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WEST OF SHETLAND DATA BUOY PROJECT - REPORT ON THE FOULA SPECTRAL WAVE DATA JANUARY 1977 to NOVEMBER 1978

NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE OF OCEANOGRAPHIC SCIENCES

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them as effectively as possible, while being aware of their limitations".

Apart from the question of period parameters, the data from the Marex buoy are discussed only briefly, and operational aspects of the project are similarly treated only briefly. A fuller technical and operational history of the project is contained in the series of reports (Refs. 21 - 26) by the Institute of Oceanographic Sciences. The data (both meteorological and oceanographic) from the Marex data buoy are fully presented in reports by Marex Ltd. (Refs. 13 - 20). The Marex reports do not include spectral data, and for this and other reasons the present report should be regarded as complementary to those referred to above.

2.1 Availability of the data

It is stressed that the data are confidential to UKOOA Oceanographic Committee participants. The content and format of the data files are described in Appendix C. The primary data products are files of the spectral data, and these can be supplied to authorised users on magnetic tape. Index files which contain an abbreviated version of the main files (they do not contain the spectral estimates) are also available.

Requests concerning these data, including requests for copies of the files should be addressed to:

Marine Information and Advisory Service,
Institute of Oceanographic Sciences,
Brook Road,
Wormley,
Godalming,
Surrey, GU8 5UB. Telephone : Wormley 4141

Recipients of this report will receive bound copies of the index files - these too are subject to confidentiality restrictions.

3. THE DATA COLLECTION SYSTEM

The data collection system consisted of the following components:

(i) The Marex data buoy, moored in the vicinity of 60°10'N, 2°55'W in a depth of about 160 m.

(ii) The back-up Waverider moored within ½ mile of the data buoy.

(iii) The receiving and recording station on the island of Foula.

(A map showing the deployment position is included as Fig. 3, and a brief description of each sub-system now follows).

3.1 The Marex data buoy

This measured a number of meteorological variables as well as the waves.

The waves were measured by sensing the heave of the buoy with a Datawell heave sensor over a 1024 second sample period which ended on each hour. The output of the heave sensor was digitised at a rate of 2Hz, and an on-board microprocessor was used to calculate a statistical summary of the resulting 2048 point digital wave record. The statistical summary, which consisted of four parameters, was recorded internally and the digital wave record was then discarded.

In addition, the buoy was equipped with a Waverider modulator and transmitter, and the output of the heave sensor was monitored and transmitted continuously by this system in the standard Datawell AM/FM format.

3.2 The back-up Waverider

A Datawell Waverider buoy was moored in the vicinity of the Marex data buoy. This transmitted information about its own heave continuously in the standard Datawell AM/FM format.

3.3 The receiving station on Foula

The receiving station was set up on South Ness on the southern tip of the island of Foula. It consisted of a Datawell Warep receiver, a digital magnetic tape data logger, an analogue (frequency modulated) magnetic tape data logger and associated power supplies and switching circuitry.

The receiver was capable of receiving data from either the data buoy or the Waverider, but only one channel could be received and recorded at any one time. The digital system was used as the primary data recording method, with the analogue system providing a back-up. The data reported herein were derived from the digital system.

4. DATA SAMPLING SCHEME

The wave information was received and recorded on a regular sample basis. A wave observation consisting of 2088 values of the heave measured at $\frac{1}{2}$ second intervals was recorded every 3 hours. The intermediate synoptic hour sequence was chosen (ie 00, 03, 06, 09 .... hours GMT), and the samples were timed to end on the hour to facilitate comparison with the results recorded on the buoy.

5. SOURCES OF THE DATA

During the early part of the project the receiver was switched to the data buoy channel as routine, but over one period when the buoy went adrift the Waverider signal was used. Later in the project, however, as reception conditions deteriorated it was decided to switch to the Waverider channel as routine. This was because it had been found that the Waverider signal was usually substantially stronger than that from the data buoy.

The data sources over various parts of the project are shown in Table 5.

5.1 Data return

Table 5.1 shows the monthly data return throughout the project, as a percentage.

The average monthly data return for 1977 was 66%, and for 1978 it was 32%. November was badly represented in both years. This is unfortunate, as November is often a month of high wave activity.

Figures 10.1.1 et seq. show time series plots of Hs. It will be noticed that from early 1978 the data started to become intermittent, progressively more of the day time and evening records being lost. This was due to radio interference caused mainly by the increasing use of the Citizen's Band, both in the immediately surrounding sea areas and more distantly.

6. TAPE TRANSLATION, QUALITY CONTROL AND DATA EDITING

Magnetic tapes from the logger were returned to the laboratory each month where they were translated and processed by a computer program designed to check for timing or tape formatting errors. In addition the program subjected each (1044 second) wave record to a number of tests to check for the presence of characteristics not normally associated with wave records of this type. The tests were based on the assumptions that a wave record should display certain simple properties consistent with the behaviour of a random process with an approximately normal distribution, and that the water surface should conform to certain well established steepness criteria.

The tests were for the following fault conditions:

(1) Test for lost data points due to format errors or telemetry failure (the latter indicated by a special signal derived from the receiver).

(2) Check for the occurrence of ten consecutive points of equal value

(instrument failure test).

(3) Check for an interval between successive up-crossings of the record mean level of greater than twenty five seconds (wandering mean test).

(4) Comparison of the difference in magnitude between successive data points with a test value based on maximum probable water slope.

(5) Comparison of absolute magnitude of data points with a test value equal to four times the record standard deviation.

Actions taken by the program were:

Single lost data points, up to a maximum number of 36 per record, indentified by the first test were replaced by the average value of the two neighbouring points. Two or more adjacent lost points caused the record to be rejected.

Failure of either test (2) or (3) caused the record to be rejected.

Faulty points, up to a maximum number of five, identified by test (4), were replaced by the average value of the two neighbouring points. Two or more adjacent faulty points caused the record to be rejected.

No alterations to the record were made on failures of test (5). Six failures, up to three of which could be consecutive, were allowed before rejecting the record.

It was found that the proportion of the records which failed the checking procedure was much higher in the case of the Foula data than for other IOS Waverider sites. This was almost entirely due to the very long range (about 50 km) to the deployment site which resulted in the data telemetry being susceptible to adjacent channel interference. This manifested itself as more or less isolated bursts of erroneous data which were often of short duration. In order to recover as much information as possible, it was decided to remove these 'spikes' from the wave records whenever it seemed reasonable to do so.

A special editing program was written which plotted each (rejected) wave record on a suitable visual display unit, and allowed the operator to specify and remove the offending data values. As each erroneous section was removed, the data values on either side of the gap were closed together to form a continuous wave record. The length of the edited wave record thus fell short of the normal length by the total number of erroneous values discarded. The operator ensured that the resulting wave record contained no spurious discontinuities in the wave elevation.

The automatic checking program generated a group of 10 error flags giving information about failures of the various tests. However, these were not carried through to the edited data file and so this information is no longer available. Instead, a new group of error flags was generated at the spectral analysis stage. If the edited wave record was less than 2000 points long it was not analysed further and a 'no data' observation was generated. If it had more than 1999 but less than 2088 points the record was considered usable, but since it had been edited one of the ten flags was set to 1, thus KFLAG(1)=1, KFLAG(2-10)=0.

A record with 2088 points had not been subjected to manual editing and all flags were set to zero, ie KFLAG(1-10)=0.

7. CALCULATION OF THE SPECTRA

A Fast Fourier Transform was performed on 2000 points of the series and the spectrum was formed by averaging over ten adjacent harmonics to give a final resolution of 0.0100 Hz. The spectral estimates were adjusted to compensate for the frequency response of the heave sensor. There were a number of other frequency-dependent effects for which no corrections have been applied. These are:

(i) The heave response of the Waverider hull

(ii) The heave response of the Marex data buoy

(iii) The response of the receiver and the interface circuitry at the shore station.

These are discussed in Appendix A. In addition the heave sensor is subject to an internal resonance at a period of about 40 seconds. Under certain circumstances this can give rise to contamination of the spectral estimates by low frequency noise. The Foula spectra appear to have low noise levels at both high and low frequencies, but nevertheless it is recommended that the first two spectral estimates in the output files be treated with caution. In this way it should be possible to avoid the accidental inclusion of low frequency noise in subsequent analyses. The lowest frequency for which a valid estimate of spectral density exists should therefore be regarded as 0.0455 Hz.

7.1 Random sampling errors

Since we are seeking to determine the statistical properties of a random process by taking measurements over a finite period of time, the results we derive will be subject to random sampling errors. In the case of the estimates of spectral density these are quite large.

Useful treatments of random sampling errors are given in books by Bendat and Piersol, 1971; and Jenkins and Watts, 1968; here we will just quote two of the main results.

The smoothed estimates referred to above which were formed by averaging 10 of the elementary Fourier components can be shown to have a Chi-squared distribution with 20 degrees of freedom. The 95% confidence interval for each estimate in this case is 0.58 to 2.1. That is, 19 times out of 20 on average the true value of the spectral density can be expected to be somewhere between 58% and 210% of the measured value. The corresponding figures for 80% confidence are 70% and 160%.

The normalised standard error of each estimate, ϵ_r, is given by

$$\epsilon_r = \sqrt{1/n}$$

where n is the number of components which are averaged. In this case with $n = 10$,

$$\epsilon_r = 32\%$$

It should be remembered that we have been considering the statistics of an individual spectral estimate. The statistics of integrated properties of the spectrum, such as the moments, are more favourable and the sampling errors correspondingly smaller.

8. QUALITY OF THE SPECTRA

Reference has already been made to the time history checking procedure and to the flag which was generated at the processing stage to indicate whether or not the wave record was edited. In addition three quantities were calculated during the analysis as an aid to quality assessment. These were:

SNRL - This is a signal to noise ratio designed to detect the presence of unusually large amounts of energy at low frequencies.

$$SNRL = 10 \times \log_{10} \left\{ \frac{3}{10} \sum_{i=9}^{18} S_i \Big/ \sum_{i=3}^{5} S_i \right\}$$

SNRH - Designed to detect the presence of high frequency noise. Defined by

$$SNRH = 10 \times \log_{10} \left\{ \sum_{i=9}^{18} S_i \Big/ \sum_{i=68}^{77} S_i \right\}$$

where S_i is the i^{th} spectral estimate above zero frequency.

The frequencies and periods corresponding to the quoted values of i are shown below

i	f_i	T_i
3	.0255	39.2
5	.0455	22.0
9	.0855	11.7
18	.1755	5.7
68	.6755	1.5
77	.7655	1.3

SCADJ1 - Taper adjustment factor. This is the square root of the factor which has been applied to the spectrum to ensure that the zeroth moment of the spectrum is equal to the variance of the time-history. Defined by

$$SCADJ1 = \sqrt{\frac{\sigma^2}{m_0}}$$

(σ^2 = variance of the record)

When no taper is applied (as in the present case) and the spectrum is valid, SCADJ1 = 1.00.

9. INTEGRATED PROPERTIES OF THE SPECTRA

The spectral moments were calculated using the equation

$$m_n = \Delta f \sum_{i=5}^{68} f_i^n S_i$$

where Δf = 0.01 Hz, and the significance of i, f_i and S_i is explained in section 8. The 7 moments, n = -2 to n = +4 were calculated.

The significant wave height Hs was defined by

$$H_s = 4\sqrt{m_0}$$

and the zero crossing period Tz by

$$T_z = \sqrt{\frac{m_0}{m_2}}$$

The spectral peakedness parameter (Goda, 1970) was calculated as

$$Q_p = \frac{2\Delta f}{m_0^2} \sum_{i=5}^{68} f_i S_i^2$$

9.1 Period parameters

One important advantage of spectral methods of structural analysis is that one is freed from the necessity of choosing a 'characteristic' or 'average' wave period with its attendant uncertainties. Often a full linear analysis is not possible or is inappropriate, but even in these cases the availability of a range of period parameters which are clearly related to the shape of the spectrum is an advantage.

A number of period parameters can be calculated from the spectral moments which have been estimated from the Foula data.

The sequence

$$\underset{n \neq 0}{T(0,n)} = \left(\frac{m_0}{m_n}\right)^{1/n}$$

is widely used.

In particular

$T(0,2) = T_z$ the zero crossing period
$T(0,1) = \overline{T}$ or TB the mean period
$T(0,-1) = T_e$ the energy period *
$T(0,-2) = T_i$ the integral period

It is therefore of considerable interest to see how these period parameters interrelate, and Figs. 9.1.1, 9.1.2., 9.1.3 show correlations between three pairs of them for the three months January, May 1977 and August 1978.

It is also important to relate the periods derived from the spectra with those calculated on the Marex data buoy. This question is treated in Appendix B.

* Strictly, the 'power period', since the power or energy flux, P, (in deep water) is given by

$$P = H_s^2 T_e / 2.04 \text{ kW}$$ per metre of wave front.

10. PRESENTATIONS OF WAVE HEIGHT STATISTICS

10.1 Time series of Hs: (Figures 10.1.1 to 10.1.8)

Each vertical line on the plots represents a valid record, and the height of the line is proportional to the value of Hs for that record. Data for each month are plotted separately, but no plot is shown for June 1978 as no valid records were obtained during that month.

These plots are included because, over the period of measurement, they give a good overall impression both of the variation of Hs and of the distribution of the valid data.

10.2 Percentage exceedance of Hs and Hmax(3hrs)

The numbers of records with Hs exceeding particular values were counted and converted to percentages of the total number of valid records. This process was repeated using Hmax(3hrs), and these two sets of results are plotted in Figure 10.2.

The maximum values of Hs and Hmax(3hrs) are 10.12 m and 19.00 m respectively.

10.3 Histogram of Hs

Figure 10.3 is a histogram of Hs, with occurrences shown as percentages of the total number of valid records. The most frequently occurring values of Hs lie between 1.0 and 1.5 metres; they account for about 17% of the total.

11. PRESENTATIONS OF WAVE PERIOD STATISTICS

11.1 Histograms of T_z, $\overline{T}$ and T_e (Figures 11.1.1, 11.1.2. and 11.1.3)

These three distributions have similar shapes; the most obvious differences between them are the ranges of the parameters, and their modal values.

