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SIZEWELL-DUNWICH BANKS FIELD STUDY

TOPIC REPORT: 6

A P Carr, H L King, A D Heathershaw and B J Lees

Wave data: observed and computed climates

Report No: 128

1981

NATURAL ENVIRONMENT RESEARCH COUNCIL

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SUMMARY

This report is the sixth in the Topic Report series concerning the Sizewell-Dunwich Banks area of East Anglia. It falls into two sections: the first outlines and discusses observed wave data while the second examines the results of computed wave refraction and ray tracking programs.

Observed wave data demonstrate that under most circumstances there is little difference in the energy reaching the coastline south of, opposite to, or north of, the Sizewell-Dunwich Banks. However, under severe storm conditions, large waves break on the banks so that there is then a substantial difference between offshore and inshore wave height thus demonstrating the sheltering effects of the banks under such circumstances.

There is a clear relationship between onshore wind velocities and wave heights and also between the volumes of beach material moved and the mean monthly wave height.

Wave refraction and wave energy computations demonstrate a marked wave focussing effect along the shoreline (notably at Sizewell-Thorpeness) when waves come from the direction of maximum fetch (heading 210°), but that where the wave approach is normal to the banks, refraction is minor, with energy being fairly uniformly distributed alongshore.

At the 'inshore' Waverider site waves computed as exceeding approximately 2.3 m are substantially overpredicted. This can be attributed to inadequacies in the computer program which fails to allow for wave breaking on the Sizewell-Dunwich Banks.

1. INTRODUCTION

Earlier reports in this series have discussed observed and residual tidal currents (Heathershaw and Lees, 1980b)and offshore sediment movement in relation to both tidal currents and wave data (Lees and Heathershaw, 1981). This report completes the series by examining wave aspects in greater detail. The report falls into two broad divisions. The first describes and discusses the observed wave data, some aspects of which have been reported elsewhere (Fortnum and Hardcastle, 1979a;Lees and Heathershaw, 1981). Thereafter, the computed wave climate is examined both visually by means of a series of computed wave refraction diagrams and through the calculations of wave energy reaching a number of targets relative to the specified energy input at the seaward boundary.

2. OBSERVED WAVE DATA

2.1 Wave Measurements

Wave data were obtained over a four-year period from January 1975 to May 1979. Initially all the data were derived from 3 frequency modulated (FM) pressure recorders situated on the sea bed some 400 m seawards of the beach off Aldeburgh, Dunwich and Southwold in a mean depth of water of approximately 8 m. However, in July 1977, these recorders were supplemented by a Waverider buoy seawards of the banks off Dunwich while a further Waverider was deployed in October 1978 between the other two Dunwich wave recording instruments. All FM units were cabled to cassette recorders located in buildings near the beach while data from the Waveriders were telemetered ashore to a similar recording system. Tables 1 to 3 list the wave records available and the various deployment dates of the instruments in more detail; Figure 2 shows the locations.

Waverider and sea bed pressure wave recorder data were logged using frequency modulation on magnetic tapes. The recordings were of 1350 seconds duration from the Waverider buoys and 675 seconds for the sea bed recorders. In both cases records were taken at intervals of 3 hours. These were replayed to give significant wave height H_s (from mean rectified wave height) and the mean zero crossing period T_z. It should be mentioned that due to the attenuation of pressure variation with depth, the pressure recorders respond less to short period waves than the Waverider buoy. To reduce this discrepancy, appropriate correction factors were calculated from an empirical formula (Draper, 1957), using the actual depth and measured T_z.

Records between June 1975 and May 1977 were fully analysed and form the basis of the Wave Data Report by Fortnum and Hardcastle (1979a). A number of figures from Fortnum and Hardcastle's report are included here, often in a slightly altered form, as part of the section on observed wave climate. After December 1977 only selected parts of the wave records were analysed, notably the FM data for Dunwich where the mean highest significant waves ($\bar{H}_s$) between March 1978 and April 1979 were compared with the volumes of beach material moved (Blackley, 1979), and the 'offshore'/'inshore' Waverider comparison of February 1979. Both these aspects are discussed below.

2.2 Wave climate

During the 2-year period 1975-1977 mean monthly wave height at both Aldeburgh and Dunwich varied between approximately 0.2 and 0.3 m for the months of May, June and July and 0.4 to 0.65 m for the August-April period. A similar picture was also shown for the more restricted data for Southwold (Figure 3).

Figures 4, 5 and 6 show the percentage exceedance of H_s and H_{max} for the summer and winter seasons for Aldeburgh, Dunwich and Southwold, respectively. Figures 7 to 9 depict the corresponding frequency histograms for wave period. The following three figures (Figures 10-12) record the duration over which given wave heights were exceeded. It is noteworthy that storms were relatively short-lived with, for instance, waves exceeding 2 m only likely to occur on average for a duration of 6 hours. Waves of 2 m or above were likely to occur about once a month.

Figures 13a, b show the mean and standard deviation of the average value of the onshore wind speed and the significant wave height, respectively. Figure 13a is based on data from the meteorological station at Gorleston, some 25 km north of Southwold; Figure 13b on the 5 site-years of FM wave data compiled between 1975 and 1977 (2 at Aldeburgh and Dunwich, 1 at Southwold). Figures 14 and 15 depict this information in a different form. Thus Figure 14 superimposes these wind and wave data while Figure 15 is a graph of onshore wind speed ($\bar{W}$) against wave height (as $\bar{H}_s$). The significance level for the correlation coefficient exceeds .001, ie better than 99.9%. The relationship shown here is a linear one but it is customary to assume that wave height α $\bar{W}_s^2$ and this relationship is used in the effective fetch calculations (Tables 5 and 6).

It had been anticipated that the waves recorded at the Dunwich beach site would be smaller than those at Aldeburgh to the S and Southwold to the N since Dunwich appears to be sheltered by the Sizewell-Dunwich banks (Figure 2). However, a statistical analysis showed no significant differences between any of the three locations. Because of this negative result this analysis is not discussed further although Figure 16 represents the same point visually. It is clear from the figure that there is little difference in mean monthly significant wave height ($\bar{H}_s$) and that such variations as do occur are not systematic. Subsequently it was decided to examine the relationship further using 2 Waverider buoys located seaward and inshore of the Sizewell-Dunwich banks (Figure 2). It was found that under most circumstances wave heights recorded at each location were identical but this relationship did not hold under extreme conditions. Figure 17 is a graph of offshore significant wave height (H_{s_o}) plotted against inshore significant wave height (H_{s_i}) for the month of February 1979. It is apparent that for offshore significant wave heights exceeding approximately 2.6 m the corresponding inshore value is less. This may be attributed to such waves breaking on the offshore banks while smaller waves are unaffected.

Figures 18 and 19 depict the relationship between the total volume of material moved as recorded by successive monthly levelling of a series of beach transects, and the corresponding mean monthly $\bar{H}_s$ value (Blackley, 1979). It is clear from Figure 19 there is good agreement with the significance level for the correlation coefficient better than 99.9%. In this context it is interesting to note that, firstly, no such correlation exists between erosion (or accretion) separately against $\bar{H}_s$ for the Sizewell-Dunwich area. Secondly, the relationship which appears to exist here was less apparent in comparable studies along the E shore of Swansea Bay on the S coast of Wales. At Swansea it was concluded that beach volume changes were too great and wave parameters too variable over a one-month period for any meaningful relationship to be detected (Heathershaw et al, 1980a). It is therefore surprising that on the East Coast site with its much greater range of angles of wave approach, its more variable coastal alignment and its increasing scope for longshore transport of beach material, that a relationship can be recognised. One possible explanation is that storm events are substantially less frequent and shorter-lived (see Figures 10-12) in the Aldeburgh-Southwold area than is the case in Swansea Bay (Fortnum and Hardcastle, 1979b). Fortnum and Hardcastle show, in their Figure 18, 3 times as many occurrences of waves exceeding 2 m at Swansea compared with the East Coast site. As a result topographic changes at Sizewell-Dunwich may be more readily associated with specific storm events.

3. COMPUTED WAVE CLIMATE

3.1 Fetch and duration characteristics

The range of wave heights present in a locally generated sea will be a function of the wind speed, fetch and duration. If either fetch or duration are limited then the sea will not reach a fully developed state. Clearly at a site in a coastal embayment, the range of fetch direction will be narrower than on a more open coastline. Furthermore, it is not sufficient to consider the geometric fetch alone (ie the distance that the wind blows over the sea surface) as being a true measure of the wind's effectiveness in generating a sea. This is because the wind transfers energy to the sea over a range of angles up to 45° on either side of the direction in which it is blowing, and thus open ocean fetches are a measure of the wave energy arriving at a point from a similar range of angles 45° on either side of the wind. In effect this assumes a fetch of infinite width whereas on an irregular coastline, or in estuaries, rivers and lakes, the fetch width may limit contributions from the full range of angles. Under these conditions wave height prediction is normally carried out in terms of effective fetch.

For the Sizewell-Dunwich area we have calculated the effective fetch characteristics at Aldeburgh, Dunwich and Southwold using the method given by the US Coastal Engineering Research Center (CERC, 1973) and outlined in Appendix A. Effective and geometric fetch characteristics are shown in Table 4 and Figure 20. Figure 20 illustrates that for most wave approach directions there is little difference between effective and geometric fetch although effective fetch is larger when directions of wave approach are sub-parallel to the shoreline.

The effective fetch characteristics (Table 4) have been used to predict wave heights at Dunwich and Southwold using the method given by Darbyshire and Draper (1963) (Figure 21). For typical wind speeds (Table 5 a, b) significant wave heights (H_s) of the order of 1.8 m are predicted and during storms (Table 6 a, b) H_s is predicted to be of the order of 5.2 m. During the period of relatively severe storms in February 1979 observed wave heights (H_s) off Dunwich Banks reached 4.55 m with local mean wind speeds of the order of 18 ms^{-1}.

3.2 Wave refraction

In this study wave refraction analyses have been carried out to elucidate the following points:

(a) the possibility of wave energy focussing by the offshore banks;

(b) the onshore and alongshore variations in wave energy.

In the following section a brief review of the salient features of wave refraction theory is given to familiarise the reader with the underlying physical processes. This description is taken from Heathershaw, Carr and King (1980a)and is based upon that given in Goldsmith et al (1974).

3.2.1 General principles

The process whereby waves are slowed, shortened and steepened as they travel into progressively shallower water is called shoaling. Typically this will not occur uniformly along a wave front and as the wave speed (or celerity) decreases in accordance with its shortest wavelength, the wave front bends as a result of the variations in celerity along the front. The combination of shoaling and wave front bending is known as refraction.

The celerity **c** of a progressive surface water wave is given by linear wave theory as

$$c^2 = \frac{gL}{2\pi} \cdot \tanh \frac{2\pi h}{L} \qquad (1)$$

where g is the acceleration due to gravity, L is the wavelength and h is the water depth.

Rearrangement of equation (1), with $c = L/T$ where T is the wave period, gives

$$L = \frac{gT^2}{2\pi} . \tanh \frac{2\pi h}{L} \tag{2}$$

For deep water $\tanh 2\pi h/L \rightarrow 1$ and so the wavelength L is a function of wave period only. The deep water assumption is valid to within 0.5% for depths greater than one-half of the wavelength.

The effects of shoaling and refraction can be estimated by linear wave theory. For example, the propagation of surface waves into shallow water may be analysed by consideration of the wave energy between vertical planes which are orthogonal to the wave crests and which intersect with the surface to produce wave rays. Energy is assumed to be transmitted between these planes, that is it does not travel along wave crests or cross wave rays. If it is further assumed that the wave period is constant and that there is no net gain or loss of energy by reflection, percolation or bottom friction, then linear wave theory provides the result,

$$\frac{H}{H_o} = K_r K_s \tag{3}$$

where H_o is the deep water wave height, H is the inshore wave height and K_r and K_s are the refraction and shoaling coefficients respectively, given by,

$$K_r = \left(\frac{b_o}{b}\right)^{\frac{1}{2}} \tag{4}$$

and

$$K_s = \left(\frac{2 \cosh^2 kh}{2kh + \sinh 2kh} \right)^{\frac{1}{2}} \tag{5}$$

Here, b_0 and b are the deep water and shallow water wave ray separations respectively (see Figure 22).

As a surface wave travels into shallower water the sea bottom exerts an influence on it, because of the effect of depth in determining the wave celerity (equation 1). When the crests of a train of waves are not parallel to the bottom contours (lines of constant depth) the section in shallow water decreases in speed in such a way that the wave crests tend to become parallel to the bathymetry. Wave refraction diagrams are used to illustrate the way in which a wave of a given period responds to the bottom topography and are constructed in accordance with the principles outlined previously, using Snell's law to determine the direction and celerity along a wave ray. Consequently it is assumed that

$$\frac{\sin \alpha_2}{\sin \alpha_1} = \frac{C_2}{C_1}, \tag{6}$$

which by optical analogy gives the angles of incidence α_1 and α_2 and the speeds c_1 and c_2 of a wave ray passing from one refractive medium into another, in this case at two different depths.

One of the major difficulties with wave refraction analyses has been due to crossed rays, or caustics, where the energy conservation principles outlined previously indicate infinite amounts of energy as the ray separation $b \rightarrow 0$. However this is not now thought to be the problem that it once was (see Goldsmith, 1974) since wave rays have been found to emerge from caustic regions on the continued ray path, the wave conditions being determined by the wave ray separation more or less as if the caustic had not been there. However, there should be a phase shift which according to Goldsmith is not observable due to the randomness of the waves in nature.

Wave refraction diagrams, incorporating the above principles, have been used extensively in this study to elucidate features of the wave climate in the Sizewell-Dunwich area. Such calculations, based on linear wave theory, can be used to predict inshore wave climates from the corresponding measured or predicted offshore climate (eg Abernethy and Gilbert, 1974). However, the calculations make certain assumptions so that they are practicable in terms of computer run-time and cost. For example:

(a) the seabed topography is approximated by a mesh of finite size which excludes the small scale features;

(b) the energy losses through breaking waves and bottom and surface stress are neglected.

3.2.2 Methods

The wave refraction calculations described here were carried out using methods developed by the Hydraulics Research Station (HRS, 1974). Details of the theory behind the computations are given in Appendix B.

In particular these computer based techniques have been used for:

(a) ray tracking (see Appendix B1) and
(b) energy calculations (see Appendix B2).

The energy calculations are done in three stages:

(a) Firstly, the sea bed topography information is used to determine energy transfer functions for the directional wave spectrum $S(f, \theta)$ at inshore target points where wave height (or energy) estimates are required. Here f is the wave frequency and θ the direction of wave propagation.

Starting at a target point ray paths are tracked outwards, in a seaward direction, for a discrete set of equally spaced frequencies. The rays are started at equally spaced angular increments suitable for the frequency. HRS found that it was possible to use larger increments for the upper end of their frequency band than for the lower (see HRS, 1974). The rays halt at 'obstacles' or on the grid boundary. Since the paths are reversible, only the rays which reach the deep water boundary are of interest, but their exact position is immaterial since the spectrum is assumed constant along the deep water boundary.

Longuet-Higgins (1957) has shown that $cc_g s(f,\theta)$ is constant along a ray path. Here c is the wave celerity and c_g is its group speed. Thus it is possible to calculate transfer functions which give the inshore frequency spectrum from an offshore directional spectrum.

(b) An offshore ('deep-water') directional spectrum can be determined from measured wave data either by assuming some form of distribution for both frequency and direction, or the frequency distribution form may be replaced by a frequency spectrum obtained directly from the wave data.

In the present study boundary conditions for the refraction model were specified using H_s and T_z values calculated from Fast Fourier Transform (FFT) spectra of the February 1979 'offshore' Waverider buoy data. Wave directions associated with particular H_s and T_z values were inferred from wind speed and direction measurements at Gorleston. H_s and T_z values so obtained were used to parameterize a Pierson-Moskowitz (PM) spectrum (HRS, 1974; Pierson and Moskowitz, 1964) at the boundary and, for each wave heading studied, waves were given a $\cos^2 \theta$ directional dependence about that particular heading.

The offshore spectral matrix is obtained by evaluating the directional spectrum at each frequency and angular segment. These segments are distinct from the angular increments mentioned in (a) and may be several orders of magnitude larger. The segment's size is chosen so that $s(f,\theta)$ is approximately independent of θ in each segment.

(c) The inshore predictions of significant wave height and mean zero crossing period can be calculated from the inshore frequency spectrum for each target point (see later).

For the wave refraction and energy transfer function calculations the sea bed topography was described by depths relative to Chart Datum (LAT) taken from IOS bathymetry and Admiralty charts. The bathymetry was digitised on a grid having overall dimensions of approximately 30 x 10 km and made up of 61 x 40 elements 0.5 x 0.25 km in size. Over the banks and shoreward of them a computer-generated sub-grid was used with spacing of 0.25 x 0.125 km in order to improve accuracy. The size and orientation of the grid (Figure 23) was chosen to include the offshore banks, to minimise the land area, and to make the x-axis roughly normal to the shore. Wave recorders and ray target sites are also marked on this figure.

3.2.3 Wave refraction diagrams

Table 7 lists the various wave refraction plots which have been calculated using water depths of 0.5 and 2.5 m, ie approximately low and high water tide level, spring tides, and wave periods of 6.0 and 7.5s. These periods correspond fairly closely to those typical for the area and those occurring during storms, respectively. Representative plots, illustrating specific points, are shown as Figures 24-30, with the remainder included in Appendix C as Figures C1-C21. The former group shows that while waves heading roughly normal to the shore (at approximately 270°) are only slightly affected by refraction (Figures 26 and 27) those from oblique angles (eg on a heading of 210° which is the generalised direction of maximum fetch) are considerably modified (Figures 24 and 25). This applies to both the 6.0 and 7.5s wave periods and both water levels. A similar phenomenon applies to oblique waves from a southerly quarter (Figure 30). Figures 28 and 29, which depict 6s period waves with a heading of 330°, show marked focussing at certain points along the foreshore.

Figure 31a-c provides a comparison of wave refraction plots based on bathymetry in 1867, 1965 and 1977. Figure 31a, b is derived from Robinson (1980) while Figure 31c was produced for the present study. In all cases the wave heading is 247° 30' (ie from ENE), the period is 8s and the water level 2 m above chart datum. It is interesting to observe the marked similarity between 1867 and 1977 plots.

3.2.4 Wave energy calculations

The offshore boundary conditions were inferred from actual waves observed at the 'offshore' Waverider buoy in February 1979. Because the North Sea is relatively shallow, and because the bathymetry seawards of the Sizewell-Dunwich Banks is irregular, some attenuation had already taken place outside the offshore grid boundary and also between this boundary and the Waverider site. Boundary conditions were therefore effectively scaled up to obtain the best agreement possible at the location of the 'offshore' Waverider (Figures 32 and 33).

It should be noted in Table 8, that in order to obtain the best agreement between observed and predicted wave heights and wave periods at the offshore Waverider buoy, values of T_z specified at the boundary are considerably shorter than those at any of the targets (including the offshore Waverider buoy itself). This difference, which is of the order of 1.5s is believed to be due to the method of parameterizing a Pierson-Moskowitz (PM) spectrum at the boundary with H_s and T_z values derived from FFT spectra of actual wave records. In particular T_z values derived in this way are biased towards higher frequencies in the PM spectrum. This was illustrated in some of the spectra from the Swansea Bay study (Heathershaw et al, 1980) although on the East Coast such a trend is less apparent. Figure 34 indicates that, in individual cases there can be good agreement between FFT and PM spectra from the East Coast data. New values of H_s and T_z obtained from the model again reflect this shift to higher frequencies.

Data were grouped for each of 4 octants (wave headings from 180° to 360°) and 2 water levels (0-1 m and 2-3 m above Admiralty Chart Datum). There were insufficient observations for the group 270°-315° (Table 8a). However, more information is available for 180°-225° and 225°-270° (Tables 8b and 8c). (It is for this reason that the regression line on Figure 32 is restricted to data between 180° and 270°.) Each Table lists the input data (as H_s, T_z and the mean direction of wave heading, θ); observed and predicted comparison for Targets 1 ('offshore') and 2 ('inshore' Waveriders); and predicted values of H_s, T_z and wave headings for Targets 3, 4 and 5. These latter targets correspond to Southwold Pier, Dunwich beach and Sizewell Nuclear Power Station, respectively. It had been planned to have a further target, number 6, at Aldeburgh, but because Aldeburgh was near the southern limit of the bathymetric grid and the bathymetry is both shallow and particularly complex offshore, it was concluded that results were unlikely to be realistic. Comparisons of observed against predicted wave data are restricted to Targets 1 and 2. For the period in question the Southwold pier wave recorder was no longer operational and, in any event, the instrumental response characteristics of the FM recorders located at Southwold and Dunwich are not directly comparable with those of the Waverider buoys.

Figure 35 provides a comparison between the predicted and observed wave heights at the 'inshore' Waverider site, Target 2 (Table 8, Figure 23). All the data points for both water levels and all four directional groupings have been included, but the regression lines are based on values between 180° and 270° only, where there is a larger data set. The effect shown here is the inability of the computer program to model wave breaking and shoaling (Compare Figure 17). For the predicted wave heights less than approximately 2.3 m there is good agreement with observed values. However, above this height predicted and observed wave heights are only poorly correlated. This can be attributed to the susceptibility of the larger waves to breaking on the offshore banks (Bascom, 1960). It must be remembered in this context that H_s represents the mean of the highest one-third of the waves and that the highest individual waves within this group would be disproportionately affected by shoaling. It is clear, therefore, that predicted wave heights are likely to be an over-estimate of those actually recorded. Nevertheless observed waves over approximately 2.2 m are rare taking the year as a whole (see Figures 4-6).

The wave attenuation indicated in Figures 17, 35 and Table 8 may be compared with that calculated from the empirical formula for re-formed wave height (ie wave height after breaking) of Keady and Coleman (1980).

$$H_r = H_o \left(0.58 \left(H_o/d \right)^{-0.8} \right) \qquad (7)$$

where H_r and H_o are the re-formed and offshore wave heights, respectively, and d is the water depth. The breaking height criterion of 0.78 d should be appropriate here (Kishi and Saeki, 1967) since the seawards slope of the Sizewell-Dunwich banks is only of the order of 1:200. The minimum still water depth over the banks is 4.0 m and the maximum breaker height therefore 3.12 m. Using Equation 7, and ignoring refraction effects, the re-formed wave height would be 2.21 m. Corresponding sets of values for the more typical still water depths of 5 and 6 m would be 3.90 and 4.68 m for breaking wave height and 2.76 and 3.31 m for re-formed wave height, respectively. These values are not dissimilar from those observed in the field.

Table 9 lists the predicted wave height (H_c) and wave energy (E_c) coefficients for Targets 1-5, classed according to the mean input direction (wave heading) at the offshore grid boundary. This information is summarized in Table 10. Values of H_c are ratios between the spectral input value of H_s at the offshore boundary and that at the respective target. The energy coefficient (E_c), is defined as

$$E_c = \frac{\int S_i(f)\,df}{\int S_o(f)\,df}$$

where $\int S_i$ represents the total energy inshore and $\int S_o$ the total energy offshore for the respective wave headings.

Although the data on which the computations were made had a substantial proportion of large waves, it was interesting to note that the predicted relative wave energy for the directions of maximum fetch (200°-270°) is very similar for both Southwold and Dunwich. This agrees well with the conclusions from the 1975-77 FM data (see Section 2.2). Maximum wave energy for the 200°-260° directions occurs at Sizewell (see Figures 24-5 and Appendix C1-7,9). Table 9 suggests that higher wave energy reaches the coastline at the shallow water level (0-1 m above Chart Datum) as compared with the 2-3 m level, but this is likely to be an artifact based on the fact that the highest observed 'offshore' wave heights all happened to occur during low tide periods. Partly for this reason and partly because of the limited comparisons available the two water levels are not differentiated in Table 10.

Table 10 indicates that although linear wave theory is inadequate to deal with the breaking waves on the Sizewell-Dunwich banks (Figure 35) it nevertheless produces a drop in the wave energy coefficients for all the wave headings listed between 200° and 260° inclusive, ie those oblique to the alignment of the offshore banks. This fall is substantial for directions between 200° and 230° where rays are initiated sub-parallel to the coastline and hence particularly subject to the nearshore bathymetry. There is a similar, but slightly less marked loss in E_c for rays between 200° and 230° from the input boundary and the 'offshore' Waverider, target 1.

In the quadrant 180°-270° (Tables 8b and 8c) there was, not surprisingly, excellent agreement between observed and predicted wave period (T_z) at the 'offshore' Waverider target, but at the 'inshore' site there were 29 out of 41 instances where the predicted wave period was longer than observed. The mean discrepancy was 0.58s, or 11.2 percent of the mean observed T_z; this appeared to have no direct relation either to recorded wave height at the site or to the offshore boundary conditions input. In work at Start Bay, S Devon, King and Hardcastle (personal communication) noted that observed wave data lost height and waves increased their period as they travelled inshore. King and Hardcastle attributed this to differences in instrumentation. In the present case the difference between observed and predicted T_z may reflect the sensitivity of Waverider buoys to short period waves, possibly in excess of the theory used in the computations.

4. CONCLUSIONS

There is widespread agreement between the observed and the computed wave climates. For example, long-term wave data from Aldeburgh, Dunwich and Southwold suggest little difference in the wave regime at any of these sites. Computations for predicted wave energy levels at Dunwich and Southwold agree with this view. This should not be taken to mean that wave energy coefficients are constant along this whole length of coast. Indeed, they suggest a concentration of energy in the Sizewell area, especially for wave headings between 230° and 300°. Wave refraction calculations also suggest that, particularly where waves come from the direction of maximum fetch (heading 210°), there are energy foci along the coast, notably between Sizewell and Thorpe Ness.

Only when wave heights exceed a certain threshold (observed mean $\sim$ 2.4 m; predicted mean $\sim$ 2.3 m) do observed and predicted values disagree with observed values being smaller. This is attributed to the filtering effect of the offshore Sizewell-Dunwich banks and it means that under atypically severe conditions the Dunwich coastline benefits from a degree of sheltering which would not occur in the absence of the banks themselves.

Vincent (1979) noted that the Dunwich area was one of two locations where his longshore sediment transport model of the East Anglian coast did not agree with the prototype. It may well be that the 'filtering effect' under extreme wave conditions is, at least in part, the explanation of this.

5. ACKNOWLEDGEMENTS

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MIAS REF. NO. 439 — ONE DEGREE SQUARE 1401 28

LOCATION
- Position: 52°09′ N 001°37′ E
- Period covered: Start date: 15 Apr 1975 End date: 31 Dec 1977
- Location: Aldeburgh, Suffolk, U.K. Sea area: North Sea.
- Mean water depth: 6 m
- Mean tidal range: 2.3 m (Spring) 1.7 m (Neap)
- Maximum currents: m/sec.

DATA CONTACT
- Organisation: Marine Information and Advisory Service,
- Address: Institute of Oceanographic Sciences, Wormley, Godalming, Surrey GU8 5UB, U.K.
- Report title: Waves Recorded at Aldeburgh, Dunwich & Southwold on the E Coast of England. IOS Report 65, 1979.

INSTRUMENT
- Instrument type: F.M. pressure unit
- Type of mounting: Tripod on sea bed
- Record duration: 10 min.
- Record interval: 3 hr.

REASON FOR RECORDING Comparative study of wave climates on the East Coast of England.

FORM AND MEDIUM OF DATA
- Original data: Frequency modulated magnetic tape.
- Processed data: Listings of Tucker-Draper statistics as printout or on digital magnetic tape.
- Analysed data: Most standard analysis presentations.

NOTES

Data collected by:
Institute of Oceanographic Sciences, U.K.

MIAS REF. NO. 440 — ONE DEGREE SQUARE 1401 28

LOCATION
- Position: 52°17′ N 001°39′ E
- Period covered: Start date: 15 Apr 1975 End date: 31 Dec 1977
- Location: Dunwich, Suffolk, U.K. Sea area: North Sea.
- Mean water depth: 8 m
- Mean tidal range: 2.1 m (Spring) 1.4 m (Neap)
- Maximum currents: m/sec.

DATA CONTACT
- Organisation: Marine Information and Advisory Service,
- Address: Institute of Oceanographic Sciences, Wormley, Godalming, Surrey GU8 5UB, U.K.
- Report title: Waves Recorded at Aldeburgh, Dunwich & Southwold on the E Coast of England. IOS Report 65, 1979.

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NOTES

Data collected by:
Institute of Oceanographic Sciences, U.K.

TABLE 1 a: Wave data listing in Marine Information Advisory Service (MIAS) records.
Aldeburgh and Dunwich until 31 December 1977

MIAS REF. NO. 441	ONE DEGREE SQUARE 1401 28
LOCATION	
Position:	52°20′ N 001°42′ E
Period covered:	Start date: 13 Jan 1975 End date: 22 Aug 1976
Location:	Southwold, Suffolk, U.K. Sea area: North Sea.
Mean water depth:	8 m
Mean tidal range:	2.0 m (Spring) 1.3 m (Neap)
Maximum currents:	m/sec.
DATA CONTACT	
Organisation:	Marine Information and Advisory Service,
Address:	Institute of Oceanographic Sciences, Wormley, Godalming, Surrey GU8 5UB, U.K.
Report title:	Waves Recorded at Aldeburgh, Dunwich & Southwold on the E Coast of England. IOS Report 65, 1979.
INSTRUMENT	
Instrument type:	F.M. pressure unit
Type of mounting:	Tripod on sea bed
Record duration:	10 min.
Record interval:	3 hr.
REASON FOR RECORDING	Comparative study of wave climates on the East Coast of England.
FORM AND MEDIUM OF DATA	
Original data:	Frequency modulated magnetic tape.
Processed data:	Listings of Tucker-Draper statistics as printout or on digital magnetic tape.
Analysed data:	Most standard analysis presentations.
NOTES	Data collected by: Institute of Oceanographic Sciences, U.K.

TABLE 1b: Wave data listing in Marine Information Advisory Serivce (MIAS) records.

Southwold until 22 August 1976.

DATE		SITE: Aldeburgh (FM Pressure Recorders)	SITE: Dunwich (FM Pressure Recorders)	SITE: Southwold (FM Pressure Recorders)	SITE: Dunwich Inshore (Waverider Buoys)	SITE: Dunwich Offshore (Waverider Buoys)
1977	Jan					
	Feb			6		
	March					
	April					
	May	a	a			
	June					
	July					15
	Aug					
	Sept					
	Oct					
	Nov					
	Dec					
1978	Jan					
	Feb			15		
	March		b			
	April					
	May					
	June					
	July					
	Aug					
	Sept					
	Oct				26	
	Nov					
	Dec					
1979	Jan					
	Feb				c	2c
	March					
	April		b			
	May	25	25		25	24

This table omits minor gaps in the records obtained, eg due to tape faults, power failures, etc. Numbers represent start and end dates of records, in respective months.

a: Records used for Wave Data Report (IOS Report No 65; by Fortnum and Hardcastle, 1979a). June 1975 to May 1977 inclusive.

b: Records from 7 March 1978 to 25 April 1979 at Dunwich used for beach volume change comparison

c: Records for February 1979 used for offshore/inshore wave comparison.

TABLE 2: Available wave data: 1 January 1977 to 25 May 1979.

OFFSHORE

Date	Buoy No
15.7.77-11.4.78	6851
11.4.78-26.10.78	67041
26.10.78-early 12.78	67144
2.2.79-24.5.79	67041

INSHORE

26.10.78-25.5.79	6489

TABLE 3: Waverider deployments: Sizewell-Dunwich.

a) ALDEBURGH

Wind Direction °T	Geometric Fetch km	Effective Fetch km
340	0.0	511.3
350	0.0	544.6
0	0.0	554.2
10	0.0	548.9
20	667.5	536.7
30	661.5	478.4
40	579.0	449.2
50	487.5	400.5
60	442.5	349.8
70	184.5	277.4
80	169.5	229.2
90	153.0	184.8
100	136.5	149.4
110	123.0	122.6
120	123.0	115.0
130	115.5	108.9
140	111.0	105.2
150	109.5	99.9
160	108.0	99.3
170	106.5	97.7
180	115.5	95.6
190	70.5	92.6
200	0.0	88.6
210	0.0	82.2
220	0.0	74.0
230	0.0	54.0

b) DUNWICH

Wind Direction °T	Geometric Fetch km	Effective Fetch km
340	0.0	2.2
350	0.0	2.7
0	0.0	192.1
10	0.0	256.3
20	2.9	297.6
30	3.8	301.6
40	832.5	297.0
50	478.5	285.3
60	435.0	267.2
70	184.5	264.1
80	169.5	250.0
90	157.5	186.3
100	141.0	152.6
110	132.0	127.1
120	123.0	120.2
130	126.0	115.0
140	118.5	111.7
150	117.0	101.3
160	115.5	98.5
170	115.5	95.1
180	124.5	89.9
190	2.3	83.5
200	0.0	74.9
210	0.0	63.5
220	0.0	45.8
230	0.0	1.7

c) SOUTHWOLD

Wind Direction °T	Geometric Fetch km	Effective Fetch km
320	0.0	0.8
330	0.0	1.2
340	0.0	149.1
350	0.0	243.7
0	1.0	338.4
10	2.0	378.0
20	649.5	402.5
30	642.0	397.1
40	825.0	381.0
50	471.0	384.4
60	429.0	369.8
70	180.0	307.3
80	166.5	248.2
90	157.5	186.0
100	142.5	153.5
110	133.5	129.1
120	133.5	123.3
130	130.5	118.8
140	121.5	115.8
150	120.0	111.2
160	121.5	101.5
170	121.5	89.1
180	127.5	75.2
190	185.5	67.1
200	13.0	57.6
210	1.9	46.5
220	1.0	33.6
230	0.0	17.6
240	0.0	3.8
250	0.0	1.2
260	0.0	0.8

TABLE 4: Geometric and effective fetches from a) Aldeburgh b) Dunwich c) Southwold.

