NUSC Technical Document 8803
December 1990

Statistical Properties of the Sea Surface Sound Dipole Source

A Paper Presented at the 120th Meeting of the Acoustical Society of America at San Diego, CA

R.M. Kennedy

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 3802) whose contributions to the document are gratefully acknowledged.

Reviewed and Approved: December 1990

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

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1990	Lecture Transcript

4. TITLE AND SUBTITLE

Statistical Properties of the Sea Surface Sound Dipole Source

5. FUNDING NUMBERS

S64838
638V11

6. AUTHOR(S)

Kennedy, R.M. (Code 3802)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Underwater Systems Center Detachment
West Palm Beach, FL 33402

8. PERFORMING ORGANIZATION REPORT NUMBER

TD 8803

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Underwater Systems Center
Newport Laboratory
Newport, RI 02841-5047

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

Presentation to the 120th Meeting of the Acoustical Society of America

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

See reverse.

14. SUBJECT TERMS

Underwater Acoustics

15. NUMBER OF PAGES

22

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

A broadband measurement (40 to 4000 Hz) of the vertical directional spectrum of the underwater ambient acoustic field was made in an acoustically isolated area where the ambient is dominated by well documented local sea conditions. Measurements, made over a one-year period, sampled a wide range of sea conditions and made possible a statistical analysis of the effects of the sea surface condition on the acoustic field. Having the total directional spectrum, unperturbed by long-distance sources, allowed the partitioning of the measurement into multiple source types; each type distinguished by its unique vertical directional pattern. An important component of the sea surface-generated radiation is a diffuse distribution of vertical dipole sources. A unique property of the present data analysis is that the dipole source strength "area density" is found by matching only that part of the total measured pressure field exhibiting a dipole pattern. This is accomplished by parametric spectral estimation procedures. The frequency spectrum of the dipole source strength is found to be a bandpass function whose parameters are statistically related to the wind-generated surface friction velocity. The results of the analysis contribute an important element to an accurate modeling of the space-time statistics of sea surface sound.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

This document is a transcript of the presentation given by Dr. Kennedy in December, 1990, at the 120th Meeting of the Acoustical Society of America, in San Diego, CA.

SLIDE 1

It is generally agreed that an important component of the sea surface-generated radiation is a diffuse distribution of vertical dipole sources.[1,2,3] Such radiators result from spray impact on the surface and the injection of nonspherical air bubbles a small fraction of a wavelength from the pressure release surface. The dipole source structure is fundamental to nearly all of the acoustic ambient prediction algorithms in current use. Despite the ubiquitous use of the term there are relatively few measurements of the source strength[4,5,6] and thus little is known about its statistical properties. It was the objective of the task being discussed here to estimate the statistical properties of these dipole source strengths.

The approach taken in this study had two components. First, a data base was accumulated from measurements of the solid angle vertical directional spectrum made in an acoustically isolated area where the acoustic ambient is dominated by the local sea conditions. Second, the dipole source strength "area density" is found by matching only that part of the total measured directional spectrum that exhibited a dipole pattern.

OBJECTIVE:

Estimate statistical properties of the sea surface-generated acoustic dipole source.

APPROACH:

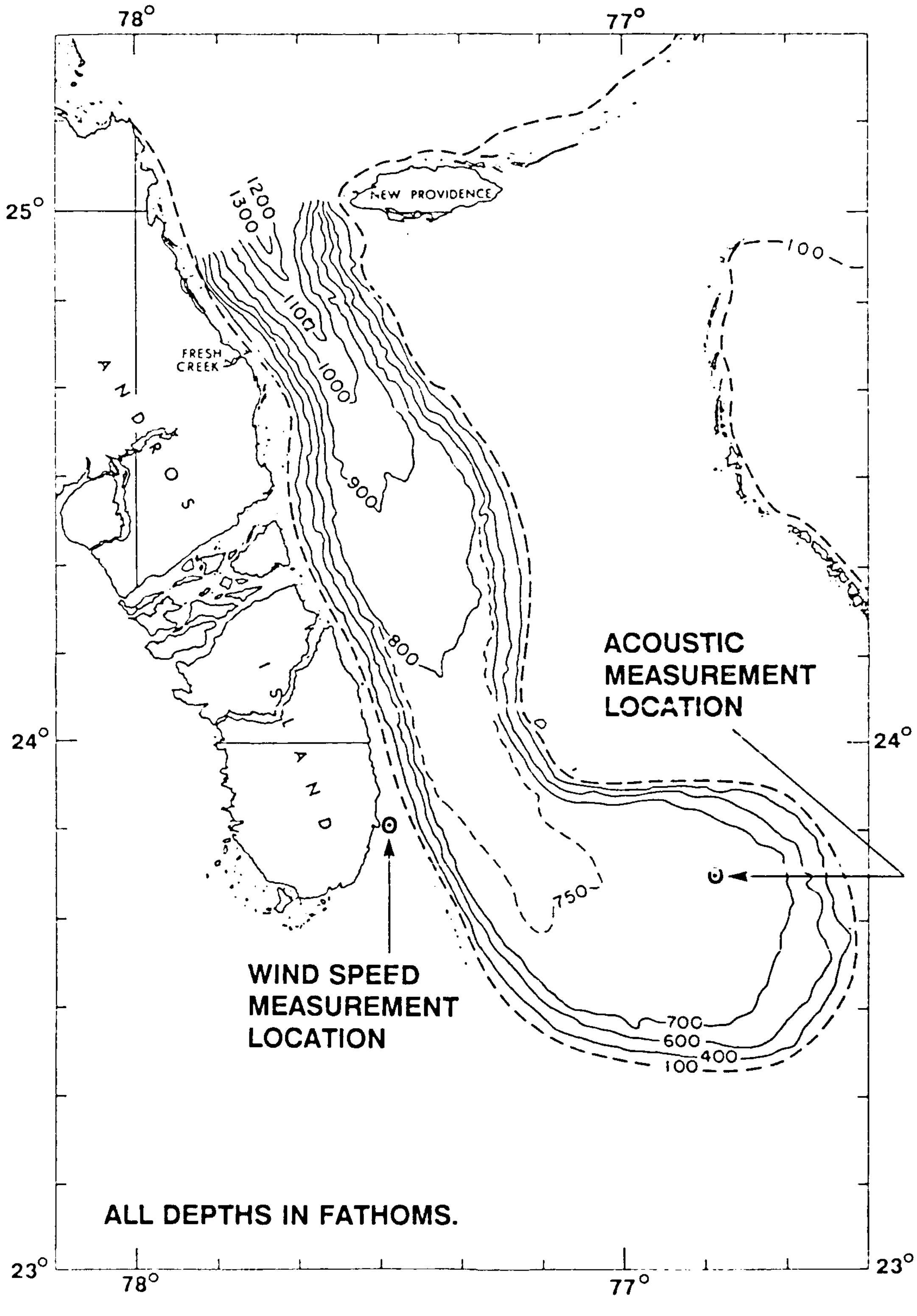
- Measure acoustic ambient directional spectrum in an acoustically isolated area where the ambient is dominated by local wind/sea conditions.
- Estimate dipole source strength by "matching" only that part of pressure field exhibiting a dipole pattern.

