AD-A214 435

NUSC Tecnical Document 8565
26 May 1989

Wind Speed Dependence of Acoustic Ambient Vertical Directional Spectra at High Frequency

A Paper Presented at the 117th Meeting of the Acoustical Society of America, Syracuse, New York, 26 May 1989

R.M. Kennedy
T.K. Szlyk
S.M. Wentworth
Test and Evaluation Department
West Palm Beach, Florida

Naval Underwater Systems Center
Newport, Rhode Island / New London, Connecticut

PREFACE

This report was prepared under Project B64838 and 638V11, Principal Investigator R.M. Kennedy (Code 3802). The work reported herein was performed as part of the Naval Underwater Systems Center program of Independent Research and Independent Exploratory Development (IR/IED), Program Manager Dr. K.M. Lima, and the Test and Evaluation Department Acoustic Range Initiative, Program Manager J.H. Keegan.

The Technical Reviewer for this report was A.B. Caron (Code 38202) whose contributions to the document are gratefully acknowledged.

Reviewed and Approved: August 1989

J.H. Keegan, Code 38
Head, Test and Evaluation Department

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release, distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) TD 8565	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Underwater Systems Center Detachment 6b OFFICE SYMBOL (If applicable) 3802	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) West Palm Beach, FL 33402	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Naval Underwater Systems Center 8b. OFFICE SYMBOL (If applicable) 38	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Newport, RI 02841	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO.: PROJECT NO.: 638V11 TASK NO.: WORK UNIT ACCESSION NO:

11. TITLE (Include Security Classification)
Wind Speed Dependence of Acoustic Ambient Vertical Directional Spectra at High Frequency

12. PERSONAL AUTHOR(S)
Kennedy, R.M. Szlyk, T.K. Wentworth, S.M.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Lecture Transcript	FROM ____ TO ____	1989 May 26	23

16. SUPPLEMENTARY NOTATION
Presentation to the 117th Meeting of the Acoustical Society of America

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	
17	01		Underwater Acoustics

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

See reverse side.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL R.M. Kennedy	22b TELEPHONE (Include Area Code): (407) 832-8566 22c. OFFICE SYMBOL: 3802

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

19. ABSTRACT

A measurement of the acoustic ambient arriving from a horizontal direction along with total acoustic intensity spectra allows one to infer both the total directional spectra and some physical characteristics of the sources of "sea surface sound." A long-term measurement of these two quantities was made at high frequency, i.e., 8 kHz to 64 kHz, in the Tongue of the Ocean, The Bahamas. The horizontally directed ambient was measured using vertically oriented line arrays and was observed for wind speeds ranging from 1 to 30 knots. The resulting data base was used to estimate the statistics of anisotropic "noise gain" relative to the isotropic "noise gain." Differences in the functional dependence and residual statistics were found for two cases: whitecaps present and not present. The relation of these results to the total directional spectra and a model of the near-surface distribution of acoustic sources are discussed.

This document is a transcript of the presentation given by Dr. Kennedy on May 26, 1989, at the 117th Meeting of the Acoustical Society of America, which was sponsored by the Sheraton University Inn and Syracuse University, in Syracuse, New York.

SLIDE 1

In this paper we present the results of an extended experiment on the directional property of underwater acoustic ambient. The measurement was one of opportunity. The sensor system was intended for a use other than what is being reported here. However, we feel that the data set, albeit incomplete, has allowed some unique observations of the wind speed dependence of the spatial character of the acoustic ambient. Furthermore, we wish to illustrate how the measurements are consistent with a rather simple model of a diffuse near-surface acoustic source structure.

The actual measurement consisted of the total sound pressure level spectra, the horizontally directed sound pressure spectra and the wind speed. The data, which was accumulated over a 1-year period, was edited so that only sea surface-related sources were presented.

The measurements were related to a simple model of the diffuse near-surface sound structure so that a total ambient vertical directional spectra could be deduced from the data. Furthermore, the character of the data, relative to the model, was used to infer certain characteristics of the source with and without whitecaps being present.

The initial motivation and objective of the data analysis was to determine the ambient vertical directional spectra as a function of wind speed.

MEASUREMENT

- Observation of:
  - Total Acoustic Sound Pressure Level
  - Horizontally Directed Sound Pressure Level
  - Wind Speed (10 m)

CONCEPTS

- *Deduce Ambient Directional Spectra*
- Infer Character of Near-Surface Source Structure