Note: The remaining angles are occluded by land.

Bearing From Dunwich (°T)	Effective Fetch (km)	Wave Height H_s (m)	
		6 hours Duration	12 hours
340	2.2	[0.17	[0.17
350	2.7	0.18]	0.18
0	192.1	1.50	1.75]
10	256.3	1.50	1.80
20	297.6	1.50	1.80
30	301.6	1.50	1.80
40	297.0	1.50	1.80
50	285.3	1.50	1.80
60	267.2	1.50	1.80
70	264.1	1.50	1.80
80	250.0	1.50	1.80
90	186.3	1.50	[1.75
100	152.6	1.50	1.70
110	127.1	1.50	1.60
120	120.1	1.50	1.60
130	115.0	1.50	1.55
140	111.7	1.50	1.55
150	101.3	1.50	1.50
160	98.5	1.50	1.50
170	95.1	[1.45	1.45
180	89.9	1.40	1.40
190	83.5	1.35	1.35
200	74.9	1.30	1.30
210	63.5	1.20	1.20
220	45.8	0.95	0.95
230	1.7	0.15]	0.15]

Values of H_s bracketed are fetch limited.

TABLE 5a: Predicted wave heights (H_s) at Dunwich for a 10 ms^{-1} wind blowing for 6 and 12 hours.

Bearing From Southwold (°T)	Effective Fetch (km)	Wave Height H_s (m) Duration 6 hours	12 hours
320	0.8	[0.00	[0.00
330	1.2	0.05]	0.05]
340	149.1	1.50	1.70
50	243.7	1.50	1.80
0	338.4	1.50	1.80
10	378.0	1.50	1.80
20	402.5	1.50	1.80
30	397.1	1.50	1.80
40	381.0	1.50	1.80
50	384.4	1.50	1.80
60	369.8	1.50	1.80
70	307.3	1.50	1.80
80	248.2	1.50	1.80
90	186.0	1.50	[1.75
00	153.5	1.50	1.70
110	129.1	1.50	1.60
120	123.3	1.50	1.60
130	118.8	1.50	1.55
140	115.8	1.50	1.55
150	111.2	1.50	1.55
160	101.5	1.50	1.50
170	89.1	[1.45	1.45
180	75.2	1.30	1.30
190	67.1	1.25	1.25
200	57.6	1.10	1.10
210	46.5	0.85	0.85
220	33.6	0.80	0.80
230	17.6	0.50	0.50
240	3.8	0.22	0.22
250	1.2	0.05	0.05
260	0.8	0.00]	0.00]

Values of H_s bracketed are fetch limited.

TABLE 5b: Predicted wave heights (H_s) at Southwold for a 10 ms^{-1} wind blowing for 6 and 12 hours.

Bearing From Dunwich (°T)	Effective Fetch (km)	Wave Height H_s (m) Duration 6 hours	12 hours
340	2.2	[0.50	[0.50
350	2.7	0.55]	0.55
0	192.1	4.70	4.85
10	256.3	4.70	5.00]
20	297.6	4.70	5.20
30	301.6	4.70	5.20
40	297.0	4.70	5.20
50	285.3	4.70	[5.15
60	267.2	4.70	5.10
70	264.1	4.70	5.10
80	250.0	4.70	5.00
90	186.3	4.70	4.85
100	152.6	4.70	4.70
110	127.1	[4.50	4.50
120	120.1	4.40	4.40
130	115.0	4.35	4.35
140	111.7	4.35	4.35
150	101.3	4.25	4.25
160	98.5	4.25	4.25
170	95.1	4.20	4.20
180	89.9	4.00	4.00
190	83.5	3.95	3.95
200	74.9	3.70	3.70
210	63.5	3.35	3.35
220	45.8	2.75	2.75
230	1.7	0.40]	0.40]

Values of H_s bracketed are fetch limited.

TABLE 6a: Predicted wave heights (H_s) at Dunwich for a 20 ms^{-1} wind blowing for 6 and 12 hours.

Bearing From Southwold (°T)	Effective Fetch (km)	Wave Height H_s (m)	
		6 hours	12 hours
20	0.8	0.42	0.42
30	1.2	0.44	0.44
40	149.1	4.70	4.70
50	243.7	4.70	5.00
0	338.4	4.70	5.20
10	378.0	4.70	5.20
20	402.5	4.70	5.20
30	397.1	4.70	5.20
40	381.0	4.70	5.20
50	384.4	4.70	5.20
60	369.8	4.70	5.20
70	307.3	4.70	5.10
80	248.2	4.70	5.00
90	186.0	4.70	4.80
100	153.5	4.70	4.70
110	129.1	4.50	4.50
120	123.3	4.40	4.40
130	118.8	4.40	4.40
140	115.8	4.40	4.40
150	111.2	4.30	4.30
160	101.5	4.25	4.25
170	89.1	4.05	4.05
180	75.2	3.80	3.80
190	67.1	3.50	3.50
200	57.6	3.10	3.10
210	46.5	2.80	2.80
220	33.6	2.30	2.30
230	17.6	1.25	1.25
240	3.8	0.66	0.66
250	1.2	0.44	0.44
260	0.8	0.42	0.42

Values of H_s bracketed are fetch limited.

TABLE 6b: Predicted wave heights (H_s) at Southwold for a 20 ms^{-1} wind blowing for 6 and 12 hours.

Wave period	Wave heading at offshore grid boundary						
	210°	225°	240°	270°	300°	330°	360°
6.5s	*	*	*	*	*	*	*
7.5s	*	*	*	*	*	*	*

TABLE 7: Ray tracking: Range of wave periods and offshore wave directions. (All sets of computations were carried out at both Chart Datum (CD) + 0.5 m and CD + 2.5 m.) In addition, in order to provide comparisons with Robinson (1980) the program was run at a water level of CD + 2.0 m, wave period 8s and heading of 247½° (ie from the ENE).

Day	Time	Input Offshore			TARGET 1 Offshore W/rider location Observed		Predicted			TARGET 2 Inshore W/rider location Observed		Predicted			TARGET 3 Southwold Predicted			TARGET 4 Dunwich Predicted			TARGET 5 Dunwich Predicted			Water level
		H_s	T_z	θ_m	H_s	T_z	H_s	T_z	θ_m	H_s	T_z	H_s	T_z	θ_m	H_s	T_z	θ_m	H_s	T_z	θ_m	H_s	T_z	θ_m	m
12	13.30	2.19	5.13	320	2.08	6.11	2.08	6.10	316	9.25	5.55	2.19	6.20	310	2.03	6.38	298	2.36	6.42	299	1.92	6.38	288	2-3
12	16.30	1.59	4.54	350	1.48	5.62	1.28	5.60	334	1.37	5.85	1.20	5.68	325	1.35	5.84	306	1.46	5.85	307	0.97	5.66	295	0-1
12	19.30	1.54	4.33	350	1.43	5.45	1.20	5.42	334	1.18	5.91	1.10	5.47	326	1.06	5.72	309	1.04	5.71	308	0.78	5.75	297	2-3
13	07.30	1.05	3.29	320	0.94	4.60	0.76	4.67	316	1.06	5.26	0.77	4.70	311	0.83	4.75	298	0.88	4.77	299	0.71	4.73	315	0-1
21	10.30	0.47	2.04	330	0.36	3.57	0.06	4.07	323	0.28	3.58	0.06	4.07	318	0.05	4.08	303	0.06	4.08	303	0.05	4.08	300	0-1
21	19.30	0.42	1.94	330	0.31	3.49	0.03	4.05	323	0.22	3.89	0.03	4.05	318	0.03	4.05	302	0.03	4.05	302	0.03	4.05	291	2-3

TABLE 8a: Input data and observed and predicted significant wave height, period and direction (θ) for targets in Sizewell-Dunwich Banks area. Wave heading (θ_m) 315°-360°. February 1979.

Water levels refer to predicted heights above Chart Datum (LAT).

H_s in metres;

T_z in seconds;

θ_m in degrees from true N.

Day	Time	Input Offshore			TARGET 1 Offshore W/rider location Observed		TARGET 1 Predicted			TARGET 2 Inshore W/rider location Observed		TARGET 2 Predicted			TARGET 3 Southwold Predicted			TARGET 4 Dunwich Predicted			TARGET 5 Sizewell Predicted			Water level m
		H_s	T_z	θ_m	H_s	T_z	H_s	T_z	θ_m	H_s	T_z	H_s	T_z	θ_m	H_s	T_s	θ_m	H_s	T_z	θ_m	H_s	T_z	θ_m	
8	13.30	1.49	3.88	190	1.06	5.06	0.73	5.0	228	0.90	5.16	0.48	5.14	244	0.46	5.32	260	0.43	5.36	264	0.71	5.21	252	0-1
8	16.30	1.67	3.35	210	1.20	4.61	0.93	4.71	235	0.92	4.53	0.70	4.75	251	0.71	4.84	264	0.67	4.86	268	0.96	4.81	257	0-1
14	01.30	4.07	5.00	220	3.08	6.02	3.18	5.99	240	2.17	5.81	2.65	6.11	255	2.58	6.33	266	2.43	6.39	270	3.32	6.32	258	2-3
14	04.30	4.60	6.29	220	3.49	7.12	3.83	7.15	240	2.51	5.63	3.31	7.31	257	3.84	7.44	268	3.79	7.51	272	4.62	7.33	262	0-1
14	16.30	5.80	7.06	210	4.43	7.78	4.46	7.84	235	2.59	5.97	3.63	3.02	232	4.17	8.15	266	4.13	8.24	270	5.18	8.02	260	0-1
14	19.30	5.43	5.87	200	4.14	6.76	3.60	6.75	232	2.87	6.51	2.66	6.87	257	2.92	7.03	263	2.88	7.15	267	3.86	6.88	257	0-1
14	22.30	4.99	5.33	200	3.64	6.30	3.08	6.27	232	2.74	6.08	2.27	6.42	247	2.05	6.75	261	1.86	6.88	265	3.00	6.70	252	2-3
15	01.30	4.82	5.48	210	3.66	6.43	3.51	6.41	236	2.68	6.34	2.78	6.54	250	2.68	6.84	264	2.49	6.94	267	3.63	6.81	255	2-3
15	04.30	5.22	6.90	210	3.98	7.64	4.00	7.69	236	2.52	6.24	3.25	7.87	252	3.73	8.00	266	3.70	8.09	270	4.64	7.87	260	0-1
15	10.30	5.06	5.47	210	3.85	6.42	3.69	6.40	236	-	-	2.92	6.53	251	2.81	6.83	264	2.61	6.93	267	3.81	6.80	255	2-3
16	10.30	3.00	4.22	220	2.24	5.35	2.19	5.35	240	1.80	3.19	1.78	5.43	254	1.65	5.58	266	1.53	5.62	270	2.13	5.58	258	2-3
16	13.30	2.56	1.47	210	1.90	3.00	-	-	-	1.43	5.17	-	-	-	-	-	-	-	-	-	-	-	-	2-3
16	16.30	2.57	4.50	220	1.75	5.59	1.80	5.58	240	1.40	4.78	1.48	5.66	256	1.66	5.79	267	1.61	5.82	271	2.07	5.73	260	0-1
16	22.30	1.96	3.12	220	1.43	4.41	1.09	4.56	240	1.16	4.49	0.85	4.58	254	0.73	4.65	267	0.66	4.67	270	0.94	4.64	258	2-3
17	10.30	1.91	2.78	220	1.39	4.12	0.85	4.37	240	1.14	4.40	0.66	4.38	254	0.55	4.42	266	0.50	4.43	271	0.72	4.41	258	2-3
17	13.30	1.14	3.25	220	1.26	4.53	1.02	4.64	240	0.96	4.21	0.80	4.67	254	0.70	4.75	267	0.63	4.76	270	0.90	4.74	258	2-3
17	16.30	1.70	4.06	220	1.23	5.17	1.21	5.19	240	1.08	4.46	0.99	5.25	255	1.09	5.36	267	1.04	5.38	271	1.37	5.32	260	0-1
17	22.30	2.09	3.11	210	1.53	4.40	1.05	6.55	235	1.01	5.13	0.76	4.58	250	0.62	4.65	264	0.55	4.67	268	0.86	4.63	255	2-3
18	10.30	2.51	3.28	200	1.08	4.55	0.73	4.67	232	0.68	5.28	0.51	4.70	247	0.49	4.81	262	0.46	4.83	266	0.72	4.76	254	0-1
18	13.30	1.21	3.28	210	0.84	4.55	0.65	4.66	235	0.55	4.95	0.48	4.69	250	0.39	4.78	264	0.35	4.81	268	0.54	4.76	255	2-3
19	13.30	0.90	3.21	220	0.60	4.49	0.52	4.62	240	0.44	5.30	0.41	4.64	254	0.35	4.72	267	0.32	4.73	270	0.46	4.71	258	2-3
19	16.30	0.25	3.55	180	0.56	4.78	0.32	4.89	225	0.45	4.67	0.18	4.95	241	0.11	5.10	257	0.08	5.25	261	0.21	5.04	247	2-3

TABLE 8b: Input data and observed and predicted significant wave height, period and direction (θ) for targets in Sizewell-Dunwich Banks area. Wave heading (θ_m)180°-225°. February 1979. Units as in Table 8a.

Day	Time	Input Offshore			TARGET 1 Offshore W/rider location Observed		Predicted			TARGET 2 Inshore W/rider location Observed		Predicted			TARGET 3 Southwold Predicted			TARGET 4 Dunwich Predicted			TARGET 5 Sizewell Predicted			Water level
		H_s	T_z	θ_m	H_s	T_z	H_s	T_z	θ_m	H_s	T_z	H_s	T_s	θ_m	H_s	T_z	θ_m	H_s	T_z	θ_m	H_s	T_z	θ_m	m
8	19.30	1.12	3.15	230	1.00	4.38	0.68	4.58	244	0.94	4.38	0.56	4.60	258	0.51	4.66	270	0.47	4.68	273	0.62	4.60	261	2-3
9	07.30	1.44	2.72	260	1.31	4.00	0.74	4.34	264	1.24	4.06	0.69	4.35	273	0.67	4.37	279	0.65	4.38	283	0.71	4.37	269	2-3
9	10.30	1.41	2.56	260	1.28	3.86	0.61	4.26	264	1.14	4.19	0.57	4.27	273	0.54	4.29	280	0.53	4.29	283	0.58	4.29	269	2-3
9	13.30	1.38	3.01	260	1.25	4.25	0.88	4.50	263	1.33	4.18	0.85	4.53	275	0.92	4.55	278	0.93	4.56	281	1.00	4.55	269	0-1
9	22.30	2.20	3.23	260	2.06	4.45	1.56	4.63	263	1.99	5.06	1.48	4.60	274	1.46	4.70	279	1.43	4.72	282	1.56	4.71	269	2-3
10	01.30	2.32	4.25	260	2.23	5.34	2.13	5.38	263	2.11	4.98	2.17	5.47	275	2.44	5.53	277	2.47	5.55	281	2.60	5.51	269	1-0
10	07.30	2.20	4.05	250	2.65	5.17	2.36	5.21	256	2.53	5.44	2.22	5.29	269	2.23	5.37	275	2.19	5.41	279	2.51	5.39	260	2-3
10	16.30	2.99	4.59	250	2.83	5.64	2.70	5.66	256	2.37	5.41	2.65	5.77	270	3.02	5.84	274	3.02	5.86	278	3.35	5.81	267	0-1
11	01.30	2.94	4.82	250	2.78	5.84	2.71	5.85	256	2.22	5.43	2.68	5.97	270	3.07	6.05	274	3.08	6.07	278	3.38	6.01	267	0-1
11	07.30	3.00	4.21	240	2.84	5.31	2.48	5.34	250	2.48	5.60	2.25	5.42	263	2.23	5.53	272	2.16	5.57	276	2.61	5.54	263	2-3
11	19.30	2.95	4.46	260	2.79	5.53	2.69	5.54	263	2.55	5.79	2.68	5.64	274	2.76	5.72	278	2.77	5.78	282	2.90	5.75	269	2-3
12	07.30	2.78	4.43	260	2.63	5.50	2.52	5.51	263	2.20	5.86	2.51	5.61	274	2.59	5.75	278	2.60	5.75	282	2.80	5.72	269	2-3
13	01.30	1.28	4.48	260	1.16	5.54	1.17	5.55	263	0.76	4.63	1.16	5.65	274	1.20	5.74	278	1.21	5.80	282	1.30	5.76	269	2-3
13	13.30	1.30	4.05	260	1.18	5.17	1.13	5.21	263	0.78	4.41	1.11	5.29	274	1.13	5.36	278	1.12	5.40	282	1.21	5.38	269	2-3
13	16.30	1.12	3.40	240	1.00	4.77	0.79	4.74	250	1.41	4.48	0.71	4.79	264	0.77	4.84	272	0.75	4.85	275	0.90	4.83	264	0-1
15	13.30	3.99	5.68	230	3.81	6.60	3.47	6.59	245	2.67	6.35	3.12	6.74	259	3.21	6.96	269	3.11	7.02	273	3.93	6.94	261	2-3
15	16.30	3.91	6.63	240	3.73	7.43	3.75	7.47	250	2.28	5.70	3.69	7.65	266	4.31	7.75	272	4.32	7.81	276	4.83	7.67	266	0-1
15	19.30	3.40	5.32	240	3.23	6.28	3.11	6.28	250	2.58	6.48	2.97	6.42	266	3.42	6.52	272	3.39	6.55	276	3.89	6.66	266	0-1
15	22.30	3.41	5.37	240	3.24	6.32	3.09	6.32	250	2.58	5.82	2.91	6.46	264	3.01	6.63	271	2.96	6.68	276	3.53	6.46	263	2-3
16	01.30	3.04	4.89	230	2.88	5.90	2.5	5.90	245	2.38	5.82	2.23	6.02	259	2.23	6.19	269	2.13	6.24	273	2.73	6.19	261	2-3
16	04.30	2.96	5.57	240	2.71	6.50	2.65	6.50	250	1.83	5.16	2.55	6.66	266	2.94	6.75	272	2.92	6.79	276	3.34	6.68	266	0-1

TABLE 8c: Input data and observed and predicted significant wave height, period and direction (θ) for targets in the Sizewell-Dunwich banks area. Wave heading (θ_m) 225°-270°. February 1979. Units as in Table 8a.

Input Offshore θ°_m	H_s (m)	T_z (s)	Target 1 Offshore w/r θ°_m	H_c	E_c	Target 2 Inshore w/r θ^{c}_m	H_c	E_c	Target 3 Southwold θ°_m	H_c	E_c	Target 4 Dunwich θ^{c}_m	H_c	E_c	Target 5 Sizewell θ°_m	H_c	E_c	Water Level (m)
180	0.85	3.55	225	.379	.222	241	.211	.069	257	.124	.024	261	.097	.015	247	.244	.092	2-3
190	1.49	3.88	228	.489	.325	244	.322	.140	260	.309	.130	264	.291	.115	252	.475	.307	0-1
200	1.51	3.28	332	.483	.425	247	.337	.207	262	.327	.195	265	.305	.170	254	.475	.410	0-1
	4.79	5.33	232	.644	.452	247	.474	.245	261	.428	.200	265	.388	.164	252	.626	.427	2-3
	5.43	5.87	232	.663	.466	248	.490	.254	263	.538	.307	267	.530	.298	257	.711	.536	0-1
210	1.21	3.28	235	.540	.532	250	.395	.285	264	.326	.193	268	.288	.151	255	.448	.366	2-3
	1.67	3.55	235	.556	.537	251	.416	.301	264	.427	.316	268	.403	.282	257	.576	.577	0-1
	2.09	3.11	235	.502	.530	250	.365	.281	264	.297	.185	268	.261	.143	255	.409	.352	2-3
	4.82	5.48	236	.729	.574	251	.576	.359	264	.334	.556	267	.288	.517	255	.614	.754	2-3
	5.06	5.47	236	.729	.574	251	.576	.359	264	.334	.556	267	.288	.516	255	.613	.753	2-3
	5.22	6.90	236	.766	.606	252	.622	.400	266	.715	.528	270	.708	.518	260	.888	.815	0-1
	5.80	7.06	236	.768	.608	252	.626	.404	266	.719	.533	270	.713	.524	260	.893	.822	0-1
220	0.90	3.21	240	.577	.640	254	.450	.390	267	.392	.295	270	.356	.244	258	.505	.491	2-3
	1.70	4.01	240	.713	.665	255	.580	.441	267	.638	.532	271	.613	.491	260	.804	.845	0-1
	1.74	3.25	240	.586	.641	254	.458	.391	267	.400	.298	270	.364	.246	258	.516	.496	2-3
	1.91	2.78	240	.445	.636	254	.343	.378	267	.289	.268	271	.261	.218	258	.375	.450	2-3
	1.96	3.12	240	.554	.639	254	.431	.387	267	.289	.372	270	.338	.238	258	.481	.482	2-3
	2.37	4.50	240	.758	.680	256	.626	.464	267	.702	.583	271	.677	.543	260	.873	.903	0-1
	3.00	4.22	240	.729	.661	254	.592	.436	266	.378	.551	270	.511	.325	258	.629	.711	2-3
	4.60	6.29	240	.833	.724	257	.720	.541	268	.834	.727	272	.823	.707	262	1.004	1.053	0-1
	4.07	5.00	240	.781	.682	255	.651	.473	266	.635	.450	270	.596	.397	258	.817	.745	2-3
230	1.12	3.15	244	.604	.740	258	.499	.505	269	.453	.415	273	.421	.359	261	.554	.621	2-3
	3.04	4.89	254	.835	.786	259	.734	.609	269	.733	.606	273	.556	.702	261	.899	.912	2-3
	3.99	5.68	245	.870	.809	259	.781	.653	269	.694	.806	273	.648	.779	261	.985	1.037	2-3
240	1.12	3.40	250	.706	.839	264	.631	.669	272	.690	.801	275	.673	.762	264	.806	1.093	0-1
	2.86	5.57	250	.925	.920	266	.890	.851	272	1.029	1.139	276	1.022	1.122	266	1.166	1.462	0-1
	3.00	4.21	250	.828	.854	263	.700	.749	272	.686	.742	276	.644	.719	263	.871	.946	2-3
	3.40	5.32	250	.914	.911	266	.873	.832	272	1.007	1.106	276	.997	1.804	266	1.145	1.429	0-1
	3.41	5.37	250	.907	.895	264	.853	.791	271	.847	.883	276	.867	.817	263	1.036	1.168	2-3
	3.91	6.63	250	.958	.952	266	.942	.921	272	1.103	1.260	276	1.104	1.262	266	1.236	1.582	0-1
250	2.80	4.05	256	.843	.920	269	.794	.816	275	.797	.823	279	.784	.795	266	.896	1.039	2-3
	2.94	4.82	256	.922	.966	270	.912	.945	274	1.043	1.238	278	1.043	1.237	267	1.151	1.506	0-1
	2.99	4.59	256	.904	.956	270	.887	.921	274	1.011	1.196	278	1.009	1.190	267	1.119	1.464	0-1
260	1.28	4.48	263	.912	.988	274	.909	.982	278	.939	1.047	282	.942	1.055	269	1.014	1.222	2-3
	1.30	4.05	263	.867	.972	274	.850	.936	278	.866	.970	282	.862	.962	269	.933	1.126	2-3
	1.38	3.01	263	.639	.951	275	.612	.875	278	.670	1.046	281	.671	1.049	269	.722	1.216	0-1
	1.41	2.56	263	.431	.942	273	.401	.815	280	.385	.752	283	.372	.704	269	.409	.847	2-3
	1.44	2.72	264	.514	.943	273	.480	.823	279	.464	.769	282	.450	.723	269	.493	.868	2-3
	2.20	3.23	263	.708	.950	274	.673	.858	279	.665	.837	282	.650	.799	269	.709	.953	2-3
	2.38	4.25	263	.897	.995	275	.906	1.015	277	1.026	1.302	281	1.037	1.330	269	1.094	1.481	0-1
	2.78	4.43	263	.907	.986	274	.903	.977	278	.931	1.038	282	.934	1.044	269	1.006	1.211	2-3
	2.95	4.46	263	.910	.987	274	.907	.980	278	.936	1.043	282	.939	1.051	269	1.011	1.217	2-3
270	0.68	3.30	272	.743	.991	281	.746	1.001	281	.825	1.223	284	.840	1.266	271	.852	1.304	0-1
280	0.54	2.39	280	.341	.992	287	.341	.990	285	.366	1.141	288	.374	1.190	275	.367	1.146	0-1
	0.70	3.83	280	.862	1.026	293	.908	1.139	288	1.054	1.535	274	1.002	1.386	293	.908	1.139	0-1
	1.31	2.22	280	.235	.991	287	.234	.983	285	.250	1.121	288	.255	1.166	275	.251	1.129	0-1
290	1.17	3.79	290	.852	1.015	293	.891	1.111	289	.905	1.147	291	.915	1.173	278	.861	1.038	2-3
300	1.21	2.68	299	.507	.993	300	.519	1.038	291	.555	1.188	294	.579	1.293	281	.515	1.025	0-1
320	1.05	3.29	316	.724	.948	311	.733	.971	298	.786	1.118	300	.841	1.279	286	.672	.818	0-1
	2.19	5.13	316	.949	.996	310	.995	1.093	298	1.042	1.201	299	1.075	1.278	288	.851	.877	2-3
330	0.42	1.94	323	.077	.881	318	.073	.787	302	.063	.579	302	.063	.586	291	.049	.355	2-3
	0.47	2.04	323	.123	.882	318	.117	.800	303	.116	.783	303	.123	.881	291	.098	.560	0-1
350	1.54	4.33	334	.744	.782	326	.716	.624	309	.687	.575	308	.677	.558	297	.507	.313	2-3
	1.59	4.54	334	.804	.760	325	.754	.670	306	.848	.847	307	.921	.998	295	.608	.436	0-1

TABLE 9: Predicted wave height (H_c) and wave energy (E_c) coefficients for Waverider and coastal targets. Directions refer to wave headings. Input values are based on data collected during February 1979.

INPUT OFFSHORE $\theta°$	TARGET															NO OF SETS OF OBSERVATION
	1: OFFSHORE WAVERIDER			2: INSHORE WAVERIDER			3: SOUTHWOLD			4: DUNWICH			5: SIZEWELL			
	$\theta°_m$	H_c	E_c	$\theta°_m$	H_c	E_c	$\theta°_m$	H_c	E_c	$\theta°_m$	H_c	E_c	$\theta°_m$	H_c	E_c	
200-210	235	.638	.530	250	.488	.310	264	<u>.445</u>	<u>.357</u>	268	<u>.417</u>	<u>.328</u>	256	.625	.518	10
220-230	241	.690	.692	256	.572	.472	268	<u>.536</u>	<u>.492</u>	272	<u>.514</u>	<u>.437</u>	259	<u>.704</u>	<u>.729</u>	12
240-250	252	.879	.913	266	.831	.833	273	.913	1.021	277	.905	.914	265	1.047	1.299	9
260	263	.754	.968	274	.738	.918	278	<u>.765</u>	.978	282	<u>.717</u>	.969	269	<u>.821</u>	1.127	9
300-350	321	<u>.561</u>	<u>.892</u>	315	<u>.472</u>	<u>.855</u>	301	<u>.585</u>	<u>.899</u>	302	<u>.611</u>	<u>.939</u>	290	<u>.471</u>	<u>.626</u>	7

TABLE 10: Mean wave height (H_c) and mean wave energy (E_c) coefficients for Waverider and coastal targets. Values are means for all predictions within the offshore directional class ($\theta°_m$) and refer to wave headings. Where H_c and E_c are underlined the original data sets show a wide spread of values, especially for 300-350° (See Table 9). 180-190°, 270°-290° and 360° are omitted because of paucity of data. Input wave heights and periods are based on data collected during February 1979.

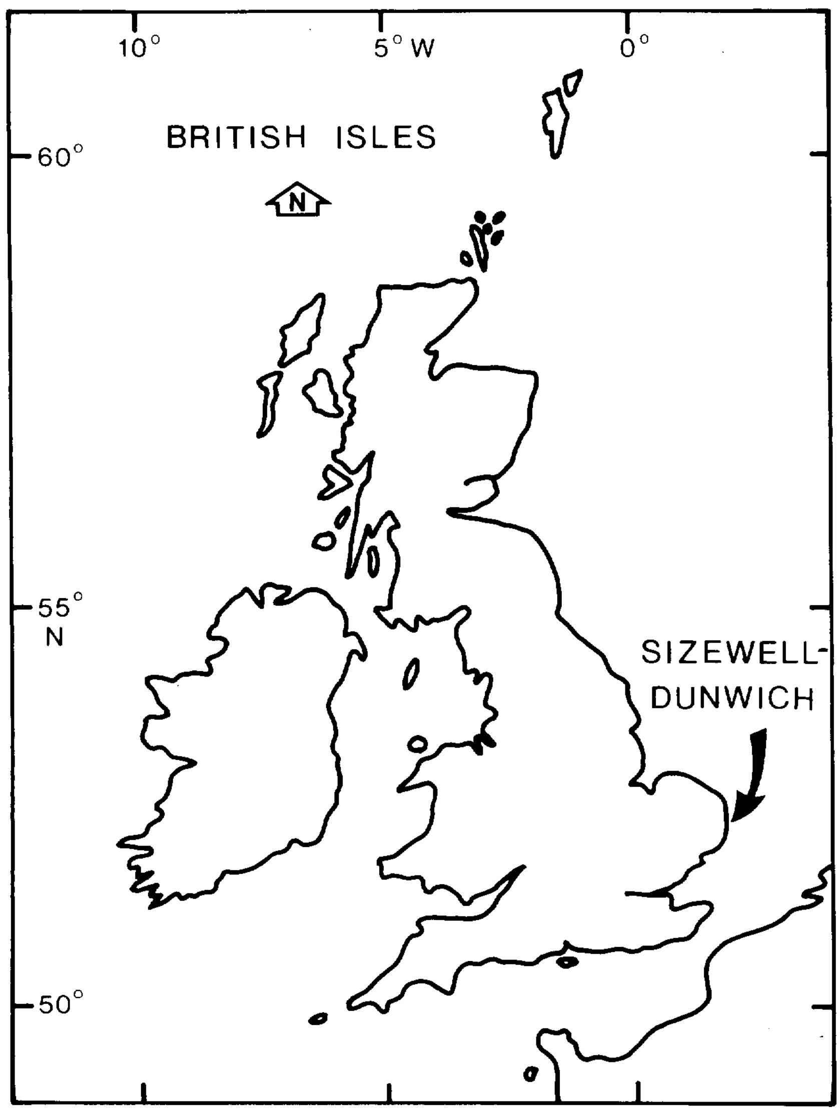


Figure 1: Location of study area.

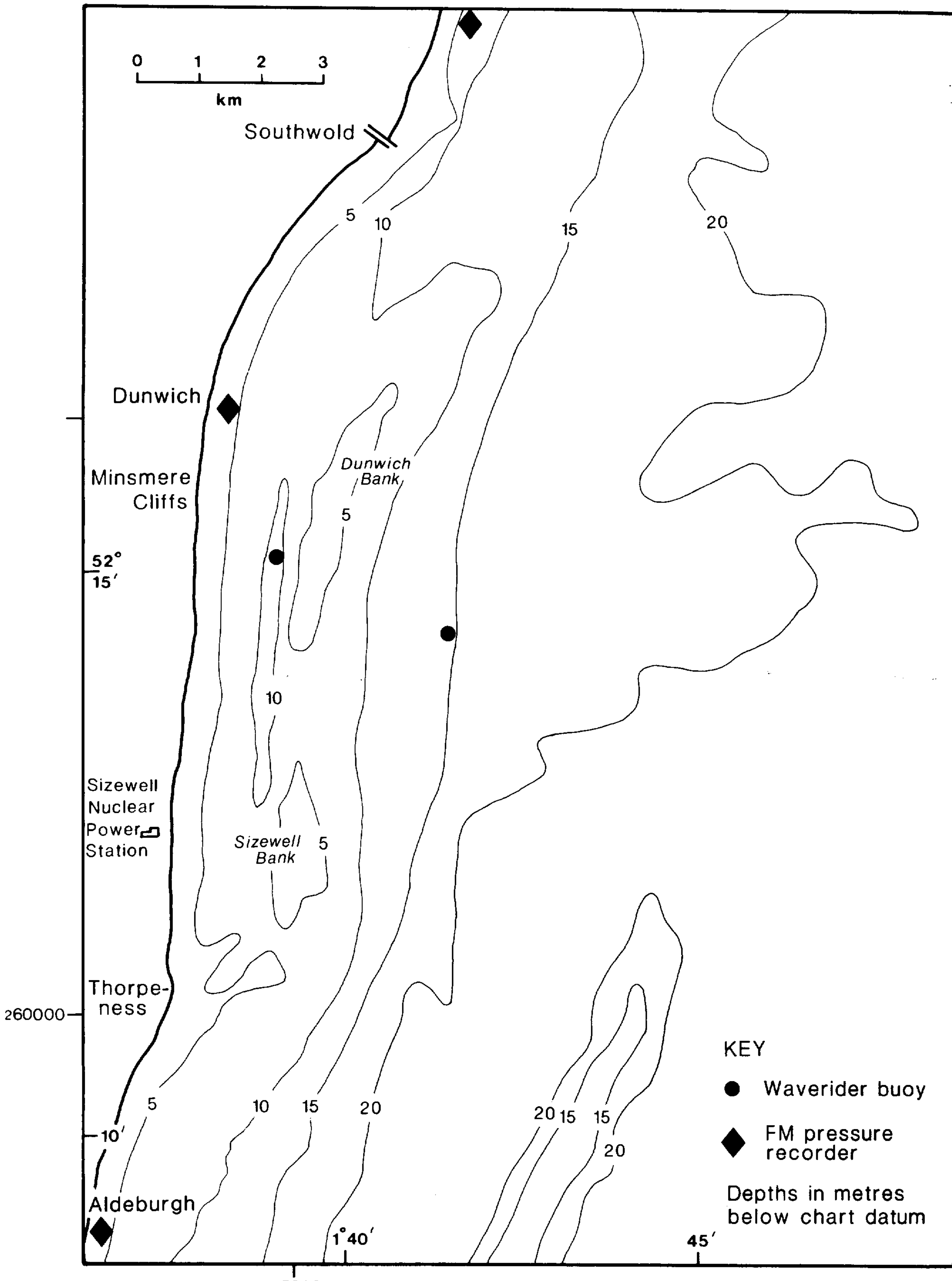


Figure 2: Location map (see also Figure 23).

