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The Nearshore Profile Model incorporating wind-wave growth

J.A. Ewing, BSc

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Registered Office: Hydraulics Research Limited,
Wallingford, Oxfordshire OX10 8BA.
Telephone: 0491 35381. Telex: 848552

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SUMMARY

The Nearshore Profile Model of H N Southgate (1989a) has been extended to include wave growth from the wind, in addition to the dissipative processes of bottom friction and wave breaking.

The model results have been compared with wave measurements over the Dunwich Bank and over the Norfolk Banks in the southern North Sea.

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1. INTRODUCTION

A one-dimensional model for waves and currents suitable for use in coastal regions has been developed by Southgate (1989a). The model is based on the equations of mass, energy and momentum and is applicable both inside and outside the surf zone. It is computationally efficient and can be used to process large quantities of input data thus enabling the study of long-term changes in nearshore regions.

The aim of the research on wave and current models for coastal regions is to develop two-dimensional models which describe nearshore processes. The evaluation of a one-dimensional model is the first step in this development.

The Nearshore Profile Model (NPM) uses the approximation of a straight coastline with parallel depth contours and determines both wave and current conditions at grid points along a profile perpendicular to the coastline.

As originally developed, the model comprised Source terms for bottom friction and wave breaking. This paper describes the extension of the physics of the model to include wind-wave growth. A spectral version of the wave model was used for the calculations. Tidal currents are not considered in this study.

Calculations are made for two different locations in the southern North Sea. In the first case, the model results are compared with wave measurements inside the Dunwich Bank for given, measured, offshore wave heights. In the second case, we evaluate the model output inshore of the Norfolk Banks using offshore wave heights provided by a deep-water wave model.

Comparisons are made against wave measurements inside the Banks.

The use of the Nearshore Profile Model over the Dunwich and Norfolk Banks assumes that these banks are approximately linear in structure. Some errors must therefore be introduced into the model results from this approximation.

2. THEORY OF THE WAVE MODELLING

2.1 The Source terms

The theory of the NPM has been given by H N Southgate (1989a), henceforth referred to as S.

The model is based on the integration of the wave action balance equation (see equation (8) of S):

$$\frac{d}{dy}\left(\frac{E\, c_{ga} \cos\mu}{\omega_r}\right) = -\frac{(D_f + D_b)}{\omega_r} \qquad (1)$$

where y is the co-ordinate in the onshore direction, E is the wave energy density ($E=1/8\rho g H^2$, where H is the wave height), c_{ga} is the relative group velocity, ω_r is the relative angular frequency, and μ is the ray direction. D_f and D_b are the Source terms for bottom friction and wave breaking respectively.

The method for determining the dissipation due to bottom friction is based on the boundary-layer model of O'Connor and Yoo (1988) which extends the work of Bijker (1966). From the work of O'Connor and Yoo, we have, for monochromatic waves,

$$D_f = \rho\, C_{fw}\, V_o^3$$

where C_{fw} is a wave-friction factor including an enhancement due to the interaction with currents. (The latter are not however considered in the report). V_o is the orbital velocity on the sea bed, given by

$$V_o = \frac{H \omega_r}{2 \sinh kh}$$

where k is the wave number and h the water depth. The expression for V_o is readily generalized to spectral waves by using the equivalent relations for orbital velocity, zero-crossing period and average wave direction. The method for the calculation of D_f follows the theory of Hasselmann and Collins (1968). (Full details of the method are given in Southgate, 1989b).

For the determination of the Source term due to wave breaking, the wave height at which breaking starts to occur is first taken from Weggel (1972) with the ratio of breaking wave height to water depth, a' = 0.78. (S uses a larger value of a' = 1.12 to tune the breaker plunge line to get better predictions of longshore currents and set-up). Following the work of Battjes and Janssen (1978), the wave height distribution in shallow water is assumed to be a Rayleigh distribution truncated at the breaker height, H_b. The rate of dissipation of broken wave energy, D_b, is then taken from the expression for a tidal bore with an appropriate empirical constant, as given in equation (18) of S.

An alternative breaking wave height coefficient can also be used in the NPM. This coefficient is based on the work of Battjes and Stive (1985), as modified by Nairn (1990), and is dependent on the incident wave steepness.

The use of the model in the southern North Sea for long profiles and in strong winds, necessitates the inclusion of physical terms describing wave growth from the wind.

For the wind input we use the expression given by Snyder et al (1981), based on the theory of Miles (1957).

$$Gu = \begin{cases} 0.25\text{x}10^{-3}(U\cos\phi/c - 1).\omega E & :\text{for } U\cos\phi > c \\ 0 & \text{otherwise} \end{cases}$$

Here U is the wind speed at 10m, ϕ is the angle between the wave and wind directions, and c is the phase velocity in water of depth h. As $G_u \propto E$, this implies an exponential growth rate for the energy density.

The additional Source term G_u was included in the right-hand side of equation (1) and in the computation of the integral on the right hand side of equation (25) of S.

The dissipative terms D_f and D_b are both negative and proportional to H^3, while the growth term, G_u, is positive and proportional to H^2.

Wave growth from a calm sea, by means of the resonance mechanism of O M Phillips, is not included in the model since, in all cases considered here, an initial wave height and spectrum are given at the end of the profile, y = 0.

2.2 Limiting spectrum

It was found necessary to include a limiting spectrum in the model calculations at high wave frequencies since wind wave growth is rapid for short wave periods.

The limiting spectrum is taken as a "Phillips" (1958) spectrum (for deep water) multiplied by the shallow water function Φ of Kitaigorodskii et al (1975). These authors showed that the concept of a saturation range could be extended to water of finite depth by means of the function Φ given by

$$\Phi = \frac{\tanh^2 kh}{(1 + 2kh/\sinh kh)}$$

where k satisfies the linear dispersion relation $\omega^2 = gk \tanh kh$.

For the rapid calculation of the shallow water function Φ we take an approximation, accurate to 4%, namely

$$\Phi = \begin{cases} 0.5\ \omega_h{}^2 & : \omega_h \leq 1 \\ 1 - 0.5(2-\omega_h)^2 & : 1 < \omega_h < 2 \\ 1 & : \omega_h \geq 2 \end{cases}$$

where $\omega_h{}^2 = (2\pi f)^2.(h/g)$.

For the Phillips deep-water spectrum, we take the expression

$$E(f) = \alpha\ g^2\ (2\pi)^{-4}\ f^{-5}$$

where f is the wave frequency (in Hz) and $\alpha = 0.016$, a value appropriate for wind seas.

3. COMPUTER PROGRAM

The spectral version (Southgate, 1989b) of the computer program developed by H N Southgate and his colleagues was used in the calculations shown in this report. Both unidirectional and directional wave spectra can be used as input to the model.

A preliminary study was made of the comparison between results using the NPM with monochromatic waves and unidirectional and directional irregular waves. The sensitivity of the results to different types of wave input is shown in Appendix 1. In general, it was found that the results from using the model with unidirectional waves were close to those for monochromatic waves. However, since wind-wave growth is very sensitive to wave period, the use of the model over long fetches (such as the Norfolk Banks) requires a spectral version of the NPM. Calculations for directional waves gave results about 7% lower than those for unidirectional waves. For reasons of economy in running the NPM and because of uncertainties in specifying the offshore directional distribution, it was decided to restrict all model runs to unidirectional random waves.

In the field studies used to validate the NPM, the parameters rms wave height, H_{rms}, and modal period, T_p, were available and not the offshore wave spectrum. To utilize this information, we follow the representation of wave spectra in the Pierson-Moskowitz (PM) form given by the International Ship Structures Congress. Namely,

$$E(f) = 0.11 H_s^2 \, T_1 \, (T_1 f)^{-5} \exp\left[-0.44 (T_1 f)^{-4}\right]$$

where H_s is the significant wave height and T_1 is the wave period obtained from the first moment of the spectrum. f is the wave frequency in Hz. For a PM spectrum $T_1 = 0.77\ T_p$ and $H_s = \sqrt{2}.H_{rms}$. Wave input at the offshore boundary of the model was defined in terms of this spectral representation at ten equally spaced periods from 3s to 12s.

