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# On Wind-induced Underwater Ambient Noise

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# ABSTRACT

A study of the wind dependence of underwater ambient noise is presented. This study includes a general theory of noise generation, status of available theories, and some recent noise measurements. The general theory indicates that the stresses and the motion of sea-air boundary contribute as a major source of wind-induced noise, and that the boundary conditions play very important roles. Even though several theories have been developed in recent years to investigate specific mechanisms of wind-induced underwater noise, careful evaluations of the theories are suggested. The wind dependence of underwater ambient noise can be identified in the frequency range 1-500 Hz (and higher) from available data. Due to possible interferences of shipping noise, system noise, and flow turbulence near the hydrophone, additional field measurements are necessary to obtain quantitative assessments of wind-induced noise in the frequency range 1-100 Hz. Recommendations are given for future research work on wind-induced noise.

ACKNOWLEDGEMENTS

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## INTRODUCTION

Underwater ambient noise has been measured and investigated intensively for the last forty years. Prior to 1970, comprehensive summaries of various ambient noise studies have been given by Knudsen et al. [42]* and by Wenz [109,110]. In general, the underwater ambient noise can be identified with three main sources: water motion, biological activities, and manmade sources. According to Wenz [110] some general features of ambient noise spectra are shown in Fig. 1. In the frequency band 1 to 10 or 20 Hz, a steep negative slope of -8 to -10 dB/Oct is frequently observed. It is suggested that the source of this noise is large-scale oceanic turbulence. From about 500 Hz to 25 Hz, the usual slope is at -5 to -6 dB/Oct. The source of this noise is in the agitation of all the sea surface, and the noise levels correlate well with wind speed and waveheight. In the band 10-500 Hz, the spectrum is highly variable. There is evidence that a major source of this component is ship traffic.

The wind dependence of underwater ambient noise has recently received considerable attention, especially in the low frequencies (1-500 Hz) [21, 115, 116, 119]. In this paper, a general theory of noise generation is presented in section I. In section II a brief description is given of the status of available theories of wind-induced underwater noise. Outlines of some recent noise measurements are stated in section III, and concluding remarks are presented in section IV. Detailed studies will be presented in separate papers.

## I. GENERAL THEORY

### A. GENERAL DIFFERENTIAL EQUATION

A general differential equation for noise generation can be derived from the continuity and momentum equations of fluid mechanics for regions that include mass and force sources. Using tensor notation, the continuity and momentum equations can be written in the forms

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho v_i) = q \qquad (1)$$

$$\frac{\partial \rho v_i}{\partial t} + \frac{\partial}{\partial x_j}(\rho v_i v_j + p_{ij}) = F_i \qquad (2)$$

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* References are not given in numerical order; they are part of the Bibliography section at the end of the text.

where $\rho$ = density, t = time, $v_i$ = component of velocity in direction $x_i$ (i = 1, 2, 3), q = mass source, $p_{ij}$ = compressive stress tensor, and $F_i$ = external force component.

By eliminating $\rho v_i$ between the two equations, it is found that

$$\frac{\partial^2 \rho}{\partial t^2} = \frac{\partial^2}{\partial x_i x_j}(\rho v_i v_j + p_{ij}) + \frac{\partial q}{\partial t} - \frac{\partial F_i}{\partial x_i} \tag{3}$$

subtracting

$$c_o^2 \frac{\partial^2 \rho}{\partial x_i^2} = \delta_{ij} c_o^2 \frac{\partial^2 \rho}{\partial x_i x_j} = \frac{\partial^2 (c_o^2 \rho \delta_{ij})}{\partial x_i x_j}$$

from both sides of Equation 3, we have

$$\frac{\partial^2 \rho}{\partial t^2} - c_o^2 \frac{\partial^2 \rho}{\partial x_i^2} = G(x_i, t) \tag{4}$$

where

$c_o$ = Speed of Sound

$T_{ij} = \rho v_i v_j + p_{ij} - c_o^2 \rho \delta_{ij}$

$G = \frac{\partial q}{\partial t} - \frac{\partial F_i}{\partial x_i} + \frac{\partial T_{ij}}{\partial x_i \partial x_j}$

Equation 4 is the general differential equation for noise generation, and it is equivalent to the similar equation given by Ross [91].

B. SOLUTION

Equation 4 is an inhomogeneous wave equation, and the general solution is known as [20]

$$\rho - \rho_0 = -\frac{1}{4\pi c_o^2}\int_V \frac{[G]}{r} dV(\vec{y})$$

$$+ \frac{1}{4\pi}\int_S \left\{\frac{1}{r}\left[\frac{\partial \rho}{\partial n}\right] - \frac{\partial}{\partial n}\left(\frac{1}{r}\right)[\rho] + \frac{1}{c_o r}\frac{\partial r}{\partial n}\left[\frac{\partial \rho}{\partial t}\right]\right\} dS(\vec{y}) \tag{5}$$

in which the symbol

$$[G] = G(\vec{y}, t - \frac{r}{c_o})$$

denotes a function with retarded time, where $r = |\vec{x} - \vec{y}|$, and $\vec{n}$ is the outward normal from the fluid. The first integral is taken over the volume V external to the boundaries, and the second integral is taken over the surface of the volume V.

By applying the divergence theorem, we have

$$\int_V \left[\frac{\partial F_i}{\partial y_i}\right]\frac{dV(\vec{y})}{r} - \frac{\partial}{\partial x_i}\int_V [F_i]\frac{dV(\vec{y})}{r} = \int_V \frac{\partial}{\partial y_i}\left[\frac{F_i}{r}\right] dV(\vec{y}) = \int_S \ell_i [F_i]\frac{dS(\vec{y})}{r} \tag{6}$$

where $\ell_i$ are the direction cosines of the outward normal from the fluid.

Similarly we have

$$\int_V \left[\frac{\partial T_{ij}}{\partial y_i \partial y_j}\right]\frac{dV(\vec{y})}{r} - \frac{\partial}{\partial x_i}\int_V \left[\frac{\partial T_{ij}}{\partial y_j}\right]\frac{dV(\vec{y})}{r} = \int_S \ell_i \left[\frac{\partial T_{ij}}{\partial y_i}\right]\frac{dS(\vec{y})}{r} \tag{7}$$

By repeating this a second time, we obtain

$$\int_V \left[\frac{\partial T_{ij}}{\partial y_j}\right]\frac{dV(\vec{y})}{r} - \frac{\partial}{\partial x_j}\int_V [T_{ij}]\frac{dV(\vec{y})}{r} = \int_S \ell_j [T_{ij}]\frac{dS(\vec{y})}{r} \tag{8}$$

From (6), (7) and (8), we have

$$\int_V \frac{[G]}{r} dV(\vec{y}) = \int_V \left[\frac{\partial q}{\partial t}\right]\frac{dV(\vec{y})}{r} - \int_V \left[\frac{\partial F_i}{\partial y_i}\right]\frac{dV(\vec{y})}{r} + \int_V \left[\frac{\partial T_{ij}}{\partial y_i \partial y_j}\right]\frac{dV(\vec{y})}{r}$$

$$= \int_V \left[\frac{\partial q}{\partial t}\right]\frac{dV(\vec{y})}{r} - \frac{\partial}{\partial x_i}\int_V [F_i]\frac{dV(\vec{y})}{r} + \frac{\partial^2}{\partial x_i \partial x_j}\int_V [T_{ij}]\frac{dV(\vec{y})}{r}$$

$$-\int_S \ell_i [F_i]\frac{dS(\vec{y})}{r} + \frac{\partial}{\partial x_i}\int_S \ell_j [T_{ij}]\frac{dS(\vec{y})}{r} + \int_S \ell_i \left[\frac{\partial T_{ij}}{\partial y_j}\right]\frac{dS(\vec{y})}{r} \tag{9}$$

The surface integral which appears in Eq. 5 can be transformed into the different form, we have

$$\int_S \left\{\frac{1}{r}\left[\frac{\partial \rho}{\partial n}\right] - \frac{\partial}{\partial n}\left(\frac{1}{r}\right)[\rho] + \frac{1}{c_o r}\frac{\partial r}{\partial n}\left[\frac{\partial \rho}{\partial t}\right]\right\} dS(\vec{y})$$

$$= \int_S \ell_i \left\{\frac{1}{r}\left[\frac{\partial \rho}{\partial y_i}\right] + \frac{1}{r^2}\frac{\partial r}{\partial y_i}[\rho] + \frac{1}{c_o r}\frac{\partial r}{\partial y_i}\left[\frac{\partial \rho}{\partial t}\right]\right\} dS(\vec{y})$$

$$= \int_S \ell_i \frac{1}{r}\frac{\partial}{\partial y_j}[\rho \delta_{ij}] dS(\vec{y}) - \int_S \ell_i \frac{\partial r}{\partial x_i}\left(\frac{1}{r^2}[\rho] + \frac{1}{c_o r}\left[\frac{\partial \rho}{\partial t}\right]\right) dS(\vec{y})$$

$$= \int_S \ell_i \frac{1}{r}\frac{\partial}{\partial y_j}[\rho \delta_{ij}] dS(\vec{y}) + \int_S \ell_j \frac{\partial}{\partial x_i}\left(\frac{1}{r}[\rho \delta_{ij}]\right) dS(\vec{y}) \tag{10}$$

