OCEANIC WHITECAPS AND ASSOCIATED, BUBBLE-MEDIATED, AIR-SEA EXCHANGE PROCESSES

BY

E.C. Monahan, I.A. Leykin, L. Li, Y. Liu
R. Marks, I.G. O'Muircheartaigh, J.W. Steele
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SEA SURFACE PHYSICS LAB
MSI, UCONN AVERY POINT

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OCTOBER 1992

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CHAPTER 1

INTRODUCTION

BY

E.C. MONAHAN

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INTRODUCTION

by

E. C. MONAHAN

The 1992 fiscal year has been one marked by major accomplishments, and set off by several highlights, as regards the activities of UConn's Sea Surface Physics Laboratory.

Our oceanic whitecap data base, accompanied by well-documented environmental data, has been greatly expanded, as a consequence of our participation in the February - March 1992 Gulf of Alaska Surface Scattering and Air-Sea Interaction Experiments, and in other autumn and winter Pacific Ocean cruises. These whitecap data collection efforts are discussed in Chapters 5, 7, and 9 of this report, while some of the results of these activities are presented in Chapters 6 and 8. Many additional whitecap data, arising from the analysis of the video imagery collected during the Gulf of Alaska Experiment, are to be found, under separate cover, in the publications numbered 84, 85, and 86, in Table 1.2. Still, additional whitecap data, in this instance from an autumn Pacific Ocean cruise, are summarized in publication 87.

An equally important, and inter-related, accomplishment has been the further upgrading of our video analysis procedures during this past year. With new, locally developed software, and with new, faster, small computers, we are now at a point where a one-hour-long video tape of the sea surface can be analyzed in just about one hour to yield whitecap (Stage A) coverage. These results are available as a series of one-second W_a-averages, or, as a set of 10-minute (or 20-minute) averages. The combined efforts of Mr. M. B. Wilson, Dr. Q. Wang, and Mr. W. Wang, in bringing our analysis procedures to their current level is to be commended.

Among the highlights of the past year for the team in our Sea Surface Physics Laboratory have been the several working visits of Professor I. G. O'Muircheartaigh of University College, Galway, and the extended training visit of three members of the staff of the Research Institute of Electric Light Source Materials, from Nanjing, Peoples Republic of China. Some details of the visit of our colleagues from Nanjing are provided in Chapter 10, while some specifics on Professor O'Muircheartaigh's activities, along with details on the specific professional activities (seminars, conference participation, etc.) of other members of our laboratory team, are listed in Table 1.1.

Our laboratory activities are going forward, as can be glimpsed from the summaries provided in Chapters 2, 4 and 11, as are our efforts at interpreting our laboratory and field observations (e.g., Chapters 3 and 12 and Appendix A). All three graduate students working in the Sea Surface Physics Laboratory are making satisfactory progress on their dissertation research.

Some measure of the concrete results of our research efforts is to be found in Table 1.2, where the recent project-related publications are listed.

TABLE 1.1: WHITECAP PROJECT LOG
1 OCTOBER 1991 - 30 SEPTEMBER 1992

17-18 October 1991: ECM participated in ONR "Dynamics of Bubbly Flows" program review/workshop, at the University of California at Santa Barbara.

17 October 1991: ECM gave talk (co-authored with Q. Wang) entitled "The Evolution of the Bubble Population Resulting from a Spilling Wave, With Due Consideration to the Influence Of Salinity, Water Temperature, and Dissolved Gas Levels" at ONR "Dynamics of Bubbly Flows" program review, at UCSB.

6 November 1991: R.H. Mellen presented paper (co-authored with I.A. Leykin) entitled "Wind-Wave Modeling and the Scattering Problem" during the fall meeting of the Acoustical Society of America in Houston, TX.

11 November 1991: ECM visited the Department of Meteorology at the University of Maryland, College Park, and discussed his research with Dr. Ferdinand Baer, Dr. Robert Hudson, and Dr. James Carton.

13 November 1991: ECM visited the Naval Oceanographic and Atmospheric Research Laboratory, Atmospheric Directorate, in Monterey, CA, where he met with Dr. Andreas Goroch and gave a seminar entitled "Estimating Near Surface Bubble Populations from Remotely Sensed Whitecap Coverage".

5 December 1991: ECM participated in SWAPP/SWADE meeting at Rosenstiel School of Marine and Atmospheric Science, University of Miami, Florida. He gave a talk on "Whitecap Observations During SWADE" during morning session.

5 December 1991: ECM gave seminar on "Near-Surface Bubble Populations Inferred from Satellite-Monitorable Oceanic Whitecap Coverage" in the Division of Applied Marine Physics and Ocean Engineering at RSMAS, University of Miami.

6 December 1991: ECM took part in an all-day SWADE planning meeting at RSMAS, University of Miami.

9 December 1991: ECM gave guest lecture at Mohegan Community College, Norwich, CT, on "Global Climate Change".

11-12 December 1991: I.A. Leykin presented a short-course, "Remote Sensing of the Oceans," (with Dr. A.D. Rozenberg) in Williamsburg, VA, organized by Science and Technology Institute of Hampton, VA.

16 December 1991: ECM visited by Dr. Edgar L. Andreas from U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH. They worked on outlining review paper on "The Role of Aerosols (and Bubbles) in Evaporation", which has been requested by ICDM Working Group A.

17 December 1991: Dr. W.M. Carey of NUSC, New London, CT, visited MSI, UConn, and discussed joint publications with ECM, MBW and Dr. Q. Wang.

2-30 January 1992: Working visit of Professor I.G. O'Muircheartaigh, University College, Galway, to UConn's Sea Surface Physics Laboratory at Avery Point, and to Department of Statistics at Storrs, to help in analysis and interpretation of Whitecap Data Sets.

23 January 1992: ECM gave seminar entitled, "Bigger Whitecaps and the Greenhouse Effect, How Wave Breaking Influences the Air-Sea Exchange of CO and Other Radiatively Important Gases", in the Department of Geology and Geophysics, Boston College, Boston, MA.

23 January 1992: Dr. I.G. O'Muircheartaigh, accompanied by ECM, visited the Mathematics Department of Boston College, and met with Dr. Jenny Baglivo. Dr. O'Muircheartaigh gave a seminar entitled "Estimation of Sea Surface Windspeed: Statistical Approaches Compared Empirically and by Simulation", in the B.C. Math Department.

27-31 January 1992: ECM attended the AGU Ocean Sciences meeting in New Orleans, LA.

27 January 1992: I.A. Leykin paper (co-authored with R.H. Mellon) entitled "Wind-Wave Bispectrum and Microwave Backscattering from the Sea" during session 012B (Laboratory Experiments II: Waves and Turbulence) of AGU Ocean Sciences meeting.

27 January 1992: ECM gave paper (co-authored with Q. Wang and M.B. Wilson) entitled "The Influence of Salinity on the Bubble Spectra Produced in the Laboratory by Breaking Waves" during session 012B of AGU Ocean Sciences meeting.

28 January 1992: ECM visited the University of South Alabama in Mobile and gave seminar, "Whitecaps and the Greenhouse Effect (II)".

29 January 1992: W.E. Asher presented a paper (co-authored with P.M. Smith and ECM) entitled "Correlation of Fractional Area Whitecap Coverage with Average Oceanic Microwave Apparent Brightness Temperature" during session 031E of AGU Ocean Sciences meeting, New Orleans, LA.

29 January 1992: ECM visited the University of New Orleans in the afternoon and gave seminar on "Air-Sea Exchange Processes and Our Global Climate" in Department of Biological Sciences.

2-4 March 1992: ECM participated in ONR Marine Boundary Layers ARI Workshop in Monterey, CA.

4 March 1992: ECM visited the Naval Postgraduate School, Monterey, CA, where Mr. D.E. Speil showed him his Bubble and Droplet Measurement Apparatus, and where he met with Dr. K.L. Davidson.

17 March 1992: ECM gave invited lecture, "Air-Sea Exchange Processes and Their Effect on Our Global Climate", at the Mystic Seaport Museum, Mystic, CT, to students in Williams College Maritime Studies Program.

6 April 1992: ECM gave guest lecture, "Global Climate Change II", to Environmental Science class at Mohegan Community College, Norwich, CT.

11-13 May 1992: ECM and Q. Wang attended the 123rd meeting of the Acoustical Society of America in Salt Lake City, Utah.

11 May 1992: R.H. Mellen presented a paper (co-authored with I.A. Leykin) entitled "Nonlinear Wind-Wave Effects in Backscatter" during spring meeting of the Acoustical Society of America in Salt Lake City, Utah.

12 May 1992: ECM presented paper (co-authored with Q. Wang) entitled "Temporal Evolution of the Bubble Plumes Generated by Breaking Waves: Acoustical Implications", in session 2A0 of the 123rd meeting of the Acoustical Society of America, and participated in panel discussion.

13 May 1992: ECM gave guest lecture entitled "Whitecaps and the Greenhouse Effect" (III), in the Department of Meteorology, University of Utah, Salt Lake City.

18 May 1992: ECM participated in ONR Air-Sea Acoustics Preliminary Data Analysis meeting at Dunsmuir Lodge, University of Victoria, Sidney, B.C.

19-21 May 1992: ECM took part in second annual ONR Air-Sea Acoustics Science meeting at Dunsmuir Lodge, University of Victoria. He presented paper, co-authored with Q. Wang and M.B. Wilson, entitled "Bubble Clouds: Dependence of Resulting Bubble Spectra on Mechanism of Air Introduction, and on Salinity", on 19 May.

22 May 1992: ECM visited Royal Roads Military College, Victoria, British Columbia, and discussed marine remote sensing with Dr. S.R. Waddell and other members of faculty. He gave invited seminar in the Physics Department of R.R.M.C. entitled "Oceanic Whitecaps: Remotely Monitorable Indicators of the Rate of Air-Sea Exchange, and of the Rate of Sea-Salt Aerosol Production".

16 June 1992: ECM visited the Weather Center and Dr. M. Goldstein at Western Connecticut State University, Danbury, and gave a seminar entitled "Breaking Waves and Air-Sea Exchange" in the Physics and Astronomy Department.

22-26 June 1992: Professor I.G. O'Muircheartaigh of University College, Galway, Ireland, participated on our behalf in the Fifth International Meeting on Statistical Climatology held in Toronto, Canada, where he presented a paper (co-authored by ECM) entitled "Modelling the Dependence of Whitecaps on Wind Speed: Hierarchical Models, and Shrunken Parameter Estimation."

24-25 June 1992: Professor Renhe Zhang, Director of the State Key Laboratory of Acoustics, Academia Sinica, Beijing, Peoples Republic of China visited the Sea Surface Physics Laboratory, M.S.I., UConn. On 24 June, he gave seminar on "Recent Advances in Underwater Acoustics in China", in Department of Marine Sciences, and on 25 June he met with ECM to discuss possible collaboration, etc.

29 June - 18 July 1992: Professor I.G. O'Muircheartaigh, University College, Galway, made his third working visit to the Sea Surface Physics Laboratory, UConn at Avery Point, and to the Department of Statistics, UConn, Storrs, during which he worked in conjunction with ECM and Wang Wei on the analysis of Whitecap Data Sets, etc.

6 July 1992: Three UNIDO Fellows, Gongchuan Wang, Yiwen Liu, and Liquan Li, of the Research Institute of Electric Light Source Materials, Nanjing, P.R.C., arrived in UConn's Sea Surface Physics Laboratory for extended training visit.

23-24 July 1992: While at the Scripps Institution of Oceanography, LaJolla, CA, ECM met with Dr. Bernard Jahne for discussion (on 23 July) of next international conference on Air-Water Gas Transfer (as they are both on the organizing committee), and with Dr. W. Ken Melville for discussion (on 24 July) of research on wave breaking and other topics of mutual interest.

28 July 1992: Dr. Bryan R. Kerman of Canada Centre for Inland Waters visited ECM at Avery Point. They discussed Acoustics Research and Whitecap Remote Sensing.

4-6 August 1992: ECM participated in ONR Dynamics of Bubbly Flows Workshop at the University of Michigan, Ann Arbor. On 5 August gave a presentation (co-authored by Q. Wang, X. Wang and M.B. Wilson) entitled, "Diverse Spectra of Air Bubbles Produced in Fresh-and Sea-Water, and Some Preliminary Findings on Air Entrainment".

11-14 August 1992: I.A. Leykin visited the Canada Centre for Inland Waters, in Burlington, Ontario, Canada. He worked with Dr. Mark Donelan on analysis of wind wave data.

13 August 1992: I.A. Leykin gave a seminar, "Observations of Wind-Wave Slopes in the Open Sea", at Canada Centre for Inland Waters.

28 August 1992: Dr. I.A. Leykin gave lecture, "Bispectral Analysis of Nonlinear Acoustical Signals with a Group Structure" at a one-day research conference at the Yale University Center for Ultrasonics and Sonics, in New Haven, CT.

9 September 1992: ECM participated in the Ninth Critical Sea Test Surface Scatter and Reverberation working group meeting at S.A.I.c. in McLean, Virginia. He gave talk, "Gulf of Alaska Experiment Whitecap Measurements" (co-authored with Q. Wang, W. Wang and M.B. Wilson) at this ONR-sponsored meeting.

TABLE 1.2: LIST OF PROJECT RELATED PUBLICATIONS FOR 1 OCTOBER 1991 - 30 SEPTEMBER 1992 INTERVAL

Note: Listings of earlier related publications are to be found in the following locations:

1) In Table 1.2, p. 13, of UConn Whitecap Report No. 1
2) In Table A.2, pp. 102-103, of UConn Whitecap Report No. 1
3) In Table 1.2, pp. 22-23, of UConn Whitecap Report No. 3
4) In Table 1.2, pp. 16-17, of UConn Whitecap Report No. 4
5) In Table 1.2, pp. 9-11, of UConn Whitecap Report No. 6
6) In Table 1.2, pp. 9-11, of UConn Whitecap Report No. 10
7) In Table 1.2, pp. 12-14, of UConn Whitecap Report No. 11

Amended Earlier Listings

56. Monahan, E.C., and T. Torgersen. 1991. "The Enhancement of Air-Sea Gas Exchange By Oceanic Whitecapping", pp. 608-617 in Air-Water Mass Transfer, Selected Papers from the Second International Symposium on Gas Transfer at Water Surfaces, S.C. Wilhelms and J.S. Gulliver, Eds., American Society of Civil Engineers, N.Y., N.Y.

57. Asher, W.E., E.C. Monahan, R. Wanninkhof, and T.S. Bates. 1991. "Correlation of Fractional Foam Coverage with Gas Transport Rates, pp. 536-548 in Air-Water Mass Transfer", Selected Papers from the Second International Symposium on Gas Transfer at Water Surfaces, S.C. Wilhelms and J.S. Gulliver, Eds., American Society of Civil Engineers, N.Y., N.Y.

Still Pending From 1989-1990 and 1990-1991

54. Monahan, E.C. 1991. "Occurrence and Evolution of Acoustically Relevant Sub-Surface Bubble Plumes and Their Associated, Remotely Monitorable, Surface Whitecaps" in Natural Physical Sources of Underwater Sound. B.R. Kerman, Ed. Kluwer Academic Publishers, Dordrecht (in press).

67. Asher, W.E., P.J. Farley, R. Wanninkhof, E.C. Monahan and T.S. Bates. 1991. "Laboratory and Field Experiments on the Correlation of Fractional Area Whitecap Coverage with Air-Sea Gas Transport". Proceedings, Fifth International Conference on Particle Scavenging and Atmosphere-Surface Exchange Processes, Richland, Washington, pp. 1-10 (submitted).

New Listings

72. Monahan, E.C., Q. Wang, W. Wang, and M.B. Wilson. 1991. "The Role of Oceanic Whitecaps and the Associated Sub-Surface Bubble Plumes in Various Air-Sea Interface Phenomena", Whitecap Report No. 11, to ONR, from MSI, UConn, (P.A. Beetham, Editor) pp. 1-123.

73. Carey, W., E. C. Monahan, J. Fitzgerald, Q. Wang and E. Parssinen. 1991. "Measurement of the Sound Produced by a Tipping Trough with Fresh and Salt Water", (5UW3), The Journal of the Acoustical Society of America, 90, pp. 2312-2313 (abstract).

74. Roy, R.A., L.A. Crum, M. Nicholas, J.A. Schindall, W.M. Carey, W.A. Conrad, W.J. Marshall, E.C. Monahan and A. Prosperetti. 1991. "Low-Frequency Acoustic Scattering from a Submerged Bubble Cloud", (6PA9), The Journal of the Acoustical Society of America, 90, pg. 2318 (abstract).

75. Mellen, R.H. and I.A. Leykin. 1991. "Wind-Wave Modeling and the Scattering Problem", (5AO8), The Journal of the Acoustical Society of America, 90, pg. 2302 (abstract).

76. Wang. Q., E.C. Monahan, and M.B. Wilson. 1991. "The Influence of Salinity on the Bubble Spectra Produced in the Laboratory by Breaking Waves", 012B-9, AGU 1992 Ocean Sciences Meeting Program and Abstract, EOS, Transactions, American Geophysical Union, 72, No. 51, p. 23 (abstract).

77. Asher, W.E., P.M. Smith and E.C. Monahan. 1991. "Correlation of Fractional Area Whitecap Coverage With Average Oceanic Microwave Apparent Brightness Temperature, 031E-6, AGU Ocean Sciences Meeting Program and Abstracts, EOS, Transactions, American Geophysical Union, 72, No. 51, p. 51 (abstract).

78. Monahan, E.C. and Q. Wang. 1992. "Temporal Evolution of the Bubble Plumes Generated by Breaking Waves: Acoustical Implications", (2AO7), The Journal of the Acoustical Society of America, 91, pp. 2322-2323 (abstract).

79. Mellen, R.H. and I.A. Leykin. 1992. "Nonlinear Wind-Wave Effects in Backscatter", (1AO9), The Journal of the Acoustical Society of America, 91, pg. 2319 (abstract).

80. O'Muircheartaigh, I. and E.C. Monahan. 1992. "Modelling the Dependence of Whitecap on Windspeed: Hierarchical Models, and Shrunken Parameter Estimation", Preprints, Fifth International Meeting on Statistical Climatology, 22-26 June 1992, Toronto, Canada, pp. 553-556.

81. Monahan, E.C. 1992. "Whitecaps and Other Bubble Assemblages Relevant to Near-Surface Acoustic Reverberation", in Ocean Acoustics Program Summary for FY 91, M.H. Orr and R.N. Baer, Eds., Office of Naval Research, Report No. 11250A92-6, pp. 141-142 (abstract).

82. Monahan, E.C., Q. Wang and M.B. Wilson. 1992. "Bubble Clouds: Dependence of Resulting Bubble Spectra on Mechanism of Air Introduction, and on Salinity", Abstracts of Presentations, Air-Sea Acoustics Meeting, Dunsmuir Lodge, 18-21 May 1992, pp. 27-30.

83. Carey, W.M., J.W. Fitzgerald, E.C. Monahan and Q. Wang. 1992. "Measurement of the Sound Produced by a Tipping Trough with Fresh and Salt Water", The Journal of the Acoustical Society of America (submitted).

84. **Wilson, M.B., S.L. Wilson and J.C. Wilson. 1992. "Analysis of Foam Cover (Stage A Whitecaps) during Cruise of R/V CORY CHOUEST (Feb/Mar 1992) and R/V J.P. TULLEY (Feb/Mar 1992)", Vol. 1. Technical Report to ONR, from M.S.I., UConn, pp. 1-38.**

85. Wilson, M.B., S.L. Wilson and J.C. Wilson. 1992. "Analysis of Foam Cover (Stage A Whitecaps) during Cruise of R/V CORY CHOUEST (Feb/Mar 1992) and R/V J.P. TULLEY (Feb/Mar 1992)", Vol 2 (R/V CORY CHOUEST Data). Technical Report to ONR, from M.S.I., UConn, pp. 1-110.

86. Wilson, M.B., S.L. Wilson and J.C. Wilson. 1992. "Analysis of Foam Cover (Stage A. Whitecaps) during Cruise of R/V CORY CHOUEST (Feb/Mar 1992) and R/V J.P. TULLEY (Feb/Mar 1992)", Vol. 3 (R/V J.P. TULLEY Data). Technical Report to ONR, from M.S.I., UConn, pp. 1-100.

87. Wilson, M.B. and W. Wang. 1992. "Analysis of Foam Cover (Stage A Whitecaps) during Cruise of R/V PARIZEAU (November 1991). Technical Report to ONR, from M.S.I., UConn, pp. 1-36.

88. Monahan, E.C., Q. Wang, W. Wang, and M.B. Wilson. 1992. "Oceanic Whitecap Coverage in the Gulf of Alaska during the February-March 1992 Surface Scattering and Air-Sea Interaction Experiment", (5pUW13), The Journal of The Acoustical Society of America, 92, pg. 2480 (abstract).

89. Leykin, I.A., L.I. Piterbarg, V.A. Kalmykov, and R.H. Mellen. 1992. "On Bispectral Analysis of Signals with a Group Structure". Proceedings of International Conference on Signal Processing, Applications and Technology. Boston, MA, November 2-5, 1992 (in press).

90. Leykin, I.A., L.I. Piterbarg, and V.A Kalmykov. 1992. "On Bispectral Analysis of Wind Waves with a Groupiness", Journal of Geophysical Research (submitted).

91. Wang, Q. 1992. "Sound Spatial Transverse Decorrelation due to Surface Wind Waves in Shallow Water", (4aUW7), The Journal of the Acoustical Society of America, 92, pg. 2417 (abstract).

CHAPTER 2

BRIEF REPORT ON BUBBLE DISTRIBUTION IN THE FRIT-MAT

BY

Q. WANG

CHAPTER 2

BRIEF REPORT ON BUBBLE DISTRIBUTIONS IN THE FRIT-MAT EXPERIMENT

by

QIN WANG

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The experiment was conducted in the Whitecap Simulation Tank IV (WST IV) from June 5 to 7, 1991. The experimental setup was nearly the same as that in the PETIT-CLUSE 4 experiment in 1989 in which the emphasis was placed on the production rate of aerosol generated from bursting bubbles. The present experiment was aimed at characterizing the bubble concentrations and fluxes which were associated with the aerosol flux measured in the PETIT-CLUSE 4 experiment.

The tank WST IV was filled with brackish water to a depth of $65cm$. The frit mat, on which 48 frits were uniformly distributed on an area of $1m \times 1m$, was submerged at $50cm$ below the water surface and in the center of the tank. The rate of air flow, which was used to produce the bubbles via the frit mat, was set to $1.37ml/sec/frit$. This is also the same flow rate as applied during the Grand CLUSE experiment in Marseille. A UConn video bubble microscope with an aperture of $3mm$ in diameter was employed to monitor the bubbles present underwater. The bubbly water was drawn up to pass through the microscope aperture via its suction of a water pump which was set at scale 1.

Figure 2 shows the horizontal distributions of the bubbles just beneath the water surface. The water temperature is $24°C$, the oxygen saturation is 95.6% and the salinity is 20°/oo. The microscope device was located at about $1cm$ beneath the water surface and at 16 positions as shown in Figure 1. The laterally-averaged bubble spectra in Figure 2 (a) indicate that the bubbles are not quite uniformly present in horizontal plane, and the spectrum in Figure 2 (b), which is the spectrum averaged over the sixteen positions, has narrow spectrum with the range of bubble radii from $40\mu m$ to $300\mu m$, especially a high peak at the bubble radii of 100--$200\mu m$.

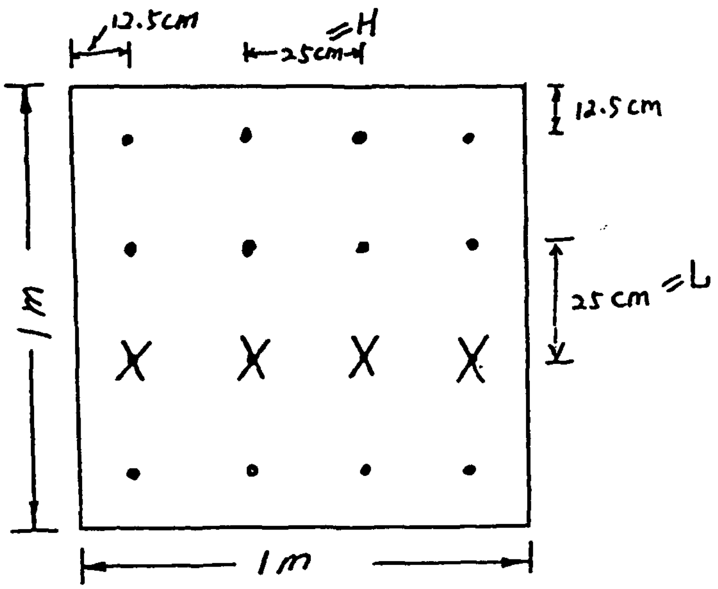
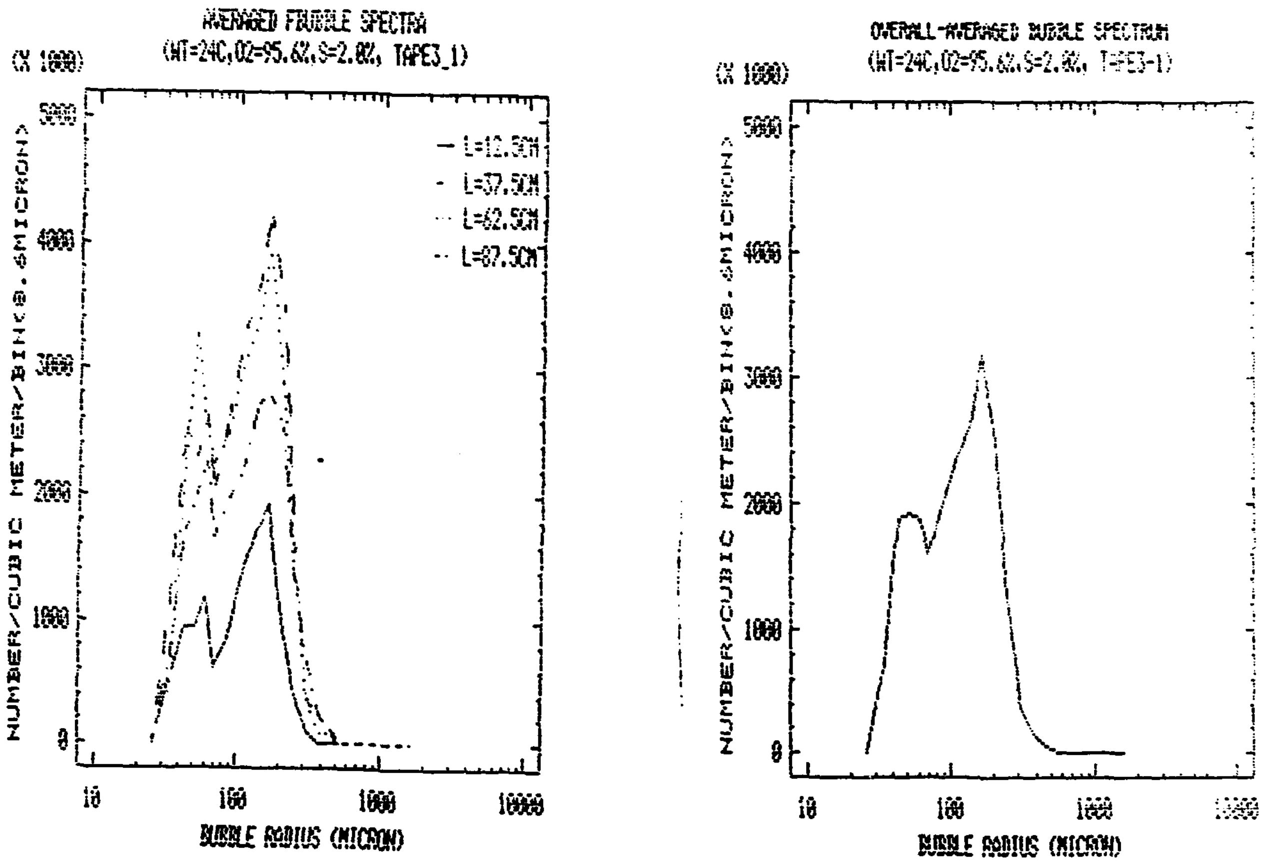


Figure 1. Diagram of Microscope Locations

The bubble distribution is slightly dependent on the water temperature as shown in Figure 3. In the three *runs*, the oxygen saturations and salinities remain unchanged. The bubble distributions were measured at three temperatures of 20°C, 22°C and 24°C, and at four locations indicated as the cross marks in Figure 1. Figure 3 shows that there exists the positive correlation between the bubble populations and the water temperature.

When the water was diluted with freshwater (tap water) during the experiment, the diluted water was undersaturated at about 78%. Three hours later, the water arrived at the saturation of 100%. At the two cases, the bubble distributions were measured. There exists some difference between the bubble distributions as indicated in Figure 4. The higher the saturation is, the more the bubbles are present under the water, which is consistent with previous results.

As we expected, the bubble distributions are significantly dependent upon salinity for a constant rate of the air flow. The water was diluted several times with the salinities of 20°/oo, 10°/oo, 5°/oo and 3°/oo. Figure 5 shows that the small bubble populations markedly increase with salinity, which is qualitatively agreeable with the results in the tipping-bucket experiment. It should be noted that the bubble populations seem to be nonlinearly proportional to the salinity.



(A) (B)

Figure 2. Averaged Bubble Spectra.

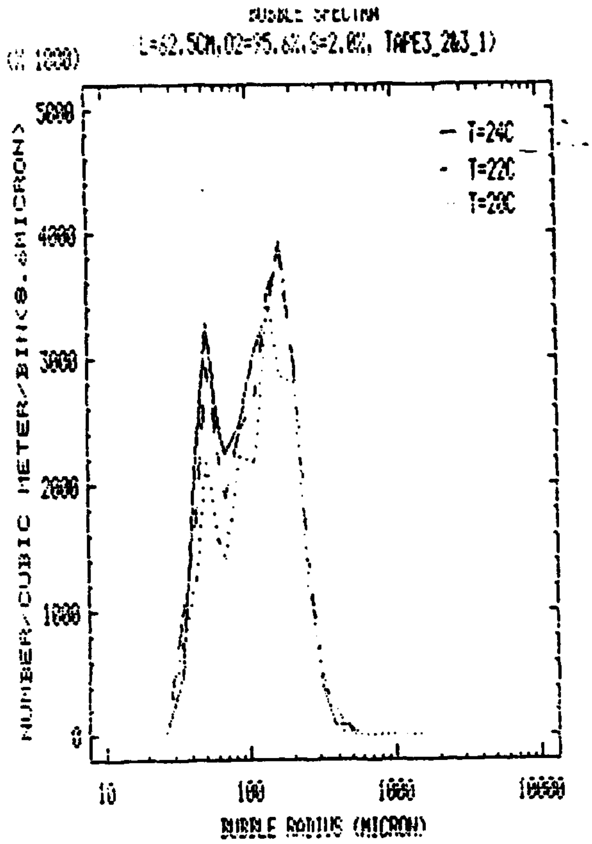


Figure 3. Temperature Dependence Of Bubble Distribution

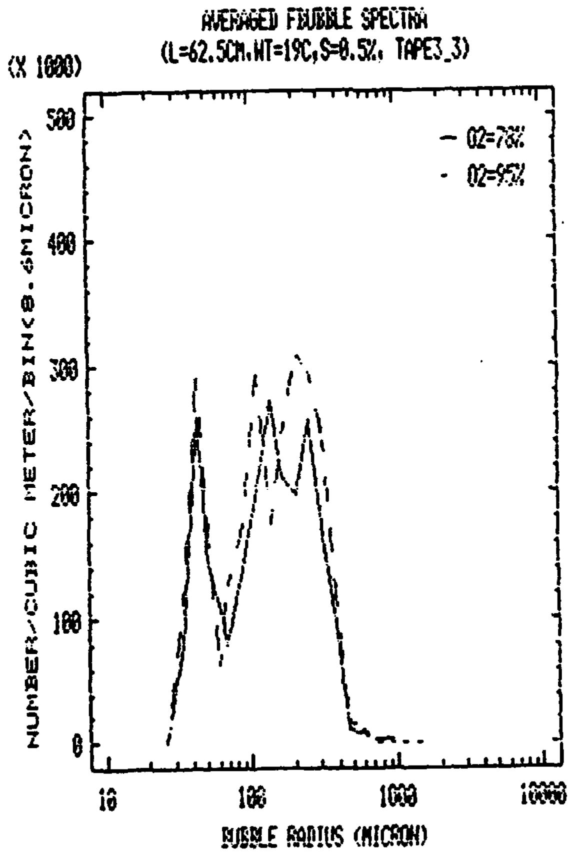


Figure 4. Oxygen Saturation Dependence of Bubble Distribution

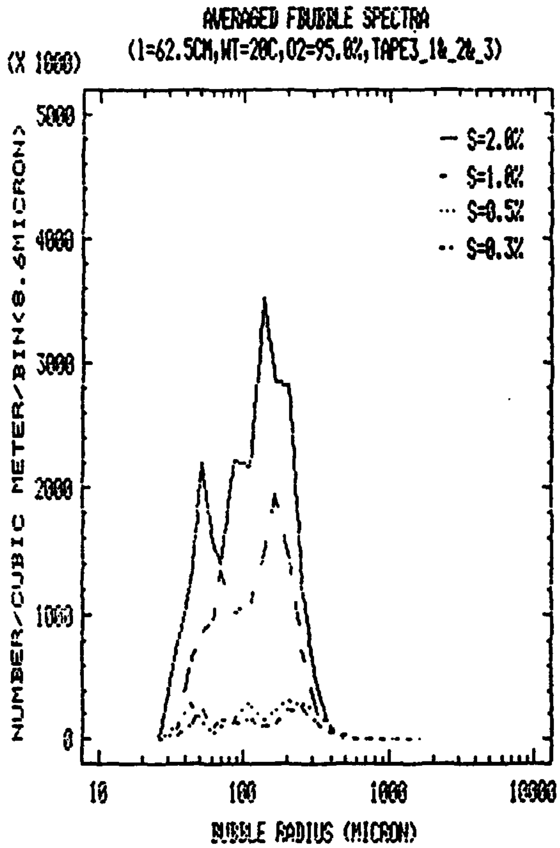


Figure 5. Salinity Dependence of Bubble Spectrum

CHAPTER 3

WATER TEMPERATURE, WATER SAMPLE AGE, AND SURFACE SLICK INFLUENCE ON JET AND FILM DROP PRODUCTION

BY

R. MARKS

CHAPTER 3

WATER TEMPERATURE, WATER SAMPLE AGE, AND SURFACE SLICK INFLUENCE INFLUENCE ON JET AND FILM DROPS PRODUCTION

by

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ABSTRACT

The production of jet/film drops from the quasi stable stream of bubbles generated in a sea water by two capillary slots have been investigated for water temperature range between 9.5°C and 22.4°C, for different ages of the water up to 3 days at laboratory temperature, as well as for the water with a visually observed slick at the surface. Obtained results indicate that with increasing water temperature, production of large droplets was enhanced. This indicates that jet drops formation strongly depends on water viscosity. Production of film drops, those between 0.25μm and 1.2μm in radius, showed no clear correlation with increasing water temperature. With increasing age of the water remaining at the laboratory temperature, it was found that production of jet drops was gradually decreased, while film droplet production was rather enhanced. Under the presence of the surface slick the production of all size droplets was diminished, particularly in the large droplet category or even eliminated for those droplets larger than 3.5μm in radius.

Obtained results indicate that bursting of the same bubble stream in warm, less viscous water, may greatly enhance sea to air transfer of marine aerosol. On the other hand increasing production of microbes in the water remaining in the laboratory conditions, may gradually decrease production of sea derived droplets. The decrease in droplets flux of 7.88% was recorded under the presence of the oil slick at the air surface for the same water body characterized by temperature about 22.4°C and the age of the water sample of 48 hours.

INTRODUCTION

Woodcock, 1949, 1952, and later on, Woodcock and Blanchard, 1955, began to investigate jet/film drops phenomenon. Since that time, extended studies on jet/film drops production have been undertaken by Blanchard and Woodcock, 1957, and Blanchard, 1963, to study their climate significance as a source of giant condensation nuclei. Later on this research has been supplemented by laboratory experiments concerned with physics of both jet and film drops formation. Interesting experiments have been performed, e.g., by Cipriano and Blanchard, 1981, investigating bubble and aerosol spectra produced by the laboratory breaking wave.

Woolf and Monahan, 1988, studying the surface slick influence on jet and film drops formation, reported that simulating breaking wave events in the laboratory tank, the production of large drops, ($r > 5\mu m$), was reduced to half or less of its previous value (without the presence of surface slick), and production of small drops ($0.5\mu m < r > 5\mu m$) was reduced by about 25-30%.

Blanchard, 1989, reported that jet droplets size and ejection height decrease with decreasing water temperature. Bowyer *et al.*, 1990, have found that with increasing water temperature, bubble-mediated production of aerosol of diameter greater than $3\mu m$ increases, while the production of small aerosols, if anything, decreases.

Stramska *et al.*, 1990, simulating breaking wave events in laboratory tank, reported that with increasing degree of oxygen saturation in the water, the whitecap-mediated production of jet and film drops increases.

Investigations presented in this report address the water temperature, water sample age and surface slick influence on jet and film droplets formation. All experimental data were collected during several experiments performed in laboratory conditions using Air-Sea Exchange Monitoring System (A-SEMS).

EXPERIMENTAL SET-UP

In a first look, the Air-Sea Exchange Monitoring System (see Figure 1) consists of a plastic bell jar of 0.083 m^3 volume, enclosing 0.0471m^2 of water surface. Inside the chamber at the depth of 0.1m, two glass capillary bubblers are mounted. A constant air flow of 79.7 $mm^3\ s^{-1}$ applied into the capillary slots produces quasi-stable stream of bubbles in quasi-stable sizes. Those bubbles, after traveling through a water column of 0.1m, burst at the water surface producing jet and film droplets.

In order to reduce the aerosol background and continuously remove portions of the particle stream, the chamber is continuously flushed with a filtered air of $0.101 \times 10^{-3}\ m^3s^{-1}$ flow rate. This provides also slight overpressure within the chamber, protecting entrance of the outside particles.

Inside the chamber, at the water surface, an internal ring confining the bubbles to the central portion of the chamber is utilized. In that way all bubbles burst at the minimum distance of 30mm from the chamber wall. Produced stream of droplets is continuously mixed by a small propeller fan.

In the chamber air thermometer, air humidity meter and water thermometer are deployed based on precision thermistors YSI 44106. Atmospheric pressure inside and outside the chamber is measured by pressure head manufactured by OMEGA Engineering Inc. Oxygen concentration in the water is measured by Dissolved Oxygen Meter, YSI, Model 58.

Size distribution and concentration of droplets inside the chamber is measured using ROYCO Particle Counter, Model 225, equipped with a Model 519 plug-in module.

Other complementary information on A-SEMS along with results from first tests and calibration are reported by Marks, 1990.

MEASUREMENTS

Experiments were performed at the Marine Sciences Institute, University of Connecticut in Groton. Data were recorded by the Data System Acquisition based on IBM-XT PC and a data board. The aerosol data within the nine size windows (see Table 1), were collected with frequency of 10Hz. Meteorology and hydrology data on air temperature, air humidity, atmospheric pressure and water temperature and oxygen concentration were recorded slower with frequency of 0.1Hz. In addition, the water salinity and conductivity were measured at the start of each run using S-C-T Meter, YSI Model 33.

The winter-type sea water drawn from the Long Island Sound in volume of $0.133 m^3$ was located in a glass aquarium. Shortly after the transfer into the laboratory environment the water were characterized by temperature of 8.0°C, salinity of 19.5°/oo and dissolved oxygen saturation ratio of 107.3% and oxygen concentration of $11.07 mg l^{-1}$.

In order to reduce gas saturation in the water, before each run an intensive bubbling in the water body were performed. Such a bubbling lasted about 5 minutes and were performed using submersible stone bubbler with air flow of $0.4 x 10^{-4} m^3 s^{-1}$. This reduced gas saturation ratio to the level of less than 105.1%. A general information on both water and the air characteristics during the experiments are assembled in Table 2.

The tank all the time has been covered by the plastic hood. During the water storage in the tank, clean filtered air have been continuously pumped into the tank hood creating sort of clean bench in the tank.

The data acquisition consisted of 2 minutes background record followed by 5 minutes record of jet/film drops production by the bursting stream of bubbles.

All data were written into two separate files: the aerosol file and the meteorology-hydrology file. An example of both files presents Table 3, where record "A" refers to number of particles recorded within 10 size windows, and record "B" refers to air and water characteristics.

Based on both data sets the size spectrum and concentration of particles at 80% of relative humidity, and total flux of sea-salt aerosol mass along with other parameters were calculated.

RESULTS AND DISCUSSION

Assuming that the stream of bubbles and their size spectrum in the water were the same for the same conditions of air flow through the capillary slots, one may compare the production of aerosol as related to the differences in the efficiency of droplets generation. Therefore, in order to compare the results,all the data were estimated as dN/dr in $min^{-1} \mu m^{-1}$, (number of droplets produced during 1 min interval per increment of droplets radius) and plotted against radius of drop r in μm. Figure 2 presents the aerosol production as dN/dr

recorded under different water temperatures ranged between 9.5°C and 22.4°C within the first 24 hours after transferring the water sample into laboratory conditions. The results show an enhancement of droplets production and their spectral size widening towards the bigger sized particles as water temperature increases. This indicates that with increasing water temperature, or in other words, with decreasing viscosity of the water, more large jet drops can be ejected from the same stream of bursting bubble. On the other hand, production of small droplets between 0.49μm to 0.95μm showed no correlation with water temperature. To generalize the presentation, a total flux of sea spray (F) in $\mu g\ m^{-2}s^{-1}$ were plotted against water temperature (Tw) in °C (see Figure 3). The data showed linear distribution described by following curve:

$$F = -0.2452 + 0.03316 \times Tw, \qquad (1)$$

and correlation coefficient of 0.99.

Further sets of experiments were concerned with the aerosol production from the same body of water aging up to 3 days in laboratory temperature. The results plotted as dN/dr versus radius of drops show gradual decrease in production of droplets and their size shift towards smaller particles with increasing time of the water sample age, (see Figure 4). This is possibly related to microbes gradually growing in the water in laboratory temperature. Microbes can be scavenged by the raising bubbles from the water column or attached to the surface film, and in turn, effectively diminish the ability of both jet and film droplets production. Similar effect, and even more evident diminishment in droplets production, was recorded under the presence of oily slick at the water surface, (see Figure 4). In this case the production of all size droplets was substantially reduced, particularly in the large droplets category or even eliminated for those droplets larger than 3.5μm in radius. This indicates that oily slick at the water surface suppress bubble-mediated droplets production and consequently all related exchange processes across the air-sea interface.

Further comparison concerns with changes in the flux of droplets in $\mu g\ m^{-2}s^{-1}$ produced by the same stream of bubbles from the same body of water aging in laboratory temperature. The results delineated by the linear curve fit (see Figure 5) showed decrease in droplets production with increasing age of the water t in hours. The distribution of data points was described by:

$$F = 1.0341 - 0.0104269 \times t \qquad (2)$$

with correlation coefficient of -0.99. In order to make a general comparison, also the flux of droplets recorded under the presence of oil slick is presented in Figure 5. In this case the flux of drops production was reduced 7.88 times compared to the flux of droplets produced from the same body of water but without oil slick at the surface.

CONCLUSIONS

With increasing water temperature, production of large drops was found to increase. This indicates that more jet drops can be generated by the same stream of bubbles from less viscous body of the same water. Therefore, the formation of jet drops strongly increases with decreasing water viscosity. Production of film drops, those between 0.25μm and 1.2μm in radius, showed no clear correlation with increasing water temperature or viscosity.

With increasing age of the water remaining at the laboratory temperature, the production of jet drops was gradually decreased, while film droplet production was slightly enhanced. This can be regarded as an important factor implicating a seasonal difference in sea-to air mass flux. Possibly lower concentrations of microorganisms in the winter and spring water enhance the atmospheric flux of the water compared to the summer or autumn conditions, when the higher concentrations of the microorganisms in the water may occur. On the other hand, however, the water temperature might have an appositive effect, enhancing the stream of droplets produced from the warm waters. Most effective exchange processes across the air-sea interface however, may take place in earlier spring when water temperature warms up preceding the intensive increase in microbes concentration. Such conditions may also create a gas supersaturation in the water (Stramska *et al.*, 1990) further enhancing bubble and aerosol production. Autumn or early winter conditions of relative low temperature and high microbe concentration in the water may therefore set-up the conditions of less effective exchange of mass across the air-water interface.

Under the presence of the surface slick the production of all size droplets was diminished, particularly in the large droplet category, or even eliminated those droplets larger than 3.5μm in radius. The estimated decrease in droplets flux was by a factor of 7.88% for the water temperature of 22.4°C and the age of the water sample of 48 hours. This indicates that increasing input of the surface active material into the earth waters may gradually decrease the water balance in the atmosphere.

ACKNOWLEDGMENTS

This project has been supported by the U.S. Office of Naval Research, via Contract N00014-87-K-0185. Martin Wilson, Spencer Trombley and Mingzhi Lu are acknowledged for developing the data acquisition system used during the experiments.

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TABLE 1. Reference parameters of the particle data acquisition system based on ROYCO Particle Counter.

Window number	Window of radius cat-off in μm	Width of radius window in μm	Mean radius in μm
1	0.25 - 0.80	0.55	0.55
2	0.80 - 1.20	0.40	0.40
3	1.20 - 1.70	0.50	1.45
4	1.70 - 2.15	0.45	1.925
5	2.15 - 2.70	0.55	2.425
6	2.70 - 3.50	0.80	3.10
7	3.50 - 4.50	1.00	4.00
8	4.50 - 5.90	1.40	5.20
9	5.90 - 10.0	4.10	7.95

TABLE 2. Air and water characteristics within the A-SEMS during the experiments

	AIR		WATER		
	Temp. in °C	Humidity in %	Temp. in °C	Oxygen sat. in %	Salinity in %
minimum	12.0	80.0	9.5	90.0	19.5
maximum	26.5	95.0	24.5	105.1	21.0

TABLE 3. Example of the data acquisition files:

(A) particle counts within the ten size windows;
(B) air/water characteristics: RH - relative humidity, Tw - water temperature, Ta - air temperature, O_2 dissolved oxygen concentration, Pi and Pa - atmospheric pressure inside and outside of the system, TIME of the record.

