I.O.S.

CHARTS OF THE O_1, K_1, N_2, M_2, AND S_2 TIDES IN THE CELTIC SEA INCLUDING M_2 AND S_2 TIDAL CURRENTS

BY

J.E. JONES

REPORT NO. 169

1983

NATURAL ENVIRONMENT RESEARCH COUNCIL

INSTITUTE OF OCEANOGRAPHIC SCIENCES

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Wormley, Godalming,
Surrey, GU8 5UB.
(0428 - 79 - 4141)

(Director: Dr. A.S. Laughton FRS)

Bidston Observatory,
Birkenhead,
Merseyside, L43 7RA.
(051 - 653 - 8633)

(Assistant Director: Dr. D.E. Cartwright)

Crossway,
Taunton,
Somerset, TA1 2DW.
(0823 - 86211)

(Assistant Director: M.J. Tucker)

When citing this document in a bibliography the reference should be given as

JONES, J.E. 1983 Charts of the O_1, K_1, N_2, M_2, and S_2 tides in the Celtic Sea including M_2 and S_2 tidal currents. *Institute of Oceanographic Sciences, Report*, No. 169, 59pp.

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BIDSTON

Charts of the O_1, K_1, N_2, M_2, and S_2 tides in the Celtic Sea including M_2 and S_2 tidal currents

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CONTENTS

SUMMARY

A two-dimensional numerical model of the West Coast of the United Kingdom has been used to compute co-tidal and co-amplitude charts for the five tidal constituents O1, K1, N2, M2 and S2 in the Celtic Sea area. Charts showing tidal current ellipse parameters for the M2 and S2 tidal currents of that area have also been drawn on the basis of results obtained from the model.

A comparison of observations and model results has been carried out and a series of scatter plots have been prepared which indicate the overall deviation of the model from observation.

This report contains the computed charts, scatter plots and tables of observations and it is intended that, by their combined use, the O1,K1, N2,M2 and S2 tides as well as the M2 and S2 tidal currents may be determined for any point in the Celtic Sea.

1 INTRODUCTION

The tidal information presented in this report was obtained from a two-dimensional numerical tidal model of the West Coast of the British Isles. The model area, delineated in Figure 1, comprised part of the sea area north of Ireland and west of Scotland (South of 56° 52′N and East of 8° 48′W), the entire Irish Sea and most of the Celtic Sea (North of 48° 48′N, East of 9° 48′W and West of 4° 12′W). The open sea boundaries of the model are represented by dashed lines in Figure 1 and the land boundaries are shown by the short straight lines approximating the actual coast.

The grid resolution of the model was 4 minutes of arc in latitude and 6 minutes of arc in longitude. This mesh size is indicated by the tick marks along the edges of Figure 1 and also by the short lines used to approximate the coast. Input consisted of prescribed elevations along the open boundaries composed of five tidal constituents O1, K1, N2, M2, S2. These were derived by reference to a number of sources including a larger model of the Continental Shelf (Flather 1976), on- and off-shore tide gauge observations (Cartwright et al 1980), and results from a hydraulic model of the English Channel. (Chabert d'Hières and Le Provost 1978).

In the numerical model itself, non-linear friction terms were used and the drying of shallow areas was also represented. Convection terms however were not included. Tide-generating forces and the effects of Earth tides and Ocean tide loading were ignored.

From an initial state of rest the model was run for the equivalent of 7 days to allow the damping out of transients. The run was then continued for a further 28 days and provided hourly values of elevation and current at each grid point. A tidal analysis was then performed to extract the five tidal constituents at each model grid point in the Celtic Sea area, both for elevations and east and north components of current. The shaded area of Figure 1 defines the Celtic Sea portion of the model as used in this report.

For the elevations, co-tidal and co-amplitude charts were then plotted, however for the currents further processing was required before the tidal current ellipse parameters could be presented in contour form.

The work described here was performed to provide basic tidal information for a programme of three-dimensional numerical modelling of the current structure and circulation in the Celtic Sea.

2 EXPLANATION OF CHARTS

2.1 General Remarks

In deciding how best to present the data produced by the model various publications were consulted (Chabert d'Hieres and Le Provost 1978, Deutsche Demokratische Republik Seehydrographischer Dienst 1975, Great Britain Hydrographic Department 1973 and 1974, Pingree and Griffiths 1982, Robinson 1979) The co-tidal and co- amplitude charts are presented in a fairly standard form. However it is difficult to present information on currents briefly and without ambiguity. Although the presentation used here produces some ambiguity in certain restricted areas of the charts, it should be possible to extract the M2 and S2 current information simply and clearly for most of the Celtic Sea.

The charts as presented here depict the coasts bordering the Celtic Sea, the 100 fathom isobath in the south-western corner, the outline of the model boundaries and the contour field appropriate to the parameter being plotted. Thus the relation of the model to the actual coastline may be seen and the model mesh size is also indicated.

Labelling of contour levels has been omitted in areas where contours are crowded, however the value of an un-numbered contour should be easily obtained by inspection.

The contour interval varies from chart to chart and is as follows:

Elevations

CONSTITUENTS	AMPLITUDE INTERVAL	PHASE INTERVAL
O1 , K1	1 cm.	10 degrees
N2	5 cm.	10 degrees
M2 , S2	10 cm.	10 degrees

Currents

PARAMETER(M2)	INTERVAL	PARAMETER(S2)	INTERVAL
a	10 cm/s	a	2 cm/s
b	10 cm/s	b	2 cm/s
α	10 degrees	α	10 degrees
$-\varepsilon/\omega$	1 hour	$-\varepsilon/\omega$	1 hour

2.2 Elevations

The co-tidal and co-amplitude contours are presented in usual form. The tidal amplitudes are given in centimetres and the phase in degrees - in the usual sense of being the lag of the phase of the tidal constituent behind the phase of the corresponding equilibrium constituent at Greenwich.

2.3 Currents

There are five charts for each of the M2 and S2 tidal current regimes and they depict the five tidal ellipse parameters.

The semi-major axis is shown in the chart labelled a, and the semi-minor axis is given on the chart labelled b . Because of the contour interval chosen,the b chart for M2 has little information along the southern Irish coast. As a guide, values of b given by the model close to this coast range from 1.5 to 4 cm/s. The orientation of the major axis is given on the chart for α : where α is the angle of the major axis to the easterly direction, constrained to lie between +90 degrees, due North and -90 degrees, due South. α =0 is therefore due East The chart labelled $-\varepsilon/\omega$ gives the time in solar hours (after transit of the M2 or S2 equilibrium constituent at Greenwich) at which the current due to the harmonic constituent is a maximum (given by a) in the direction α . Here, ε denotes the phase lead and ω the angular speed of the constituent. The fifth chart gives the direction of rotation of the current vector.

Restricting α to lie between +90 degrees and -90 degrees has led to a rather convoluted appearance to the $-\varepsilon/\omega$ contours in areas where the direction of the semi-major axis is close to the North-South direction, shown on the charts in the vicinity of headlands where tidal streams merge or diverge. This restriction on α however was felt necessary to indicate unambiguously the times of ebb and flood currents. In the Celtic Sea as a whole, flood currents are generally in an Easterly direction

Note also the "amphidromes" in the α chart. These are not current amphidromes ie. where tidal currents are zero; rather they are points where the tidal ellipse approaches circularity and the distinction between major and minor axis becomes ambiguous. These areas also produce further convolutions in the $-\varepsilon/\omega$ charts.

3 COMPARISON WITH OBSERVATIONS

A survey was next carried out to assess how closely the model reproduced the actual tidal regime in the Celtic Sea. The locations of the tide-gauge and curent meter observations used for comparison purposes are given in Figures 2 and 3.

For the elevations, harmonic constants derived from tide-gauge observations were compared with constants derived at the nearest corresponding points of the numerical model grid. These comparisons are given in Table I. Scatter plots were drawn and are presented here with a distinction between on-shore tide gauges (dots) and off-shore tide-gauges (crosses).

As a further step a linear regression was carried out on each scatter plot with the assumption that the observations were correct and the model results contain all the errors. The regression line is drawn on each scatter plot and the regression coefficients of r (correlation), m (slope) and b (intercept) are noted below each graph.

To give an idea of the confidence level in the regression line two further dashed lines have been drawn placed at a distance of two standard errors of estimate each side of the regression line. Their interpretation is as follows: given any observed value there is a 95% chance that the corresponding model value will lie between the dashed lines on the vertical line through the selected observed value.

For the currents a different approach was required.

In general at a current meter station there may be two or three current meters located at different levels through the water column. As the model provides only depth-integrated currents it is necessary in some way to average out the current meter observations at each station to provide an "observed" depth-integrated current.

From each current meter harmonic constants were derived for both the East and North components of current. For each component a parabolic fit through depth was applied and thus an average harmonic constant could be determined. In the case of only one current meter it was necessarily assumed that the components of current derived from the meter represented the average values.

Combining the East and North components of each depth-integrated harmonic constant the "observed" tidal ellipses could then be calculated. The model results and the comparisons are given in Table II. As for the elevations, scatter plots and regression lines were drawn for the ellipse parameters excepting rotation.

4 HOW TO USE THE CHARTS

4.1 Elevations

It is a simple matter to extract the O1, K1, N2, M2, or S2 tide at any point in the Celtic Sea by reference to the appropriate chart.

If it is required generally to know how far the actual tidal constants may deviate from the model values given by the charts, reference may be made to the corresponding scatter plot. Having obtained a value from the chart find this value on the vertical (ie. model) axis on the scatter plot and from this point draw a horizontal line across the graph. The intersection of this line with the upper and lower dashed lines defines a lower and upper observed value respectively which may be read off on the horizontal (observed) axis. One can say that the model value obtained from the chart lies at the upper 95% limit of the lower observed value and the lower 95% limit of the upper observed value.

If more specific information is required for a particular area Table I may be consulted and a comparison made between observations and model results in the particular locality.

4.2 Currents

By combination of the five M2 (or S2) charts giving a, b, α , $-\varepsilon/\omega$ and rotation, the depth-integrated tidal ellipse may be constructed generally for any point in the Celtic Sea.

From the chart giving a the semi-major axis may be drawn, while from the chart giving b the semi-minor axis may be found.

The inclination of the semi-major axis to the easterly direction is given by α read from the appropriate chart. The time of the maximum current , a, in that direction is given by the $-\varepsilon/\omega$ chart as explained previously.

As for the elevations, scatter plots have been drawn for the ellipse parameters and these may be used in a similar fashion to determine how far the model tidal ellipses deviate from those found in nature.

Table II also enables comparisons to be made in local areas.

5 REMARKS

5.1

It is an assumption of the regression lines drawn on the scatter plots that all the observations are correct. However this need not necessarily be the case. Apart from possible instrumental problems the constants themselves may be subject to apparent change, such as K1-see below.

Tables I and II contain several instances of tide gauges or current meters fairly close to each other or even observations taken at the same location but at different times. These give an indication of the variations possible in the observed values.

In addition the observed values quoted in this report may be updated from time to time as the results of new measurements.

5.2

It may be noted that the comparisons between the observed and model results for the K1 tide are substantially poorer than for the rest of the components.

This is due to the difficulty in determining the actual K1 tide from observations. It cannot be separated from the tidal constituents P1 and S1 without using records of at least six months and one year respectively. Only a few on-shore tide gauges provide records of this length; off- shore tide gauges usually provide records of one month's duration. Problems with the K1 tide in the Celtic and Irish Seas have been noted elsewhere (Baker and Alcock 1983). In the present case the poor comparison may be due to the fact that a large number of the off-shore tide gauge measurements were made in 1978, a time when the nodal factors reduced the K1 amplitude to a smaller than average value. Under these conditions K1 can nearly cancel with P1 twice a year near the equinoxes. Therefore at this time the S1 component may have been a significant proportion of the K1 signal in any harmonic analysis.

Furthermore the S1 signal may contain a significant radiation tide which varies from place to place in the Celtic Sea. For an off-shore measurement, having obtained a value for K1 it is possible to estimate what proportion of this value is actually due to S1 by reference to a nearby on-shore tide gauge measurement(provided of course that this tide gauge has produced at least one year of data). However this may be a very approximate procedure as the radiational part of the S1 tide may be different between the on- and off-shore positions. As an example at Station H two analyses which respectively ignore S1 and then include it using St. Marys as a reference give the following results for the K1 amplitude: No S1, 7.1 cm.; Including S1, 10.2 cm. The error in the amplitude can thus be of the order of 30%.

5.3

In addition to the M2 and S2 tidal currents, the east and north components of current for the O1, K1, and N2 tidal currents have been extracted.These are available in tabular form at I.O.S. Bidston.

5.4

It is a point worth noting that the α charts for the M2 and S2 currents are very similar. There is perhaps a difference of only ten degrees between them at any point. Thus the semi-major axes of the M2 and S2 tidal ellipses are very nearly aligned and so it may be stated that the maximum tidal current due to the M2 and S2 components, generally throughout the Celtic Sea,can simply be taken as the arithmetic sum of the individual maximum currents.

6 ACKNOWLEDGEMENTS

The help is gratefully acknowledged of N.S. Heaps who originated the West Coast model, A.M. Davies for the tidal harmonic analysis program, M.J. Howarth for providing the current meter observations , J.M. Vassie and D.E. Cartwright for discussion on the K1 tide and R.A. Smith for preparing some of the diagrams. The work described in this report was funded by the Department of Energy of the United Kingdom.

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TABLE I (i) LOCATION OF TIDE GAUGES

STATION	CODE	LAT. °	′	LONG. °	′
Cobh	CO	51	50 N	8	18 W
Devonport	DE	50	22	4	11
Milford Haven	MI	51	44	5	02
Appledore	AP	51	03	4	12
Castletown	CA	51	39	9	54
Coverak	CV	50	01	5	05
Falmouth	FA	50	09	5	03
Fowey	FO	50	20	4	38
Lizard Point	LZ	49	57	5	12
Mevagissey	ME	50	16	4	47
Newlyn	NE	50	06	5	33
Pembroke Dock	PD	51	42	4	56
Porthleven	PL	50	05	5	19
St. Marys	SM	49	55	6	19
Baltimore	BL	51	29	9	23
St. Ives	SI	50	12	5	28
Roberts Cove	RC	51	44	8	19
Tenby	TE	51	40	4	42
Instow	IN	51	04	4	10
Padstow	PA	50	33	4	56
Boscastle	BO	50	42	4	42
Lundy	LU	51	11	4	40
Barrow Bridge	BB	52	23	6	56
Fishguard	FI	52	00	4	58
Ilfracombe	IL	51	13	4	07
Wexford	WX	52	20	6	27
Wicklow	WK	52	59	6	02
Rosslare	RO	52	15	6	21
Aberystwyth	AY	52	25	4	05
Nefyn	NF	52	57	4	34
Aberporth	AB	52	09	4	32
Oa	OA	51	03	7	00
Ob	OB	48	37	9	42
B	B	51	45	6	36
C	C	51	20	6	30
D	D	50	36	6	08
F	F	50	33	7	32
G	G	49	39	8	30
H	H	48	55	9	21
Oc	OC	52	06	5	48
On	ON	52	04	5	47

TABLE I (ii) AMPLITUDES (CM.)

	O1		K1		N2		M2		S2	
	OBS	CALC	OBS	CALC	OBS	CALC	OBS	CALC	OBS	CALC
CO	3.4	4.3	2.1	3.4	25.5	24.0	138.1	142.3	43.3	45.7
DE	5.5	6.0	7.7	7.9	31.6	31.1	169.1	162.0	60.3	54.8
MI	7.1	7.8	5.9	8.2	42.2	38.9	224.9	222.7	81.8	78.7
AP	6.7	7.7	6.7	8.2	48.2	50.3	254.2	293.6	92.0	102.7
CA	1.2	3.0	4.5	4.2	22.8	23.1	108.6	126.7	34.8	43.5
CV	5.2	5.9	7.3	7.5	34.1	26.4	163.1	162.9	53.9	51.5
FA	7.9	5.9	8.8	7.6	36.6	27.2	163.7	163.3	56.1	52.0
FO	6.1	5.9	5.8	7.7	33.8	29.7	165.8	164.0	53.9	53.7
LZ	6.1	5.9	6.4	7.1	33.8	25.7	161.5	164.0	55.2	51.0
ME	5.2	5.9	7.6	7.7	29.9	29.2	161.5	164.0	53.9	53.5
NE	5.3	5.9	6.2	6.8	32.3	27.4	169.7	168.4	56.8	52.5
PD	6.7	7.8	4.9	8.2	43.6	38.9	229.2	222.7	84.7	78.7
PL	4.6	5.9	7.0	6.9	33.2	26.2	164.9	165.2	51.5	51.3
SM	5.5	6.1	5.4	6.2	34.6	31.8	176.5	178.0	60.7	59.2
BL	1.0	2.6	2.0	1.3	20.0	22.0	114.0	126.4	37.0	42.1
SI	5.3	6.7	5.9	7.1	41.9	39.4	219.7	225.4	78.0	77.1
RC	3.7	4.0	1.8	3.0	25.2	23.6	137.2	140.5	42.9	45.1
TE	10.0	7.7	12.0	8.1	49.0	46.9	262.0	272.7	101.0	95.5
IN	7.0	7.7	5.0	8.2	57.0	50.3	251.0	293.6	84.0	102.7
PA	5.0	7.1	7.0	7.4	50.0	42.4	245.0	243.8	94.0	84.7
BO	5.0	7.3	6.0	7.6	46.0	44.3	236.0	255.4	89.0	89.1
LU	5.9	7.6	4.6	7.9	51.5	46.4	257.6	269.4	93.4	94.4
BB	4.8	6.0	3.7	5.9	26.5	23.5	145.0	139.9	48.6	47.5
FI	7.9	9.0	7.4	10.1	28.0	26.6	135.8	151.5	53.3	56.2
IL	6.4	7.8	6.4	8.3	58.1	52.5	308.0	307.9	111.9	107.1
WX	7.0	8.3	6.7	9.4	7.3	10.5	48.8	65.7	22.6	27.1
WK	9.8	10.4	16.5	12.8	16.1	11.3	79.8	52.9	17.2	18.4
RO	7.2	8.2	6.3	9.2	9.5	11.3	56.0	70.9	24.4	28.6
AY	9.0	9.9	8.5	11.5	28.3	27.7	150.8	157.6	56.9	58.9
NF	10.7	10.6	9.7	12.8	29.1	24.5	140.4	136.0	49.6	47.7
AB	7.7	9.5	8.1	10.9	29.0	26.3	141.2	149.5	53.4	55.9
OC	6.7	7.8	5.9	8.4	20.0	21.0	104.0	121.9	42.1	45.8
ON	8.1	7.8	7.8	8.4	21.8	21.0	111.6	121.9	44.0	45.8
OA	4.8	5.5	4.1	5.0	31.1	29.2	162.6	170.3	55.0	58.0
OB	6.8	6.7	6.8	6.4	24.9	25.3	115.7	122.8	39.1	43.4
B	5.5	6.0	4.1	5.8	26.7	25.8	144.6	151.5	49.3	52.7
C	5.4	6.0	4.6	5.7	31.5	29.5	165.7	172.2	56.7	59.6
D	5.8	6.3	5.2	6.3	38.6	34.2	190.6	197.2	65.1	67.7
F	4.9	5.3	4.6	4.8	31.4	27.9	157.4	162.6	52.2	55.0
G	5.8	5.9	8.4	5.5	29.1	25.4	137.8	143.7	46.5	49.3
H	6.6	6.6	10.2	6.0	26.4	25.8	123.0	127.7	41.4	44.9

TABLE I (iii) PHASES (DEGREES)