4. COMPARISON OF MODEL RESULTS WITH WAVE DATA OVER THE DUNWICH BANK

The Institute of Oceanographic Sciences, Taunton (Carr et al, 1981), have made wave measurements, together with surveys of tidal currents and bathymetry, over the Sizewell-Dunwich Banks from January 1975 to May 1979. Two waverider buoys were deployed on either side of the Dunwich Bank (where the water depth is about 4.5m at mid-tide level) separated by a distance of about 3 km (See Fig 1).

The most detailed set of wave measurements was made during February 1979 and is considered in this report. Wave spectra were taken during the measurements but are no longer available. All comparisons given in this report are therefore based on the rms wave height and mean wave period.

The bathymetry along the profile between the two waverider buoys was extracted from the Hydrographic Department chart. Depths relative to chart datum were obtained at 250m intervals on the seaward side of the Bank and at 125m intervals over and inshore of the Bank. The profile depths commenced at the offshore waverider buoy: the profile direction was 105 degrees. Tidal variations were measured by Carr et al (1981) and their values are used in this report.

4.1 The influence of the wind input

Wind speed and direction at Gorleston are available for the period of the wave measurements and were used as input to the Source term for wind-wave growth in the NPM. A "mark-up" factor of 1.11, appropriate to the direction sector of the measurements, was used for the wind estimates over the sea (See Hydraulics Research Report EX 1665, January 1988).

The computations with the NPM were made for the cases given in Tables 8b and 8c of Carr et al (1981), when the wind speed was greater than 10 m/s. These values of the wind speed and direction are given in Table 1 together with the measured offshore wave height and period and estimated wave direction, Θ_m. In the calculations the wave breaking term of Battjes and Stive (1985) was used.

Table 1 shows that the result of including the wind input, for winds exceeding 10 m/s, increases the rms wave height over the Dunwich Bank by about 4%. It may therefore be anticipated that, over longer fetches as discussed later in this report, the wind input is an important Source term in the NPM. The results from the NPM are however about 20% lower than measured values of the rms wave height.

4.2 The influence of the wave breaking term

Calculations using the NPM over banks and shoals are very sensitive to the Source term for wave breaking. Three different formulations are considered: First, the formula due to Weggel (1972) with a breaker wave height to water depth ratio of a' = 0.78. Second, the representation of wave breaking due to Battjes and

Stive (1985). Lastly, calculations with the formula of Weggel with a' = 1.0. This latter value has been recently proposed by Hughes and Borgman (1987) based on a measured data set of high quality collected at the Field Research Facility, North Carolina. (We note that S uses a larger value of a' = 1.12 to tune the breaker plunge line to get better predictions of longshore currents and set-up).

The computations were made for situations in Table 8b of Carr et al (1981) and are shown in Table 2. As before, offshore wave data were taken from the waverider buoy measurements. The calculated values of H_{rms} for the three wave breaking formulations are compared with the measured values at the inner waverider buoy.

For rms wave heights less than about 1m there is no difference between the three model results since the water depth exceeds 4.5m and the Source terms for wave breaking are all negligible.

Wave breaking becomes important for wave heights exceeding about 1m. In this case, the analysis of Table 2 shows that the formulation of Weggel with a factor a' = 1.0 gives good agreement with the measurements. The two other wave breaking formulations give results on average 10% to 20% lower than the measured wave heights. Figure 2 shows the model results compared with wave measurements when a' = 1.0 is chosen in Weggel's formula.

5. COMPARISON OF MODEL RESULTS WITH WAVE DATA OVER THE NORFOLK BANKS

The banks off East Anglia were chosen for a further evaluation of the NPM. The Norfolk Banks have an approximately linear aspect and are therefore suitable for use with the model. A directional WAVEC buoy has been deployed off Cromer by the Institute of Oceanographic Sciences, Wormley (Clayson and Ewing 1988), from December 1985 to June 1987. Data from HR's hindcasting wave model, HINDWAVE (Hawkes 1987), were used to provide an estimate of the offshore wave height and period in the absence of any offshore wave measurements.

The calculations were made over a profile of length 84 km extending in a North-East to South-West direction and thus covering the bank system (See Figs 3 and 4). The profile was digitized at intervals of about 150m over the banks and 1km elsewhere from the offshore point where wave data from HINDWAVE was taken to the position of the WAVEC buoy 20 km off Cromer.

The three offshore banks - Viking, Swarte and Broken - lie in depths of about 15m, while the four inner banks - Well, Inner, Ower and Leman - are at approximately 5m depth. Finally, the inshore wave measurements were made at a depth of 31m.

Wind speed and direction measured at Gorleston are available for the period of the measurements. Allowance for wind speed and direction over the sea was made, as previously discussed in section (4.1). Values of the wind speed and direction used in the calculations are shown in Table 3.

Tidal data were obtained from the Admiralty Tide Tables for the period of interest, based on predictions for Immingham and Secondary Port characteristics given for Cromer. It was assumed that no tidal height variation occurred along the profile; this is a reasonable assumption as shown by the co-range lines in the southern North Sea.

5.1 Model calculations: the influence of the wind input

A particular two-day period, 1 and 2 February 1986, was selected for the comparison between model and measured wave heights. During this period the WAVEC buoy showed that the mean wave direction was close to 045 degrees and thus nearly along the profile. Wind speeds ranged from 12 m/s to 20 m/s during the two days.

Values of wave height and period from HINDWAVE were fitted to a Pierson-Moskowitz spectrum and the model calculations were made for unidirectional, random waves with a period bandwidth of 1 sec extending from 3 sec to 14 sec.

The short period waves grow rapidly over a fetch of 84 km. It was therefore found necessary to include a limiting spectrum in the model calculations, as given in section 2.2.

The wave breaking term of Weggel (1972) with a breaker wave height to water depth ratio of a' = 1.0 was used in the calculations shown in Table 3.

Results of H_{rms} from the NPM, with and without wind input, are compared with measured values from the WAVEC buoy. The calculations with wind input always lead to better agreement with the measurements. The mean ratio of H_{rms} (observed)/H_{rms}(measured) was found to be 0.97. The rms deviation of model wave heights from measured values was found to be 0.2m (Without wind input this ratio was 0.71). The agreement between the NPM and measurements is remarkably close.

A graph of the variation of H_{rms} along the profile for 15.30 hrs on 2 February 1986 is shown in Figure 5. It is interesting to note the difference between results with and without wind input and also the rapid decrease in wave height over the Well and Ower Banks. Inshore of the Leman Bank little dissipation takes place due to the increased water depth (See Fig 4) and the wave height increases due to the wind. The agreement with the WAVEC buoy at the end of the profile is good.

Another comparison of model and measured values of H_s is shown in Figure 6. (This figure is an extract from Figure 5 of SR Report 218, October 1989). The dashed curve shows the results from the deep-water version of HINDWAVE. There is clearly much better agreement with measured data when the NPM is used in conjunction with HINDWAVE off Cromer.

5.2 Further model calculations

5.2.1 <u>The influence of wave refraction</u>

The normal to the bathymetry off the Norfolk Banks lies in a direction 045 degrees. (The bathymetry along the profile is shown in Fig 4). The wind records at Gorleston were inspected for situations with steady wind speed and direction within about 30 degrees of the normal of 045 degrees. One such period was identified - 14 and 15 February 1986 - which also coincided with WAVEC buoy measurements off Cromer.

The Gorleston winds, with appropriate "mark-up", were used to infer offshore wave heights from the output of HINDWAVE. For the two-day period selected, the wind direction lay between 070° and 100° with measured wave direction (after refraction) of about 065°. The wind speeds during the period ranged between 9 and 14 m/s.

Table 4 compares the results of rms wave height, Hrms, with measured values. (The wave breaking term of Weggel, with ratio of breaker wave height to water depth of 1.0 was assumed). The average ratio of model to measured wave height was found to be 1.14. This ratio is greater than the comparable one for normal wave incidence of 0.97, given previously in Table 3.

