FILE.

INTERNAL DOCUMENT 141.

I.O.S.

An analysis of a year of sea-level dat

at Flat Holm, Severn Estuary.

J. J. Evans and D. T. Pugh

Internal Document

No. 141

October 1981

INSTITUTE OF OCEANOGRAPHIC SCIENCES

NATURAL ENVIRONMENT RESEARCH COUNCIL

INSTITUTE OF OCEANOGRAPHIC SCIENCES

Wormley, Godalming,
Surrey, GU8 5UB.
(042-879-4141)

(Director: Dr. A. S. Laughton)

Bidston Observatory,
Birkenhead,
Merseyside, L43 7RA.
(051-652-2396)
(Assistant Director: Dr. D. E. Cartwright)

Crossway,
Taunton,
Somerset, TA1 2DW.
(0823-86211)
(Assistant Director: M.J. Tucker)

An analysis of a year of sea-level data at Flat Holm, Severn Estuary.

J. J. Evans and D. T. Pugh

Internal Document

No. 141

October 1981

Institute of Oceanographic Sciences
Bidston Observatory
Birkenhead
Merseyside, U.K.

Abstract

A year of sea-level data from Flat Holm has been analysed as part of the studies for a proposed Severn Barrage Scheme. Special techniques were developed to allow analysis of records which dried out for the lowest 2.8 m of the range. The annual modulation in the amplitude of the principal semi-diurnal lunar tide, M_2, was found to be significantly larger than that normally found around Britain, but comparison with analyses of data collected from Flat Holm in 1885 shows that there is no measureable secular change in M_2.

Introduction

During 1979 and 1980 an intensive survey of tidal sea-level variations was made in the Severn Estuary and Bristol Channel, by both the Institute of Oceanographic Sciences, and the Hydraulics Research Station. These measurements have been reported (HRS, 1980a, b; Alcock and Pugh, 1980) in detail. During the planning of this programme it was agreed that a year of sea level measurements should be made at Flat Holm in order to investigate annual tidal variations. This report summarises the observations and the subsequent analyses and considers the significance of the variations observed.

Narrative

The details of the recorder installation at Flat Holm were given in Alcock and Pugh (1980). The gauge was a standard pneumatic bubbler system with a differential Aanderaa pressure transducer and magnetic tape logger. The pressure point outlet for the gauge was located at the end of the Trinity House jetty. This was the only suitable deep-water position on the island which had the necessary protection and stability for a one year installation. Unfortunately the level at the end of this jetty dried out at low water on spring tides, so that the lowest part of the range was not recorded.

The site was visited on six occasions during the year by IOS personnel; details of these visits are given in Table 1. Between IOS visits the gauge was inspected regularly by the resident Trinity House staff, who also collected weekly water samples for salinity determination, and made weekly measurements of water temperature. These temperature and salinity readings were converted to density. During initial analysis a density of 1022 Kg m^{-3} was used to convert pressure to level, but these measurements indicated that 1020 Kg m^{-3} was a more appropriate final annual mean.

Five data tapes were obtained and four (265/7 to 265/10) were processed to give a continuous series. While 265/8 was being processed, a datum shift was noticed, starting on 9 November 1980. The Trinity House Keepers traced the cause to a cut in the tubing from the recorder to the pressure point, which they repaired on 12 February 1981.

The gauge was finally removed on 16 July 1981. A total of 10242 hours of data were obtained from 1700 on 14 May 1980 to 1000 on 16 July 1981. The data were found to be of good quality, apart from the period of cut tube.

Analysis

The method of analysis of the clipped records from Flat Holm has been described and justified elsewhere (Evans and Pugh, 1982). A least squares curve was fitted only to those readings which represented real water levels. The small gaps in the data during servicing were not interpolated.

During the period when the tube was cut, the gauge had a different drying level, that of the cut, then the remainder of the data. Because the period of this datum shift fell in the middle of the year to be analysed, it was necessary to adjust the datum so that a common analysis could be made. Direct levelling between the two outlets was not possible and so an alternative method, involving comparisons with Avonmouth sea levels was adopted.

The Port of Bristol Authority supplied data from the Avonmouth gauge for the period of the cut and for adjacent periods when the gauge was working normally. Two periods were studied, one encompassing the time of the cut (26 October 1980 to 29 November 1980), and one encompassing the time of the repair (27 January 1981 to 11 March 1981). The water levels at Avonmouth and Flat Holm, at high water were compared. The highest 15 minute level recorded near high water was taken as the true high water level at Flat Holm, without significant error. The difference in the recorded corresponding high water levels between the two sites were tabulated for each period.

These level differences were then plotted (Figure 1) against the level of high water at Avonmouth. The plot shows two groups of points along two parallel lines, from the periods of cut and uncut tube. The mean difference was calculated for each group of data at (5.77 ± 0.20) m and (3.77 ± 0.19) m respectively. The data from the period when the tube was cut was therefore adjusted to the normal datum level by adding 2.00 m. An alternative analysis of the data, in terms of the differences for separate level bands of the Avonmouth high water level, produced different adjustment factors, but the variations were at the 0.03 m level, which was considered acceptable for this study.