(A)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	TIME
299	211	81	43	24	2	1	0	0	0	00:46:26:9
301	196	86	43	27	8	5	1	0	0	0:46:30:48
296	181	112	58	40	9	4	3	0	0	0:46:33:56
302	207	96	55	39	15	1	1	1	0	0:46:36:75
311	193	90	51	37	19	5	2	0	0	0:46:40:98
267	167	68	37	26	9	2	0	0	0	0:46:44:11
328	214	102	58	39	17	1	0	0	0	0:46:47:24
277	161	78	40	29	11	4	1	0	0	0:46:51:63
294	196	85	33	26	13	3	0	0	0	0:46:54:76
264	178	81	38	23	8	1	0	0	0	0:46:57:89
318	209	100	57	42	15	4	1	0	0	0:47:1:8

(B)

RH(%)	Tw(°F)	Ta(°F)	O_2(%)	Pi(inch)	Pa(inch)	TIME
86.29	75.78	77.65	90.38	30.13	30.13	0:46:23:12
85.40	75.74	77.65	90.62	30.13	30.13	0:46:27:46
85.39	75.74	77.57	90.62	30.13	30.13	0:46:30:65
84.71	75.78	77.74	90.62	30.13	30.13	0:46:33:78
84.37	75.83	77.83	90.62	30.13	30.13	0:46:38: 1
84.20	75.78	77.92	90.86	30.13	30.13	0:46:41:14
84.20	75.83	77.92	91.11	30.13	30.13	0:46:44:27
84.56	75.78	77.96	91.11	30.14	30.13	0:46:48:67
85.25	75.74	77.83	90.62	30.14	30.13	0:46:51:80
85.42	75.83	77.78	90.62	30.13	30.13	0:46:54:93

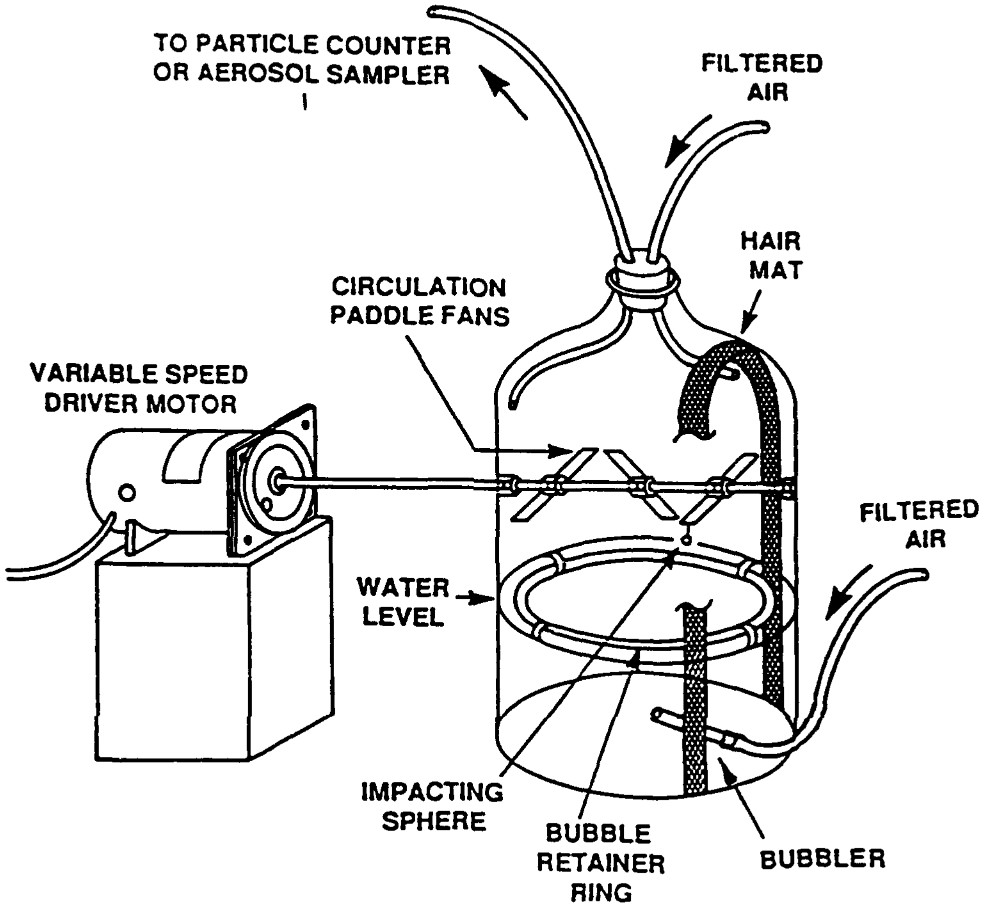


Figure 1. Air-Sea Exchange Monitoring System.

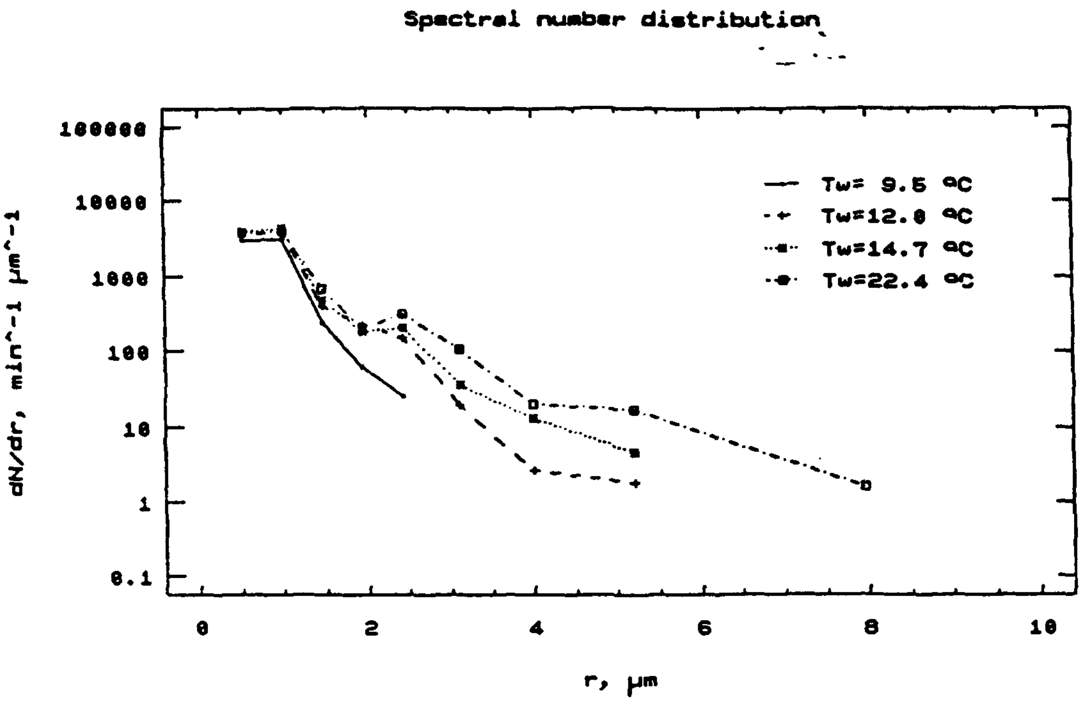


Figure 2. The droplet production as dN/dr in $min^{-1}\mu m^{-1}$ plotted against mean droplet radius for different water temperatures.

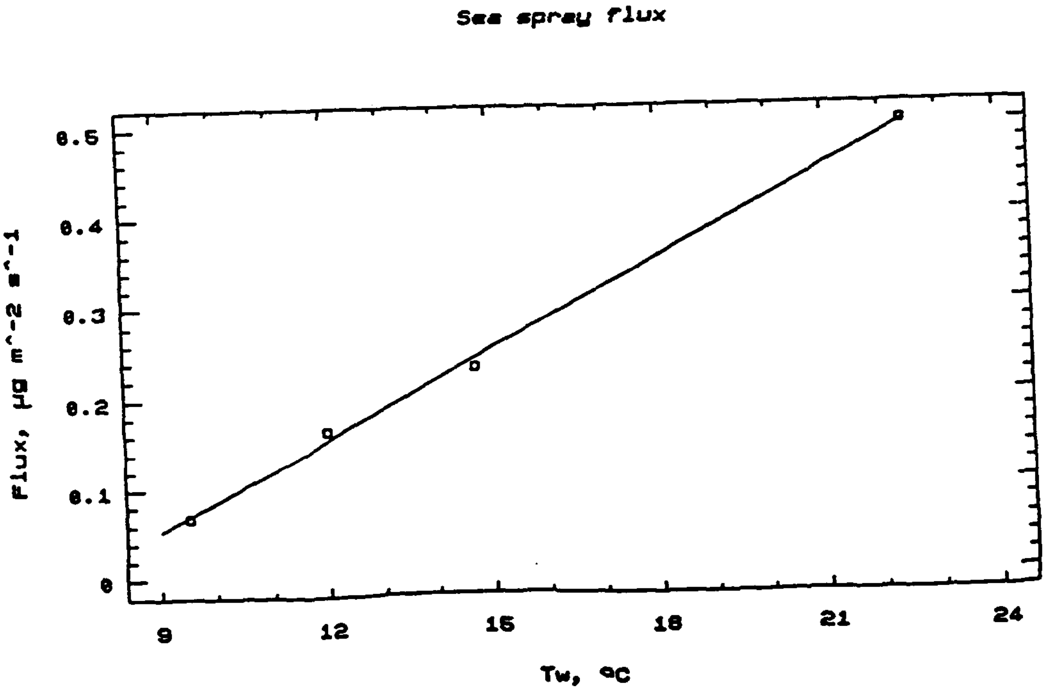


Figure 3. Sea spray flux as a function of water temperature.

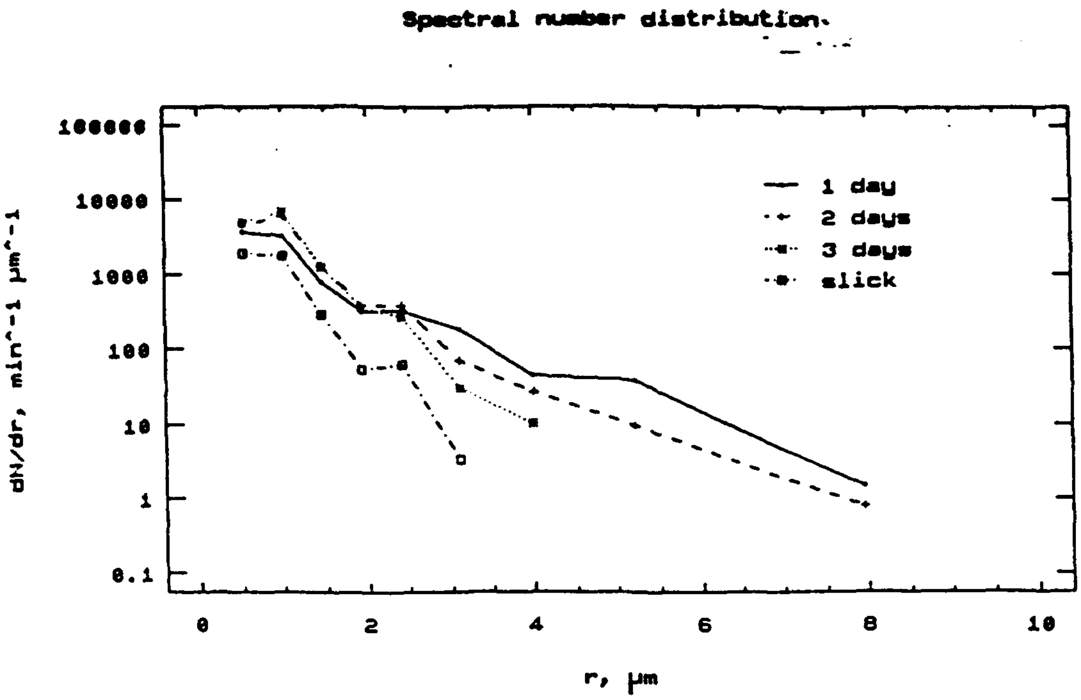


Figure 4. Droplets production per unit incremental radius per one minute interval for different age of the water sample and presence of the oil surface slick.

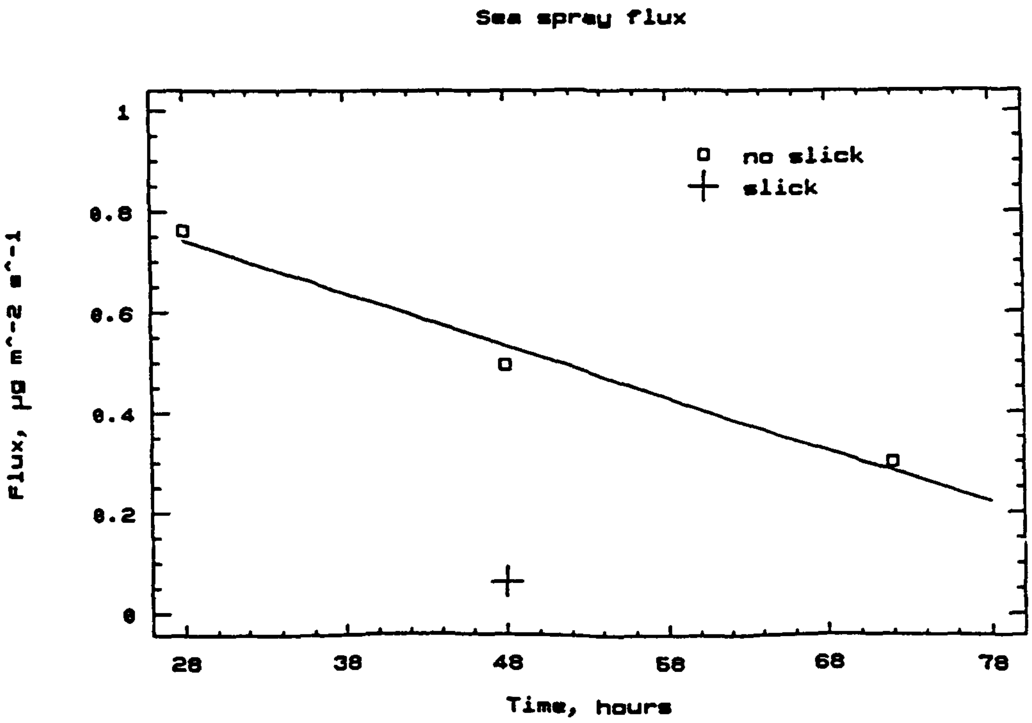


Figure 5. Sea spray flux recorded for different age of the water sample and presence of the oil surface slick.

CHAPTER 4

SIZE DISTRIBUTION OF BUBBLES BY SINGLE NEEDLE

BY

Q. WANG

CHAPTER 4

SIZE DISTRIBUTION OF BUBBLES BY SINGLE NEEDLE

by

Qin Wang

Marine Sciences Institute, University of Connecticut, Groton, CT 06340

An experiment for the measurement of size distribution of bubbles generated by a Mississippi-University single needle was conducted in WST III tank for both fresh water and brackish water form November 29 to December 1, 1991. The main purpose of this experiment is to gain a better understanding of bubble-spectrum dependency on overpressure and of salinity influence on size distribution of bubble.

The tank was filled with water to a depth of 60*cm*. Water temperature was measured to be roughly 19°C during the experiment. The single needle connected with an air pump was set about 25*cm* below the water surface and a UCONN bubble microscope was located at the water surface and just above the single needle. The microscope with an aperture of about 1 inch in diameter can be used to measure bubble with radius from 300μm to 5000μm. The overpressure is the pressure difference between the atmospheric pressure and the pressure inside the hose connected with the needle and was set at 0.5, 1.0, 5.0 and 10.0*psi* for both fresh water and brackish water with a salinity of 20%. A software program written in C language with an aid of mouse device was developed to analyze the bubble images.

Figure 1 shows the bubble spectra for fresh water at four different overpressures of 0.5, 1.0, 5. and 10.0*psi*. It is noted that the size distributions clearly show a peak at about 2542μm in bubble radius at low overpressure and that more smaller bubbles are produced as overpressure increases.

The size distributions for brackish water at salinity of 20% are shown in Figure 2. As expected, the distribution pattern for brackish water is tremendously different from that for fresh water. Many smaller bubbles with the radius less 300μm were produced and the bubble distribution appears a bi-model. A large peak is always present at bubble radius less than 300μm and the peak slightly shifts to the smaller bubble radius as overpressure increases. It is also noted that the second peak occurs at roughly 2200μm in bubble radius and the relative value of this peak decreases with overpressure.

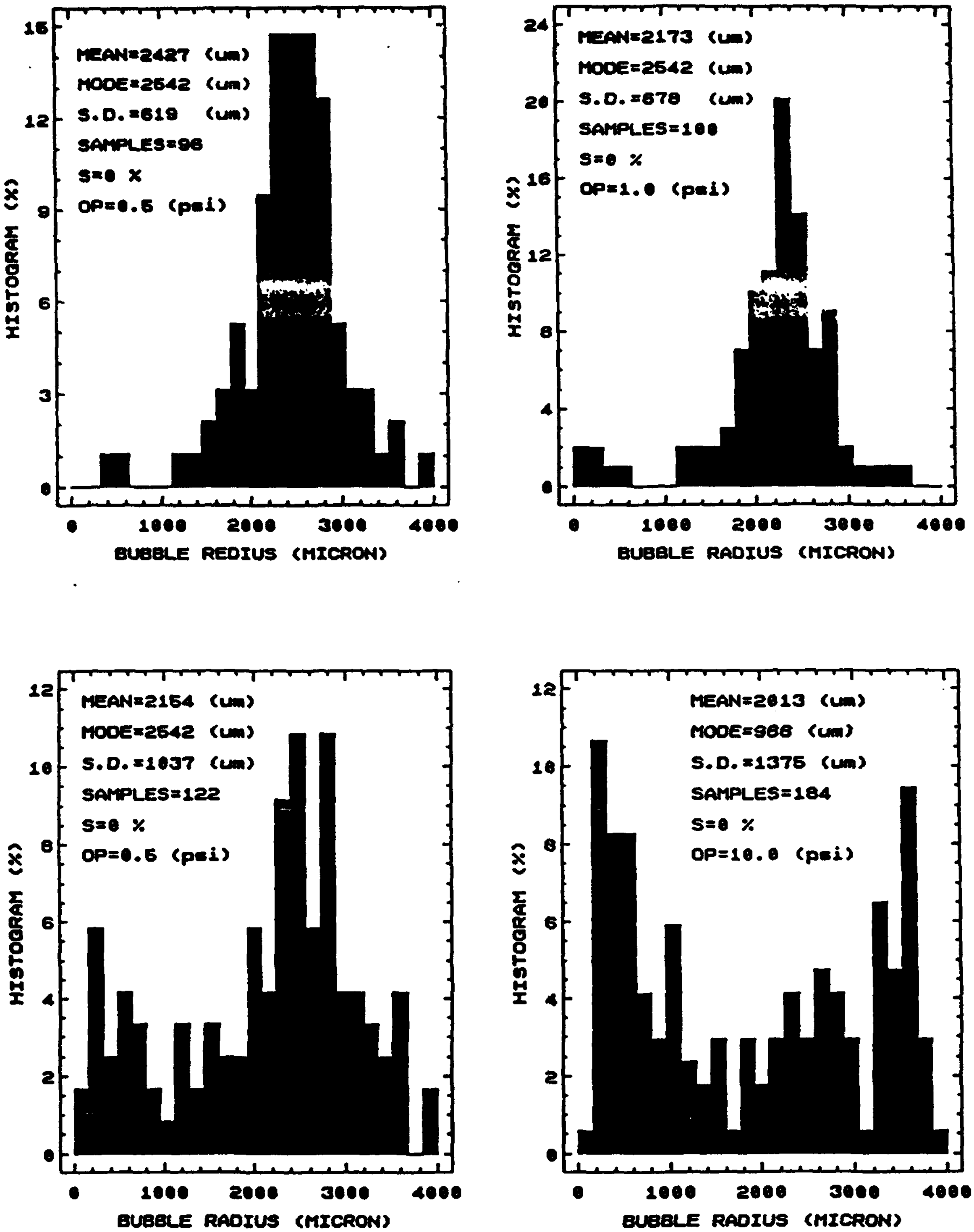


Figure 1. Bubble size distributions for fresh water, $S = 0°/oo$, $T_w = 19°C$.

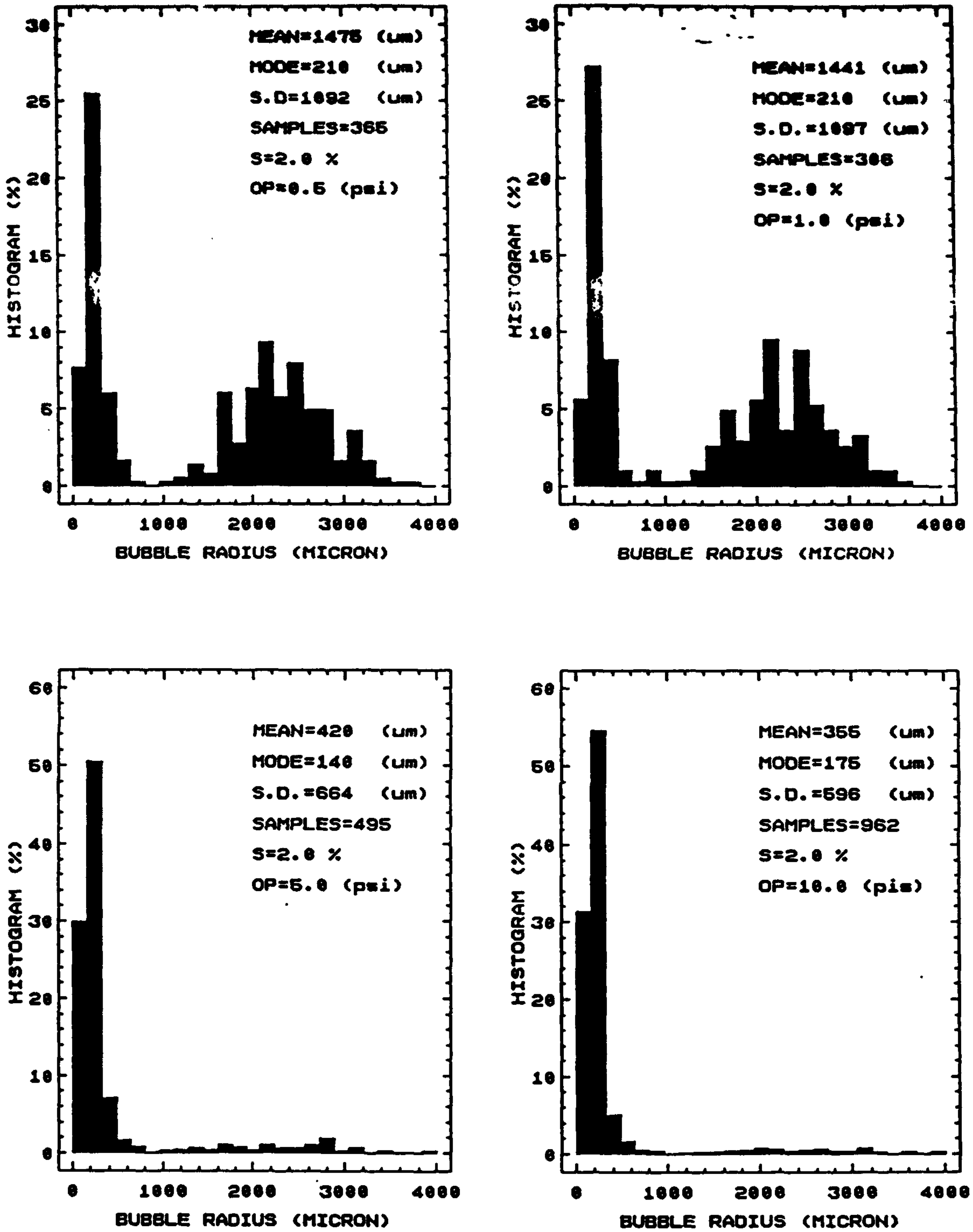


Figure 2. Bubble size distributions for brackish water, $S = 20°/oo$, $T_w = 19°C$.

CHAPTER 5

TRIP REPORT: SEATTLE, WA., TO SEA, AND RETURN; 28 OCT.-5 NOV.1991

BY

M.B. WILSON AND J.W. STEELE

CHAPTER 5

TRIP REPORT
SEATTLE, WASHINGTON, TO SEA, AND RETURN
28 OCTOBER TO 5 NOVEMBER 1991
M.B. WILSON AND J.W. STEELE

Arrived Seattle, Washington, approximately 1430, 22 October 1991. Raining.

Arranged accommodations and checked in with Port Captain's office. Was advised that the ship would not be available until Thursday, 24 October. Parking is at a premium. Paid University $10.00 for permit to end of month. Cloudy, overcast, intermittent rain.

Thursday, 24 October. Arrived at the Port Captain's office and made arrangements to on load equipment. Finished on load about 1600. Met with Dr. Harry DeFerrari and were assigned berthing on the ship. No meals were being served to the science party while the ship was in port. Cloudy, overcast, intermittent rain.

Friday, 25 October. Commenced assembly of equipment. Assembled the raft on the 01 level, port side aft, about Frame 75. Located electronics equipment in the Hydro Lab, port side, Frame 70, on the main deck. Positioned and taped down electronics equipment. Completed the assembly of the structural raft components. Weather improved. Cold, windy and cloudy, some rain.

Saturday, 26 October. Finished raft assembly, mounted all equipment, but did not wire up. Did not install the battery. Wired up the electronics and the computer in the Hydro Lab. Tested the computer, all seems well. Requested by Dr. DeFerrari to do video recordings of Whitecaps when instrumentation is in the water. As we did not have a camera system to dedicate to this task, I borrowed a hand held camera from the ship, and will procure 20 hours of video tape. The camera is an 8mm Sony "Handycam". Procured one 12 volt battery and battery charger for use at sea. Weather..same as yesterday.

Sunday, 27 October. Completed wiring up control box on raft. Completed running air hoses from control station in Hydro Lab to 01 deck. Will test system on Monday. Procured nine video tapes for recording Whitecaps.

Monday, 28 October. Time 0930, underway for fueling. Approximately 1800, underway for Operations Area. Started testing of systems. Computer checks out, no problems. Installed Wordstar 5.5. Both bubble cameras check-out, with the exception of the number 2 camera strobe compartment. Found water in the space where the strobe bulb is housed. Also found problems with the mast camera; need to pull and adjust the iris. Attended Science Conference. The intent of the cruise is to moor four large buoys in approximately 3200 to 3500 meters of water. Ship will transit to operation area and arrive Wednesday, about 0100. They will commence mapping of the proposed mooring area prior to 0800 on Wednesday. Tried to hook-up DAS-16 to Void Fraction Meter. Inadvertently shorted cable, and cable overheated. Repaired short, and checked system. No apparent damage. Will check further tomorrow. Weather cloudy, some light rain, no Whitecaps.

Tuesday, 29 October. Pulled Camera No. 2, to dry out and reseal strobe cavity. Found bulb wires broken at the solder joint. Resoldered and sealed up the bulb cavity. In working to seal the joint, broke the bulb. Reopened, replaced the bulb and tested. When closing the cavity again, broke the bulb. The replacement bulbs are slightly larger in tube diameter than the original bulbs. Made gasket to increase depth of the compartment. Installed new bulb, tested and resealed. When sealed in place, the bulb did not work. Will defer problem. Have extreme difficulty in making solder joints due to wind and weather. Pulled mast camera and adjusted iris setting to achieve excellent picture. Automatic iris will correct this problem. Verified all wiring connections and powered up whole unit. Checked all components. Found a "hang-up" with the position rod. It appears that some rust or dirt is in the pinion rack. Will pull and clean it tomorrow. With that, and the exception of the No. 2 camera strobe, all units check-out at the raft. We are in transit to Op Area and should arrive about 0100, 30 October. Weather is cold, damp, overcast and winds are calm. No Whitecaps.

Wednesday, 30 October. Set the mooring for the University of Miami Buoy. Pulled and cleaned out the rack for the pinion gear on the position indicator. Tried to run the void fraction meter using the computer program. Discovered that the dissolved oxygen probe reads about 20 counts low. It appears to be fairly consistent. The program "MARTSJT" does not save to disk. Cannot find the problem, will continue to work on it. Weather has turned mild, overcast, no wind, no Whitecaps.

Thursday, 31 October. Set the moorings for two WHOI buoys, a weather buoy and a wave rider. Continued to work on the program. Finally was able to save data to file. Do not know how I fixed it. It just seemed to start working. Exercised the unit. Filled the Void Fraction Meter with water, checked out the relief valve and the air systems. Modified the program as I had given Spencer the wrong parameters for "waiting". Discovered that the pressure sensor started giving erratic readings. Further tests showed a complete breakdown of the sensor. It gives full scale output with zero gage pressure. This causes the A/D board to record 4095 counts, no matter what the input pressure is. I do not have spare sensor on board. Tried to jar the sensor loose using both a 100 psig pressure and a 20 inch vacuum, to no avail. The Void Fraction Meter is 00C. Videotaped the launching of the WHOI Wave Rider Buoy at the request of George Tupper of WHOI. Told him I would be glad to reproduce it and send a copy to him at WHOI, Woods Hole, Mass., 02543. For info: OMNET: G. TUPPER; Phone (508) 457-2000 ext. 2693. The weather remains mild and overcast. Whitecap activity is almost nil.

Friday, 1 November. System is O.K. except as noted. We will not put the raft in the water today, as there is still one more WHOI moor to be made. Will take video recordings as the weather dictates. Current conditions are overcast and mild; some swells are building.

Saturday, 2 November. Winds 25 - 30 knots. Will put in the raft tethered systems (three), including the MSI unit, after removing a flotation collar from the WHOI buoy moored last evening. Will try Camera No. 2 without the strobe. Will replace the strobe, if necessary after the first launch. Battery voltage 12.33 volts. Put reference marks on both Camera No.'s 1 and 2 video tapes. Tested water pump, test O.K. Camera No. 3 looks good. We will rig pick-up lines and then be ready to go. Relocated float to main deck. Will stream Dr. Ming Su's array over the stern and the raft over the port side.

The launching of the raft will be held up until about 1400, as the Captain determined that only one unit will be in the water at a time. Changed launch time to 1215. In the water at 1230. Set all cameras to record. The intake of the upper Camera, No. 2, is approximately 4 inches below the water. The lower Camera, No. 1, is 19 inches below the water. The center of the Void Fraction Meter is 10 inches below the water. The height of the mast Camera is 85 inches above the water. The picture shows both the port and starboard floats.

The Void Fraction Meter is 00C. The raft is riding well, but the rope on the drogue is not long enough, and the drogue is not large enough. J.S. took some video of the raft as it bobs about. There are problems with the No. 2 Camera. It appears that there is electrical discharge interference.

Changed tapes on the Sony recorder. The raft is ranging from the bow to the stern of the ship. Talked to the Mate to see if he could hold it off the after quarter. Several times the raft ranged up under the bow. Changed the Sony tape, put in tape No. 3. Sony recorder failed.

Indication is slack tape. Could not open the housing to correct. Swapped video inputs, put the signal for the mast camera into the AG-1960, in place of the No. 2 Camera input. Replaced Sony recorder with the spare. Raft has ranged up under the bow again. Tried to pick up No. 2 Camera signal on Sony. Could not get it. Lost signal on mast camera. Report of raft banging around, up and under the bow. Determined to retrieve the raft. Hauled raft to stern and put lines on. While attempting to put hook on, the raft turned over. Righted the raft and set it on deck.

Damage: Parted video signal cables for Camera No. 2 and for the mast camera. Pulled Void Fraction position cable from water-tight box stuffing tube, allowing watertight compartment to flood while raft was inverted. Damage from flooding included complete wetting of the dissolved oxygen meter and of the electronics package. Removed and washed both components in fresh water and set them to dry. Determined that repair of system was not possible at sea.

Sunday, 3 November. Weather is overcast, intermittent rain. Continued with video registration of sea surface. Departed station about 1800.

Monday, 4 November. Weather, fog and rain. Commenced breaking down equipment.

Some observations: The Void Fraction Meter position indicator needs to be rebuilt with a means of access to the internals. We could not disassemble the unit for cleaning. It appears Dave Good assembled the unit and then built the case around it. We had sufficient access to clean the problem area on the rack, but this was only luck.

The 3/8 inch hoses are too long. The action of the air piston on the V/F meter is much too slow. Need either larger diameter hoses, or to mount a local air supply on the raft. Larger hoses would make the tether even more cumbersome.

Since we know that the V/F works, we should build another out of PVC or stainless steel or some other stronger, less brittle materials. Each time we work around the unit, I worry that we will damage it.

Need to modify the access housing for the strobe bulbs. Recommend that the end cap be modified to have clips to hold the bulbs in place, relative to the camera field and that we incorporate an "O" ring seal both around the housing and for the cable entrance.

Recommend that we do away with some of the high weight on the raft. Use a smaller, lighter mast pole, use guy wires instead of pipe for the bracing and lower the mast. The surface looking camera, with a wide angle lens, covers the area between the forward floats and is still lower than the mast platform.

Do not plan to install any instrumentation on the mast pole. Instead mount all above surface instruments on the forward pipes. Any additional weight can be compensated by the addition of ballast aft.

Make three new floats, incorporating a battery in two of them and a compressed air tank in the third. This will allow the use of the Void Fraction Meter with short, stainless steel lines.

Structurally, make the raft body stronger and lighter. Use tubing and trusses to stiffen and lighten.

Use either a two step float or a greater rake to the floats to make them more responsive to wave action.

WHITECAP LOG
28 October - 5 November 1991
On Board R/V THOMAS G. THOMPSON (AGOR - 23)
Martin B. Wilson

WHITECAP LOG: At the request of Dr. Harry DeFerrari, procured ten (10) eight millimeter tapes to be used in taking whitecap readings for analysis at MSI, UCONN.

A Sony "Handycam" was used to make the recordings. The camera will be hand held and five minute recordings will be taken if the whitecap activity is small. If the activity warrants, ten minute recordings will be taken.

Monday, 28 October. Underway to Fuel Pier. 1800. Underway for sea.

Tuesday, 29 October. Transit to Operations Area. No whitecap activity.

Wednesday, 30 October. Set mooring for University of Miami Buoy. No appreciable whitecaps. Video cassette No. 1 -- Record of launching of the University of Miami Buoy.

Thursday, 31 October. Set mooring for WHOI Weather Buoy. No appreciable whitecaps.

All video tape recordings are taken within a ten mile radius of Lat. 49 deg. 10 min. N.; Long. 131 Deg. 53 min. W. Recordings are taken from the bridge level with the height of eye at 46'6" above the surface of the ocean. The height of the anemometer above the surface of the ocean is 79 feet. Wind velocity is measured in knots.

Video Cassette No. 2 -- Time 1505. Recorded five minutes of video to document "No Whitecaps" (Tape time 00:00 to 05:03). Wind speed/dir. 10/270; Bar. 1025.5mm, Wet/dry bulb 56/55.4F; water temp. 14.3C.

Time 18:30. Recorded approximately 20 minutes of data on launch of WHOI Wave Rider Buoy at the request of George Tupper.

Friday, 1 November. Weather overcast, light rain.

Video Cassette No. 2 -- Time 1300. Recorded approximately 16 minutes of whitecap data (00:26:05 - 00:39:00). Wind speed/dir. 13/165; Bar 1019.8mm; Wet/dry bulb 56.8/57F; water temp. 14.3C.

Video Cassette No. 2 -- Time 1600. Recorded eleven minutes of whitecap data (00:39:00 - 00:50:00). Wind speed/dir. 16/160; Bar 1019.0mm; Wet/dry bulb 56.8/.57F; water temp. 14.3C.

Video Cassette No. 2 -- Time 1700. Recorded 10 minutes of whitecap data (00:50:00 - 01:00:00). Wind speed/dir. 20/160; Bar 1019.3mm; Wet/dry bulb 56.8/57F; water temp. 14.3C.

Saturday, 2 November. Weather overcast, light intermittent rain.

Video Cassette No. 2 -- Time 0755. Recorded five minutes of video registration, whitecaps (01:00:00 - 01:05:00). Wind speed/dir. 28/185; Bar 1015.2mm; Wet/dry bulb 57.6/58F; water temp. 14.5C. Cut short as raft was to go in water.

Video Cassette No. 2 -- Time 1035. Recorded four minutes and thirty six seconds of video registration, whitecaps (01:05:00 - 01:09:36). Wind speed/dir. 20/186; Bar 1016.3mm; Wet/dry bulb 58/58F; water temp. 14.5C. Cut short as battery failed. Changed battery.

Video Cassette No. 2 -- Time 1130. Recorded ten minutes of video registration, whitecaps (01:09:36 - 01:20:00). Wind speed/dir. 22/170; Bar 1016.8mm; Wet/dry bulb 58/58.5F; water temp. 14.5C.

Video Cassette No. 2 -- Time about 1245. Requested Joe Steele videotape the operations of the Bubble Raft. Tape segment (01:20:00 - 01:26:15).

Video Cassette No. 2 -- Time 1557. Recorded ten minutes of video registration, whitecaps (01:26:15 - 01:36:30). Wind speed/dir. 22/175; Bar 1015.8mm; Wet/dry bulb 58/59F; water temp. 14.1C.

Video Cassette No. 2 -- Time about 1706. Recorded 10 minutes of video registration, whitecaps (01:36:30 - 01:46:30). Wind speed/dir. 23/170; Bar. 1013.8mm; Wet/dry bulb 58/59F; Water temp. 14.1C.

Sunday, 3 November. Weather overcast, light intermittent rain.

Video Cassette No. 2 -- Time 0856. Recorded eight minutes of whitecap data (01:46:30 - 01:54:30). Wind speed/dir. 24/180; Bar 1008.8mm; Wet/dry bulb 58.8/59.5F; Water temp. 14.5C. Limited to eight minutes due to battery life. Changed battery, also changed video tape to tape No. 3.

Video Cassette No. 3 -- Time about 1008. Recorded ten minutes of whitecap data. (00:00:00 - 00:10:00). Wind speed/dir. 24/180; Bar. 1008.5mm; Wet/dry bulb 58.6/59F; Water temp. 14.5C.

Video Cassette No. 3 -- Time 1120. Recorded six minutes of video registration, whitecaps (00:10:00 - 00:16:45). Wind speed/dir. 25/180; Bar 1008.1mm; Wet/dry bulb 58.8/59F; water temp. 14.4C.

Video Cassette No. 3 -- Time about 1235. Recorded ten minutes of whitecap data (00:16:45 - 00:27:00). Wind speed/dir. 25/180; Bar. 1006.8mm; Wet/dry bulb 58.6/59F; Water temp. 14.2C.

Video Cassette No. 3 -- Time 1357. Recorded ten minutes of whitecap data (00:27:00 - 00:37:30). Wind speed/dir. 24/185; Bar 1007.5mm; Wet/dry bulb 59/59F; Water temp. 14.3C.

Video Cassette No. 3 -- Time about 1530. Recorded ten minutes of whitecap data (00:37:30 - 00:47:36). Wind speed/dir. 20/239; Bar. 1008.0mm; Wet/dry bulb 59/59F; Water temp. 14.2C.

Secured recording, low visibility.

Monday, 4 November. Weather overcast and mild. Enroute Point Juliet, and Juan de Fuca Straits.

CHAPTER 6

REPORT: WHITECAP ANALYSIS OF VIDEO REGISTRATION, PACIFIC COAST CRUISE, OCT/NOV 1991

BY

M.B. WILSON

CHAPTER 6

Report
Whitecap Analysis of Video Registration
Pacific Coast Cruise
October/November, 1991

This report consists of one (1), five and one quarter double side, high density data disk labeled "MIAMIDATA1". Appended is a copy of the directory of that data disk.

Appended also are graphic presentations of the whitecap one second averages for each of the analysis intervals. The information to construct these graphs is contained in a data file labeled "ttxyy". The header information contained in these printouts is in the corresponding "z" file. The file system is described below.

There are fifteen data sets, consisting of the reduction of video information recorded between 31 October and 3 November 1991. The information was recorded during the University of Miami cruise on board the R/V THOMAS G. THOMPSON, out of Seattle Washington. The video record was made using a Sony "Handycam", and 8 millimeter Maxell EX-M 120 video tape, in the NTSC video format. The recordings were generally of ten minutes duration.

Upon return to the Marine Sciences Institute at the University of Connecticut, the 8 millimeter tapes were transcribed to half inch VHS format tape for analysis.

The analysis utilized a Panasonic AG-1960 VHS recorder to reproduce the video registration, a Hamamatsu C-1143 area analyzer, and a locally developed interface to an IBM compatible 386 computer. Each segment was reviewed for suitability for analysis, insuring that the area of interest was free from extraneous registrations, such as sunlight reflecting on the waters, etc. The video signal was then sent through the Hamamatsu, where a threshold value was determined such that the individual pixels in the video image representing Stage "A" whitecaps were identified. The number of these pixels, for each of thirty video frames per second, divided by the total number of pixels within the bounded "area of interest", provides the whitecap fraction for that video frame. This information is sent to the computer via the local interface, where the on-second average is determined and saved to disk. At the end of the analysis interval, the overall whitecap fraction, and the additional statistical values are computed and saved to file.

Each of the data files is labeled "tt201", "tt202"...where "tt" stands for "THOMAS G. THOMPSON", the platform recorded from. The first digit of the numerical sequence following is the consecutive number of the tape cassette used on that cruise. The last two digits in the sequence represent the data interval analyzed.

The header of each data interval printout is a shell which is used to record common data such as the title, tape/event number, the meteorological data, and any comments thought necessary by the analyst. The shell file is identified by the tape/event number plus the letter "z".

The graph is the plot of the one second averages derived during analysis, plotted as the log (W + .0001).

The remainder of the information presented is statistically derived data.

A copy of the locally generated Turbo Pascal program is provided. A copy of this report is also included.