Substituting from (9) and (10) into (5) we obtain

$$\begin{aligned}
\rho - \rho_o = {} & \frac{1}{4\pi c_o^2}\int_V \left[\frac{\partial q}{\partial t}\right]\frac{dV(\vec{y})}{r} \\
& - \frac{1}{4\pi c_o^2}\,\frac{\partial}{\partial x_i}\int_V [F_i]\frac{dV(\vec{y})}{r} \\
& + \frac{1}{4\pi c_o^2}\,\frac{\partial^2}{\partial x_i \partial x_j}\int_V [T_{ij}]\frac{dV(\vec{y})}{r} \\
& - \frac{1}{4\pi c_o^2}\int_S \ell_i [F_i]\frac{dS(\vec{y})}{r} \\
& + \frac{1}{4\pi c_o^2}\int_S \ell_i \frac{\partial}{\partial y_j}[T_{ij} + c_o^2 \rho \delta_{ij}]\frac{dS(\vec{y})}{r} \\
& + \frac{1}{4\pi c_o^2}\,\frac{\partial}{\partial x_i}\int_S \ell_j [T_{ij} + c_o^2 \rho \delta_{ij}]\frac{dS(\vec{y})}{r} \qquad (11)
\end{aligned}$$

By substituting for $T_{ij} = \rho v_i v_j + p_{ij} - c_o^2 \rho \delta_{ij}$ , Equation 11 can be written in the form

$$\begin{aligned}
\rho - \rho_o = {} & \frac{1}{4\pi c_o^2}\int_V \left[\frac{\partial q}{\partial t}\right]\frac{dV(\vec{y})}{r} \\
& - \frac{1}{4\pi c_o^2}\,\frac{\partial}{\partial x_i}\int_V [F_i]\frac{dV(\vec{y})}{r} \\
& + \frac{1}{4\pi c_o^2}\,\frac{\partial^2}{\partial x_i \partial x_j}\int_V [T_{ij}]\frac{dV(\vec{y})}{r} \\
& + \frac{1}{4\pi c_o^2}\int_S \ell_i \left[\frac{\partial}{\partial y_j}(\rho v_i v_j + p_{ij}) - F_i\right]\frac{dS(\vec{y})}{r} \\
& + \frac{1}{4\pi c_o^2}\,\frac{\partial}{\partial x_i}\int_S \ell_j [\rho v_i v_j + P_{ij}]\frac{dS(\vec{y})}{r} \qquad (12)
\end{aligned}$$

By utilizing (2), we have

$$\rho - \rho_o = \frac{1}{4\pi c_o^2}\int_V \left[\frac{\partial q}{\partial t}\right]\frac{dV(\vec{y})}{r}$$

$$- \frac{1}{4\pi c_o^2}\frac{\partial}{\partial x_i}\int_V [F_i]\frac{dV(\vec{y})}{r}$$

$$+ \frac{1}{4\pi c_o^2}\frac{\partial}{\partial x_i \partial x_j}\int_V [T_{ij}]\frac{dV(\vec{y})}{r}$$

$$- \frac{1}{4\pi c_o^2}\int_S \ell_i \left[\frac{\partial \rho v_i}{\partial t}\right]\frac{dS(\vec{y})}{r}$$

$$+ \frac{1}{4\pi c_o^2}\frac{\partial}{\partial x_i}\int_S \ell_j [\rho v_i v_j + p_{ij}]\frac{dS(\vec{y})}{r} \qquad (13)$$

Equation 13 is more general than the solutions given in the literature. For example, if we drop the sources terms and choose specific boundary conditions, we can reduce Equation 13 to the result of Powell [87]. Furthermore, if there is zero velocity and the solid boundaries, we have the result of Curle [20]. If the boundary effect is neglected, we have the result of Lighthill [57,58].

## C. INTERPRETATION

The five terms on the right of Equation 13 represent the various sources of noise generation.

1. The first term on the right involves the rate of mass source, q. However, if we consider Equation 1 as the continuity equation of the fluid mixture, the mass source should equal to zero.

2. The second term, the external force acting on the volume, is of dipole nature. The importance of this term depends on the nature of the force and the scales of time and space.

3. The third term, involving the turbulent stresses ( $T_{ij}$ ) and the compressible stresses ( $P_{ij}$ ) in the fluid volume, is the term which Lighthill derived and showed to be of quadrupole nature.

4. The fourth term, involving the motion of the boundary, acts as a monopole.

5. The fifth term, involving the turbulent stresses and the compressible stresses acting on the boundary, is of dipole nature.

For the problems of wind-induced underwater ambient noise, the last two terms are of the most importance. The stresses and the motion of sea-air boundary contribute the major sources of wind-induced underwater noise. However, the dynamics and the interactions of the sea-air interface are very complicated, involving wave motions, instabilities, breaking, impacts, bubbles, currents and turbulence.

## II. STATUS OF THEORIES

Several theories have been proposed to relate the underwater ambient noise with surface winds. The proposed noise generating mechanisms can be divided into four groups. The first group [38,115] considers that wind turbulence is a source of the underwater ambient noise. The second [9,31,36,47,60,68] deals with the interactions of ocean surface waves. The third group [28] treats the interaction of surface waves with oceanic turbulence. The fourth [109,116] considers the spray and bubbles to be sources of ambient-noise. A comprehensive investigation of the first three mechanisms has been given by Yen and Perrone [119]. Their study mainly concerns itself with the wind-generated noise spectrum below 10 Hz. When considering only the low frequency noise, the formulation can be simplified. The statistical nature of ambient noise is emphasized instead of deriving a deterministic model.

### A. WIND TURBULENCE

The fluctuations of wind turbulence would generate underwater ambient noise due to the wind action on the sea-air interface. The mechanisms of sea-air interaction are very complex even though considerable advancements have been made in the recent years [14,50,59,65,72,85,90,95,96,98,117]. The role of wind turbulence in the generation of underwater ambient noise has received limited study. Recently, Wilson [115] extends the development of the theory of turbulent pressure fluctuation intiated by Isakovick and Kur'yanov [38]. The theory of Isakovick and Kur'yanov is based on the model of noise generated directly by the forces of the wind on the water, i.e., on the same mechanism as that which produces ocean surface waves. For low-frequency sound waves where the wavelength is much greater than the height of the surface wave, the sea surface is considered as a horizontal plane. It is shown that the spectral density of the underwater sound field is related to the space-time spectral density of the wind turbulent pressure fluctuations on the surface of water. Since there are no direct measurements of the wind turbulent pressure fluctuations on the sea surface, it is necessary to use indirect data for the flow past solid boundaries with various degrees of roughness. This gives a basis for the assumption that for wind flow over the ocean, roughness is dictated by the surface wave of the ocean. Thus the spectral density of the underwater noise can be determined indirectly by relating it to the sea surface spectrum which has been measured by different researchers. Due to the different methods of calculation, the results of Wilson are significantly different from that of Isakovick and Kur'yanov. In the frequency band 5 to 50 Hz, Wilson showed that the wind speed and frequency dependence of the calculated source spectrum level agrees well with data measured in the northeastern Pacific Ocean under low shipping noise conditions.

### B. SURFACE WAVE INTERACTION

The noise-generating mechanisms of surface wave interactions have been studied by several investigators. It is known that the pressure fluctuations, which are caused by the linearized surface waves, penetrate into the water up to a distance of the order of a wavelength. However, Longuet-Higgins [60] showed that the interaction of two surface waves would form pressure fluctuations which do not decrease with depth. Based on a model of quadratic interactions of oppositely traveling surface waves, and incorporating several surface wave spectral models, Hughes [36] estimated noise spectral level for the range 1-3000 Hz. In comparison with the measurements of Perrone [80], it is shown that reasonable agreement with measurements exists for frequencies less than 10 Hz; however, the wrong spectral shape is shown at higher frequencies.

### C. SURFACE WAVES AND OCEANIC TURBULENCE INTERACTION

Noise generation by the interaction of surface waves and oceanic turbulence has been studied by Goncharov [28]. The motion of water particles in the surface layer of the ocean is affected by surface waves, but also by oceanic turbulence. Since particle speed is much greater in a surface wave than it is in turbulent motion, it might appear that the surface wave interaction is the only important mechanism. However, the noise radiated by surface wave interaction is a second order quantity, so the noise radiated by the interaction of surface waves and oceanic turbulence may be important for certain frequencies. Under certain assumptions concerning the properties of the turbulence, Goncharov showed that the estimated source spectrum levels are in reasonable agreement with experimental data at 10 Hz and 100 Hz.

### D. SPRAY AND BUBBLES

Wenz [109,110] suggested that in the band 50 Hz to 20K Hz, the ambient noise is mainly wind-dependent noise from bubbles and spray. Recently the noise source spectrum levels for the impact of spray have been investigated by Wilson [116] in the band 50 to 1000 Hz. An empirical approach was used based on the recent measurement of white capping index as a function of wind speed, the noise measurements of Morris [74], and the impact results of Franz [24].

## III. RECENT DATA OF AMBIENT NOISE

By studying several recently gathered data sets of underwater ambient noise, it was found that the ambient noise spectra vary, depending on location, time, frequency, hydrophone depth, and wind speed. Some representative results are given in the following:

### A. LOCATION

The typical noise spectra [41] for Sites A and C are shown in Figure 2. Both Sites A and C were located in the eastern North Pacific Center Water areas. In comparison with a noise spectrum of the South Pacific Ocean, Figure 3 clearly indicates the influence of more shipping activity in the Northeast Pacific. The characteristics of a shipping component are shown in Figure 3, and a contribution from whales is also apparent in the North Pacific spectrum.

### B. HYDROPHONE DEPTH AND WIND SPEED

A comparison of noise spectrum level by Shooter at two hydrophone depths, 3572 m and 4572 m, with wind speed is shown in Figure 4. At 224 Hz, the dependence of the noise spectrum on wind speed and hydrophone depth is obvious. Ambient noise levels were measured by Morris [74] at two deep water sites in northeastern Pacific Ocean that were separated by about 1000 miles. Analyses of the data indicate that at frequencies less than 100 Hz the noise level decreases with increasing depth. These low-frequency noise levels are independent of the wind speed. At frequencies 100 Hz and above, noise levels and the depth dependence of noise are controlled by the wind-induced noise.

