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NOTE N-629

SEA SURFACE REFLECTION STRENGTH
FROM ACOUSTIC, RADAR, LASER, AND SLOPE SPECTRA MEASUREMENTS

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September 1969

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SEA SURFACE REFLECTION STRENGTH
FROM ACOUSTIC, RADAR, LASER, AND SLOPE SPECTRA MEASUREMENTS

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ABSTRACT

Measurements for various wind speeds v of wind-blown water surface characteristics by acoustic, radar, and two optical means provide estimates of sea surface reflection strength. The analysis suggests that reflection strength decreases about as v^{-1} from near unity for wind speed less than five knots to an asymptotic value of approximately 0.1 above 20 knots with an uncertainty of a factor of 3.

As an aside, correlation lengths for sea surface slope and curvature are estimated by manipulation and integration of the slope spectra measurements.

FOOTNOTE TO ABSTRACT

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* Director, Systems Evaluation Division

On a rough surface with zero mean slope, the number N of local maxima or minima of elevation per unit area A is given by (Refs. 1, 2)

$$dN/dA = \pi^{-2} \ (\sigma_{z''}/\sigma_{z'})^2 \qquad (1)$$

where σ^2 is variance and z' and z'' are first and second derivatives of surface elevation. Maxima and minima of a surface are, of course, points at which local normals and normals to the mean surface coincide. Suppose that instead of this, one were interested in the number density of points at which a ray impinging on the surface at angle ϕ from the tangent surface was reflected identically along the incident ray. The number density of such points is given by (Refs. 2, 3)

$$dN/dA = \pi^{-2} \ (\sigma_{z''}/\sigma_{z'})^2 \ \exp\left[-\tfrac{1}{2}\left(\frac{\cot\phi}{\sigma_{z'}}\right)^2\right] \quad . \qquad (2)$$

In both Eqs. 1 and 2 the term $(\sigma_{z''}/\sigma_{z'})$ bears relationship to a correlation distance on the surface. In the simplest terms, let σ_z^2 be surface elevation variance and $\sigma_{z'}^2$ be surface slope variance, the latter not very large; then, one may define a correlation length r_z for elevation as

$$\sigma_z/r_z = \tan \sigma_{z'} \cong \sigma_{z'} \qquad (3)$$

that is

$$r_z = \sigma_{z'}/\sigma_z \quad . \qquad (4)$$

Thus $\sigma_{z''}/\sigma_{z'}$ is a correlation length for surface slope and Eq. 1 suggests there is one surface maximum or minimum every ten ($\cong \pi^2$) square slope-correlation-lengths.

If one be interested in the reflectance of a surface for either acoustic or electromagnetic waves, then in addition to the number of reflecting "facets" on the surface one needs to know the effective reflecting area at each suitably disposed point. Now if a point on a surface has a suitable orientation for reflecting to a given point, then one expects (Ref. 3)--albeit on intuitive grounds--that the suitable orientation will remain suitable over the correlation length for surface curvature, $r_{z''}$. From Eq. 4 one expects that correlation length for surface curvature is given by

$$r_{z''} = \sigma_{z'''}/\sigma_{z''} \tag{5}$$

where $\sigma^2_{z'''}$ is the variance of the surface elevation third derivative. The effective reflecting area A_{eff} may be taken as $\pi r^2_{z''}$ if the wavelength of the incident radiation is very small compared to $r_{z''}$.

If dN/dA is the number density of reflecting facets and $\pi r^2_{z''}$ is the effective area then on the average, the reflection strength J of the surface average over an area large compared to $r^2_{z'}$, is

$$\begin{aligned} J &= \pi^{-2} \; (\sigma_{z''}/\sigma_{z'})^2 \; (\pi r^2_{z''}) \; \exp\left[-\tfrac{1}{2}\left(\frac{\cot\phi}{\sigma_{z'}}\right)^2\right] \\ &= J_o \; \exp\left[-\tfrac{1}{2}\left(\frac{\cot\phi}{\sigma_{z'}}\right)^2\right] \end{aligned} \tag{6}$$

where

$$J_o \equiv \pi^{-1} \; (\sigma^2_{z''}/\sigma_{z'}\sigma_{z'''})^2$$

and any $\sigma = \sigma(v)$.

When determined from experimental data, J is to be corrected for transmission losses and may be specified as applicable to a length unit squared at one length unit from the surface (Ref. 3). Usually reflection will be important relative to scattering only when ϕ is near $\pi/2$.

Now there are data in the literature for reflection strengths of wind-blown surfaces for acoustic (Ref. 3) and electromagnetic radiation (Refs. 4, 5, 6, 7). There are in addition laboratory data (Ref. 8) on wind-blown water surface slope spectra which may be used to calculate the coefficient of the exponential in Eq. 6--i.e., J_o. Thus one may test the theory and intuition which led to Eq. 6.

