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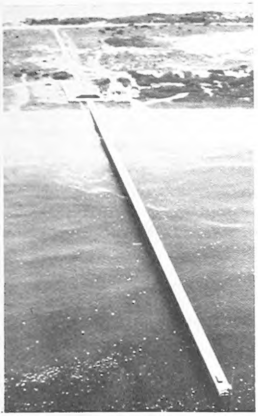

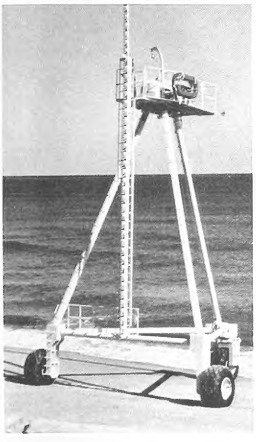

TECHNICAL REPORT CERC-88-8

ANNUAL DATA SUMMARY FOR 1986
CERC FIELD RESEARCH FACILITY

Volume I

MAIN TEXT AND APPENDIX A

by

Herman C. Miller, Adele Militello, Michael W. Leffler
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Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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

This report provides basic data and summaries for the measurements made during 1986 at the US Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center's (CERC's) Field Research Facility (FRF) in Duck, NC. The report includes comparisons of the present year's data to cumulative statistics from 1980 to the present.

Summarized in this report are meteorological and oceanographic data, monthly bathymetric survey results, samples of quarterly aerial photography, and descriptions and hourly data for 13 storms that occurred during the year.

The year was highlighted by the close passage of Hurricane Charley in August. Waves with 4-m significant height were measured at a location 6 km from shore.

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Water waves--statistics (LC)

19. ABSTRACT (Continued).

This report is eighth in a series of annual summaries of data collected at the FRF. The seven previous ones are as follows:

a. CERC Miscellaneous Report 82-16, which summarizes data collected during 1977-79.

b. Technical Report CERC-84-1, which summarizes data collected during 1980.

c. Technical Report CERC-85-3, which summarizes data collected during 1981.

d. Technical Report CERC-86-5, which summarizes data collected during 1982.

e. Technical Report CERC-86-9, which summarizes data collected during 1983.

f. Technical Report CERC-86-11, which summarizes data collected during 1984.

g. Technical Report CERC-87-13, which summarizes data collected during 1985.

These reports are available from the WES Technical Report Distribution Section of the Information Technology Laboratory, Vicksburg, MS.

PREFACE

Data and data summaries presented herein were collected during 1986 and compiled at the US Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center's (CERC's) Field Research Facility (FRF) in Duck, NC. This report is the eighth in a series of annual FRF data summaries carried out under CERC's Coastal Flooding and Storm Protection Program, FRF Measurements and Analysis Work Unit 31537. CERC Program Manager is Dr. C. Linwood Vincent.

The report was prepared by Mr. Herman C. Miller, Oceanographer, FRF, under direct supervision of Mr. William A. Birkemeier, Acting Chief, FRF Group, Engineering Development Division (EDD), and Mr. Thomas W. Richardson, Chief, EDD; and under general supervision of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., chief and Assistant Chief, CERC, respectively. Ms. Adele Militello, Computer Specialist, assisted with data analysis and report preparation; and Messrs. Michael W. Leffler, Computer Programmer Analyst, assisted with data collection and analysis; William E. Grogg, Jr., Electronics Technician, assisted with instrumentation; and Brian L. Scarborough, Amphibious Vehicle Operator, assisted with data collection. The National Oceanic and Atmospheric Administration/National Ocean Service maintained the tidal gage and provided statistics for summarization.

This report was edited by Ms. Shirley A. J. Hanshaw, Information Products Division, Information Technology Laboratory, WES.

Commander and Director of WES during the publication of this report was COL Dwayne G. Lee, EN; Technical Director was Dr. Robert W. Whalin.

CONTENTS

* A limited number of copies of Appendix B (Volume II) were published under separate cover. Copies are available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA. 22161.

ANNUAL DATA SUMMARY FOR 1986
CERC FIELD RESEARCH FACILITY

PART I: INTRODUCTION

Background

1. The US Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center's (CERC's) Field Research Facility (FRF), located on 712,250 square metres at Duck, NC (Figure 1), consists of a 561-m-long research pier and accompanying office and field support buildings. The FRF is located near the middle of Currituck Spit along a 100-km unbroken stretch of shoreline extending south of Rudee Inlet, VA, to Oregon Inlet, NC. The FRF is bordered by the Atlantic Ocean to the east and Currituck Sound to the west. The Facility is designed to (a) provide a rigid platform from which waves, currents, water levels, and bottom elevations can be measured, especially during severe storms; (b) provide CERC with field experience and data to complement laboratory and analytical studies and numerical models; (c) provide a manned field facility for testing new instrumentation; and (d) serve as a permanent field base of operations for physical and biological studies of the site and adjacent region.

2. The research pier is a reinforced concrete structure supported on 0.9-m-diam steel piles spaced 12.2 m apart along the pier's length and 4.6 m apart across the width. The piles are embedded approximately 20 m below the ocean bottom. The pier deck is 6.1 m wide and extends from behind the duneline to about the 6-m water depth contour at a height of 7.8 m above the National Geodetic Vertical Datum (NGVD). The pilings are protected against sand abrasion by concrete erosion collars and against corrosion by a cathodic system.

3. An FRF Measurements and Analysis program has been established to collect basic oceanographic and meteorological data at the site, reduce and analyze these data, and publish the results.

4. This report, which summarizes data for 1986, continues a series of annual reports begun in 1980.

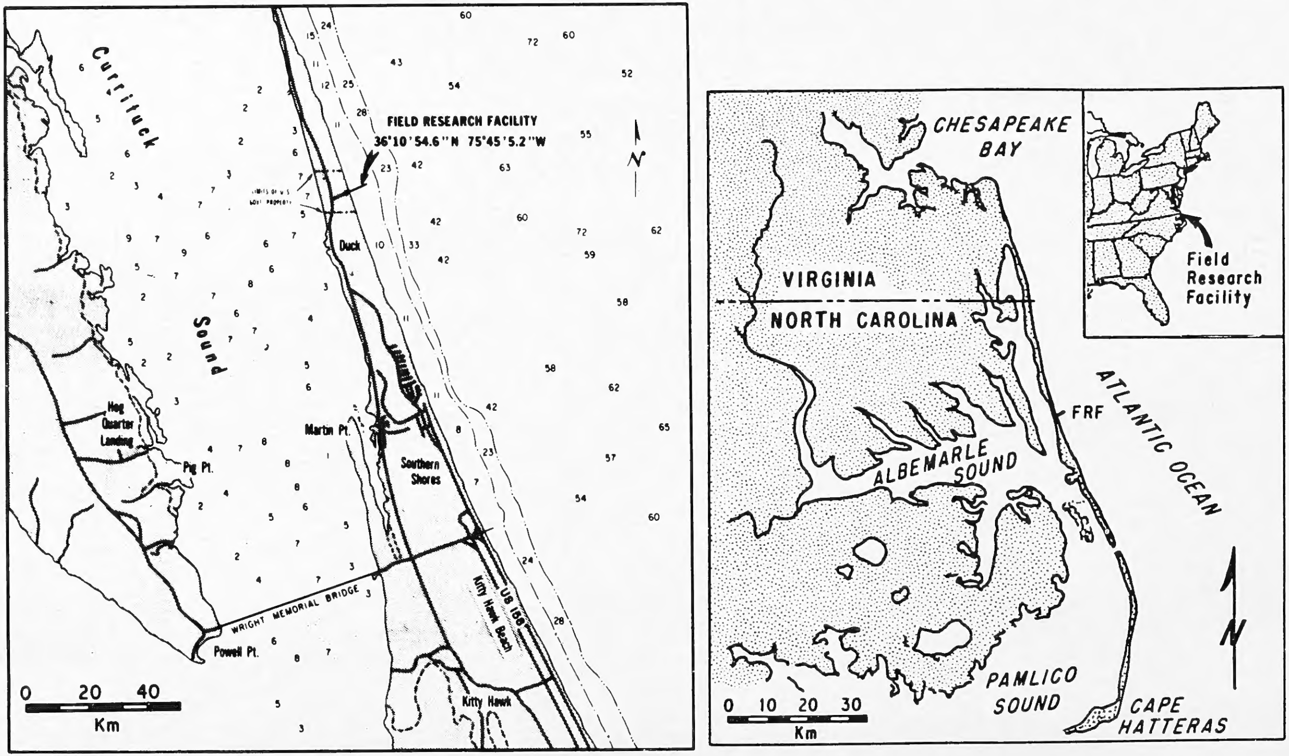


Figure 1. FRF location map

Organization of Report

5. This report is organized into nine parts and two appendixes. Part I is an introduction; Parts II through VIII discuss the various data collected during the year; and Part IX describes the storms that occurred. Appendix A presents the bathymetric surveys conducted during the year, and Appendix B (published under separate cover as Volume II) contains wave data statistics.

6. In each part of this report, the respective instruments used for monitoring the meteorological or oceanographic conditions are briefly described along with data collection and analysis procedures and data results. The instruments were interfaced with the primary data acquisition system, a Data General Corporation (Westboro, MA) NOVA-4 minicomputer located in the FRF laboratory building. More detailed explanations of the design and operation of the instruments may be found in Miller (1980). Readers' comments on the format and usefulness of the data presented are encouraged.

Availability of Data

7. Table 1 is intended as a quick reference guide to show the dates for which various types of data are available. In addition to the wave data summaries in the main text, more extensive summaries for each of the wave gages are provided in Volume II, as discussed above.

8. The annual data summary herein summarizes daily observations by month and year to provide basic data for analysis by users. Daily measurements and observations have already been reported in a series of monthly Preliminary Data Summaries (Field Research Facility 1986). If individual data for the present year are needed, the user can obtain detailed information (as well as the monthly and previous annual reports) from the following address:

USAE Waterways Experiment Station
Coastal Engineering Research Center
Field Research Facility
SR Box 271
Kitty Hawk, NC 27949-9440

Although the data collected at the FRF are designed primarily to support ongoing CERC research, use of the data by others is encouraged. The WES/CERC

Table 1

1986 Data Availability

	Gage Number	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
		1 2 3 4 5	1 2 3 4	1 2 3 4	1 2 3 4 5	1 2 3 4	1 2 3 4	1 2 3 4 5	1 2 3 4	1 2 3 4	1 2 3 4 5	1 2 3 4	1 2 3 4
WEATHER													
Anemometer	632	* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *
Atm. Pressure	616	* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *
Air Temperature	624	* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *	/ / - / /	* * / -	/ * * *	* * * * *	* * * *	* * * *
Precipitation		* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *
WAVES													
Offshore Waverider	630	/ * * * *	* * * *	* * * *	* * * * *	* * * /	* * * *	* / / * *	* * * /	/ * * /	* * * * *	* * * *	* * - -
Nearshore Waverider	640	* * * * *	* * * *	* * * *	* * * * *	* * / /	* * * *	* / / * *	* * * /	/ * * /	* * * * /	* / * /	/ / * *
Pier End	625	* * * * *	* * * *	* * * *	* * * * *	* * * /	- - - -	- - - - -	- - - -	- - / /	* * * * /	* * * *	* * * *
Pier Nearshore	645	* * * * *	* * * *	* * * *	/ / * * *	/ / / /	/ * / *	* / / / *	* * * /	* * * /	* * * * /	* * * *	* * * *
CURRENTS													
Pier End		* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *	* * * * *	* * / *	* * * *	* * * * *	* * * /	* * * *
Midsurf		* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *	* * * * *	* * / *	* * * *	* * * * *	* * * /	* * * *
Beach		* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *	* * * * *	* * / *	* * * *	* * * * *	* * * /	* * * *
PIER END TIDE GAGE		* * * * /	/ * * *	* * * *	* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *
WATER CHARACTERISTICS													
Temperature		* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *	* * * * *	* * / *	* * * *	* * * * *	* * * /	* * * *
Visibility		* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *	* * * * *	* * / *	* * * *	* * * * *	* * * /	* * * *
Density		/ * * * *	* * * *	* * * *	/ / * * *	* * * *	* * * *	* * * * *	* * / *	* * * *	* * * * *	* * * /	* * * *
BATHYMETRIC SURVEYS		week 4: *	week 4: *				week 2: *	week 4: *		week 1: *			week 1: *
PHOTOGRAPHY													
Beach		* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *	* * * * *	* * * *	* * * *
Aerial		week 2: *			week 3: *				week 3: *		week 3: *		

Notes: * Full week of data obtained
/ Less than 7 days of data obtained
- No data obtained

Coastal Engineering Information and Analysis Center (CEIAC) is responsible for storing and disseminating most of the data collected at the FRF. All data requests should be in writing and addressed to:

Commander and Director
US Army Engineer Waterways Experiment Station
ATTN: Coastal Engineering Information Analysis Center
PO Box 631
Vicksburg, MS 39180-0631

Tidal data other than the summarizes in this report can be obtained directly from the following address:

National Oceanic and Atmospheric Administration
National Ocean Service
ATTN: Tide Analysis Branch
Rockville, MD 20852

A complete explanation of the exact data desired for specific dates and times will expedite filling any request; an explanation of how the data will be used will help CEIAC or the National Oceanic and Atmospheric Administration (NOAA)/National Ocean Service (NOS) determine if other relevant data are available. For information regarding the availability of data for all years contact CEIAC at (601) 634-2012. Costs for collecting, copying, and mailing will be borne by the requester.

PART II: METEOROLOGY

9. This section summarizes the meteorological measurements made during the current year and in combination with all previous years. Meteorological measurements during storms are given in Part IX.

10. Mean air temperature, atmospheric pressure, and wind speed and direction were computed for each data file which consisted of data sampled four times per second for 20 min every 6 hr beginning at or about 0100, 0700, 1300, and 1900 eastern standard time (EST); these hours correspond to the time that the National Weather Service (NWS) creates daily synoptic weather maps. During storms, hourly data recordings were made.

Air Temperature

11. The FRF enjoys a typical marine climate which moderates the temperature extremes of both summer and winter.

Measurement instruments

12. A Yellow Springs Instrument Company, Inc. (YSI) (Yellow Springs, OH), electronic temperature probe with analog output interfaced to the FRF's computer was operated beside the NWS's meteorological instrument shelter located 43 m behind the dune (Figure 2). To ensure proper temperature readings, the probe was installed 3 m above ground inside a "coolie hat" to shade it from direct sunlight yet provide proper ventilation.

Results

13. Daily air temperature values are shown in Figure 3. Average air temperature statistics are tabulated in Table 2 and illustrated in Figure 4.

Atmospheric Pressure

Measurement instruments

14. Electronic atmospheric pressure sensor. Atmospheric pressure was measured with a YSI electronic sensor with analog output located in the laboratory building at 9 m above NGVD. Data were recorded on the FRF computer. Data from this gage were compared with those from an NWS aneroid barometer to ensure proper operation.

Figure 2. FRF gage locations

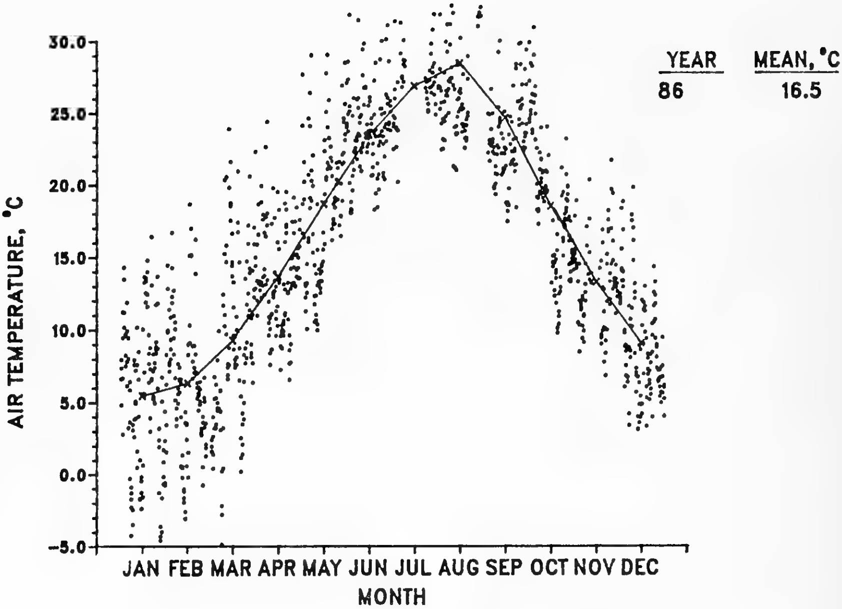


Figure 3. Daily and monthly mean air temperature values

Table 2

Mean Meteorological Statistics

	Precipitation, mm				Mean Air Temperature °C		Mean Atmospheric Pressure mb		Wind			
	1986	1978-1986							1986		1980-1986	
Month	Total	Mean	Maxima	Minima	1986	1983-1986	1986	1983-1986	Speed m/sec	Direction deg	Speed m/sec	Direction deg
Jan	44	91	180	44	5.5	5.1	1019.6	1017.7	2.1	278	2.5	321
Feb	20	74	84	20	6.3	6.4	1015.7	1016.8	2.4	328	1.7	330
Mar	38	81	168	35	9.3	9.3	1020.8	1015.7	1.4	342	1.4	334
Apr	66	89	182	0	13.6	13.9	1014.2	1014.0	1.3	336	0.4	216
May	20	71	239	20	18.7	19.0	1016.7	1015.7	0.3	80	0.6	171
Jun	89	77	130	27	23.5	23.3	1015.5	1015.5	1.3	163	1.0	173
Jul	96	87	200	19	26.9	25.9	1014.3	1016.1	1.5	182	1.7	198
Aug	221	110	221	30	28.5	26.1	1017.5	1016.7	1.2	108	0.5	51
Sep	42	83	160	5	24.6	22.0	1021.1	1018.6	2.0	43	1.9	14
Oct	17	62	143	17	18.5	18.5	1020.5	1020.2	2.2	8	2.6	15
Nov	46	85	145	26	13.2	13.3	1021.7	1018.4	3.1	20	2.2	338
Dec	68	70	131	4	9.0	8.7	1021.0	1020.4	3.6	341	2.3	320
Average	64	81			16.5	16.0	1018.2	1017.2	1.0	354	0.9	340
Total	766	1061										

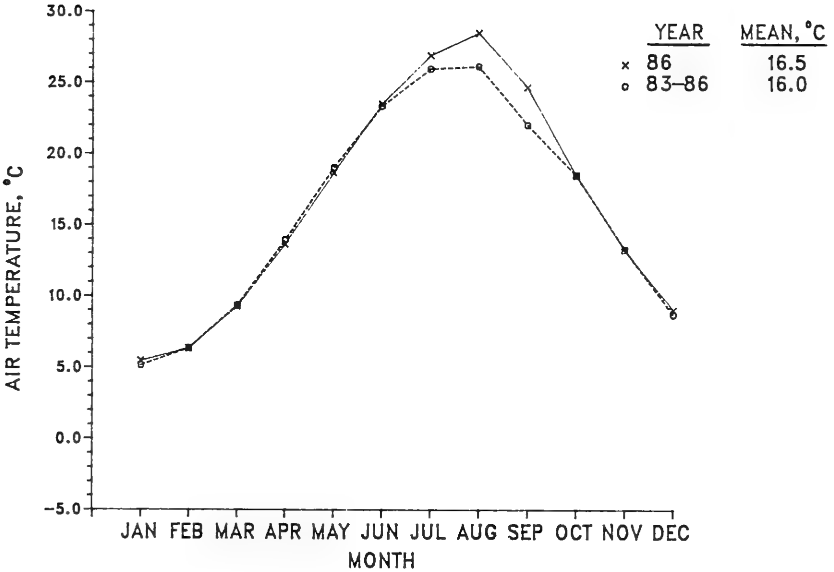


Figure 4. Mean monthly air temperatures

15. Microbarograph. A Weathertronics, Inc. (Sacramento, Calif.), recording aneroid sensor (microbarograph) located in the laboratory building also was used to continuously record atmospheric pressure variation.

16. The microbarograph was compared daily with the NWS aneroid barometer, and adjustments were made as necessary. Maintenance of the microbarograph consisted of inking the pen, changing the chart paper, and winding the clock every 7 days. During the summer, a meteorologist from the NWS checked and verified the operation of the barometer.

17. The microbarograph was read and inspected daily using the following procedure:

a. The pen was zeroed (where applicable).

b. The chart time was checked and corrected, if necessary.

c. Daily reading was marked on the chart for reference.

d. The starting and ending chart times were recorded, as necessary.

e. New charts were installed when needed.

Results

18. Daily atmospheric pressure values are presented in Figure 5, and summary statistics are presented in Table 2 and Figure 6.

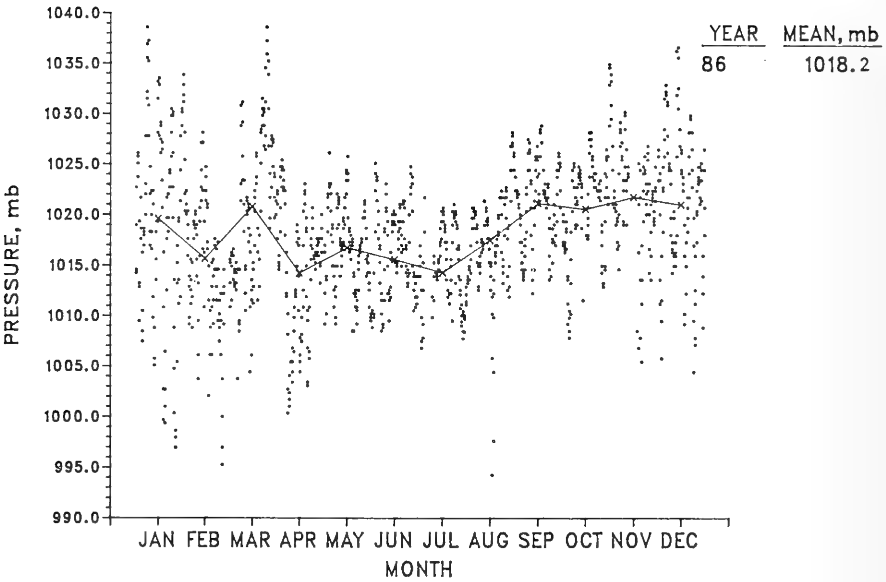


Figure 5. Daily and monthly mean atmospheric pressure values

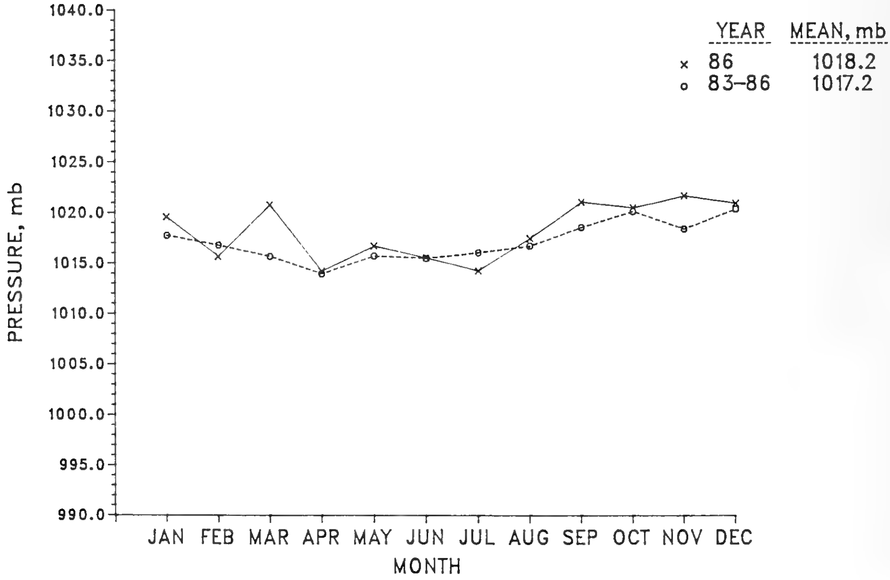


Figure 6. Mean monthly atmospheric pressure

Precipitation

19. Precipitation is generally well distributed throughout the year. Precipitation from midlatitude cyclones (northeasters) predominates in the winter, while local convection (thunderstorms) accounts for most of the summer rainfall.

Measurement instruments

20. Electronic rain gage. A Belfort Instrument Company (Baltimore, MD) 30-cm weighing rain gage, located near the instrument shelter 47 m behind the dune, measured daily precipitation. According to the manufacturer, the instrument's accuracy was 0.5 percent for precipitation amounts less than 15 cm and 1.0 percent for amounts greater than 15 cm.

21. The rain gage was inspected daily, and the analog chart recorder was maintained by procedures similar to those for the microbarograph.

22. Plastic rain gage. An Edwards Manufacturing Company (Alberta Lea, MN) True Check 15-cm-capacity clear plastic rain gage with a 0.025-cm resolution was used to monitor the performance of the weighing rain gage. This gage, located near the weighing gage, was compared daily; and very few discrepancies were identified during the year.

Results

23. Daily precipitation values are shown in Figure 7. Total precipitation for each month during this year and average totals for all years combined are shown in Figure 8, while similar statistics are presented in Table 2.