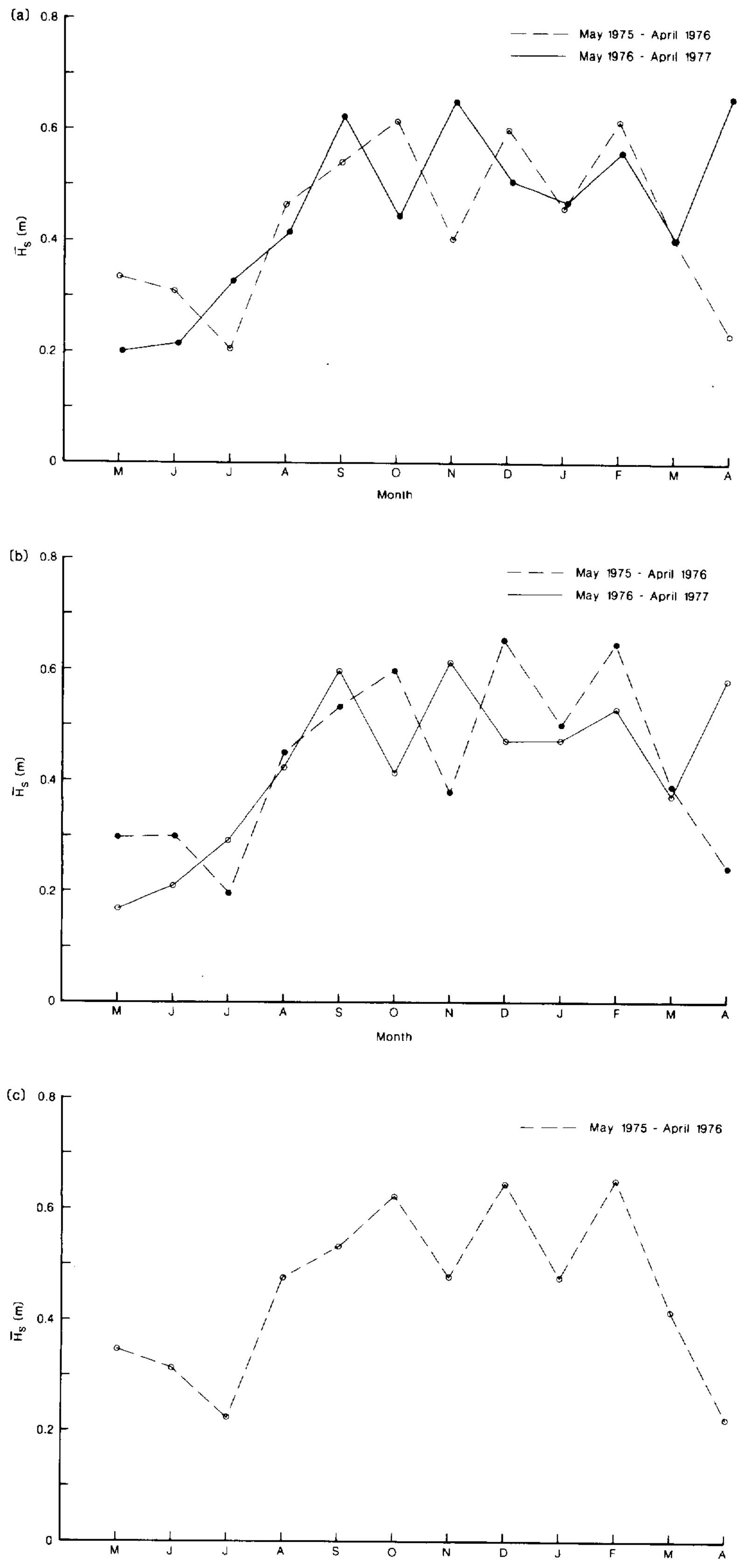
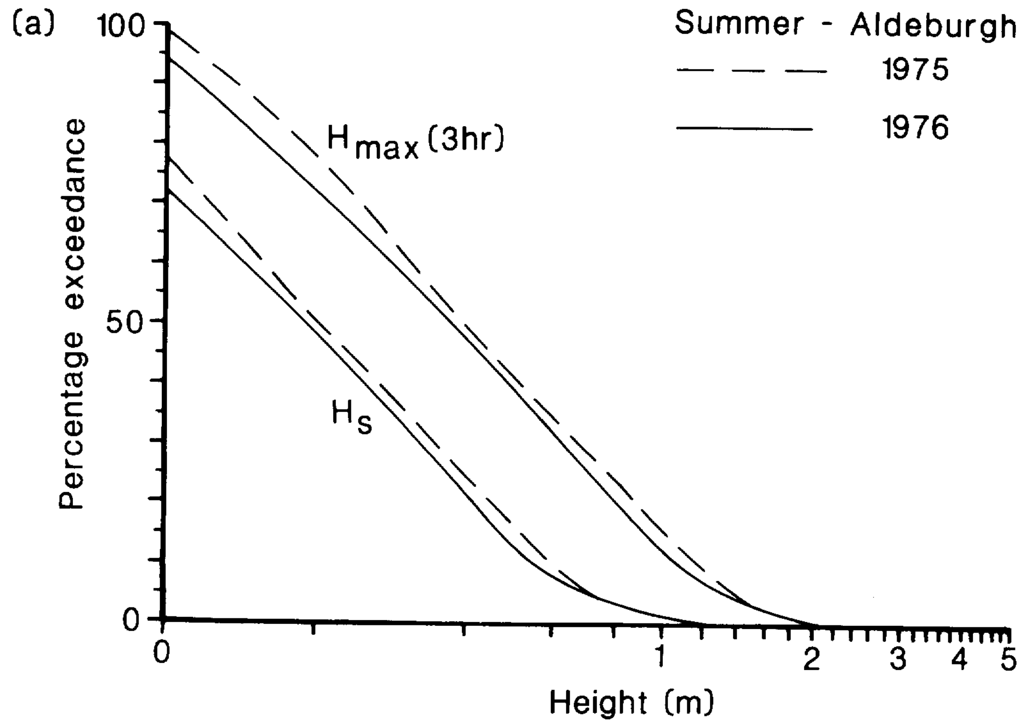


Figure 3: Seasonal variations in mean monthly wave height a) Aldeburgh
b) Dunwich
c) Southwold



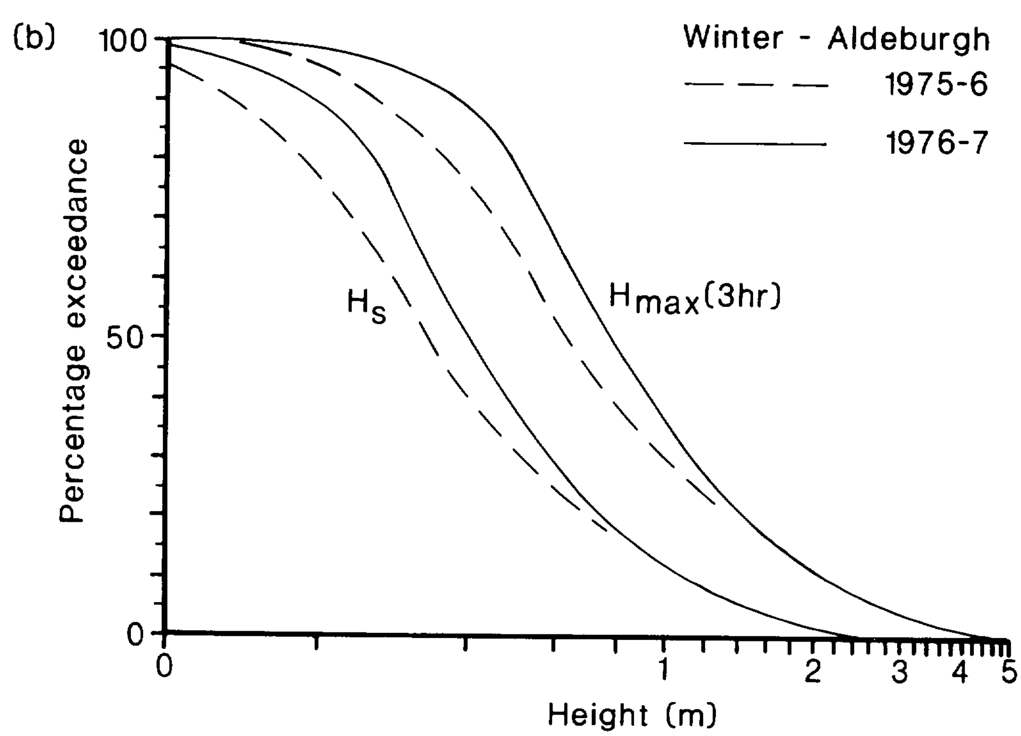


Figure 4: Percentage exceedance of H_s and H_{max} at Aldeburgh: a) Summer b) Winter.

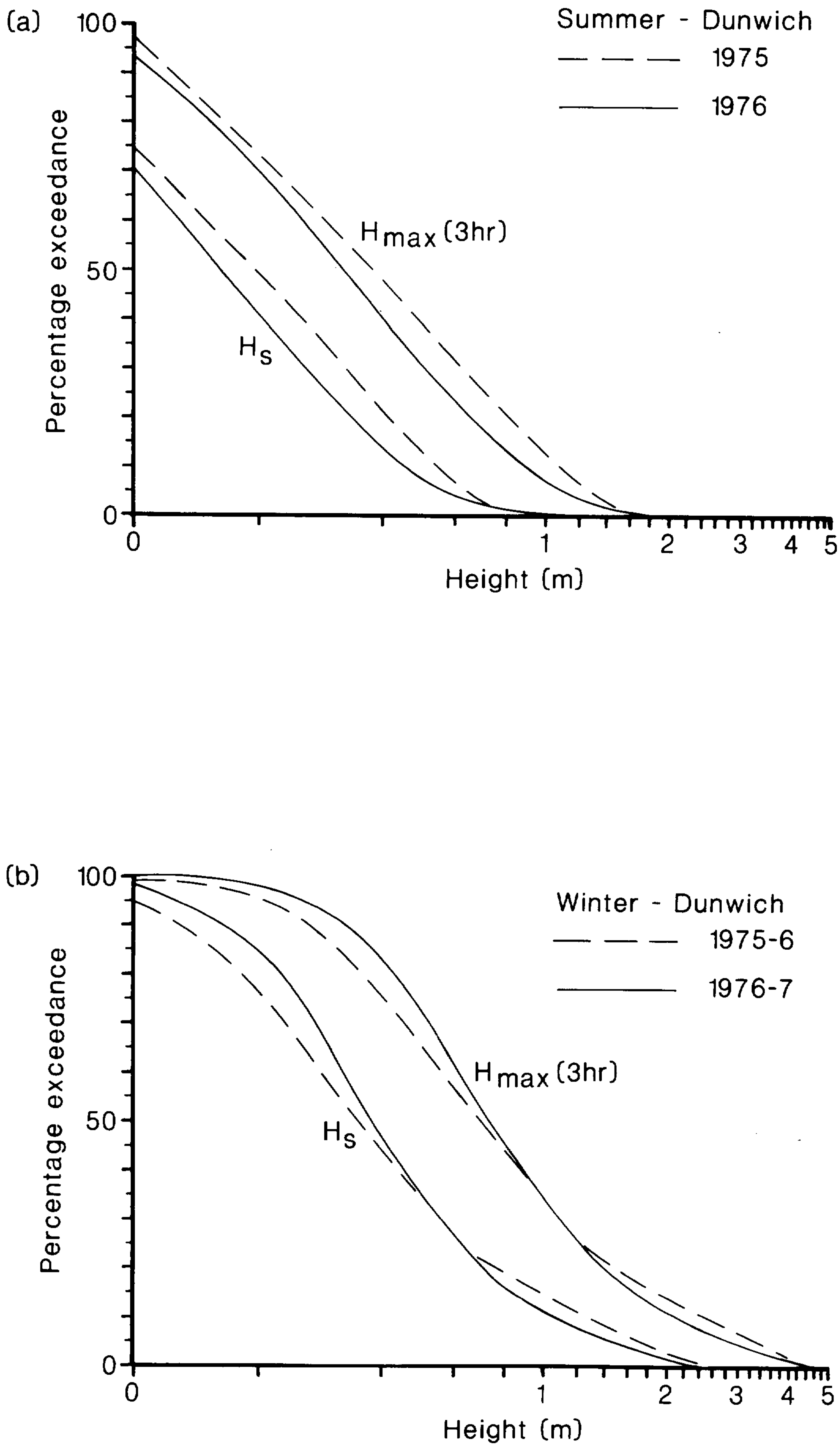


Figure 5: Percentage exceedance of H_s and H_{max} at Dunwich: a) Summer b) Winter.

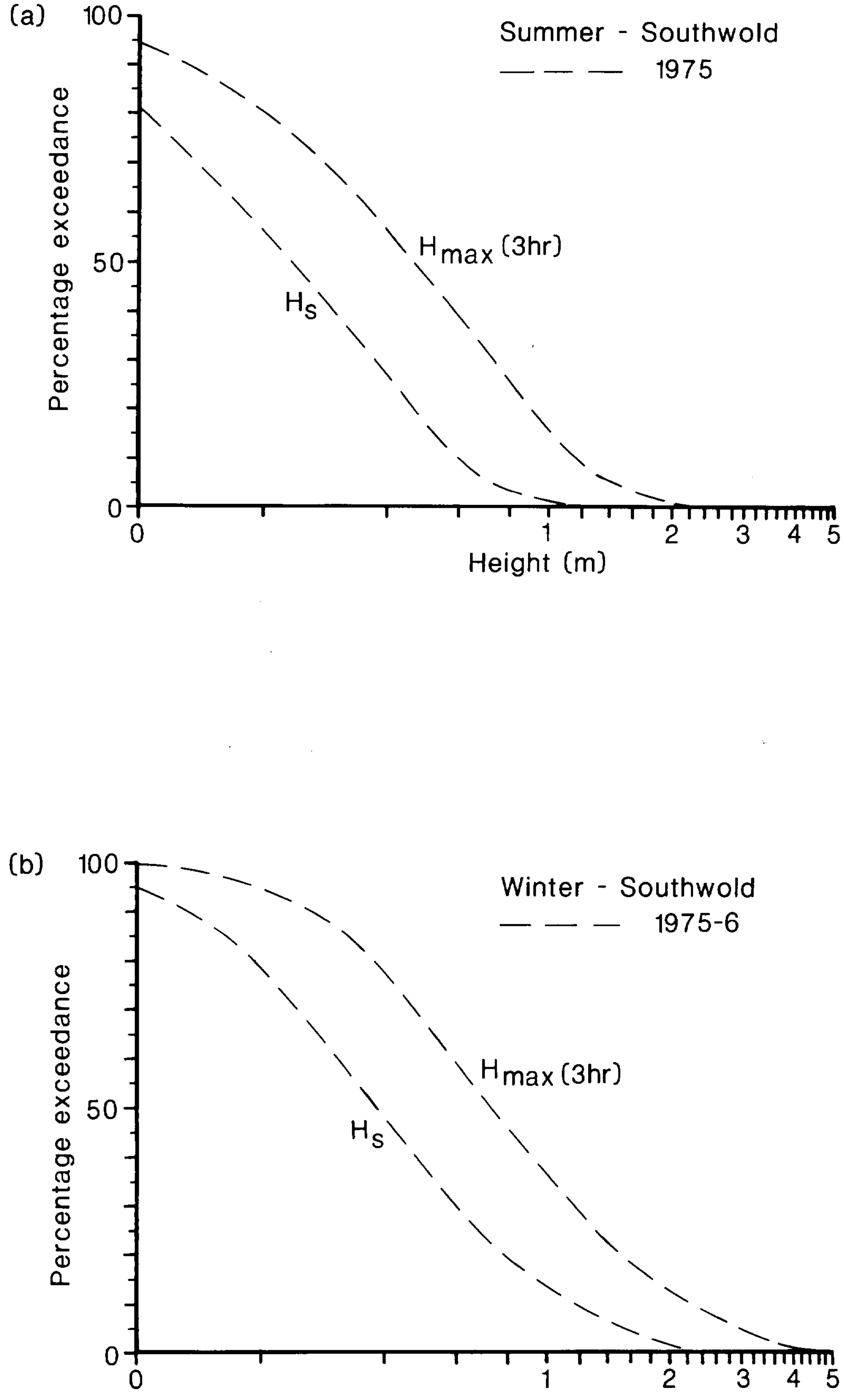


Figure 6: Percentage exceedance of H_s and H_{max} at Southwold: a) Summer b) Winter.

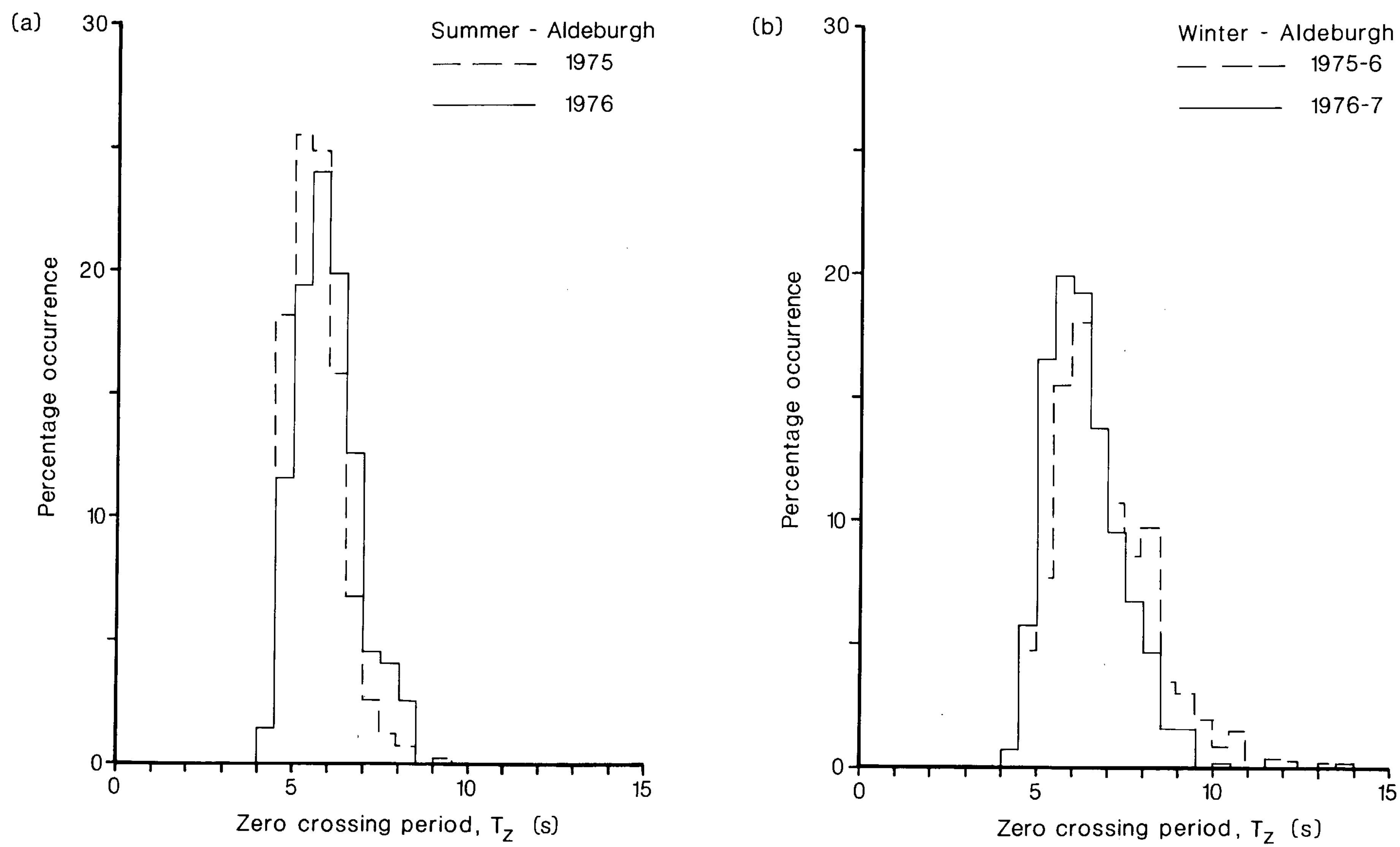


Figure 7: Frequency histograms of zero crossing period (T_z) in seconds: Aldeburgh a) Summer b) Winter

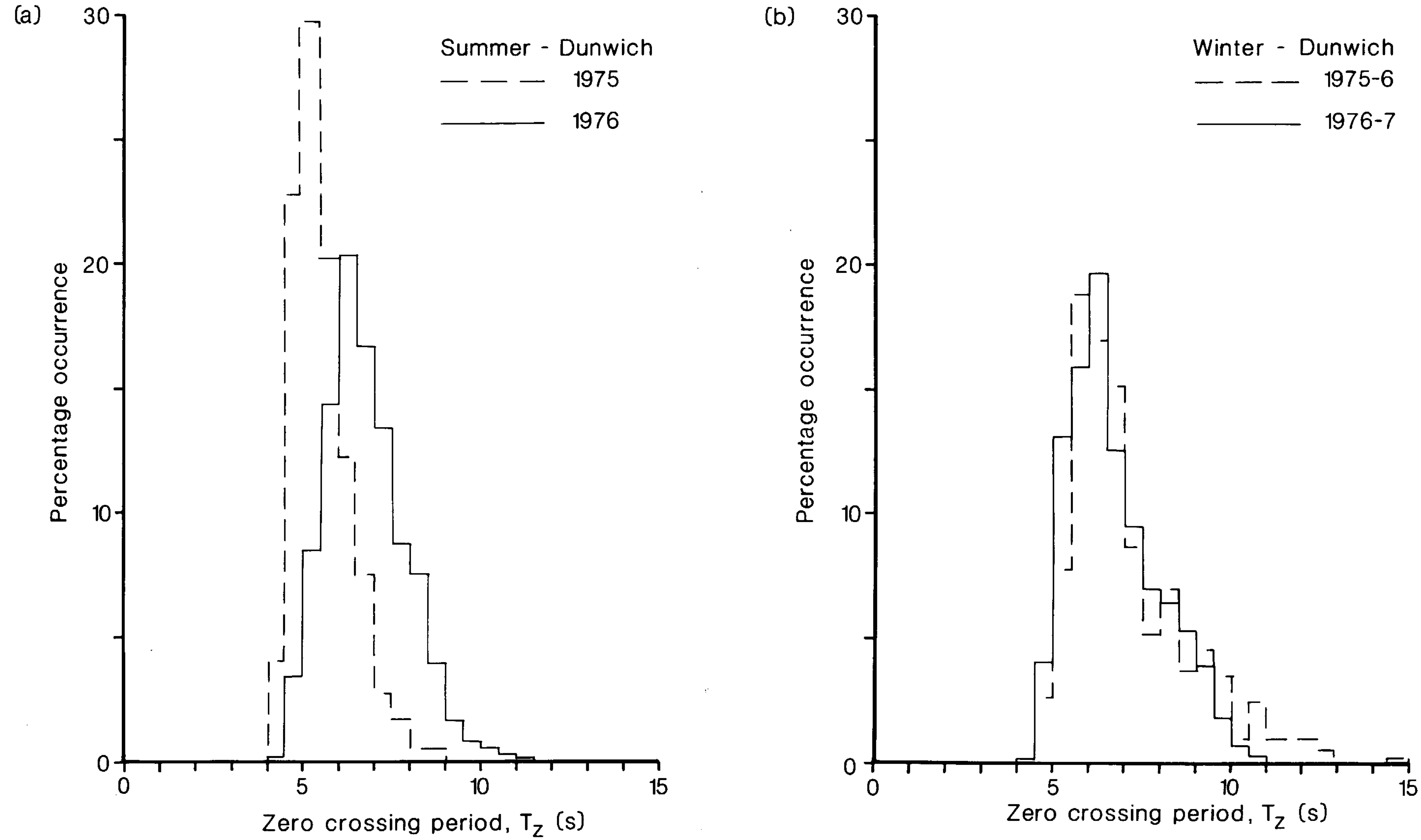


Figure 8: Frequency histograms of zero crossing period (T_z) in seconds: Dunwich a) Summer b) Winter.

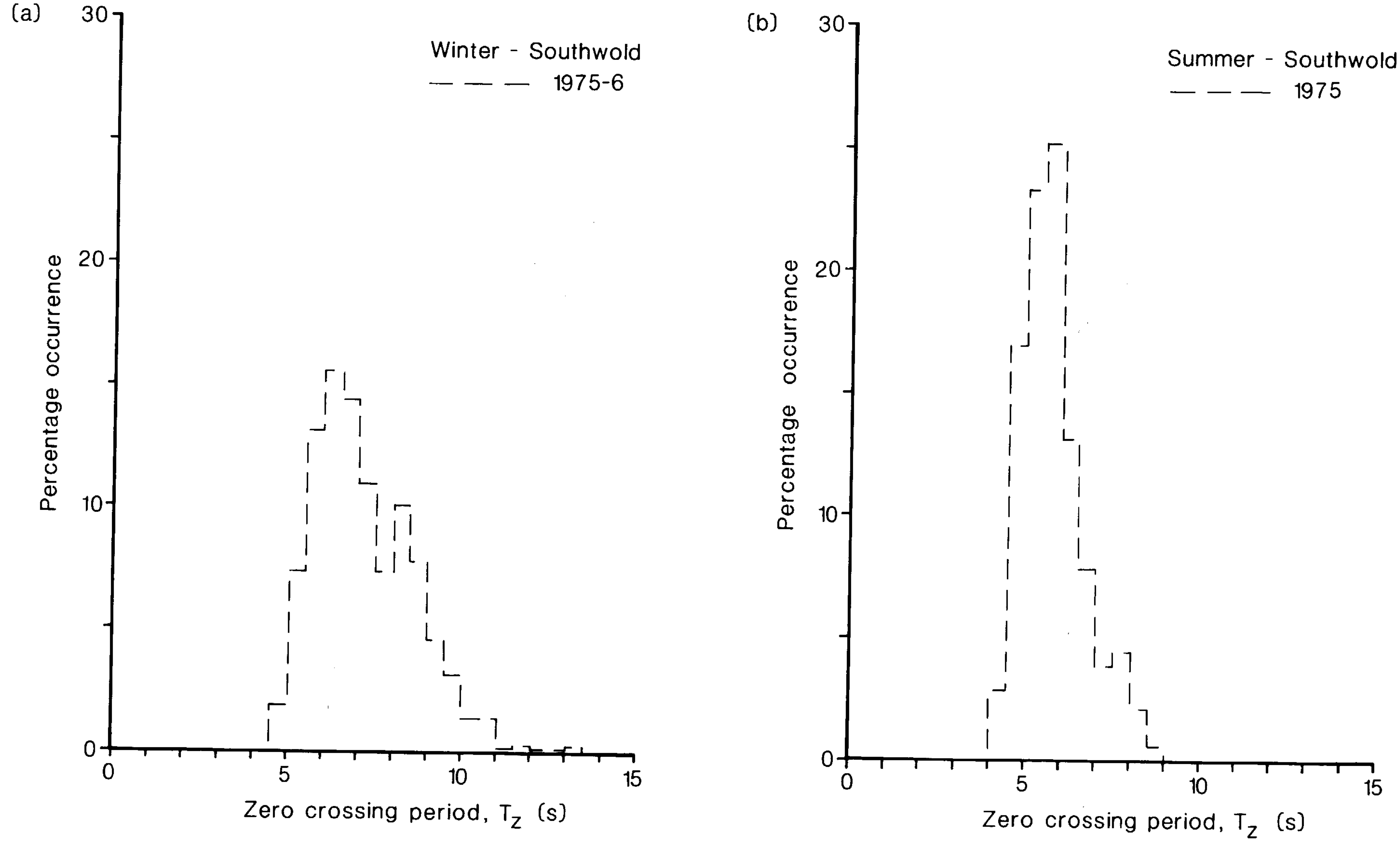
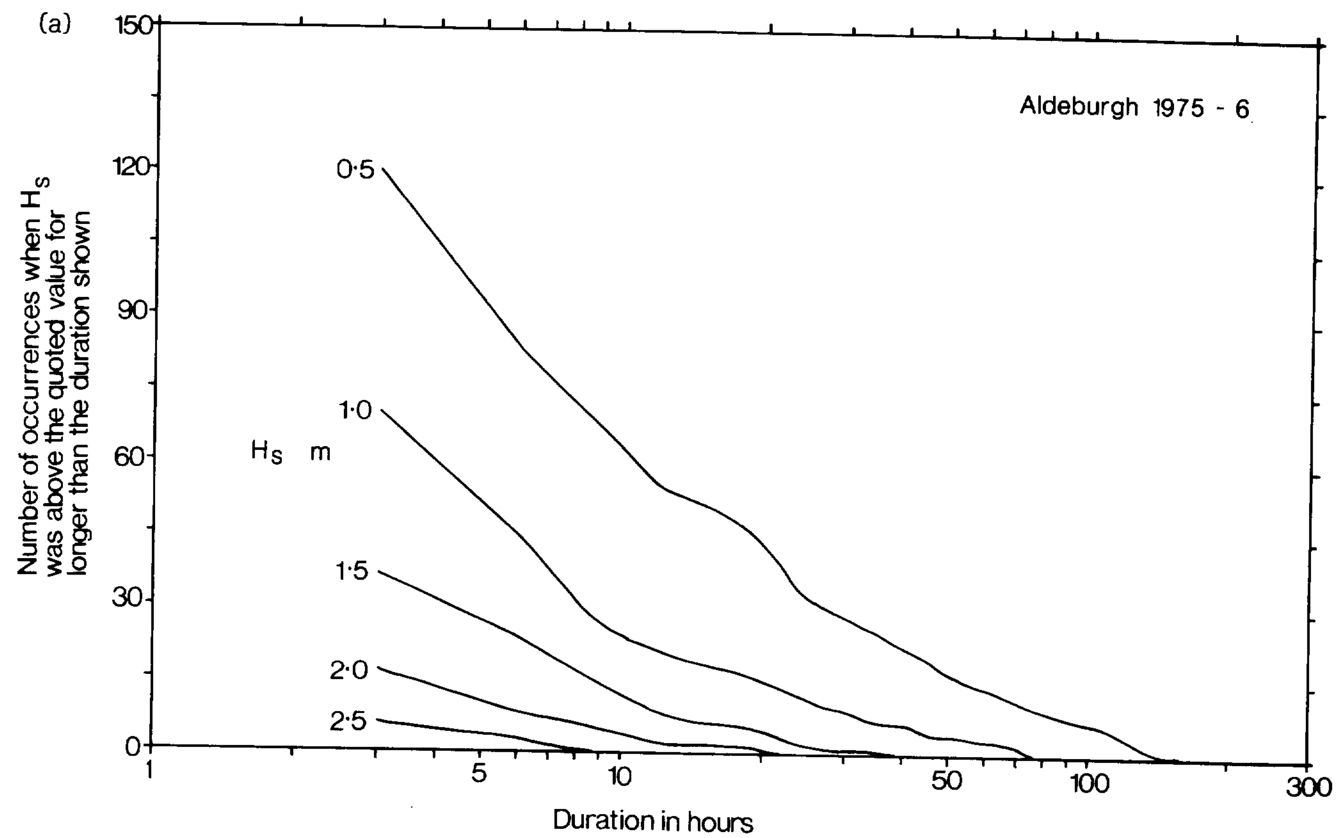


Figure 9: Frequency histograms of zero crossing period (T_z) in seconds: Southwold a) Summer b) Winter.



