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Introduction

A two-dimensional numerical model of the north-west European continental shelf, developed principally for storm surge forecasting, is being used to investigate the distribution over the region of extreme currents associated with tides and surges. The procedure adopted is to reproduce, using the model, the water movements associated with the tides and with a number of storms. An analysis of the results, constrained where possible to agree with available observations, will provide the required distributions of extreme conditions.

The computed tides and surges are examined separately, their respective treatments proceeding along different lines. For tides, the approach is through harmonic analysis, suitable assumptions applied to the harmonic constants leading to estimates of perigean spring conditions. For surges a statistically based analysis is required. In order to extend the predictive capability to return periods of the order of 50 years, reference to long time series of coastal observations is necessary. The basic model runs covering the ten storm periods selected (see Table 1) are complete. The analysis remains to be done.

The purpose of the present note is to make available some preliminary results.

The model

The numerical model employed covers the continental shelf seas surrounding the British Isles, with a grid (see Figure 1) having resolution $\frac{1}{2}^{\circ}$ in longitude and $\frac{1}{3}^{\circ}$ in latitude, amounting to a spacing between calculation points of about 30 km. The model employs depth averaged equations so that the dependent variables are the sea surface elevation, ζ , and the east and north-directed components, u, v respectively, of the depth mean current.

It is important to note that the actual currents at any chosen depth may differ from the depth mean values. These differences should be most pronounced near the sea surface for wind driven motion (storm surges) and close to the sea bed (for both tides and surges). The computed currents should, however, be typical of those found over a good part of the water column.

The use of the model for tidal problems has been described by Flather (1976), and for surges in a number of papers referred to in Flather (1979). Separation of the motion into its components is achieved by subtracting a solution in which only the tide is included from an equivalent solution taking into account the meteorological forcing. The result is the model surge generated in the presence of the tide and thereby including important effects associated with tide-surge interaction.

Tides

The model tide is based on the two largest constituents, M_2 and S_2 only, which, in combination provide a spring-neap cycle. Diurnal constituents are ignored. A harmonic analysis of computed elevations and currents over one month from period A (Table 1) provided grid point values of the amplitude and phase lag of each of the dependent variables for each constituent. From these, the following parameters defining the associated tidal current ellipses were computed.

a_i: the semi-major axis (cm/s)

b_i: the semi-minor axis (cm/s) : a positive value indicating that the current vector rotates anticlockwise; a negative value indicating clockwise rotation

$g_i^{(\alpha)}$ the phase in degrees of the first maximum of current following high water at Greenwich of the equilibrium constituent

α_i orientation of the major axis of the ellipse in degrees measured clockwise from north, and hence the direction of the current at time $g_i^{(\alpha)} / \sigma_i$ after equilibrium HW at Greenwich, where σ_i is the speed of the constituent in degrees/hour and i is M or S to indicate M_2 or S_2.

The equivalent parameters for the maximum tidal currents were taken to be

$$a_{max} = a_M(1+A) + a_S(1+B),$$

$$b_{max} = b_M(1+A) + b_S(1+B),$$

$$g_{max}^{(\alpha)} = g_M^{(\alpha)},$$

$$\alpha_{max} = \alpha_M,$$

the factors A and B being chosen to account for the additional constituents N_2, $2N_2$, μ_2 and K_2. An examination of the available current and elevation data suggests that, typically,

$N_2 / M_2 \sim 0.19$

$2N_2 / M_2 \sim 0.03$

$\mu_2 / M_2 \sim 0.03$

$K_2 / S_2 \sim 0.28$

so that suitable values are $A = 0.25$, $B = 0.28$. The result corresponds to perigean spring tides (effectively equinoctial spring tides with the moon at perigee) and closely approximate highest astronomical tide.

The distributions of the parameters a_{max}, b_{max}, $g_{max}^{(\alpha)}$ and α_{max} over the shelf are plotted in Figures 2-5. The results are similar to distributions of the equivalent parameters for mean spring tides due to Sager and Sammler (Atlas der Gezeitenströme für die Nordsee, den Kanal und die Irische See, Seehydrographischer Dienst, DDR, Rostock 1975), but with the magnitudes of a_{max} and b_{max} increased.

Typical errors in computed M_2 elevations are 10% in amplitude and 10^o in phase (see Flather 1976). Since the surface tides are produced by net water transports which depend directly on the depth mean currents, similar errors might, in general, be expected to apply to the latter. Additional errors might arise (i) in coastal regions where shallow water constituents, M_4, M_6, $2MS_2$ etc., neglected here, may be significant, and (ii) where local variations due to small scale topography become important, since they cannot be resolved by the model. It is known also that the tidal currents are diurnal in an area of the continental shelf to the west of the Hebrides, and clearly the present estimates may be unreliable there.