## C. FREQUENCY AND WIND SPEED

The variation of the ambient noise level over a 30-day period and the corresponding variation in wind speeds are presented graphically in Figure 5 in the frequency range 11-2816 Hz. Three qualitative conclusions based on Figure 5 have been drawn by Perrone [80]: (1) The ambient-noise-level curves bearing a striking resemblence to the wind-speed curves in the 141-2816 Hz bands indicate a strong wind dependence in the upper bands. (2) Very little wind dependence is apparent in the 17-112 Hz bands, except at very high wind velocities. (3) In the two lowest frequency bands (center frequencies at 11 Hz and 14 Hz), wind dependence may be obtained. A more recent analysis of the same ambient noise data by Perrone in the frequency range 0.6-12 Hz is shown in Figure 6. Based on Figure 6, the following conclusion can be drawn: (1) The wind dependence can be observed in the 2-12 Hz bands. (2) Little wind dependence is apparent in the 0.6 Hz band due to the limitation of system noise.

## D. ONE-YEAR AMBIENT NOISE MEASUREMENTS NEAR BERMUDA

The data presented in the open literature by Perrone [80] were obtained during January 1966 from a single omnidirectional hydrophone located near Bermuda at a 4400 m depth. Much more information can be obtained from a NUSC Technical Report [83]. In that report, the results of ambient noise data recorded simultaneously during a one-year period between January and December 1966 from five hydrophones located near Bermuda at depths of 30, 400, 1100, 2400 and 2500 fm (55, 730, 2000, 4400 and 4500 m) are presented. The locations of hydrophones and wind-speed sensors are shown in Figures 7 and 8. The data in Figure 9 are the yearly summary of ambient noise spectra for eight 5-knot wind speed groups and for each of the five hydrophone depths. In the same figure, the histograms illustrating the total number of a 2 minute ambient noise sample contained in the yearly spectra are also given. The ambient noise spectra display variation as a function of wind speed and hydrophone depth. The wind dependence is apparent in the yearly summary of ambient noise spectra even for the deepest hydrophones.

# IV. CONCLUDING REMARKS

Based on this study of wind-induced underwater ambient noise, the following qualitative remarks can be made.

## A. FREQUENCY RANGE OF WIND DEPENDENCE

Wind dependence of underwater ambient noise can be observed in the frequency range 1-500 Hz (and higher) in available data. Due to possible interferences of shipping noise, system noise, and flow turbulence near the hydrophone, additional field measurements are necessary to obtain quantitative assessments of wind-induced noise in the frequency range 1-100 Hz. It is especially necessary that environmental data, such as winds, waves, and currents, be recorded simultaneously with the noise data.

## B. LOCATION AND HYDROPHONE DEPTH

Wind-induced underwater noise is expected to vary with location and hydrophone depth. From the theory of noise generation, Equation 13 indicates that the boundary conditions play very important roles in underwater noise generation. The direct roles are the prescribed external conditions and the reflection of noise.

Furthermore, the boundary conditions affect surface waves, currents and oceanic turbulence, and those quantities contribute to the ambient noise as indicated in Equation 13. Due to the boundary effects, the measurements near Bermuda may not be typical of wind-induced noise in the open ocean. Additional long-term measurements at different typical locations would be useful for the investigation of underwater ambient noise.

## C. THEORY AND MEASUREMENT

Mechanisms of wind-induced underwater ambient noise can be expressed mathematically in the form of Equation 13. As mentioned, the boundary conditions play important roles for underwater noise generation. The stresses and motion of the sea-air boundary contribute the major sources of wind-induced noise. However, calculations or estimations of the right hand side of Equation 13 are very difficult because the mechanisms of the interactions of the sea-air interface are very complex. Even though several theories have been developed in recent years to investigate specific mechanisms of wind-induced underwater noise, careful evaluations of the existing theories are necessary for the following reasons. First, the range of validity is limited for a specific theory due to simplifying assumptions of the derivation. Second, most theories rely on the knowledges of waves and turbulence; however, knowledge of the statistical properties of turbulence and waves in sea-air interaction regions is lacking, particularly in the frequency range 1-500 Hz. Third, there are very few ideal noise measurements for the evaluation of theories, and the results of data analyses may depend on the techniques of data processing.

## D. RECOMMENDATIONS

1. Detailed evaluation of available data of wind-induced underwater ambient noise should be carried out in the frequency range 1-500 Hz.

2. Comparison of various theories of wind-induced underwater noise should be carried out in the frequency range 1-500 Hz.

3. Data analyses should be extended to cover the available data in frequency range from 1 to 100 Hz. In order to evaluate the possible effect of data processing, it is recommended that two independent methods of data processing will be used to analyze a selected data set.

4. Mechanisms of wind-induced noise should be investigated in conjunction with the current research work of sea-air interactions, ocean dynamics and turbulence. Nonlinear interactions and instabilities should be emphasized.

5. Whenever possible, future underwater noise experiments should include such environmental data as wind speeds, waves, and currents.

6. Designed experiments should be carried out for various typical locations, such as deep open ocean, with and without ridges. Continuous measurements of one year are desirable to investigate the statistical properties and the variation of ambient noise with time.

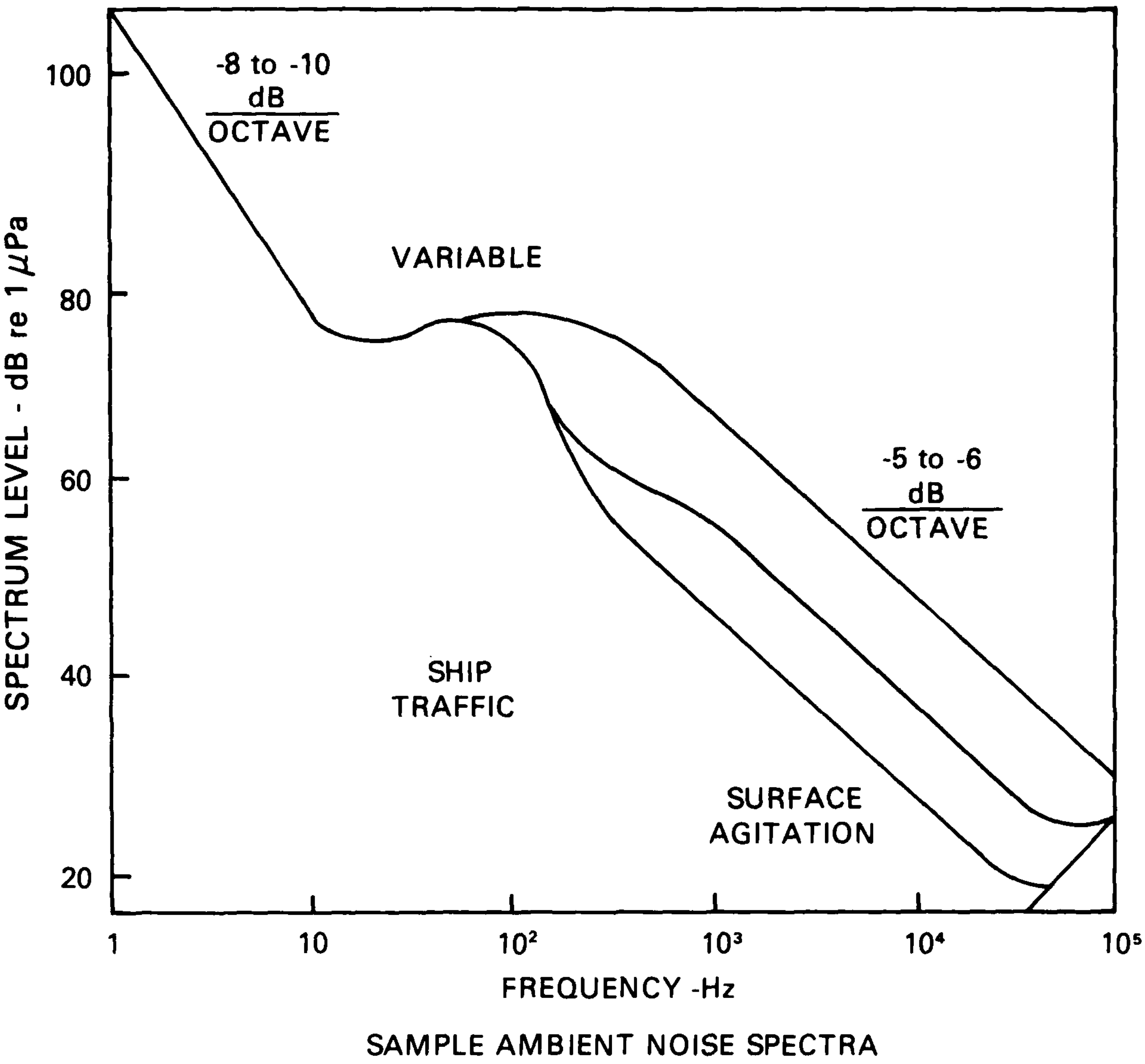

Figure 1. General characteristics of underwater ambient noise spectra (Wenz, 1972)