ACOUSTIC BASIS

For the past 20 years and more, acoustic reverberation measurements of the sea surface have been made as a function of acoustic frequency (0.6 to 60 kHz), grazing angle $2 \le \phi \le 90$ deg, and wind speed $0.5 \le v \le 37$ knots. These have been accumulated by Martin (Ref. 3). Many of these measurements, especially at 60 kHz ($\lambda \cong 2.5$ cm), are near enough to normal incidence to the sea surface that using Eq. 6, both $\sigma_{z'}$ and $\pi^{-1} (\sigma^2_{z''}/\sigma_{z'}\sigma_{z'''})^2$ may be separately found. The analysis in this manner of the acoustic data leads to (Ref. 3)

$$\sigma^2_{z'} = 0.011 + 0.0005 \ v \qquad (7)$$

and

$$\pi^{-1} (\sigma^2_{z''}/\sigma_{z'}\sigma_{z'''})^2 = 0.83 \ v^{-0.738} \qquad (8)$$

each for wind speed v in knots between 2 and 20. If $v \geqslant 20$ knots, J_o takes on a constant value equal approximately to 0.05--i.e., -13 decibels. Although Eq. 7 appears to overestimate $\sigma^2_{z'}$ at low wind speeds in comparison with the $\sigma^2_{z'}$ data of Cox and Munk for clean water surface, it is not very different at $v \cong 10$ knots. The data of Cox and Munk (Ref. 9) are represented by

$$\sigma^2_{z'} = 0.0015 + 0.00132\ v \qquad (9)$$

with wind speed v again in knots. Equation 9 averages down- and cross-wind components of variance. Since the Cox and Munk data are by far more accurate and extensive, $\sigma^2_{z'}$ from Eq. 9 may be used to remove one unknown in the analysis of the acoustic data. In this event, a re-evaluation leads to the data of Table 1. For comparison of various measurement means, the following logarithmic least-squares fit ("llsf") is calculated.

$$(J_o)_{acoustic} = 10\ v^{-1.68} \qquad (10)$$

again with a constant value of 0.05 for $v \geqslant 20$ knots. A plot of the acoustic data of Table 1 and of Eq. 10 is shown in Fig. 1.

RADAR BASIS

For the past ten years and more, radar measurements of the normal incidence radar reflectance of ocean surface have been made. Data which best suit the present needs are those of Hoover and Urick (Ref. 4), Grant and Yaplee (Ref. 5), and Campbell (Ref. 6). These data taken for various conditions of radar beamwidth, radar frequency are shown in Table 2 with wavelength of radiation, 0.86, 1.25, 3.0, 3.2, 3.4 cm, indicated. An "llsf" of the data, for comparison, yields

$$(J_o)_{radar} = 3.4\ v^{-0.61} \tag{11}$$

with v in knots. A plot of the radar data of Table 2 and of Eq. 11 is shown in Fig. 2.

LASER BASIS

There have been few optical measurements of water surface reflection strength versus wind speed. One such by Kirk (Ref. 7) accomplished with an argon laser at 0.4880 microns gives values shown in Table 3 and plotted in Fig. 3. The data of Kirk show the same order of magnitude for reflection strength and the same trend and leveling out near v = 20 knots, and are represented by an "llsf" given as

$$(J_o)_{laser} = 21\ v^{-1.58} \tag{12}$$

SLOPE SPECTRUM BASIS

Finally, there are available the laboratory measurements of one-dimensional slope spectra versus wind speed of Cox (Ref. 8) which may be modified to estimate the functional $\pi^{-1}\ (\sigma^2_{z''}/\sigma_{z'}\sigma_{z'''})^2$. Cox's data are given as f S(f,v) where f is wave slope frequency and S is the one-dimensional slope spectrum as a function of both f and v, the wind speed. Immediately one may calculate $\sigma^2_{z'}$ from Cox's data, shown in Table 4, as

$$\begin{aligned} \sigma^2_{z'} &= \int S(f)\ df \\ &\equiv \int f\ S(f)\ d(\ln f) \end{aligned} \tag{13}$$

because the data are given for $\Delta(\log f) = 0.1$.

However, to obtain $\sigma^2_{z''}$ and $\sigma^2_{z'''}$ some modification of the variable f S(f) must be made. Let $E_{z'}(f) \equiv S(f)$ where the subscript z′ indicates a power spectrum of slope as a function of frequency.

As it is true (Ref. 10), for wave number $k = 2\pi f/c$ where c is the wave phase velocity, that

$$\sigma^2 = \int E(k)\, dk \tag{14}$$

and that

$$E_{z''}(k) = k^2\, E_{z'}(k) \tag{15}$$

and

$$E_{z'''}(k) = k^4\, E_{z'}(k) \tag{16}$$

in order to proceed it is necessary to make the slope spectrum [f S(f)] a function of k as

$$E_{z'}(k) = f^{-1}\, [f\, S(f)]\, df/dk \tag{17}$$

where df/dk comes from the dispersion relation

$$f^2 = (2\pi)^{-2}\, (gk + \sigma k^3/\rho)\ . \tag{18}$$

In Eq. 18, g is acceleration due to gravity and σ and ρ are the surface tension and density of the wavy fluid--water in the present case.

The operations made possible by Eqs. 14 through 18 have been carried out for the four wind speeds of Cox's data (v = 3.18, 6.08, 9.20, 12.02 m/sec) and the resulting values of $\pi^{-1}\ (\sigma^2_{z''}/\sigma_{z'}\sigma_{z'''})^2$ are shown in Table 2 at wind speeds corrected from laboratory scale to at-sea scale (Ref. 3) (v = 4.3, 8.1, 13.5, 19.0 knots). The data of

Table 5 which have an "llsf" given by

$$(J_o)_{spectra} = 0.51 \, v^{-0.86} \tag{19}$$

are plotted together with this equation in Fig. 4.

Appendix A discusses the variation with wind speed of the individual variances and the surface correlation lengths implied by these.