Wind Speed and Direction

24. Winds at the FRF are dominated by tropical maritime air masses which create low to moderate, warm southern breezes; artic and polar air masses which produce cold winds from northerly directions; and smaller scale cyclonic, low pressure systems, which originate either in the tropics (and move north along the coast) or on land (and move eastward offshore). The dominant wind direction changes with season, being generally from northern directions in the fall and winter and from southern directions in the spring and summer. It is common for fall and winter storms (northeasters) to produce winds with average speeds in excess of 15 m/sec.

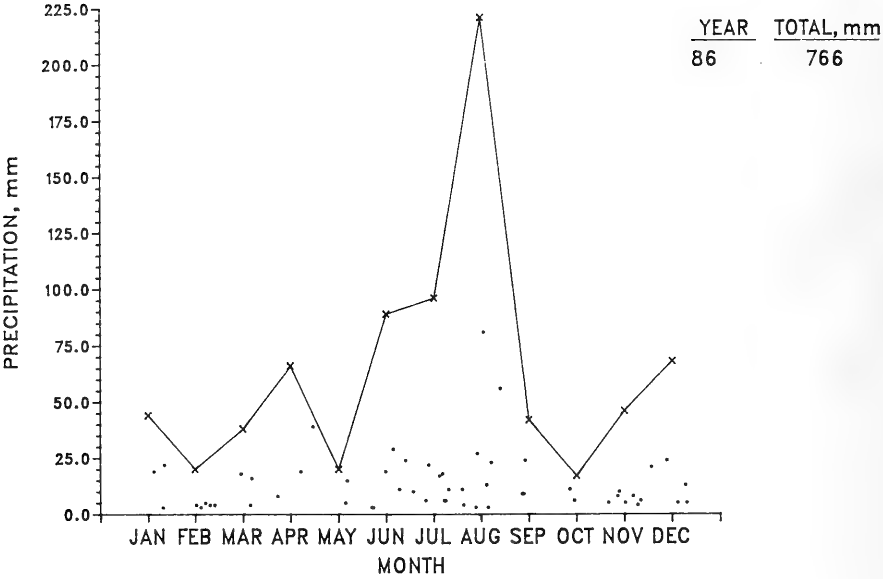


Figure 7. Daily and monthly total precipitation values

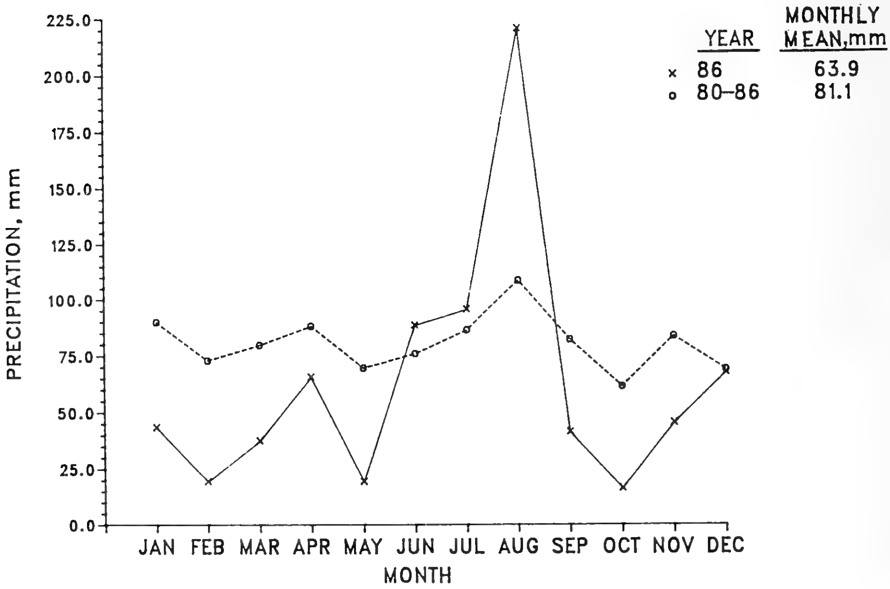


Figure 8. Mean monthly precipitation

Measurement instrument

25. Winds were measured on top of the laboratory building at an elevation of 19.1 m (Figure 2) using a Weather Measure Corporation (Sacramento, CA) Skyvane Model W102P anemometer. Wind speed and direction data were collected on the FRF computer as well as on a strip-chart recorder. The anemometer manufacturer specifies an accuracy of ±0.45 m/sec below 13 m/sec and 3 percent at speeds above 13 m/sec, with a threshold of 0.9 m/sec. Wind direction accuracy is ±2 deg with a resolution of less than 1 deg. The anemometer was calibrated semiannually at the National Bureau of Standards in Gaithersburg, MD, and is within the manufacturer's specifications.

Results

26. Annual and monthly joint probability distributions of wind speed versus direction were computed. Winds speeds were resolved into 3-m/sec intervals, while the directions were at 22.5-deg intervals (i.e. 16-point compass direction specifications). These distributions are presented as wind "roses," such that the length of the petal represents the frequency of occurrence of wind blowing from the specified direction, and the width of the petal is indicative of the speed. Resultant directions and speeds were also determined by vector averaging the data (see Table 2). Wind statistics are presented in Figures 9 through 11.

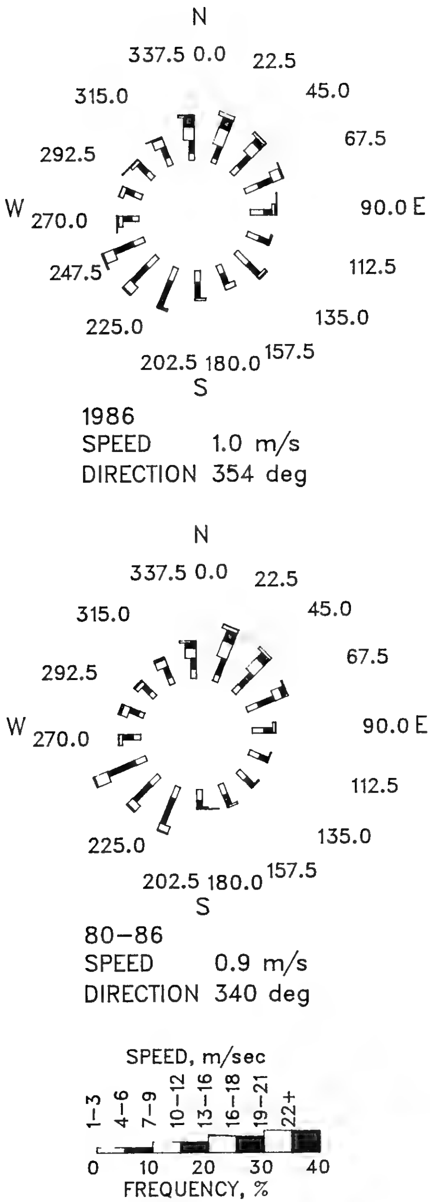


Figure 9. Annual wind roses

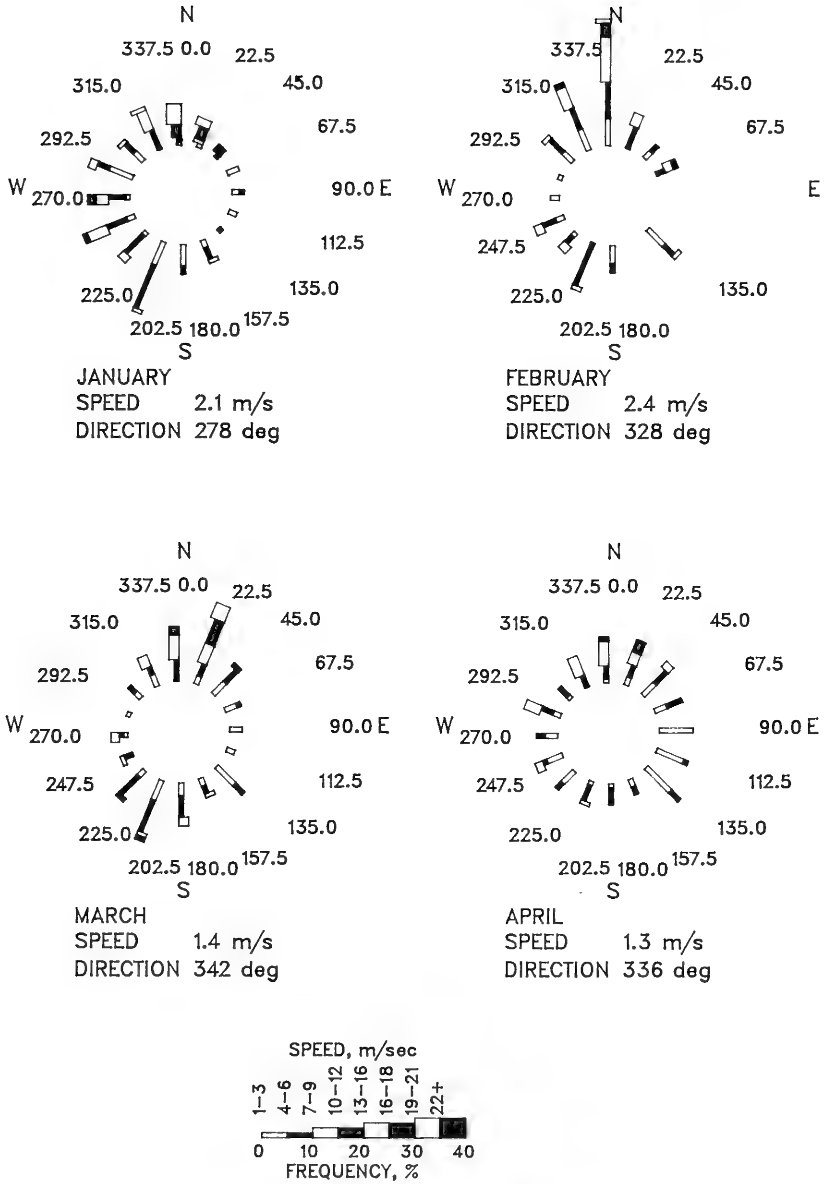


Figure 10. Monthly wind roses for 1986 (Sheet 1 of 3)

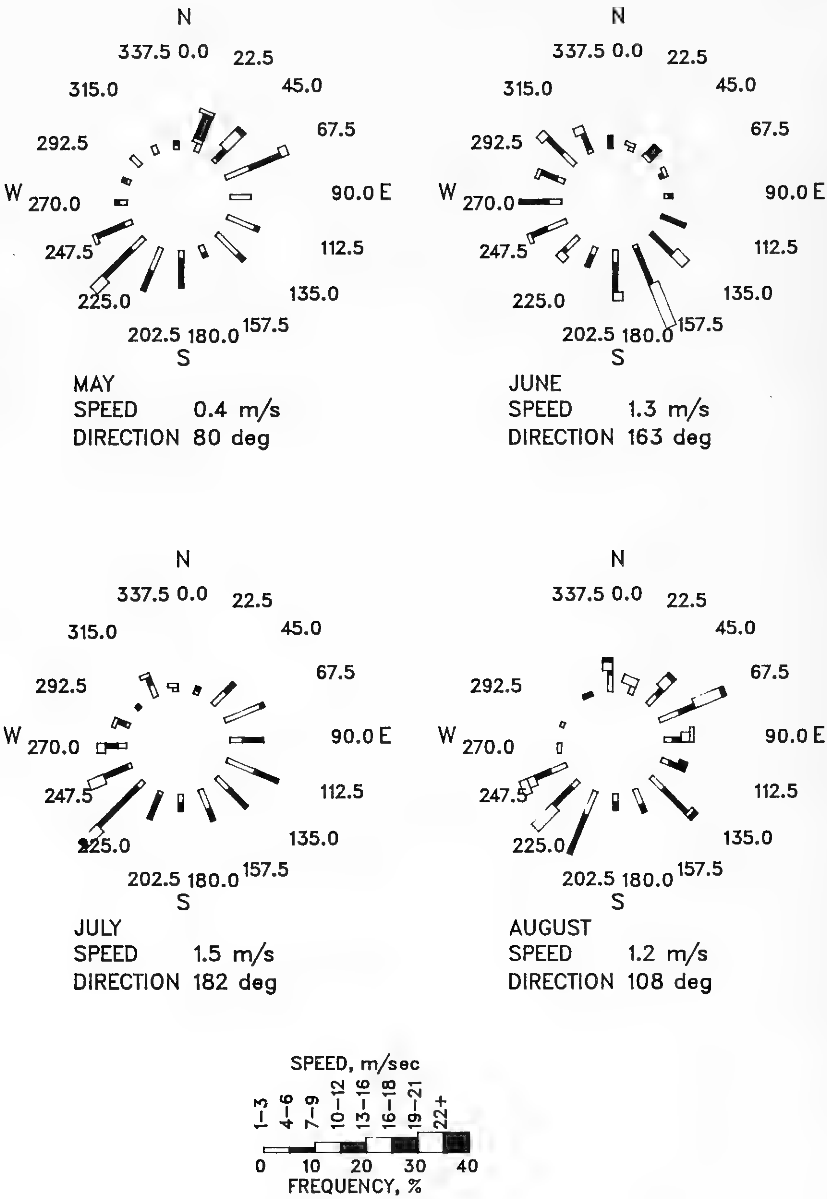
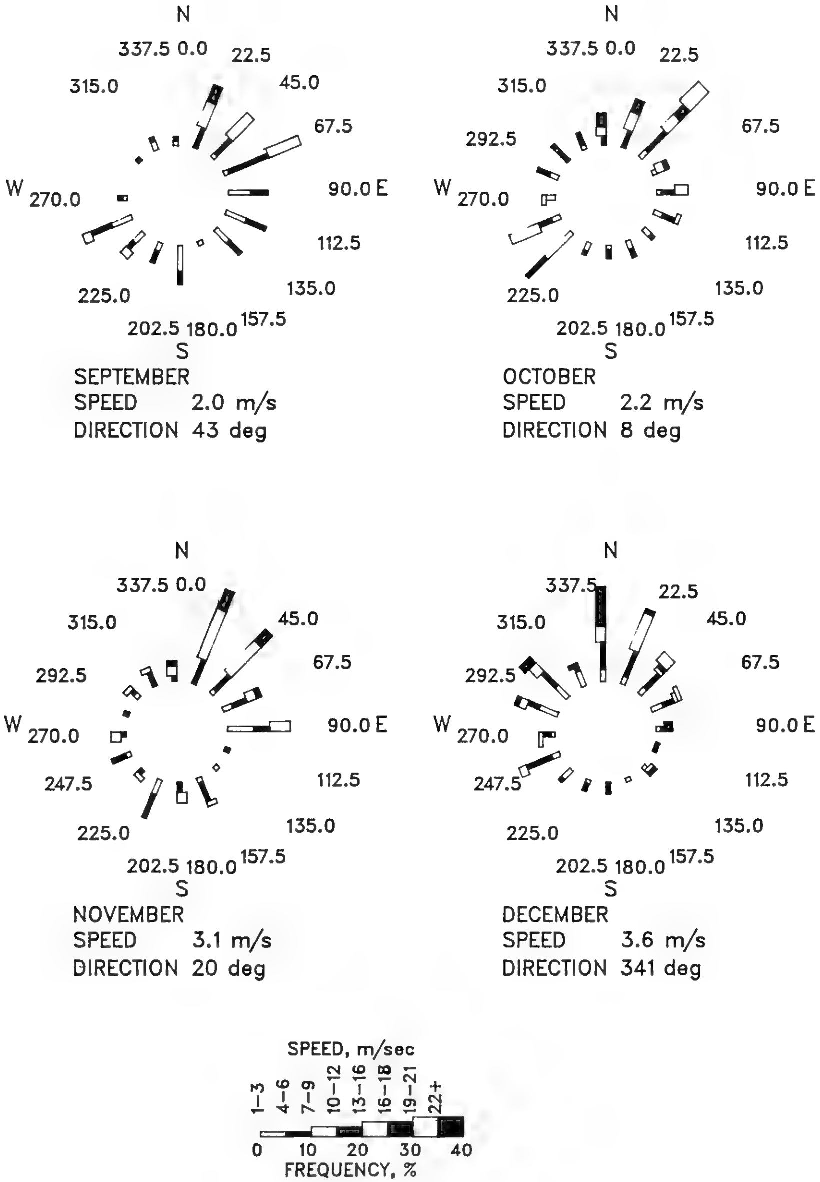


Figure 10. (Sheet 2 of 3)



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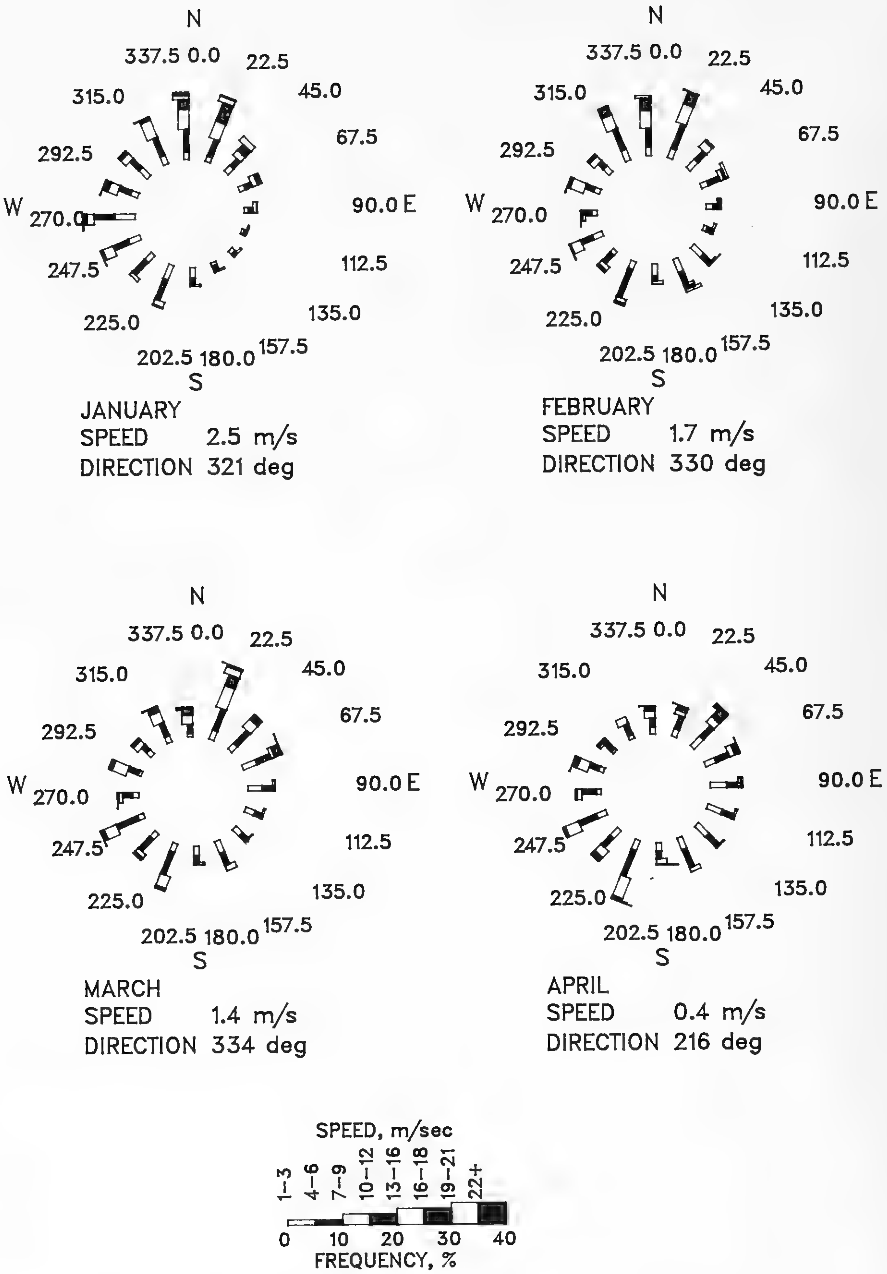
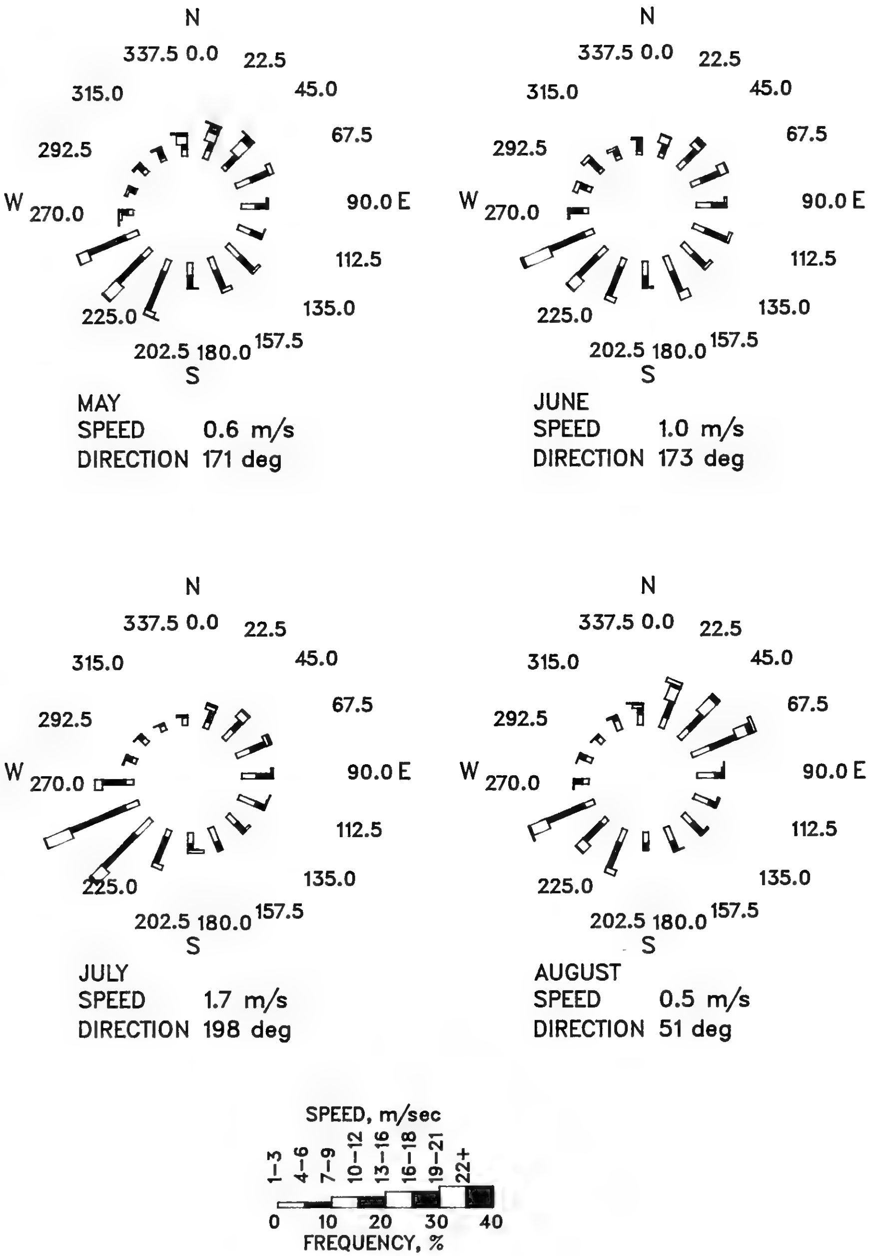


Figure 11. Monthly wind roses for 1980 through 1986 (Sheet 1 of 3)



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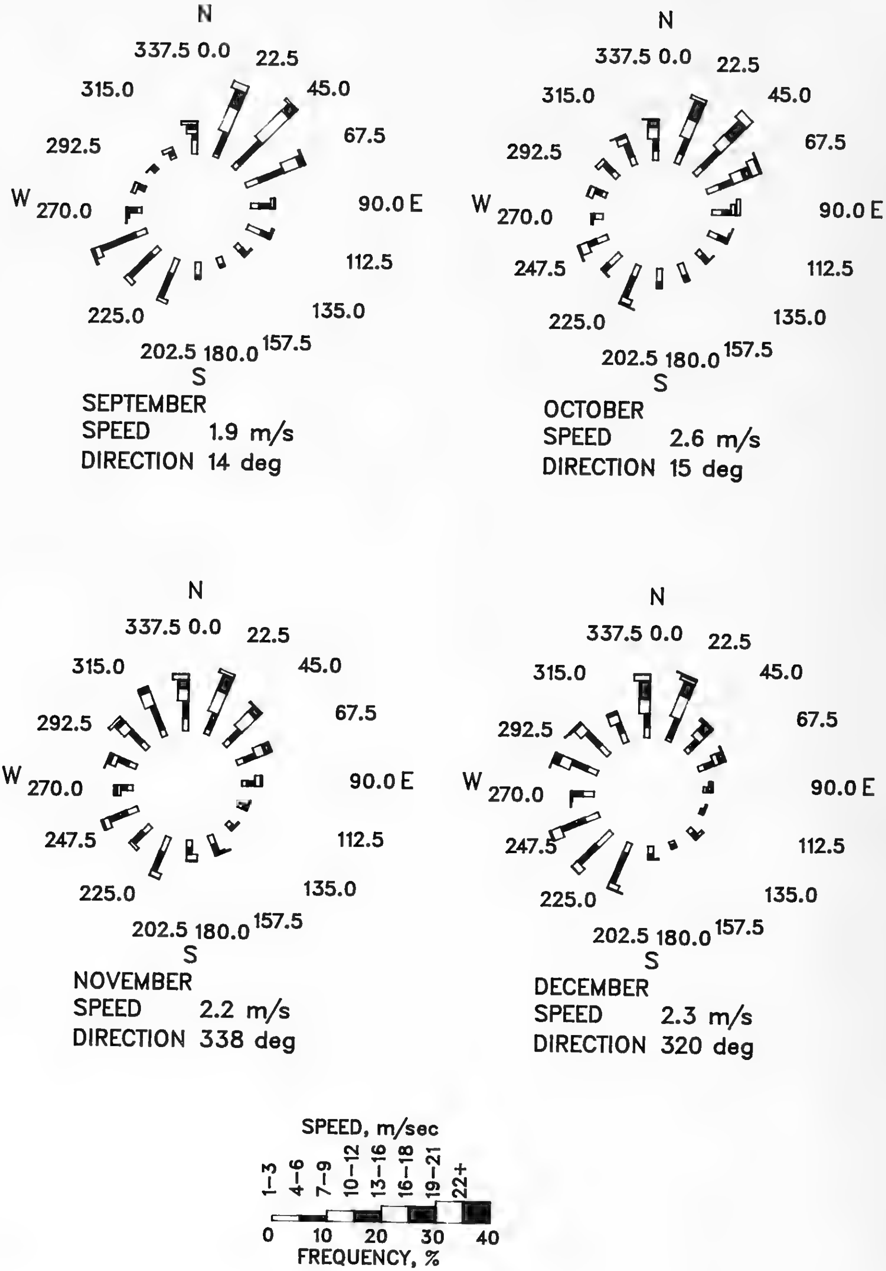

Figure 11. (Sheet 3 of 3)

PART III: WAVES

27. This section presents summaries of the wave data. A discussion of individual major storms is given in Part IX and contains additional wave data for times when wave heights exceeded 2 m at the seaward end of the FRF pier. Appendix B (published as Volume II) provides more extensive summaries of the data for each gage, including height and period distributions, wave direction distributions, persistence tables, and spectra during storms. Signals from the wave gages were routinely sampled similarly to the meteorological data described in Part II.