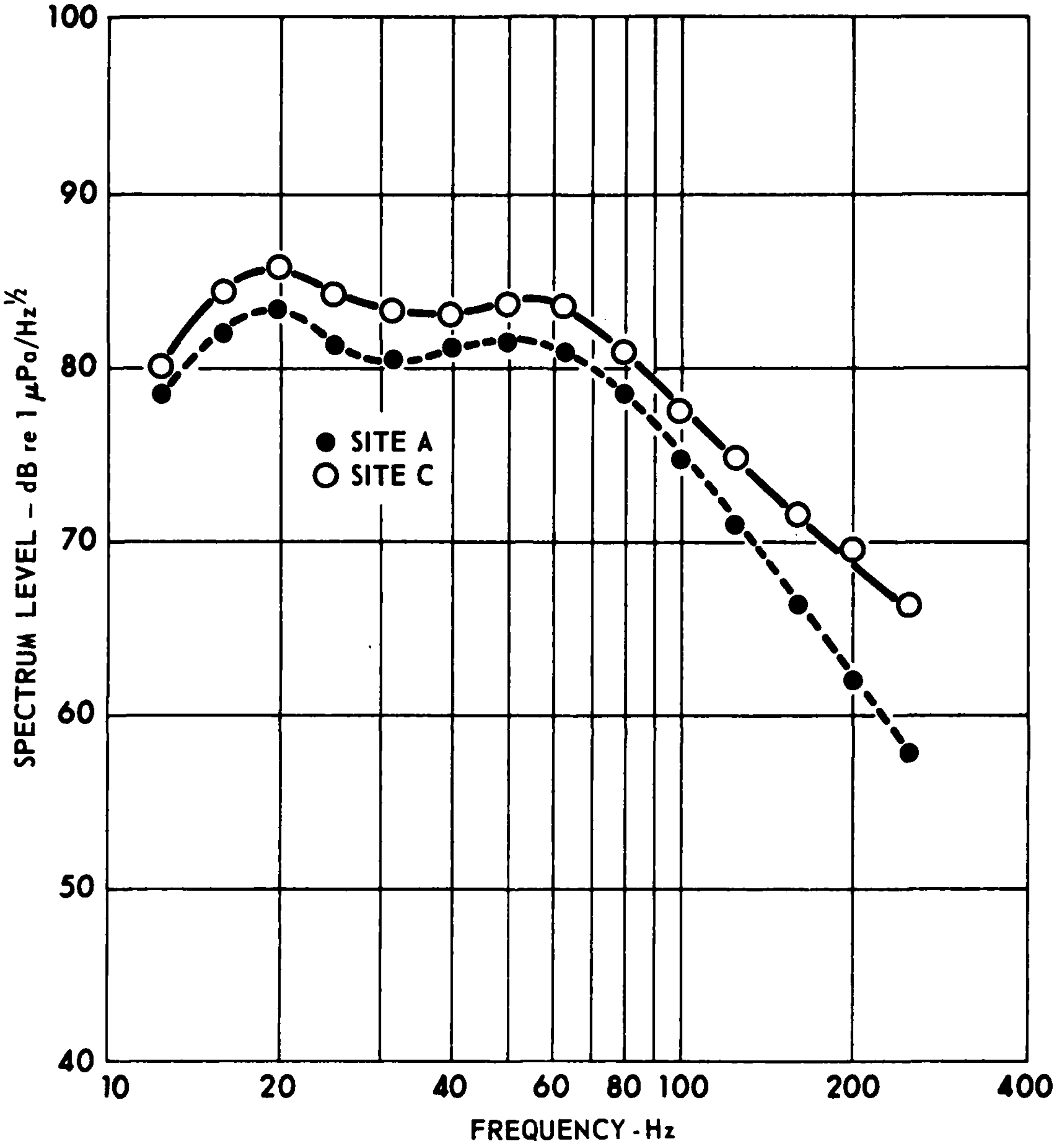

Figure 2. Comparison of noise levels at five sites in the North Pacific (Kibblewhite, Shooter, and Watkins, 1976)

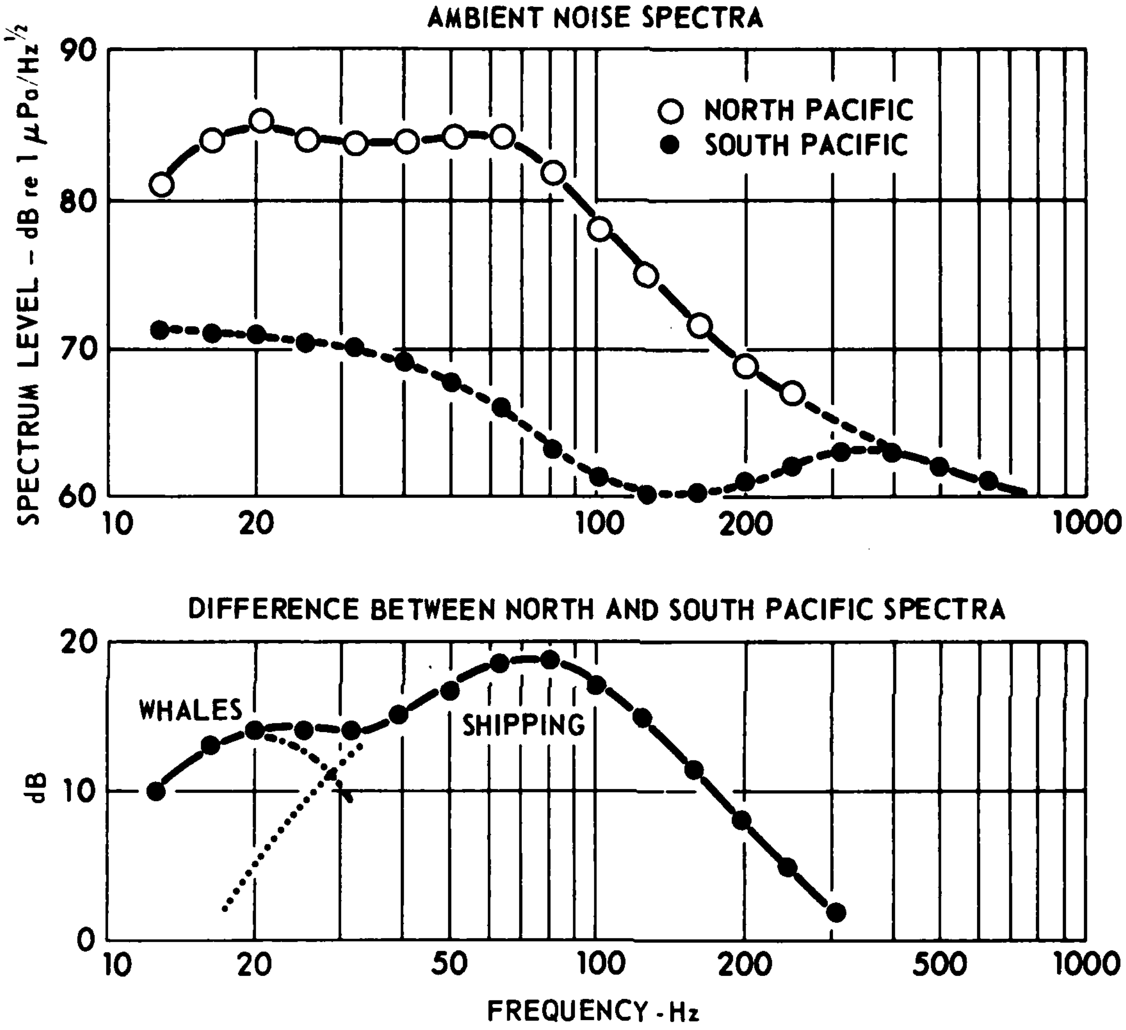

Figure 3. Comparison of North and South Pacific ambient noise spectra (Kibblewhite, Shooter, and Watkins, 1976)

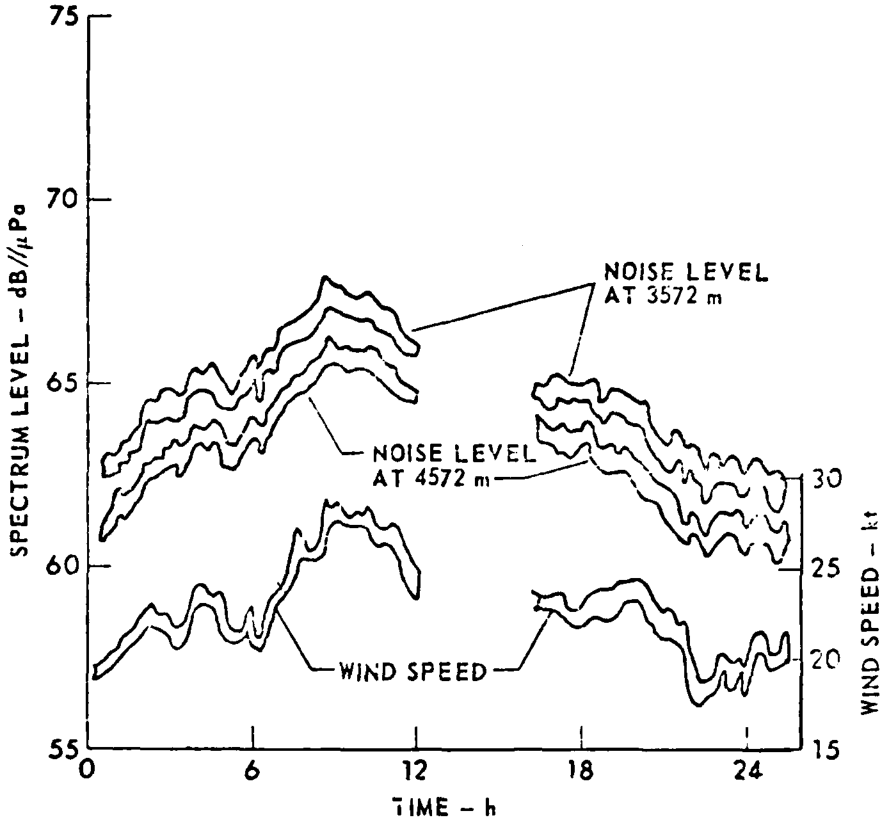

Figure 4. Comparison of noise level (at 224 Hz) at 3572 m and 4572 m with wind speed (Unpublished data of Shooter at ARL, University of Texas at Austin. Used by permission.)