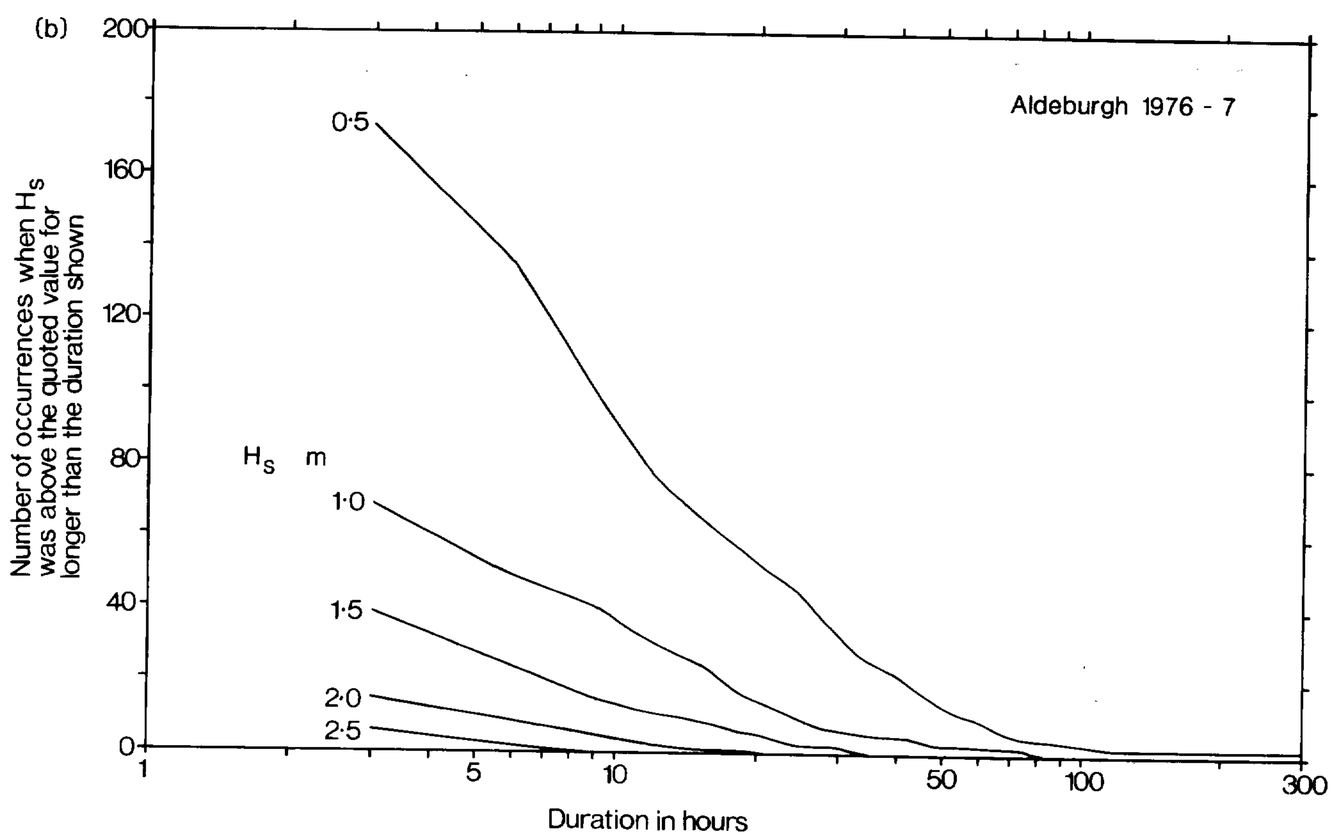


Figure 10: Persistence of storms: Aldeburgh a) 1975-6 b) 1976-7.

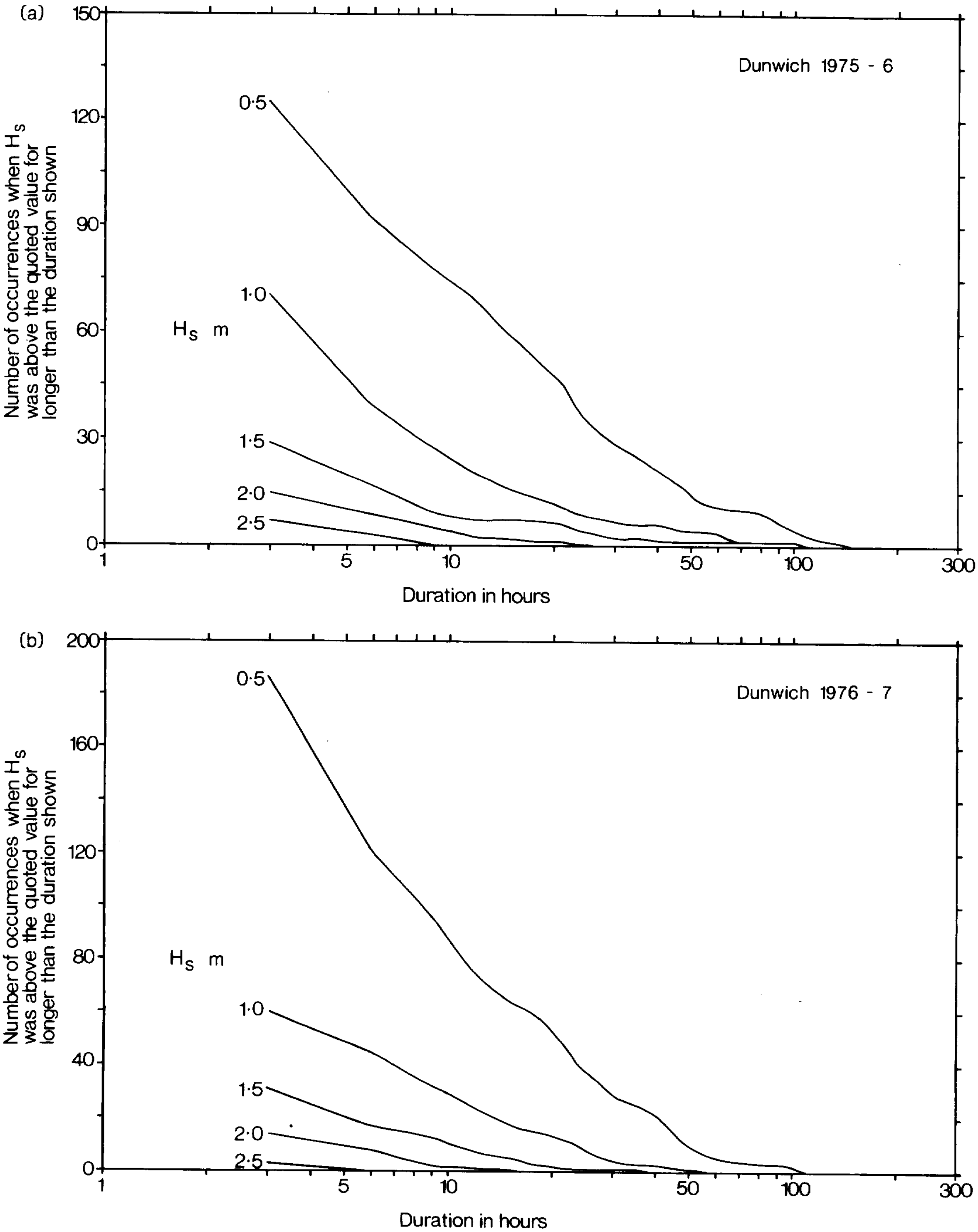


Figure 11: Persistence of storms: Dunwich a) 1975-6 b) 1976-7.

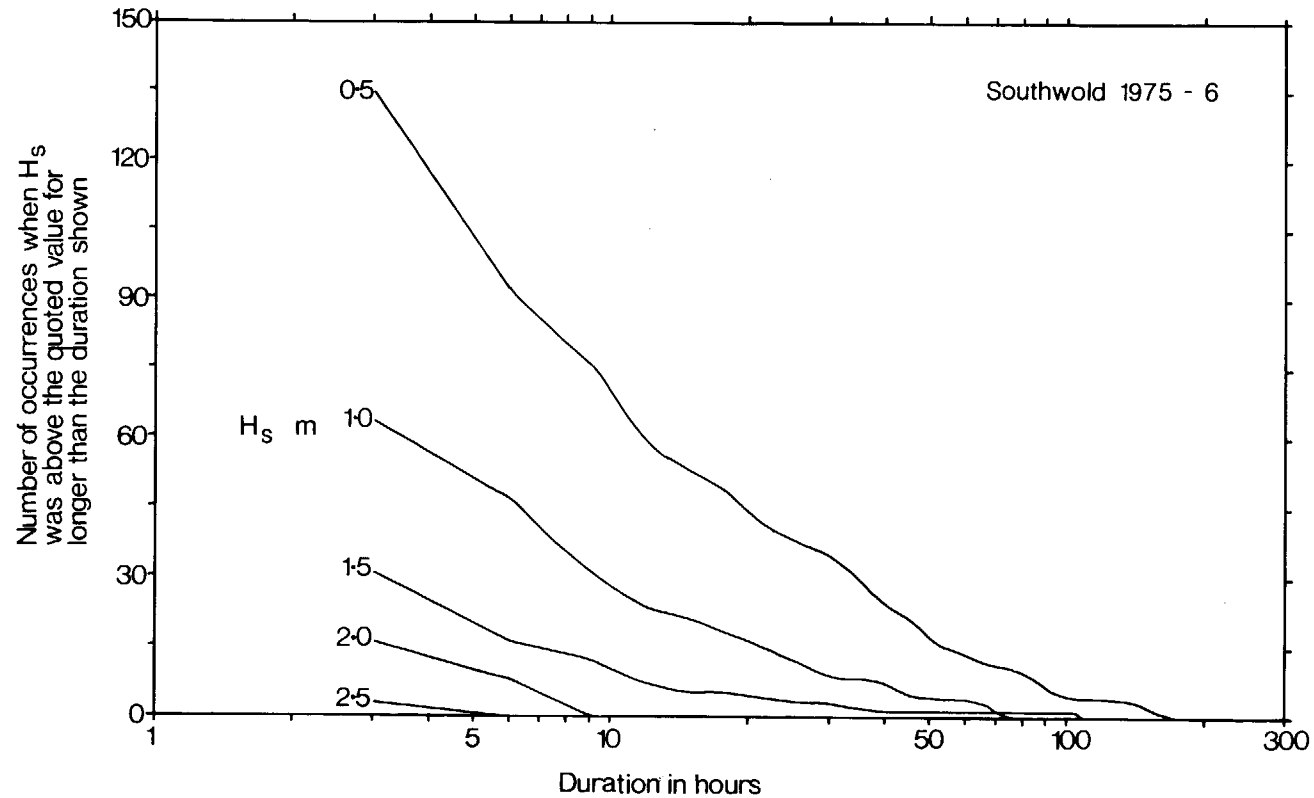


Figure 12: Persistence of storms: Southwold 1975-6.

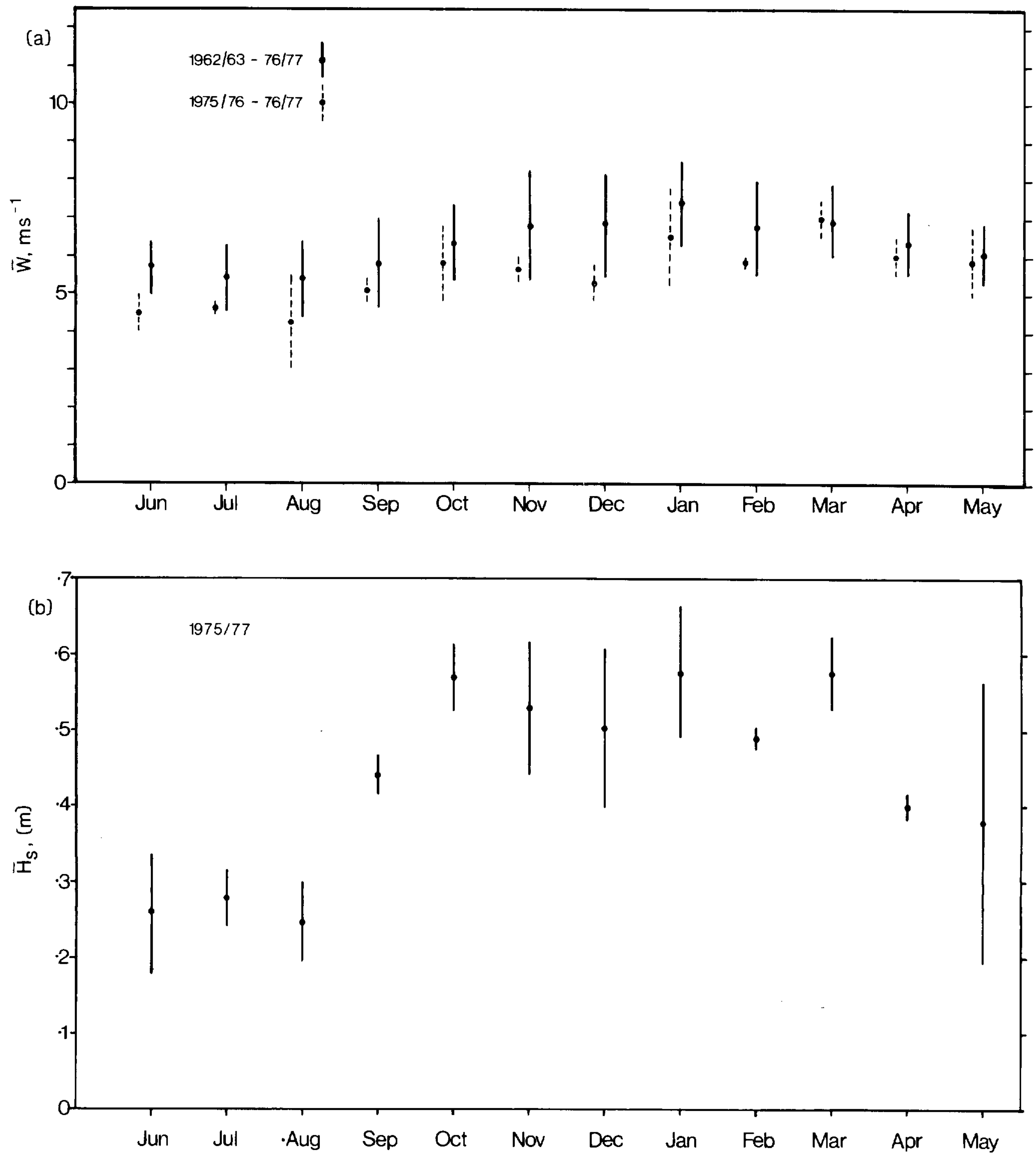


Figure 13: Mean and standard deviation of: a) mean monthly wind speed, $\bar{W}$,at Gorleston
b) mean monthly significant wave height($\bar{H}_s$)
at Aldeburgh, Dunwich and Southwold.

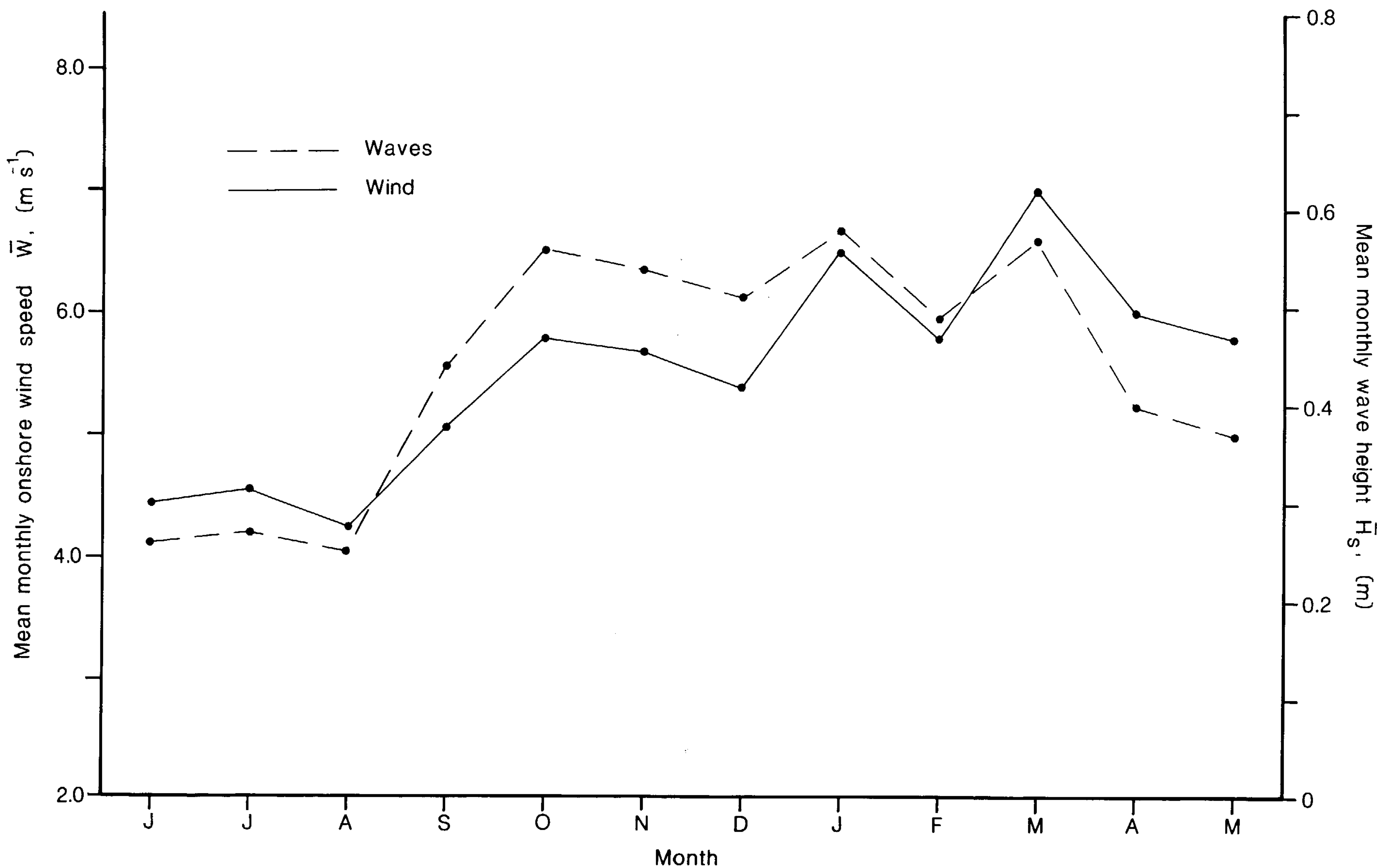


Figure 14: Comparison between mean monthly wind speed ($\bar{W}$) at Gorleston and mean monthly significant wave height ($\bar{H}_s$) at Aldeburgh, Dunwich and Southwold. All site years 1975–77.

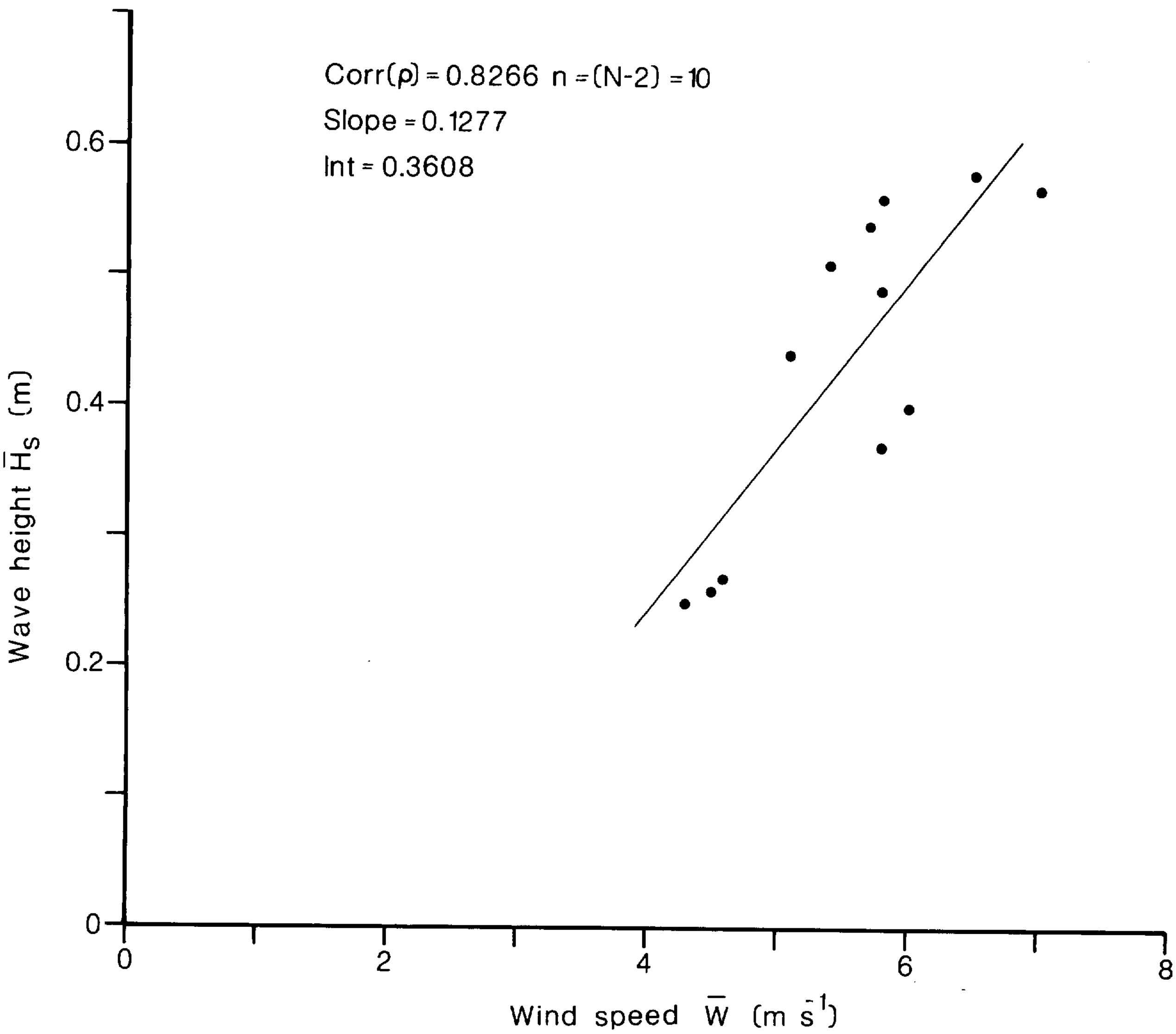


Figure 15: Relationship between mean monthly wind speed ($\bar{W}$) at Gorleston and mean monthly significant wave height ($\bar{H}_s$) for Aldeburgh, Dunwich and Southwold. All site years 1975-77.

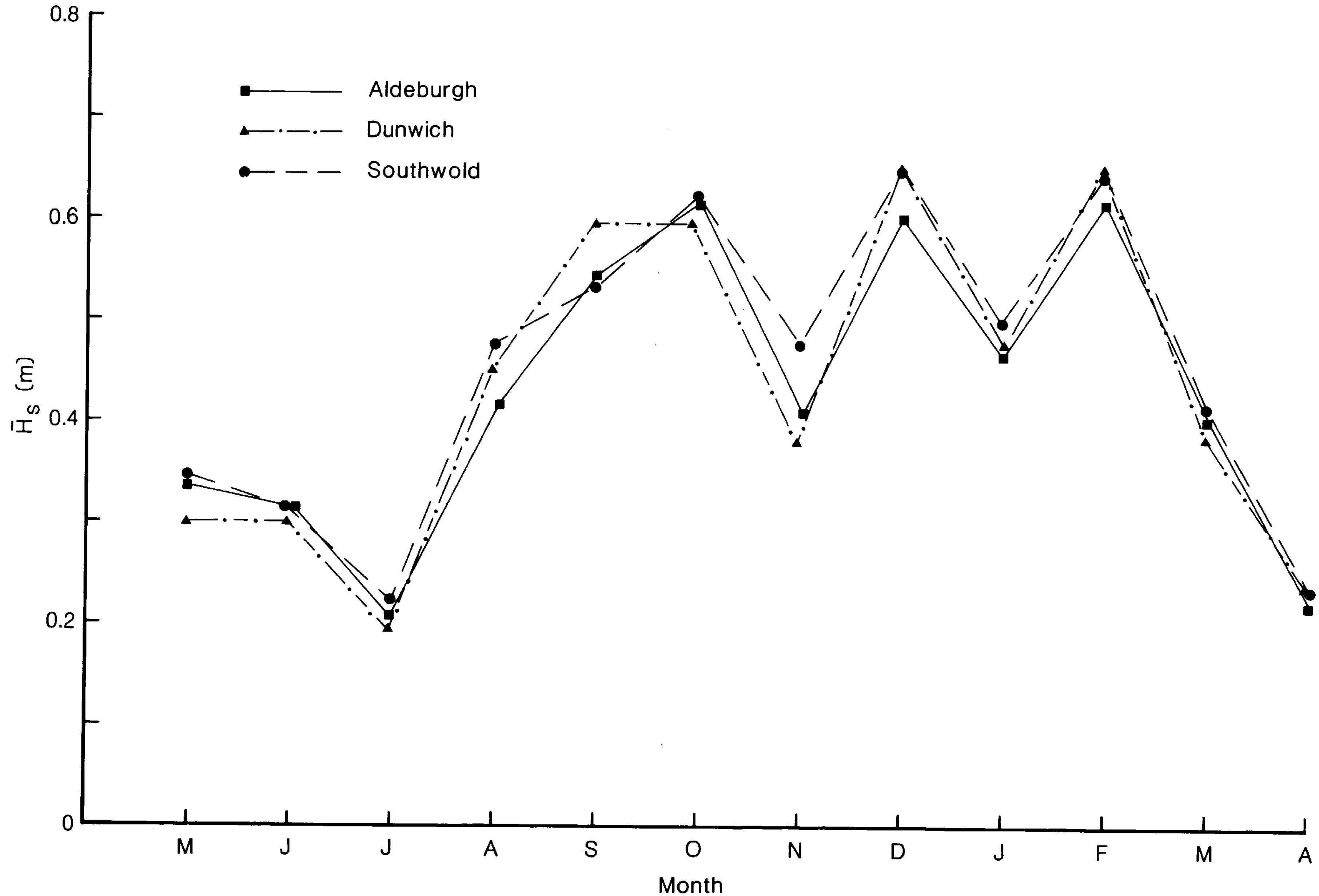


Figure 16: Comparison of mean monthly significant wave height ($\bar{H}_s$) for Aldeburgh, Dunwich and Southwold. All site years 1975-77.

	Lower element H_{s_i} < 2.3m	Upper element H_{s_i} > 2.3m
Corr.(ρ)	0.9247	0.5853
Signif. level	0.001	0.01
Slope	0.8629	0.2435
Intercept	0.0455	1.6736

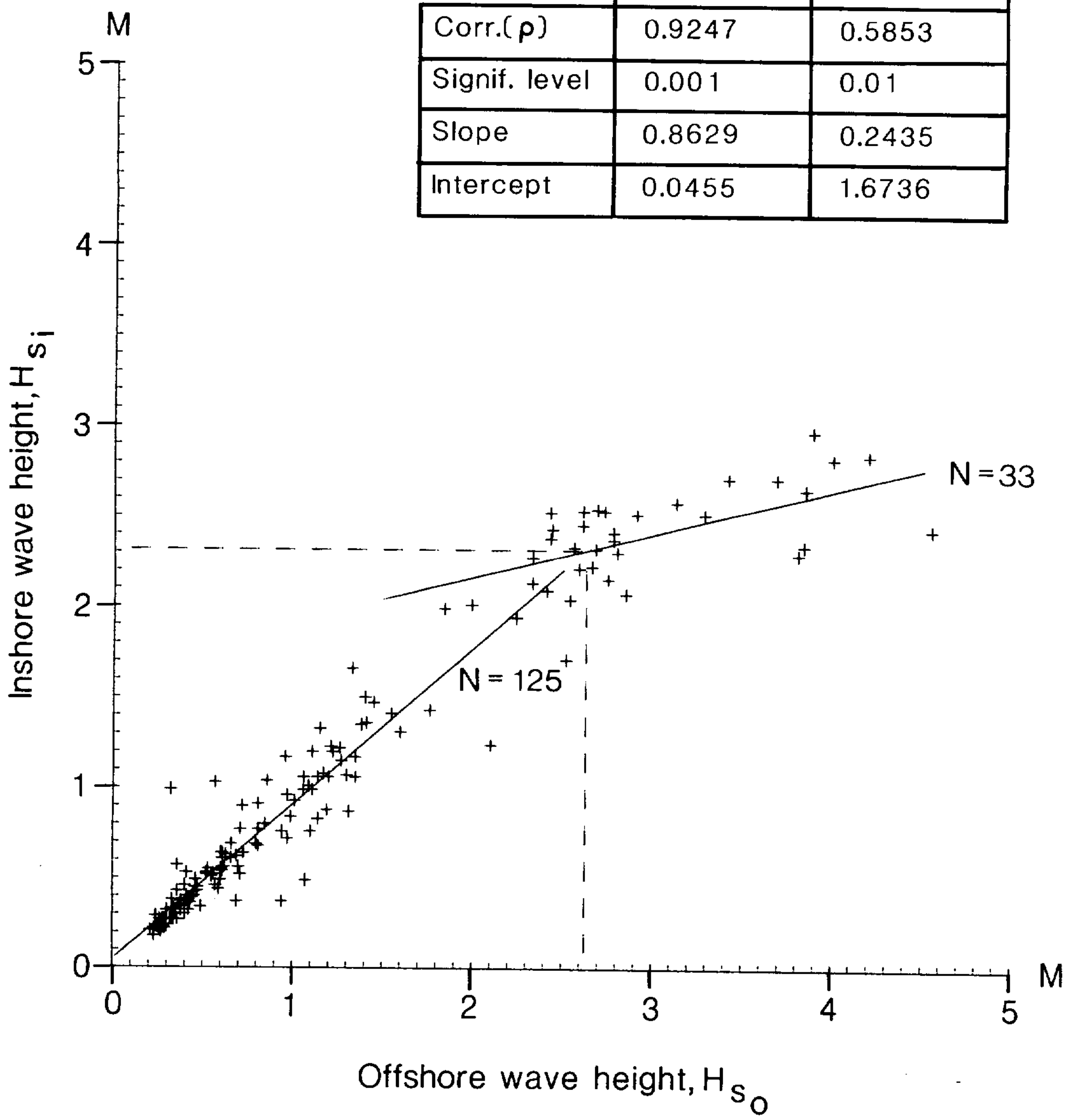


Figure 17: Relationship of offshore to inshore observed significant wave height (H_s). February 1979. The intercept for H_{s_i}<2.3 m is not significantly different from zero at the 5% level; the broken lines represent the point of intersection of the regression lines. For details, including the derivation of the 2.3 m 'cut-off', see p12 and Figure 35.

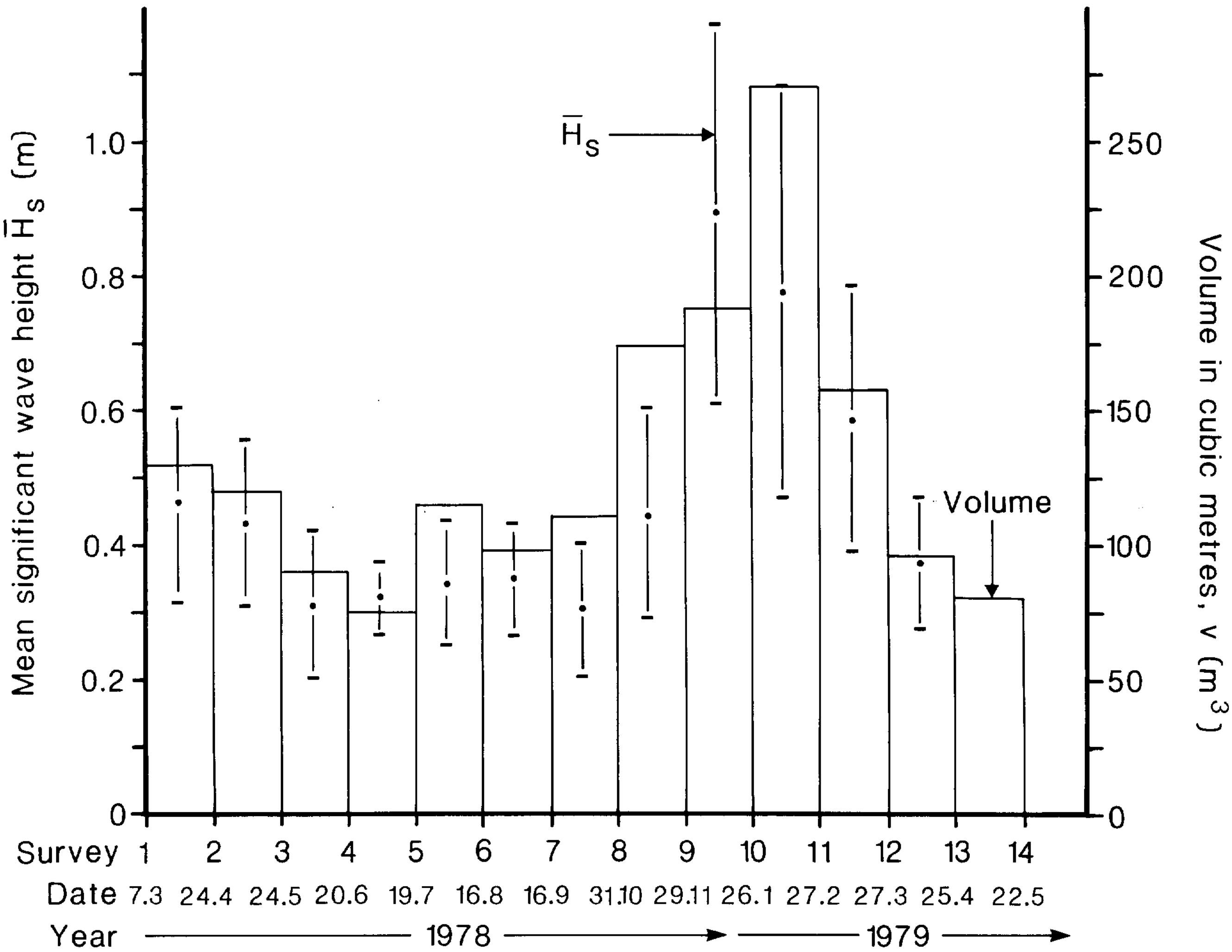


Figure 18: Comparison between total monthly volume of beach material moved in cubic metres and mean monthly significant wave height ($\bar{H}_s$) at Dunwich. For details see text.

