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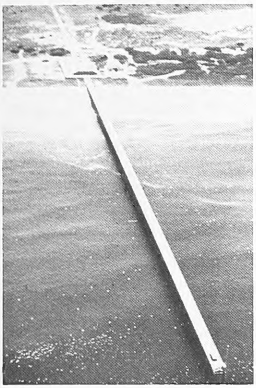

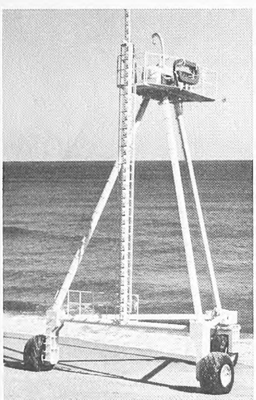

TECHNICAL REPORT CERC-87-13

ANNUAL DATA SUMMARY AND CLIMATOLOGICAL EVALUATION CERC FIELD RESEARCH FACILITY, 1985

Volume I
MAIN TEXT AND APPENDIXES A AND B

by

Herman C. Miller, Adele Militello, Michael W. Leffler,
William E. Grogg, Michael M. Dominguez

Coastal Engineering Research Center

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

September 1987
Final Report

Approved For Public Release, Distribution Unlimited

Prepared for DEPARTMENT OF THE ARMY
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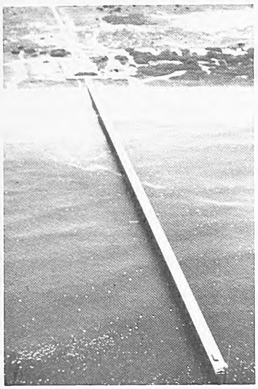

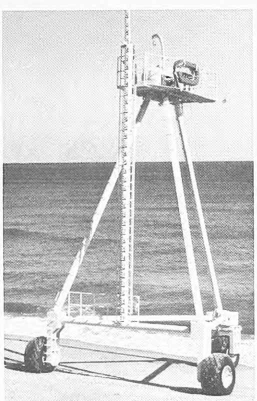

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19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This report provides basic data and summaries for the measurements made during 1985 at the US Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center's (CERC's) Field Research Facility (FRF) in Duck, N. C. The report includes comparisons of the present year's data to those of previous years and 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 tropical storms Ana in July and Henri in September and Hurricanes Claudette in August and Gloria in September. Waves over 6 m were measured, at a location 6 km from shore, during Hurricane Gloria.

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Meteorologic research--statistics (LC)
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Oceanographic research stations--North Carolina--Duck (LC)
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19. ABSTRACT (Continued).

This report is seventh in a series of annual summaries of data collected at the FRF. The six previous reports 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.

These reports are available from the WES Technical Report Distribution Section of the Technical Information Center, Vicksburg, Miss.

PREFACE

Data and data summaries presented herein were collected during 1985 and compiled at the US Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center's (CERC's) Field Research Facility (FRF) in Duck, N. C. This report is the seventh in a series of annual FRF data summaries carried out under CERC's Waves and Coastal Flooding Program.

The report was prepared by Mr. Herman C. Miller, Oceanographer, FRF, under direct supervision of Mr. Curtis Mason, former 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 Scientist, assisted with software development and data analysis; and Messrs. Michael W. Leffler, Computer Programmer Analyst, assisted with data collection and analysis; William E. Grogg, Jr., Electronics Technician, assisted with instrumentation; and Michael M. Dominguez, Amphibious Vehicle Operator, assisted with data collection. The National Oceanic and Atmospheric Administration/National Ocean Service maintained the tide gage and provided statistics for summarization.

In addition, special thanks are extended to Messrs. William A. Birkemeier, Research Hydraulic Engineer, for his supervision of the FRF surveying program and Jeff Halpin, Computer Scientist, for his help in converting analysis and summarization software to the new computer system. 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, CE; Technical Director was Dr. Robert W. Whalin.

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

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ANNUAL DATA SUMMARY AND CLIMATOLOGICAL EVALUATION
CERC FIELD RESEARCH FACILITY, 1985

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, N. C. (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, N. C. 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 is the seventh in a series of annual reports and summarizes the data collected during 1985. Data for previous years are summarized by Miller (1982 and 1984) and Miller et al. (1985, 1986a, 1986b, and 1986c).

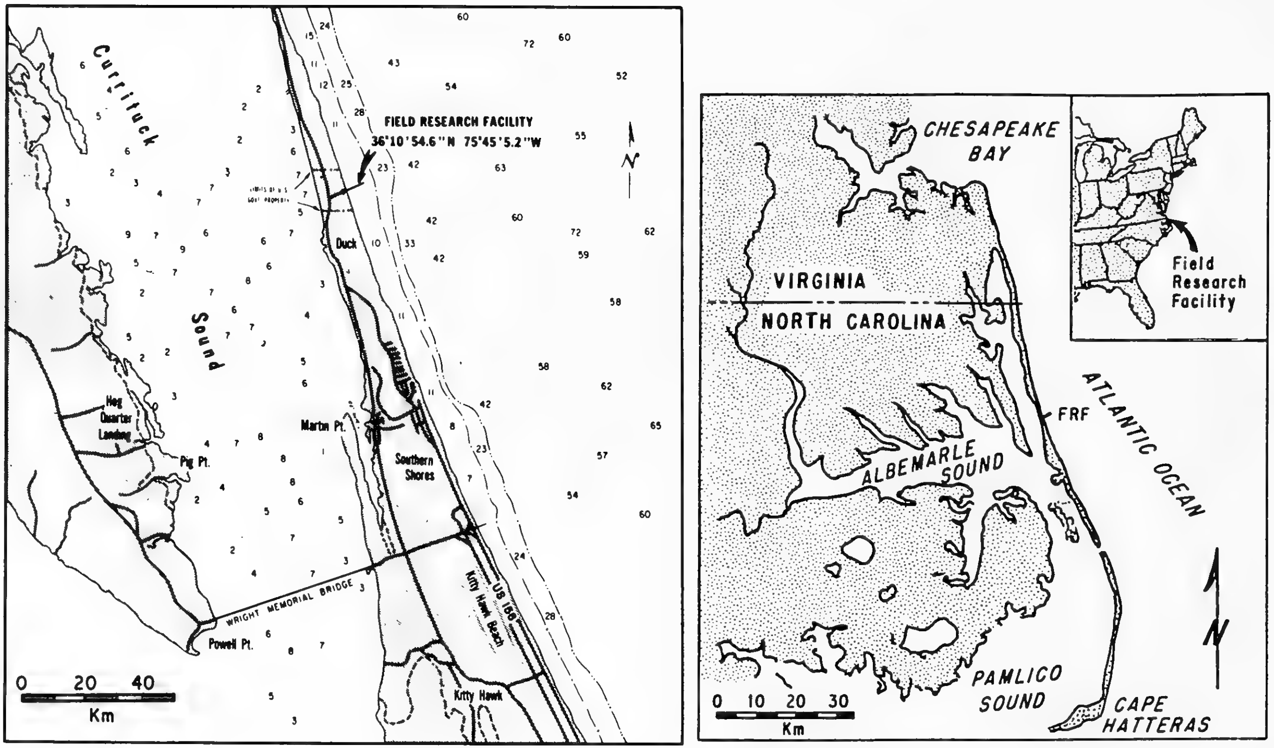


Figure 1. FRF location map

Organization of Report

5. This report is organized as follows:

   a. Part I - Introduction.

   b. Part II - Meteorology.

   c. Part III - Waves.

   d. Part IV - Currents.

   e. Part V - Tides and Water Levels.

   f. Part VI - Water Characteristics.

   g. Part VII - Surveys.

   h. Part VIII - Photography.

   i. Part IX - Storms.

In each part of this report, the respective instruments used for monitoring the meteorological or oceanographic conditions are briefly described. These instruments are interfaced with the primary data acquisition system, a Data General Corporation (Westboro, Mass.) NOVA-4 minicomputer located in the FRF laboratory building. More detailed explanations of the instrument design and operation may be found in Miller (1980). Additionally, each part of the report presents data collection and analysis procedures as well as results.

6. As a result of reader comments on prior reports, this report has been reorganized. Now, with the instrument descriptions and the data collection and analysis procedures in the same section as the data, it will be more convenient to find the information necessary for proper interpretation of the results. Another revision in the report involves the wave data which in the past has been included in Appendix B but is now being published under separate cover as Appendix C (Volume II) which contains gage histories; wave height, period, and direction distributions and other statistics; and spectra during storms. As usual, 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 and Appendix B, more extensive summaries for each of the gages are provided under separate cover as discussed above.

Table 1

1985 Data Availability

8. The annual data summary herein summarizes daily observations by month, season, and year to provide basic data for analysis by users. Daily observations have been reported also in the 1985 series of monthly Preliminary Data Summaries (Field Research Facility 1985) which summarize the same types of data shortly after they were collected. If individual data are needed, the user can obtain detailed information (as well as the monthly reports) from the following address:

USAE Waterways Experiment Station
Coastal Engineering Research Center
Field Research Facility
SR Box 271
Kitty Hawk, N. C. 27949

9. 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 Coastal Engineering Information and Analysis Center (CEIAC) is responsible for storing and disseminating most of the data presented or alluded to in this report. 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, Miss. 39180-0631

Tidal data other than the summaries 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, contact CEIAC at (601) 634-2017. Costs for collecting, copying, and mailing will be borne by the requester.

PART II: METEOROLOGY

10. This section summarizes the meteorological measurements made at the FRF in 1985. A discussion of the data and a comparison with those of previous years are also presented. Appendix B contains hourly wind speed and direction and atmospheric pressure values during storm conditions.

11. Mean air temperature, atmospheric pressure, and wind speed and direction were computed based on 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. prior to collection, each gage signal was first amplified and then biased to ensure a 0- to 5-V range.

Air Temperature

12. The FRF enjoys a typical marine climate which moderates the extremes of both summer and winter. During the warmest months, July and August, the monthly air temperature averaged nearly 25° C. Lowest air temperatures occur during January, averaging about 5° C.

Measurement instruments

13. A Yellow Springs Instrument Company, Inc. (YSI) (Yellow Springs, Ohio) electronic temperature probe with analog output interfaced to the FRF's NOVA-4 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 sun yet provide proper ventilation.

Results

14. Present year. The average air temperature for the year was 16° C. After a very cold winter, monthly mean for January was only 2.6° C, temperatures rose to the mid-twenties during the summer (see Table 2). Autumn temperatures remained mild through November for which the monthly mean was 15.9° C.

15. Present versus past years. In comparison to prior years, the air temperatures for 1985 were very cold during January and February, milder

Figure 2. FRF gage locations

Table 2

Monthly Mean Air Temperature and Atmospheric Pressure Statistics

Month	Air Temperature, °C			Atmospheric Pressure, mb*		
	1985	1983-1984	1983-1985	1985	1983-1984	1983-1985
Jan	2.6	6.2	5.0	1012.9	1019.2	1017.1
Feb	5.1	7.1	6.4	1019.8	1015.7	1017.2
Mar	10.3	8.9	9.4	1017.7	1012.0	1014.0
Apr	16.1	13.0	14.0	1015.7	1012.9	1013.9
May	19.3	19.0	19.1	1013.6	1016.4	1015.4
Jun	23.0	23.4	23.3	1013.8	1016.3	1015.5
Jul	25.3	26.1	25.8	1016.0	1016.9	1016.6
Aug	24.9	25.6	25.3	1017.5	1016.0	1016.5
Sep	22.9	20.3	21.0	1016.7	1018.4	1017.8
Oct	19.7	17.9	18.5	1019.4	1020.4	1020.0
Nov	15.9	11.8	13.3	1016.7	1017.9	1017.5
Dec	7.0	9.4	8.6	1019.1	1020.7	1020.2
Annual	16.0	15.7	15.8	1016.9	1016.9	1016.8

* Multiply millibars by 100.0 to obtain pascals.

during spring and autumn, and near normal during the summer, as shown in Figure 3. The annual average air temperature was 0.3° C above the average for 1983 and 1984.

16. All years. The coldest month of the year is January, with an average temperature of 5.0° C (Table 2). Temperatures slowly increase through March. In the spring the temperature rises more than 9° C, then it remains near 25° C through July and August. By the end of autumn the temperatures fall 17° C. The annual average temperature is consistently near 15.8° C.

Atmospheric Pressure

Measurement instruments

17. 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 at least once a week to ensure proper operation.

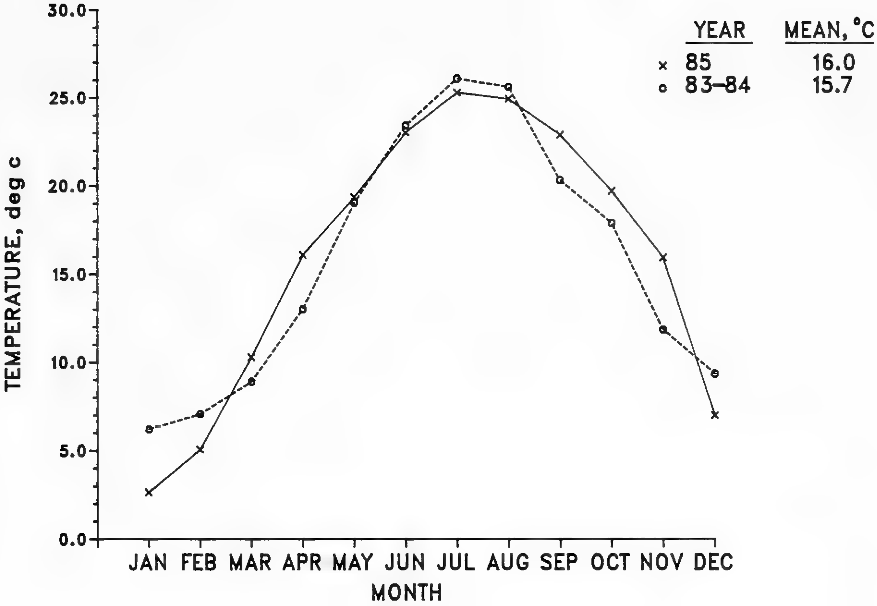


Figure 3. 1985 mean monthly air temperatures

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

19. 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.

20. 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

21. Present year. Average atmospheric pressure for the year was 1016.6 mb. The lowest monthly average pressures occurred in January, May, and June, while the highest occurred in February, March, October, and December (Table 3).

Table 3

Precipitation Statistics

Month	Total 1985, mm	Mean 1978–1984, mm	Mean 1978–1985, mm	1978–1985 Extremes Maxima, mm	1978–1985 Extremes Minima, mm
Jan	126	94	98	180	45
Feb	68	86	84	127	46
Mar	35	98	90	168	35 (1985)
Apr	0	111	97	182	0 (1985)
May	35	88	81	239	35 (1985)
Jun	62	77	75	130	27
Jul	67	90	87	200	19
Aug	30	103	94	220	30 (1985)
Sep	71	94	91	160	5
Oct	143	55	66	143 (1985)	20
Nov	145	80	88	145 (1985)	26
Dec	4	83	73	131	4 (1985)
Annual	786	1079	1042		
Monthly avg.	66	88	85		

22. Present versus past years. The average atmospheric pressure for 1985 was 0.3 mb lower than in prior years. Although February through April had significantly higher monthly mean pressures (Figure 4) the largest difference (6.3 mb below climatology) was the very low pressures experienced in January.

23. All years. Typically the monthly mean atmospheric pressures are lowest during March and April and highest in October and December. The annual average is 1016.8 mb, very near standard atmospheric pressure.

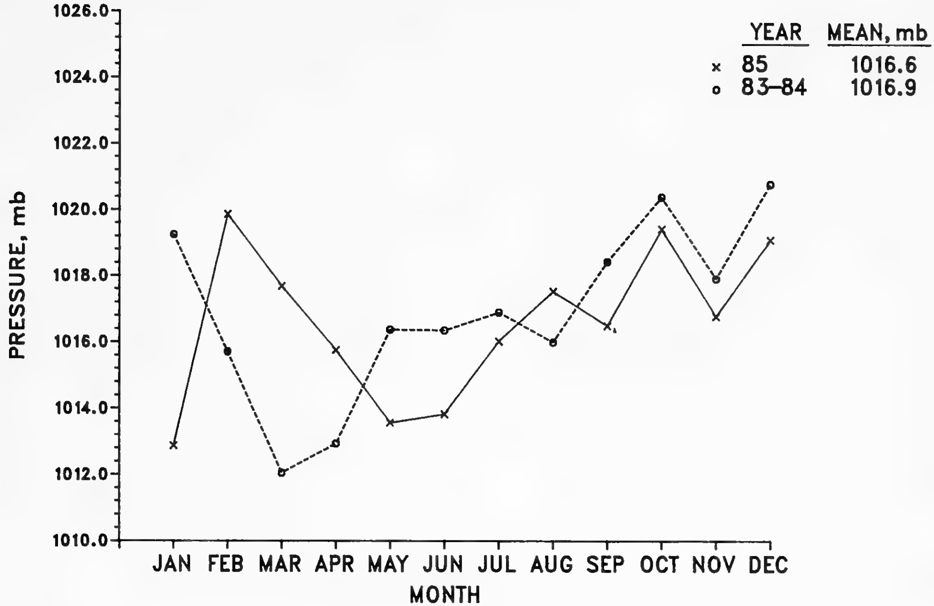


Figure 4. Mean monthly atmospheric pressure

Precipitation

24. Precipitation is generally well distributed throughout the year, averaging 104 cm annually. Precipitation from midlatitude cyclones predominates in the winter, while local convection (thunderstorms) accounts for most of the summer rainfall.

Measurement instruments

25. 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.

26. The rain gage was inspected daily, and the analog chart recorder was maintained by the procedures listed in paragraph 19.

27. Plastic rain gage. A Edwards Manufacturing Company (Alberta Lea, Minn.) 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 checked daily, and very few discrepancies were identified throughout the year.

Results

28. Present year. The annual total was 786 mm for an average of 66 mm per month. Precipitation during 1985 was poorly distributed throughout the year (Table 3). January had a total of 126 mm; April was dry; both October and November received over 140 mm; and December had only 4 mm.

29. Present versus past years. In comparison to records since 1978, there was substantially less precipitation during 1985. Monthly average totals are typically 25 percent higher, and the precipitation is more evenly distributed throughout the year (as shown in Figure 5).

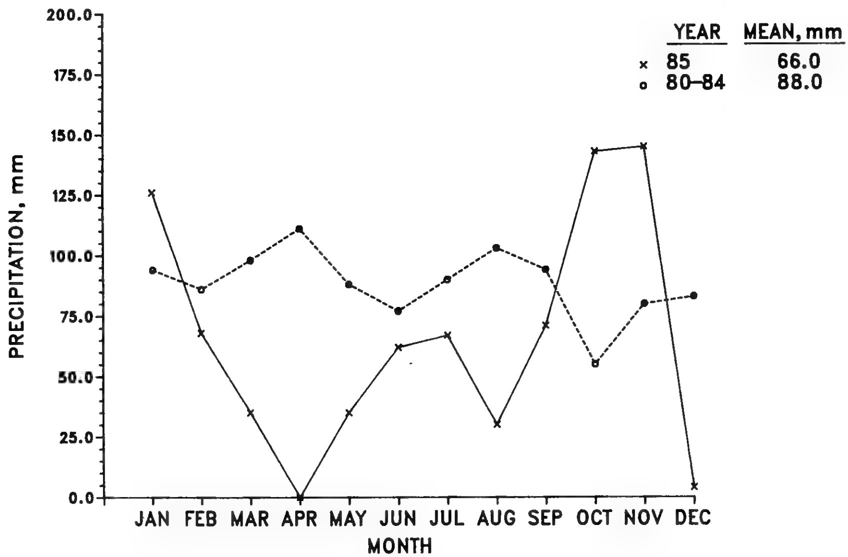


Figure 5. Mean monthly precipitation

30. All years. There were five monthly minima during 1985, including three in a row for March through May (see Table 3). Ironically, there were two maxima in October and November.