An analysis of a 355 day period of data (from 15 May 1980 to 4 May 1981) was made for 60 harmonic constituents and for the mean sea level, Z_0 . The record was also divided into 14 sets of 29 days of data, and these sets were analysed for 27 harmonic and 8 related constituents (Alcock and Pugh, 1980). The relationships were those used in the previously reported analysis. Table 2 gives details of the way in which the data were blocked and analysed, and also the percentage of the time for which measurements above the gauge zero level were available for analysis. For November, December and January, the percentage is low because of the cut tube.

Table 3 summarises the results of the year's analysis and Table 4 gives the mean results from the 14 separate 29 day analyses. The purpose of Table 4 is to give some feeling of the confidence to be placed in analyses of data from a single 29-day period in the region. The standard errors quoted in Table 4 may be used as an indication of the confidence limits for the constituent amplitudes and phases given in Table 3.

The values given in Table 3 are the ones to be used for predictions of future tides at Flat Holm. They have been adjusted for a mean water density of 1020 Kg m^{-3} subsequent to analysis, as have the values in Table 4.

The values of extreme phases given in Table 4 indicate range rather than maximum and minimum values, because these have no obvious meaning in the context of a noisy cyclic parameter.

Discussion

The variations in the amplitudes and phases of the M_2 and S_2 constituents through the year are shown in Figure 2 and Figure 3. Figure 4 shows the standard deviation of the residuals and the mean sea level variations through the year.

The M_2 amplitude shows a significant modulation which is much greater than that which can be attributed to density variations (Figure 5) in the data reduction process. The greatest amplitudes were recorded during the summer months, in common with observations in the North Sea (Pugh and Vassie, 1976). However, the proportional and absolute modulations are much greater, probably because of strong shallow water effects in the Severn Estuary. Thus M_2 has a minimum amplitude of 3.72 m and a maximum amplitude of 4.06 m in September and June respectively. These values only apply for the year of observation, and computations of the effect of their variability on the available tidal power should be based on analyses of several years of data. The values obtained from the 1 year analysis at Flat Holm compare favourably with the 29-day values published in the earlier report, which they now replace as the best available.

Three months of daylight readings from 1885, at Flat Holm, had been previously analysed at Bidston. The values of the amplitudes and phases of M_2 and S_2 obtained from the 1885 data are plotted in Figures 2 and 3 for the appropriate months. The amplitudes are very similar and indicate no significant change, but there appears to be a systematic difference in the phases. However, examination of the original analyses showed that there was some ambiguity about the time kept in 1885, and it has not proved useful to pursue this further.

The annual range of mean sea level variations, 0.31 m, is typical of the seas around Britain, as is confirmed by a longer extract from the Newlyn mean sea levels (Figure 6), for the period 1978-80.

This work was commissioned by the Department of Energy as part of the studies for the Severn Barrage Scheme.

References

Alcock, G.A. and D.T. Pugh, 1980. Observations of tides in the Severn Estuary and Bristol Channel, Institute of Oceanographic Sciences, Internal Report No. 112.

Evans, J.J. and D.T. Pugh, 1982. Analysing clipped sea-level records for harmonic tidal constituents, to appear in the International Hydrographic Review, July 1982.

Hydraulics Research Station, 1980 a, The Severn Estuary, Recording of tidal levels in 1979. Report No. Ex 912.

Hydraulics Research Station, 1980 b, The Severn Estuary, Recording of tidal levels in 1980. Report No. Ex 943.

Pugh, D.T. and J.M. Vassie, 1976. Tide and surge propagation in the Dowsing region of the North Sea, Deutche Hydrographische Zeitschrift, 29, 163-213.

VISIT NUMBER AND PURPOSE	FIRST READING	LAST READING	TIMING ERROR	GAUGE
1 INSTALLATION 09-10/05/08 Gauge installed 9-10 May 1980 Gauge plugged in 11.42 10/05/80	11.45.00 10/05/80	-	-	105
2 SERVICE VISIT 14/05/80 Gauge 105 faulty, replaced. Two loggers fitted 265,106.	16.20.45 14/05/80	-	-	106/9
	16.15.29 14/05/80	-	-	265/7
3 SERVICE VISIT 18/06/80 106 removed	-	14.51.05 18/06/80	20 s gain	106/9
265 tape changed	-	14.30.30 18/06/80	1 s gain	265/7
265 new tape, battery and air supply fitted	14.45.31 18/06/80	-	-	265/8
4 SERVICE VISIT 09/10/80 265 tape changed	-	11.59.57 09/10/80	34 s loss	265/8
265 new tape, battery and air supply fitted	12.30.30 09/10/80	-	-	265/9
5 SERVICE VISIT 27/01/81 265 tape changed	-	13.00.04 27/01/81	26 s loss	265/9
265 new tape, battery and air supply fitted	13.27.30 27/01/81	-	-	265/10
6 DISCONNECTION 16/07/81 265 gauge switched off and removed	-	10.11.51 16/07/81	39 s loss	265/10