	O1		K1		N2		M2		S2	
	OBS	CALC	OBS	CALC	OBS	CALC	OBS	CALC	OBS	CALC
CO	45.8	32.7	155.5	179.9	128.9	120.4	149.6	143.5	194.2	184.2
DE	348.4	342.8	108.7	105.1	137.2	136.8	154.4	150.9	206.7	202.8
MI	356.5	355.3	125.0	127.4	152.2	145.4	173.1	169.8	216.7	210.7
AP	358.0	349.4	140.0	119.8	147.0	133.9	165.0	157.7	211.0	200.3
CA	347.8	359.8	44.1	97.1	103.1	102.6	128.2	129.4	158.6	161.6
CV	336.0	339.1	128.0	104.6	124.0	127.8	143.0	141.7	192.0	190.0
FA	352.0	339.9	128.0	104.8	125.0	131.6	147.0	143.5	196.0	192.8
FO	307.0	341.2	97.0	104.6	126.0	135.7	148.0	145.0	198.0	197.8
LZ	324.0	336.5	115.0	104.0	120.0	112.2	137.0	134.7	186.0	179.3
ME	355.0	340.8	12.0	104.6	132.0	135.0	151.0	146.2	206.0	196.7
NE	343.9	335.2	110.4	103.7	115.6	101.9	135.3	129.7	178.8	171.4
PD	10.0	355.3	149.0	127.4	158.0	145.4	174.0	169.8	218.0	210.7
PL	356.0	335.8	109.0	104.0	113.0	105.6	135.0	131.6	185.0	174.5
SM	341.1	337.5	99.6	101.9	110.0	100.3	130.1	128.3	170.8	167.6
BL	43.0	2.7	27.0	39.6	150.0	103.0	169.0	131.0	207.0	164.2
SI	336.0	339.3	107.0	107.9	118.4	110.3	137.6	135.5	181.9	176.0
RC	42.7	31.4	155.3	179.0	123.2	119.4	144.9	142.5	189.4	182.5
TE	1.0	354.4	119.0	125.6	155.0	144.0	170.0	168.2	215.0	210.3
IN	5.1	349.4	119.0	119.8	145.1	133.9	172.0	157.7	224.0	200.3
PA	332.0	343.5	110.9	112.9	123.5	118.7	149.0	143.2	192.0	184.2
BO	17.0	345.0	112.9	114.8	104.5	122.5	143.0	146.8	201.0	188.0
LU	0.6	350.3	125.7	120.9	141.1	133.6	162.6	157.5	207.6	199.6
BB	42.0	34.4	170.2	177.4	137.3	125.7	157.1	148.5	206.4	194.5
FI	10.6	10.6	151.9	147.7	188.7	173.8	207.6	196.9	247.9	236.3
IL	349.8	351.4	123.6	122.3	143.3	139.7	161.7	163.2	208.0	206.6
WX	53.0	39.3	191.0	180.7	189.0	146.9	188.0	163.5	254.0	217.5
WK	12.5	42.8	157.5	183.4	226.2	274.7	254.9	302.7	313.5	318.7
RO	35.2	39.0	182.3	180.5	150.5	144.6	156.9	162.1	219.8	215.5
AY	17.8	16.2	162.9	154.5	210.8	195.7	229.5	218.6	266.7	256.5
NF	25.0	25.9	169.9	165.1	247.2	233.0	269.5	257.2	303.2	291.6
AB	15.2	14.0	150.2	151.8	193.3	186.4	218.4	209.4	257.7	247.6
OC	25.3	20.6	157.2	158.9	167.7	154.4	179.7	176.1	228.5	219.7
ON	30.6	20.6	155.6	158.9	171.2	154.4	183.8	176.1	229.6	219.7
OA	352.6	0.8	114.2	130.2	124.0	118.7	144.2	142.8	189.5	183.8
OB	329.4	329.8	101.4	96.1	86.5	88.3	106.9	106.6	140.1	139.8
B	21.1	18.7	127.0	156.5	132.0	130.4	154.1	153.4	201.6	197.2
C	7.8	5.9	112.5	138.9	129.7	126.8	151.5	150.5	196.9	192.7
D	353.6	347.8	106.5	115.6	123.0	114.6	142.1	139.6	186.3	180.2
F	352.0	352.0	91.5	115.6	114.6	110.0	136.2	134.4	177.5	173.5
G	334.7	337.5	80.3	98.0	100.4	96.7	122.0	120.3	158.4	156.2
H	329.3	331.0	73.1	92.7	91.7	91.1	112.4	108.6	146.2	142.4

TABLE II (i) LOCATION OF CURRENT METERS

STATION	LAT. °	LAT. ′	LONG. °	LONG. ′
C78	51	19 N	6	35 W
C80	51	20	6	30
B78	51	45	6	38
C73	51	03	7	00
A73	51	24	7	40
E78	51	28	7	50
FRC80	51	37	8	09
E80	51	21	8	31
E75	50	27	5	54
D78	50	36	6	08
D73	50	45	6	27
F78	50	32	7	29
K80	50	30	9	49
L71	52	05	5	08
E74	52	09	5	11
D74	52	16	5	35
J73	52	05	5	46
FRC79	52	04	6	40
D75	51	19	4	44
A80	51	00	5	32
H73	51	55	5	58
G73	51	34	6	23
MBA34	49	03	4	17
MBAE2	49	27	4	42
MBA32	49	51	5	05
G78	49	37	8	35
MBA35	48	51	5	30
L80	48	47	7	03
DB1	48	43	8	58

TABLE II (ii) M2 TIDAL CURRENTS

	a		b						ROTATION*	
STATION	OBS	CALC	OBS	CALC	OBS	CALC	OBS	CALC	OBS	CALC
C78	23.1	25.4	11.1	7.7	28.1	34.0	4.9	4.7	+	+
C80	24.6	25.8	9.6	8.3	38.7	38.4	5.3	5.0	+	+
B78	32.4	29.3	1.3	6.5	41.1	43.7	6.7	5.8	+	+
C73	25.4	29.3	1.0	3.7	29.6	28.6	4.0	3.8	+	-
A73	19.8	21.6	3.1	3.7	22.9	26.1	3.8	4.0	-	-
E78	18.1	20.8	1.7	3.7	23.2	27.7	3.6	3.8	-	-
FRC80	17.4	19.3	2.3	3.0	28.2	31.5	3.2	3.6	-	-
E80	23.8	25.3	5.2	4.7	26.0	25.6	3.5	3.5	-	-
E75	49.3	52.3	6.1	8.3	42.3	40.2	3.5	2.9	-	-
D78	40.3	41.1	1.7	2.7	32.1	36.2	3.4	3.3	-	-
D73	31.6	35.2	0.9	1.8	32.5	34.7	3.7	3.5	+	-
F78	30.6	34.6	9.4	12.9	28.0	33.3	3.3	3.3	-	-
K80	23.1	27.8	11.6	13.4	22.0	24.7	3.0	2.9	-	-
L71	62.0	86.2	5.5	4.5	35.4	44.4	8.8	6.9	+	+
E74	84.0	85.7	1.8	3.8	41.9	50.0	7.2	7.0	+	+
D74	84.9	95.1	1.2	1.9	67.9	63.6	7.6	7.4	+	+
J73	89.3	95.8	0.1	2.6	56.0	64.6	7.7	7.3	-	+
FRC79	54.5	52.7	5.3	9.9	1.0	5.6	7.2	6.8	-	-
D75	61.0	71.1	12.8	10.5	9.4	18.0	2.9	3.0	+	+
A80	38.0	38.1	15.5	17.0	19.2	21.5	3.4	3.3	+	+
H73	71.3	71.8	5.2	6.3	61.9	68.3	7.6	7.2	+	+
G73	37.2	33.5	7.9	8.8	64.7	59.1	6.8	6.3	+	+
MBA34	69.8	74.5	1.6	2.3	3.8	4.4	4.0	3.3	-	+
MBAE2	36.7	54.7	4.6	8.7	17.1	17.4	4.1	3.9	-	-
MBA32	51.0	53.2	2.6	5.7	6.7	18.9	4.5	4.4	-	-
G78	32.7	40.5	16.4	24.3	42.0	44.3	2.9	2.8	-	-
MBA35	58.3	55.9	16.8	20.7	27.0	46.7	2.9	2.7	-	-
L80	48.2	47.7	25.0	29.3	48.3	45.3	2.2	2.2	-	-
DB1	35.7	48.9	22.1	32.6	54.4	56.6	2.5	2.5	-	-

*: + = anticlockwise ; - = clockwise

TABLE II (iii) S2 TIDAL CURRENTS

STATION	a OBS	a CALC	b OBS	b CALC	OBS	CALC	OBS	CALC	ROTATION* OBS	ROTATION* CALC
C78	10.2	10.7	2.4	1.8	27.4	30.2	6.0	5.8	+	+
C80	10.7	10.6	3.1	2.6	32.4	33.1	6.3	5.9	+	+
B78	11.2	11.2	1.4	0.7	33.3	34.0	7.3	7.2	+	+
C73	11.8	12.3	0.5	1.9	33.4	29.0	5.5	5.2	-	-
A73	10.2	10.6	0.9	2.0	21.9	26.0	5.3	5.3	-	-
E78	9.0	10.4	0.2	1.9	22.2	26.9	5.1	5.3	-	-
FRC80	9.1	9.3	1.0	1.2	28.9	29.6	5.1	5.2	-	-
E80	10.8	11.0	2.1	2.0	25.6	23.8	5.4	5.2	-	-
E75	20.2	20.5	2.9	3.8	42.9	37.3	5.0	4.1	-	-
D78	15.3	16.7	0.8	2.9	31.8	38.4	4.9	4.5	-	-
D73	19.2	14.2	7.3	1.8	59.9	34.7	4.2	4.9	-	-
F78	12.5	14.3	3.6	6.4	25.7	33.2	4.8	4.7	-	-
K80	8.6	13.0	4.4	6.8	22.2	31.0	4.6	4.8	-	-
L71	23.2	26.5	1.6	1.7	37.2	43.8	8.4	8.0	-	+
E74	26.3	26.5	0.7	1.6	40.8	49.3	8.5	8.2	+	+
D74	29.8	29.7	1.5	1.1	43.6	62.8	8.9	8.6	-	+
J73	27.5	29.7	0.2	1.1	51.5	64.4	8.9	8.5	+	+
FRC79	17.9	16.3	1.8	3.2	1.6	5.6	8.2	7.6	-	-
D75	21.7	25.2	4.5	3.0	12.2	20.3	4.6	4.6	+	+
A80	15.6	15.0	4.3	4.0	21.2	27.6	5.1	4.8	+	+
H73	23.9	22.4	2.3	2.7	59.7	67.9	8.8	8.4	+	+
G73	12.3	11.5	1.2	3.4	60.4	50.3	7.8	7.1	+	+
MBA34	29.7	31.7	0.1	1.0	3.3	11.3	5.4	5.0	+	-
MBAE2	16.1	23.3	1.9	3.3	15.0	16.4	5.5	5.4	-	-
MBA32	23.1	23.6	0.5	2.1	8.3	19.4	5.9	5.8	+	-
G78	12.7	15.2	6.2	9.7	39.9	43.4	4.4	4.2	-	-
MBA35	23.7	21.5	6.1	7.9	26.0	43.1	4.5	4.2	-	-
L80	18.2	17.8	9.1	12.4	45.6	42.3	3.8	3.8	-	-
DB1	12.9	17.1	8.0	11.9	52.9	59.5	4.1	3.9	-	-

* : + = anticlockwise ; - = clockwise

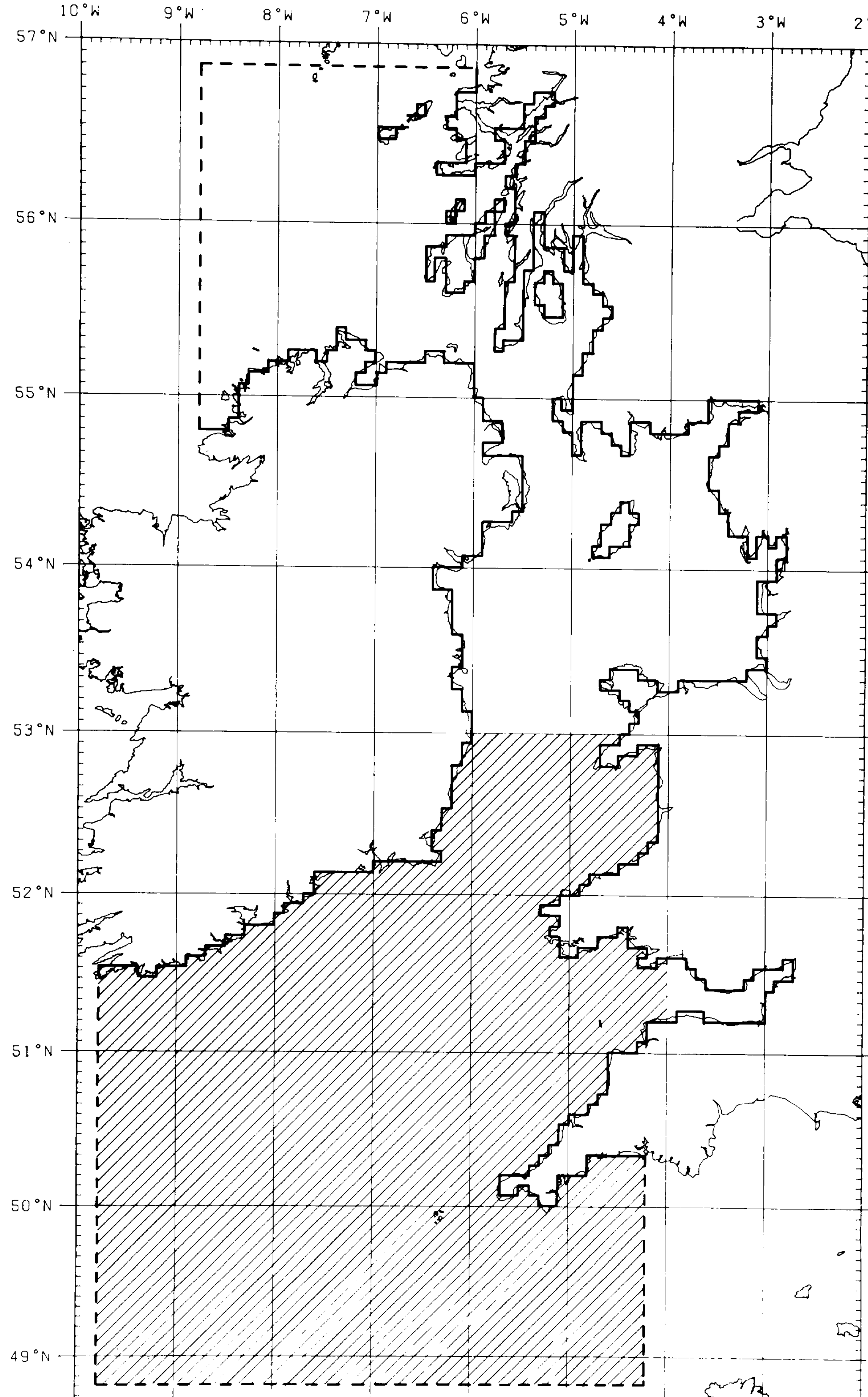


FIGURE 1

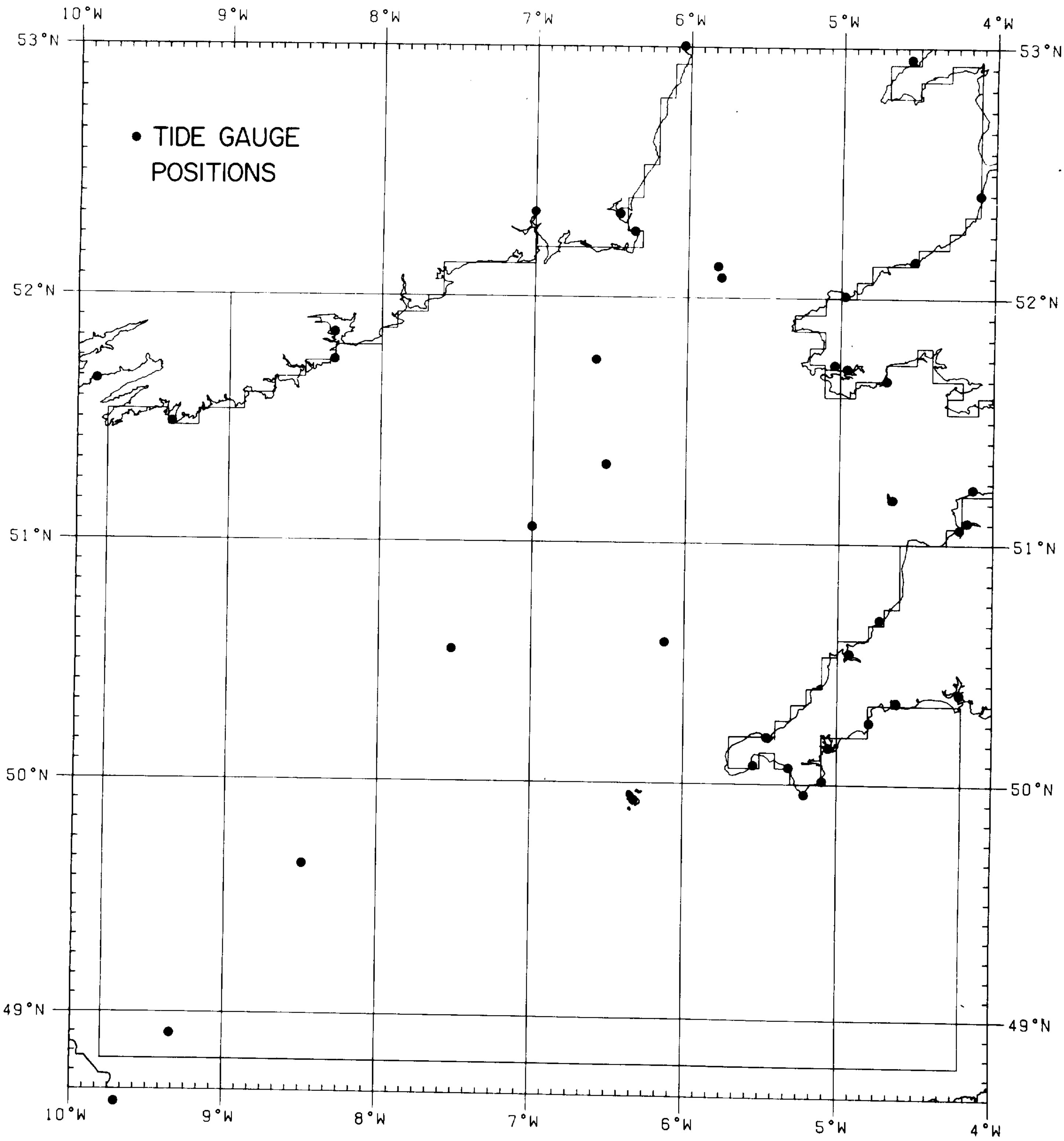
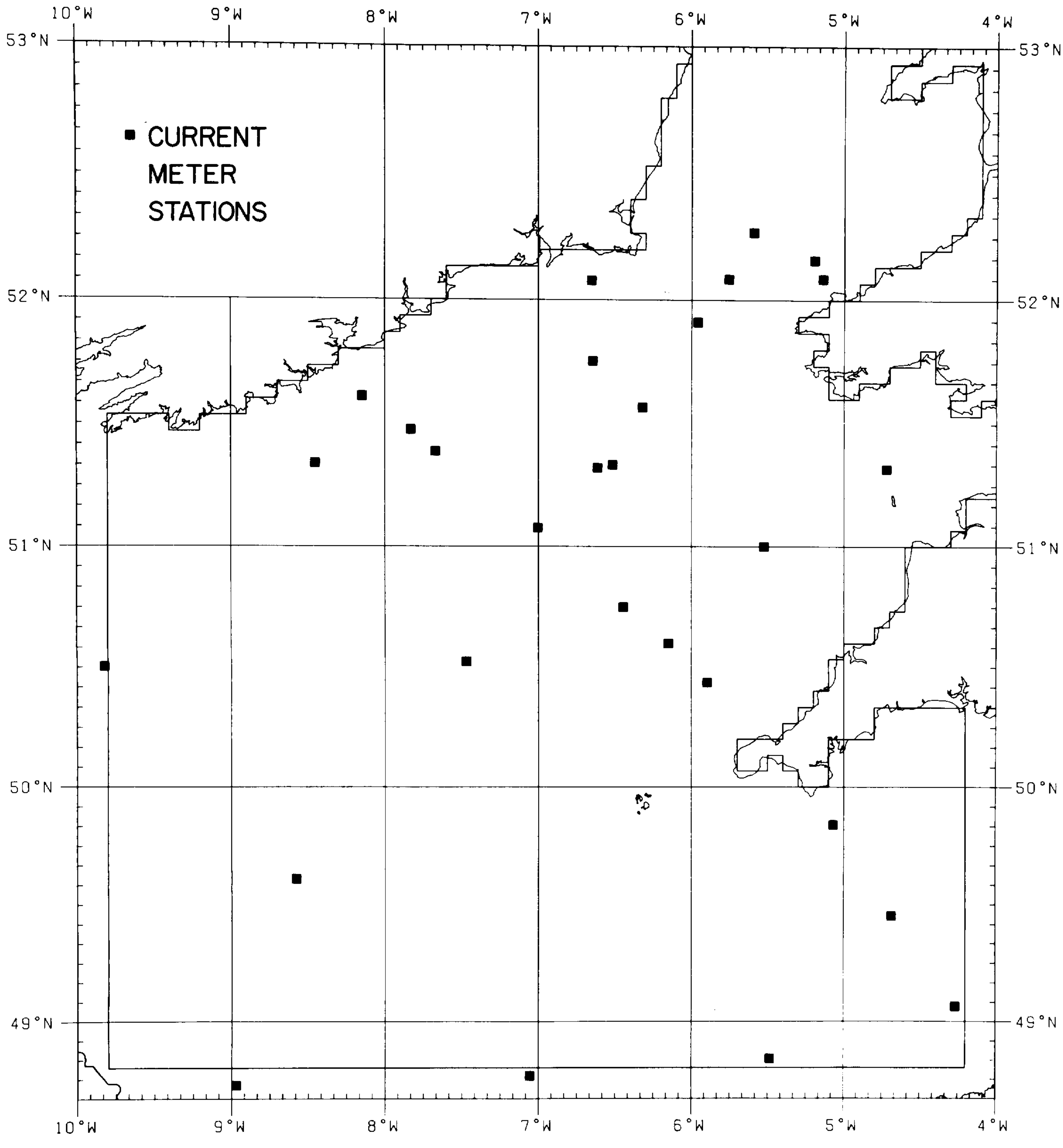
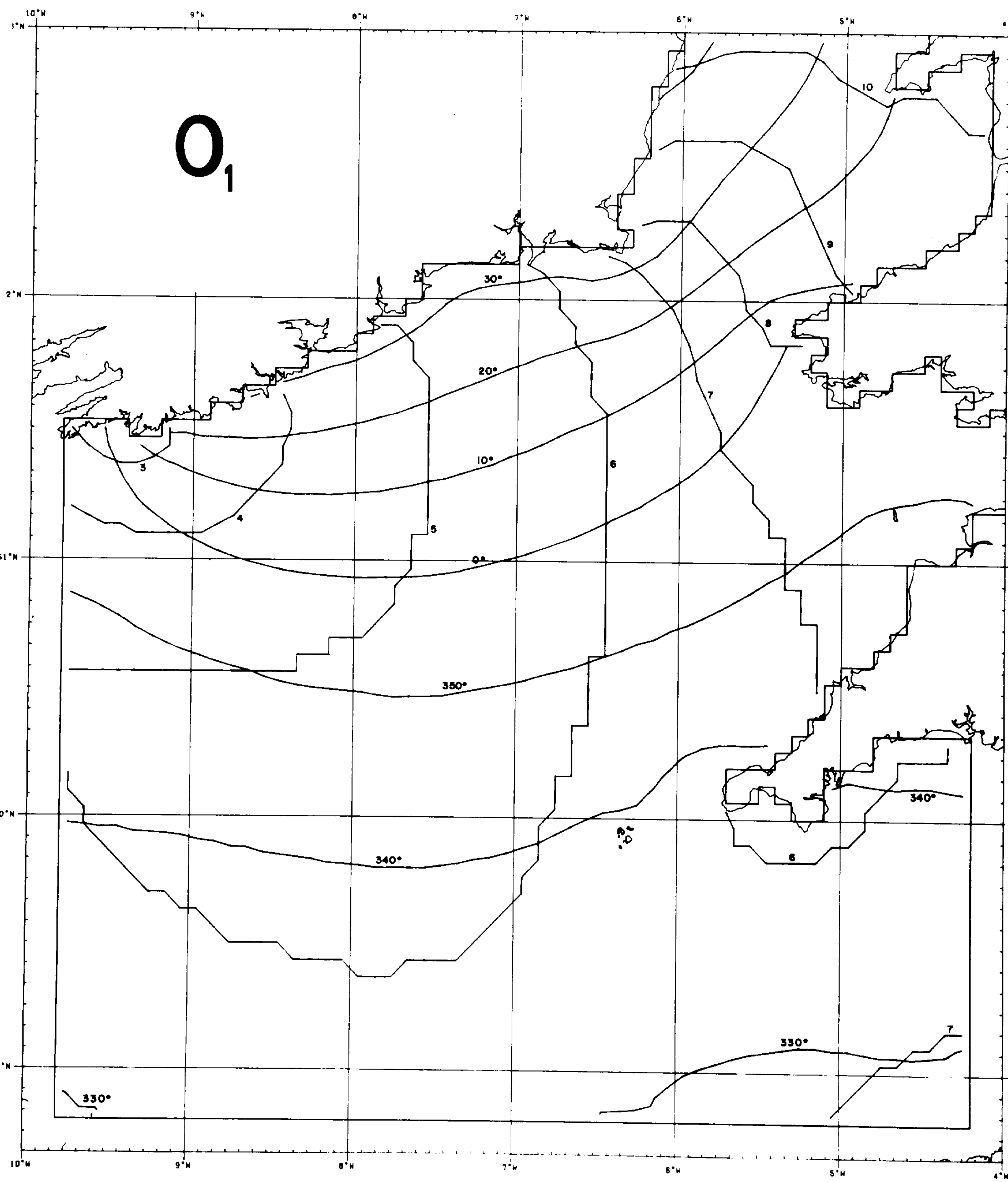