Surges

The storm periods (Table 1) for which surges have been computed include some of the most severe of recent years. In particular, the surges on 3 January 1976 and 11-12 January 1978, combined with the tides, produced levels on parts of the north-east coast of England comparable with those of 31 January 1953 (Townsend 1979). On the continental coast, the highest levels yet recorded in Hamburg occurred on 3 January 1976. Mean wind speeds over parts of the United Kingdom were such as are likely to be exceeded only once in about 50 years (Shaw, Hopkins and Caton, 1976; King 1979). The storms of 2 January 1976 and 11 November 1977 also produced exceptionally high levels on the west coast.

A preliminary examination of computed surge elevations and currents during periods A, F, I and J has been carried out to determine the largest computed values. Since, as indicated above, some extreme meteorological and coastal surge conditions are included, these simple maxima should give a useful indication of the magnitudes attainable. The results for currents and elevations are shown in Figures 6 and 7.

Comparing Figures 6 and 2, it is clear that surge currents can exceed the largest tidal currents in many areas, notably in the central, northern and eastern North Sea, and parts of the outer shelf to the north and west of Britain.

The distribution of maximum surge elevation (Figure 7) differs significantly from the estimated 50 year surge heights given in the Department of Energy's notes (Offshore installations : guidance on design and construction, 1977). Most important, in parts of the central, southern and eastern North Sea, the present work suggests that total (wind and pressure induced) surges may exceed by a considerable amount those inferred from the guidance notes. Since our computed maxima at continental North Sea ports are, in many cases, lower than observed (see, for example, Flather and Davies 1978 Figure 6) there appears to be good reason to believe that levels shown in Figure 7 are underestimates rather than overestimates in these areas.

Surge elevation and current maxima are not simply related to local wind and atmospheric pressure, rather they arise as a result of the integrated effect of the changing meteorological forces acting, for a period of one or two days, over the entire region in the presence of the tides. Thus, there is no reason, in general, to expect the largest surge elevation to occur as a result of the strongest local wind, nor for conditions leading to the largest elevations at a point also to give the strongest currents there. This complexity makes it difficult to tackle the problem from the point of view of determining the required extremes as the response of the sea to previously defined extreme meteorological conditions, since it is not clear how one should specify the wind and pressure fields in order to produce the required extremes of oceanographic variables. This difficulty is avoided in the method adopted for the present investigation, which is based entirely on real storm events. Ishiguro (1976) actually determines for each point the direction and duration of the uniform wind (and pressure field), suddenly imposed, which gives the maximum surge elevation there.

This information, together with estimates of extreme wind speeds, leads to a distribution of highest surge elevations differing markedly from that shown in Figure 7. The differences may be explained in terms of the assumptions made in the respective approaches. For practical purposes it would seem prudent to take the largest estimate from whichever source.

References

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Table 1 :

Storm periods covered by shelf model solutions.

	Period	Includes NORSWAM storms
A.	14/11 - 18/12/73	25, 30, 33
B.	14 - 20/12/74	19
C.	2 - 8/1/75	59
D.	19 - 26/1/75	60
E.	24/11 - 5/12/75	61, 62
F.	31/12/75 - 6/1/76	63
G.	16 - 24/1/76	64
H.	29/3 - 2/4/77	-
I.	8 - 18/11/77	-
J.	9 - 12/1/78	-