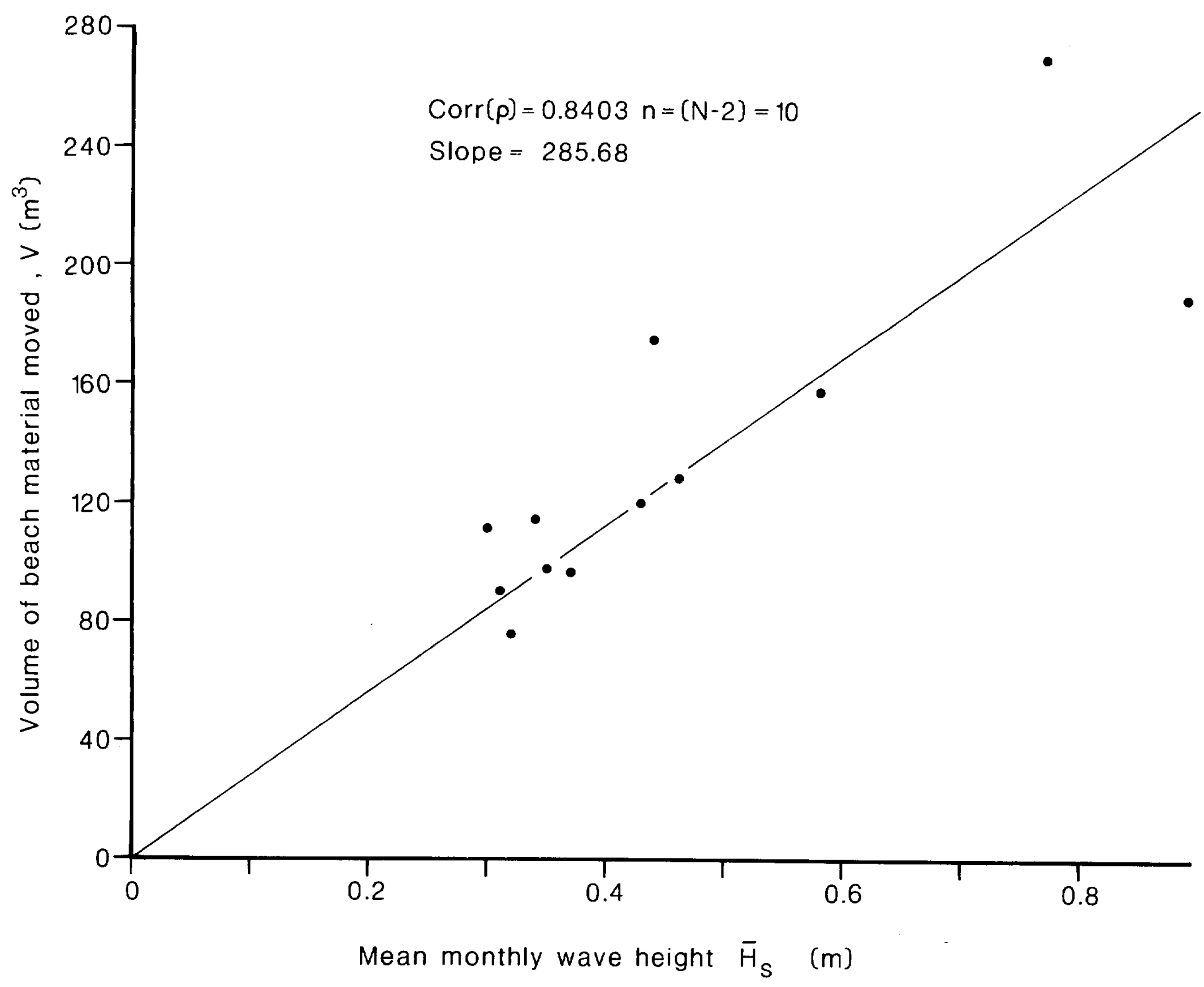


Figure 19: Relationship between monthly significant wave height ($\bar{H}_s$) at Dunwich and total monthly volume of beach material moved (V) in cubic metres. For details see text. The regression line has been forced through the origin.

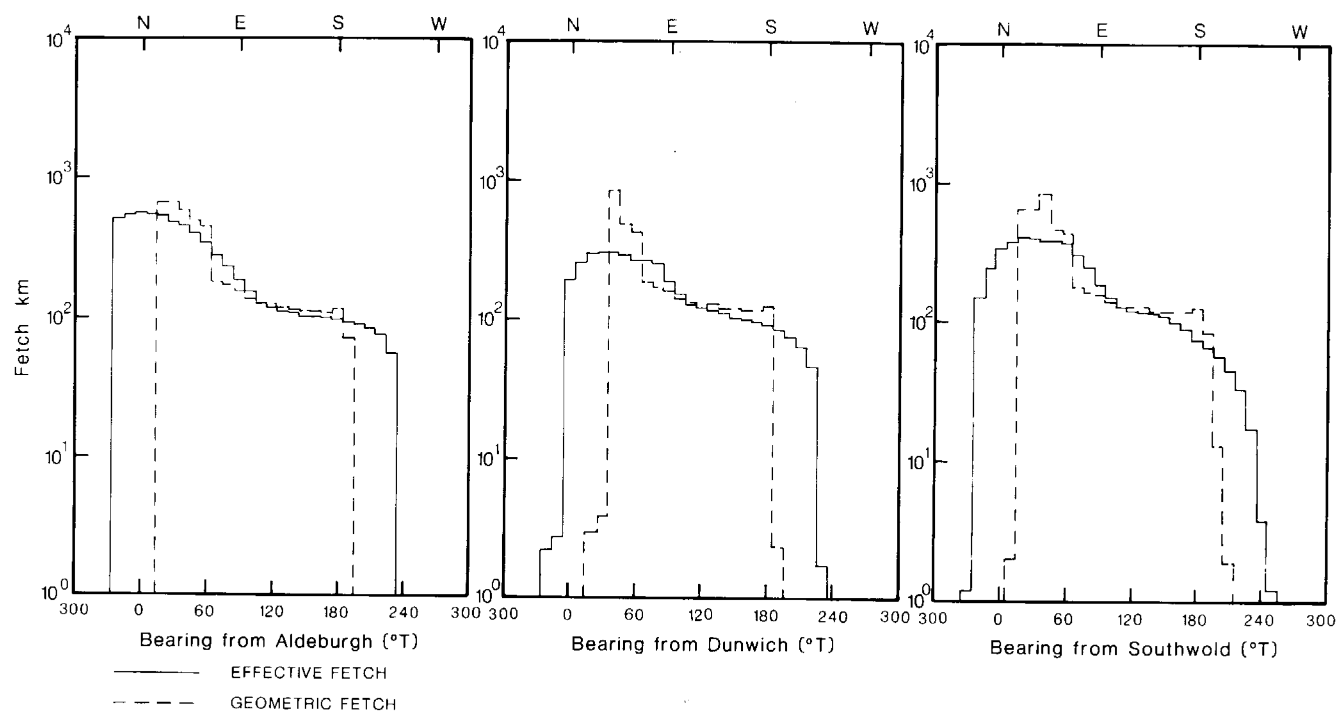


Figure 20: Effective fetch v geometric fetch: Aldeburgh, Dunwich and Southwold.

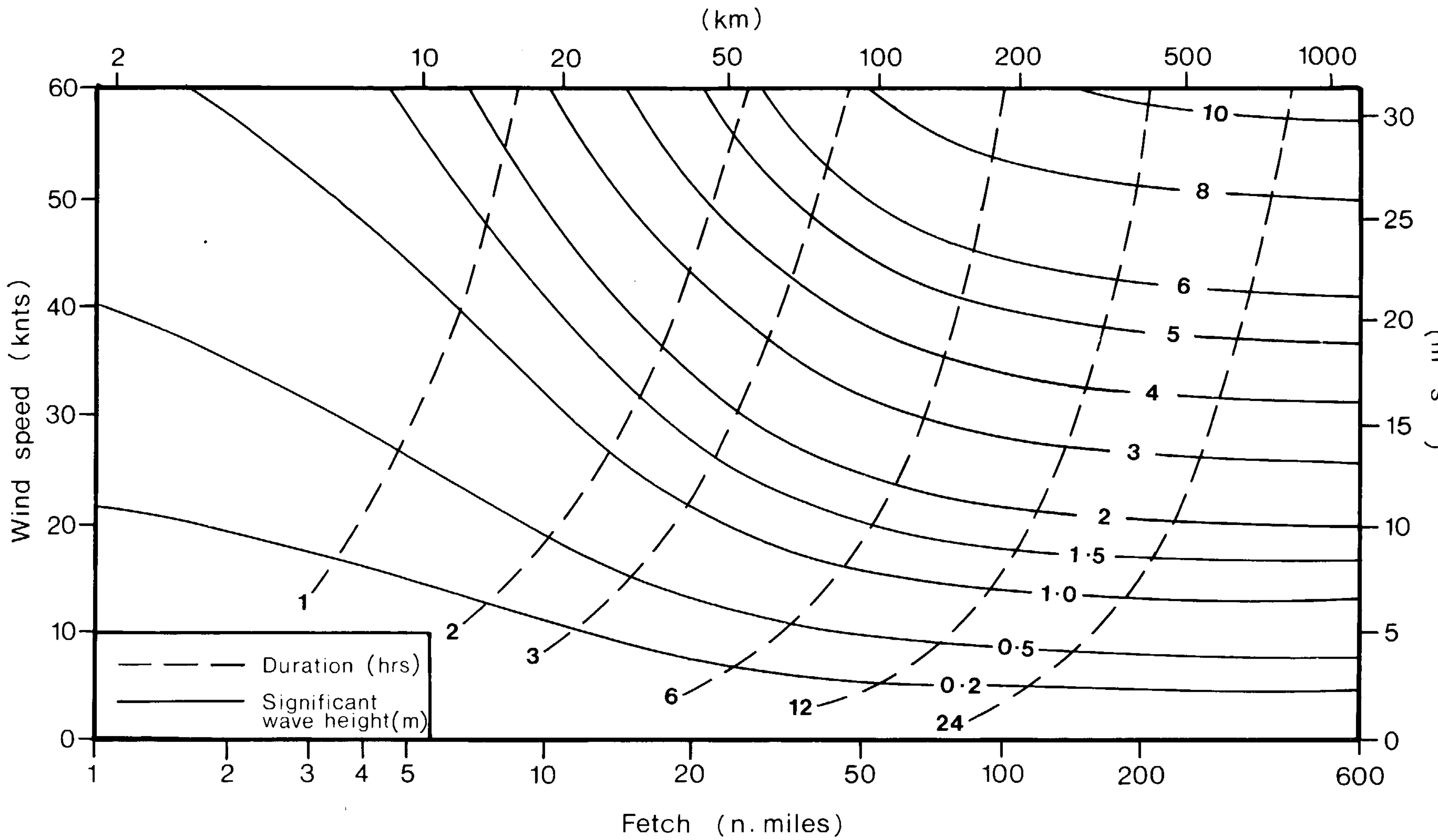


Figure 21: Wave height prediction curves (after Darbyshire and Draper, 1963) used to estimate significant wave heights (H_s) for different wind speeds (Tables 6a, b) from the effective fetch characteristics shown in figure 20.

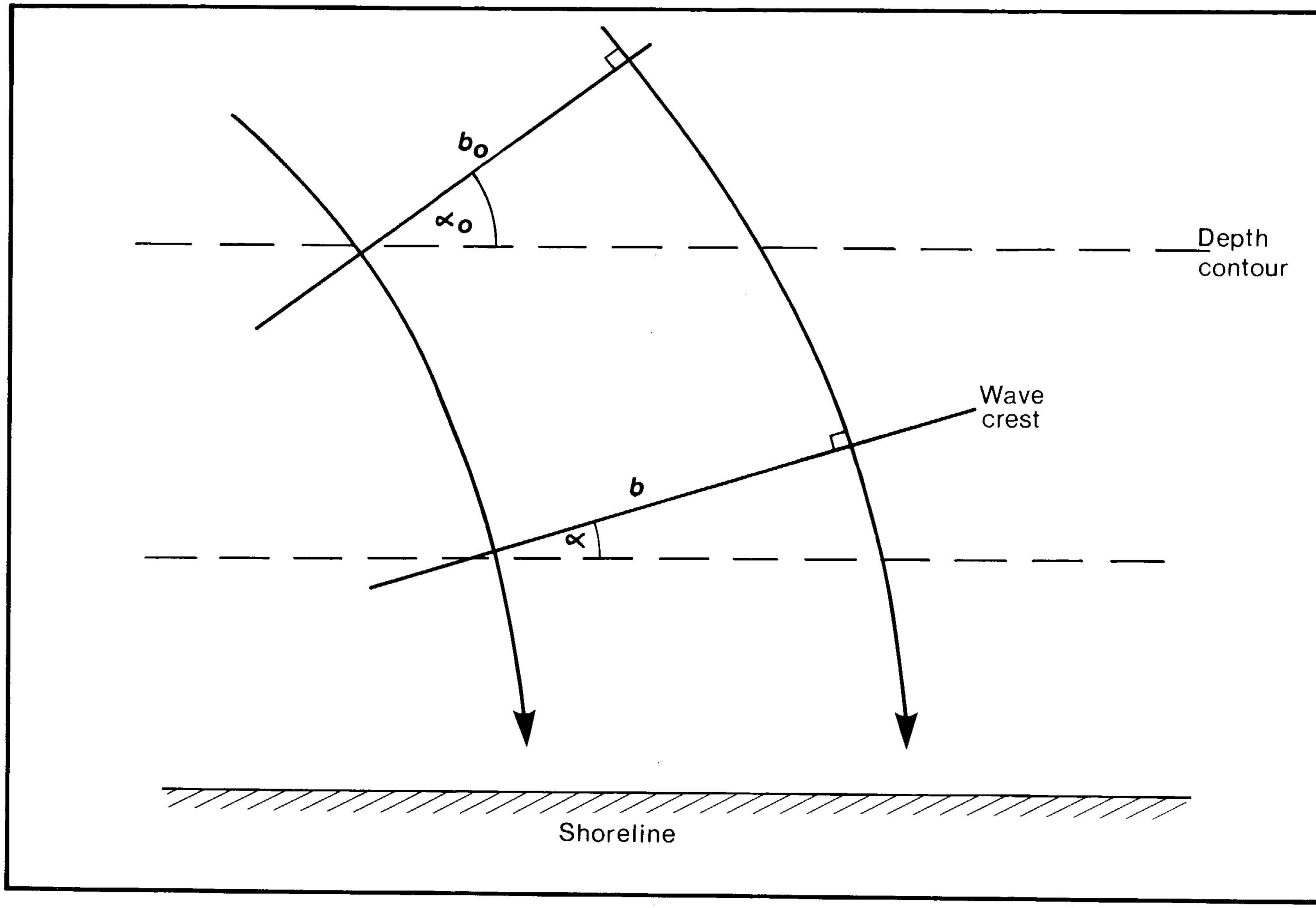
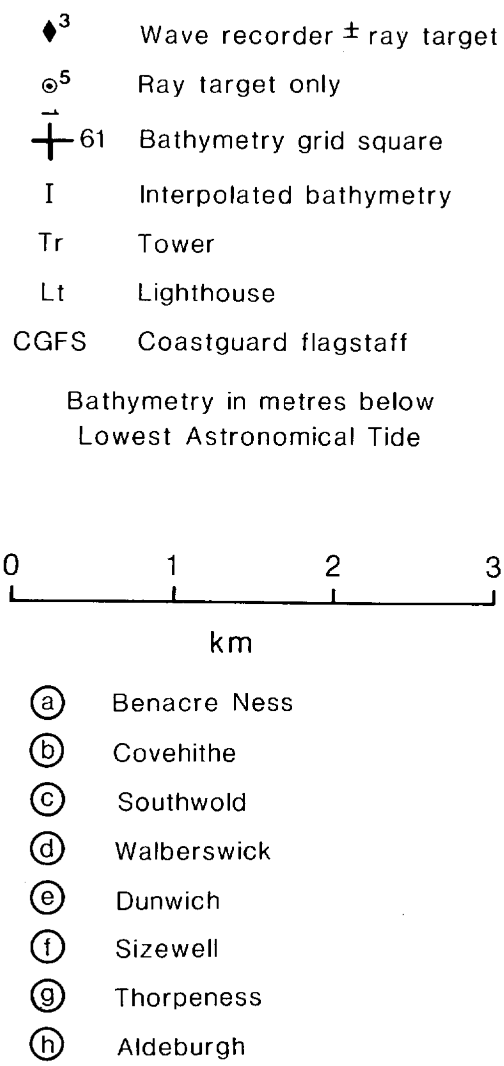


Figure 22: Schematic presentation of wave refraction processes.



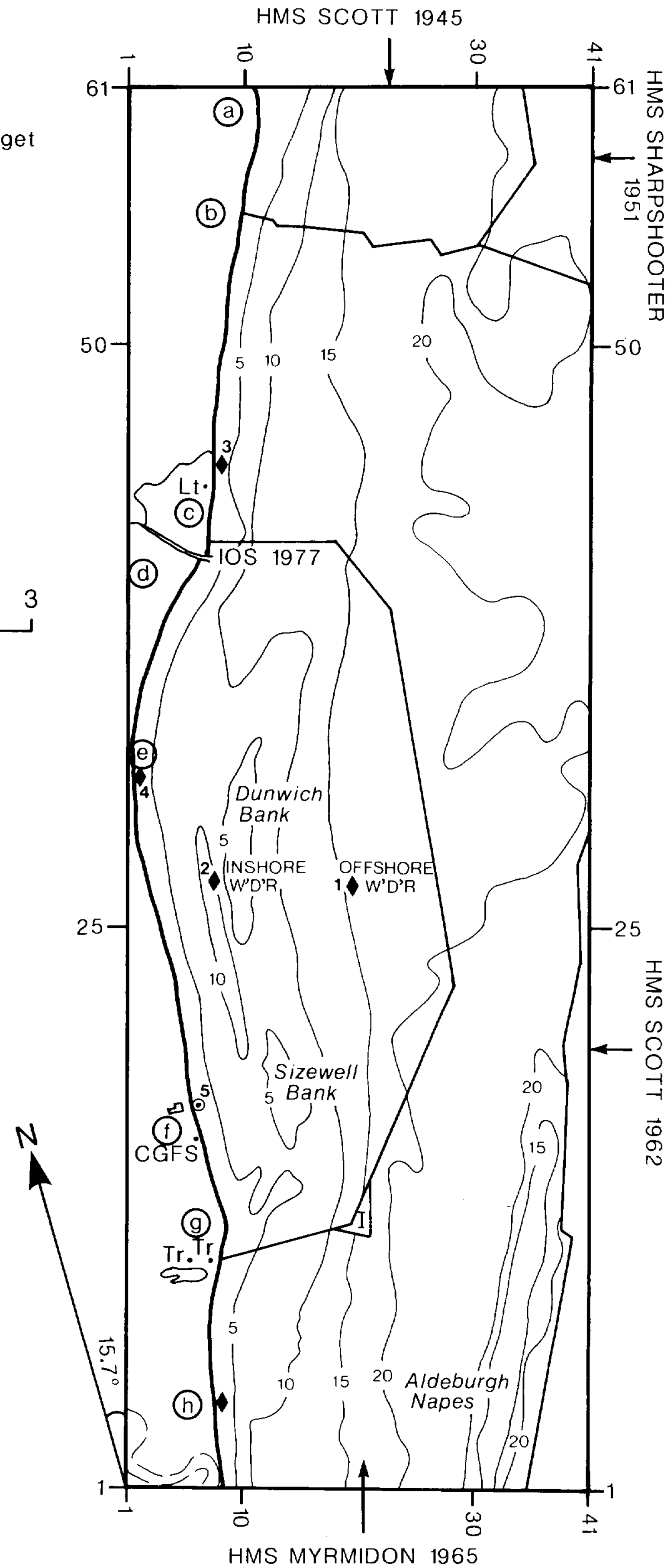


Figure 23: Area covered by wave refraction grid; sources of bathymetric data; location of wave recorders, and ray targets for wave energy computations.

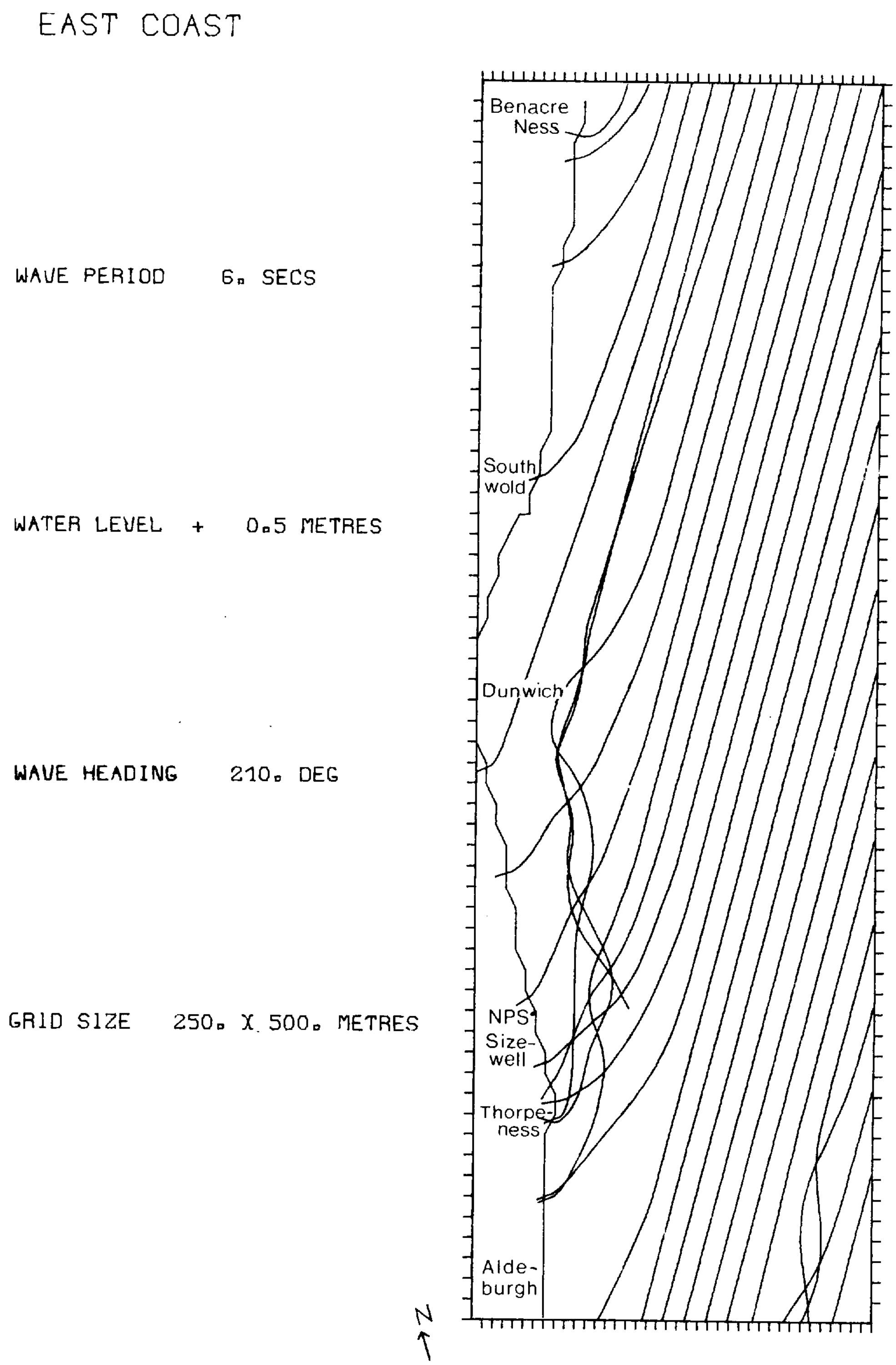


Figure 24: Wave refraction diagram showing principal places (NPS = nuclear power station).