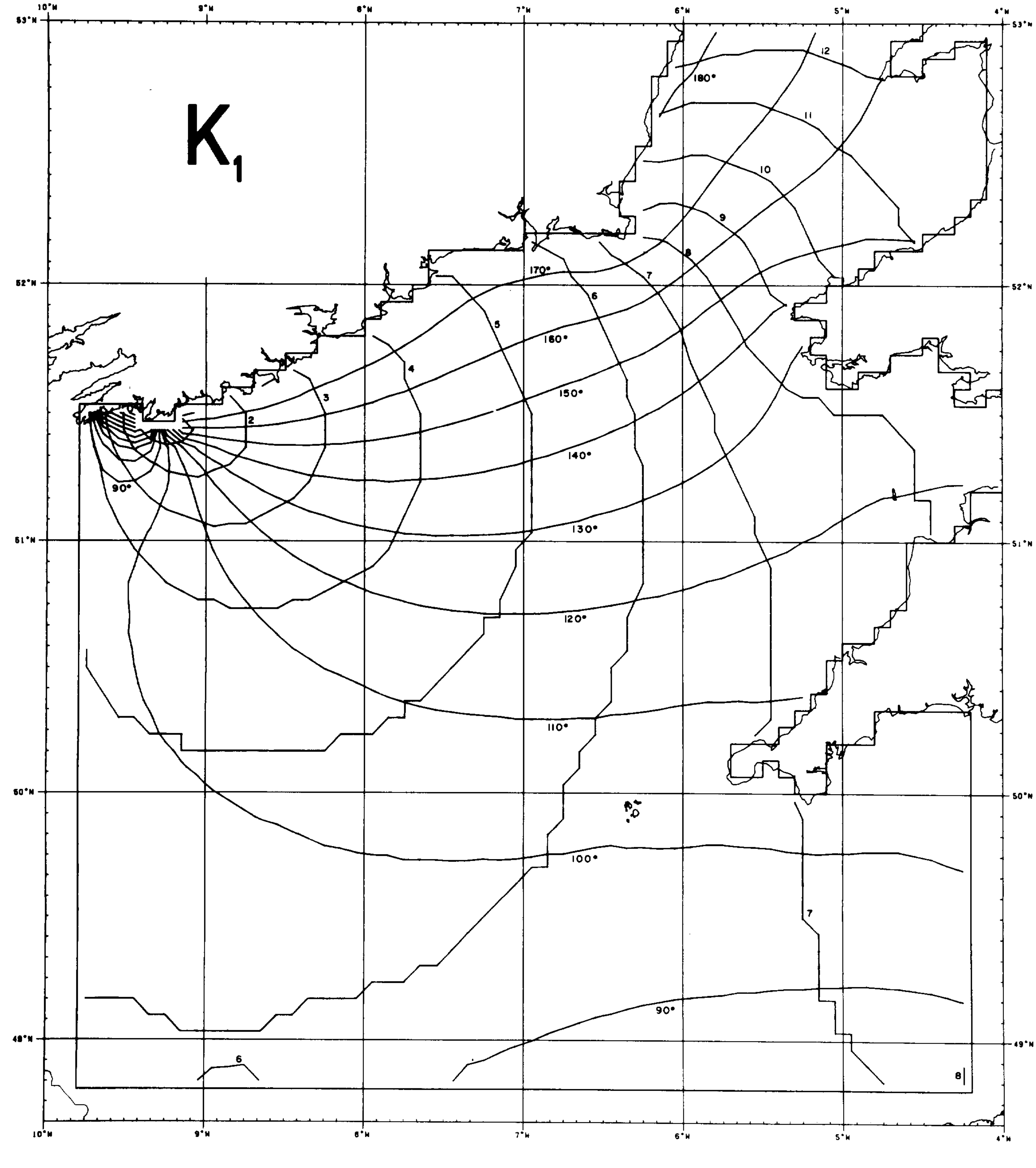
FIGURE 2



CURRENT
METER
STATIONS
10°W
9°W
8°W
7°W
6°W
5°W
4°W
53°N
52°N
51°N
50°N
49°N

FIGURE 3


O1
30°
20°
10°
0°
350°
340°
340°
330°
330°
3
4
5
6
7
8
9
10
6
7
10°W
9°W
8°W
7°W
6°W
5°W
4°W
53°N
52°N
51°N
50°N
49°N


K1
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7°W
6°W
5°W
4°W
53°N
52°N
51°N
50°N
49°N
180°
170°
160°
150°
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110°
100°
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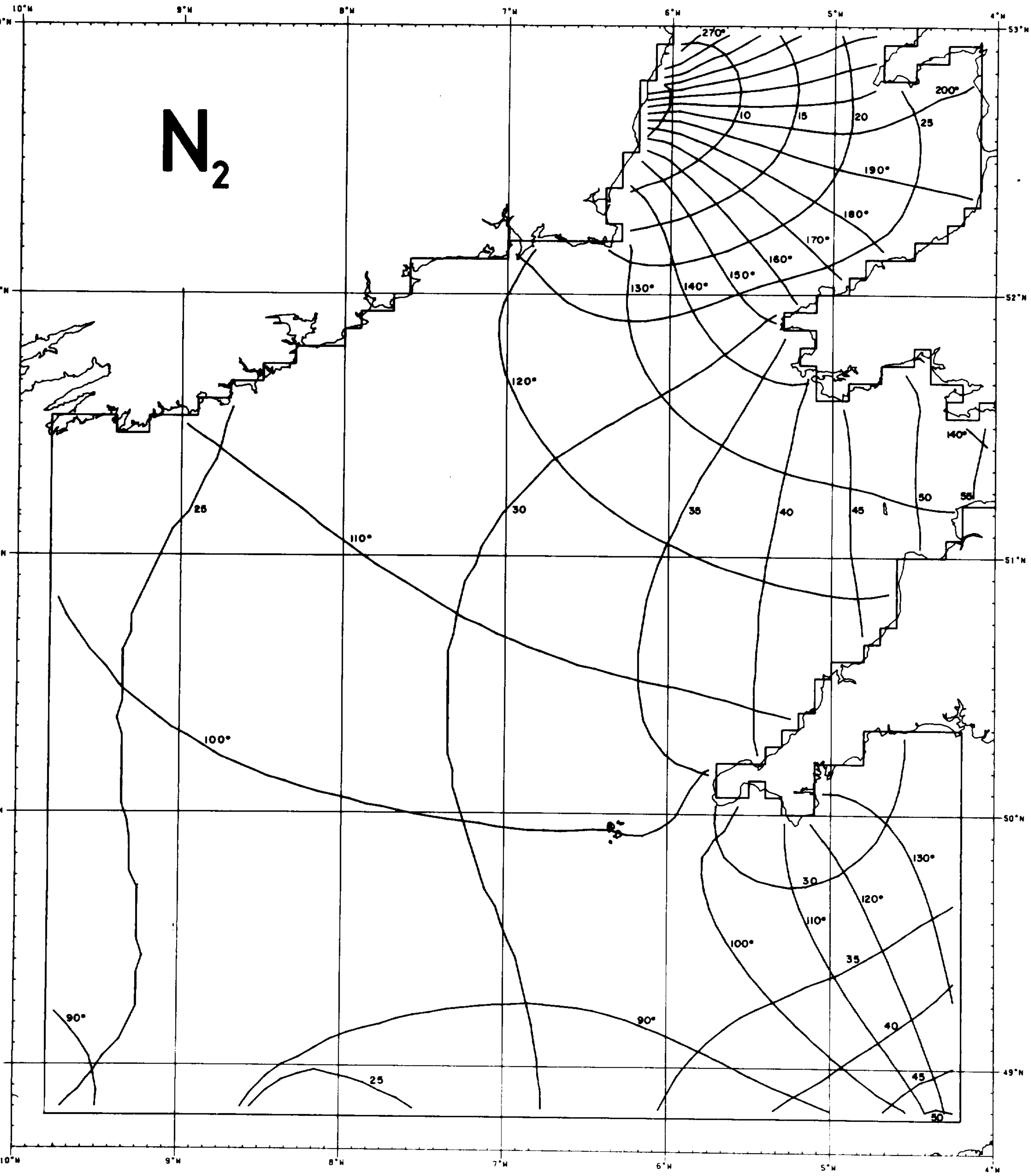
8
9
10
11
12


N2
10°W
9°W
8°W
7°W
6°W
5°W
4°W
53°N
52°N
51°N
50°N
49°N
270°
200°
10
15
20
25
190°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
25
30
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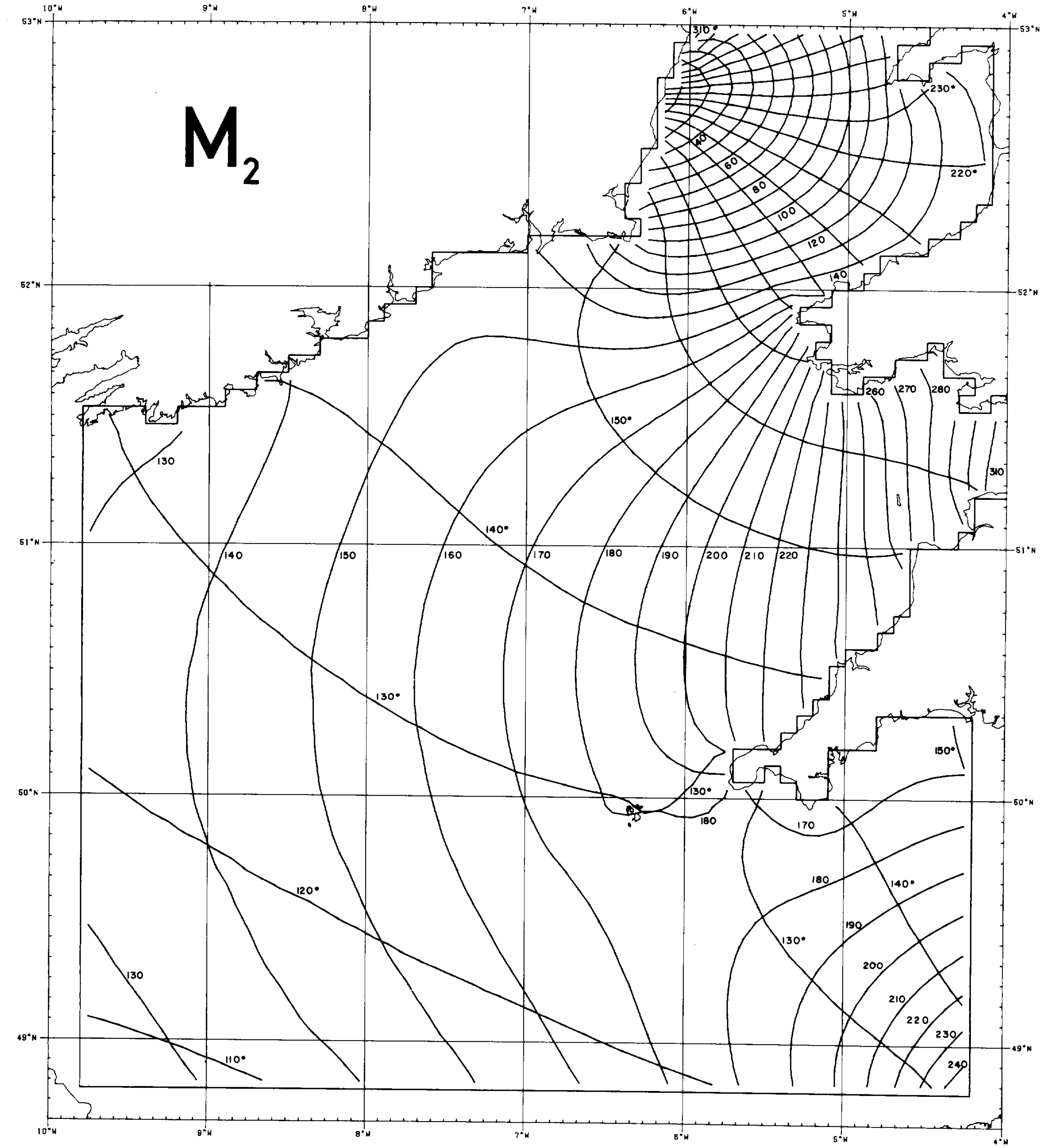
45
50
90°
90°
25