5.2.2 <u>Calculations for low wave heights</u>

A 2-day period of low wave heights (and near normal incidence) at Cromer was identified from the WAVEC buoy records. Wind speeds at Gorleston were found to be about 6 m/s. For the selected period - 11 and 12 March 1986 - the offshore wave heights input to the NPM were taken, as before, from the output of HINDWAVE. (The offshore wave periods were taken as 5 sec). For the short wave periods of about 5 sec, and low wave heights, dissipative effects are small and the main influence is wave growth from the wind. Table 5 shows the results. There is good agreement between results from the NPM and wave measurements considering the low levels of wave energy (Hrms $<$ 0.5m). The average ratio of model to measured wave heights was found to be 1.10.

5.3 Effect of changing the offshore wave height

In a previous section very good agreement was found between model and measured wave heights at inshore points with wave data input from HINDWAVE at the offshore boundary to the NPM. This section considers the sensitivity of the inshore results to the offshore wave height.

One particular record, 00.30 hours, on 1 February 1986, was chosen for the tests. The original energy spectrum given by HINDWAVE was then scaled by factors of 0.4, 0.6, 0.8 and 2.0 to investigate the influence of offshore wave height.

The results are shown in Figure 7. There is an initial wave growth before reaching the Well Bank. Dissipative processes then dominate with the result that the wide difference in initial offshore wave heights is greatly reduced once the Bank is passed. Passage over the next three banks - Inner, Ower and Leman - reduce the range of wave heights from 2.1m to about 2.4m. Finally, in the deeper water inshore of the Leman Bank, wind wave growth dominates over the last 20 km to the WAVEC buoy with the range of wave heights from 2.8m to 3.0m. (The dashed curve shows the results for the case where wind wave input is omitted from the calculations). Similar results were found in other cases but are not shown here.

5.3.1 Structure of the Source terms

We now discuss the contributions to the overall energy balance by considering the individual Source terms at three points along the profile. Point A is in deep water, Point B is at the Wells Bank, Point C is in the deeper water inshore of the banks, (See Fig 4).

The Source terms at the point A, B and C are shown in Figure 8. We define the Source terms by the following notation:

- G_u : the input term from the wind
- D_f : the dissipative term for bottom friction
- D_b : the dissipative term for wave breaking in shallow water

At points A and C the wind input G_u dominates over bottom friction (except for very long periods) and the Source term for wave breaking is negligible (see Figs 8a and 8c). This accounts for the slow increase in wave height in the regions before and after the banks.

At the Wells Bank, all three Source terms are important, as shown in Figure 8b. We show three calculations for the wave breaking term : namely, Weggel's formulation with a wave height to water depth ratio of 0.8 and 1.0 and the formulation of Battjes and Stive. In all three cases, the combined effect of D_f and D_b dominates over the wind input to give the dramatic reduction in wave height seen at the Wells Bank in Figure 7.

The influence on wave height of the three wave breaking terms is shown in Figure 9 for the record of 00.30 hours, 1 February 1986. As noted previously, the results with Weggel's formula and a coefficient of 1.0 give the closest agreement with measurements. The formula of Battjes and Stive gives the lowest wave heights at the WAVEC buoy position.

6. CONCLUSIONS

The Nearshore Profile Model of Southgate (1989a) includes two Source terms representing bottom friction and wave breaking. The model was modified to include wave growth due to the wind and has been evaluated against measured wave data for two locations in the southern North Sea.

The first evaluation involved a comparison against wave measurements inside the Dunwich Bank for given, measured, offshore wave conditions. The wind input, using data from Gorleston, was found to increase the rms wave height inshore of the Bank by about 4% for wind speeds greater than 10 m/s. The best results from the model were obtained using the wave breaking formula of Weggel (1972) with a breaking wave height to water depth ratio of 1.0, based on the recent field work of Hughes and Borgman (1987).

The second evaluation of the model considered the Norfolk Banks. The offshore wave height and period were taken from the output of HINDWAVE, in the absence of measured wave data, and the results from the Nearshore Profile Model were compared with measured wave heights off Cromer. The wind input to the model, over the profile length of 84 km, was found to be a very important Source term.

For low wave heights the Source term for wind-wave growth dominates over the two dissipative Source terms. Good agreement was found between model and measured wave heights in this situation.

The model results at inshore points off the Norfolk Banks were found to be rather insensitive to the offshore wave height. This is due to the marked reduction in wave height due to bottom friction and wave breaking which occurs over the Well Bank and other inshore banks. The reduced wave heights inshore of the banks have a smaller range of values than those offshore due to the form of the three Source terms.

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Tables

Table 1 : Comparison of model and measured values of rms wave height (for wind speeds greater than 10 m/s) with and without the wind input Source term

Measured data at Dunwich are taken from Tables 8b and 8c of Carr et al (1981)

Day/Time Feb 1979	Offshore values H_{rms} m	Offshore values Tp s	Wind data U m/s	Wind data θ deg	Tidal level m	Measured H_{rms} m	Model H_{rms}(m) (unidir) wind input	Model H_{rms}(m) (unidir) no wind input
From Table 8b:								
14/0130	2.18	7.7	18.9	040	2.5	1.54	1.60	1.54
14/0430	2.47	9.1	19.4	040	0.5	1.78	1.15	1.12
14/1630	3.13	9.9	20.0	030	0.5	1.84	1.24	1.21
14/1930	2.93	8.6	20.0	020	0.5	2.04	1.23	1.21
14/2230	2.57	8.1	20.0	020	2.5	1.94	1.70	1.64
15/0130	2.59	8.2	19.4	030	2.5	1.90	1.70	1.65
15/0430	2.79	9.8	19.4	030	0.5	1.79	1.19	1.17
16/1030	1.58	6.8	12.0	040	2.5	1.27	1.35	1.29
16/1630	1.24	7.2	10.9	030	0.5	0.99	0.90	0.88
From Table 8c:								
09/2230	1.46	5.7	11.4	090	2.5	1.41	1.38	1.29
10/0130	1.58	6.8	10.3	080	2.5	1.50	0.98	0.97
10/0730	1.88	6.6	13.7	070	2.5	1.80	1.70	1.58
10/1630	2.01	7.2	13.1	070	0.5	1.68	1.27	1.24
11/0130	1.97	7.5	14.3	070	0.5	1.58	1.26	1.23
11/0730	2.02	6.8	14.3	060	2.5	1.76	1.72	1.64
11/1930	1.98	7.1	13.1	080	2.5	1.81	1.71	1.63
15/1330	2.71	8.5	16.6	080	2.5	1.90	1.87	1.83
15/1630	2.65	9.5	16.6	060	0.5	1.62	1.29	1.27
15/1930	2.29	8.0	16.6	060	0.5	1.83	1.29	1.26
15/2230	2.30	8.1	14.8	060	2.5	1.83	1.80	1.73
16/0130	2.04	7.6	14.3	060	2.5	1.69	1.54	1.49
16/0430	1.92	8.3	15.4	060	0.5	1.30	1.25	1.22

Average value of H_{rms}(model)/H_{rms}(measured) = 0.83

Average value of H_{rms}(model: no wind input)/H_{rms}(measured) = 0.79

Table 2 : Comparison of model and measured values of rms wave height at Dunwich for three wave breaking formulations

Day/Time Feb 1979	Offshore values H_{rms}	T_p	Wind data U	θ	Measured H_{rms}	Model H_{rms}(m) (unidir) Weggel a'=0.78	Weggel a'=1.0	Battjes & Stive
	m	s	m/s	deg	m	m	m	m
08/1330	0.75	6.5	4.6	010	0.63	0.62	0.62	0.62
08/1630	0.85	5.9	1.1	020	0.65	0.71	0.71	0.71
14/0130	2.18	7.7	18.9	040	1.54	1.80	2.06	1.60
14/0430	2.47	9.1	19.4	040	1.78	1.30	1.56	1.15
14/1630	3.13	9.9	20.0	030	1.84	1.32	1.60	1.24
14/1930	2.93	8.6	20.0	020	2.04	1.33	1.62	1.23
14/2230	2.57	8.1	20.0	020	1.94	1.85	2.15	1.70
15/0130	2.59	8.2	19.4	030	1.90	1.86	2.17	1.70
15/0430	2.79	9.8	19.4	030	1.79	1.31	1.57	1.19
15/1030	1.58	6.8	12.0	040	1.27	1.45	1.46	1.35
15/1630	1.24	7.2	10.9	030	0.99	1.00	1.00	0.90
15/2230	1.01	5.6	8.0	040	0.82	0.94	0.94	0.94
17/1030	0.98	5.3	7.4	040	0.81	0.91	0.91	0.91
17/1330	0.89	5.8	7.4	040	0.68	0.82	0.82	0.82
17/1630	0.87	6.6	6.9	030	0.77	0.71	0.71	0.71
17/2230	1.08	5.6	8.0	040	0.72	1.00	1.00	1.00
18/1030	0.76	5.8	4.0	020	0.48	0.64	0.64	0.64
18/1330	0.59	5.8	3.4	030	0.39	0.54	0.54	0.54
19/1330	0.42	5.7	1.1	320	0.31	0.38	0.38	0.38
19/1630	0.40	6.1	1.1	340	0.32	0.37	0.37	0.37

Averaged value of H_{rms}(model: Weggel, a' = 0.78) = 0.88

Averaged value of H_{rms}(model: Weggel, a' = 1.0) = 1.02

Averaged value of H_{rms}(model: Battjes & Stive) = 0.81

Table 3 : Comparison of model and measured values of rms wave height at Cromer with and without the wind input Source term.