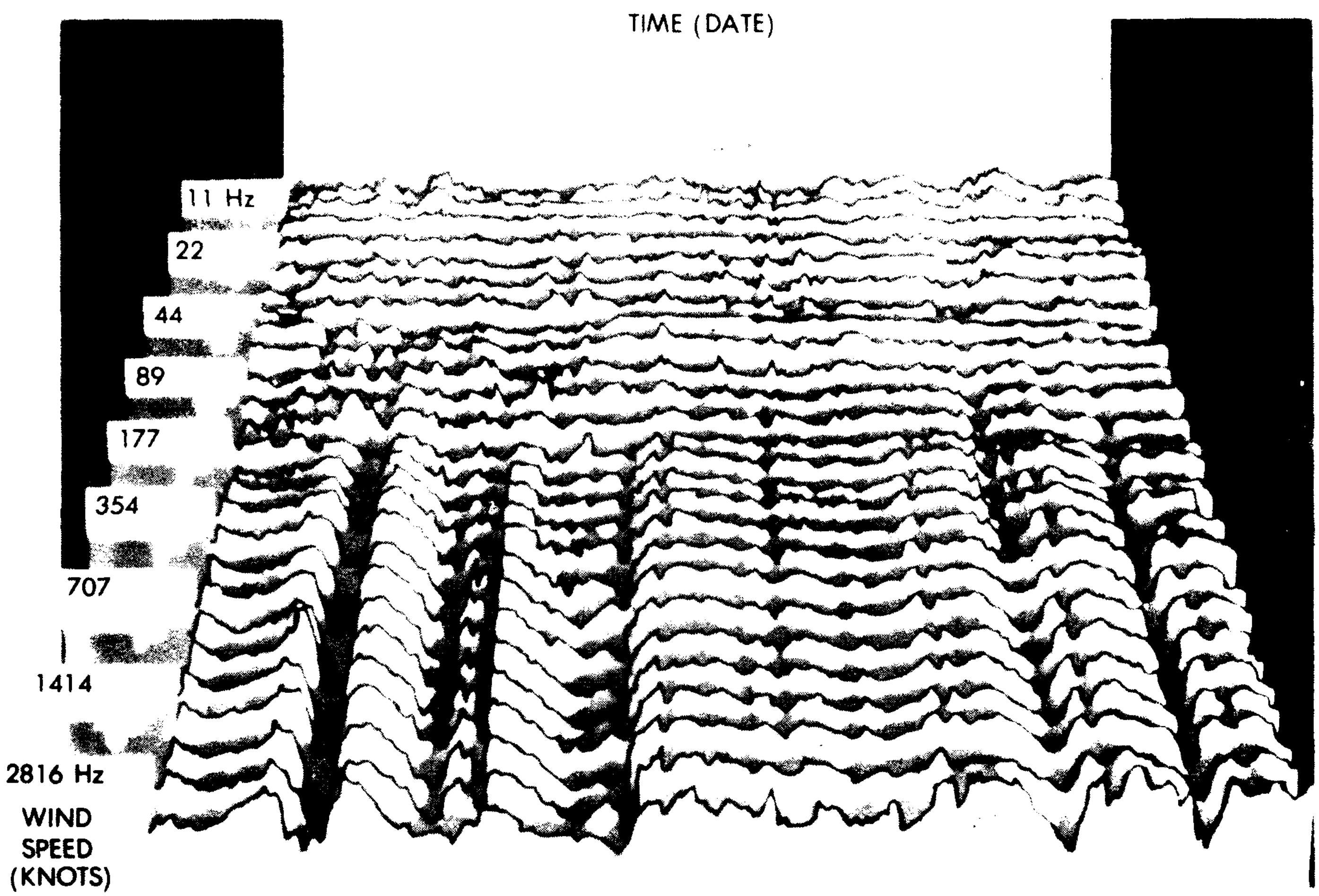

Figure 5. Variations in ambient noise levels and wind speed with time in 11-2816 Hz range (Perrone, 1969)

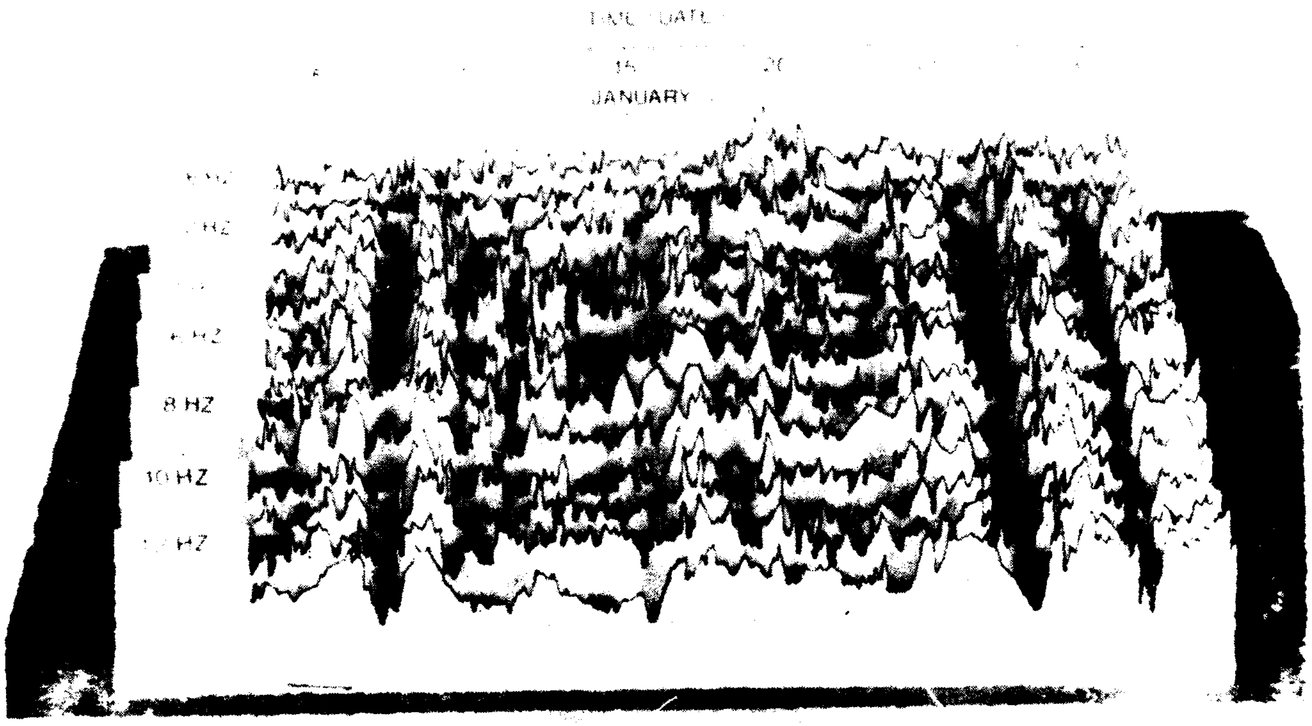

Figure 6. Variation in ambient noise levels and wind speed with time in 0.6-12.0 Hz range (Unpublished data of Perrone at the Naval Underwater Systems Center, New London. Used by permission.)

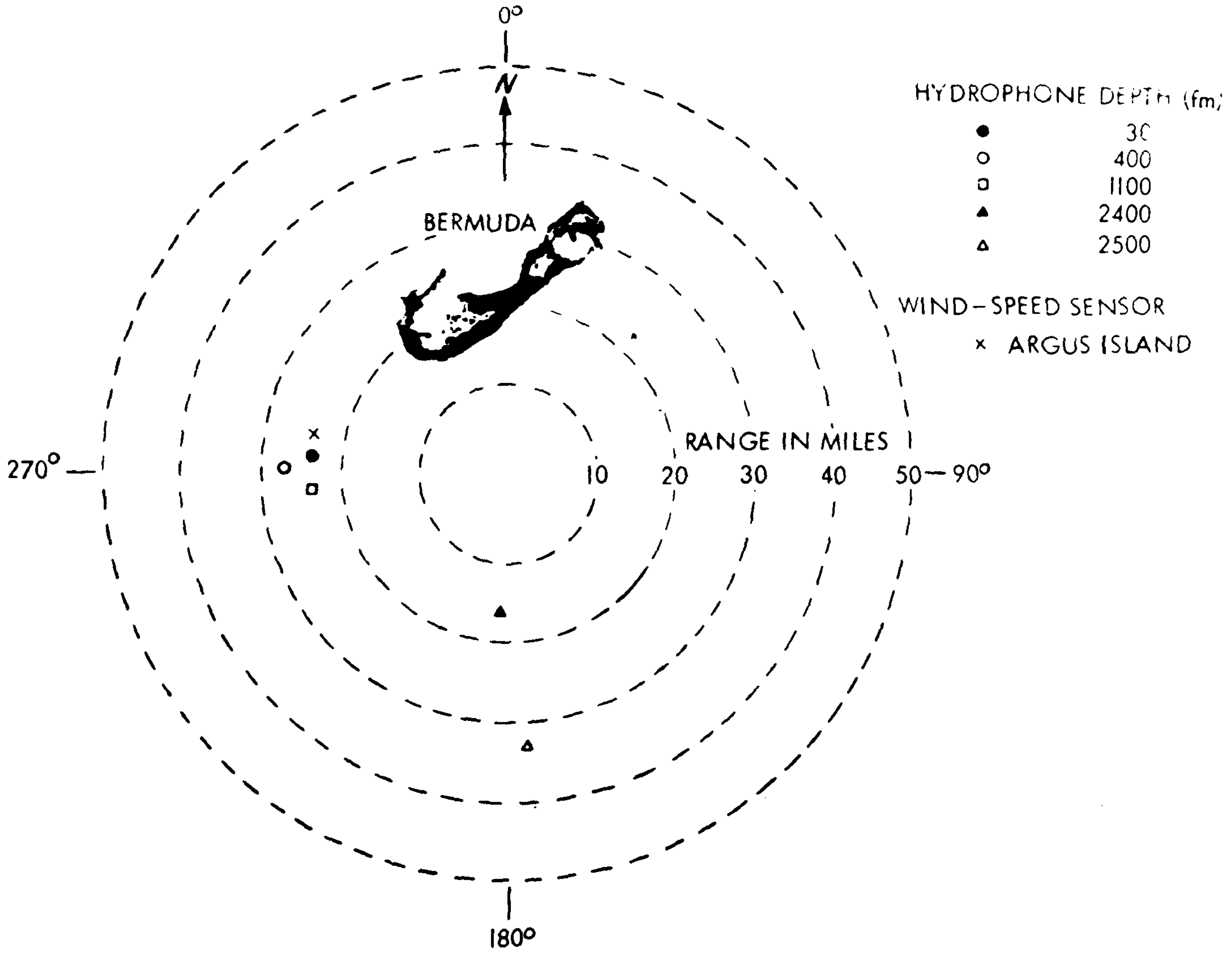

Figure 7. Hydrophone and wind speed sensor locations (Perrone, 1976)