M2
10°W
9°W
8°W
7°W
6°W
5°W
4°W
53°N
52°N
51°N
50°N
49°N
310°
230°
220°
40
60
80
100
120
140
260
270
280
310
150°
130
140°
140
150
160
170
180
190
200
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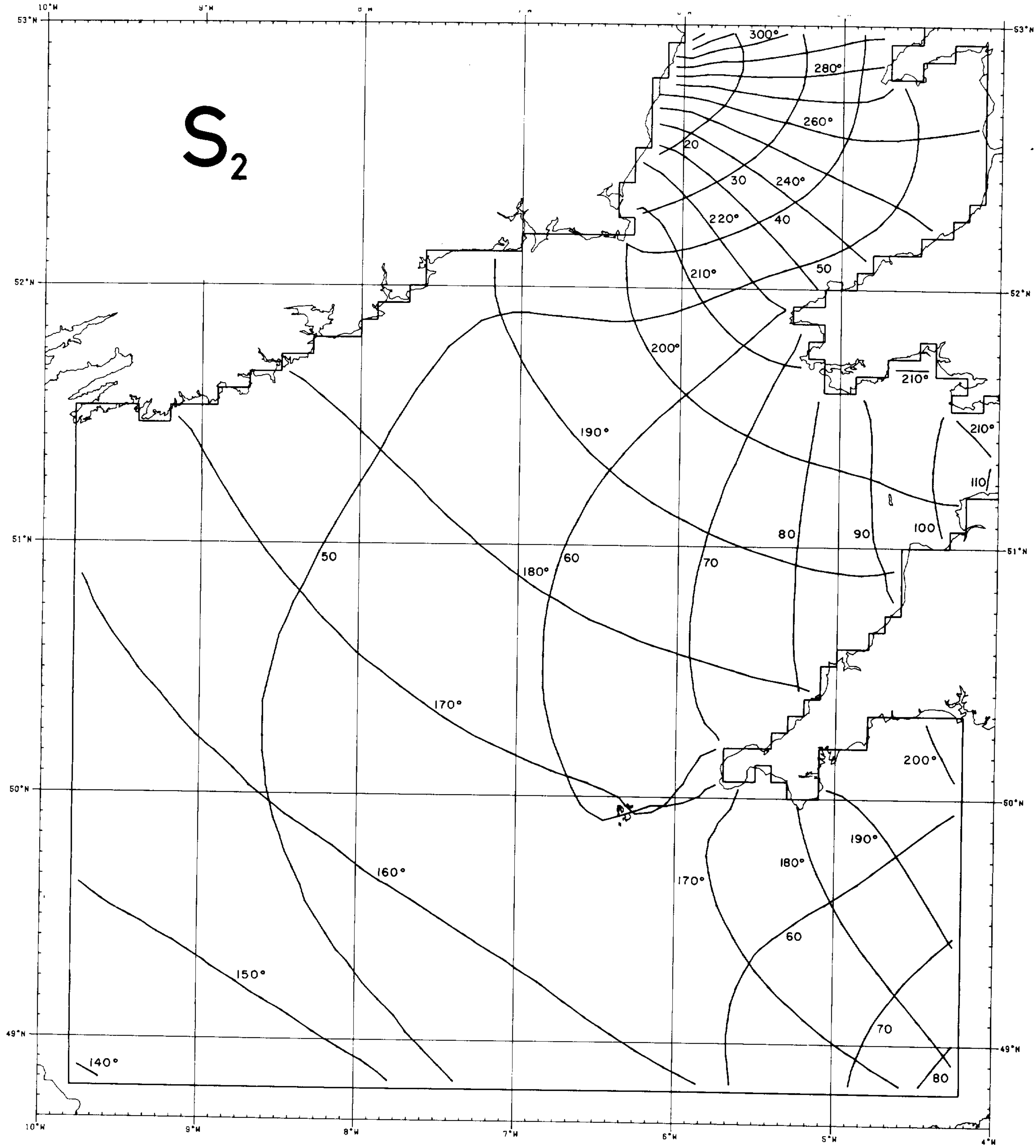
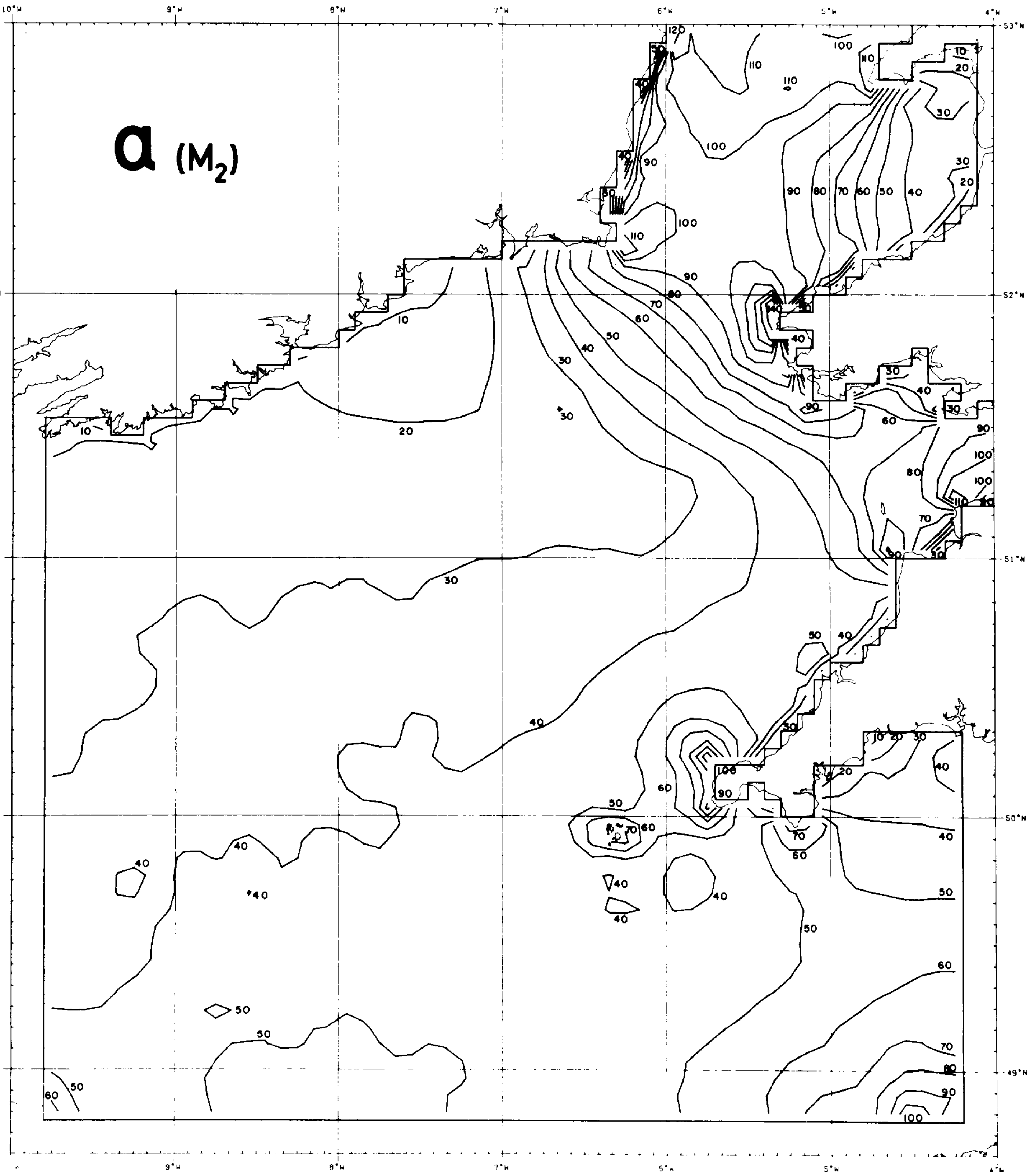
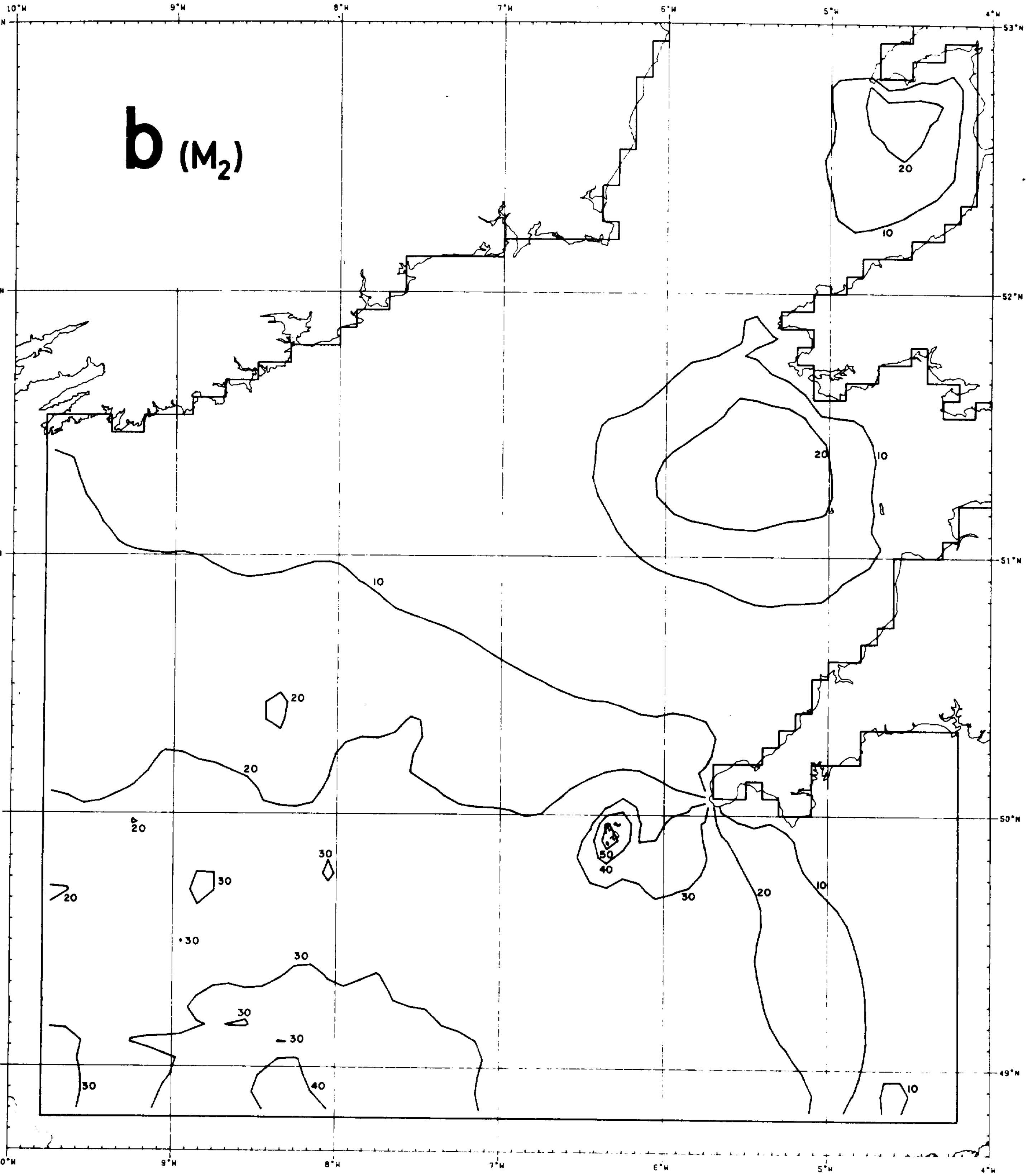
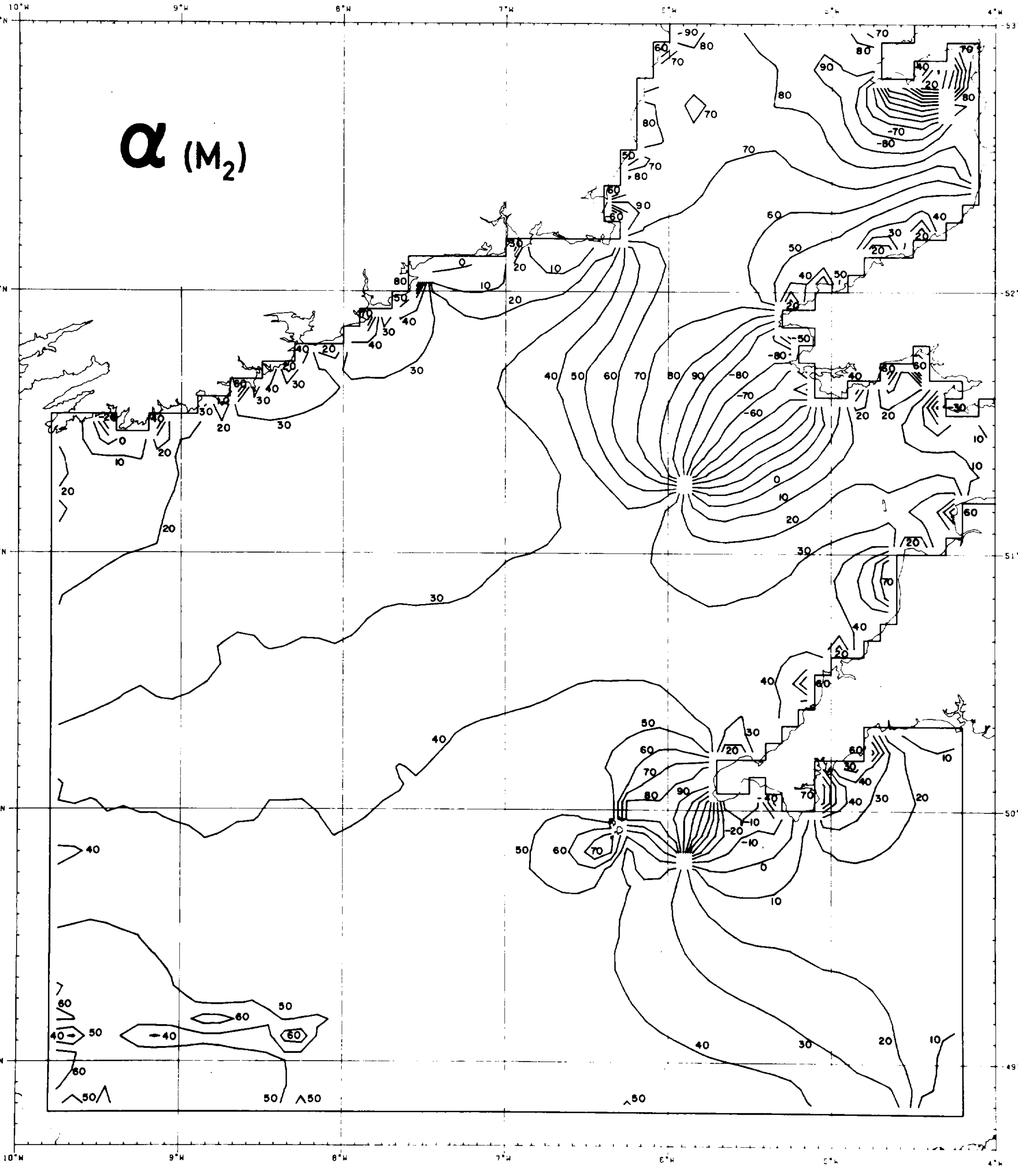
200
210
220
230
240

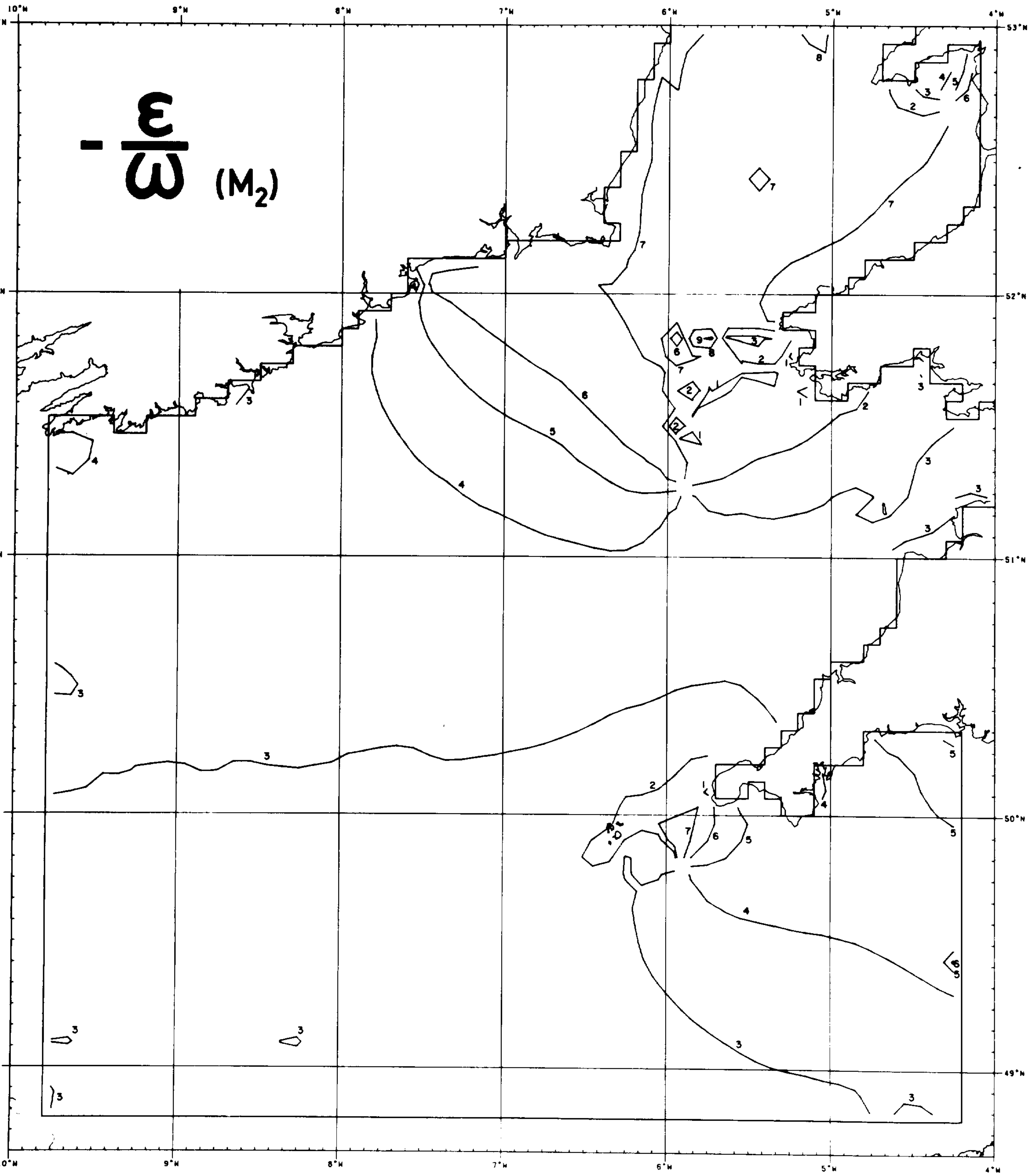


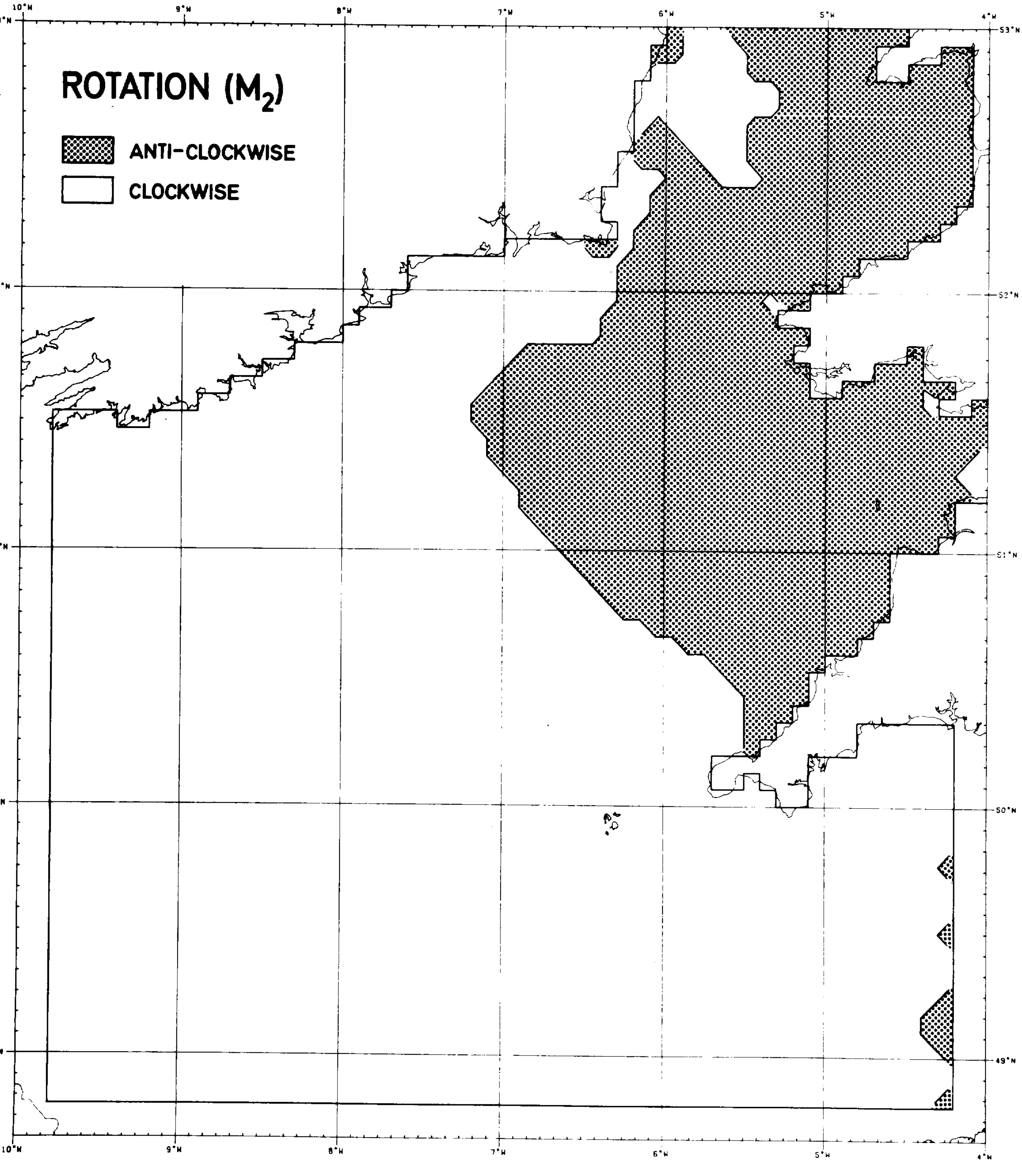
S2
300°
280°
260°
240°
220°
210°
200°
190°
180°
170°
160°
150°
140°
20
30
40
50
60
70
80
90
100
110
210°
200°
190°
180°
170°
60
70
80
53°N
52°N
51°N
50°N
49°N
10°W
9°W
8°W
7°W
6°W
5°W
4°W

