoustic properties for calcarenite and sand from Duncan et al. (Duncan et al., 2009) and for silt from Desharnais and Chapman (Desharnais and Chapman, 1999), the noise intensity N_{nv} (Equation (3)) is shown in the 3rd column of Table 1, and that for N_{nh} (Equation (4) et al.) is shown in the 4th column. Corresponding values obtained by numerical integration of Equation (2) are shown in the table in parenthesis. These latter values may be presumed definitive as they use the precise values of $|R(\beta)|$ vs angle for each seafloor.

Clearly, Equation (3) is accurate in predicting noise in the vertical zone in all three cases. Further, the equations for the near-horizontal zone provide good estimates compared with the numerical data from Equation (2). Significantly, the expectation that the noise intensity in the near-horizontal zone has an approximately-inverse relation to the value of F appears realized, from examination of values in the 4th column with reference to the respective values of F in the 2nd column. These values of F were obtained from calculations of $|R(\beta)|$ vs angle based on the geoacoustic properties for the respective seafloors. Also of note is the dependence of total noise intensity, in the 5th column, on the seafloor type, e.g. 4.8 dB more noise for sand vs silt.

Table 1: Noise Intensity from Zones of Vertical Angle, Shallow Ocean

Seafloor Type	Bottom loss parameter F dB/radian	Noise Intensity near-vertical zone N_{nv} watts/m^2	Noise Intensity near-horizontal zone N_{nh} watts/m^2	Noise Intensity over all angles N watts/m^2
calcarenite	48.5	1.847 I_d (1.806 I_d)	0.331 I_d (0.345 I_d)	(5.585 I_d)
sand	2.87	0.993 I_d (1.006 I_d)	4.87 I_d (4.760 I_d)	(13.092 I_d)
silt	17.0	0.887 I_d (0.887 I_d)	0.735 I_d (0.878 I_d)	(4.358 I_d)

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