SLIDE 2

The Tongue of the Ocean in the Bahamas was the location of the measurement. It is a relatively deep water basin totally isolated from global shipping. The actual cul-de-sac measurement location is further shielded from transiting vessels north of the site by the landmass north of the location. There is no place to transit to in the cul-de-sac itself so shipping is nearly nonexistent in the vicinity of the sensor system. The acoustic measurement is some 30 nmi from the anemometer which is 10 m above the water surface.

The data base consists of 101 trials taking place over a ten-month period. The minimum time between trials is 48 hours which for the most part assured statistical independence.

MEASUREMENT LOCATIONS



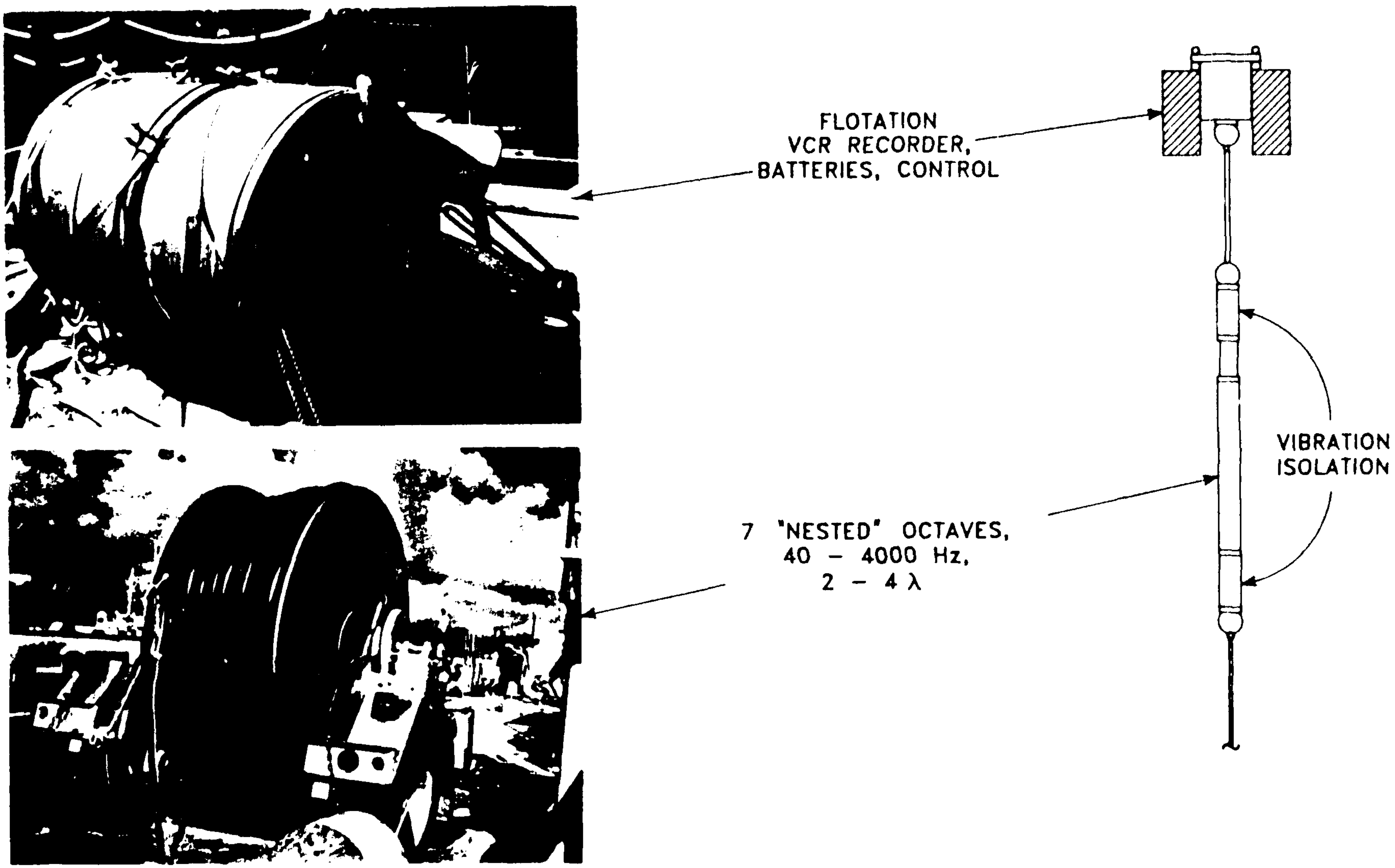
SLIDE 3

The measurement system objective was a broadband characterization of the diffuse acoustic ambient field. This slide shows the acoustic sensor system used.[7] It consisted of a vertical hydrophone array which covered the two decade frequency range of 40 to 4000 Hz with seven octavely nested antennas each with a modest 2 to 4 wavelength aperture. A parametric spectral estimation algorithm that modeled the media refraction and source directional characteristics was then used to obtain higher angular resolution near the horizontal direction.[7]

The seven octaves were recorded sequentially by synchronously recording the eight 14-bit hydrophone signals from each antenna system on video cassette recorders. The depth and tilt of the vertical hydrophone array were also recorded.

The brightly colored syntactic foam collar around the instrumented pressure vessel maintains the verticality of the system within a small fraction of the hydrophone array angular resolution.

INSTRUMENTATION SUMMARY



SLIDE 4

This slide summarizes the procedure used to obtain the dipole source area density function.[7] The first step in the data processing is to estimate all possible cross spectral density (CSD) functions between hydrophone outputs. These terms are the elements of the CSD matrix on the left-hand side of the first equation. The left-hand side of the equation is the weighted quadratic form of the CSD matrix which calculates the beamformed output. Equivalently, the right-hand side is also the beamformed output found by the solid angle integral of the product of the ambient directional spectrum and the hydrophone array pattern function. The procedure was to model the directional spectrum as a sum of terms with unknown linearly occurring parameters which are then evaluated so as to minimize the mean square difference between the left and right-hand sides of the equation.

The form of the model is ad hoc, physically based, and all of the components of the model occur historically in the acoustic ambient literature.[7] For our present purpose there are three requirements of the model. First, the sum of the components must adequately represent the measurements. Second, the components must be distinguishable from each other, and third, one of the terms must model a diffuse field of vertical surface dipoles. The latter term is shown explicitly in the slide. It consists of the independent addition of all possible sources contributing to a specific elevation angle at the observation point per unit solid angle. The radiation from each source is propagated to the observer with a quite general solution of the wave equation incorporating all pertinent bottom, surface, and water column terms. The parameter, a_D, is the source area density evaluated by linear least squares estimation problem. It's dimension is μpa^2 per Hz per m^2.

PARAMETRIC SPECTRAL ESTIMATION SUMMARY

Measured CSD Matrix; LSE; Directional Spectrum Model

* $$\underset{\sim}{D}^{T}(\phi_S)\, \underset{\sim}{S}_p(\omega)\, \underset{\sim}{D}^{*}(\phi_S) \stackrel{LSE}{=} 2\pi \int_0^{\pi} d\phi\, \sin\phi\, B^2(\phi', \phi_S) \sum_{n=0}^{N} a_n X_n(\phi)$$

$\underset{\sim}{D}^{T}(\phi_S)$ is steering vector to elevation angle ϕ_S
$B^2(\phi', \phi_S)$ is antenna pattern function
ϕ is elevation angle