Wind Speed and Direction

31. Winds at the FRF are dominated by tropical maritime air masses which create low to moderate, warm southern breezes; Arctic 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. The annual resultant wind direction is from the north-northwest. It is common for fall and winter storms (northeasters) to produce winds with average speeds in excess of 15 m/sec.

Measurement instrument

32. Winds were measured on top of the laboratory building at an elevation of 19.1 m (Figure 2) using a Weather Measure Corporation (Sacramento, Calif.) Skyvane Model W102P anemometer. Wind speed and direction data were incorporated into the automated data collection and analysis program and were collected continuously 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 is calibrated semiannually at the National Bureau of Standards in Gaithersburg, Md., and is within the manufacturer's specifications.

33. Annual, seasonal, and monthly joint probability distributions of wind speed versus direction were computed. Wind 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 in 3-m/sec intervals. Resultant directions and speeds were also determined by vector averaging the data.

Results

34. Present year. Winds during the year blew primarily from the northeastern and southwestern quadrants as shown in Figure 6. The wind blew from north through east-northeast 40.8 percent of the time and south-southwest through west-southwest 26.5 percent of the time. Wind speed exceeded 10 m/sec

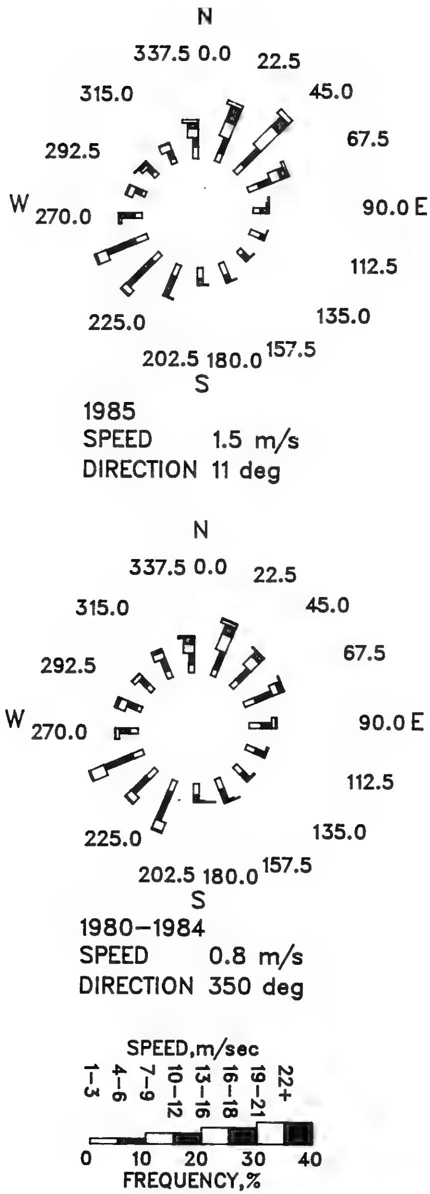


Figure 6. Comparison of annual wind roses, 1985 versus 1980-1984

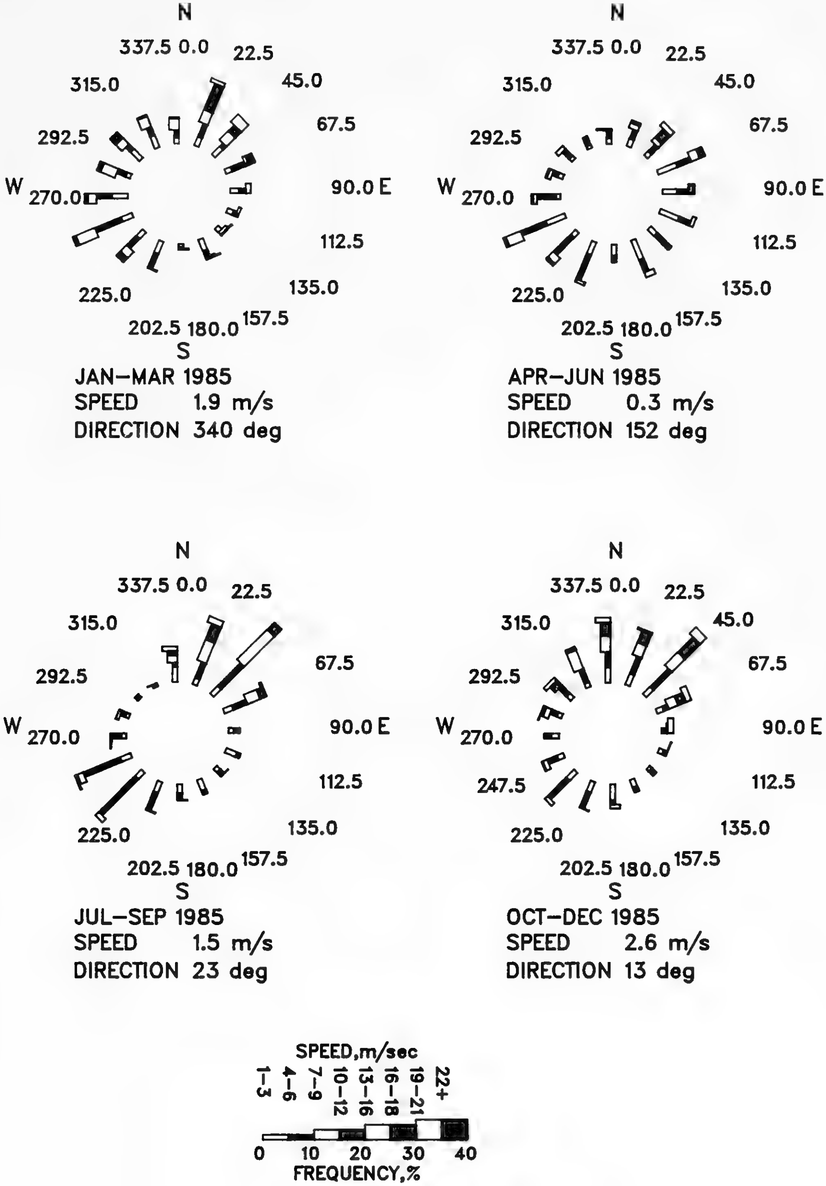


Figure 7. Seasonal wind roses, 1985

13.4 percent of the time, including three occasions when the wind speed exceeded 15 m/sec. More than three out of every four times, when the speed exceeded 10 m/sec, the winds blew from north through east-northeast.

35. Strong seasonal tendencies measured during the year are shown in Figure 7. During January through March the winds had a bimodal distribution approximately equally split between the northeastern quadrant and the southwestern quadrants. Wind speeds exceeded 10 m/sec 16.8 percent of the time during the season. Winds were from southerly directions in the Spring with less than 8 percent exceeding 10 m/sec. Though predominantly from the northeastern quadrant during the summer, relatively low speeds were measured 31 percent of the time from the southwestern quadrant. During October through December winds exceeded 10 m/sec 19.5 percent of the time and were predominantly from northerly directions.

36. Present versus past years. In comparison to prior years there were fewer occurrences of winds from the southwestern quadrant and more from the northeastern quadrant, particularly from July through December. General differences in the distribution of wind directions can be seen in Table 4. Depending on the quadrant the resultant direction is in, the tendency for more northerly or southerly and easterly or westerly direction can be seen. For example, the annual distribution for 1985 has a resultant direction of 11 deg while the 1980 through 1984 resultant is 350, indicating both had a northerly tendency. On the other hand, during 1985 winds blew more frequently from easterly directions in comparison to prior years when there was a westerly predominance.

37. All years. Winds at the FRF tend to blow most often from the northeasterly and southwesterly quadrants (Figure 8). Predominant wind direction varies with season; however, winds in excess of 10 m/sec tend to blow most often from north through east-northeast. The most significant effect the addition of the 1985 data had on the annual distribution of winds was a slightly higher frequency of winds from the northeast and a corresponding lower frequency from south-southwest.

Table 4

Resultant Wind Speed and Directions Relative to True North

Month	1985 Speed m/sec	1985 Direction deg	1980-1984 Speed m/sec	1980-1984 Direction deg	1980-1985 Speed m/sec	1980-1985 Direction deg
			Annual			
Jan-Dec	1.5	11	0.8	350	0.9	358
			Seasonal			
Jan-Mar	1.9	340	1.9	351	1.9	348
Apr-Jun	0.3	152	0.9	205	0.7	201
Jul-Sep	1.5	23	0.1	79	0.5	29
Oct-Dec	2.6	13	1.9	1	2.1	5
			Monthly			
Jan	3.6	336	2.5	349	2.7	346
Feb	1.0	323	1.7	354	1.5	350
Mar	1.1	8	1.5	349	1.4	352
Apr	0.5	60	0.9	219	0.6	216
May	0.6	118	0.9	207	0.7	198
Jun	1.1	215	0.9	190	0.9	195
Jul	1.7	238	1.8	217	1.7	220
Aug	1.9	69	0.3	21	0.5	51
Sep	2.3	20	1.8	45	2.0	31
Oct	3.9	41	2.1	31	2.6	35
Nov	2.9	5	2.0	343	2.2	351
Dec	3.0	297	2.1	345	2.1	334

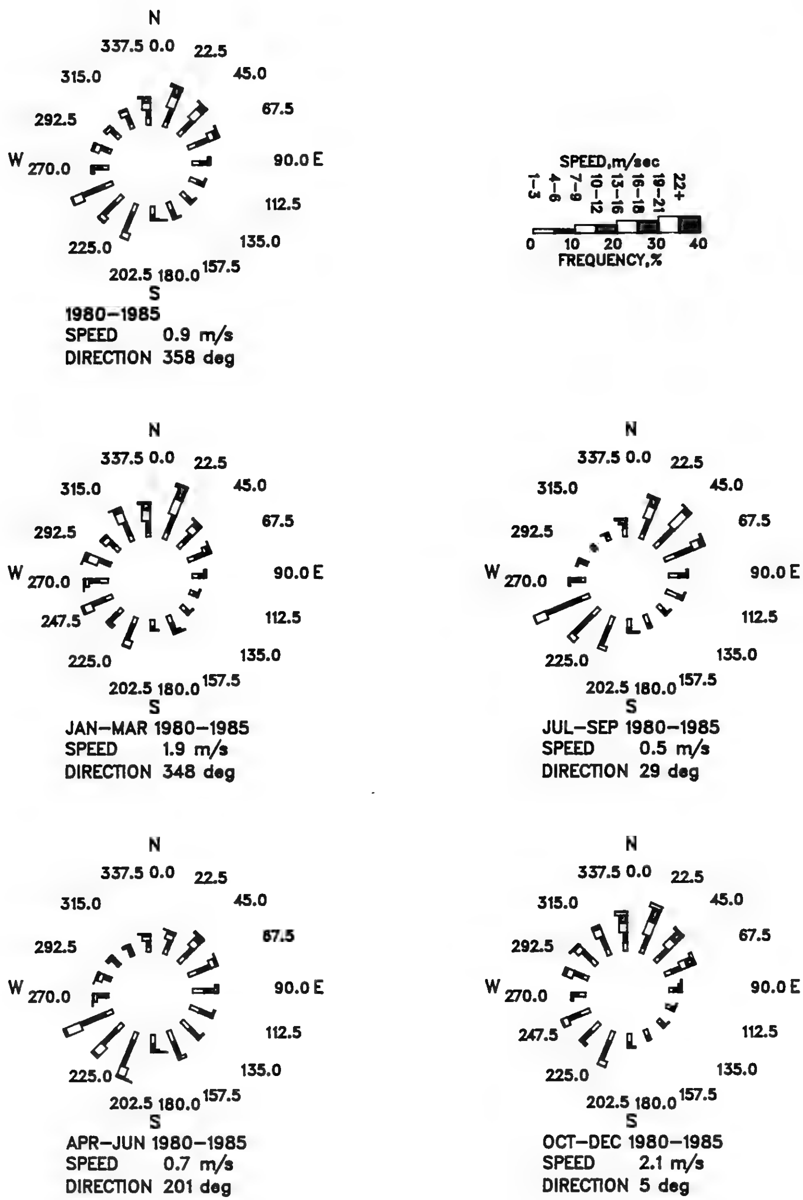


Figure 8. Annual and seasonal wind roses for 1980-1985

PART III: WAVES

38. This section presents summaries of the wave data. A discussion of individual major storms is given in Part IX, and Appendix B contains hourly wave data for times when the heights H_{mo} exceeded 2 m at the seaward end of the FRF pier. Appendix C (published as Volume II) provides 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 in accordance with guidelines indicated in paragraph 11.

39. Daily wave height and period values for Gage 630, located 6 km from shore, and Gage 625, located at the seaward end of the FRF pier, are presented in Figures 9 and 10, respectively. The annual mean wave height (measured at the seaward end of the FRF pier) is 0.9 m, with a standard deviation of 0.6 m. Although the portion of the North Carolina coast in the vicinity of the FRF experiences a fairly low frequency of occurrence of direct hurricane strikes (on the average of once every 42 years), more frequent near-misses can cause high wave conditions at the FRF. Wave height in excess of 2 m can be expected to occur 7 percent of the time, or 600 hr per year.

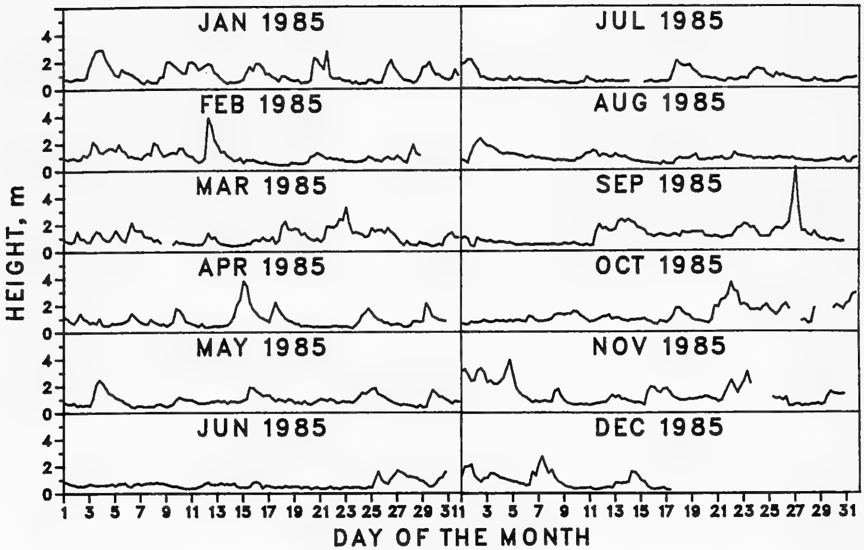
40. Wave periods generally vary between 6 and 12 sec, with an annual mean peak spectral period of 8.8 sec and a standard deviation of 2.8 sec. Wave periods tend to be longest during the fall and shortest during the summer.

41. 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).

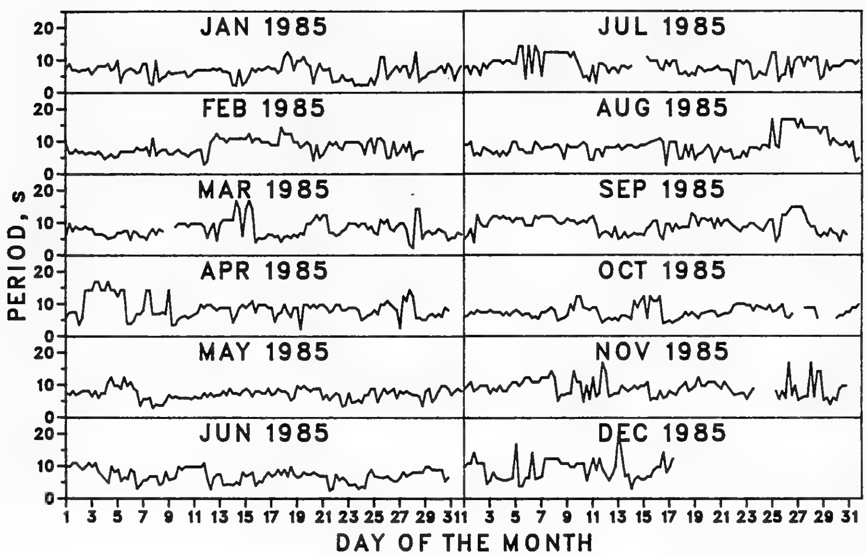
Measurement Instruments

Staff gages

42. 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

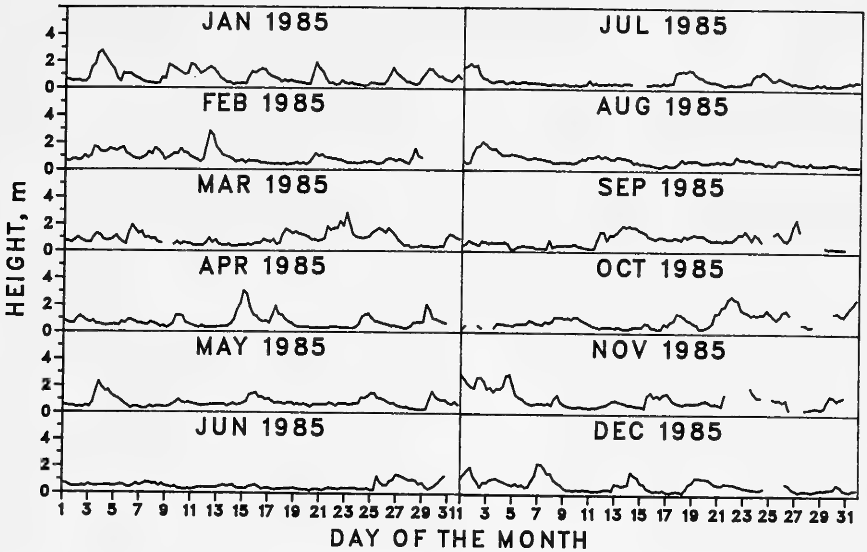


a. Wave height

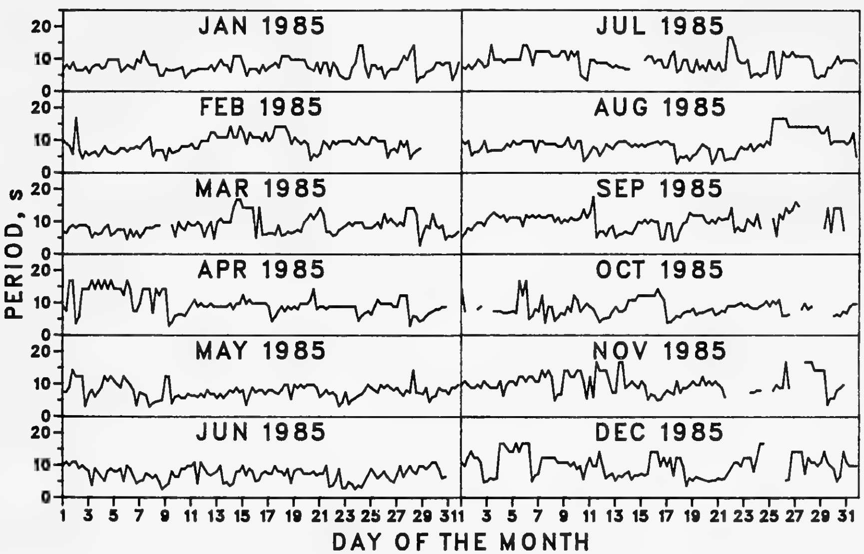


b. Wave period

Figure 9. Time-histories of wave height and period for Gage 630



a. Wave height



b. Wave period

Figure 10. Time-histories of wave height and period for Gage 625

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. Gage accuracy is about 1 percent, with a 0.1 percent full-scale resolution. (Full scale is 9.4 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

43. Two Datawell Laboratory for Instrumentation (Haarlem, The Netherlands) Waverider buoy gages (Gage 630 located 6 km and Gage 640 located 1 km from shore), 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 states that wave amplitudes are correct to within 3 percent of their actual value for wave frequencies between 0.065 and 0.5 Hz (corresponding 15- to 2-sec wave periods). The manufacturer specifies the error can increase to 10 percent for wave periods in excess of 20 sec.