TABLE 1

		NUMBER OF VALUES POSSIBLE	NUMBER OF VALUES USED IN ANALYSIS	% USED IN ANALYSIS	NUMBER OF BLOCKS
MAY 136-164	1980	2784	2361	84.8	44
JUNE 165-193		2784	2412	86.6	41
JULY 194-222		2784	2435	87.5	40
AUGUST 223-251		2784	2419	86.9	38
SEPTEMBER 252-280		2784	2458	88.3	35
OCTOBER 281-309		2784	2447	87.9	37
NOVEMBER 310-338		2784	1912	68.7	54
DECEMBER 339-001		2784	1773	63.7	57
JANUARY 002-030	1981	2784	1754	63.0	58
FEBRUARY 031-059		2784	2111	75.8	49
MARCH 060-088		2784	2406	86.4	40
APRIL 089-117		2784	2344	84.2	43
MAY 118-146		2784	2411	86.6	42
JUNE 147-175		2784	2388	85.8	43
355 DAY ANALYSIS 15.5.80-4.5.81		34080	27710	81.3	540

TABLE 2

INSTITUTE OF OCEANOGRAPHIC SCIENCES

List of Harmonic Constants.

Place: Flat Holm

Latitude	Longitude L	Standard time S	Records	
			Length	Central day
51°23'N	3°07'W	GMT	355 Days	314/1980

Flat Holm Island Bristol Channel May 1980 - May 1981
Standard Pneumatic Bubbler System with Aanderaa Pressure Transducer

Analysis of all 15 minute unfiltered values
Gauge dried out for lower 2.8 m of range
Units are metres
Total variance = 7.076 m^2 (S.D. = 2.66 m)
Residual variance = 0.037 m^2 (S.D. = 0.19 m)

	H	g		H	g		H	g		H	g
A_0Z	3.713	-	$2Q_1$	0.005	63.8	OQ_2	0.039	71.9	MO_3	0.009	197.7
Sa	0.062	192.7	σ_1	0.005	138.8	MNS_2	0.097	241.8	M_3	0.043	192.4
Ssa	0.018	322.3	Q_1	0.031	328.7	$2N_2$	0.051	230.2	SO_3	0.011	161.4
Mm	0.033	347.9	ρ_1	0.005	171.6	μ_2	0.355	251.4	MK_3	0.012	252.4
MSf	0.071	42.3	O_1	0.083	3.4	N_2	0.723	174.2	SK_3	0.021	305.4
Mf	0.050	102.6	MP_1	0.005	290.2	ν_2	0.168	153.6			
			M_1	0.012	202.6	OP_2	0.058	147.5	MN_4	0.061	3.6
			χ_1	0.004	321.6	M_2	3.895	190.0	M_4	0.163	31.6
			π_1	0.002	177.5	MKS_2	0.063	335.7	SN_4	0.014	58.4
			P_1	0.030	130.2	λ_2	0.106	173.0	MS_4	0.084	58.4
			S_1	0.015	65.9	L_2	0.285	168.3	MK_4	0.030	74.2
			K_1	0.063	139.5	T_2	0.073	239.6	S_4	0.027	86.2
			ψ_1	0.004	170.8	S_2	1.350	245.6	SK_4	0.012	191.4
			ϕ_1	0.004	181.7	R_2	0.016	269.9			
			θ_1	0.003	274.6	K_2	0.392	243.1	$2MN_6$	0.013	205.8
			J_1	0.004	250.8	MSN_2	0.077	45.3	M_6	0.027	224.5
			SO_1	0.006	38.2	KJ_2	0.017	176.4	MSN_6	0.011	244.0
			OO_1	0.005	322.8	$2SM_2$	0.098	68.4	$2MS_6$	0.035	281.7
									$2MK_6$	0.008	226.9
									$2SM_6$	0.015	271.3
									MSK_6	0.014	0.6

TABLE 3

Constituent	H Mean	H SD	H SE	H Min	H Max	G Mean	G SD	G SE	G Range	
ZO	3.722	0.081	0.022	3.831	3.518					
MM	0.083	0.063	0.017	0.230	0.020	202.1	118.1	31.6	358.2	18.7
MSF	0.077	0.043	0.011	0.164	0.019	41.0	54.4	14.5	153.8	315.3
Q_1	0.033	0.013	0.003	0.071	0.010	340.6	46.7	12.5	139.5	13.0
O_1	0.088	0.012	0.003	0.115	0.073	0.7	9.0	2.4	347.2	23.7
M_1	0.013	0.008	0.002	0.033	0.003	203.4	28.6	7.6	258.1	147.4
K_1	0.068	0.014	0.004	0.095	0.040	134.0	17.4	4.7	171.9	112.0
J_1	0.016	0.009	0.002	0.029	0.006	210.4	80.1	21.4	322.8	87.9
OO_1	0.023	0.013	0.003	0.057	0.010	222.2	104.1	27.8	346.1	49.9
Mu_2	0.358	0.062	0.017	0.478	0.260	250.1	9.6	2.6	267.4	236.5
N_2	0.738	0.094	0.025	0.896	0.598	174.0	7.9	2.1	189.6	165.3
M_2	3.901	0.110	0.029	4.061	3.721	189.9	0.9	0.2	191.2	188.4
L_2	0.307	0.088	0.024	0.454	0.121	165.3	22.7	6.1	204.9	125.5
S_2	1.379	0.037	0.010	1.442	1.295	246.2	2.1	0.6	250.7	243.1
$2SM_2$	0.095	0.037	0.010	0.158	0.046	66.2	22.1	5.9	91.7	12.6
MO_3	0.011	0.007	0.002	0.022	0.002	214.2	62.0	16.6	307.5	51.9
M_3	0.044	0.008	0.002	0.065	0.032	192.0	4.7	1.3	202.0	185.7
MK_3	0.013	0.007	0.002	0.030	0.003	224.6	72.6	19.4	317.9	33.0
MN_4	0.064	0.025	0.007	0.113	0.026	8.5	30.7	8.2	80.6	320.8
M_4	0.166	0.048	0.013	0.260	0.116	30.1	3.3	0.9	34.5	22.0
SN_4	0.032	0.019	0.005	0.093	0.010	167.9	131.9	35.3	329.7	1.6
MS_4	0.073	0.031	0.008	0.147	0.017	42.3	25.2	6.7	90.9	335.2
$2MN_6$	0.024	0.010	0.003	0.038	0.009	177.1	30.8	8.2	222.6	126.5
M_6	0.032	0.016	0.004	0.048	0.002	205.8	67.0	17.9	283.6	5.2
MSN_6	0.026	0.010	0.003	0.041	0.009	235.5	58.4	15.6	289.4	78.7
$2MS_6$	0.048	0.019	0.005	0.077	0.005	274.0	17.5	4.7	312.7	237.7
$2SM_6$	0.020	0.010	0.003	0.042	0.010	317.5	29.8	8.0	250.4	1.7