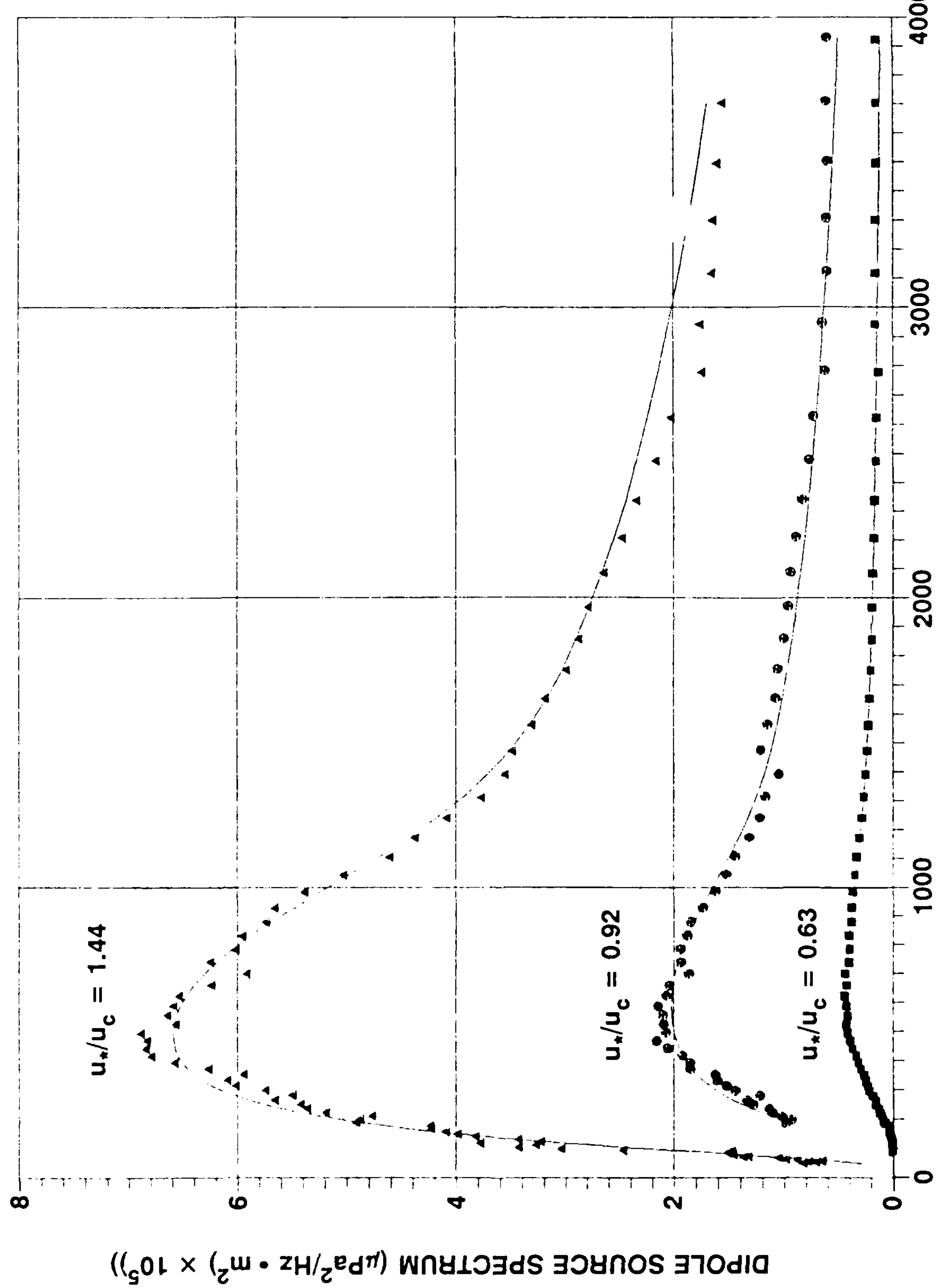
* **Dipole Term of Interest**

$$a_D X_D(\phi) = a_D \sum_{\substack{\text{all} \\ \phi' \to \phi}} \frac{\cos^2\phi'\, T(\underset{\sim}{x}_S, \underset{\sim}{x}_R; \phi', \phi)}{\dfrac{\sin\phi}{r}\ \dfrac{d\phi}{dr}}$$

T( ) is propagation term between $\underset{\sim}{x}_S$ and $\underset{\sim}{x}_R$