Digital Data Analysis and Summarization

44. 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.

45. The program computes the first five moments of the distribution of sea surface elevations then edits the digital data file by checking for "jumps" and "spikes" and for the data points out of the 0- to 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 there is a problem with the file. If the variance is less than 0.001 m^2, the record is not analyzed. After editing, the first five moments of the distribution of sea surface elevations were 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.

46. 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 combination with the varying width of the period intervals, only a discrete set of period values is possible (Table 5). 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 C (Volume II) for Gage 625 during storm wave conditions.

Results

Present year

47. Spatial variation. The distribution of wave heights for all four gages operated during the year is shown in Figure 11. For a given frequency of occurrence, wave heights were highest at Gage 630 (located in the deepest

Table 5

Spectral Band and Peak Period Specifications

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	

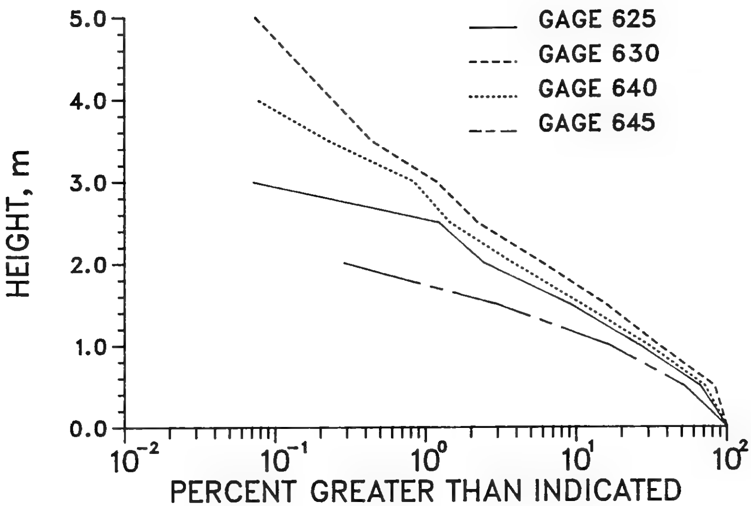


Figure 11. Annual wave height distributions, 1985

water) and lowest at Gage 645 (located at the landward end of the pier), as shown in the tabulation below:

Gage Number	Location	Depth, m
630	6 km from shore	18.0
640	1 km from shore	8.5
625	Pier end	8.0
645	Landward end of pier	3.5

Refraction, bottom friction, and wave breaking contribute to the observed differences in height. 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 occasionally out to Gage 640. This occurrence is a major reason for the differences in the distributions between Gage 630 and the inshore gages for the highest 1 percent of the waves. 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.

48. The distribution of wave periods for all of the gages is shown in Figure 12. Although the distributions of wave periods for all gages were similar, Gage 630 tended to have the lowest percentage of wave periods 10 sec or longer, and Gage 645 tended to have the highest percentage of wave periods less than 6 sec.

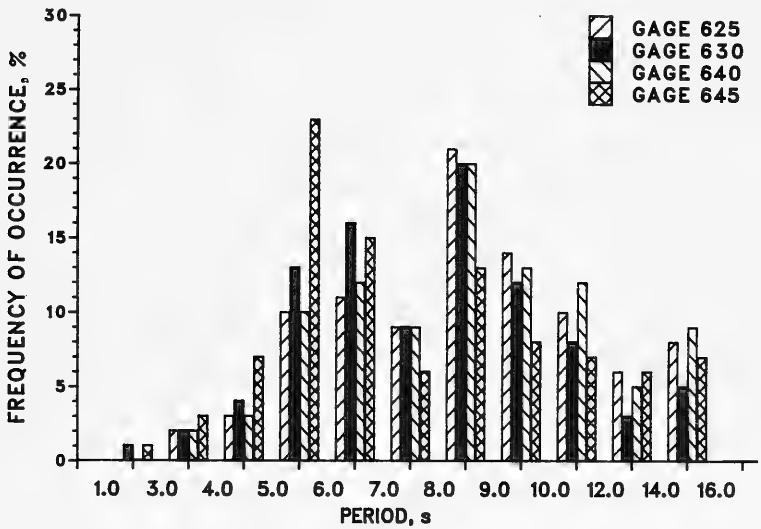
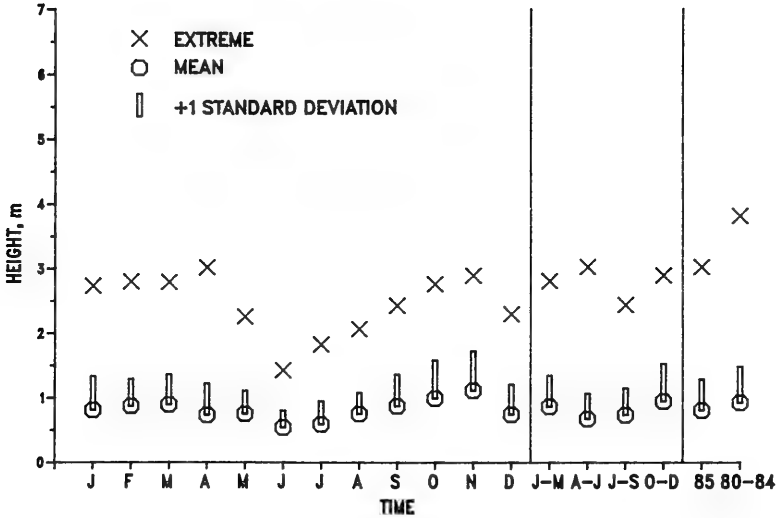
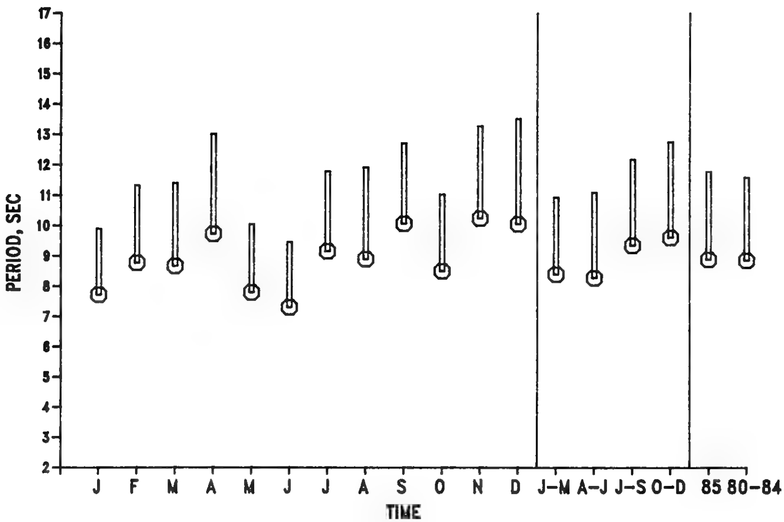


Figure 12. Annual wave period distributions, 1985

49. Temporal variation. Temporal height and period trends for Gages 625 and 630 are shown in Figures 13 and 14, respectively, and are consistent with those for Gages 640 and 645. Wave heights tended to be above the annual mean during the winter months, dropping below the annual mean by the

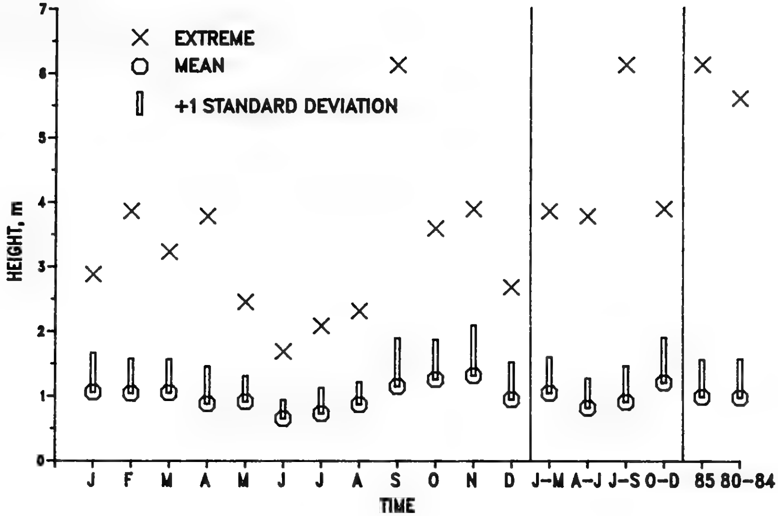


a. Wave height

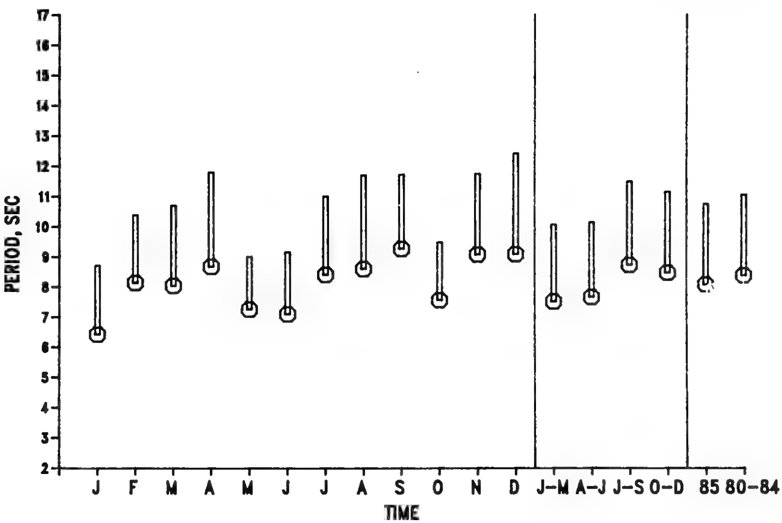


b. Wave period

Figure 13. Wave statistics for Gage 625, 1985



a. Wave height



b. Wave period

Figure 14. Wave statistics for Gage 630, 1985

end of spring and start of summer and then increasing to the highest values during autumn. Wave periods were less consistent; however, there was a tendency for lower mean periods during winter and spring and higher periods during summer and autumn.

50. Although the wave height and period distributions for each gage differed, seasonal tendencies were similar to those shown for Gage 625 in Figures 15 and 16. Over 6.2 percent of the waves during October through December

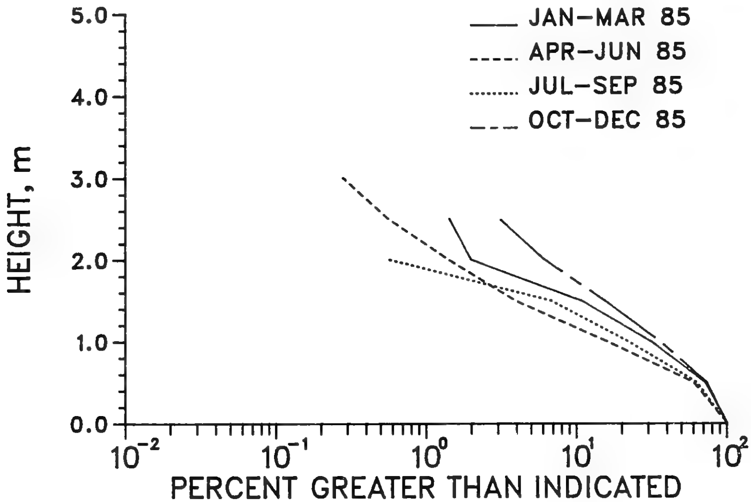


Figure 15. Seasonal wave height distributions for Gage 625, 1985

exceeded 2 m, 2 percent during January through March, 1.4 percent during April through June, and only 0.56 percent during July through September. Wave periods of 10, 12, and 14 sec or longer tended to occur most frequently during July through December, while periods of 8 sec were measured over 25 percent of the time during January through June.

51. The distribution of wave directions for the year, based on daily visual observations (Figure 17), revealed that waves approached the pier from the south side 60 percent of the time. Seasonal distributions of the wave directions indicate approximately an even split between north and south for January through March, while approximately 70 percent of the waves approached from the south during April through September. During October through

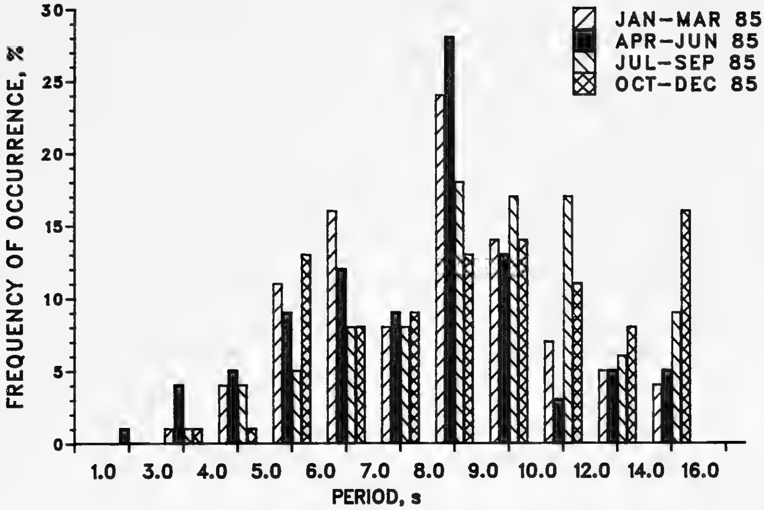


Figure 16. Seasonal wave period distributions for Gage 625, 1985

December 53 percent were from the south, 5 percent shore normal, and 42 percent from the north.

Present versus past years

52. In general, wave heights during the year were lower than those during past years. However, the highest wave conditions, to date, were measured during Hurricane Gloria on 27 September when the H_{mo} exceeded 6.1 m (Gage 630), with an associated wave period over 14 sec. The annual distributions for Gage 625 are shown in Figure 18. Heights over 2 m occurred almost 4 percent less frequently during 1985 primarily because of a very mild winter, as shown in Figure 19. With the exception of fewer 10-sec and more 8-sec periods, wave periods were nearly identical (Figure 20).

53. Wave directions, on the other hand, were somewhat different from those of other years, as emphasized by Table 6 and Figure 17. Table 6 shows the resultant (vector averaged) wave height and direction. As can be seen the annual direction is normal to the pier (oriented at 70 deg relative to true north) during 1985, while there has been more of a northerly tendency during prior years. With the exception of September, wave directions were predominantly from the south from March through October 1985.

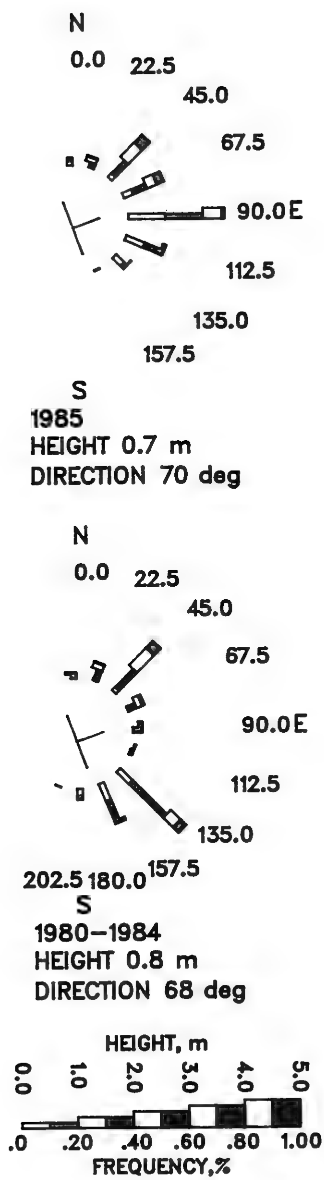


Figure 17. Comparison of annual wave roses, 1985 versus 1980-1984

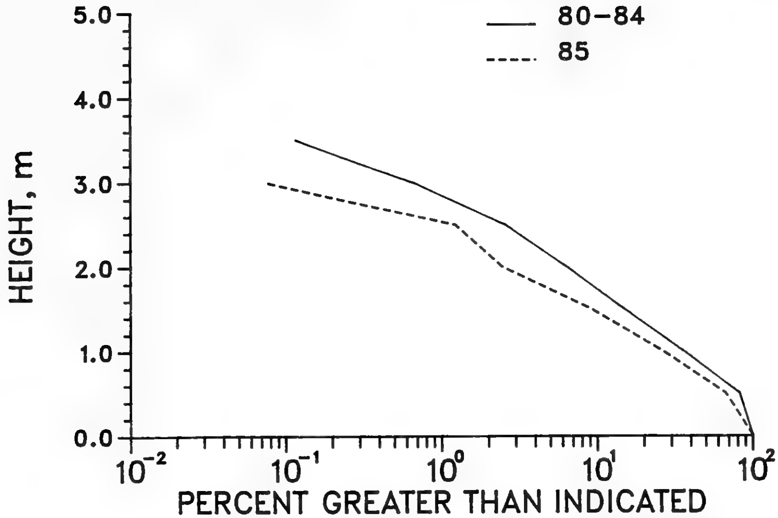


Figure 18. Comparison of annual wave height distributions for Gage 625

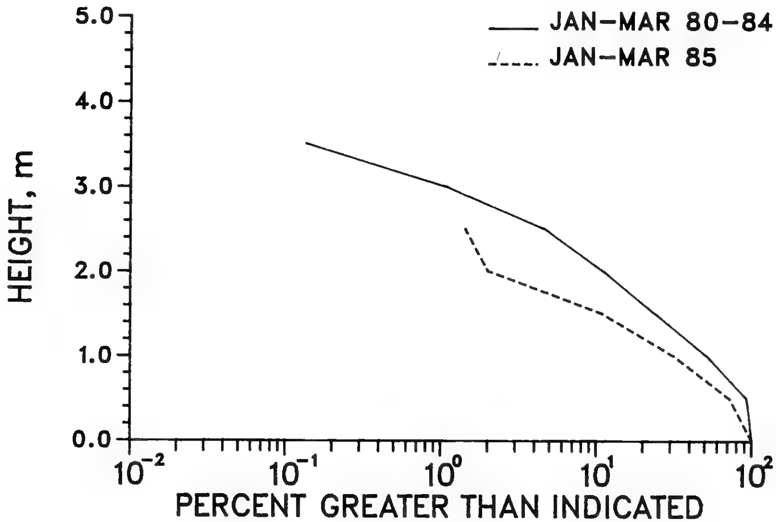


Figure 19. Comparison of January through March wave height distributions for Gage 625

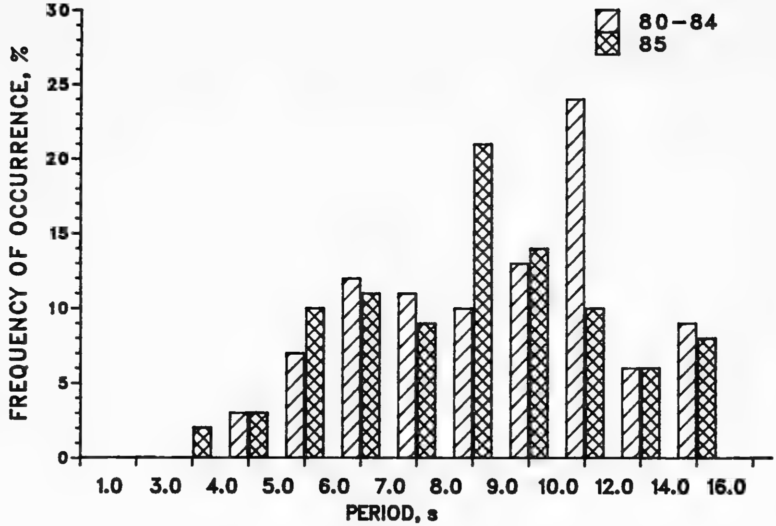


Figure 20. Comparison of annual wave period distributions for Gage 625

<u>All years</u>

54. The 6 years of data from 1980 through 1985 provide the most complete description of the wave climate at the FRF. Annual wave height distributions for all of the gages are presented in Figure 21. Gage 640 is a new installation this year. It is located at approximately the seaward extent of the breaker zone. Only 1 year of data is available from it, however. Offshore at Gage 630, heights can be expected to exceed 2 m over 8 percent of the time, 3 m about 1.2 percent of the time, and to occasionally exceed 4 m. At the seaward end of the pier (Gage 625), heights can be expected to exceed 2 m about 5.7 percent of the time and 3 m less than 1 percent. Seasonal height variation is summarized by examining data for Gage 625. Mean seasonal heights are near 1 m during the winter and autumn and near 0.7 m during spring and summer (Figure 22). During January through March and October through December heights can be expected to exceed 3 m approximately 1 percent of the time. During April through June the heights exceed 2 m approximately 1.2 percent of the time, while during July through September they exceed the same height over 2.1 percent (Figure 23).

