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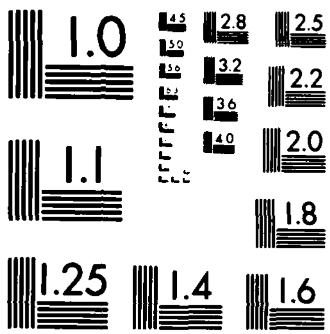

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SAI INTERIM SCATTERING MODEL/ICE (SISM/ICE)

SAI-84/1100

SCIENCE APPLICATIONS, INC.

SAI INTERIM SCATTERING MODEL/ICE (SISM/ICE)

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SAI INTERIM SCATTERING MODEL/ICE (SISM/ICE)

SAI-84/1100

April 1984

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A reflection loss model for acoustic propagation under Arctic sea ice is described. It is applicable over the frequency range of 0 to 45 degrees. A sequence of scattering loss formulas based on perturbation techniques provides a smooth transition in frequency to an asymptotic loss level, based on a boss model, at the highest frequencies. Probabalistic techniques are used to relate the

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SAI INTERIM SCATTERING MODEL/ICE (SISM/ICE)

The SAI Interim Scattering Model/Ice (SISM/ICE) is a reflection loss model for the coherent reflected field in ice-covered environments. The standard deviation of roughness is the only parameter required by the model for predictions. A contour map of the standard deviation of roughness in meters, shown in Figure 1, is from Buck.[1] It is already available to Fleet users as part of Buck's empirical transmission-loss model. The range of validity of SISM/ICE is from 0-5000 Hz and 0-45 degrees. A sequence of scattering-loss formulas based on perturbation techniques provides a smooth transition in frequency to an asymptotic loss level at the highest frequencies. The perturbation formulas are derived in Bass and Fuks[2] and are summarized in Stokes.[3] The derivation of the formula for the asymptotic loss level is contained in Burke and Twersky[4] and is the same one used in Diachok.[5] In addition, probabilistic techniques derived by R. Greene are used to relate the standard deviation of roughness to the ice-roughness parameters required by the individual reflection-loss formulas.

Ice Roughness Parameters

The under-ice surface is considered to be flat with cylindrical bosses of elliptical cross section.

The bosses:

1) have a half-width-to-depth ratio of 1.6, as suggested by Diachok,[5]
2) have a Rayleigh depth distribution,

