Forecasting Research

Forecasting Research Division
Technical Report No. 45

Running the global wave model with shallow water depth information

by

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April 1993

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1 Introduction

Forecasts of wave height and direction from the global wave model are used by the Ship's Routeing forecasters in CFO to route voyages across the oceans. These are in deep water (>200m depth) for most of the time. Forecasts from the global model are also used to provide offshore forecasts for the North Sea after t+36 hours. Here, depending on the wavelengths present, the water may be effectively shallow. There is also increasing interest in providing forecast wave data in the South China Sea and the Gulf of Mexico, for the offshore oil industry. These operations are often in areas of 'shallow' water, with depths less than 200m.

The regional wave model run at the UK Met Office already includes the effects of shallow water on the wave spectrum. This note describes the impact of including shallow water effects in the global wave model, at a resolution of 0.833 degrees latitude by 1.25 degrees longitude.

Section 2 of this paper briefly describes the shallow water source terms; Section 3 gives details of the depth dataset used and assesses the likely impact. In Section 4 the results of a parallel run are described, and Sections 5 and 6 summarise and give recommendations for operational implementation.

2 Shallow water source terms

Three separate effects are included when shallow water terms are included in the UK Met Office wave model. These are a) the shallow water group velocity is used, b) bottom friction is accounted for, and c) refraction by the depth gradient is calculated. Full details of the physics of these terms are to be described in a later Technical Note, however brief details are given here.

a) Wave energy is advected with the group velocity, which is a function of wave frequency. For waves in shallow water the group velocity is also a function of depth. Within the wave model, shallow water group velocities are calculated at depth intervals of 1m down to 200m depth. For water of depth 200m or greater the deep water value for group velocity is used.

b) When waves travel into water shallower than about one quarter their wavelength, the wave induced motion at the sea bed becomes significant. The physical effect arising from this depends on the nature of the sea bed, and the different mechanisms are discussed in more detail in Shemdin (1978) (and will be reviewed in a later Technical Note). However the averaged affect of these processes on the wave model grid scale is well represented by a simple expression for the associated sink of wave energy:

$$S_{bf} = - \text{Const } g\, k^2 \ \{U\}\ E(f,\theta) \ / \ [\ 2\pi f \cosh(kH)]^2$$

where k is the shallow water wave number, H is the depth, g the acceleration due to gravity, E the wave energy density and {U} is the mean orbital velocity at the sea bed of the water in the wave at the sea bed, given by :

$$\{U\}^2 = \int\int [gk/2\pi f \cosh(kH)]^2 \ E \ df \ d\theta$$

c) As a wave propagates into shallower water it is refracted by the varying depth gradient. Phase speeds are less in shallow water. Frequency of the wave is conserved, but the wavenumber k is not conserved as the wave moves into shallower water. The shallow water dispersion relationship, $\omega^2 = g\, k \tanh(kH)$, relates wave frequency to wavenumber and depth. The refraction acts to turn the wave energy but does not alter the frequency or amount of wave energy present. This is why waves generally approach parallel to a beach.The source term is:

$$dE/dt = - d\ \{(c_g.\nabla\ \theta)\ E\ \}\ /\ d\theta$$

In the UK Met Office wave model the gradients of sea bed topography are calculated using centred differences, with the depth at coast points set to zero. The refraction function is calculated using an upstream difference scheme. Refraction is calculated at all wave model 'sea' points, for frequencies lower than 0.15Hz.

3 Global depth dataset

Depths were taken from a one twelfth degree US Navy dataset, used in the UK Met Office for ocean and climate modelling. The depths were averaged to a half degree grid, and then interpolated onto the wave model grid at 0.833 by 1.25 degrees resolution. The depths in the wave model were not smoothed. No account was taken of tidal or other causes of deviation of the sea surface from the geoid.

Figure 1 shows the depths used in the global wave model. It is clear that the majority of the water is greater than 200m depth, so is 'deep' water for the wave model. There are several important areas with depths less than 200m, shown in Figure 2. These are 2a) the North Sea, 2b) the South China Sea, 2c) the China Sea, 2d) N Australia, and 2e) the Falkland Islands. The Gulf of Mexico (Figure 2f) is mostly greater than 200m depth. However the inclusion of depth information does not necessarily mean that these areas will be 'shallow' water for the range of wavelengths normally present. Figure 3 shows the (approximate) depth in which deep water waves of a given frequency will first feel the sea bed. (The depth plotted is taken as one quarter the deep water wavelength). Clearly if no waves of this wavelength or longer are present then there will be no impact from including shallow water information at that gridpoint. The effects of shallow water are thus more important for swell than for windsea.

4 Results of a parallel run

The global shallow water version of the wave model has been run in parallel with the operational model for several weeks, starting from 4th March 1993. An assessment of the global coverage of differences in wave height (Figure 4) shows only small differences in mid ocean, with larger differences noticeable in some of the shallow water areas mentioned above. Differences greater than 10cm are shaded.

In the North Sea there are differences of up to 30cm wave height in coastal waters, with a total wave height of 3m to 3.5m (Figure 5a and 5b). There is little difference in the southern North Sea, where wave heights are up to 2.5m. Results from the global shallow water run may be compared with the operational Global and European model output (Figure 6a,b,c). The results show little difference in wave height between all three models under normal circumstances. There is more detail present in the European model, since Orkney and the Shetlands are included and the coastlines are better resolved, giving improved wave heights under fetch limited conditions. When wave heights reach several metres, it is clear that the inclusion of bottom friction in both the global shallow and European model runs reduces the peak wave height by up to 0.5m, from eg 5m to 4.5m. (See for example the maximum wave height south of Ireland in Figure 6). Generally, as wave height increases, the peak of the spectrum moves towards lower frequency, hence longer wavelength. In these cases the global shallow run is closer to the European model than is the global deep water operational.

Differences in wave direction may be seen particularly in the shallower waters of the southern North Sea and at coast points (Figure 7). In deep water there is little or no difference in wave direction between the control and shallow runs. Wave direction is output from the wave model by calculating the components of wave energy at each grid point. Thus all wave energy, even if from more than one separate wave train, is counted. Where more than one wave train is present at a point, the calculated direction can be misleading, and where the relative amplitude of wave systems varies from one point to the next, there can be differences in wave direction at adjacent gridpoints. For example in Figure 7 west of the Hebrides the shallow water version has reduced the amount of swell from the NE at several points, so the direction is predominantly that of the windsea, from the NW, rather than from the NE at these points.

In the South China Sea the differences in wave height are confined close to the coasts and are much smaller than seen in the North Sea (Figure 8). The area is effectively deep water for the waves present. Differences in wave direction may be seen close to the coasts and at coast points, because of refraction effects (Figure 9). These cannot be verified as no observations are available. Here again the shallow run has removed some of the swell energy from the NE so that in the eastern South China Sea the wave direction in the shallow run at several gridpoints follows the windsea, from south of west, different to the operational model which is dominated by swell from the NNE. Although the mean wave directions are different at these points there is negligible difference in wave height.

Similar differences between the shallow and control runs are noticeable in the China Sea and around the Falkland Islands and close to Japan.

<u>COSTS</u>

Estimates of costs for the global model from 6-timestep runs in batch are :

	CPU	**elapsed**	**machine**
GLOBAL DEEP	160 sec	28 sec	67% of 8-CPU
GLOBAL SHALLOW	195 sec	45 sec	54% of 8-CPU

An increase of approximately 35 sec CPU (22%) per 6 hours run.

The bulk of the increase comes from calculations performed in the physics subroutine:

PHYSICS costs	**CPU**	**elapsed**	**% machine**
GLOBAL DEEP	79 sec	13 sec	54% of 8-CPU
GLOBAL SHALLOW	101 sec	25 sec	60% of 8-CPU

ADVECTION costs	**CPU**
GLOBAL DEEP	61.2 sec
GLOBAL SHALLOW	59.9 sec

<u>FILE SIZES</u>

Including depth information does not alter the size of the wave model forecast file. The deep-water file already holds a value of 200m depth at each gridpoint.

5 SUMMARY

There is a clear case dependent improvement from including shallow water physics in the global wave model. Where the waves are in shallow water there is an improvement in modelled wave height. Differences are most noticeable over the N Sea, for wave heights greater than (approx) 2m, and in such cases the global shallow water values are closer to the wave heights from the European wave model. Thus using the global shallow water model would provide a more consistent forecast for Aberdeen Weather Centre. Differences in direction may be seen in shallow water and at coast points, and in open water <200m where swell may be reduced thus giving more emphasis to the windsea direction in the calculation of mean wave direction.. These cannot be verified. At the time of the trial there was little impact seen in the South China Sea, the water there is effectively deep for the wavelengths present. Apart from small differences in wave height in the North Sea in moderate sea state, there was no wave height difference at any of the buoy locations used in routine verification of the operational global wave model.