CONCLUSION

In what has gone before, acoustic, radar, laser and slope spectra data have been interpreted to normal incidence reflection strengths of wind-blown water surfaces and for each of these data sources, a logarithmic least-squares fit has been made. These "llsf" relations are given by Eqs. 10, 11, 12, and 19. But as these equations represent the data sources they might be used to calculate "data" so as to obtain an average or consensus of the sources. Thus, using these four equations, a reflection strength, the logarithmic average of the four, has been calculated for v = 2.5 to 20 knots in steps of 2.5 knots and this used as a data basis for averaging. The consensus "llsf" is given by

$$(J_o)_{consensus} = 4.4 \, v^{-1.16} \tag{20}$$

with v in knots, and this is shown in Fig. 5.

Inasmuch as surface reflectance of a smooth sea surface would ideally be unity, it appears that for $v \leq 2.5$ knots, surface reflection strength approaches unity, that for $v \geq 20$ knots, surface reflection strength attains an asymptotic value of about 0.1, and that between 2.5 and 20 knots wind speed, surface reflection strength decreases approximately as v^{-1} with an uncertainty of a factor of three or so.

The foregoing suggests that some additional interpretation is warranted. In its most elaborate form, $(\sigma^2_{z''}/\sigma_{z'}\sigma_{z'''})^2$ may be written in terms of $E_z(k)$ using the form of Eqs. 15 and 16 as

$$(\sigma^2_{z''}/\sigma_{z'}\sigma_{z'''})^2 = \frac{\left[\int k^4 E_z(k)dk\right]^2}{\int k^2 E_z(k)dk \int k^6 E_{z'''}(k)dk} \qquad (21)$$

The form of Eq. 21 is familiar from turbulence theory (Ref. 11) in which potential energy represented by the elevation stochastic variable z is replaced by the kinetic energy turbulent velocity variable, u′, say. In the case of fluid turbulent velocities, Batchelor (Ref. 11) shows that the right-hand side of Eq. 20 tends to a limit as the main stream velocity v gets large as with surface roughness although there is no low velocity asymptote evidenced. This congruence is hardly surprising however for certainly the turbulent air stream over the rough sea surface is engaging in an energy exchange.

Rather than finishing with Eq. 20 as a description of sea surface reflection strength, one is tempted because of the stochastic--possibly Gaussian--character of air surface energy interchange and the high and low wind speed asymptotes to replace Eq. 20 with an error integral fit with variable ln v. The result of a first effort at this is given for both $J_o(v)$ and $N_o(v)$ in decibels--i.e., with $N_o(v) = 10 \log J_o(v)$ by

$$N_o(v) = (A/\sqrt{2\pi}\sigma)\int_{-\infty}^{x} \exp\left\{-\tfrac{1}{2}[(x'-\mu)/\sigma]^2\right\}dx' \qquad (22)$$

which is the canonical form, with $x = \ln v$ and $A = -10$, $\mu = \ln$ (9.5 knots) and $\sigma = \ln$ (1.95 knots).

Both Eqs. 20 and 22 are shown in Fig. 6. Equation 22 suggests that surface roughness--as evidenced by surface elevation derivatives--generates slowly until $v \cong 5$ knots, becomes very rough as v increases from 5 to 20 knots, and adds little roughness beyond 20 knots. Notwithstanding the validity of the exponential integral interpretation, the foregoing description is consonant with experiments and in accord with observation and intuition.

REFERENCES

1. P. Swerling, "Statistical Properties of Contours of Random Surfaces," IRE Trans. Inform. Theory, 8, 315-321, 1962.
2. J.J. Martin, "Sea Surface Roughness and Acoustic Reverberation: An Operational Model," J. Acoust. Soc. Am., 40, 697-710, 1966.
3. J.J. Martin, "Acoustic Reverberation at the Sea Surface: Surface and Sublayer Spectra vis-a-vis Scattering and Reflection," Defense Documentation Center # AD 645 541, 1966.
4. R.M. Hoover and R.J. Urick, "Sea Clutter in Radar and Sonar," IRE Convention Record, Pt. A, 17-22, 1957.
5. G.R. Grant and B.S. Yaplee, "Back Scattering from Water and Land at Centimeter and Millimeter Wavelengths," Proc. IRE, 45, 976-982, 1957.
6. James P. Campbell, "Back-Scattering Characteristics of Land and Sea at X-Band," Nat'l. Conf. Proc. PGANE-IRE & IAS, May 1958.
7. R.L. Kirk, "Surface Evaluation and Definition Program," Electro-Optical Systems, Inc., Report 7067, Contract NOw 66-0509-c, 13 December 1966.
8. C.S. Cox, "Measurements of Slopes of High-Frequency Wind Waves," J. Marine Res. 16, 199-225, 1958.
9. C.S. Cox and W.H. Munk, "Measurements of the Roughness of the Sea Surface from Photographs of the Sun's Glitter," J. Opt. Soc. Am., 44, 838-850, 1954.