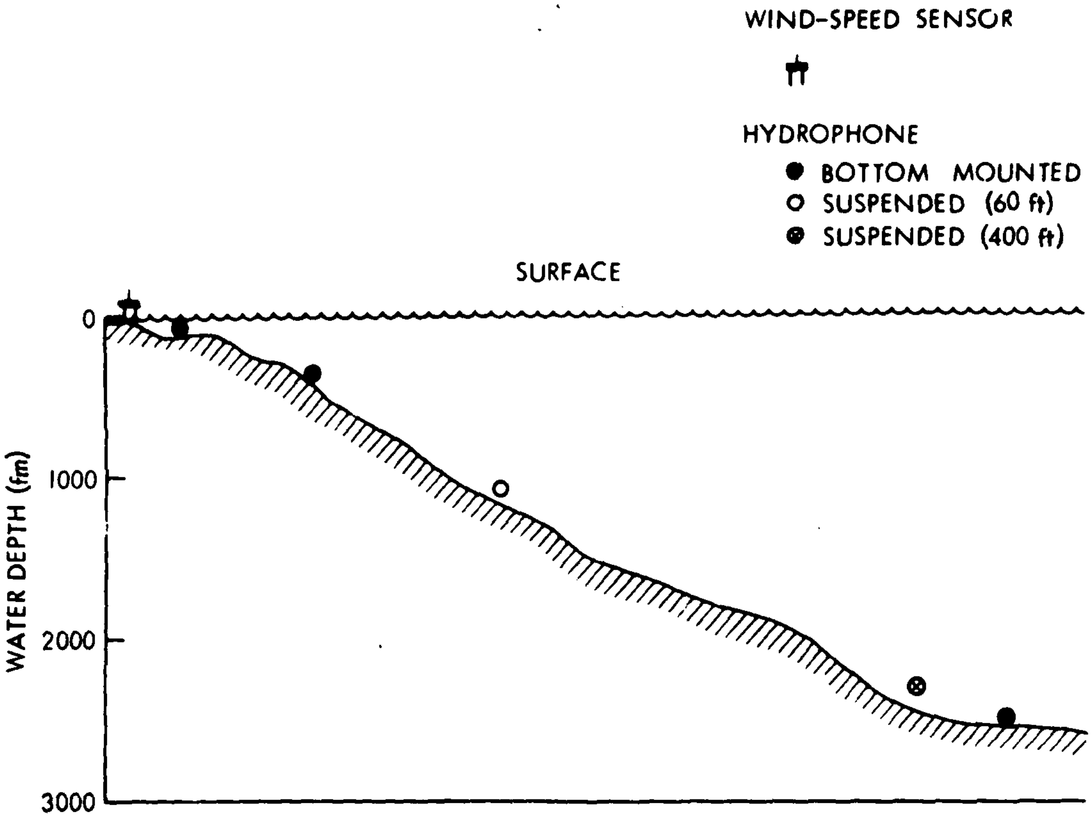

Figure 8. Hydrophone depths (Perrone, 1976)

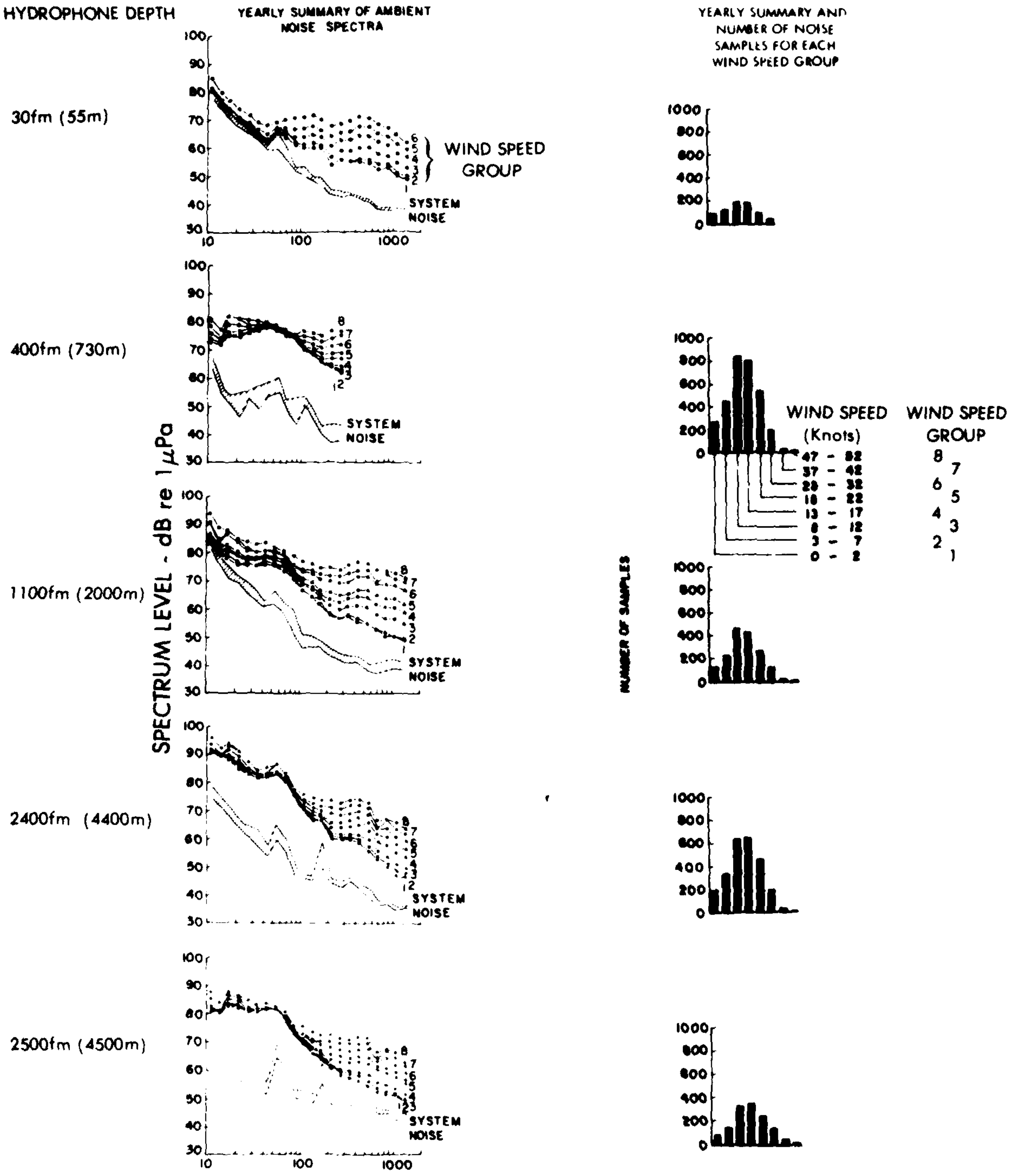

Figure 9. Yearly summary of ambient noise measurement program off Bermuda (Perrone, 1976)

## BIBLIOGRAPHY

1. R. A. Antonia, A. J. Chambers, and N. Phan-Thien, Taylor's Hypothesis and Spectra of Velocity and Temperature Derivatives in a Turbulent Shear Flow, Boundary-layer Meteor., 19, 19-29, 1980.

2. R. A. Antonia and A. J. Chambers, Wind-wave-induced Disturbances in the Marine Surface Layer, J. Phys. Oceanog., 3, 611-621, 1980.

3. E. M. Arase and T. Arase, Ambient Sea Noise in the Deep and Shallow Ocean, J. Acoust. Soc. Am., 42, 73-77, 1967.

4. T. Arase and E. M. Arase, Deep-sea Ambient-noise Statistics, J. Acoust. Soc. Am., 44, 1679-1684, 1968.

5. E. H. Axelrod, B. A. Schoomer, and W. A. Von Winkle, Vertical Directionality of Ambient Noise in the Deep Ocean at a Site Near Bermuda, J. Acoust. Soc. Am., 37, 77-83, 1965.

6. G. R. Bachelor, The Theory of Homogeneous Turbulence, Cambridge University Press, New York, 1953.

7. A. Y. Basovich, Transformation of the Surface Wave Spectrum Due to the Action of an Internal Wave, Izv. Atmos. Oceanic Phys., 15, 448-452, 1979.

8. R. F. Bergeron, Jr., Aerodynamics Sound and the Low-wavenumber Wall-pressure Spectrum of Nearly Incompressible Boundary-layer Turbulence, J. Acoust. Soc. Am., 54, 123-133.

9. L. M. Brekhovskikh, Underwater Sound Waves Generated by Surface Waves in the Ocean, Izv. Atmos. Oceanic Phys., 2, 970-980.

10. L. M. Brekhovskikh, Acoustics and the Ocean, Sov. Phys. Acoust., 24, 361-365, 1978.

11. B. M. Buck and C. R. Greene, Arctic Deep-water Propagation Measurements, J. Acoust. Soc. Am., 36, 1526-1533, 1964.

12. M. K. Bull, Wall-pressure Fluctuations Associated with Subsonic Turbulent Boundary Layer Flow, J. Fluid Mech., 28, 719-754, 1967.

13. D. M. Chase, Modeling the Wavevector-frequency Spectrum of Turbulent Boundary Layer Wall Pressure, J. Sound and Vibr., 70, 29-67, 1980.