SLIDE 5

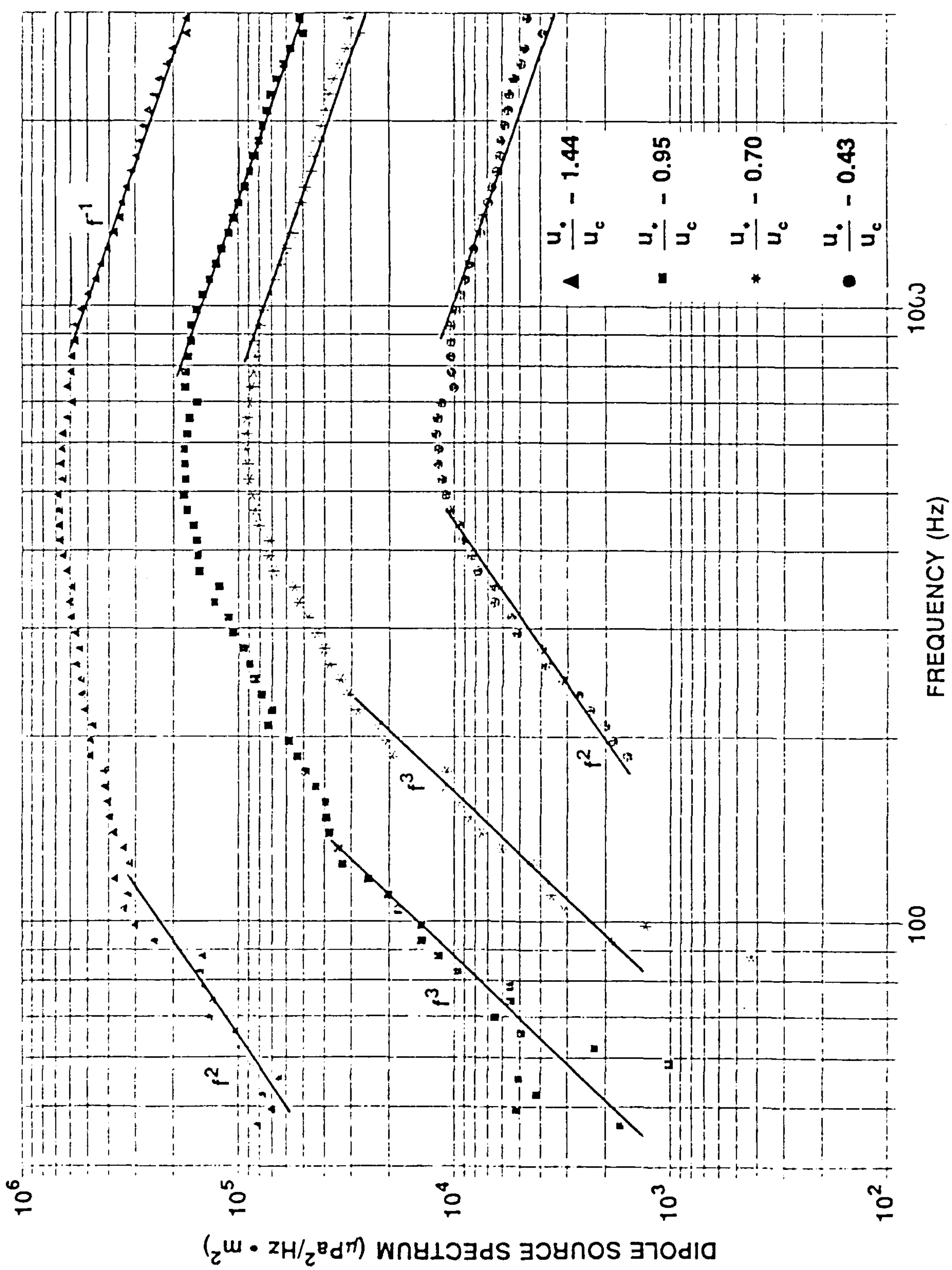
This linear axis figure illustrates the general character of the dipole source frequency spectrum. The abscissa is frequency and the ordinate is spectrum level. These are three examples of the over 100 such spectra found. The spectrum are clearly bandpass with a decaying high frequency end and an abrupt low frequency cutoff. The shape is reminiscent of gravity wave spectra and the data smoothing functions illustrated are the same analytical form used to model gravity wave spectra but with quite different parameters. The environment is parametized by the nondimensional surface friction velocity used by B.R. Kerman;[3] i.e., the surface friction velocity is nondimensioned by the minimum phase speed of the capillary-gravity wave field. Unity value of this coefficient represents the onset of clearly visible spilling whitecaps.



DIPOLE SOURCE SPECTRUM (μPa²/Hz • m²) × 10⁵)
FREQUENCY (Hz)
u*/uc = 1.44
u*/uc = 0.92
u*/uc = 0.63
0
2
4
6
8
0
1000
2000
3000
4000

SLIDE 6

Repeating the previous slide, only this time with the more familiar logarithmic scales, allows an examination of the low frequency character of the data. While the high frequency spectra is uniformly inversely proportional to frequency with an exponent typically slightly greater than one the low frequency falloff rate varies widely. Sections of the spectra can be fit with 2nd and 3rd power exponents. No regularity of these low frequency shapes with the environmental parameter could be found.