55. Seasonal wave period variation for all years of data combined are

Table 6

Resultant Wave Height and Directions

Month	1985 Height, m	1985 Direction deg True N	1980-1984 Height, m	1980-1984 Direction deg True N	1980-1985 Height, m	1980-1985 Direction deg True N
			Annual			
Jan-Dec	0.7	70	0.8	68	0.8	68
			Seasonal			
Jan-Mar	0.8	66	1.0	63	0.9	64
Apr-Jun	0.6	79	0.6	78	0.6	78
Jul-Sep	0.6	73	0.6	72	0.6	72
Oct-Dec	0.8	65	1.0	63	0.9	64
			Monthly			
Jan	0.7	58	1.0	55	0.9	56
Feb	0.8	69	1.0	66	1.0	67
Mar	0.8	71	0.9	67	0.9	67
Apr	0.7	85	0.7	72	0.7	75
May	0.6	76	0.7	78	0.6	78
Jun	0.4	74	0.6	84	0.5	83
Jul	0.5	79	0.4	80	0.4	80
Aug	0.7	76	0.6	72	0.6	73
Sep	0.7	66	0.9	68	0.8	68
Oct	0.9	80	1.1	66	1.0	68
Nov	0.9	68	0.9	60	0.9	61
Dec	0.6	43	0.9	64	0.8	61

shown in Figure 22. The histogram of seasonal wave period in Figure 24 shows periods of 10 to 11.9 sec occurring most often and periods of 12 sec or longer occurring most often during winter and autumn.

56. The tendency for higher waves to be associated with longer wave periods is shown in Table 7. These joint distributions of wave height and period for Gages 630 and 625 are based on over 7,300 observations each. The values presented can be converted to percent by dividing by 100.

57. Annual and seasonal wave directions are shown in Figure 25. Waves can be expected to approach from the north side of the pier 52 percent of the time, within 1 deg of shore normal 8 percent, and from the south 40 percent. However, when the wave heights exceed 2 m at Gage 625, 80 percent of the time the approach will be from the north side, 7 percent shore normal, and 13 percent from the south.

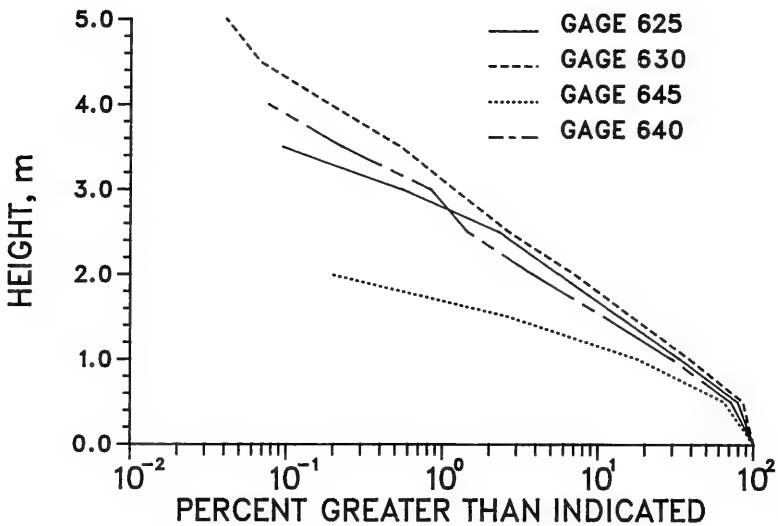
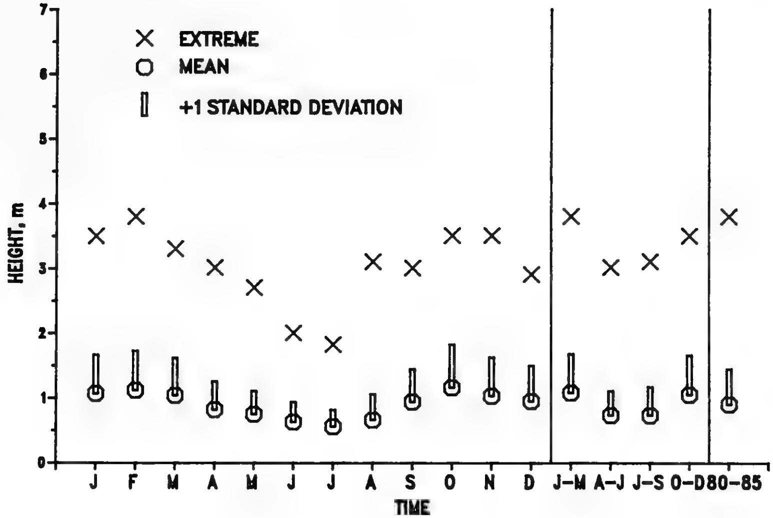
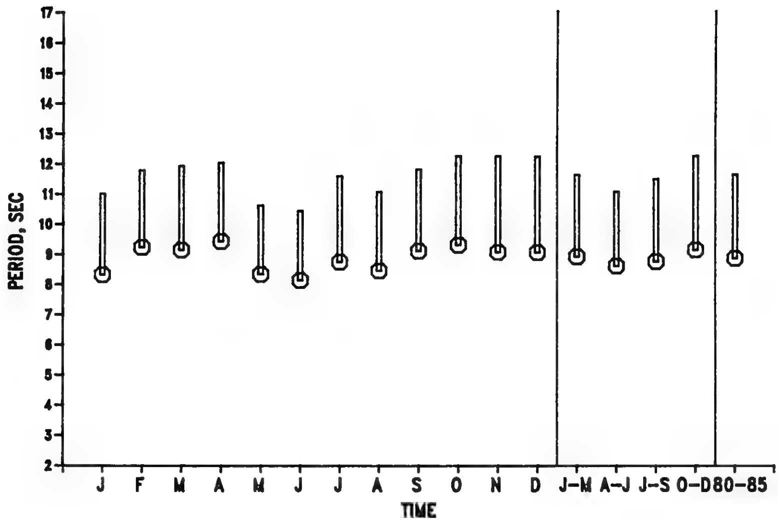


Figure 21. Annual wave height distributions, 1980-1985



a. Wave height



b. Wave period

Figure 22. Wave statistics for Gage 625, 1980-1985

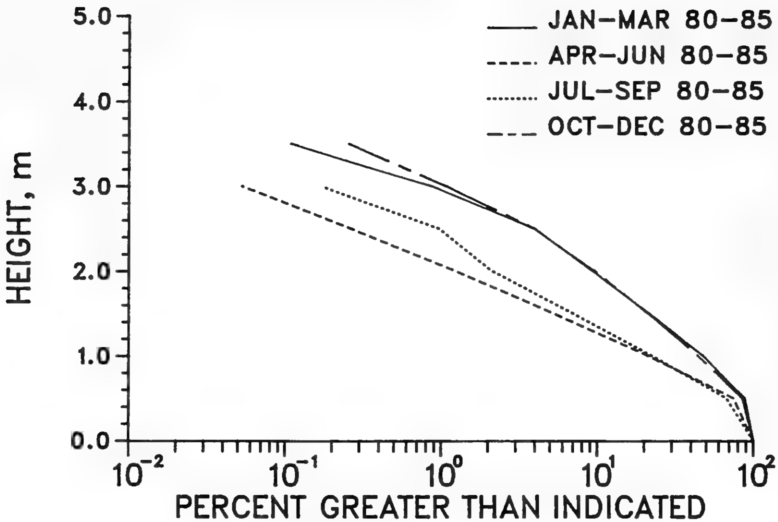


Figure 23. Seasonal wave height distribution for Gage 625, 1980-1985

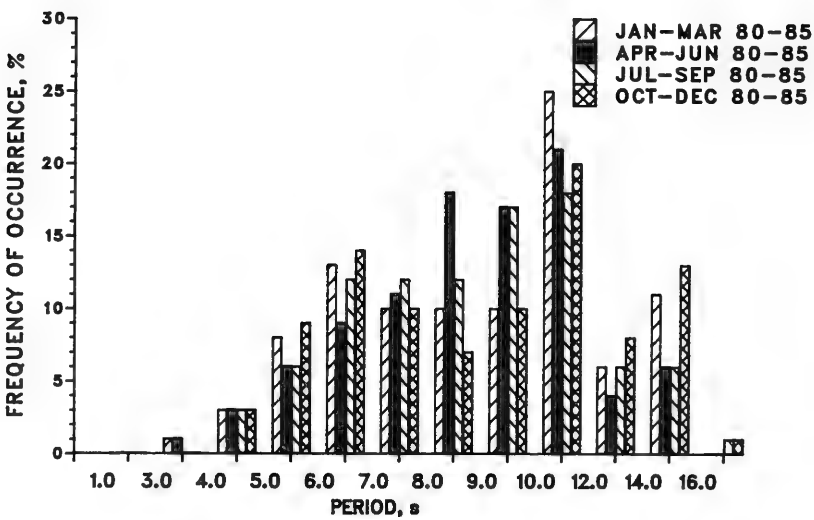


Figure 24. Seasonal wave period distributions for Gage 625, 1980-1985

Table 7

Joint Distribution of Wave Height Versus Period, 1980-1985

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	22	15	27	58	96	117	271	320	255	90	153	5	1429
0.50 - 0.99	30	114	264	452	589	510	658	697	926	179	229	23	4671
1.00 - 1.49	.	7	102	344	469	292	209	198	414	50	157	5	2247
1.50 - 1.99	.	.	7	118	281	123	66	62	137	45	96	7	942
2.00 - 2.49		.	.	26	76	85	45	43	79	35	49	3	441
2.50 - 2.99		.	.	.	5	34	18	19	34	11	28	.	149
3.00 - 3.49		.	.	.	.	3	12	15	19	5	11	.	65
3.50 - 3.99		.	.	.	.	.	1	9	14	7	4	.	35
4.00 - 4.49		.	.	.	.	.	1	.	8	1	1	.	11
4.50 - 4.99		.	.	.	.	.	.	.	3	.	.	.	3
5.00 - GREATER		.	.	.	.	.	.	.	.	3	1	.	4
TOTAL	52	136	400	998	1516	1164	1281	1363	1889	426	729	43	

Gage 625

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	11	24	38	51	112	205	345	388	428	218	227	19	2066
0.50 - 0.99	4	70	242	372	493	442	593	713	1017	238	311	45	4540
1.00 - 1.49	.	1	62	273	409	259	173	178	427	51	177	4	2014
1.50 - 1.99	.	.	3	62	196	134	55	62	142	54	99	8	815
2.00 - 2.49	.	.	.	1	30	46	24	41	74	51	62	3	332
2.50 - 2.99		.	.	.	4	15	23	27	41	20	45	3	178
3.00 - 3.49		.	.	.	.	.	4	4	16	9	12	.	45
3.50 - 3.99		.	.	.	.	.	.	.	4	1	4	.	9
4.00 - 4.49		.	.	.	.	.	.	.	.	.	.	.	0
4.50 - 4.99		.	.	.	.	.	.	.	.	.	.	.	0
5.00 - GREATER		.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	15	95	345	759	1244	1101	1217	1413	2149	642	937	82	

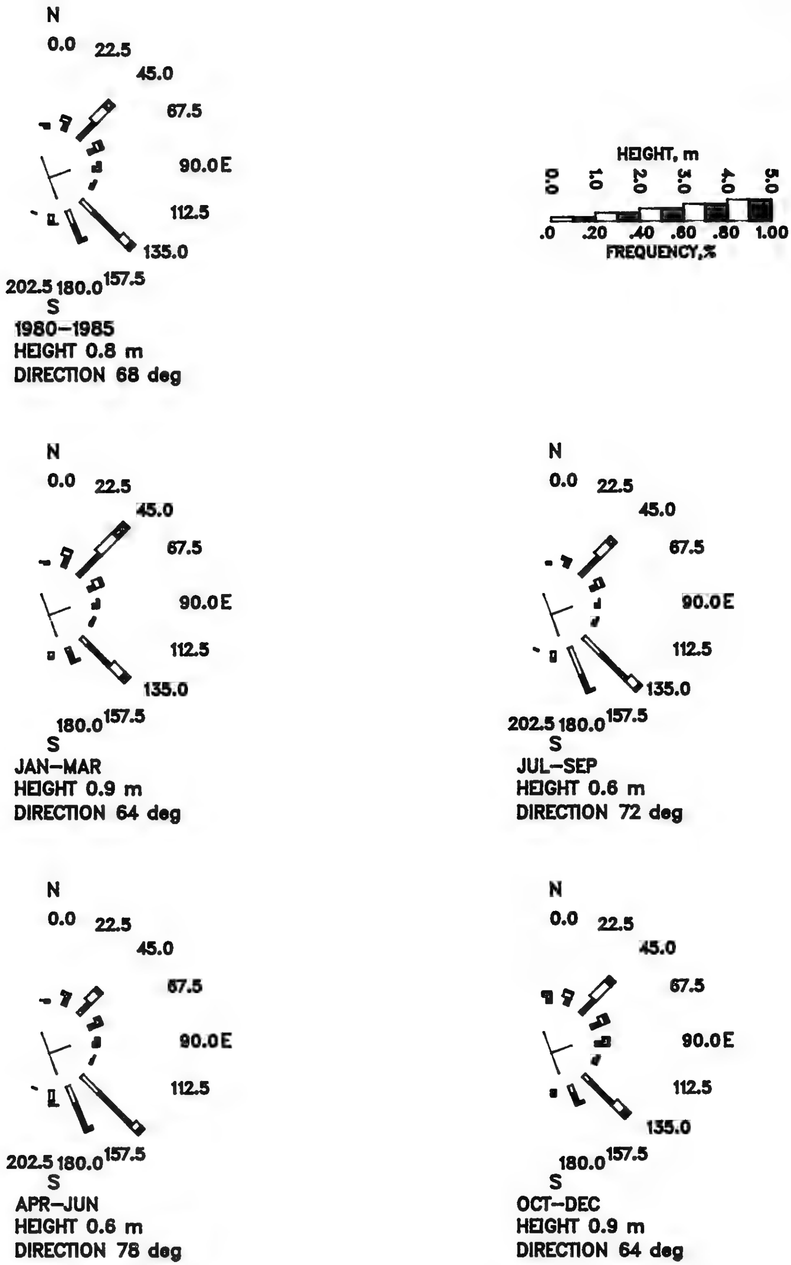


Figure 25. Annual and seasonal wave roses, 1980-1985

PART IV: CURRENTS

58. 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

59. Near 0700 hours 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

Present year

60. Spatial variation. Figure 26 shows the daily 1985 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 (Table 8 and Figure 27) were directed southward at the beach location and near zero at the pier end and midsurf locations. There was a strong tendency for more northward directed currents at the midsurf locations than at the beach from April through November.

61. Temporal variation. During January through March the currents were most often southward, though frequent reversals were observed at the seaward end of the pier during March. For April there were more northward currents at the midsurf than at the beach. May and June had frequent reversals, and the monthly means were low. During August, October, and November there were predominantly northward currents at the midsurf while at the beach there were frequent reversals. Currents were directed southward during December.

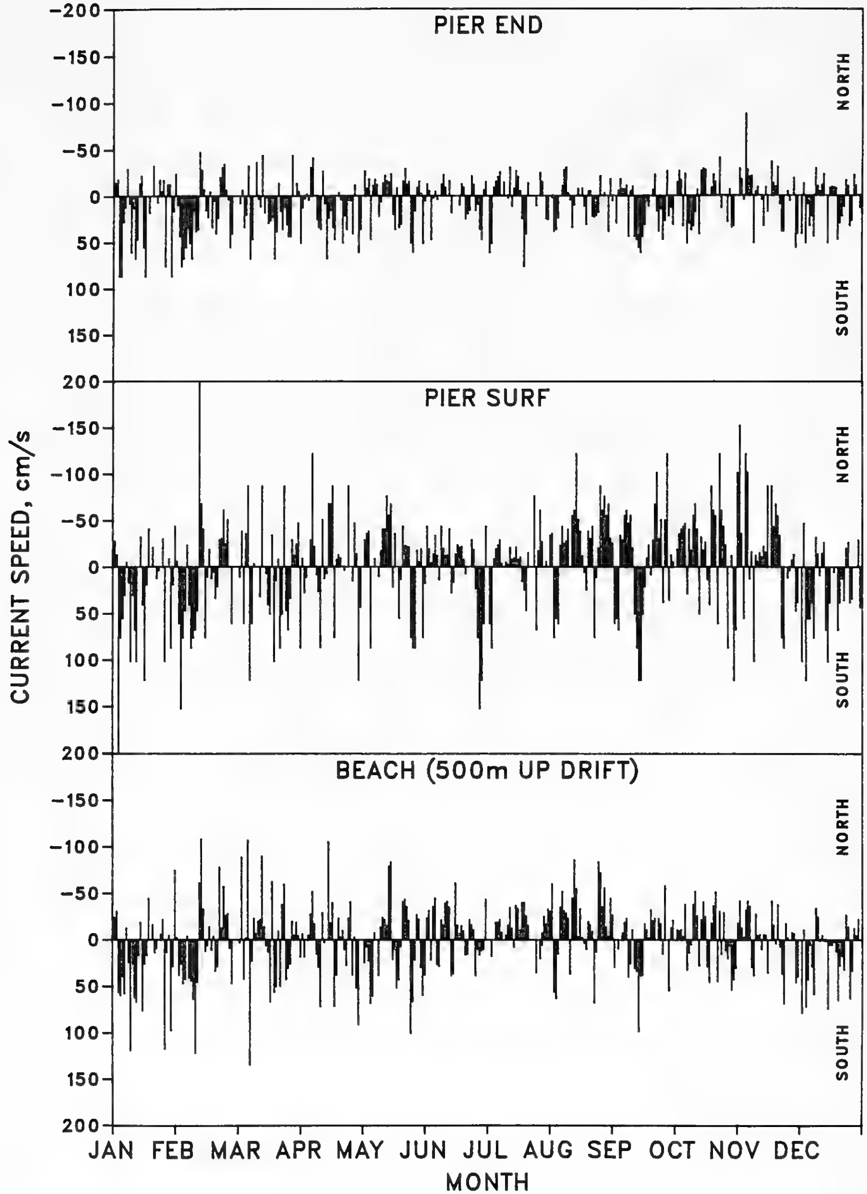


Figure 26. Daily surface currents, 1985

Table 8

Annual and Monthly Longshore Surface Currents at the FRF*

	Beach, cm/sec			Pier Midsurf, cm/sec			Pier End, cm/sec		
Month	1985	1980–1984	1980–1985	1985	1981–1984	1981–1985	1985	1980–1984	1980–1985
Jan	23	17	17	33	21	23	19	23	22
Feb	7	10	11	12	5	6	20	22	17
Mar	–1	16	14	14	11	12	15	17	14
Apr	3	4	5	–7	–2	–1	17	11	8
May	8	–4	–2	–2	–10	–8	3	8	8
Jun	–7	–7	–6	2	–16	–11	4	6	1
July	–14	–16	–12	–4	–23	–19	4	3	0
Aug	–18	–10	–6	–25	–12	–15	7	11	6
Sep	5	2	4	–3	0	2	16	14	11
Oct	–2	5	7	–19	12	5	3	13	10
Nov	–1	12	10	–17	14	7	–2	14	12
Dec	16	8	8	25	16	16	9	11	12
Annual	1	3	4	1	1	1	10	13	10

* + = southward; – = northward.