Day/Time Feb 1986	Offshore values (HINDWAVE) H_{rms} m	T_p s	Wind data U m/s	θ deg	Tidal level m	Measured H_{rms}(m)	Model H_{rms}(m) wind input	no wind input
1/0030	2.79	8.19	17.7	050	4.2	3.05	2.96	1.92
1/0330	2.36	7.60	17.7	050	2.2	2.52	2.42	1.53
1/0630	2.79	8.19	18.9	040	1.9	2.33	2.49	1.52
1/0930	2.79	8.19	19.5	040	3.7	2.77	2.82	1.84
1/1230	3.30	9.17	20.0	030	4.3	3.01	2.99	1.99
1/1530	4.41	10.7	18.9	030	2.6	2.85	2.59	1.67
1/1830	4.41	10.7	18.9	030	2.1	2.81	2.48	1.54
1/2130	5.03	11.4	18.9	040	3.7	3.03	2.89	2.53
2/0030	5.03	11.4	18.3	050	4.0	3.00	2.78	1.88
2/0330	5.65	12.0	17.7	060	3.0	2.55	2.50	1.65
2/0630	5.65	12.0	13.7	060	2.1	2.32	1.89	1.43
2/0930	5.03	11.4	12.0	050	3.8	2.05	2.13	1.84
2/1230	5.03	11.4	13.2	050	3.9	2.21	2.27	1.86
2/1530	4.40	10.7	14.3	040	2.4	2.12	2.04	1.51
2/1830	4.40	10.7	14.3	050	1.9	2.09	1.92	1.38
2/2130	3.80	10.0	13.7	060	3.5	2.14	2.28	1.82

Averaged value of H_{rms}(model)/H_{rms}(measured) = 0.97
(Wind input)

Averaged value of H_{rms}(model)/H_{rms}(measured) = 0.71
(No wind input)

Table 4 : Comparison of model and measured values of wave height at Cromer showing the influence of wave refraction

Day/Time Feb 1986	Offshore values (HINDWAVE) H_{rms} m	Tp s	Wind data U m/s	θ deg	Tidal level m	Measured θ_m deg	H_{rms} m	Model H_{rms} m
14/0030	1.56	6.29	14.3	080	4.1	079	1.94	2.20
14/0630	1.95	6.96	13.1	070	1.8	082	1.37	1.94
14/1230	1.95	6.96	14.3	080	4.2	079	2.11	2.39
14/1830	2.36	7.60	14.3	100	1.8	067	1.86	2.17
15/0030	2.36	7.60	12.6	100	4.1	056	2.08	2.23
15/0630	1.95	6.96	12.0	100	1.7	048	1.58	1.82
15/1230	1.47	6.29	9.2	080	4.2	055	1.63	1.57
15/1830	1.56	6.29	9.7	080	1.7	057	1.36	1.50

Averaged value of H_{rms}(model)/H_{rms}(measured) = 1.14

Table 5 : Comparison of model and measured values of wave height at Cromer. Situations with low wave heights

Day/Time Mar 1986	Offshore values (HINDWAVE) H_{rms} m	T_p s	Wind data U m/s	θ deg	Tidal level m	Measured θ_m deg	H_{rms} m	Model H_{rms} m
11/1530	0.24	5.00	4.0	100	1.9	085	0.26	0.35
11/1830	0.31	5.00	3.4	100	5.0	068	0.40	0.32
11/2130	0.37	5.00	3.4	080	4.3	062	0.50	0.41
12/0030	0.37	5.00	2.9	050	1.0	059	0.40	0.36
12/0330	0.46	5.00	1.6	060	1.6	060	0.26	0.45
12/0630	0.24	5.00	4.0	060	4.6	068	0.23	0.35
12/0930	0.20	5.00	5.1	100	4.7	099	0.35	0.32
12/1230	0.23	5.00	5.7	110	1.7	117	0.45	0.36

Averaged value of H_{rms}(model)/H_{rms}(measured) = 1.10

Figures

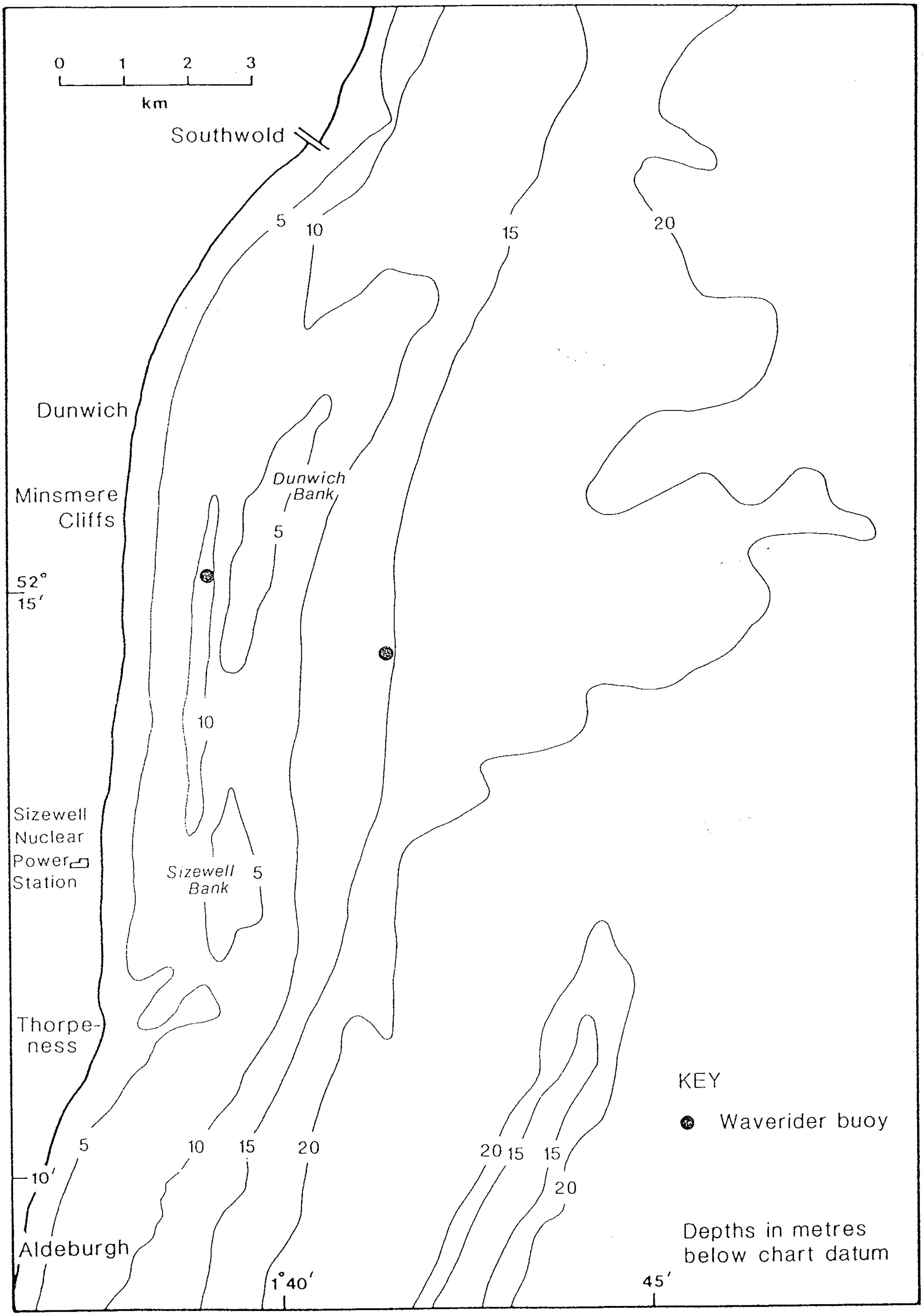

Fig 1 Location of two waverider buoys over the Dunwich Bank (after Carr et al.,1981).