6 RECOMMENDATIONS

a) The global wave model should be extended to include shallow water effects.

b) The trial should continue, to assess the impact on swell arriving in the S China Sea from the monsoon or from tropical storms.

REFERENCES:

Shemdin, O Hasselmann, K, Hsiao, S V and Herterich, K	1978	Nonlinear and linear bottom interaction effects in shallow water. in Turbulent Fluxes through the sea surface, wave dynamics and prediction. Plenum Press, pp 347 - 370

FIGURES:

Figure 1 Global sea depths. Depths < 200m are shaded.

Figure 2 Global model depths by region.
a) The North Sea
b) The South China Sea
c) The China Sea
d) North Australia
e) The Falkland Islands
f) The Gulf of Mexico
Shading is light for 0-60m, medium for 60-120m and dark for 120-180m. Contour interval 10m.

Figure 3 Depth at which deep-water waves of a given frequency first feel the sea bed.

Figure 4 Wave height differences Operational minus Shallow. VT 12z 30/3/1993.
Contour interval 10cm, differences $>$ 10cm shaded.

Figure 5 a) Wave height differences over the North Sea. Shading 0.1-0.2m (light), 0.2-0.3m (medium) and $>$0.3m (dark).
b) Operational global model wave heights over the N Sea.
Shading 0-3m light, 3-6m medium and $>$6m dark.

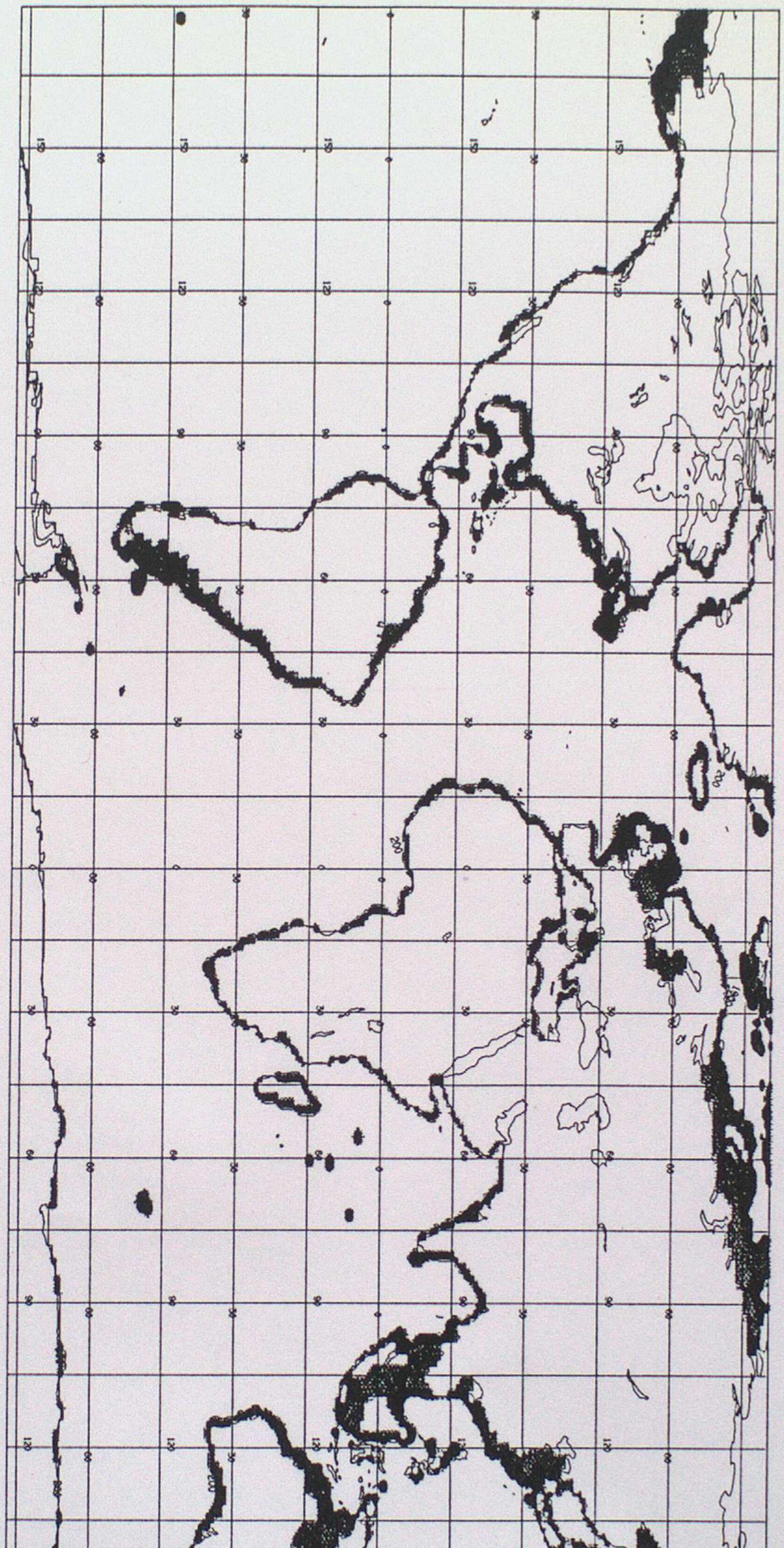
Figure 6 a) Operational, b) shallow water and c) European model wave heights over the N Sea.
VT 12z 30/3/1993. Shading as Figure 5b

Figure 7 Wave directions over the North Sea. Solid arrows operational, dashed arrows from shallow run.

Figure 8 Wave height differences over the South China Sea. Contour interval 0.1m

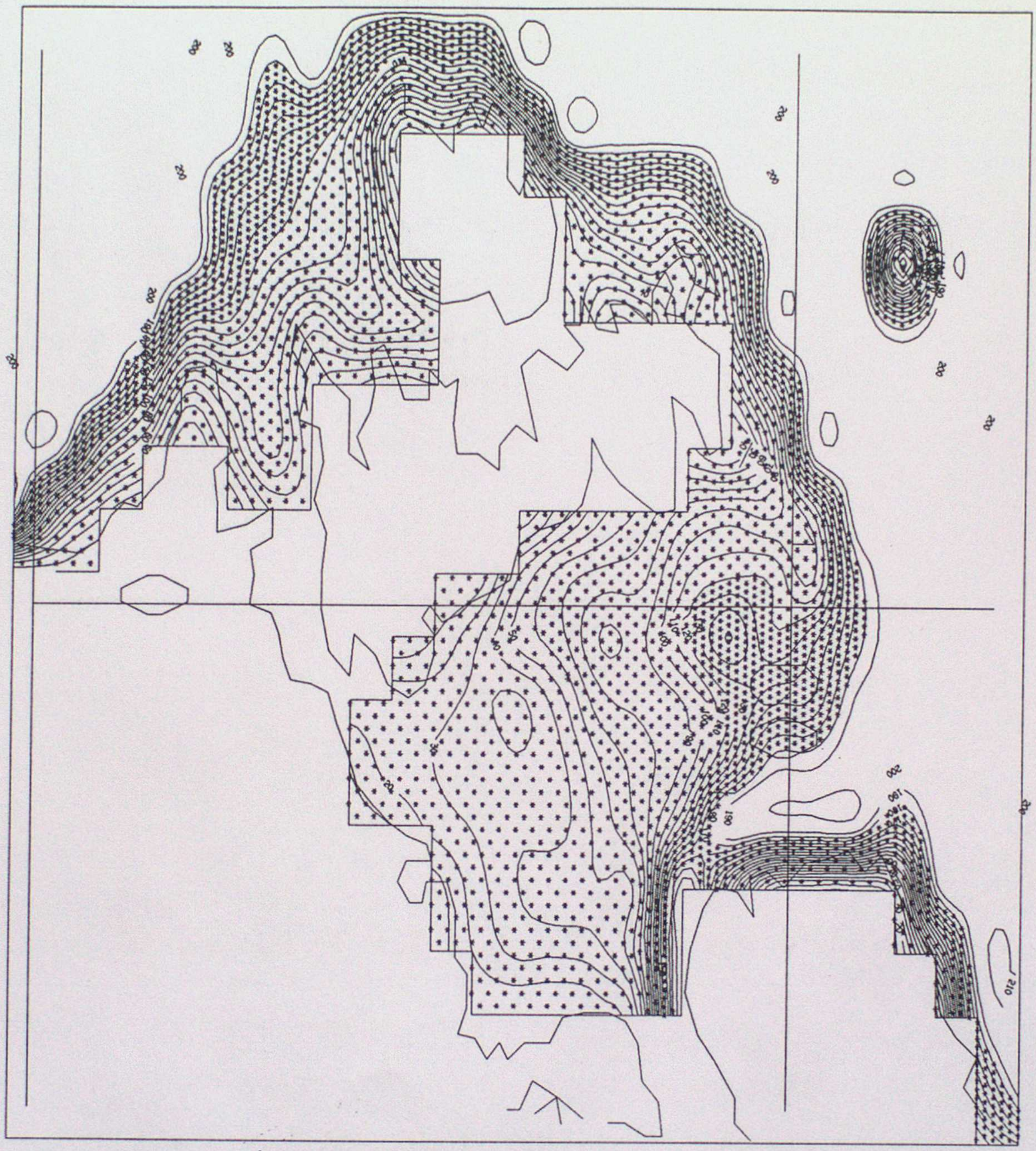
Figure 9 Wave directions over the South China Sea