Mean Results from 14 29 day Analyses

S.D = Standard Deviation   H = Amplitude in metres

S.E = Standard error   G = Phase in degrees

= SD/(No of monthly analysis)$^{\frac{1}{2}}$

TABLE 4

Figure captions

Figure 1. Height differences between high water at Avonmouth and high water at Flat Holm plotted against the high water level at Avonmouth.

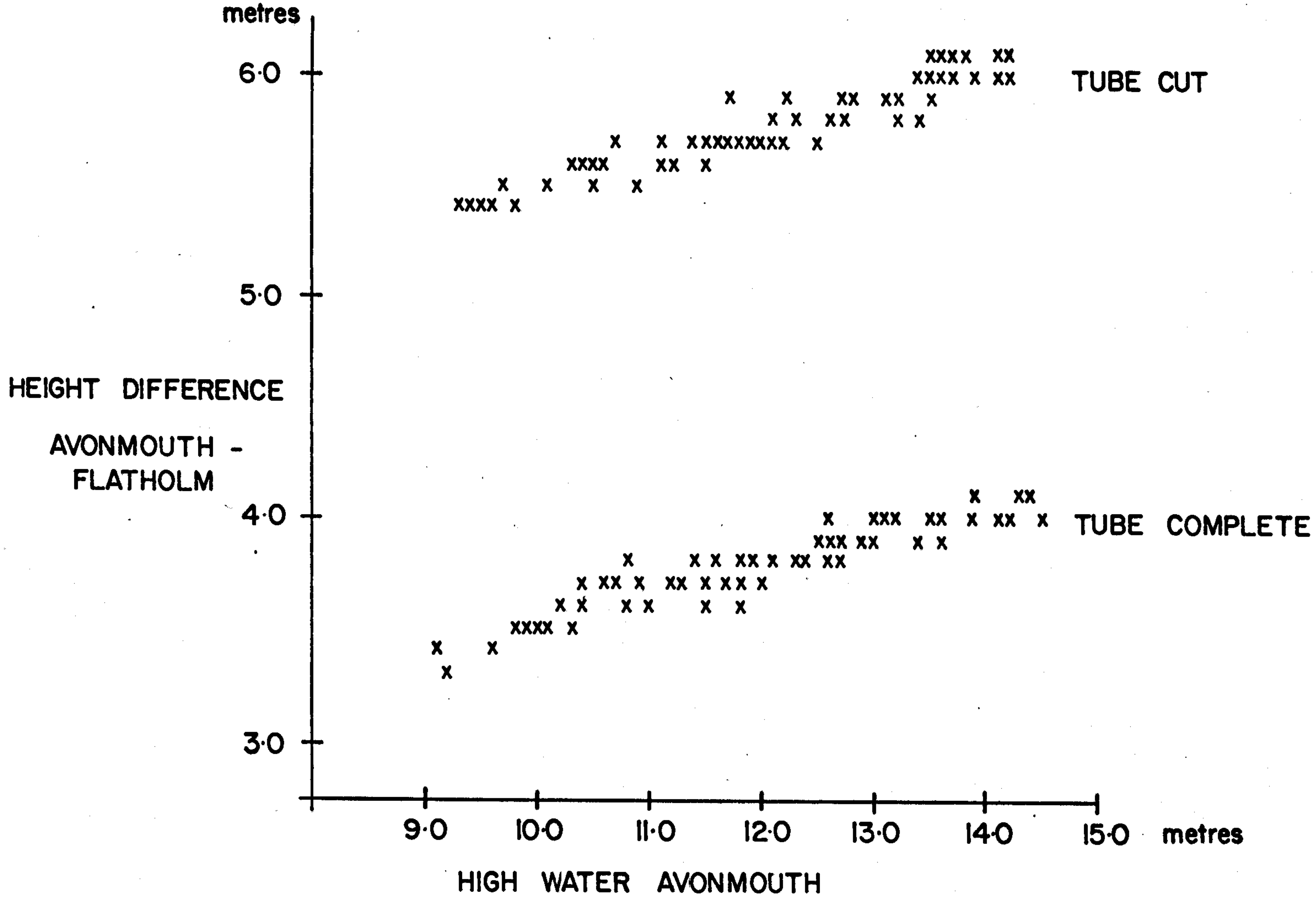
Figure 2. Amplitude of M_2 and S_2 gained from 14 29 day analysis from May 1980 to June 1981. Also shown are the amplitude of M_2 and S_2 for May, June and July 1885.