28. Wave directions (similar to wind directions) at the FRF are seasonally distributed. Waves approach most frequently from north of the pier in the fall and winter and south of the pier in the summer, with the exception of storm waves which approach twice as frequently from north of the pier. Annually, waves are approximately evenly distributed between north and south (resultant wave direction being almost shore-normal).

Measurement Instruments

29. The wave gages included two buoys and two wave staff gages located as follows:

Gage Number	Location	Average Depth, m
630	6 km from shore	-18.0
640	1 km from shore	-9.0
625	Pier end	-8.0
645	Landward end of pier	-3.5

Staff gages

30. Two Baylor Company (Houston, TX) parallel cable inductance wave gages (Gage 645 at sta 7+80 and Gage 625 at sta 19+00 (Figure 2)) were mounted on the FRF pier. Rugged and reliable, these gages require little maintenance except to keep tension on the cables and to remove any material which may cause an electrical short between them. They were calibrated prior to installation by creating an electrical short between the two cables at known distances along the cable and recording the voltage output. Electronic signal conditioning amplifiers are used to ensure that the output signals from the gages are within a 0- to 5-V range. Manufacturer-stated gage accuracy is

about 1.0 percent, with a 0.1 percent full-scale resolution; full scale is 14 m for Gage 625 and 8.5 m for Gage 645. These gages are susceptible to lightning damage, but protective measures have been taken to minimize such occurrences. A more complete description of the gages' operational characteristics is given by Grogg (1986).

Buoy gages

31. Two Datawell Laboratory for Instrumentation (Haarlem, The Netherlands) Waverider buoy gages (Gage 630 and 640) measure the vertical acceleration produced by the passage of a wave. The acceleration signal is double-integrated to produce a displacement signal which is transmitted by radio to an onshore receiver. The manufacturer stated that wave amplitudes are correct to within 3 percent of their actual value for wave frequencies between 0.065 and 0.500 Hz (corresponding 15- to 2-sec wave periods). The manufacturer also specified that the error gradually increased to 10 percent for wave periods in excess of 20 sec. The results in this report were not corrected for the manufacturer's specified amplitude errors. However, to ensure that the buoys were within the manufacturer's specifications, they were calibrated semiannually.

Digital Data Analysis and Summarization

32. Thompson (1977) and Harris (1974) describe the procedure used for analyzing and summarizing the digital wave data contained in this report. The procedure is based on a Fast Fourier Transform (FFT) spectral analysis of 4,096 data values (1,024 sec sampled at 4 Hz) for each file processed.

33. The analysis program computes the first five moments of the distribution of sea surface elevations then edits the digital data by checking for "jumps" and "spikes" and for data points out of the 0- and 5-V range. A jump is defined as a data value greater than 2.5 standard deviations from the previous data value, while a spike is a data value 5 standard deviations or more from the mean. If less than 5 jumps or spikes in a row are found, the program linearly interpolates between acceptable data and replaces the erroneous data values. If more than 5 jumps or spikes in a row or a total of 100 bad data points for the file are found, the program stops interpolating and editing. At this point the program analyzes the data and prints a flag indicating that there is a problem with the file. If the variance is less than 0.001 m^2, the

record is not analyzed. After program editing is completed, the first five moments of the distribution of sea surface elevations are again computed. A cosine bell data window was applied to increase the resolution for the energy spectrum of the file; use of the data window is discussed by Harris (1974). After application of the data window, the program computes the variance spectrum (proportional to the energy spectrum) using the FFT procedure. After the data files are analyzed, the results are eliminated for files that are flagged as bad or appear inconsistent with simultaneous observations from nearby gage sites. Frequently the spectrum and/or distribution function of sea surface elevations are examined to determine if the data were acceptable. After the analysis results are edited, monthly summaries of wave heights and periods are generated.

34. Unless otherwise specified, wave height in this report refers to the energy-based parameter H_{mo} (defined as four times the standard deviation of the sea surface elevations). Wave period T_p is defined as the period associated with the maximum energy in the spectrum which is resolved by partitioning the spectrum into frequency bands of equal width and determining the band with the maximum energy density. The period reported is the reciprocal of the center frequency (e.g. T_p = 1/frequency) of the spectral band. Since the spectral bands are of equal frequency width, namely 0.010742 Hz (i.e. 11/1,024 sec), the analysis provides uniform resolution in frequency. However, the resolution in period is not uniform since the period intervals become larger for lower frequencies. Because of the combination with the varying width of the period intervals, only a discrete set of period values is possible, as shown below:

Band Number	Upper Limit of Frequency Band Hz	Corresponding Period Lower Limit of Band, sec	T_p Associated with Center Frequency of Band, sec	T_p Not Reported sec
6	0.065	15.3	16.8	
7	0.076	13.1	14.2	15
8	0.087	11.5	12.3	13
9	0.098	10.2	10.9	11
10	0.108	9.2	9.8	

Complete information about the energy contained in all frequency bands can best be obtained by inspecting the full spectrum, examples of which are included in Appendix B (Volume II) for Gage 625 during storm wave conditions.

Results

35. The wave conditions for the year are summarized in Figure 12. For all four gages, the distributions of wave height for the current year and all years combined are presented in Figures 13 and 14, respectively. Accordingly, the distributions of wave period are presented in Figures 15 and 16, respectively.

36. Refraction, bottom friction, and wave breaking contribute to the observed differences in height and period. During the most severe storms when the wave heights exceed 3 m at the seaward end of the pier, the surf zone (wave breaking) has been observed to extend past the end of the pier and occasionally out to Gage 640. This occurrence is a major reason for the differences in the distributions between Gage 630 and the inshore gages. The wave height statistics for the staff gage (Gage 645), located at the landward end of the pier, were considerably lower than those for the other gages. In all but the calmest conditions, this gage is within the breaker zone. Consequently, these statistics represent a lower energy wave climate.

37. For the current year and all years combined, monthly mean, standard deviation, and extreme wave height and period statistics are presented for all four gages in Tables 3 through 10.

38. For the current year and combined with all years, monthly wave height distributions (Figures 17 and 18, respectively) and wave period distributions (Figures 19 and 20, respectively) for Gage 630 are presented to show the typical temporal variability of the wave conditions. Similar plots for the other gages are included in Appendix B.

39. Annual and monthly joint distributions of wave height versus wave period for Gage 630 are presented for 1986 in Tables 11 and 12, respectively, and for all years combined in Tables 13 and 14, respectively. Similar distributions for the other gages are included in Appendix B.

40. Annual distributions of wave directions, based on daily observations of direction at the seaward end of the pier, and height from Gage 625 (or Gage 640 when data for Gage 625 were unavailable) are shown in Figure 21. Monthly wave "roses" for 1986 and all years combined are presented in Figures 22 and 23, respectively.

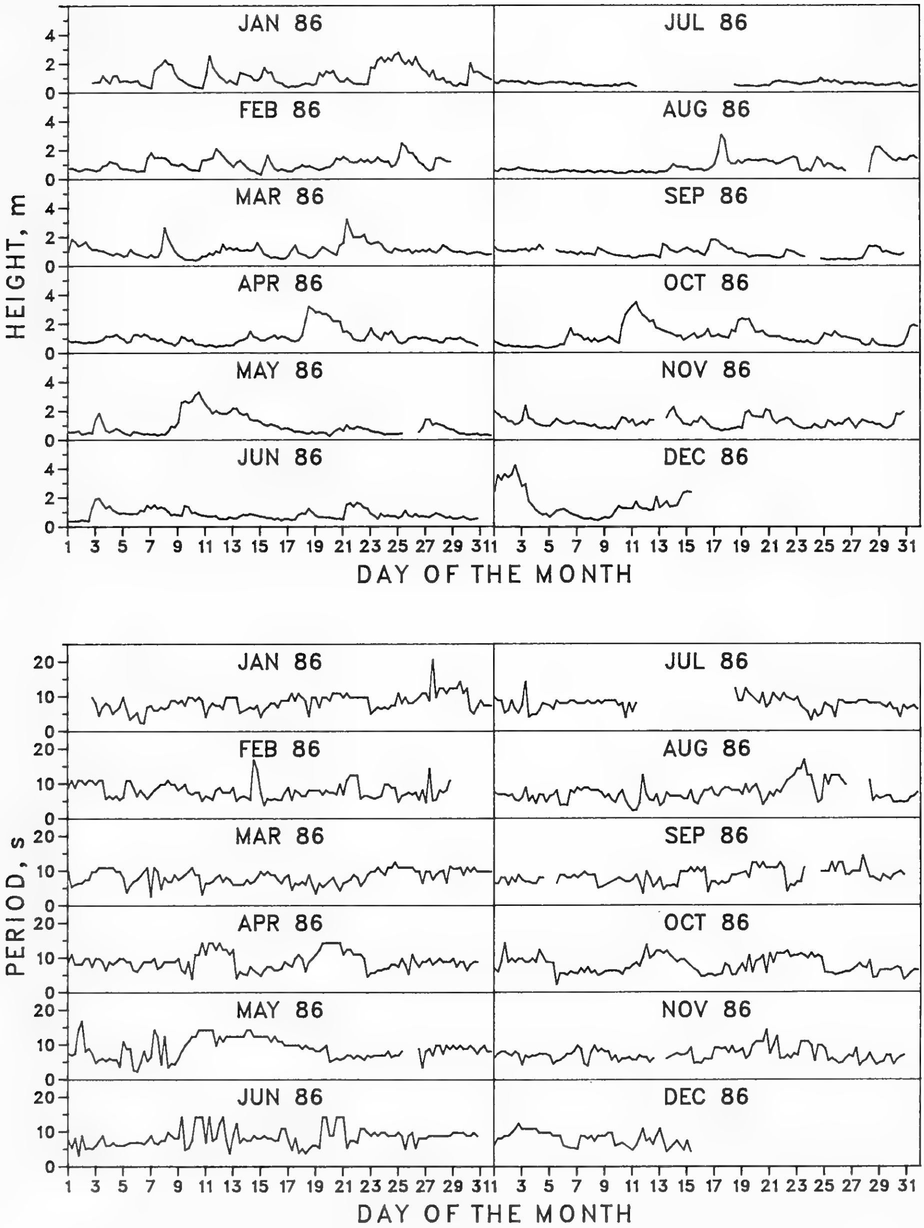

Figure 12. Time-histories of wave height and period for Gage 630

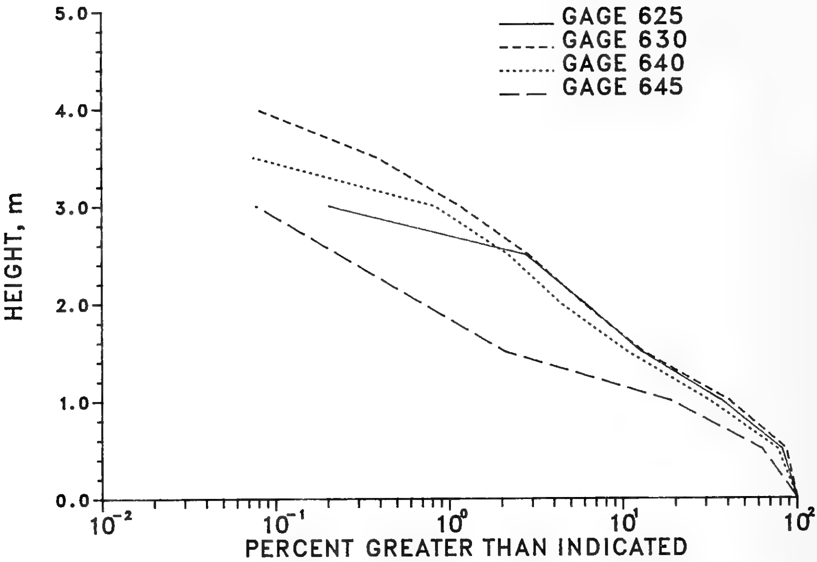

Figure 13. 1986 annual wave height distributions

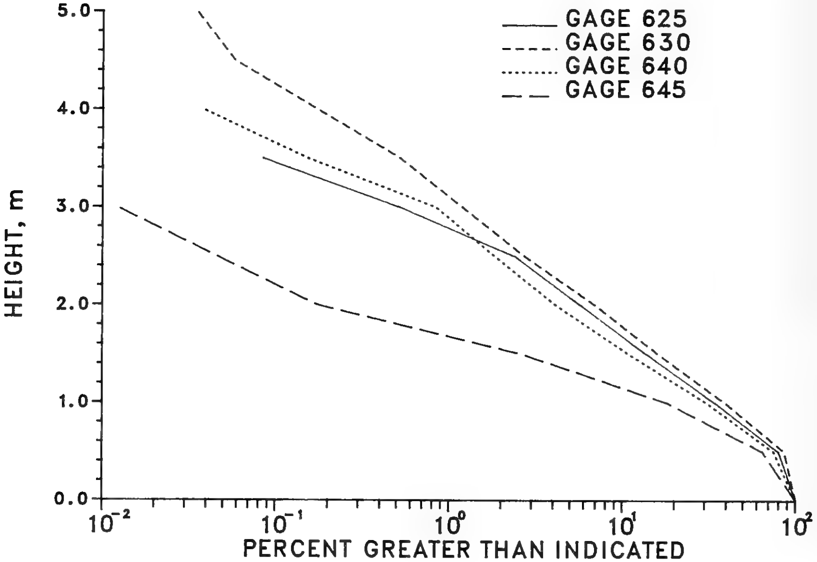

Figure 14. Annual distribution of wave heights for 1980 through 1986

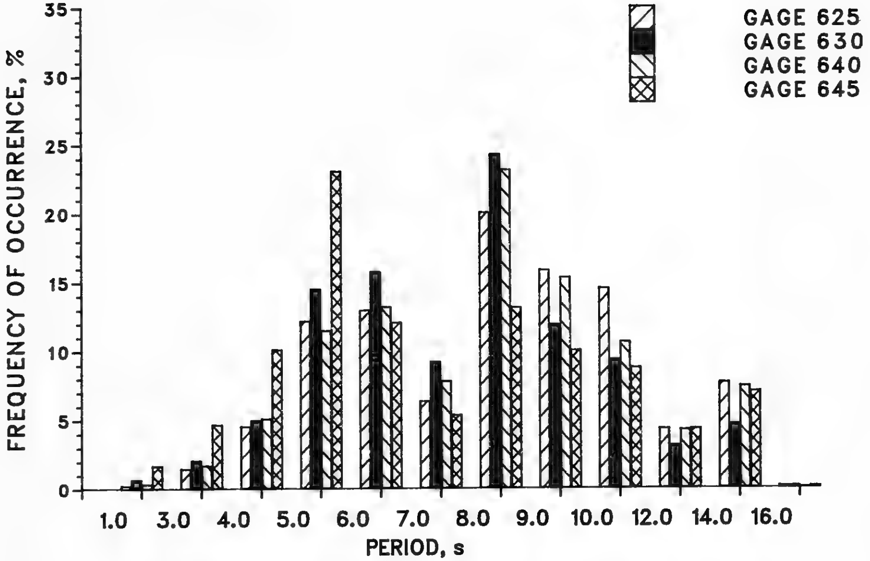

Figure 15. 1986 annual wave period distributions

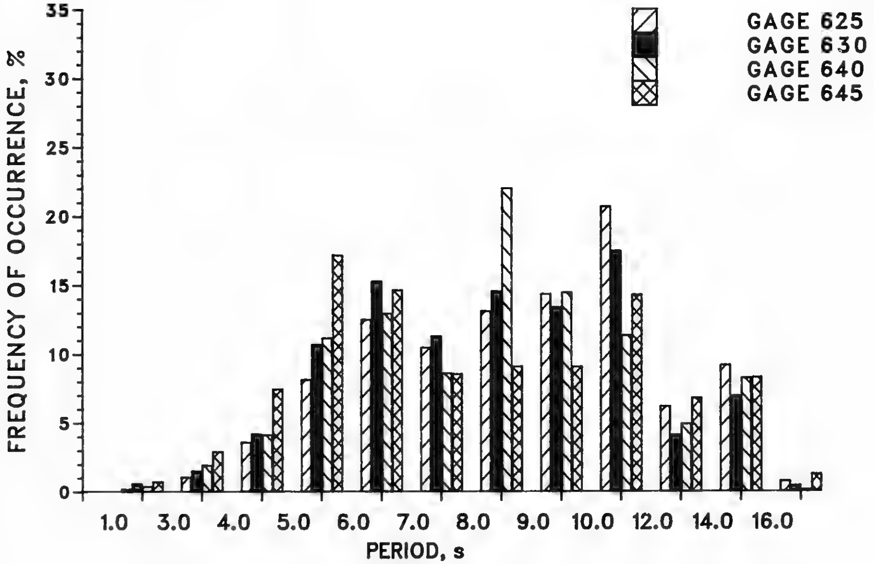

Figure 16. Annual distribution of wave periods for 1980 through 1986

Table 3

1986 Mean, Standard Deviation, and Extreme

H_{mo} and T_p for Gage 625

Month	Height: Mean m	Height: Std.Dev. m	Period: Mean sec	Period: Std.Dev. sec	Extreme: Height m	Extreme: Date	Number Obs.
Jan	1.0	0.6	8.8	2.6	2.7	25	122
Feb	1.0	0.4	8.7	2.8	2.0	25	110
Mar	1.0	0.5	7.9	2.0	2.4	21	106
Apr	1.0	0.6	9.3	2.5	3.0	19	113
May	1.0	0.8	9.7	3.1	3.0	10	116
Jun	0.9	0.6	7.4	1.2	1.9	3	14
Sep	0.7	0.3	10.3	2.6	1.2	28	46
Oct	1.0	0.6	8.4	2.7	2.9	10	112
Nov	1.1	0.4	7.8	2.5	2.0	14	116
Dec	1.1	0.7	8.6	2.6	3.1	2	123
Annual	1.0	0.6	8.7	2.7	3.1	Dec	978

Table 4

1980-1986 Mean, Standard Deviation, and Extreme

H_{mo} and T_p for Gage 625

Month	Height: Mean m	Height: Std.Dev. m	Period: Mean sec	Period: Std.Dev. sec	Extreme: Height m	Extreme: Date	Number Obs.
Jan	1.1	0.6	8.4	2.7	3.5	'83	706
Feb	1.1	0.6	9.2	2.6	3.8	'83	702
Mar	1.1	0.6	9.0	2.8	3.3	'83	758
Apr	0.9	0.5	9.4	2.6	3.0	'85	697
May	0.8	0.5	8.5	2.5	3.0	'86	801
Jun	0.7	0.4	8.1	2.4	2.0	'83	618
Jul	0.6	0.3	8.8	2.9	1.8	'85	533
Aug	0.7	0.5	8.5	2.7	3.1	'81	620
Sep	1.0	0.5	9.2	2.8	3.0	'83	647
Oct	1.2	0.7	9.2	3.0	3.5	'80	803
Nov	1.1	0.6	8.9	3.2	3.5	'81	767
Dec	1.0	0.6	9.0	3.1	3.1	'86	729
Annual	0.9	0.6	8.9	2.8	3.8	Feb 83	8381

Table 5

1986 Mean, Standard Deviation, and Extreme H_{mo} and T_p for Gage 630

Month	Height Mean m	Height Std.Dev. m	Period Mean sec	Period Std.Dev. sec	Extreme Height m	Extreme Date	Number Obs.
Jan	1.1	0.7	8.3	2.6	2.7	25	115
Feb	1.1	0.5	7.9	2.3	2.5	25	110
Mar	1.1	0.5	8.2	2.1	3.2	21	119
Apr	1.1	0.6	9.0	2.5	3.2	18	120
May	1.0	0.7	8.8	3.0	3.3	10	119
Jun	0.9	0.4	8.3	2.6	2.0	3	117
Jul	0.6	0.2	7.9	2.0	0.9	24	93
Aug	0.9	0.5	7.3	2.7	3.0	17	114
Sep	0.9	0.4	8.3	2.1	1.8	17	106
Oct	1.2	0.7	7.8	2.5	3.5	11	116
Nov	1.2	0.4	7.1	1.9	2.3	3	117
Dec	1.6	1.0	8.1	2.1	4.2	2	54
Annual	1.1	0.6	8.1	2.5	4.2	Dec	1300

Table 6

1980-1986 Mean, Standard Deviation, and Extreme H_{mo} and T_p for Gage 630

Month	Height Mean m	Height Std.Dev. m	Period Mean sec	Period Std.Dev. sec	Extreme Height m	Extreme Date	Number Obs.
Jan	1.2	0.6	7.9	2.7	4.5	'83	754
Feb	1.2	0.6	8.6	2.6	4.3	'83	681
Mar	1.1	0.6	8.7	2.7	4.7	'83	760
Apr	0.9	0.5	8.6	2.7	3.8	'85	741
May	0.8	0.4	7.9	2.3	3.3	'86	769
Jun	0.7	0.3	7.7	2.2	2.1	'81	712
Jul	0.6	0.3	8.1	2.6	2.1	'85	706
Aug	0.7	0.4	8.0	2.4	3.6	'81	706
Sep	1.0	0.6	8.6	2.6	6.1	'85	730
Oct	1.2	0.7	8.7	2.8	4.3	'82	822
Nov	1.1	0.6	8.1	2.9	4.1	'81	648
Dec	1.2	0.7	8.3	2.8	5.6	'80	645
Annual	1.0	0.6	8.3	2.6	6.1	Sep 85	8674

Table 7

1986 Mean, Standard Deviation, and Extreme H_{mo} and T_p for Gage 640

Month	Height Mean m	Height Std.Dev. m	Period Mean sec	Period Std.Dev. sec	Extreme Height m	Extreme Date	Number Obs.
Jan	0.9	0.6	8.7	2.3	2.8	25	117
Feb	1.0	0.4	8.5	2.4	2.0	25	106
Mar	1.0	0.5	8.2	2.0	2.3	21	119
Apr	1.0	0.6	9.2	2.6	3.2	19	118
May	1.0	0.8	9.9	3.1	3.3	10	116
Jun	0.8	0.4	9.0	2.7	1.8	3	115
Jul	0.5	0.2	8.1	2.3	0.8	21	91
Aug	0.8	0.5	7.9	2.8	2.8	17	115
Sep	0.8	0.3	8.7	2.3	1.7	16	106
Oct	1.1	0.7	8.3	2.7	3.1	11	113
Nov	1.1	0.4	7.5	2.3	2.0	1	112
Dec	1.2	0.6	8.5	2.5	3.6	1	100
Annual	0.9	0.6	8.6	2.6	3.6	Dec	1328

Table 8

1985-1986 Mean, Standard Deviation, and Extreme H_{mo} and T_p for Gage 640

Month	Height Mean m	Height Std.Dev. m	Period Mean sec	Period Std.Dev. sec	Extreme Height m	Extreme Date	Number Obs.
Jan	0.9	0.6	8.3	2.5	2.8	'86	231
Feb	1.0	0.4	8.5	2.6	3.0	'85	209
Mar	1.0	0.5	8.4	2.3	3.0	'85	240
Apr	0.9	0.6	9.5	3.0	3.7	'85	235
May	0.9	0.7	8.9	2.9	3.3	'86	240
Jun	0.7	0.4	8.2	2.6	1.8	'86	233
Jul	0.6	0.3	8.9	2.5	1.9	'85	211
Aug	0.9	0.5	8.2	2.9	2.8	'86	186
Sep	0.9	0.4	9.3	2.3	2.0	'85	199
Oct	1.1	0.7	8.2	2.7	3.5	'85	224
Nov	1.2	0.7	8.8	3.0	4.1	'85	214
Dec	1.0	0.6	9.2	3.2	3.6	'86	213
Annual	0.9	0.6	8.7	2.8	4.1	Nov 85	2635