It may be seen from Figure 11.1.1 that all spectrally derived values of Tz lie between 2 and 11.5 seconds; the maximum frequency is about 16% for Tz between 6.0 and 6.5 seconds. In Figure 11.1.2 the range of $\overline{T}$ is 2.5 to 13 seconds, and 6.5 to 7.0 seconds is the modal class (about 14½%); and in Figure 11.1.3 the range of Te is 4.0 to 15.5 seconds and the modal class is 7.5 - 8 seconds (about 12½%).

12. PRESENTATIONS OF SPECTRAL PEAKEDNESS STATISTICS (Figure 12.)

Values of Goda's spectral peakedness parameter, Q_p, are mostly between 1 and 5 although two isolated values occur between 5.75 and 6.25. The most frequently occurring values are between 1.75 and 2.25.

13. PRESENTATIONS OF JOINT DISTRIBUTIONS OF WAVE HEIGHT AND WAVE PERIOD

Scatter diagrams of Hs with Tz, $\overline{T}$ and Te (Figures 13.1, 13.2 and 13.3). These figures show thenumbers of wave records having particular combinations of values of Hs and period parameters (Tz, $\overline{T}$ or Te). The numbers of wave records are presented as parts per thousand (based on a total number of valid observations of 2761), except for those which would be less than one part per thousand; these are shown instead as single occurrences and are distinguished by being underlined.

Comparisons between the three figures are similar to those observed between Figures 11.1.1, 11.1.2 and 11.1.3. A line of limiting steepness of 1 : 14 has been drawn on Figure 13.1 upon or below which all but three observations lie.

REFERENCES

1. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - WINTER 1973/74 Fitzroy Station - Recorded for W.S.O.S.G. Marex Report No. 77 - June 1974.
2. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - SPRING 1974 Fitzroy Station - Recorded for W.S.O.S.G. Marex Report No. 94 - August 1974.
3. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - SUMMER 1974 Fitzroy Station - Recorded for W.S.O.S.G. Marex Report No. 111 - December 1974.
4. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - AUTUMN 1974 Fitzroy Station - Recorded for W.S.O.S.G. Marex Report No. 158 April 1975.
5. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - DECEMBER 1973-NOVEMBER 1974. Fitzroy Station - Recorded for W.S.O.S.G. Marex Report No. 172 - July 1975.
6. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - WINTER 1974/75 Fitzroy Station - Recorded for W.S.O.S.G. Marex Report No. 184 - September 1975.
7. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - SPRING 1975 Fitzroy Station - Recorded for W.S.O.S.G. Marex Report No. 187 - October 1975.
8. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - SUMMER 1975 Fitzroy Station - Recorded for U.K.O.O.A. Marex Report No. 200 - December 1975.
9. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - AUTUMN 1975 Fitzroy Station - Recorded for U.K.O.O.A. Marex Report No. 214 - March 1976.
10. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - DECEMBER 1974-NOVEMBER 1975. Fitzroy Station - Recorded for W.S.O.S.G. Marex Report No. 233 - May 1976.
11. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - WINTER 1975/76 Fitzroy Station - Recorded for U.K.O.O.A. Marex Report No. 239 - August 1976.
12. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - SPRING 1976 Fitzroy Station - Recorded for U.K.O.O.A. Marex Report No. 252 - October 1976.

13. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - WINTER 1976/77 Foula Data Buoy - Recorded for U.K.O.O.A. Marex Report No. 330 - December 1977.

14. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - SPRING 1977 Foula Data Buoy - Recorded for U.K.O.O.A. Marex Report No. 338 - February 1978.

15. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - SUMMER/AUTUMN 1977 Foula Data Buoy - Recorded for U.K.O.O.A. Marex Report No. 349 - April 1978.

16. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - DECMBER 1976-NOVEMBER 1977. Foula Data Buoy - Recorded for U.K.O.O.A. Marex Report No. 357 - June 1978.

17. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - WINTER 1977/1978 Foula Data Buoy - Recorded for U.K.O.O.A. Marex Report No. 371 - October 1978.

18. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - SPRING 1978 Foula Data Buoy - Recorded for U.K.O.O.A. Marex Report No. 385 - January 1979.

19. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - SUMMER AND AUTUMN 1978 Foula Data Buoy - Recorded for U.K.O.O.A. Marex Report No. 402 - May 1979.

20. ENVIRONMENTAL CONDITIONS WEST OF THE SHETLANDS - DECEMBER 1977-DECEMBER 1978. Foula Data Buoy - Recorded for U.K.O.O.A. Marex Report No. 411 - June 1979.

West of Shetland Data Buoy Project:

21. First Report - IOS Internal document No. 11 April 1977.

22. Second Report - IOS Internal document No. 16 October 1977.

23. Third Report - IOS Internal document No. 24 February 1978.

24. Fourth Report - IOS Internal document No. 36 August 1978.

25. Fifth Report - IOS Internal document No. 47 April 1979.

26. Technical and Operational difficulties experienced on the UKOOA Foula Project - IOS Internal document No. 30 (1978)

BENDAT J.S. and PIERSOL, A.G. Random data: Analysis and Measurement, New York, Interscience, 1971.

GODA, Y. (1970). Numerical Experiments on Wave Statistics with Spectral Simulation. Port and Harbour Research Institute. Report 9, No. 3.

JENKINS, G.M. and WATTS, D.G. Spectral Analysis and its Applications, San Fransisco, Holden Day 1968.

TABLE 5

Source of Data

Start		End		Source
Time	Date	Time	Date	
1500	14 January 1977	1500	10 March 1977	MDB (02)
1800	10 March 1977	0900	13 April 1977	W/R(6679)
1200	13 April 1977	1500	25 Nov. 1977	MDB (03)
1800	25 Nov. 1977	1500	3 May 1978	W/R(6679)
1800	3 May 1978	1800	12 July 1978	MDB (02)
2100	12 July 1978	2100	30 Nov. 1978	W/R(6679)

MDB = Marex Data Buoy (serial number)
W/R = Waverider (serial number)

TABLE 5.1

Monthly Data Return

Month	1977	1978
January	48	46
February	93	5
March	80	30
April	78	69
May	86	42
June	63	No data
July	53	38
August	55	69
September	69	58
October	74	18
November	7	10
December	90	No data

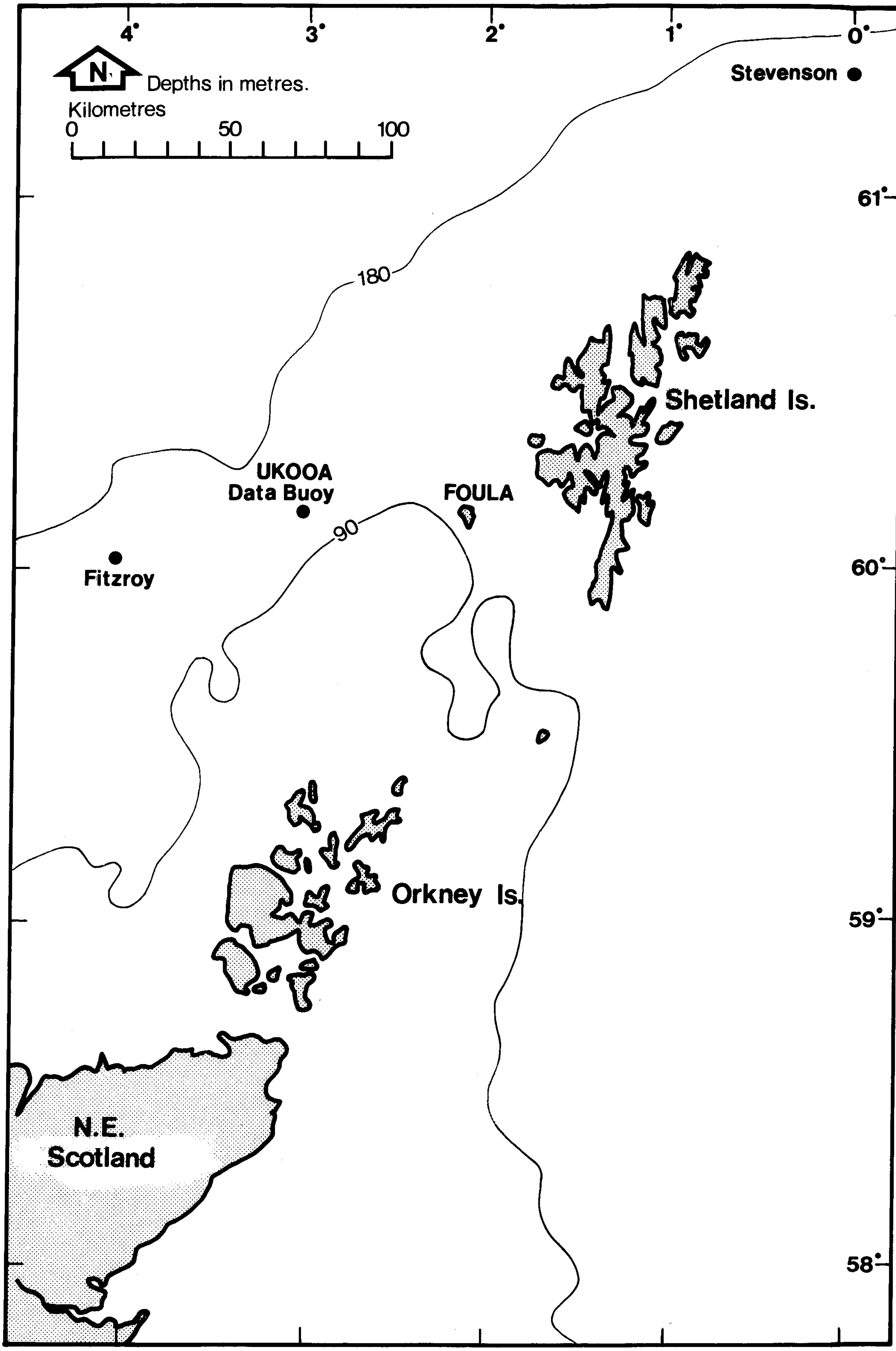
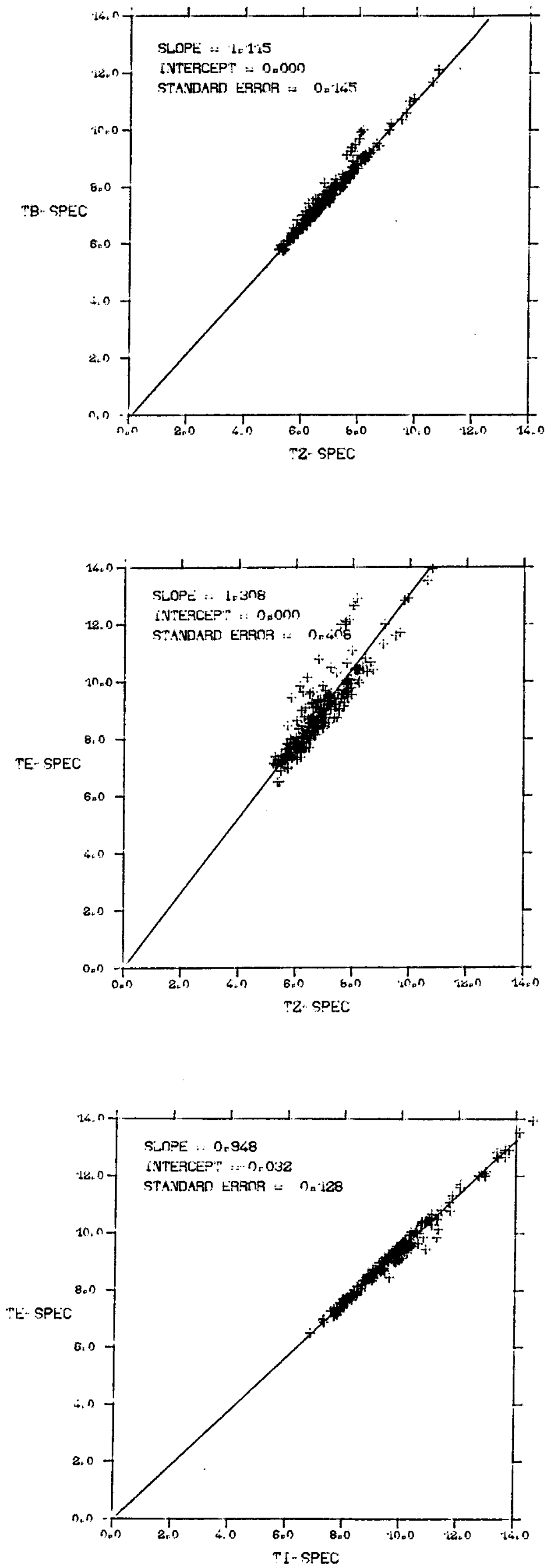
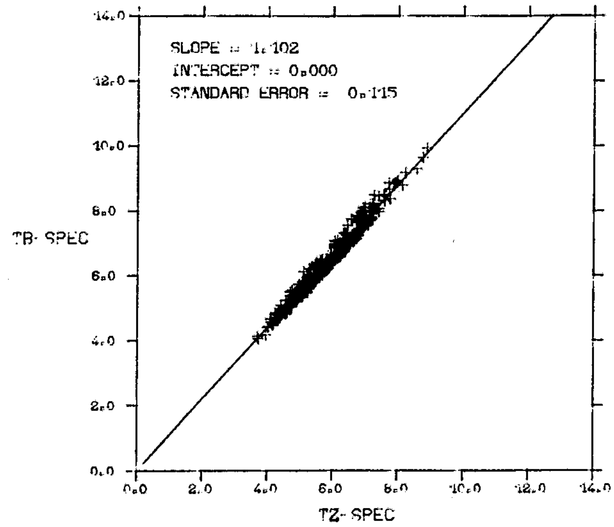

4°
3°
2°
1°
0°
N
Depths in metres.
Kilometres
0
50
100
Stevenson
61°
180
Shetland Is.
UKOOA
Data Buoy
FOULA
90
Fitzroy
60°
Orkney Is.
59°
N.E.
Scotland
58°