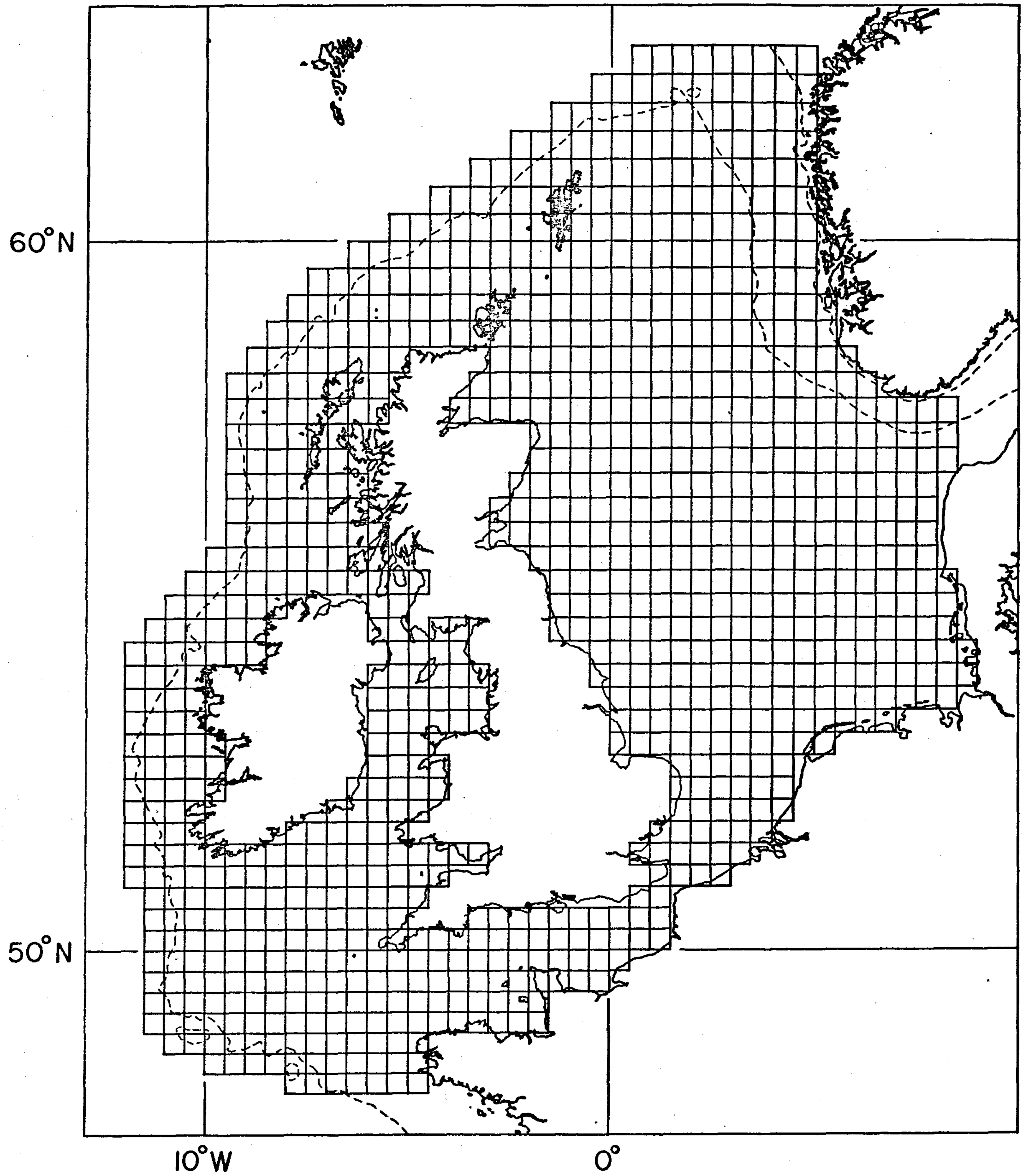

Figure 1: CSM grid

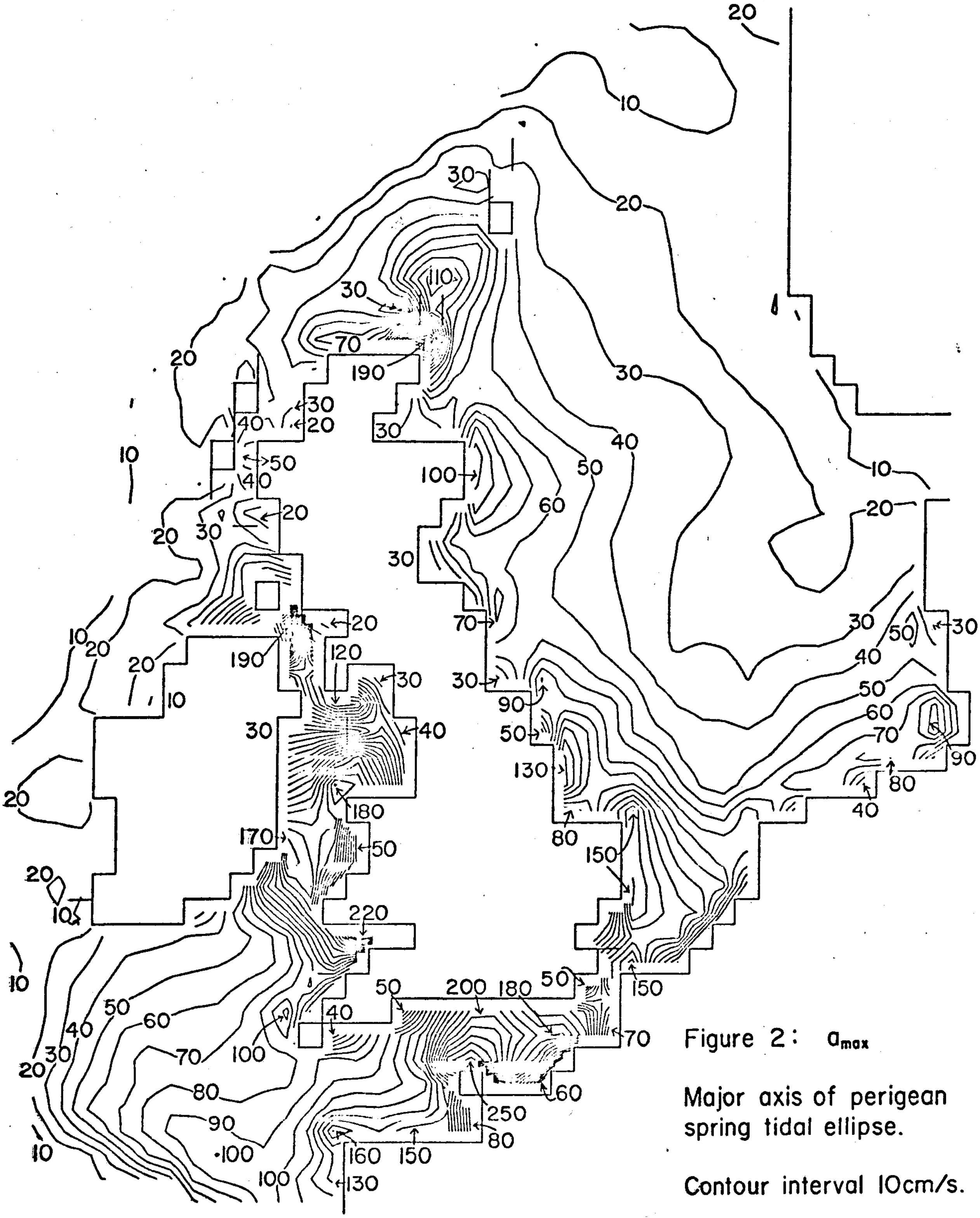

Figure 2: a_{max}

Major axis of perigean spring tidal ellipse.

Contour interval 10cm/s.