Table 9

1986 Mean, Standard Deviation, and Extreme

H_{mo} and T_p for Gage 645

Month	Height Mean m	Height Std.Dev. m	Period Mean sec	Period Std.Dev. sec	Extreme Height m	Extreme Date	Number Obs.
Jan	0.7	0.4	7.6	3.1	1.5	4	116
Feb	0.7	0.4	7.1	2.9	1.7	12	111
Mar	0.7	0.4	7.5	3.4	1.5	23	120
Apr	0.6	0.4	8.5	3.4	1.8	15	116
May	0.6	0.3	6.9	2.3	1.6	3	122
Jun	0.5	0.2	6.3	1.9	1.1	30	115
Jul	0.5	0.3	7.8	2.6	1.3	1	118
Aug	0.6	0.3	8.4	3.4	1.3	2	115
Sep	0.8	0.5	9.5	3.2	2.1	27	117
Oct	0.9	0.4	7.4	1.9	1.8	22	103
Nov	0.8	0.5	9.5	3.5	1.9	21	112
Dec	0.6	0.5	9.2	4.1	2.1	7	112
Annual	0.7	0.4	8.0	3.2	2.1	Dec	1377

Table 10

1980-1986 Mean, Standard Deviation, and

Extreme H_{mo} and T_p for Gage 645

Month	Height Mean m	Height Std.Dev. m	Period Mean sec	Period Std.Dev. sec	Extreme Height m	Extreme Date	Number Obs.
Jan	0.8	0.4	7.7	3.1	2.0	'80	673
Feb	0.8	0.4	8.4	3.2	2.0	'83	678
Mar	0.8	0.4	8.2	3.5	2.3	'80	757
Apr	0.7	0.3	8.5	3.4	1.8	'85	676
May	0.6	0.3	7.8	3.1	1.9	'86	751
Jun	0.5	0.3	7.6	3.0	1.3	'82	710
Jul	0.5	0.2	7.9	3.0	1.3	'85	717
Aug	0.6	0.3	7.7	2.9	1.7	'82	742
Sep	0.7	0.4	8.6	3.3	2.1	'85	705
Oct	0.9	0.5	8.8	3.3	2.2	'82	766
Nov	0.8	0.4	8.4	3.6	2.0	'81	754
Dec	0.7	0.4	8.3	3.6	2.1	'85	741
Annual	0.7	0.4	8.2	3.3	2.3	Mar 80	8670

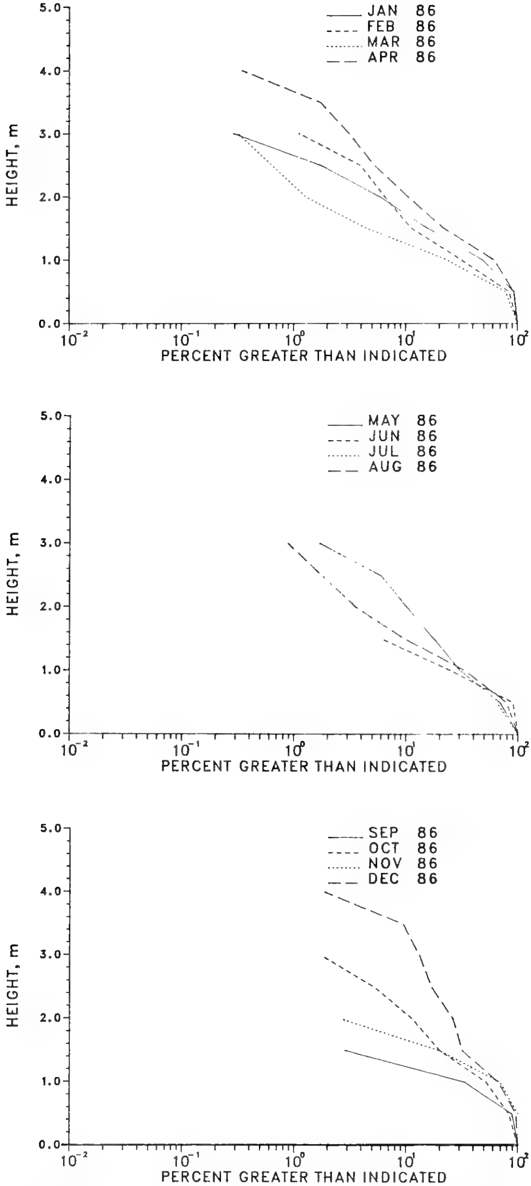

Figure 17. 1986 monthly wave height distributions for Gage 630

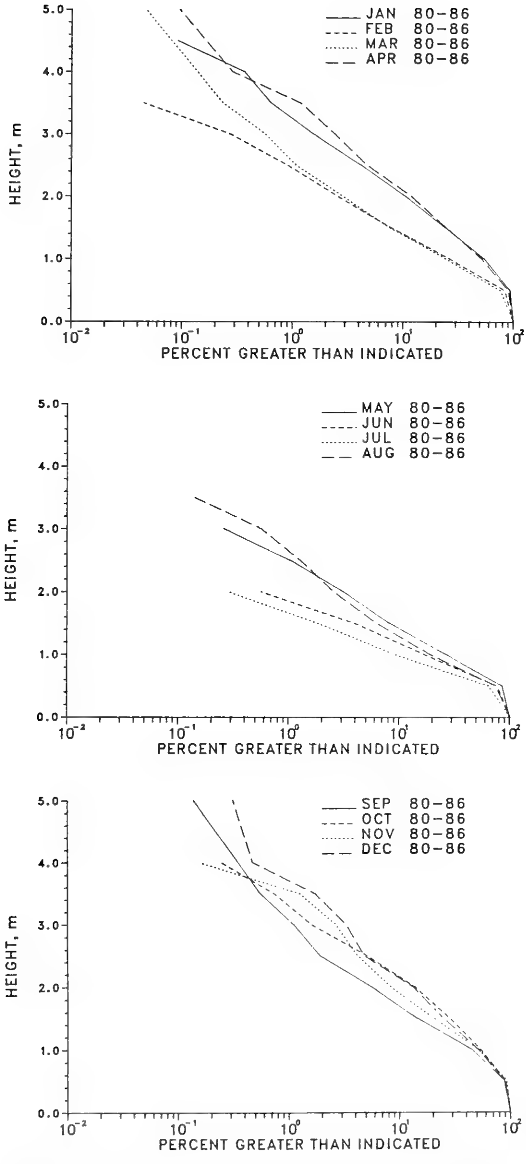

Figure 18. 1980 through 1986 monthly wave height distributions for Gage 630

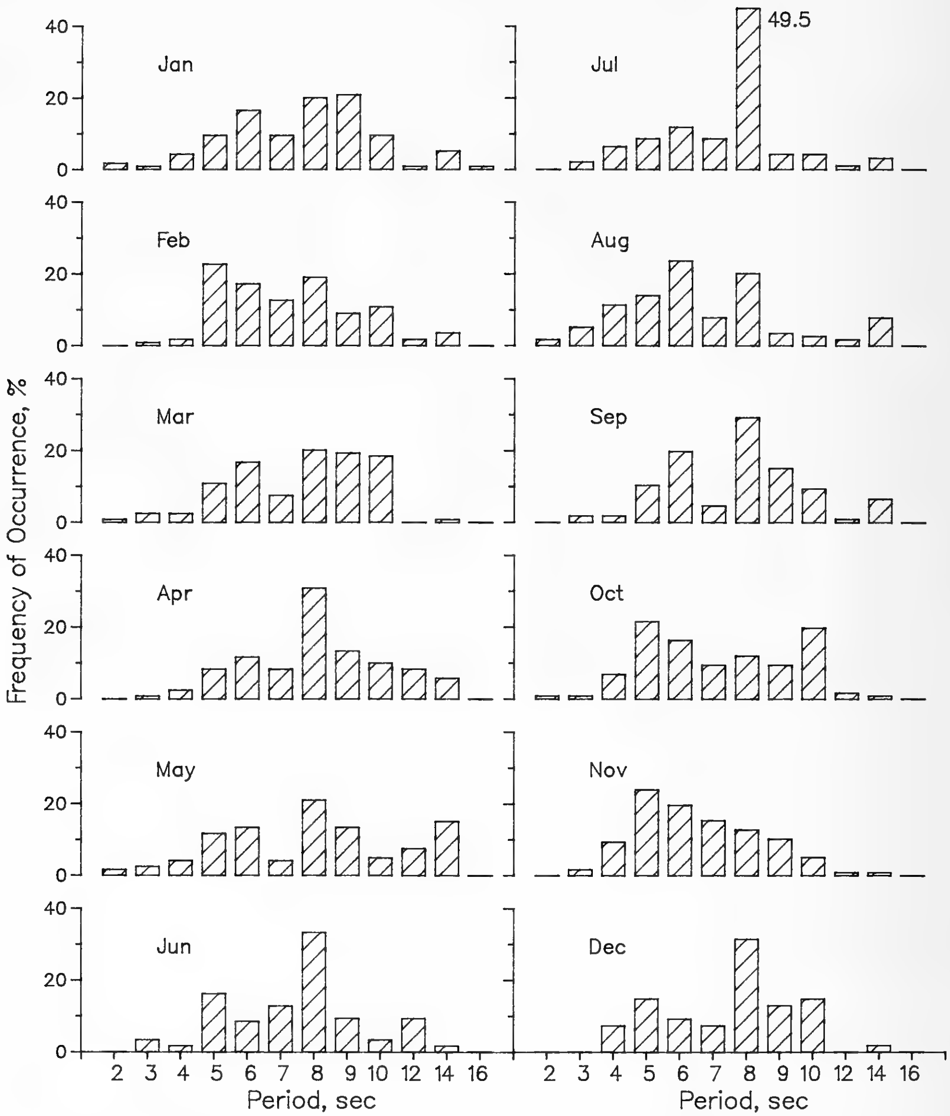

Figure 19. 1986 monthly wave period distributions for Gage 630

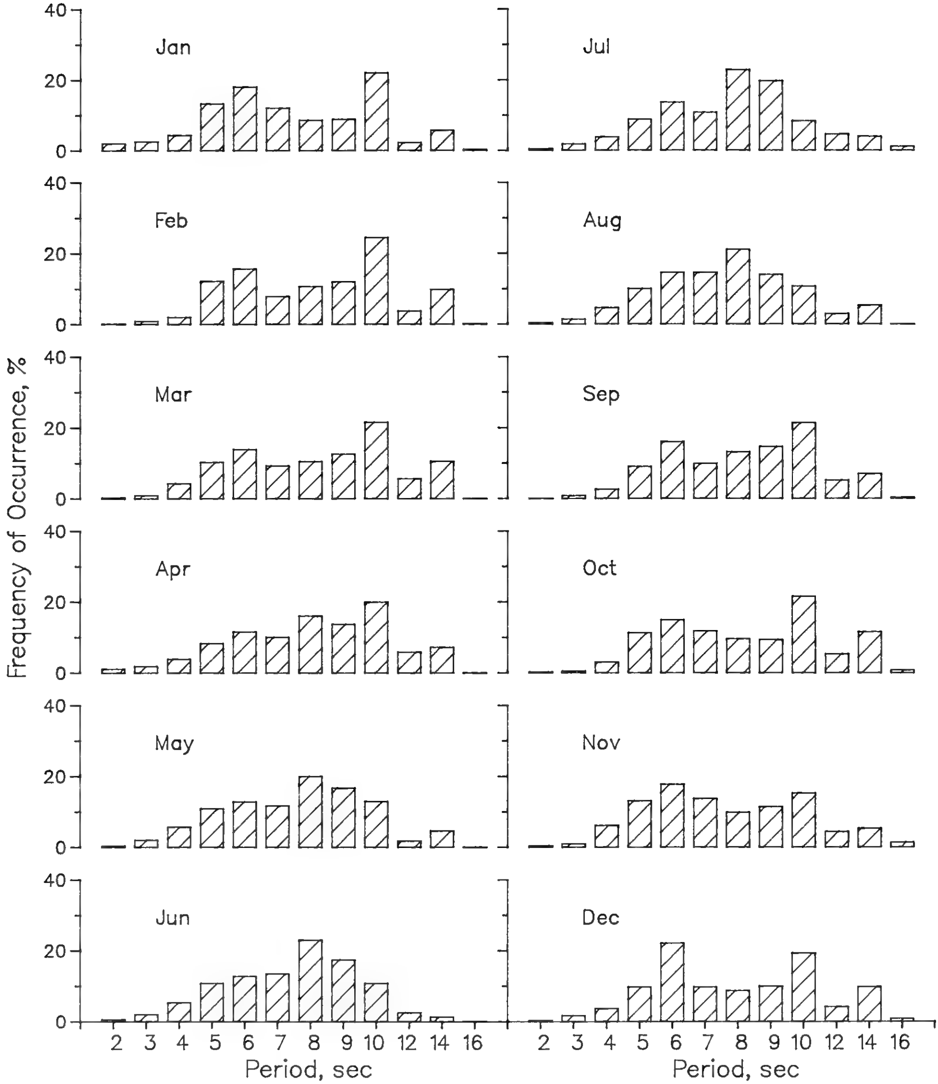

Figure 20. 1980-86 monthly wave period distributions for Gage 630

Table 11

1986 Joint Distribution of H_{mo}

versus T_p for Gage 630

ANNUAL
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	23	23	46	77	177	100	485	154	77	46	115	.	1323
0.50 - 0.99	38	154	162	500	569	385	1331	700	462	138	169	.	4608
1.00 - 1.49	.	23	254	646	531	292	400	254	246	15	85	8	2754
1.50 - 1.99	.	.	15	200	177	69	85	38	77	15	46	.	722
2.00 - 2.49	.	.	15	23	100	23	46	15	15	54	15	.	306
2.50 - 2.99	.	.	.	.	8	38	23	8	46	31	15	.	169
3.00 - 3.49	.	.	.	.	8	8	38	8	.	8	8	.	78
3.50 - 3.99	.	.	.	.	.	.	15	8	.	.	8	.	31
4.00 - 4.49	.	.	.	.	.	.	.	.	8	.	.	.	8
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	61	200	492	1446	1570	915	2423	1185	931	307	461	8	

Table 12

1986 Monthly Joint Distribution of

H_{mo} versus T_p for Gage 630

MONTH JAN
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	87	.	.	.	87	87	435	261	174	.	261	.	1392
0.50 - 0.99	87	87	261	87	435	435	609	1478	348	87	261	.	4175
1.00 - 1.49	.	.	174	348	435	261	435	174	261	.	.	87	2175
1.50 - 1.99	.	.	.	435	174	.	261	174	87	.	.	.	1131
2.00 - 2.49	.	.	.	87	435	87	261	.	.	.	.	.	870
2.50 - 2.99	.	.	.	.	87	87	.	.	87	.	.	.	261
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	174	87	435	957	1653	957	2001	2087	957	87	522	87	

MONTH FEB
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	.	.	.	.	.	91	.	.	.	91	.	.	182
0.50 - 0.99	.	91	91	909	545	545	1182	364	818	91	91	.	4727
1.00 - 1.49	.	.	91	1273	727	364	545	545	273	.	273	.	4091
1.50 - 1.99	.	.	.	91	273	273	91	.	.	.	.	.	728
2.00 - 2.49	.	.	.	.	182	.	91	.	.	.	.	.	273
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	91	182	2273	1727	1273	1909	909	1091	182	364	0	

MONTH MAR
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	.	.	.	.	84	.	252	84	84	.	.	.	504
0.50 - 0.99	84	252	.	336	420	336	1008	1008	1008	.	.	.	4452
1.00 - 1.49	.	.	252	504	840	252	336	672	672	.	84	.	3612
1.50 - 1.99	.	.	.	252	168	84	336	168	84	.	.	.	1092
2.00 - 2.49	.	.	.	.	84	.	.	.	.	.	.	.	84
2.50 - 2.99	.	.	.	.	.	84	84	.	.	.	.	.	168
3.00 - 3.49	.	.	.	.	84	.	.	.	.	.	.	.	84
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	84	252	252	1092	1680	756	2016	1932	1848	0	84	0	

(Continued)

(Sheet 1 of 4)

MONTH APR
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	.	.	.	.	.	.	167	.	167	167	167	.	668
0.50 - 0.99	.	83	167	250	417	583	1917	1083	583	167	167	.	5417
1.00 - 1.49	.	.	83	417	750	250	917	167	167	.	167	.	2918
1.50 - 1.99	.	.	.	83	.	.	.	.	.	.	.	.	83
2.00 - 2.49	.	.	.	83	.	.	.	.	.	250	.	.	333
2.50 - 2.99	.	.	.	.	.	.	.	.	83	250	83	.	416
3.00 - 3.49	.	.	.	.	.	.	83	83	.	.	.	.	166
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	83	250	833	1167	833	3084	1333	1000	834	584	0	

MONTH MAY
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	.	.	168	168	504	168	1261	420	84	84	252	.	3109
0.50 - 0.99	168	252	168	756	672	252	588	588	168	84	168	.	3864
1.00 - 1.49	.	.	84	168	168	.	168	168	84	84	336	.	1260
1.50 - 1.99	.	.	.	84	.	.	.	.	84	168	420	.	756
2.00 - 2.49	.	.	.	.	.	.	.	84	.	168	168	.	420
2.50 - 2.99	.	.	.	.	.	.	84	84	84	84	84	.	420
3.00 - 3.49	.	.	.	.	.	.	.	.	.	84	84	.	168
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	168	252	420	1176	1344	420	2101	1344	504	756	1512	0	

MONTH JUN
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	.	85	85	256	.	171	256	.	85	85	.	.	1023
0.50 - 0.99	.	256	.	513	342	598	2906	769	85	855	171	.	6495
1.00 - 1.49	.	.	85	684	427	342	85	171	85	.	.	.	1879
1.50 - 1.99	.	.	.	171	85	171	85	.	85	.	.	.	597
2.00 - 2.49	.	.	.	.	.	.	.	.	.	.	.	.	0
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	341	170	1624	854	1282	3332	940	340	940	171	0	

(Continued)

(Sheet 2 of 4)

Table 12 (Continued)

MONTH JUL
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	.	.	.	108	538	430	1935	.	215	.	323	.	3549
0.50 - 0.99	.	215	645	753	645	430	3011	430	215	108	.	.	6452
1.00 - 1.49	.	.	.	.	.	.	.	.	.	.	.	.	0
1.50 - 1.99	.	.	.	.	.	.	.	.	.	.	.	.	0
2.00 - 2.49	.	.	.	.	.	.	.	.	.	.	.	.	0
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	215	645	861	1183	860	4946	430	430	108	323	0	

MONTH AUG
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	88	175	263	351	526	.	614	.	88	.	.	.	2105
0.50 - 0.99	88	263	351	614	1228	351	702	88	88	88	702	.	4563
1.00 - 1.49	.	88	526	175	175	439	526	263	88	88	.	.	2368
1.50 - 1.99	.	.	.	175	351	.	.	.	.	.	88	.	614
2.00 - 2.49	.	.	.	88	88	.	.	.	.	.	.	.	176
2.50 - 2.99	.	.	.	.	.	.	88	.	.	.	.	.	88
3.00 - 3.49	.	.	.	.	.	.	88	.	.	.	.	.	88
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	176	526	1140	1403	2368	790	2018	351	264	176	790	0	

MONTH SEP
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	.	.	.	.	.	.	189	660	.	.	283	.	1132
0.50 - 0.99	.	94	.	377	849	283	2075	660	755	94	377	.	5564
1.00 - 1.49	.	94	189	566	943	189	660	189	189	.	.	.	3019
1.50 - 1.99	.	.	.	94	189	.	.	.	.	.	.	.	283
2.00 - 2.49	.	.	.	.	.	.	.	.	.	.	.	.	0
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	188	189	1037	1981	472	2924	1509	944	94	660	0	

(Continued)

(Sheet 3 of 4)

MONTH OCT
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	86	.	.	.	345	172	603	345	.	86	86	.	1723
0.50 - 0.99	.	86	259	517	603	259	172	259	948	.	.	.	3103
1.00 - 1.49	.	.	431	1207	259	172	259	259	603	.	.	.	3190
1.50 - 1.99	.	.	.	431	259	.	.	.	172	.	.	.	862
2.00 - 2.49	.	.	.	.	172	.	86	86	172	86	.	.	602
2.50 - 2.99	.	.	.	.	.	259	.	.	86	.	.	.	345
3.00 - 3.49	.	.	.	.	.	86	86	.	.	.	.	.	172
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	86	86	690	2155	1638	948	1206	949	1981	172	86	0	

MONTH NOV
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	.	.	.	.	.	.	.	.	.	.	.	.	0
0.50 - 0.99	.	85	.	427	427	342	855	684	256	.	.	.	3076
1.00 - 1.49	.	85	855	1624	940	855	256	256	.	.	85	.	4956
1.50 - 1.99	.	.	85	342	513	256	171	85	256	.	.	.	1708
2.00 - 2.49	.	.	.	.	85	85	.	.	.	85	.	.	255
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	170	940	2393	1965	1538	1282	1025	512	85	85	0	

MONTH DEC
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	.	.	.	.	.	185	185	.	.	.	.	.	370
0.50 - 0.99	.	.	.	556	.	.	1296	1111	.	.	.	.	2963
1.00 - 1.49	.	.	185	741	741	370	741	.	741	.	.	.	3519
1.50 - 1.99	.	.	185	185	.	.	.	.	185	.	.	.	555
2.00 - 2.49	.	.	370	.	185	185	185	.	.	.	.	.	925
2.50 - 2.99	.	.	.	.	.	.	.	.	370	.	.	.	370
3.00 - 3.49	.	.	.	.	.	.	370	.	.	.	.	.	370
3.50 - 3.99	.	.	.	.	.	.	370	185	.	.	185	.	740
4.00 - 4.49	.	.	.	.	.	.	.	.	185	.	.	.	185
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	0	740	1482	926	740	3147	1296	1481	0	185	0	

(Sheet 4 of 4)

Table 13

1980-1986 Joint Distribution of

H_{mo} versus T_p for Gage 630

ANNUAL
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS)												TOTAL
	1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	
0.00 - 0.49	22	16	30	61	108	114	303	295	228	83	148	5	1413
0.50 - 0.99	31	120	249	459	586	491	759	697	857	173	220	20	4662
1.00 - 1.49	.	9	125	390	478	292	237	206	389	45	146	6	2323
1.50 - 1.99	.	.	8	130	265	115	69	59	128	40	89	6	909
2.00 - 2.49	.	.	2	25	80	76	45	39	69	38	44	2	420
2.50 - 2.99	.	.	.	.	6	35	18	17	36	14	27	.	153
3.00 - 3.49	.	.	.	.	1	3	16	14	16	6	10	.	66
3.50 - 3.99	.	.	.	.	.	.	3	9	12	6	5	.	35
4.00 - 4.49	.	.	.	.	.	.	1	.	8	1	1	.	11
4.50 - 4.99	.	.	.	.	.	.	.	.	2	.	.	.	2
5.00 - GREATER	.	.	.	.	.	.	.	.	.	2	1	.	3
TOTAL	53	145	414	1065	1524	1126	1451	1336	1745	408	691	39	

Table 14

1980-1986 Joint Distribution of

H_{mo} versus T_p for Gage 630

MONTH JAN
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS)												TOTAL
	1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	
0.00 - 0.49	133	13	.	119	66	13	199	106	252	27	80	.	1008
0.50 - 0.99	66	239	265	385	424	358	265	517	889	106	279	.	3793
1.00 - 1.49	.	.	146	531	610	265	119	119	557	.	80	13	2440
1.50 - 1.99	.	.	27	265	491	265	80	93	252	13	53	.	1539
2.00 - 2.49	.	.	.	27	199	212	106	27	146	53	27	13	810
2.50 - 2.99	.	.	.	.	13	93	66	27	53	27	53	.	332
3.00 - 3.49	.	.	.	.	.	.	27	.	27	.	.	.	54
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	13	.	.	.	13
4.50 - 4.99	.	.	.	.	.	.	.	.	13	.	.	.	13
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	199	252	438	1327	1803	1206	862	889	2202	226	572	26	

MONTH FEB
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS)												TOTAL
	1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	
0.00 - 0.49	.	.	.	.	29	15	88	.	44	29	147	.	352
0.50 - 0.99	15	73	103	367	470	235	470	617	1204	29	191	15	3789
1.00 - 1.49	.	15	103	602	631	250	367	382	646	117	250	.	3363
1.50 - 1.99	.	.	.	162	323	220	103	103	191	88	147	.	1337
2.00 - 2.49	.	.	.	88	117	29	44	73	117	73	132	.	673
2.50 - 2.99	.	.	.	.	.	44	.	.	147	29	88	.	308
3.00 - 3.49	.	.	.	.	.	.	.	15	44	15	29	.	103
3.50 - 3.99	.	.	.	.	.	.	.	15	15	.	.	.	30
4.00 - 4.49	.	.	.	.	.	.	.	.	44	.	.	.	44
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	15	88	206	1219	1570	793	1072	1205	2452	380	984	15	

