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A simplified formula for viscous and chemical absorption in sea water

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A simplified expression is presented for predicting the absorption of sound in sea water, retaining the essential dependence on temperature, pressure, salinity, and acidity of the more complicated formula on which it is based [R. E. Francois and G. R. Garrison, ''Sound absorption based on ocean measurements. Part II: Boric acid contribution and equation for total absorption,'' J. Acoust. Soc. Am. **72**, 1879–1890 (1982)]. The accuracy of the simplified formula is demonstrated by comparison with the original one for a range of oceanographic conditions and frequencies between 100 Hz and 1 MHz. © *1998 Acoustical Society of America.* [S0001-4966(98)05203-5]

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INTRODUCTION

Ocean sound is attenuated by two main mechanisms: viscous absorption, which is significant at high frequency (above 100 kHz); and chemical relaxation effects, primarily due to boric acid at low frequency (up to a few kHz), and magnesium sulphate at intermediate frequencies (up to a few 100 kHz). The magnitude of these effects varies in a complicated way with frequency, pressure, temperature, salinity, and acidity.[1,2] Here we present a simplified version of the Francois–Garrison equation which makes the dependence on these variables more transparent, while retaining similar accuracy.

A third chemical relaxation due to magnesium carbonate is sometimes included in absorption equations.[3] The Francois–Garrison equation does not incorporate an explicit $MgCO_3$ relaxation, but because it is based on ocean measurements, any effect is included implicitly in the other terms.

For notation and units we use α for attenuation in dB/km, f for frequency in kHz, z for depth in km, T for temperature in °C, and S for salinity in ppt. This notation is identical to that of Francois and Garrison.[2]

I. SIMPLIFIED FORMULA

To simplify the full Francois–Garrison formula (referred to hereafter as FG) we first expand temperature, salinity and acidity about reference values of $T=0\,°\mathrm{C}$, $S=35\,\mathrm{ppt}$, and $p\mathrm{H}=8$, respectively. Retaining only highest order terms, this immediately simplifies the boric acid and magnesium sulphate relaxation frequencies (in kHz)

$$f_1 = 0.78(S/35)^{1/2} e^{T/26} \quad \text{(for boron)}, \tag{1}$$

$$f_2 = 42 e^{T/17} \quad \text{(for magnesium)}. \tag{2}$$

Applying a similar analysis to the coefficient terms, and in particular fitting a simple exponential to the bicubic expression for the temperature dependence of the pure water contribution (A_3 in FG), we obtain our end result (in dB/km)

$$\begin{aligned}\alpha = {} & 0.106\,\frac{f_1 f^2}{f^2+f_1^2}\,e^{(p\mathrm{H}-8)/0.56} \\ & + 0.52\left(1+\frac{T}{43}\right)\left(\frac{S}{35}\right)\frac{f_2 f^2}{f^2+f_2^2}\,e^{-z/6} \\ & + 0.00049 f^2 e^{-(T/27+z/17)}.\end{aligned} \tag{3}$$

We have found that this simplified formula retains reasonable accuracy (to within 10% of FG between 100 Hz and 1 MHz) for the following oceanographic conditions:

$$-6<T<35\,°\mathrm{C} \quad (S=35\ \mathrm{ppt},\ p\mathrm{H}=8,\ z=0)$$

$$7.7<p\mathrm{H}<8.3 \quad (T=10\,°\mathrm{C},\ S=35\ \mathrm{ppt},\ z=0)$$

$$5<S<50\ \mathrm{ppt} \quad (T=10\,°\mathrm{C},\ p\mathrm{H}=8,\ z=0)$$

$$0<z<7\ \mathrm{km} \quad (T=10\,°\mathrm{C},\ S=35\ \mathrm{ppt},\ p\mathrm{H}=8).$$

II. RESULTS

Figure 1 shows predicted volume attenuation plotted versus frequency using FG and Eqs. (1)–(3) above for four oceans of differing characteristics (Table I), based on Fig. 3 of Ref. 3 and Table VII of Ref. 4. On a logarithmic scale the differences between the two equations are almost imperceptible so we have also plotted the percentage difference for the same four oceans (Fig. 2). Departures from FG are mostly less than 5% and always less than 10% for these cases. These differences are comparable with the stated accuracy (±5%–10%) of FG itself.[2]