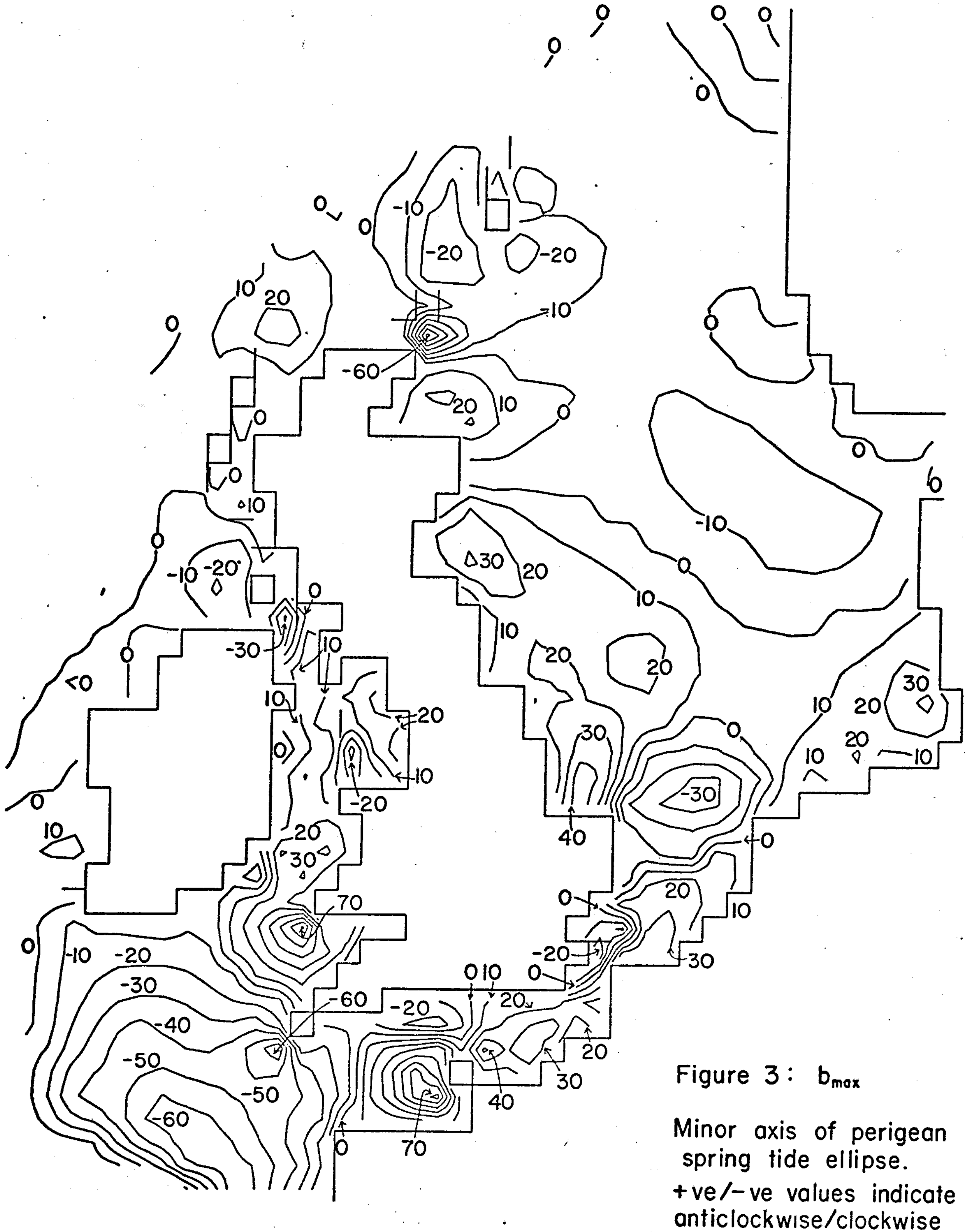

Figure 3: b_{max}

Minor axis of perigean spring tide ellipse.

+ve/−ve values indicate anticlockwise/clockwise rotation.

Contour interval 10 cm/s.