MONTH MAR
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS)												TOTAL
	1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	
0.00 - 0.49	13	.	.	13	66	13	92	53	158	79	79	.	566
0.50 - 0.99	13	92	237	395	434	421	487	697	855	197	237	.	4065
1.00 - 1.49	.	.	197	382	553	368	289	303	737	79	421	.	3329
1.50 - 1.99	.	.	.	224	250	79	92	92	237	118	158	.	1250
2.00 - 2.49	.	.	.	13	53	39	53	53	79	53	79	.	422
2.50 - 2.99	.	.	.	.	26	13	13	13	13	26	53	.	157
3.00 - 3.49	.	.	.	.	13	.	13	26	53	13	.	.	118
3.50 - 3.99	.	.	.	.	.	.	.	26	13	.	13	.	52
4.00 - 4.49	.	.	.	.	.	.	13	.	.	.	13	.	26
4.50 - 4.99	.	.	.	.	.	.	.	.	13	.	.	.	13
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	26	92	434	1027	1395	933	1052	1263	2158	565	1053	0	

(Continued)

(Sheet 1 of 4)

Table 14 (Continued)

MONTH APR
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	.	13	27	27	40	13	378	256	175	94	121	.	1144
0.50 - 0.99	108	162	243	432	513	540	837	661	1188	324	324	.	5332
1.00 - 1.49	.	13	121	256	445	337	270	297	432	81	162	.	2414
1.50 - 1.99	.	.	.	94	135	108	40	67	148	13	108	.	713
2.00 - 2.49	.	.	.	27	27	.	27	67	40	40	.	.	228
2.50 - 2.99	.	.	.	.	.	13	27	.	13	40	13	.	106
3.00 - 3.49	.	.	.	.	.	.	13	27	.	.	.	.	40
3.50 - 3.99	.	.	.	.	.	.	13	.	.	.	.	.	13
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	108	188	391	836	1160	1011	1605	1375	1996	592	728	0	

MONTH MAY
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	13	13	39	104	169	182	403	286	182	26	65	.	1482
0.50 - 0.99	26	195	416	702	650	715	1170	1144	676	26	130	.	5850
1.00 - 1.49	.	.	104	208	364	182	299	208	351	13	117	.	1846
1.50 - 1.99	.	.	13	52	91	26	117	.	78	39	91	.	507
2.00 - 2.49	.	.	.	26	13	65	.	26	.	39	39	.	208
2.50 - 2.99	.	.	.	.	.	.	13	13	13	26	13	.	78
3.00 - 3.49	.	.	.	.	.	.	.	.	.	13	13	.	26
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	39	208	572	1092	1287	1170	2002	1677	1300	182	468	0	

MONTH JUN
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	28	42	70	112	253	379	576	590	225	28	14	.	2317
0.50 - 0.99	28	154	393	688	702	660	1447	983	660	225	42	.	5982
1.00 - 1.49	.	.	56	239	225	211	239	140	126	.	70	.	1306
1.50 - 1.99	.	.	14	42	84	84	28	14	70	.	.	.	336
2.00 - 2.49	.	.	.	.	14	14	14	14	.	.	.	.	56
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	56	196	533	1081	1278	1348	2304	1741	1081	253	126	0	

(Continued)

(Sheet 2 of 4)

MONTH JUL
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS)												TOTAL
	1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	
0.00 - 0.49	14	28	57	99	312	297	935	892	382	170	326	28	3540
0.50 - 0.99	28	127	283	496	822	637	1218	1020	453	297	71	85	5537
1.00 - 1.49	.	28	42	198	212	113	71	57	.	.	.	.	721
1.50 - 1.99	.	.	.	71	14	28	42	.	.	.	.	.	155
2.00 - 2.49	.	.	.	14	.	.	14	.	.	.	.	.	28
2.50 - 2.99	.	.	.	.	.	.	.	.	.	.	.	.	0
3.00 - 3.49	.	.	.	.	.	.	.	.	.	.	.	.	0
3.50 - 3.99	.	.	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	42	183	382	878	1360	1075	2280	1969	835	467	397	113	

MONTH AUG
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS)												TOTAL
	1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	
0.00 - 0.49	14	42	85	127	227	269	538	567	411	85	142	.	2507
0.50 - 0.99	28	85	255	567	765	793	1289	722	552	198	326	.	5580
1.00 - 1.49	.	14	127	227	255	312	184	99	57	14	.	.	1289
1.50 - 1.99	.	.	.	57	170	57	28	.	14	.	42	.	368
2.00 - 2.49	.	.	.	28	28	14	28	.	14	.	14	.	126
2.50 - 2.99	.	.	.	.	14	.	28	.	14	.	14	.	70
3.00 - 3.49	.	.	.	.	.	14	14	.	14	.	.	.	42
3.50 - 3.99	.	.	.	.	.	.	.	14	.	.	.	.	14
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	42	141	467	1006	1459	1459	2109	1402	1076	297	538	0	

MONTH SEP
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS)												TOTAL
	1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	
0.00 - 0.49	.	14	14	41	14	14	68	342	342	164	110	14	1137
0.50 - 0.99	.	55	137	274	562	397	712	644	1192	192	260	.	4425
1.00 - 1.49	.	14	96	479	644	384	438	260	425	68	178	14	3000
1.50 - 1.99	.	.	14	68	301	123	55	151	55	14	96	.	877
2.00 - 2.49	.	.	.	41	82	27	14	41	96	41	27	.	369
2.50 - 2.99	.	.	.	.	.	41	27	14	.	.	.	.	82
3.00 - 3.49	.	.	.	.	.	.	.	14	14	14	14	.	56
3.50 3.99	.	.	.	.	.	.	.	.	14	14	14	.	42
4.00 - 4.49	.	.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	14	.	.	14
TOTAL	0	83	261	903	1603	986	1314	1466	2138	521	699	28	

(Continued)

(Sheet 3 of 4)

Table 14 (Concluded)

MONTH OCT
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	24	.	.	.	61	73	207	158	255	49	146	.	973
0.50 - 0.99	.	49	158	316	450	389	462	353	973	170	365	12	3697
1.00 - 1.49	.	.	146	633	401	243	134	195	474	109	182	.	2517
1.50 - 1.99	.	.	.	170	450	85	61	73	182	109	268	49	1447
2.00 - 2.49	.	.	.	12	122	231	61	61	182	61	109	12	851
2.50 - 2.99	.	.	.	.	12	134	24	73	49	12	49	.	353
3.00 - 3.49	.	.	.	.	.	24	12	.	12	.	36	.	84
3.50 - 3.99	.	.	.	.	.	.	.	24	.	24	.	.	48
4.00 - 4.49	.	.	.	.	.	.	.	.	24	.	.	.	24
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	24	49	304	1131	1496	1179	961	937	2151	534	1155	73	

MONTH NOV
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	15	15	15	31	46	77	46	139	123	77	170	.	754
0.50 - 0.99	31	46	370	540	556	494	432	525	725	185	185	77	4166
1.00 - 1.49	.	31	216	494	772	478	216	293	386	15	108	46	3055
1.50 - 1.99	.	.	15	216	340	216	108	46	139	77	15	15	1187
2.00 - 2.49	.	.	.	31	62	77	139	31	31	31	15	.	417
2.50 - 2.99	.	.	.	.	.	31	15	31	62	.	15	.	154
3.00 - 3.49	.	.	.	.	.	.	31	77	.	15	15	.	138
3.50 - 3.99	.	.	.	.	.	.	.	.	62	31	15	.	108
4.00 - 4.49	.	.	.	.	.	.	.	.	.	15	.	.	15
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	46	92	616	1312	1776	1373	987	1142	1528	446	538	138	

MONTH DEC
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD

HEIGHT(METERS)	PERIOD(SECONDS) 1.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9	7.0-7.9	8.0-8.9	9.0-9.9	10.0-11.9	12.0-13.9	14.0-15.9	16.0-LONGER	TOTAL
0.00 - 0.49	.	16	62	62	16	31	93	171	171	186	419	16	1243
0.50 - 0.99	31	155	124	357	729	233	295	481	884	124	202	62	3677
1.00 - 1.49	.	.	140	419	682	388	233	124	434	31	171	.	2622
1.50 - 1.99	.	.	16	140	543	109	78	62	155	.	47	.	1150
2.00 - 2.49	.	.	31	.	248	186	47	78	109	62	78	.	839
2.50 - 2.99	.	.	.	.	.	31	.	31	78	.	16	.	156
3.00 - 3.49	.	.	.	.	.	.	93	16	31	.	16	.	156
3.50 - 3.99	.	.	.	.	.	.	31	31	47	.	16	.	125
4.00 - 4.49	.	.	.	.	.	.	.	.	16	.	.	.	16
4.50 - 4.99	.	.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER	.	.	.	.	.	.	.	.	.	16	16	.	32
TOTAL	31	171	373	978	2218	978	870	994	1925	419	981	78	

(Sheet 4 of 4)

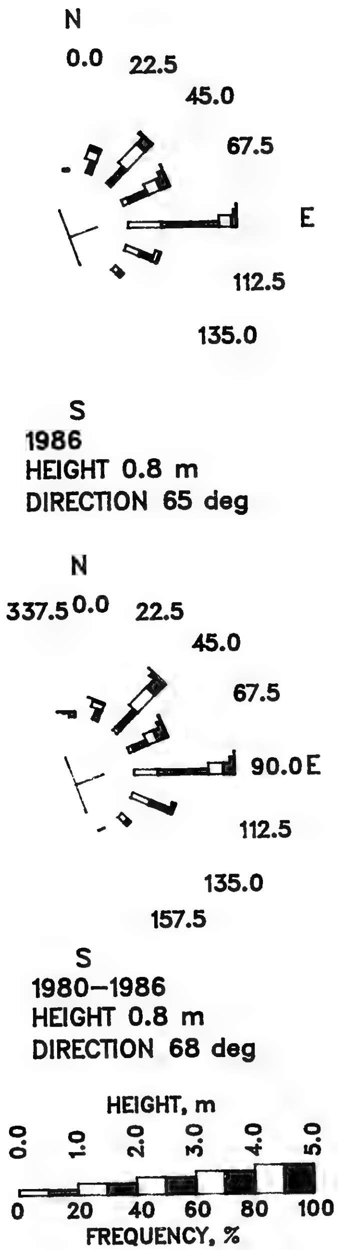

Figure 21. Annual wave roses

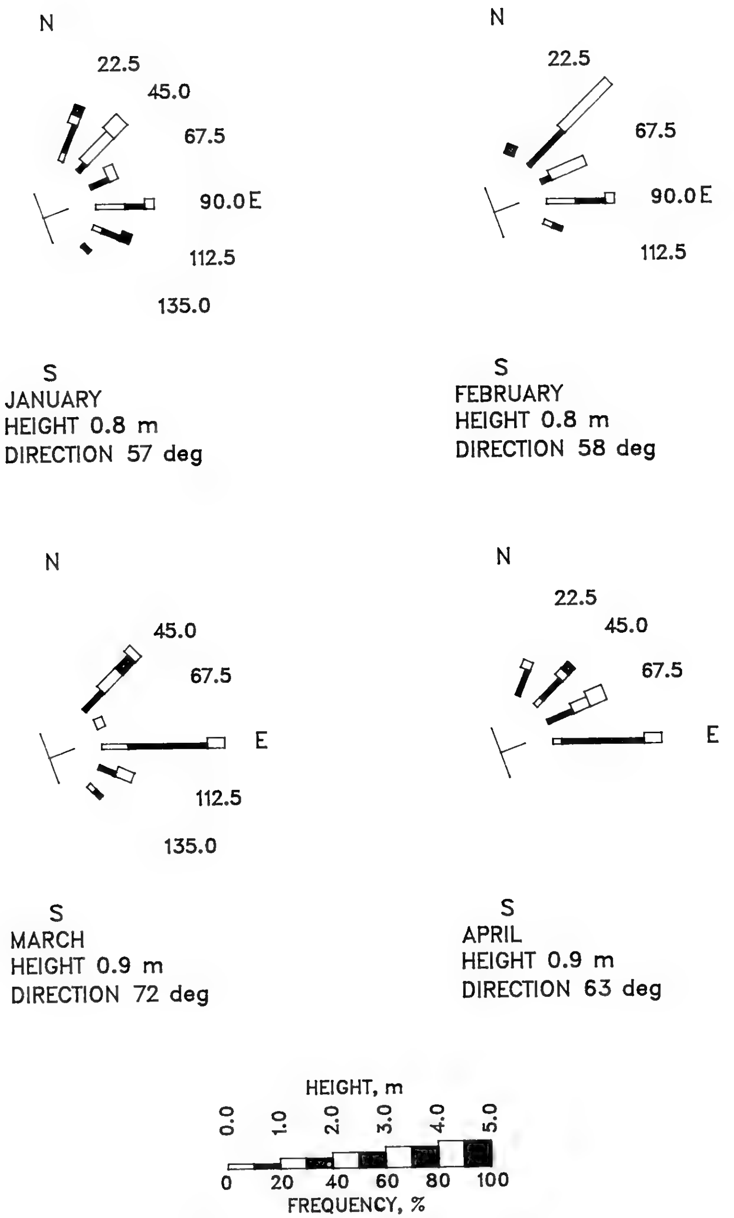

Figure 22. Monthly wave roses for 1986 (Sheet 1 of 3)

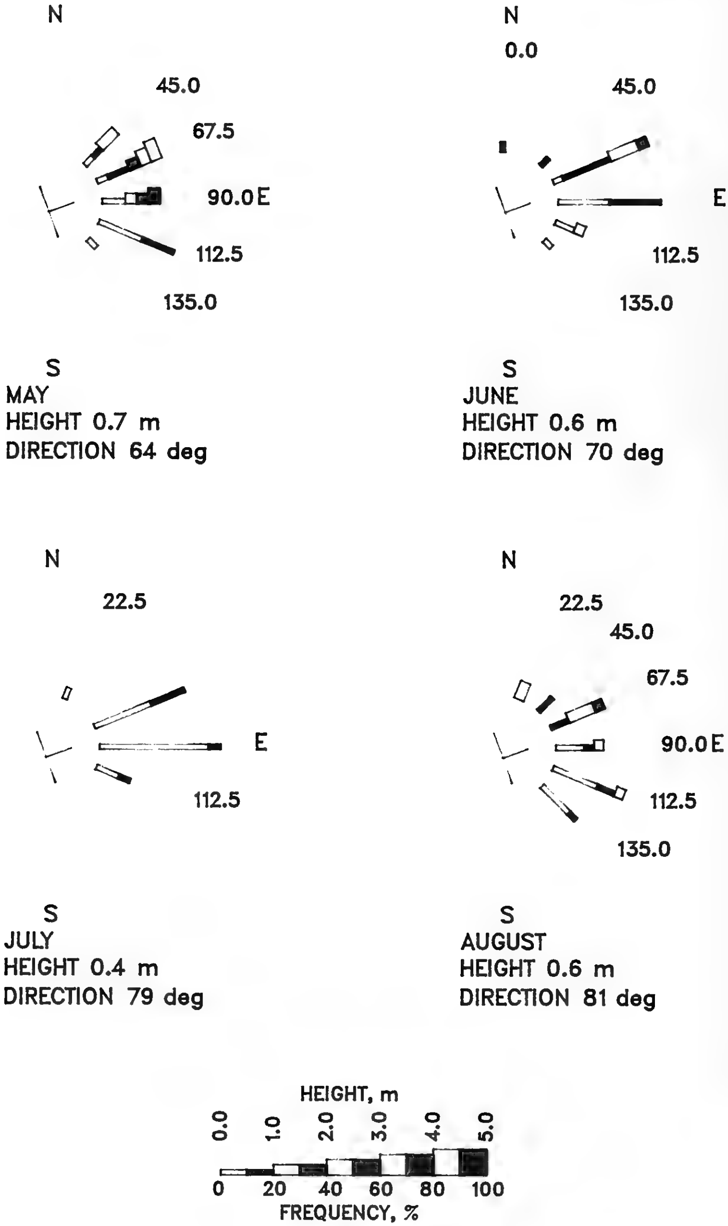

Figure 22. (Sheet 2 of 3)

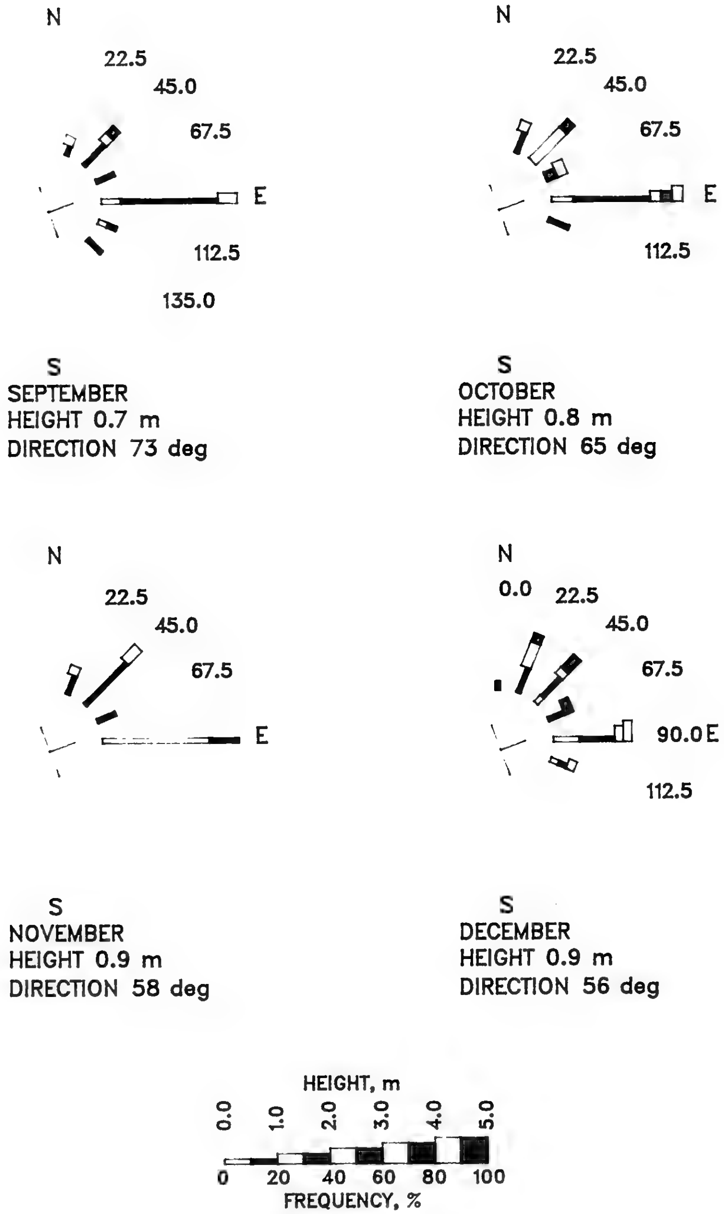

Figure 22. (Sheet 3 of 3)

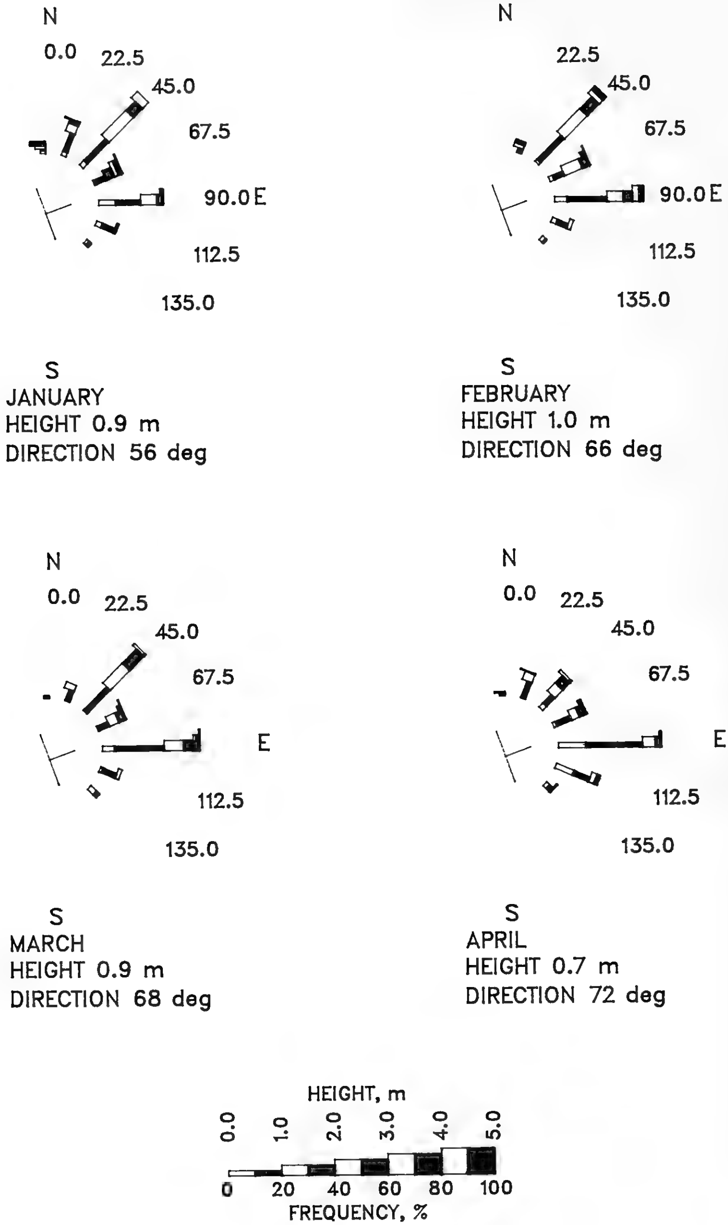

Figure 23. Monthly wave roses for 1980 through 1986 (Sheet 1 of 3)

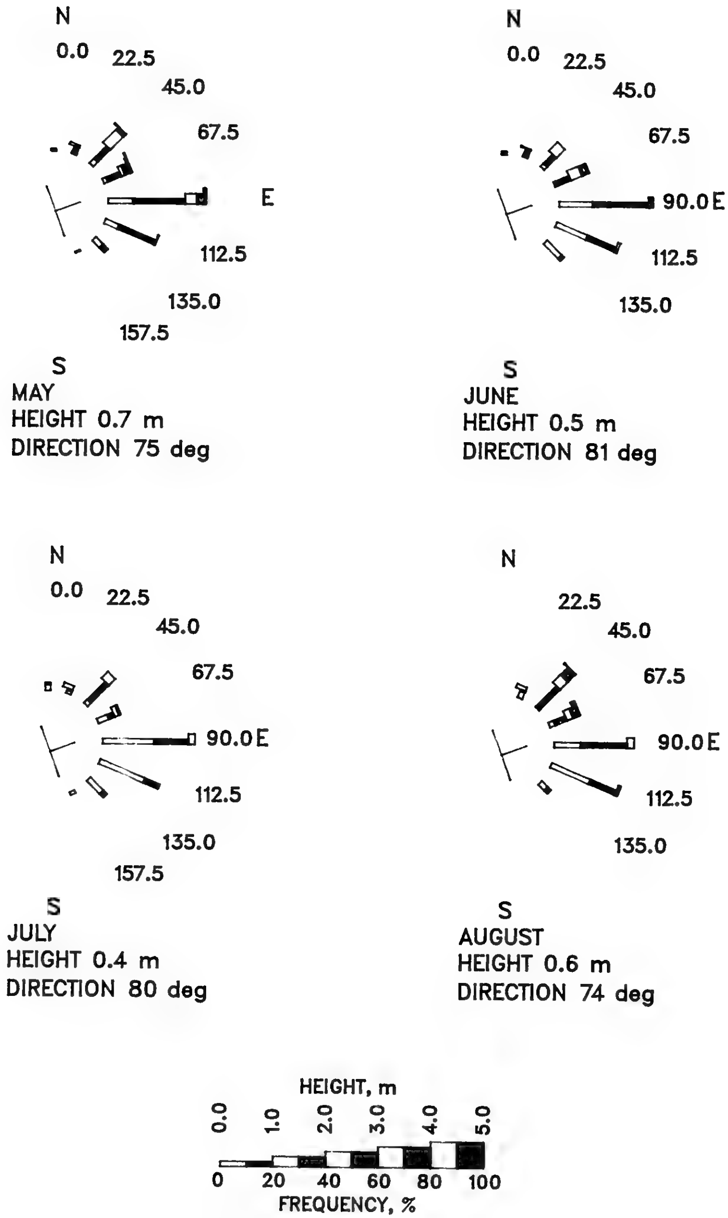

Figure 23. (Sheet 2 of 3)

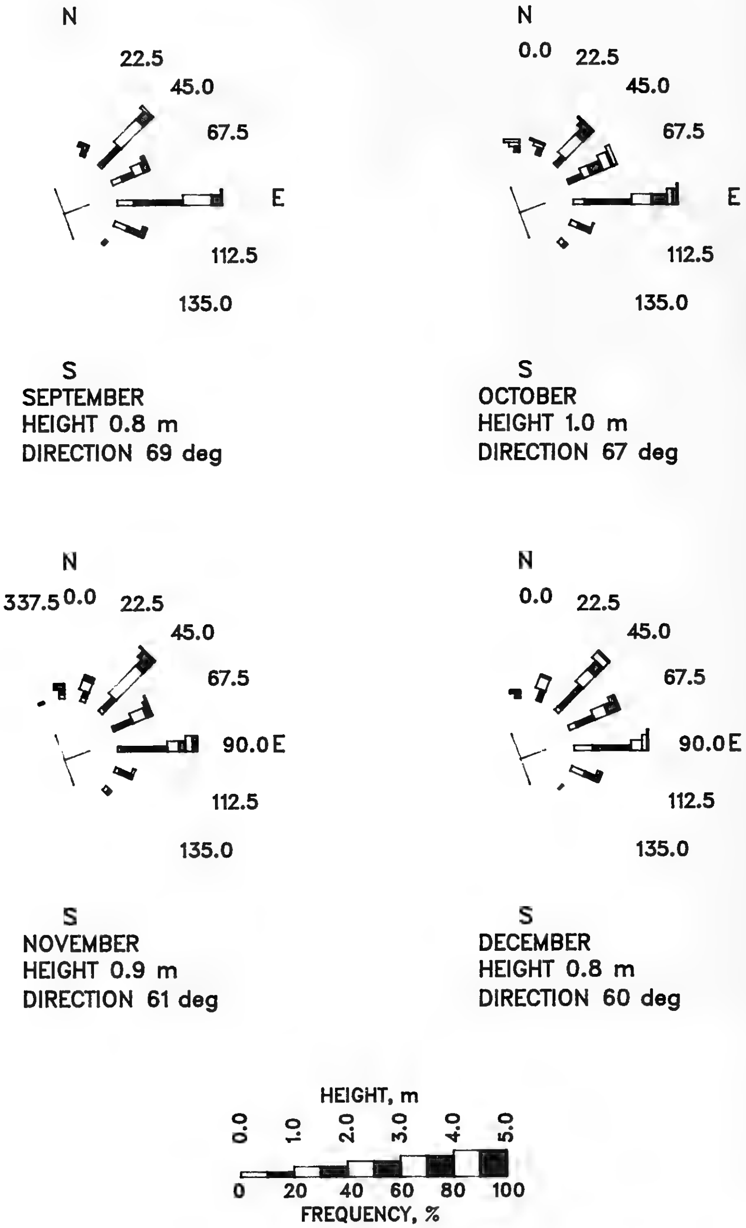

Figure 23. (Sheet 3 of 3)

PART IV: CURRENTS

41. Surface current speed and direction at the FRF are influenced by winds, waves, and indirectly, by the bottom topography. The extent of the respective influence varies daily. However, winds tend to dominate the currents at the seaward end of the pier, while waves dominate within the surf zone.