Figure 1



DEPTHS on global wave model grid

Figure 2a



DEPTHS on global wave model grid

Figure 2b

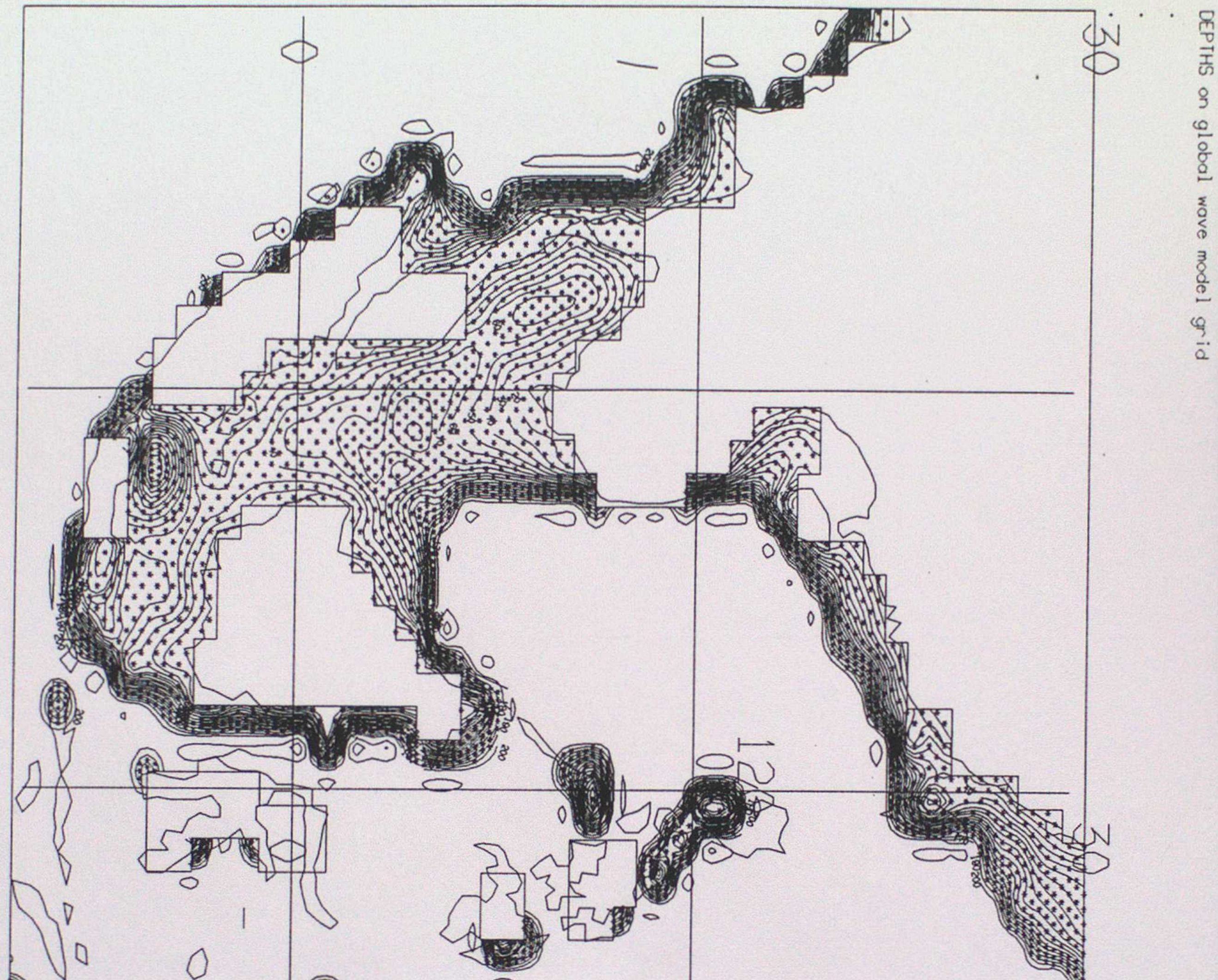