Volume in drive A is MIAMIDATA1
Volume Serial Number is 3A37-11ED
Directory of A:/

WHITE CAP	5888	12-10-91	11:39a
WC_ANALY	3712	12-10-91	11:16a
TT201	3920	12-06-91	11:12a
TT201z	446	12-06-91	11:12a
TT202	8400	12-06-91	11:34a
TT202z	446	12-06-91	11:35a
TT203	8120	12-06-91	11:49a
TT203z	446	12-06-91	11:49a
AGOR PAS	9578	12-04-91	12:32p
TT204	7700	12-04-91	1:02p
TT204z	446	12-04-91	1:03p
TT205	3500	12-06-91	12:10p
TT205z	446	12-06-91	12:12p
TT206	2800	12-06-91	12:16p
TT206z	446	12-06-91	12:16p
TT207	8400	12-06-91	12:29p
TT207z	446	12-06-91	12:28p
TT304	8400	12-06-91	1:58p
TT304z	446	12-06-91	1:58p
TT208	7700	12-06-91	12:42p
TT208z	446	12-06-91	12:42p
TT209	7700	12-06-91	12:54p
TT209z	446	12-06-91	12:54p
TT210	6300	12-06-91	1:05p
TT210z	446	12-06-91	1:06p
TT301	7700	12-06-91	1:23p
TT301z	446	12-06-91	1:23p
TT302	4900	12-06-91	1:32p
TT302z	446	12-06-91	1:33p
TT303	8400	12-06-91	1:45p
TT303z	446	12-06-91	1:45p
TT305	8400	12-06-91	2:11p
TT305z	446	12-06-91	2:11p
AGORPLOT PAS	9239	02-21-91	11:38a
34 File(s)		205824 bytes free	

ANALYSIS OF THOMPSON(AGOR-23) CRUISE DATA

TAPE/EVENT NUMBER :tt201   DATE : 10/31/1991   STARTING TIME : 1505:

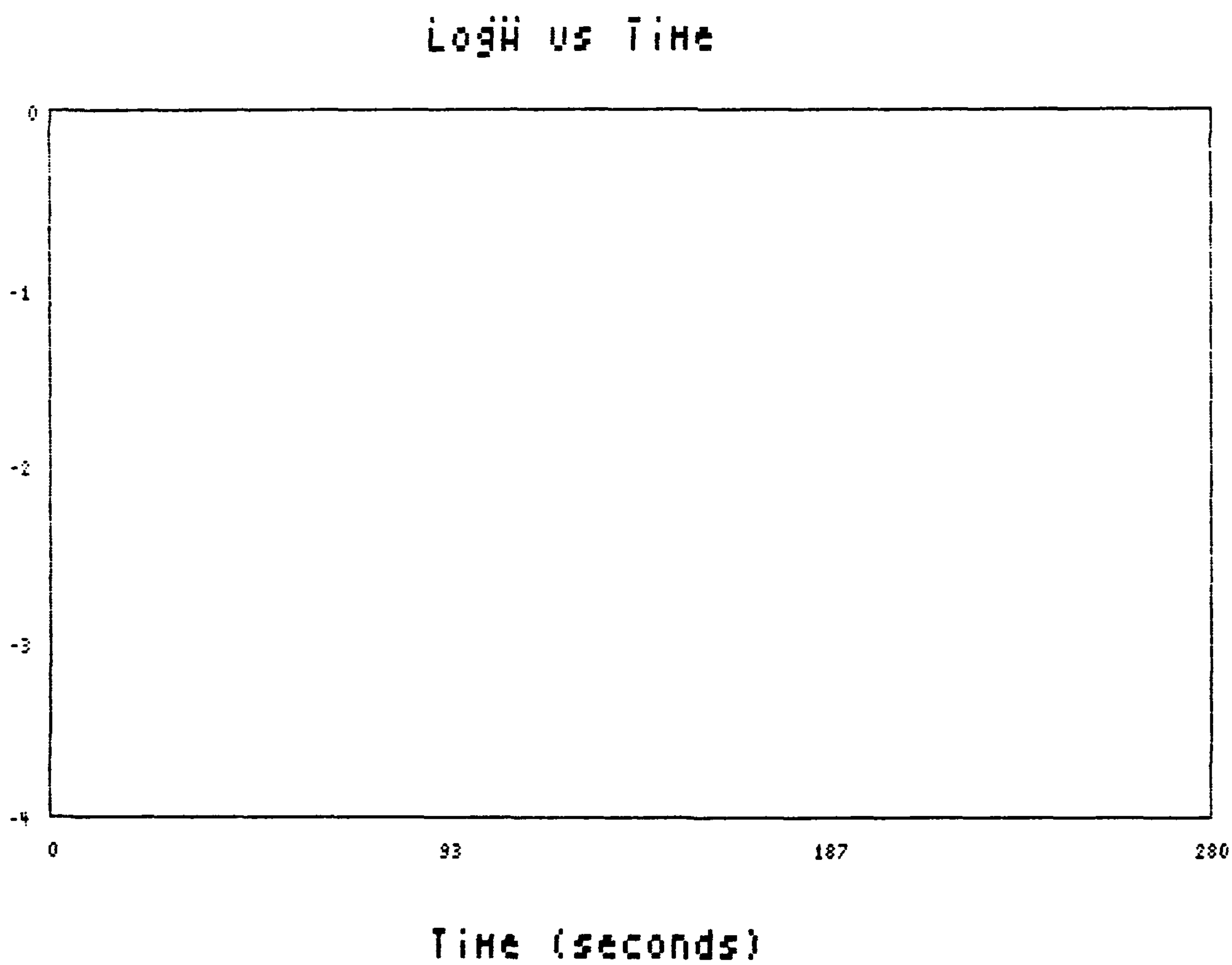
WHITECAP AVERAGE :	0.0000000	VARIANCE :	0.0000000
SKEWNESS :	0.0000000	KURTOSIS :	0.0000000

THRESHOLD VALUE : 4.30

METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
5.0	270	13.3	14.3	UNSTABLE

COMMENTS :



ANALYSIS OF THOMPSON(AGOR-23) CRUISE DATA

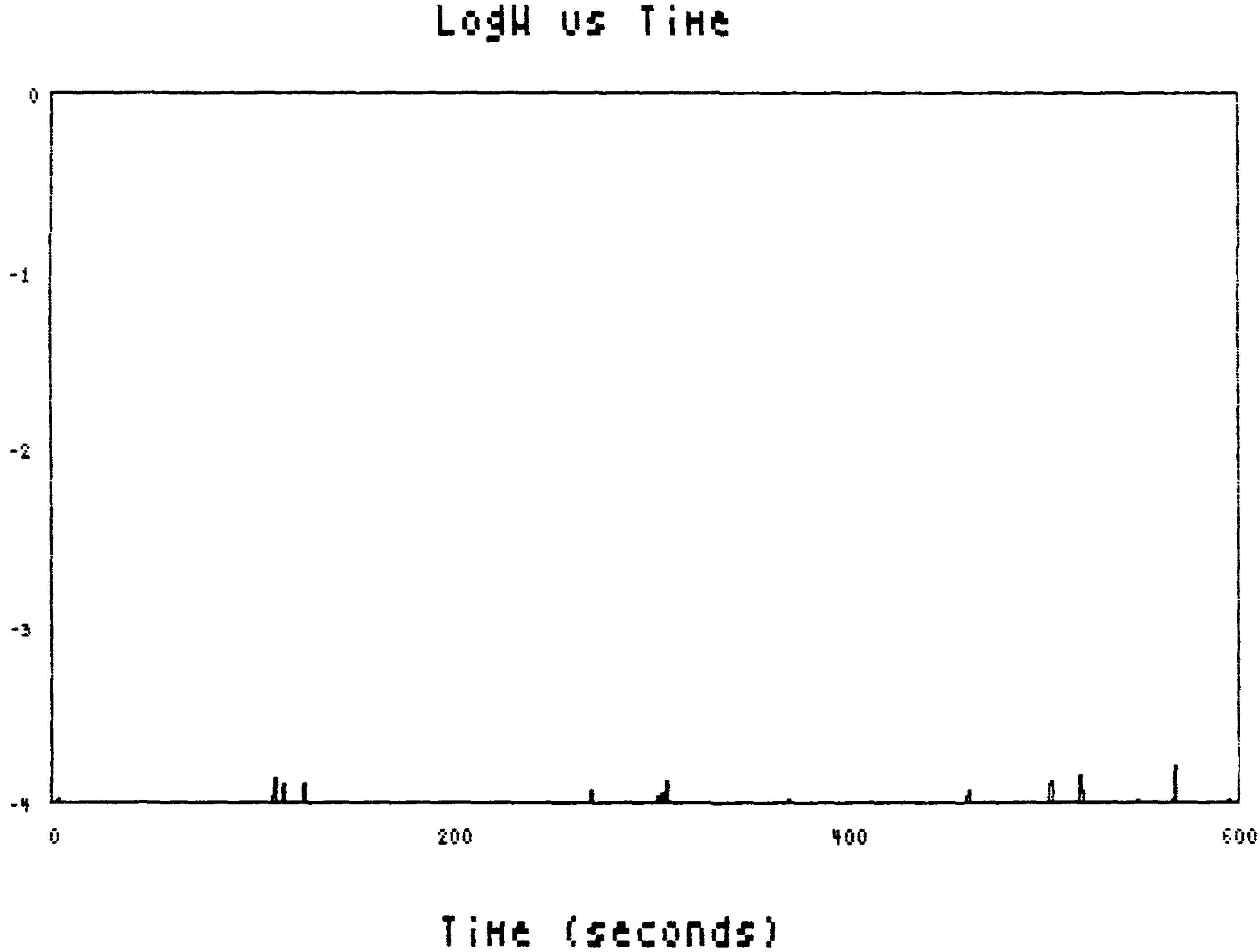
TAPE/EVENT NUMBER :TT202   DATE : 11/01/1991   STARTING TIME : 1300:

WHITECAP AVERAGE : 0.0000006   VARIANCE : 0.0000000
SKEWNESS : 8.9878633   KURTOSIS : 92.4207315

THRESHOLD VALUE : 4.25
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
6.5	165	13.9	14.3	UNSTABLE

COMMENTS :



ANALYSIS OF THOMPSON(AGOR-23) CRUISE DATA

TAPE/EVENT NUMBER :TT203 DATE : 11/01/1991 STARTING TIME : 1551:

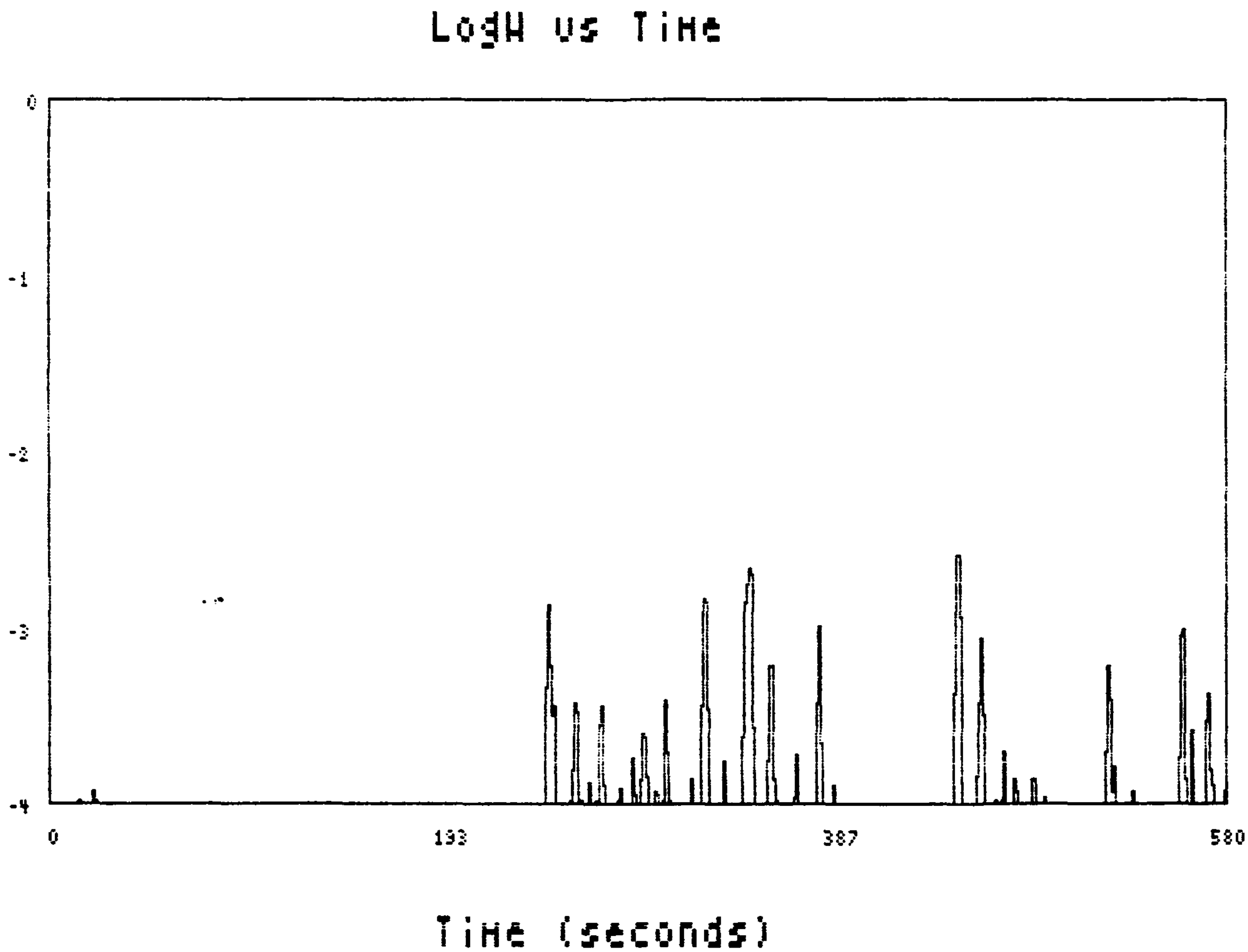
WHITECAP AVERAGE :	0.0000492	VARIANCE :	0.0000001
SKEWNESS :	6.8825584	KURTOSIS :	52.5304284

THRESHOLD VALUE : 4.00

METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
8.0	160	13.9	14.3	UNSTABLE

COMMENTS :



ANALYSIS OF THOMPSON(AGOR-23) CRUISE DATA

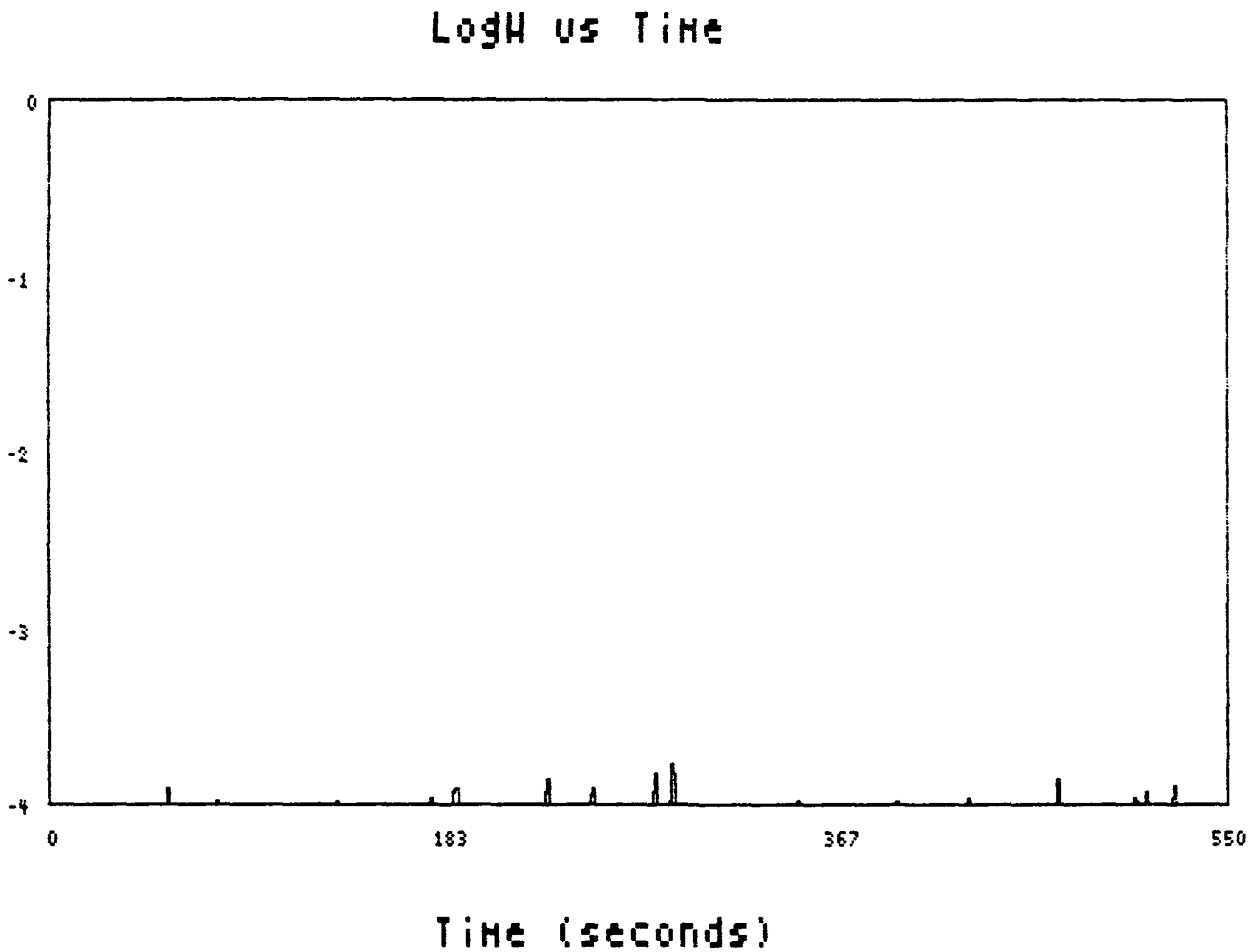
TAPE/EVENT NUMBER :TT204   DATE : 11/01/1991   STARTING TIME : 1700:

WHITECAP AVERAGE : 0.0000007   VARIANCE : 0.0000000
SKEWNESS : 8.8170928   KURTOSIS : 86.9225665

THRESHOLD VALUE : 4.45
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
10.0	160	13.9	14.3	UNSTABLE

COMMENTS :



ANALYSIS OF THOMPSON(AGOR-23) CRUISE DATA

TAPE/EVENT NUMBER :TT205 DATE : 11/01/1991 STARTING TIME : 0856:

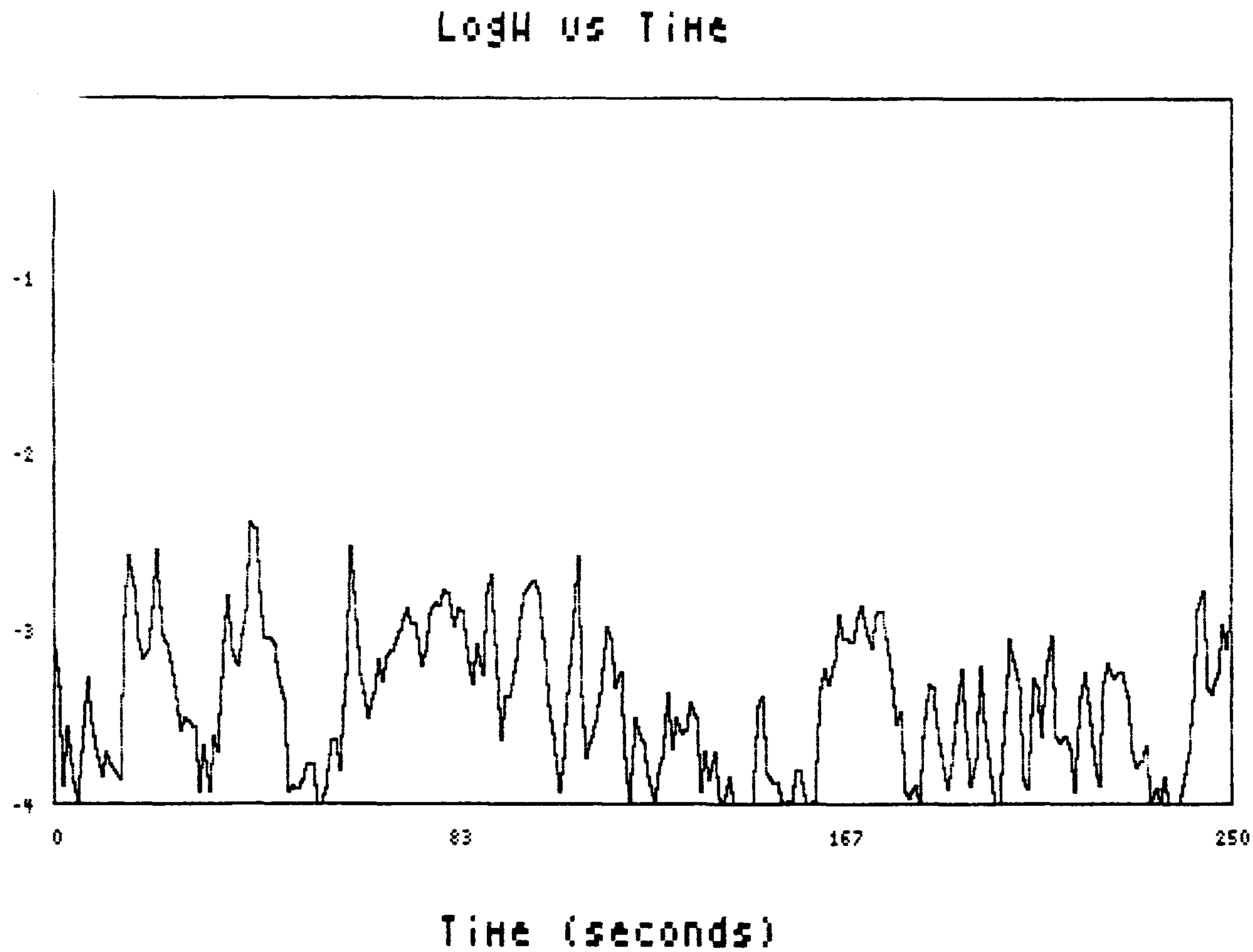
WHITECAP AVERAGE :	0.0004568	VARIANCE :	0.0000003
SKEWNESS :	2.4482069	KURTOSIS :	8.2221955

THRESHOLD VALUE : 4.40

METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
14.0	185	14.4	14.5	UNSTABLE

COMMENTS :



ANALYSIS OF THOMPSON(AGOR-23) CRUISE DATA

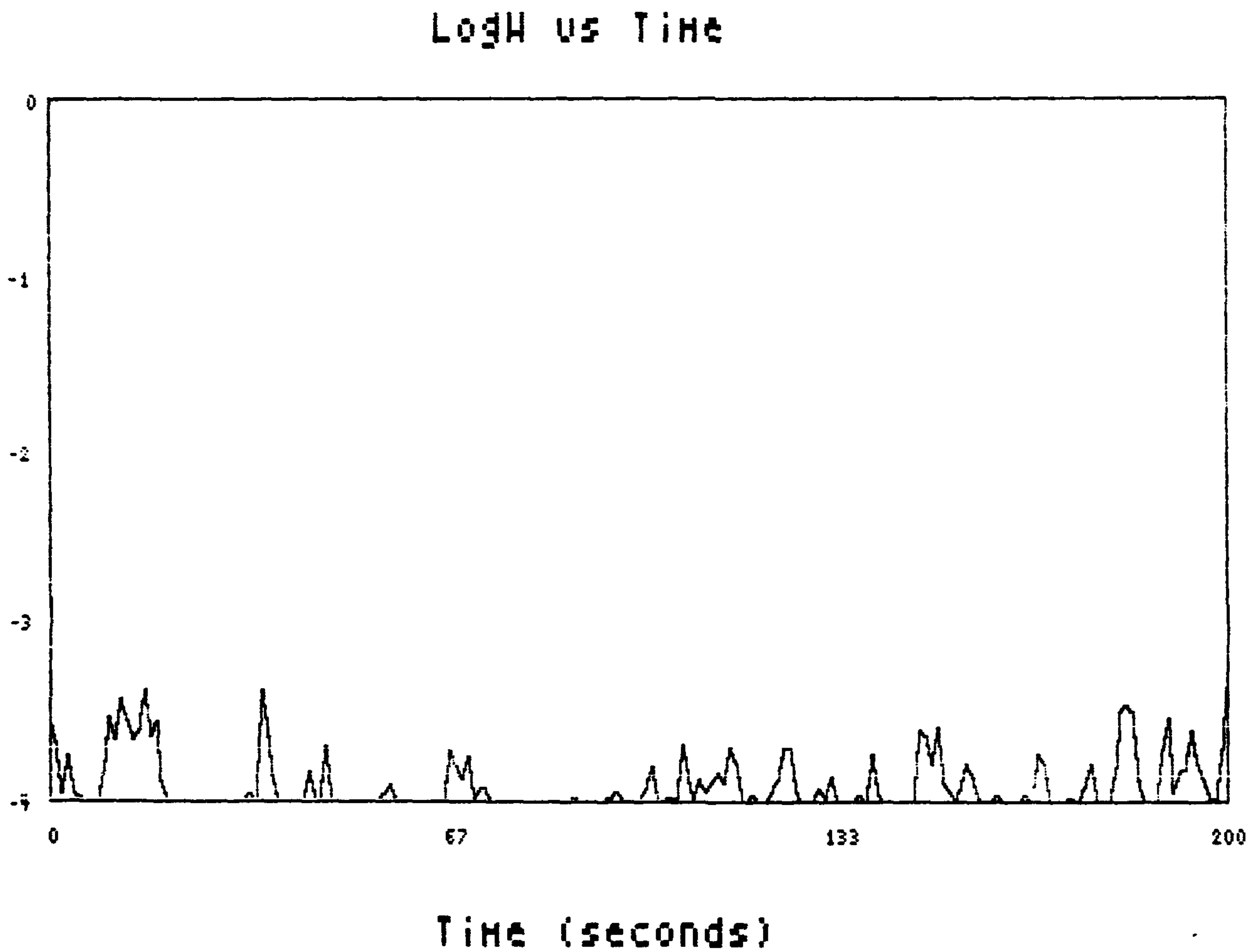
TAPE/EVENT NUMBER :TT206   DATE : 11/01/1991   STARTING TIME : 1036:

WHITECAP AVERAGE : 0.0000331   VARIANCE : 0.0000000
SKEWNESS : 3.3989046   KURTOSIS : 15.8665992

THRESHOLD VALUE : 4.40
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
10.0	186	14.4	14.5	UNSTABLE

COMMENTS :



ANALYSIS OF THOMPSON(AGOR-23) CRUISE DATA

TAPE/EVENT NUMBER :TT207 DATE : 11/01/1991 STARTING TIME : 1129:

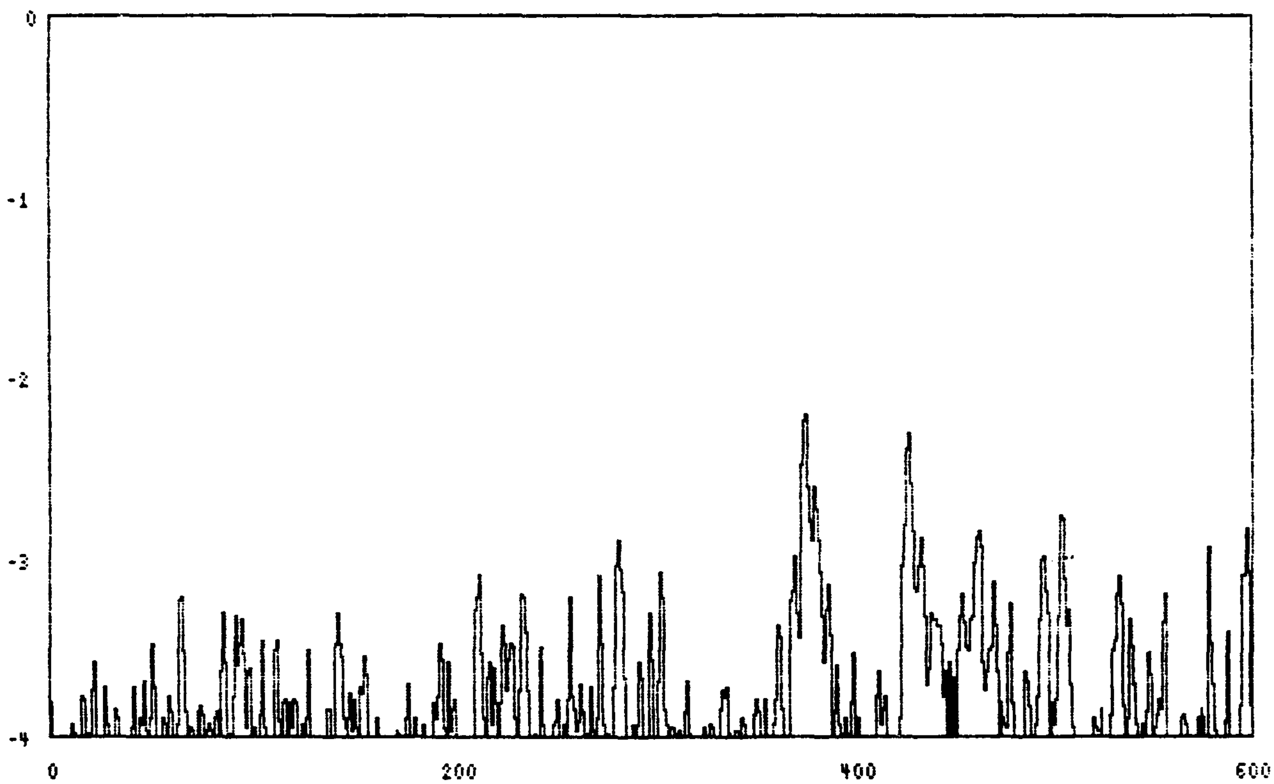
WHITECAP AVERAGE : 0.0001743 VARIANCE : 0.0000003
SKEWNESS : 6.9742151 KURTOSIS : 61.6049044

THRESHOLD VALUE : 4.40
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
11.0	170	14.7	14.5	UNSTABLE

COMMENTS :

LogW vs Time



Time (seconds)

ANALYSIS OF THOMPSON(AGOR-23) CRUISE DATA

TAPE/EVENT NUMBER :TT208 DATE : 11/01/1991 STARTING TIME : 1557:

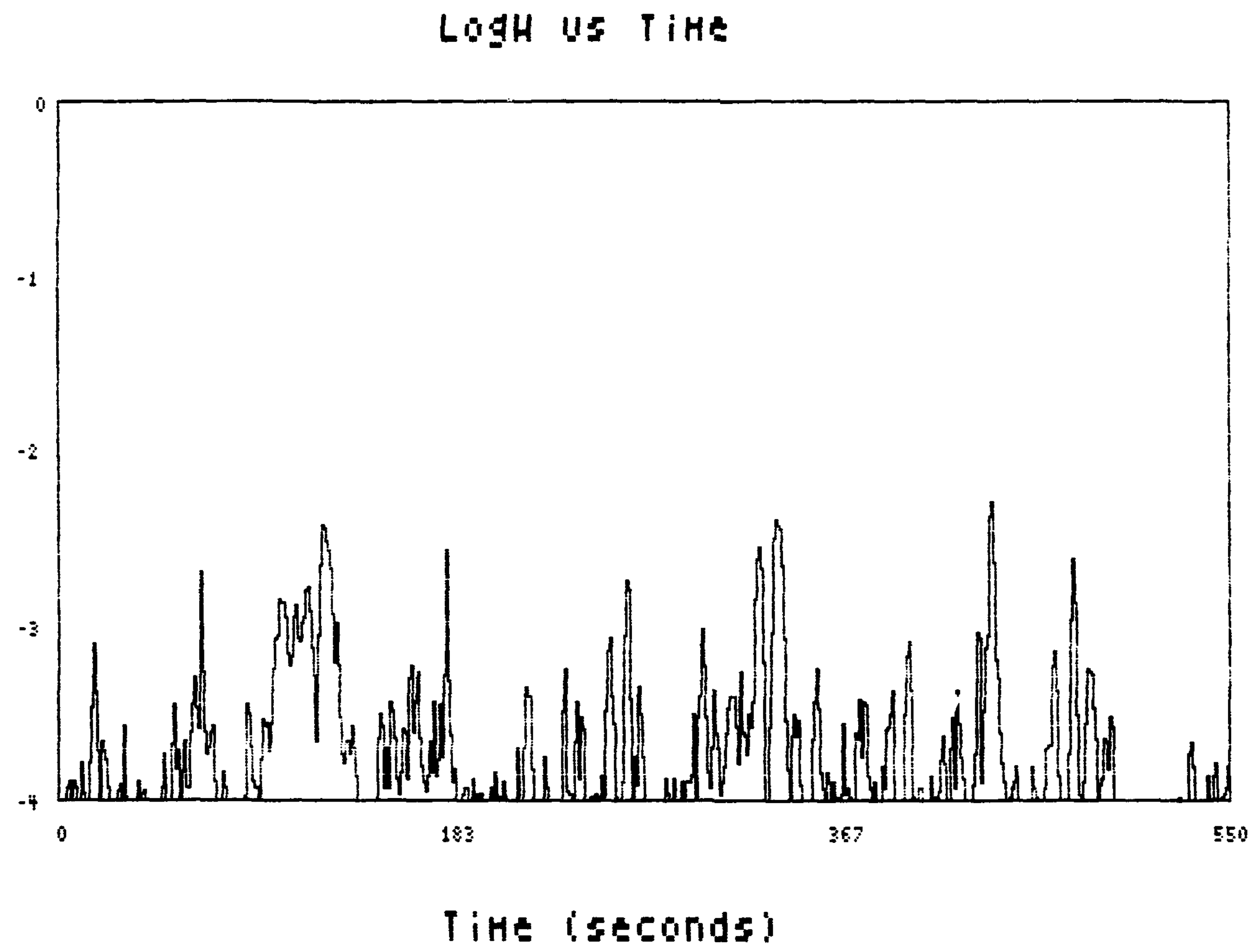
WHITECAP AVERAGE :	0.0002188	VARIANCE :	0.0000003
SKEWNESS :	4.5203389	KURTOSIS :	24.0654440

THRESHOLD VALUE : 4.40

METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
11.0	175	15.0	14.1	UNSTABLE

COMMENTS :



ANALYSIS OF THOMPSON(AGOR-23) CRUISE DATA

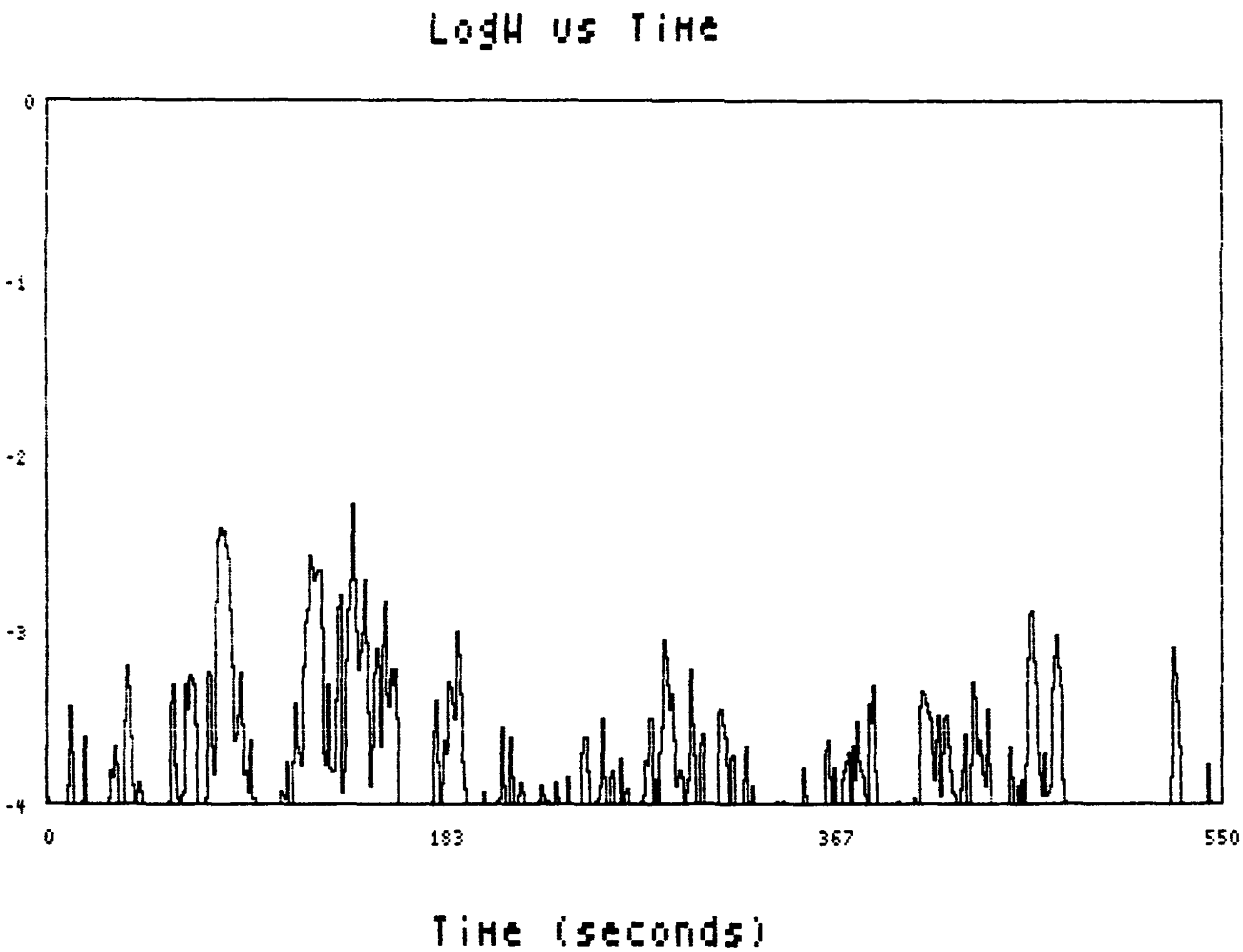
TAPE/EVENT NUMBER :TT209   DATE : 11/01/1991   STARTING TIME : 1707:

WHITECAP AVERAGE : 0.0001651   VARIANCE : 0.0000002
SKEWNESS : 5.5105612   KURTOSIS : 37.7174884

THRESHOLD VALUE : 4.40
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
11.5	170	15.0	14.1	UNSTABLE

COMMENTS :



ANALYSIS OF THOMPSON(AGOR-23) CRUISE DATA

TAPE/EVENT NUMBER :TT210   DATE : 11/03/1991   STARTING TIME : 0858:

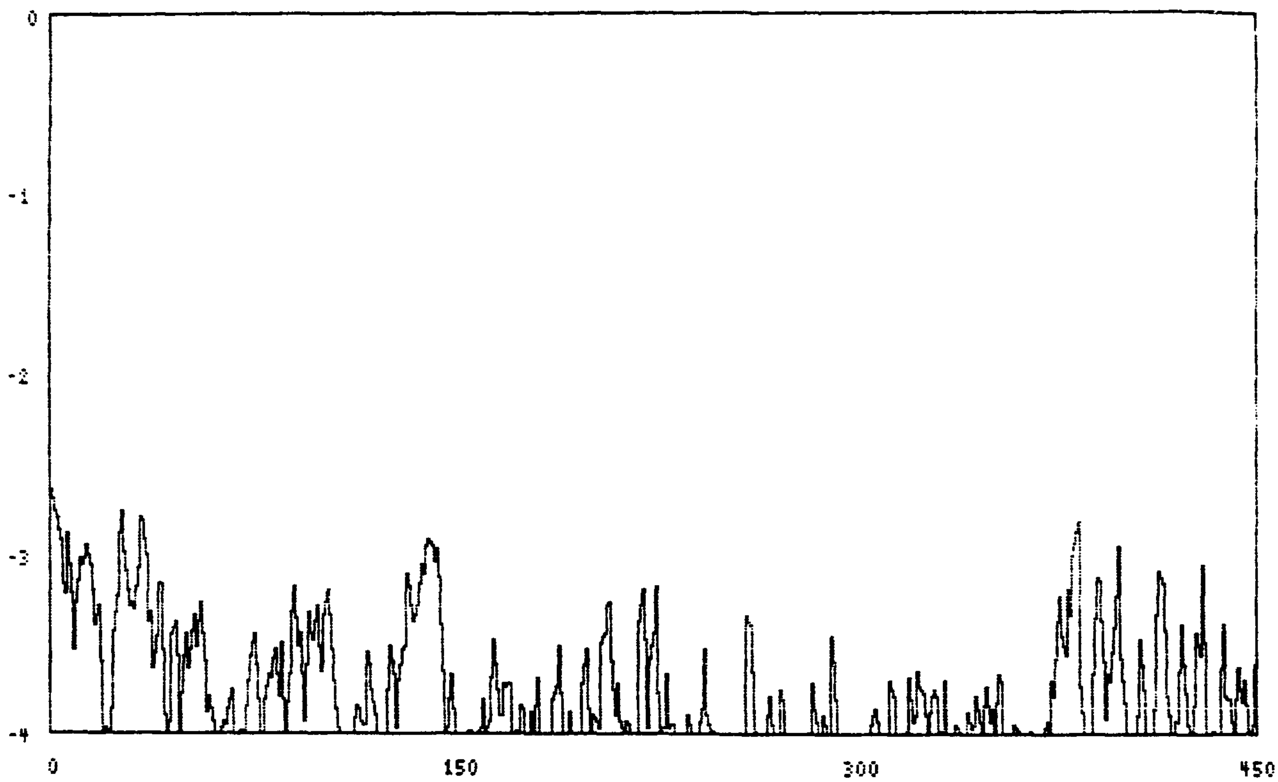
WHITECAP AVERAGE : 0.0001645   VARIANCE : 0.0000001
SKEWNESS : 2.9802295   KURTOSIS : 10.5839186

THRESHOLD VALUE : 4.40
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
12.0	180	15.0	14.5	UNSTABLE

COMMENTS :

LogW vs Time



Time (seconds)

ANALYSIS OF THOMPSON(AGOR-23) CRUISE DATA

TAPE/EVENT NUMBER :TT301   DATE : 11/03/1991   STARTING TIME : 1006:

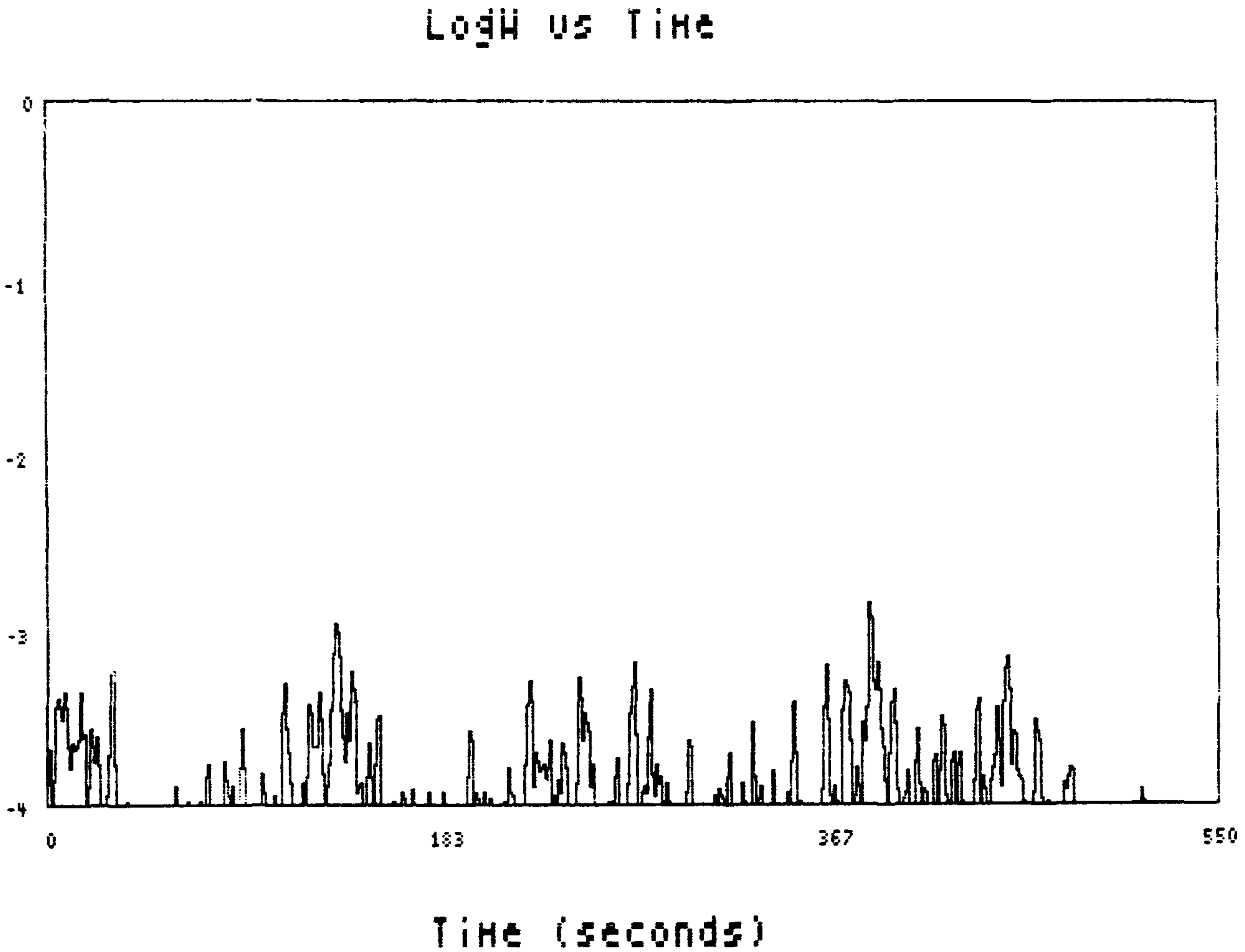
WHITECAP AVERAGE :	0.0000616	VARIANCE :	0.0000000
SKEWNESS :	4.1889444	KURTOSIS :	24.6928547

THRESHOLD VALUE : 4.40

METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
12.0	180	15.0	14.5	UNSTABLE

COMMENTS :



ANALYSIS OF THOMPSON(AGOR-23) CRUISE DATA

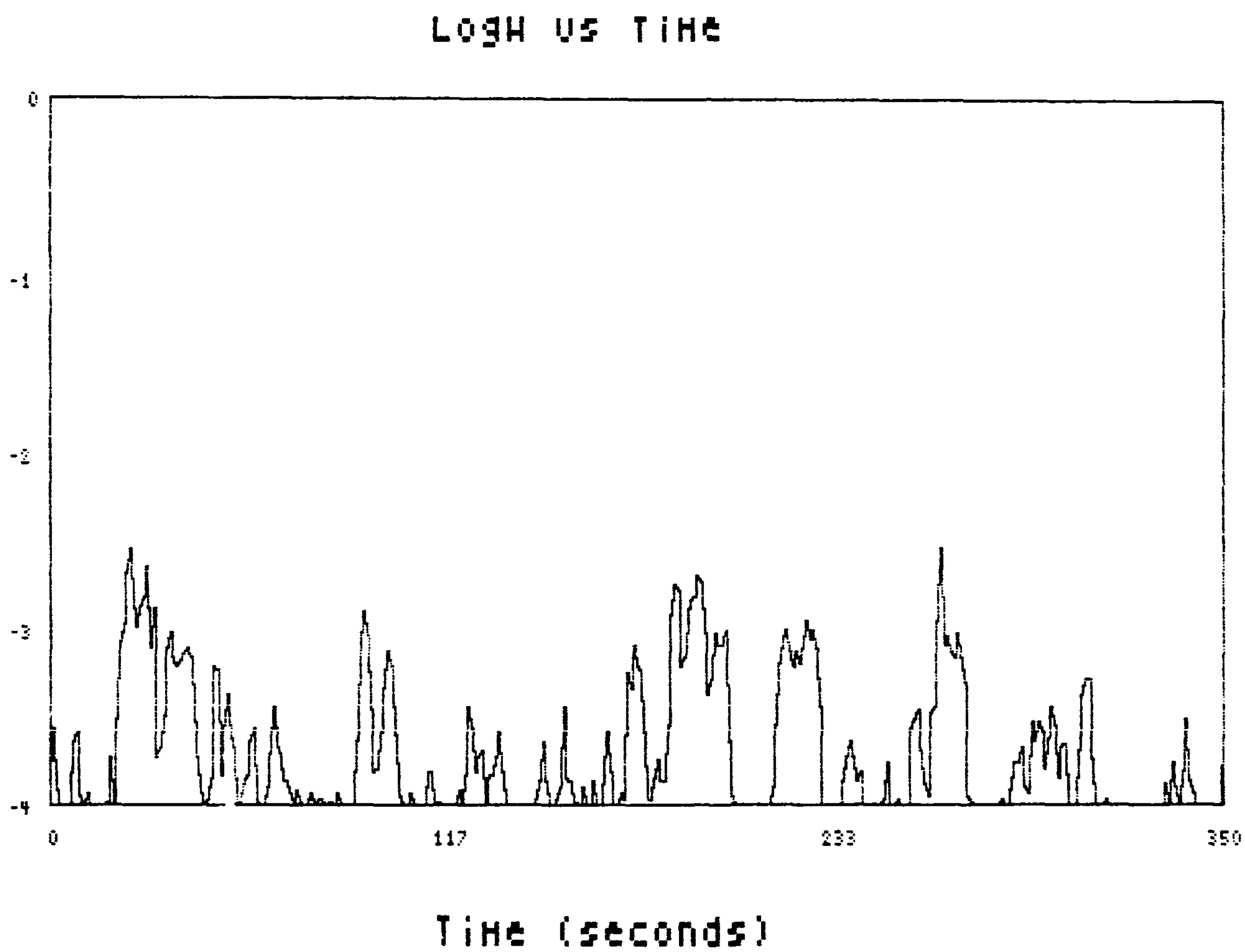
TAPE/EVENT NUMBER :TT302 DATE : 11/03/1991 STARTING TIME : 1103:

WHITECAP AVERAGE : 0.0002156 VARIANCE : 0.0000002
SKEWNESS : 3.0143139 KURTOSIS : 11.3343240

THRESHOLD VALUE : 4.35
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
12.5	180	15.0	14.4	UNSTABLE

COMMENTS :