Figure 3. As for figure 2 showing phases of M_2 and S_2.

Figure 4. Showing the value of Zo (mean sea level) and the standard deviation of the residual gained from 14 29 day analyses from May 1980 - June 1981.

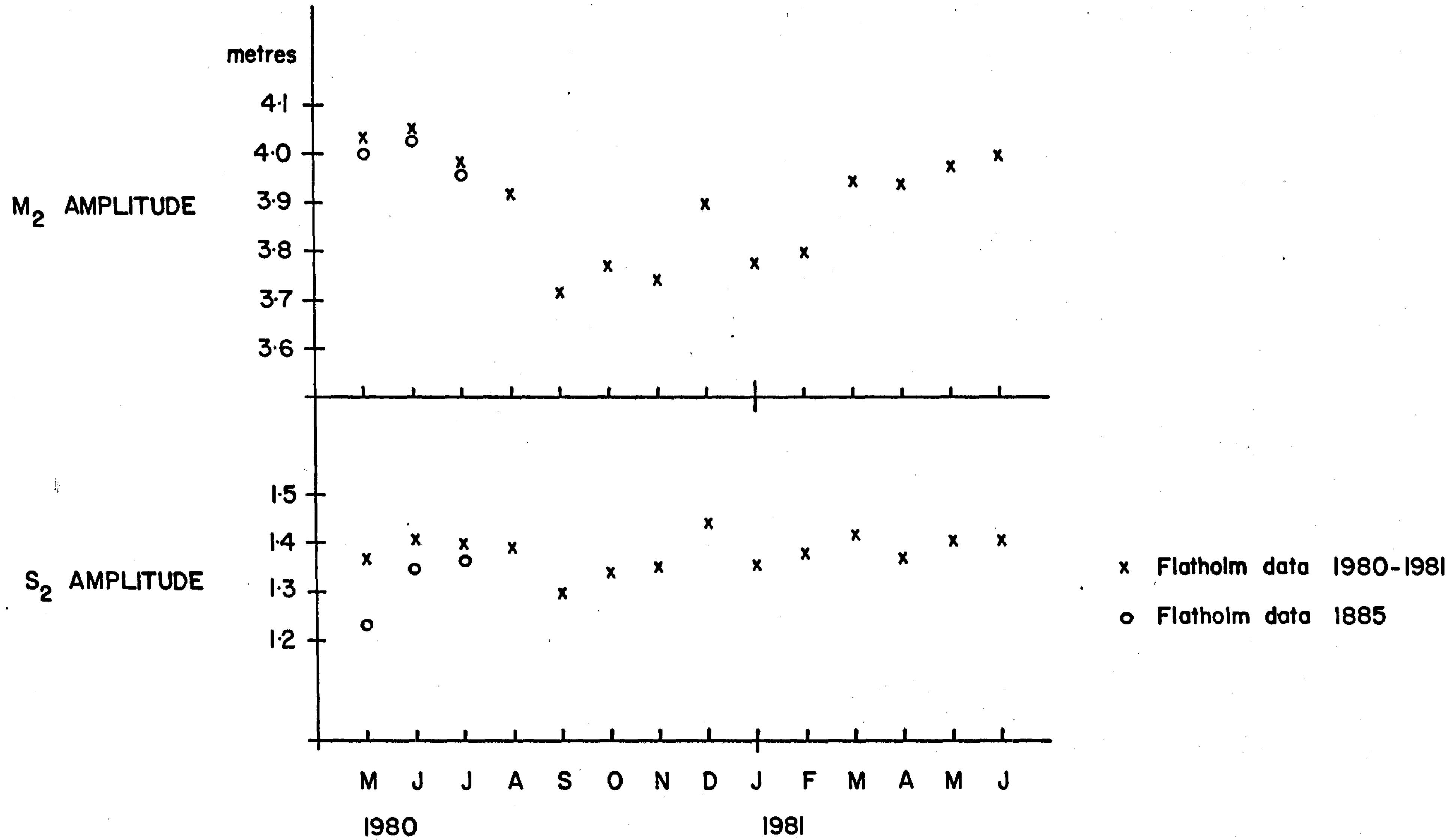
Figure 5. Water temperature, salinity and density variations over the recording period.