10. L.N. Sneddon, Fourier Transforms, McGraw-Hill Book Co., Inc., 1951.

11. G.K. Batchelor, The Theory of Homogeneous Turbulence, Cambridge University Press, 1960.

TABLE 1. ACOUSTICALLY MEASURED WATER SURFACE REFLECTION STRENGTH VERSUS WIND SPEED

Wind Speed, v, Knots	Reflection Strength, $J_o(v)$
2	2
3.5	0.63
4.5	1.6
5	0.63
5.5	1
6.5	0.63
8	0.40
8.5	0.25
10	0.13
11.5	0.2
12	0.13
15	0.063
16	0.0003
21	0.2

TABLE 2. RADAR MEASURED WATER SURFACE REFLECTION STRENGTH VERSUS WIND SPEED (REFS. 4, 5, 6)

Wavelength, cm	Wind Speed, $\overline{v}$, knots	Reflection Strength, $J_o(v) = \sigma/4\pi$
0.86	7.5	3.5
	12.5	3.2
	17.5	2.1
	20.5	2.3
1.25	7.5	1.6
	12.5	1.25
	17.5	1.00
	22.5	1.25
3.0	2	8.0
	4	8.0
	9	2.0
3.2	2.5	0.63
	7.5	0.63
	12.5	0.33
	17.5	0.13
3.4	2.5	0.45
	7.5	0.32
	12.5	0.20
	17.5	0.08

TABLE 3. LASER-MEASURED WATER SURFACE REFLECTION STRENGTH VERSUS WIND SPEED (REF. 7)

Wind Speed, v, Knots	Reflection Strength, $J_o(v)$, (-)
9.3	0.74
12.3	0.28
18.2	0.21
19.1	0.22

TABLE 4. FREQUENCY-BIASED WIND BLOWN WATER SURFACE ABSOLUTE VALUES*

$$f\left[E_{z'}(f)\right]_1$$

Frequency, cps	v_{lab}, m/sec 3.18	6.08	9.20	12.02
0.857	6.30 E-5	1.25 E-4	3.16 E-4	1.99 E-3
1.07	1.25 E-4	2.51 E-4	1.00 E-3	5.01 E-3
1.35	1.00 E-4	3.16 E-4	1.00 E-3	3.98 E-3
1.71	1.00 E-3	1.99 E-3	2.51 E-3	1.00 E-2
2.15	5.01 E-5	5.01 E-4	1.00 E-3	1.99 E-2
2.71	5.01 E-5	3.16 E-4	7.94 E-3	1.58 E-1
3.41	2.51 E-4	7.94 E-4	1.00 E-1	2.51 E-1
4.29	2.51 E-4	1.58 E-2	2.51 E-1	1.25 E-1
5.40	2.51 E-3	1.00 E-1	7.94 E-2	1.00 E-1
6.80	1.25 E-2	1.00 E-1	5.01 E-2	1.00 E-1
8.57	3.98 E-2	3.98 E-2	6.30 E-2	1.25 E-1
10.7	2.51 E-2	2.51 E-2	3.16 E-2	1.58 E-1
13.5	1.00 E-2	3.16 E-2	3.98 E-2	1.58 E-1
17.1	1.25 E-2	2.51 E-2	2.51 E-2	1.25 E-1
21.5	1.99 E-2	3.16 E-2	2.51 E-2	1.00 E-1
27.1	2.51 E-2	5.01 E-2	2.51 E-2	1.00 E-1
34.1	2.51 E-2	5.01 E-2	2.51 E-2	1.00 E-1
42.9	1.58 E-2	7.94 E-2	3.16 E-2	7.94 E-2
54.0	2.51 E-3	1.25 E-1	3.16 E-2	1.00 E-1
68.0	1.00 E-3	6.30 E-2	2.51 E-2	3.98 E-2
85.7	1.58 E-4	3.98 E-2	2.51 E-2	3.98 E-2
107.	2.51 E-4	1.99 E-2	2.51 E-2	3.16 E-2
135.	2.51 E-5	6.30 E-3	1.58 E-2	2.51 E-2
171.	-- --	1.58 E-3	1.00 E-2	1.58 E-2
215.	-- --	3.16 E-4	3.98 E-3	7.94 E-3
271.	-- --	1.00 E-4	1.25 E-3	3.16 E-3
341.	-- --	3.16 E-5	6.30 E-4	1.99 E-3
429.	-- --	3.16 E-4	2.51 E-4	2.51 E-3
540.	-- --	2.51 E-3	2.51 E-3	1.00 E-2
$(\Delta \ell n f)\Sigma f E_z(f)$	6.78 E-2	1.87 E-1	2.07 E-1	4.61 E-2

*Values are accurate to ± 0.05 in base ten logarithm.

TABLE 5. WATER SURFACE REFLECTANCE PARAMETER VARIATION WITH LABORATORY WIND SPEED (BASED ON COX SLOPE SPECTRA)

Wind Speed, v		Reflection Strength Parameter
m/sec	knots*	$\pi^{-1} (\sigma^2_{z''}/\sigma_{z'}\ \sigma_{z'''})^2$ (-)
3.18	4.3	0.16
6.08	8.1	0.076
9.20	13.5	0.055
12.02	19.0	0.044

*Corrected for laboratory and at-sea scales.

APPENDIX A

WIND-BLOWN WATER SURFACE VARIANCES AND CORRELATION LENGTHS VERSUS WIND SPEED

The variances which lead to Table 2 and the correlation lengths which may be calculated from them have interest in themselves. Table A-1 gives these individual variances as a function of the two wind speeds mentioned. The values of σ_z^2, in Table 3 are several times larger than those expected from Cox and Munk's Eq. 9 and this is conjectured as due to the especially clean water surface of the laboratory experiment which would inhibit very little the formation of capillary waves hence large slope variance. Notwithstanding the slope variance discrepancy between laboratory and sea-going conditions and depending upon the wave number distribution of this discrepancy, one expects that the ratios of variances--as in Table 2--are less affected and that the trends indicated are valid. If indeed Eq. 4 is formally suitable for determining correlation lengths on a wind-blown surface, then Table A-1 may be used to find slope and curvature correlation lengths. These are given in Table A-2 for the four wind speeds of Cox.