Figure 2c

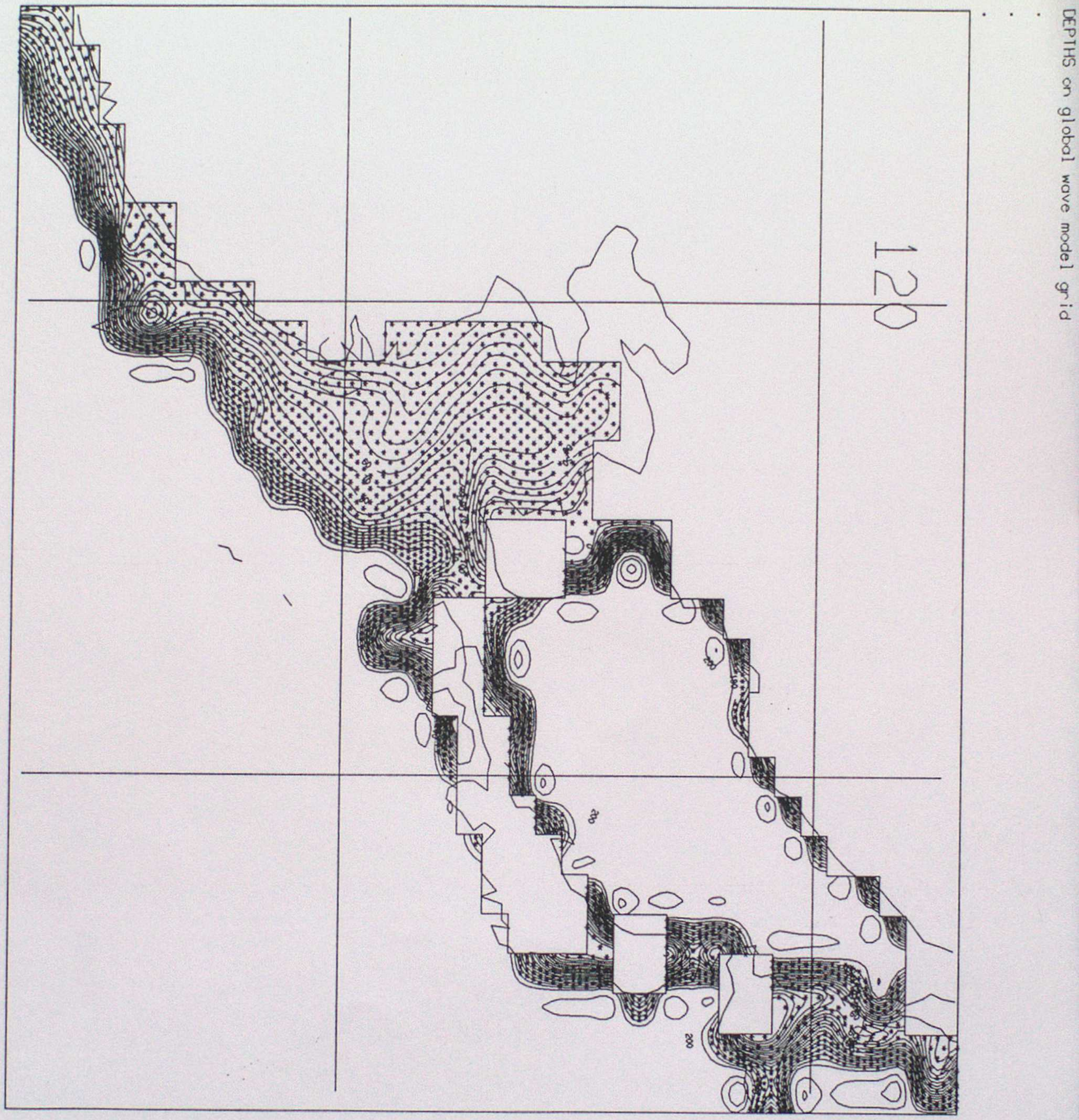


Figure 2d

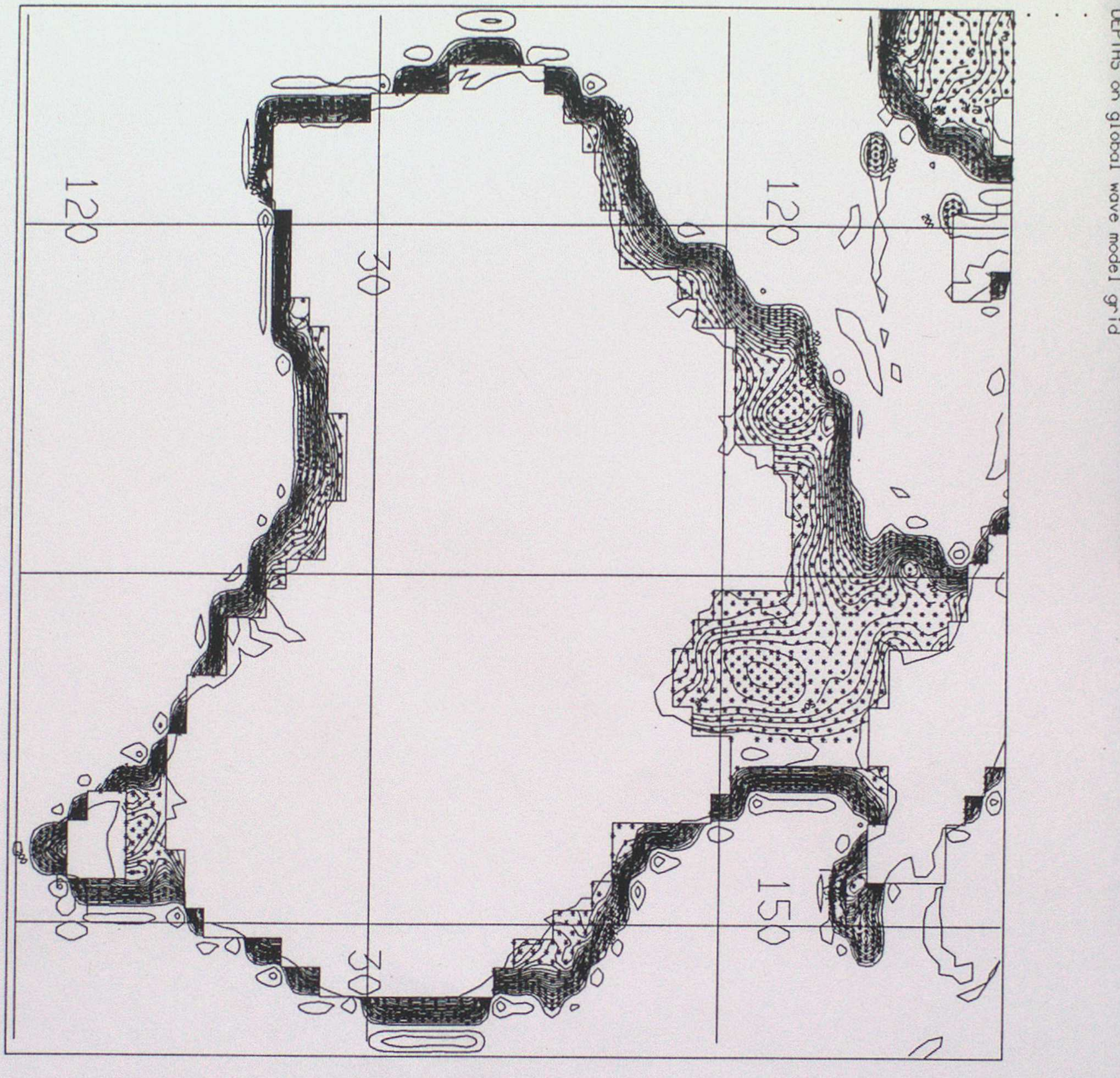
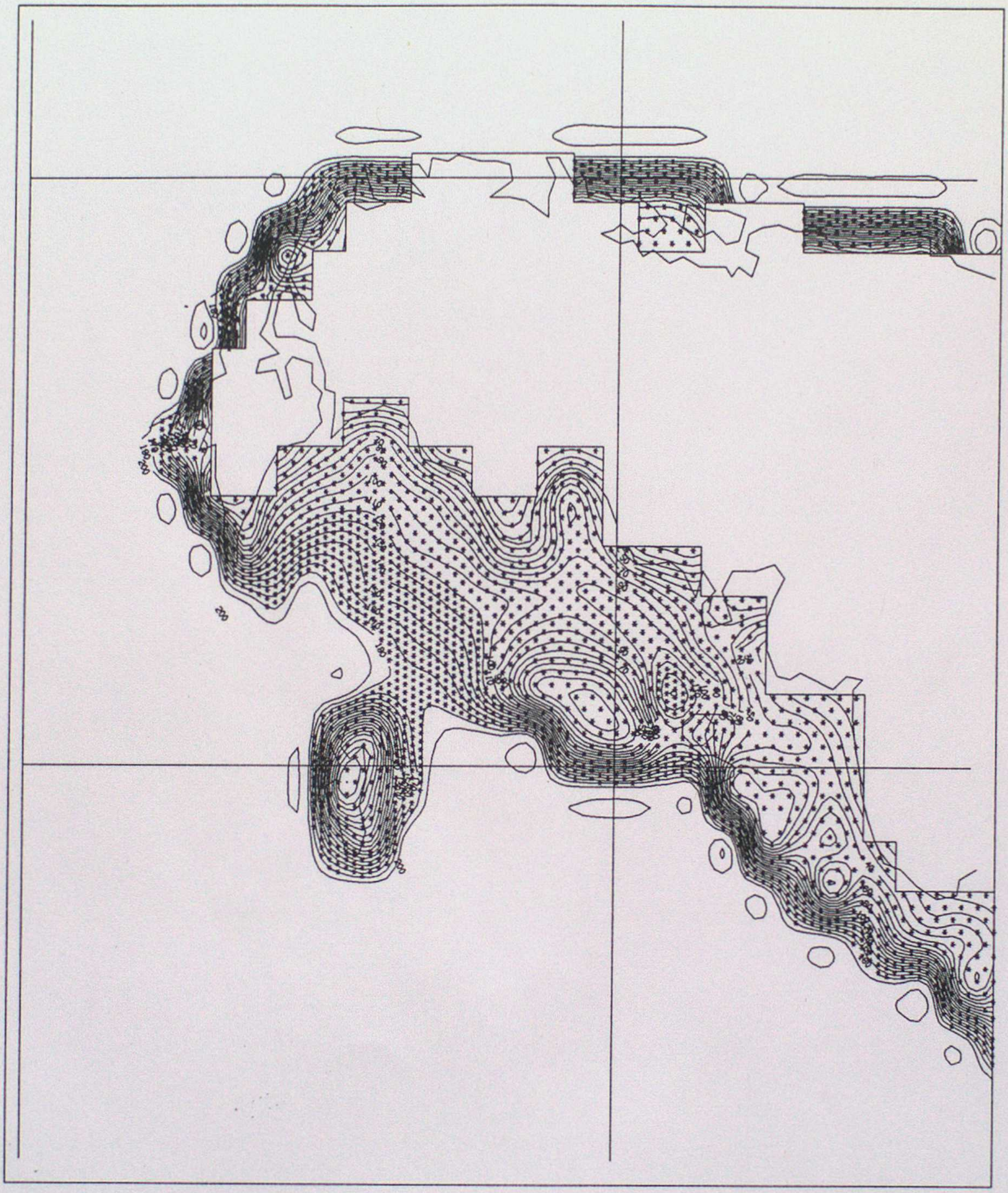