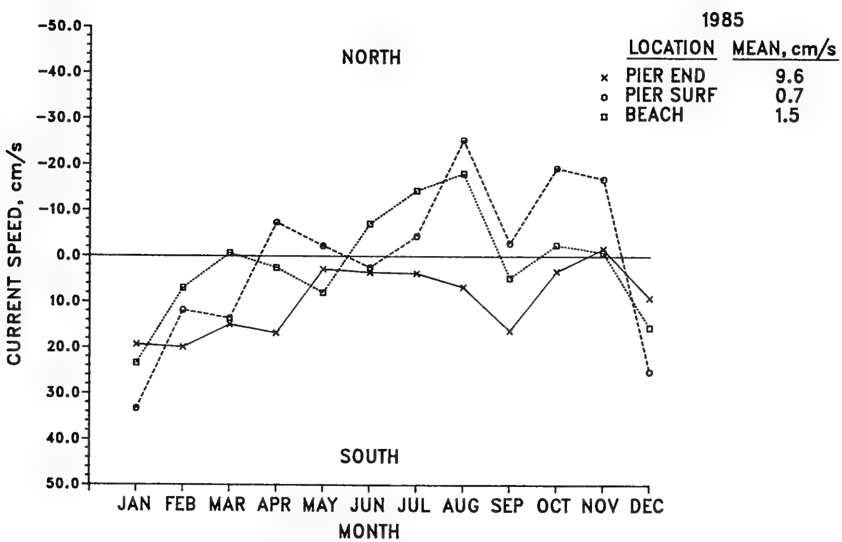


Figure 27. Monthly mean currents, 1985

Present versus past years

62. In previous years, the currents measured at the beach and midsurf locations were directed southward during the cold months and northward from June through August with frequent reversals during the transition months, May and September. At the seaward end of the pier, the currents were predominantly southward all year long. In 1985, the monthly mean currents were predominantly southward or highly mixed at the pier end location, as can be seen in Figure 28. At the midsurf location there were frequent reversals during June through August and predominantly northward directed currents during November and December (Figure 29). The currents were highly mixed during March, October, and November at the beach location (Figure 30). The annual mean at the midsurf location was approximately equal to that for previous years, while at the other locations the means reflect the higher frequencies of southward currents at the beach and northward currents at the seaward end of the pier.

All years

63. Considering all of the years combined (Figure 31), currents were directed southward most often during January through March and October through December and northward most often during June through August. While the beach and midsurf locations show the currents tended toward both directions, at the pier end the overall monthly means were southward.

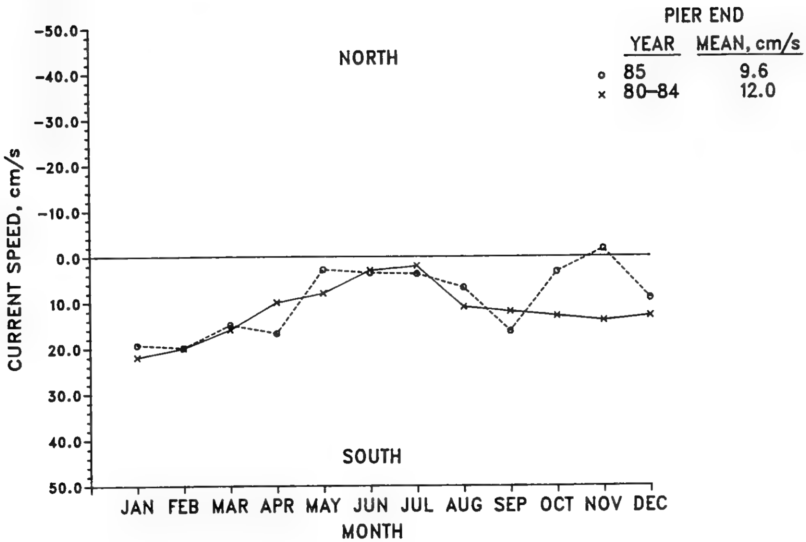


Figure 28. Comparison of surface currents at the pier end

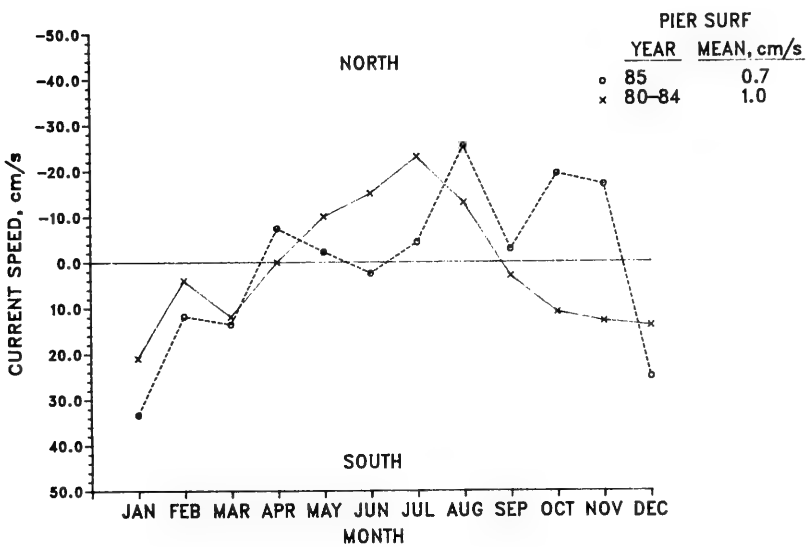


Figure 29. Comparison of surface currents at the midsurf

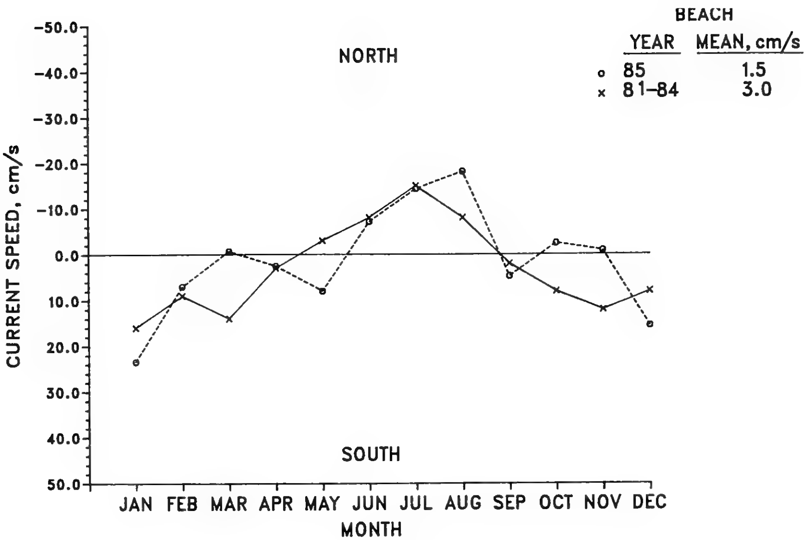


Figure 30. Comparison of surface currents at the beach

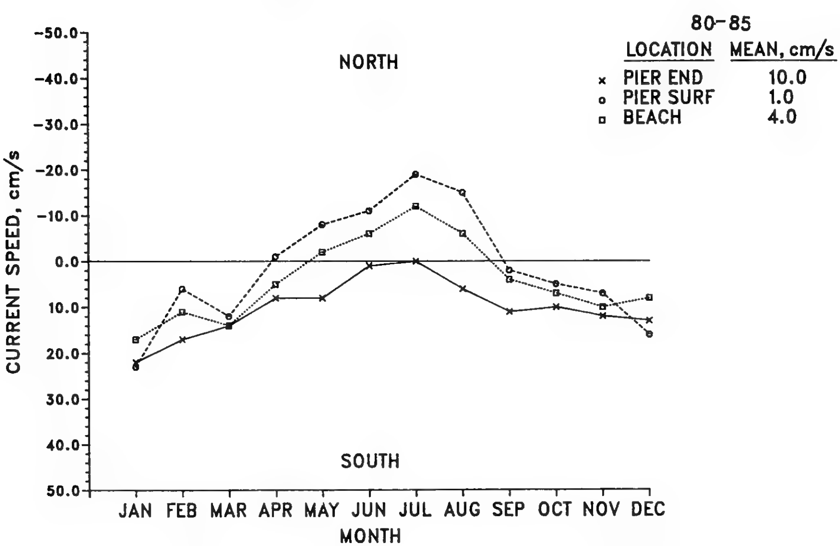


Figure 31. Mean surface currents, 1980-1985

PART V: TIDES AND WATER LEVELS

Measurement Instrument

64. 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, Oreg.) 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.

65. The tide 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.

66. 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.

67. 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 punch 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 form 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. The monthly or annual mean sea level (MSL) reported is the average of the hourly heights, while the mean tide level (MTL) is midway between mean high water (MHW) and mean low water (MLW) which are the averages of the daily high and low water levels, respectively, relative to NGVD.

Results

Present year

68. Tide height statistics for 1985 are presented in Table 9. Tides at the FRF are semidiurnal with both daily high and low tides approximately equal. The annual mean range was 96 cm while MSL was 11 cm above NGVD. The highest water level (136 cm) occurred on 14 December during moderate 10 m/sec winds from the north coincident with the monthly spring tide.

Present versus past years

69. Figure 32 shows the monthly tide statistics for 1985 and the previous years. Although MSL increased during the first 11 months of the year, the sharp fall in December kept it within 1 cm of the 12-cm average for previous years. Figure 33 compares the distribution of daily high and low water levels and hourly tide heights for the current year versus previous years. Except for the lack of extremely high or low water levels during 1985, the distributions are essentially equivalent.

All years

70. Based on the distribution of the tide heights for all years (Figure 34), the tide can be expected to exceed 110 cm for 0.27 percent of the time (24 hr). Likewise, the heights can be expected to be less than -80 cm for 0.22 percent of the time (19 hr).

Table 9

1985 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
Jan	54	8	9	-38	92	98	19	91	22
Feb	51	1	2	-49	100	100	7	-78	23
Mar	48	0	1	-47	95	70	24	-81	8
Apr	52	3	4	-45	97	97	7	-93	6
May	60	11	11	-38	98	126	3	-88	1
Jun	57	8	8	-41	98	100	28	-60	27
Jul	59	10	11	-38	97	111	1	-69	16
Aug	63	15	16	-32	95	101	1	-61	28
Sep	65	18	18	-30	95	103	13	-64	28
Oct	67	20	20	-28	95	106	31	-61	28
Nov	72	25	25	-22	94	124	2	-77	12
Dec	55	7	8	-41	96	136	14	-82	27,28
1985	59	10	11	-37	96	136	Dec	-93	Apr
1979-1984	61	11	12	-39	100	149	Nov 1981	-119	Mar 1981
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

* Measurements are in centimetres.

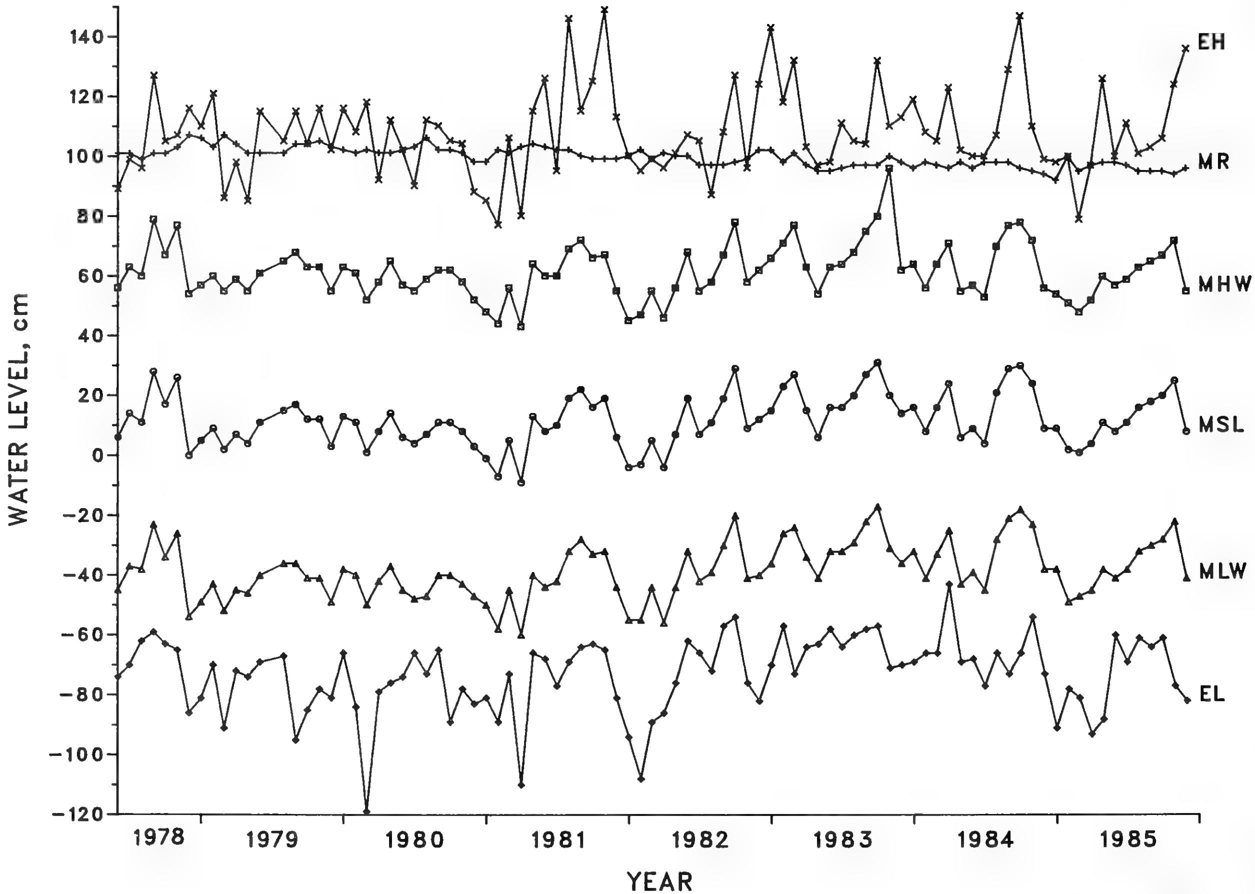


Figure 32. Monthly tide and water level statistics, 1978-1985

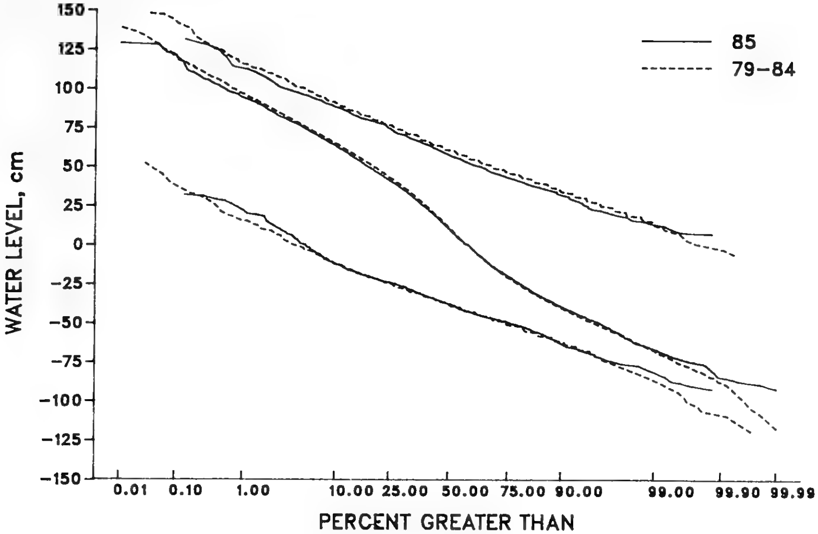


Figure 33. Comparison of hourly tide heights and daily high and low water level distributions, 1979-1984 versus 1985

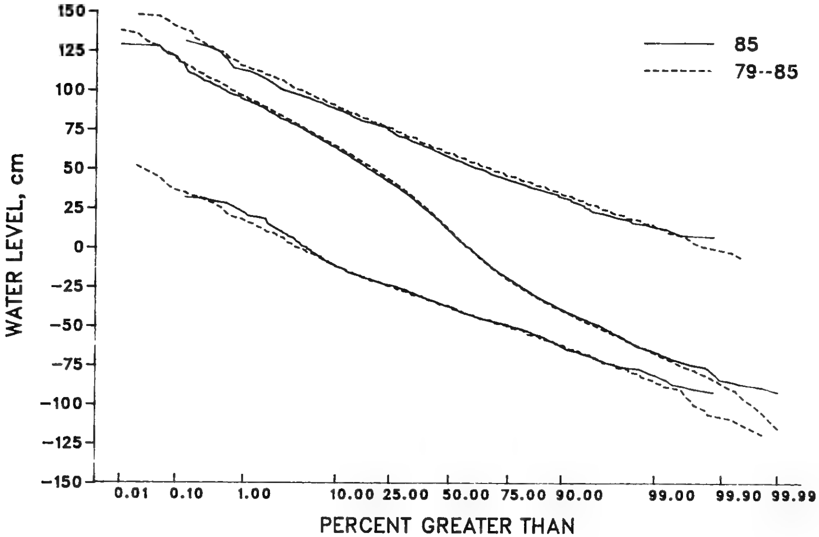


Figure 34. Distribution of hourly tide heights and daily high and low water levels, 1979-1985

PART VI: WATER CHARACTERISTICS

71. Results of daily measurements at the seaward end of the FRF pier, surface water temperature, visibility, and density are presented in this section. 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 piled up warm surface water along the shoreline, while offshore winds caused colder bottom water to circulate up resulting in low temperatures.

Temperature

Present year

72. Daily sea surface water temperatures (Figure 35) were measured with a NOS bucket and thermometer. Monthly mean temperatures (Table 10) varied with the air temperatures (see Table 2) with approximately a 1-month lag.

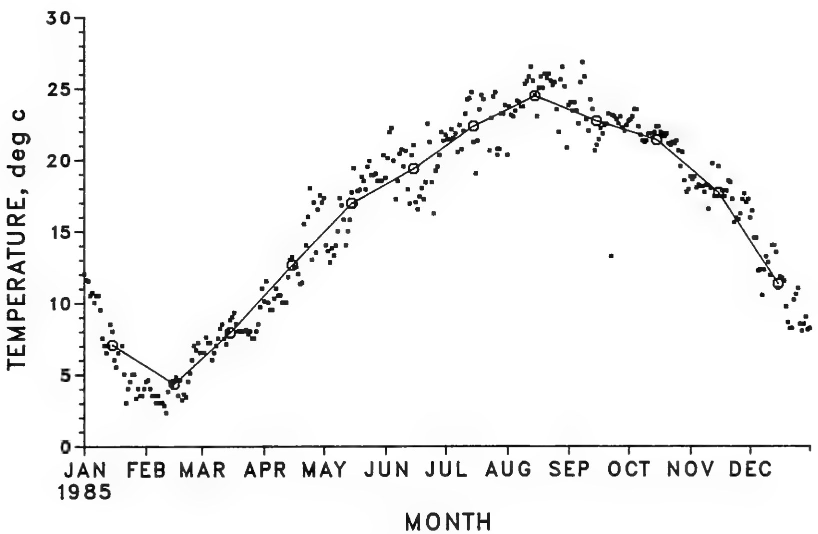


Figure 35. Daily sea surface water temperatures, 1985

Table 10

Mean Surface Water Characteristics

Month	Temperature, °C 1985	1980–1984	1980–1985	Visibility, m 1985	1980–1984	1980–1985	Density, g/cm^3 1985	1980–1984	1980–1985
Jan	7.0	5.0	5.4	1.4	1.2	1.2	1.0255	1.0238	1.0241
Feb	4.3	4.6	4.5	2.2	1.5	1.6	1.0248	1.0237	1.0239
Mar	7.9	6.3	6.6	3.5	1.4	1.7	1.0245	1.0233	1.0235
Apr	12.6	10.5	10.8	2.8	2.0	2.1	1.0241	1.0231	1.0233
May	17.0	14.8	15.1	2.6	2.4	2.4	1.0240	1.0230	1.0232
Jun	19.4	19.4	19.4	4.0	3.6	3.6	1.0235	1.0215	1.0219
Jul	22.3	21.5	21.4	3.3	3.7	3.6	1.0227	1.0219	1.0221
Aug	24.4	23.0	23.3	2.7	3.0	2.9	1.0216	1.0207	1.0208
Sep	22.7	22.6	22.5	2.6	1.9	2.0	1.0213	1.0213	1.0213
Oct	21.4	18.8	19.2	2.6	1.1	1.4	1.0208	1.0222	1.0219
Nov	17.7	14.0	14.6	1.2	0.9	0.9	1.0221	1.0235	1.0232
Dec	11.3	10.0	10.2	1.3	1.1	1.1	1.0232	1.0240	1.0238
Annual	15.7	14.2	14.4	2.5	2.0	2.1	1.0232	1.0227	1.0228

Present versus past years

73. In general, the temperatures were warmer during 1985 than in prior years. With the exception of February, June, and September, monthly means (see Figure 36) were consistently over 1 deg warmer resulting in an annual difference of 1.5° C.