Thus for the cleanest wind-blown water surfaces, the fine scale roughness is of the order of millimeters; this scale is probably much larger for at-sea condition.

TABLE A-1. WATER SURFACE SLOPE, CURVATURE AND ELEVATION THIRD DERIVATIVE VARIANCES VERSUS LABORATORY WIND SPEED

Wind Speed, v		Slope $\sigma^2_{z'}$	Curvature $\sigma^2_{z''}$	Third Derivative $\sigma^2_{z'''}$
m/sec	Knots*	(-)	(cm^{-2})	(cm^{-4})
3.18	4.3	0.044	1.40	97.1
6.08	8.1	0.105	4.20	708
9.20	13.5	0.24	11.9	3,460
12.02	19.0	0.51	23.9	8,150

*Corrected for laboratory and at-sea scales.

TABLE A-2. WATER SURFACE SLOPE AND CURVATURE CORRELATION LENGTHS VERSUS LABORATORY AND WIND SPEED

Wind Speed, v		Correlation Length, r	
m/sec	Knots*	Slope, z' cm	Curvature, z'' cm
3.18	4.3	0.17	0.12
6.08	8.1	0.16	0.077
9.20	13.5	0.14	0.059
12.02	19.0	0.15	0.054

*Corrected for laboratory and at-sea scales.

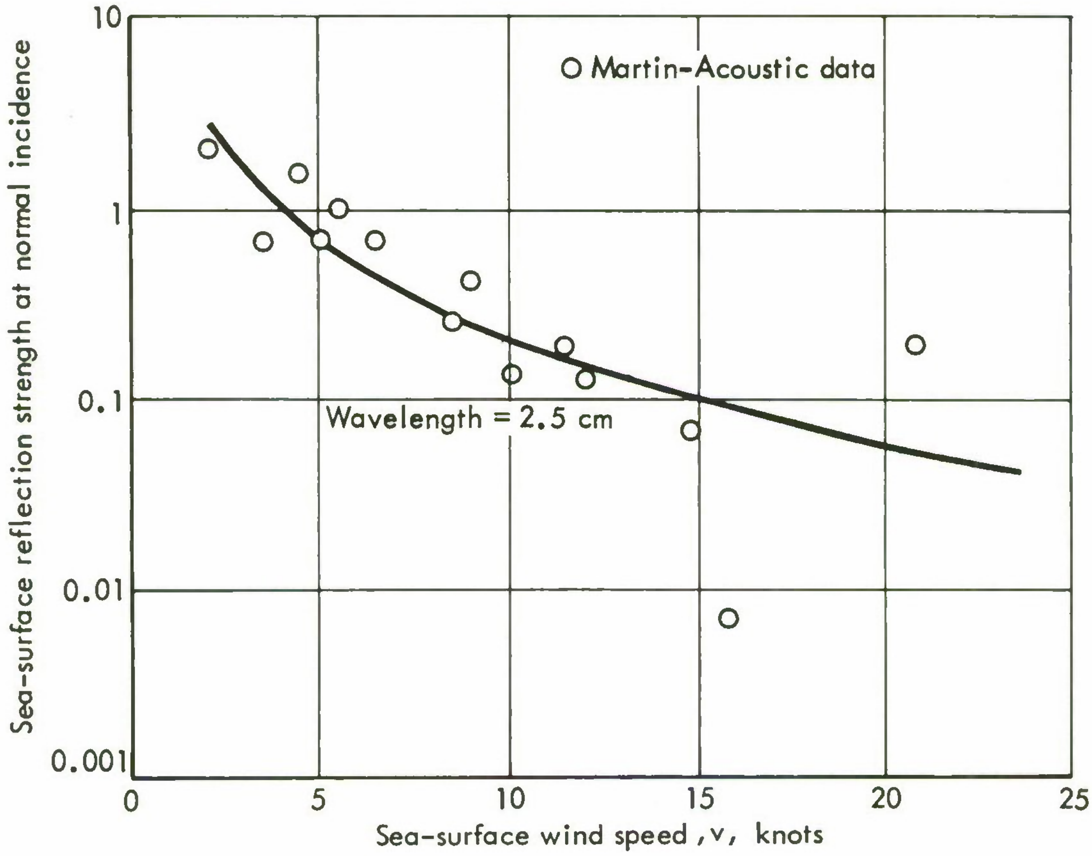
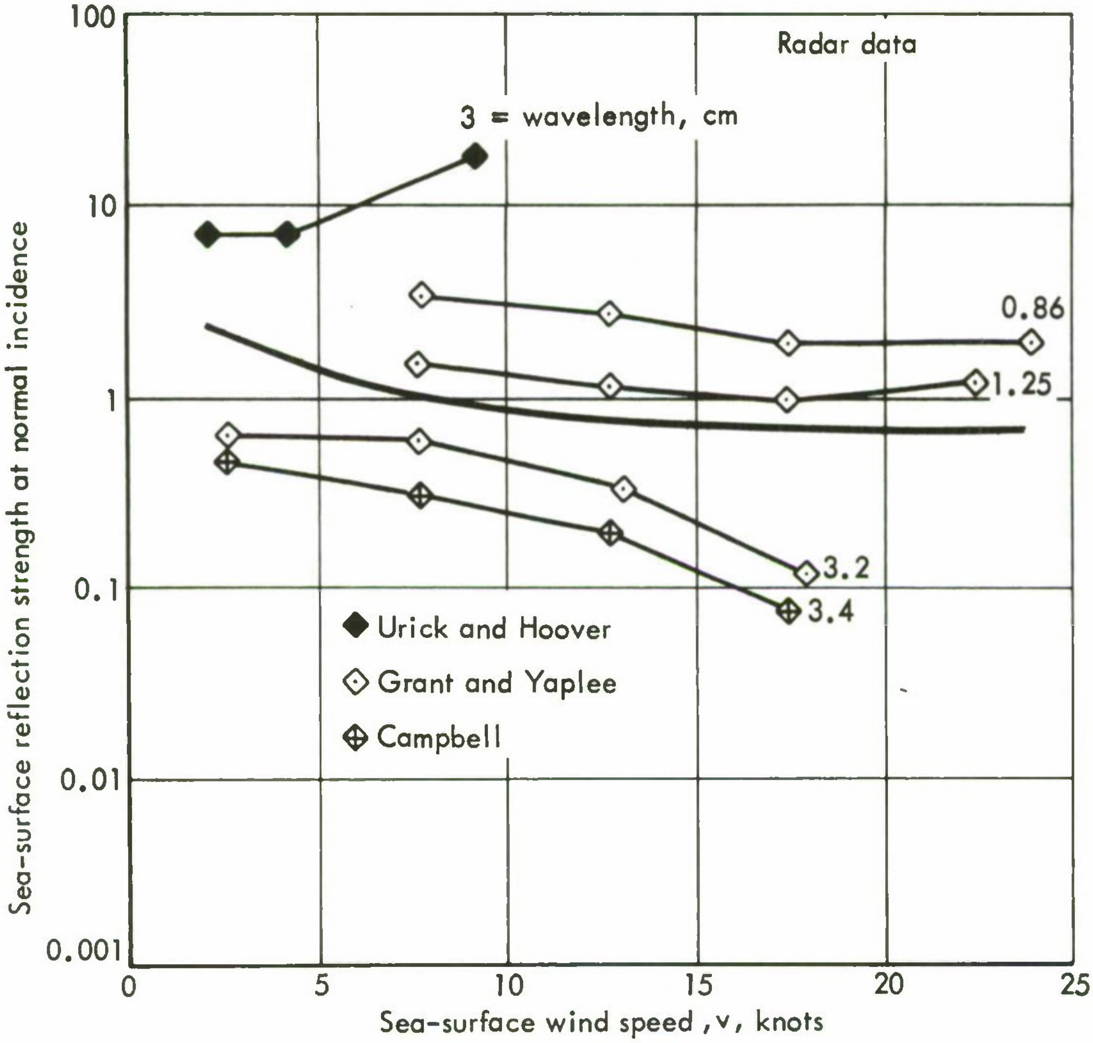