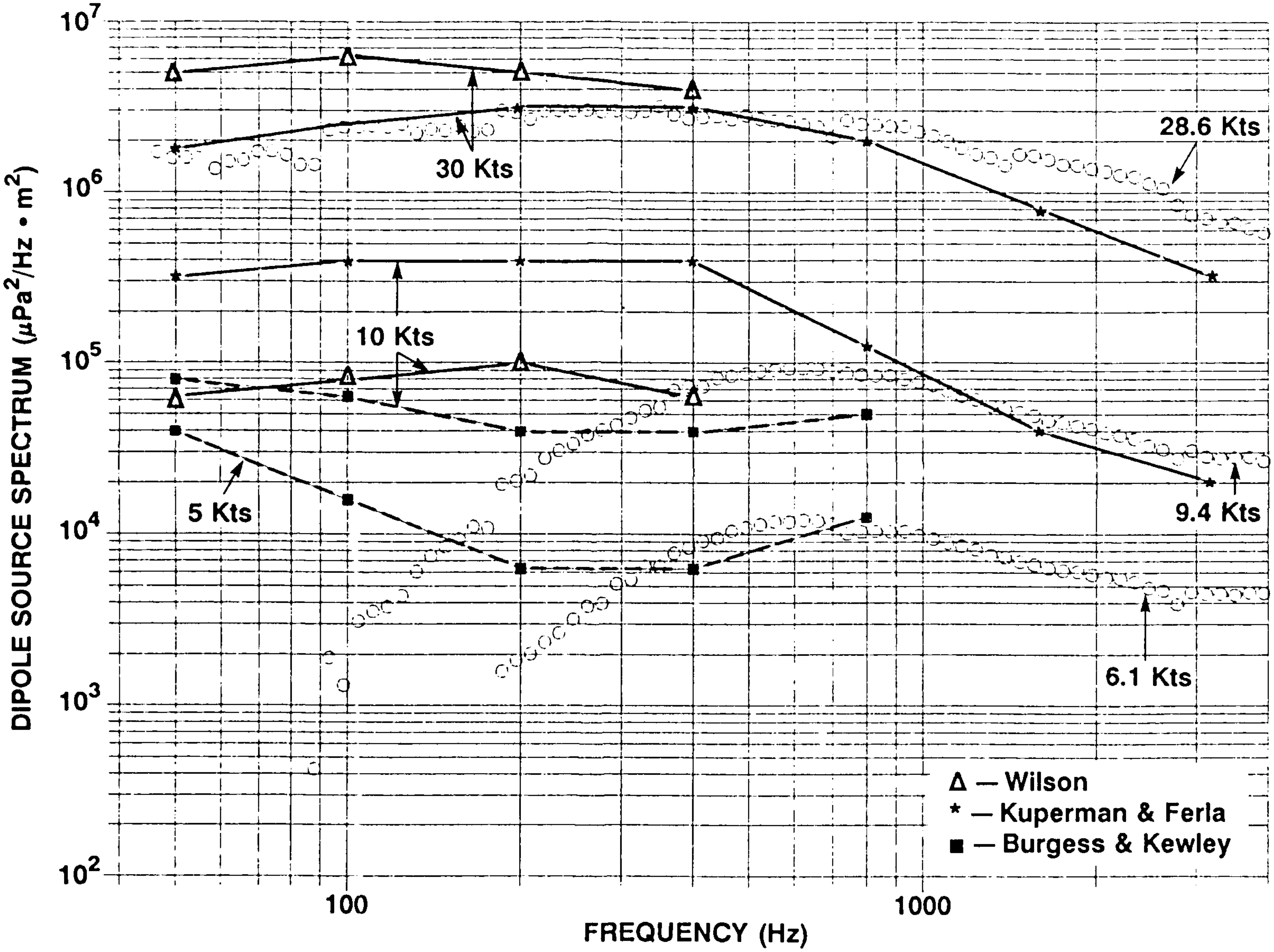


DIPOLE SOURCE SPECTRUM (μPa²/Hz • m²)
10⁶
10⁵
10⁴
10³
10²
FREQUENCY (Hz)
100
1000
f²
f³
f³
f²
f¹
u*/uc = 1.44
u*/uc = 0.95
u*/uc = 0.70
u*/uc = 0.43

SLIDE 7

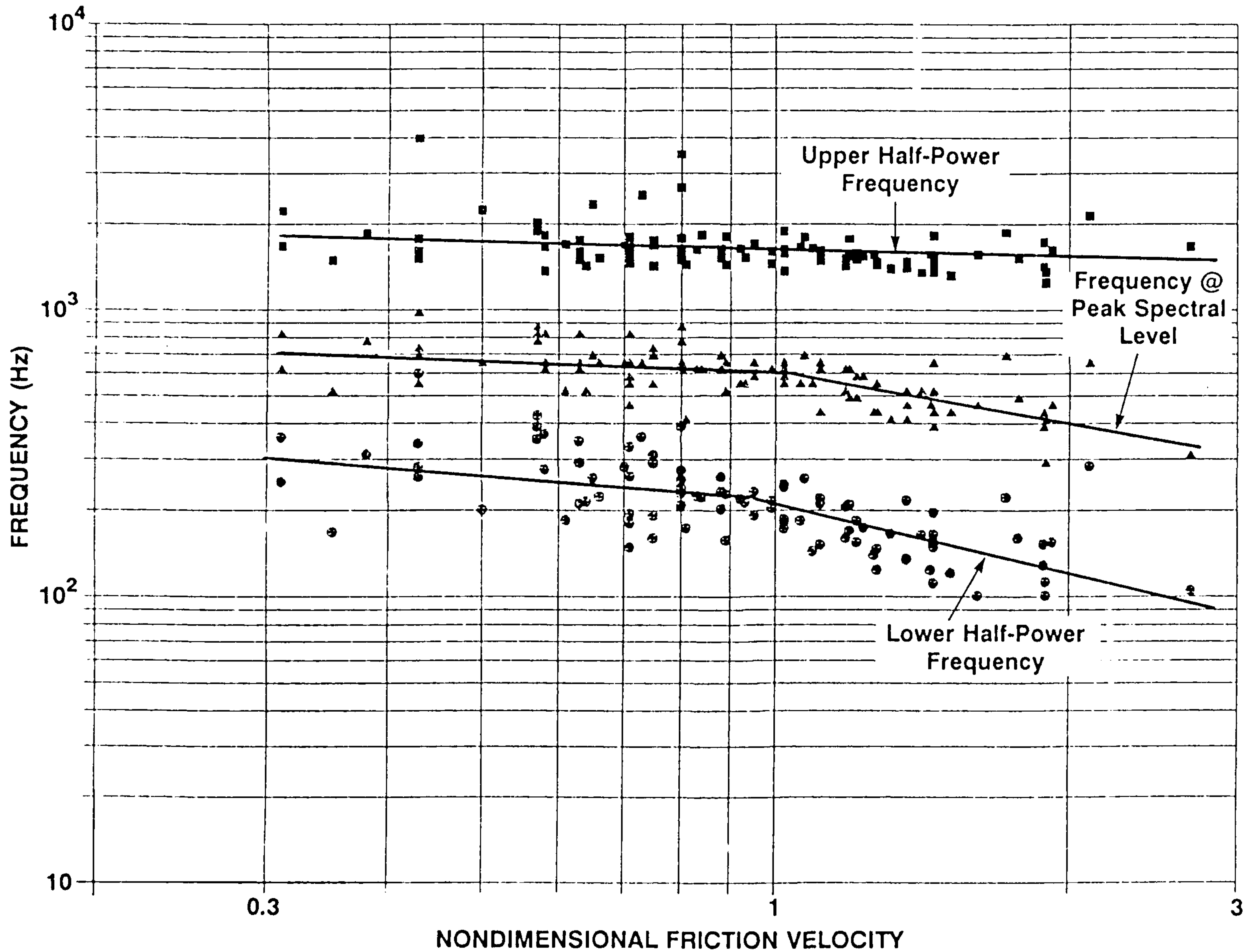
In this figure example dipole source area spectrum are compared with previous measurements.[4,5,6] The log-log axis presentation is the same as the previous slide but the environmental parameter is changed to be the 10 m wind speed with examples chosen to match the previous data. The comparison indicates two points. First, this data generally agrees with previous estimates when spilling breakers are numerous. This is particularly true with the Kuperman and Ferla[6] data. Second, when spilling breakers are not present the abrupt falloff in the spectrum occurring in the present data is not observed in the previous measurements.