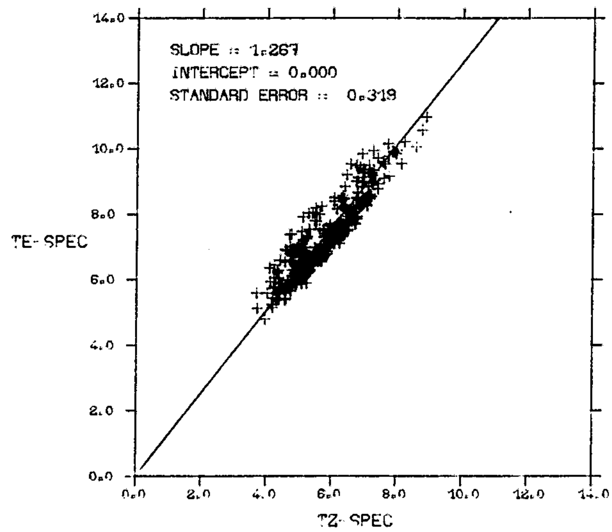
Fig. 3

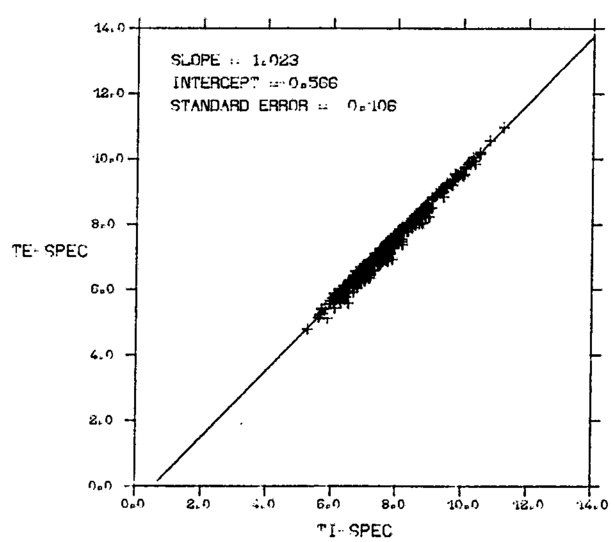


Comparisons of spectral period parameters
for January 1977.

Fig. 9·1·1

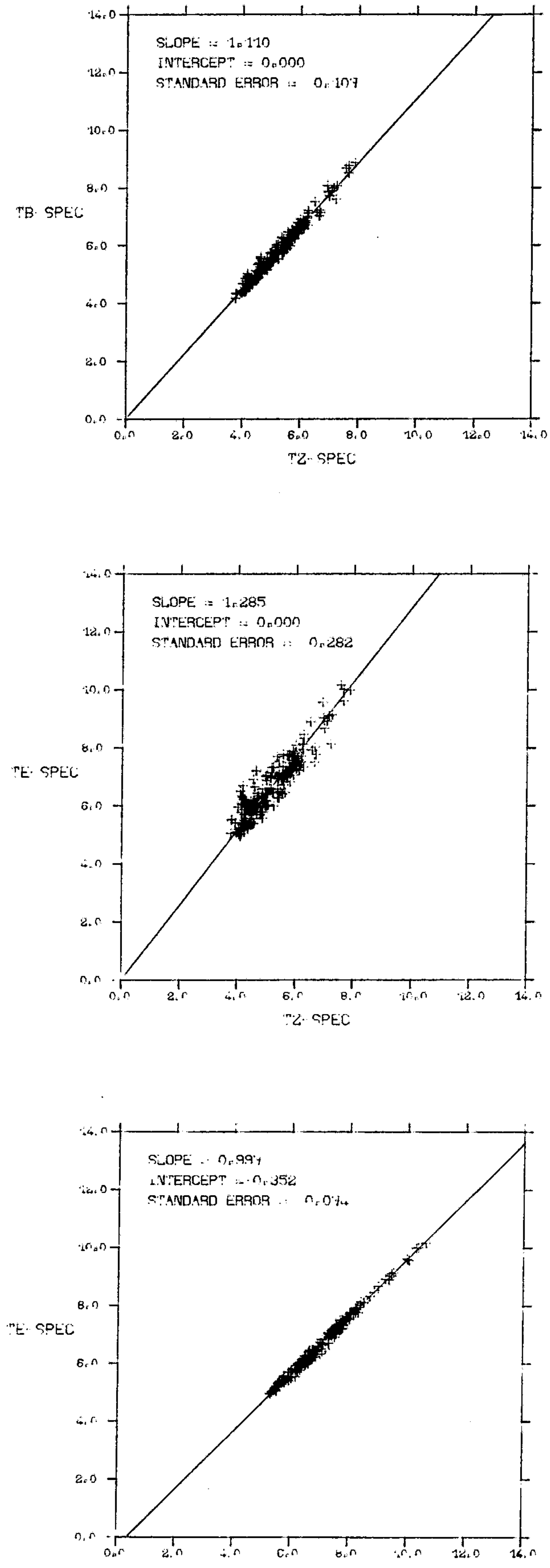






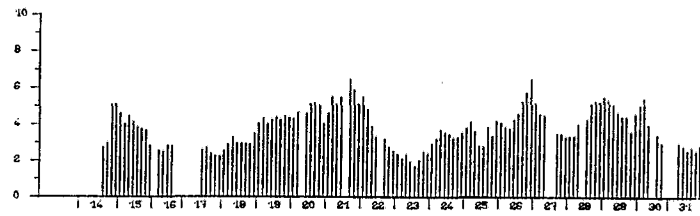
Comparisons of spectral period parameters for May 1977.

Fig. 9·1·2



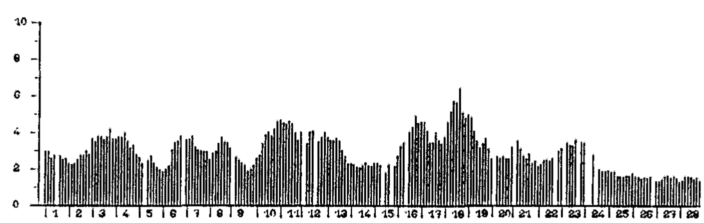
Comparisons of spectral period parameters for August 1978.

Fig. 9·1·3



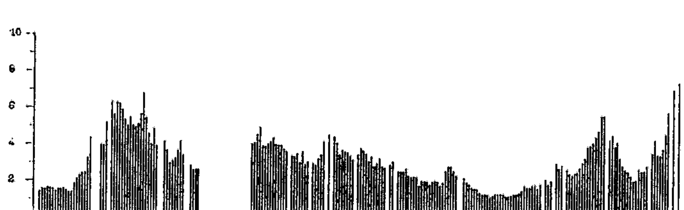
WAVE DATA RECEIVED FOULA JANUARY 1977

YEAR NO. 77 MONTH NO. 1 HS(METRES)



WAVE DATA RECEIVED FOULA FEBRUARY 1977

YEAR NO. 77 MONTH NO. 2 HS(METRES)

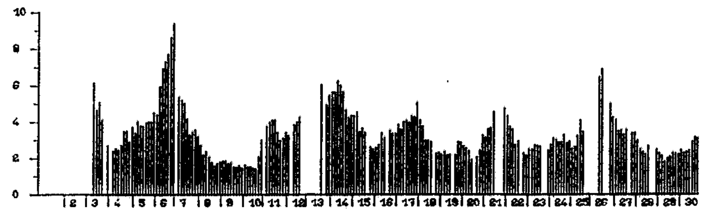


WAVE DATA RECEIVED FOULA.MARCH 1977

YEAR NO. 77 MONTH NO. 3 HS(METRES)

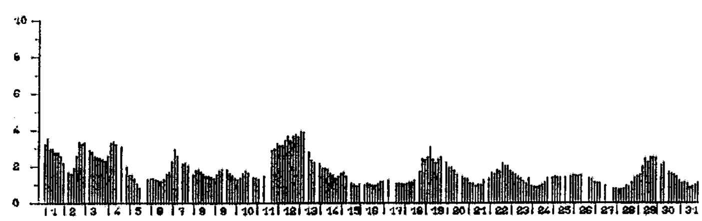
Time series of Hs

Fig. 10·1·1



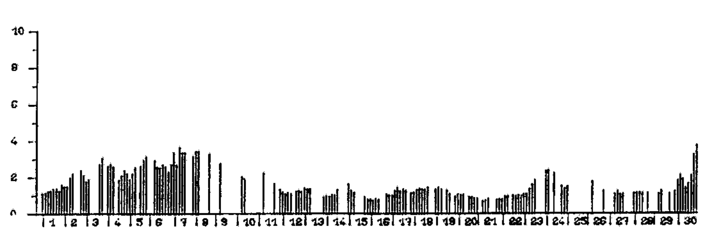
WAVE DATA RECEIVED FOULA. APRIL 1977

YEAR NO. 77 MONTH NO. 4 HS(METRES)



WAVE DATA RECEIVED FOULA. MAY 1977

YEAR NO. 77 MONTH NO. 5 HS(METRES)

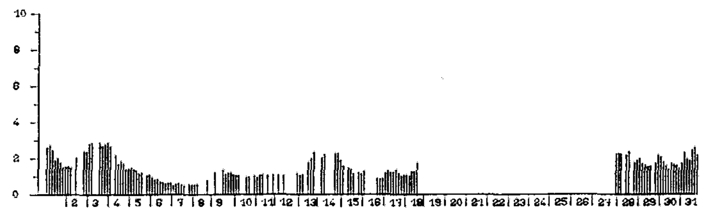


WAVE DATA RECEIVED FOULA. JUNE 1977

YEAR NO. 77 MONTH NO. 6 HS(METRES)

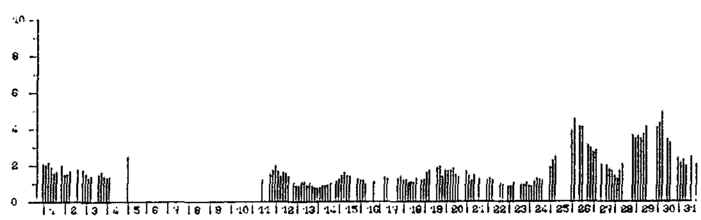
Time series of Hs

Fig. 10·1·2



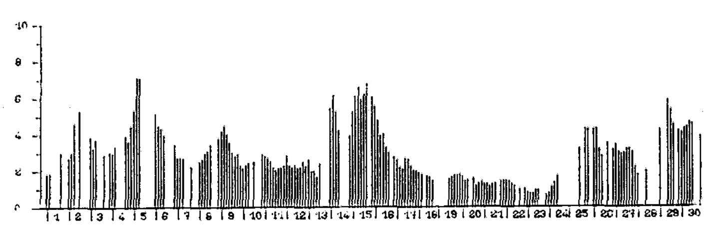
WAVE DATA RECEIVED FOULA. JULY 1977

YEAR NO. 77 MONTH NO. 7 HS(METRES)



WAVE DATA RECEIVED FOULA. AUGUST 1977

YEAR NO. 77 MONTH NO. 8 HS(METRES)

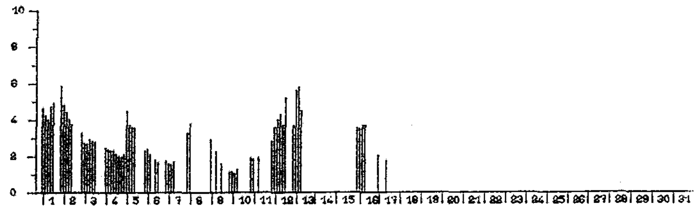


WAVE DATA RECEIVED FOULA. SEPTEMBER 1977

YEAR NO. 77 MONTH NO. 9 HS(METRES)

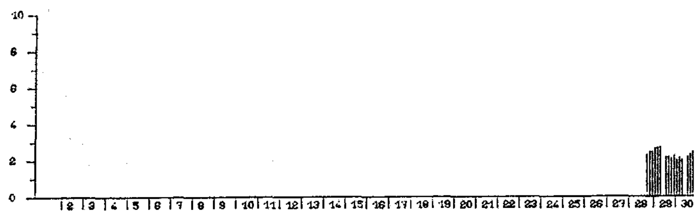
Time series of Hs

Fig 10·1·3



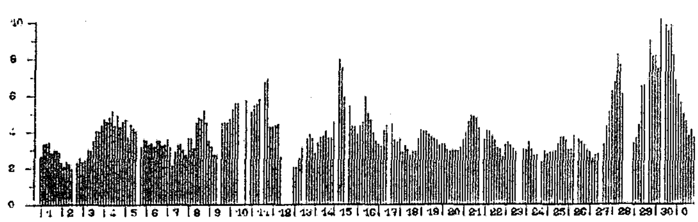
WAVE DATA RECEIVED FOULA. OCTOBER 1977

YEAR NO. 77 MONTH NO. 10 HS(METRES)



WAVE DATA RECEIVED FOULA. NOVEMBER 1977

YEAR NO. 77 MONTH NO. 11 HS(METRES)

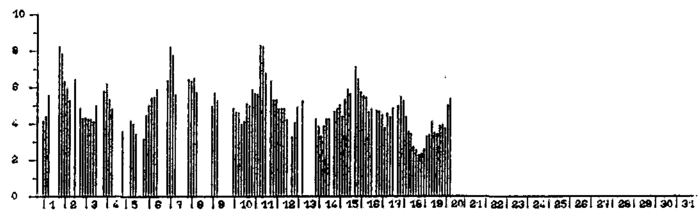


WAVE DATA RECEIVED FOULA. DECEMBER 1977

YEAR NO. 77 MONTH NO. 12 HS(METRES)

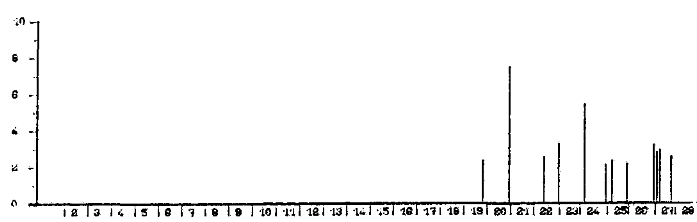
Time series of Hs

Fig. 10·1·4



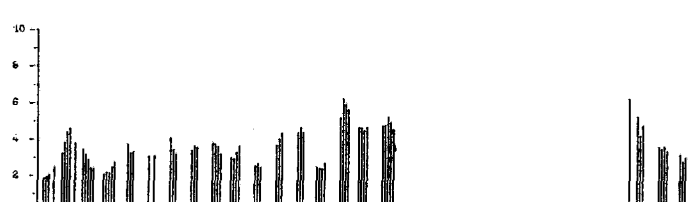
WAVE DATA RECEIVED FOULA. JANUARY 1978

YEAR NO. 78 MONTH NO. 1 HS(METRES)



WAVE DATA RECEIVED FOULA. FEBRUARY 1978.