Observations

42. Near 0700 EST, daily observations of surface current speed and direction were made at (a) the seaward end of the pier, (b) the midsurf position on the pier, and (c) 10 to 15 m from the beach 500 m updrift of the pier. Surface currents were determined by observing the movement of dye on the water surface.

Results

43. Figure 24 shows the daily measurements at the beach, pier midsurf, and pier end locations. Since the relative influences of the winds and waves vary with position from shore, the current speeds and, to some extent, direction vary at the beach, midsurf, and pier end locations. Magnitudes generally are largest at the midsurf location and lowest at the end of the pier. Annual mean currents are presented in Table 15 and in Figures 25 through 27.

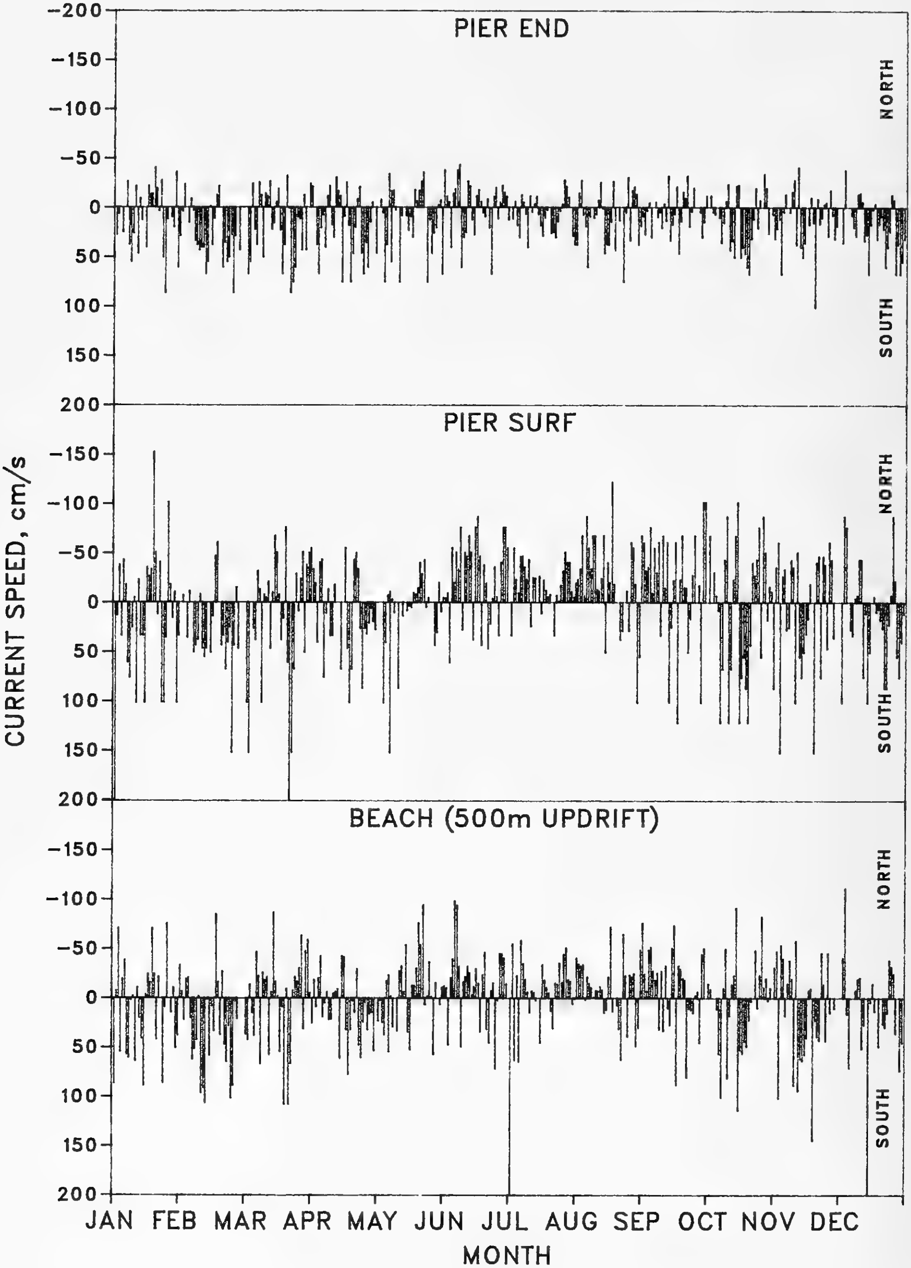

Figure 24. Daily surface currents for 1986

Table 15

Mean Longshore Surface Currents*

Month	Pier End, cm/sec 1986	Pier End, cm/sec 1980-1986	Pier Midsurf, cm/sec 1986	Pier Midsurf, cm/sec 1980-1986	Beach, cm/sec 1986	Beach, cm/sec 1981-1986
Jan	12	21	16	22	11	16
Feb	29	19	30	9	28	13
Mar	17	14	17	13	4	13
Apr	19	10	13	1	11	6
May	12	9	12	-5	-5	-2
Jun	1	1	-25	-13	-14	-7
Jul	8	1	-19	-19	-2	-11
Aug	11	7	-24	-16	-9	-6
Sep	6	10	-20	-1	-10	2
Oct	16	11	9	6	8	7
Nov	14	12	10	7	15	11
Dec	22	14	16	16	17	9
Annual	14	11	3	1	5	4

* + = southward; - = northward.

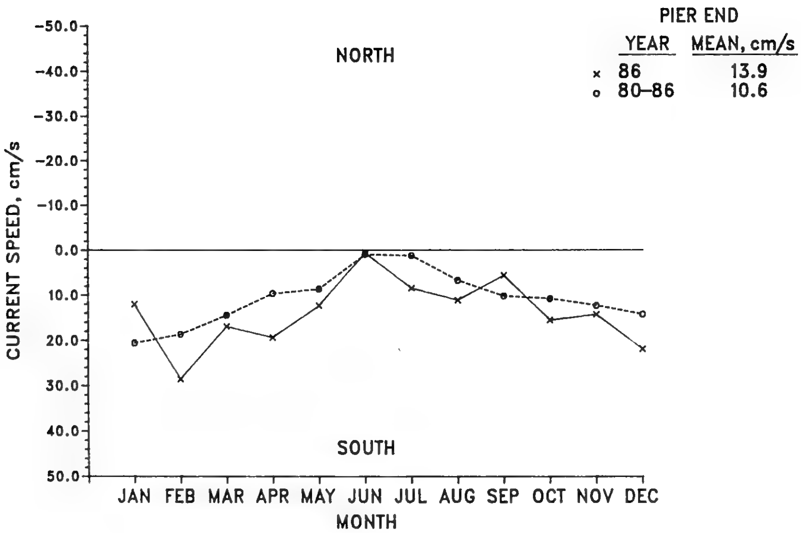

Figure 25. Monthly mean currents at the pier end

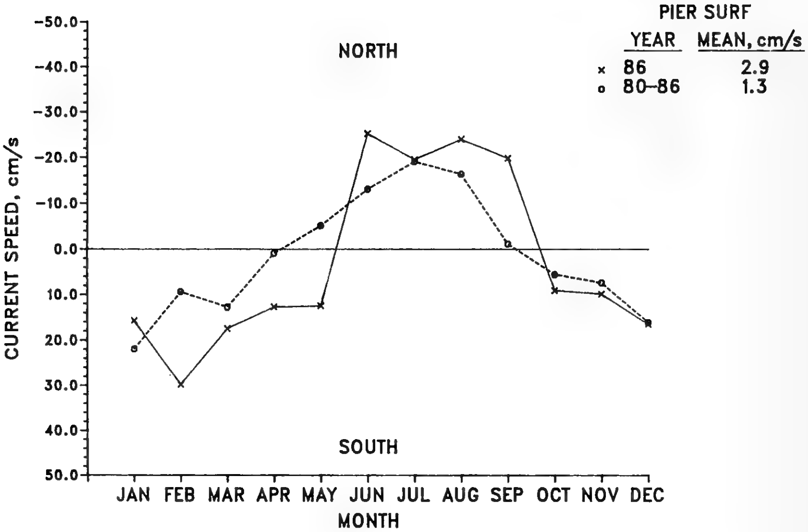

Figure 26. Monthly mean currents at the midsurf

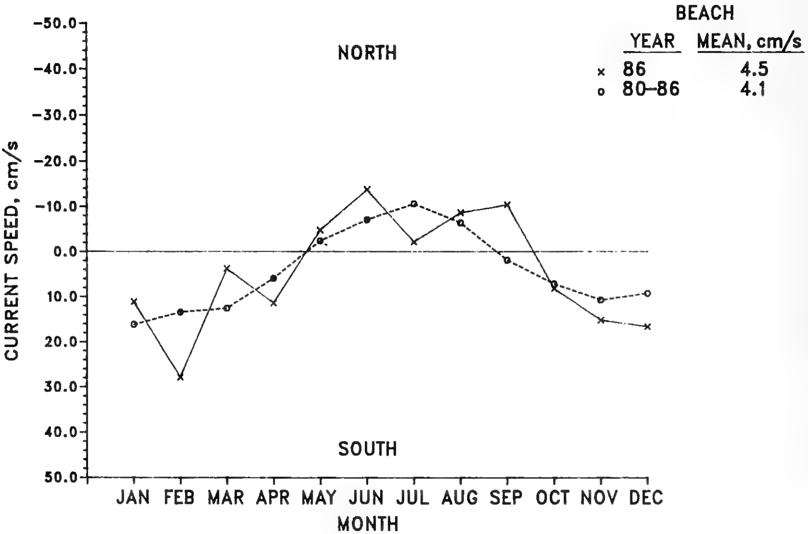

Figure 27. Monthly mean currents at the beach

PART V: TIDES AND WATER LEVELS

Measurement Instrument

44. Water level data were obtained from a NOAA/NOS control tide station (sta 865-1370) located at the seaward end of the research pier (Figure 2) by using a Leupold and Stevens, Inc. (Beaverton, OR), digital tide gage. This analog-to-digital recorder is a float-activated, negator-spring, counterpoised instrument that mechanically converts the vertical motion of a float into a coded, punched paper tape record. The below-deck installation at pier sta 19+60 consisted of a 30.5-cm-diam stilling well with a 2.5-cm orifice and a 21.6-cm-diam float.

45. Operation and tending of the tide gage conformed to NOS standards. The gage was checked daily for proper operation of the punch mechanism and for accuracy of the time and water level information. The accuracy was determined by comparing the gage level reading with a level read from a reference electric tape gage. Once a week, a heavy metal rod was lowered down the stilling well and through the orifice to ensure free flow of water into the well. During the summer months, when biological growth was most severe, divers inspected and cleaned the orifice opening as required.

46. The tide station was inspected quarterly by a NOAA/NOS tide field group. Tide gage elevation was checked using existing NOS control positions, and the equipment was checked and adjusted as needed. NOS and FRF personnel also reviewed procedures for tending the gage and handling the data. Any specific comments on the previous months of data were discussed to ensure data accuracy.

47. Digital paper tape records of tide heights taken every 6 min were analyzed by the Tides Analysis Branch of NOS. An interpreter created a digital magnetic computer tape from the punched paper tape which was then processed on a large computer. First, a listing of the instantaneous tidal height values was created for visual inspection. If errors were encountered, a computer program was used to fill in or recreate bad or missing data using correct values from the nearest NOS tide station and accounting for known time lags and elevation anomalies. The data were plotted, and a new listing was generated and rechecked. When the validity of the data had been confirmed, monthly tabulations of daily highs and lows, hourly heights (instantaneous

height selected on the hour), and various extreme and/or mean water level statistics were computed.

Results

48. Tides at the FRF are semidiurnal with both daily high and low tides approximately equal. Tide height statistics are presented in Table 16. Figure 28 plots the monthly tide statistics for all available data, and Figure 29 compares the distribution of daily high and low water levels and hourly tide heights. The monthly or annual mean sea level reported is the average of the hourly heights, while the mean tide level is midway between mean high water and mean low water which are the averages of the daily high and low water levels, respectively, relative to NGVD. Mean range is the difference between mean high and low water levels, and the lowest water level for the month is the extreme low water while the highest water level is the extreme high water level.

Table 16

Tide Height Statistics*

Month or Year	Mean High Water	Mean Tide Level	Mean Sea Level	Mean Low Water	Mean Range	Extreme High	Date	Extreme Low	Date
1986									
Jan	41	-7	-7	-55	96	99	11	-108	10
Feb	65	16	16	-32	96	107	25	-59	10
Mar	45	-4	-3	-52	97	81	1	-96	9
Apr	69	21	21	-28	97	117	24	-48	25
May	62	14	14	-34	96	114	9	-71	5
Jun	52	4	4	-44	94	99	22	-78	19
Jul	61	14	14	-32	93	106	20	-48	26
Aug	64	17	18	-29	93	117	18	-63	11
Sep	64	17	17	-30	94	92	4	-66	19
Oct	73	26	26	-22	95	112	10	-46	5
Nov	67	19	19	-29	96	108	6	-54	2, 29
Dec	63	15	16	-34	97	123	2	-70	5
1986	60	13	13	-35	95	123	Dec	-108	Jan
Prior Years									
1985	59	10	11	-37	96	136	Dec	-93	Apr
1984	64	16	16	-32	97	147	Oct	-77	Jul
1983	68	19	19	-30	98	143	Jan	-73	Mar
1982	58	8	9	-42	99	127	Oct	-108	Feb
1981	59	8	9	-42	101	149	Nov	-110	Apr
1980	59	8	8	-43	102	118	Mar	-119	Mar
1979	60	9	9	-43	103	121	Feb	-95	Sep
1979-1986	61	11	12	-38	99	149	Nov 1981	-119	Mar 1980

* Measurements are in centimetres.

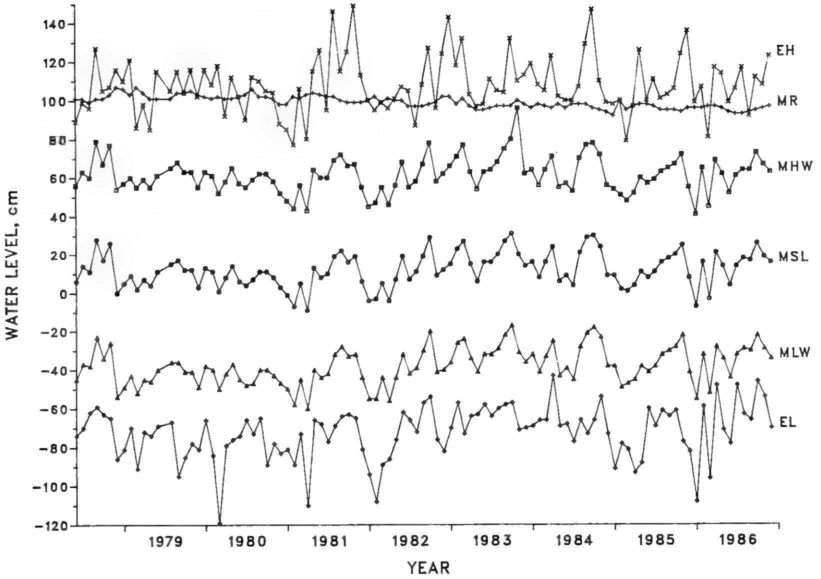

Figure 28. Monthly tide and water level statistics relative to NGVD

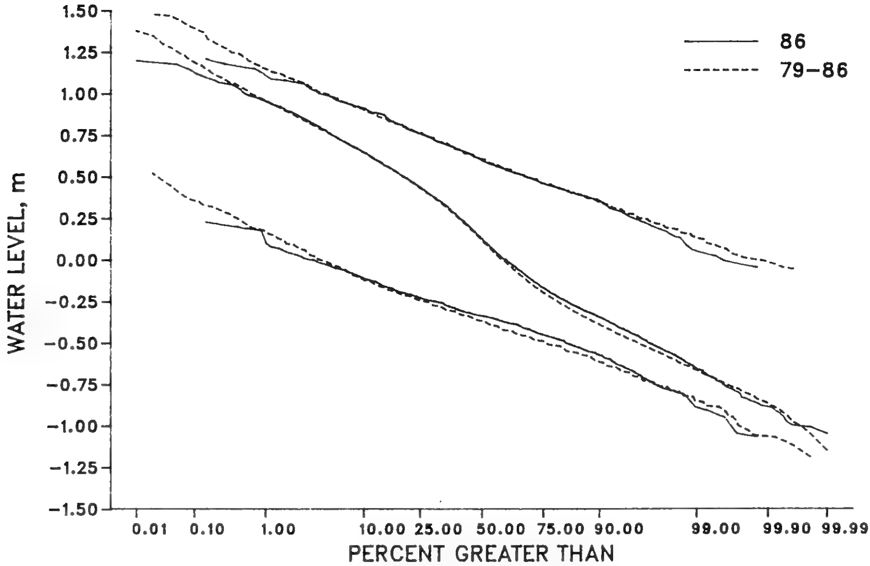

Figure 29. Distributions of hourly tide heights and high and low water levels

49. Monthly averages of daily measurements of surface water temperature, visibility, and density at the seaward end of the FRF pier are given in Table 17. The summaries represent single observations made near 0700 EST and, therefore, may not reflect daily average conditions, since such characteristics can change within a 24-hr period. Large temperature variations were common when there were large differences between the air and water temperature and variations in wind direction. From past experience, persistent onshore winds pile up warmer surface water along the shoreline, while offshore winds cause colder bottom water to circulate upward resulting in lower temperatures.

Table 17

Mean Surface Water Characteristics

	Temperature, °C		Visibility, m		Density, g/cm³	
Month	1986	1980-1986	1986	1980-1986	1986	1980-1986
Jan	7.6	5.7	1.3	1.2	1.0247	1.0238
Feb	5.3	4.7	2.1	1.6	1.0228	1.0233
Mar	6.4	6.6	2.6	1.4	1.0230	1.0230
Apr	11.6	11.0	2.2	2.0	1.0218	1.0226
May	15.2	15.1	2.5	2.4	1.0222	1.0226
Jun	19.3	19.4	3.6	3.6	1.0227	1.0216
Jul	22.8	21.7	4.9	3.8	1.0218	1.0216
Aug	22.4	23.2	3.4	2.9	1.0215	1.0205
Sep	22.7	22.5	1.9	2.0	1.0215	1.0210
Oct	19.5	19.3	1.3	1.3	1.0223	1.0217
Nov	15.6	14.8	1.0	0.9	1.0226	1.0227
Dec	10.2	10.2	1.1	1.0	1.0224	1.0232
Annual	14.9	14.4	2.4	2.0	1.0224	1.0223

Temperature

50. Daily sea surface water temperatures (Figure 30) were measured with an NOS water sampler and thermometer. Monthly mean temperatures (Table 17 and Figure 31) varied with the air temperatures (see Table 2).

Visibility

51. Visibility in coastal nearshore waters depends on the amount of salts, soluble organic material, detritus, living organisms, and inorganic

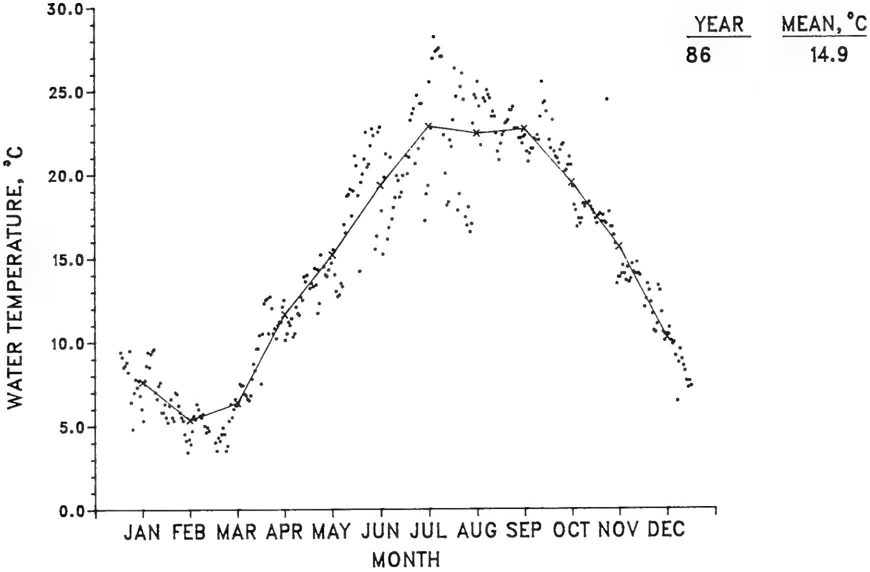

Figure 30. Daily and monthly mean sea surface water temperatures

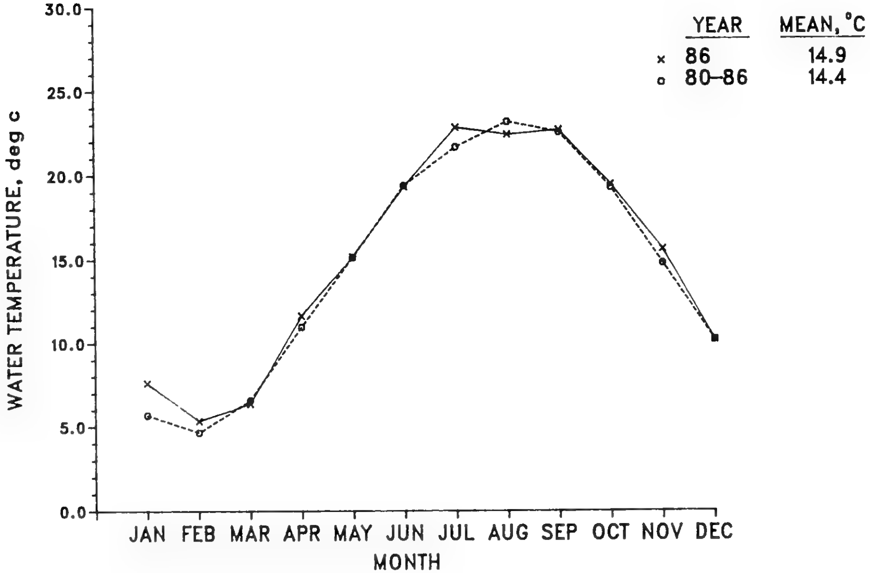

Figure 31. Monthly mean surface water temperatures

particles in the water. These dissolved and suspended materials change the absorption and attenuation characteristics of the water which vary daily and yearly.

52. Visibility was measured with a 0.3-m-diam secci disk and, similar to water temperature, variation was related to onshore and offshore winds. Onshore winds moved warm clear surface water toward shore, while offshore winds brought up colder bottom water with large concentrations of suspended matter. Figure 32 presents the daily surface visibility values for the year. Large variations were common, and visibility less than 1 m was expected in any month.

53. Monthly means are given in Table 17 and shown in Figure 33.

Density

54. Daily surface density values, shown in Figure 34, were measured with a hydrometer. Monthly means are given in Table 17 and plotted in Figure 35.