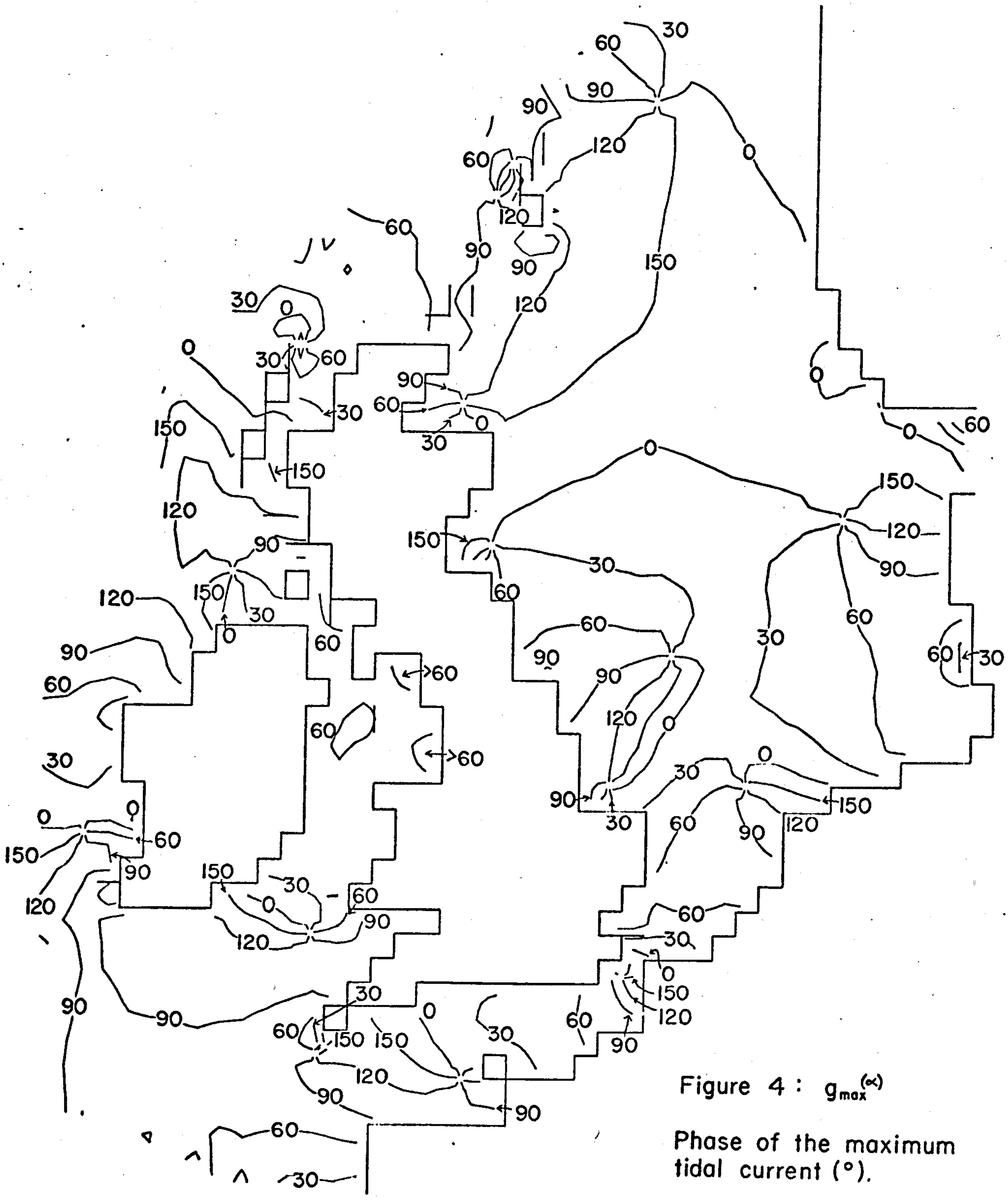

Figure 4 : $g_{max}^{(\alpha)}$

Phase of the maximum tidal current (°).