YEAR NO. 78 MONTH NO. 2 HS(METRES)

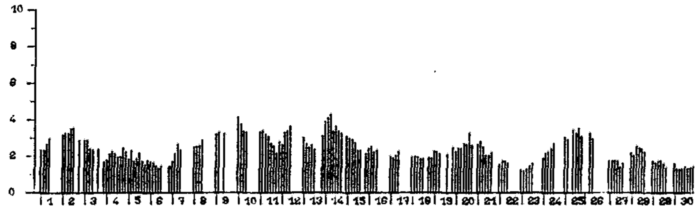


WAVE DATA RECEIVED FOULA. MARCH 1978.

YEAR NO. 78 MONTH NO. 3 HS(METRES)

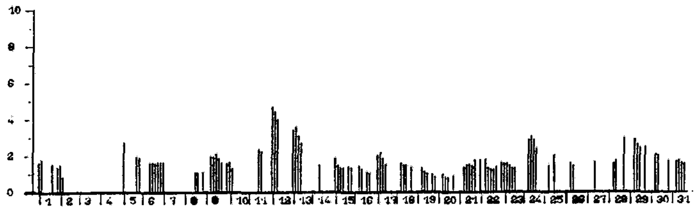
Time series of Hs

Fig. 10·1·5



WAVE DATA RECEIVED FOULA. APRIL 1978

YEAR NO. 78 MONTH NO. 4 HS(METRES)



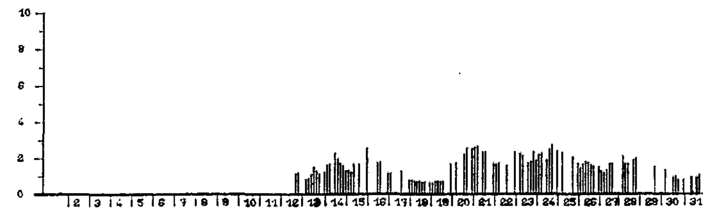
WAVE DATA RECEIVED FOULA .MAY 1978

YEAR NO. 78 MONTH NO. 5 HS(METRES)

No data received
for June 1978

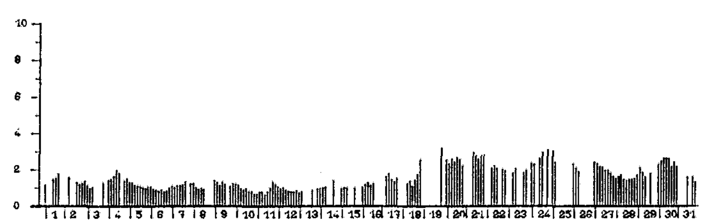
Time series of Hs

Fig. 10·1·6



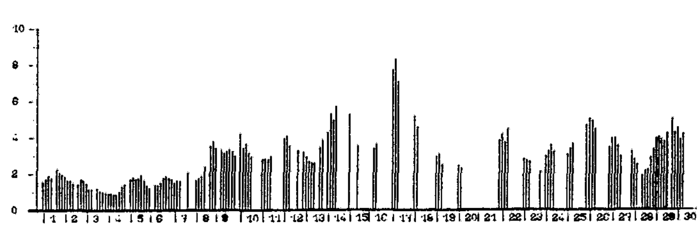
WAVE DATA RECEIVED FOULA. JULY 1978.

YEAR NO. 78 MONTH NO. 7 HS(METRES)



WAVE DATA RECEIVED FOULA. AUGUST 1978.

YEAR NO. 78 MONTH NO. 8 HS(METRES)

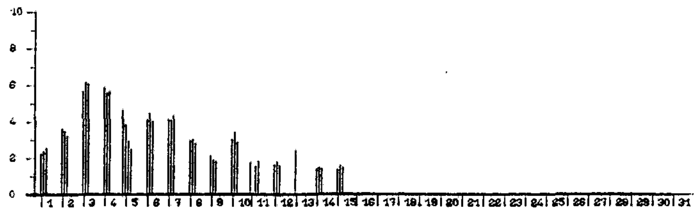


WAVE DATA RECEIVED FOULA. SEPTEMBER 1978.

YEAR NO. 78 MONTH NO. 9 HS(METRES)

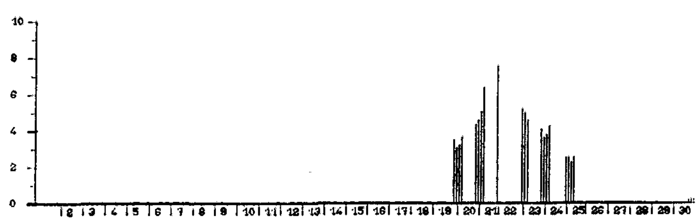
Time series of Hs

Fig. 10·1·7



WAVE DATA RECEIVED FOULA.OCTOBER 1978.

YEAR NO. 78 MONTH NO. 10 HS(METRES)



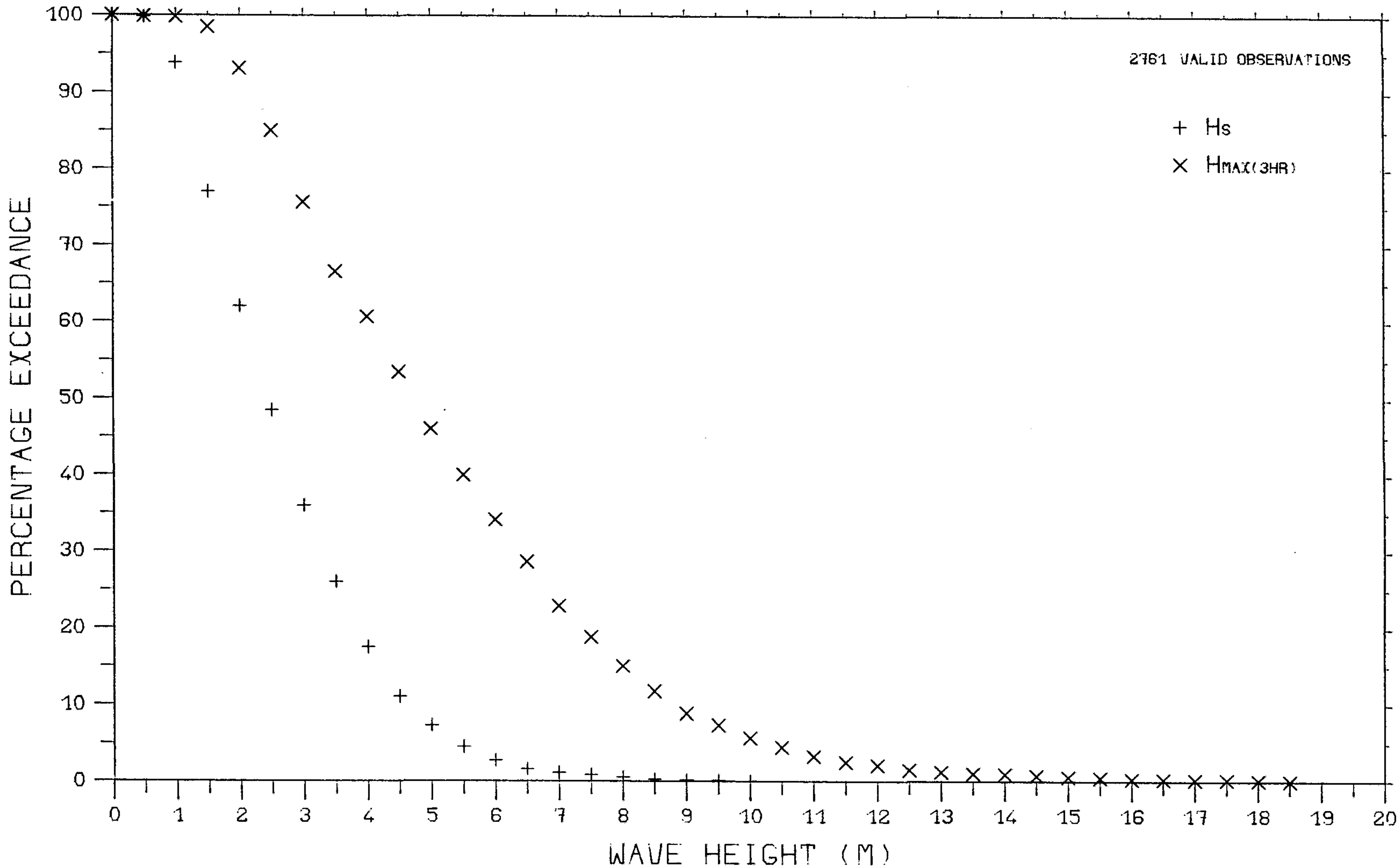
WAVE DATA RECEIVED FOULA. NOVEMBER 1978.

YEAR NO. 78 MONTH NO. 11 HS(METRES)

Time series of Hs

Fig. 10·1·8

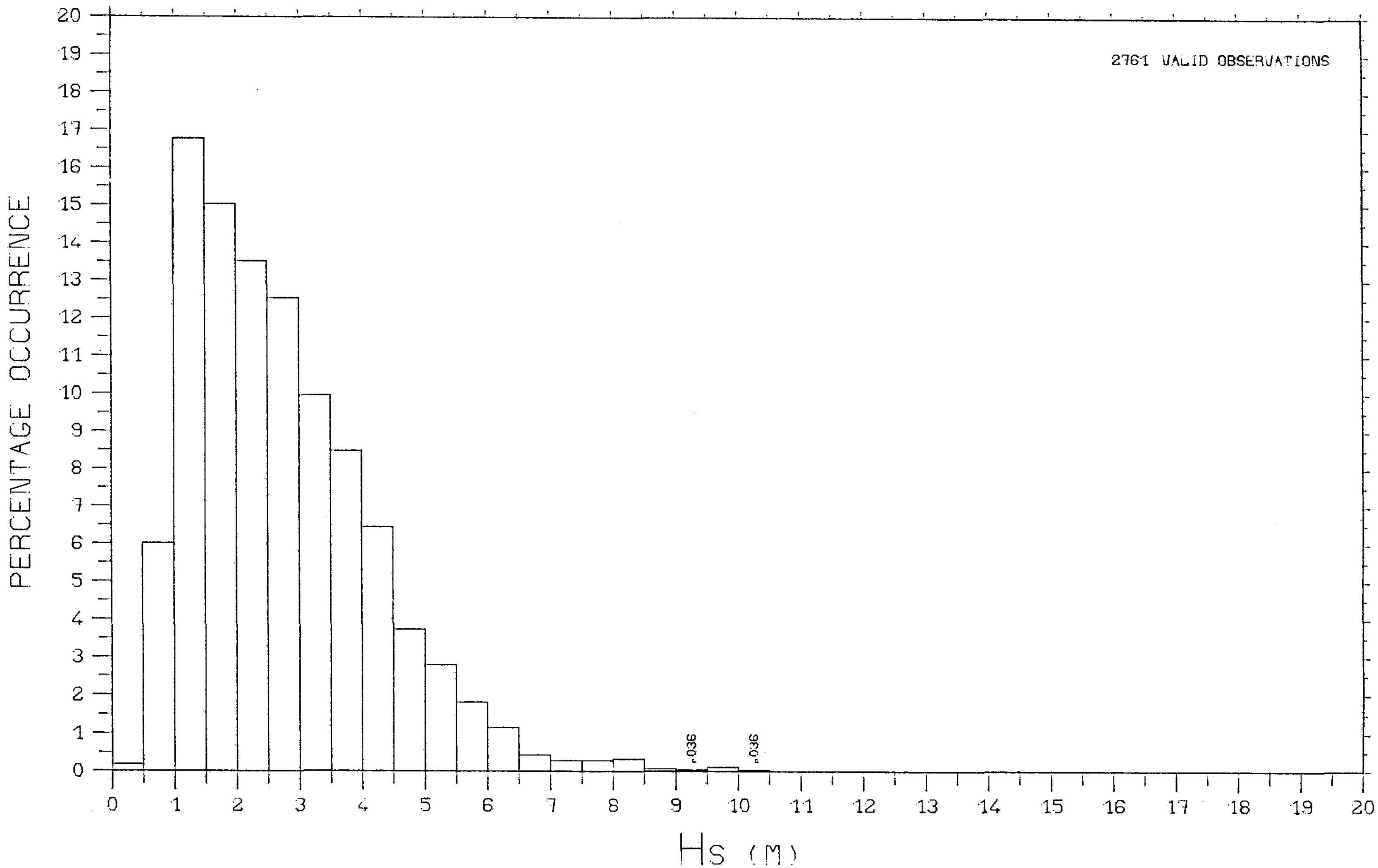
Fig. 10·2



PERCENTAGE EXCEEDANCE OF Hs AND HMAX(3HR)