All years

74. The distribution of surface water temperatures for all years combined is shown in Figure 37. Temperatures in excess of 25° C can be expected almost 5 percent of the time (or 18 days per year), while temperatures below 4° C can be expected 21 days per year.

Visibility

75. Visibility in coastal nearshore waters depends on the amount of salts, soluble organic material, detritus, living organisms, and inorganic particles in the water. These dissolved and suspended materials change the absorption and attenuation characteristics of the water which vary daily and yearly.

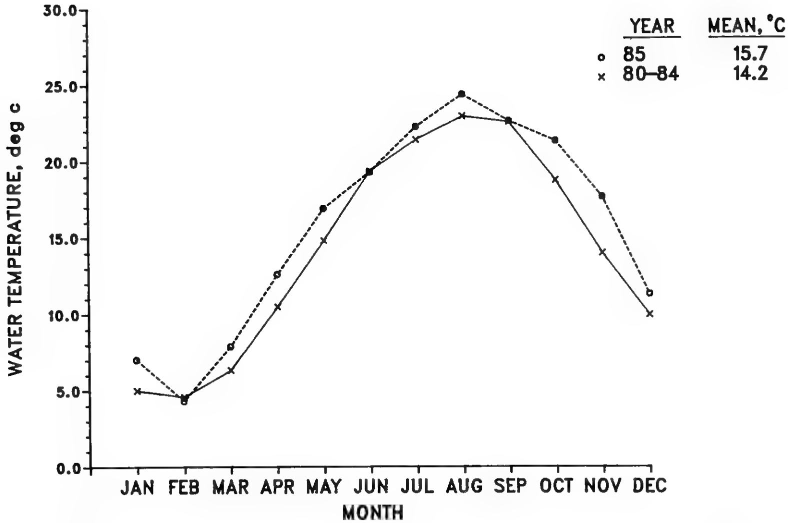


Figure 36. Comparison of mean surface water temperatures

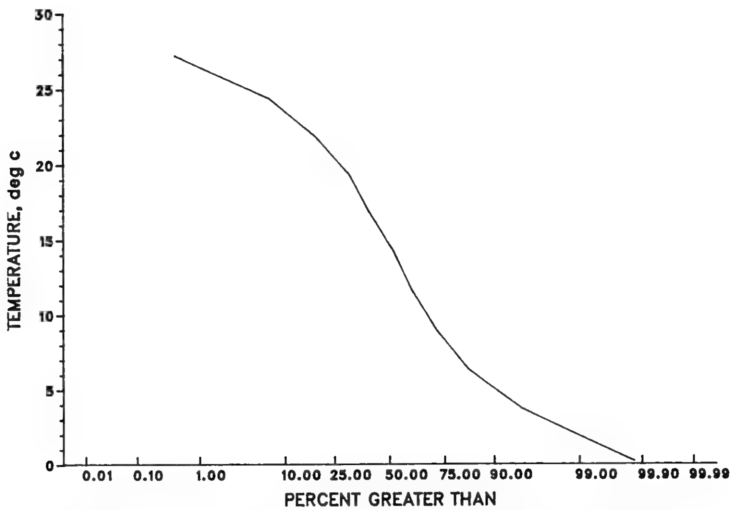


Figure 37. Distribution of surface water temperatures, 1980-1985

76. 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.

Present year

77. Figure 38 presents the surface visibility values for the year. Large variations were common, and visibility less than 1 m was expected in any month.

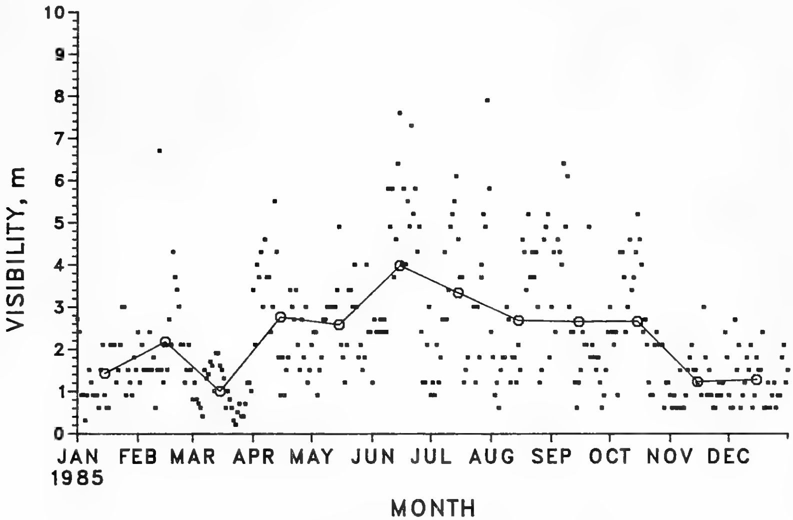


Figure 38. Daily sea surface water visibility, 1985

Present versus past years

78. In general, visibility was higher than in prior years. In particular, during October the monthly mean was 2.7 m, over 1.5 m higher than the average for past Octobers (Figure 39). The annual mean was 0.34 m above that during prior years (Table 10).

All years

79. Throughout the year the visibility averages over 2 m with an associated 1.1-m standard deviation (Table 10). During June and July the visibility was over 3.6 m (standard deviation over 1.5 m), while during November the average is under 1 m, and the deviation is only 0.5 m. Figure 40 shows the

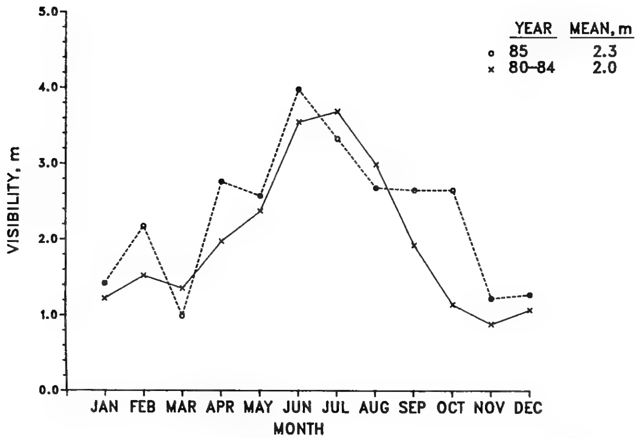


Figure 39. Comparison of mean surface water visibility

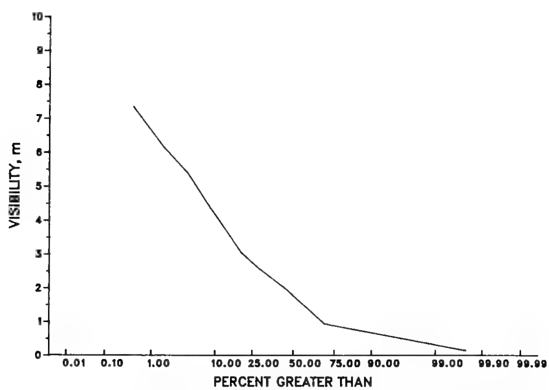


Figure 40. Distribution of surface water visibility, 1980-1985

distribution of visibility for all years combined. Approximately 5 percent of the time the visibility can be expected to exceed 5 m, while over 30 percent of the time it is less than 1 m.

Density

Present year

80. Daily surface density values presented in Figure 41 were measured with a hydrometer. Density, similar to temperature and visibility, shows considerable scatter.

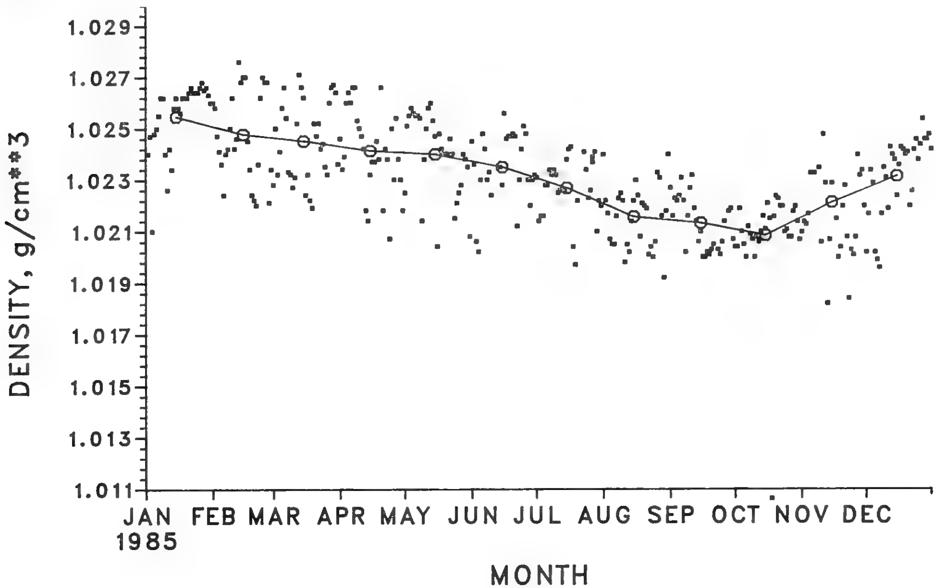


Figure 41. Daily sea surface water density, 1985

Present versus past years

81. In comparison to prior years, monthly mean density was higher before September and lower from October through December (Figure 42).

All years

82. The annual mean density was 1.0228 g/cm^3 with an associated standard deviation of 0.002 g/cm^3 (see Table 10). The distribution of density for all years combined is presented in Figure 43.

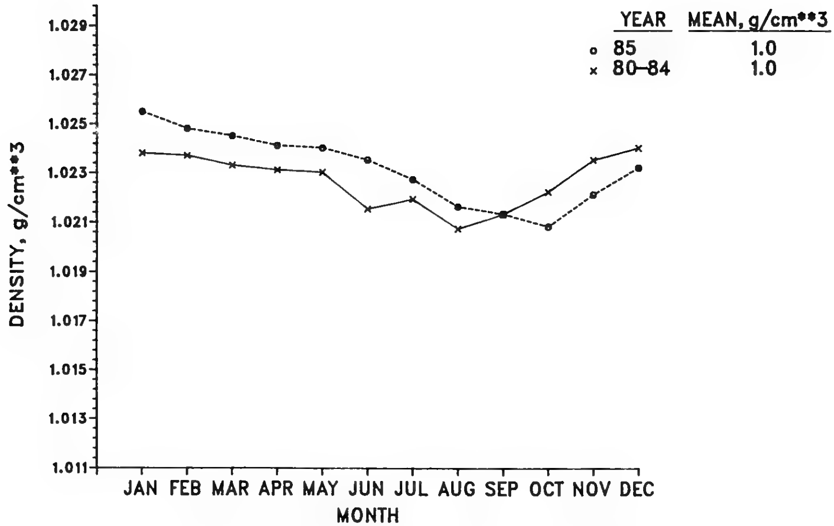


Figure 42. Comparison of mean sea surface water density

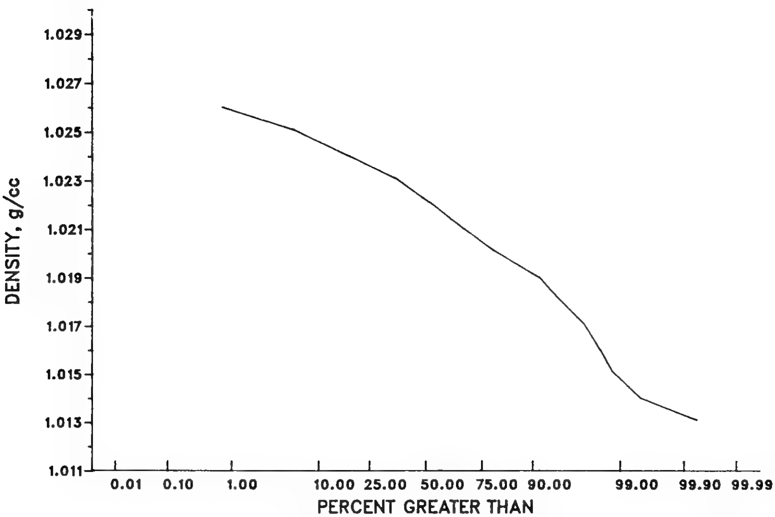


Figure 43. Distribution of surface water density, 1981-1985

PART VII: SURVEYS

83. 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.

84. 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 trough runs under much of the pier, ending in a scour hole at the pier end where depths are up to 3.0 m greater than the adjacent bottom.

85. The research pier introduces a perturbation in bathymetry (Figure 44) in the form of a permanent trough under the pier, apparently a result of the interaction of waves and currents with the pilings. The trough deepens under the seaward end of the pier and 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).

86. 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.

87. Profiles were obtained monthly and after storms by using the Coastal Research Amphibious Buggy (CRAB), a 10.7-m-tall amphibious tripod, and a Zeiss Elta-2 total station surveying system described by Birkemeier and Mason (1984). The profile locations are shown on each figure in Appendix A. The 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.

88. The pier, beach, nearshore, and offshore data were reduced to position (X,Y) and depth (Z) triplets relative to established monumentation and NGVD, respectively. The data were listed, and a display of the profiles (i.e. distance along the range versus elevation) were generated for inspection. After the data were edited, another set of routines was used to compute

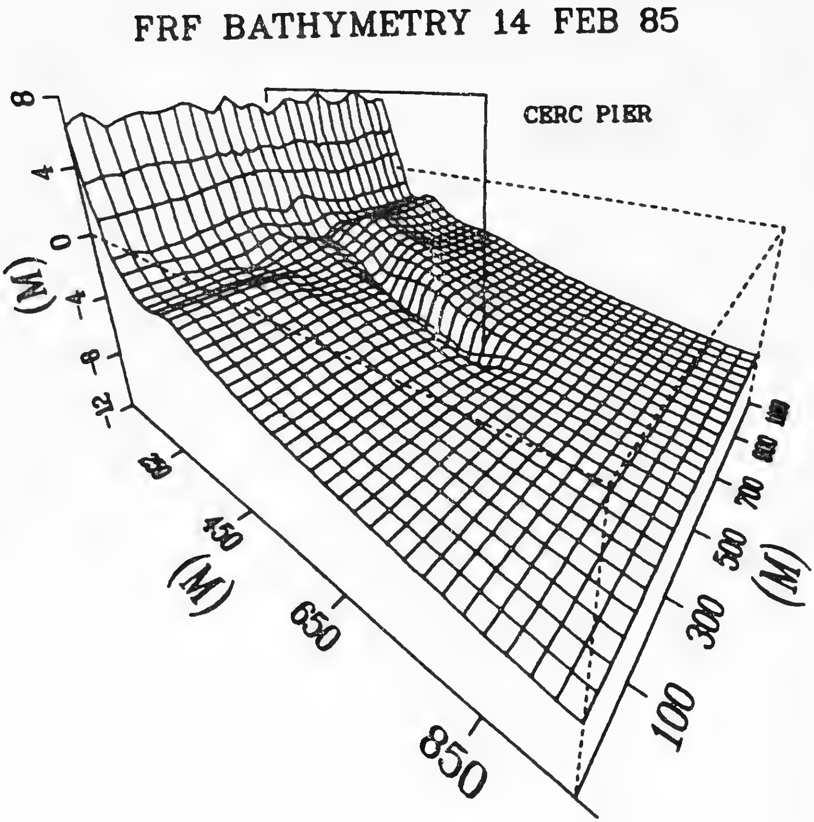


Figure 44. Permanent trough under the FRF pier (14 February 1985)

contour diagrams of the bottom topography and time sequences of bottom elevations at selected locations along the pier.

Bottom Elevation Histories

89. Useful for interpretation of the wave data from Gages 645 and 625 located under the pier, a history of the bottom elevations is presented at their respective pier stations, sta 7+80 (238 m) and sta 19+00 (579 m). Histories at intermediate locations, 323 and 433 m, are also included (Figure 45). Variations of elevation under the pier are caused by natural processes (such as profile changes caused by bar movement) as well as scour

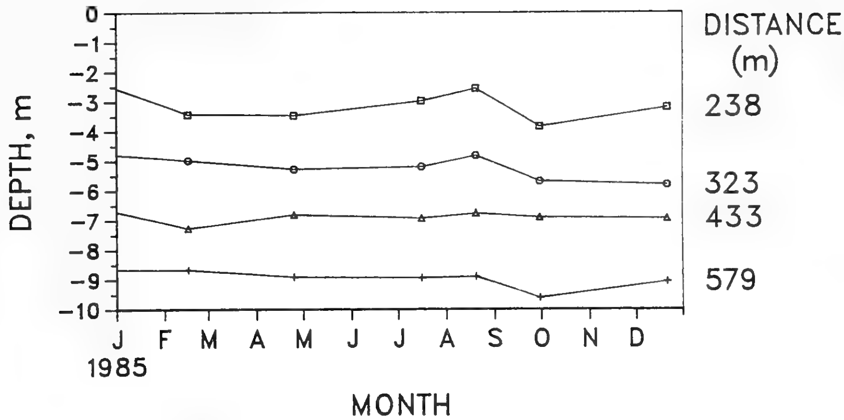


Figure 45. Time-history of bottom elevations at selected locations under the FRF pier

resulting from the interaction of the pier piles with waves and currents. Throughout the year the scour hole at the seaward end of the pier varied approximately 0.9 m, which is relatively low in comparison to some prior years when the variation was observed to exceed 2 m in a year.

90. After an initial deepening of 0.8 m in February, at the 238-m distance, sediment slowly accumulated until September when it was again near -2.4 m. Hurricane Gloria in September caused 1.4 m of erosion. During this time, 0.8 m of scour was measured at the seaward end of the pier.

Bathymetry

91. Contour diagrams created from the data obtained during the bathymetric surveys are presented in Appendix A; change diagrams showing major areas of erosion and accretion in the survey area are also presented. Profile lines surveyed are indicated on each contour diagram.

PART VIII: PHOTOGRAPHY

Aerial Photographs

92. Aerial photography was taken quarterly by 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. Table 11 summarizes the available aerial photographs. The flight lines covered are shown in Figure 46. Figure 47 is a sample of the imagery obtained (9 February 1985).

Table 11

Aerial Photography Inventory for 1985

Date	Flight Lines	Format
9 Feb	2 and 3	Color
15 May	2 and 3	Color
23 Aug	1 and 3	B/W
28 Sep	1	B/W
26 Oct	2 and 3	Color

Beach Photographs

93. Daily color slides of the beach were taken using a 35mm camera from the same location on the pier looking north and south (Figure 48). 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.