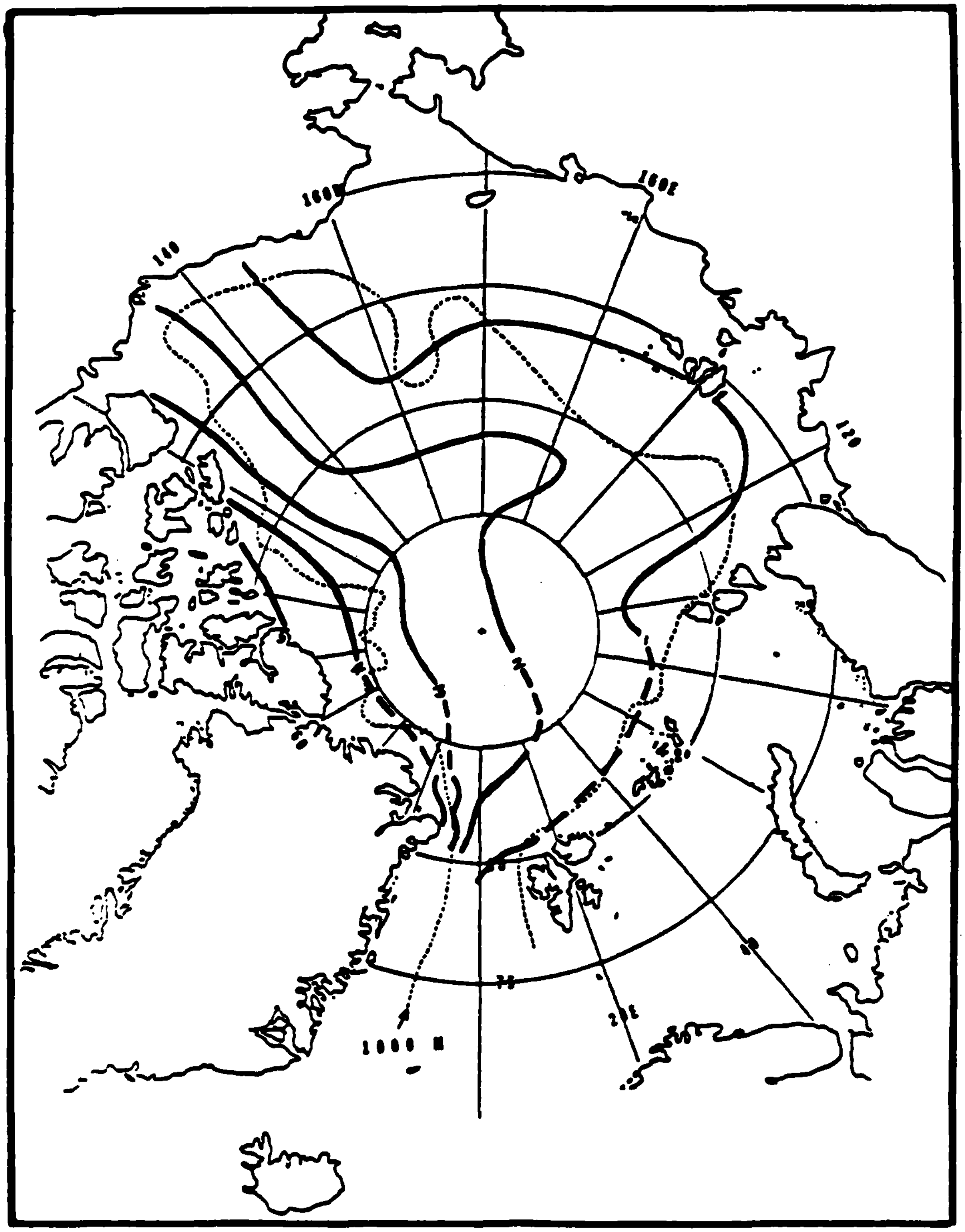

Figure 1. Contours of standard deviation ice depth (m) per LeSchack (Ref. 1 & 2). Dotted line (...) is 1000 m depth contour.

3) have random orientation,

4) have random spacing along a track.

Based on these assumptions, the standard deviation of roughness is related to the ridge keel parameters by the formula:

$$\sigma^2 = \frac{4 R_0 h^3}{\Delta} - \frac{\pi^2 R_0{}^2 h^4}{\Delta^2} , \tag{1}$$

where:

σ is the standard deviation of roughness,

$R_0 = 1.6$ is the half-width-to-depth ratio,

Δ is the mean keel spacing, and

h is the mean keel depth.

Under-ice roughness spectra measured along a track can be well approximated by the function:

$$\frac{c}{(\beta^2 + K^2)^{3/2}} , \tag{2}$$

where K ($=2\pi/\lambda$) is the wave number of the roughness component in the surface. This function has an asymptotic fall-off for large K of the form:

$$\frac{c}{K^3} . \tag{3}$$

The standard deviation of roughness derived from such a spectrum is:

$$\sigma^2 = \frac{2c}{\beta^2} . \tag{4}$$

The roughness spectrum derived from the bossed surface has the same asymptotic behavior as Eq. (3), where the coefficient c can be calculated to be:

$$c = \frac{\pi h}{8\Delta R_0} . \tag{5}$$

Derivation of Ice-Roughness Parameters from Standard Deviation Roughness

It is assumed that of all the ridge parameters, the mean spacing is the most slowly varying as a function of the standard deviation of roughness. It is assigned a constant representative value of 100 meters:

$$\Delta = 100 \text{ m} . \tag{6a}$$

The mean ridge-keel depth (h) in meters, can be found as the solution of Eq. (1) by the iteration:

$$h_{n+1} = [(\Delta/4R_0)(\sigma^2 + \pi^2 R_0{}^2 h_n{}^4/\Delta^2)]^{1/3} , \tag{6b}$$

where:

$$R_0 = 1.6 . \tag{6c}$$

The asymptotic coefficient (c), of the spectral model, Eq. (2), is calculated using Eq. (5):

$$c = \pi h/8\Delta R_0 \tag{6d}$$

The β coefficient of the spectral model is calculated using Eq. (4):

$$\beta = (2c/\sigma^2)^{1/2} . \tag{6e}$$

Reflection-Loss Formulas

In terms of the ice-roughness parameters, four formulas for the reflected power $|R^2|$ are evaluated. The predicted value of $|R^2|$ is the maximum of the four calculated values.