FOULA JAN 1977 - NOV 1978

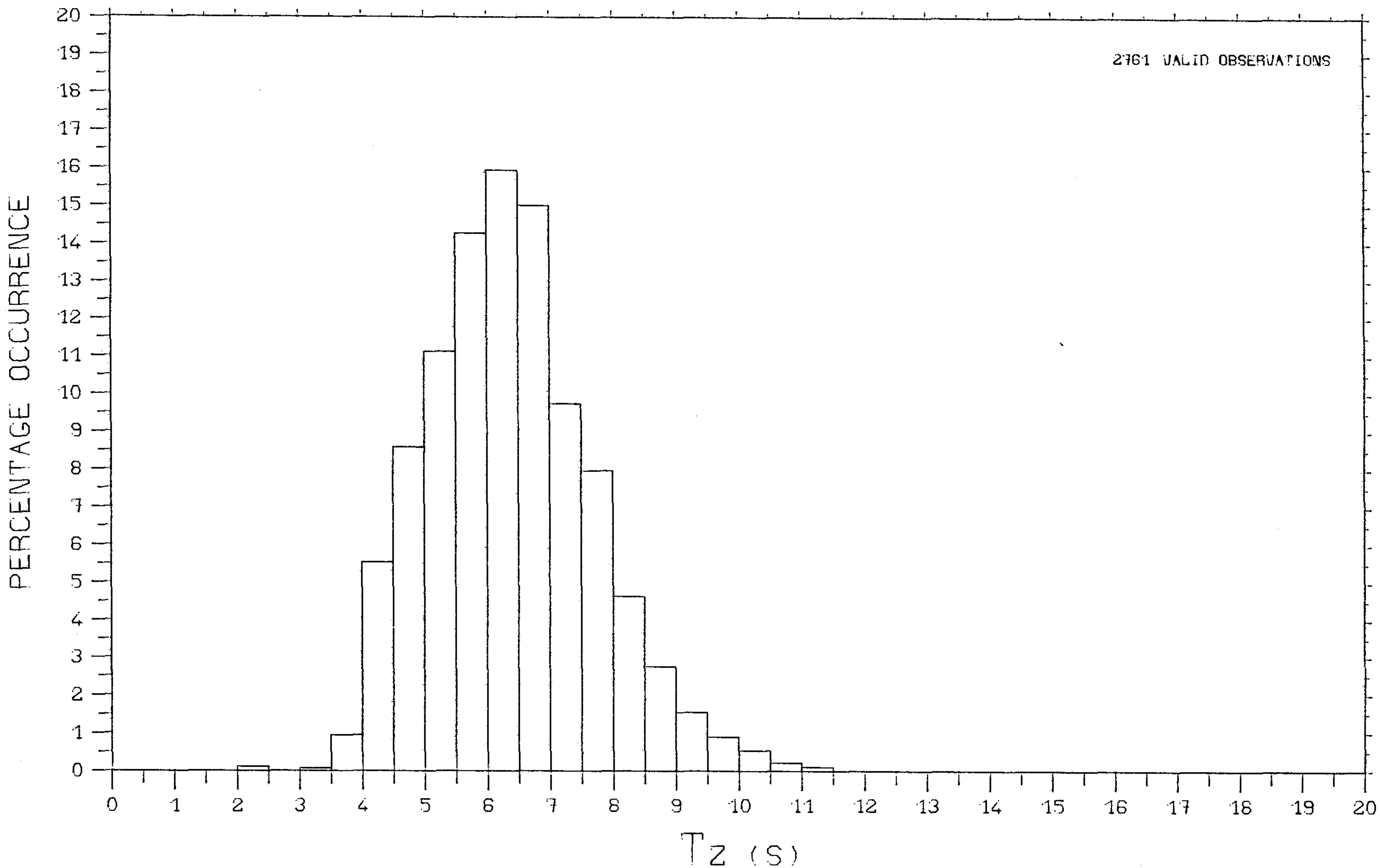
Fig. 10·3



PERCENTAGE OCCURRENCE OF Hs

FOULA JAN 1977 - NOV 1978

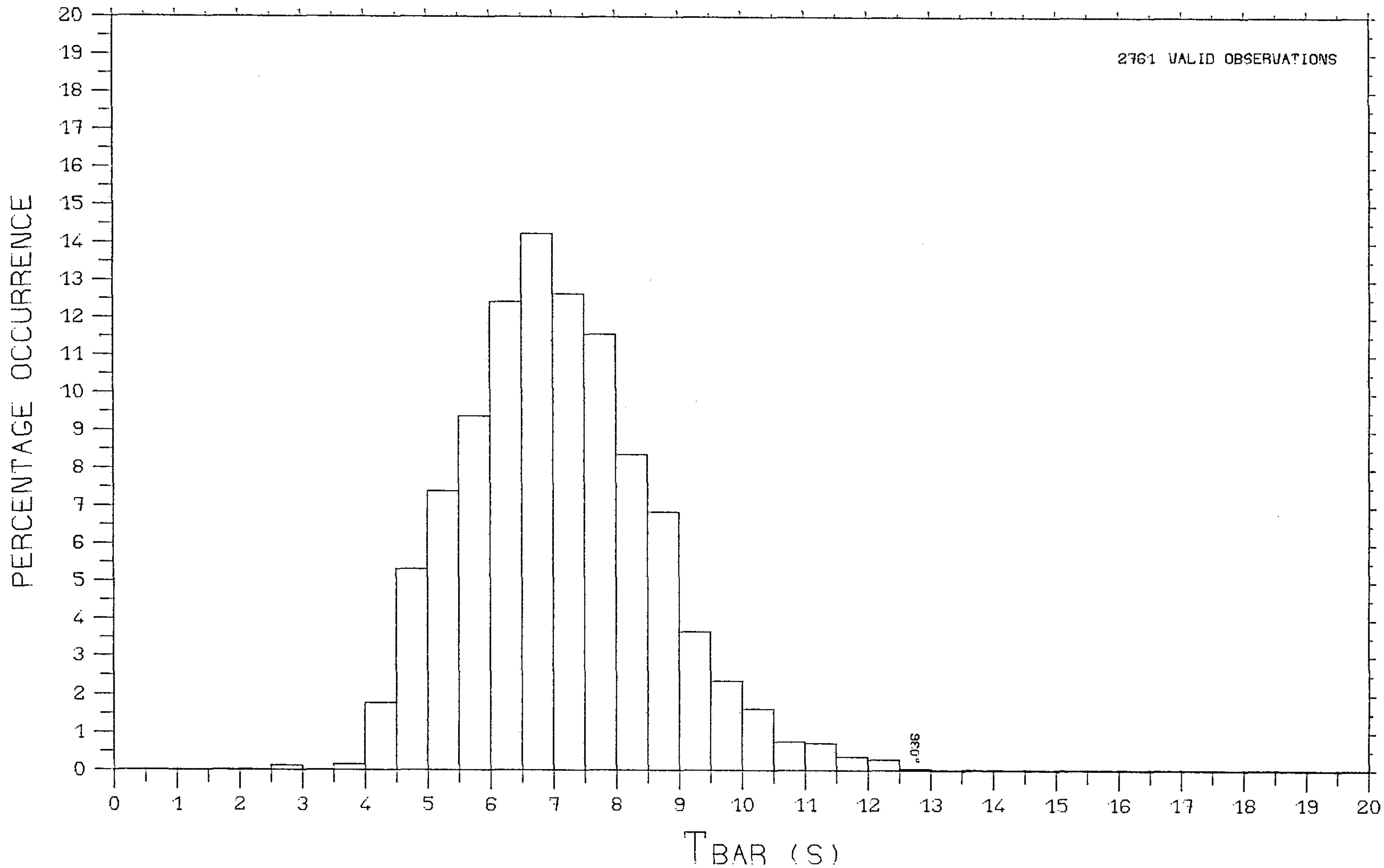
Fig. 11·1·1



PERCENTAGE OCCURRENCE OF Tz

FOULA JAN 1977 - NOV 1978

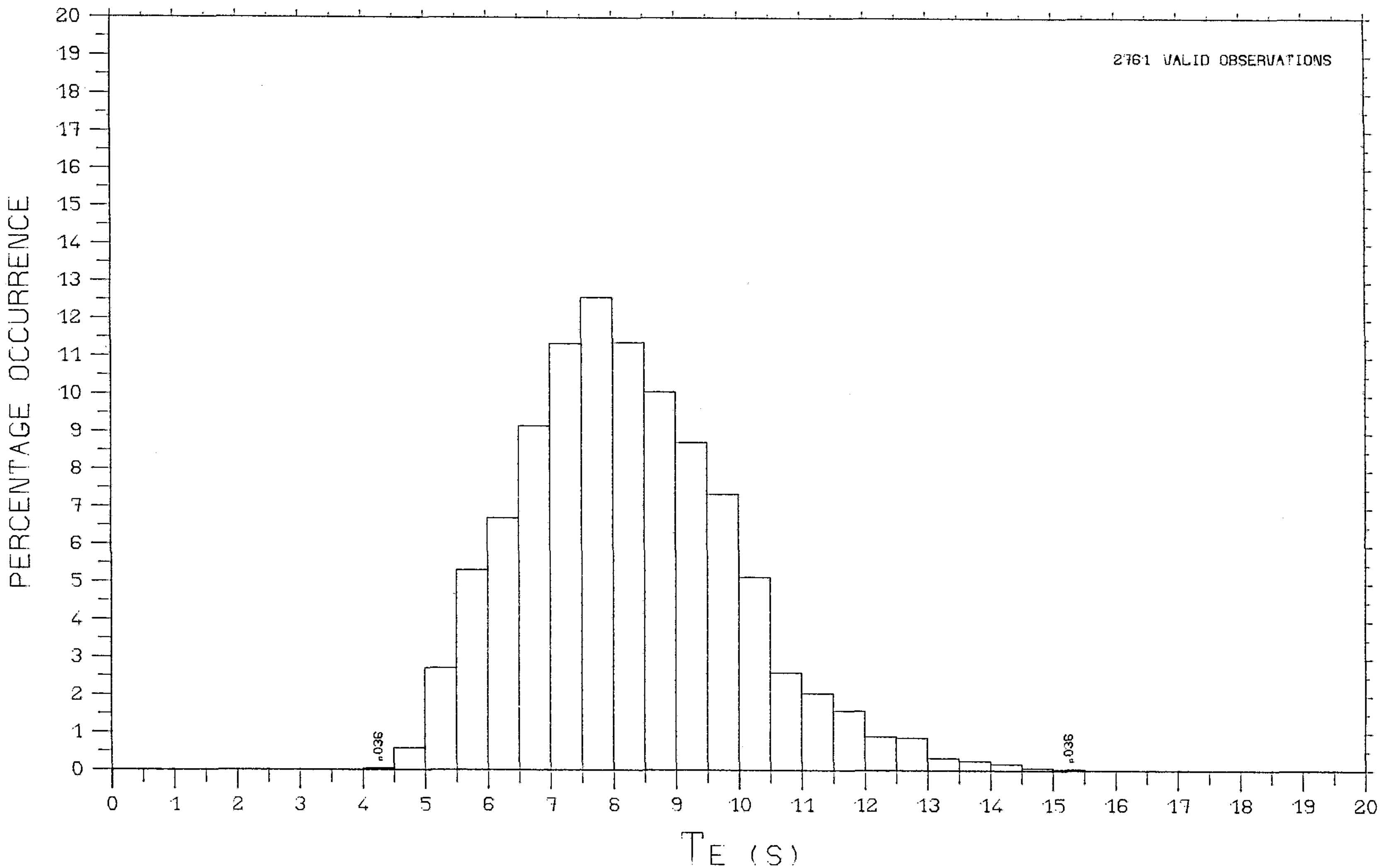
Fig 11·1·2



PERCENTAGE OCCURRENCE OF TBAR

FOULA JAN 1977 - NOV 1978

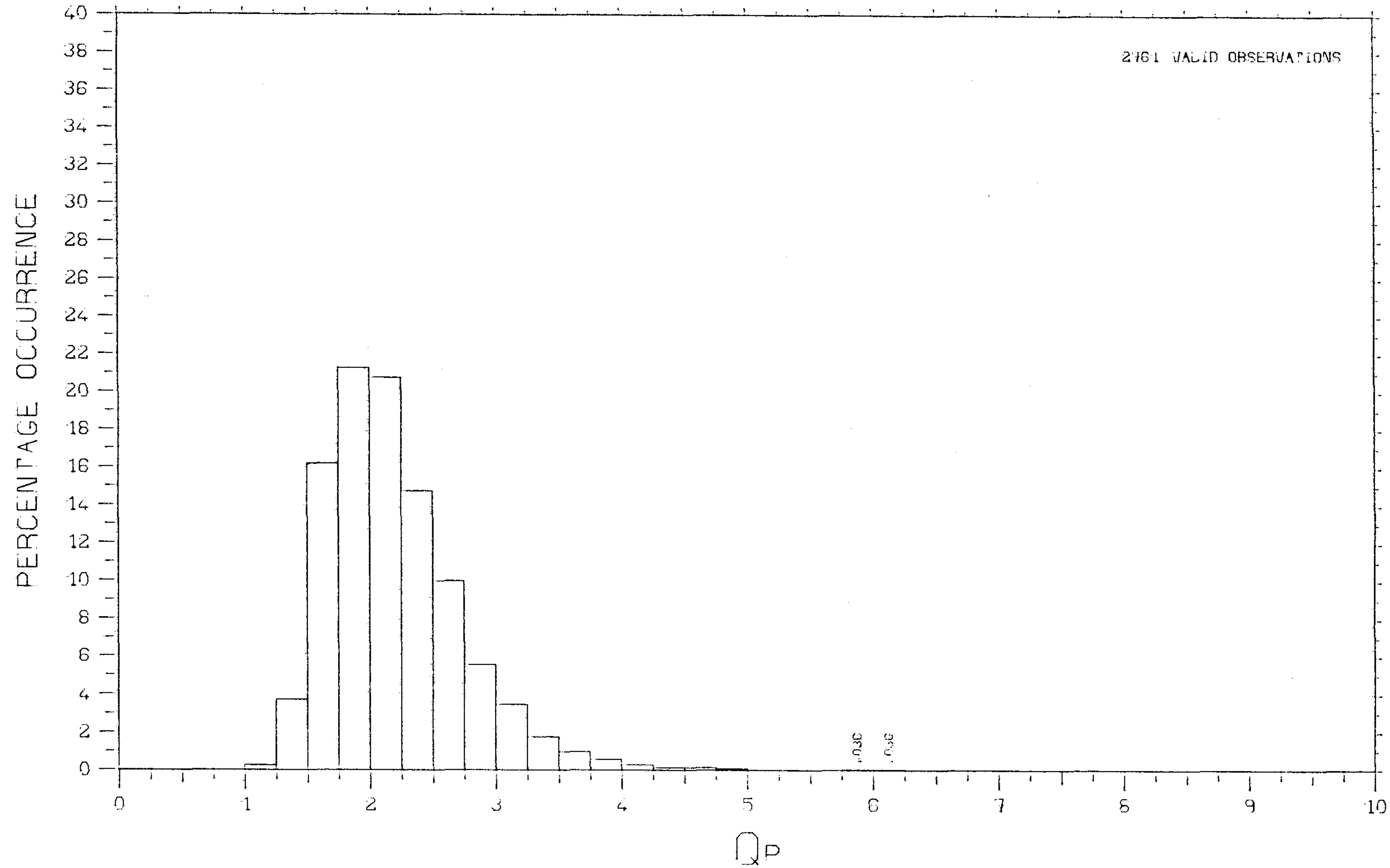
Fig. 11·1·3



PERCENTAGE OCCURRENCE OF T_E

FOULA JAN 1977 - NOV 1978

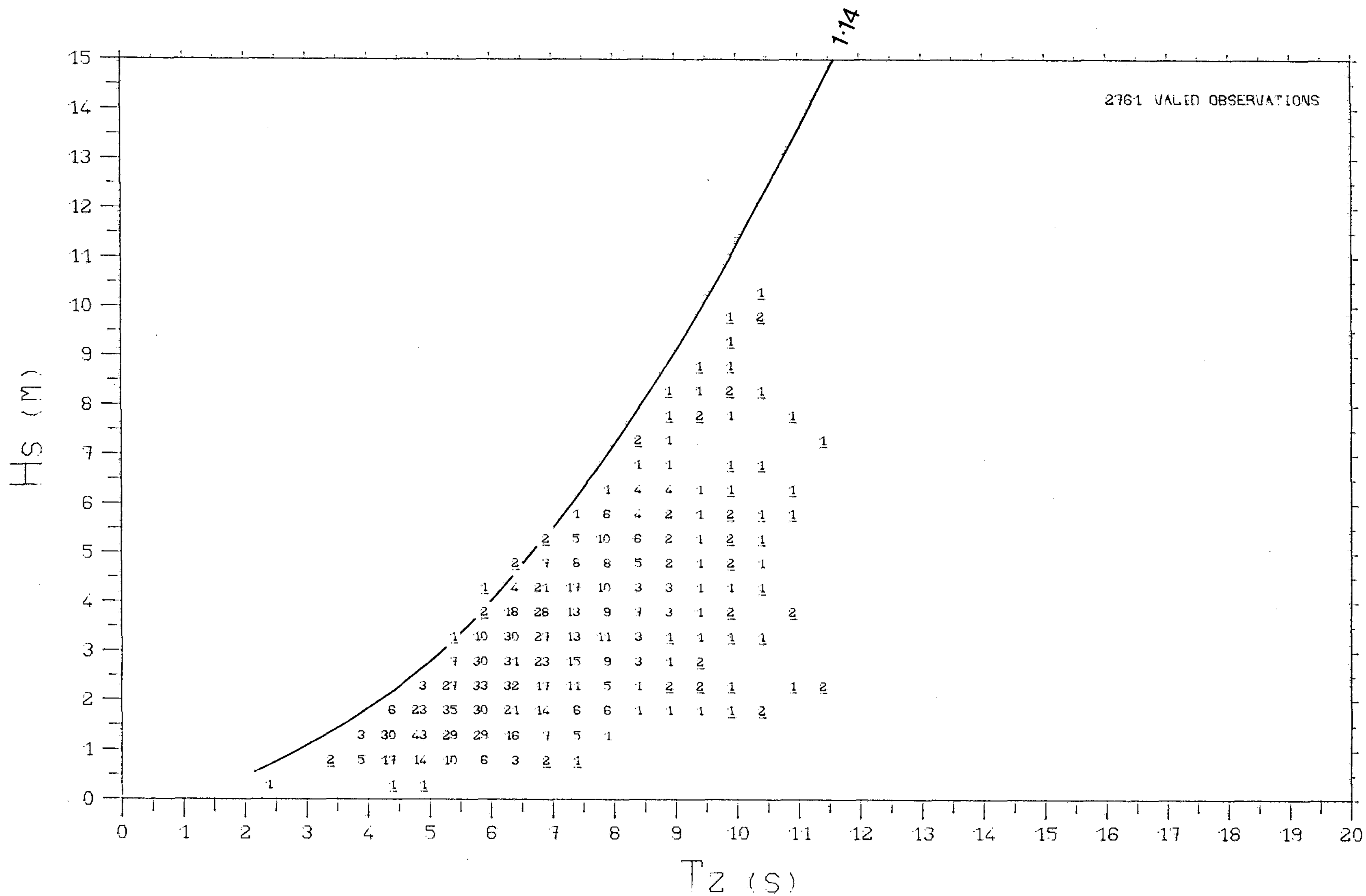
Fig. 12 ·



PERCENTAGE OCCURRENCE OF QP

FOULA JAN 1977 - NOV 1978

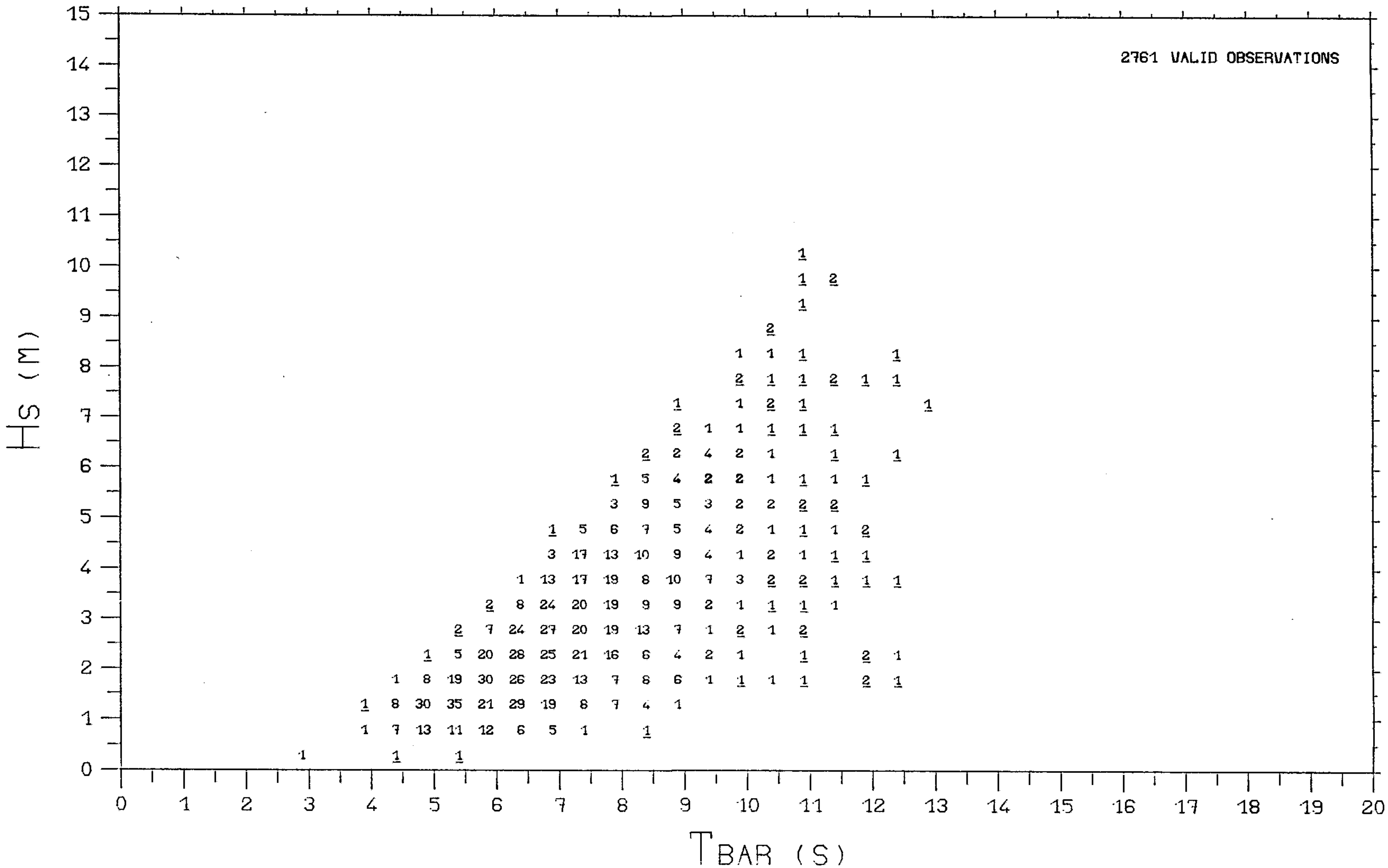
Fig. 13·1



SCATTER DIAGRAM OF Hs AND Tz (PPT)

FOULA JAN 1977 - NOV 1978

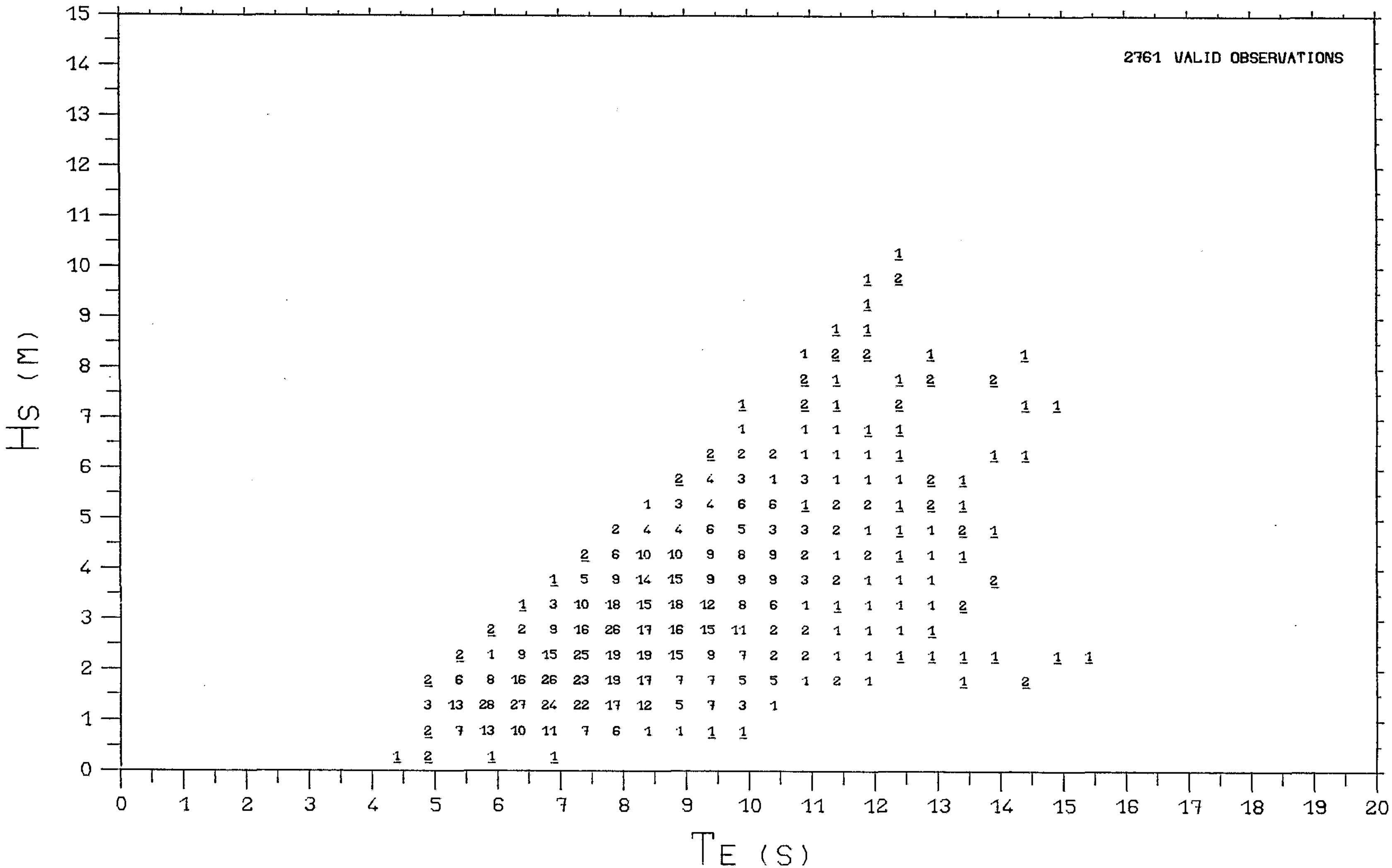
Fig. 13·2



SCATTER DIAGRAM OF HS AND TBAR (PPT)

FOULA JAN 1977 - NOV 1978

Fig. 13·3



SCATTER DIAGRAM OF Hs AND TE (PPT)

FOULA JAN 1977 - NOV 1978

APPENDIX A

Frequency response of measurement and analysis system

Figure A1 shows a graph of the overall response of the Waverider buoy, the Warep receiver and the interface circuitry. The effect of the double integrator has been eliminated by applying a correction function - it will be noticed that this function has been curtailed at periods larger than 25 seconds. Apart from this the main feature is the hump at high frequencies; this is almost entirely due to the hydrodynamic response of the Waverider hull, although there is also a contribution from the response of the Warep receiver. Figure A1 is thus a graph against frequency of the residual response of the measurement and analysis system when the Waverider buoy was the data source. It shows that the spectral estimates are correct over the important range of frequency but that there is a substantial overemphasis at high frequencies. When considering Figure A1 it should be remembered that the spectral density at these high frequencies might be 2, 3 or more orders of magnitude smaller than at the spectral peak, so that the practical effect of this error will be minimal.

No detailed information on the response of the Marex data buoy was available and so the corresponding graph for data from that source could not be included. However, it is reasonable to assume a similar response except that the high frequency overemphasis would be absent or much reduced.