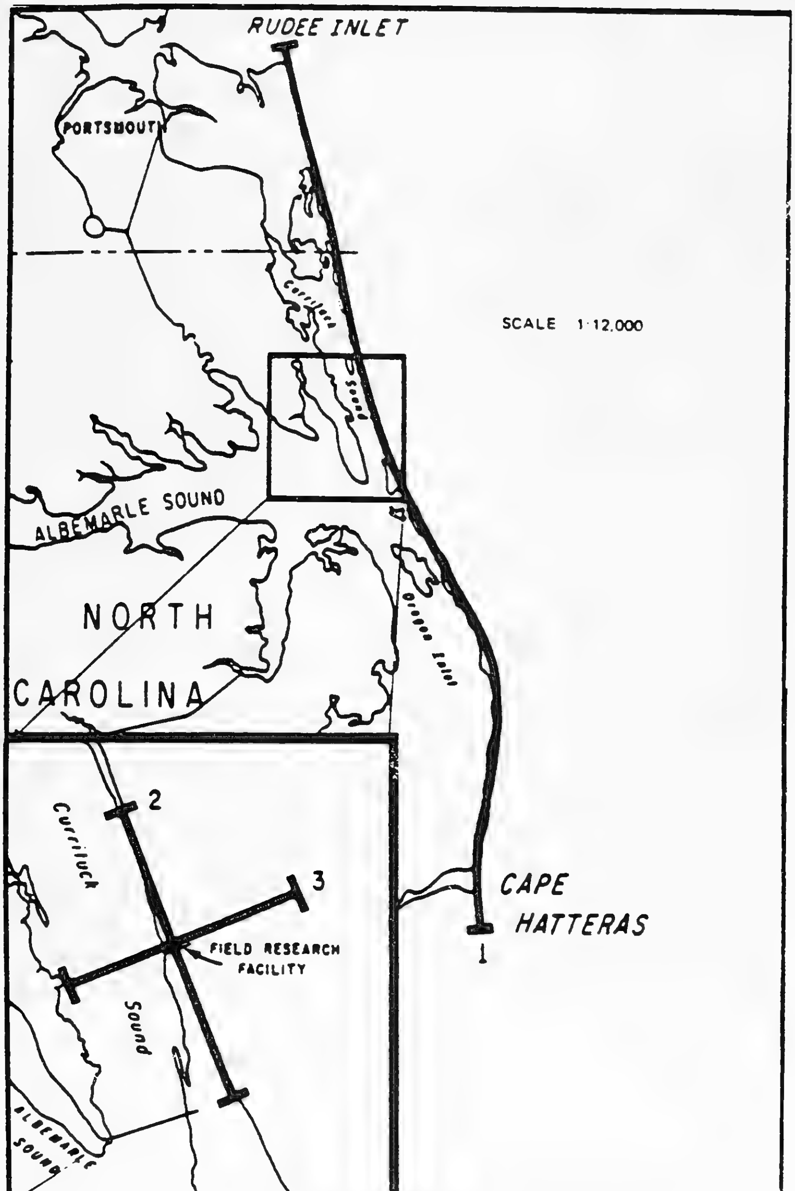


Figure 46. Aerial photography flight lines

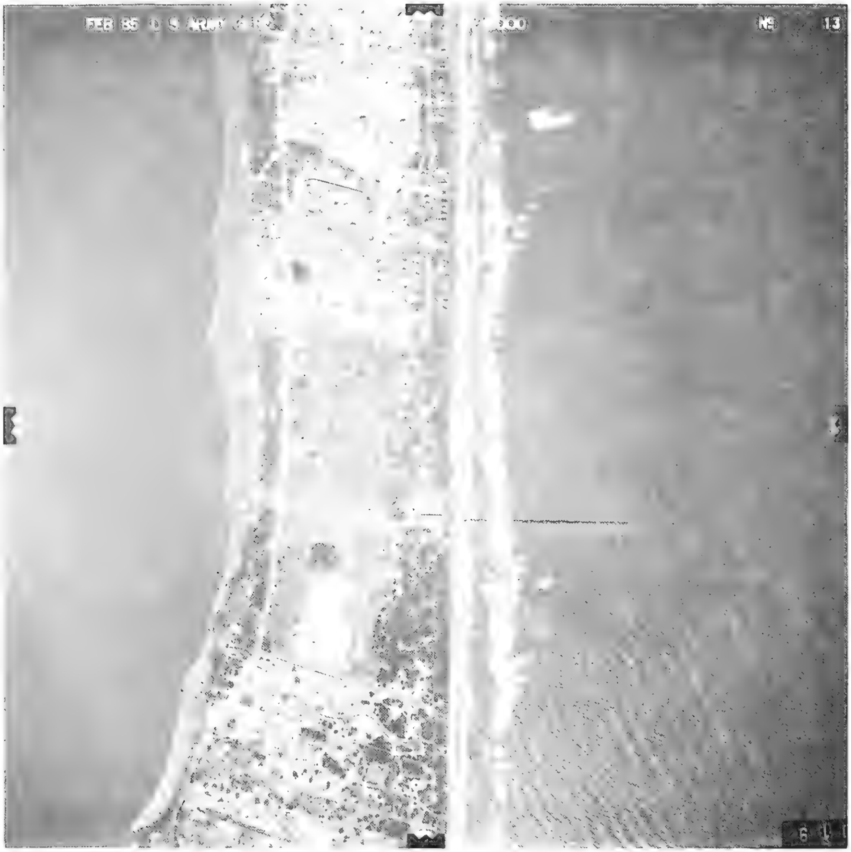


Figure 47. Sample aerial photograph taken 9 February 1985

a. North

b. South

Figure 48. Sample photographs of the FRF beach taken 17 August 1985

PART IX: STORMS

94. This section discusses the details of storms affecting the FRF. As used here, "storms" are defined as times when the wave height parameter H_{mo}, equals or exceeds 2.0 m at the seaward end of the FRF pier. Hourly data collected during such times are presented in Appendix B. Sample spectra from the Baylor gage at the seaward end of the pier are given in Appendix C (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 1984) and the Mariner's Weather Log series (US Department of Commerce 1984, 1985).

95. There were 13 storms during the year: only one for 3 consecutive days, five for 2 days, and seven for a single day. The number of storms during 1985 was below the annual average of 16 for prior years. A description of these storms is provided below.

- a. 3-4 January 1985. A cold front extending from New England to the Gulf of Mexico began moving eastward on 2 January and crossed the North Carolina coastline early on 3 January. A low pressure system developed over the Gulf of Mexico and traveled rapidly up the east coast behind the front (Figure B1).
- b. 12 February 1985. On 11 February, a frontal wave located slightly east of the Mississippi River produced two low pressure centers over Mobile, Ala. and St. Louis, Mo. By 12 February, the two lows had converged over central Virginia (Figure B2).
- c. 22-23 March 1985. A low pressure system originating over the Pacific Ocean was located east of northern Florida by 22 March. The storm moved rapidly up the east coast, passing the FRF on the 23rd before proceeding into the Atlantic (Figure B3).
- d. April 1985. On 14 April, a low pressure system formed 241 km east of Charleston, S.C., and began moving north along the coast. By 0700 EST on the 15th, the low was located directly over Cape Hatteras, N.C., and continued traveling northward throughout the day (Figure B4). On 29 April, a Canadian high produced strong winds at the FRF after pushing a cold front east past the FRF (Figure B5).
- e. 3 May 1985. Behind a cold front that moved past the FRF, strong winds from a Canadian high pressure system produced the high waves for a short time (Figure B6).
- f. 2 August 1985. A low pressure system off New England moved south to Cape Hatteras behind a cold front that was pushed offshore by a huge Canadian high pressure system (Figure B7).

g. 27 September 1985. On the morning of 27 September, Hurricane Gloria passed over the FRF. Although predicted to affect the area with 67+ m/sec winds, the actual path was slightly seaward of the coast, resulting in less than hurricane force winds at the FRF. In addition, Gloria's rapid passage coincided with low tide which minimized her impact. The storm approached Wilmington, N.C., from the southeast, veering to the north late on 26 September. Picking up speed, the storm's eye passed over Cape Hatteras, N.C., at approximately 0130 EST on 27 September with the western edge of the eye passing over the FRF at approximately 0230 EST. Continuing to gain speed, Gloria made landfall at Long Island, N.Y., early that afternoon. Changes to the beach and dune were minimized by the hurricane's rapid passage and the timing of maximum surge (see FRF Preliminary Data Summary for September 1985) near the astronomical low water (Figure B8).

h. October 1985. On 21-22 October, Genesis of an Atlantic low off Cape Hatteras and a relatively stationary high pressure system over New England produced strong winds for days at the FRF (Figure B9). On 31 October, high waves were first generated by strong easterly winds associated with a large high pressure system centered over New England on 1 November. By 2 November, the remnant of Hurricane Juan, which had struck Louisiana, spawned a new storm over Cape Hatteras, N.C. This storm rapidly moved offshore into the Atlantic (Figure B10).

i. 4-5 November 1985. This low pressure system developed on 3 November along a cold front in the Gulf of Mexico. The storm followed a northerly track over the Appalachian Mountains and was located over western North Carolina early on 4 November. Slowly continuing north, the storm was centered over Maryland on 5 November and off the New England coast by the 6th (Figure B11).

j. December 1985. On 1-2 December a weak low pressure system developed in Georgia on 30 November and quickly moved past the FRF on 1 December (Figure B12). Forming on a stationary front over Florida early on 6 December, this storm rapidly moved northeast into the Atlantic well off the North Carolina coast on the morning of the same day (Figure B13).

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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 meters 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. Hatched areas 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.

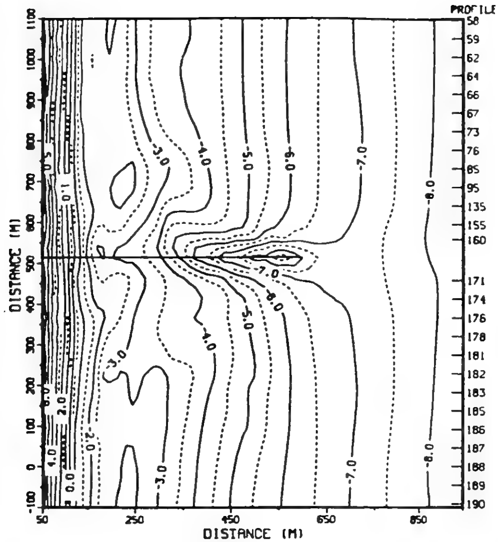

Figure A1. 14 February bathymetry

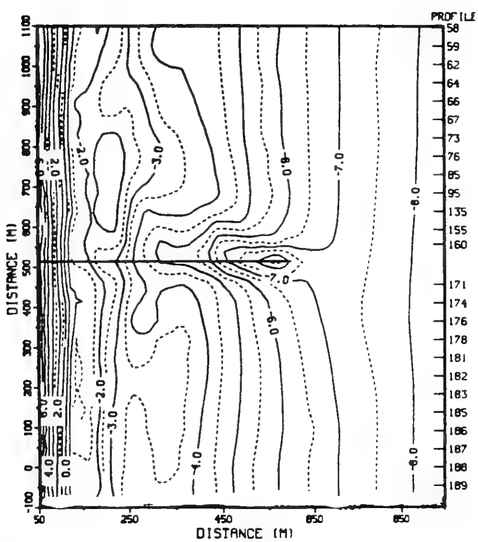

Figure A2. 23 April bathymetry

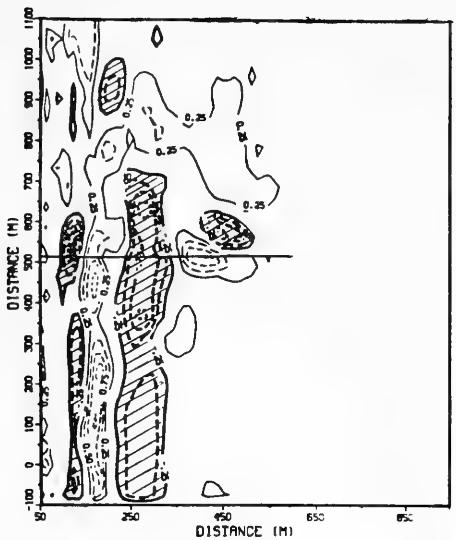

Figure A3. 14 February to 23 April
change diagram

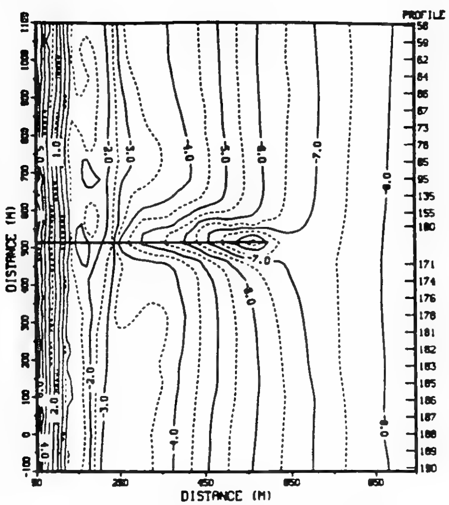

Figure A4. 15 July bathymetry

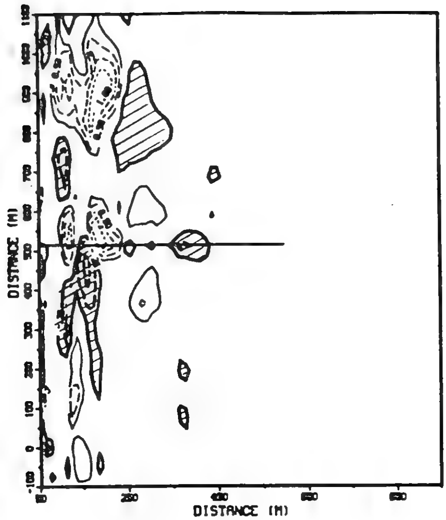

Figure A5. 23 April to 15 July
change diagram

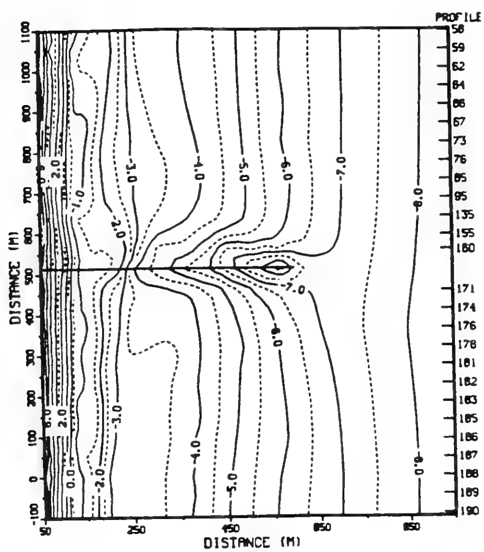

Figure A6. 21 August bathymetry

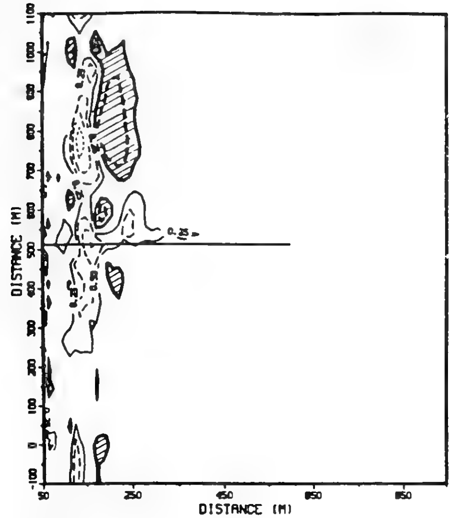

Figure A7. 15 July to 21 August
change diagram

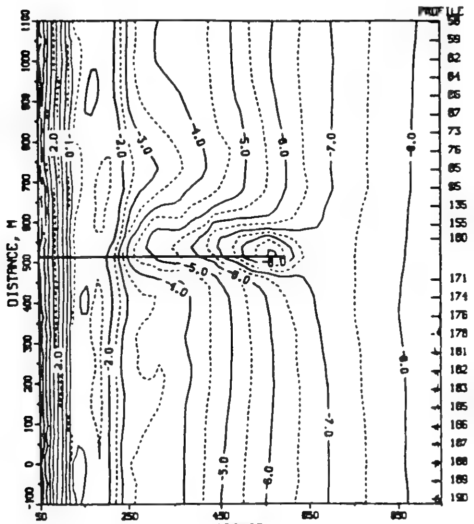

Figure A8. 28 September bathymetry

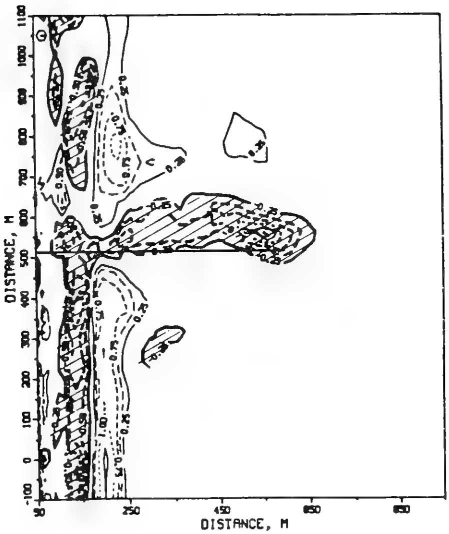

Figure A9. 21 August to 28 September change diagram

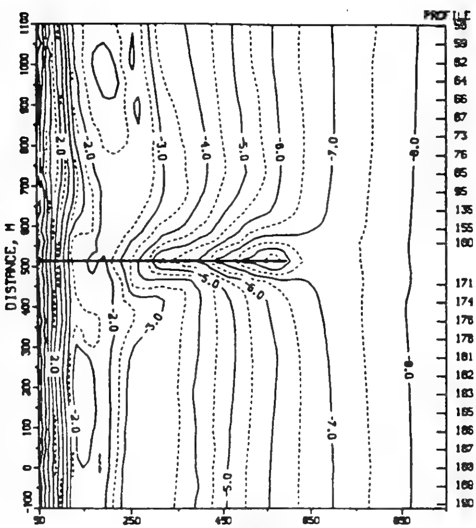

Figure A10. 19 December bathymetry

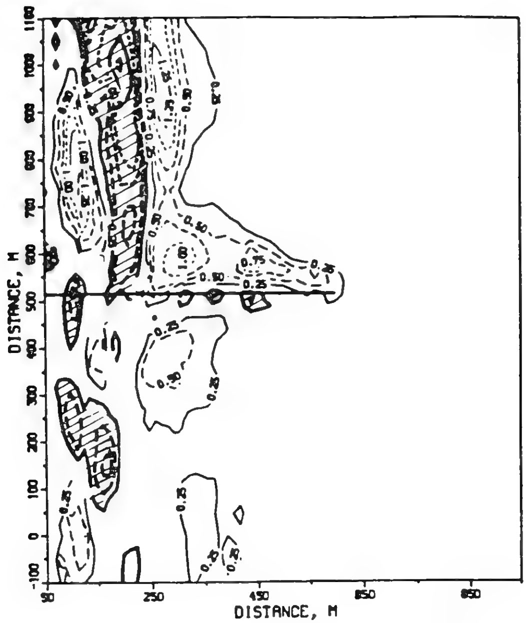

Figure A11. 28 September to 19 December change diagram

APPENDIX B: STORM DATA

1. Whenever the wave height H_{mo} exceeded 2 m at the seaward end of the Field Research Facility (FRF) pier, data were collected hourly. Available data for the 13 storms (reported in Part IX of the main text) are presented in Figures B1-B13.

Atmospheric Pressure

2. Reported in millibars, atmospheric pressure data are useful for documenting the type of storm, the passage of fronts, and the intensity of the atmospheric pressure system.

Wind Speed and Direction

3. Local winds are generally responsible for the wave conditions at the FRF. Wind speed is reported in metres per second.