Figure 2e



DEPTHS on global wave model grid

Figure 2f

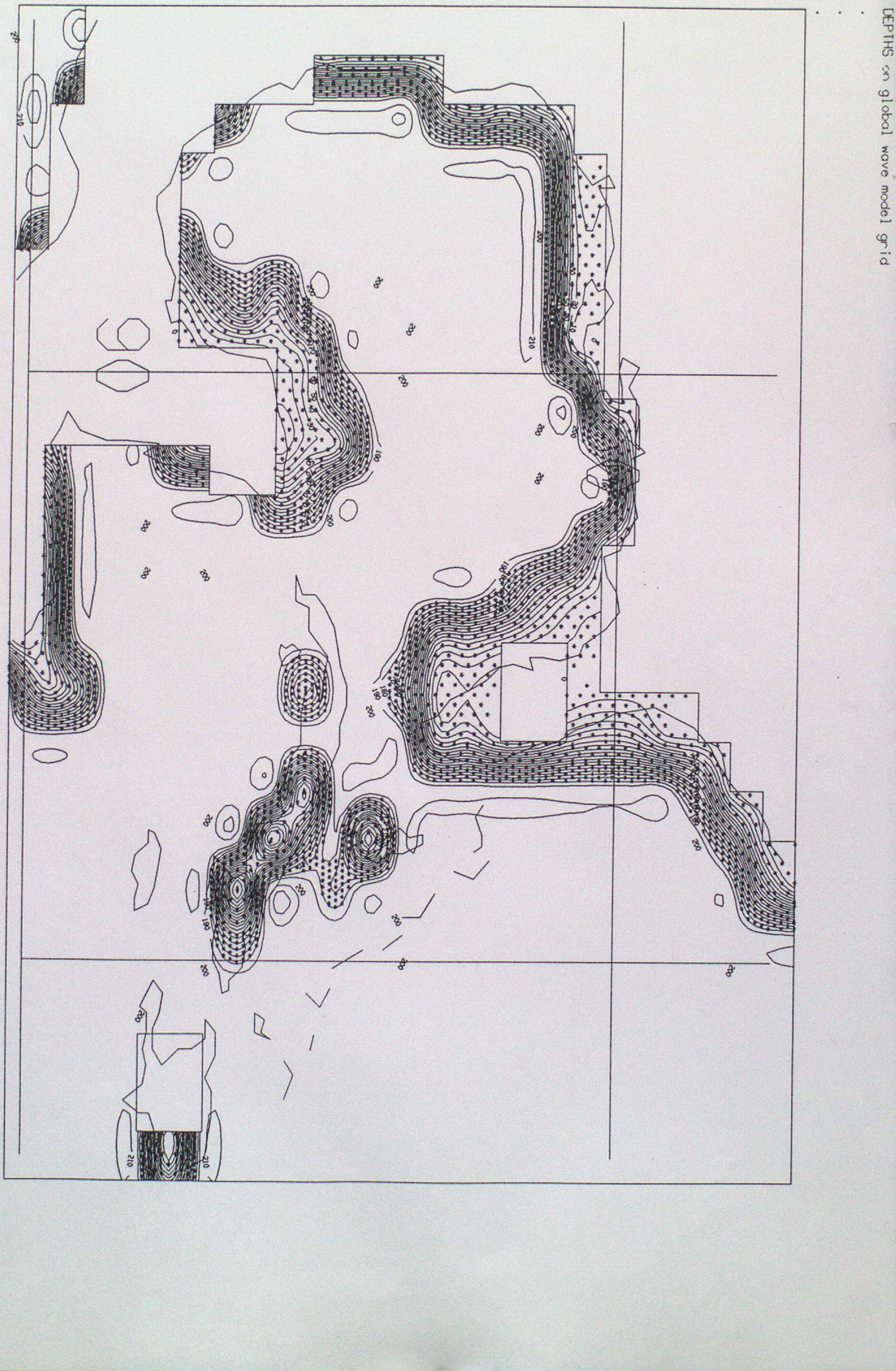


Figure 3 Depth at which waves of a given frequency start to feel the sea bottom

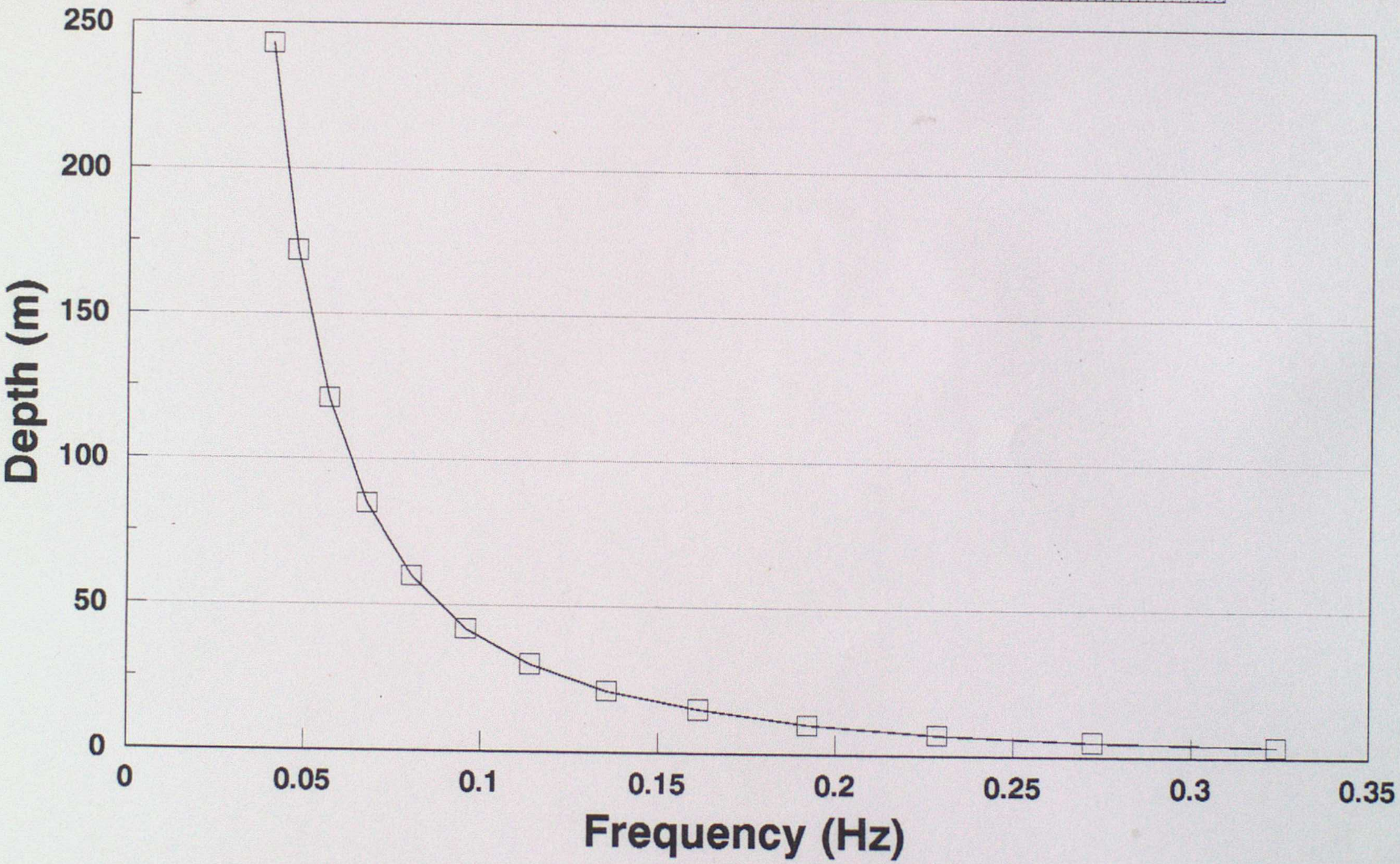


Figure 4

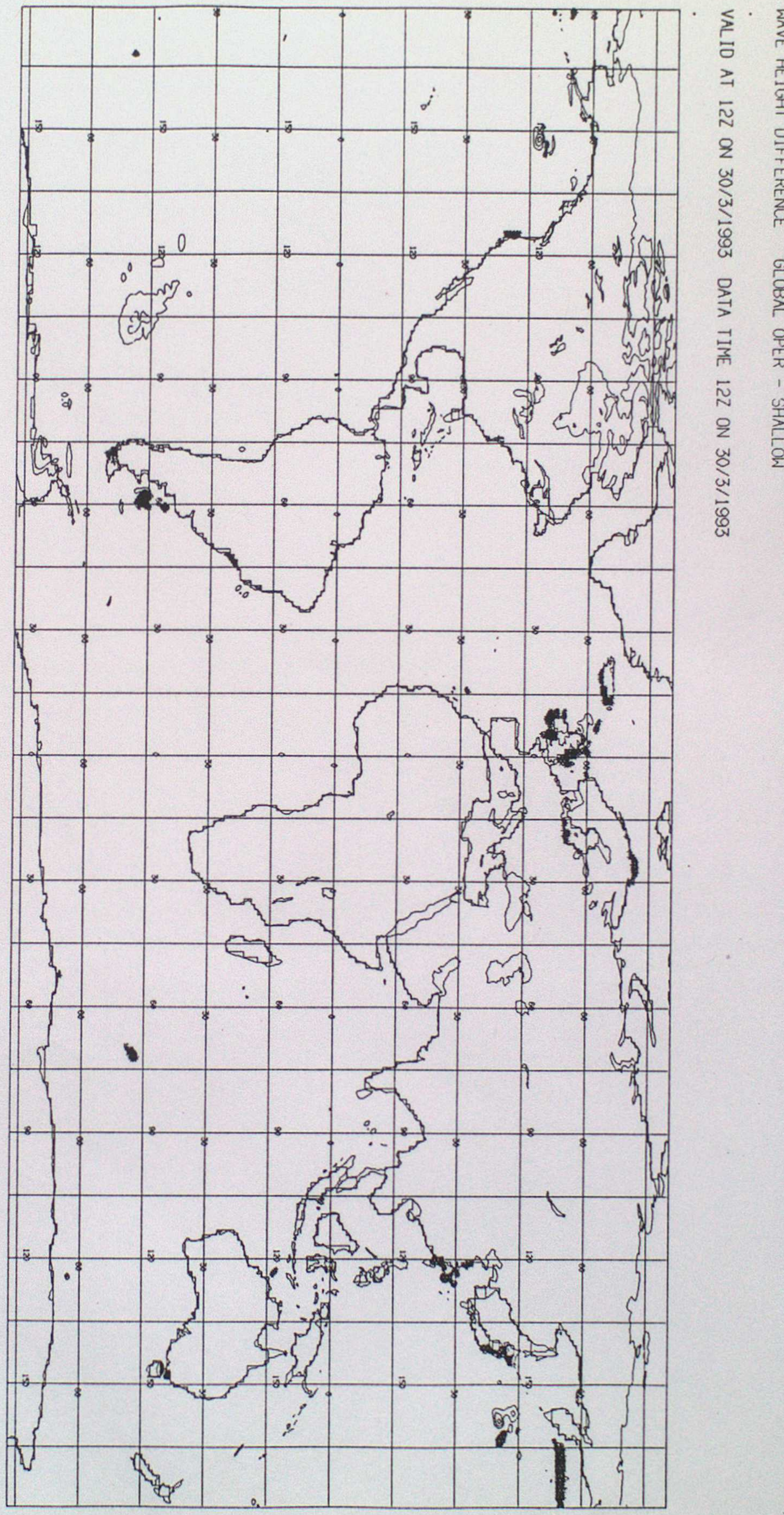