ANALYSIS OF THOMPSON(AGOR-23) CRUISE DATA

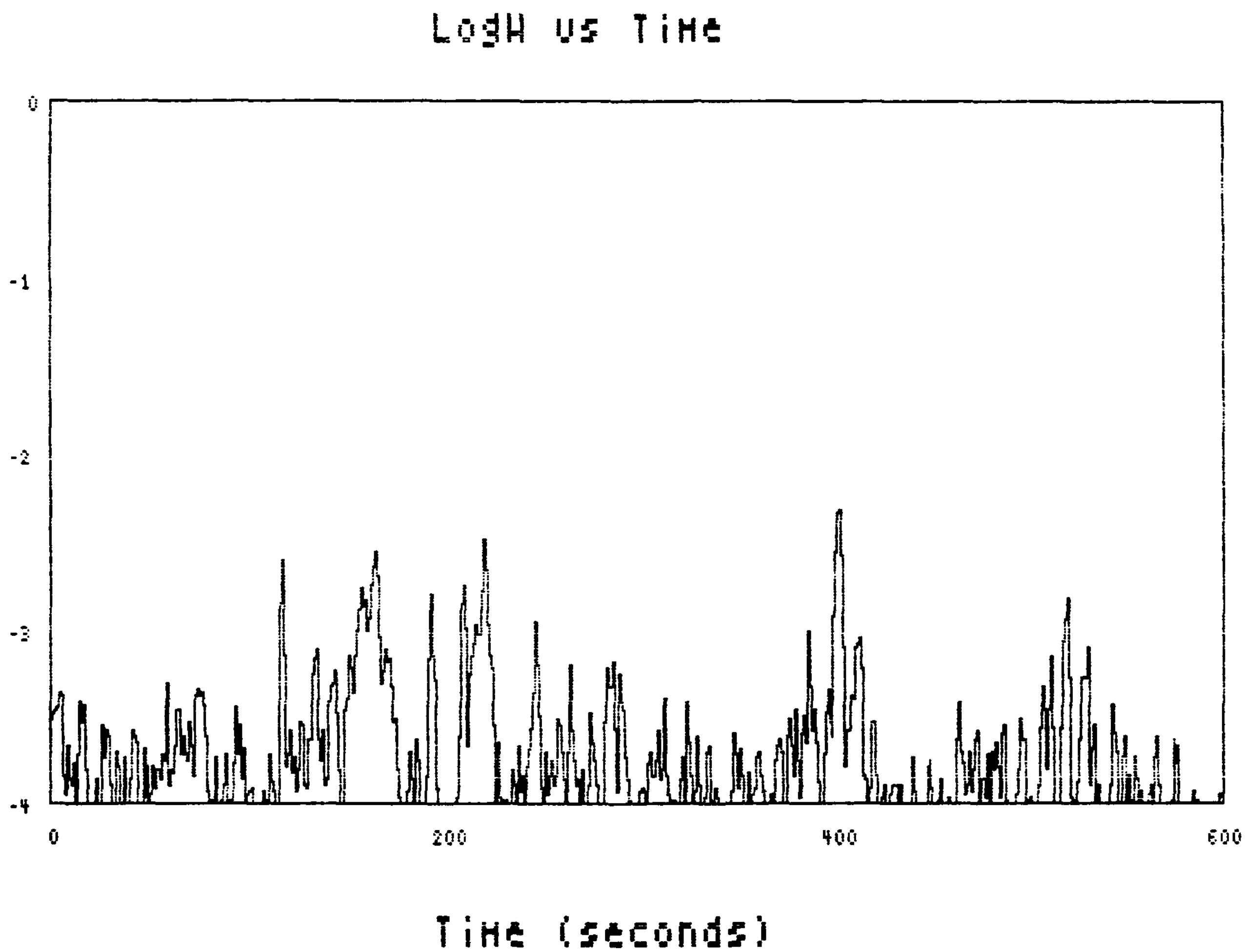
TAPE/EVENT NUMBER :TT303 DATE : 11/03/1991 STARTING TIME : 1234:

WHITECAP AVERAGE : 0.0001903 VARIANCE : 0.0000002
SKEWNESS : 5.2880977 KURTOSIS : 37.4589216

THRESHOLD VALUE : 4.35
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
12.5	180	15.0	14.2	UNSTABLE

COMMENTS :



ANALYSIS OF THOMPSON(AGOR-23) CRUISE DATA

TAPE/EVENT NUMBER :TT304   DATE : 11/03/1991   STARTING TIME : 1357:

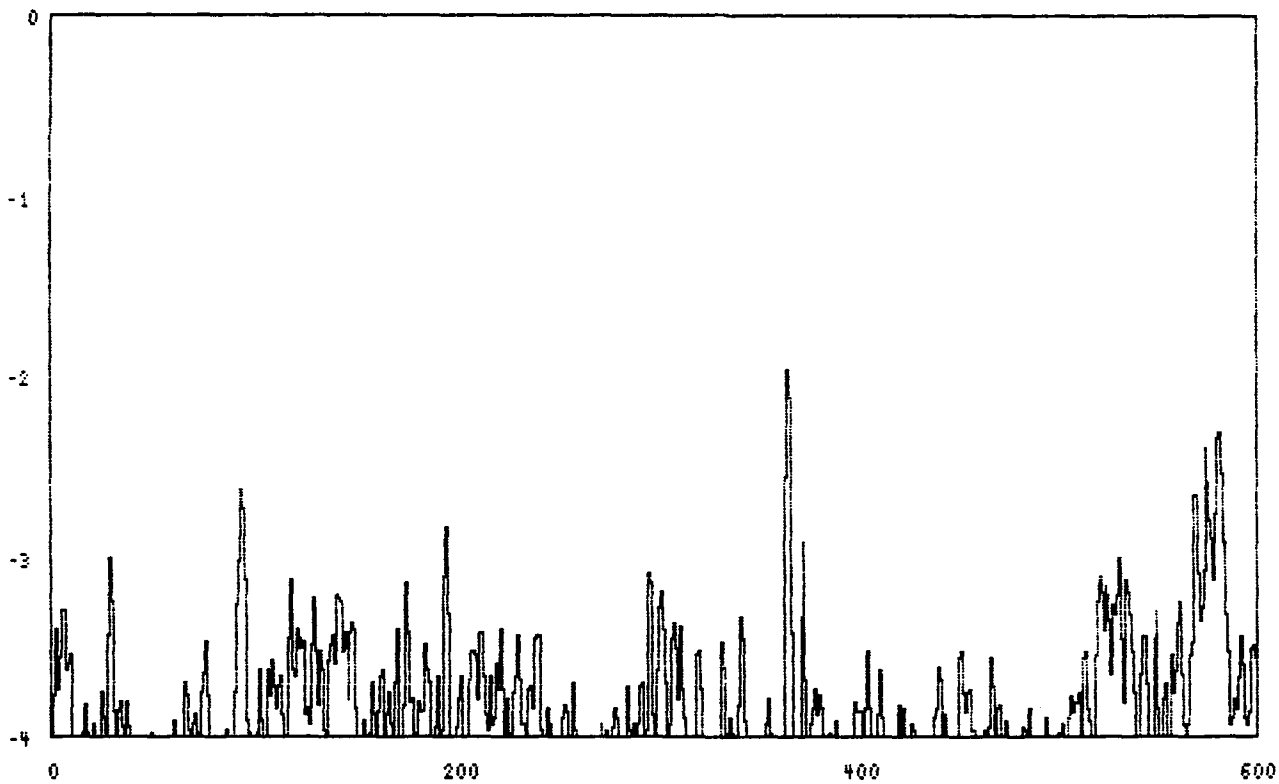
WHITECAP AVERAGE : 0.0001719   VARIANCE : 0.0000004
SKEWNESS : 9.9477062   KURTOSIS :124.1692928

THRESHOLD VALUE : 4.35
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
12.0	185	15.0	14.3	UNSTABLE

COMMENTS :

LogW vs Time



Time (seconds)

ANALYSIS OF THOMPSON(AGOR-23) CRUISE DATA

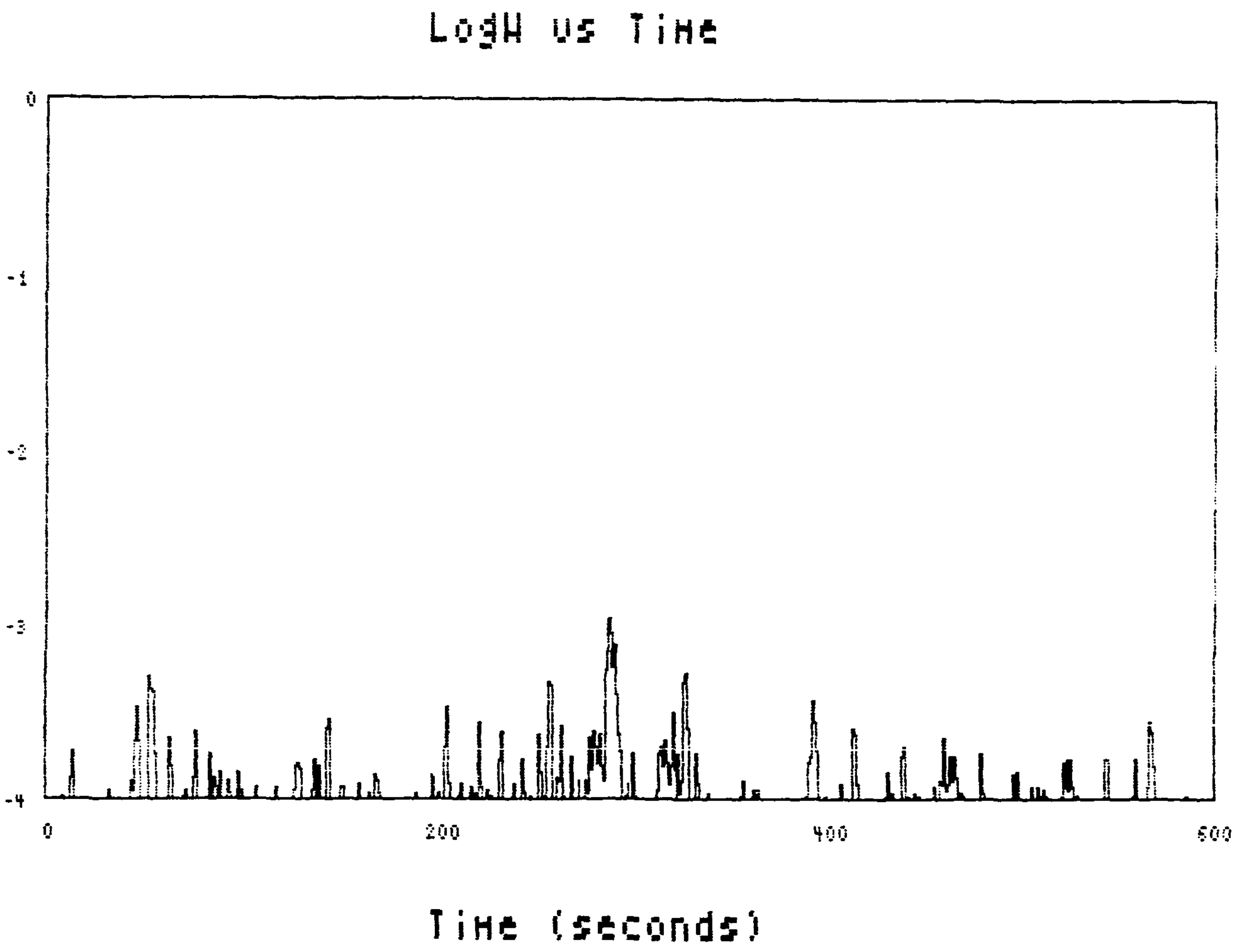
TAPE/EVENT NUMBER :TT305   DATE : 11/03/1991   STARTING TIME : 1529:

WHITECAP AVERAGE : 0.0000239   VARIANCE : 0.0000000
SKEWNESS : 6.6380939   KURTOSIS : 57.8709198

THRESHOLD VALUE : 4.30
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
10.0	239	15.0	14.2	UNSTABLE

COMMENTS :



CHAPTER 7

TRIP REPORT: WHITECAP VIDEO INSTALLATIONS, R/V THOMAS G. THOMPSON AND R/V CORY CHOUEST

BY

M.B. WILSON

CHAPTER 7

Trip Report
Whitecap Video Installations,
R/V THOMAS G. THOMPSON
and
R/V CORY CHOUEST

BACKGROUND

The video system which was installed onboard the Canadian R/V PARIZEAU was shipped to the University of Washington, at Seattle for installation on the R/V THOMAS G. THOMPSON. A second video system, consisting of the items listed in the shipping document, enclosed, was shipped to the R/V CORY CHOUEST, at Port Wheneme, CA. for installation.

INSTALLATION

Departed 0515, 26 December, 1991, from home, Ledyard, CT, enroute Green Airport for 0730 flight to Seattle, Washington. Arrived onboard R/V Thomas G. Thompson at 1545. Tried to locate the video system, which should have been onboard. The system was shipped from IOS Sidney, Victoria, B.C., on the 16th of December. Could not locate, and as it was the end of the work day, could not locate anyone knowledgeable of its location.

27 December 1991

Called IOS Sidney and obtained the shipping information of the system. Could not talk to Canadian Freightways to learn the disposition, as there was no answer to repeated phone calls. I was able to determine that the University of Washington was informed on the 18th of December that the system was in Seattle, and the University should arrange for their shipping agent to have it cleared through customs and delivered. The system was still in bonded storage. As there was no chance to install the intended system in time to support Dr. Harry DiFerrari's cruise, I obtained the ship's Sony "Handycam" in it's watertight container and determined that it could be used.

28 December 1991

Procured the necessary materials and video tapes for installation. The plan is to lash a camera tripod to the rail at Frame 63 on the 04 level and mount the camera there. This was accomplished and should work out well.

29 December 1991

Roughed out a new set of operating instructions and logs for the upcoming cruise. Reviewed the set-up and operation of the system with the ships electronics technician. He will pass the equipment and information on to the University of Miami group. All procured materials will remain with the ship. All exposed video tape will be sent to the Marine Sciences Institute for analysis.

30 December 1991

Typed up and put in final form the new operating instructions. Made arrangements with the Marine Superintendent, Mr. Bill Jeffers, for the shipment of the University of Connecticut video system to be released from bonded storage and shipped directly to M.S.I.

31 December 1991

Departed University of Washington for Los Angeles and Port Wheneme to do install on CORY CHOUEST.

1 January 1992

Arrived at Port Wheneme.

2 January 1992

Reported to the Naval Civil Engineering Laboratory and the CORY CHOUEST. Inspected UConn equipment and arranged to have it delivered onboard the CORY CHOUEST. Reported to the CORY CHOUEST and received badge and started checkout of cabling.

3 January 1992

Set-up equipment in "Library". Procured necessary pipe and fittings to mount the camera shelter on the 04 level, port side, forward end.

4 January 1992

Procured proper BNC fittings for 8281 cable. Installed camera shelter on the 04 level, same location as last installation. Replaced BNC fittings and tested system. All systems with the exception of the Sony camera check-out.

5 January 1992

Tested various components of the Sony camera. Found problem and repaired. Tested complete system. All test satisfactory. Turned systems over to APL representative. Installation complete.

6 January 1992

Departed Port Wheneme for UConn, M.S.I.

7 January 1992

Arrived at UConn, M.S.I., 1100.

CHAPTER 8

REPORT: WHITECAP ANALYSIS OF VIDEO REGISTRATION, CANADIAN R/V PARIZEAU, PACIFIC COAST CRUISE, NOVEMBER 1991

BY

W. WANG AND M.B. WILSON

CHAPTER 8

Report
Whitecap Analysis of Video Registration
Canadian R/V PARIZEAU
Pacific Coast Cruise
November 1991
W. Wang and M.B. Wilson

This report consists of one (1), five and one quarter, double sided, high density data disk labeled "Parizeau 1". Appended is a copy of the directory of that data disk.

Appended also are graphic presentations of the whitecap one second averages for each of the analysis intervals. The information to construct these graphs is contained in a data file labeled "Pttdd". The header information contained in these printouts is in the corresponding "z" file. The file system is described below.

There are thirty data sets, consisting of the reduction of video information recorded between 16 and 27 November 1991. The information was recorded during the I.O.S. Sidney cruise onboard the R/V PARIZEAU, out of Vancouver Island, B.C. The video record was made using a Sony Model DXC 1800-P Color Video Camera, recording on 20 minute, 3/4" Umatic tape, in the PAL video format. The video recorder was a Sony Model VO 4800 PS. The recordings were generally of twenty minutes duration.

The analysis utilized a Sony VP 5030 video cassette player to reproduce the video registration, a Hamamatsu C-1143 area analyzer and a locally developed interface to an IBM-compatible 386 computer. Each segment was reviewed for suitability for analysis, insuring that the area of interest was free from extraneous registrations, such as sunlight reflecting on the waters, etc. The video signal was then sent through the Hamamatsu, where a threshold value was determined such that the individual pixels in the video image representing Stage "A" Whitecaps were identified.

The number of these pixels, for each of twenty-five video frames per second, divided by the total number of pixels within the bounded "area of interest", provides the whitecap fraction for that video frame. This information is sent to the computer via the local interface, where the one-second average is determined and saved to disk. At the end of the analysis interval, the overall mean whitecap fraction and the additional statistical quantities are computed and saved to file.

Each of the data files is labeled "Pttdd" where "P" stands for "Parizeau", the platform recorded from. The first two (tt) digits of the numerical sequence following is the consecutive number of the tape cassette used on that cruise. The last two digits (dd) in the sequence represent the data interval analyzed. The number "1" represents the first of two ten minute data intervals on the tape, while "2" represents a data segment from the second recording on that tape. Note that some tapes had twenty minutes of continuous recordings. Only one analysis was made in most of those cases.

The header of each data interval printout is a shell which is used to record common data such as the title, tape/event number, the meteorological data, and any comments thought necessary by the analyst. The shell file is identified by the tape/event number plus the letter "z".

The graph is the plot of the one-second averages derived during analysis, plotted as the log (w + .0001).

The remainder of the information presented is statistically derived data.

A copy of the locally generated Turbo Pascal program is provided. A copy of this report is also included.

Several tapes were not analyzed for various reasons. In addition, the results of some analysis intervals are not consistent with historical data. Much of this is attributed to the locations where the data sets were taken. From the chart of the operating area, (Chart No.), it is noted that much of the video registration was made in sheltered waters. In several data tapes, land can be seen in the background.

ANALYSIS RECORD

PAL92-001	-------	One and Two	Not analyzed; no met data
PAL92-002	-------	Three	Not analyzed; no met data.
PAL92-003	-------	Four and Five	Not analyzed; excessive solar reflection. No met data
PAL92-004	P0401	Six	Analyzed; ten min.
		Seven	Not analyzed; no met data.
PAL92-005	-------	Eight and nine	Not analyzed; no met data.
PAL92-006	-------	Ten and Eleven	Not analyzed; no met data.
PAL92-007	-------	Twelve and Thirteen	Not analyzed; no met data.
PAL92-008	-------	Fourteen and Fifteen	Not analyzed; no met data.
PAL92-009	-------	Sixteen and Seventeen	Not analyzed; no met data.
PAL92-010		Eighteen	Not analyzed; no met data, too dark.
PAL92-011	-----	Nineteen	Not analyzed; no met data, too dark.
PAL92-012	P1201 & 02	Twenty	Analyzed; Two ten min. segments.
PAL92-013	P1301 & 02	Twenty- one	Analyzed; Two ten min. segments.
PAL92-014	P1401 & 02	Twenty-two	Analyzed; Two ten min. segments.
PAL92-015	P1501	Twenty-three	Analyzed; One ten min. segment.
PAL92-016	P1601	Twenty-four	Analyzed; One ten min. segment.
PAL92-017	P1701 & 02	Twenty-five	Analyzed; Two ten min. segments.
PAL92-018	P1801	Twenty-six	Analyzed; One ten min. segment.
PAL92-019	P1901	Twenty-seven	Analyzed; One ten min. segment.
PAL92-020	-------	Twenty-eight	Not analyzed; too dark.
PAL92-021	P2101	Twenty-nine	Analyzed; One ten min. segment.
PAL92-022	P2201	Thirty	Analyzed; One ten min. segment.
PAL92-023	P2301	Thirty-one	Analyzed; One ten min. segment.
PAL92-024	P2401	Thirty-two	Analyzed; One ten min. segment.
PAL92-025	P2501	Thirty-three	Analyzed; One ten min. segment.
PAL92-026	P2601	Thirty-four	Analyzed; One ten min. segment.
PAL92-027	P2701	Thirty-five	Analyzed; One ten min. segment.
PAL92-028	-------	Thirty-six	Not analyzed; too dark.
PAL92-029	P2901	Thirty-seven	Analyzed; One ten min. segment.
PAL92-030	P3001	Thirty-eight	Analyzed; One ten min. segment.
PAL92-031	P3101	Thirty-nine	Analyzed; One ten min. segment.
PAL92-032	P3201	Forty	Analyzed; One ten min. segment.
PAL92-033	P3301	Forty-one	Analyzed; One ten min. segment.
PAL92-034	P3401	Forty-two	Analyzed; One ten min. segment.
PAL92-035	P3501	Forty-three	Analyzed; One ten min. segment.
PAL92-036	P3601	Forty-four	Analyzed; One ten min. segment.
PAL92-037	P3701	Forty-five	Analyzed; One ten min. segment.
PAL92-038	P3801	Forty-six	Analyzed; One ten min. segment.

WordStar

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0401	8.4k	P0401Z	.5k	P1201	8.4k	P1201Z	.4k
1202	7.0k	P1202Z	.4k	P1301	8.4k	P1301Z	.4k
1302	8.4k	P1302Z	.4k	P1401	8.4k	P1401Z	.4k
1402	8.4k	P1402Z	.4k	P1501	8.4k	P1501Z	.4k
1601	8.4k	P1601Z	.4k	P1701	8.4k	P1701Z	.4k
1702	8.4k	P1702Z	.4k	P1801	8.4k	P1801Z	.4k
1901	8.4k	P1901Z	.4k	P2101	8.4k	P2101Z	.4k
2201	8.4k	P2201Z	.4k	P2301	8.4k	P2301Z	.4k
2401	8.4k	P2401Z	.4k	P2501	7.0k	P2501Z	.4k
2601	8.4k	P2601Z	.5k	P2701	8.4k	P2701Z	.4k
2901	8.4k	P2901Z	.4k	P3001	8.4k	P3001Z	.4k
3101	8.4k	P3101Z	.4k	P3201	8.4k	P3201Z	.4k
3301	8.4k	P3301Z	.4k	P3401	3.5k	P3401Z	.4k
3501	8.4k	P3501Z	.4k	P3601	8.4k	P3601Z	.4k
3701	8.4k	P3701Z	.4k	P3801	8.4k	P3801Z	.4k
RZUPLOT.PAS	9.2k	PRZU_PAL.PAS	12k	REPORT	13k		

ANALYSIS OF PARIZEAU CRUISE DATA

TAPE/EVENT NUMBER :P0401 DATE : 11/16/1991 STARTING TIME : 1304;

WHITECAP AVERAGE : 0.0003844 VARIANCE : 0.0000009
SKEWNESS : 3.6528190 KURTOSIS : 15.1743924

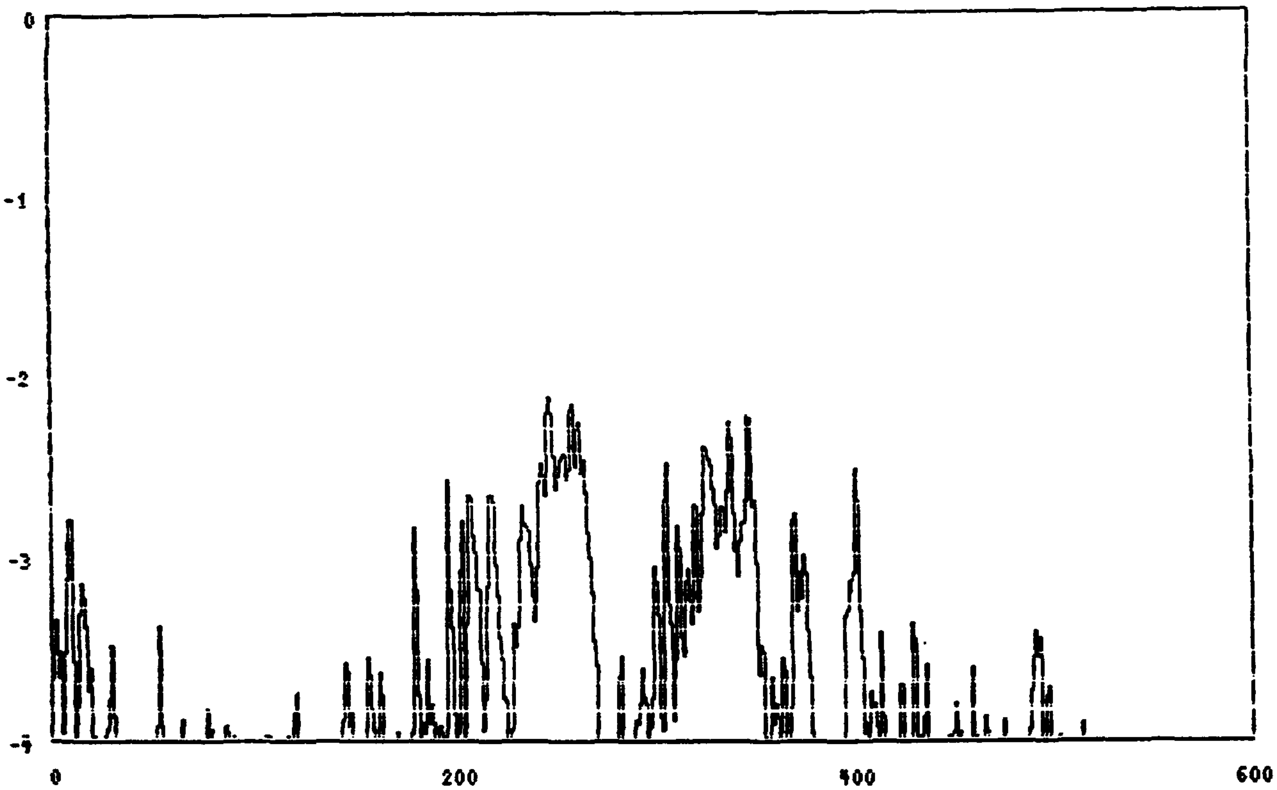
THRESHOLD VALUE : 4.90
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
0.9	218.0	10.3	9.0	STABLE

COMMENTS :

WIND SPEED SEEMS TOO LOW

LogW vs Time



Time (seconds)

ANALYSIS OF PARIZEAU CRUISE DATA

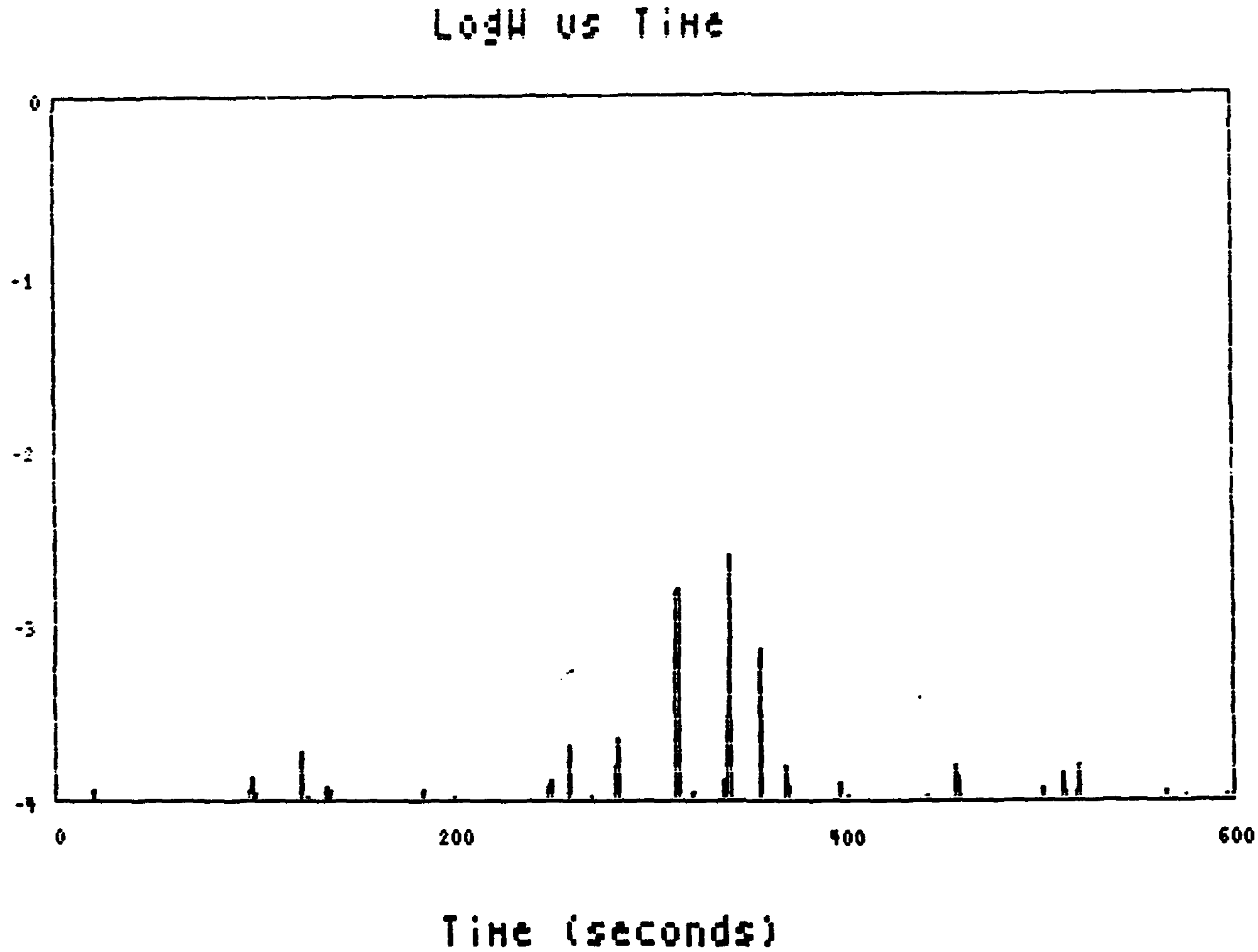
TAPE/EVENT NUMBER :P1201   DATE : 11/20/1991   STARTING TIME : 1414:

WHITECAP AVERAGE : 0.00C0109   VARIANCE : 0.0000000
SKEWNESS : 14.5580950   KURTOSIS :227.2817107

THRESHOLD VALUE : 4.65
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
7.5	284.7	7.3	8.7	UNSTABLE

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

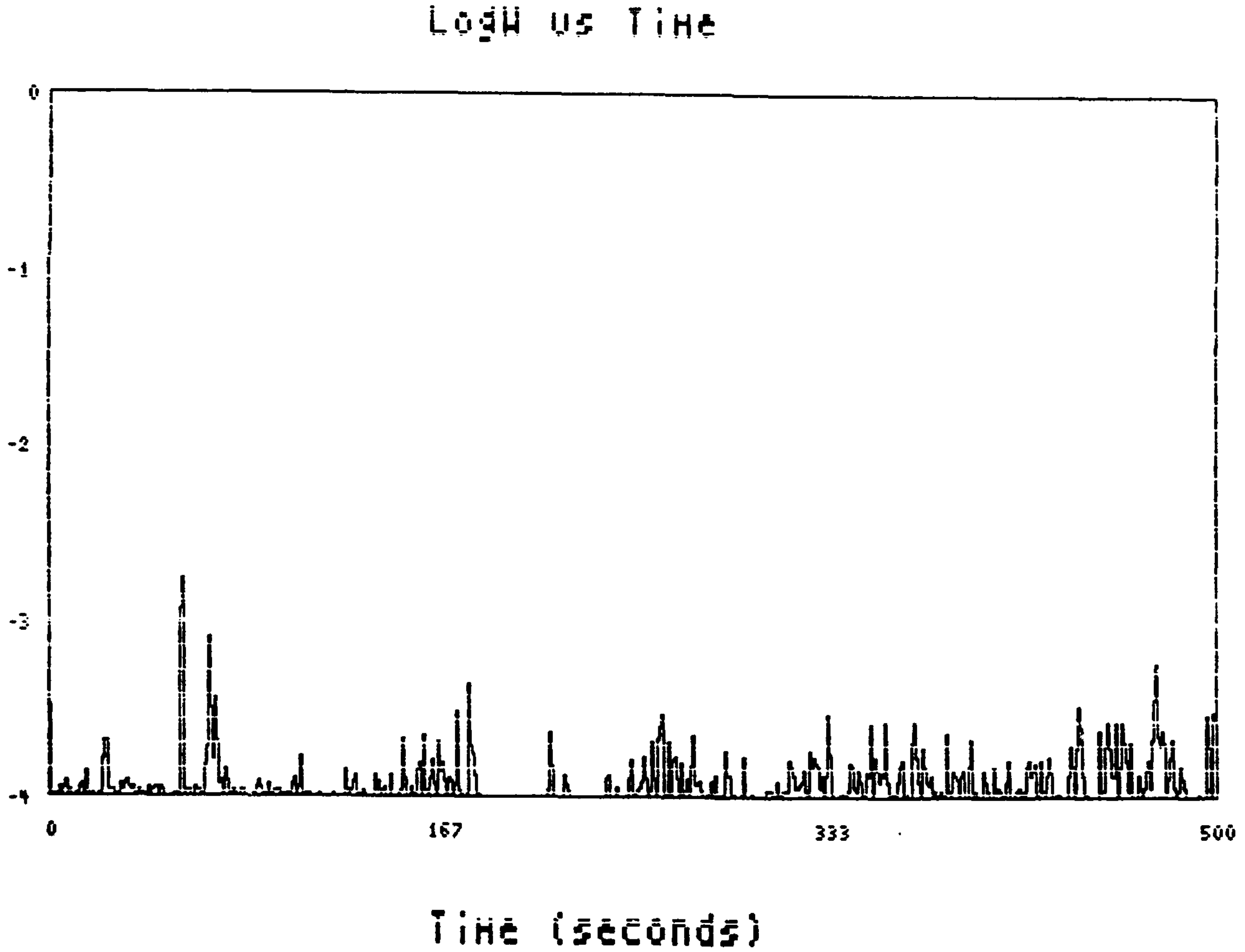
TAPE/EVENT NUMBER :P1202   DATE : 11/20/1991   STARTING TIME : 1424:3

WHITECAP AVERAGE : 0.0000304   VARIANCE : 0.0000000
SKEWNESS : 10.3223813   KURTOSIS :135.7666633

THRESHOLD VALUE : 4.30
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
7.3	293.8	7.3	8.7	UNSTABLE

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

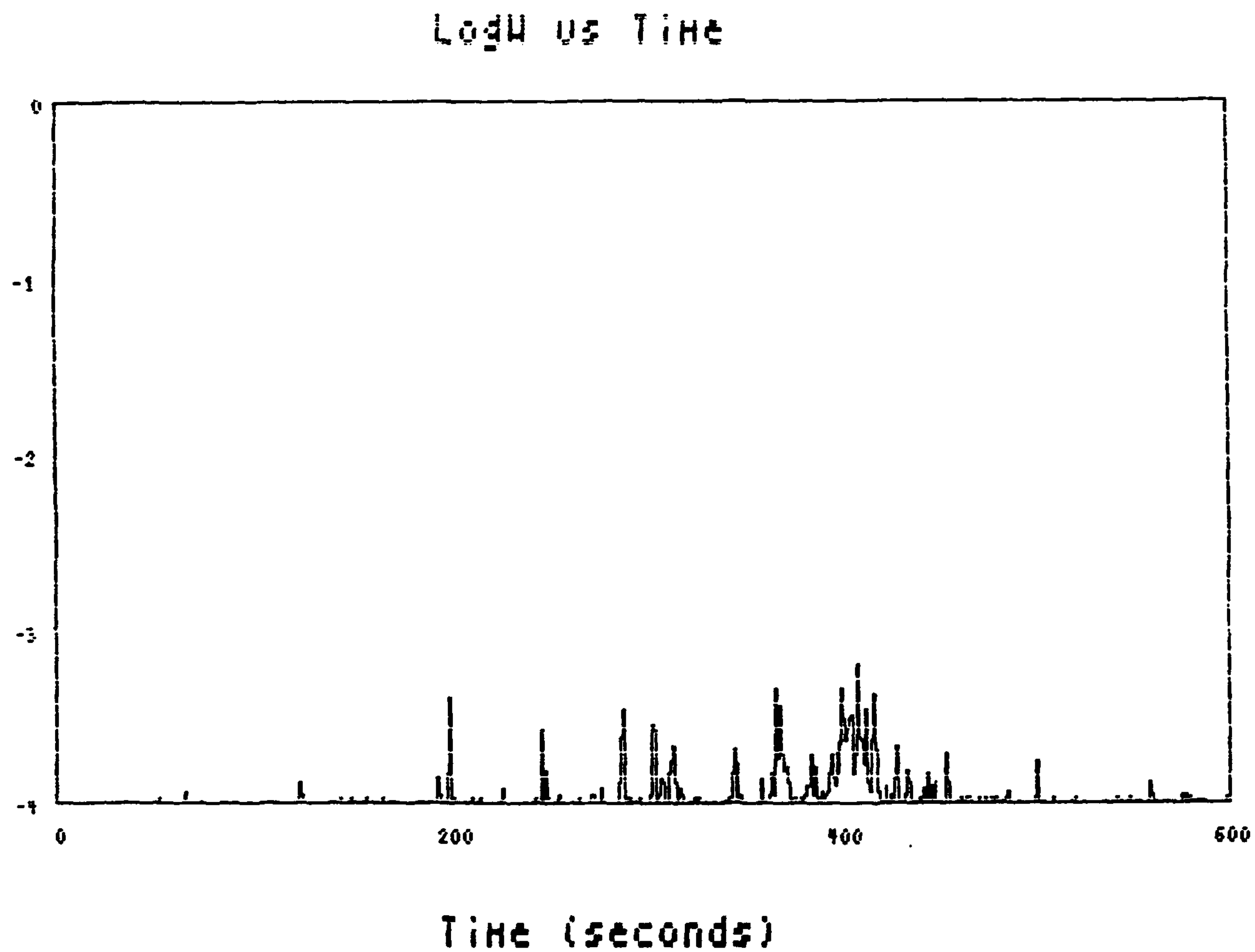
TAPE/EVENT NUMBER :P1301   DATE : 11/20/1991   STARTING TIME : 1514:

WHITECAP AVERAGE : 0.0000151   VARIANCE : 0.0000000
SKEWNESS : 7.1049117   KURTOSIS : 66.6264930

THRESHOLD VALUE : 3.65
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
5.6	318.2	7.1	8.7	UNSTABLE

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

TAPE/EVENT NUMBER :P1302   DATE : 11/20/1991   STARTING TIME : 1524:

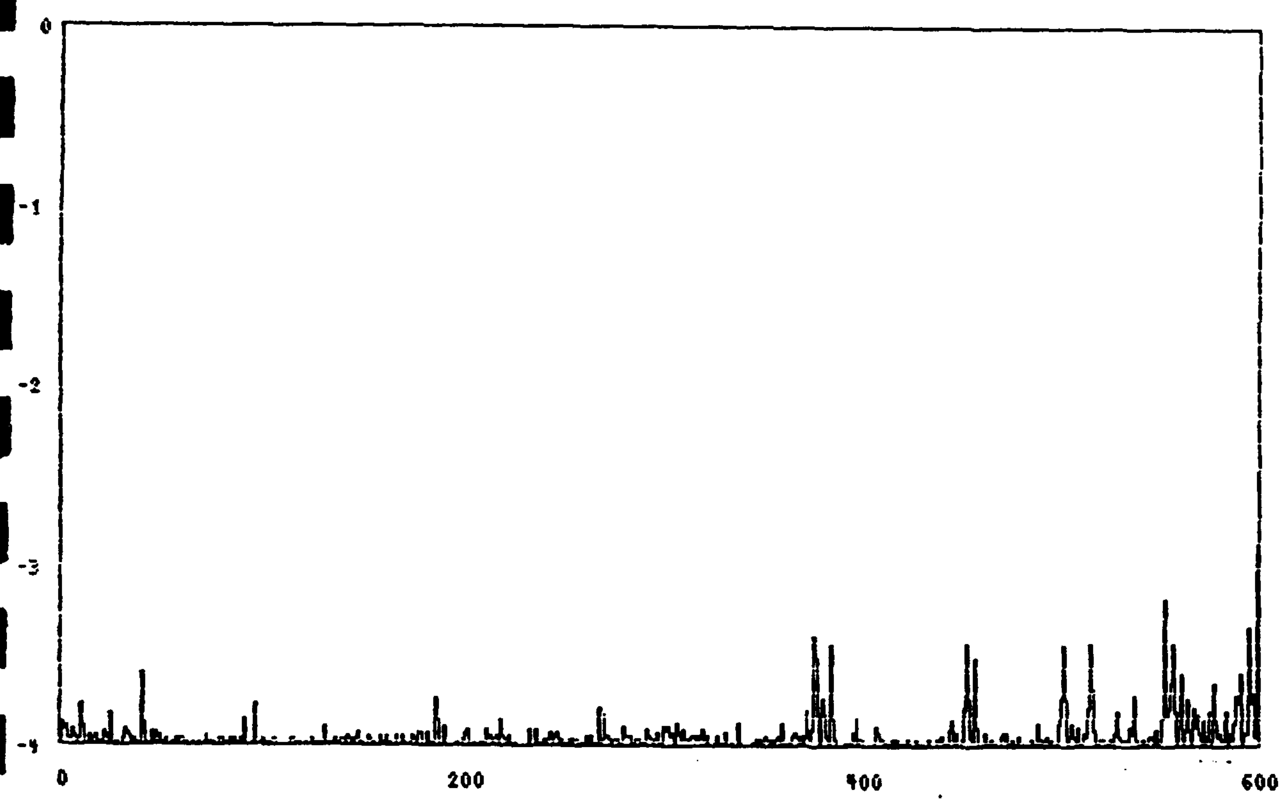
WHITECAP AVERAGE : 0.0000201   VARIANCE : 0.0000000
SKEWNESS : 12.3564962   KURTOSIS :178.4586110

THRESHOLD VALUE : 3.73
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
5.2	320.7	6.8	8.6	UNSTABLE

COMMENTS :

LogH vs Time



Time (seconds)

ANALYSIS OF PARIZEAU CRUISE DATA

TAPE/EVENT NUMBER :P1401 DATE : 11/20/1991 STARTING TIME : 1542:

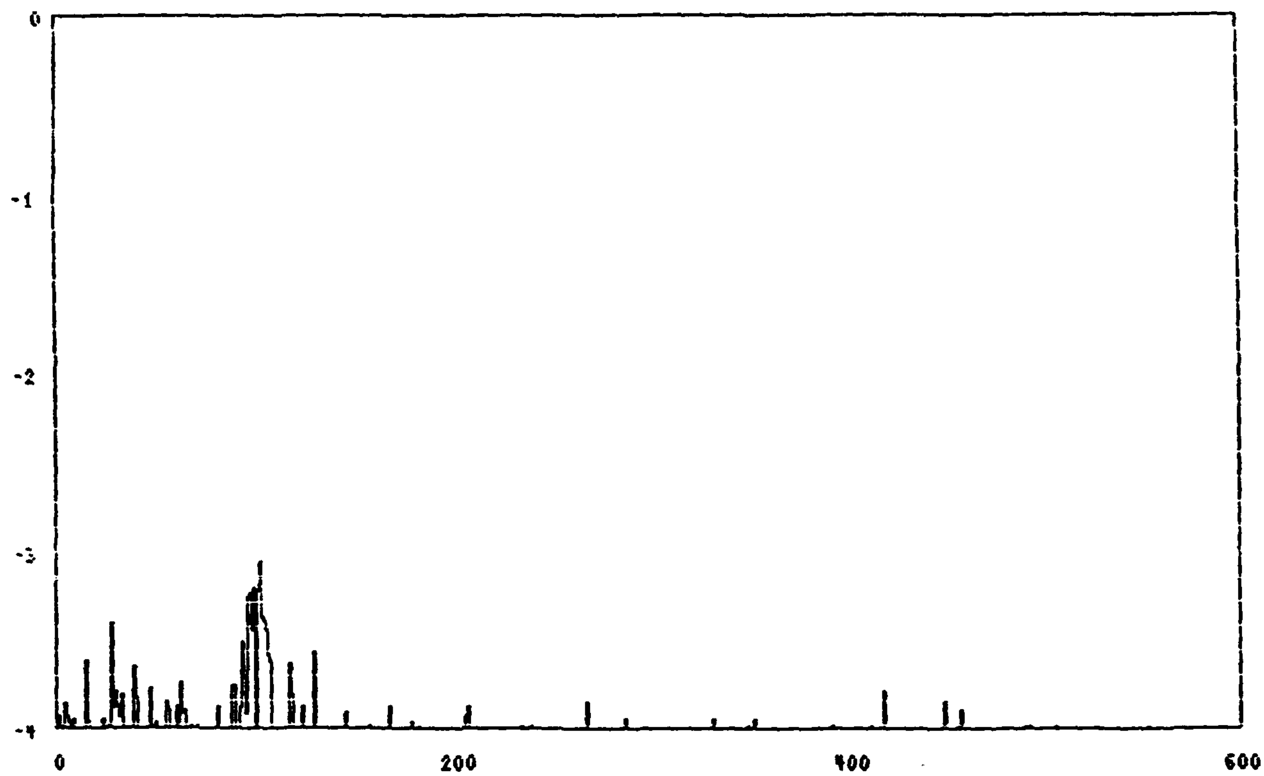
WHITECAP AVERAGE : 0.0000114 VARIANCE : 0.0000000
SKEWNESS : 7.7496369 KURTOSIS : 70.1938518

THRESHOLD VALUE : 5.14
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
4.7	297.8	6.6	8.6	UNSTABLE

COMMENTS :

LogW vs Time



Time (seconds)