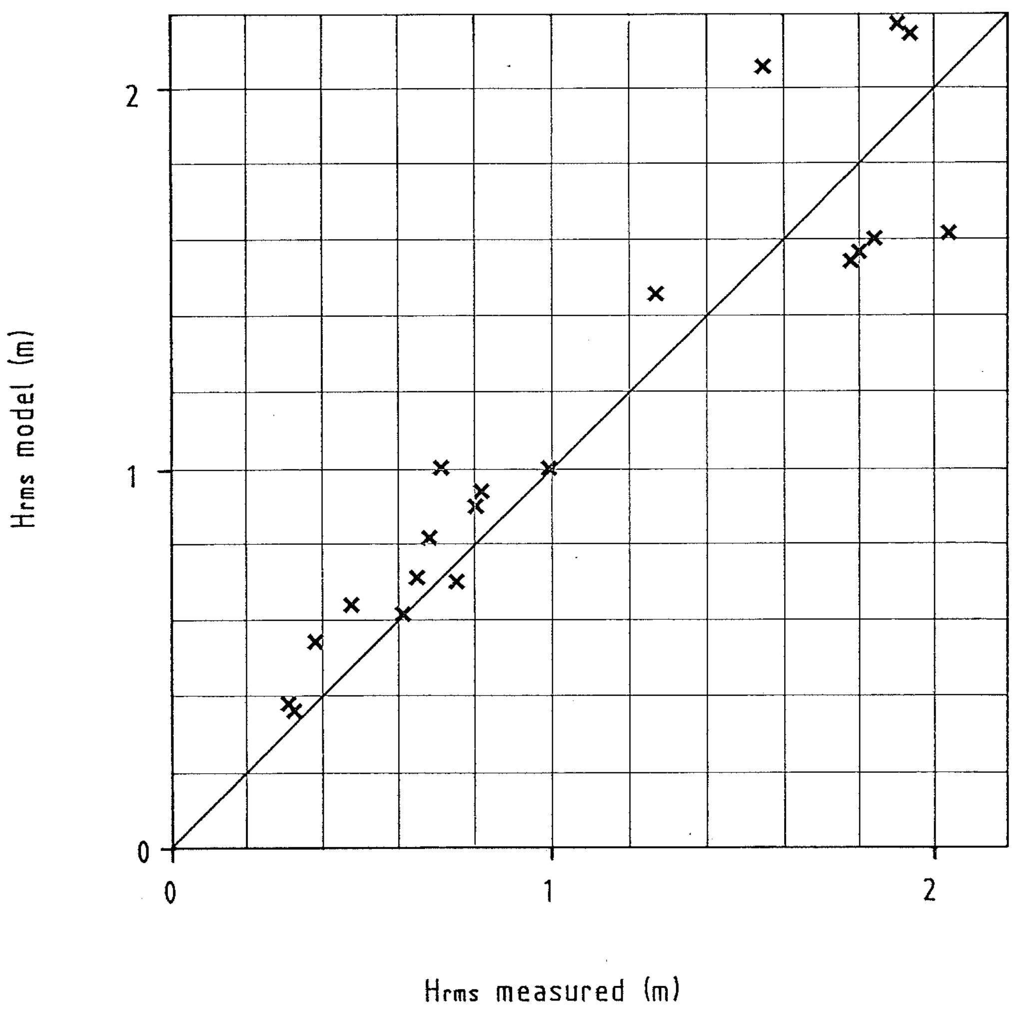

Fig 2 Comparison of model and measured values of rms wave height at Dunwich Bank. Calculations with the formula of Weggel (1972) for a'=1.0.

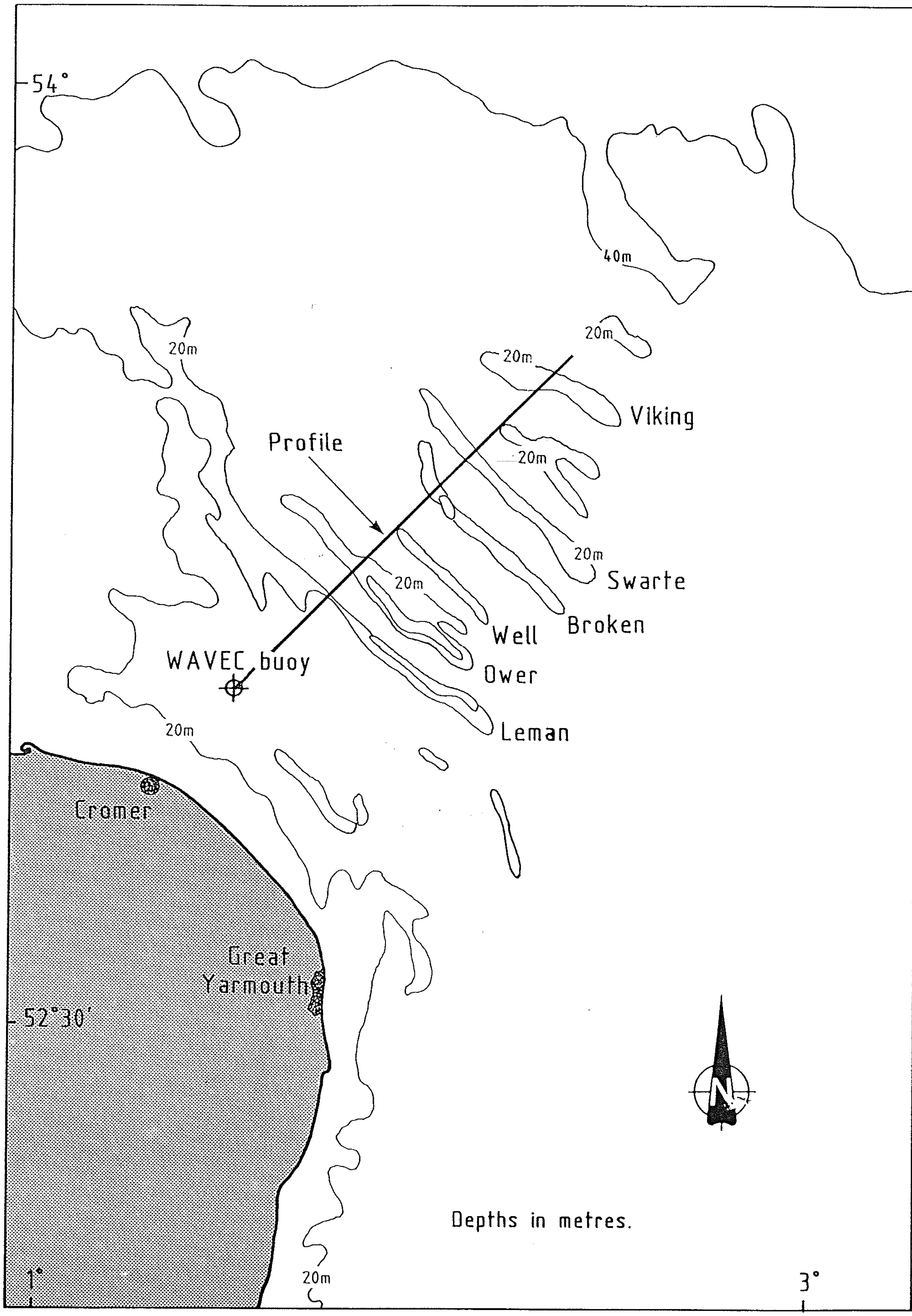

Fig 3 Location of profile off Norfolk coast together with position of WAVEC buoy.