WAVE HEIGHT DIFFERENCE GLOBAL OPER - SHALLOW
VALID AT 12Z ON 30/3/1993 DATA TIME 12Z ON 30/3/1993

Figure 5a

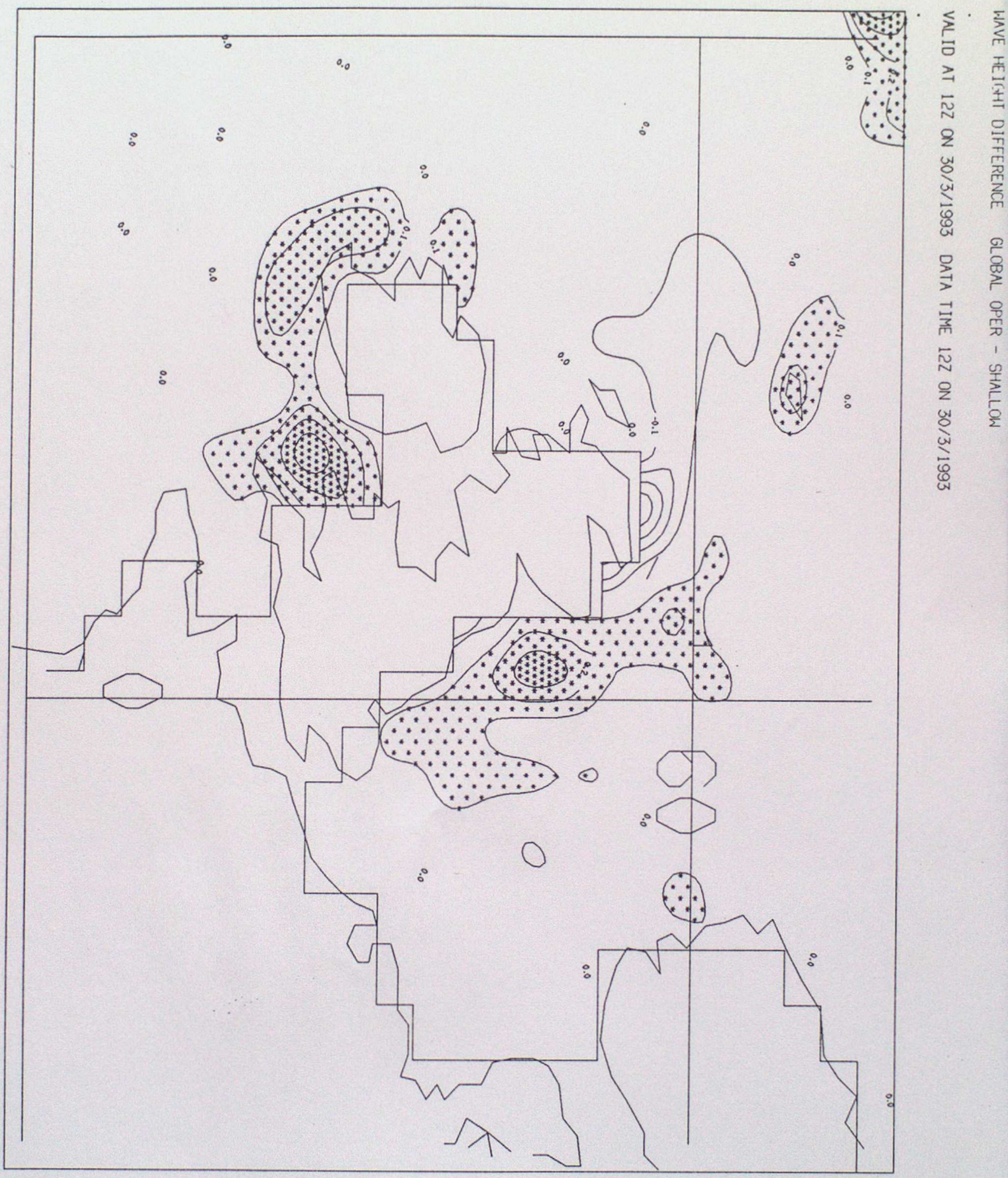

WAVE HEIGHT DIFFERENCE GLOBAL OPER - SHALLOW
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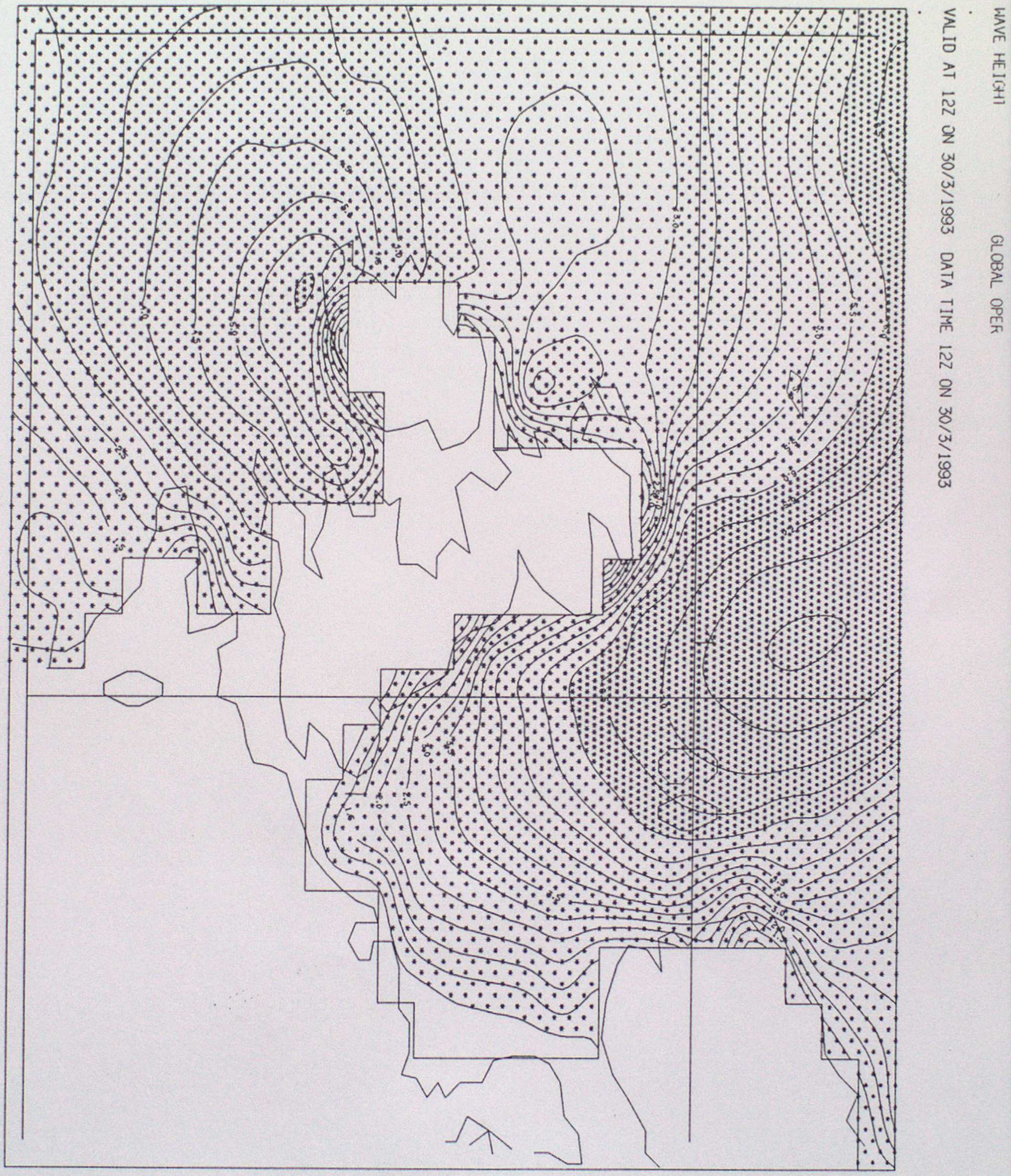
Figure 5b