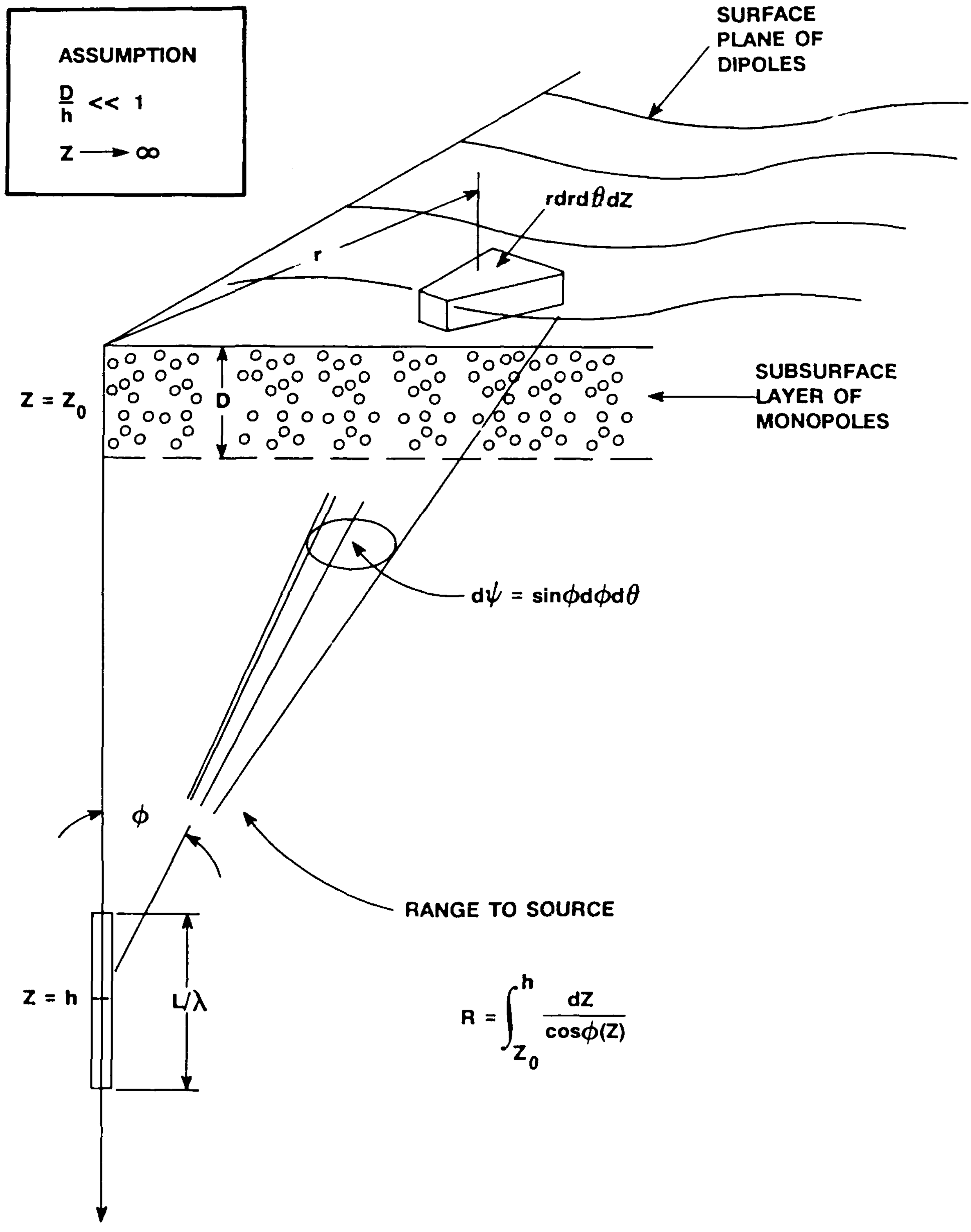
OBJECTIVES

- Determine Wind Speed Dependence of High-Frequency Vertical Directivity Caused by the Sea Surface

SLIDE 2

We begin by describing and defining the geometry of the model and the experiment. The observation is made with a deep vertical line array of hydrophones. Two sources are considered in the model: a horizontally uniform plane of statistically independent dipole sources located at $z = 0$, and a subsurface layer of statistically independent monopoles located between the planes defined by $z = 0$ and $z = D$. The monopoles, while horizontally uniform, have an arbitrary vertical density distribution. Each differential volume of sources contributes to a differential solid angle at the receiver. Three important assumptions are made. First, the line array is much deeper than the deepest source, so the direct path and the reflected path off the pressure release surface arrive at the receiver with the same vertical angle. Second, the water depth and bottom reflection loss are such that no significant acoustic energy is reflected from the bottom. Third, the frequency range of the measurements, which is 8 to 32 kHz, is sufficiently high that the propagation is adequately modeled using the Eikonal equation approximation.

MODEL GEOMETRY



SLIDE 3

There are two resulting vertical directivity functions calculated: one for the surface plane of dipoles and one for the subsurface layer of monopoles. The former is well known and is not repeated here.[1] The second is less known and is shown in this slide. The expression consists of three multiplicative terms. First is the propagation loss resulting from geometric spreading and media absorption. Second, the denominator term is a geometrical term relating the change in surface area of the source volume to the change in solid angle of the directional density function. Third is the vertical integral of the depth density distribution of the monopole sources modified by a term which accounts for the average reflection coefficient for randomly rough surfaces.[2] If one asserts a functional form for the vertical density distribution, then the integral may be evaluated and the vertical directivity function becomes a two-parameter function of the vertical source angle. The two parameters are length scales; that is, the surface roughness and the characteristic depth of the monopole density distribution nondimensionalized by the acoustic wavelength.