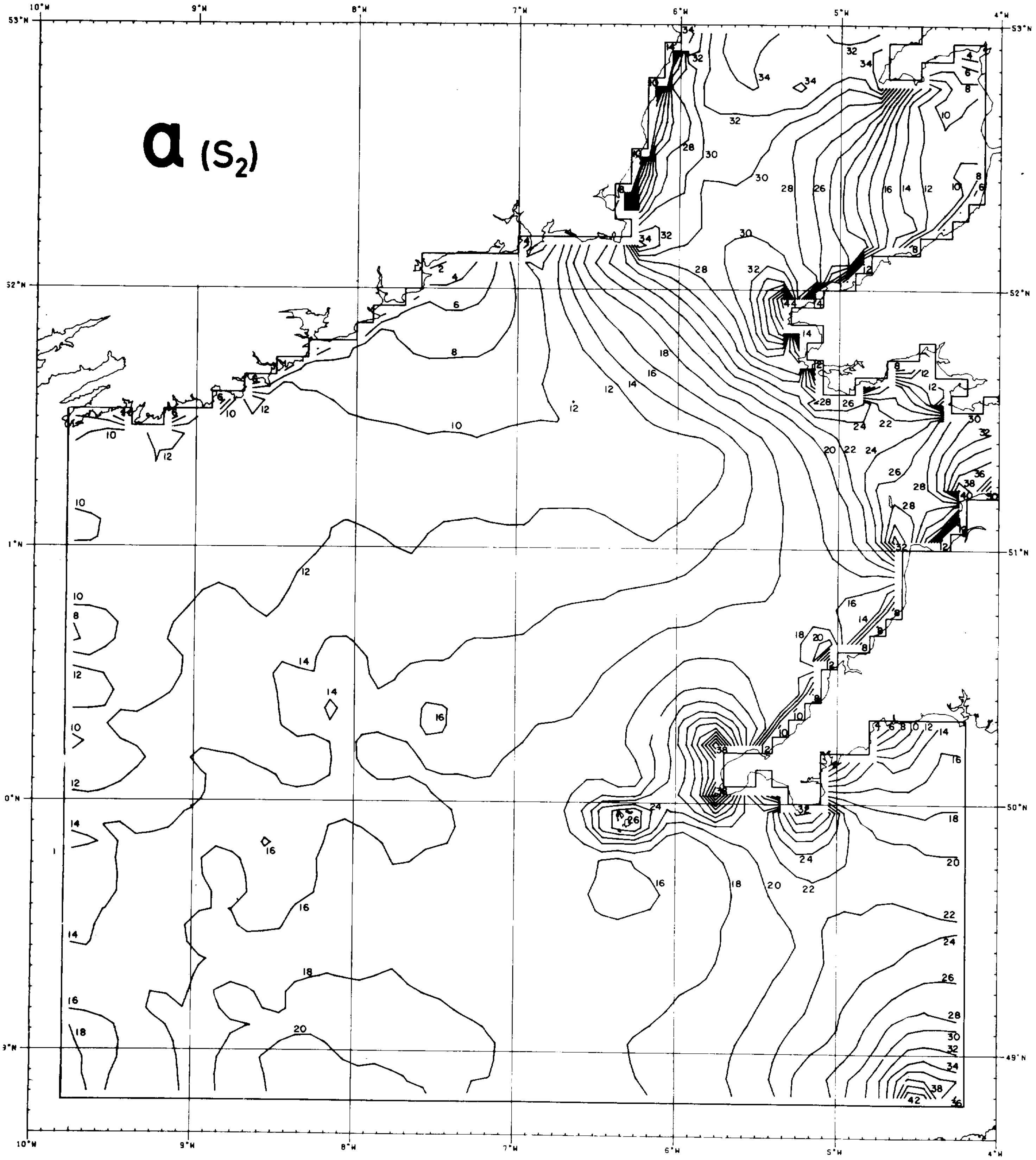

a (M2)
10°W
9°W
8°W
7°W
6°W
5°W
4°W
53°N
52°N
51°N
50°N
49°N

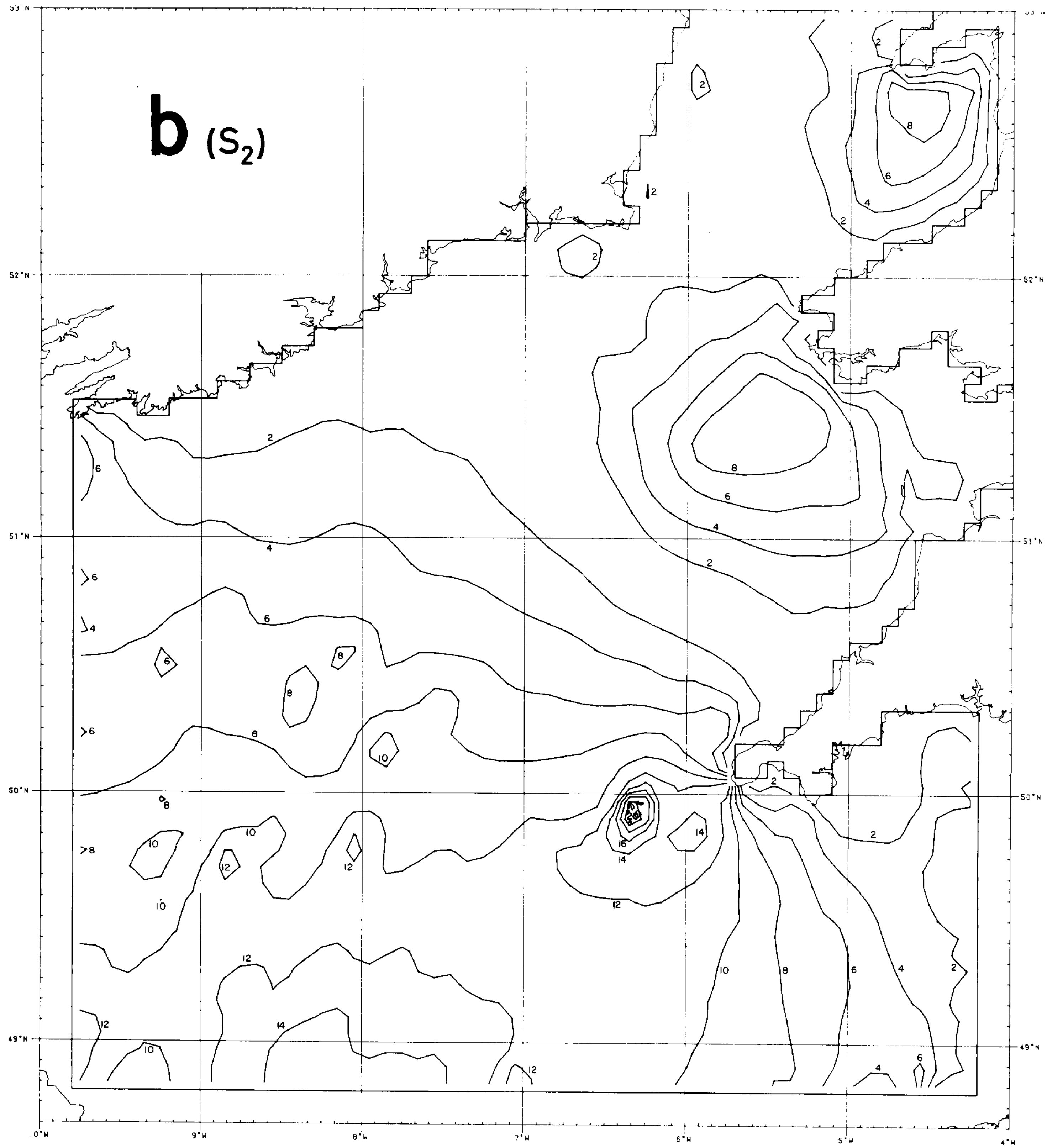

b (M2)
10°W
9°W
8°W
7°W
6°W
5°W
4°W
53°N
52°N
51°N
50°N
49°N
10
20
30
40
50

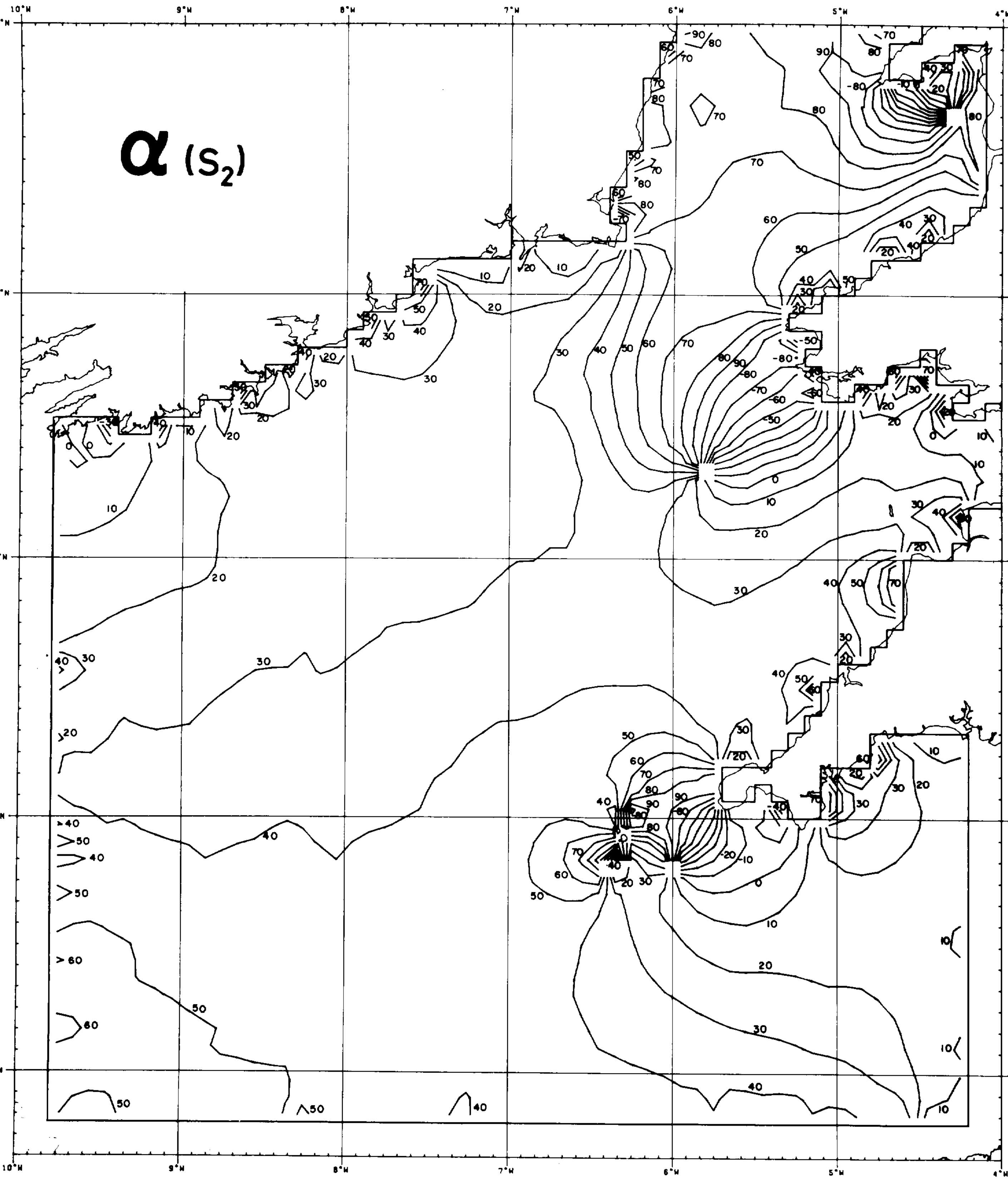

α (M2)
10°W
9°W
8°W
7°W
6°W
5°W
4°W
53°N
52°N
51°N
50°N
49°N

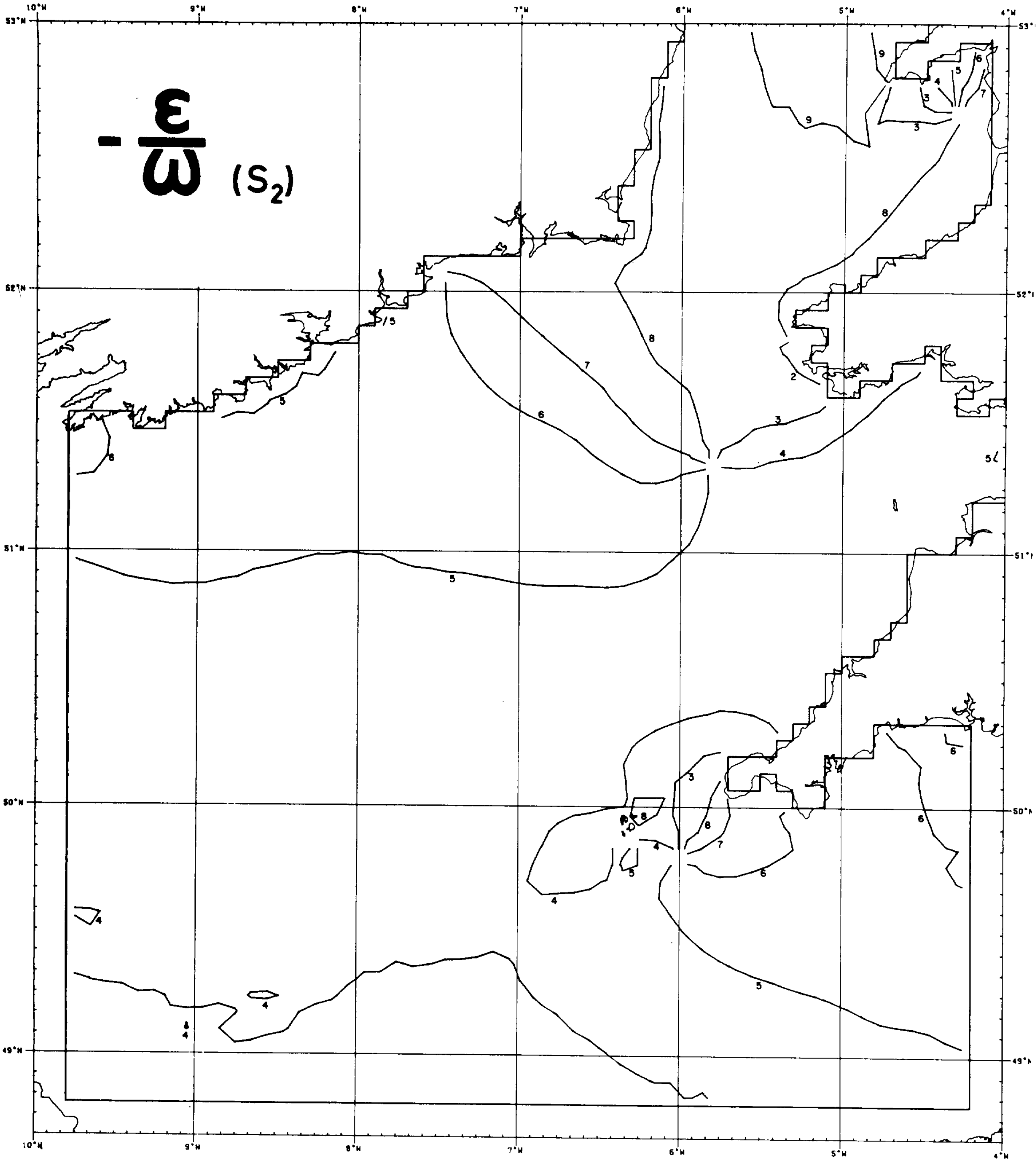

- ε / ω (M2)
10°W
9°W
8°W
7°W
6°W
5°W
4°W
53°N
52°N
51°N
50°N
49°N

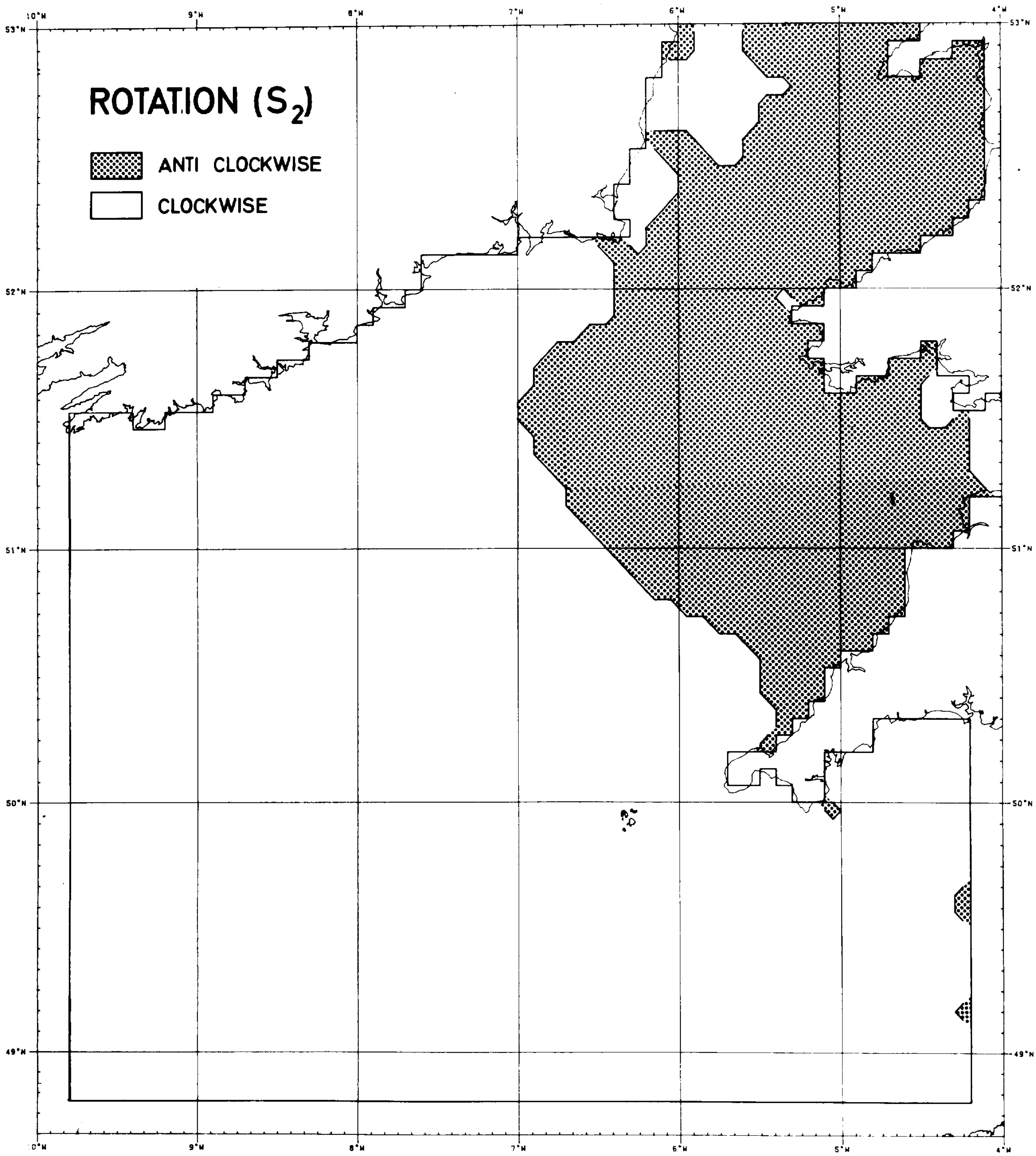

ROTATION (M_2)
ANTI-CLOCKWISE
CLOCKWISE
10°W
9°W
8°W
7°W
6°W
5°W
4°W
53°N
52°N
51°N
50°N
49°N

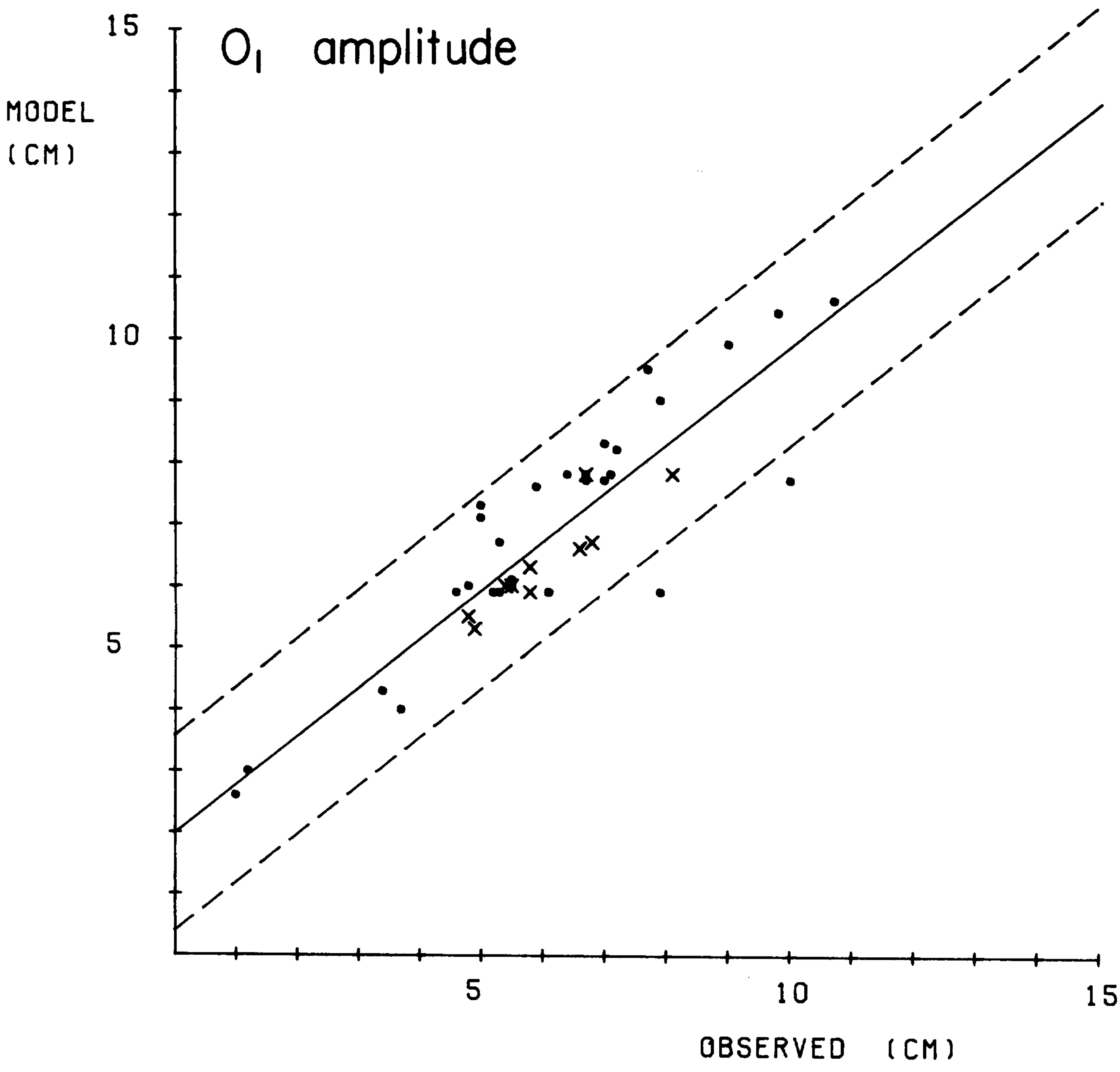

a (S2)
10°W
9°W
8°W
7°W
6°W
5°W
4°W
53°N
52°N
51°N
50°N
49°N


b (S2)
53°N
52°N
51°N
50°N
49°N
10°W
9°W
8°W
7°W
6°W
5°W
4°W

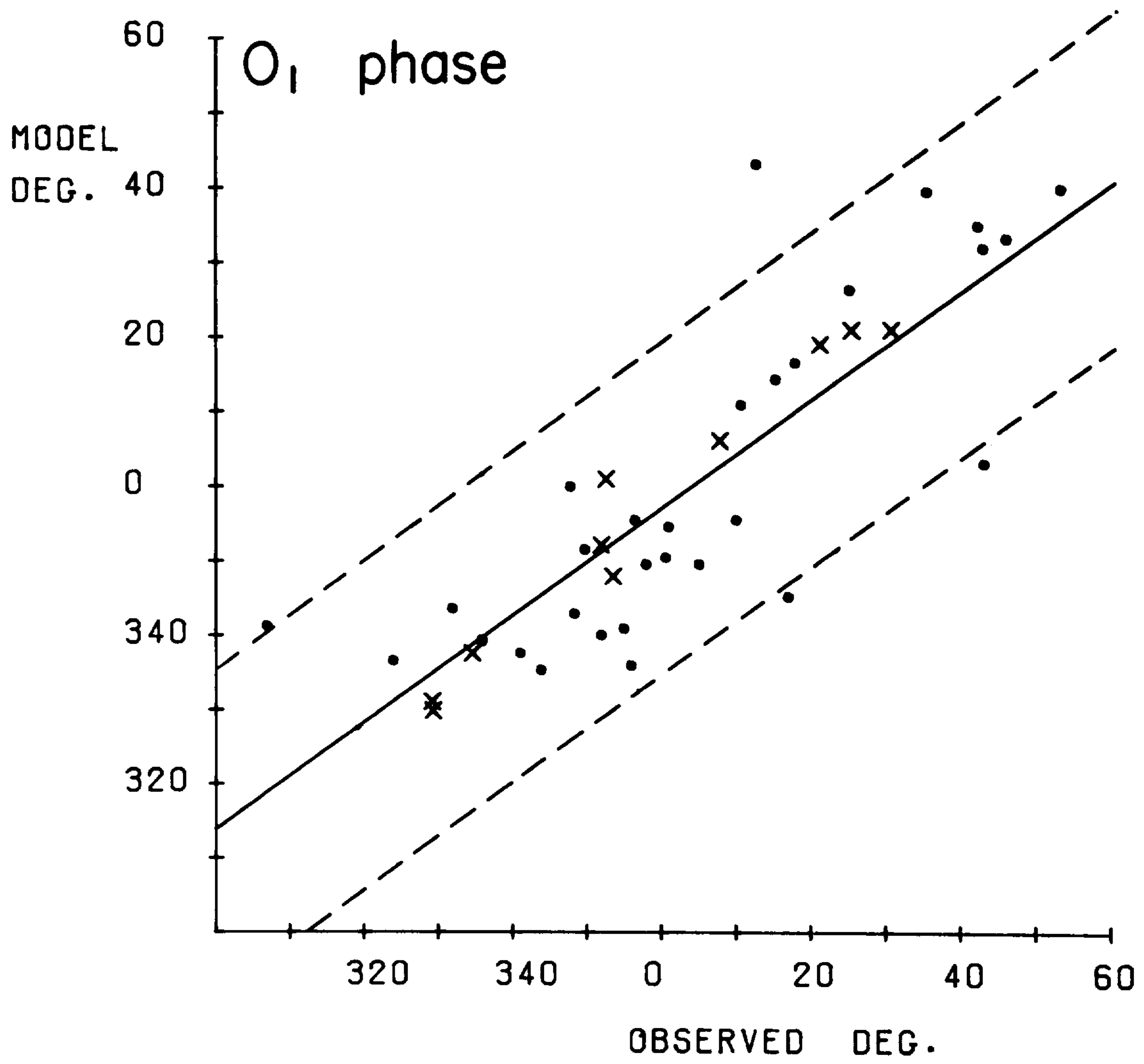

α (S2)
10°W
9°W
8°W
7°W
6°W
5°W
4°W
53°N
52°N
51°N
50°N
49°N


$-\frac{\varepsilon}{\omega}$ (S_2)
10°W
9°W
8°W
7°W
6°W
5°W
4°W
53°N
52°N
51°N
50°N
49°N