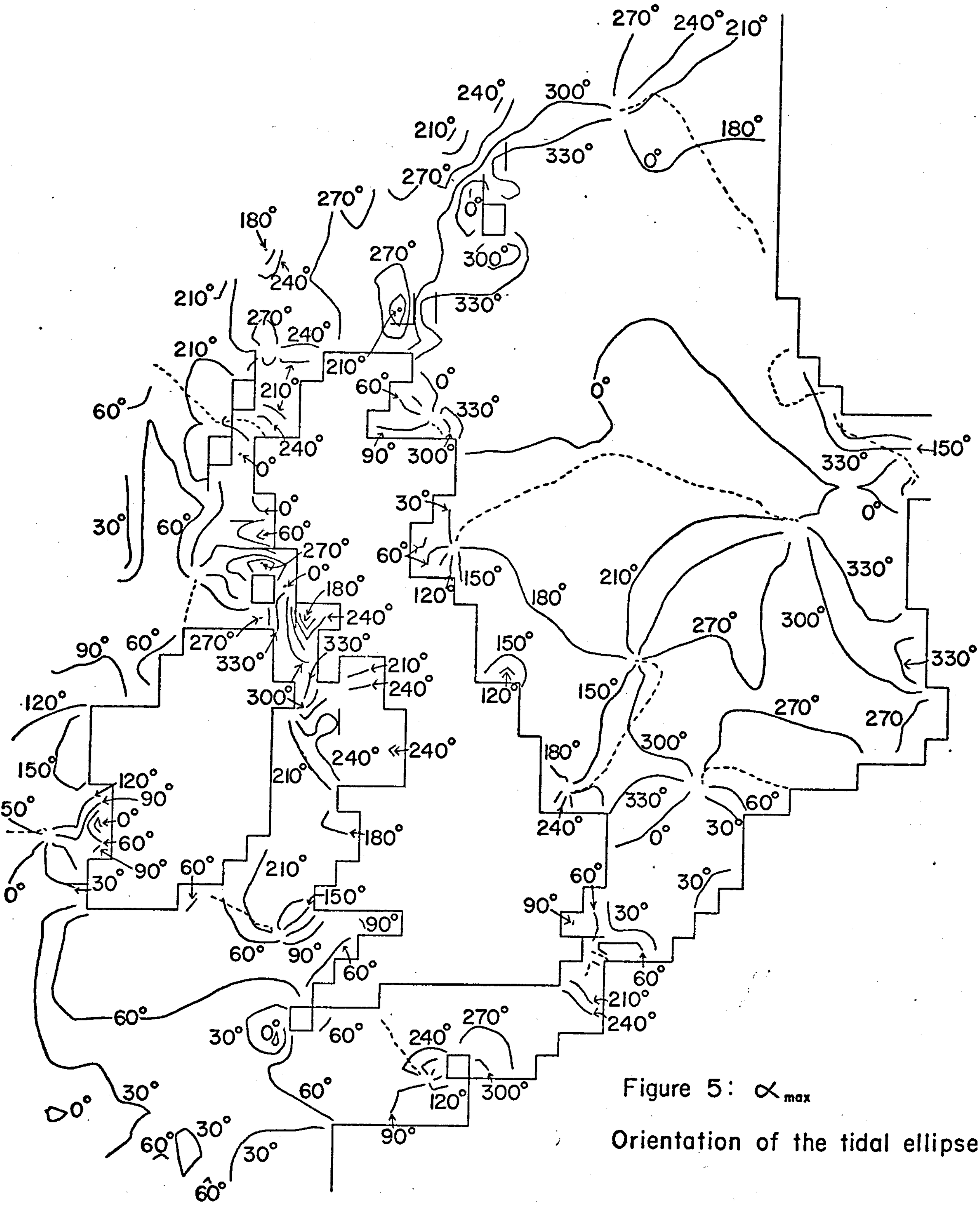

Figure 5: α_{max}

Orientation of the tidal ellipse.

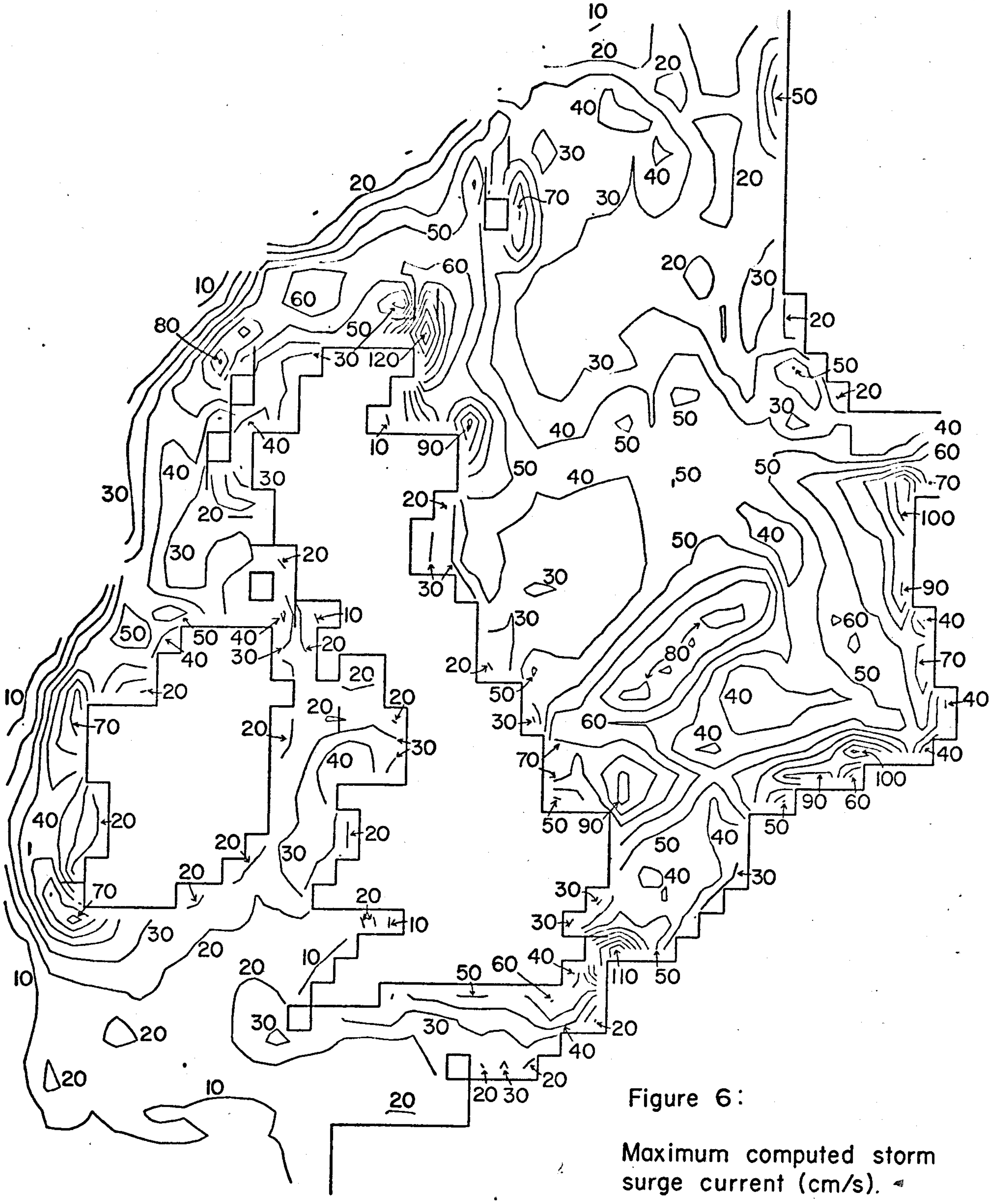

Figure 6:

Maximum computed storm surge current (cm/s).