BASIC ANALYTICAL RESULT

- Vertical Directivity Function for Subsurface Monopole Layer

$$N(\phi) = \frac{\left(\frac{P_0}{R} e^{-nR}\right)^2}{\left(\frac{\sin\phi}{r} \frac{d\phi}{dr}\right)} \int_0^D dz M(z) \left[(1+\alpha^2) - 2\alpha \cos[2kz \cos\phi_s]\right]$$

$M(z)$ is Vertical Distribution of Monopole Sources

k is Acoustic Wavenumber

$\alpha = e^{-k^2 \sigma^2 \cos\phi}$

σ is rms Surface Roughness

n is Ocean Attenuation Term

- Given a Vertical Distribution Form ($M(z)$) the Vertical Directivity Function ($N(\phi)$) Reduces to a Two-Parameter (kD and $k\sigma$) Function of the Source Angle

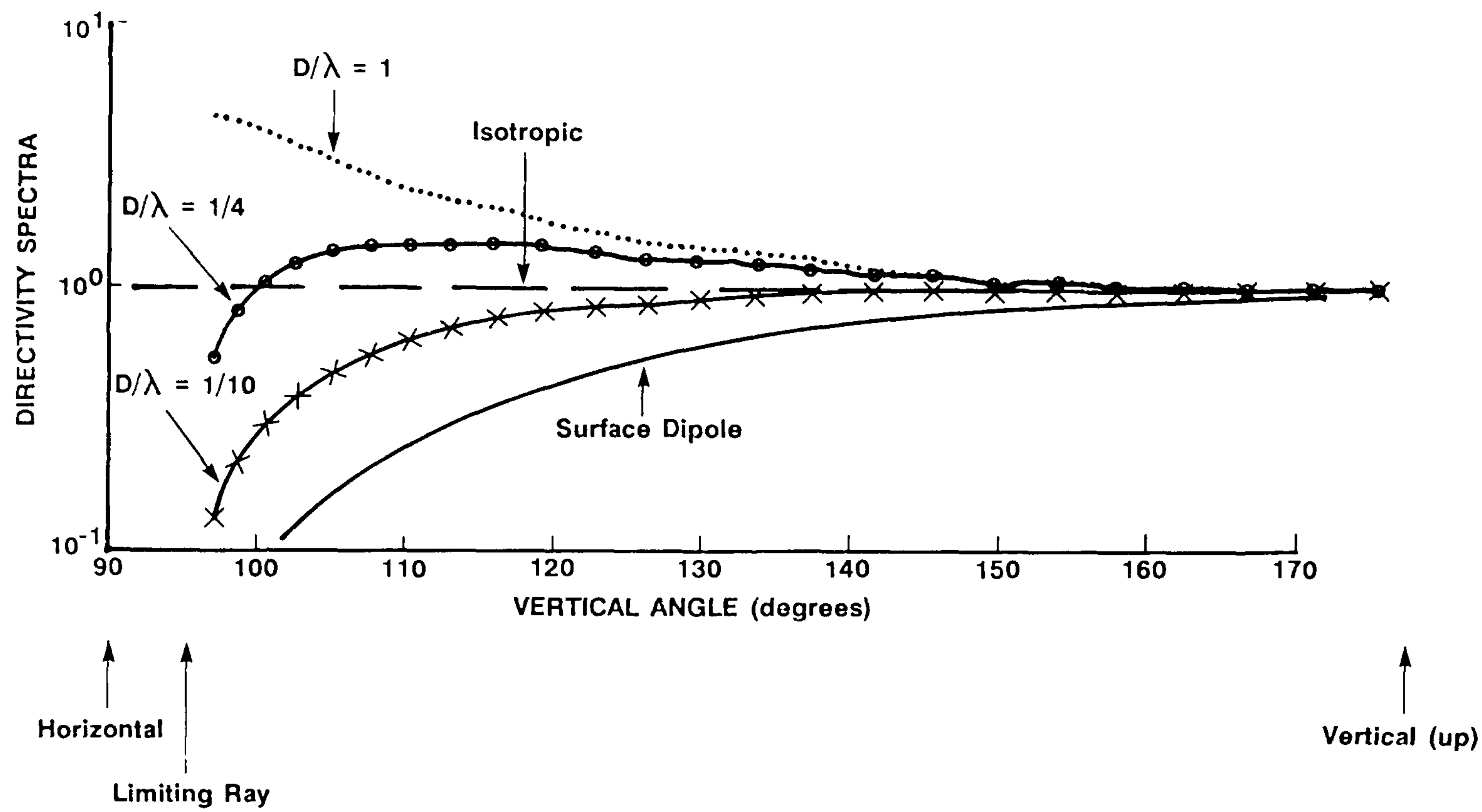
SLIDE 4

A typical calculated directivity function is shown in this slide. The abscissa is the vertical elevation angle with 180 degrees being vertical upwards. The ordinate is the directional spectral density with the vertical value arbitrarily set to 1. In the calculation the surface sound velocity was significantly greater than existed at the 125-m receiver so that a limiting ray condition occurs at about 95 degrees. This was done to minimize the computational time and was not typical of the experiment conditions. Here the surface is smooth and the frequency is 10 kHz. The calculation was performed for a rather fast surface velocity so that the acoustic wavelength at the surface is 15.5 cm. The directivity function for the surface plane of dipoles is shown as a reference, and the directivity pattern for an isotropic acoustic field is shown as a horizontal line. Superimposed on these two references are the directional spectra for a subsurface layer of monopoles with an exponentially distributed vertical density distribution function. The figure illustrates this spectra for three values of the characteristic depth of the monopole vertical distribution. In physical units the depths are 1.5 cm, 6 cm and 15.5 cm.

When the characteristic depth scale is a small fraction of the acoustic wavelength (we refer to this as acoustically thin), then the familiar result is that the layer acts like a dipole whose source strength vanishes as the layer thickness vanishes.[3] This is shown in the figure where we see that the thin layer approximates the dipole. In the opposite case, when the layer is acoustically thick, a monopole and its image produce a multilobe pattern function. Numerous such sources acting independently then produce a more vertically uniform source energy distribution, which makes the layer act like a monopole source.