ANALYSIS OF PARIZEAU CRUISE DATA

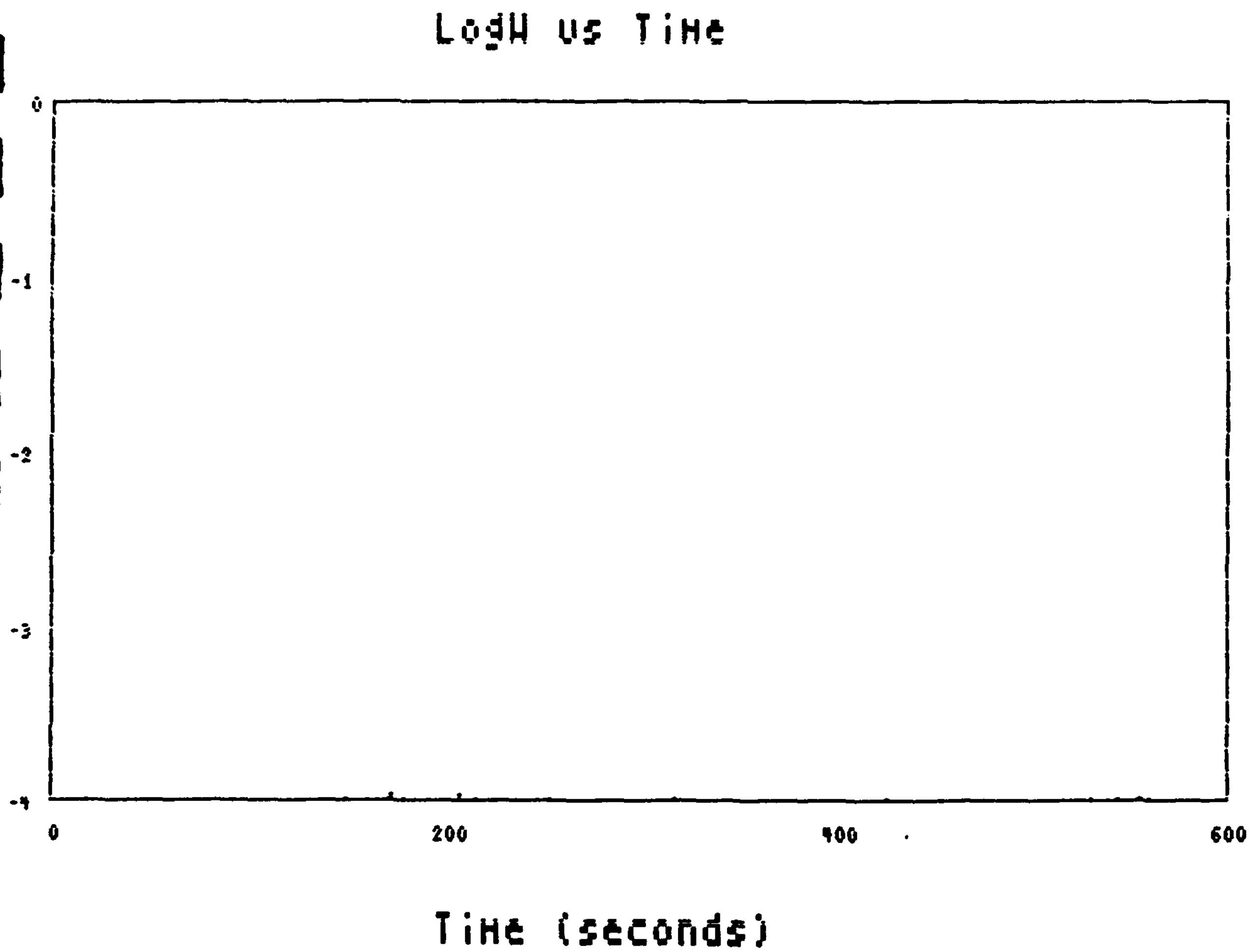
TAPE/EVENT NUMBER :P1402 DATE : 11/20/1991 STARTING TIME : 1552:

WHITECAP AVERAGE : 0.0000001 VARIANCE : 0.0000000
SKEWNESS : 7.4740594 KURTOSIS : 61.3635189

THRESHOLD VALUE : 6.15
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
2.5	303.7	6.0	8.6	UNSTABLE

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

TAPE/EVENT NUMBER :P1501   DATE : 11/22/1991   STARTING TIME : 0945:

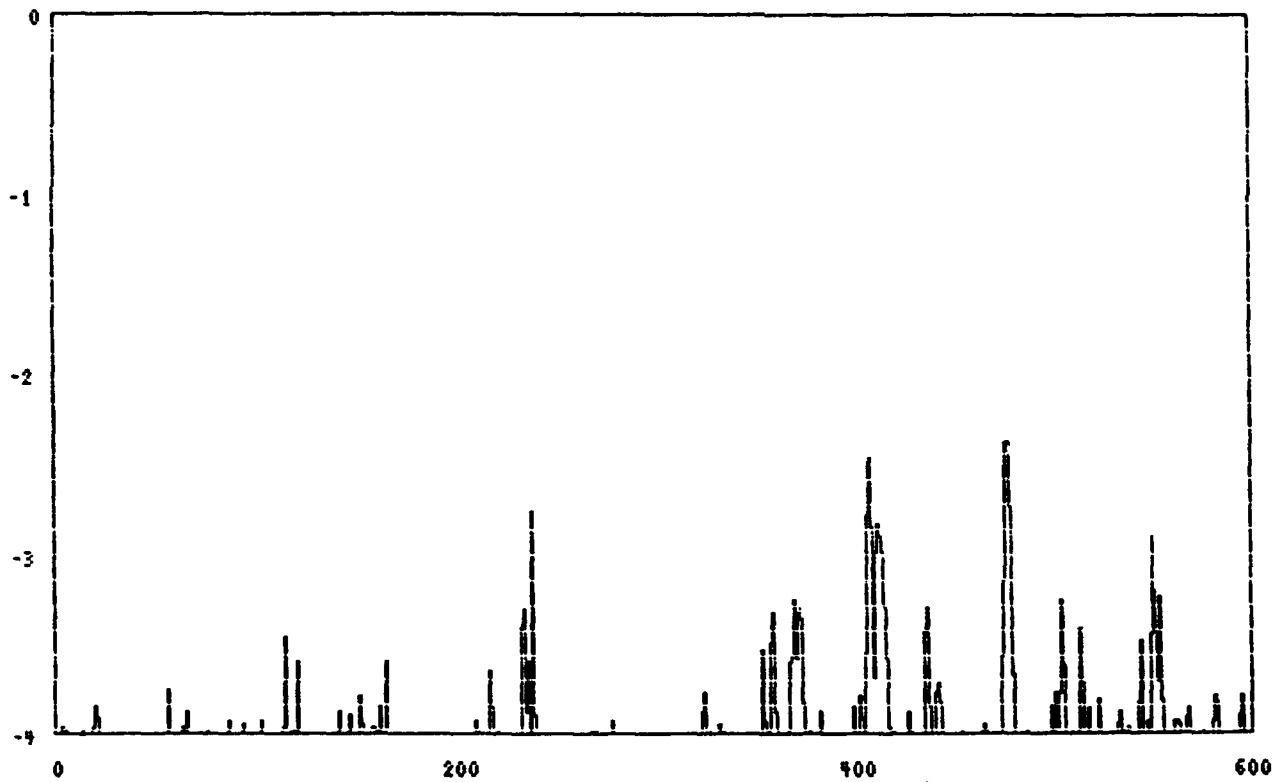
WHITECAP AVERAGE : 0.0000569   VARIANCE : 0.0000001
SKEWNESS : 9.3543318   KURTOSIS :101.3742163

THRESHOLD VALUE : 4.97
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
0.4	27.3	7.5	7.4	NEUTRAL

COMMENTS :

LogW vs Time



Time (seconds)

ANALYSIS OF PARIZEAU CRUISE DATA

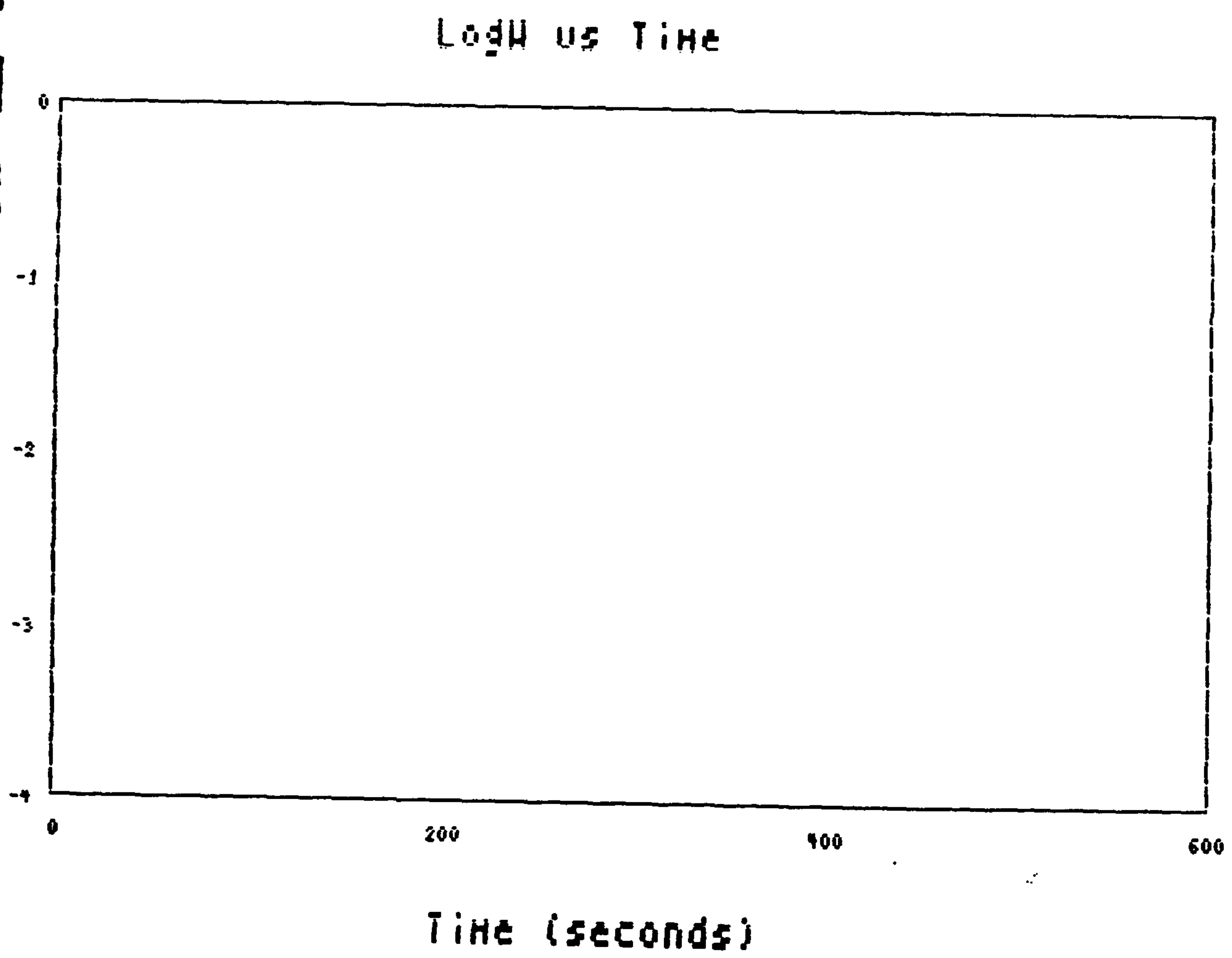
TAPE/EVENT NUMBER :P1601 DATE : 11/22/1991 STARTING TIME : 1042:

WHITECAP AVERAGE :	0.0000000	VARIANCE :	0.0000000
SKEWNESS :	0.0000000	KURTOSIS :	0.0000000

THRESHOLD VALUE : 5.80

W_S(m/s)	W_D	T_air	T_water	STABILITY
0.1	214.8	7.9	9.2	UNSTABLE

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

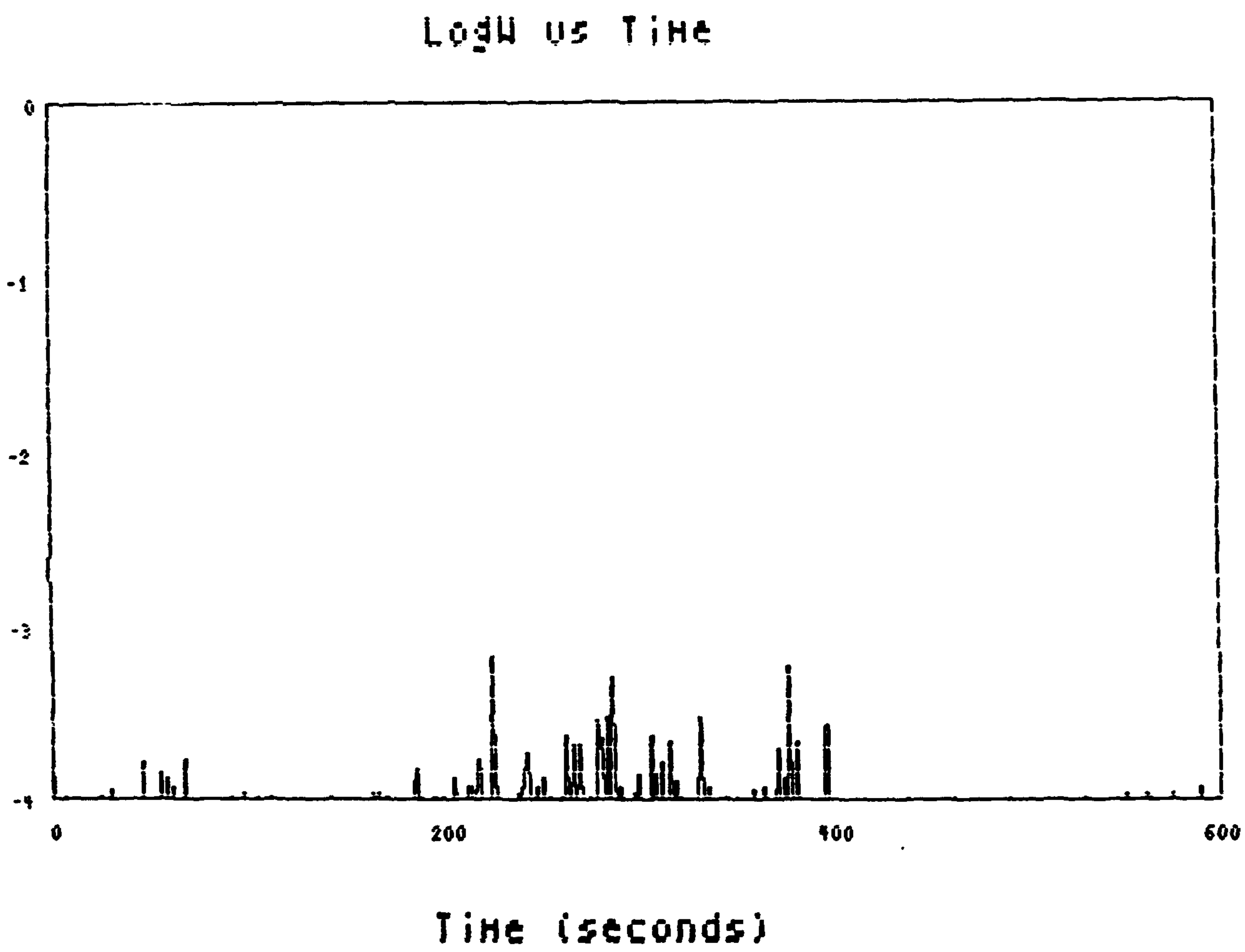
TAPE/EVENT NUMBER :P1701   DATE : 11/22/1991   STARTING TIME : 1303:

WHITECAP AVERAGE : 0.0000132   VARIANCE : 0.0000000
SKEWNESS : 20.8692488   KURTOSIS :473.4309214

THRESHOLD VALUE : 4.23
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
7.2	110.3	7.3	7.8	UNSTABLE

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

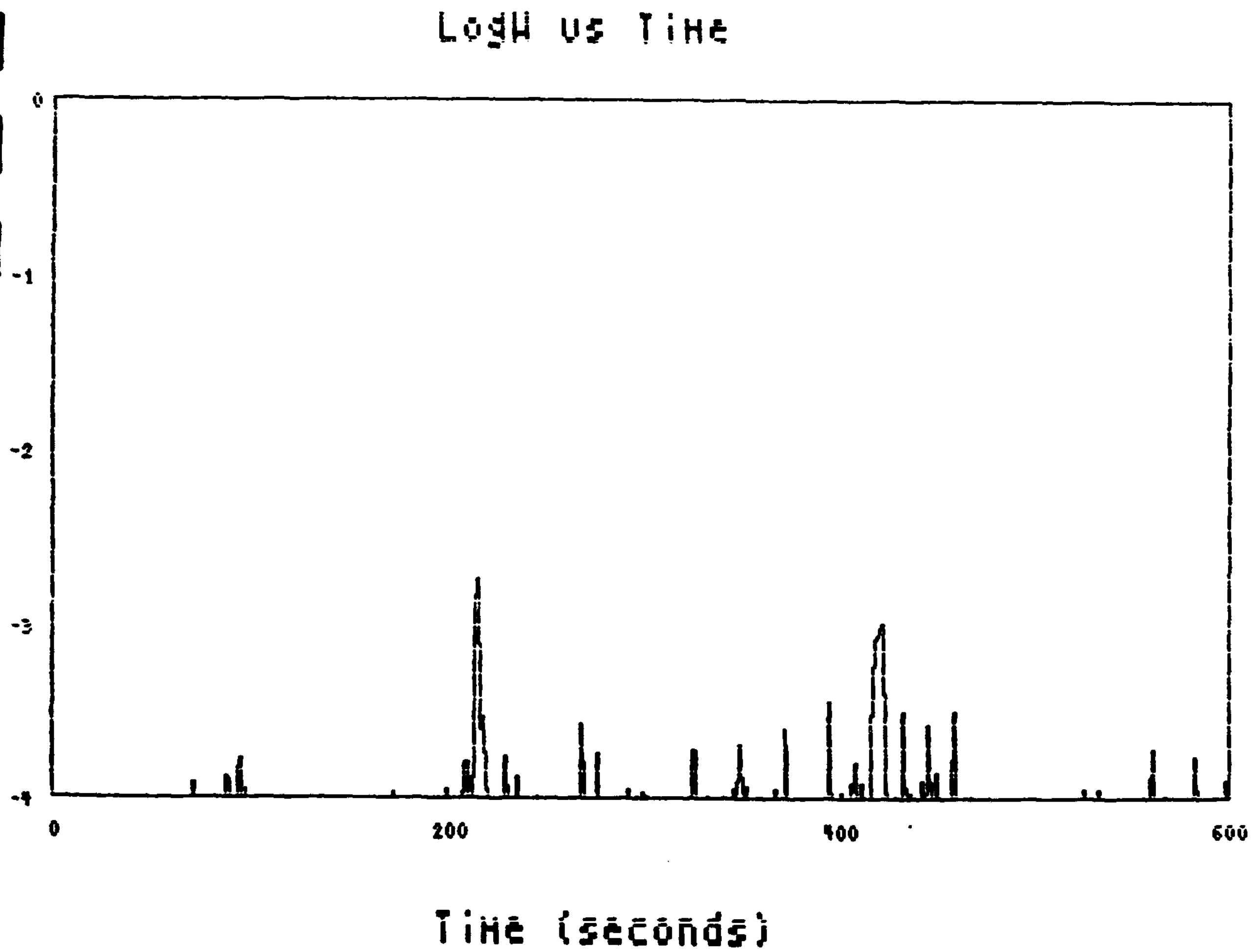
TAPE/EVENT NUMBER :P1702   DATE : 11/22/1991   STARTING TIME : 1314:

WHITECAP AVERAGE : 0.0000196   VARIANCE : 0.0000000
SKEWNESS : 9.3383636   KURTOSIS :101.5262508

THRESHOLD VALUE : 4.65
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
6.9	107.0	7.3	7.8	UNSTABLE

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

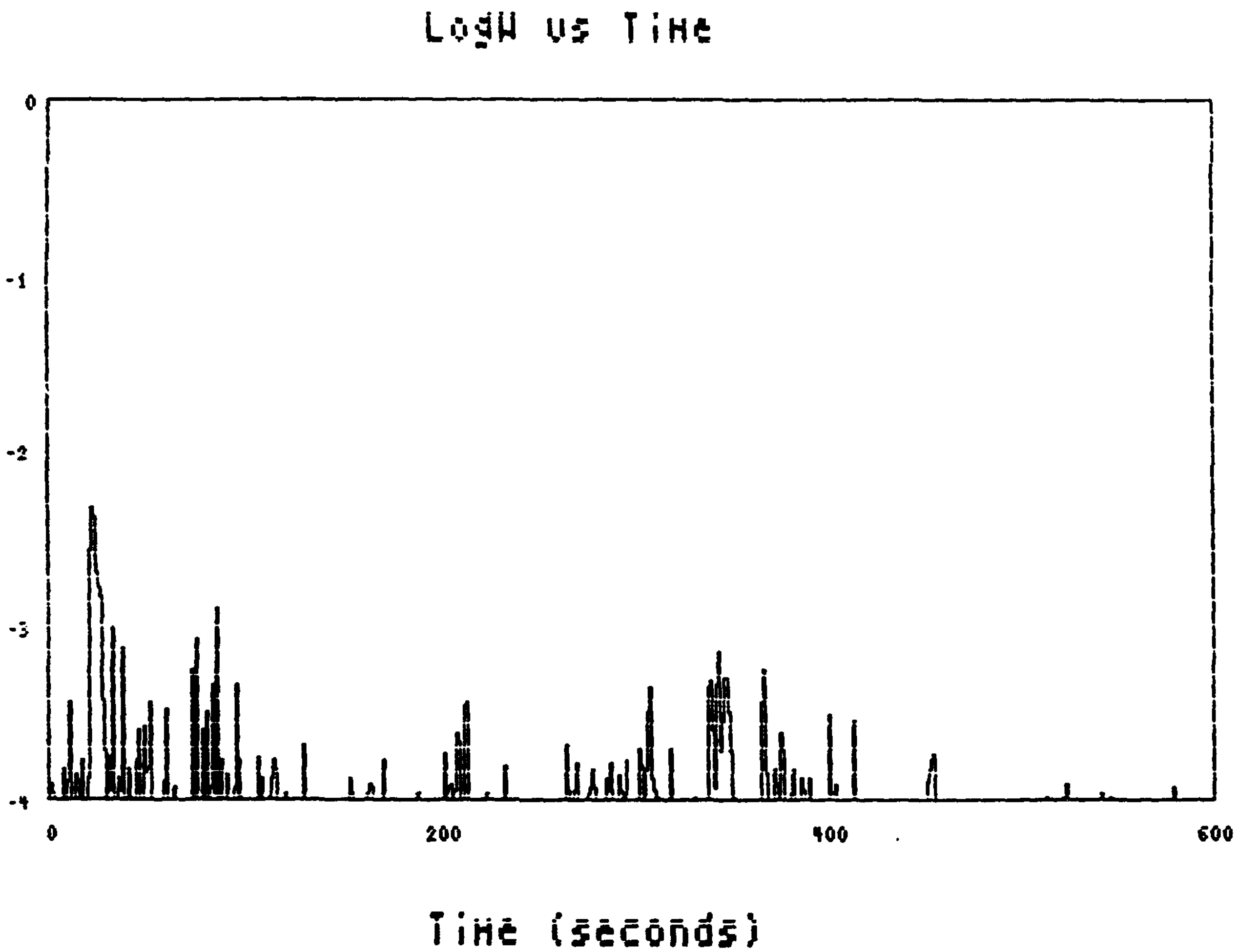
TAPE/EVENT NUMBER :P1801   DATE : 11/22/1991   STARTING TIME : 1411;3

WHITECAP AVERAGE : 0.0000569   VARIANCE : 0.0000001
SKEWNESS : 9.9624441   KURTOSIS :111.6415950

THRESHOLD VALUE : 4.90
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
6.7	101.5	7.3	7.9	UNSTABLE

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

TAPE/EVENT NUMBER :P1901 DATE : 11/22/1991 STARTING TIME : 1505:2

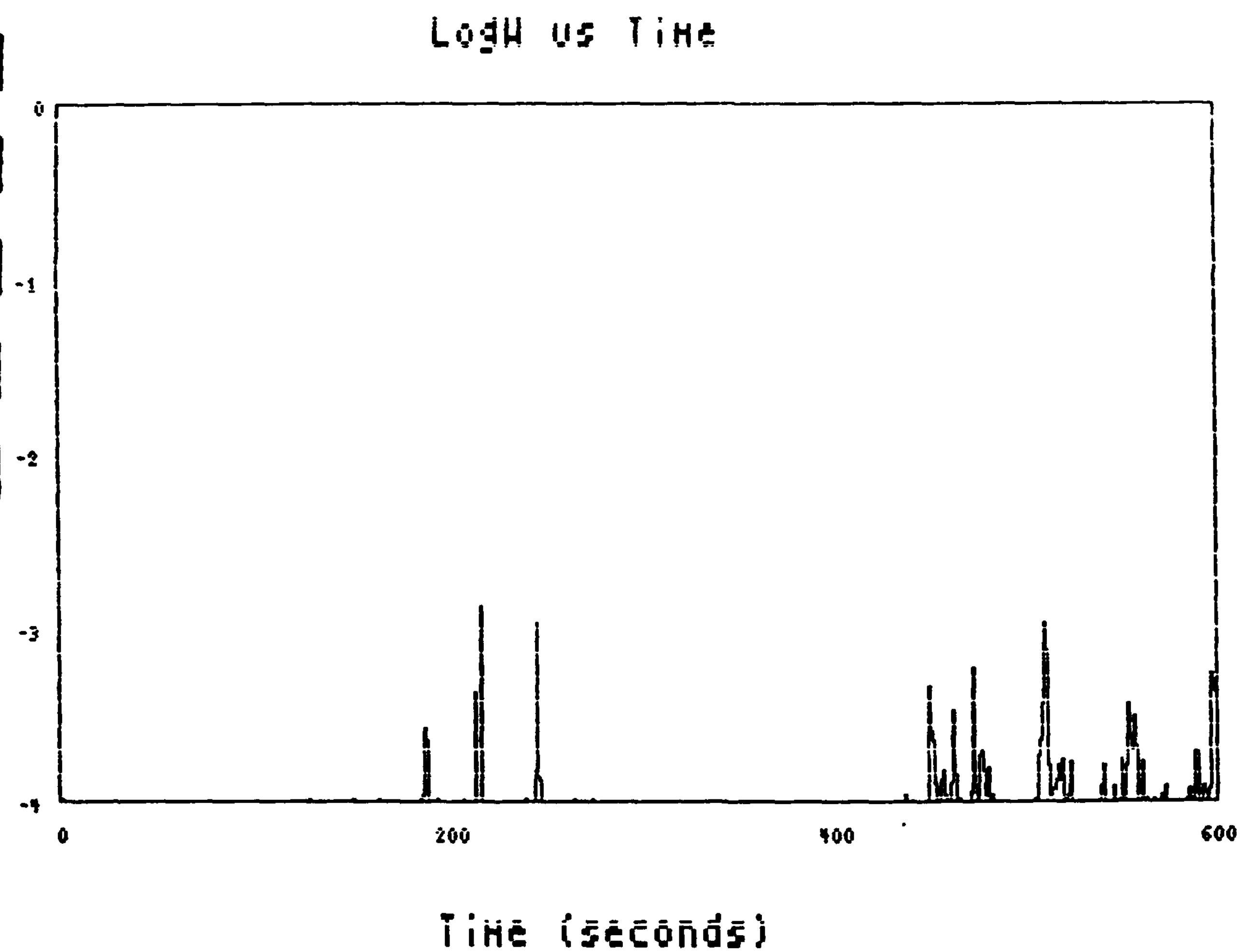
WHITECAP AVERAGE :	0.0000168	VARIANCE :	0.0000000
SKEWNESS :	9.0197536	KURTOSIS :	96.0927393

THRESHOLD VALUE : 4.75

METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
6.8	112.6	7.2	8.0	UNSTABLE

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

TAPE/EVENT NUMBER :P2101   DATE : 11/23/1991   STARTING TIME : 1357:1

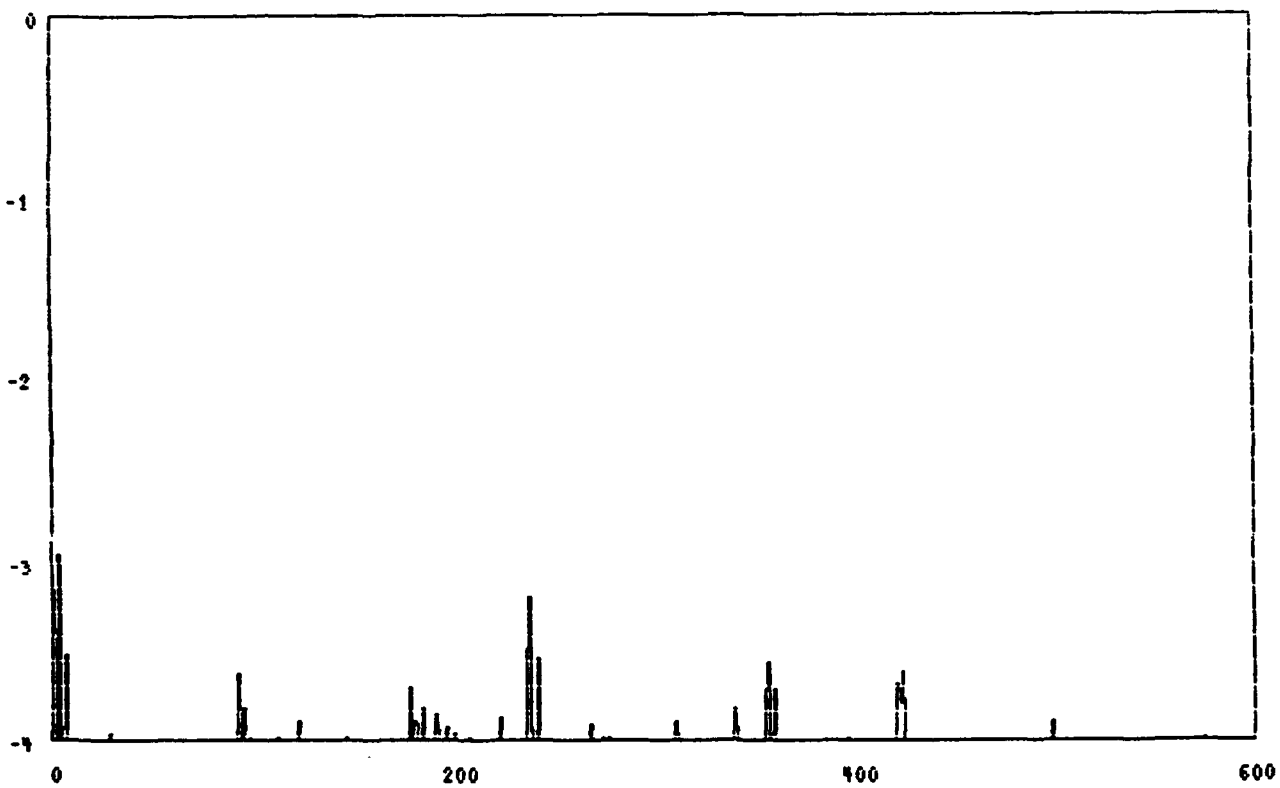
WHITECAP AVERAGE : 0.0000075   VARIANCE : 0.0000000
SKEWNESS : 12.7362352   KURTOSIS :192.3394856

THRESHOLD VALUE : 5.15
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
1.3	279.6	7.6	6.6	STABLE

COMMENTS :

LogW vs Time



Time (seconds)

ANALYSIS OF PARIZEAU CRUISE DATA

TAPE/EVENT NUMBER :P2201   DATE : 11/24/1991   STARTING TIME : 0947:3

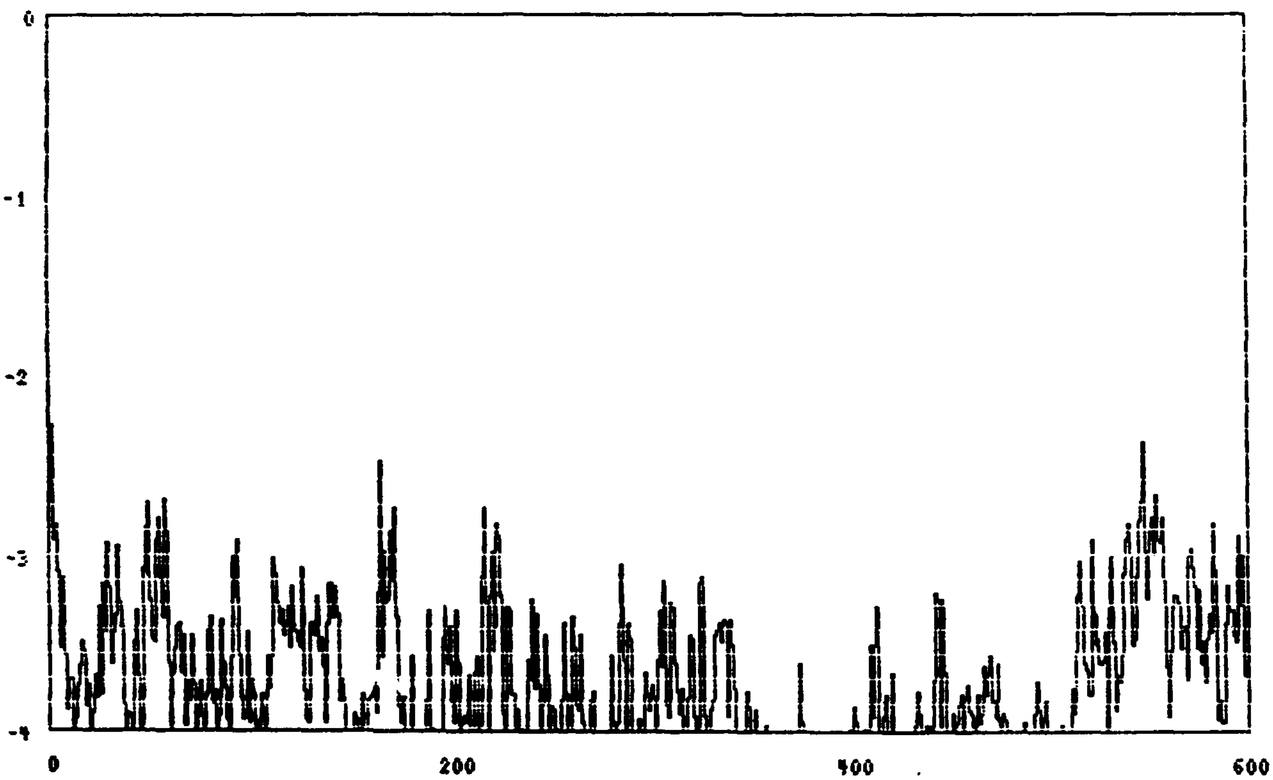
WHITECAP AVERAGE : 0.0002237   VARIANCE : 0.0000002
SKEWNESS : 4.8310393   KURTOSIS : 36.2775712

THRESHOLD VALUE : 4.60
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
12.4	110.8	8.2	8.5	NEUTRAL

COMMENTS :

LogW vs Time



Time (seconds)

ANALYSIS OF PARIZEAU CRUISE DATA

TAPE/EVENT NUMBER :P2301   DATE : 11/24/1991   STARTING TIME : 1105:1

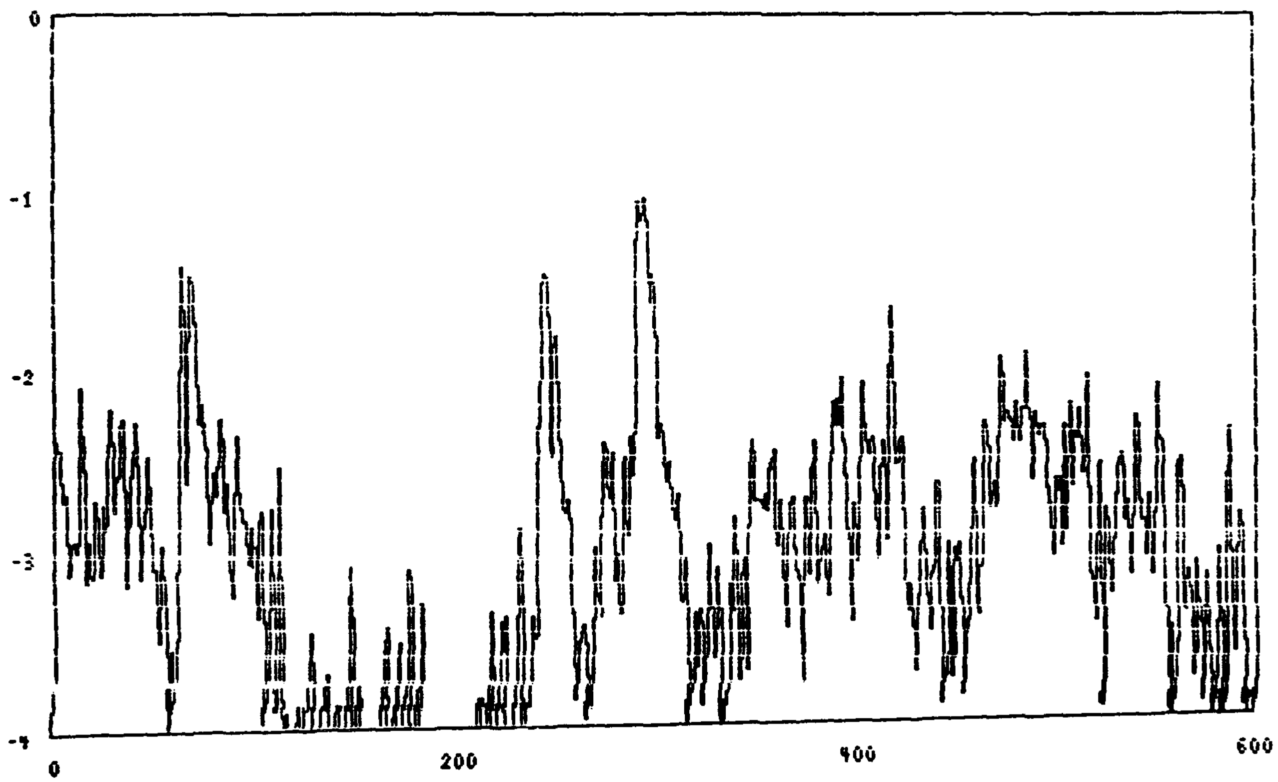
WHITECAP AVERAGE : 0.0031191   VARIANCE : 0.0000774
SKEWNESS : 6.6575065   KURTOSIS : 51.9690484

THRESHOLD VALUE : 5.50
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
10.6	98.2	8.9	8.5	NEUTRAL

COMMENTS :

LogW vs Time



Time (seconds)

ANALYSIS OF PARIZEAU CRUISE DATA

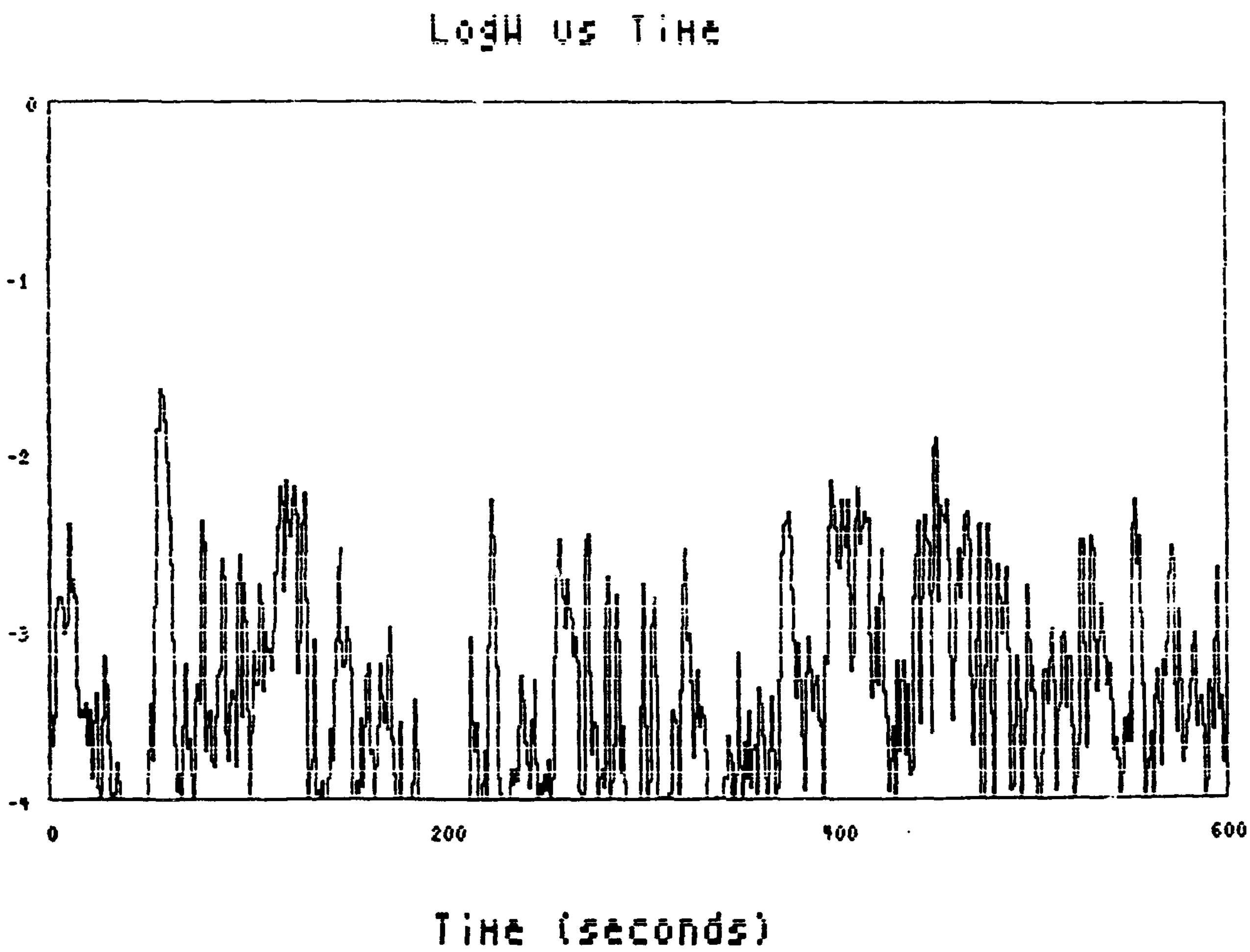
TAPE/EVENT NUMBER :P2401   DATE : 11/24/1991   STARTING TIME : 1154:

WHITECAP AVERAGE : 0.0010019   VARIANCE : 0.0000045
SKEWNESS : 5.1501460   KURTOSIS : 37.7070728

THRESHOLD VALUE : 4.21
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
11.9	116.4	8.8	8.5	NEUTRAL

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

TAPE/EVENT NUMBER :P2501Z   DATE : 11/25/1991   STARTING TIME : 1327

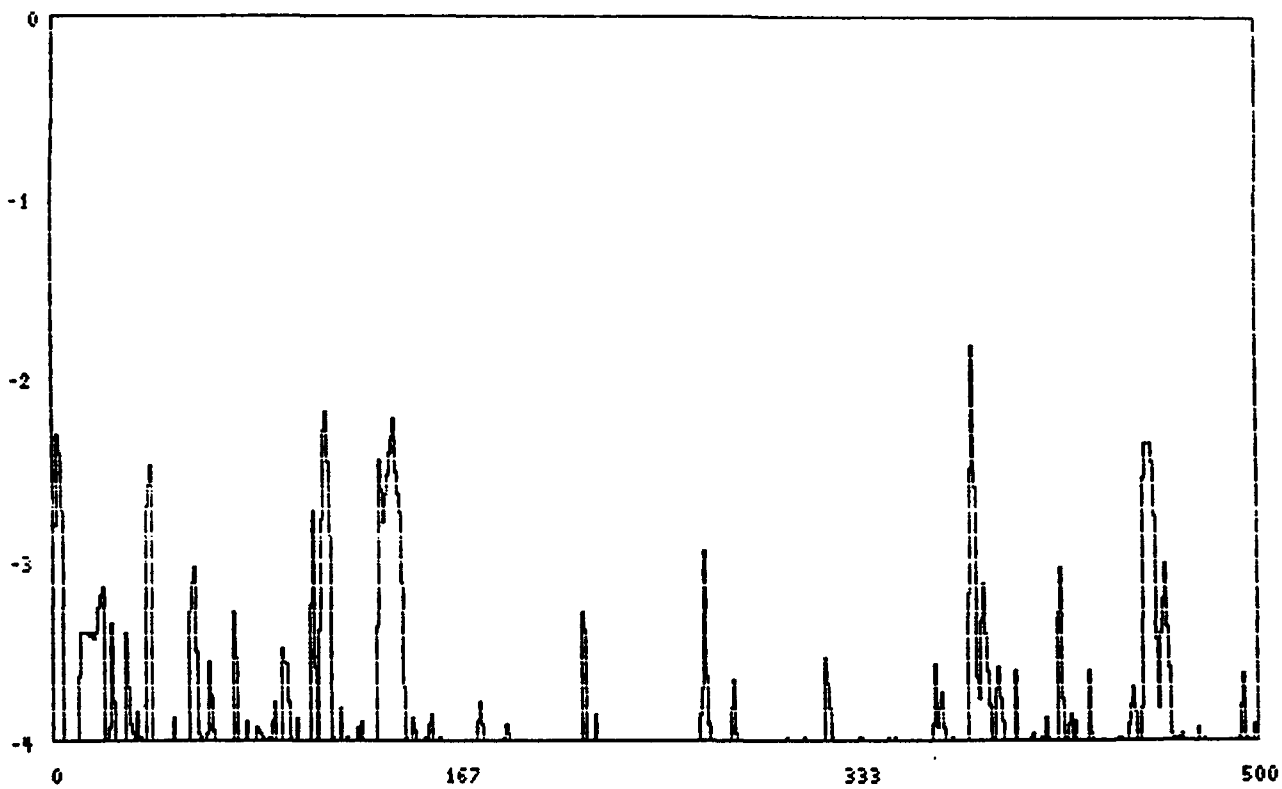
WHITECAP AVERAGE : 0.0002297   VARIANCE : 0.0000010
SKEWNESS : 8.2876240   KURTOSIS : 96.4513809

THRESHOLD VALUE : 4.20
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
10.3	92.0	8.9	8.5	NEUTRAL

COMMENTS :

LogW vs Time



Time (seconds)