4. Wind direction, referenced to true (star) north, indicates the directions from which the winds are blowing, e.g., winds blowing from west to east are referred to as having an angle of 270 deg.

Wave Direction

5. Referenced to true (star) north, the wave direction measurements are taken at the seaward end of the FRF pier. The pier axis (considered perpendicular to the beach at the FRF) is oriented 70 deg east of true north; consequently, wave angles greater than 70 deg imply the waves were coming from the south side of the pier.

Gage 625 H_{mo}

6. The wave height, measured in metres, was that obtained from the staff wave gage located at the seaward end of the FRF pier.

Wave Period

7. The peak spectral wave period in seconds from Gage 625 is reported.

Water Levels

8. Reported in centimetres and referenced to the National Geodetic Vertical Datum, the water levels were obtained from the National Ocean Services primary tide sta 865-1370 at the seaward end of the FRF pier.

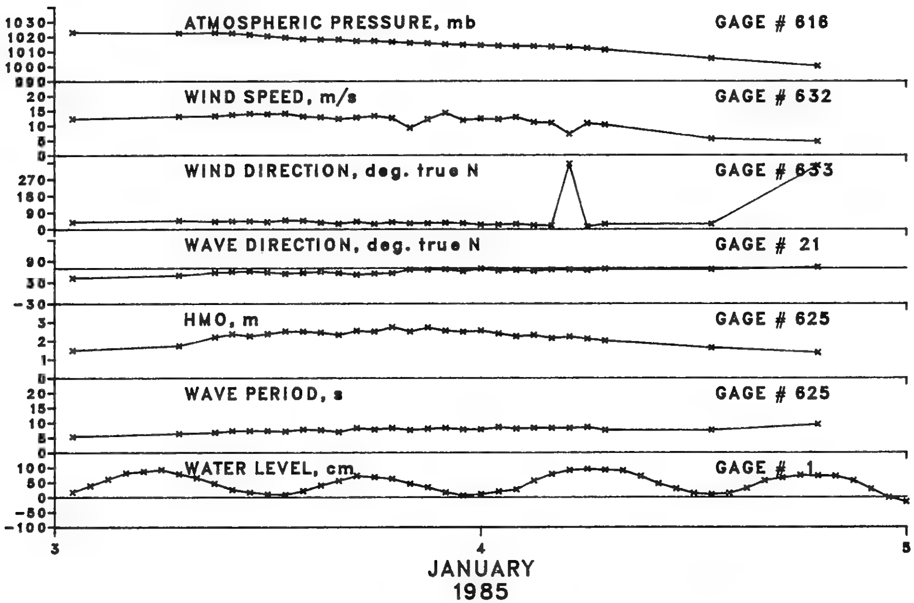

Figure B1. Storm data for 3-4 January 1985

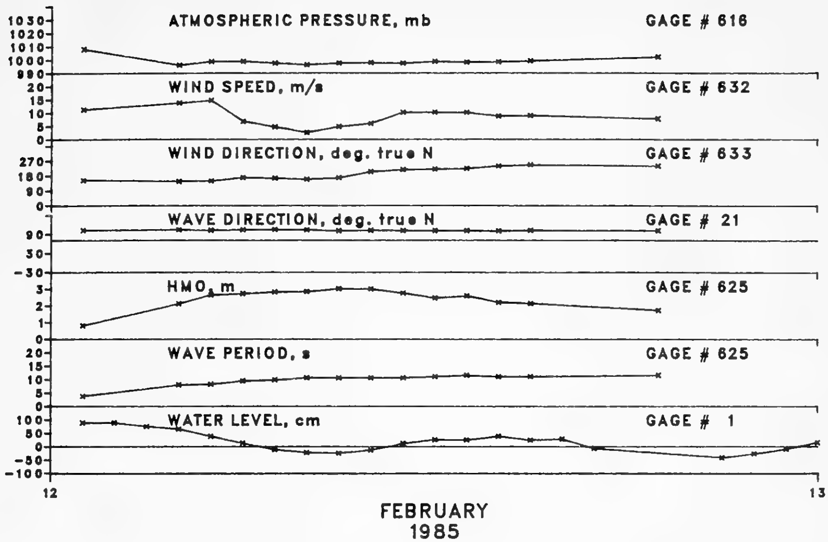

Figure B2. Storm data for 12 February 1985

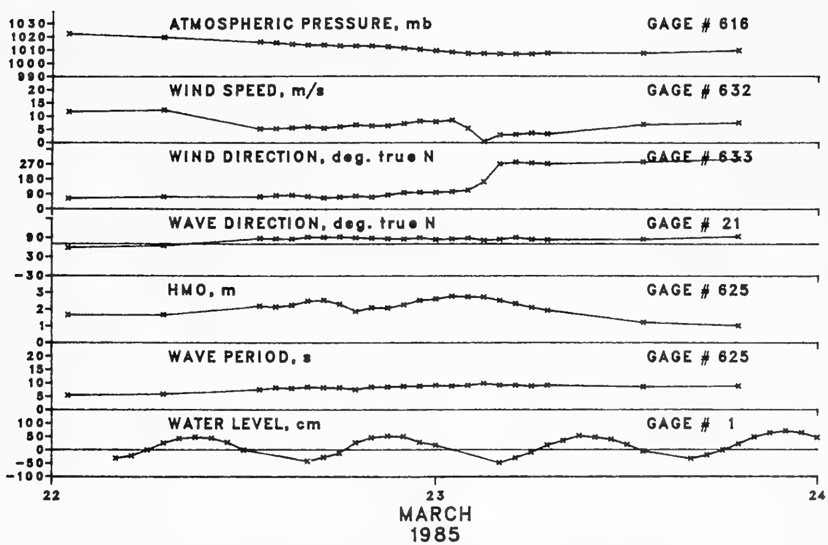

Figure B3. Storm data for 22-23 March 1985

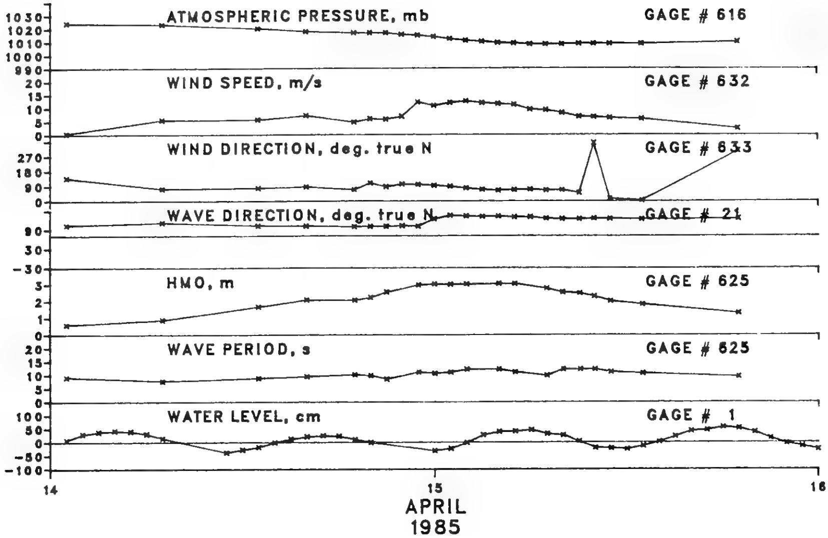

Figure B4. Storm data for 14-15 April 1985

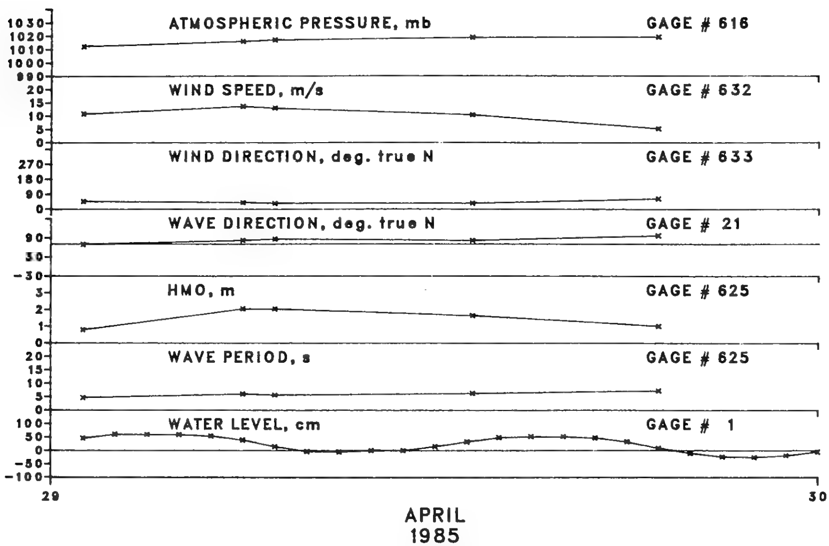

Figure B5. Storm data for 29 April 1985

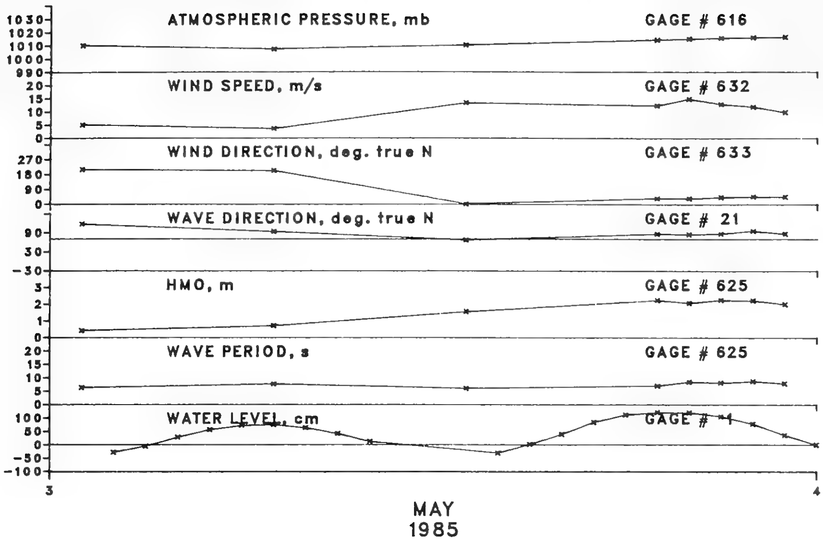

Figure B6. Storm data for 3 May 1985

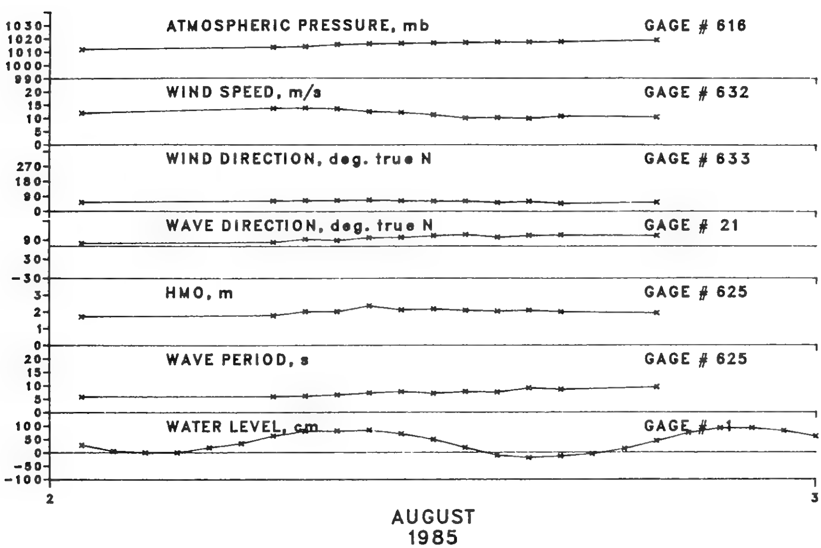

Figure B7. Storm data for 2 August 1985

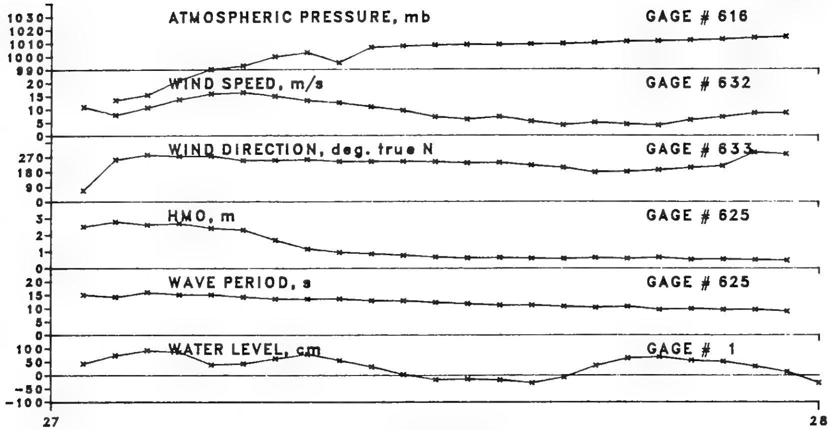

Figure B8. Storm data for 27 September 1985

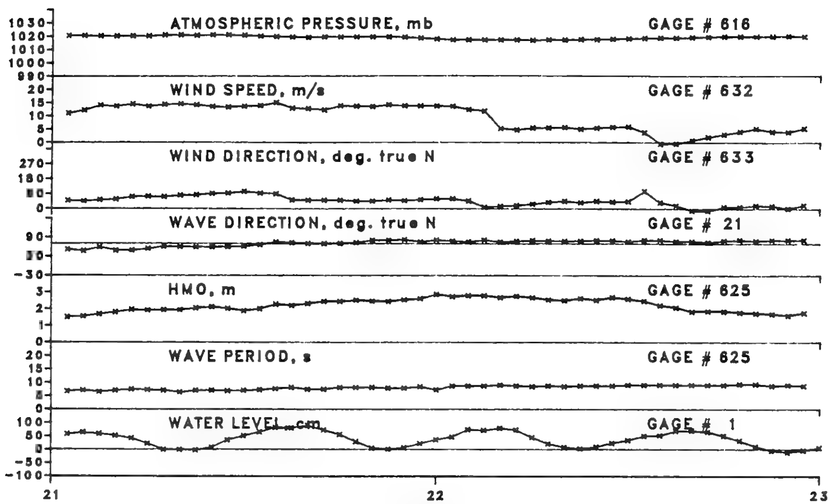

Figure B9. Storm data for 21-22 October 1985

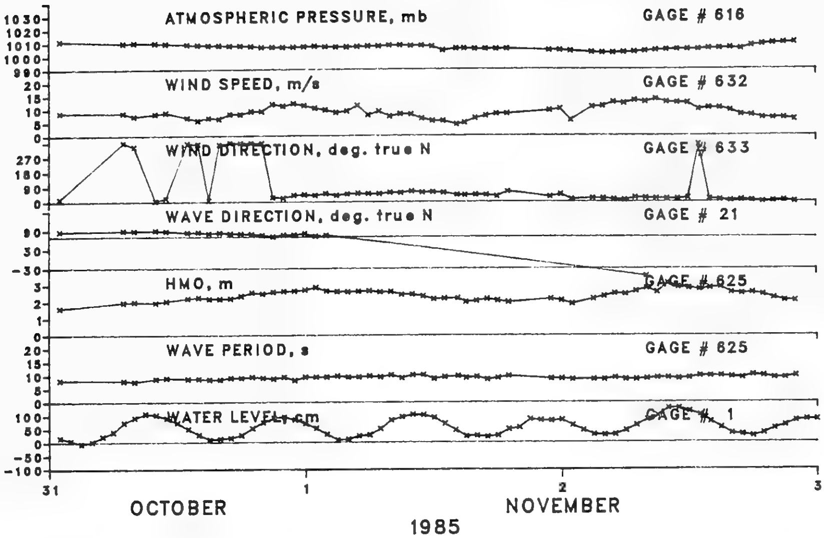

Figure B10. Storm data for 31 October through 2 November 1985

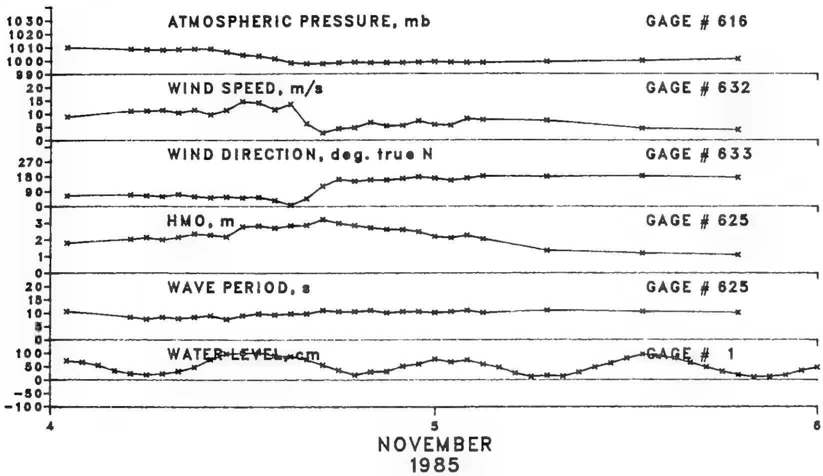

Figure B11. Storm data for 4-5 November 1985

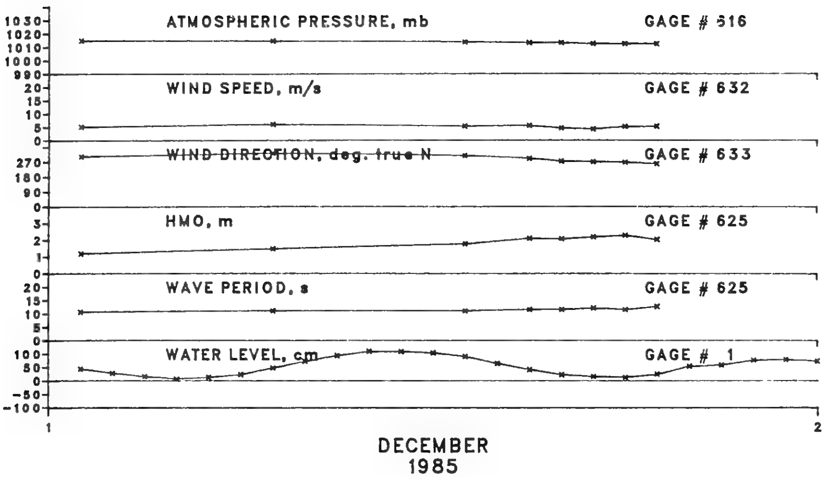

Figure B12. Storm data for 1 December 1985

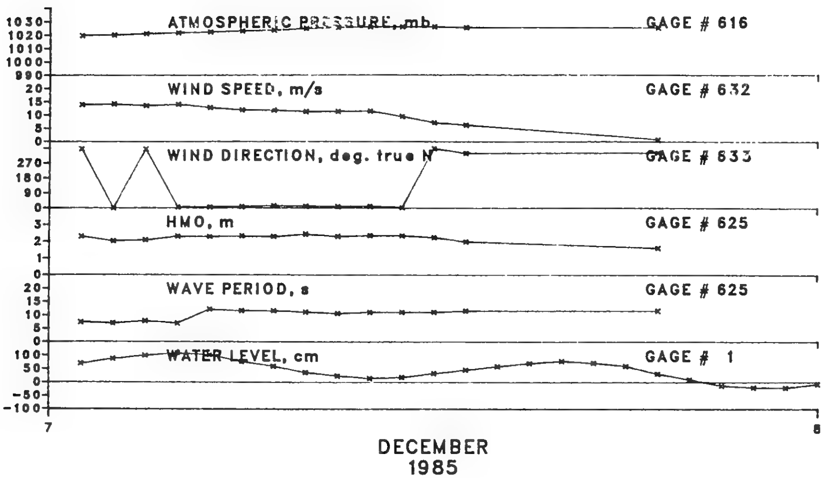

Figure B13. Storm data for 7 December 1985