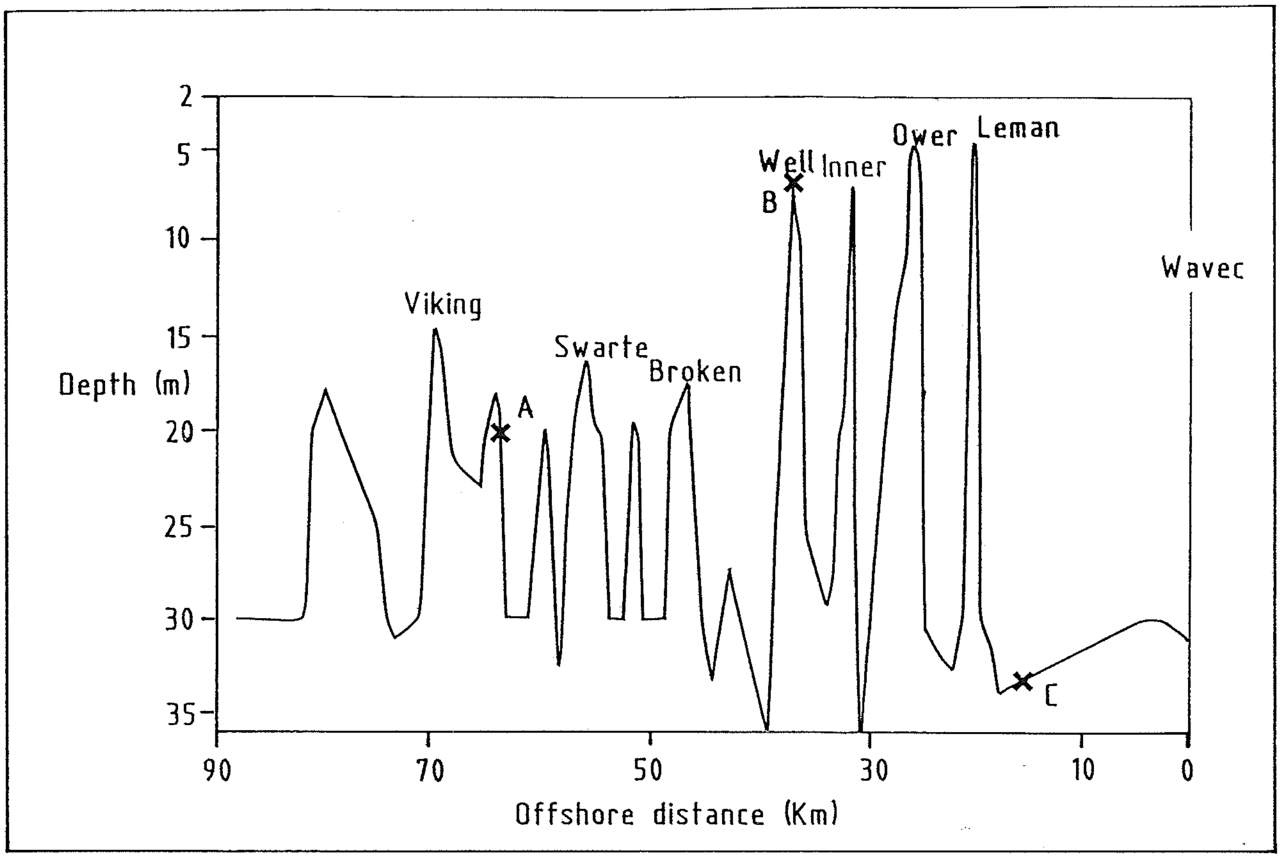

Fig 4 Bathymetry along the profile for the Norfolk Banks. Points A,B and C show positions where the Source terms are considered.

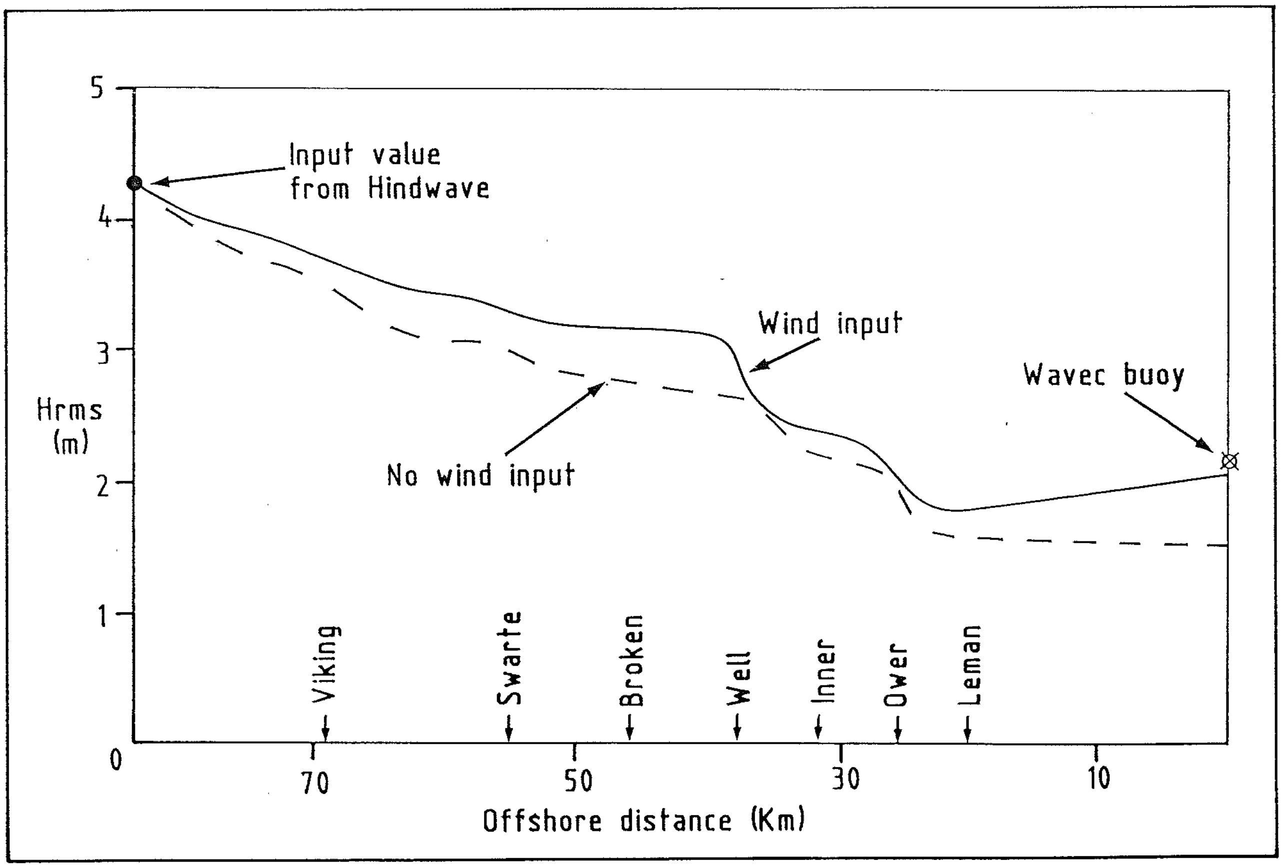

Fig 5 Variation of model wave heights along the profile, with and without wind input. Record of 1530 hours, 2 February 1986.