EAST COAST

WAVE PERIOD 7.5 SECS

WATER LEVEL + 2.5 METRES

WAVE HEADING 210. DEG

GRID SIZE 250. X 500. METRES

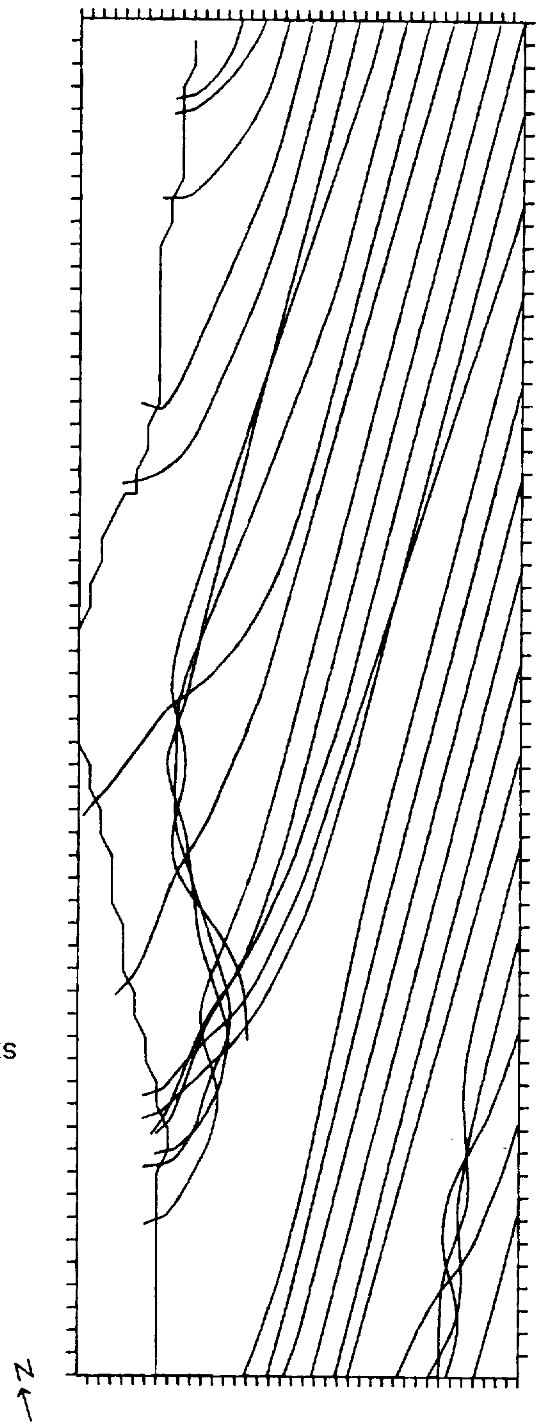


Figure 25

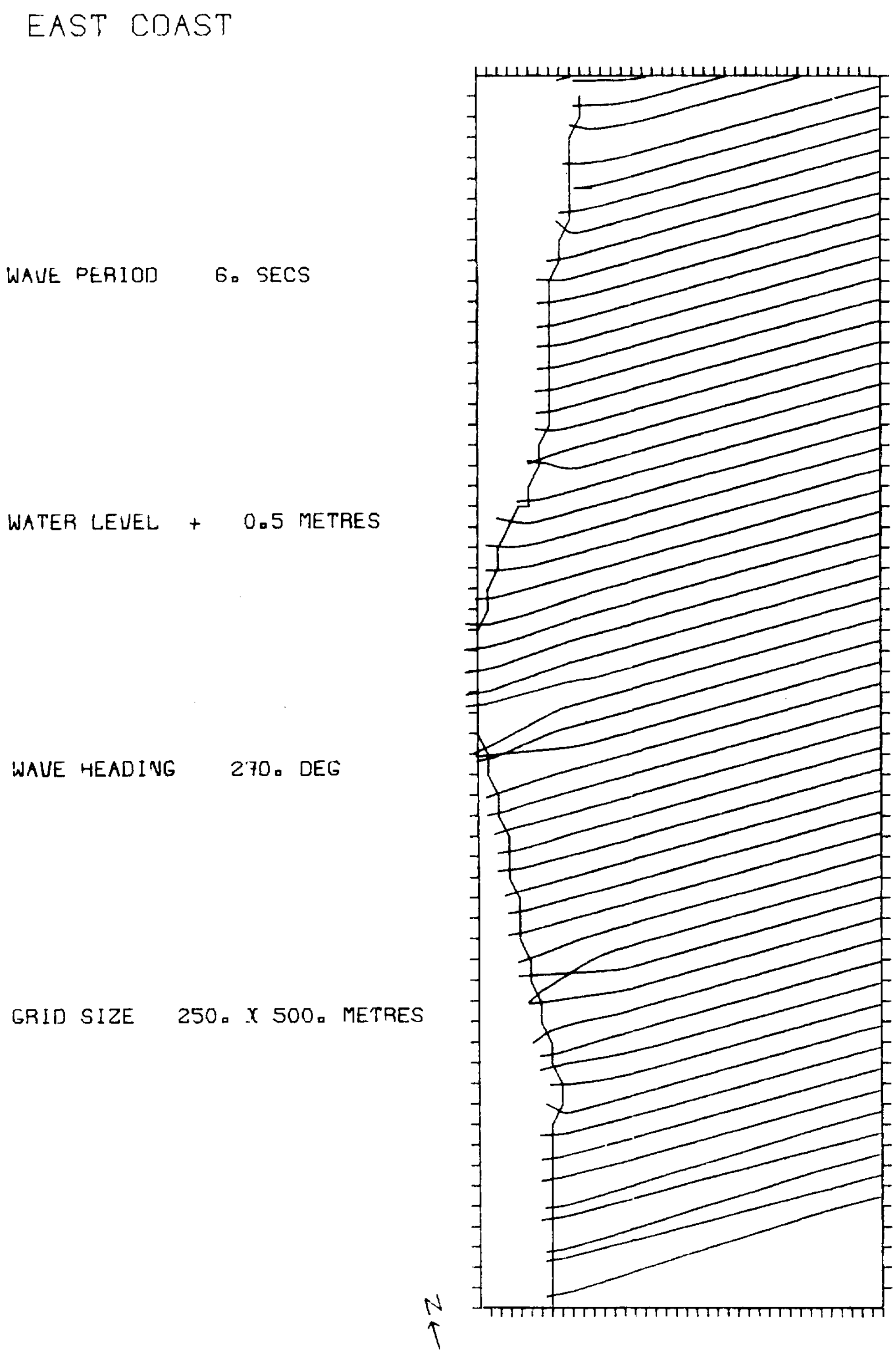

EAST COAST
WAVE PERIOD 6. SECS
WATER LEVEL + 0.5 METRES
WAVE HEADING 270. DEG
GRID SIZE 250. X 500. METRES
N

Figure 26

EAST COAST

WAVE PERIOD 6. SECS

WATER LEVEL + 2.5 METRES

WAVE HEADING 270. DEG

GRID SIZE 250. X 500. METRES

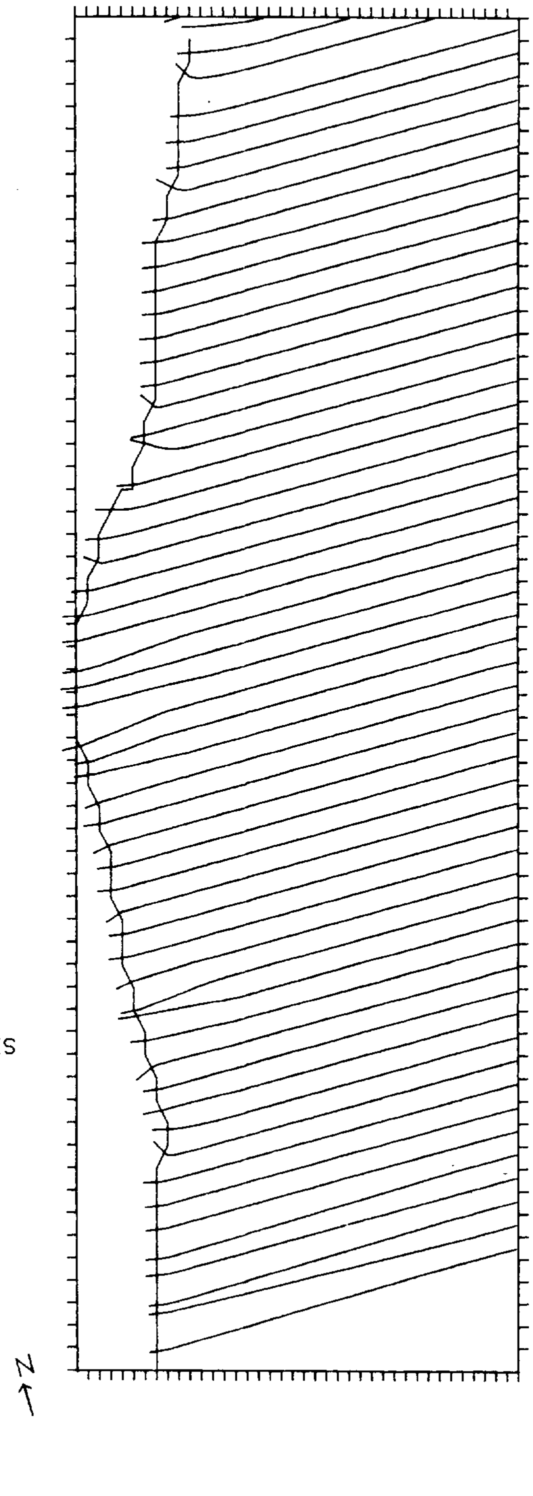


Figure 27

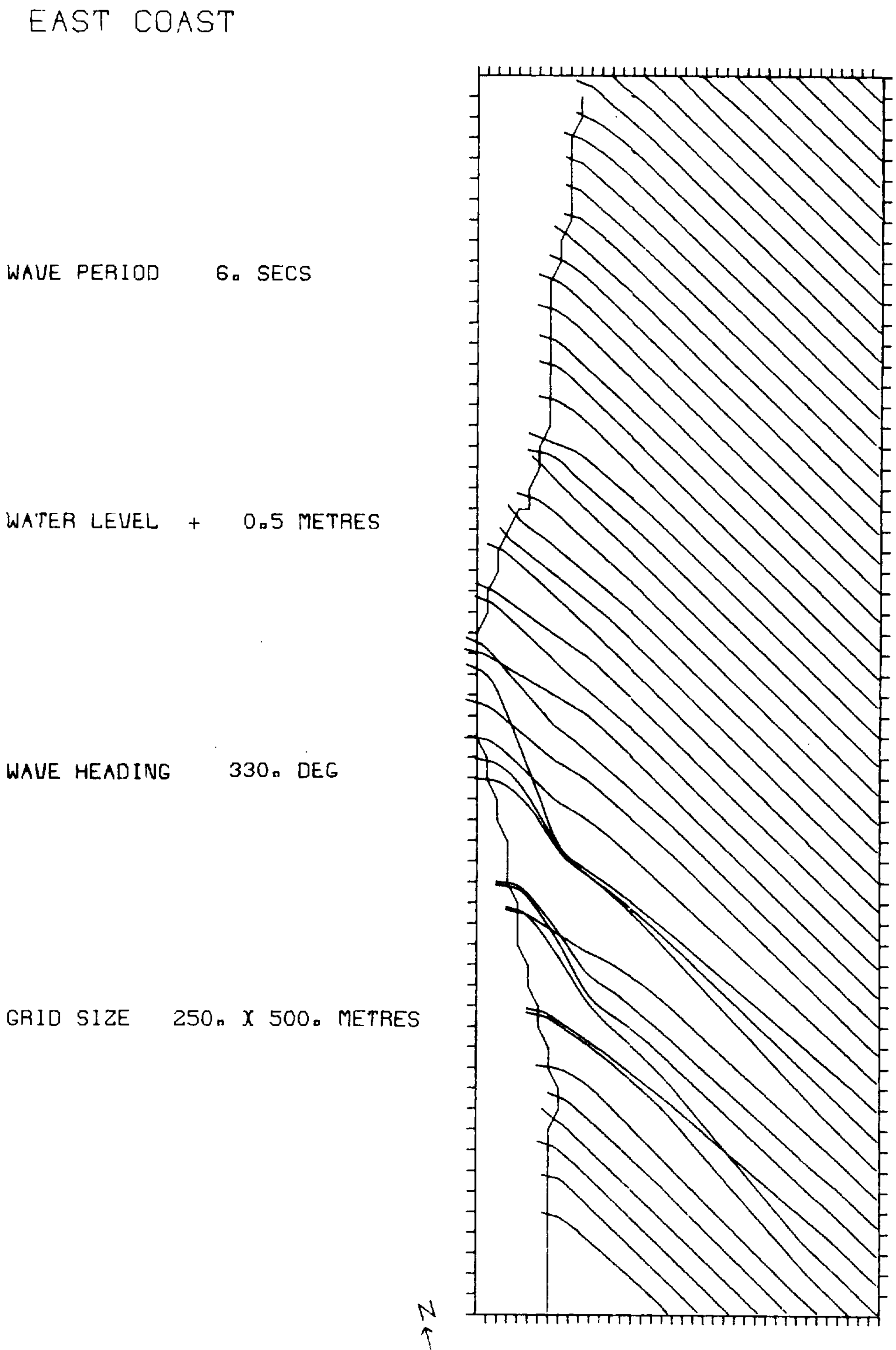

EAST COAST
WAVE PERIOD 6. SECS
WATER LEVEL + 0.5 METRES
WAVE HEADING 330. DEG
GRID SIZE 250. X 500. METRES
N

Figure 28

EAST COAST

WAVE PERIOD 6. SECS

WATER LEVEL + 2.5 METRES

WAVE HEADING 330. DEG

GRID SIZE 250. X 500. METRES

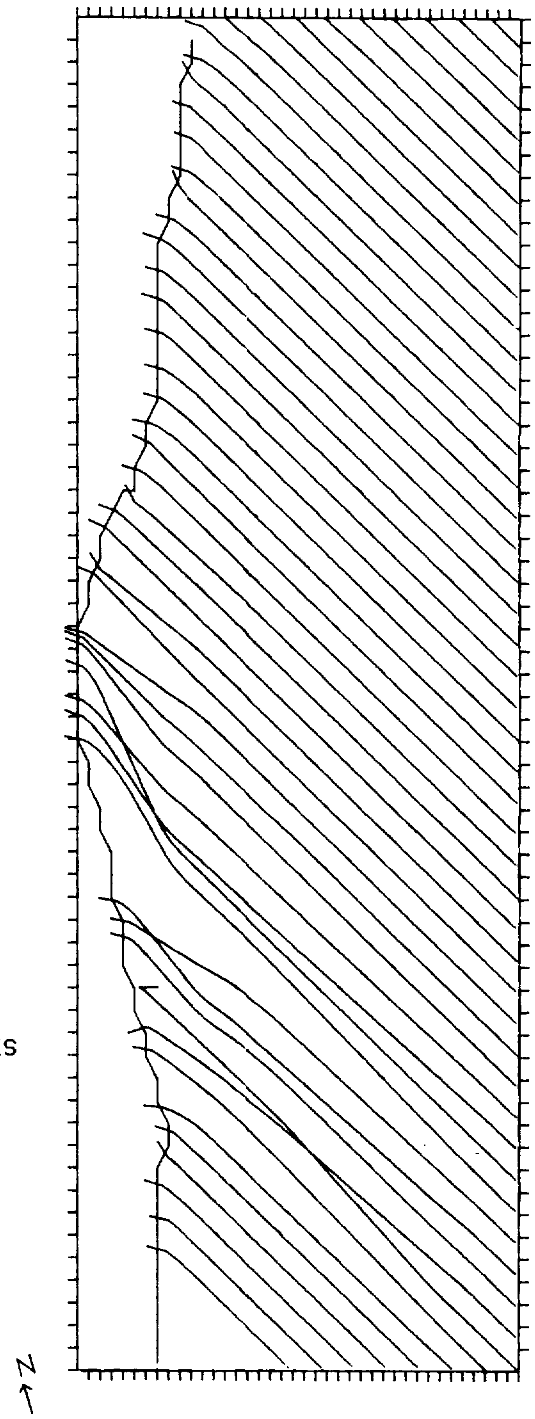


Figure 29

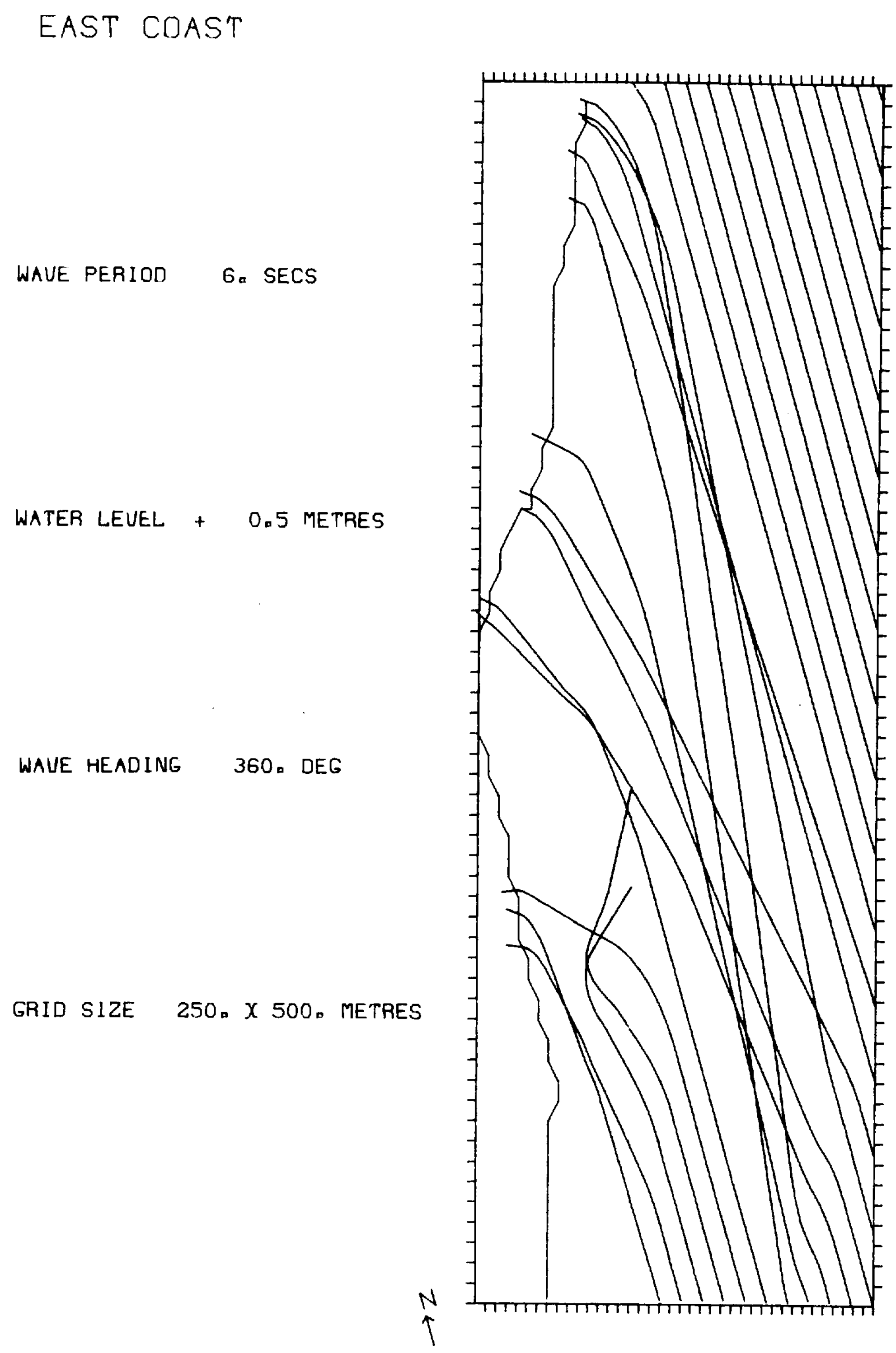

EAST COAST
WAVE PERIOD 6. SECS
WATER LEVEL + 0.5 METRES
WAVE HEADING 360. DEG
GRID SIZE 250. X 500. METRES
N

Figure 30

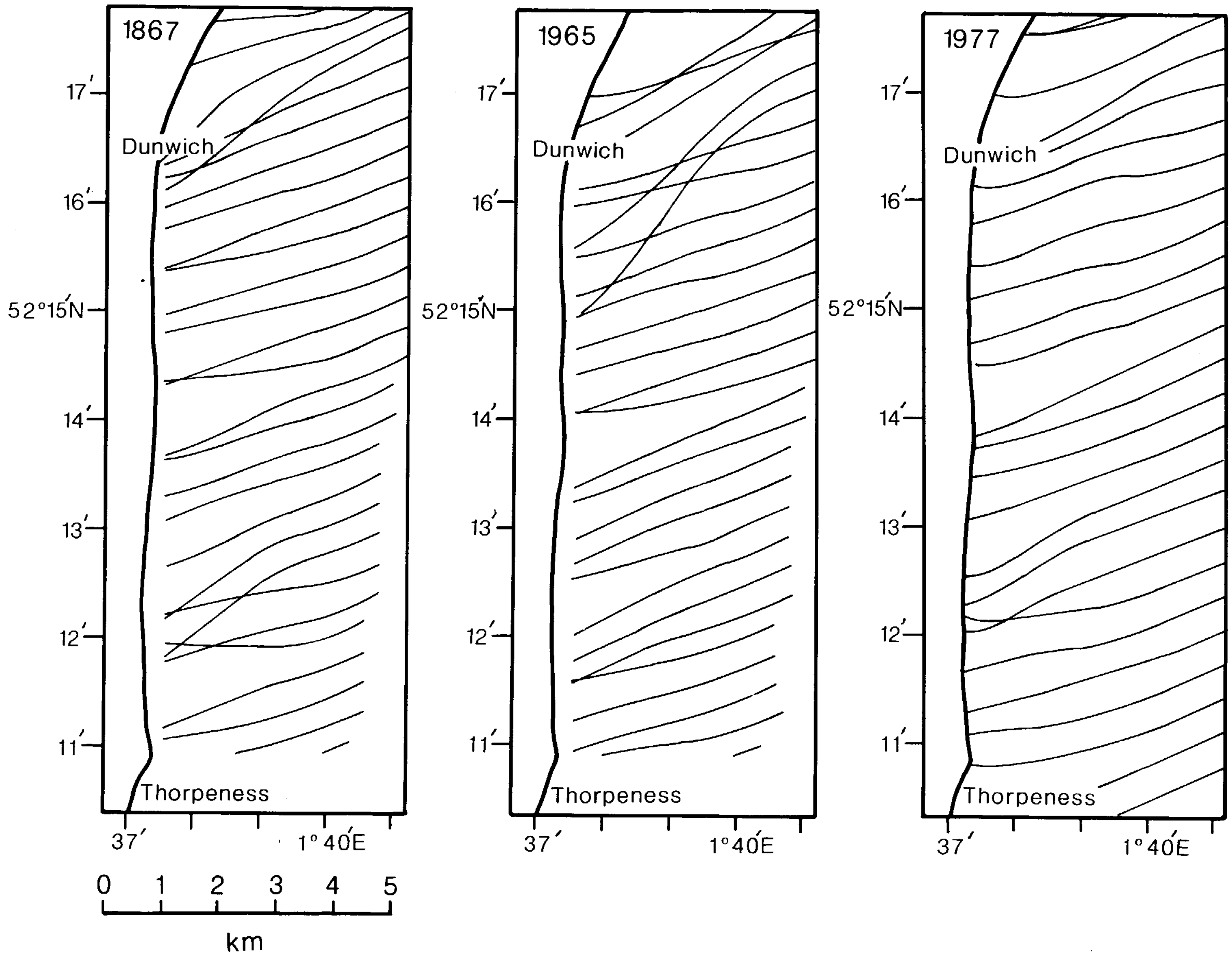


Figure 31: Wave refraction diagrams for 1867, 1965 and 1977. 1867 and 1965 are taken from Robinson (1980).

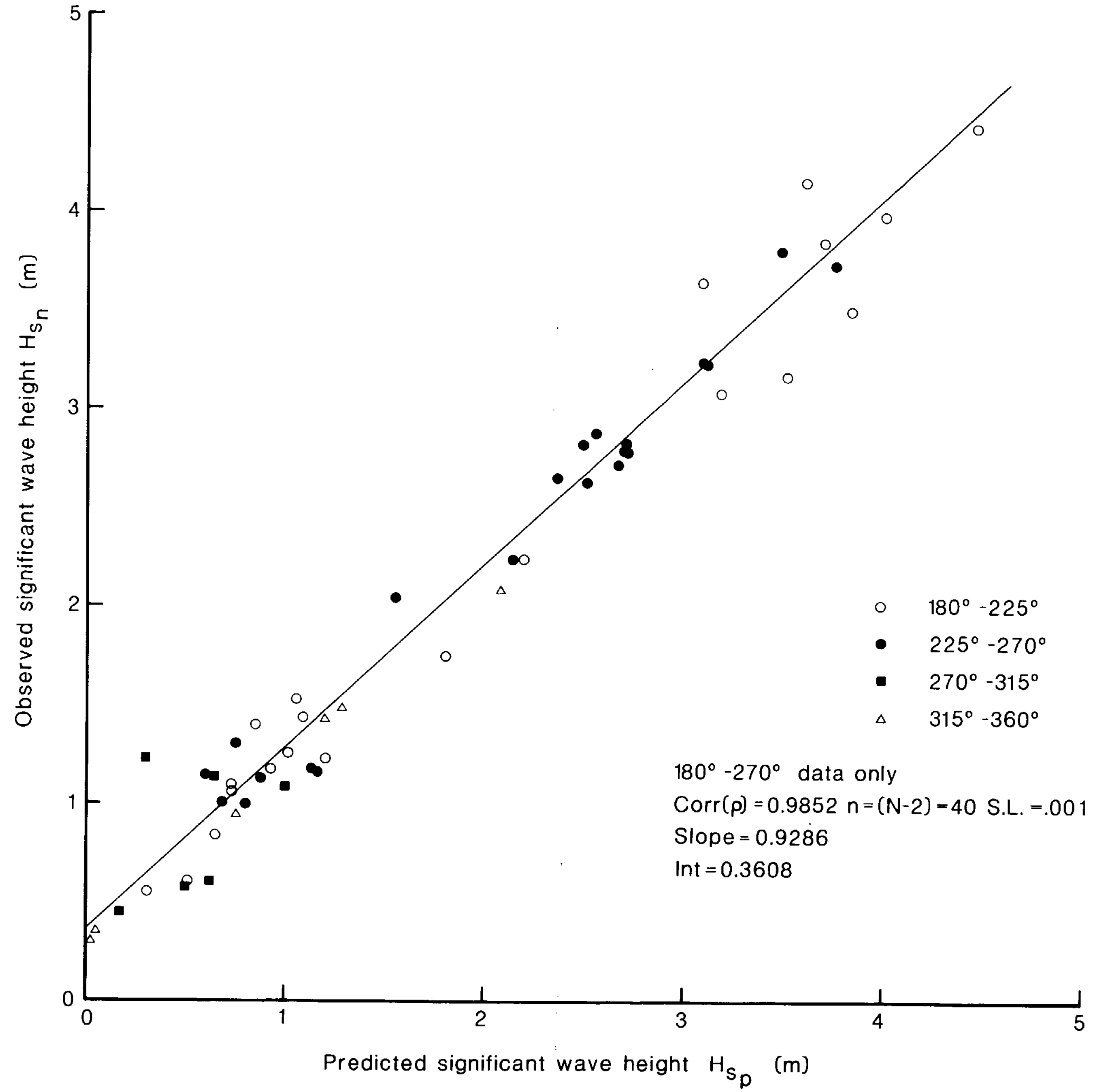


Figure 32: Offshore v predicted wave heights for 'offshore' Waverider buoy site.

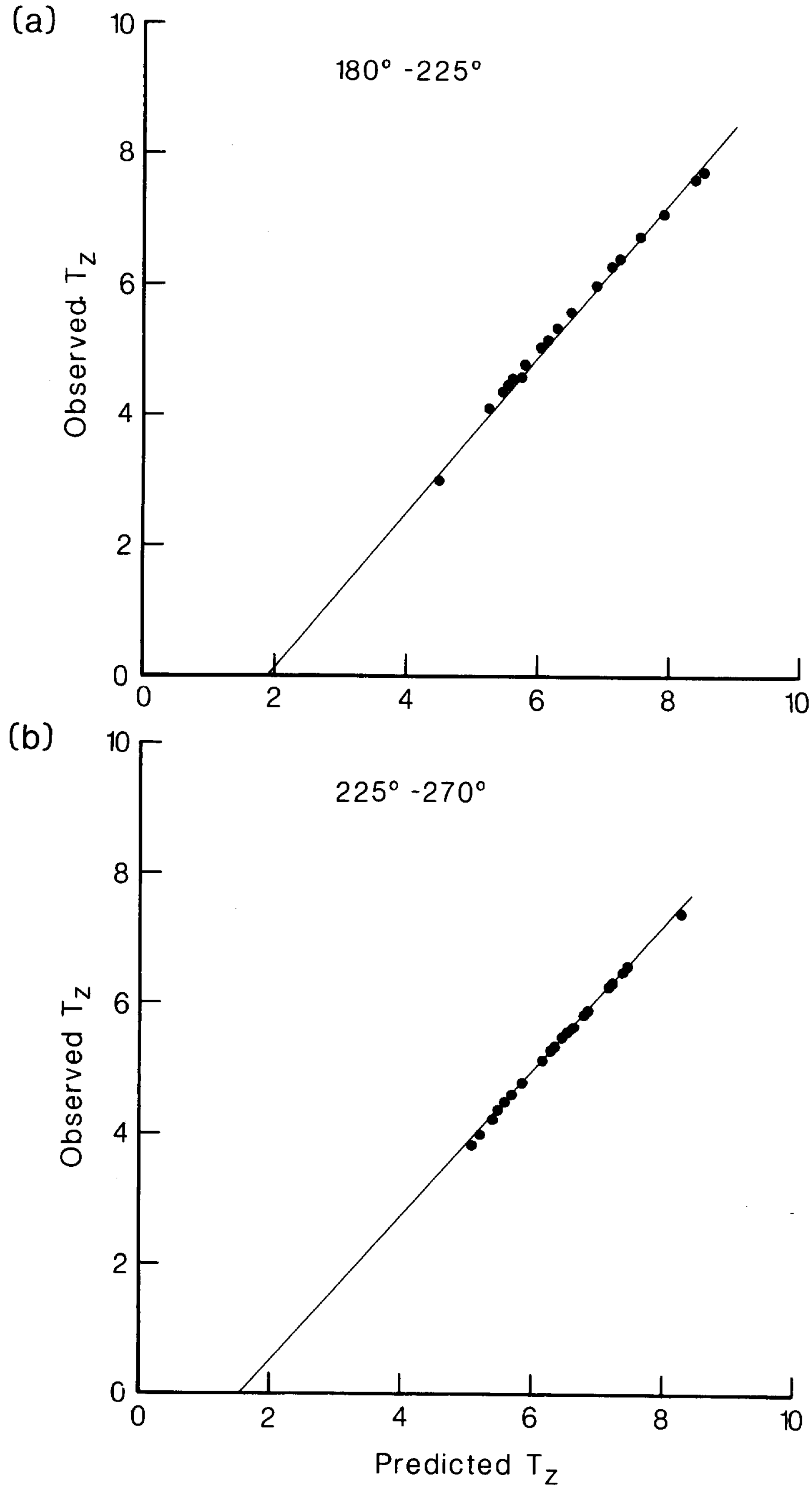


Figure 33: Observed v predicted wave periods (T_z) for 'offshore' Waverider buoy site a) Wave heading of 180°-225° b) Wave heading of 225°-270°.

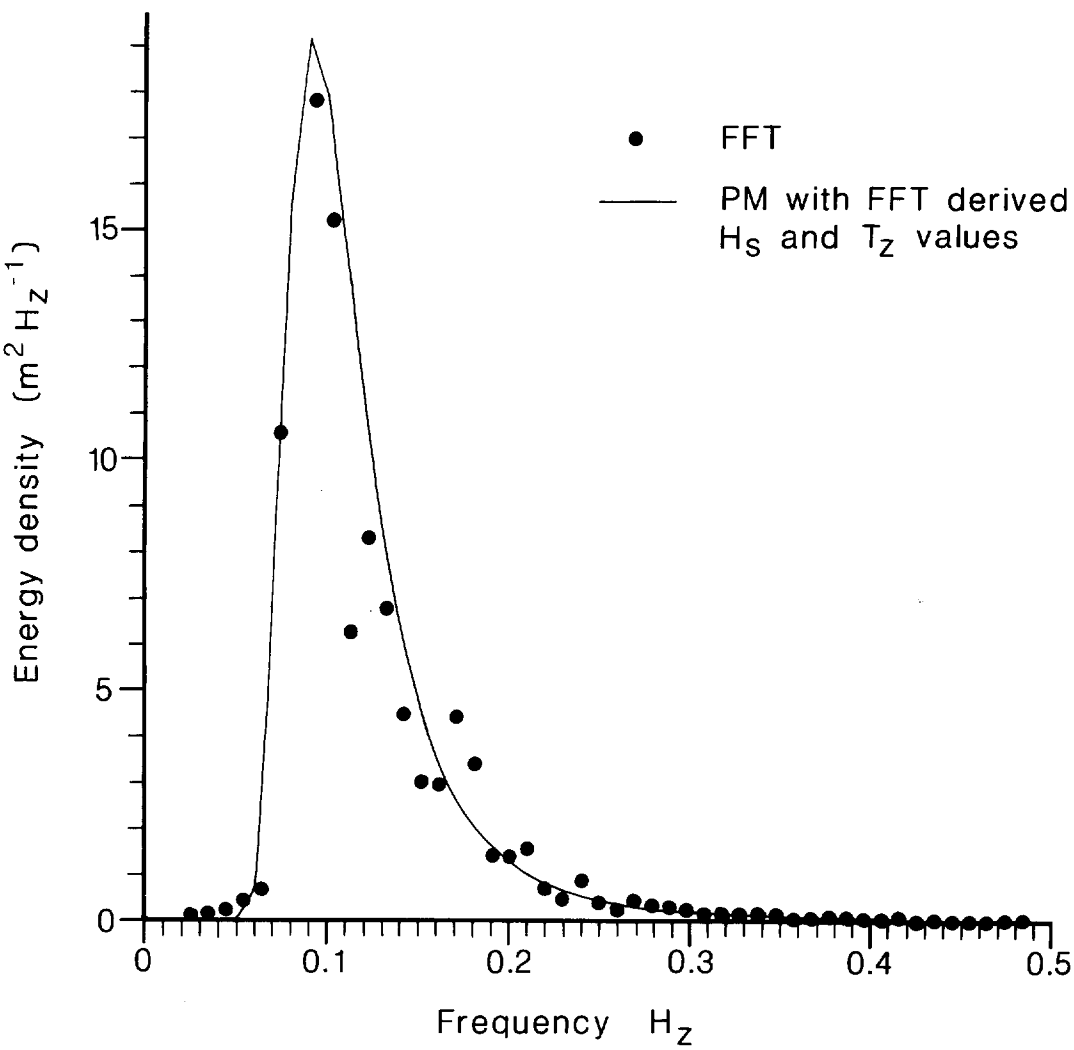


Figure 34: Fast Fourier Transform (FFT) of actual wave record for 1630 hrs on 14 February 1979. H_s = 4.43 m; T_z = 7.78 s. The Pierson-Moskowitz (PM) spectrum with FFT derived H_s and T_z is shown. Note the close agreement between the two in this instance.

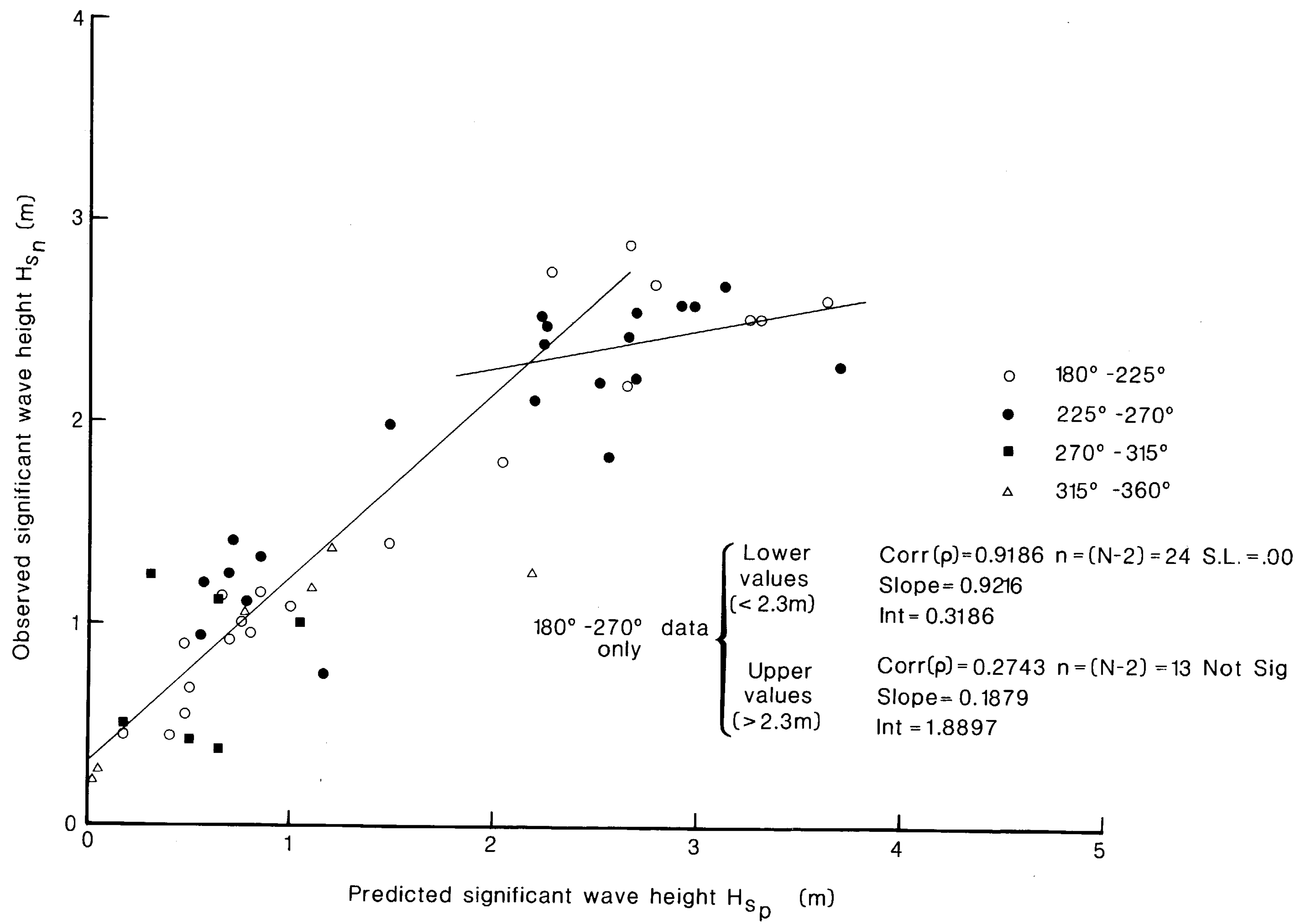


Figure 35: Observed v predicted wave heights (H_s) for 'inshore' Waverider buoy site.

APPENDIX A

CALCULATION OF EFFECTIVE FETCH

Effective fetches given in Table 1 were calculated using the method given by CERC (1973).

Consider waves arriving at Point A in Figure A1. The wave height for a particular wind speed W blowing from the direction shown is some function of the sum of all the wind energy components acting along the radial fetches X_i, out to $\pm$ 45° either side of the wind direction multiplied by the radial fetch. Thus -

$$\text{wave height at A} \propto \sum_{i=1}^{N} (W \cos \alpha_i)^2 X_i \ .$$

This wave height is equivalent to that which would be given by radial fetches X_i' ; corresponding to an effective geometric fetch in deep water of X_{eff} where

$$X_i' \cos \alpha_i = X_{eff} \ . \qquad (A.1)$$

Thus

$$\sum_{i=1}^{N} (W \cos \alpha_i)^2 X_i = \sum_{i=1}^{N} (W \cos \alpha_i)^2 X_i' \qquad (A.2)$$

which from equation (A.1) gives

$$X_{eff} = \frac{\sum X_i \cos^2 \alpha_i}{\sum \cos \alpha_i} \ . \qquad (A.3)$$

The values of X_{eff} shown in Table 1 were calculated using measured geometric fetches (X_i) and for angles out to 40°, in steps of 10°, on both sides of the assumed wind direction. Effective fetch bearings were taken in 10° intervals from 0° to 350° .

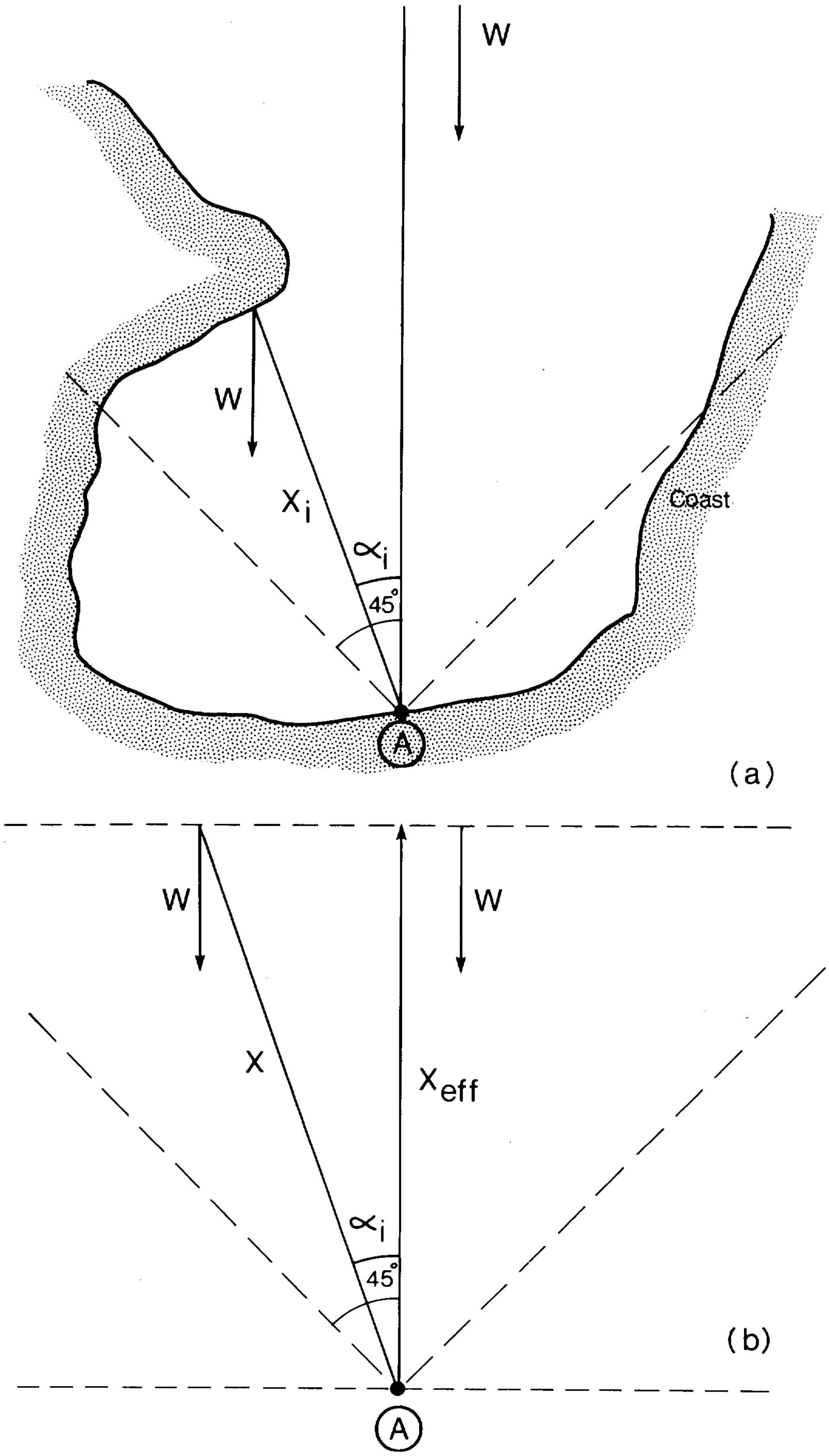


Figure A1

APPENDIX B

DETAILS OF WAVE REFRACTION CALCULATIONS

The following description of the wave refraction analysis program is taken from King and Hardcastle (1980). For full details see Abernethy and Gilbert (1974).