ANALYSIS OF PARIZEAU CRUISE DATA

TAPE/EVENT NUMBER :P2601   DATE : 11/24/1991   STARTING TIME : 1412

WHITECAP AVERAGE : 0.0117205   VARIANCE : 0.0010495
SKEWNESS : 4.5748392   KURTOSIS : 25.6038286

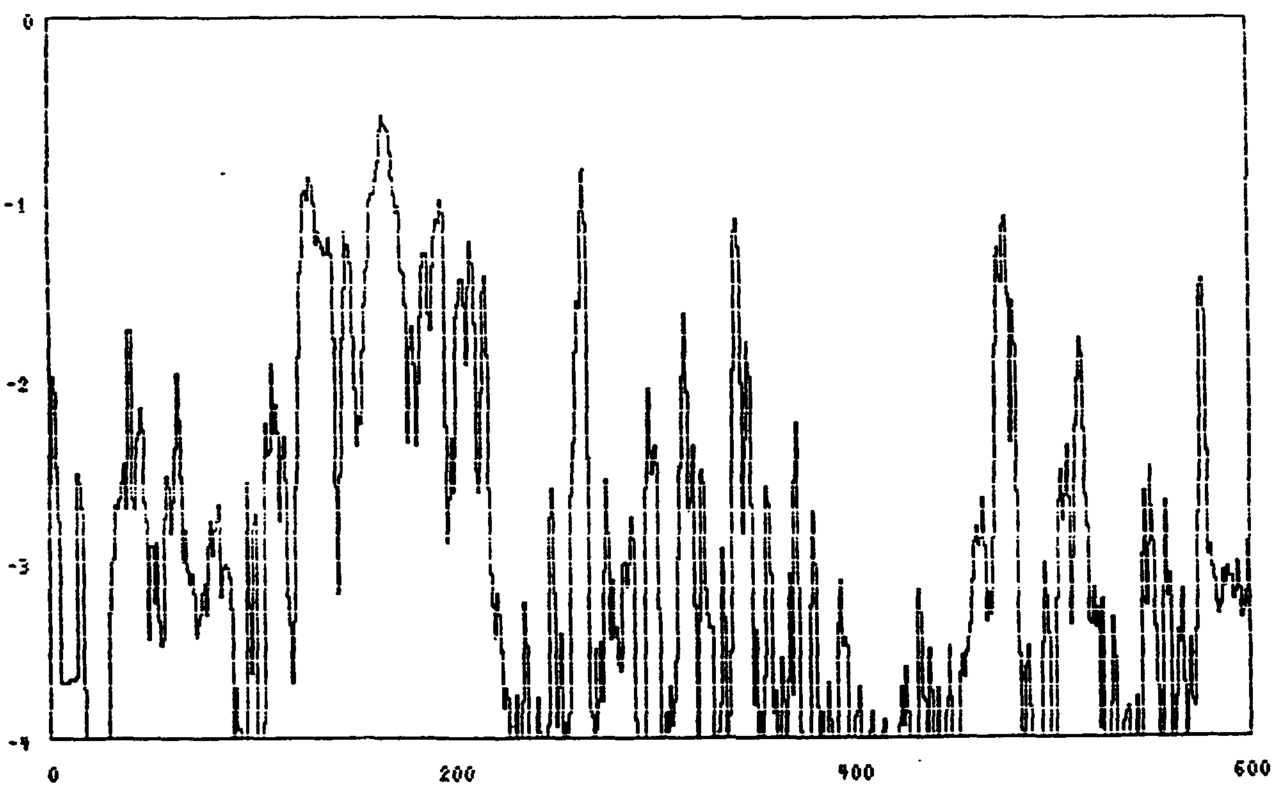
THRESHOLD VALUE : 4.30
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
11.7	95.6	9.0	8.5	NEUTRAL

COMMENTS :

some breaking waves may be produced by the ship

LogW vs Time



Time (seconds)

ANALYSIS OF PARIZEAU CRUISE DATA

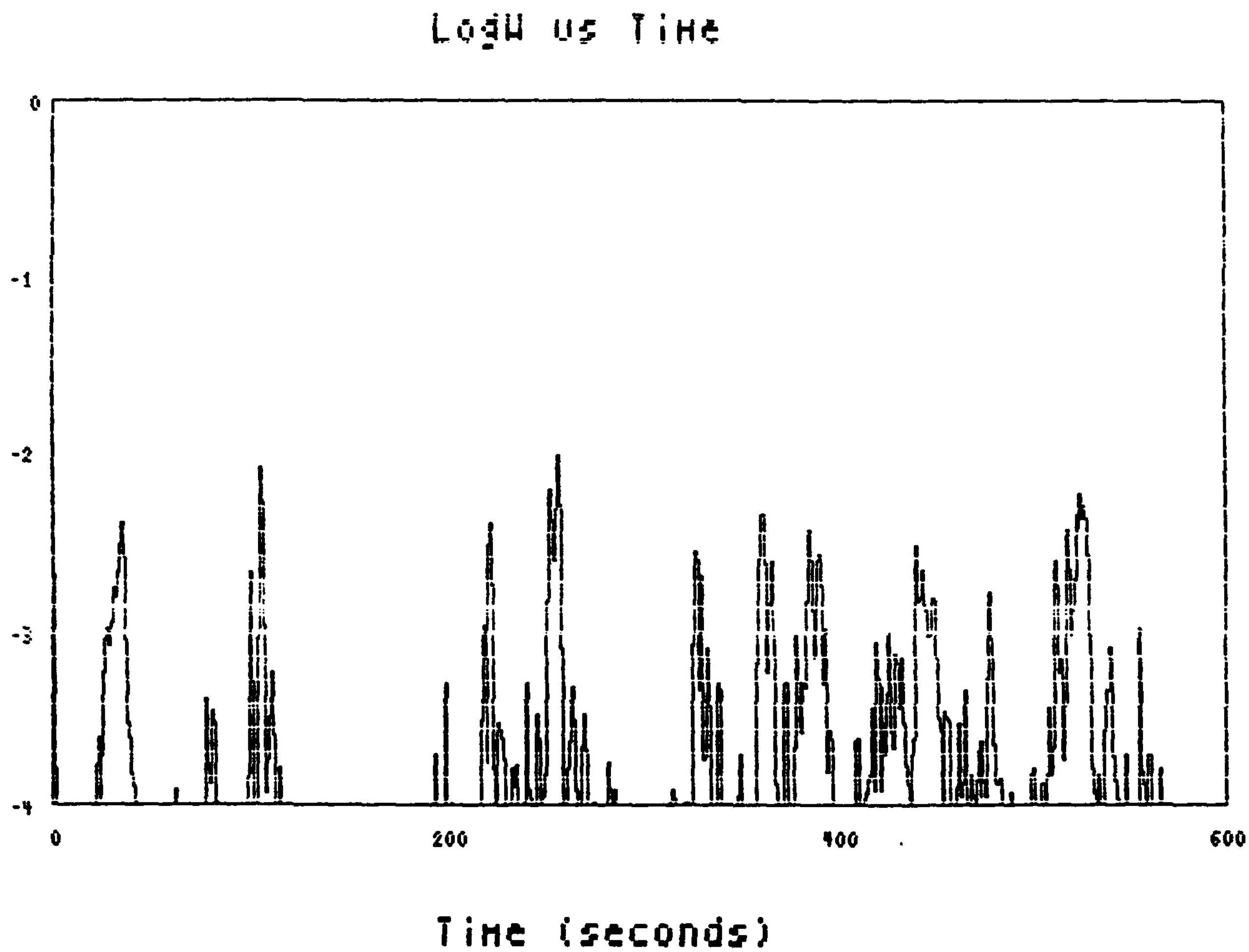
TAPE/EVENT NUMBER :P2701   DATE : 11/24/1991   STARTING TIME : 1530:0

WHITECAP AVERAGE : 0.0003574   VARIANCE : 0.0000010
SKEWNESS : 4.3253777   KURTOSIS : 23.2092333

THRESHOLD VALUE : 4.73
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
12.4	91.2	9.3	8.5	STABLE

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

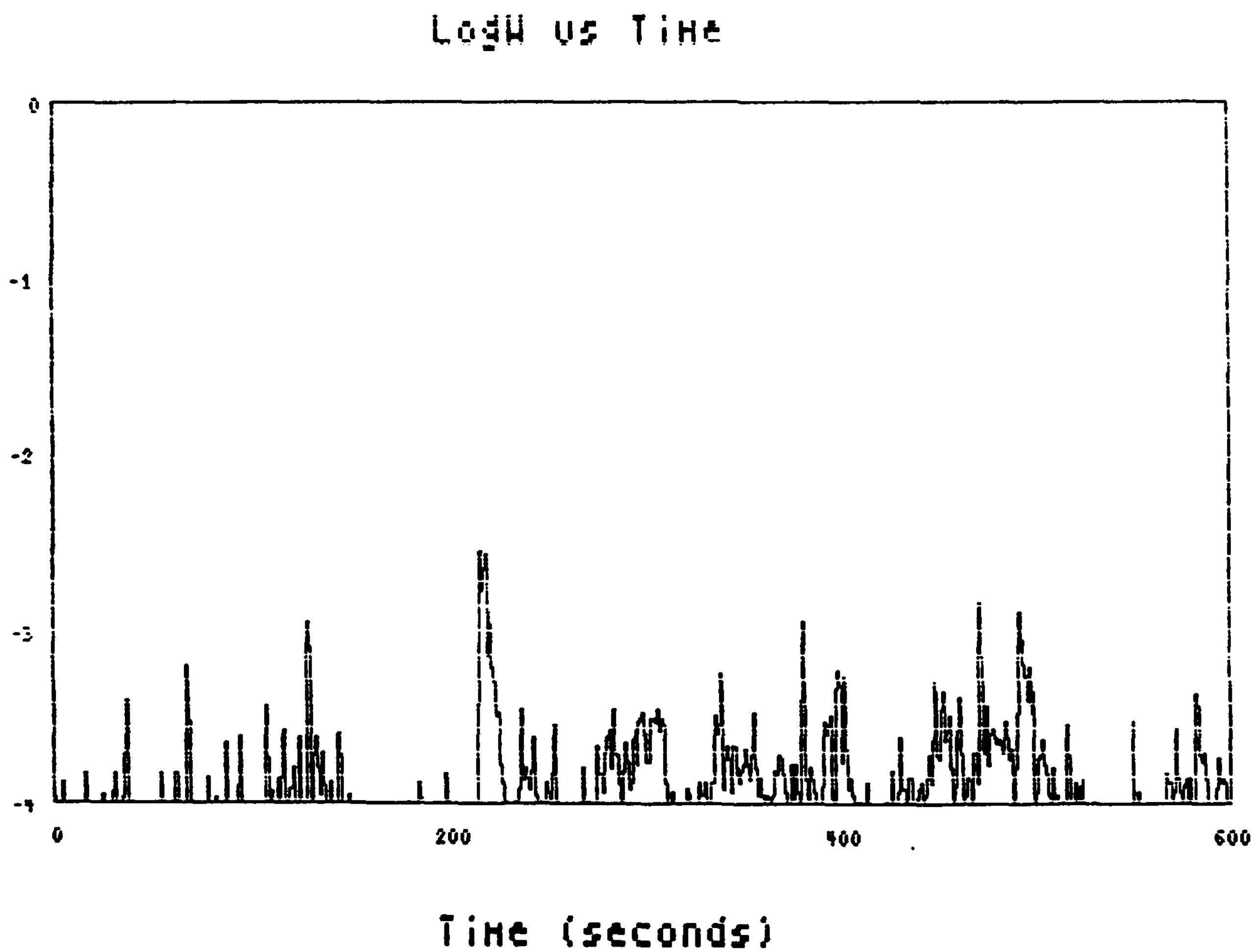
TAPE/EVENT NUMBER :P2901   DATE : 11/26/1991   STARTING TIME : 0930:

WHITECAP AVERAGE : 0.0000768   VARIANCE : 0.0000001
SKEWNESS : 6.8635863   KURTOSIS : 59.0307328

THRESHOLD VALUE : 4.35
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
0.1	271.5	7.9	8.3	NEUTRAL

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

TAPE/EVENT NUMBER :P3001   DATE : 11/26/1991   STARTING TIME : 1026:

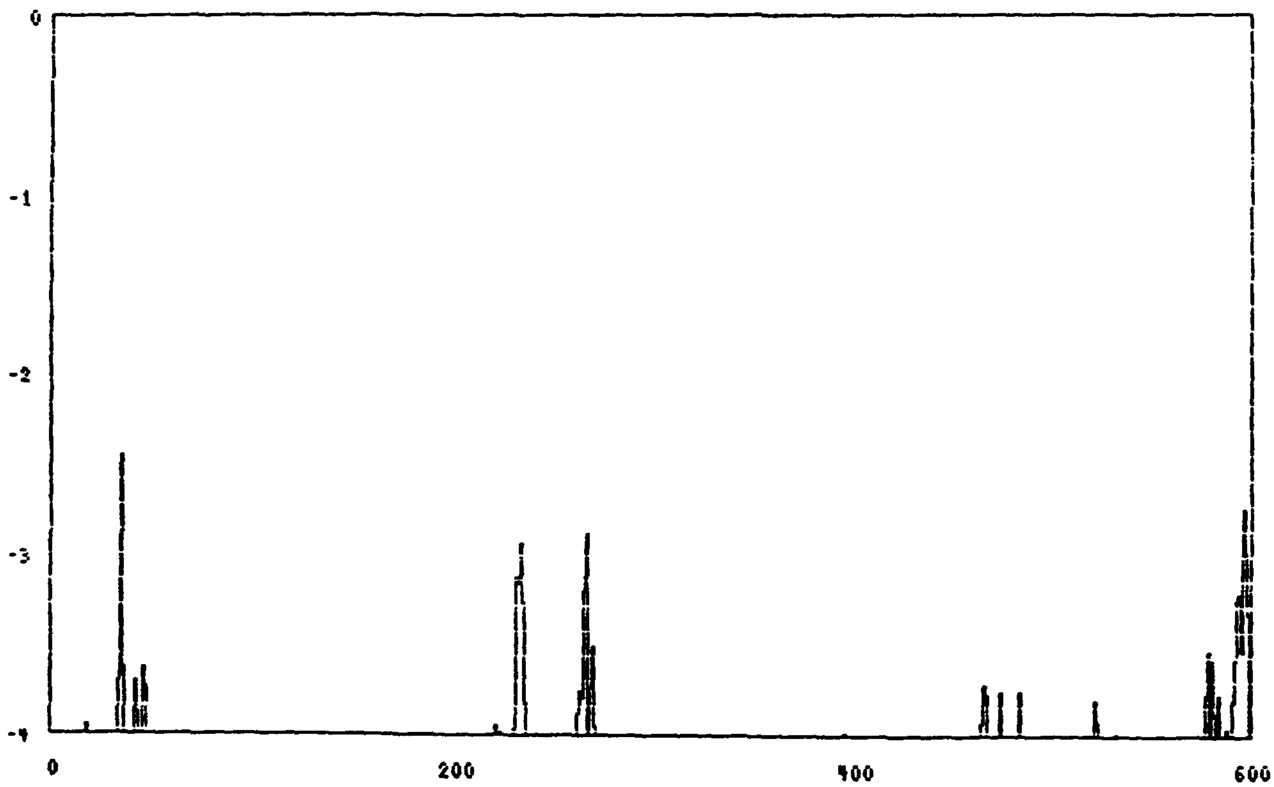
WHITECAP AVERAGE : 0.0000255   VARIANCE : 0.0000000
SKEWNESS : 12.6071348   KURTOSIS : 196.4808135

THRESHOLD VALUE : 4.45
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
5.5	105.2	7.8	7.7	NEUTRAL

COMMENTS :

LogW vs Time



Time (seconds)

ANALYSIS OF PARIZEAU CRUISE DATA

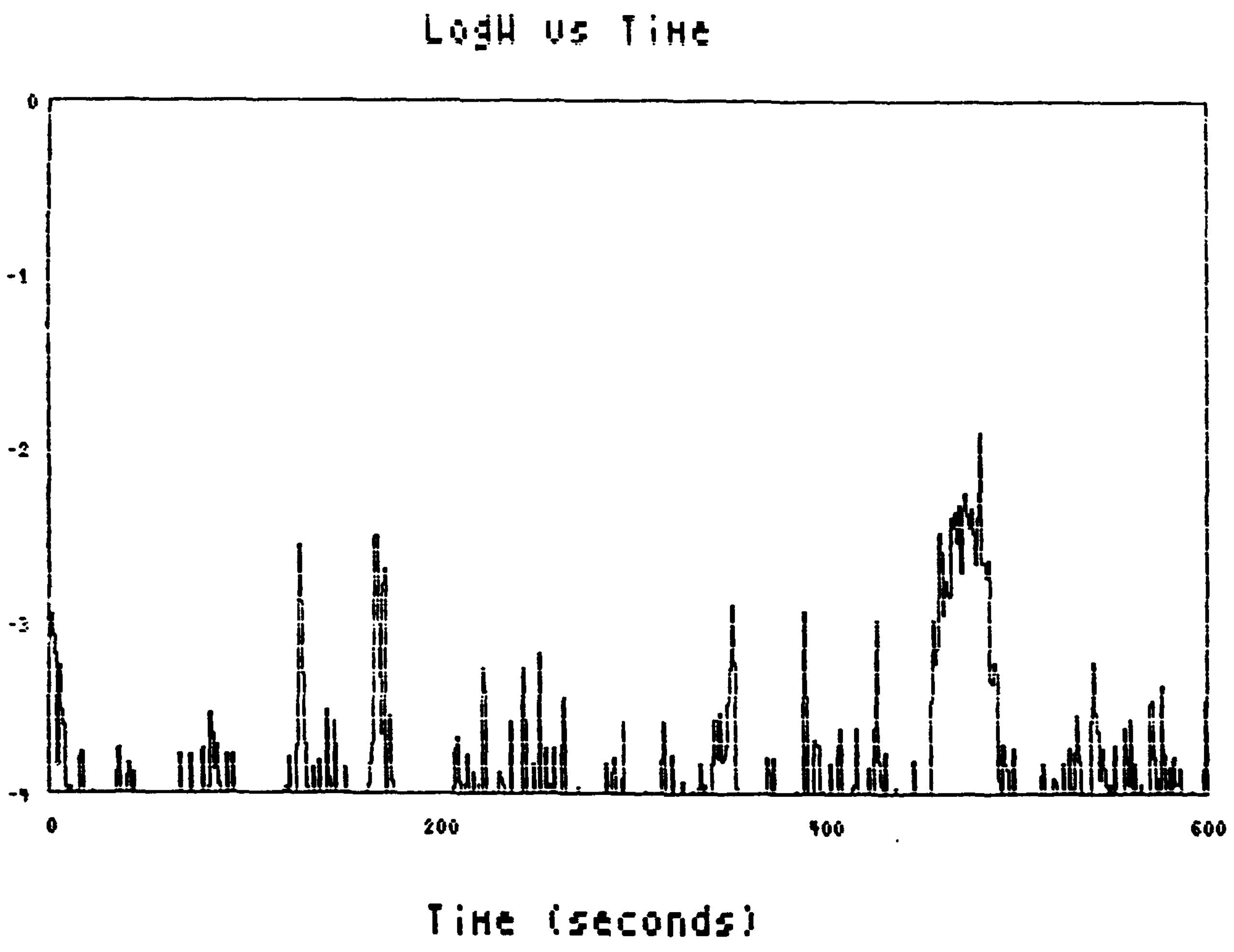
TAPE/EVENT NUMBER :P3101   DATE : 11/26/1991   STARTING TIME : 1115:

WHITECAP AVERAGE : 0.0002082   VARIANCE : 0.0000007
SKEWNESS : 7.3542451   KURTOSIS : 77.3365405

THRESHOLD VALUE : 4.58
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
7.6	136.2	7.9	8.4	UNSTABLE

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

TAPE/EVENT NUMBER :P3201 DATE : 11/26/1991 STARTING TIME : 1246:

WHITECAP AVERAGE : 0.0000052 VARIANCE : 0.0000000
SKEWNESS : 24.3632402 KURTOSIS :592.6851462

THRESHOLD VALUE : 4.55
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
5.1	159.8	7.7	8.4	UNSTABLE

COMMENTS :

LogW vs Time

Time (seconds)

ANALYSIS OF PARIZEAU CRUISE DATA

TAPE/EVENT NUMBER :P3301   DATE : 11/27/1991   STARTING TIME : 0813:

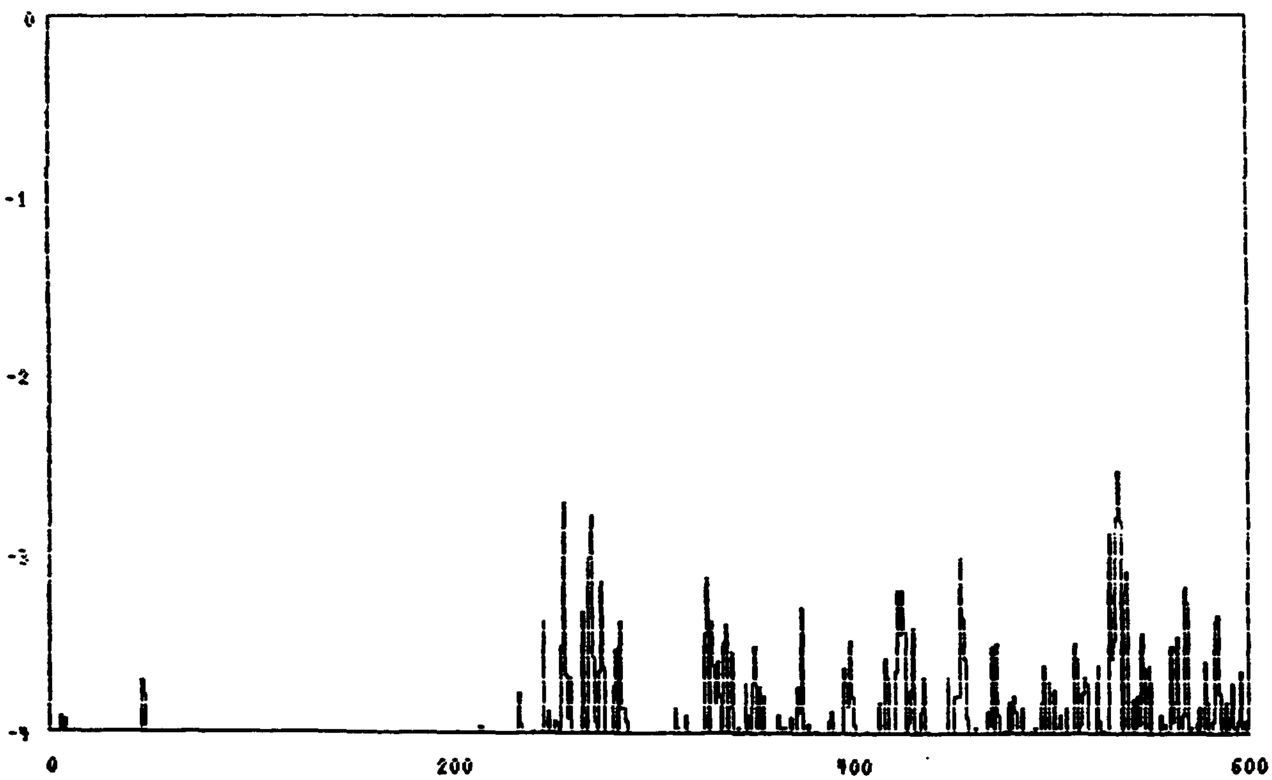
WHITECAP AVERAGE : 0.0000504   VARIANCE : 0.0000000
SKEWNESS : 8.0190927   KURTOSIS : 82.0743687

THRESHOLD VALUE : 4.98
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
8.0	309.4	7.0	8.4	UNSTABLE

COMMENTS :

LogW vs Time



Time (seconds)

ANALYSIS OF PARIZEAU CRUISE DATA

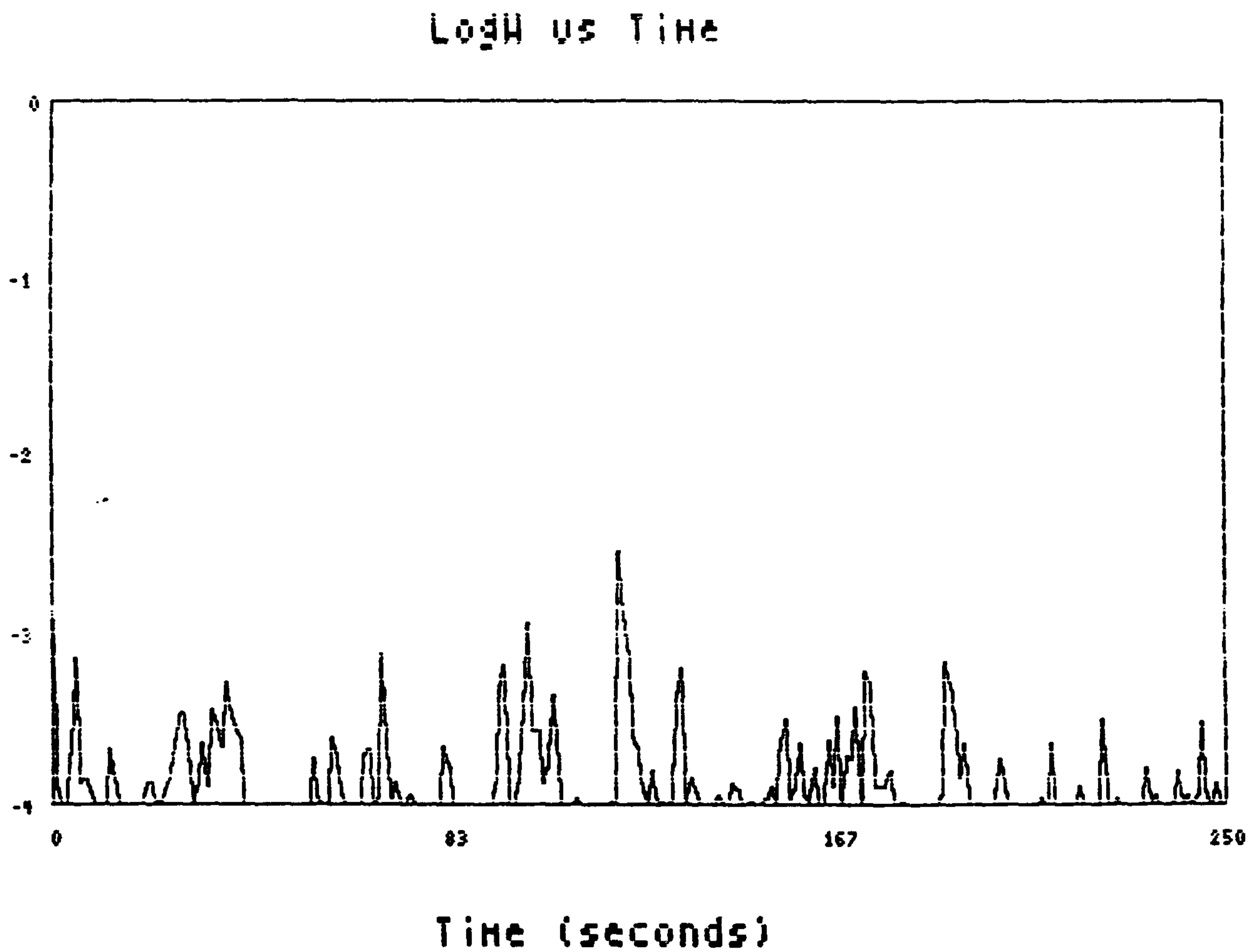
TAPE/EVENT NUMBER :P3401 DATE : 11/27/1991 STARTING TIME : 0928:

WHITECAP AVERAGE : 0.0000767 VARIANCE : 0.0000001
SKEWNESS : 6.8274728 KURTOSIS : 61.9832597

THRESHOLD VALUE : 5.10
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
5.3	18.0	7.2	8.4	UNSTABLE

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

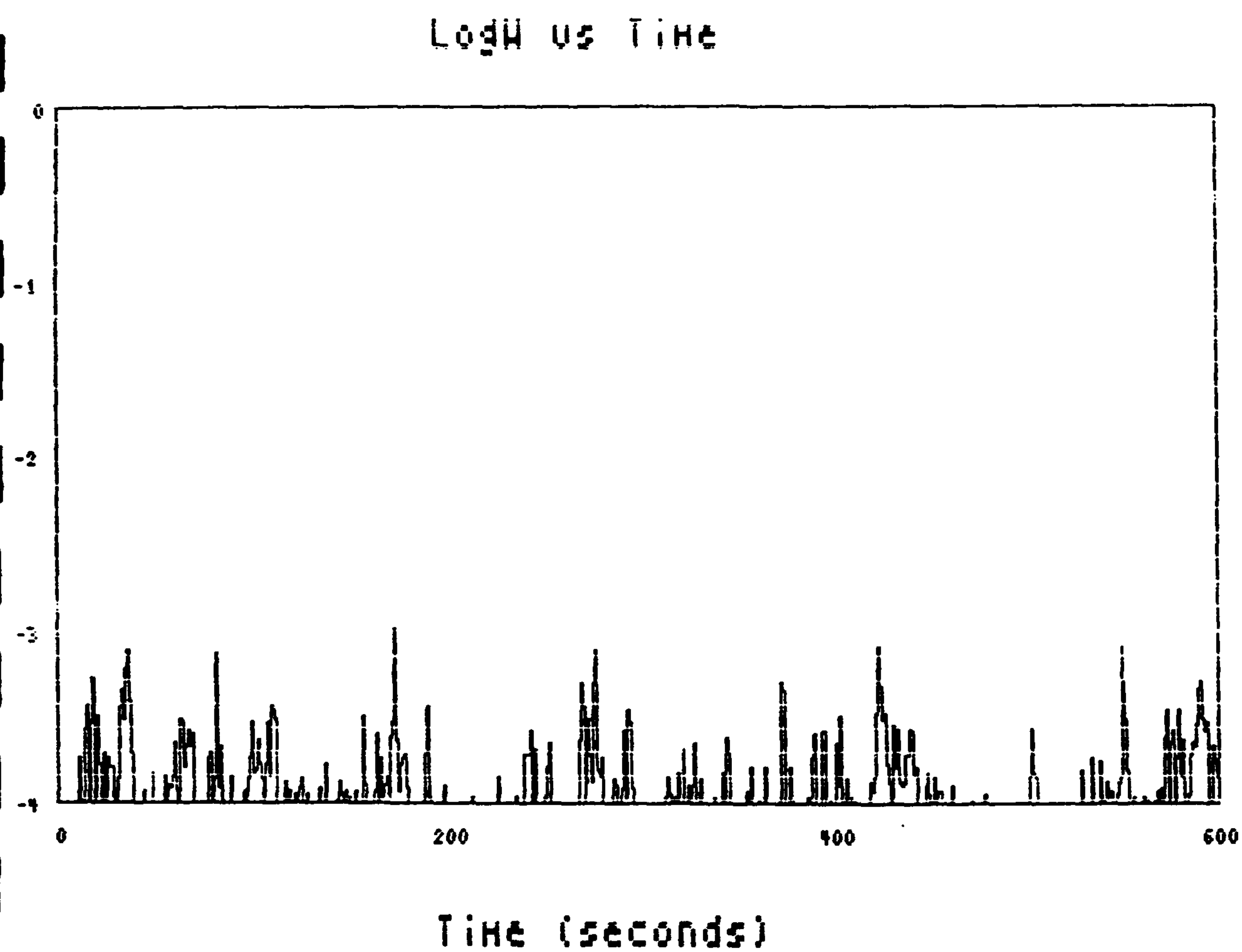
TAPE/EVENT NUMBER :P3501   DATE : 11/27/1991   STARTING TIME : 1012:

WHITECAP AVERAGE : 0.0000460   VARIANCE : 0.0000000
SKEWNESS : 4.3926254   KURTOSIS : 25.5618650

THRESHOLD VALUE : 4.97
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
5.6	84.6	7.3	8.4	UNSTABLE

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

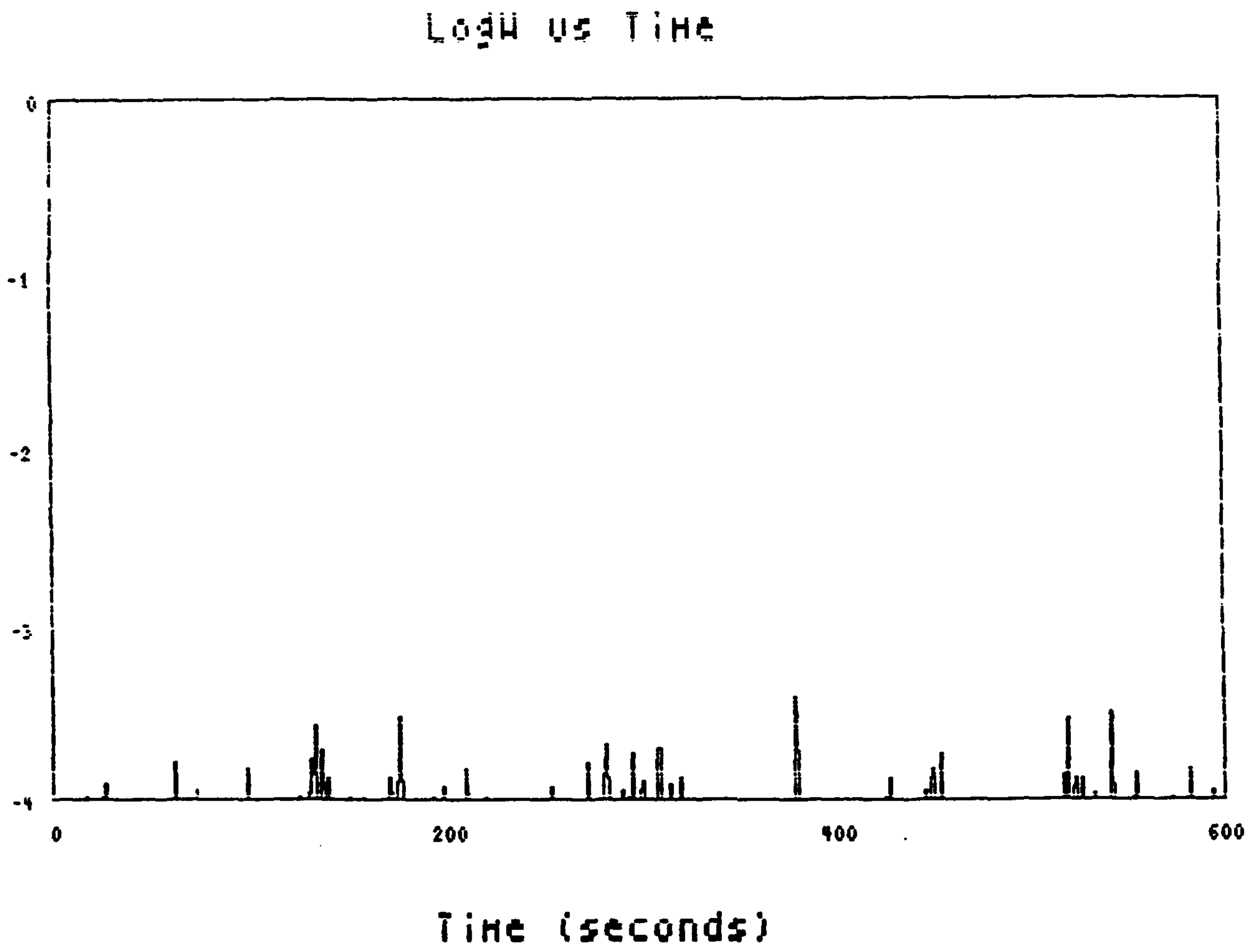
TAPE/EVENT NUMBER :P3601 DATE : 11/27/1991 STARTING TIME : 1115:

WHITECAP AVERAGE : 0.0000048 VARIANCE : 0.0000000
SKEWNESS : 7.3381058 KURTOSIS : 64.3046982

THRESHOLD VALUE : 4.05
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
5.2	70.2	7.9	8.4	UNSTABLE

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

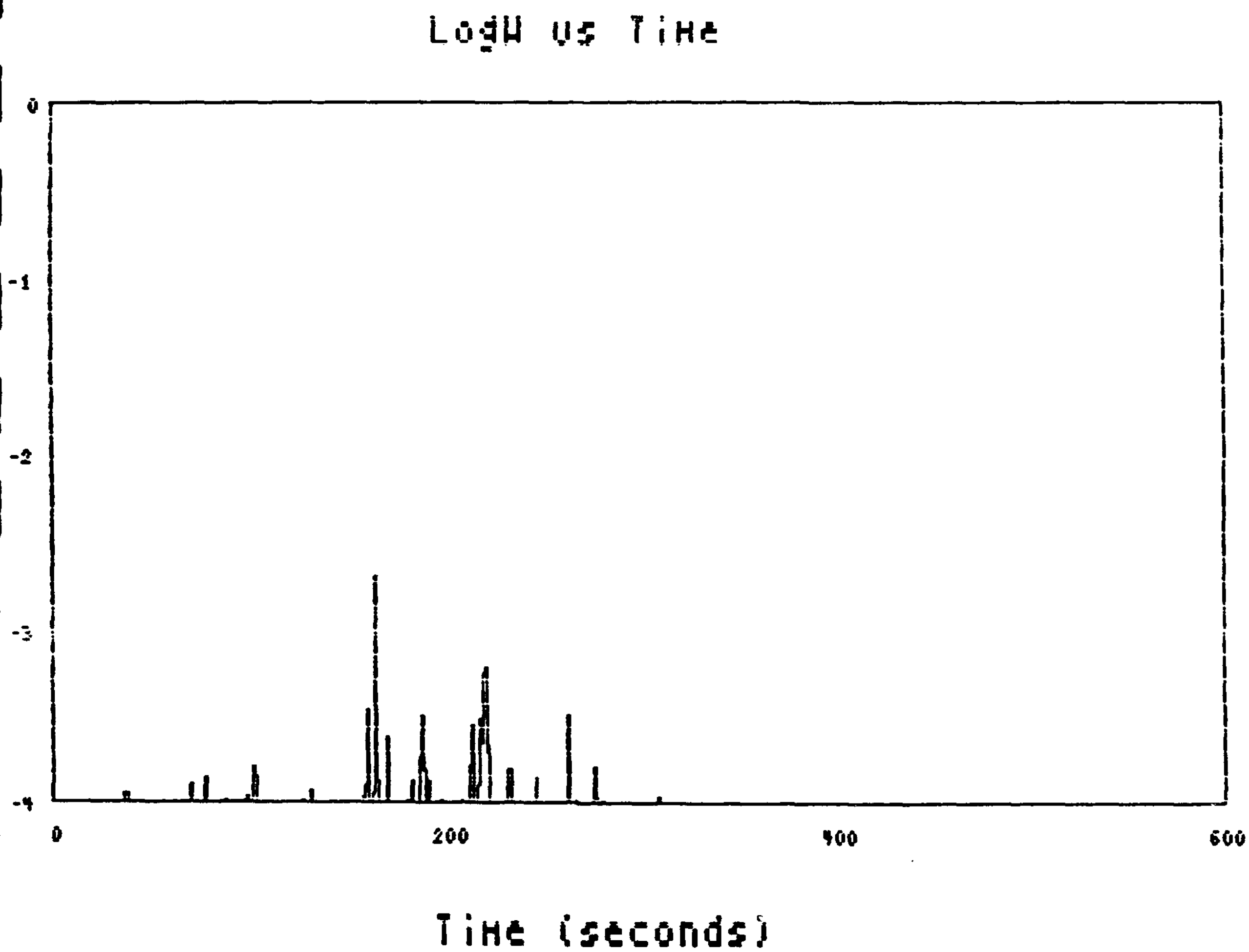
TAPE/EVENT NUMBER :P3701   DATE : 11/27/1991   STARTING TIME : 1255:

WHITECAP AVERAGE : 0.0000113   VARIANCE : 0.0000000
SKEWNESS : 14.9889557   KURTOSIS :241.1786579

THRESHOLD VALUE : 4.28
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
6.3	323.2	8.3	8.3	NEUTRAL

COMMENTS :



ANALYSIS OF PARIZEAU CRUISE DATA

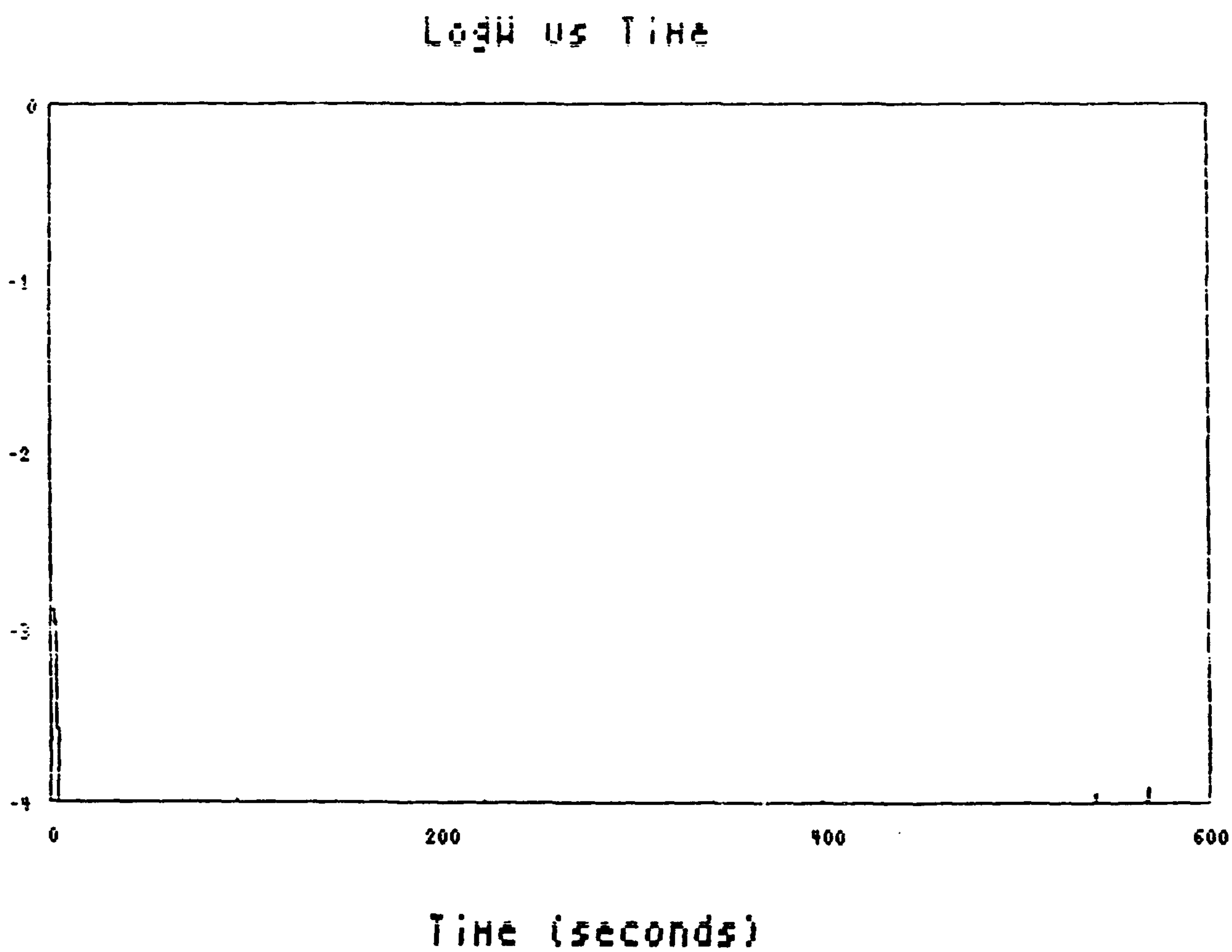
TAPE/EVENT NUMBER :P3801   DATE : 11/27/1991   STARTING TIME : 1527

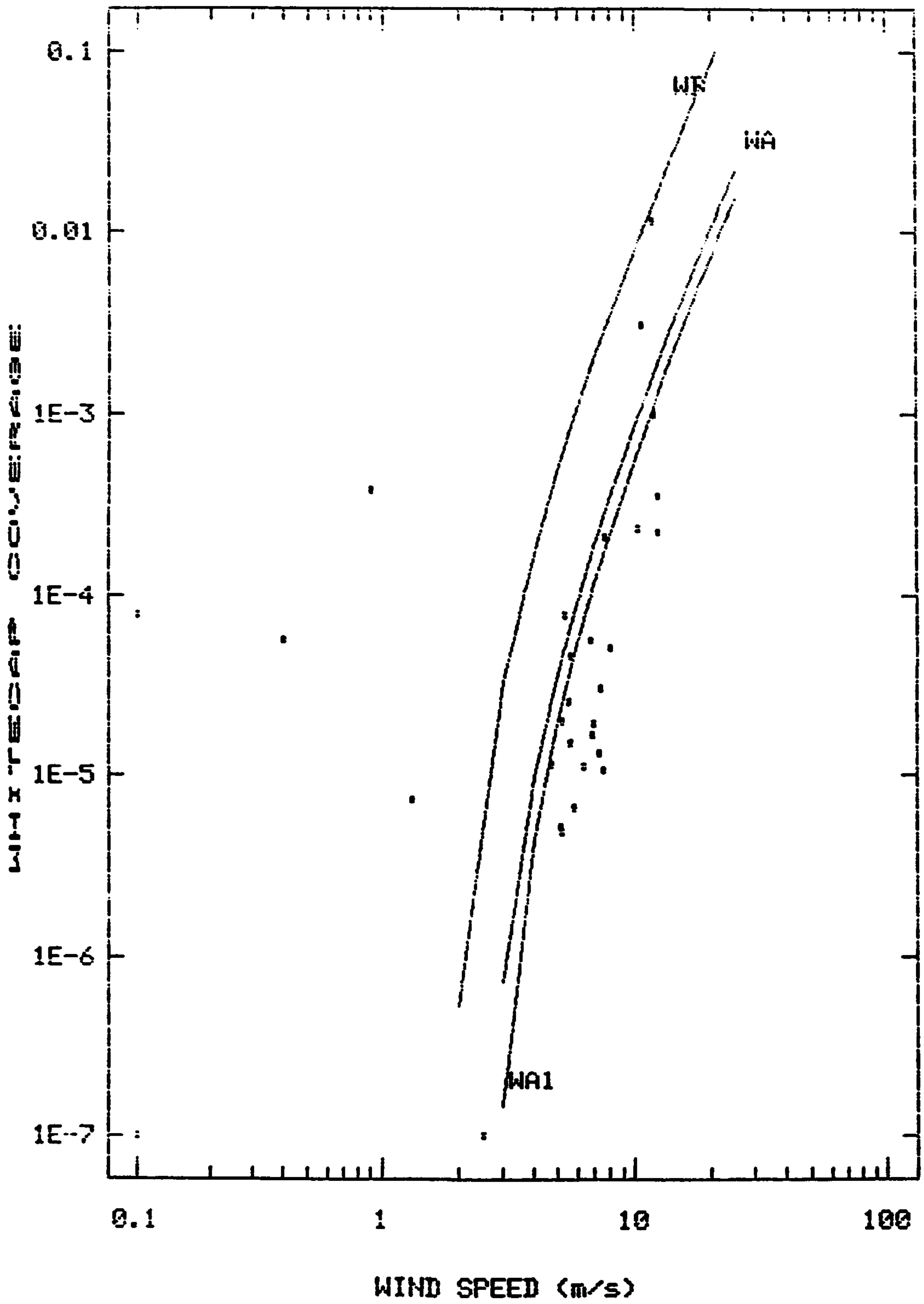
WHITECAP AVERAGE : 0.0000066   VARIANCE : 0.0000000
SKEWNESS : 12.8031989   KURTOSIS :166.9343644

THRESHOLD VALUE : 4.38
METEROLOGICAL DATA :

W_S(m/s)	W_D	T_air	T_water	STABILITY
5.8	308.0	8.1	8.3	NEUTRAL

COMMENTS :




0.1
0.01
1E-3
1E-4
1E-5
1E-6
1E-7
WHITECAP COVERAGE
WF
WA
WA1
0.1
1
10
100
WIND SPEED (m/s)

CHAPTER 9

TRIP REPORT: WHITECAP VIDEO INSTALLATION, R/V TULLEY, IOS, SIDNEY, BC

BY

M.B. WILSON

CHAPTER 9

Trip Report
Whitecap Video Installation
R/V TULLEY
I.O.S. Sidney, British Columbia.