FIGURE 1.

J4-22-68-1



Radar data
3 = wavelength, cm
0.86
1.25
3.2
3.4
Urick and Hoover
Grant and Yaplee
Campbell
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25
Sea-surface reflection strength at normal incidence
Sea-surface wind speed ,v, knots

FIGURE 2.

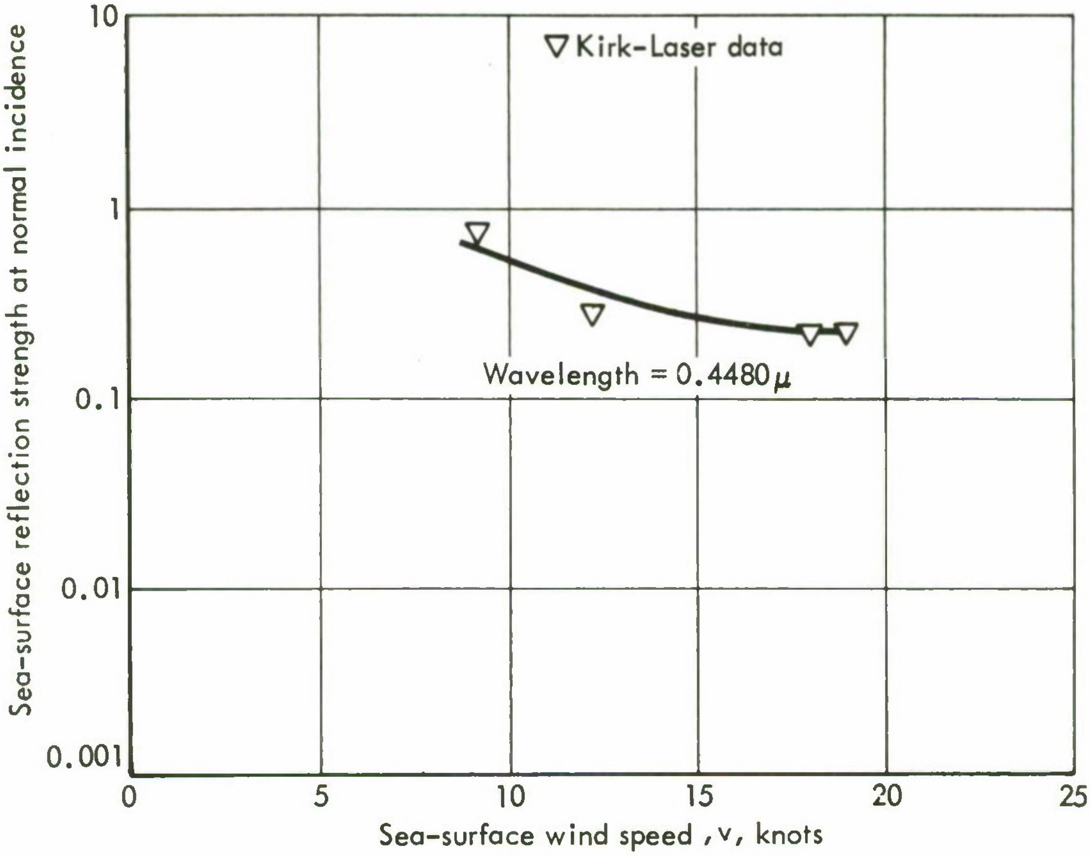
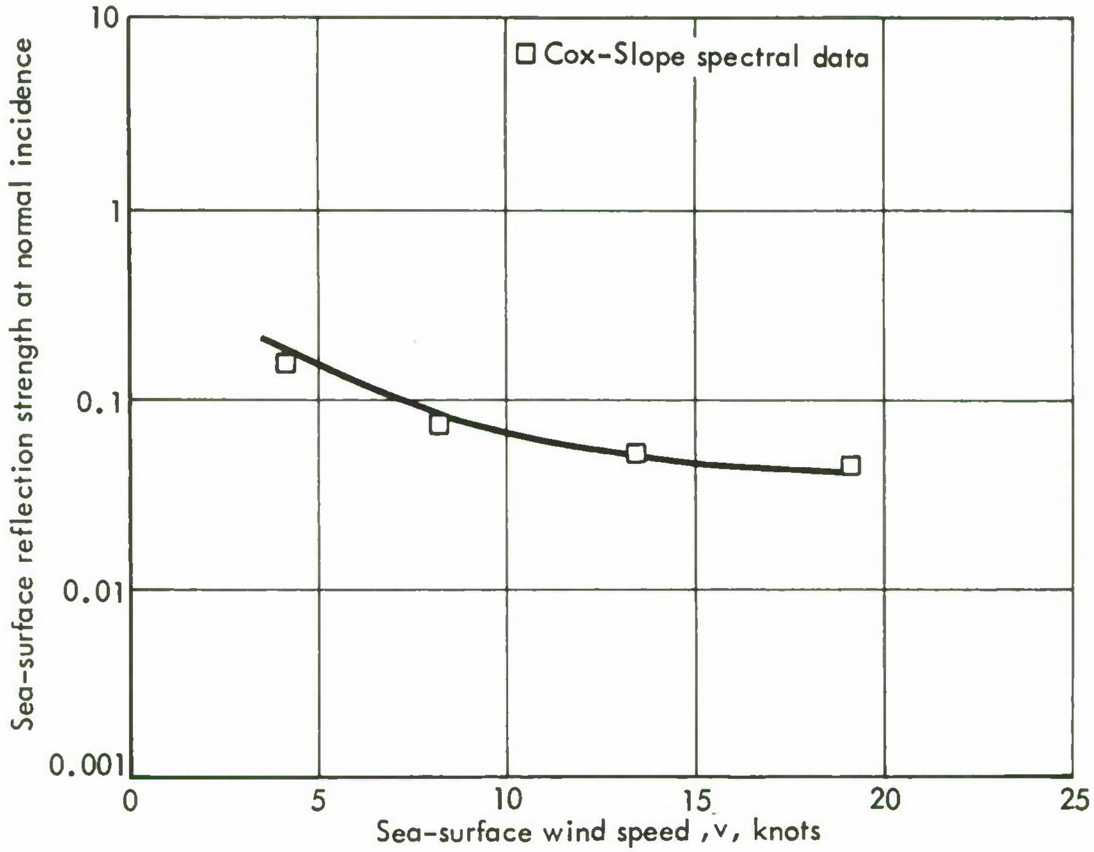


FIGURE 3.

J4-22-68-3



Cox-Slope spectral data
Sea-surface reflection strength at normal incidence
10
1
0.1
0.01
0.001
0
5
10
15
20
25
Sea-surface wind speed , v, knots

FIGURE 4.