WAVE HEIGHT GLOBAL OPER
VALID AT 12Z ON 30/3/1993 DATA TIME 12Z ON 30/3/1993

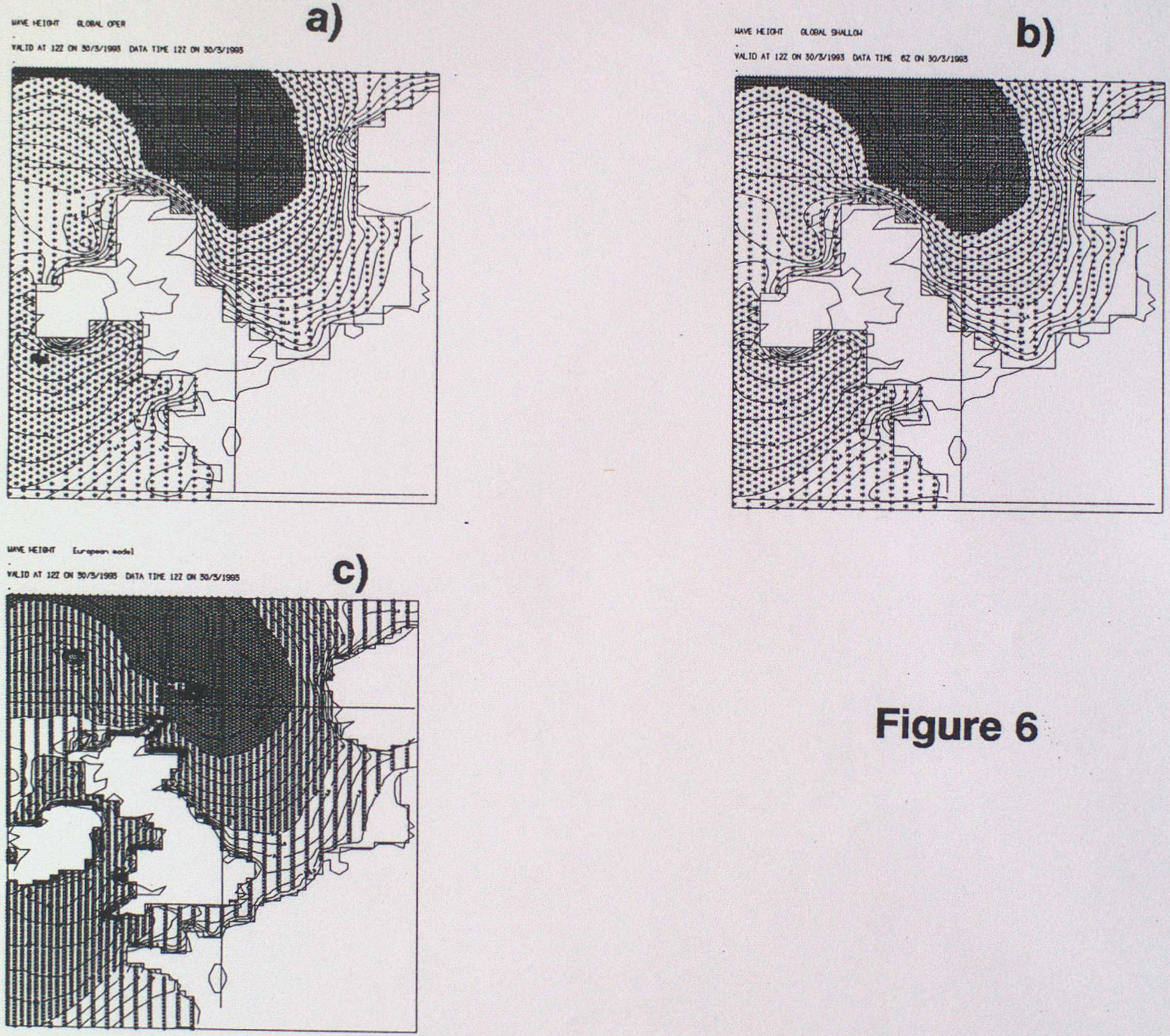

a)
WAVE HEIGHT GLOBAL OPER
VALID AT 12Z ON 30/3/1993 DATA TIME 12Z ON 30/3/1993
b)
WAVE HEIGHT GLOBAL SHALLOW
VALID AT 12Z ON 30/3/1993 DATA TIME 6Z ON 30/3/1993
c)
WAVE HEIGHT European model
VALID AT 12Z ON 30/3/1993 DATA TIME 12Z ON 30/3/1993

Figure 6

Figure 7

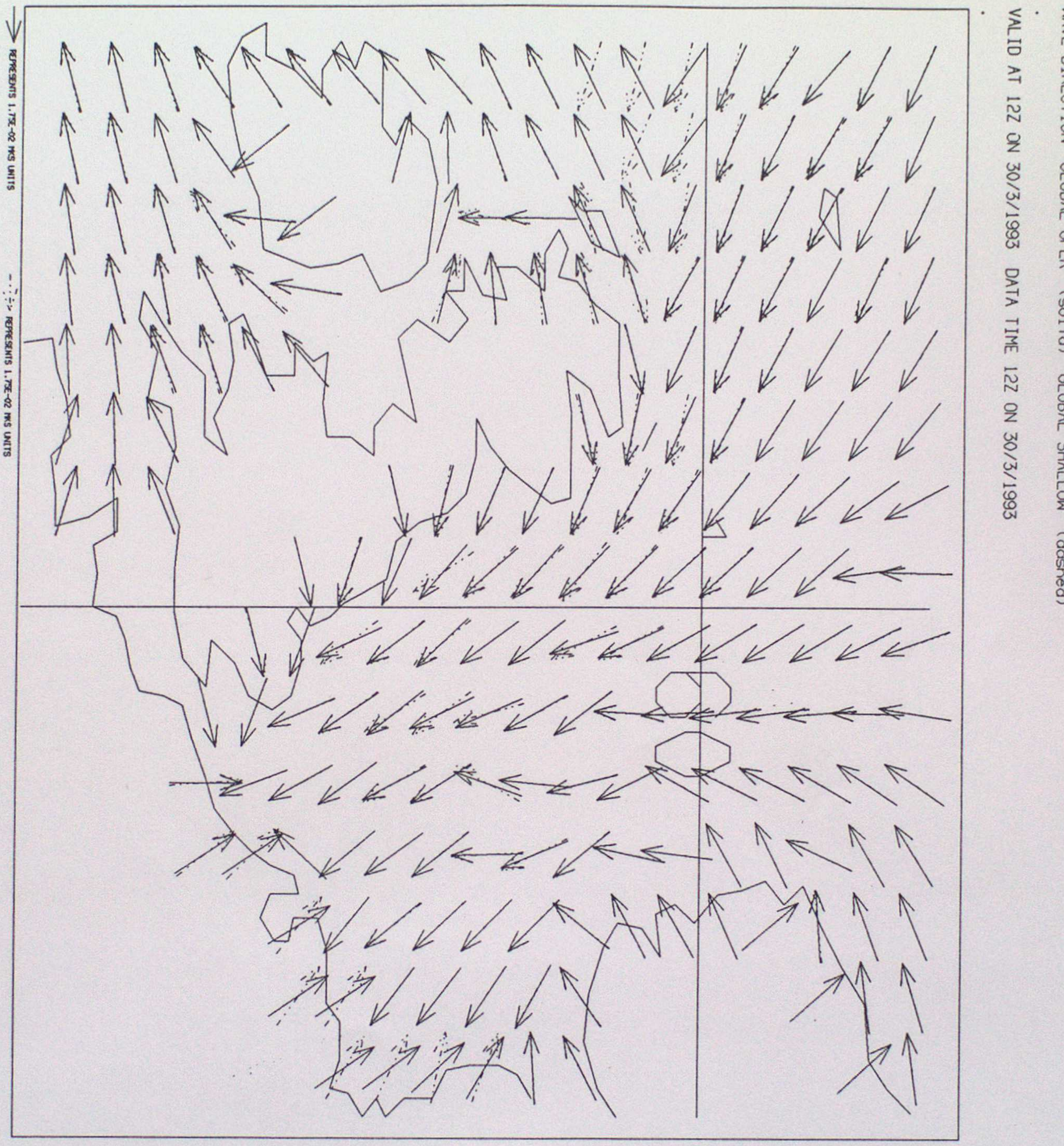

WAVE DIRECTION GLOBAL OPER (solid) GLOBAL SHALLOW (dashed)
VALID AT 12Z ON 30/3/1993 DATA TIME 12Z ON 30/3/1993
REPRESENTS 1.75E-02 MKS UNITS
REPRESENTS 1.75E-02 MKS UNITS