Monday, 10 February 1992:
Shipped video equipment to Seattle, WA. Hold for pick-up by MBW. I will transport the video equipment across the border.

Wednesday, 12 February 1992:
Departed home (Ledyard, CT) at 0530 for Greene Airport, using my vehicle. 0735, en route to Seattle, WA, U.S. Air Flight 697. 1245, arrived Seattle. Picked-up rental vehicle and video equipment from air freight forwarding company, and proceeded to U.S./Canadian Border. There was no problem clearing either U.S. or Canadian Customs. Proceeded to Tsawwassen B.C., ferry landing. Caught 1900 ferry to Swartz Bay and arrived at the Hotel Sidney shortly before 2100.

Thursday, 13 February 1992:
Proceeded to I.O.S. Sidney for meeting with Mr. Steven Hill on the installation of the video equipment. Arranged to store the equipment overnight. Met with Mr. Mark Travarro on the results of the whitecap video from the cruise of the R/V PARIZEAU. As a result of that meeting, Mr. Travarro provided charts of the areas where the whitecap video registration was taken. He will also attempt to provide a copy of the ship's CSAIL data in a format we can access. I was instructed not to go on board the TULLEY until they had a chance to off load equipment from a prior cruise, about 0930 on 14, February.

Friday, 14 February 1992:
Arrived onboard the TULLEY and made arrangements to have MSI equipment lifted on board. Installed the video cameras, wiring, and assembled the electronics, checked out the systems and powered up the systems for test. Pictures on both systems look good. Left systems run all night. Remaining work consists of final location and installation of the electronics package.

Saturday, 15 February 1992:
Returned to the ship and completed the physical installation. Discussed the operation of the systems with Mr. Jeff Hansen and Mr. Robert Waterworth of Johns Hopkins APL. Instructed them on operation and packaging of the systems for shipment to UConn at end of cruise. Left system operating.

Sunday, 16 February 1992:
Returned to ship to check video systems prior to departure. Systems were working properly. Informed J. Hansen that installation was complete and that I was departing the area.
I was able to catch the 1000 ferry from Swartz Bay to Tsawwassen, B.C. and drove to Seattle, WA. Remained overnight in Seattle.

Monday, 17 February 1992:
Made arrangements to change 2245 flight to an earlier (1335) flight. Returned to Providence, RI (Green Airport) arriving 2305. Picked up my vehicle from long term parking and drove to Ledyard, CT (home). Arrived home at 0025, 18 February. Trip completed.

CHAPTER 10

A SUMMARY FOR THE THREE-MONTH TESTING TECHNIQUE TRAINING

BY

G. WANG, Y. LIU AND L. LI

CHAPTER 10

A Summary for the Three-month Testing Technique Training

Sponsored by UNIDO

Gongquan Wang, Yiwei Liu and Liquani Li[1]

09 September 1992

Development of sciences and technology is closely related to the improvement of the corresponding testing technique. In some cases, the testing technique and means may determine how the related scientific research goes.

Under the leadership of Dr. E.C. Monahan, the Sea Surface Physics Lab, Marine Sciences Institute, UConn, has made a lot of scientific achievements. Besides, this lab is equipped with many sophisticated instruments and some other advanced computerized data analysis systems.

We have been assigned by United Nations Industrial Development Organization (UNIDO) to participate in a three-month testing technique training program at the lab. A training plan was made on basis of the current research and the instruments available in the lab. An emphasis is placed on the learning of some advanced testing technique principle and its applications by lecturing and reading technical papers and books. We have been demonstrated the operation of the various instruments and have practiced on those equipments and encouraged to participate in some experimental work. Furthermore, we have been arranged to visit several labs outside the University to observe some advanced instrumentation. Through the entire training program, we have gained a lot of technical experiences and broadened our knowledge which will be very helpful for our future work. We all satisfy what we gained during the training period and are very grateful to Dr. Monahan and his colleagues for their favorable efforts making our training possible.

I. Experimental Work

We have participated in the preparation of the wave-wave interaction experiment in which the parameter J will be yielded from measuring size spectra of bubbles underwater and size distributions of the associated aerosols in air.

A. Light Source of Bubble Video Microscope

We assisted the colleagues in the lab to build two flash LED lights sources for the submergible bubble video microscope, and learned how the video microscope takes bubble image underwater and how its corresponding computerized bubble image analysis system works. We are surprised that the hardware and software are so efficient to obtain bubble size spectrum.

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[1]These fellows, from Research Institute of Electric Light Source Materials Under Ministry of Light Industry, P.R. China, have been assigned by UNIDO to participate in a 3-month technique training program at the Sea Surface Physics Lab beginning on 3 July.

B. Particle Measuring System (PMS)

We got familiar with the laser scattering technique, circuit design and data acquisition of the PMS equipment. On consideration of the PMS manufacturer's suggestion, we modified the interface circuit between the PMS instrument and IBM personal computer in order to monitor the PMS activity signal which indicates the saturation of the PMS measurement, and did a lot of work for testing the interface, through which we also learned some interface technique.

II. Computer Technique

We noted that the laboratory emphasizes on the applications of some modern computer technique to their work, which makes the research more efficient and accurate. We have been demonstrated several software, such as MATLAB, TURBO PASCAL V6.0, STATGRAPH, WORDPERFECT V5.1 and NORTON UTILITIES, and have practiced them in IBM personal computers 486/33 and 386/25. We also learned some advanced applications for scientific calculation, graphics, word processing and data acquisition.

III. Signal Processing

We built an anti-alias filter and an operation amplifier which may be used with DASH-16 A/D-D/A board as an acoustical signal acquisition system for monitoring underwater bubble noise. Some digital spectrum techniques were lectured for measuring frequency response of linear system. We successfully applied these methods to obtain the frequency responses of the filter and amplifier, from which we found these robust techniques are very useful for our own research.

IV. Reading Technical Paper

We are interested in advanced techniques and their applications of electronic circuits and read some technical papers and books available at the laboratory and at the Avery Point Library, such as National Semiconductor Corp. serial reference books, from which we got a better understanding of modern electronics.

We read several papers related to Mie scattering theory which can be applied to the measurement of size distributions of tiny bubbles and aerosols. We note that the PMS instrument uses the Mie scattering technique to monitor aerosol with diameter from 0.5 micron to 47 micron. By reading some recent technical papers and reports, we know that some American companies are developing apparatus by using Dynamic Light Scattering technique for measuring very fine particle with radius of several nanometers.

V. Library and Reference Material

We were impressed that most American libraries have some advanced computerized searching systems with compact disk information storage and readers can access to the system to find much useful information of technical materials, which is much different from the library in our institute. Through the whole training, we learned how to operate the searching system at Avery Point Library and at UConn Storrs library. We also became familiar with library archives and searching of micro-file materials.

CHAPTER 11

AIR ENTRAINMENT BY PLUNGING LIQUID JETS

BY

X. WANG

CHAPTER 11

AIR ENTRAINMENT BY PLUNGING LIQUID JETS

Xingsheng Wang

Marine Sciences Department, University of Connecticut, Groton, Connecticut

ABSTRACT

An experiment which simulates the jet aspect of a breaking wave was conducted to study the effects of temperature, salinity, and angle (θ) between a jet and the surface of a liquid, on air entrainment by jets. The results indicate that as the temperature of the liquid increases, the entrained air increases; as the salinity of liquid increases, the air entrained decreases, and, as angle (θ) between the jet and the surface of the liquid decreases, the entrained air increases. These results can be explained by the changes of surface tension and viscosity and are similar to the results reported in fresh and salt water whitecap coverage which also depend on temperature and salinity.

1. INTRODUCTION

A liquid jet impacting a liquid surface will cause air entrainment when the velocity of the jet exceeds a critical value. An impacting jet often occurs in many industrial processes and in nature. Chemical engineers introduce air into liquids to increase gas-liquid contact, to agitate the liquid phase and to produce foams and froth.

Plunging liquid jets have been employed to study bubble production by breaking wind wave (1) and falling liquid streams (2). Falling liquid streams are helpful in modeling plunging breaking waves (3). Koga (1) used plunging liquid jets to simulate the mechanism of bubble formation in waves where intermittent bubble entrainment by an ordered covergent flow occurs on the leading slope near the crest. Detsch *et al.* (4,5) use plunging liquid jets to obtain the critical angles for air bubble entrainment by jets for different liquid surface conditions.

In the present study, fresh water and salt water are employed to explore air entrainment by jets. Factors including the velocity of jets, the distance between the nozzle and the surface of the water, the temperature and salinity of water, and the angles between jets and the water surface are investigated.

2. EXPERIMENT

2.1 The design of the experiment

A Sketch of the apparatus used is shown in figure A. A liquid pump circulates water around the system, and maintains the level of water in the tank constant. The volume of entrained air is read from the air flowmeter, the principle being that the rate of air flow which is entrained to the outside of the containment cylinder by the jet is equal to the air volume which flows through the air flowmeter into the cylinder when the pressure inside cylinder is maintained equal to the pressure in the open air. The balance of pressure inside the cylinder and in the open air can be maintained by adjusting the air flowmeter. The pressure difference is monitored by viewing the output of a D/P gauge on the computer screen.

2.2 Experiments

For a specific nozzle diameter:

a. Nozzle near the water surface (*L = 20mm*)

1. Different water temperature: various velocities of jet, measure entrained air
2. Different jet plunging angle: various velocities of jet, measure entrained air.
3. Different water salinity: various velocities of jet, measure the entrained air.

b. Nozzle above water surface L2, L3, repeat 1, 2, 3, above.
Then use different nozzle diameter to repeat above a, b.

3. RESULTS AND CONCLUSIONS

3.1 Different distance between nozzle and the surface of water

From Figure 1 and Figure 2, with different L, the rate air entrainment is different, this is largely attributable to the boundary layer of jets, although the velocity of jets also increase as L become greater, the increase is small according to the Bernoli equation.

3.2 Different angles between jet and the surface of water

According to Koga (1), at the critical point for bubble entrainment, the downward force of the jet flow and the restoring upward pressure force of surface tension are balanced. The downward force is assumed to be proportional to the dynamic pressure $1/2pV^3$ of jet, and the upward pressure can be written as $\sigma(1/r_1+1/r_2)$, where p is density of water, V the velocity of the jet flow, σ the surface tension ,and r_1 and r_2 are the radii of curvature of the water surface in the vertical and horizontal section.

When the angle (θ) decreases, r_2 increases, so the quantity $\sigma(1/r_1 + 1/r_2)$ decreases, and it is easy for jets to entrain air into water. This is in agreement with the experimental result of Figure 3 and Figure 4.

3.3 Different temperatures

As temperature rises, the surface tension and viscosity decrease as follows:

$$\sigma = \sigma_0(1-t/t_1)^n (6)$$

$t=10\ C, \mu = 1304 \mu\ pa\ sec$ (7)

$t=40\ C, \mu = 655 \mu\ pa\ sec$

where σ_0 is the surface tension at $t\ C$, t_1 is a temperature within a few degrees of the critical temperature, and n is a constant that lies between 1 and 2.

When σ decreases, it is easy for jets to entrain air into the water, this is in agreement with the results of the experiments summarized in Figures 10-14, this is also in agreement with the field whitecap measurements which depended on the temperature (8), when the temperature is high, the coverage of whitecap is large; when the temperature is low, the coverage of whitecaps is small for the same wind conditions.

3.4 Different salinity

As salinity rises, the kinematic viscosity increase as follows:

fresh water

0 C 20 C

0.01787 0.01004

salt water

0 C 20 C

0.0101826 0.01049 ($cm^2/sec.$)

It is more difficult for jets to entrain air into salt water, as surface tension becomes greater in salt water. The amount of entrained air is less in salt water than in fresh water for the same jet parameters. This is in agreement with the experimental results shown in figure 5 and figure 6.

It seems that fresh water whitecap coverage should be larger than salt water whitecap coverage under similar conditions, but in fact, according to Monahan (10,11), under the same meteorolical conditions, salt water whitecap coverage are much larger than fresh whitecap coverage. This can be explained by noting the different viscosity and bubble spectrum, as salt water viscosity is greater than fresh water viscosity, as the salt-water whitecap area decay is slower than that of fresh-water whitecaps. According to laboratory comparisons, salt-water whitecap areas decay almost exponentially with a time constant of 3.85 seconds, whereas the decay constant for fresh-water Whitecap is 2.54 seconds. From a comparison of the bubble spectra in salt- and fresh-water, the salt water bubble spectrum is much smaller than fresh water bubble spectrum, so it takes longer for bubbles in salt water to rise to the surface and decay than in fresh water.

3.5 Conclusion

These experiments have demonstrated clearly that the boundary layer of jet, jet plunging angle, and liquid temperature and salinity affect the production of air bubbles and their downward entrainment. A thick boundary layer, high temperature, low salinity and small jet plunging angle increase the downward air entrainment, whereas a thin boundary layer, low temperature, high salinity and large jet plunging angles decrease the downward air entrainment.

Reference

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11. Monahan, E.C., and C.R. Zietlow, "Laboratory Comparisons of Fresh-water and Salt-water Whitecaps". J. Geo. Res. 74(28) (1960), pp. 6961-6967.

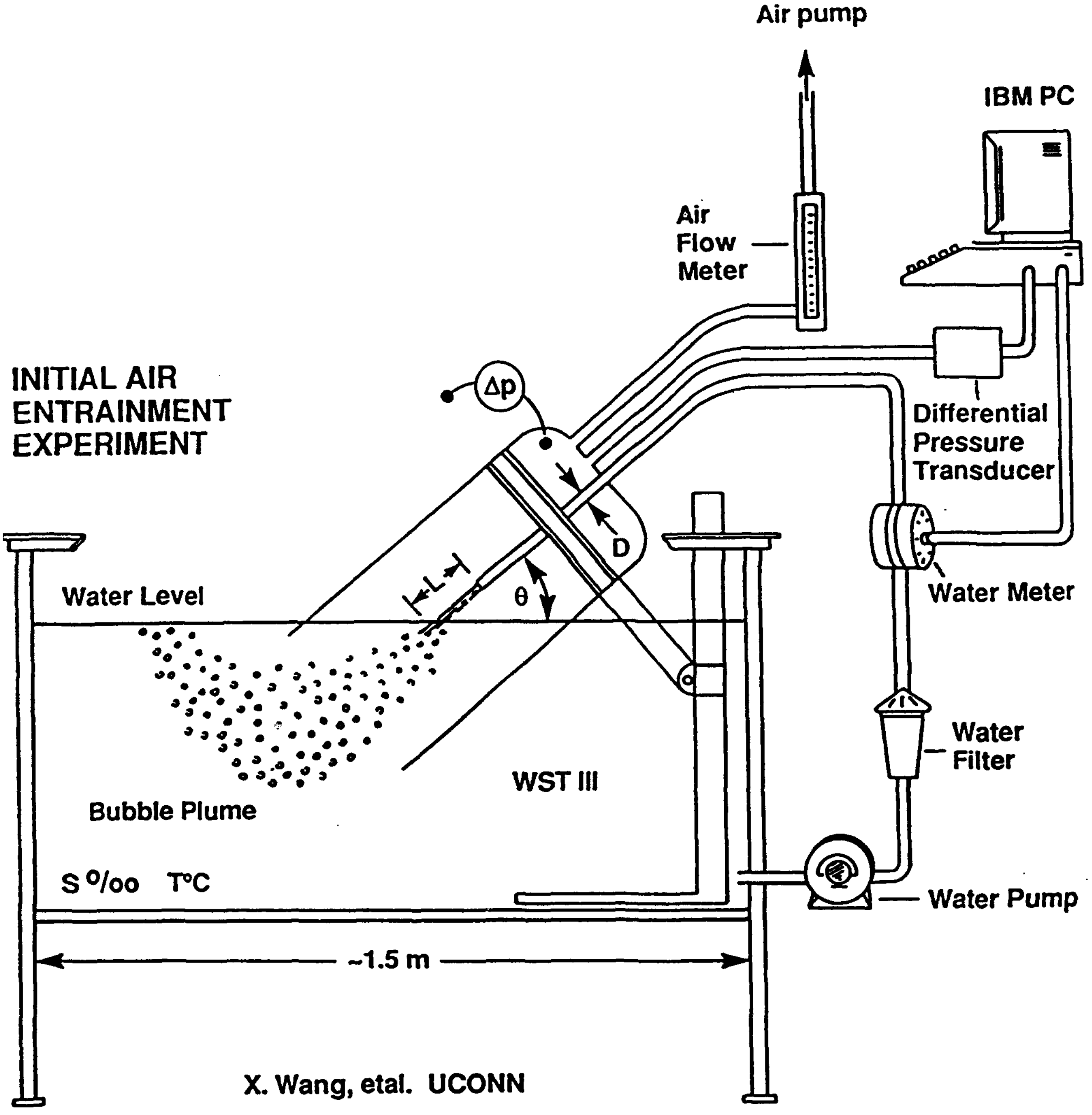
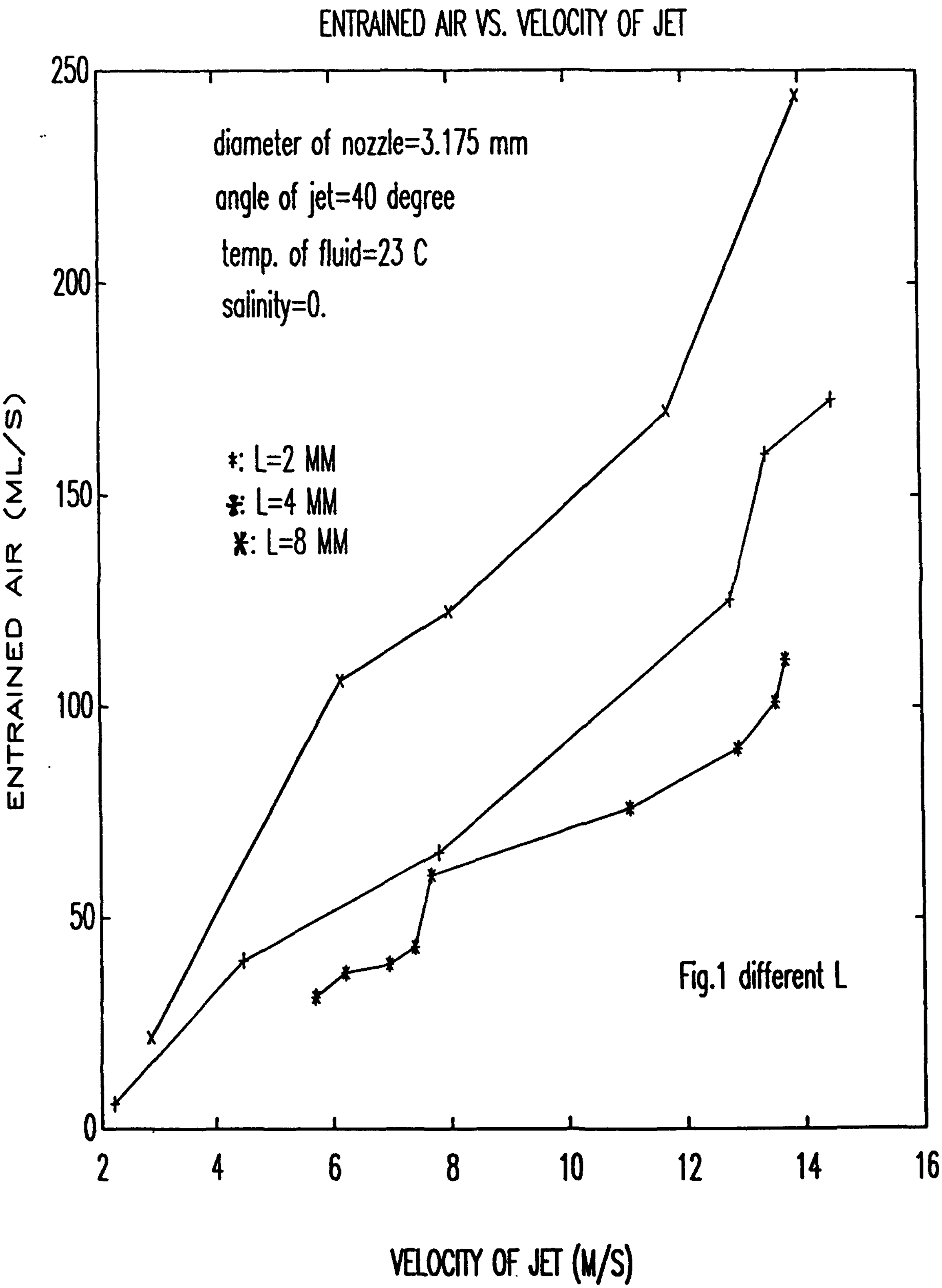
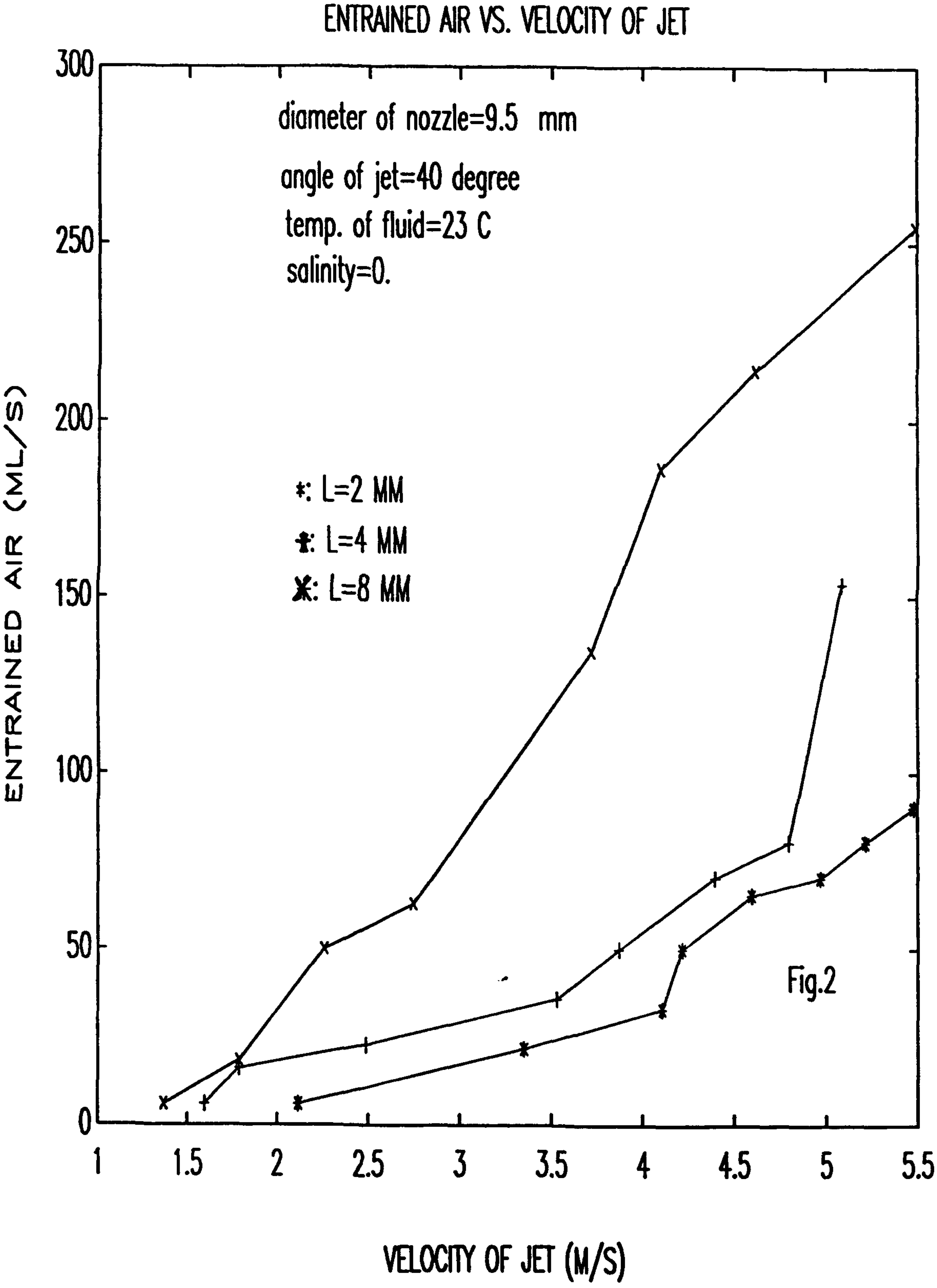
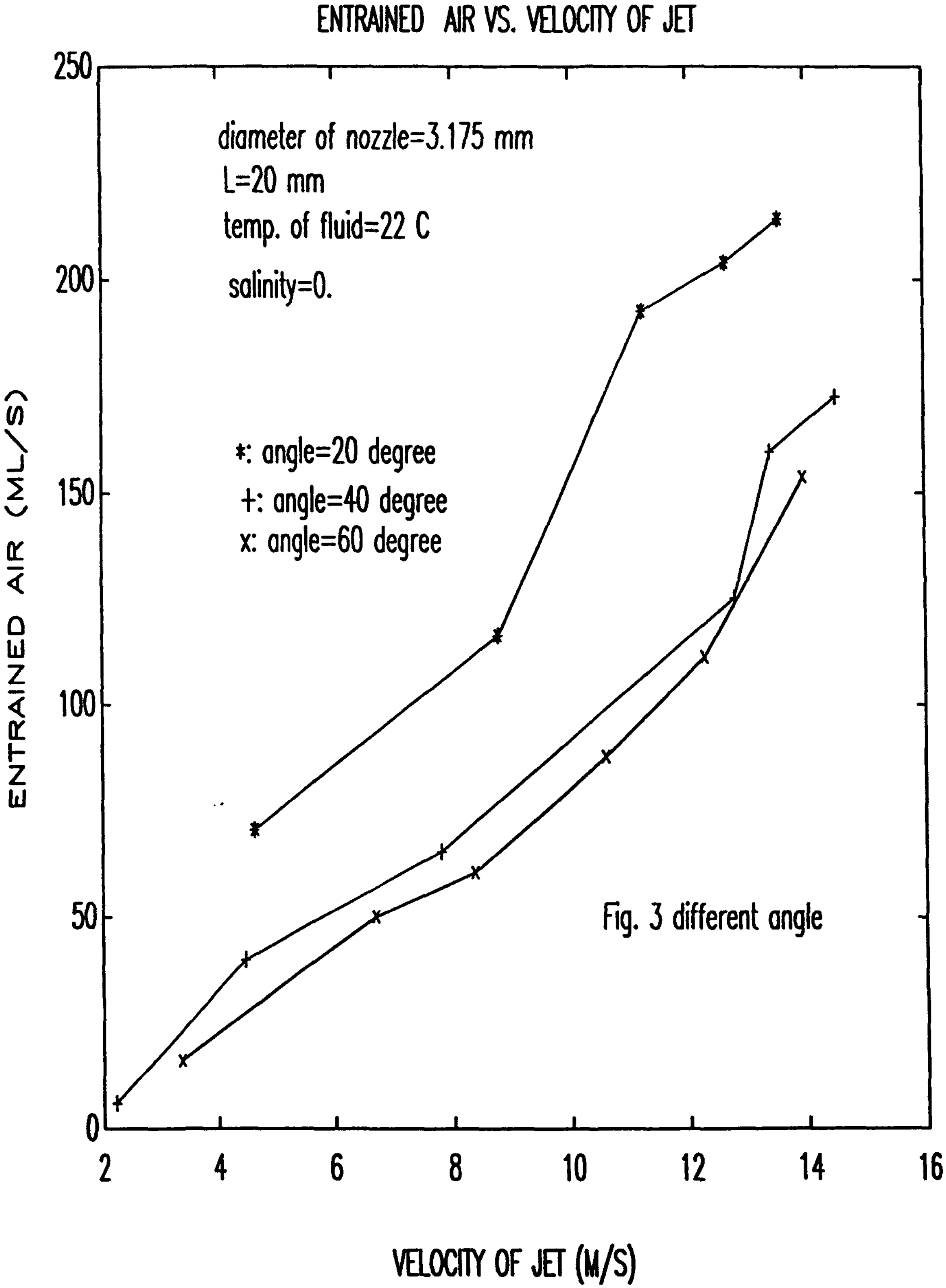
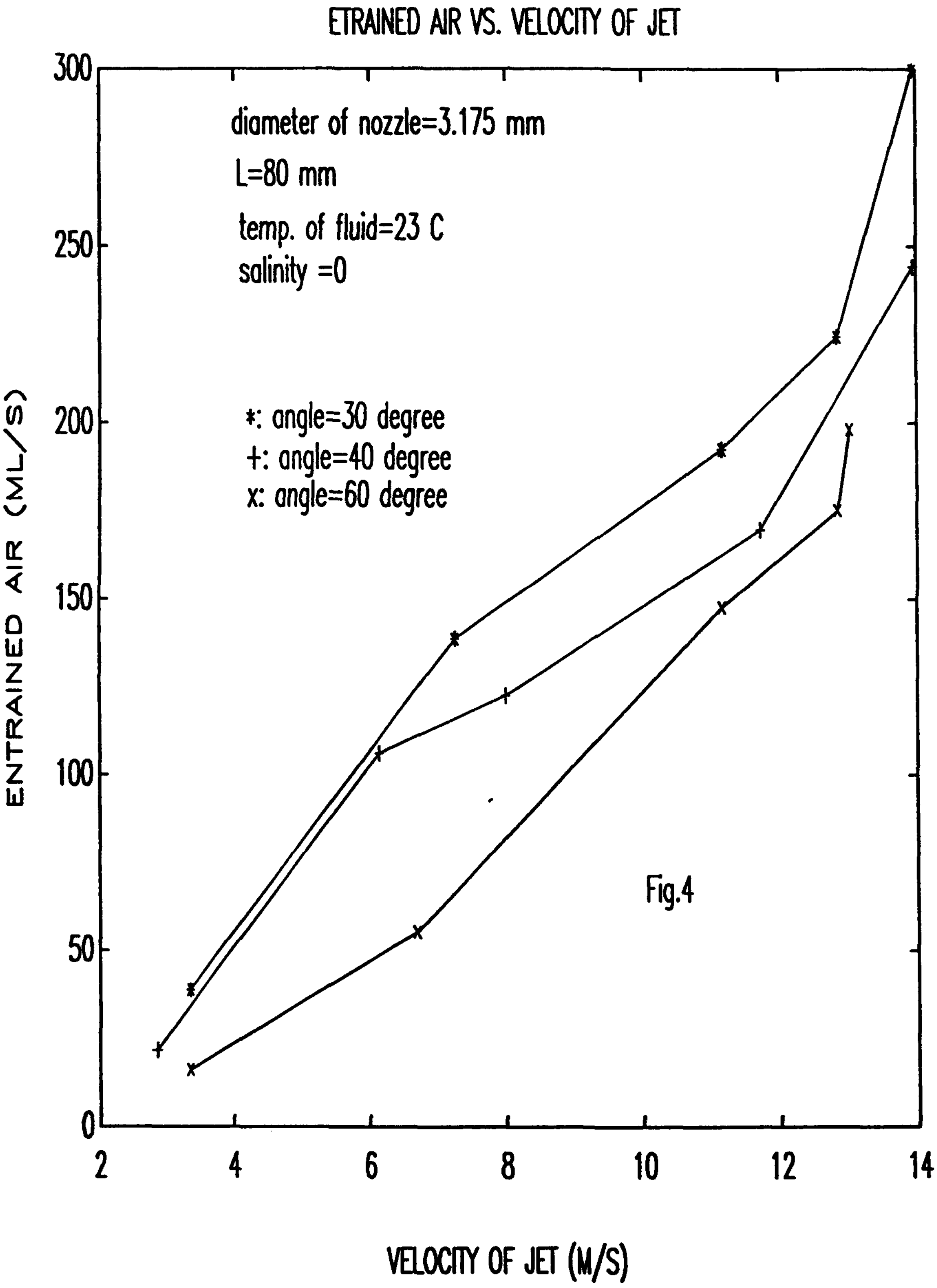

Air pump
IBM PC
Air
Flow
Meter
INITIAL AIR
ENTRAINMENT
EXPERIMENT
Δp
Differential
Pressure
Transducer
D
Water Meter
Water Level
L
θ
Water
Filter
WST III
Bubble Plume
S ⁰/oo T°C
Water Pump
~1.5 m
X. Wang, etal. UCONN

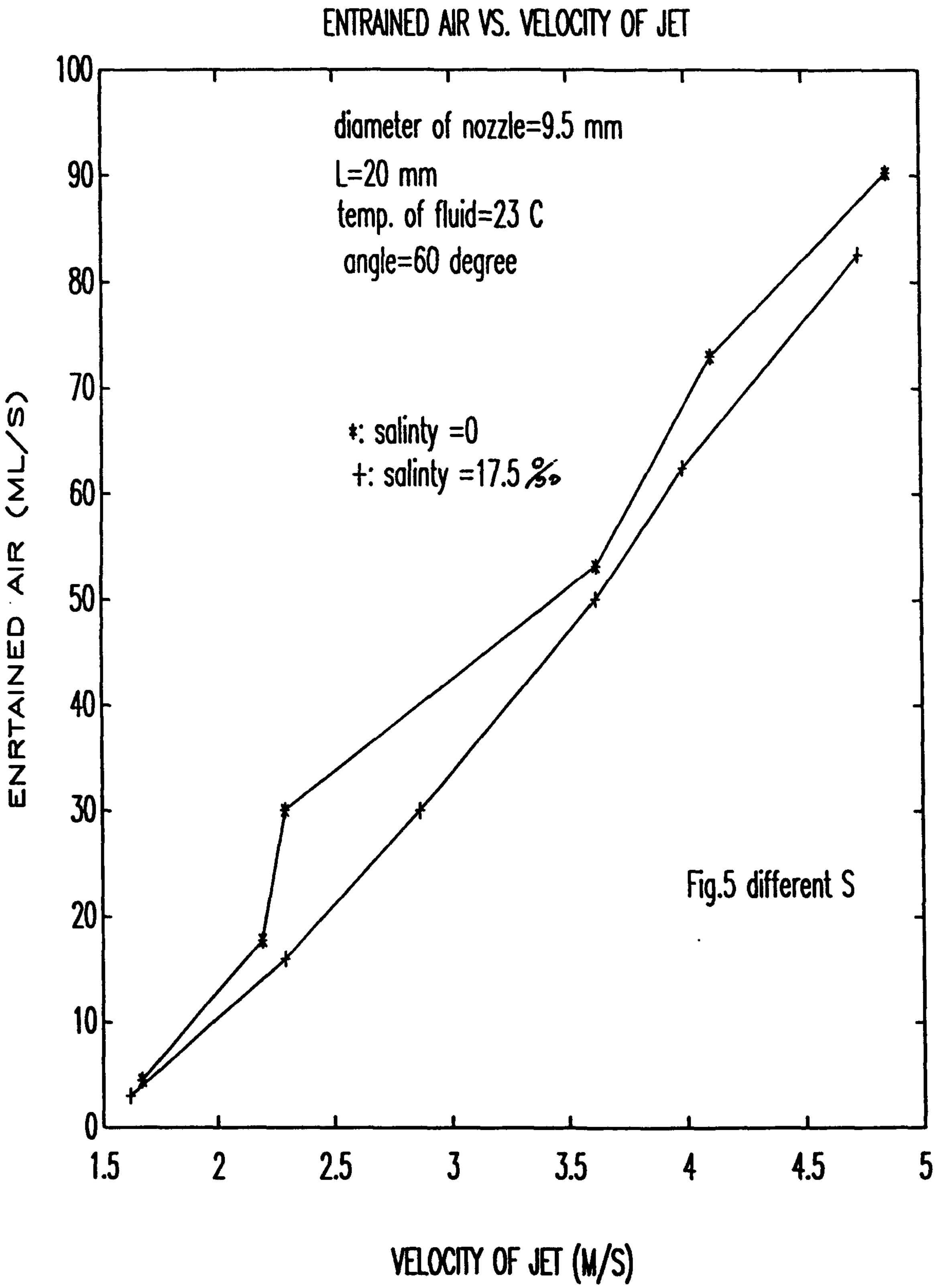
Figure A


ENTRAINED AIR VS. VELOCITY OF JET
diameter of nozzle=3.175 mm
angle of jet=40 degree
temp. of fluid=23 C
salinity=0.
*: L=2 MM
*: L=4 MM
*: L=8 MM
Fig.1 different L
ENTRAINED AIR (ML/S)
VELOCITY OF JET (M/S)
250
200
150
100
50
0
2
4
6
8
10
12
14
16

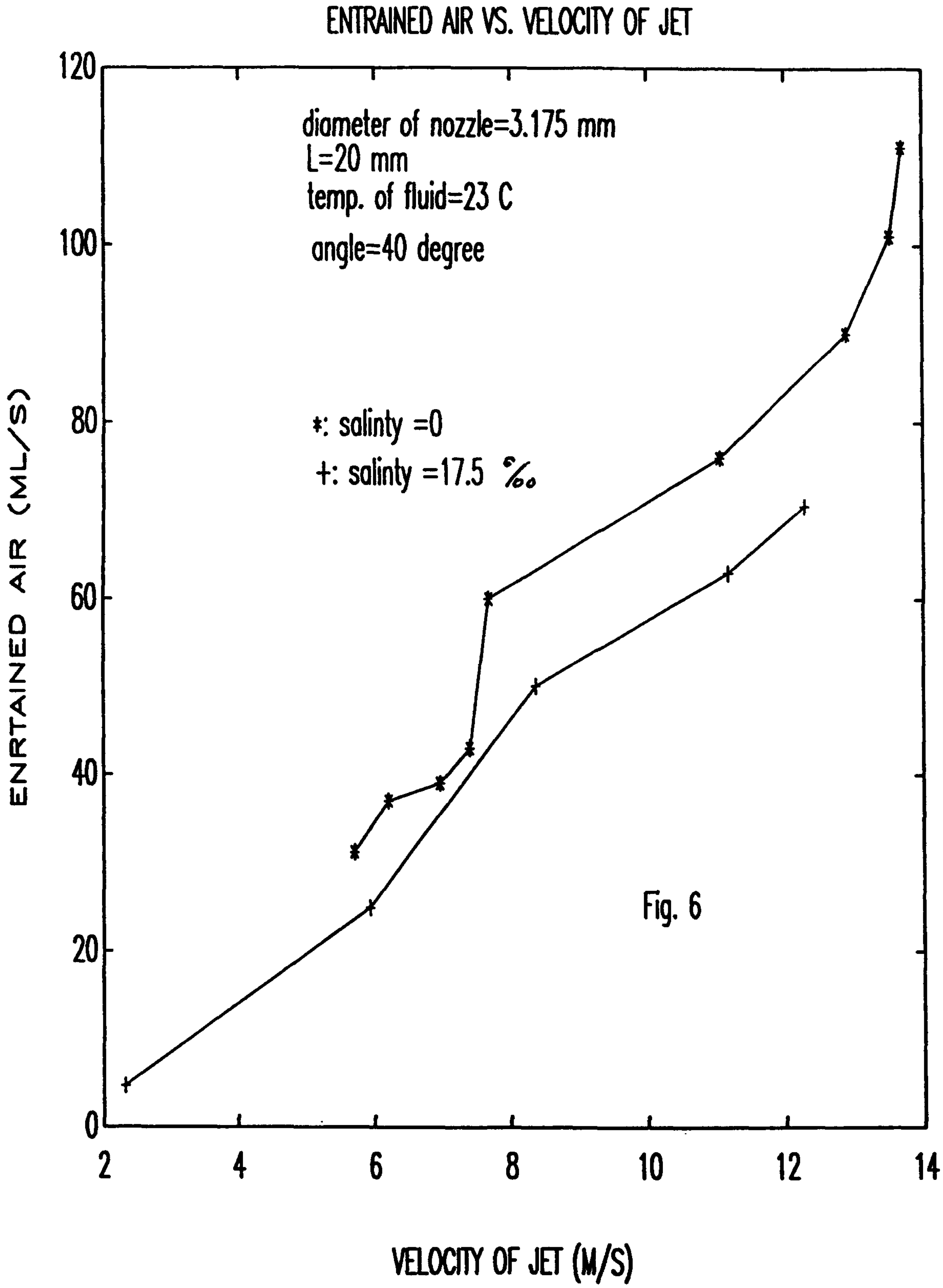

ENTRAINED AIR VS. VELOCITY OF JET
diameter of nozzle=9.5 mm
angle of jet=40 degree
temp. of fluid=23 C
salinity=0.
*: L=2 MM
*: L=4 MM
*: L=8 MM
Fig.2
ENTRAINED AIR (ML/S)
VELOCITY OF JET (M/S)
0
50
100
150
200
250
300
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5


ENTRAINED AIR VS. VELOCITY OF JET
diameter of nozzle=3.175 mm
L=20 mm
temp. of fluid=22 C
salinity=0.
*: angle=20 degree
+: angle=40 degree
x: angle=60 degree
Fig. 3 different angle
ENTRAINED AIR (ML/S)
VELOCITY OF JET (M/S)
0
50
100
150
200
250
2
4
6
8
10
12
14
16


ETRAINED AIR VS. VELOCITY OF JET
diameter of nozzle=3.175 mm
L=80 mm
temp. of fluid=23 C
salinity =0
*: angle=30 degree
+: angle=40 degree
x: angle=60 degree
Fig.4
ENTRAINED AIR (ML/S)
VELOCITY OF JET (M/S)
0
50
100
150
200
250
300
2
4
6
8
10
12
14



ENTRAINED AIR VS. VELOCITY OF JET
diameter of nozzle=9.5 mm
L=20 mm
temp. of fluid=23 C
angle=60 degree
*: salinty =0
+: salinty =17.5 %o
Fig.5 different S
ENRTAINED AIR (ML/S)
VELOCITY OF JET (M/S)
0
10
20
30
40
50
60
70
80
90
100
1.5
2
2.5
3
3.5
4
4.5
5


ENTRAINED AIR VS. VELOCITY OF JET
diameter of nozzle=3.175 mm
L=20 mm
temp. of fluid=23 C
angle=40 degree
*: salinty =0
+: salinty =17.5 ‰
Fig. 6
ENRTAINED AIR (ML/S)
VELOCITY OF JET (M/S)
0
20
40
60
80
100
120
2
4
6
8
10
12
14