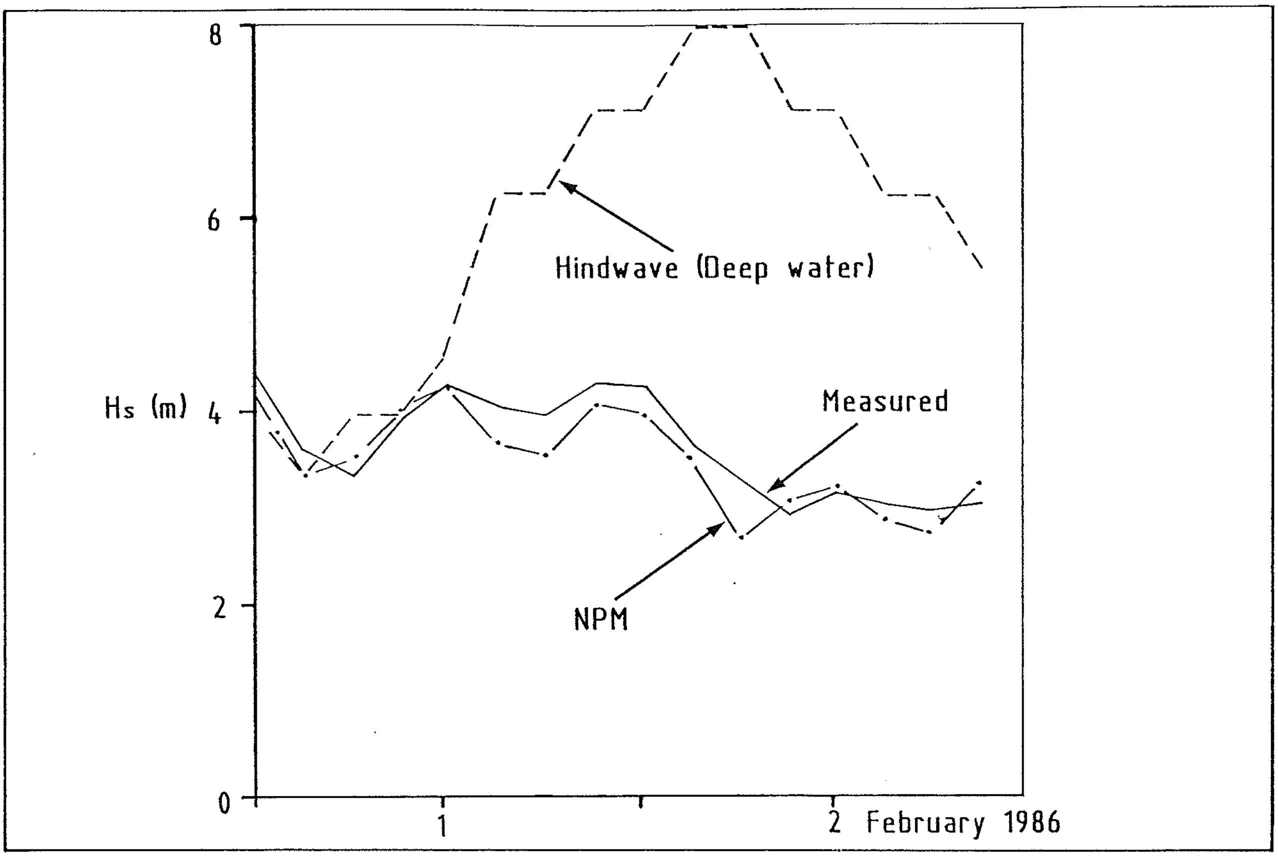

Fig 6 Comparison of results from the NPM with Wavec measurements and also deep-water calculations from HINDWAVE off Cromer.

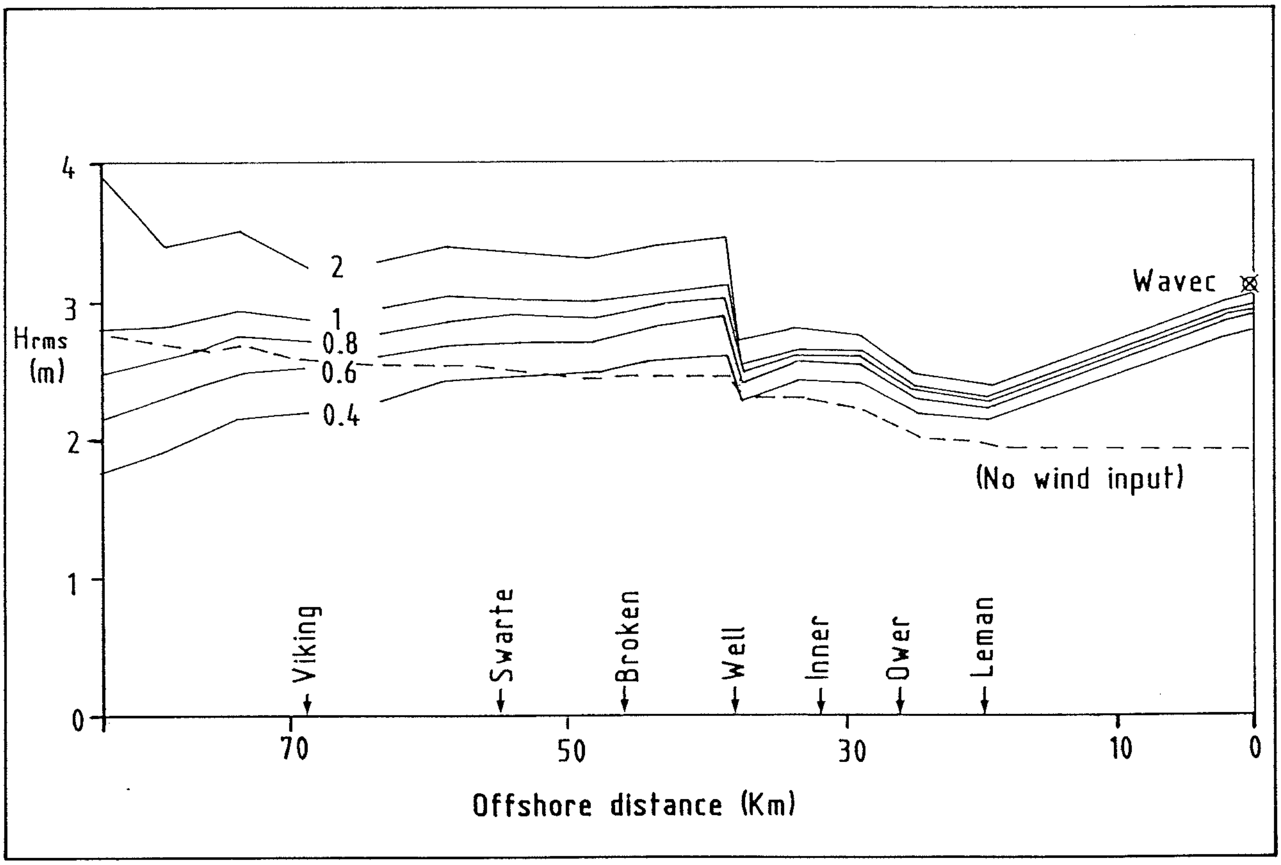

Fig 7 Influence of offshore wave height on values along the profile. Numbers indicate scaling of the spectrum by factors of 0.4,0.6,0.8,1 and 2. The dashed line shows the calculation for no wind input.