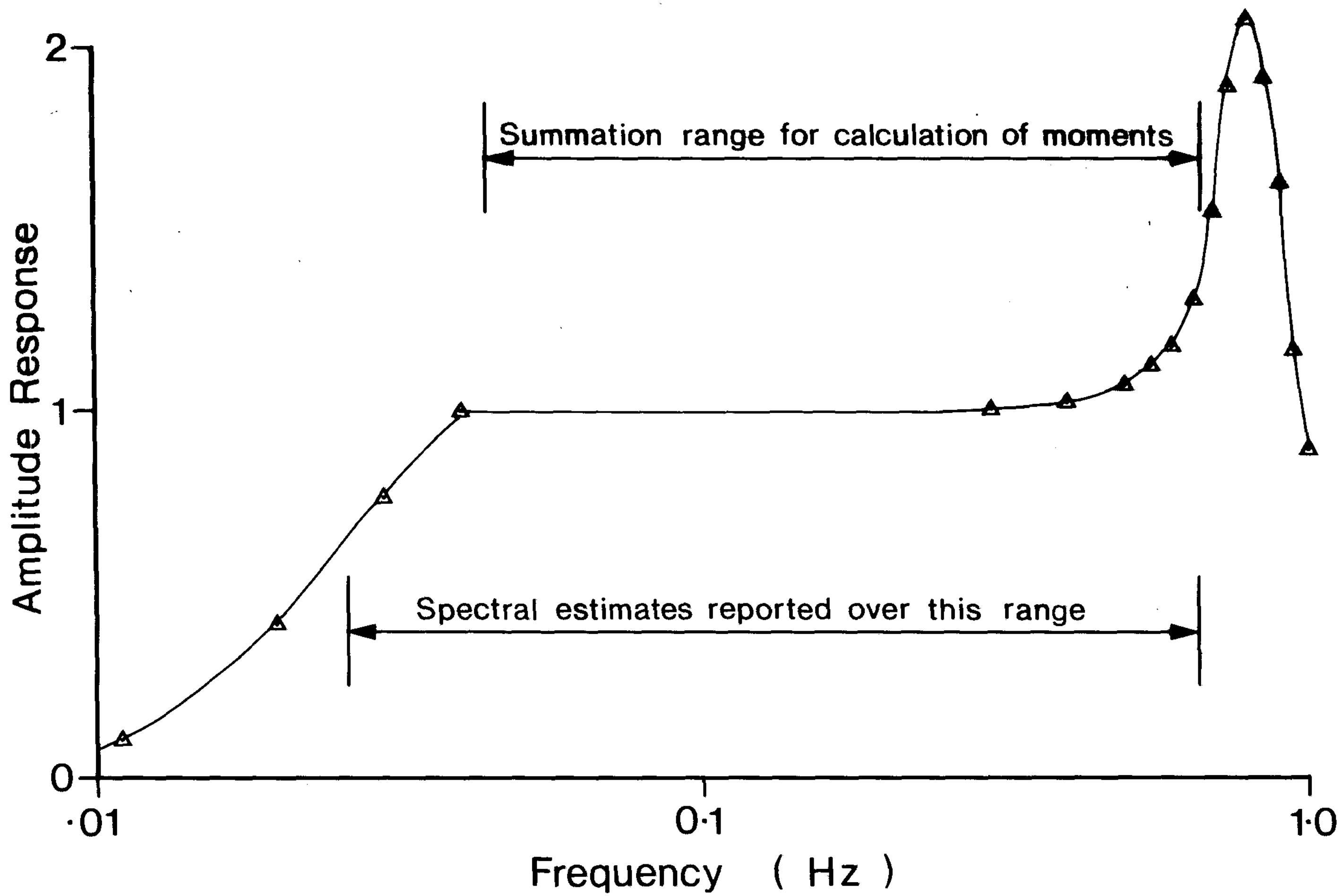


Fig. A1 Overall response of measurement & analysis system.(Waverider buoy)

APPENDIX B

Relationships between period parameters computed on the Marex buoy and those estimated from the Foula spectra

INTRODUCTION

In wave climate studies, the sea state is often described by the two parameters Hs and Tz, the significant wave height and the mean zero-crossing period.

Hs was originally defined as the mean height of the highest one third of the waves but for many practical purposes the definition

$$H_s = 4\sqrt{m_0}$$

has been adopted, m_0 being the zeroth moment of the variance spectrum. The two definitions give values of the significant wave height which differ systematically by a small amount which is now well documented.

The position with regard to Tz is rather less satisfactory. It has been shown (Rice (1944, 1945)) that the mean zero crossing period of a Guassian random process is given by

$$T_z = \sqrt{\frac{m_0}{m_2}}$$

The appearance of the second moment m_2 in this equation indicates that Tz is sensitive to the high frequency content of the process (ie the wave record in our case). If the high frequency performances of all wave measuring and recording systems were perfect or even similar, this fact would not matter too much, but unfortunately they are not, and Tz is found to vary considerably depending on the instrument and the recording system used and the analysis procedure adopted.

The great majority of wave data available to offshore engineers were collected using Shipborne Wave Recorders or Waverider buoys and were recorded using pen chart recorders. Wave periods abstracted from the records produced by these two instruments differ at the short periods because of the Shipborne Wave Recorder's more attenuated response at high frequencies.

The introduction of digital recording brought further complications. A digital system does not have the mechanical frequency response limitations inherent in a pen recorder, nor the mechanical 'stiction' between pen and paper. Moreover, the detection of zero-crossings is not limited by the eye's finite resolution.

All these factors tend to increase the number of zero-crossings in the digital record; in effect the more extended and linear high frequency response of the recording system allows a more faithful reflection of the high frequency content of the sea surface.

However, if the wave signal is contaminated by even small amounts of electrical noise before digitization, or if the zero reference of the analogue to digital converter is not absolutely quiet and stable, spurious zero-crossing periods will be introduced.

The net result of all these effects is that digital recording and processing systems tend to produce shorter zero-crossing periods than do pen-chart/human analysis.

During trials of the buoy prototype processor Marex observed discrepancies between the values of period computed by the processor and those taken from simultaneously recorded pen-charts. These discrepancies were probably due to a combination of the effects described above. Marex decided to introduce a modified definition of a zero-crossing into the microprocessor program which ensured that fewer zero-crossings were counted and that the wave periods were in better agreement with those extracted from the pen-chart records.

The prototype processor continued in use from the start of the project in December 1976 until mid-1978. At this time the production processor was introduced, the first successful recording period commencing on 8 August and continuing until 3 September 1978.

The production processor included an improved analogue to digital converter and the zero-crossing algorithm in the program was changed back to a straightforward definition. These actions resulted in shorter wave periods being computed on the buoy than had previously been the case.

Correlations presented

In order to give an understanding of the size of the discrepancies involved, correlations between several pairs of period parameters were made for each of the months, January 1977, May 1977 and August 1978. In January and May the data recorded on Foula was transmitted by the Marex data bouy; however in August the Waverider buoy was the source of data. The following notation is used:

Tz-MDB - Tz computed by the processor on the Marex buoy

Tz-SPEC - Tz computed from the spectrum estimated from the corresponding record recorded on Foula

TB-SPEC - $\bar{T}$ computed from the spectrum estimated from the corresponding record recorded on Foula

TE-SPEC - Te computed from the spectrum estimated from the corresponding record recorded on Foula

The straight line on the graphs is drawn to pass through the origin of each graph and the centroid of the data. The 'standard error' shown is simply the RMS perpendicular distance of the plotted points from the straight line; it has units of seconds. The slope of the line was chosen to minimise this quantity.

Discussion of correlations

Tz-MDB : Tz-SPEC Figure B1

The data for both January and May 1977 show some scatter and a pronounced bias, Tz-MDB being greater than Tz-SPEC. The scatter is more pronounced in the May data and the bias is greater. The August 1978 data shows less scatter and the bias at 9.8% is about half of that in the earlier data.

Tz-MDB : TB-SPEC Figure B2

Once again the data for January and May 1977 are scattered, May being particularly affected. Tz-MDB is greater than TB-SPEC on average, the bias for January being 5.5% and for May being 13.6%. The August 1978 data shows much less scatter, and a very small bias of 1.6%.

Tz-MDB : TE-SPEC Figure B3

The graph for January 1977 is rather scattered, with May 1977 more so. In January a bias of 9.9% is in evidence, Tz-MDB being smaller than TE-SPEC. In May the bias is reduced to 1.8%, Tz-MDB being smaller on average. As before the August 1978 data show less scatter. Tz-MDB in this case is 15.6% smaller than TE-SPEC on average.

CONCLUSIONS

Clearly, the improvements incorporated in the production processor have resulted in more consistent (less scattered) estimates of Tz; however it must be remembered that for a number of reasons very few data were collected by the data buoy after August 1978, and so the great majority of the data were collected by the prototype processor.

Thus it would appear that the spectral period parameter which best approximates the non-spectral period parameters reported by Marex during the Foula project is Te. However in view of the highly scattered results this approximation should be treated with caution.

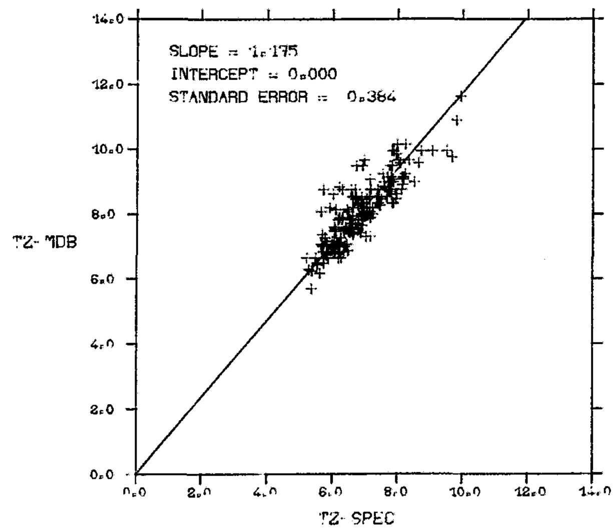
IOS FILL-IN WAVE PERIODS

In order to complete the investigation into the period parameters available from the Foula project, a comparison was made between the periods calculated on the Marex buoy, and periods calculated by IOS from the corresponding time history data recorded on the island of Foula (called Foula 3 in the figure).

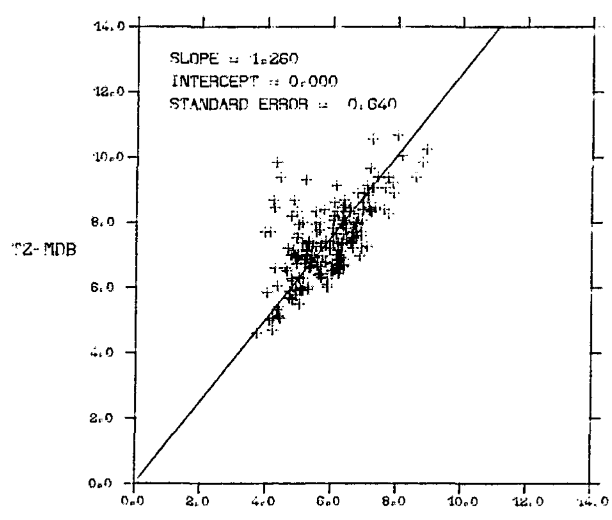
This comparison was carried out for similar data periods to those used above. Figure B4 shows the results. The plots for January and May 1977 reveal systematic differences in the two estimates of period accompanied by considerable scatter. The difference amounts to about 6% with the IOS periods being the longer, and are due to a difference in the algorithms used to define zero-crossings. The results for August 1978 are rather less scattered; the increased bias reflects the change of algorithm on the buoy.

REFERENCE

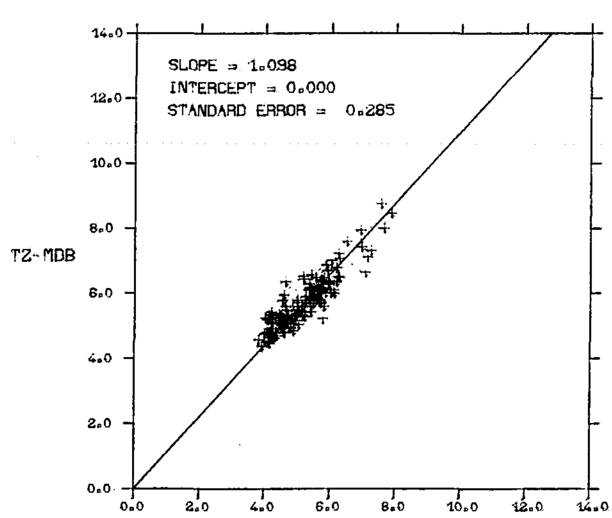
RICE, S.O. (1944/5). Mathematical Analysis of Random Noise. Bell System Technical Journal, 23, 1944 and 24, 1945.