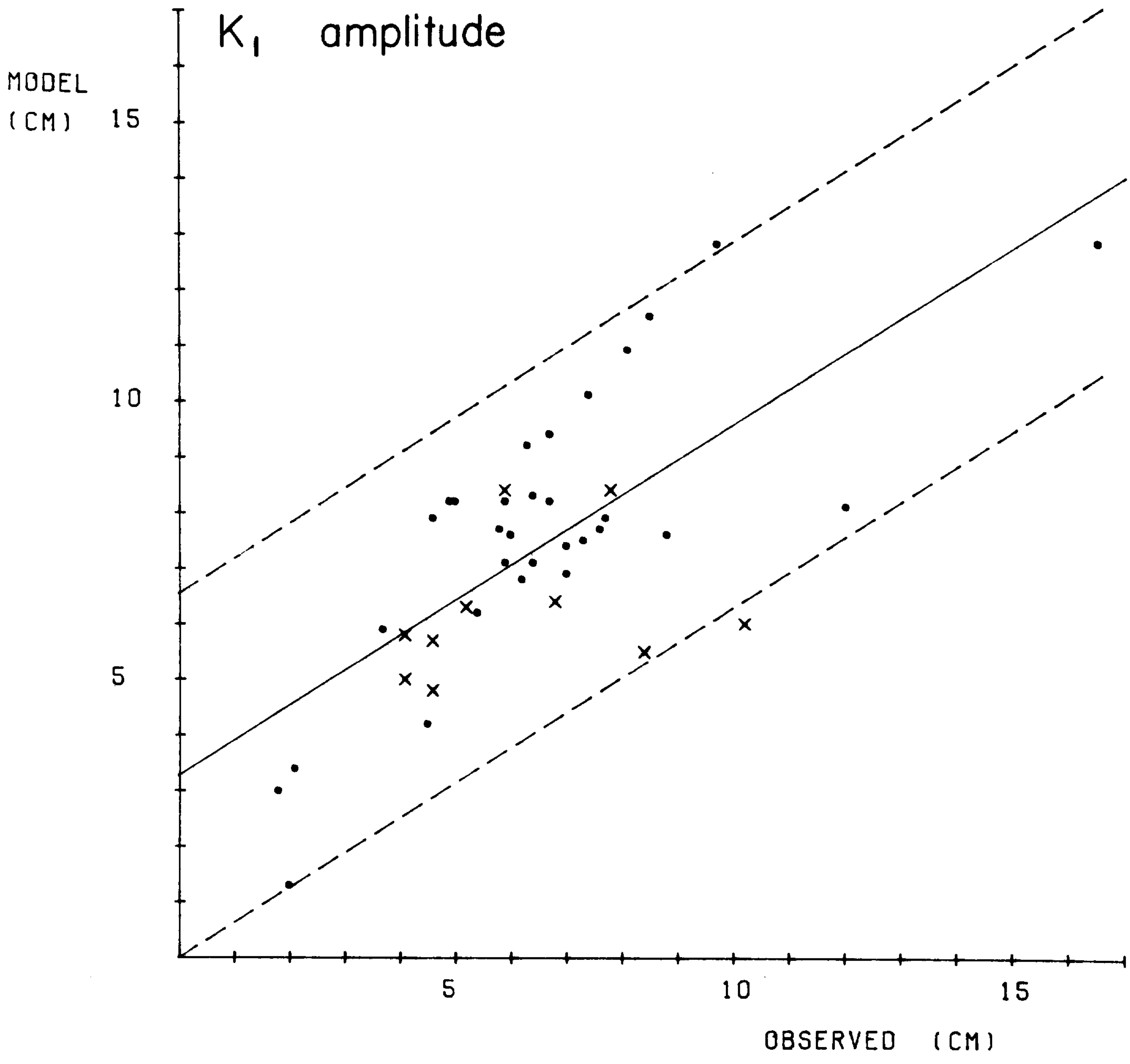

ROTATION (S2)
ANTI CLOCKWISE
CLOCKWISE
10°W
9°W
8°W
7°W
6°W
5°W
4°W
53°N
52°N
51°N
50°N
49°N



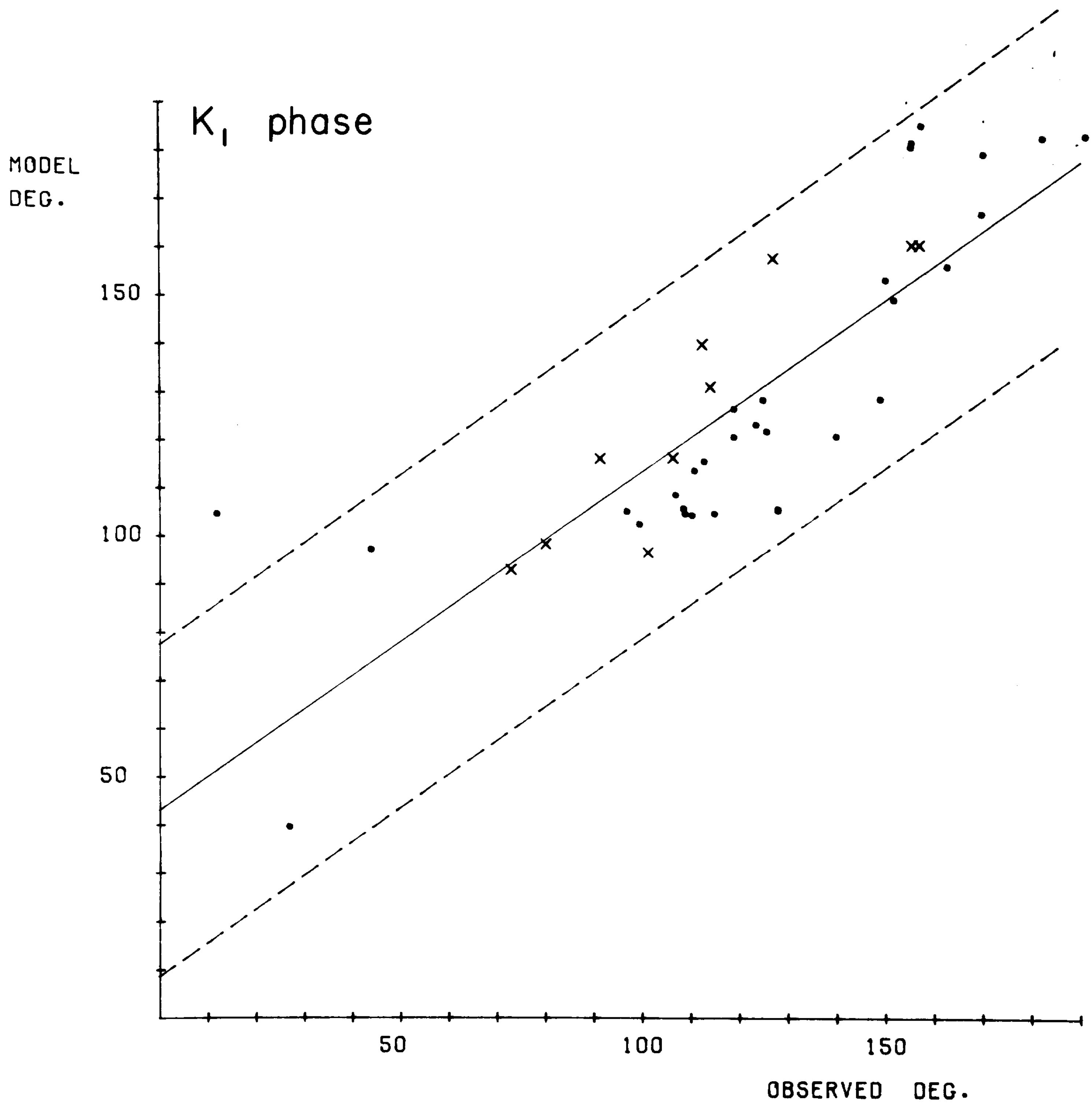
r=0.887; m=0.787; b=1.98



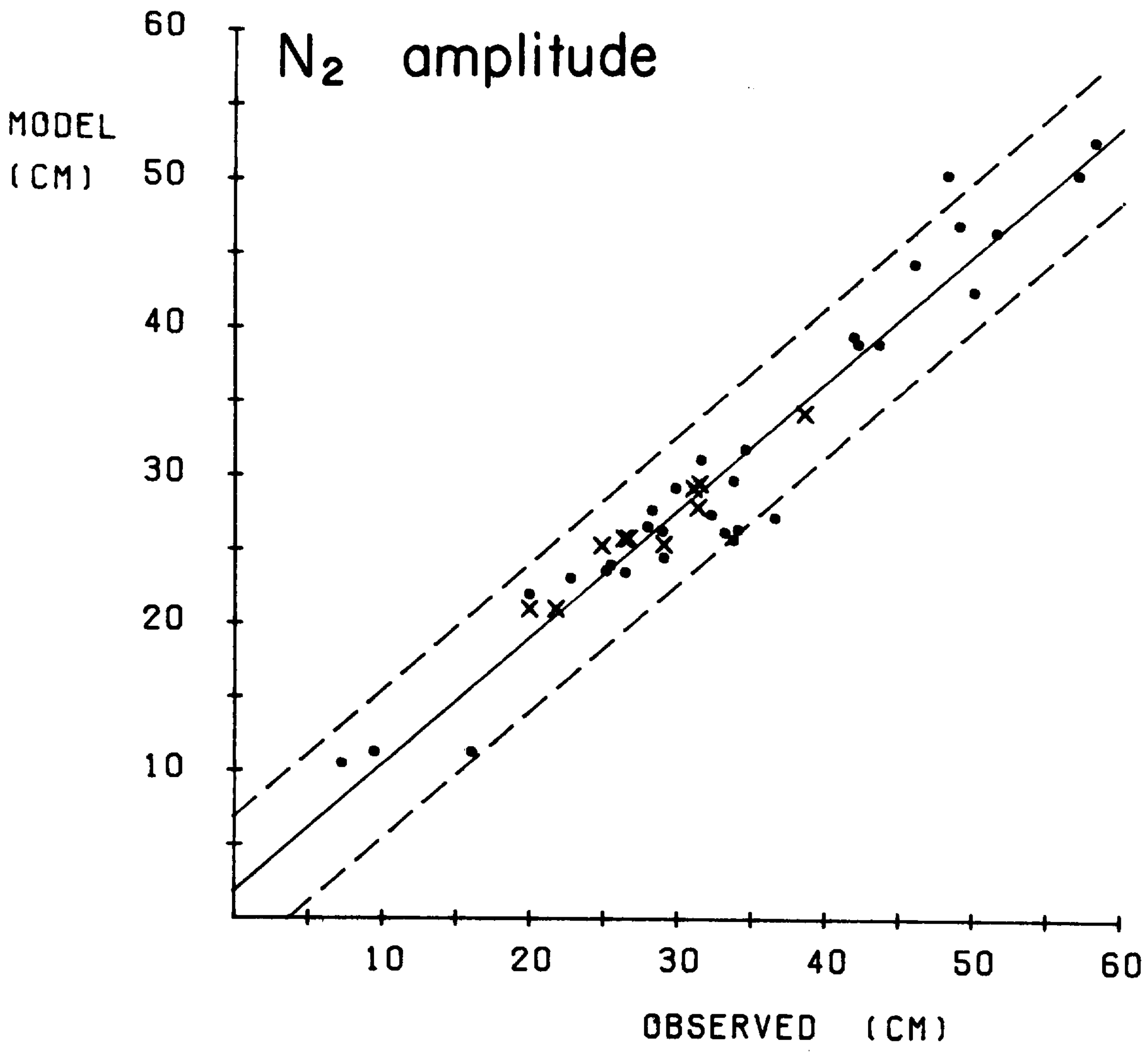
r=0.847: m=0.728: b=-2.79



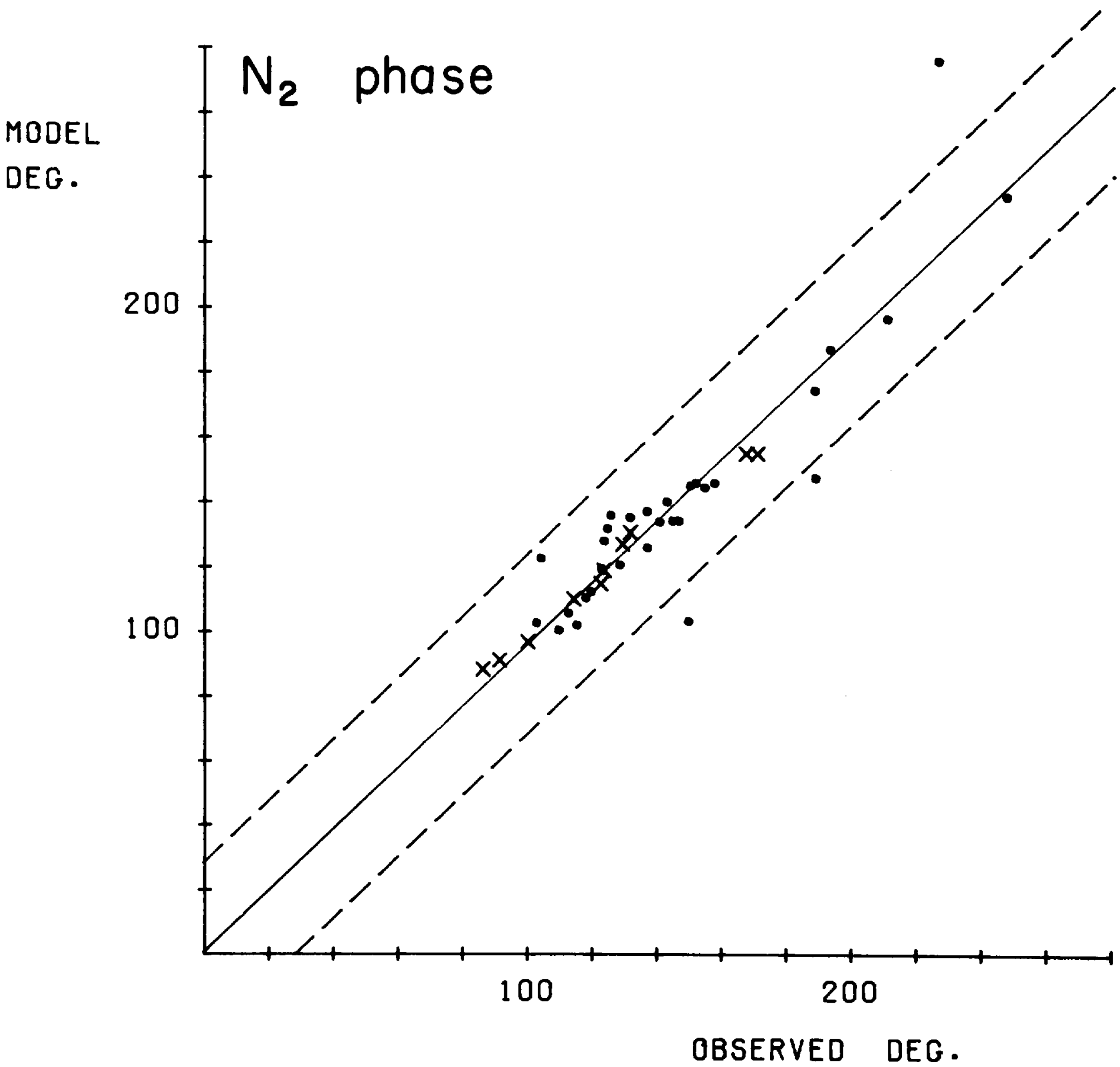
r=0.709; m=0.629: b=3.27



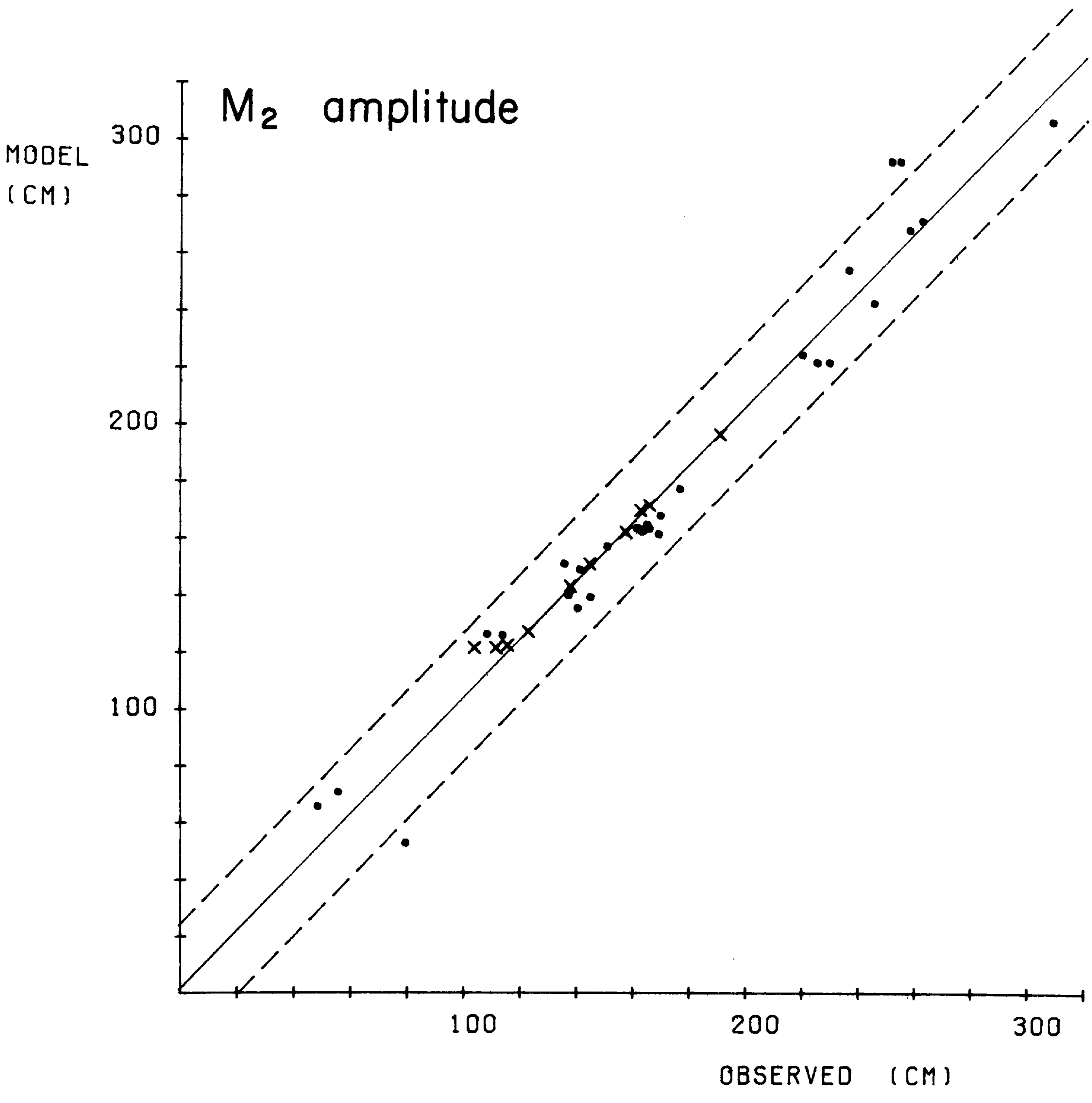
r=0.836; m=0.697; b=43.08