RELATION TO OTHER MEASUREMENTS



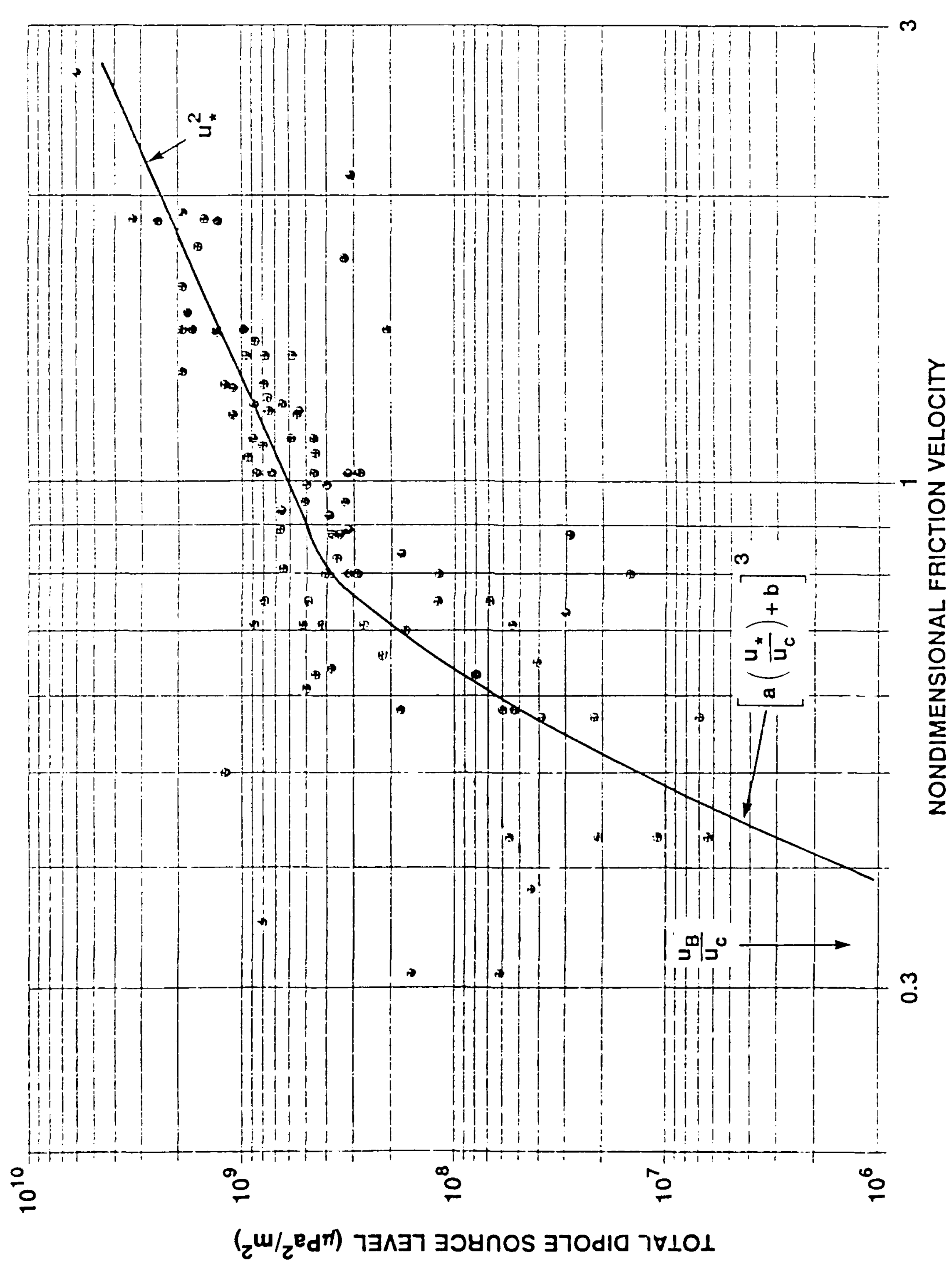
SLIDE 8

This figure quantifies the first order description of the bandpass character of the data. The abscissa is the logarithm of the nondimensional friction velocity and the ordinate is frequency in Hz. The figure shows the frequency at which each of the measured spectrum peaked and the upper and lower half-power points. It is seen that while the upper frequency changes little, both the frequency of peak energy and the lower half-power frequency are inversely proportional to the surface friction velocity with a break point at incipient spilling breakers. Numerically the actual bandwidth is nearly 1400 Hz, independent of the environmental variable.