Choose the maximum of:

- Low Frequency-Free Surface Formula

$$|R|^2 = 1 - 4 \sin\theta \; k^2\sigma^2(1 - \pi^2 c \; (\sin\theta)/2) \; , \qquad (7a)$$

- High Frequency-Free Surface Formula

$$|R|^2 = 1 - 4 \sin\theta \; (1.198) \; c \; (k/\beta)^{3/2} \; , \qquad (7b)$$

- High Frequency-Rigid Surface Formula

$$|R|^2 = \begin{cases} \dfrac{(\sin\theta - x)^2 + x^2}{(\sin\theta + x)^2 + x^2} \; , & x < \sin\theta \; , \\ .2 \; , & x > \sin\theta \; , \end{cases} \qquad (7c)$$

where:

$$x = 1.311 \; c \; (k/\beta)^{1/2} \; .$$

- Asymptotic Twersky formula

$$|R|^2 = (\sin\theta - x)^2/(\sin\theta + x)^2 \; , \qquad (7d)$$

where:

$$x = n\ L \cos(\theta - \gamma),$$
$$\tan\gamma = \rho^{-2}\tan\theta,$$
$$L^2 = w^2(\tan^2\theta + \rho^4)/(\tan^2\theta + \rho^2),$$
$$w = R_0\ \pi\ h/2,$$
$$\rho = 2/(R_0\pi),$$
$$n = 1/\Delta.$$

In all of formulas 7a-7d, θ is grazing angle and k is the acoustic wavenumber in inverse meters.

Conclusion

SISM/ICE is suggested as an interim scattering-loss model in ice-covered environments. It is based on several simplifications and assumptions. However it fulfills the requirement for a loss model with a wide range of validity, based on the only known environmental parameter, the standard deviation of roughness. SISM/ICE can be used with acoustic propagation models such as FACT and RAYMODE to predict the coherent propagating field. There may also be a significant propagating incoherent component at the higher frequencies, which would not be predicted by these models. As propagation models become available which can describe the propagating incoherent field, SISM/ICE can be extended to give the scattering kernel for the incoherent field. The details for doing this are contained in Refs. 2, 3, and 4.

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Appendix

REFLECTION LOSS CURVES FOR REPRESENTATIVE ARCTIC ENVIRONMENTS USING SISM/ICE

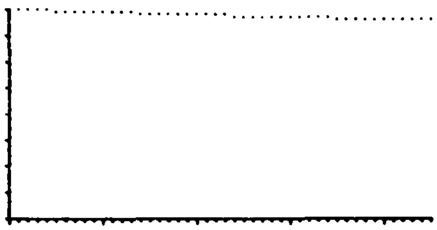
The curves are evaluated for: Standard Deviation of Roughness, sigma = 2 m and 4 m, and frequencies (Hz), Freq = 20, 50, 100, 200, 800, 3500, 5000.

- The vertical scale represents the power reflection coefficient, R^2. The scale goes from .2 to 1.0 in units of .1.

- The horizontal scale represents grazing angle in degrees. The scale goes from 0 to 45° by degree.

FREQ =20
SIGMA=2

R^2= .2 TO 1.0



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FREQ =50
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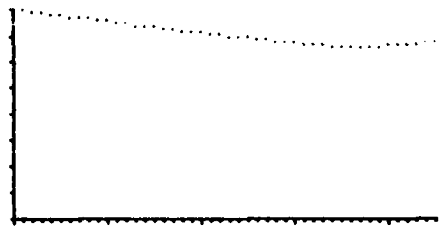
R^2= .2 TO 1.0



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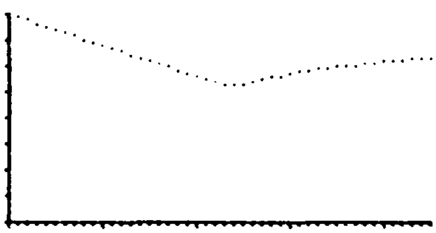
R^2= .2 TO 1.0



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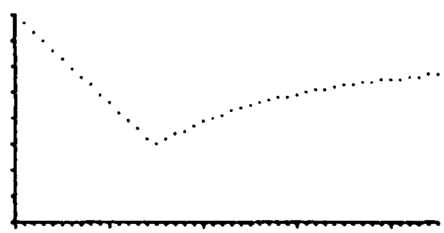
R^2= .2 TO 1.0