Jan. 1977



May 1977



Aug. 1978

Fig. B 1

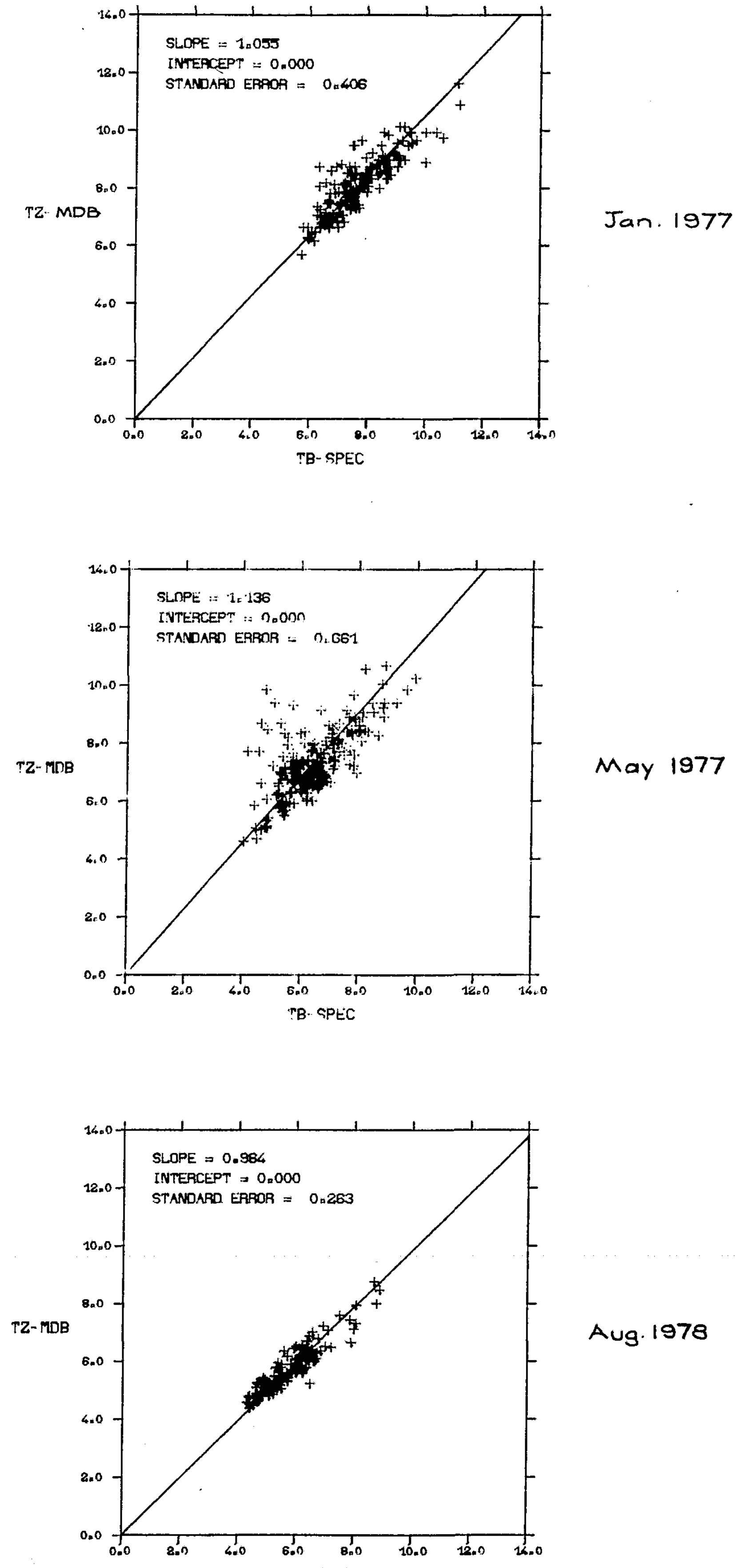
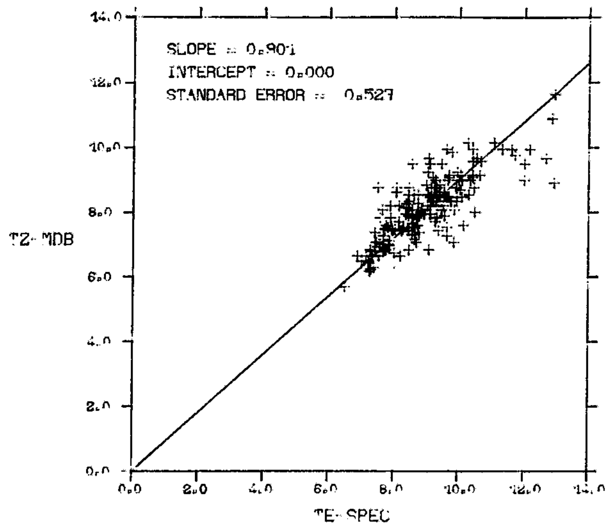
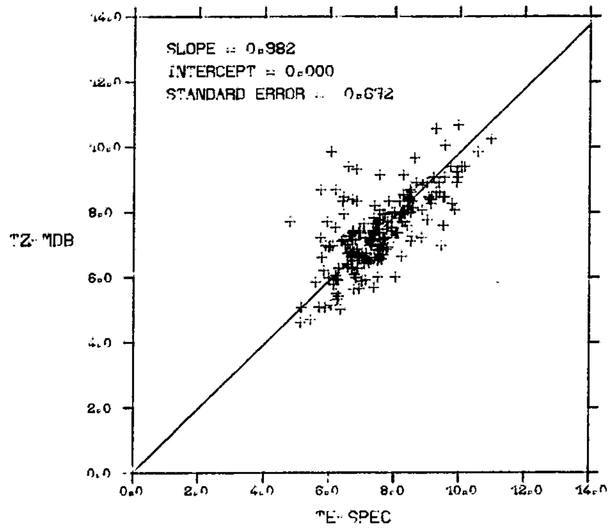

SLOPE = 1.055
INTERCEPT = 0.000
STANDARD ERROR = 0.406
TZ-MDB
TB-SPEC
Jan. 1977
SLOPE = 1.136
INTERCEPT = 0.000
STANDARD ERROR = 0.661
TZ-MDB
TB-SPEC
May 1977
SLOPE = 0.984
INTERCEPT = 0.000
STANDARD ERROR = 0.263
TZ-MDB
TB-SPEC
Aug. 1978

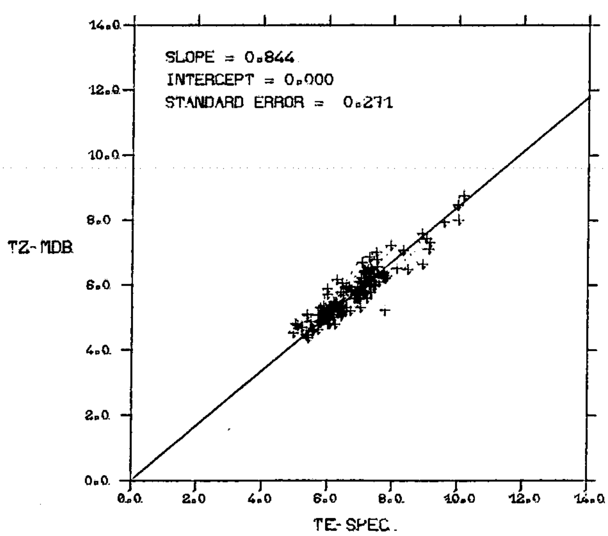
Fig. B2



Jan. 1977



May 1977



Aug. 1978

Fig. B 3

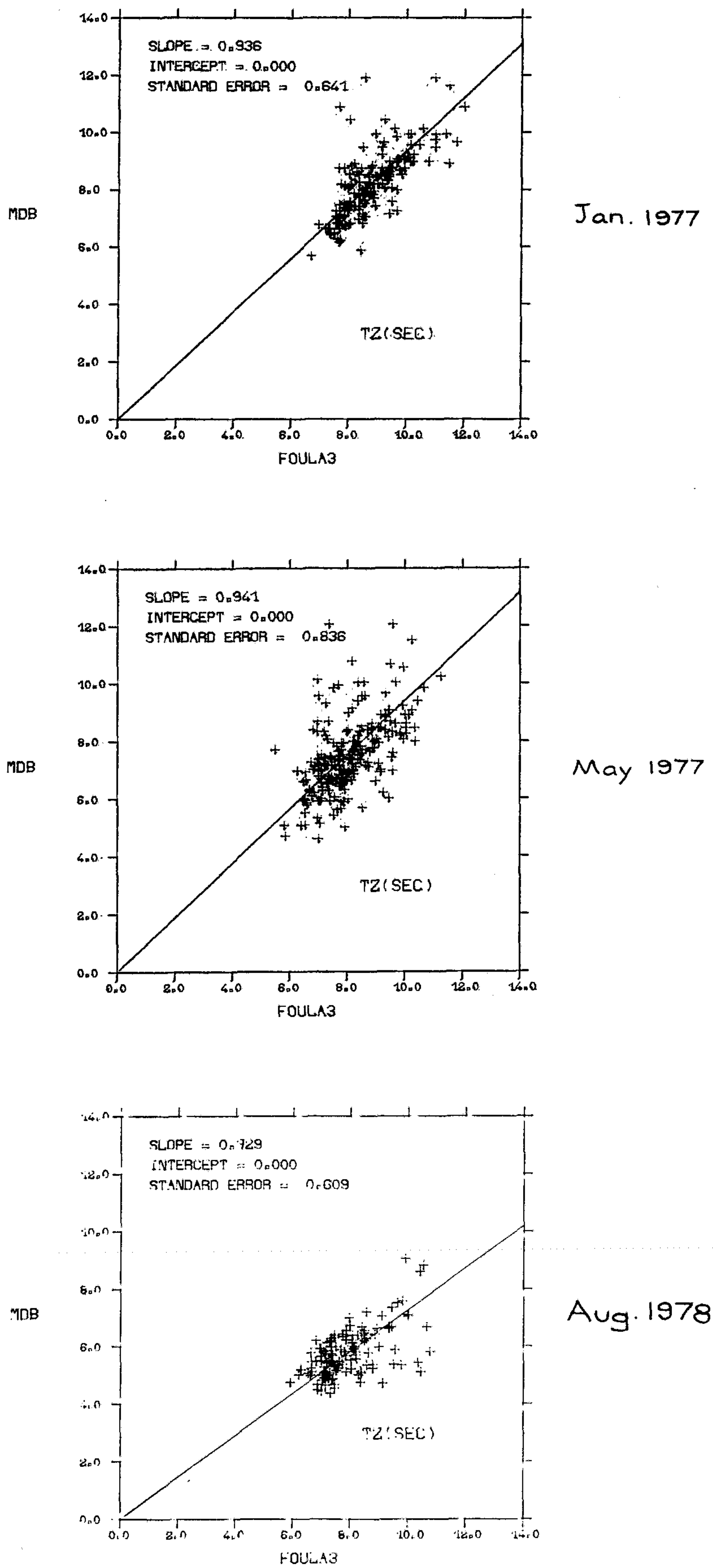

SLOPE = 0.936
INTERCEPT = 0.000
STANDARD ERROR = 0.641
MDB
TZ(SEC)
FOULA3
Jan. 1977
SLOPE = 0.941
INTERCEPT = 0.000
STANDARD ERROR = 0.836
MDB
TZ(SEC)
FOULA3
May 1977
SLOPE = 0.729
INTERCEPT = 0.000
STANDARD ERROR = 0.609
MDB
TZ(SEC)
FOULA3
Aug. 1978

Fig. B 4

APPENDIX C

Format and content of spectral data files

The data are contained in monthly files which contain formatted records with a uniform length of 96 characters. The entry in the output file corresponding to one digital site wave recording will be called an 'observation'. Hereafter, 'record' will mean 'logical record'.

Spectral file structure

Each file contains data for one calendar month and the files are named in an ordered sequence.

The contents of the spectral files are described below. However, on the standard IOS transfer tape a record containing the file name is written at the beginning of each file. This record is in addition to those detailed below.

Record 1

Data header record FORMAT (5X, 40A1, 51X)

Record 2

ISITE - Site Code - C for Foula

INST - Instrument Code - W for Waverider or Marex buoy

FORMAT (2A1, 94X)

Record 3

ISTY - Nominal year of first observation

ITD - Nominal day number of first observation

ITH - Nominal time of first observation (Hours)

ITM - Nominal time of first observation (Minutes)

FORMAT (1X, I2, 1X, I3, 1X, 2I2, 84X)

The rest of each file consists of the observations, which are described below.

File termination

There is a logical end of file record which takes the place of Record 1 of the next observation after the end of the data:

ISTY (LEOF)
NDAY (LEOF)
IHR (LEOF)
MIN (LEOF)

FORMAT (5X, I2, 2X, I3, 3X, 2I2, 77X)

This record is written as all 9's to signify the end of the month, or all 8's to signify the end of the data series. If the end of the month is also the end of the series, 8's are written.

In addition, files are terminated by an IBM-compatible EOF mark on the IOS standard transfer tape.

Format of observation

Each observation consists of 18 records.

Each record consists of 96 characters.

These records contain the following information:

<u>Record 1</u>

ISTY	Last two digits of year
NDAY	Day number
IHR	Hour
MIN	Minutes
HS	Significant wave height
TZ	Mean zero-crossing period
SNRL	Quality figure, low frequencies
SNRH	Quality figure, high frequencies
SCADJ1	Taper adjustment factor
KFLAG	(1-10) Validation flags
NREC	Record number (address) of this record with respect to the beginning of the file.

FORMAT (5X, I2, 2X, I3, 3X, 2I2, 5(3X,F6.2), 2X, 1ØI1, 4X, I5, 11X)

<u>Record 2</u>

RM(1-7) - Moments of spectrum order -2 to +4

QP - Goda's spectral peakedness parameter

FORMAT (8E12.5)

<u>Records 3-18</u>

Tabulation of FREQ (I) frequency (Hz) and
S (I) spectral density (m^2/Hz)

as 64 pairs, arranged 4 per record as follows:

```
FREQ (1)     S(1)          FREQ (17)     S(17)- - - - FREQ (49) S(49)
FREQ (2)     S(2)          FREQ (18)     S(18)- - - - FREQ (50) S(50)
   |           |              |             |              |
   |           |              |             |              |
   |           |              |             |              |
FREQ (16)    S(16)         FREQ (32)     S(32)- - - - FREQ (64) S(64)
```

This can be read using the following statement:

```
READ (n, 8ØØ)   (( FREQ (N+M-1), S(N+M-1), M=1, 49, 16), N=1, 16)
8ØØ FORMAT (4(3X, F6.4, 3X, E12.5))
```

'No data' record

If the wave recording for a particular time was not available or contained less than 2000 points when edited, a 'no-data' observation was generated.

Only Record 1 appears in a 'no-data' observation, and in this all real numbers are set to 99.99, and the validation flags are set to 9. NREC, the record address continues to increment correctly.

Index file structure

Index files are a separate file series which contain a subset of the information contained in the spectral files. The following records are included.

Record 1 Data header record with year and month

Record 2 Site/Instrument code

and then records 1 and 2 of each observation as they appear in the spectral file. These files can be listed on a line printer for use as a hard-copy index.