14. P. C. Chang and I. Cheng, Interaction Subrange Spectra of Turbulent Wind Over and Air-Water Interface, J. Phys. Oceanog., 3, 273-280, 1972.

15a. C. S. Cox, Measurements of Slopes of High-frequency Wind Waves, J. Mar. Res., 16, 199-225, 1958.

15b. C. S. Cox, Comments on Dr. Phillips Paper, J. Mar. Res., 16, 241-245, 1958.

16. G. M. Corcos, The Structure of the Turbulent Pressure Field in Boundary-layer Flows, J. Fluid Mech., 18, 353-378, 1964.

17. D. D. Craik, Nonlinear Evolution and Breakdown in Instable Boundary Layers, J. Fluid Mech., 99, 247-265, 1980.

18. B. F. Cron, B. C. Hassell and F. J. Keltonic, Comparison of Theoretical and Experimental Values of Spatial Correlation, J. Acoust. Am., 37, 523-529, 1965.

19. W. W. Crouch and P. J. Burt, The Logarithmic Dependence of Surface Generated Ambient-sea-noise Spectrum Level on Wind Speed, J. Acoust. Soc. Am., 51, 1066-1072, 1972.

20. N. Curle, The Influence of Solid Boundaries upon Aerodynamic Sound, Proc. R. Soc. Lond., A231, 505-514, 1955.

21. O. I. Diachok, Dependence of Infrasonic Ambient Noise Levels on Wind Speed and Surface Wave Properties, J. Acoust. Soc. Am., 68, 573-574(A), 1980.

22. R. A. Finger, L. A. Abbagnaro and B. B. Bauer, Measurements of Low-Velocity Flow Noise on Pressure and Pressure Gradient Hydrophones, J. Acoust. Soc. Am., 65, 1407-1412, 1979.

23. G. R. Fox, Ambient-noise Directivity Measurements, J. Acoust. Soc. Am., 36, 1537-1540, 1964.

24. G. J. Franz, Splashes as Sources of Sound in Liquids, J. Acoust. Soc. Am., 31, 1080-1096, 1959.

25. V. G. Gasenko, V. E. Nakoryakov and I. R. Shreiber, Nonlinear Disturbances in a Liquid Containing Gas Bubbles, Sov. Phys. Acoust., 25, 385-388, 1980.

26. P. R. Gent and P. A. Taylor, A Note on Separation Over Short Wind Waves, Boundary-Layer Meteorol., 1, 65-87, 1977.

27. V. P. Glotov, Low-frequency Sound Scattering by Wind-generated air bubbles Below a Sea Surface with Large-scale Roughness, Sov. Phys. Acoust., 24, 485-488, 1978.

28. V. V. Goncharov, Sound Generation in the Ocean by the Interaction of Surface Waves and Turbulence, Izv. Atmos. Oceanic Phys., 6, 1189-1196, 1970.

29. G. P. Haddle and E. J. Skudrzyk, The Physics of Flow Noise, J. Acoust. Soc. Am., 46, 130-157, 1969.

30. R. J. Hansen, D. L. Hunston and C. C. Ni, An Experimental Study of Flow-generated Waves on a Flexible Surface, J. Sound and Vibr., 68, 317-334, 1980.

31. E. Y. Harper and P. G. Simpkins, On the Generation of Sound in the Ocean by Surface Waves, J. Sound and Vibr. 37,, 185-193, 1974.

32. K. Hasselmann, D. B. Ross, P. Müller and W. Sell, A Parametric Wave Prediction Model, J. Phys. Oceanogr., 6, 200-228, 1976.

33. R. H. Hill, Laboratory Measurement of Heat Transfer and Thermal Structure Near an Air-water Interface, J. Phys. Oceanogr., 2, 190-198, 1972.

34. J. O. Hinze, Turbulence, McGraw-Hill Book Company, New York, 1959.

35. M. S. Howe, The Role of Surface Shear Stress Fluctuations in the Generation of Boundary Layer Noise, J. Sound and Vibr. 65, 159-164, 1979.

36. B. Hughes, Estimate of Underwater Sound (and Infrasound) Produced by Nonlinearly Interacting Ocean Waves, J. Acoust. Soc. Am., 60, 1032-1039, 1976.

37. U. Ingard, Influence of Fluid Motion Past a Plane Boundary on Sound Reflection, Absorption, and Transmission, J. Acoust. Soc. Am., 31, 1035-1036, 1959.

38. M. A. Isakovich and B. F. Kur'yanov, Theory of Low-frequency Noise in the Ocean, Sov. Phys. Acoust., 16, 49-58, 1970.

39. B. Johns and R. J. Jefferson, The Numerical Modeling of Surface Wave Propagation in the Surf Zone, J. Phys. Oceanogr., 10, 1061-1069, 1980.

40. A. C. Kibblewhite and R. N. Denham, Low-frequency Acoustic Attenuation in the South Pacific Ocean, J. Acoust. Soc. Am., 49, 810-815, 1970.

41. A. C. Kibblewhite, J. A. Shooter, and S. L. Watkins, Examination of Attenuation of Very Low Frequencies Using the Deep-water Ambient Noise Field, J. Acoust Soc. Am., 60, 1040-1047, 1976.

42. V. O. Knudsen, R. S. Alford and J. W. Emling, Underwater Ambient Noise, J. Mar. Res., 7, 410-429, 1948.

43. W. E. Kohler, Pulse Propagation in a Randomly Perturbed Ocean: Single Pulse Statistics, J. Acoustic Soc. Am., 68, 1177-1183, 1980.

44. J. Kone, Y. Fujinawa and G. Naito, High-frequency Components of Ocean Waves and their Relation to Aerodynamics Roughness, J. Phys. Oceanogr., 3, 197-202, 1973.

45. M. S. Korman and R. T. Beyer, The Scattering of Sound by Turbulence in Water, J. Acoust. Soc. Am., 67, 1980-1987, 1980.

46. R. H. Kraichmam, Pressure Fluctuations in Turbulent Flow over a Flat Plate, J. Acoust. Soc. Am., 28, 379-390, 1956.

47. E. Y. T. Kuo, Deep-sea Noise Due to Surface Motion, J. Acoust. Soc. Am., 43, 1017-1024, 1968.

48. W. A. Kuperman, Spatial Correlation of Surface Generated Noise in a Stratified Ocean, J. Acoust. Soc. Am., 67, 1988-1996, 1980.

49. W. A. Kuperman and F. Ingenito, Attenuation of the Coherent Component of Sound Propagating in Shallow Water with Rough Boundaries, J. Acoust. Soc. Am., 61, 1178-1187, 1977.

50. B. M. Lake and H. C. Yuen, A New Model for Nonlinear Wind Waves, Part 1. Physical Model and Experimental Evidence, J. Fluid Mech. 88,, 33-62, 1978.

51. M. T. Landahl, Wave Mechanics of Boundary Layer Turbulence and Noise, J. Acoust. Soc. Am., 67, 824-831, 1975.

52. L. D. Landau and E. M. Lifshitz, Fluid Mechanics, Pergamon Press, New York, 1959.

53. G. C. Lauchle, On the Radiated Noise due to Boundary-layer Transition, J. Acoust. Soc. Am., 67, 158-158, 1980.

54. W. S. Liggett, Jr. and M. J. Jacobson, Covariance of Noise in Attenuating Media, J. Acoust. Soc. Am., 36, 1183-1194, 1964.

55. W. S. Liggett, Jr. and M. J. Jacobson, Covariance of Surface-generated Noise in a Deep Ocean, J. Acoust. Soc. Am., 38, 303-312, 1965.

56. W. S. Liggett, Jr. and M. J. Jacobson, Noise Coveriance and Vertical Directivity in a Deep Ocean, J. Acoust. Soc. Am., 39, 280-288, 1966.

57. M. J. Lighthill, On Sound Generated Aerodynamically I. General Theory, proc. R. Soc. Lond., A211, 564-587, 1952.

58. M. J. Lighthill, On Sound Generated Aerodynamically II. Turbulence as a Source of Sound, Proc. R. Soc. Lond., A222, 1-32, 1954.

59. R. B. Long, A Parametrical Model for the Vertical Structure of the Induced Atmospheric Pressure Field Above a Spectrum of Surface Gravity Waves, J. Fluid Mech., 99, 163-183, 1980.

60. M. S. Longuet-Higgins, A Theory of the Origin of Microseisms, Philos. Trans. R. Soc. Lond., A243, 1-35, 1950.

61. M. S. Longuet-Higgins, The Generation of Capillary Waves by Steep Gravity Waves, J. Fluid Mech., 16, 138-159, 1963.

62. M. S. Longuet-Higgins, A Model of Flow Separation at a Free Surface, J. Fluid Mech., 57, 129-148, 1973.

63. M. S. Longuet-Higgins, The Deformation of Steep Surface Waves on Water. I. A Numerical Method of Computation, Proc. R. Soc. Lond., A350, 1-26, 1976.

64. M. S. Longuet-Higgins, The Deformation of Steep Surface Waves on Water. II. Growth of normal-mode instabilities, Proc. R. Soc. Lond., A364, 1-28, 1978.

65. M. S. Longuet-Higgins, Modulation of the Amplitude of Steep Wind Waves, J. Fluid Mech., 99, 705-713, 1980.

66. I. D. Lozovatsky, R. V. Ozmidor and M. L. Pyzhevich, Statistical Horizontal-structure Properties of Small-scale Turbulence in the Ocean, Izv. Atmos. Oceanic Phys., 15, 205-209, 1979.