Upper Half-Power Frequency
Frequency @ Peak Spectral Level
Lower Half-Power Frequency
FREQUENCY (Hz)
10
10^2
10^3
10^4
0.3
1
3
NONDIMENSIONAL FRICTION VELOCITY

SLIDE 9

The final figure displays the frequency integral of the previous spectrum; i.e., the total dipole source level in μpa^2 per m^2. This variable is displayed on a logarithmic scale on the ordinate. The abscissa is again nondimensional friction velocity. Also indicated in the figure is u_B which is identified by E.C. Monahan and M. Lu[8] as the lowest values of the friction velocity for which there is bubble injection from the water surface into the water column. This is a 10 m wind speed value of about 2 to 2.5 m/s. For friction velocity between u_B and u_c the data is highly variable but monotonically increasing. Taking the attitude that the source level should increase with bubble injection rate, an analytical form typically fit to whitecap coverage data was used in this region. Above u_c the now compact data was readily fit with a power law. With this in mind we see that the figure is consistent with the idea that there are three regimes present. First, there are no dipole sources present below u_B/u_c. Second, the dipole source level is proportional to the bubble injection rate until the onset of visible spilling breakers. The source level, like the bubble injection rate, is highly variable when parametized by the surface friction velocity indicating that other near-surface dynamics are active. In fact, whitecap coverage may well be the better independent variable in this range. Once the nondimensional friction velocity exceeds unity the variability decreases dramatically and the dipole source level becomes proportional to the surface wind stress.



TOTAL DIPOLE SOURCE LEVEL ($\mu Pa^2/m^2$)
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
NONDIMENSIONAL FRICTION VELOCITY
0.3
1
3
u_*^2
$\left[a\left(\frac{u_*}{u_c}\right)+b\right]^3$
$\frac{u_B}{u_c}$

SLIDE 10

The final figure is a summary.

SUMMARY

Dipole Source Frequency Spectrum

- Bandpass process
  - Upper frequency independent of wind stress
  - Lower frequency inversely proportional to wind stress
  - Frequency of peak spectrum is inversely proportional to wind stress

Dipole Source Sound Pressure Level

- No dipole sources prior to bubble injection ($u_*/u_c < 0.3$)
- Dipole source SPL proportional to u_*^3 ($0.3 < u_*/u_c < 1$)
- Dipole source SPL proportional to wind stress ($u_*/u_c > 1$)

Dipole Source Area Density Function Model Presented

REFERENCES

1. W.M. Carey and D. Browning, "Low Frequency Ocean Ambient Noise: Measurements and Theory," Sea Surface Sound, edited by B.R. Kerman, Kluwer Academic Publishers, Boston, MA, 1988.

2. 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.

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

4. A.S. Burgess and D.J. Kewley, "Wind-Generated Surface Noise Source Levels in Deep Water East of Australia," Journal of the Acoustical Society of America, vol. 73, pp. 201-210, 1983.

5. J.H. Wilson, "Wind-Generated Noise Modeling," Journal of the Acoustical Society of America, vol. 73, no. 8, pp. 211-216, Jan. 1983.

6. W.A. Kuperman and M.C. Ferla, "A Shallow Water Experiment to Determine the Source Spectrum Level of Wind-Generated Noise," Journal of the Acoustical Society of America, vol. 77, no. 6, June 1985.

7. R.M. Kennedy and T.V. Goodnow, "Measuring the Vertical Directional Spectra Caused by Sea Surface Sound," IEEE Journal of Oceanic Engineering, vol. 15, no. 4, October 1990.

8. E.C. Monahan and M. Lu, "Acoustically Relevant Bubble Assemblages and Their Dependence on Meteorological Parameters," IEEE Journal of Oceanic Engineering, vol. 15, no. 4, October 1990.

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
DARPA Dr. [illegible]. Elinthorpe	1
DTIC	12
DTRC (Code 1925) G.M. J[illegible]bsen	1
(Code 0100) R.E. Metrey	1
NAVPGSCOL H. Medwin	2
NOAA/Miami Dr. J. Proni, H. Bezdek	1
NOARL (Code 113) Dr. [illegible] Adams	1
(Code 321) Dr. P. Smith	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 11250A) M. Orr	1
(Code 11250) R. Baer	1
Applied Measurement Systems, Inc., Hollywood, FL; B.L. Douglass	1
Applied Research Laboratory, State College, PA; Dr. S. McDaniels	1
AT&T Bell Laboratories, Whippany, NJ; Dr. J.R. Eickmeyer	1
Canada Center for Inland Waters, Atmospheric Environment Service, Burlington, Ontario, Canada; Dr. B. Kerman	1
Defense Research Establishment Pacific, Victoria, BC; Dr. R. Chapman	1
Florida Atlantic University, Boca Raton, FL; S. Glegg	1
General Electric Co., Andros Island, Bahamas; L.A. Lindquist	1
GRD Consultants, Delray Beach, FL; G.R. Desmarais	1
Planning Systems, Inc., New London, CT; W.M. Leen	1
Massachusetts Institute of Technology, Cambridge, MA I. Dyer	1
MPL, Scripps Institution of Oceanography, La Jolla, CA; W. Hodgekist	1
University of Miami, Coral Gables, FL; Dr. F. Tappert, Dr. H. Deferrari	2
University of Mississippi, University, MS; Dr. L.A. Crum	1