Figure 8

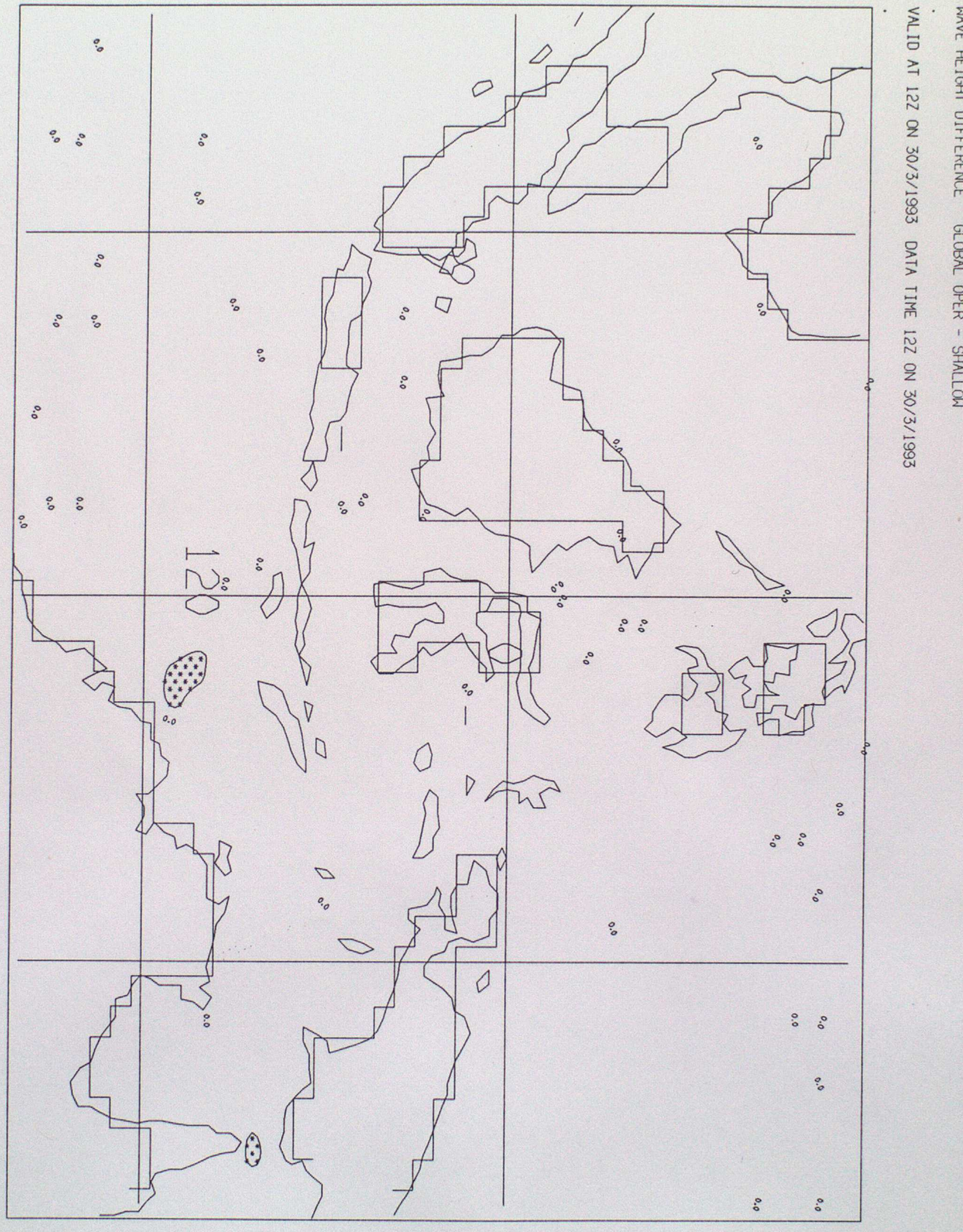
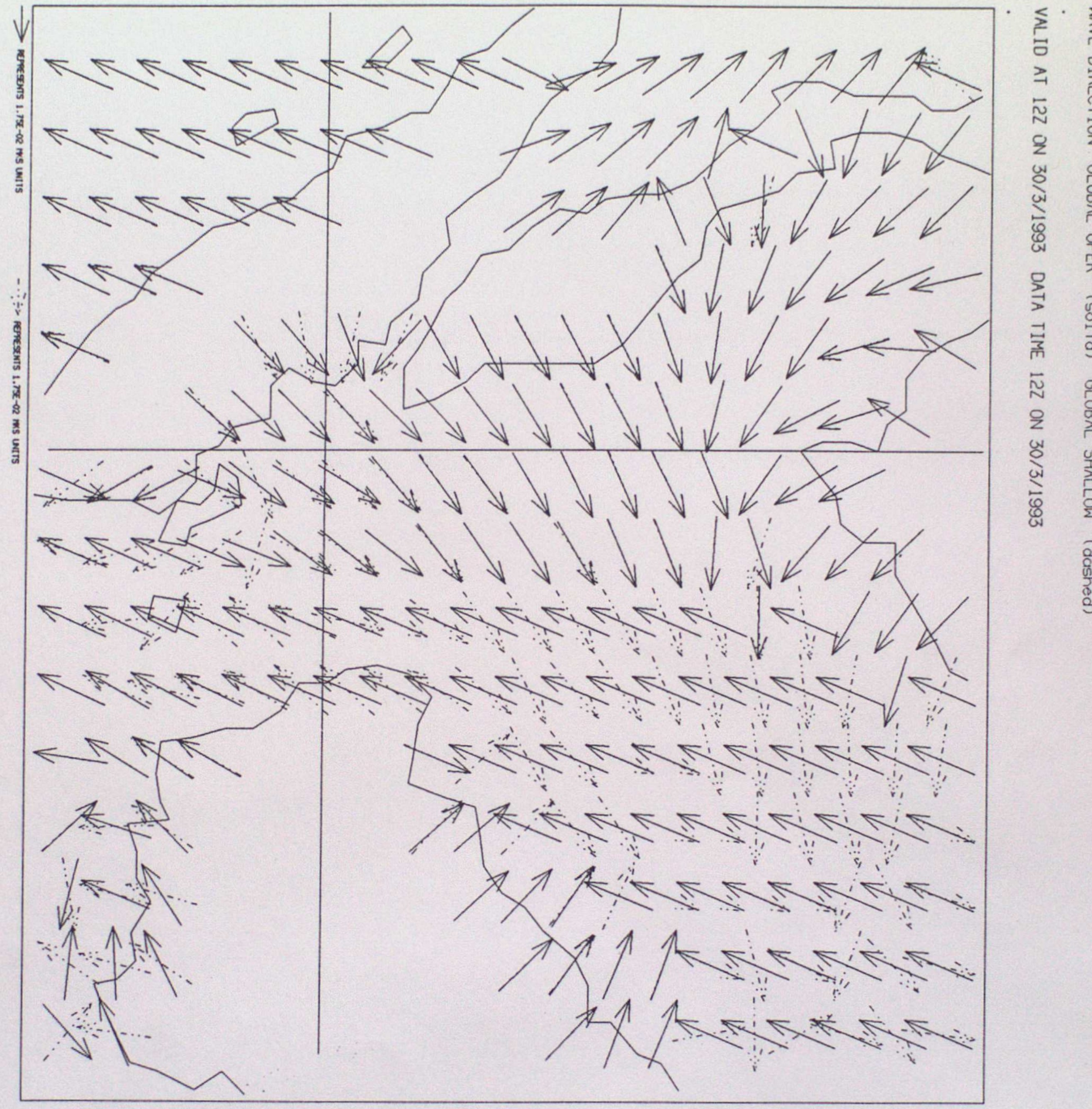

WAVE HEIGHT DIFFERENCE GLOBAL OPER - SHALLOW
VALID AT 12Z ON 30/3/1993 DATA TIME 12Z ON 30/3/1993
120

Figure 9



WAVE DIRECTION GLOBAL OPER (solid) GLOBAL SHALLOW (dashed)
VALID AT 12Z ON 30/3/1993 DATA TIME 12Z ON 30/3/1993
REPRESENTS 1.75E-02 M/S UNITS
REPRESENTS 1.75E-02 M/S UNITS

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