B.1 Ray Tracking

Linear wave theory gives the result that

$$\sigma c = g \tanh \frac{\sigma h}{c} \tag{B.1}$$

where σ is the angular frequency of the wave ,
c is the phase speed (or celerity) of the wave ,
h is the water depth and
g is the acceleration due to gravity .

If the seabed is defined over a rectangular set of grid points and a diagonal drawn across each rectangle, the depths (h) are defined in terms of a series of triangles, in which the celerity (c) may be interpolated using the formula

$$c = px + qy + r \tag{B.2}$$

where p , q and r are constants. This formula is continuous across all triangle boundaries and furthermore by using the linear representation of c in equation (B.2) and Snell's Law (equation 6) it can be shown that the ray path through any triangle is an arc of a circle. Thus given a wave frequency and initial direction, a wave ray may be tracked from any starting point within the grid area, triangle by triangle, until it reaches an end point.

B.2 Energy Transfer Functions

Let the directional wave spectrum be defined by $S(f, \theta)$ where f is frequency and θ is direction. It can be shown (Longuet-Higgins, 1957) that, by making certain assumptions, $S(k_1, k_2)$ is constant along a wave ray path, where $\underline{k} = (k_1, k_2)$ is a two dimensional (vector) wave number. Transforming from wave number space to frequency and direction space to maintain volume elements of energy gives

$$S(f,\theta)\,df\,d\theta = S(k_1,k_2)\,dk_1\,dk_2 \tag{B. 3}$$

whence

$$S(k_1,k_2) = S(f,\theta)\frac{df}{dk_1}\cdot\frac{d\theta}{dk_2} \tag{B.4}$$

which since $dk_1\,dk_2 = k\,dk\,d\theta$, where $k = |\underline{k}|$ gives ,

$$S(k_1,k_2) = S(f,\theta)\frac{1}{k}\cdot\frac{df}{dk}\ . \tag{B.5}$$

Since the group velocity of waves is by definition

$$c_g = \frac{d\omega}{dk} \tag{B.6}$$

where $\omega = 2\pi f$ and since $k = c/2\pi f$ then equation (B.5) becomes

$$S(k_1,k_2) = \frac{c\,c_g}{f}\cdot S(f,\theta) = \text{constant}\ . \tag{B.7}$$

Thus from Longuet-Higgins (1957) $c\,c_g\,S(f,\theta)$ is constant along a ray path whenever f is constant. Therefore by defining $S_i(f,\theta_i)$ and $S_o(f,\theta_o)$ as the inshore and offshore spectra then from (B.7)

$$(c\,c_g)_i\ S_i(f,\theta_i) = (c\,c_g)_o\ S_o(f,\theta_o) \tag{B.8}$$

or

$$S_i(f,\theta_i) = \mu(f)\ S_o(f,\theta_o) \tag{B.9}$$

where

$$\mu(f) = \frac{(c\,c_g)_o}{(c\,c_g)_i}\ . \tag{B.10}$$

To obtain inshore values for H_s and T_z, $S_i(f)$ is required where

$$S_i(f) = \int_{\theta_{i_1}}^{\theta_{i_2}} S_i(f,\theta_i)\,d\theta_i \tag{B.11}$$

$$= \mu(f)\int_{\theta_{i_1}}^{\theta_{i_2}} S_o(f,\theta_o)\,d\theta_i \tag{B.12}$$

where θi_1 to θi_2 is the range of interest at the target point. Assuming that $S_o(f, \theta_o)$ is sufficiently smooth then

$$S_o(f, \theta_o) = \sum_{n=1}^{N} \frac{A_n(f)}{\Delta_o \theta} H(\theta - n\Delta_o\theta) \qquad (B.13)$$

where

- $\Delta_o\theta$ is the angular segment of the offshore direction ,
- N is the number of segments ,
- $A_n(f)$ is the total energy at frequency f in directional segment n (ie $n\Delta_o\theta \leq \theta_o \leq (n+1)\Delta_o\theta$),
- $H(x)$ = 1 if $0 < x \leq \Delta_o\theta$,
  = 0 otherwise .

Substituting for $S_o(f, \theta_o)$ in the expression for $S_i(f)$ and approximating the integral by a summation over the number of rays arriving at the inshore target point(ray paths are reversed after tracking) gives

$$S_i(f) = \mu(f) \frac{\Delta_i\theta}{\Delta_o\theta} \sum_{n=1} N_n A_n(f) = \sum_n A_n T_n \qquad (B.14)$$

where

$$T_n(f) = \mu(f) N_n \frac{\Delta_i\theta}{\Delta_o\theta} \qquad (B.15)$$

and $\Delta_i\theta$ is the angle between rays arriving at the target point and N_n is the number of rays whose offshore direction θ_o is in the nth directional segment.

The inshore H_s and T_z values can be calculated from the zero and second order moments of $S(f)$ (Cartwright and Longuet-Higgins, 1956). That is

$$H_s = 4M_o^{1/2} \quad \text{and} \quad T_z = 2\pi(M_o/M_2)^{1/2} \qquad (B.16)$$

where

$$M_o = \int_0^\infty S(f)\,df \quad \text{and} \quad M_2 = 4\pi^2\int_0^\infty f^2 S(f)\,df. \qquad (B.17)$$

For the computations the integrals are replaced by summations, assuming Δf is sufficiently small. To obtain an estimate of the mean inshore wave direction $\bar{\theta}(f)$, the series approximation (B.13) for is substituted in the definition of the mean vector at the target point, namely

$$\bar{V} = \frac{\int_{\theta_{i_1}}^{\theta_{i_2}} S_i(f, \theta_i)\, e^{i\theta_i}\, d\theta_i}{\int_{\theta_{i_1}}^{\theta_{i_2}} S_i(f, \theta_i)\, d\theta_i} \; . \qquad \text{(B.18)}$$

Thus

$$\bar{\theta}(f) = \tan^{-1} \sum_n A_n(f)\, V_n(f) \Big/ \sum_n A_n(f)\, U_n(f) \qquad \text{(B.19)}$$

where

$$U_n(f) + i\, V_n(f) = \mu(f)\, \frac{\Delta_i \theta}{\Delta_0 \theta} \sum_{\substack{\text{rays in} \\ \text{segment} \\ n}} e^{i\theta_i} \; . \qquad \text{(B.20)}$$

Thus the transfer functions (see Section 3.2) T_n , U_n , V_n are calculated from

$$\begin{pmatrix} T_n \\ U_n \\ V_n \end{pmatrix} (f) = \mu(f)\, \frac{\Delta_i \theta}{\Delta_0 \theta} \sum_{\substack{\text{rays in} \\ \text{segment} \\ n}} \begin{pmatrix} 1 \\ \cos\theta_i \\ \sin\theta_i \end{pmatrix} \qquad \text{(B.21)}$$

for the set of frequencies $\{f_m : m = 1, \ldots\ldots\, M\}$ and stored in a file as the matrix elements $T_{nm} = T_n(f_m)$, $U_{nm} = U_n(f_m)$ and $V_{nm} = V_n(f_m)$. Once these functions are available it is a relatively fast calculation to determine $S_i(f_m)$ and $\bar{\theta}(f_m)$ from equations (B.14) and (B.19) and from the offshore spectral matrix $\{A_{nm} = A_n(f_m)\}$.

B.3 Offshore wave spectrum forms

The offshore values $\{A_{nm}\}$ can be estimated in a variety of ways. Since it is usually the frequency spectrum $S(f)$ that is studied rather than $S(f, \theta)$, the directional distribution is assumed. Thus

$$S_0(f, \theta) = S_0(f)\, G(\theta) \qquad \text{(B.22)}$$

where

$$G(\theta) = \frac{2}{\pi} \cdot \cos^2(\theta - \theta_m) \qquad \text{(B.23)}$$

for $|\theta - \theta_m| \leq \pi/2$ and where θ_m is the mean direction (Hasselman, 1973).

Values of $S_0(f)$ can either be taken directly from a frequency spectral analysis of the offshore wave data, or can be estimated using a theoretical (empirical) approximation (eg Pierson-Moskowitz).

Since the available offshore wave data was mostly in the form of H_s and T_z values, the approximation used for this comparison was one derived from the Pierson-Moskowitz spectrum to include the parameters H_s and T_z. Thus

$$S_0(f) = \frac{H_s^2}{4\pi T_z^4 f^5} \cdot e^{-\frac{1}{\pi (T_z f)^4}} . \qquad \text{(B.24)}$$

Thus values of $\{A_{nm}\}$ were calculated from the approximation

$$A_{nm} = A_n(f_m) = S_0(f_m) . G(\theta_n) . \Delta_0\theta \qquad \text{(B.25)}$$

where θ_n is the direction representative of the n th offshore directional segment.

APPENDIX C

WAVE REFRACTION DIAGRAMS

	Water depth (m)	Wave period (s)	Wave heading (^{o}T)
Figure C1	0.5	7.5	210
C2	2.5	6.0	210
C3	0.5	6.0	225
C4	0.5	7.5	225
C5	2.5	6.0	225
C6	2.5	7.5	225
C7	0.5	6.0	240
C8	0.5	7.5	240
C9	2.5	6.0	240
C10	2.5	7.5	240
C11	0.5	7.5	270
C12	2.5	7.5	270
C13	0.5	6.0	300
C14	0.5	7.5	300
C15	2.5	6.0	300
C16	2.5	7.5	300
C17	0.5	7.5	330
C18	2.5	7.5	330
C19	2.5	6.0	360
C20	0.5	7.5	360
C21	2.5	7.5	360

Note: Other wave refraction diagrams fall in the main text as Figures 24-30.

Place names are shown on Figure 24 only.