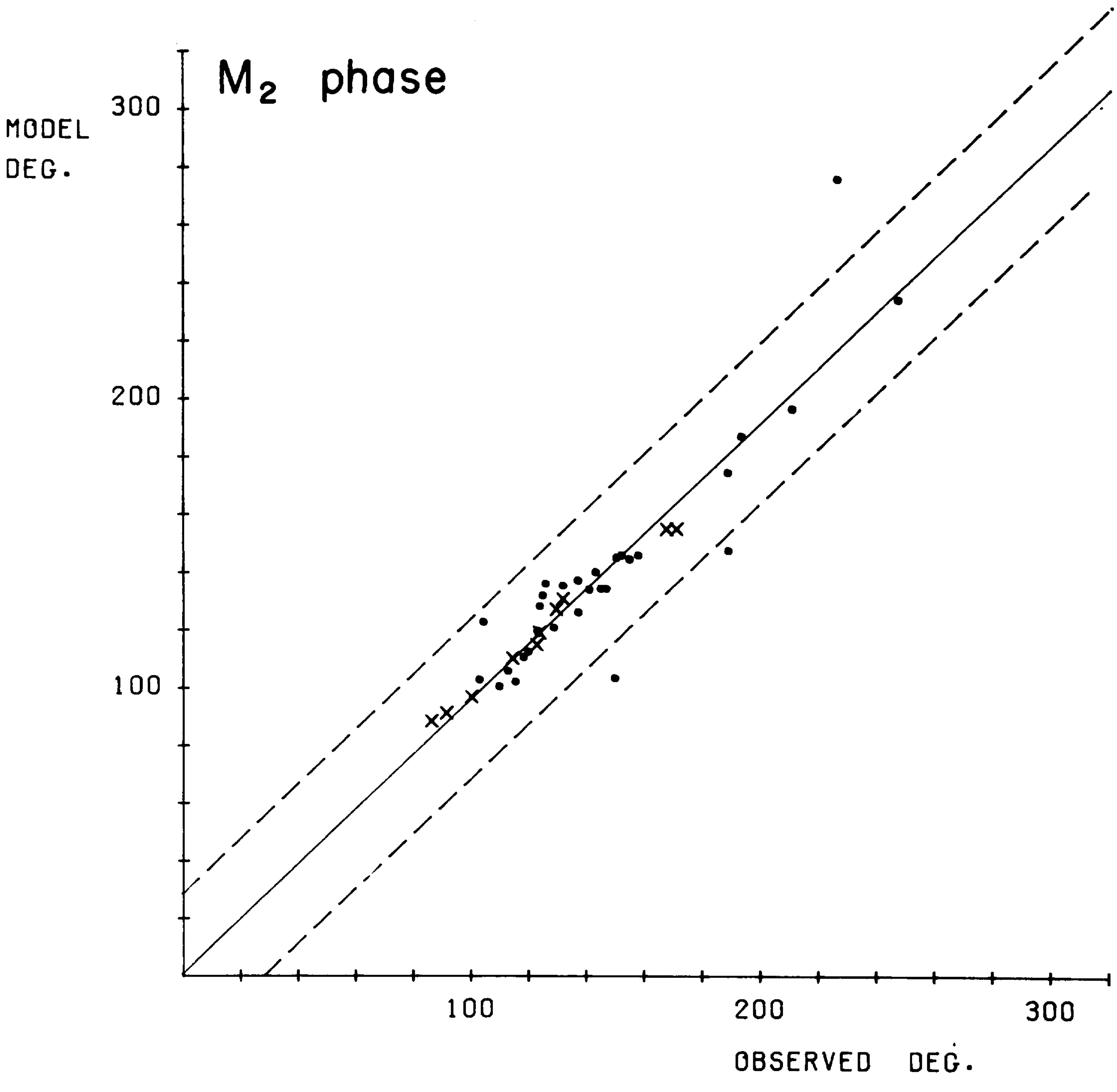
r=0.969; m=0.861; b=1.79



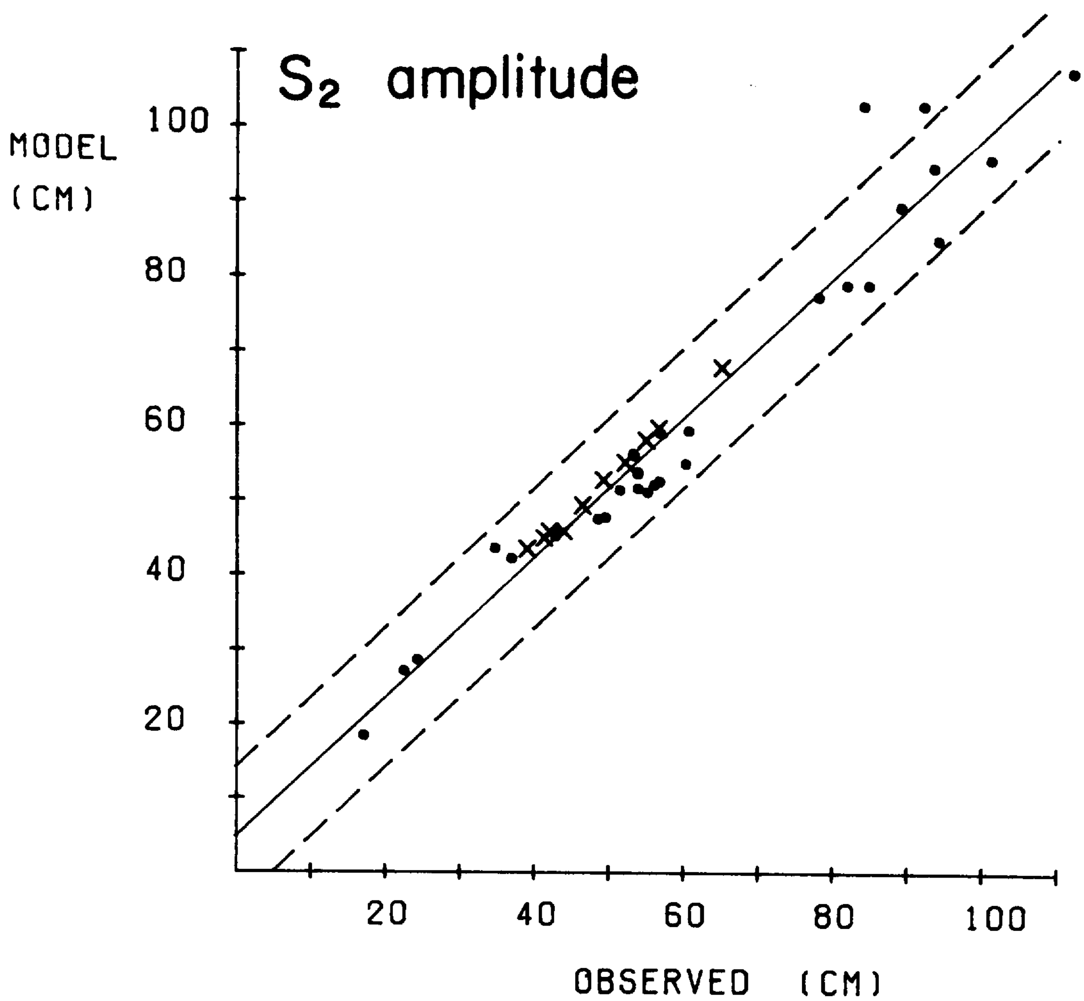
r=0.922; m=0.951; b=0.74



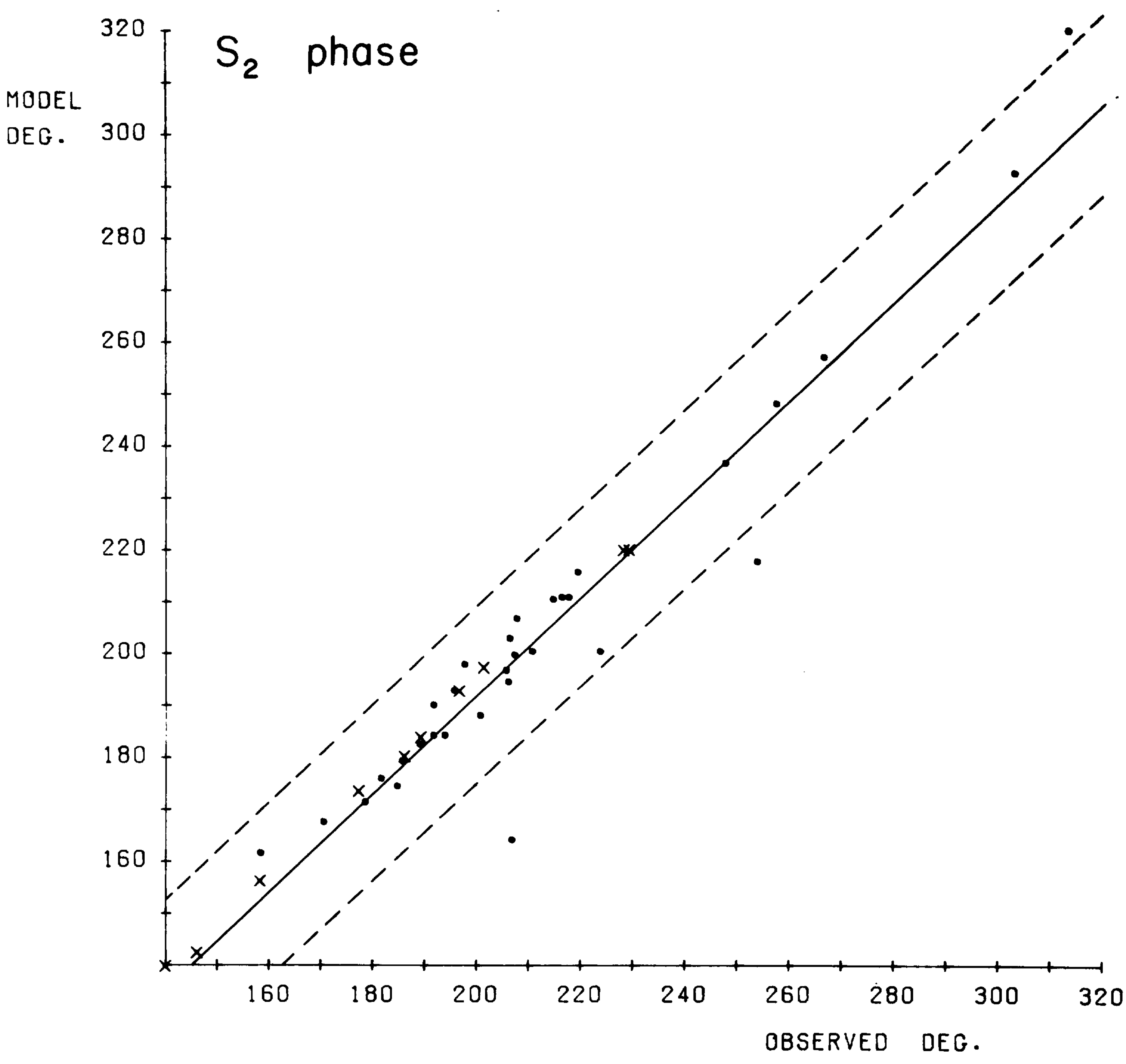
r=0.981: m=1.030: b=1.18



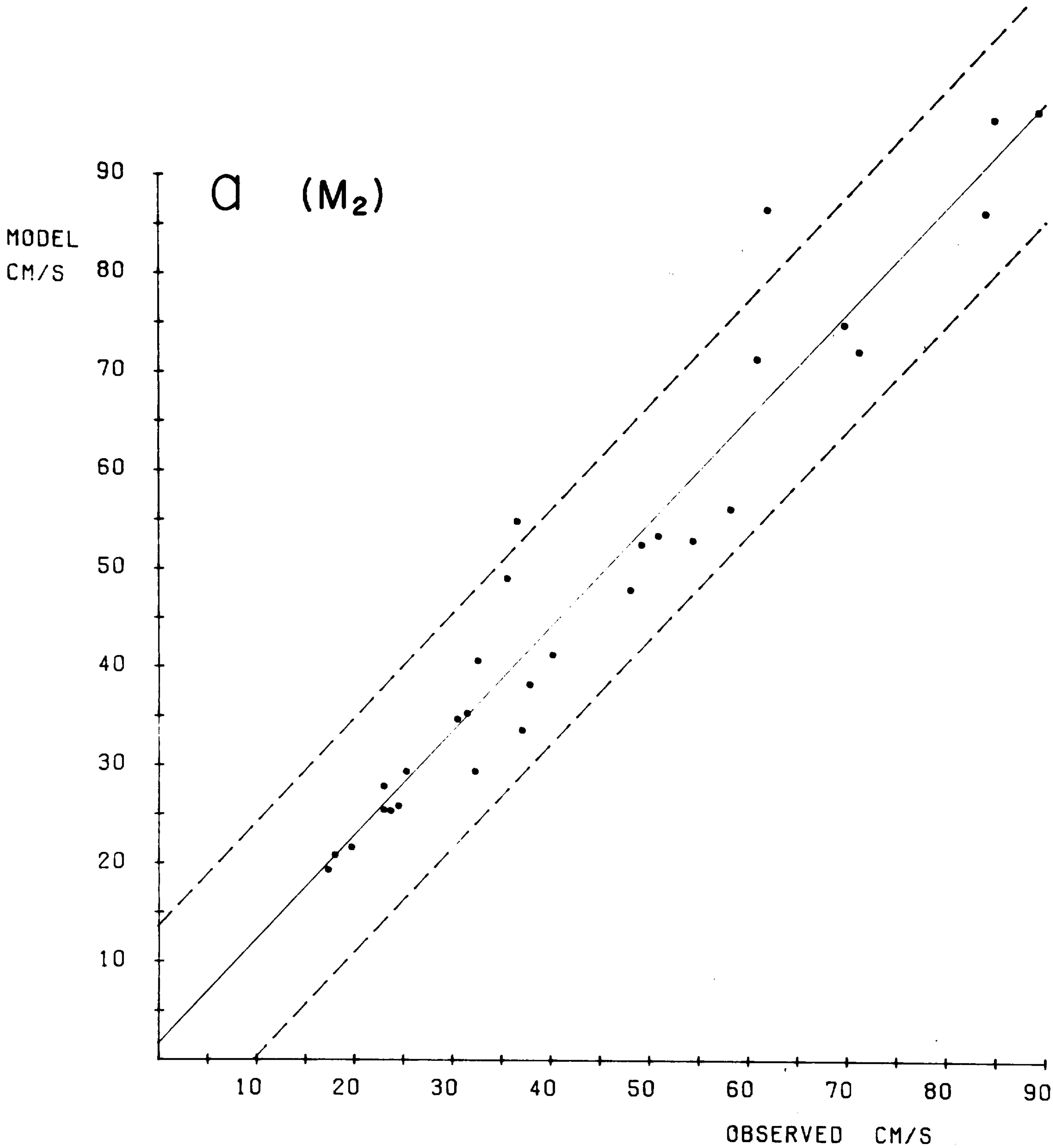
0.953: m=1.019: b=-7.01



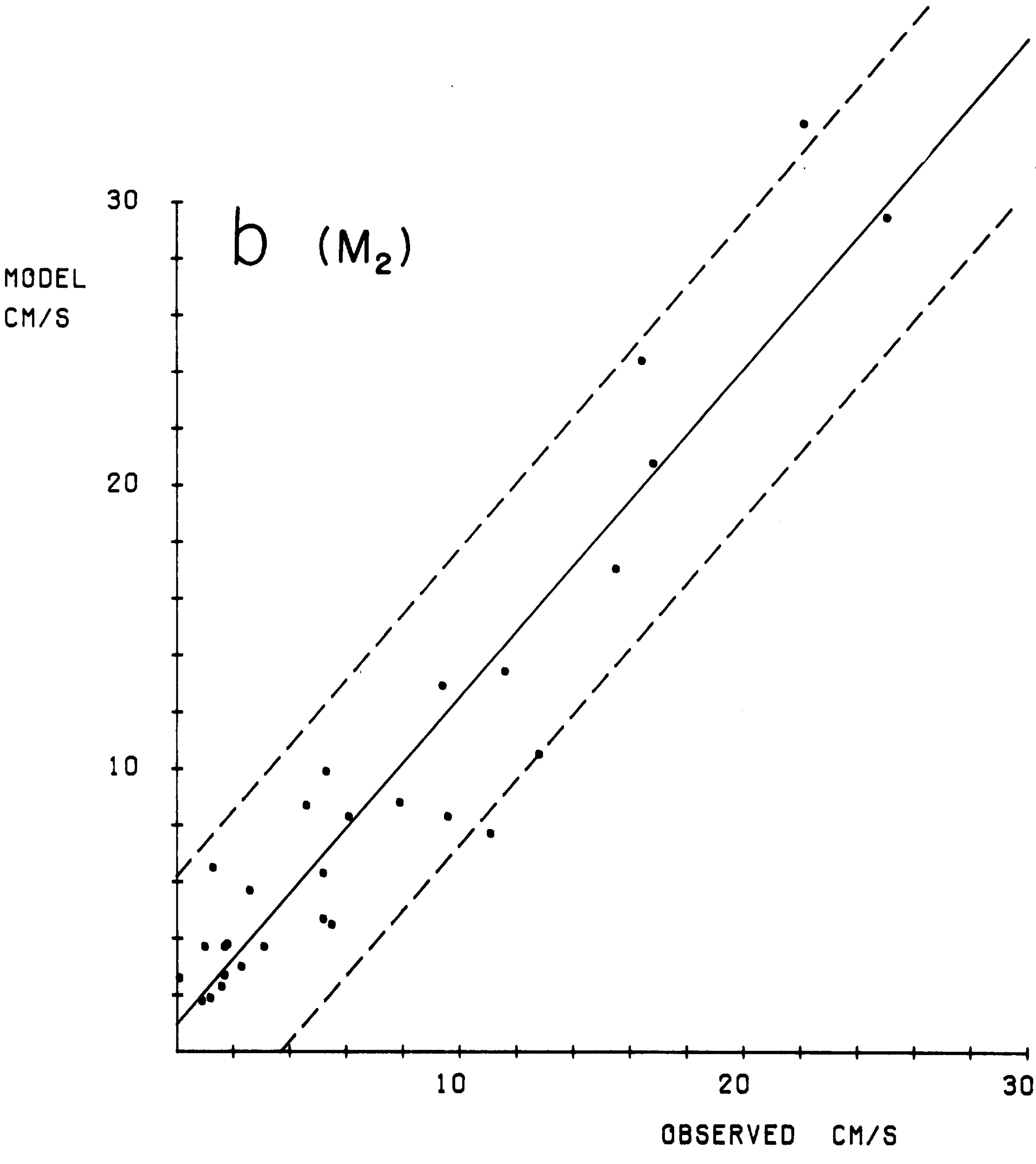
r=0.974; m=0.936; b=4.72



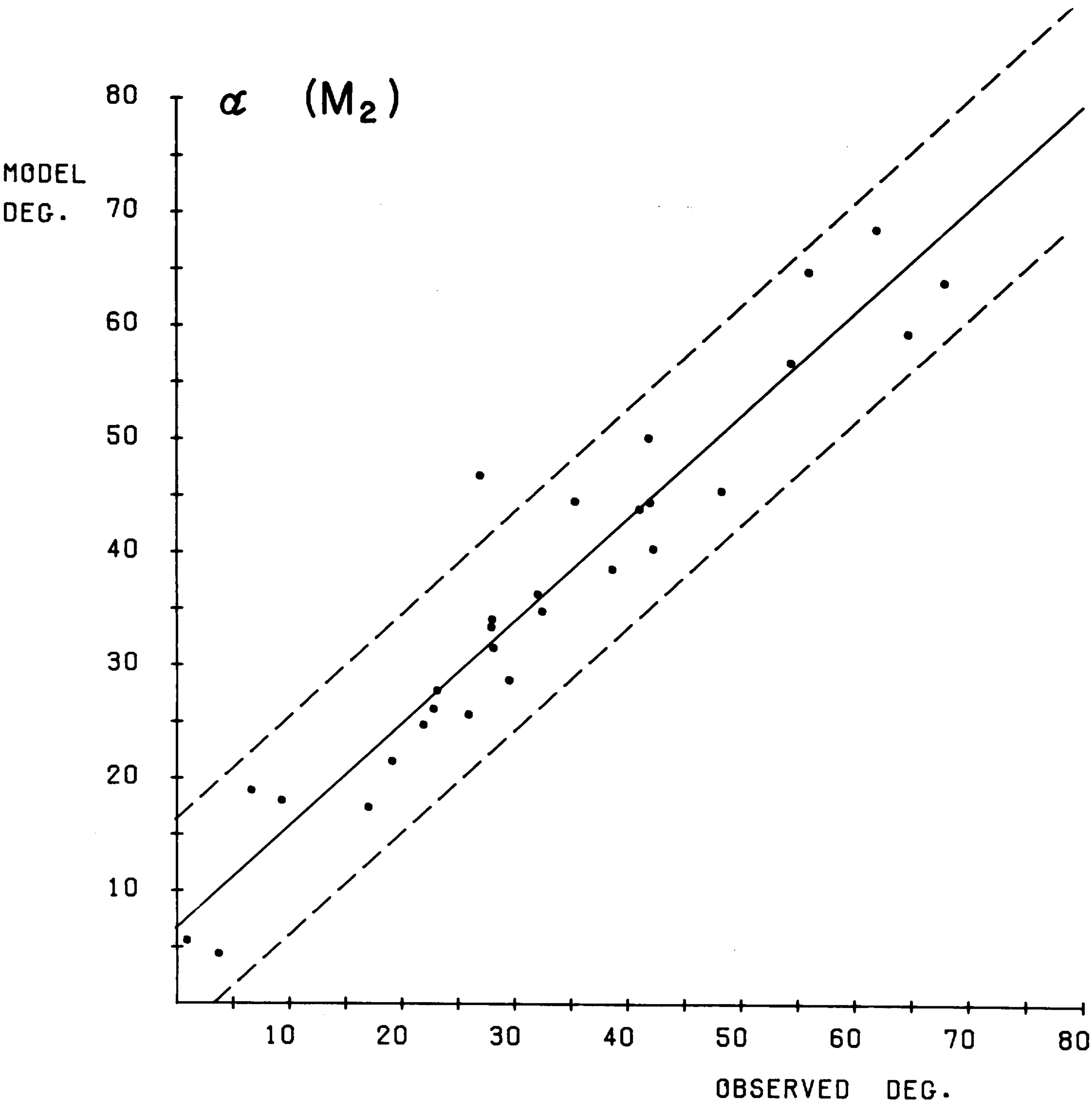
r=0.969: m=0.939; b=4.39