Figure 6. Monthly mean sea level values from Newlyn, Cornwall for 1978 to 1980.



metres
6·0
5·0
4·0
3·0
TUBE CUT
TUBE COMPLETE
HEIGHT DIFFERENCE
AVONMOUTH -
FLATHOLM
9·0
10·0
11·0
12·0
13·0
14·0
15·0
metres
HIGH WATER AVONMOUTH

Figure 1



metres
4·1
4·0
3·9
3·8
3·7
3·6
M2 AMPLITUDE
1·5
1·4
1·3
1·2
S2 AMPLITUDE
x Flatholm data 1980-1981
o Flatholm data 1885
M J J A S O N D J F M A M J
1980
1981

Figure 2

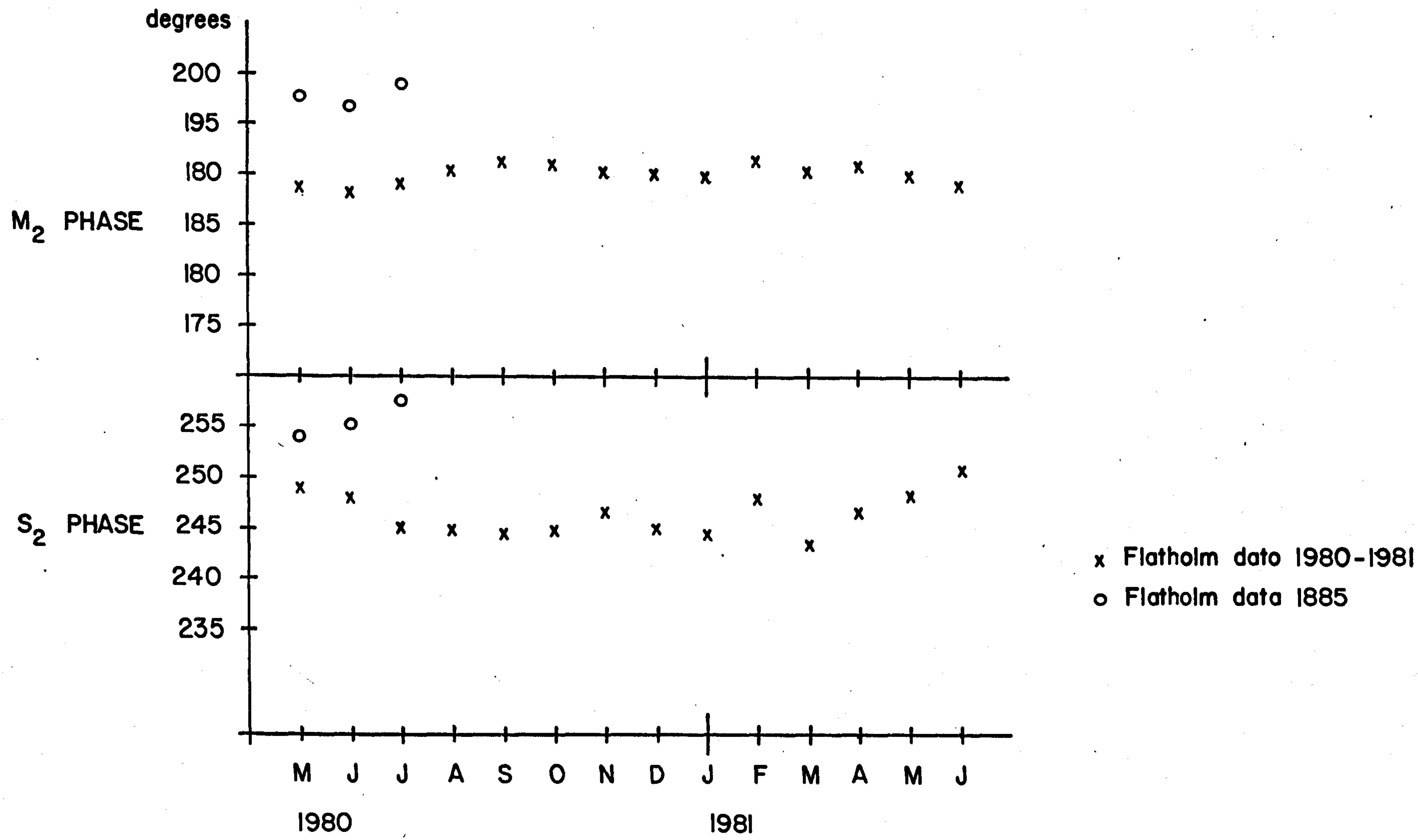

degrees
200
195
180
185
180
175
M2 PHASE
255
250
245
240
235
S2 PHASE
M
J
J
A
S
O
N
D
J
F
M
A
M
J
1980
1981
x Flatholm dato 1980-1981
o Flatholm data 1885