III. CONCLUSIONS

We apply Occam's razor to the absorption equation of Francois and Garrison.[2] The resulting equations [see Eqs. (1)–(3) above] are much simpler than the original, but retain similar accuracy. This simplicity makes it possible to reach some simple conclusions by inspection. For example we observe that:

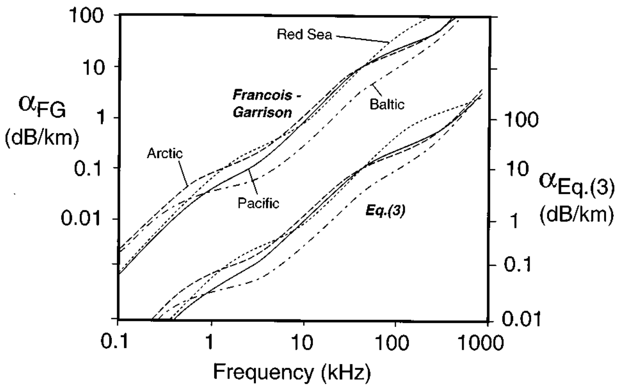

FIG. 1. Volume absorption coefficients for the four oceans from Table I, calculated using FG (upper curves) and Eq. (3) (lower curves).

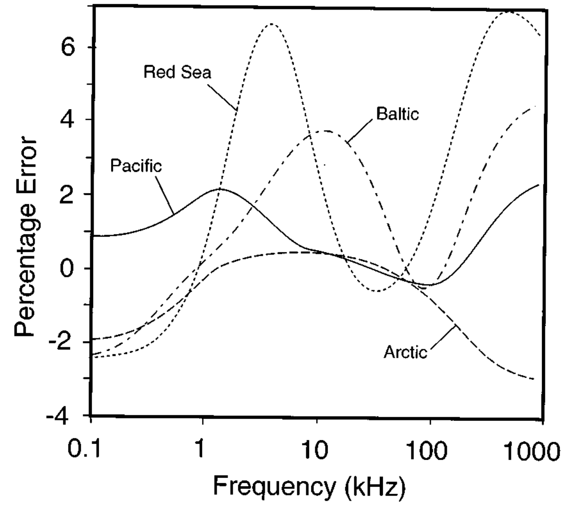

FIG. 2. Percentage difference between Eq. (3) and FG for the four oceans of Table I, calculated as $100\,[\alpha_{\mathrm{Eq.\,(3)}}-\alpha_{\mathrm{FG}}]/\alpha_{\mathrm{FG}}$.

- increasing acidity (decreasing pH) decreases low frequency absorption (up to the boron relaxation at f_1), with no effect at higher frequencies (hence the low absorption below 1 kHz in the Pacific Ocean);
- increasing salinity decreases absorption at low frequency ($\ll f_1$) and increases absorption at high frequency ($\gtrsim f_1$), hence the low absorption above 1 kHz in the Baltic Sea;
- increasing temperature decreases absorption at all frequencies except in the immediate vicinity of the relaxation frequencies f_1 and f_2, where absorption is *increased* (hence the high absorption at the relaxation frequencies in the Red Sea and the high absorption at all other frequencies in the Arctic Ocean);

TABLE I. Oceanographic parameters used for Figs. 1 and 2.

	pH	S(ppt)	T(°C)	z(km)
Pacific Ocean	7.7	34	4.0	1.0
Red Sea	8.2	40	22.0	0.2
Arctic Ocean	8.2	30	−1.5	0.0
Baltic Sea	7.9	8	4.0	0.0

- increasing depth (or pressure) decreases absorption at high frequency ($\gtrsim f_1$), with no effect at lower frequencies.

Of course, all of these conclusions follow also from the original FG equation, but they are not obvious by straightforward inspection.

ACKNOWLEDGMENT

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