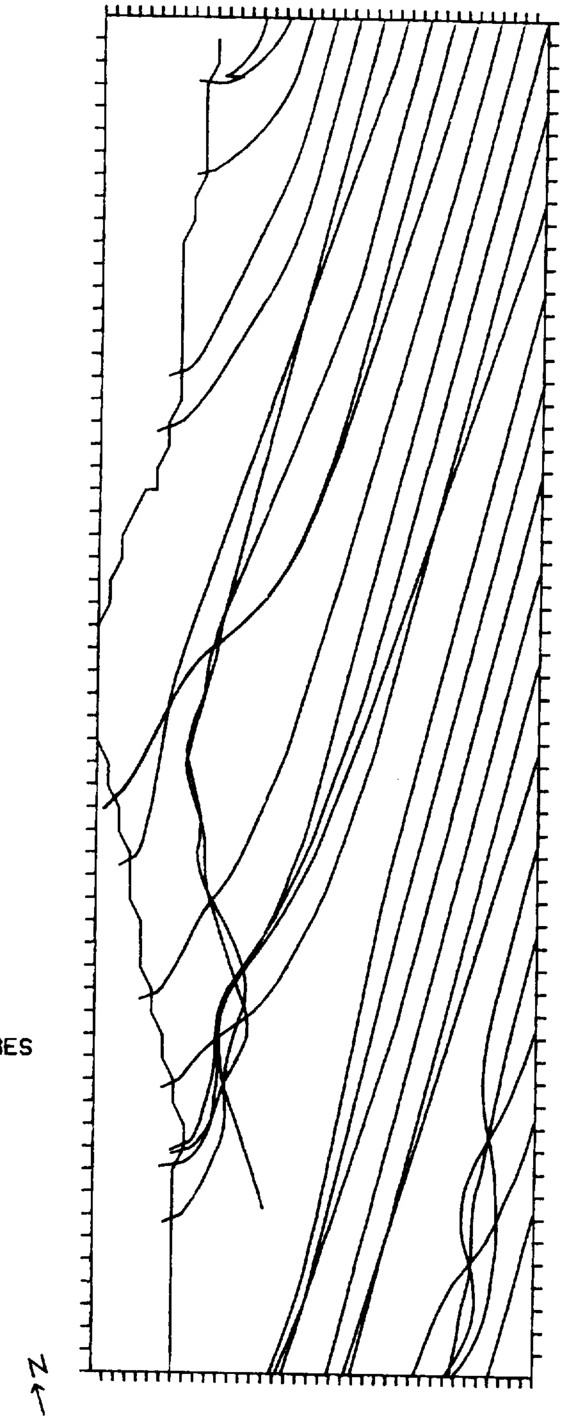
EAST COAST

WAVE PERIOD   7.5 SECS

WATER LEVEL +   0.5 METRES

WAVE HEADING   210. DEG

GRID SIZE   250. X 500. METRES



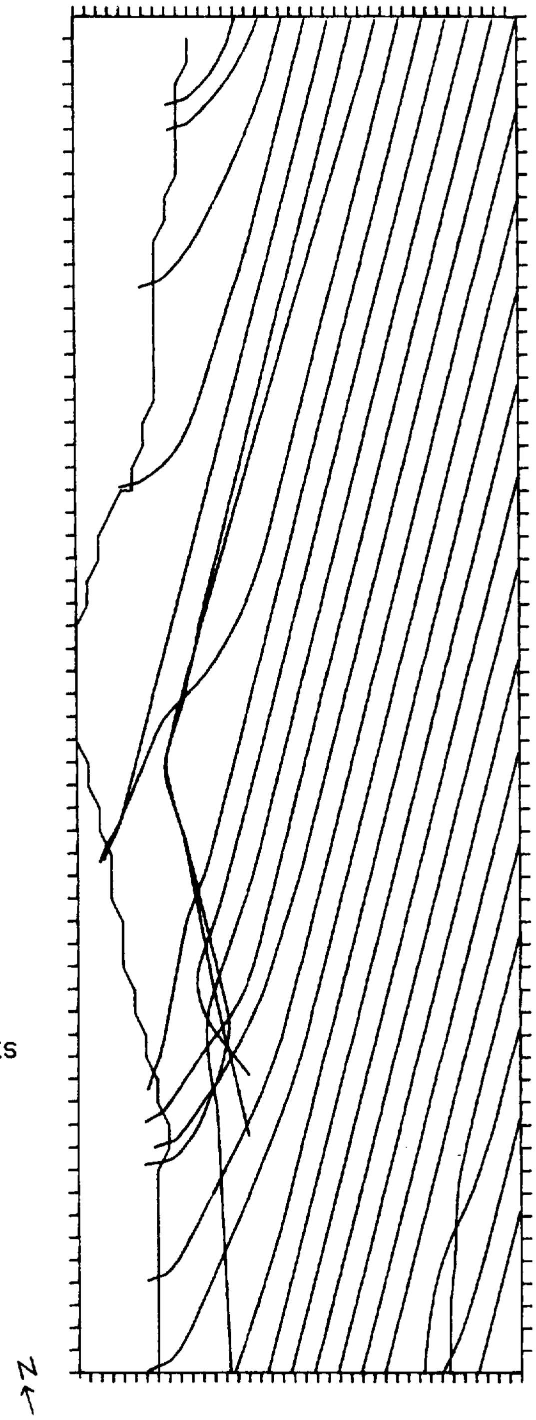
EAST COAST

WAVE PERIOD 6. SECS

WATER LEVEL + 2.5 METRES

WAVE HEADING 210. DEG

GRID SIZE 250. X 500. METRES



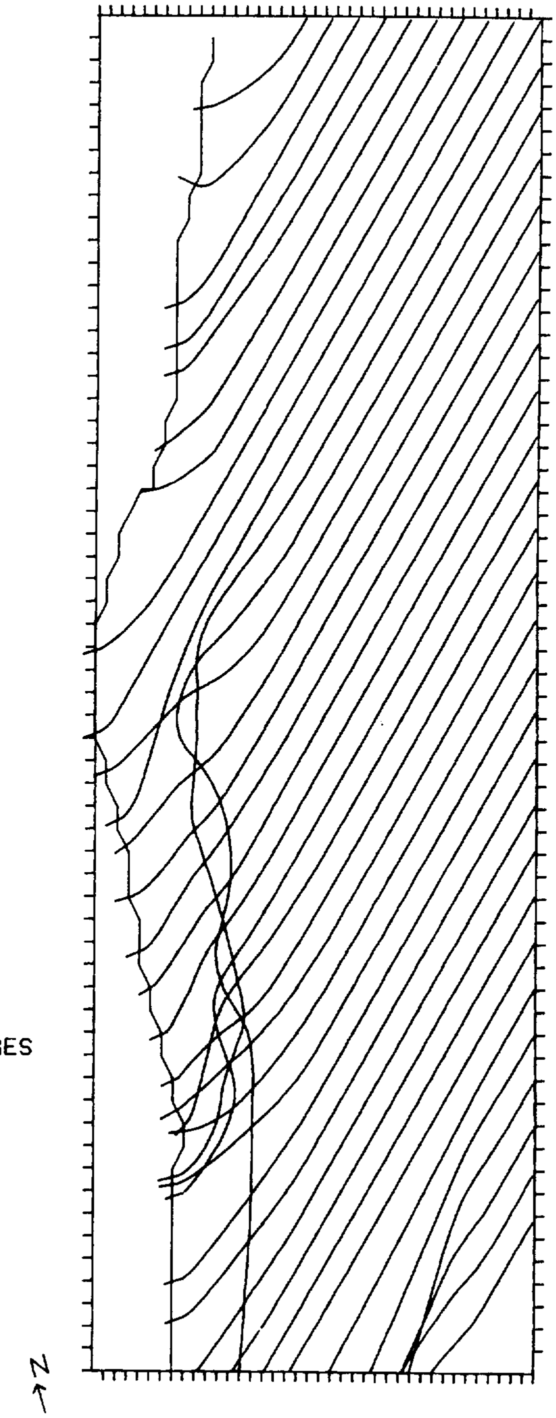
EAST COAST

WAVE PERIOD 6. SECS

WATER LEVEL + 0.5 METRES

WAVE HEADING 225. DEG

GRID SIZE 250. X 500. METRES



C3

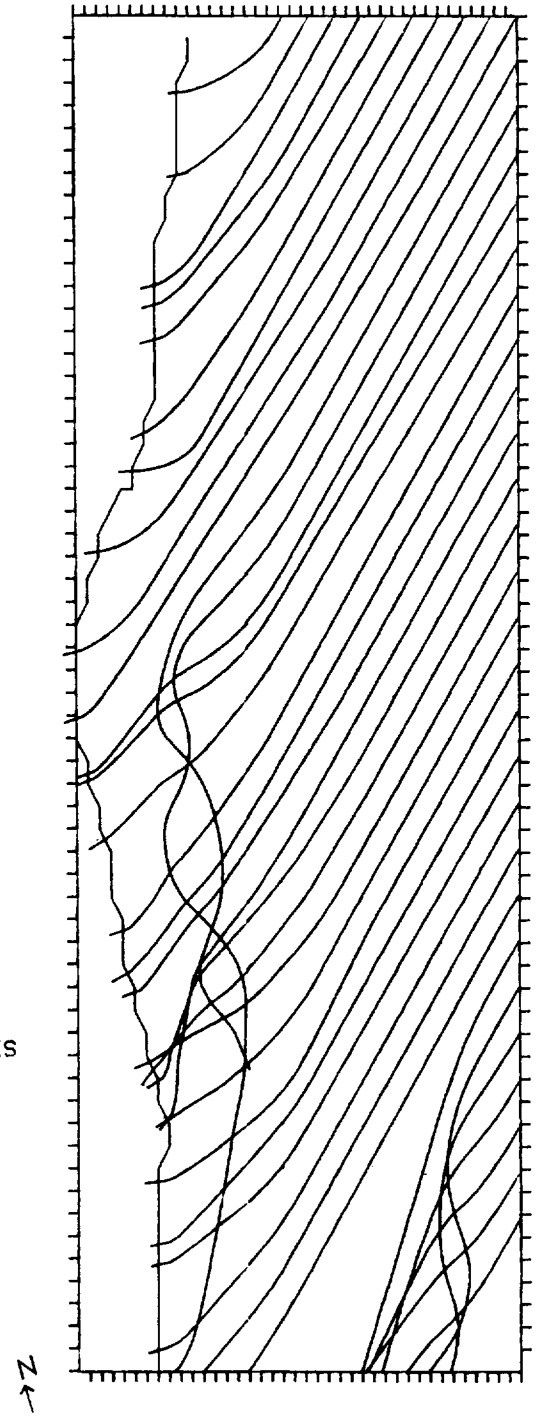
EAST COAST

WAVE PERIOD   7.5 SECS

WATER LEVEL +   0.5 METRES

WAVE HEADING   225. DEG

GRID SIZE   250. X 500. METRES



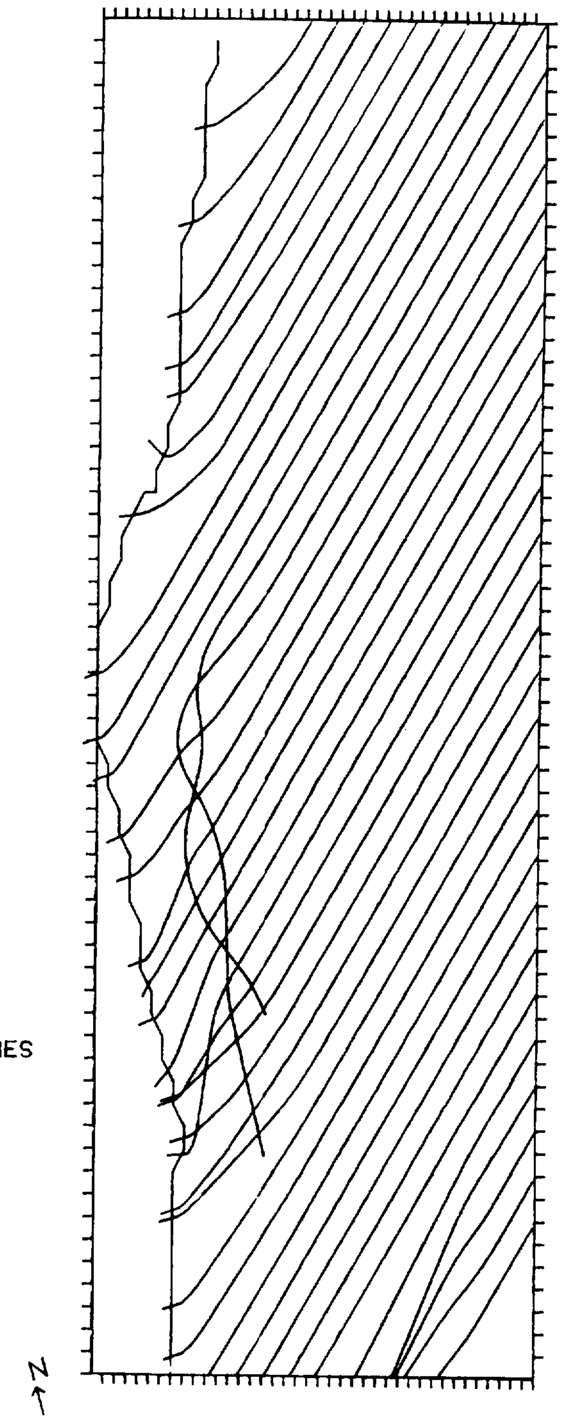
EAST COAST

WAVE PERIOD 6. SECS

WATER LEVEL + 2.5 METRES

WAVE HEADING 225. DEG

GRID SIZE 250. X 500. METRES



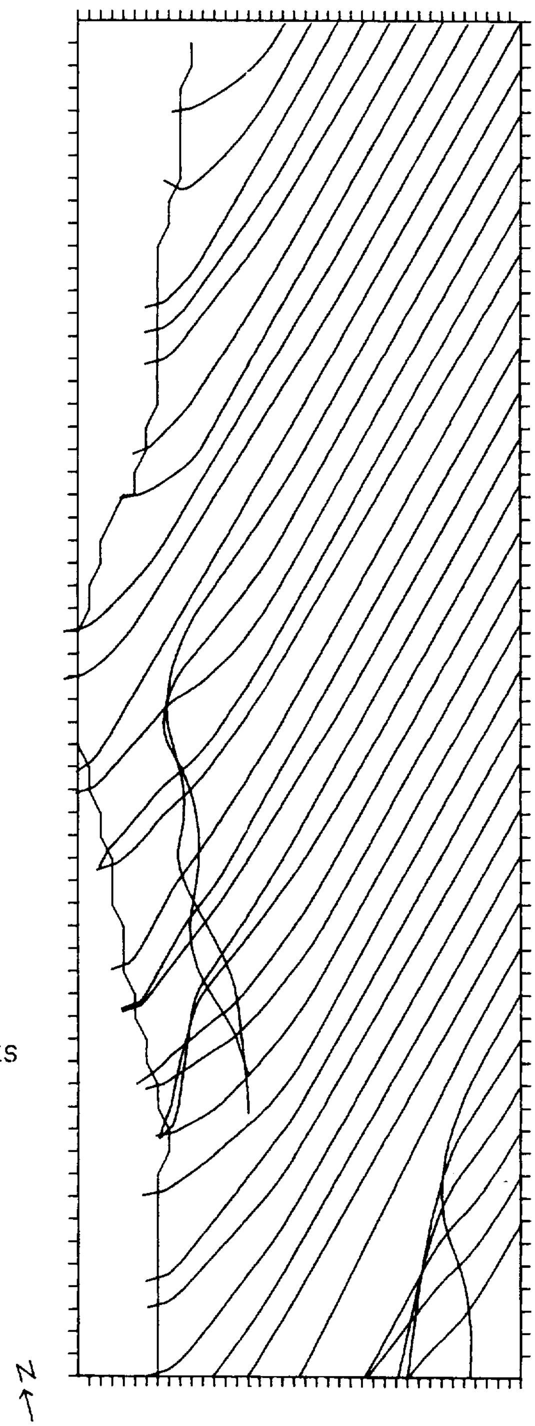
EAST COAST

WAVE PERIOD 7.5 SECS

WATER LEVEL + 2.5 METRES

WAVE HEADING 225. DEG

GRID SIZE 250. X 500. METRES



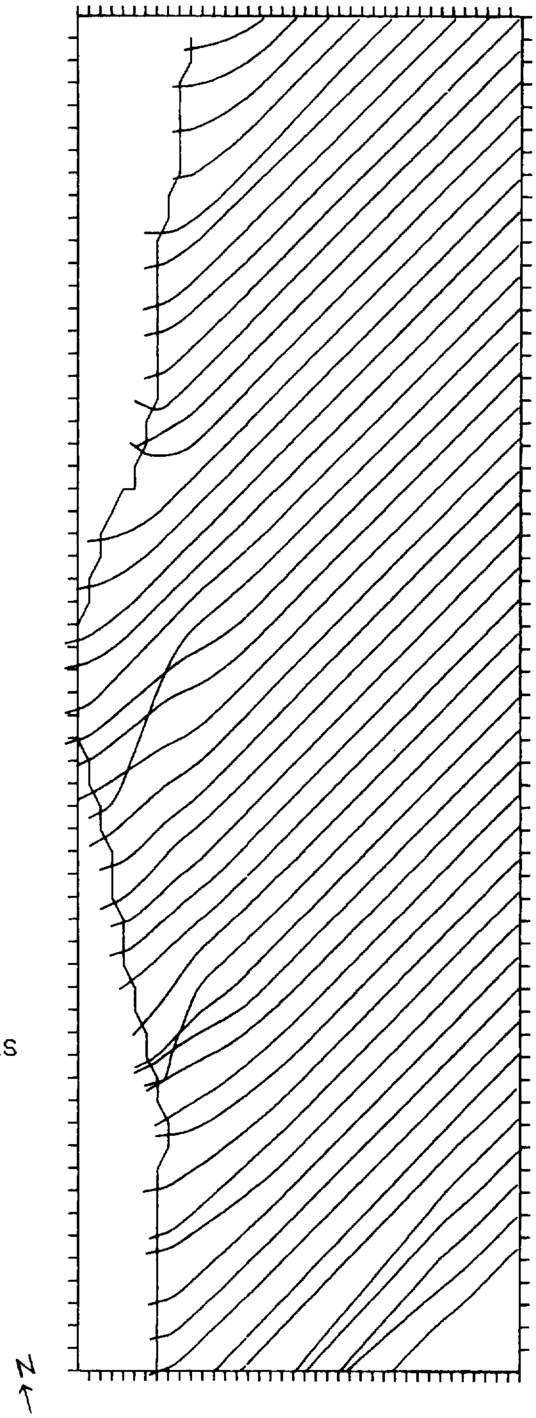
EAST COAST

WAVE PERIOD 6. SECS

WATER LEVEL + 0.5 METRES

WAVE HEADING 240. DEG

GRID SIZE 250. X 500. METRES



C7

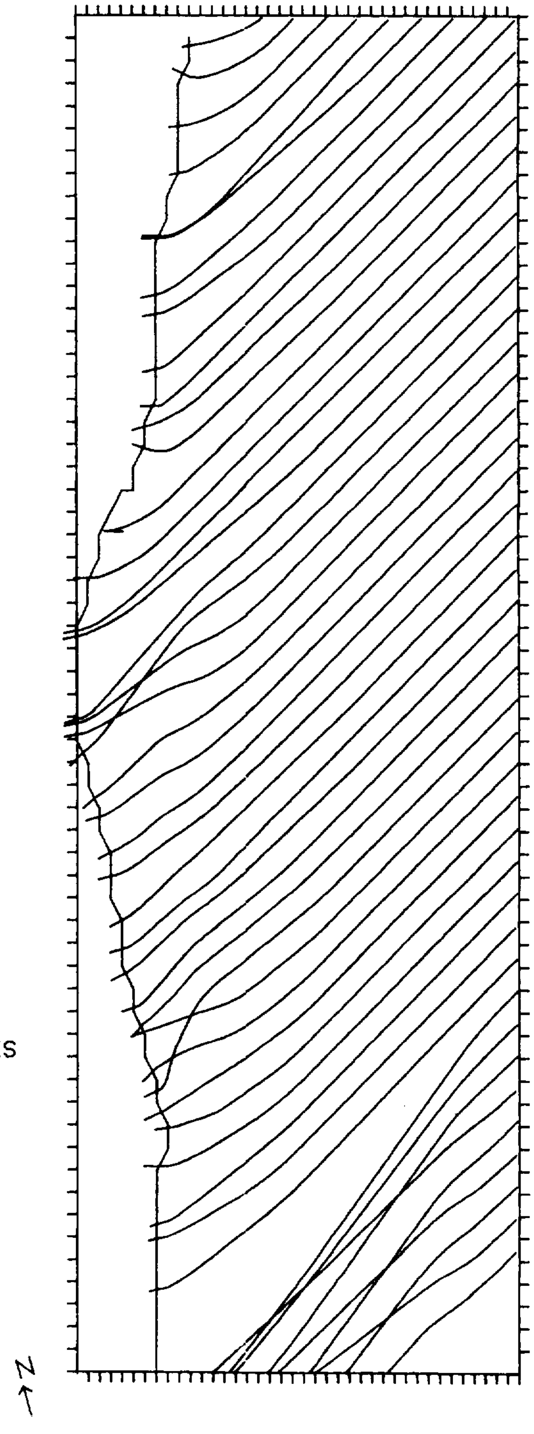
EAST COAST

WAVE PERIOD 7.5 SECS

WATER LEVEL + 0.5 METRES

WAVE HEADING 240. DEG

GRID SIZE 250. X 500. METRES



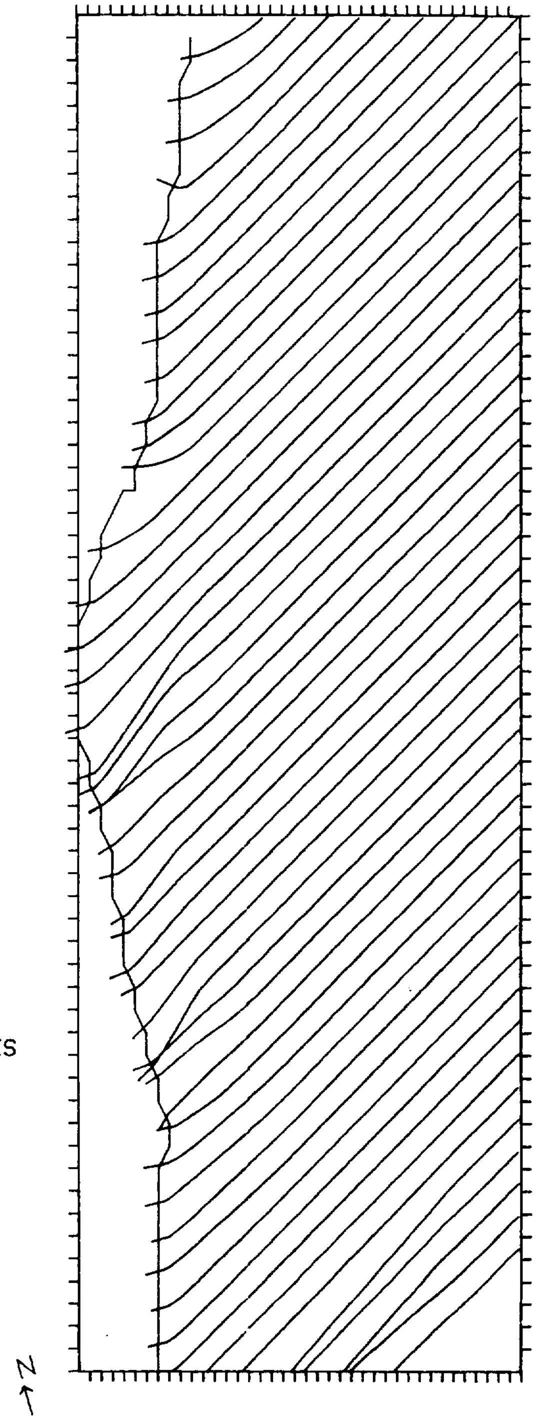
EAST COAST

WAVE PERIOD 6. SECS

WATER LEVEL + 2.5 METRES

WAVE HEADING 240. DEG

GRID SIZE 250. X 500. METRES



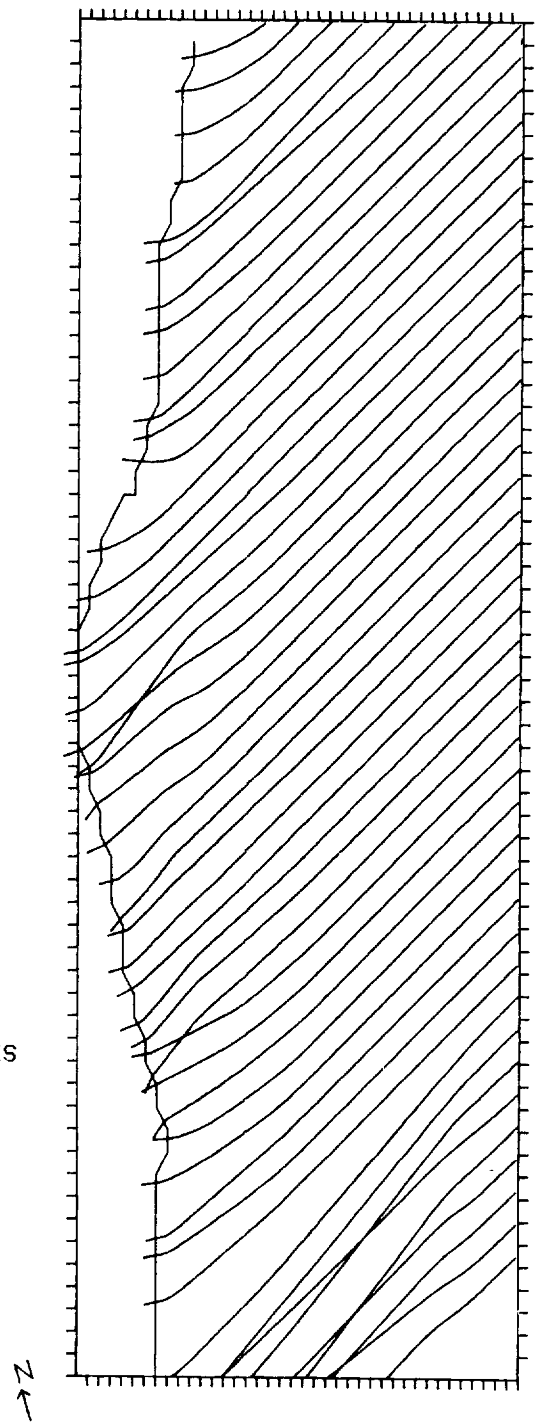
EAST COAST

WAVE PERIOD 7.5 SECS

WATER LEVEL + 2.5 METRES

WAVE HEADING 240. DEG

GRID SIZE 250. X 500. METRES



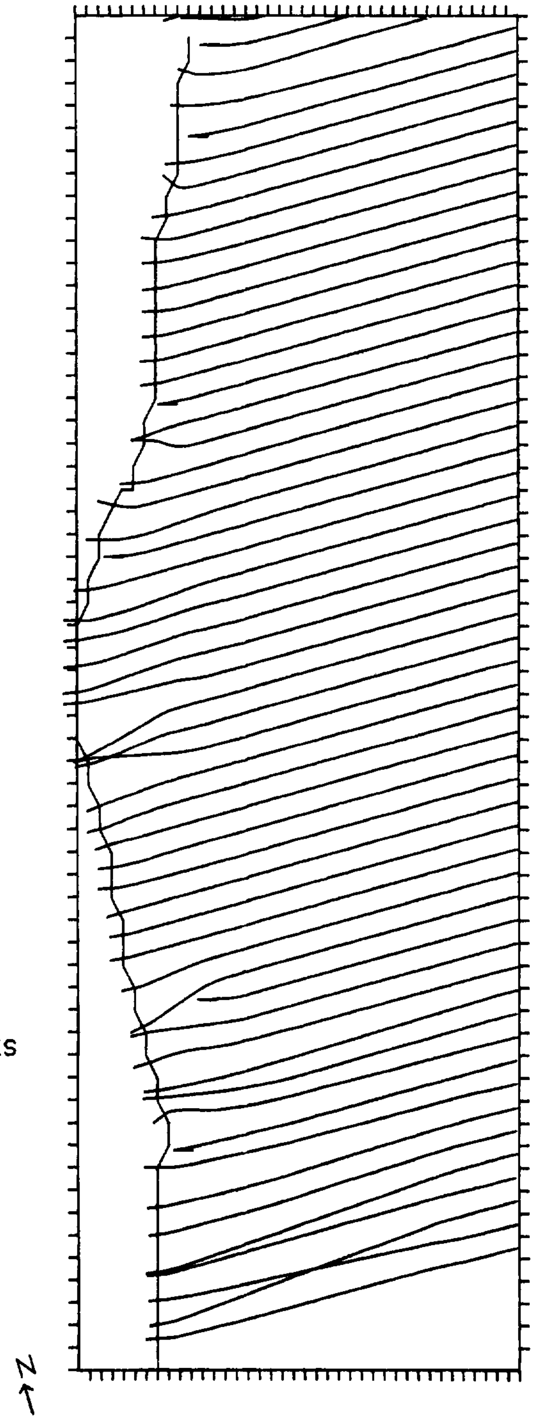
EAST COAST

WAVE PERIOD 7.5 SECS

WATER LEVEL + 0.5 METRES

WAVE HEADING 270. DEG

GRID SIZE 250. X 500. METRES



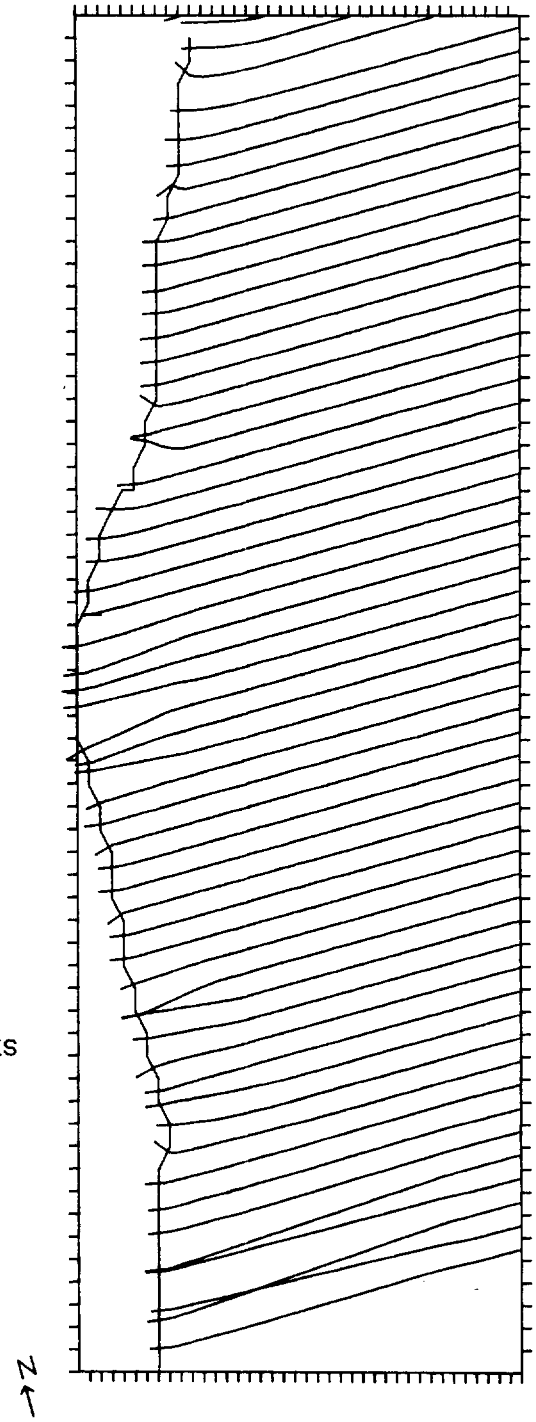
EAST COAST

WAVE PERIOD 7.5 SECS

WATER LEVEL + 2.5 METRES

WAVE HEADING 270. DEG

GRID SIZE 250. X 500. METRES



C12

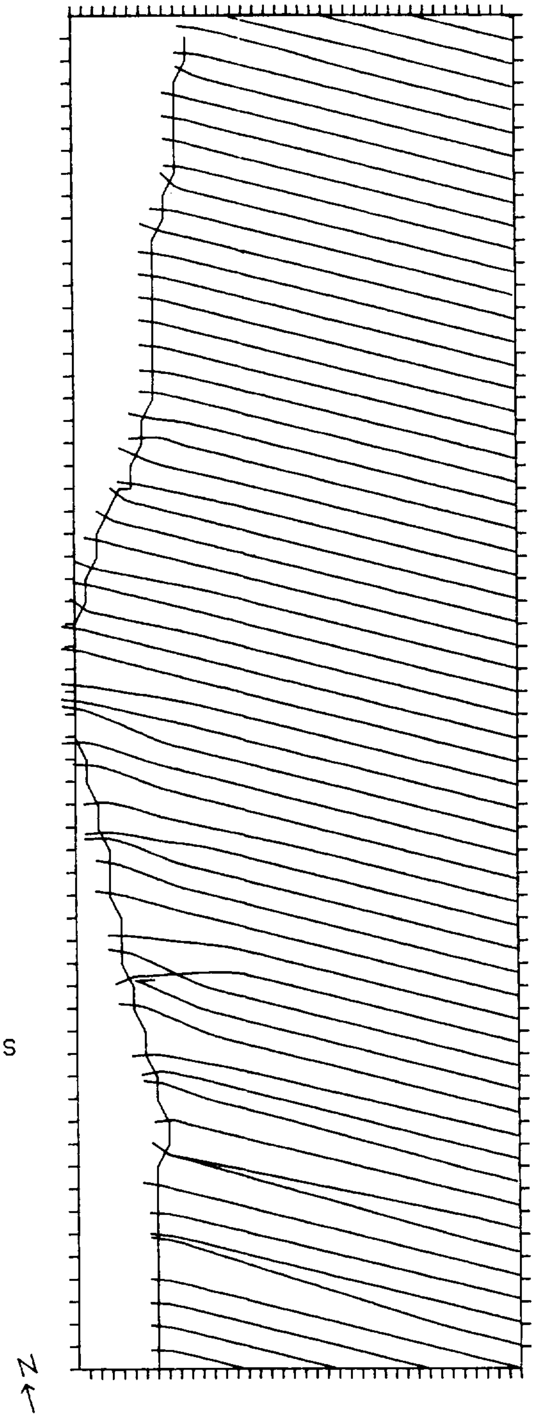
EAST COAST

WAVE PERIOD 6. SECS

WATER LEVEL + 0.5 METRES

WAVE HEADING 300. DEG

GRID SIZE 250. X 500. METRES



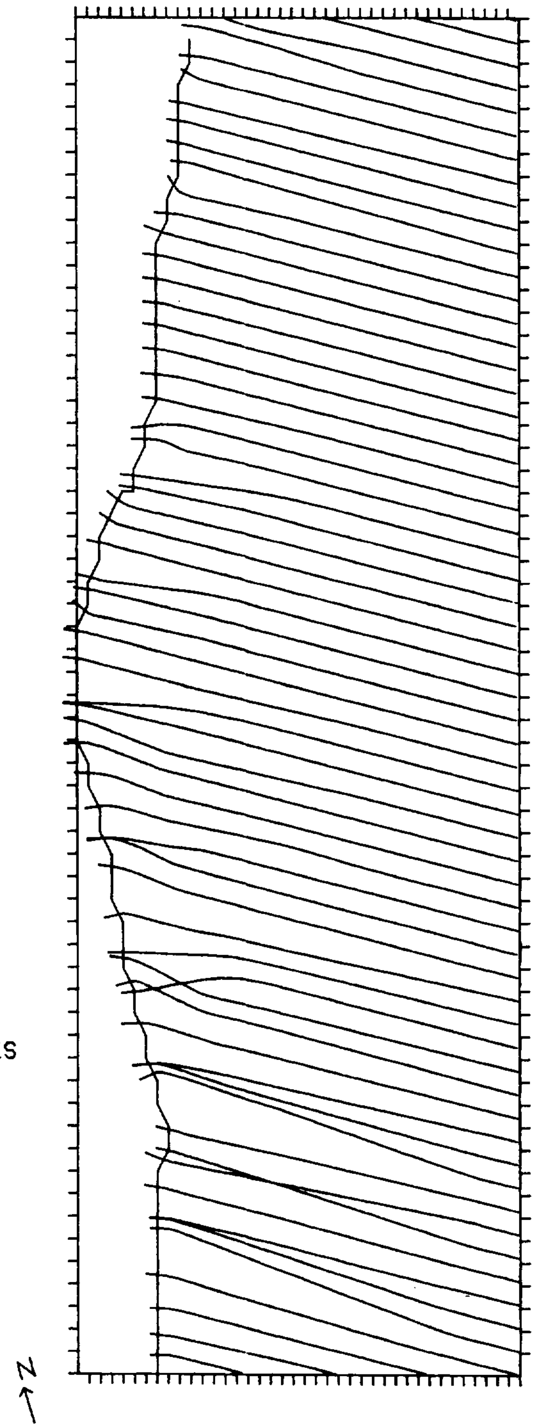
EAST COAST

WAVE PERIOD 7.5 SECS

WATER LEVEL + 0.5 METRES

WAVE HEADING 300. DEG

GRID SIZE 250. X 500. METRES



C14

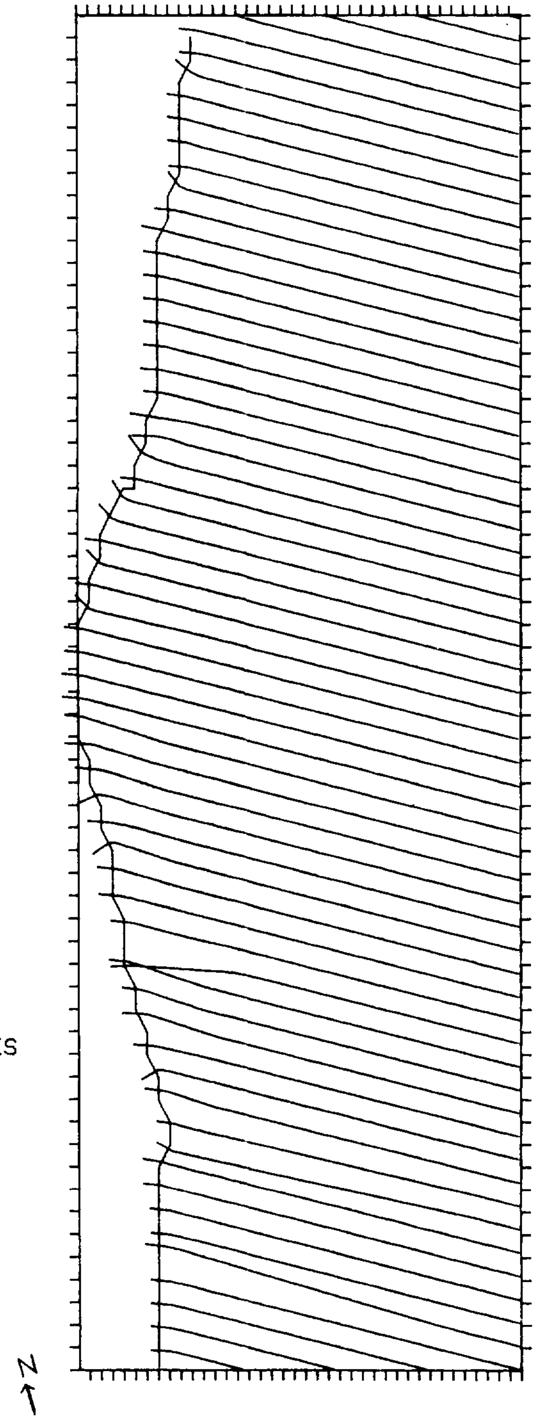
EAST COAST

WAVE PERIOD 6. SECS

WATER LEVEL + 2.5 METRES

WAVE HEADING 300. DEG

GRID SIZE 250. X 500. METRES



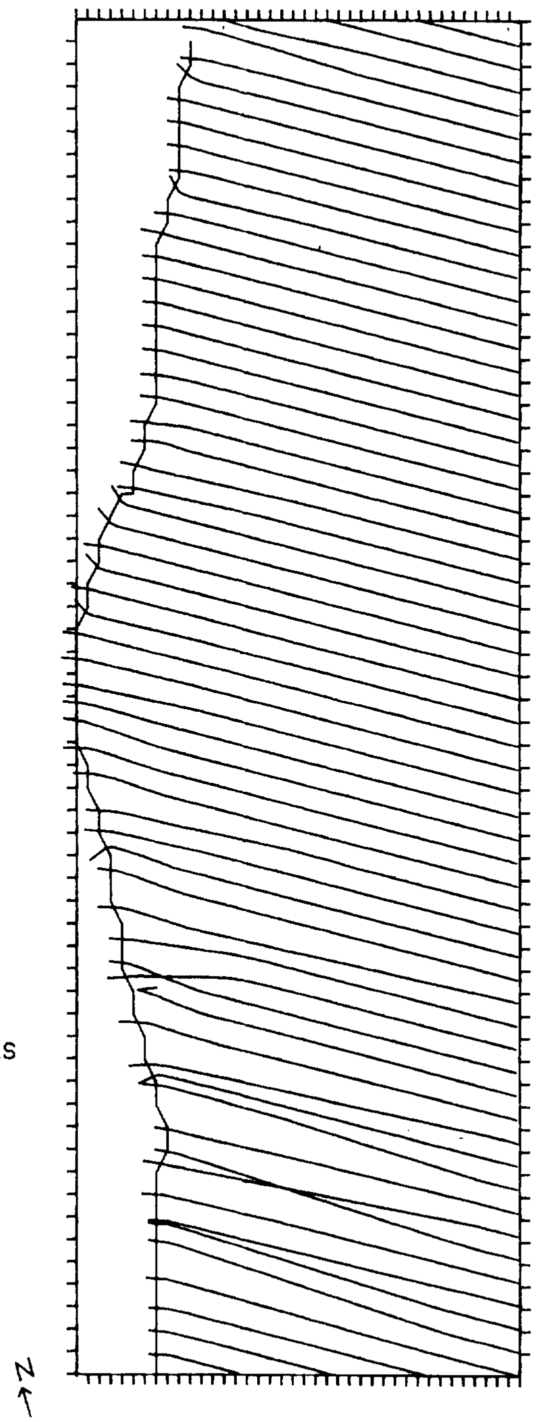
EAST COAST

WAVE PERIOD   7.5 SECS

WATER LEVEL +   2.5 METRES

WAVE HEADING   300. DEG

GRID SIZE   250. X 500. METRES



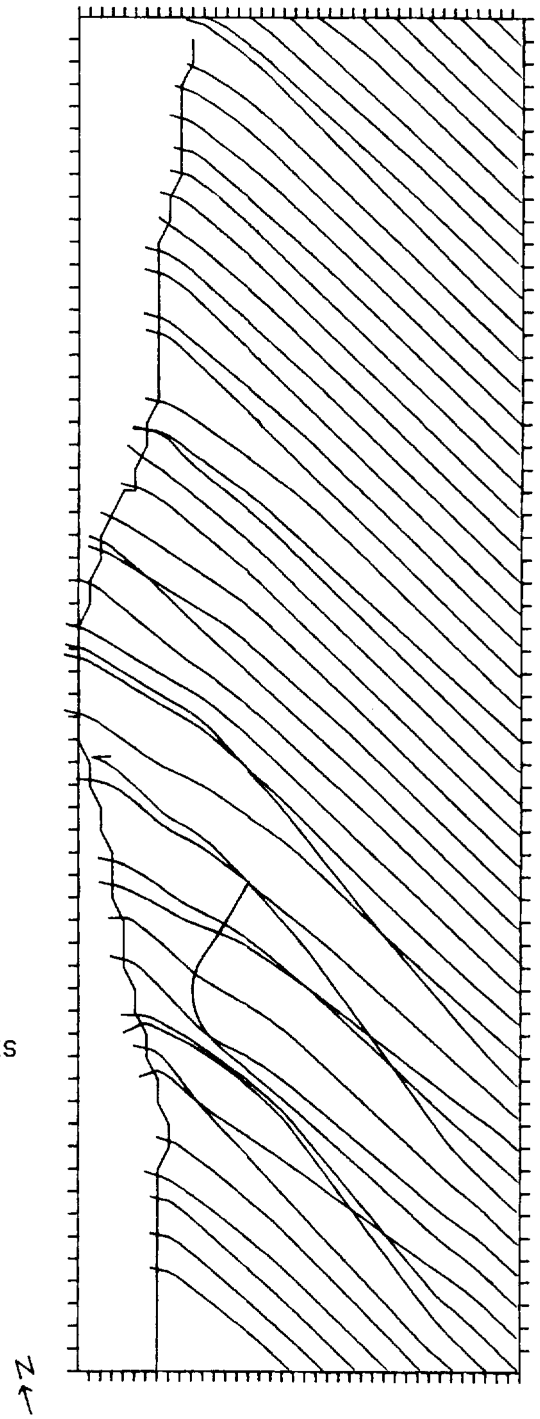
EAST COAST

WAVE PERIOD   7.5 SECS

WATER LEVEL +   0.5 METRES

WAVE HEADING   330. DEG

GRID SIZE   250. X 500. METRES



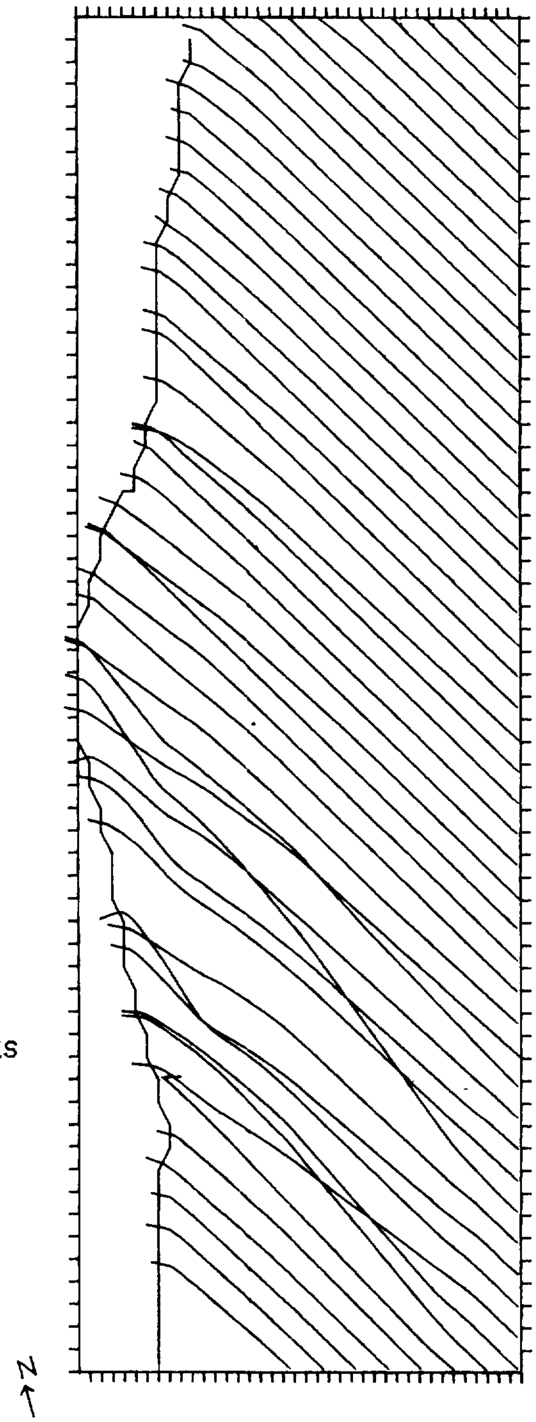
EAST COAST

WAVE PERIOD 7.5 SECS

WATER LEVEL + 2.5 METRES

WAVE HEADING 330. DEG

GRID SIZE 250. X 500. METRES



C18

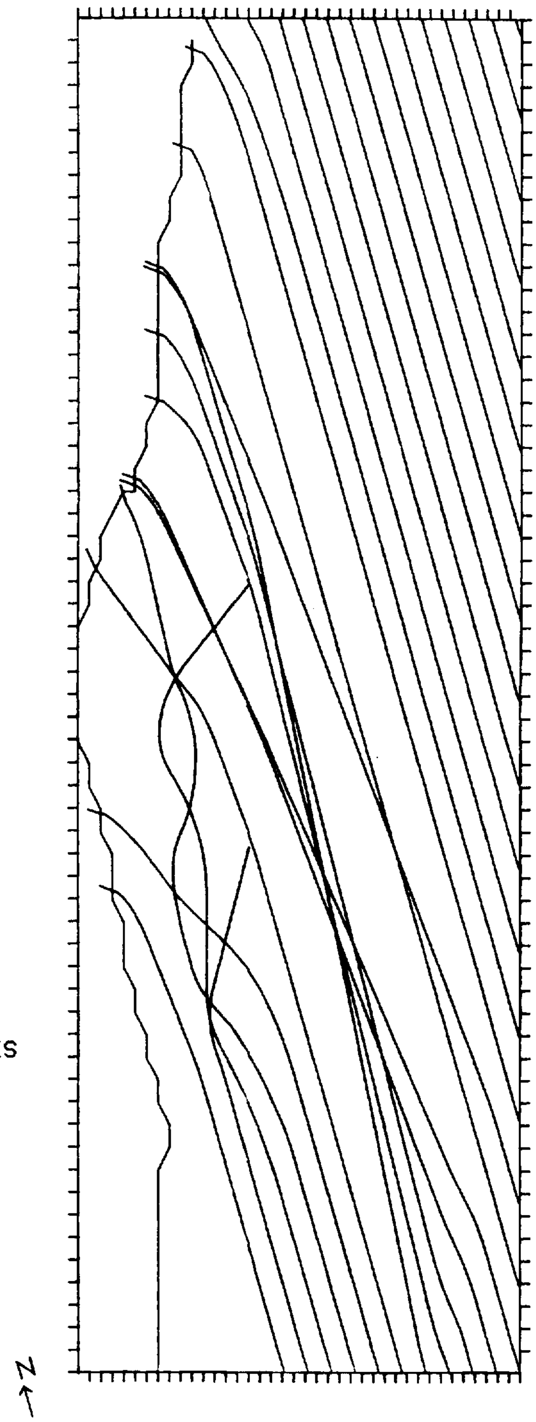
EAST COAST

WAVE PERIOD 6. SECS

WATER LEVEL + 2.5 METRES

WAVE HEADING 360. DEG

GRID SIZE 250. X 500. METRES



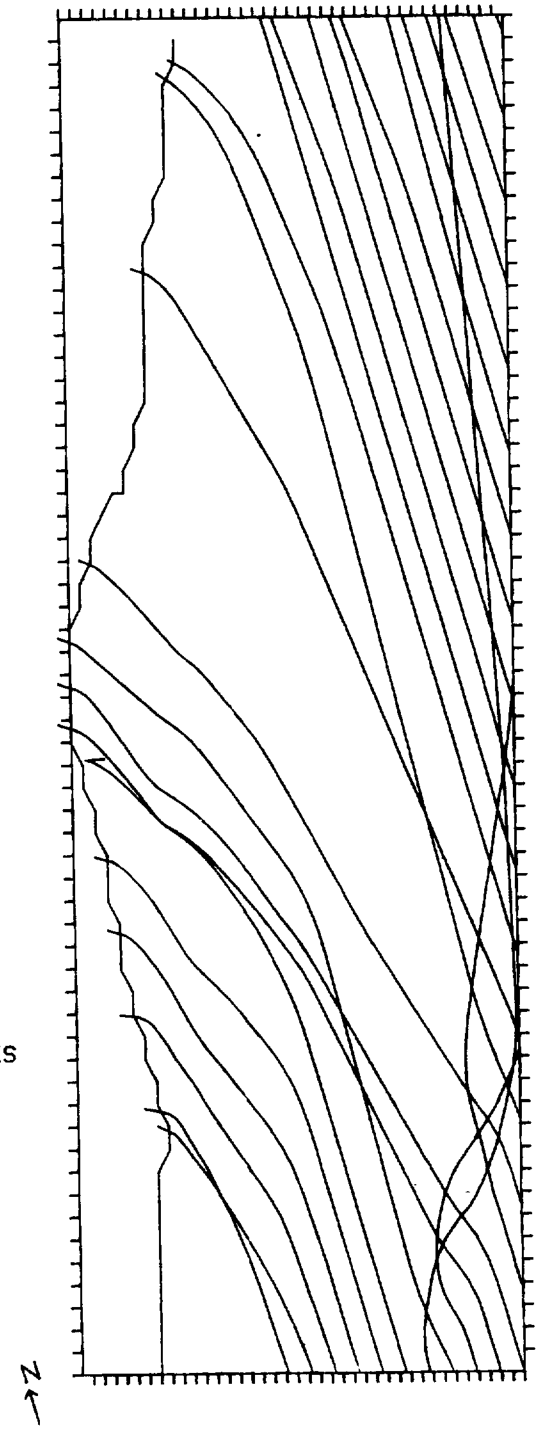
EAST COAST

WAVE PERIOD 7.5 SECS

WATER LEVEL + 0.5 METRES

WAVE HEADING 360. DEG

GRID SIZE 250. X 500. METRES



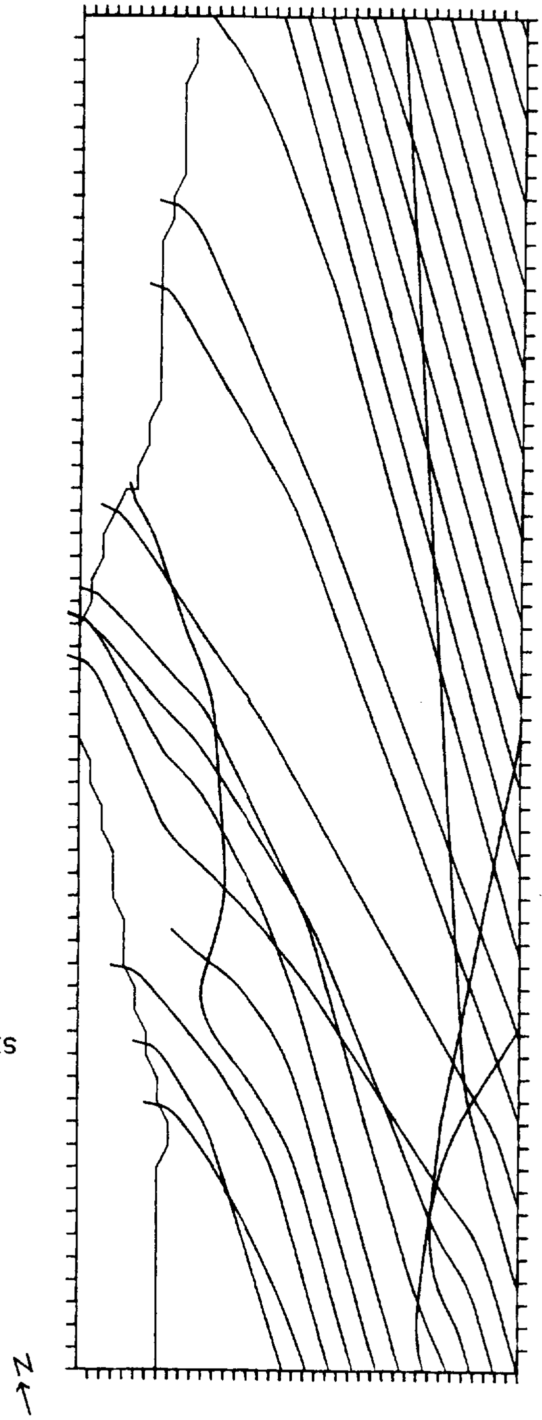
EAST COAST

WAVE PERIOD 7.5 SECS

WATER LEVEL + 2.5 METRES

WAVE HEADING 360. DEG

GRID SIZE 250. X 500. METRES



C21