[4] The resulting directional spectra at the near-horizontal angles is thus seen to rise above the isotropic spectral distribution. Our measurements of the horizontally directed acoustic ambient are thus seen as a sensitive measure of this structure, if in fact it exists. A convenient metric is "antenna noise gain," which is the ratio of the hydrophone signal to the antenna signal. We see from this figure that the gain will be large relative to the isotropic value when the source is "dipole like" and small

VERTICAL DIRECTIVITY FUNCTION FOR EXPONENTIALLY DISTRIBUTED MONOPOLE SUBSURFACE LAYER

(f = 10000 Hz)
$M(z) = \exp[-z/D]$
Smooth Surface ($\sigma = 0$)



relative to the isotropic value when the source is "monopole like." Please try to keep this in mind as we view the measured results.

While time does not permit our showing it here, a non-zero surface roughness is seen to make a thin layer act more like a monopole as it reduces the coherence of the surface reflection.

SLIDE 5

This slide summarizes the details of the experiment. The acoustic sensors were placed in the middle of the TOTO basin in The Bahamas. The 1830-m water depth was large relative to the 125-m sensor depth, which was in turn large compared with the subsurface layer of bubbles. The nearest basin escarpment was 12 kilometers from the transducers. The system consisted of a single hydrophone and two vertical hydrophone arrays. The vertical antennas were hard-wired so that only the "broadside" beam in the horizontal direction was available. These sensors were sampled over a 1-year period. Sound pressure level spectra were calculated from the resulting time series. Spectral levels at 8, 16, and 32 kHz were recorded in a database along with the wind speed measured 10 meters above the sea surface in the shallows some 13 kilometers from the acoustic measurement. All data samples that contained indications of biological or industrial contaminations were removed. The resulting database seen here contained 215 samples.

EXPERIMENT DESCRIPTION

- **Geometry**
  - TOTO, The Bahamas
  - 1830 m Water Depth
  - 125 m Receiver Depth
  - 12 km from Escarpments

- **Acoustics**
  - 1 Hydrophone
  - 2 Vertical Line Arrays
    - 10λ at 16 and 32 kHz (5° Beamwidth)
    - 5λ at 8 kHz (10° Beamwidth)

- **Environmental**
  - May '88 to April '89 (215 Data Sets)
  - Anemometer 10 m High, 13 km from Measurement