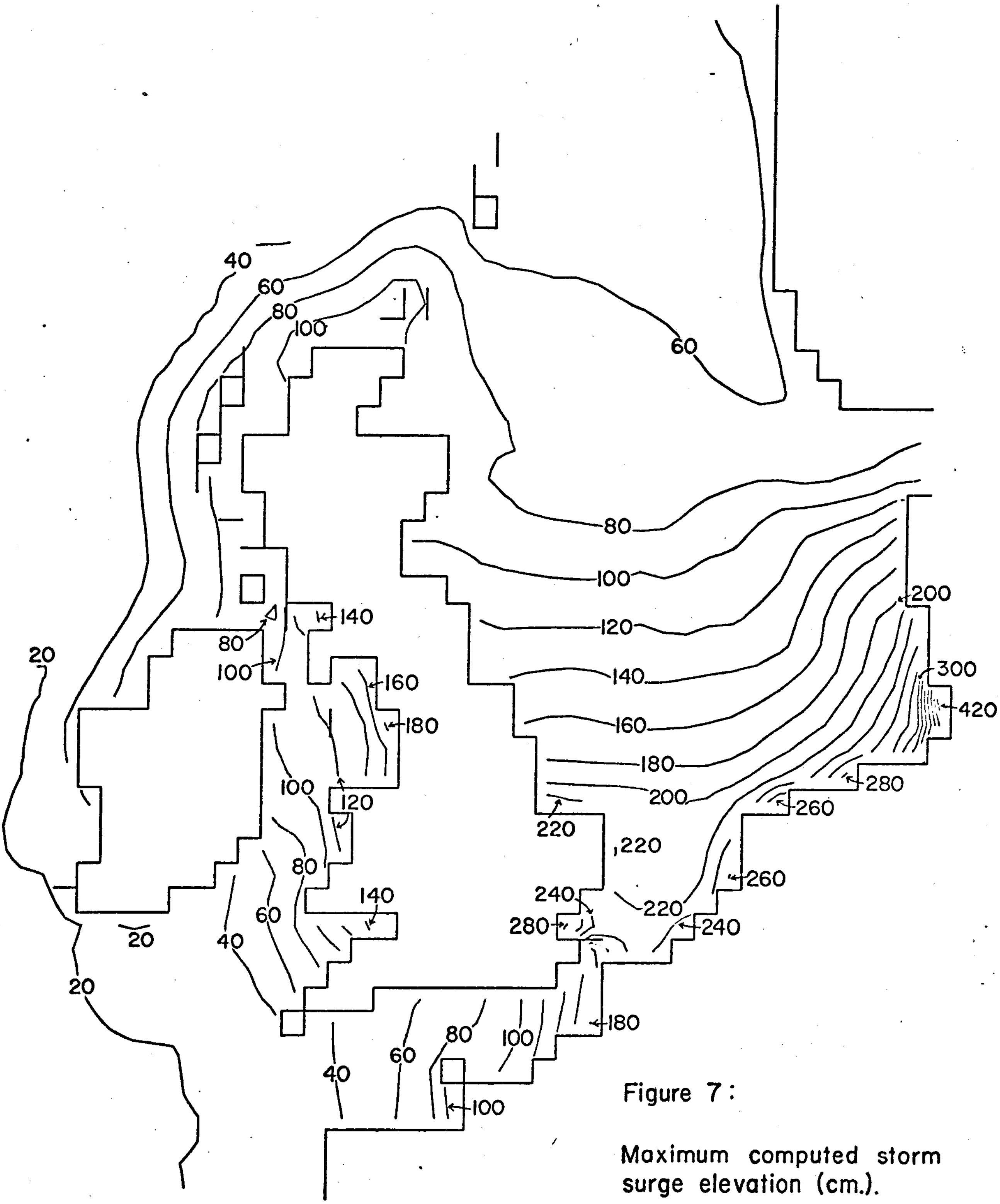

Figure 7:

Maximum computed storm surge elevation (cm.).