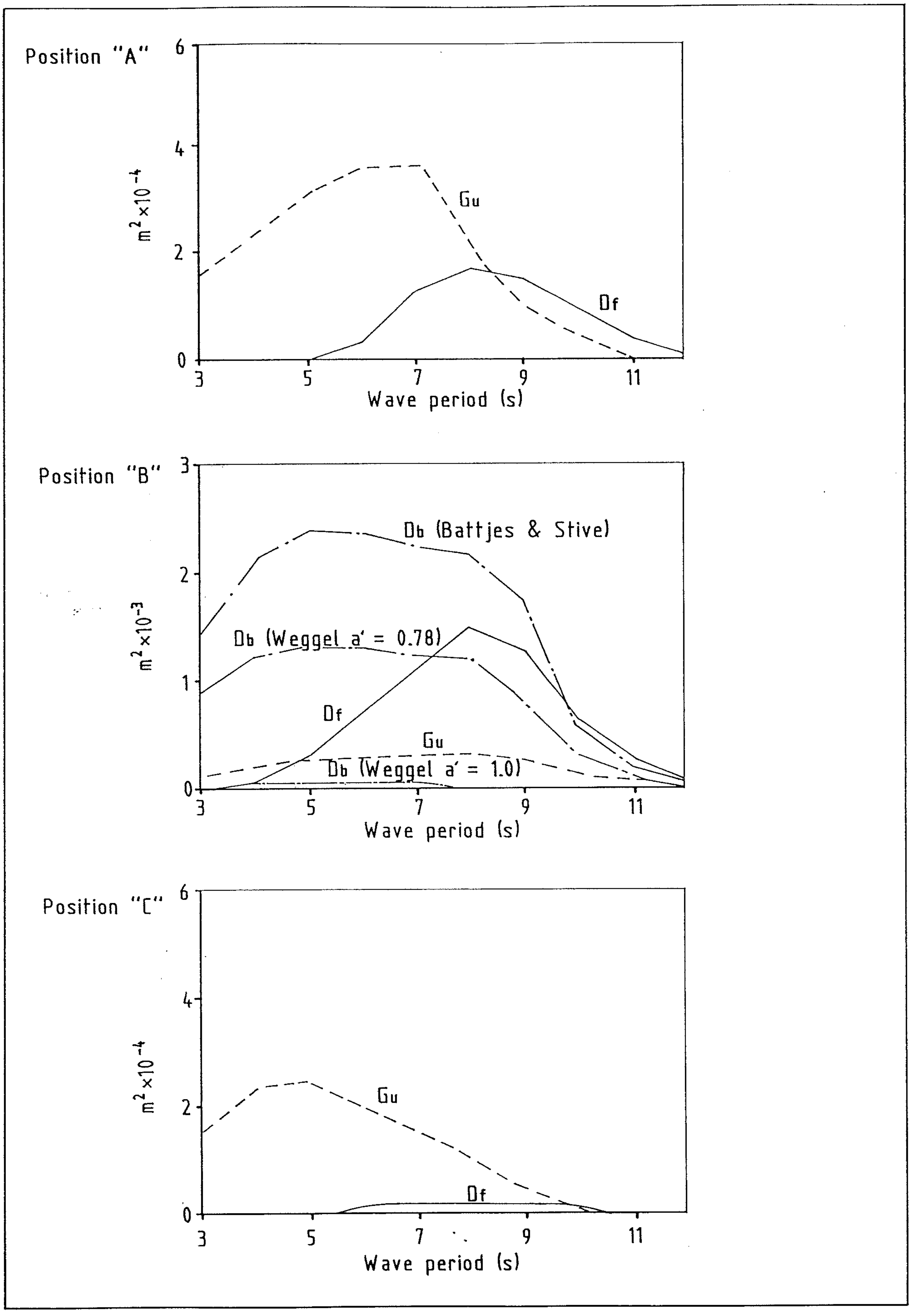

Fig 8 Source terms at positions A, B and C for record of 0030 hours, 1 February 1986.

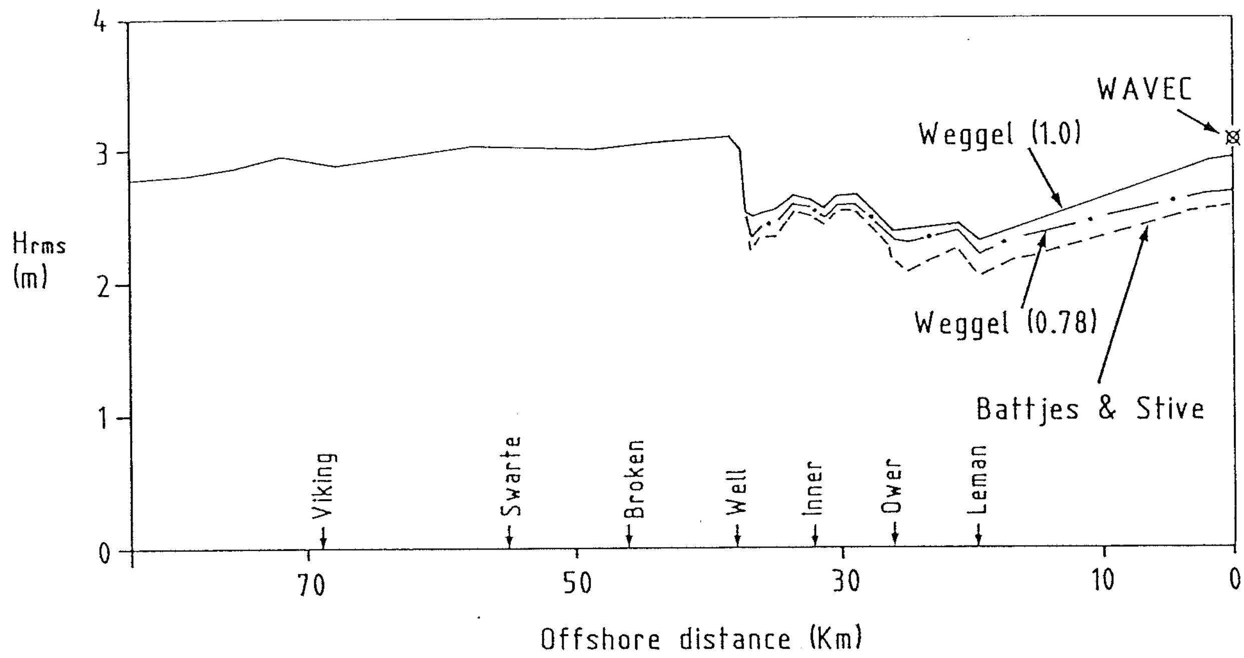

Fig 9 Influence of different wave breaking formulations on inshore wave heights.
(Record of 0030 hours, February 1986).

Appendices

APPENDIX 1

Comparison of the Nearshore Profile Model with monochromatic, unidirectional and directional waves

APPENDIX 1

Comparison of the Nearshore Profile Model with monochromatic, unidirectional and directional waves

The NPM was run for monochromatic, unidirectional and directional waves with measured input data at the Dunwich Bank (Carr et al, 1981). The wave breaking term of Weggel (1972) with a' = 0.78 was chosen for the calculations. Measured values of the rms wave height and peak period were used directly in the program for monochromatic waves. For spectral wave input, these values were fitted to the Pierson-Moskowitz spectral form, as discussed in section 3 of this report. The frequency spectra were defined in terms of the energy in equal bands of wave period from 3s to 12s. For the directional wave input, a $\cos^6(\Theta-\Theta_m)$ distribution was taken about the mean direction, Θ_m. Values of the directional spreading wave calculated every 10 degrees for five values centred about the mean wave direction, Θ_m.

Table A1 shows the results of the calculations compared with the measurements of wave height. The unidirectional spectral calculations give results, on average, very close to those for monochromatic waves. The directional wave input gives results about 7% lower than for unidirectional and monochromatic waves.

TABLE A.1

Day/Time Feb 1979	Offshore values H_{rms} m	T_p s	Θm deg	Measured H_{rms} m	Model, H_{rms} mono. m	uni. m	dir. m
8/1330	0.75	6.5	48	0.63	0.58	0.59	0.53
8/1630	0.85	5.9	55	0.65	0.69	0.70	0.62
14/0130	2.18	7.7	60	1.54	1.73	1.67	1.45
14/0430	2.47	9.1	60	1.78	1.29	1.27	1.08
14/1630	3.13	9.9	55	1.84	1.37	1.30	1.16
14/1930	2.93	8.6	52	2.04	1.38	1.30	1.16
14/2230	2.57	8.1	52	1.94	1.86	1.77	1.55
15/0130	2.59	8.2	56	1.90	1.87	1.78	1.57
15/0430	2.79	9.8	56	1.79	1.33	1.28	1.12
15/1030	1.58	6.8	60	1.27	1.35	1.32	0.96
15/1630	1.24	7.2	60	0.99	0.99	0.95	0.83
15/2230	1.01	5.6	60	0.82	0.88	0.90	0.81
17/1030	0.98	5.3	60	0.81	0.86	0.88	0.79
17/1330	0.89	5.8	60	0.68	0.77	0.79	0.71
17/1630	0.87	6.6	60	0.77	0.72	0.71	0.69
17/2230	1.08	5.6	55	0.72	0.93	0.95	0.85
18/1030	0.76	5.8	52	0.48	0.61	0.62	0.56
18/1330	0.59	5.8	55	0.39	0.51	0.53	0.47
19/1330	0.42	5.7	60	0.31	0.37	0.38	0.34
19/1630	0.40	6.1	45	0.32	0.33	0.35	0.31