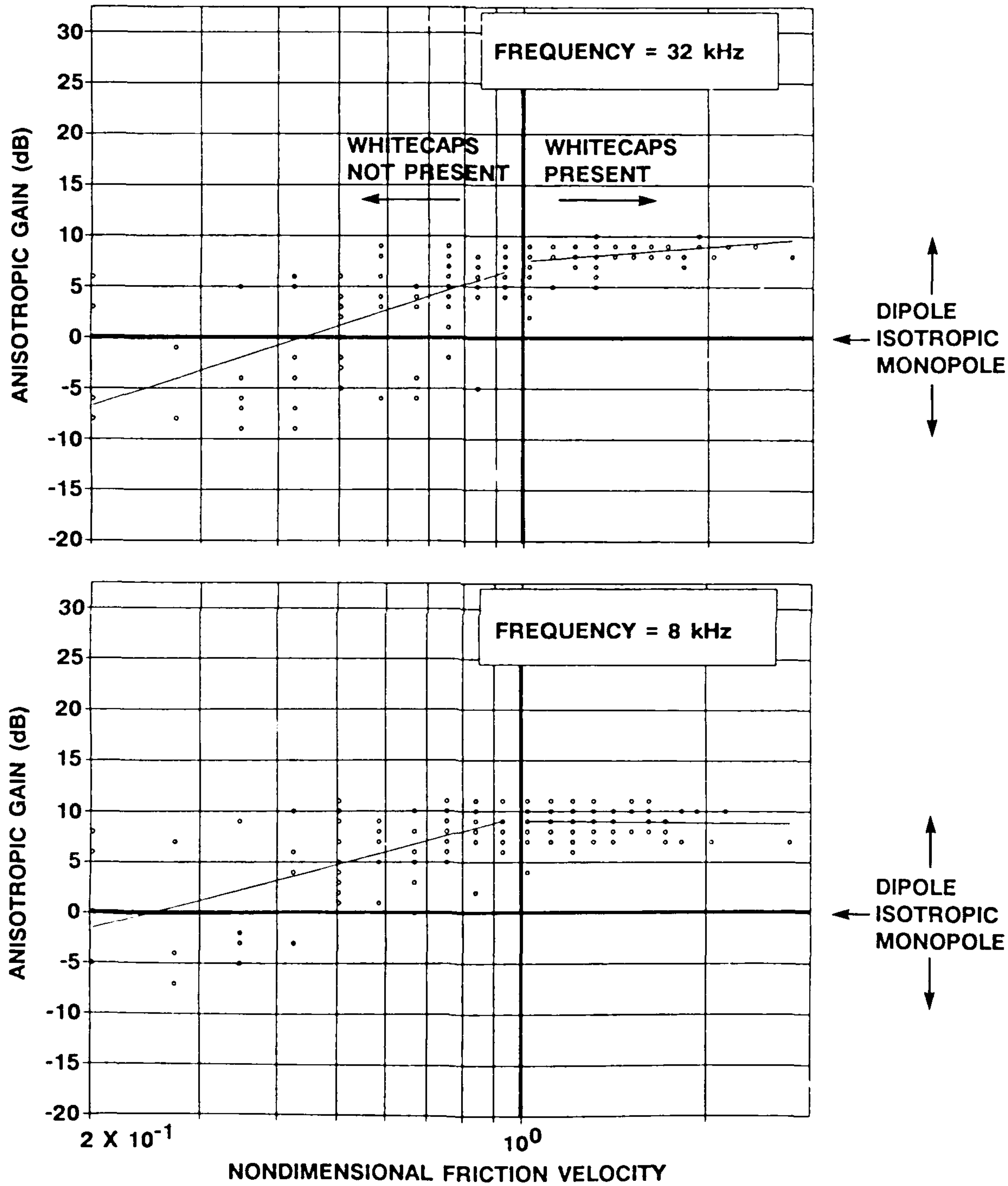
SLIDE 6

The horizontally directed antenna outputs were normalized by the hydrophone levels. The inverse of this ratio is termed the "antenna noise gain." The phenomena that we wish to describe is best illustrated by comparing -- that is, normalizing -- the "antenna noise gain" by the calculated "directivity index," which is the "antenna noise gain" in an isotropic pressure field. We will refer to this measured gain relative to the gain in an isotropic pressure field as the "anisotropic gain." Thus the ordinates of these figures are a measure of the noise gain of the antennas relative to an isotropic field. This is shown in the figures as a dark horizontal line at 0 dB. Recalling our previous slide, we will label values of the anisotropic gain greater than 1 as due to a "dipole like" source and values less than 1 as due to a "monopole like" source. This is shown to the right of the figures.

Wind speed is the basic independent variable of our experiment. Following B.R. Kerman's 1980 work,[5] we convert the measured 10-m wind speed values to surface friction velocity nondimensionalized by the minimum phase speed of the capillary-gravity surface wave field. The abscissa of the figures are thus nondimensional friction velocity. A dark vertical line is shown for a unity value of the nondimensional variable. We labeled the region less than 1 as not having whitecaps present, and for values of the independent variable greater than 1 we labeled this region as having whitecaps present.

The figures show the measured results at 8 and 32 kHz. The 16 kHz data, not shown, is quite similar. One sees a distinctly different character to the data depending on the existence or nonexistence of whitecaps. With whitecaps present the anisotropic gain is only weakly dependent on wind speed and the results are well predicted by the independent variable. Without whitecaps present there is a general trend to the data that matches a power law with an exponent near 2. However, the independent variable is no longer a good predictor of the anisotropic gain. It appears that for each value of the nondimensional friction velocity there is a significant range of gains observed.