67. H. W. Marsh, Sound Reflection and Scattering from the Sea Surface, J. Acoust. Soc. Am. 35, 240-244, 1963.

68. H. W. Marsh, Origin of the Knudsen Spectra, J. Acoust. Soc. Am., 35, 409-410, 1963.

69. H. W. Marsh, Wind Stress and Roughness Length Over Breaking Waves, J. Phys. Oceanogr., 7, 702-710, 1977.

70. J. R. McGrath, Infrasonic Sea Noise at the Mid-Atlantic Ridge Near 37°N, J. Acoust. Soc. Am., 60, 1290-1299, 1976.

71. J. W. Miles, On the Reflection of Sound at an Interface of Relative Motion, J. Acoust. Soc. Am., 29, 226-228, 1957.

72. H. Mitsuyasu, F. Tasai, T. Suhara, S. Mizuno, M. Ohkusu, T. Honda and K. Rikishi, Observation of the High-Frequency Spectrum of Ocean Surface Waves, J. Phys. Oceanogr., 7, 882-891, 1977.

73. H. Mitsuyasu, F. Tasai, T. Suhara, S. Mizuno, M. Ohkusu, T. Honda and K. Rikishi, Observation of the Directional of the Ocean Waves Using a Cloverleaf Buoy, J. Phys. Oceanogr. 5, 750-760, 1975.

74. G. B. Morris, Depth Dependence of Ambient Noise in the Northeastern Pacific Ocean, J. Acoust. Soc. Am., 64, 581-590, 1978.

75. M. K. Myers, On the Acoustic Boundary Condition in the Presence of Flow, J. Sound and Vibration, 71, 429-434, 1980.

76. G. R. Offen and S. J. Kline, A Proposed Model of the Bursting Process in the Turbulent Boundary Layers, J. Fluid Mech., 70, 209-228, 1975.

77. R. L. Panton, A. L. Goldman, R. L. Lowery and M. M. Reischman, Low-frequency Pressure Fluctuation in Axisymmetric Turbulent Boundary Layers, J. Fluid Mech., 97, 299-319, 1980.

78. F. A. Payne, Effect of Ice Cover on Shallow-Water Ambient Sea Noise, J. Acoust. Soc. Am., 36, 1942-1947, 1964.

79. F. A. Paye, Further Measurements on the Effect of Ice Coveron Shallow-water Ambient Sea Noise, J. Acoust. Soc. Am., 41, 1374-1376, 1967.

80. A. J. Perrone, Deep-ocean Ambient-noise Spectra in the Northwest Atlantic, J. Acoust. Soc. Am., 46, 762-770, 1970.

81. A. J. Perrone, Ambient-noise-spectrum Levels as a Function of Water Depth, J. Acoust. Soc. Am. 46, 762-770, 1969.

82. A. J. Perrone, Infrasonic and Low-frequency Ambient Measurements on the Grand Banks, J. Acoust. Soc. Am., 55, 754-758, 1974.

83. A. J. Perrone, Summary of a One-year Ambient Noise Measurement Program Off Bermuda, NUSC TR 4979, 1976.

84. A. J. Perrone and L. A. King, Analysis Technique for Classifying Wind- and Ship-generated Noise Characteristics, J. Acoust. Soc. Am., 58, 1186-1189, 1975.

85. O. M. Phillips, The Dynamics of the Upper Ocean, Cambridge University Press, New York, 2nd Edition, 1977.

86. C. L. Piggott, Ambient Sea Noise at Low Frequencies in Shallow Water of the Scotian Shelf, J. Acoust. Soc. Am., 36, 2152-2163, 1964.

87. A. Powell, Aerodynamic Noise and Plan Boundary, J. Acoust. Soc. Am., 32, 982-990.

88. I. Proudman, The Generation of Noise by Isotropic Turbulence, Proc. R. Soc. Lond., A214, 119-132, 1952.

89. H. S. Ribnear, Reflections, Transmissions, and Amplifications of Sound by a Moving Medium, J. Acoust. Soc. Am., 29, 435-441, 1957.

90. J. Richman and C. Garrett, The Transfer of Energy and Momentum by the Wind to the Surface Mixed Layer, J. Phys. Oceanogr., 7, 876-881, 1977.

91. D. Ross, Mechanics of Underwater Noise, Pergamon Press, New York, 1976.

92. S. Sethuraman, A Case of Persistent Breaking of Internal Gravity Waves in the Atmospheric Surface Layer Over the Ocean, Boundary-layer Meteorol., 19, 67-80, 1980.

93. A. Shooter and S. K. Mitchell, Observations of Acoustic Sidebands in CW Tones Received at Long Ranges, J. Acoust. Soc. Am., 60, 829-832, 1976.

94. R. D. Short and J. P. Toomy, Predicting the Post-detection Data Load for Passive Sonars, J. Acoust. Soc. Am. 68, 1980.

95. S. D. Smith, Wind Stress and Heat Flux Over the Ocean in Gale Force Winds, J. Phys. Oceanogr., 10, 709-726, 1980.

96. R. L. Snyder, A Field Study of Wave-induced Pressure Fluctuations Above Surface Gravity Waves, J. Mar. Res., 32, 497-531, 1974.

97. R. L. Snyder, R. B. Long, J. Irish, D. G. Hunley, and N. C. Pflaum, An Instrument to Measure Atmospheric Pressure Fluctuations Above Surface Gravity Waves, J. Mar. Res., 32, 485-496, 1974.

98. R. L. Street and A. W. Miller, Jr., Determination of the Aqueous Sublayer Thickness at an Air-water Interface, J. Phys. Oceanogr. 7, 110-117, 1977.

99. M. Strasberg, Nonacoustic Noise Interference in Measurements of Infrasonic Ambient Noise, J. Acoust. Soc. Am., 66, 11487-1493, 1979.

100. R. J. Talham, Ambient-sea-noise Model, J. Acoust. Soc. Am., 36, 1541-1544, 1964.

101. C. W. K. Tam and P. J. Morris, The Radiation of Sound by the Instability Waves of a Compressible Plane Turbulent Shear Layer, J. Fluid Mech., 98, 349-381, 1980.

102. K. Taylor, A Transformation of the Acoustic Equation with Implication, Proc. R. Soc. Lond., A363, 271-281, 1978.

103. K. Taylor, Acoustic Generation by Vibrating Bodies in Homentropic Potential Flow at Low Mach Number, J. Sound and Vibration, 65, 125-136, 1979.

104. R. J. Urick, Correlative Properties of Ambient Noise at Bermuda, J. Acoust. Soc. Am., 40, 1108-1111, 1966.

105. J. Vanden-Broeck and J. B. Keller, A New Family of Capillary Waves, J. Fluid Mech., 98, 161-169, 1980.

106. E. A. Vecchio and C. A. Wiley, Noise Radiated from a Turbulent Boundary Layer, J. Acoust. Soc. Am., 53, 596-561, 1973.

107. K. I. Volyak and V. S. Etkin, Nonlinear Interaction of Weakly Modulated Surface and Sound Waves, Izv. Atmos. Oceanic Phys., 15, 376-380, 1979.

108. G. M. Wenz, Some Periodic Variations in Low-frequency Acoustic Ambient Noise Levels in the Ocean, J. Acoust. Soc. Am., 33, 64-74, 1961.

109. G. M. Wenz, Acoustic Ambient Noise in the Ocean: Spectra and Sources, J. Acoust. Soc. Am., 34, 1936-1956, 1962.

110. G. M. Wenz, Review of Underwater Acoustic Research: Noise, J. Acoust. Soc. Am., 51, 1010-1024, 1972.

111. F. M. White, A Unified Theory of Turbulent Wall Pressure Fluctuations, USL TR629, NUSC, New London, CT, 1964.

112. P. H. White, Effect of Transducer, Size, Shape, and Surface Sensitivity on the Measurement of Boundary-layer Pressure, J. Acoust. Soc. Am., 41, 1358-1363, 1967.

113. W. W. Willmarth, Structure of Turbulence in Boundary Layers, Adv. Appl. Mech., 15, 159-254, 1975.

114. W. W. Willmarth, Pressure Fluctuation Beneath Turbulent Boundary Layers, Ann. Rev. Fluid Mech., 7, 13-38, 1975.

115. J. H. Wilson, Very Low Frequency (VLF) Wind-generated Noise Produced by Turbulent Pressure Fluctuation in the Atmosphere Near the Ocean Surface, J. Acoust. Soc. Am., 66, 1499-1507, 1979.

116. J. W. Wilson, Low-frequency Wind-generated Noise Produced by the Impact of Spray with the Ocean's Surface, J. Acoust. Soc. Am. 63, 952-956, 1980.

117. J. Wu, Wind-stress Coefficients Over Sea Surface Near Neutral Conditions-a Revisit, J. Phys. Oceanogr., 10, 727-740, 1980.

118. A. M. Yaglom, Heat and Mass Transfer Between a Rough Wall and Turbulent Fluid Flow at High Reynolds and Péctect Numbers, J. Fluid Mech., 62, 601-623, 1974.

119. N. Yen and A. J. Perrone, Mechanisms and Modeling of Wind-induced Low-frequency Ambient Sea Noise NUSL TR5833, 1979.

120. H. C. Yuen and B. M. Lake, Instabilities of Waves on Deep Water, Ann. Rev. Fluid Mech., 12, 303-334, 1980.

121. S. N. Zelenskii and S. V. Pasechnyi, Characteristic Functional of Sound Field in Randomly Inhomogeneous Media, Sov. Phys. Acoust., 24, 383-389, 1973.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A study of the wind dependence of underwater ambient noise is presented. This study includes a general theory of noise generation, status of available theories, and some recent noise measurements. The general theory indicates that the stresses and the motion of sea-air boundary contribute to the major sources of wind-induced noise, and that the boundary conditions play important roles of underwater noise. Though several theories have been developed in recent years to investigate specific mechanisms of wind-induced underwater noise, careful evaluations of the theories are suggested. The wind dependence of underwater ambient noise can be identified in the frequency range 1-500 Hz (and higher) from available data. Due to possible interferences of shipping noise, system noise, and flow turbulence near the hydrophone, additional field measurements are necessary to obtain quantitative assessments of wind-induced noise in the frequency range 1-100 Hz. Recommendations are given for the future research works of wind-induced noise.