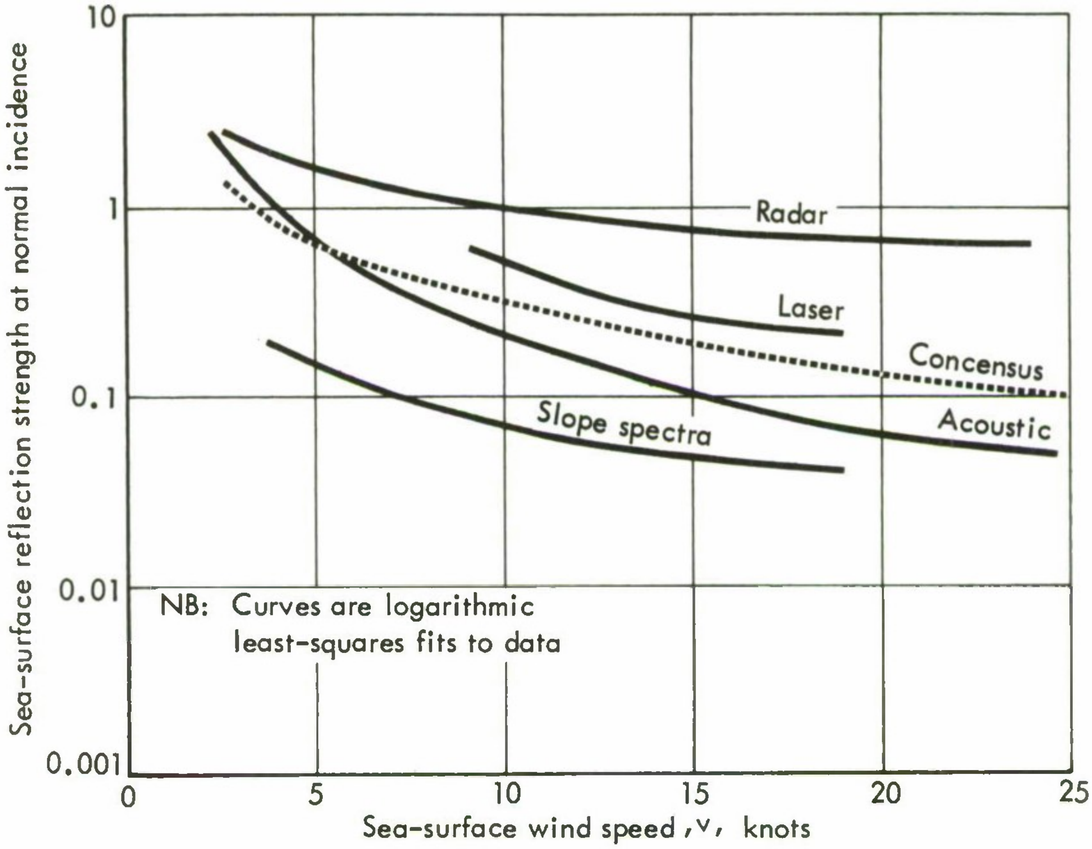


FIGURE 5.

J4-22-68-5

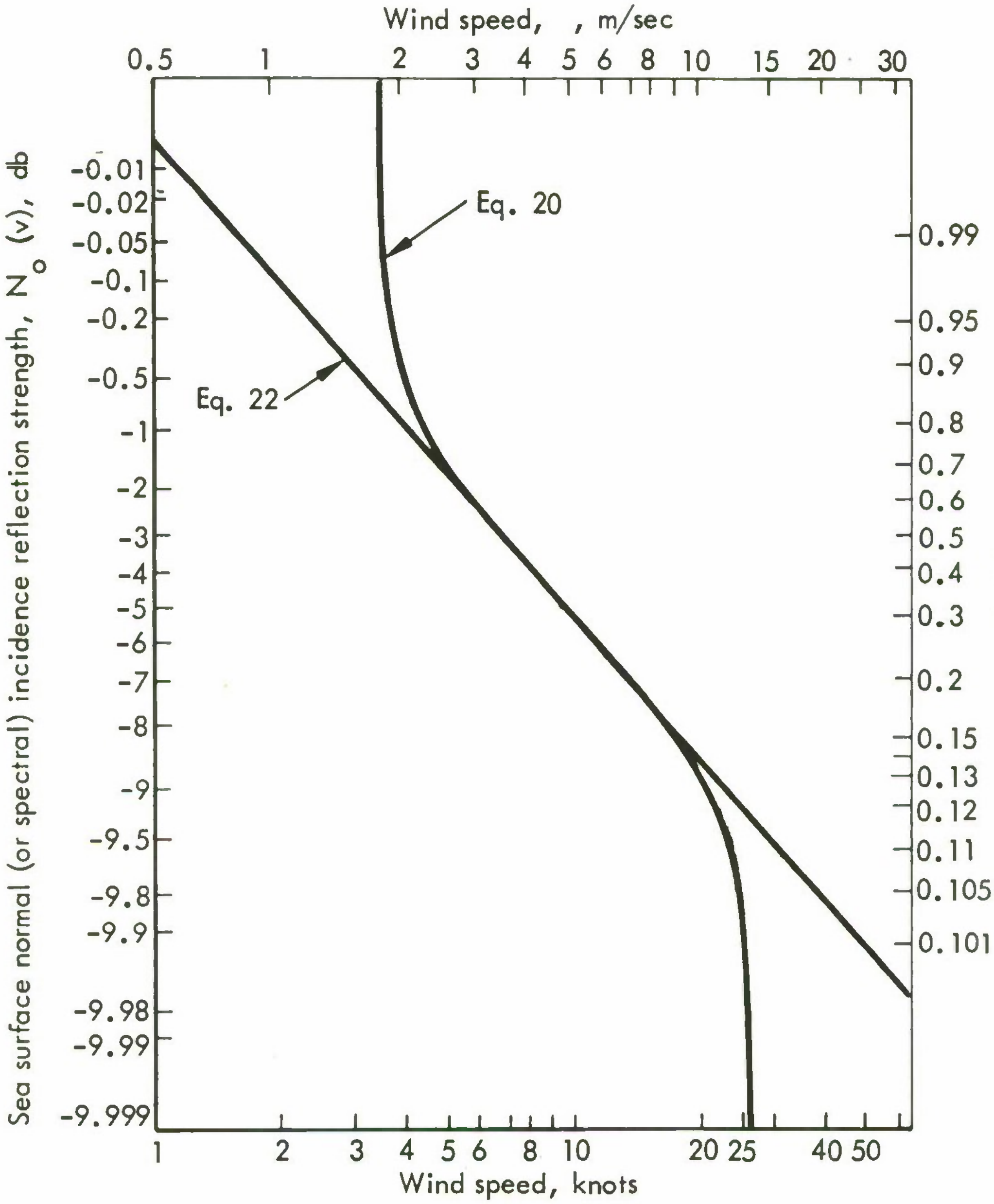


FIGURE 6.

J4-22-68-6

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