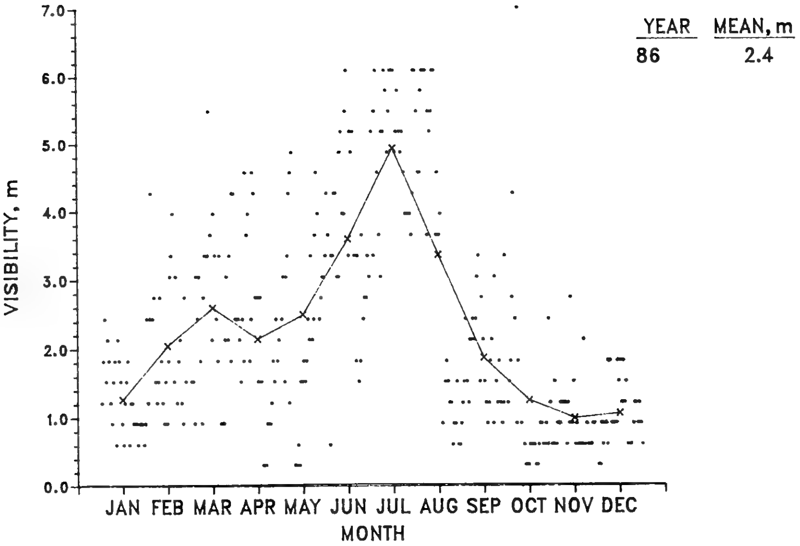

Figure 32. Daily and monthly mean sea surface water visibility

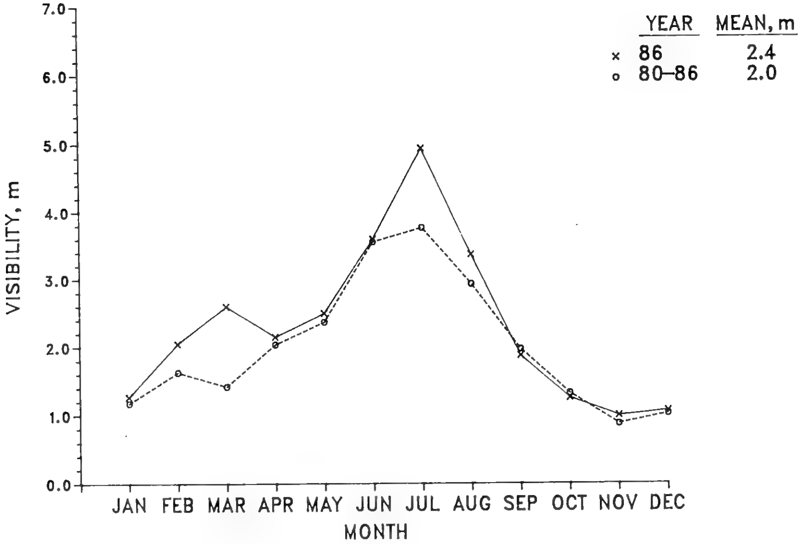

Figure 33. Monthly mean surface water visibility

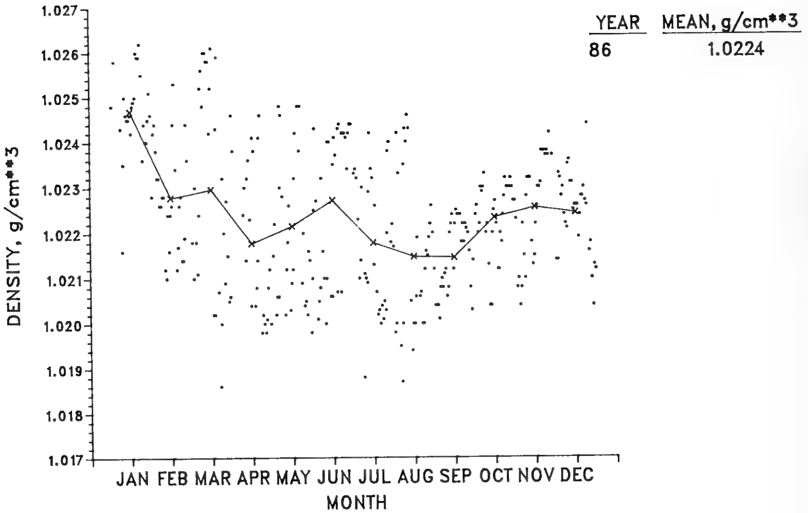

Figure 34. Daily sea surface water density

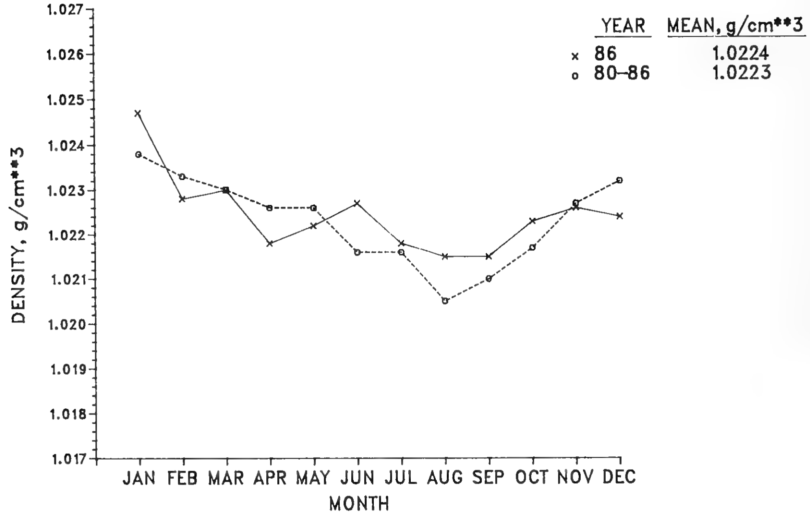

Figure 35. Monthly mean sea surface water density

PART VII: SURVEYS

55. Waves and currents interacting with bottom sediments produce changes in the beach and nearshore bathymetry. These changes can occur very rapidly in response to storms or slowly as a result of persistent but less forceful seasonal variations in wave and current conditions.

56. Nearshore bathymetry at the FRF is characterized by regular shore-parallel contours, a moderate slope, and a barred surf zone (usually an outer storm bar in water depths of about 4.5 m and an inner bar in water depths between 1.0 and 2.0 m). This pattern is interrupted in the immediate vicinity of the pier where a permanent trough runs under much of the pier, ending in a scour hole where depths can be up to 3.0 m greater than the adjacent bottom (Figure 36). This trough, which apparently is the result of the interaction of waves and currents with the pilings, varies in shape and depth with changing wave and current conditions. The pier's effect on shore-parallel contours occurs as far as 300 m away, and the shoreline may be affected up to 350 m from the pier (Miller, Birkemeier, and DeWall 1983).

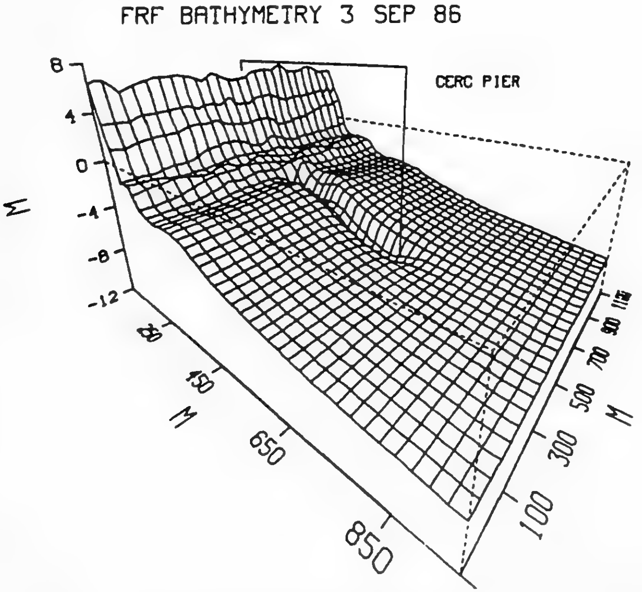

Figure 36. Permanent trough under the FRF pier, 3 September 1986

57. To document the temporal and spatial variability in bathymetry, surveys were conducted approximately monthly of an area extending 600 m north and south of the pier and approximately 950 m offshore. Contour maps resulting from these surveys along with plots of change in elevation between surveys are given in Appendix A.

58. All surveys utilized the Coastal Research Amphibious Buggy (CRAB), a 10.7-m-tall amphibious tripod, and a Zeiss Elta-2 electronic surveying system described by Birkemeier and Mason (1984). The profile locations are shown on each figure in Appendix A. Survey accuracy was about ±3 cm horizontally and vertically. Monthly soundings along both sides of the FRF pier were collected by lowering a weighted measuring tape to the bottom and recording the distance below the pier deck. Soundings were taken midway between the pier pilings to minimize errors caused by scour near the pilings.

59. A history of bottom elevations below Gages 645 and 625 is presented in Figure 37 for their respective pier stations of sta 7+80 (238 m) and sta 19+00 (579 m) along with intermediate locations, 323 and 433 m.

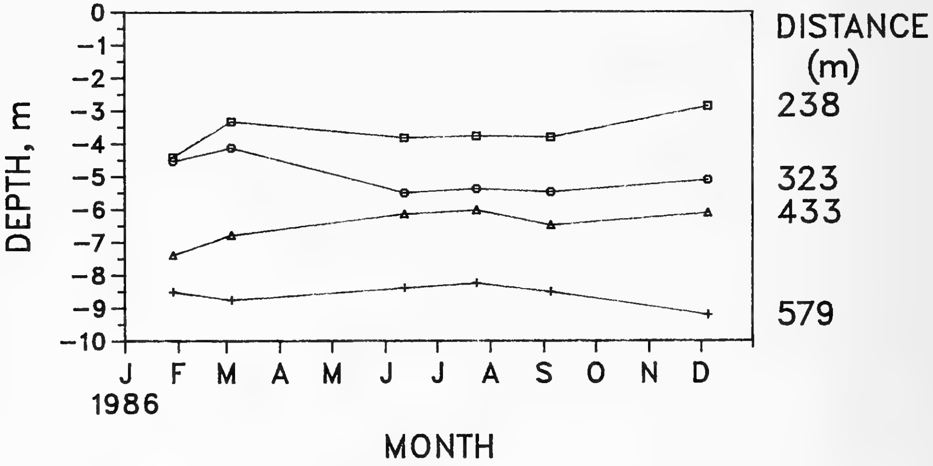

Figure 37. Time-history of bottom elevations at selected locations under the FRF pier

PART VIII: PHOTOGRAPHY

Aerial Photographs

60. Aerial photography was taken quarterly using a 23-cm aerial mapping camera at a scale of 1:12,000. All coverage was at least 60 percent overlap, with flights flown as closely as possible to low tide between 1000 and 1400 EST with less than 10 percent cloud cover. The flight lines covered are shown in Figure 38. Figure 39 is a sample of the imagery obtained on 1 October 1986, and the available aerial photographs for the year are:

Date	Flight Lines	Format
9 Jan	2	Color
	3	B/W
19 Apr	2	Color
	3	B/W
18 Aug	1	B/W
25 Aug	2	Color
	3	B/W
1 Oct	2	Color
	3	B/W

Beach Photographs

61. Daily color slides of the beach were taken using a 35mm camera from the same location on the pier looking north and south (Figure 40). The location from which each picture was taken, as well as the date, time, and a brief description of the picture, was marked on the slides.

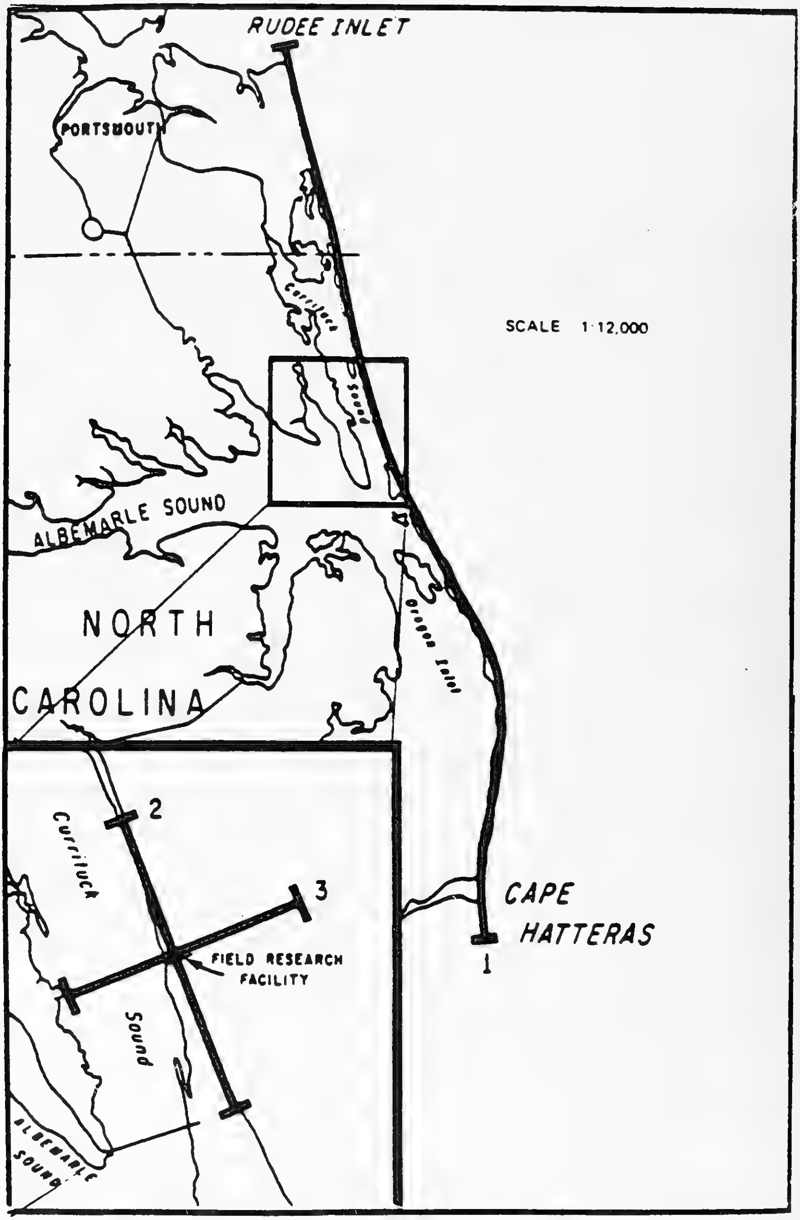

Figure 38. Aerial photography flight lines

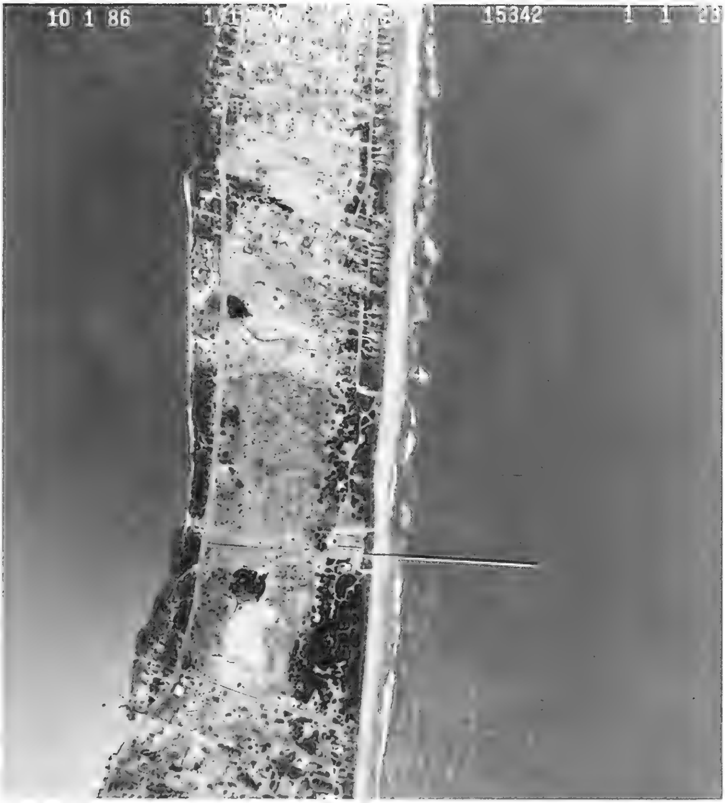

Figure 39. Sample aerial photograph, 10 October 1986

a. North

b. South

Figure 40. Sample photographs of the FRF beach, 12 August 1986

PART IX: STORMS

62. This section discusses the details of storms affecting the FRF during the year. As used here, "storms" are defined as times when the wave height parameter H_{mo} equaled or exceeded 2.0 m at the seaward end of the FRF pier. Sample spectra from Baylor Gage 625, located at the seaward end of the pier, are given in Appendix B (Volume II). Pre- and/or poststorm bathymetry diagrams are given in Appendix A. Detailed information on the track of each storm was taken from the NOAA Daily Weather Maps (US Department of Commerce 1986).

a. 11 January 1986 (Figure 41). Developing in the Gulf of Mexico on 9 January, this weak storm tracked across central Florida, moved northeast into the Atlantic, and passed the FRF well offshore. Winds exceeded 14 m/sec (NNE), and the maximum H_{mo} (Gage 625) of 2.1 m was recorded at 0600 EST on 11 January. The lowest barometric pressure reading was 1016.2 mb at 2300 EST on 10 January. There was no precipitation.

b. 23-25 January 1986 (Figure 42). This storm was the result of an arctic high-pressure system that moved across Canada on the 23rd. The storm center was positioned north of the Great Lakes on the 24th and over Maine on the 25th. Winds subsided as the storm moved east and offshore. Cold, northerly winds exceeded 16 m/sec, and wave heights exceeded 2.7 m (Gage 630).

c. 25 February (Figure 43). Following the passage of a cold front early on 25 February, strong northerly winds (maximum speed of 14.40 m/sec at 0700 EST on the 25th) generated by a strong Canadian high-pressure system in conjunction with a weak storm well out in the Atlantic briefly produced waves exceeding 2 m. A maximum H_{mo} (Gage 625) of 2.1 m was recorded at 1400 EST on the 25th.

d. 7-8 March 1986 (Figure 44). Late on 7 March, a cold front associated with a strong storm centered over Maine in conjunction with a large high-pressure system over North Dakota passed off the North Carolina coast. Strong north winds behind the front generated large waves at the FRF. Winds exceeded 13 m/sec (NW), and the maximum H_{mo} (Gage 625) of 2.5 m was recorded at 0200 EST on 8 March.

e. 21-22 March 1986 (Figure 45). Strong NNE winds generated by a large midwestern high-pressure system began to buffet the FRF late on 20 March. Winds exceeded 15 m/sec (NNE), and the maximum H_{mo} (Gage 625) of 2.5 m was recorded at 0800 EST on 21 March. A total of 20 mm of precipitation was also recorded.

f. 18-21 April 1986 (Figure 46). Developing over Chesapeake Bay early on 16 April, this storm slowly moved to the east reaching maximum strength on 19 April while located well offshore. Peak

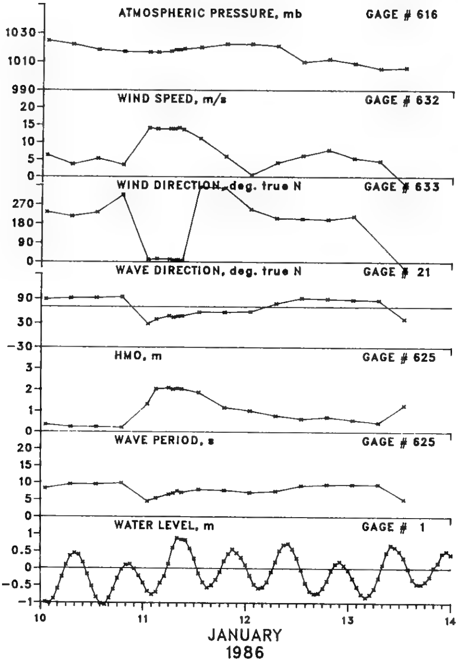

Figure 41. Storm data for 10-12 January 1986

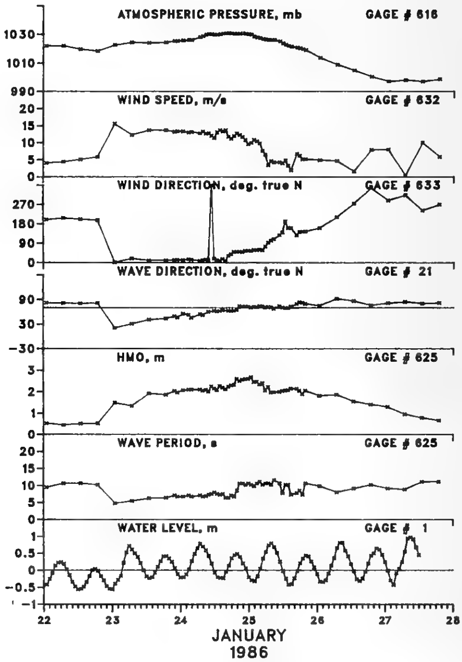

Figure 42. Storm data for 22-26 January 1986

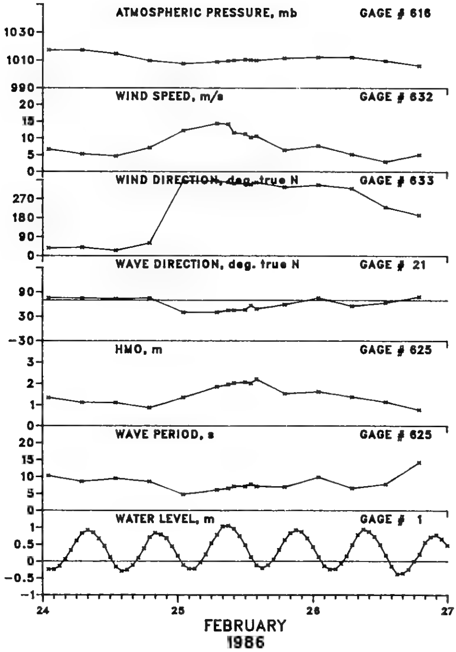

Figure 43. Storm data for 24-26 February 1986

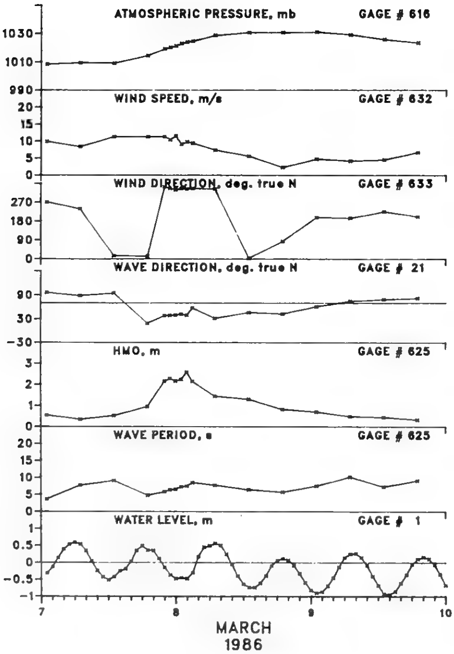

Figure 44. Storm data for 7-9 March 1986

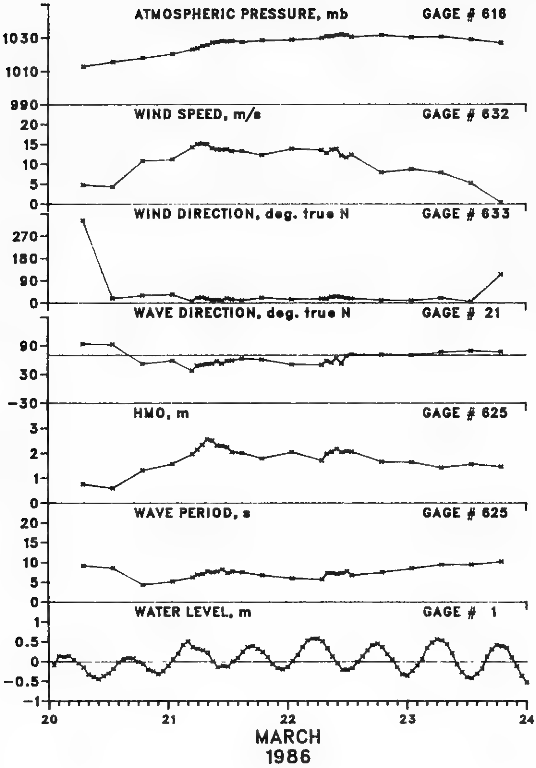

Figure 45. Storm data for 20-23 March 1986

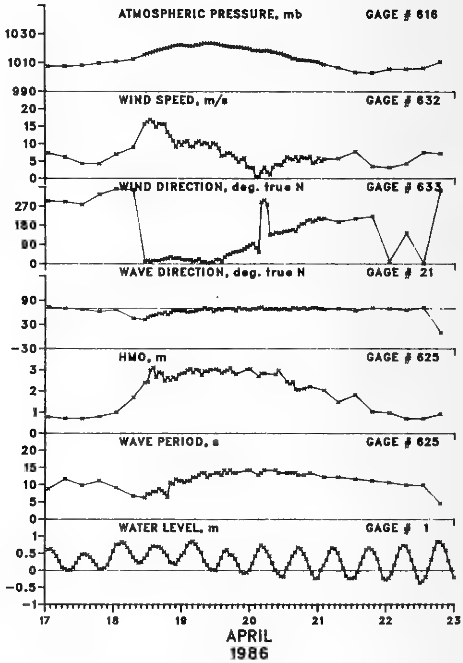

Figure 46. Storm data for 17-22 April 1986

sustained winds at the FRF approached 17 m/sec, and the maximum H_{mo} (Gage 625) of 3.2 m was recorded at 1700 EST on the 19th. The lowest barometric pressure reading was 1004 mb at 1300 EST on the 16th. Total precipitation was 19 mm.

g. 9-13 May 1986 (Figure 47). Developing well out in the north Atlantic on 8 May, this storm, in combination with a high-pressure system in central Canada, began to affect the FRF on the same day. As a result of its very slow movement, long-period storm waves (up to 16 sec) were recorded through 13 May, well after local winds had subsided. Winds approached 14 m/sec (NE), and the maximum H_{mo} (Gage 625) of 3.1 m was recorded at 1800 EST on 10 May. The lowest barometric reading was 1008.9 mb at 0100 EST on 8 May. There was no precipitation.

h. 17 August 1986 (Figure 48). A tropical depression located in the Gulf of Mexico on 12 August slowly tracked across the southeastern US and became stationary off the South Carolina coast early on 15 August. Slowly gaining strength, the low became Tropical Storm Charley early on 16 August with the eye remaining stationary off South Carolina. Reaching minimal hurricane strength early on 17 August, Hurricane Charley slowly turned north, gaining speed but not intensity as the day progressed. Charley's eye passed over the FRF between 1530 and 1700 EST that afternoon. Wave heights near the end of the pier (Gage 640) remained above 2 m for only 8 hr with heights dropping dramatically following the passage of the eye and the switching of the wind direction. Sustained easterly winds exceeded 24 m/sec with the highest gust reaching 33 m/sec at about 1500 EST. The maximum gust following the eye's passage was 24 m/sec from the WSW. The maximum H_{mo} (Gage 640, 1 km offshore) of 3.4 m (9.8 period) was recorded at 1600 EST. At Gage 630 (6 km offshore), the maximum H_{mo} was 4.0 m. The lowest barometric pressure reading was 988.5 mb at 1530 EST. Total precipitation was 81 mm.

i. 10-12 October 1986 (Figure 49). Strong NE winds generated by a Canadian high-pressure system first affected the FRF early on 10 October following the passage of a cold front. Winds reached 15 m/sec (NE) and remained over 10 m/sec for 41 consecutive hr producing a storm surge of about 0.5 m. The maximum H_{mo} (Gage 640) of 3.3 m (period = 8.7 sec) was recorded on 11 October at 0800 EST. Total precipitation was 11 mm.

j. 18-19 October 1986 (Figure 50). Developing off Cape Hatteras, NC, early on 16 October, this weak storm travelled slowly up the East Coast and was located off New England early on 18 October. The weak storm, in conjunction with a strong high-pressure system center over the Great Lakes, generated strong NNE winds at the FRF on 18 October. Winds peaked near 14 m/sec (NNE) at 1500 EST on 18 October with the maximum H_{mo} (Gage 625) of 2.4 m (period = 9.7 sec) recorded on 19 October at 0400 EST. There was no precipitation.