"ARRAY GAIN" DEPENDENCE ON WIND SPEED

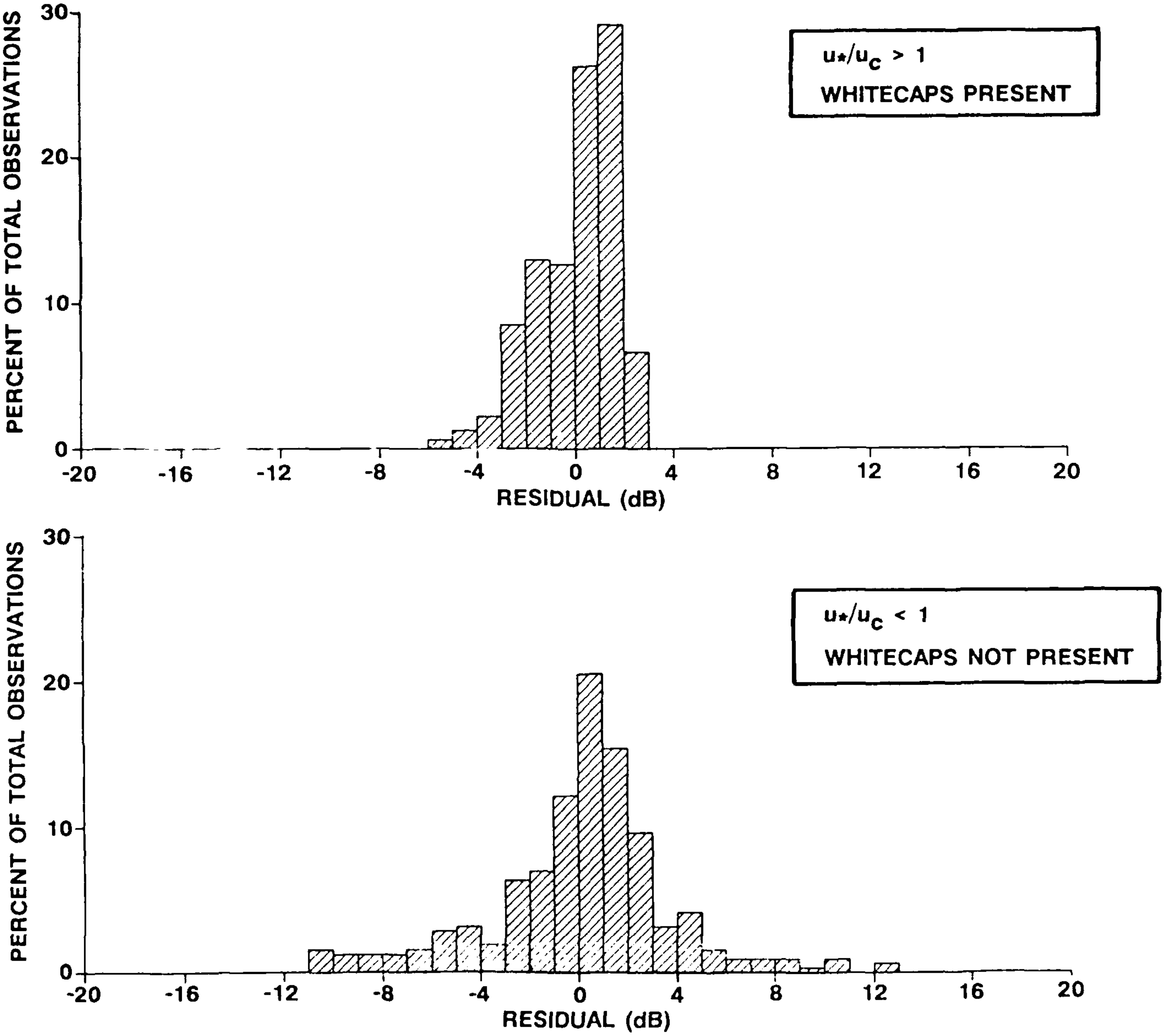


SLIDE 7

The relative variability of the anisotropic gain with and without whitecaps present is seen in this slide which presents the histograms of the residuals of the anisotropic gains about the regression lines of the previous slide. The abscissa is the residual in decibels, and the ordinate is the percentage of the total number of observations. The upper graph is with whitecaps present, and the lower graph is without whitecaps present. The greater variability of the anisotropic gain without whitecaps present observed on the previous slide is again evident. However, the histogram now shows another characteristic difference between the two cases; that is, the whitecaps-present case has a significant asymmetry to the histogram. A coefficient of skewness estimated for the two cases is four times as large in the whitecaps-present case as it was in the whitecaps-not-present case. With whitecaps present the anisotropic gain appears to have a physical limit to it. The variability of the measurement is limited to the lower side of the extreme value. This is consistent with our previous discussion which indicated that the maximum possible gain occurs for the purely dipole source. Not surprisingly, the source model with whitecaps present is a surface plane of dipoles caused by a ready supply of spray and an acoustically thin layer of bubbles.

If there is some validity to our model, then without whitecaps present there is significant variability in the effective depth of the monopole layer for a given wind speed, indicating that other variables such as turbulence, internal waves, and previous wind history are contributing factors. However, on the average the characteristic depth of the monopole layer is decreasing with an increasing wind speed. Because the intensity is increasing with wind speed, the decrease in characteristic depth is probably the result of a supply of shallower monopoles and not a redistribution of the existing ones.