Figure 3

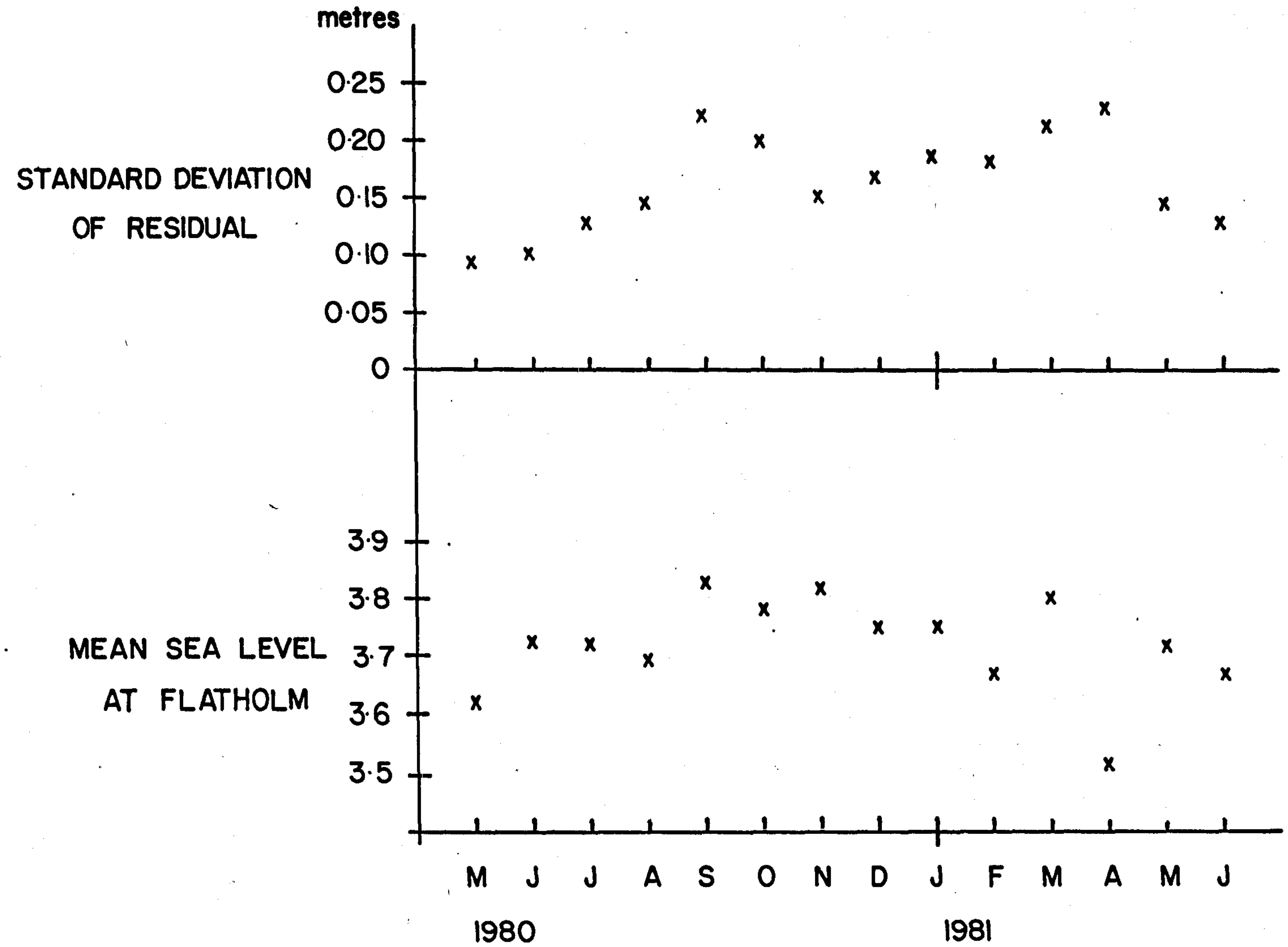
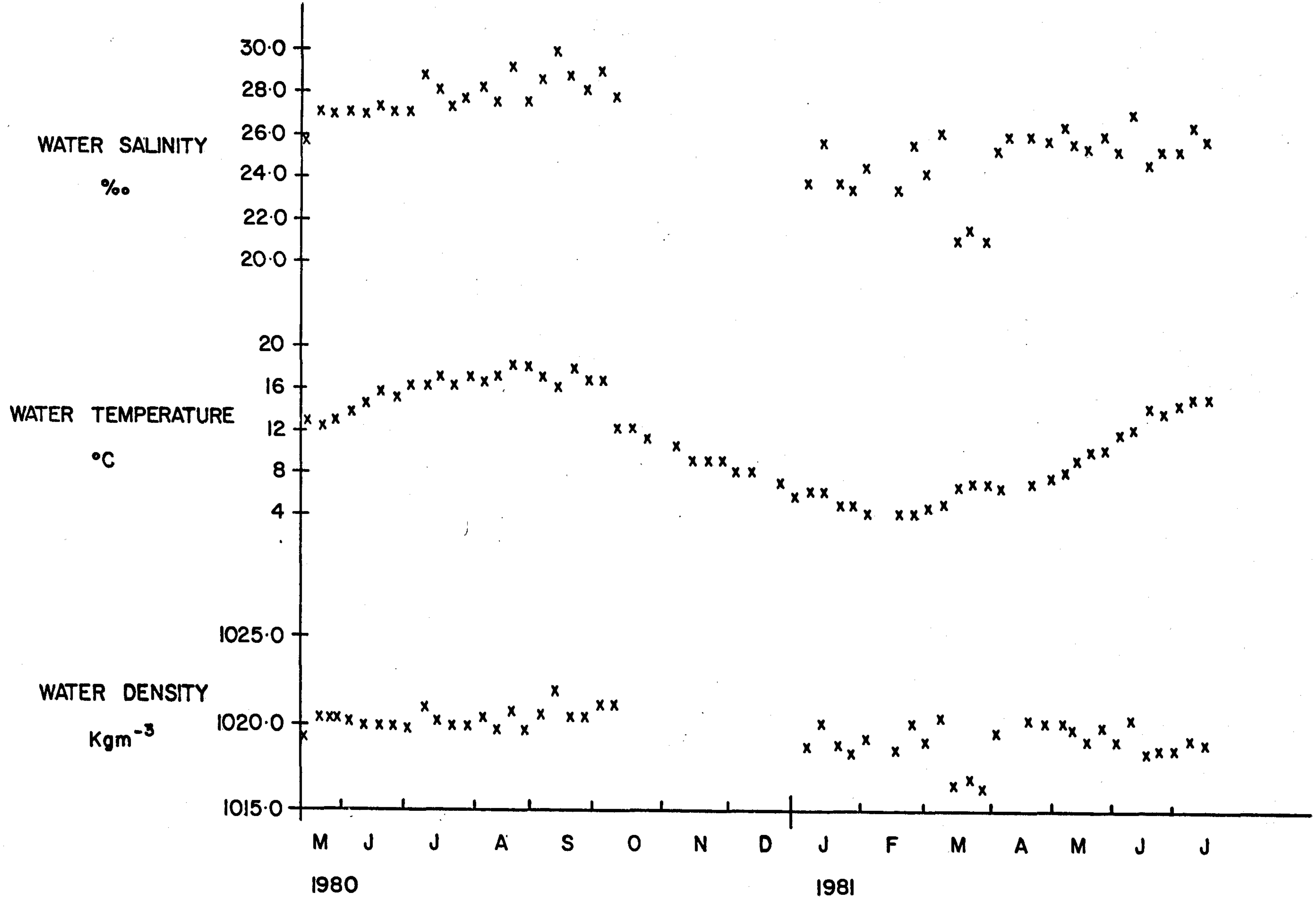