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FREQ =800
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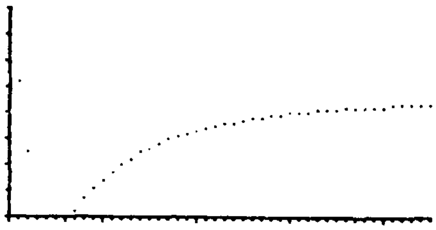
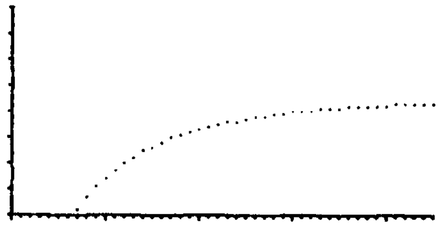
R^2= .2 TO 1.0



ANGLE = 0 TO 45°

FREQ =3500
SIGMA=2

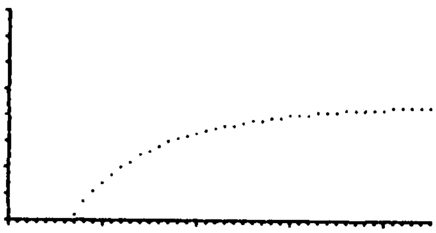
R^2= .2 TO 1.0



ANGLE = 0 TO 45°

FREQ =5000
SIGMA=2

R^2= .2 TO 1.0



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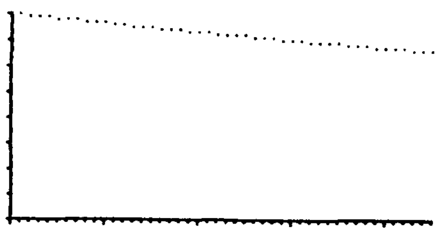
FREQ =20
SIGMA=4

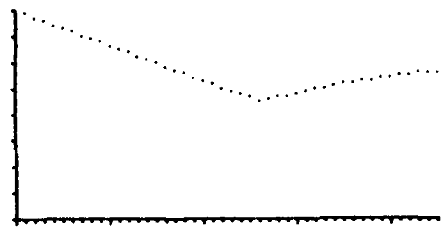
R^2= .2 TO 1.0



ANGLE = 0 TO 45°

FREQ =50
SIGMA=4

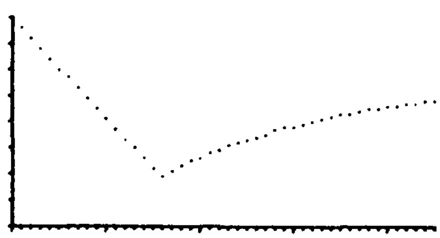
R^2= .2 TO 1.0



ANGLE = 0 TO 45°

FREQ =100
SIGMA=4

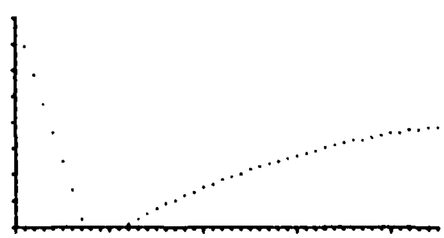
R^2= .2 TO 1.0



ANGLE = 0 TO 45°

FREQ =200
SIGMA=4

R^2= .2 TO 1.0



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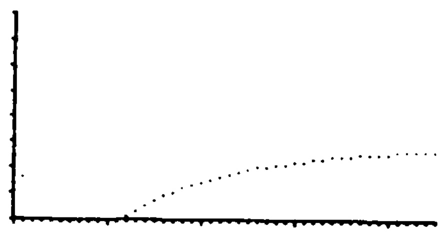
R^2= .2 TO 1.0



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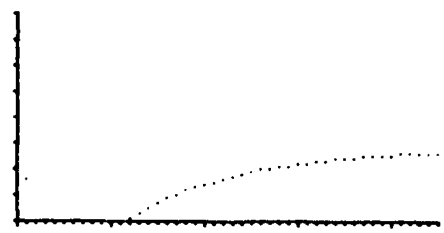
FREQ =3500
SIGMA=4

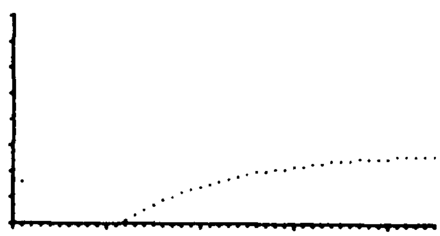
R^2= .2 TO 1.0



ANGLE = 0 TO 45°

FREQ =5000
SIGMA=4

R^2= .2 TO 1.0



ANGLE = 0 TO 45°

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