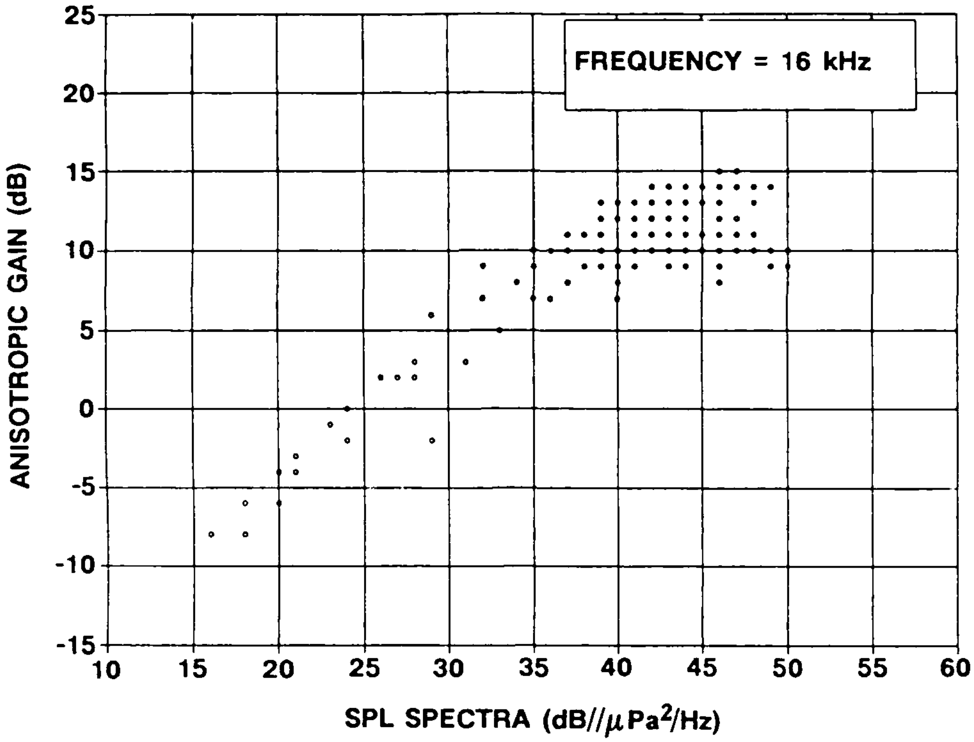
DISTRIBUTION OF ANISOTROPIC GAIN

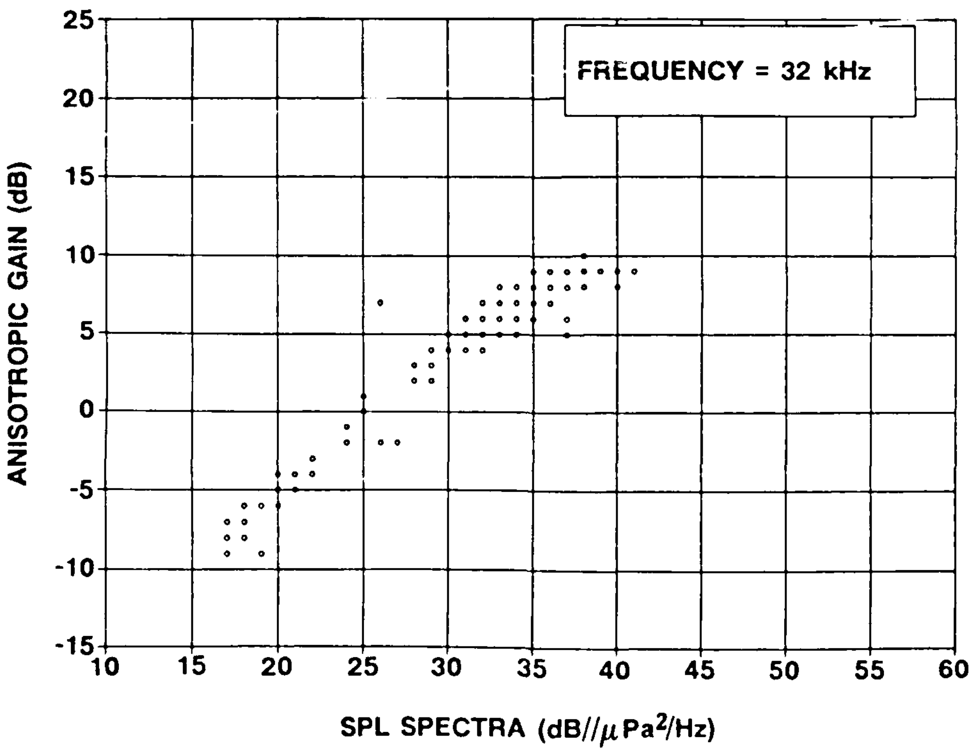


SLIDE 8

In the previous slide we saw that wind speed is not a good predictor of the vertical anisotropic gain and presumably of the vertical directivity spectra without whitecaps present. We associated this loss of correlation of the acoustic variability with wind speed as being caused by other near-surface environmental variables. We did, however, find that total acoustic intensity is a useful independent variable when the whitecaps are not present. This is shown in this slide, which presents the anisotropic gain as a function of total acoustic sound pressure level for all the data at 16 and 32 kHz. The 8 kHz data shows a similar dependence although with somewhat more variability. Thus at low wind speeds the total acoustic intensity is a good measure of the "acoustic state" of the near-surface sources and is thus a good indicator of the vertical directivity spectra.

"ARRAY GAIN" DEPENDENCE ON TOTAL SOUND PRESSURE LEVEL





SLIDE 9

This paper describes the results of a data analysis task that infers the acoustic ambient directional spectra caused by sea surface sources of sound from measurements of the horizontally directed acoustic ambient. A theoretical analysis shows that the near-horizontal value of the directional spectra is a sensitive measure of the entire directional spectra resulting from a diffuse source field consisting of a plane of surface dipoles and a subsurface layer of monopoles. An extended measurement of the horizontal value of the array gain of three vertical antennas covering the frequency range of 8 to 32 kHz was undertaken. The results of the analysis indicated a clear wind speed dependence in the horizontally steered antenna gain resulting from a wind speed dependence in the acoustic ambient vertical directional spectra. The observed array gain was found to dichotomize into categories of either whitecaps present or whitecaps not present, with distinctly different behaviors in each category. The measurements are at least consistent with a high frequency sea surface sound model, valid with whitecaps present, which consists of a surface plane of dipole sources and an acoustically thin layer of monopoles presumably resulting from a ready supply of spray and bubbles caused by the whitecapps. With no whitecaps present the source