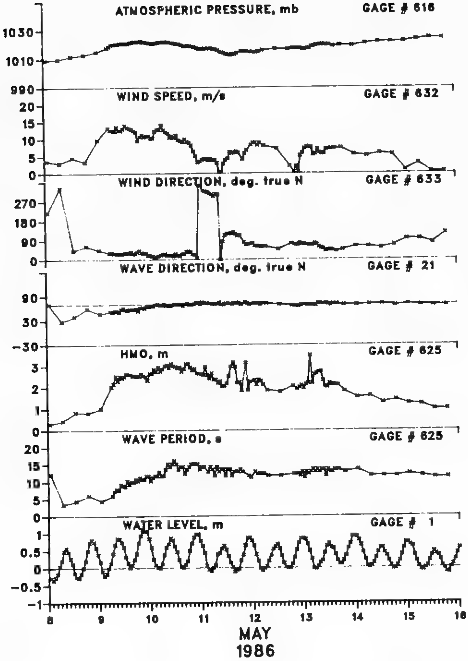

Figure 47. Storm data for 8-15 May 1986

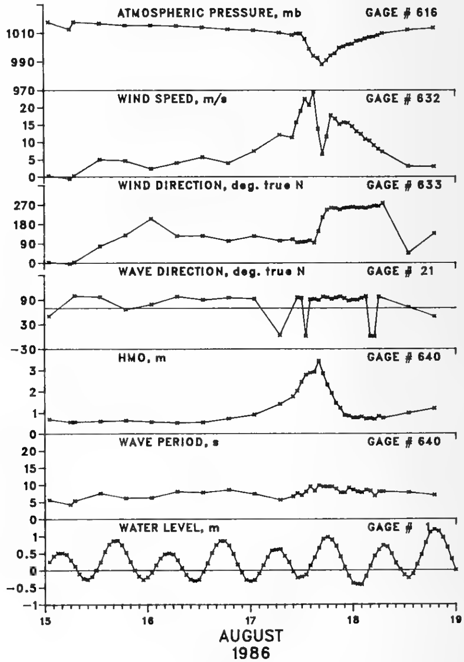

Figure 48. Storm data for 16-18 August 1986

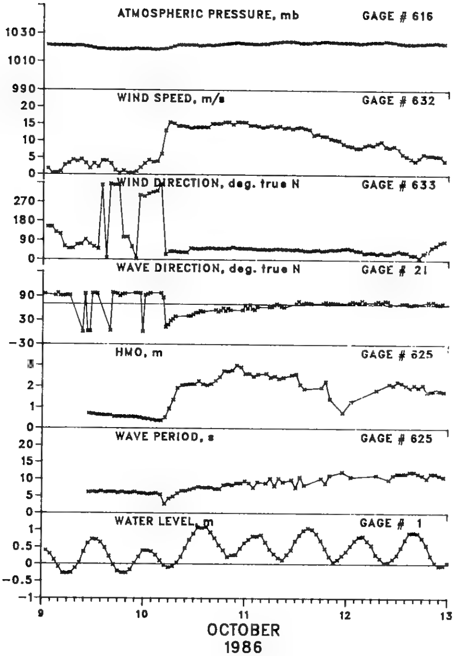

Figure 49. Storm data for 9-12 October 1986

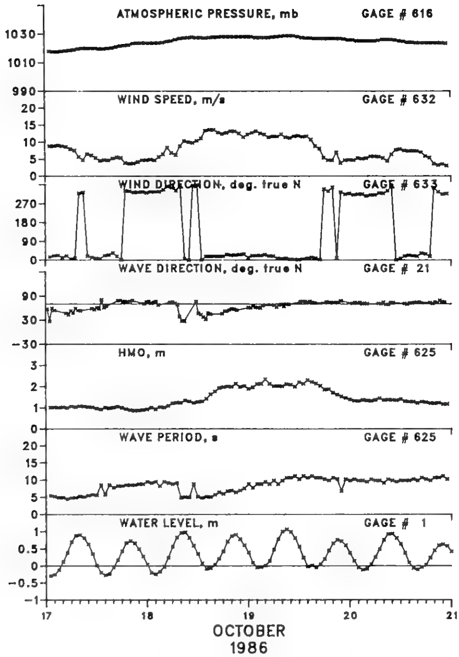

Figure 50. Storm data for 17-20 October 1986

k. 1-3 December 1986 (Figure 51). Following the classic pattern for the development of a major northeaster, this storm was spawned in the Gulf of Mexico early on 28 November. By 1 December, the storm center had moved into the Atlantic Ocean off northern Florida. The blocking effects of a strong Canadian high-pressure system served to both slow the storm's movement up the East Coast and contribute to the onshore gale force winds which buffeted the FRF for a substantial period of time. By 2 December, the storm was still located south of the FRF. However, later in the day it accelerated and was centered over New England on 3 December. Onshore winds exceeded 18 m/sec (NE) at 1900 EST on 1 December but remained above 15 m/sec for 22 hr. The maximum H_{mo} (Gage 625) of 3.1 m (9.8-sec period) was recorded at 0700 EST on 2 December. The lowest barometric reading was 1005.9 mb at 0100 EST on 3 December. Total precipitation was 21 mm.

l. 24 December 1986 (Figure 52). This storm developed in the Gulf of Mexico. However, its northeasterly track took it well inland (west of the Appalachians) which substantially reduced its effect on the East Coast. Onshore winds approached 14 m/sec (SE) but were above 10 m/sec for only 3 hr. The maximum H_{mo} (Gage 625) of 2.7 m (10.3-sec period) was recorded at 1800 EST on 24 December. The lowest barometric reading was 1004.2 mb at 1900 EST on 24 December. Total precipitation was 18 mm.

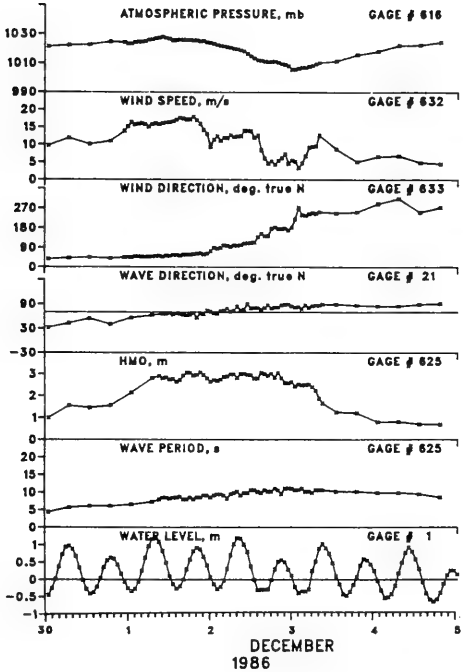

Figure 51. Storm data for 30 November-4 December 1986

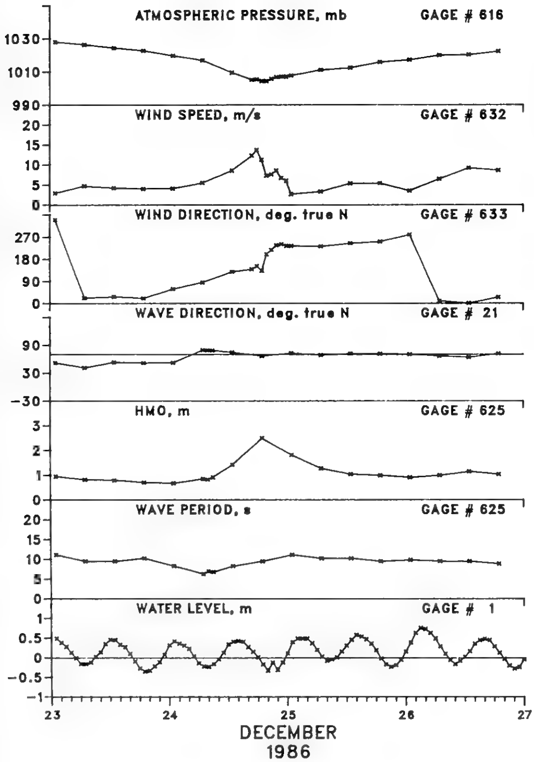

Figure 52. Storm data for 23-26 December 1986

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APPENDIX A: SURVEY DATA

1. Contour diagrams constructed from the bathymetric survey data are presented in this appendix. The profile lines surveyed are identified on each diagram. Contours are in half metres referenced to National Geodetic Vertical Datum (NGVD). The distance offshore is referenced to the Field Research Facility (FRF) monumentation baseline behind the dune.

2. Change in FRF bathymetry diagrams constructed by contouring the difference between two contour diagrams are also presented with contour intervals of 0.25 m. Wide contour lines show general areas of erosion. Other areas correspond to areas of accretion. Although these change diagrams are based on considerable interpolation of the original survey data, they do facilitate comparison of the contour diagrams.

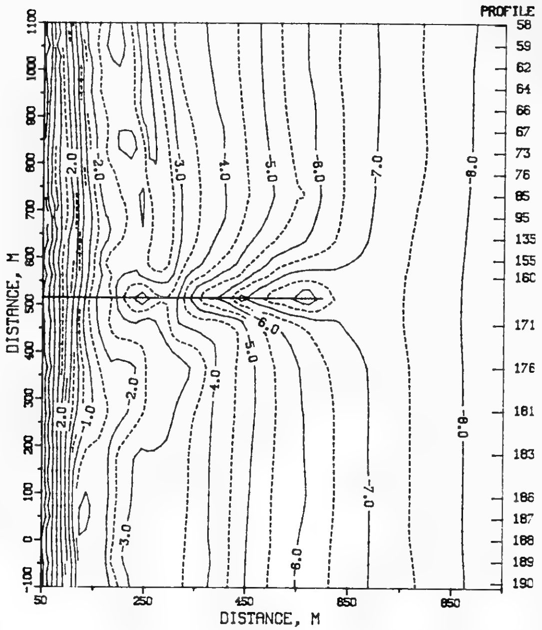


Figure A1. 22 January 1986 bathymetry

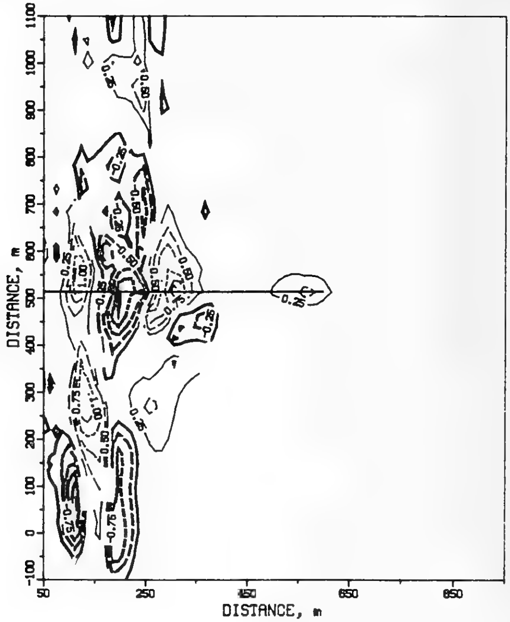
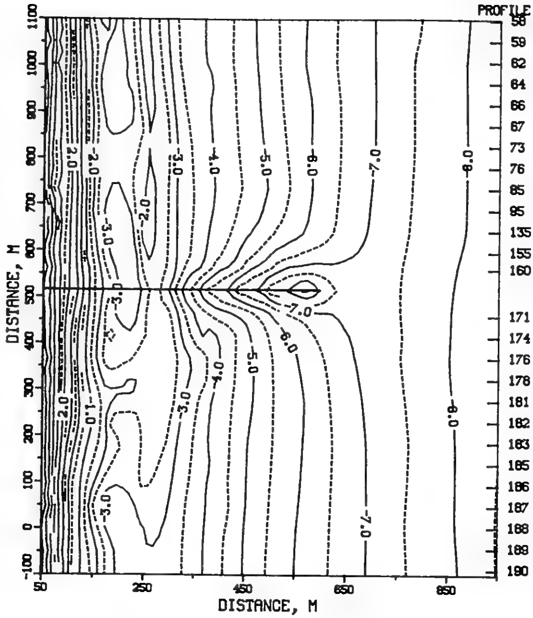


Figure A2. 19 December 1985 to 22 January 1986 change diagram

Figure A3. 28 February 1986 bathymetry



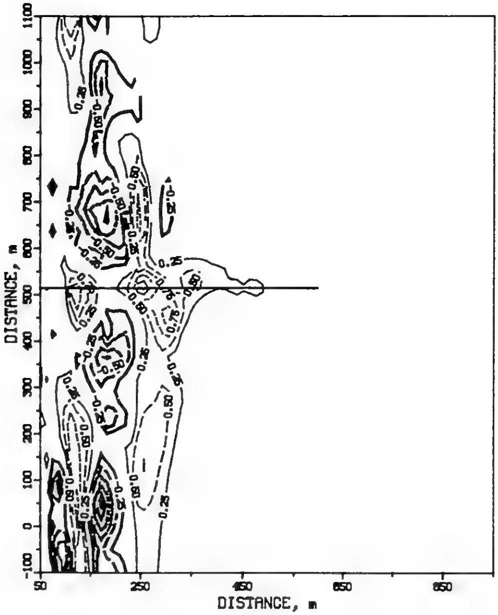


Figure A4. 22 January to 28 February 1986 change diagram

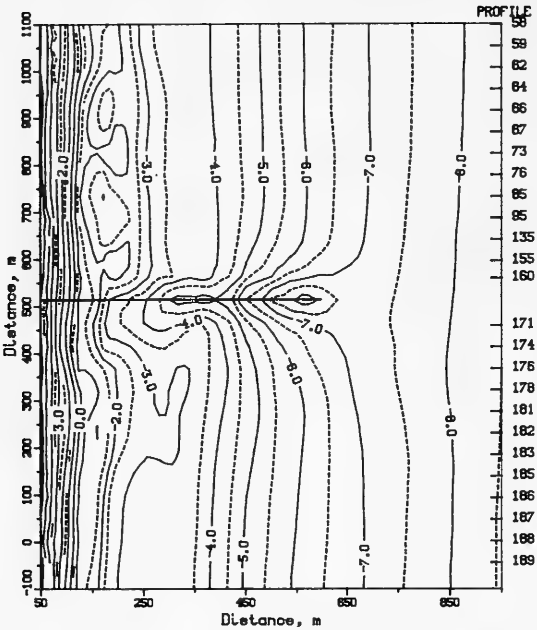


Figure A5. 11 June 1986 bathymetry

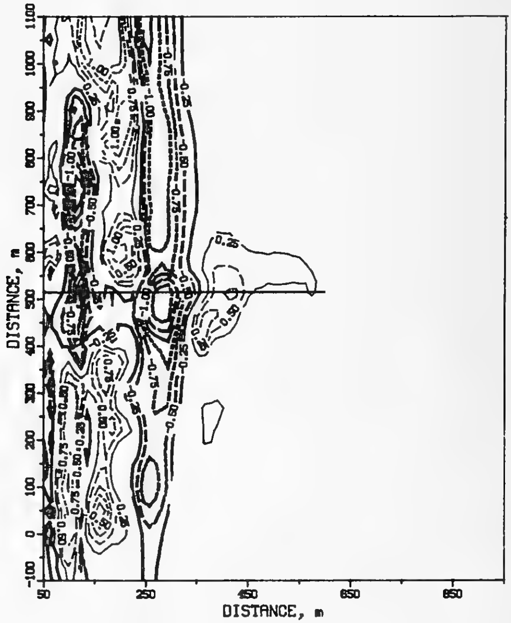
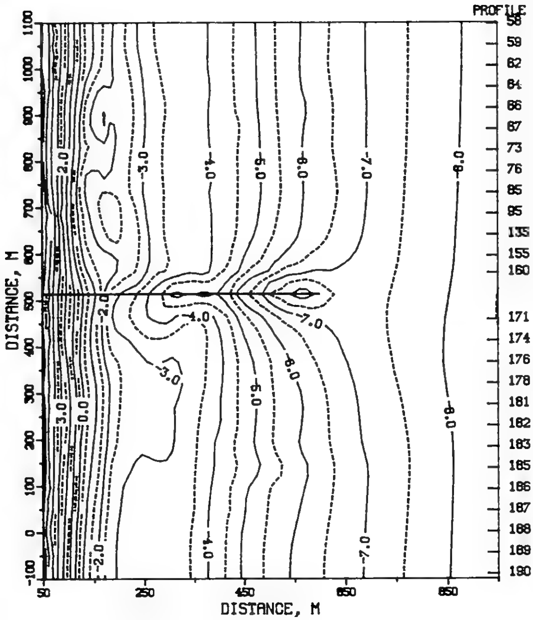


Figure A6. 28 February to 11 June 1986 change diagram

Figure A7. 23 July 1986 bathymetry



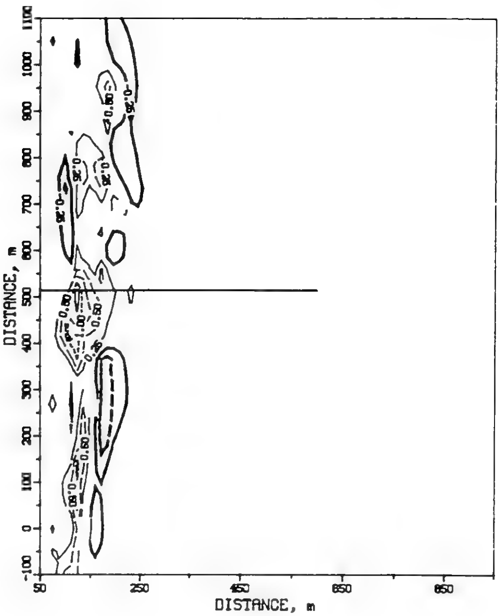


Figure A8. 11 June to 23 July 1986 change diagram

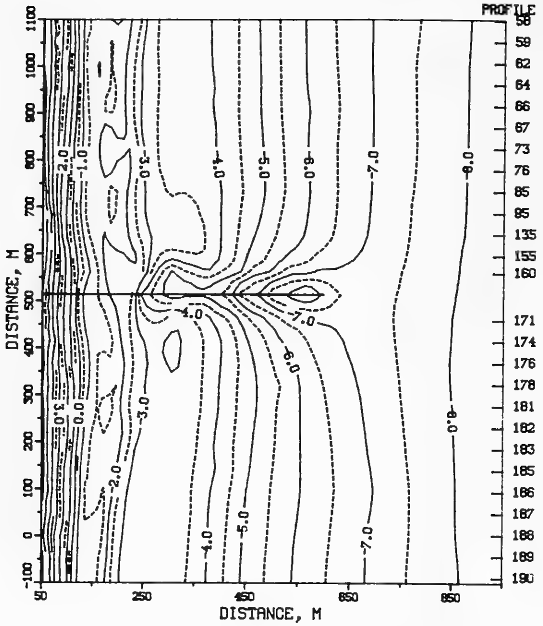


Figure A9. 3 September 1986 bathymetry

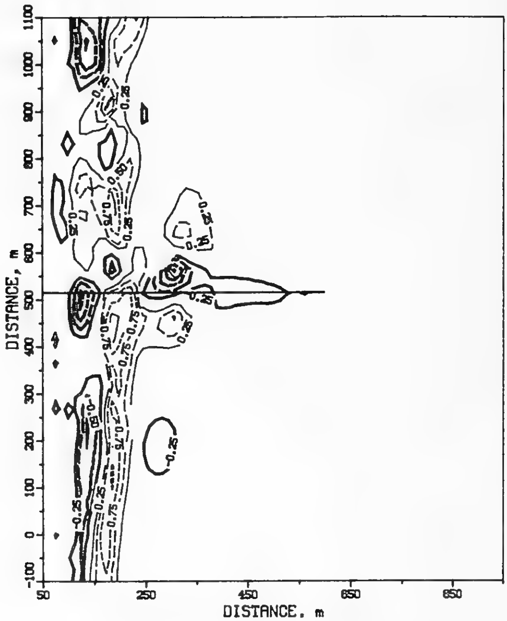


Figure A10. 23 July to 3 September 1986 change diagram

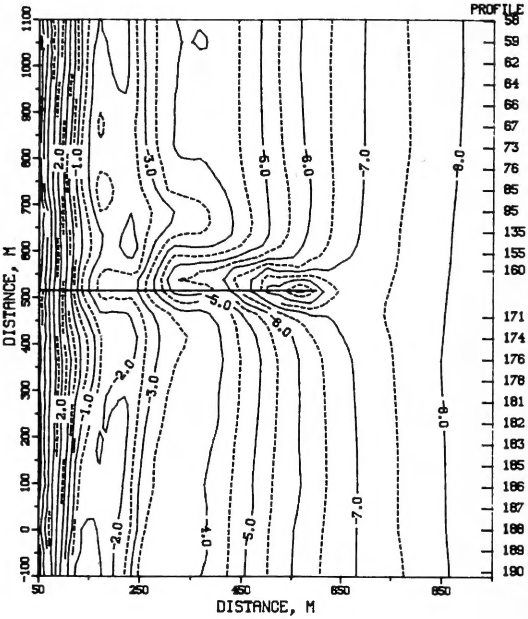


Figure A11. 5 December 1986 bathymetry

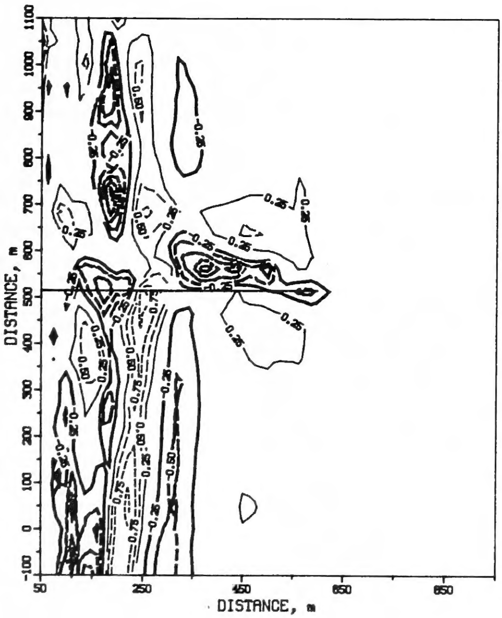


Figure A12. 3 September to 5 December 1986 change diagram

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