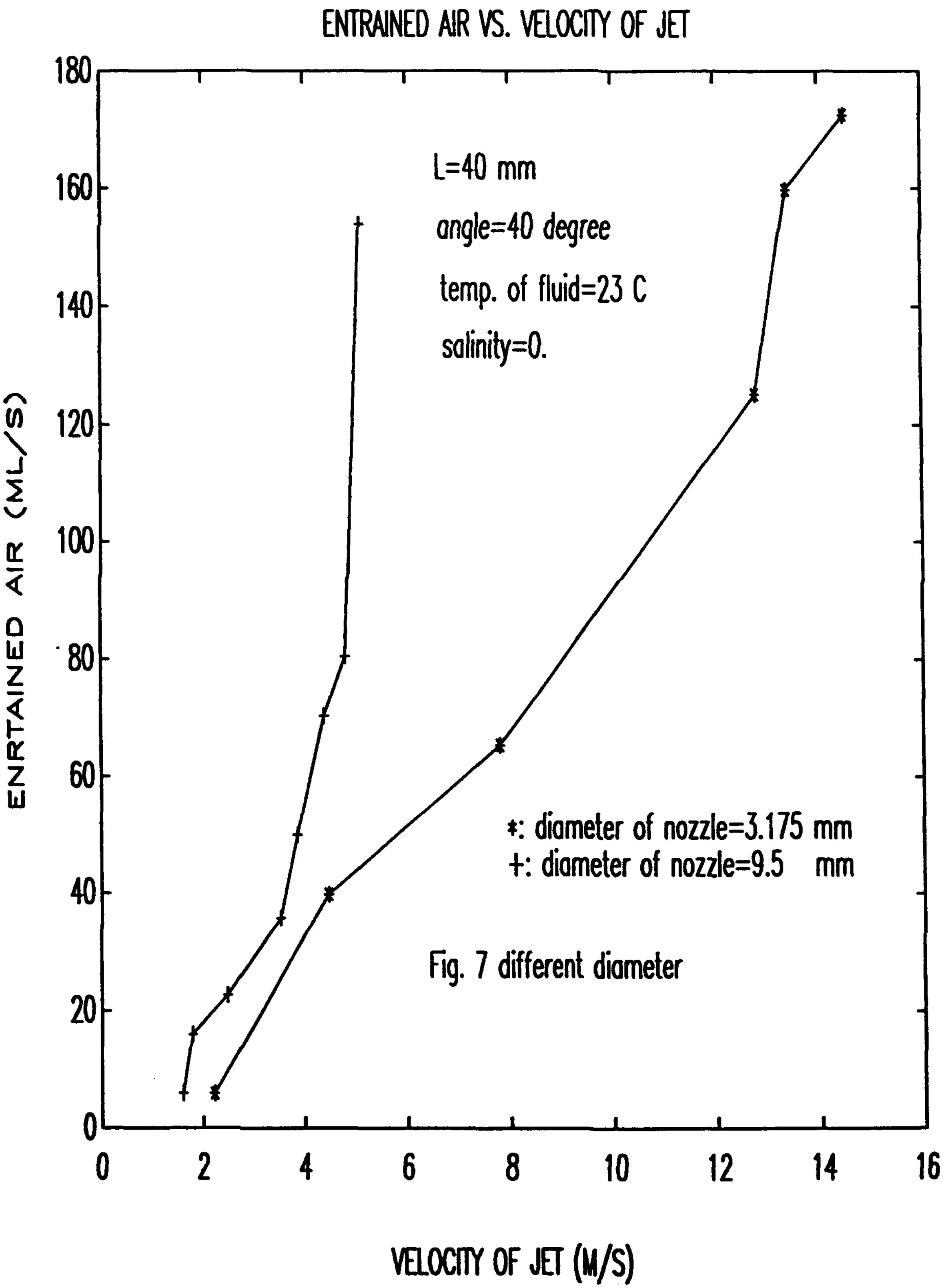
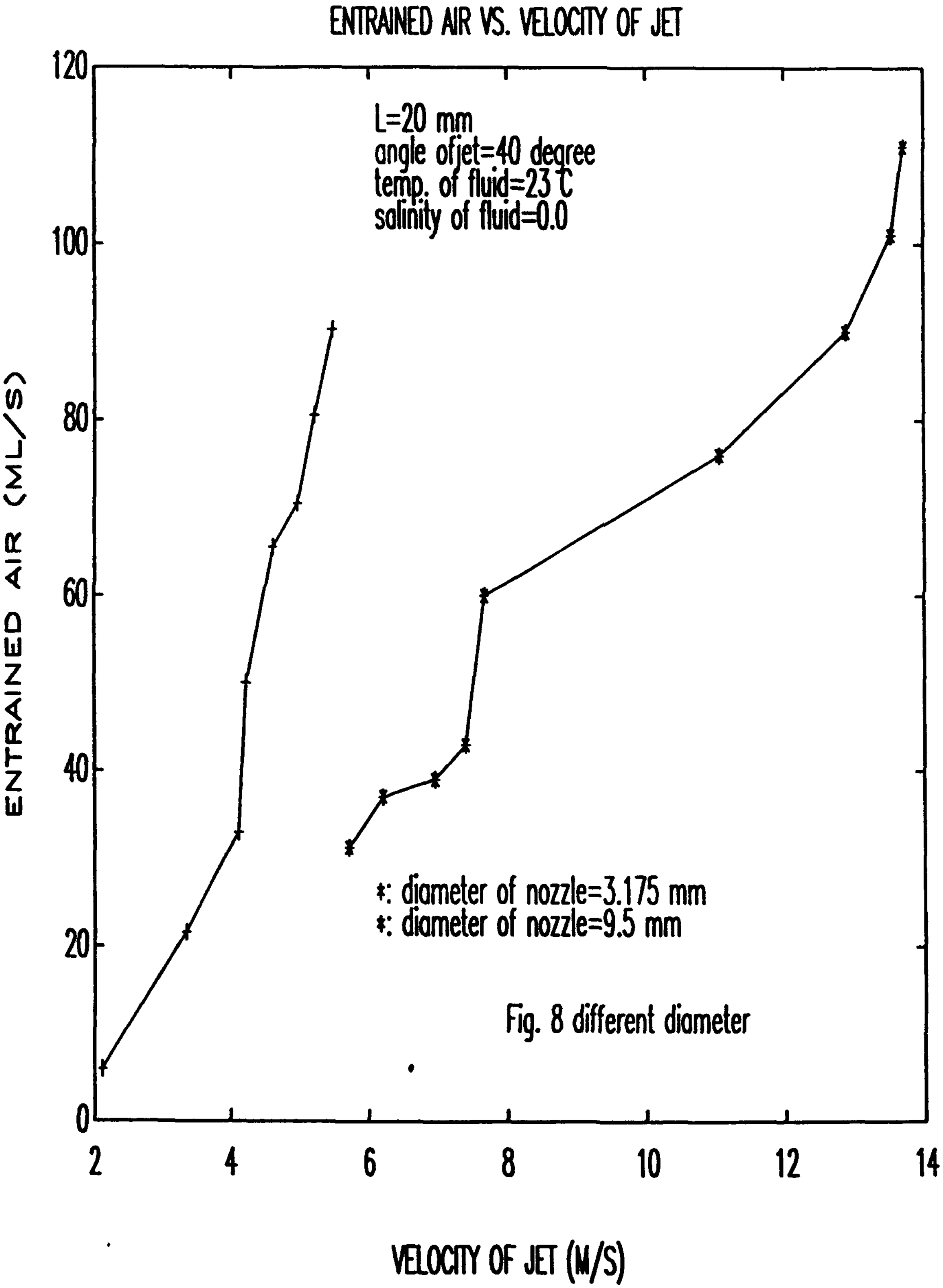


Fig. 7 different diameter


ENTRAINED AIR VS. VELOCITY OF JET
L=20 mm
angle ofjet=40 degree
temp. of fluid=23 C
salinity of fluid=0.0
*: diameter of nozzle=3.175 mm
*: diameter of nozzle=9.5 mm
Fig. 8 different diameter
ENTRAINED AIR (ML/S)
VELOCITY OF JET (M/S)
0
20
40
60
80
100
120
2
4
6
8
10
12
14

ENTRAINED AIR VS. VELOCITY OF JET

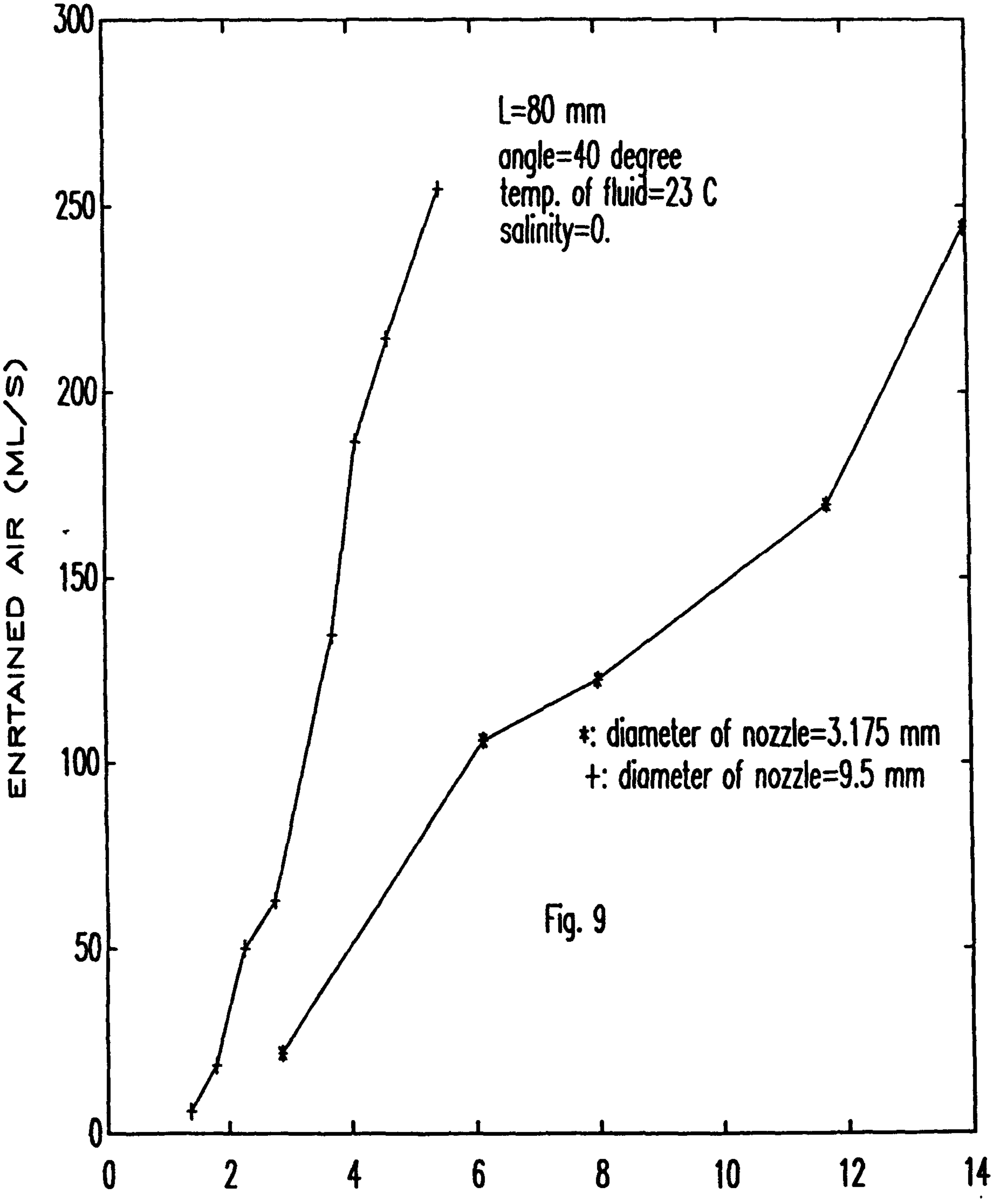
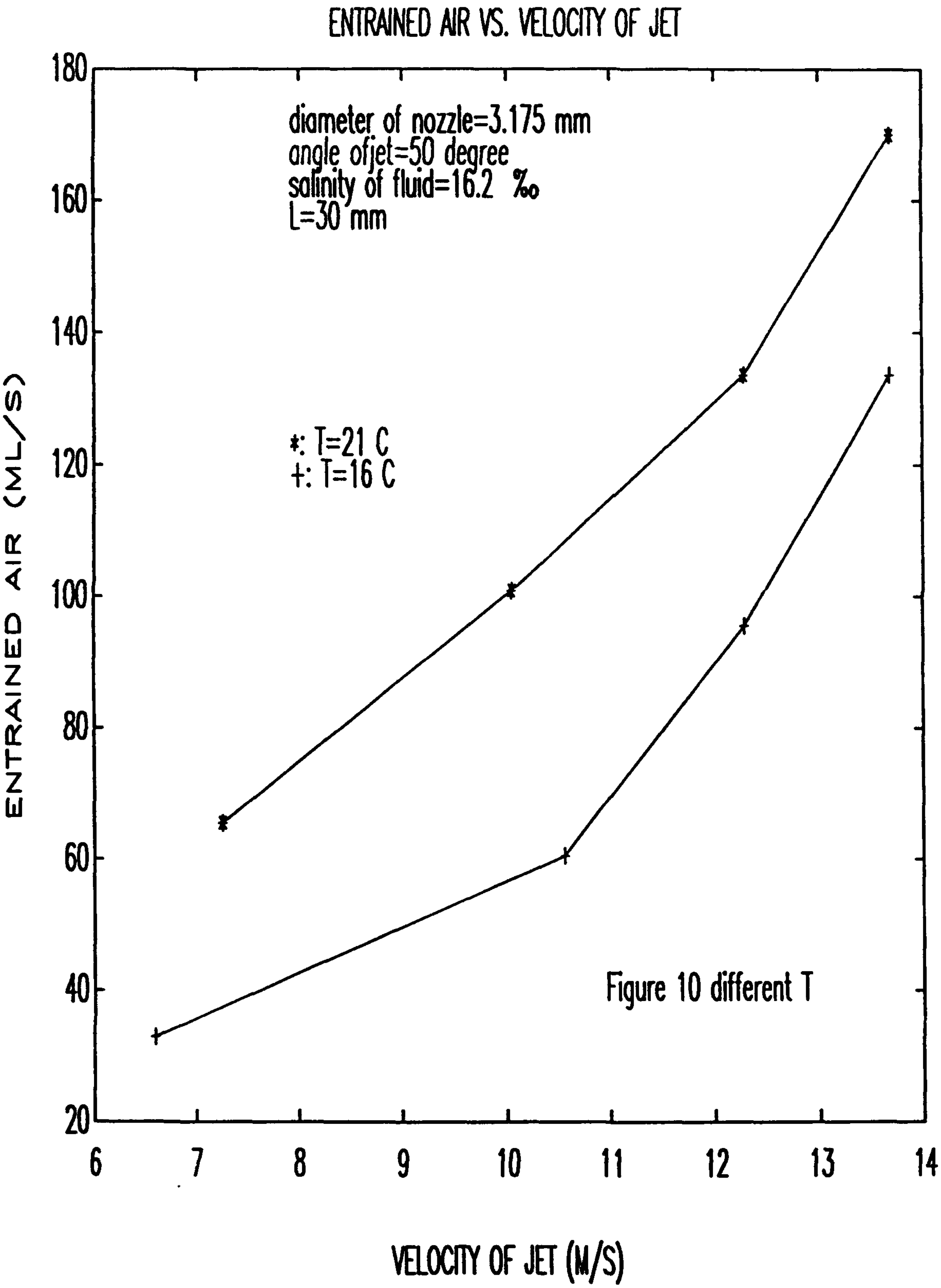
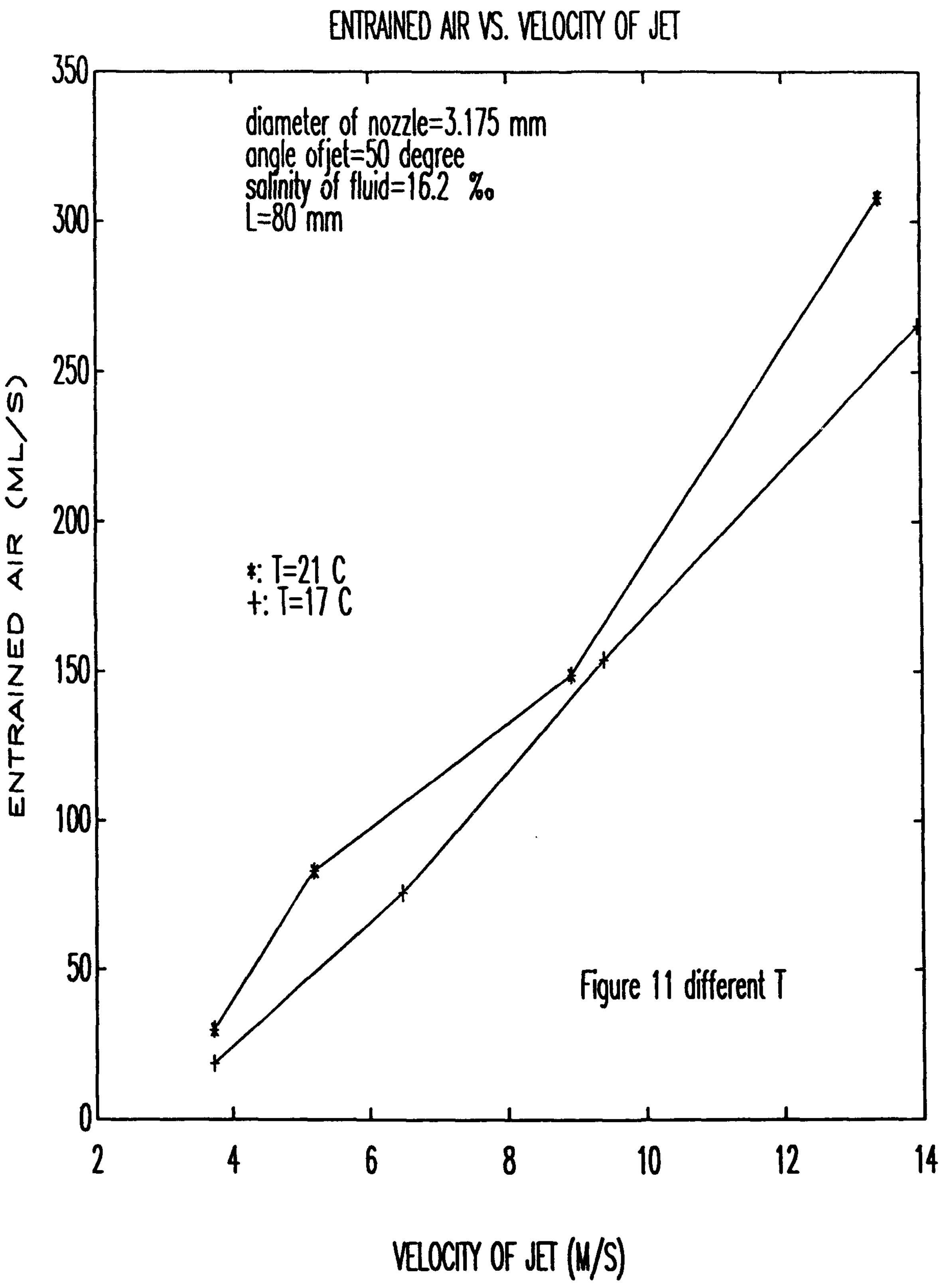


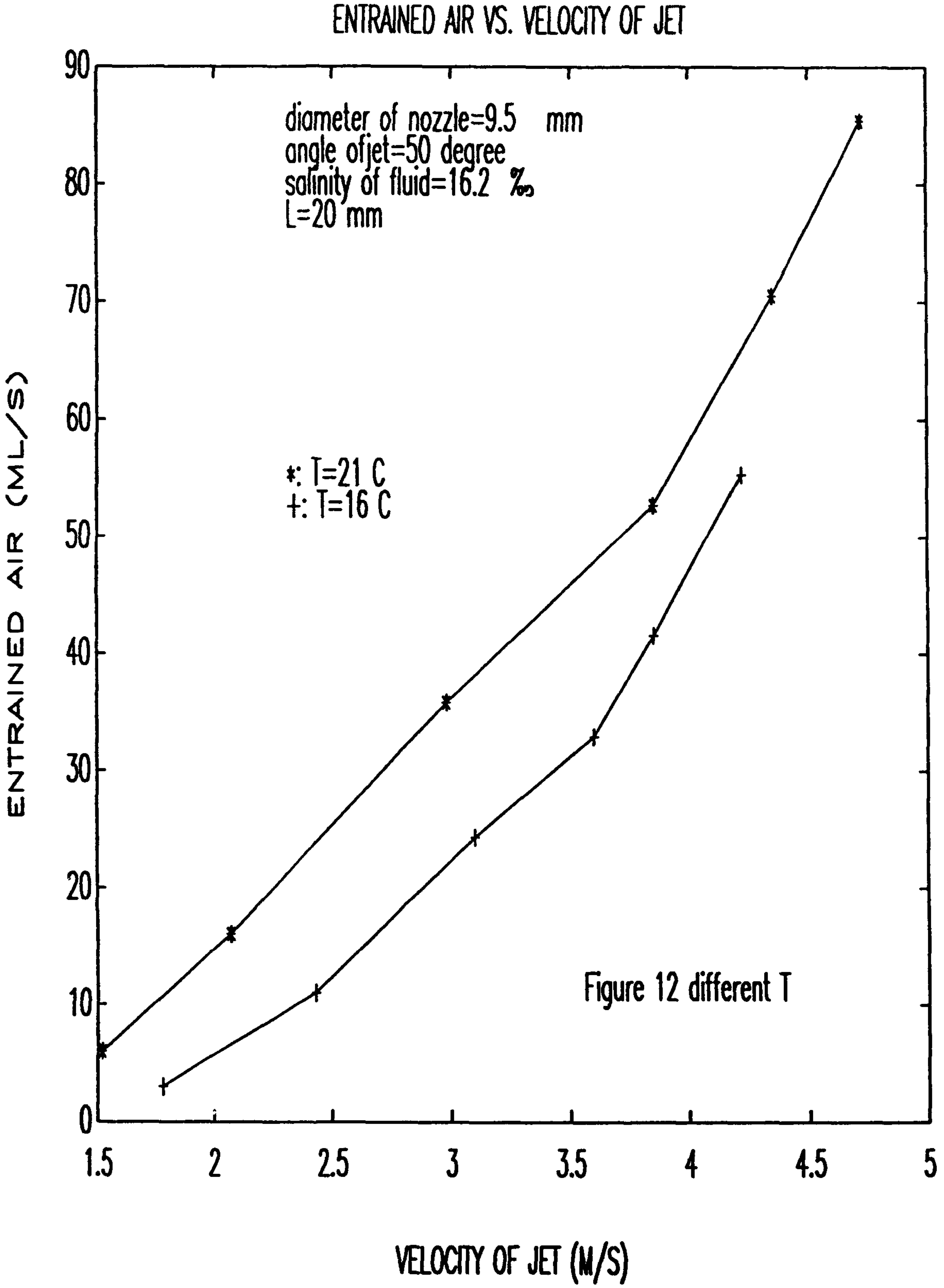
Fig. 9

VELOCITY OF JET (M/S)


ENTRAINED AIR VS. VELOCITY OF JET
diameter of nozzle=3.175 mm
angle ofjet=50 degree
salinity of fluid=16.2 ‰
L=30 mm
*: T=21 C
+: T=16 C
Figure 10 different T
ENTRAINED AIR (ML/S)
VELOCITY OF JET (M/S)
180
160
140
120
100
80
60
40
20
6
7
8
9
10
11
12
13
14



ENTRAINED AIR VS. VELOCITY OF JET
diameter of nozzle=3.175 mm
angle ofjet=50 degree
salinity of fluid=16.2 ‰
L=80 mm
*: T=21 C
+: T=17 C
Figure 11 different T
ENTRAINED AIR (ML/S)
VELOCITY OF JET (M/S)
0
50
100
150
200
250
300
350
2
4
6
8
10
12
14



ENTRAINED AIR VS. VELOCITY OF JET
diameter of nozzle=9.5 mm
angle ofjet=50 degree
salinity of fluid=16.2 ‰
L=20 mm
*: T=21 C
+: T=16 C
Figure 12 different T
ENTRAINED AIR (ML/S)
VELOCITY OF JET (M/S)
0
10
20
30
40
50
60
70
80
90
1.5
2
2.5
3
3.5
4
4.5
5

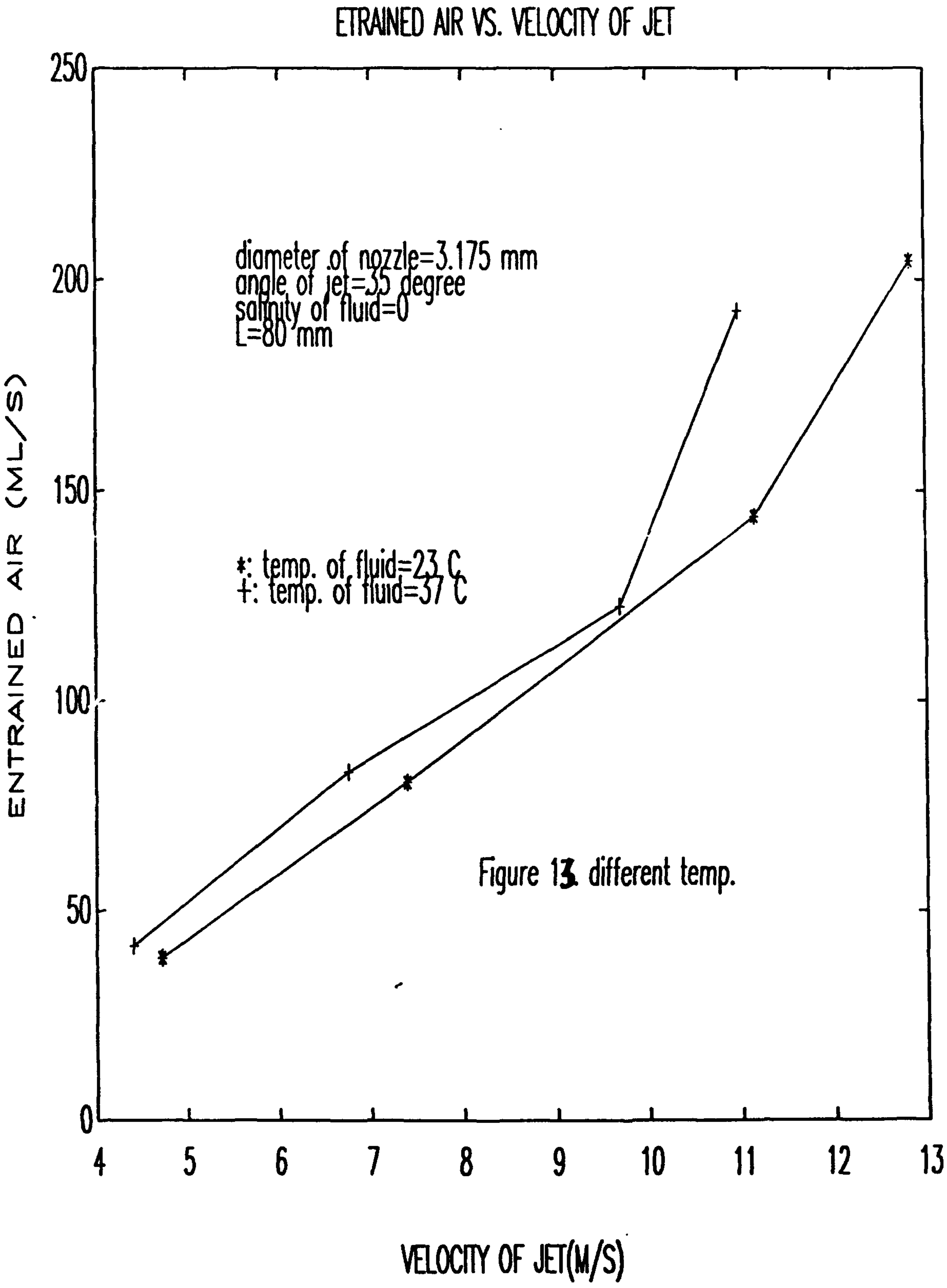
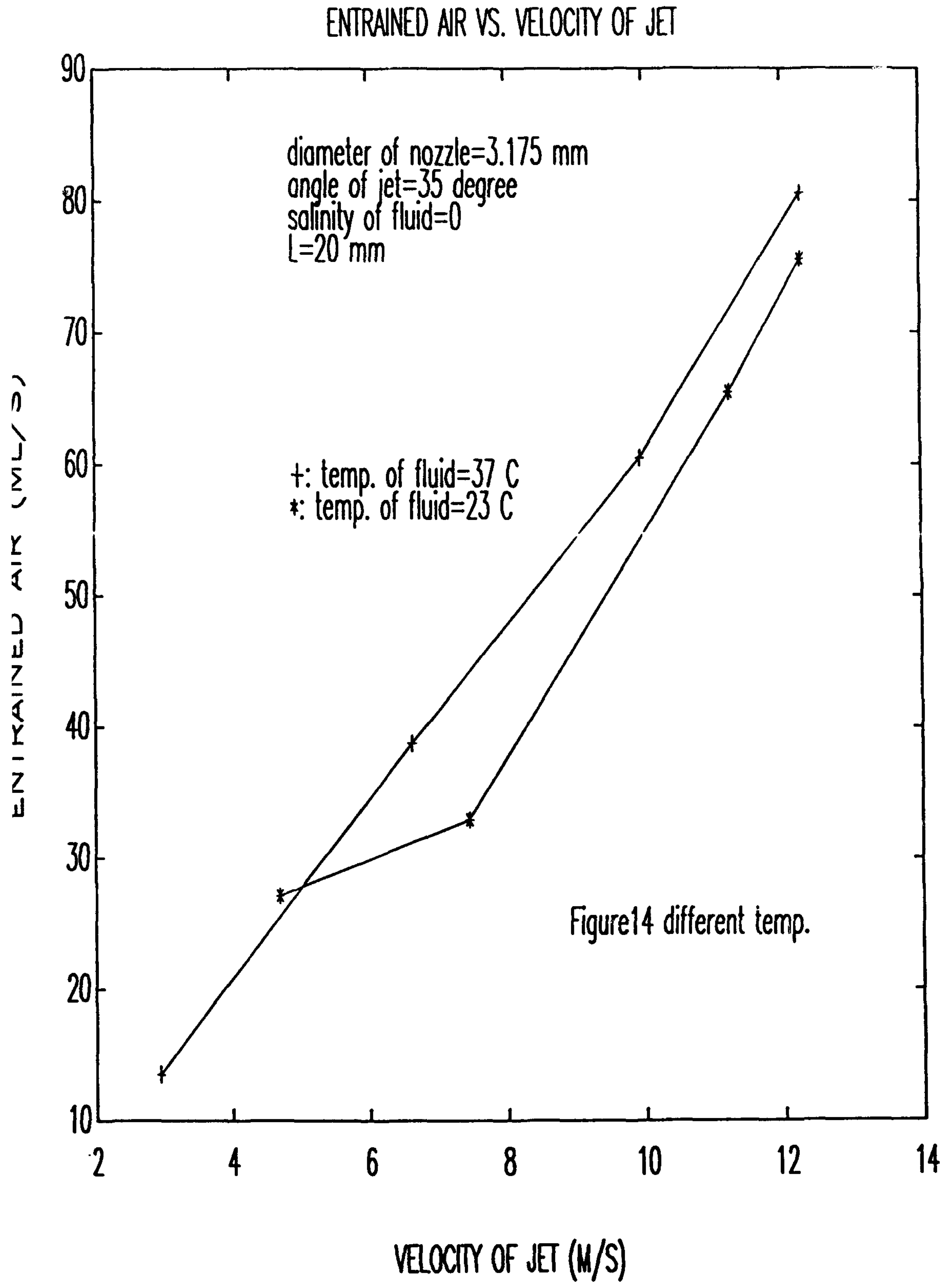


Figure 13. different temp.


ENTRAINED AIR VS. VELOCITY OF JET
diameter of nozzle=3.175 mm
angle of jet=35 degree
salinity of fluid=0
L=20 mm
+: temp. of fluid=37 C
*: temp. of fluid=23 C
Figure14 different temp.
ENTRAINED AIR (ML/S)
VELOCITY OF JET (M/S)
90
80
70
60
50
40
30
20
10
2
4
6
8
10
12
14

CHAPTER 12

WIND WAVES AND OCEANIC WHITECAP COVERAGE

BY

I.A. LEYKIN

CHAPTER 12

WIND WAVES AND OCEANIC WHITECAP COVERAGE

I.A. Leykin

As a part of our research program in 1992, a study of the wind waves in their relation to oceanic whitecap coverage was conducted. A main goal of this study was, first, to investigate nonlinear properties of wind waves that are important for further understanding of wave breaking process and therefore for parametrization of whitecap coverage, and second, to correlate parameters of wind waves and whitecap coverage from the available data sets. Three following projects were pursued:

1. Nonlinear Geometry of Wind Waves as Derived via Bispectral Analysis of Wind-Wave Records

This work aimed at investigation of nonlinear geometry of the roughened sea surface by means of bispectral analysis of experimental wave records is a continuation of a study that was conducted by I.A. Leykin and R.H. Mellen in 1991 with the support of ONR (Code 1241). As it was shown by analysis of wind waves measured in a small wind-wave tank at UConn under a moderate wind speed (see I.A. Leykin and R.H. Mellen "Wind-Wave Bispectrum and Microwave Backscattering from the Sea"). Proceedings of AGU Ocean Sciences Meeting, Jan. 1992, New Orleans, LA), asymmetry of the wave profile is determined by nonlinear components of the wave spectrum that are bound to the main component W_m corresponding to the spectral maximum.

For the purpose of the present study, we used wave records measured by Dr. Mark Donelan (who is our co-investigator for this part of a study) in a laboratory tank at Canada Center for Inland Waters, Burlington, Canada. The data were collected at wave fetch from 4.2 to 28.5 m/s and under wind speeds from 7 to 21 m/s. The results of bispectral analysis of these data are in a good agreement with our previous measurements at UConn tank. Thus, analysis of the bicoherence and the biphase demonstrates that a marked nonlinear relationship exists not only between the main component W_m and its high-order harmonics, but, to a some degree, between W_m and all the other spectral components as well. The stable non-zero values of the biphase that are observed at frequencies $W > W_m$, range from 30° to 60°, indicating a significant vertical asymmetry of the wave profile (i.e., wave crests are tilted forward). It is shown that biphase is an important parameter for both the description and modelling of the nonlinear sea-surface geometry.

The results of his study will be presented in a paper by I.A. Leykin, M. Donelan and R.H. Mellen "Bispectral Analysis of Wind Waves Measured in a Laboratory Tank" where a possible application of the measured bispectral characteristics of wind waves to parametrization of wave breaking and to remote sensing is discussed. This paper is now in preparation for Journal of Fluid Mechanics.

2. The Relationship Between Oceanic Whitecap Coverage and the Wind-Wave Parameters

A goal of this study was to investigate the dependence of oceanic whitecap coverate on the parameters of wind waves using the whitecap and wave data collected during the HEXMAX experiment in the North Sea in 1986. The fraction of the sea surface covered by whitecaps W_A was determined by analyzing video tapes recorded at the off-shore platform, and the frequency spectra of wind waves were measured simultaneously with a wave-rider buoy. The data selected for the present analysis correspond to the developing wind waves (wind speeds U from 9 to 20 m/s) with the values of U/C_m ranging from 1 to 2, where C_m is the phase speed of the energy-containing waves.

A semi empirical model that describes the dependence of whitecap coverage W_A on the wind speed and wave age is proposed. According to this model, probability of breaking of individual wave crests B is determined from the existing theoretical models (Huang *et al.*, 1986; Srokosz, 1986) that correlates B with the variance of the surface slopes and with the surface drift w hile the spatial statistics of whitecaps and its dependence on wind speed is estimated from the available experimental data (Bortkovskii, 1988).

A paper by I.A. Leykin and E.C. Monahan, "The Relationship Between Oceanic Whitecap Coverage and Wind-Wave Parameters" is now in preparation for the Journal of Physical Oceanography.

3. Variability of Wind-Wave Spectra in the Vicinity of the Gulf Stream Under Varied Atmospheric Stability Conditions

As was shown recently (Hwang and Shemdin, 1988; Keller *et al.*, 1985, 1989), atmospheric stability affects significantly microwave backscattering from the sea. However, the effect of stability conditions on the energy-containing components of wind waves is still very poorly studied. During the SWADE experiment in 1991, wind-wave spectra were measured from several buoys in the Gulf Stream region. In a present study, more than 90 spectra corresponding to the wind speeds U from 9 to 18 m/s and to the difference between the air and water temperature from -2.4°C to +7.0°C were analyzed and compared with stability conditions.

The dimensionless variance of surface displacement $^2g^2/U^4$ (g is acceleration of gravity) was determined, and a spectral shape n was estimated by fitting the experimental spectra with the power law $S(W) = W^{-n}$ within the frequency range$W_m < W\ 3W_m$ (W_m is the spectral maximum frequency). No noticeable effect of stability conditions on the values of $^2g^2/U^4$ and n was found.

The preliminary results of this study were presented at SWAPP/SWADE Meeting (Woods Hole, MA, December 1992) and at AGU Fall Meeting (San Francisco, CA, December 1992). A paper by I.A. Leykin and E.C. Monahan, "Observations of Wind-Wave Spectra in the Vicinity of the Gulf Stream Under Varied Atmospheric Stability Conditions", is now in preparation for the Journal of Geophysical Research.

APPENDIX A

MODELLING THE DEPENDENCE OF WHITECAP ON WINDSPEED: HIERARCHAL MODELS AND SHRUNKEN PARAMETER ESTIMATION

BY

I.G. O'MUIRCHEARTAING AND E.C. MONAHAN

Modelling the dependence of whitecap on windspeed: hierarchical models, and shrunken parameter estimation

Iognáid Ó Muircheartaigh,
University College Galway, Ireland
and
Edward C. Monahan,
Marine Sciences Institute,
University of Connecticut, U.S.A.

1 Introduction

Gaver and Lehoczky (1987) describe the concept of *hierarchical* stochastic models. A wide variety of stochastic modelling situations arising in pracical applications can be conveniently approached by using such models. These models incorporate two types of variability: variability *within* a unit or population member and variability *between* units. This paper applies the concept to the problem of modelling the dependence on windspeed of oceanic whitecap coverage, and oceanic whitecrest coverage; in the former case eleven, and in the latter case ten, distinct data sets are available. Hierarchical models are utilized to determine the degree of compatibility between the data sets, and to enable estimation of model parameters in a manner which incorporates both types of variability described above.

2 Hierarchical Models

For a full description of hierarchical models see Gaver and Lehoczky (1987). In the present application, we are given k datasets (units), and our observations (within units) consist of measurements of windspeed (u) and whitecap coverage (w). On the basis of previous studies, we transform the data as follows:

$$W = w^{1/3} \qquad (1)$$

$$U = u(g\nu)^{-1/3} \qquad (2)$$

(where g is the accelaration due to gravity, and ν is the kinematic viscosity of sea water), and apply the following *hierarchical* model to the transformed data:
within dataset variation:

$$W_{ij} = \beta_i U_{ij} + \epsilon_i \qquad (3)$$

$$\epsilon_i \sim N(0, \sigma_i^2) \qquad (4)$$

for $i = 1, \ldots, k$ and $j = 1, \ldots, n_i$,

and between dataset variation:

$$\beta_i \sim N(\beta, \sigma_\beta^2) \qquad (5)$$

for $i = 1, \ldots, k$. This is often referred to as the *superpopulation* from which the individual β_i can be considered drawn at random.
Following standard methodology, the likelihood may be written

$$\mathcal{L} = \prod_{i=1}^{k} \prod_{j=1}^{n_i} \mathcal{L}_{ij} \qquad (6)$$

where

$\mathcal{L}_{ij}(\beta, \sigma_\beta^2) \propto$

$$\int_{-\infty}^{\infty} \frac{1}{\sigma_i} e^{-\frac{1}{2}\left(\frac{W_{ij}-\beta_i U_{ij}}{\sigma_\beta}\right)^2} \frac{1}{\sigma_\beta} e^{-\frac{1}{2}\left(\frac{\beta_i-\beta}{\sigma_\beta}\right)^2} d\beta_i \quad (7)$$

Letting $l_{ij} = ln(\mathcal{L}_{ij})$, and omitting details, we obtain

$$l_{ij} \propto \frac{\left(U_{ij}W_{ij}\sigma_\beta^2 + \beta\sigma_i^2\right)^2}{\sigma_i^2\sigma_\beta^2\left(U_{ij}^2\sigma_\beta^2 + \sigma_i^2\right)}$$

$$-\frac{\left(W_{ij}\sigma_\beta^2 + \beta^2\right)}{\sigma_i^2\sigma_\beta^2} - ln(U_{ij}^2\sigma_\beta^2 + \sigma_i^2) \quad (8)$$

and hence the loglikelihood may be written

$$l(\beta, \sigma_\beta^2, \sigma_i^2) = \sum_{i=1}^{k}\sum_{j=1}^{n_i} l_{ij} \quad (9)$$

3 Parameter estimation

Parameter estimation for this problem involves three separate but related stages, viz,.

3.1 Empirical Bayes estimation of σ_i^2

Each σ_i, $(i = 1, \ldots, k)$, is estimated by the residual mean square error, $\hat{\sigma}_i^2$, for the regression of W on U with no intercept term included in the model. Following conventional empirical Bayes methodology, these parameters are assumed known for the further stages of the estimation procedure, as described below.

3.2 Maximum likelihood estimation of superpopulation parameters

The likelihood, as described in equation (9), and assuming σ_i^2 known, is a function of two variables β and σ_β^2. This function was numerically maximized using the IMSL statistical package, and confidence regions for the ML estimates $\hat{\beta}$ and $\hat{\sigma}_\beta^2$ were obtained by using the likelihood ratio test procedure which specifies that all (β, σ_β^2) values such that

$$-2\left[ln\left(\frac{\mathcal{L}(\beta, \sigma_\beta^2)}{\mathcal{L}(\hat{\beta}, \hat{\sigma}_\beta^2)}\right) \leq \chi^2_{(1-\alpha)}(2\text{ d.f.})\right] \quad (10)$$

constitute an approximate $100(1-\alpha)\%$ confidence region for (β, σ_β^2). The issue of whether or not all the data sets may have come from populations with identical β's is then addressed by determining whether or not the confidence region derived includes $\sigma_\beta^2 = 0$.

3.3 Empirical Bayes estimation of the individual β_i

From equations (3) and (4), it is easy to show that the posterior probability density function of β_i is

$$f(\beta_i | U_{ij}, W_{ij}, \sigma_i^2) \sim N(\mu_{ij}, \sigma_{ij}^2)$$

for $i = 1, \ldots, k$ and $j = 1, \ldots n_i$, where

$$\mu_{ij} = \frac{\frac{U_{ij}W_{ij}}{\sigma_i^2} + \frac{\beta}{\sigma_\beta^2}}{\frac{U^2}{\sigma_i^2} + \frac{1}{\sigma_\beta^2}} \quad (11)$$

$$\sigma_{ij}^2 = \frac{1}{\frac{U^2}{\sigma_i^2} + \frac{1}{\sigma_\beta^2}} \quad (12)$$

Accordingly, combining the information in a given data set with the (empirical Bayes) estimates of the superpopulation parameters, it follows that, if U_i represents the set of U observations for data set i, and W_i the corresponding set of W observations, then

$$f(\beta_i|U_i, W_i, \sigma_i^2) \sim N(\hat{\beta}, \hat{S}_i^2)$$

where

$$\hat{\beta}_i = \frac{\sum_{j=1}^{n_i} \mu_{ij}/\sigma_{ij}^2}{\sum_{j=1}^{n_i} 1/\sigma_{ij}^2} \quad (13)$$

$$\hat{S}_i^2 = \frac{1}{\sum_{j=1}^{n_i}(1/\sigma_{ij}^2)} \quad (14)$$

$\hat{\beta}_i$ is an individualized (pooled, shrunken) estimate of the parameter β_i for the population from which data set i was selected. It has the very reasonable property that when σ_β^2 is large (i.e. large variations between the data sets) then the contribution of the superpopulation factor (i.e. the data sets other than data set i) is small, and when σ_β^2 is small (i.e. the data sets relatively uniform), the contribution of the superpopulation factor is substantial.

4 Data and analysis

4.1 Data

The models described in section 2 were used to describe the dependence of oceanic whitecap and oceanic whitecrest coverage on windspeed. In the case of whitecaps, eleven distinct datasets (average number of obvervations: 40) and in the case of whitecrests, ten distinct datasets (average number of observations: 44) were available. Due to space limitations, it is not possible in this paper to give a complete description of these datasets, but this can and will be provided on request.

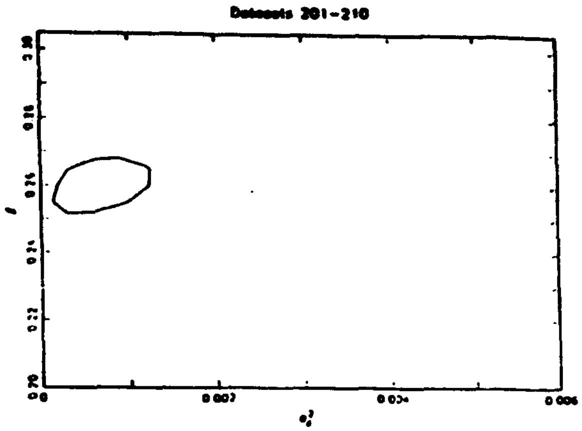


Figure 1: 95% confidence contour

4.2 Analysis

4.2.1 Superpopulation parameter estimation

The results of maximizing the likelihood described in equation (9) are presented in Table 1.

DATA SETS	$\hat{\beta}$	$\hat{\sigma}_\beta^2$
101 - 112	0.470	0.0014
201 - 210	0.260	0.0007

Table 1: Superpopulation parameter estimates.

In Figure 1 we present the 95% confidence contour for (β, σ_β^2) described in equation (10) for datasets 201-210. This region does not include $\sigma_\beta^2 = 0$, and accordingly the hypothesis that $\sigma_\beta^2 = 0$ would be rejected at the 5% significance level. Two points are worth noting in relation to this: firstly, a 99% confidence region would include $\sigma_\beta^2 = 0$; secondly, by taking account of the size of $\hat{\sigma}_\beta$, the formula given in equation (13) gives appropriate weighting to the diversity or otherwise of the datasets in producing shrunken estimates of β_i. Identical conclusions apply to datasets 101-112, but are omitted for reasons of space limitations.

4.3 Shrunken estimates of regression parameters

In Tables 2 (for whitecaps) and 3 (for whitecrests) we present the simple least squares estimates $\bar{\beta}_i$ and the shrunken or pooled estimates $\hat{\beta}_i$ [as described in equation (13)] of $\beta_i, i = 1, \ldots, k$. In parentheses, after each such estimate, we give the standard error of the estimate.

DATA SET	β_i (ls)	β_i (shrunken)
101	0.442(0.016)	0.462(0.008)
102	0.446(0.023)	0.464(0.012)
103	0.534(0.023)	0.480(0.009)
104	0.508(0.013)	0.481(0.007)
105	0.277(0.021)	0.400(0.013)
106	0.407(0.025)	0.458(0.011)
107	0.577(0.017)	0.500(0.009)
109	0.468(0.026)	0.469(0.015)
110	0.552(0.026)	0.490(0.013)
111	0.430(0.010)	0.452(0.007)
112	0.480(0.013)	0.475(0.009)

Table 2: Estimates of β_i, whitecaps.

In examining the results in Tables 2 and 3, it will be noted that the shrinkage of the estimates of β_i is much more pronounced for the whitecrest than for the whitecap data. This is due to the fact that the superpopulation variance (σ_β^2) is substantially smaller (by a factor of about 9) for the whitecrest data. This in turn leads to the superpopulation mean (β) being given much larger weighting [via the formula in equation (13)] in the case of the whitecrest data.

DATA SET	β_i (ls)	β_i (shrunken)
201	0.216(0.016)	0.256(0.008)
202	0.282(0.014)	0.266(0.005)
203	0.232(0.012)	0.257(0.006)
204	0.443(0.031)	0.267(0.003)
205	0.344(0.010)	0.283(0.005)
206	0.260(0.012)	0.264(0.006)
207	0.300(0.015)	0.275(0.008)
208	0.262(0.014)	0.264(0.007)
209	0.250(0.004)	0.255(0.003)
210	0.224(0.006)	0.243(0.005)

Table 3: Estimates of β_i, whitecrests

4.4 Conclusions

This methodology provides a simple means of achieving a balance between the two strategies of combining a number of disparate data sets into a single data set, on the one hand, and treating each set separately, on the other. It is intuitively appealing in that the amount of pooling (shrinkage) is proportional to the extent of homogeneity among the datasets.

Acknowledgement

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References

[1] Gaver, D.P., Lehoczky, J.P. (1987) Statistical Analysis of Hierarchical Stochastic Models : Examples and Approaches. *Annals of Operations Research* 8 217–227.