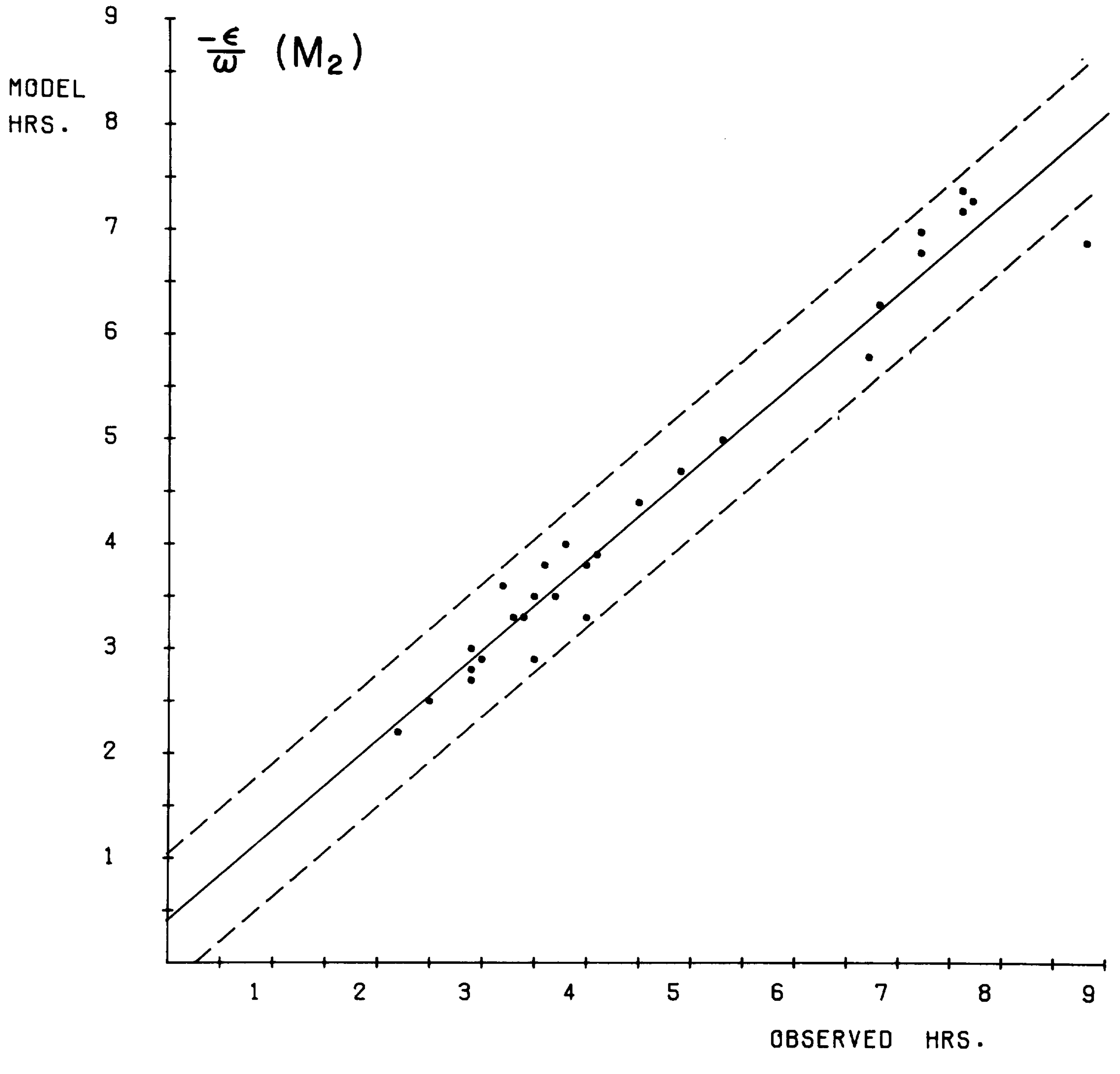
r=0.965; m=1.055; b=1.66



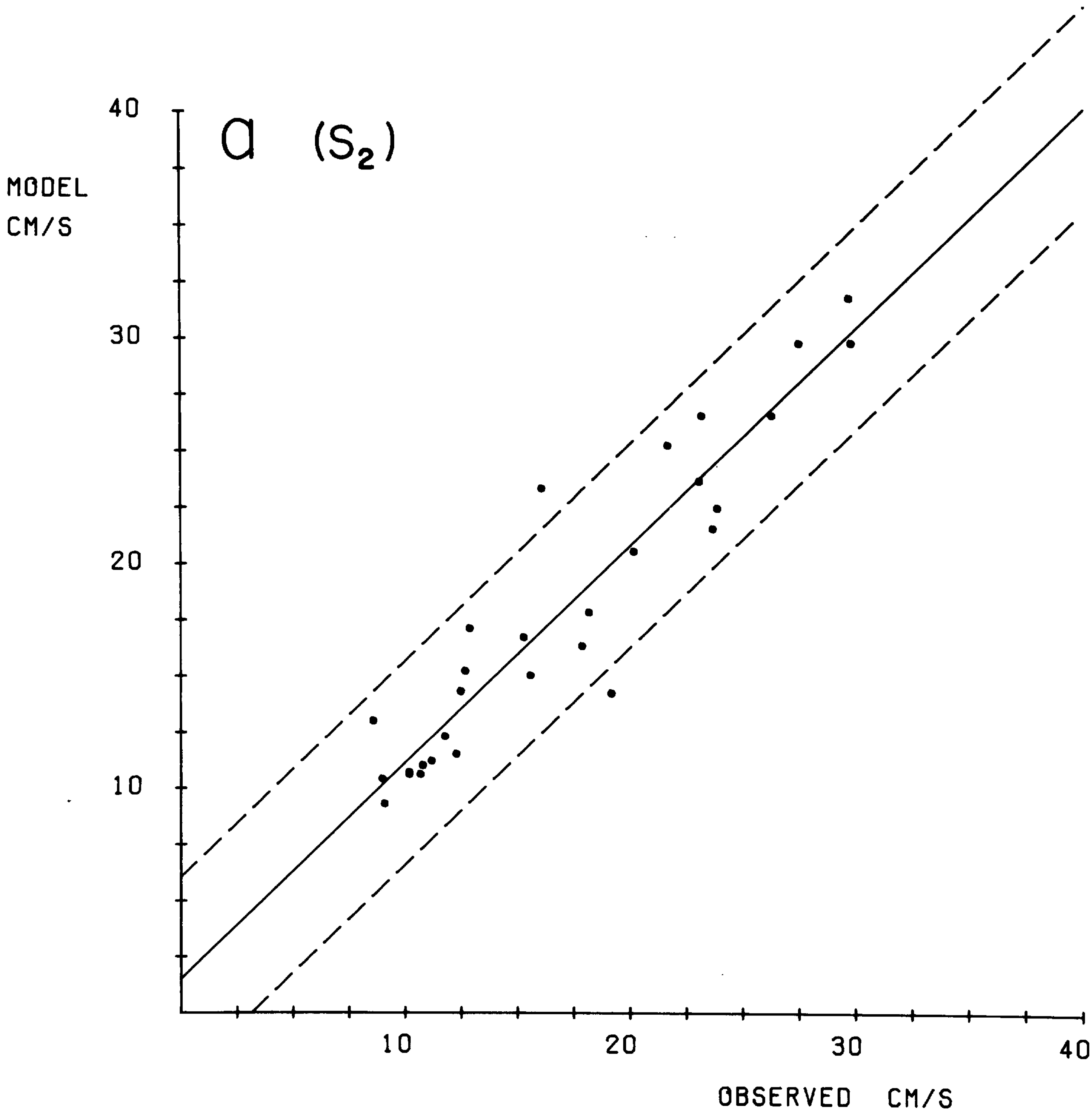
r=0.946; m=1.153; b=0.96



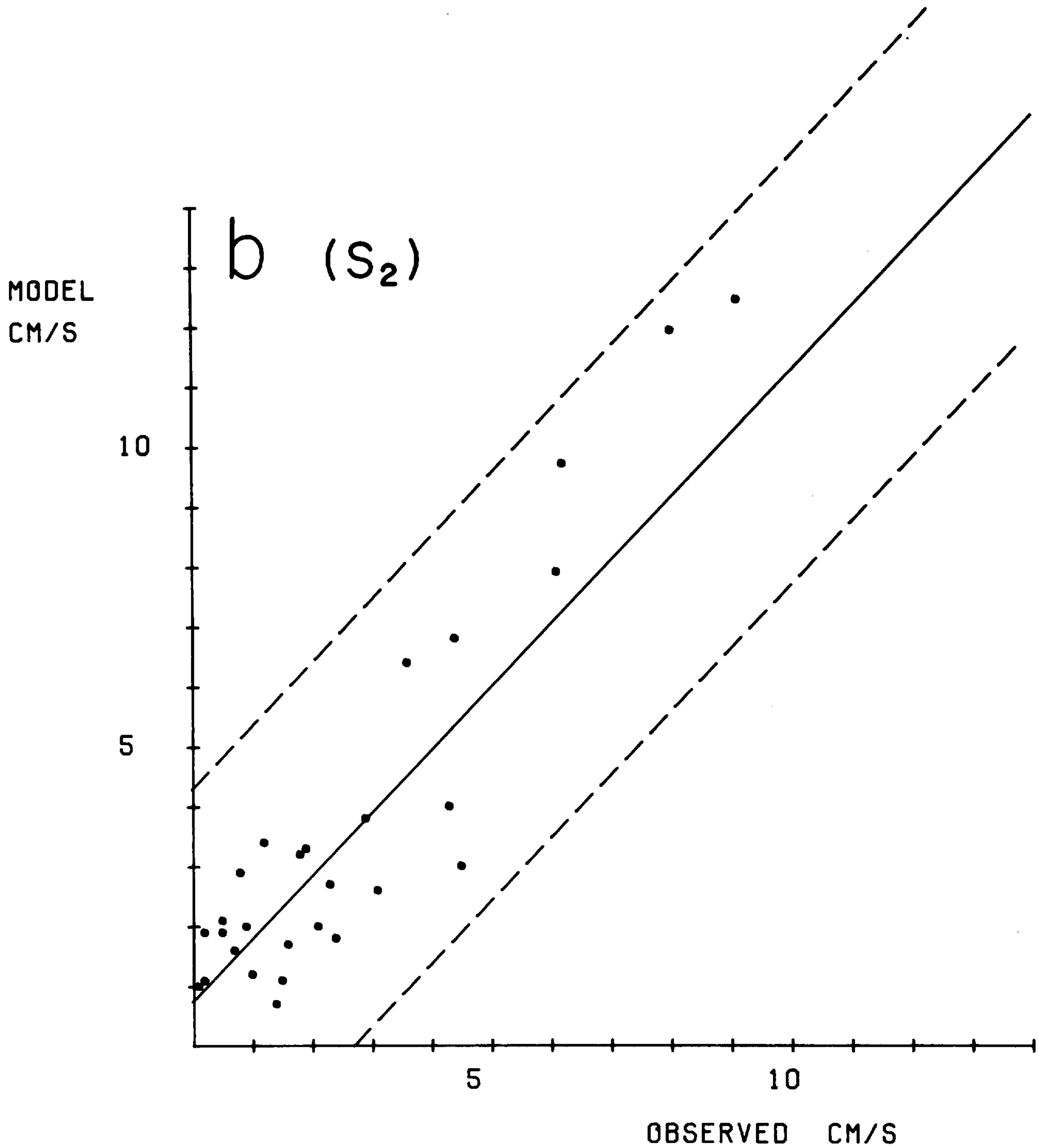
r=0.955; m=0.904: b=6.65



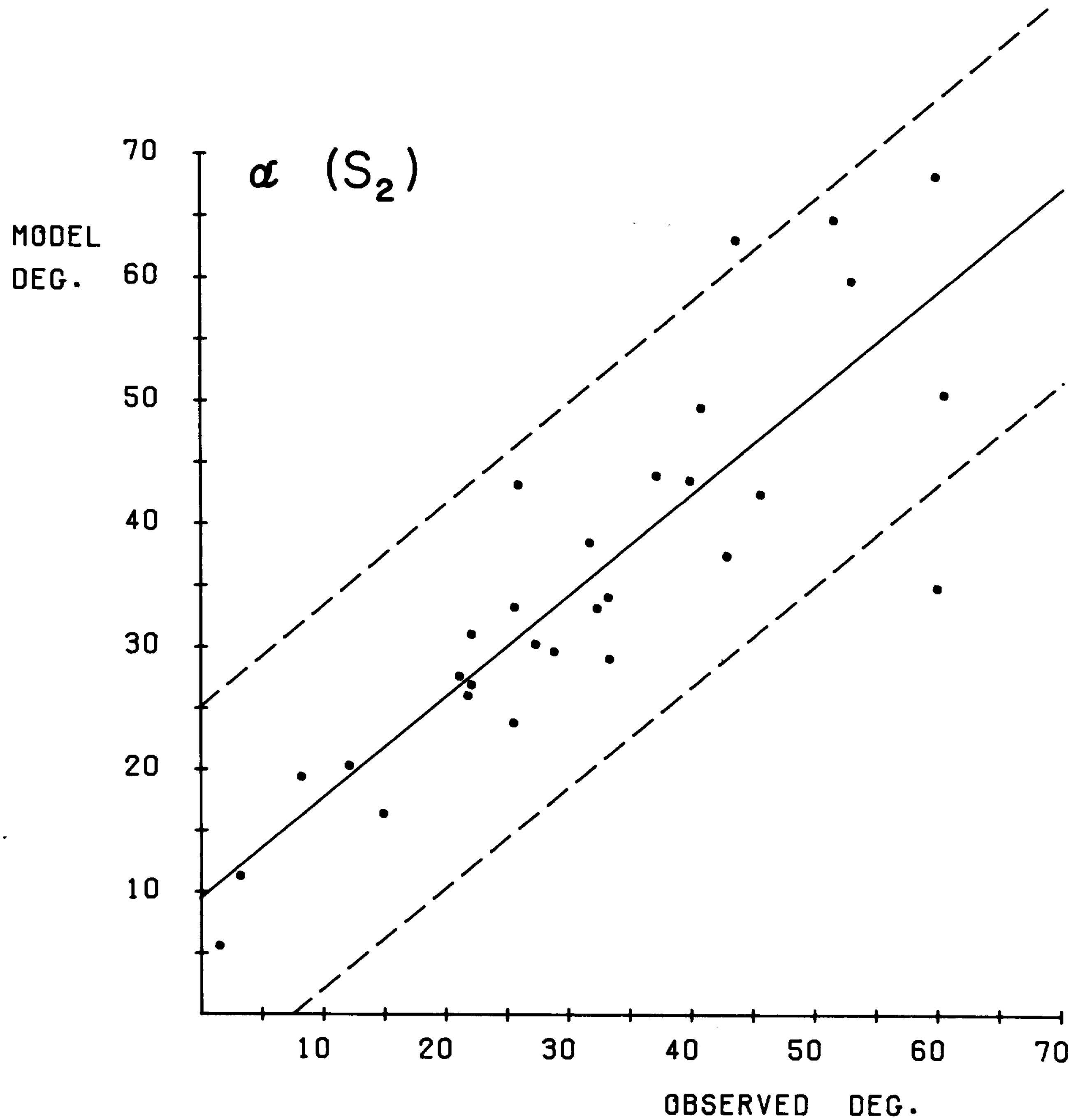
r=0.981; m=0.860: b=0.40



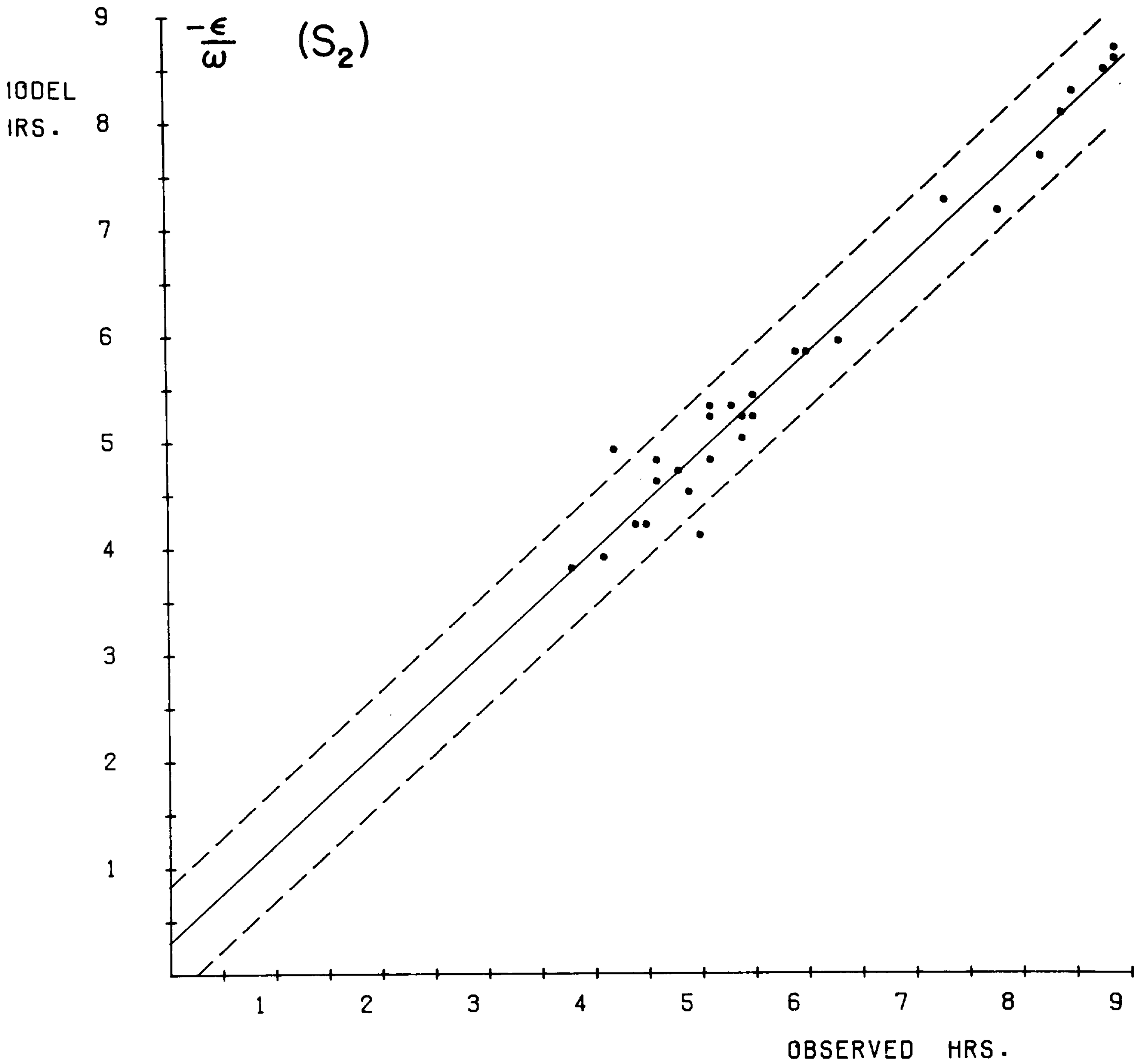
r=0.941; m=0.961; b=1.49



r=0.822; m=1.048; b=0.74



r=0.858; m=0.820; b=9.46



r=0.984: m=0.914: b=0.29