structure is altered. It appears to be dominated by an acoustically thick layer of monopoles with a characteristic depth scale that increases with decreasing wind speed. Because the acoustic intensity also decreases with decreasing wind speed, the larger depth scale is presumably a result of the loss of a supply of shallower monopoles and not a redistribution in the existing ones.

SUMMARY

- Measurements of the Horizontally Directed Acoustic Ambient Were Observed for a Variety of Wind Speed Conditions
- Vertical Directional Spectra at Near-Horizontal Angles is Shown to Sensitively Discriminate Between Surface Dipoles and Acoustically Thin and Thick Subsurface Layers of Monopoles
- Measurements are Consistent With a Sea Surface Sound Model of:
  - Surface Dipoles and Acoustically Thin Subsurface Layers of Monopoles With Whitecaps Present
  - Acoustically Thick Layers of Monopoles Without Whitecaps Present

REFERENCES

1. R.J. Urick, Principles of Underwater Sound, 2nd ed., McGraw-Hill Book Company, New York, NY, 1975.

2. C.S. Clay and H. Medwin, Acoustical Oceanography, Principles and Applications, John Wiley & Sons, New York, NY, 1977.

3. J.E. Ffowcs Williams and Y.P. Guo, "Mechanisms of Sound Generation at the Ocean Surface," Sea Surface Sound, edited by B.R. Kerman, Kluwer Academic Publishers, Boston, MA, 1988.

4. R.D. Hallett and R.M. Heitmeyer, "Noise Generation by Bubbles Formed in Breaking Waves," Sea Surface Sound, edited by B.R. Kerman, Kluwer Academic Publishers, Boston, MA, 1988.

5. B.R. Kerman, "Underwater Sound Generation by Breaking Waves," Journal of the Acoustical Society of America, vol. 75, 1984, p 148.

INITIAL DISTRIBUTION LIST

Addressee	Number of Copies
COMNAVSEASYSCOM (Code 63D) CDR E. Graham	1
(PMS393A) CDR S. Logue	1
(PMS393N) J.H. Fuchs	1
COMNAVAIRSYSCOM (Code 421) T. Ramirez	1
CNA	1
DTIC	12
DTRC (Code 1925) G.M. Jebsen	1
(Code 0100) R.E. Metrey	1
NAVPGSCOL H. Medwin	2
NOAA/Miami H. Bezdek	1
NOSC J. Rohn	1
OCNR (Code 1121GS) O. Brandt	1
(Code 1122ML) M. Briscoe	1
(Code 1125) L.G. Johnson	1
(Code 1125AR) R.F. Obrachta	1
(Code 1125OA) M. Orr	1
Applied Measurement Systems, Inc., Hollywood, FL; B.L. Douglass	1
General Electric Co., Andros Island, Bahamas; L.A. Lindquist	1
GRD Associates, Delray Beach, FL; G.R. Desmarais	1
Planning Systems, Inc., New London, CT; W.M. Leen	1
MPL, Scripps Institution of Oceanography, La Jolla, CA; W. Hodgekist	1