metres
0·25
0·20
0·15
0·10
0·05
0
STANDARD DEVIATION
OF RESIDUAL
3·9
3·8
3·7
3·6
3·5
MEAN SEA LEVEL
AT FLATHOLM
M J J A S O N D J F M A M J
1980
1981

Figure 4



WATER SALINITY
‰
30·0
28·0
26·0
24·0
22·0
20·0
WATER TEMPERATURE
°C
20
16
12
8
4
WATER DENSITY
Kgm-3
1025·0
1020·0
1015·0
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
1980
1981

Figure 5

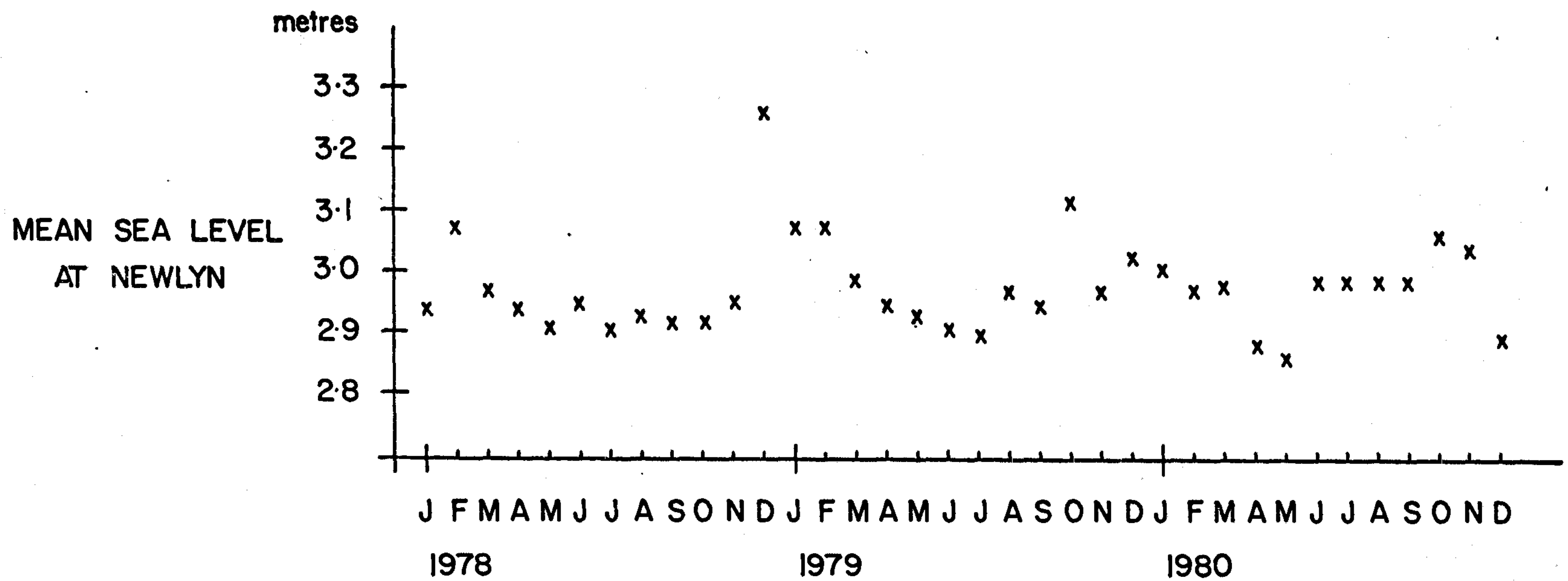

metres
3·3
3·2
3·1
3·0
2·9
2·8
MEAN SEA LEVEL
AT NEWLYN
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1978
1979
1980

Figure 6