ROYAL OBSERVATORY, HONG KONG

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THE ANALYSIS AND PREDICTION OF TIDES AT CHI MA WAN, KO LAU WAN, LOK ON PAI, TAI O, TSIM BEI TSUI AND WAGLAN ISLAND

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1. INTRODUCTION

Since the 1940's, tidal predictions for Hong Kong have been computed by the United Kingdom Institute of Oceanographic Sciences. The tidal predictions at North Point which was taken to be the standard port, were then computed by the harmonic method. Those at both locations in Hong Kong were obtained from North Point results using the time/height adjustment method.

In 1983, a software package for tidal analysis and prediction using the harmonic method was acquired by the Royal Observatory, Hong Kong from the Institute of Ocean Sciences, Canada. The program was successfully adapted and implemented enabling the Royal Observatory to begin producing tidal predictions for Hong Kong from 1987 onwards. A description of the method is given in Ip & Wai (1990).

In the first two tide tables produced by the Royal Observatory, which were for 1987 and 1988, only for Quarry Bay (QUB)* were the tidal predictions prepared from harmonic analysis. For the other locations in the RO's tide gauge network shown in Fig. 1, the time/height adjustment method in which correction factors were obtained through correlations between tide data at these stations and that of Quarry Bay were used instead.

Since then harmonic analysis had been completed for Tai Po Kau (TPK) by Poon and Chiu (1988), and the tidal predictions published in the 1989 and 1990 tide tables for this station were computed from them.

It then remained to carry out harmonic analysis for the tides at Chi Ma Wan, Ko Lau Wan, Lok On Pai, Tai O, Tsim Sha Tsui and Waglan Island, and to see if the harmonic method can improve the accuracy of tide predictions for these locations. This is the objective of the present work. Predictions for Quarry Bay is considered as representative of the tides within the harbour, in view of the size of the area. So it is not necessary to compute the tidal prediction for Tamar explicitly.

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* In January 1951, an automatic tide gauge was installed at Arsenal Yard in Hong Kong. It was then moved to North Point in October 1952 (Watts 1959). Since then North Point was taken as the standard port. In 1985, reclamation at North Point necessitated the relocation of the tide gauge there to Quarry Bay. The set-up at Quarry Bay is similar to that at North Point. It is sited at a location approximately half a kilometre to the east of the North Point tide gauge. The tidal characteristics at both locations are almost the same. Comparison of records from both tide gauges for the period September 1985 to March 1986 showed no noticeable difference. From 1986 onwards Quarry Bay became the standard port of Hong Kong. Tidal records from both gauges, particularly for the purpose of harmonic analysis and prediction, are treated as from one gauge. For the sake of brevity, these two tide gauges will be referred to as Quarry Bay in this report.

The objectives of the present work are

(a) to analyse using the harmonic method, the tides at Chi Ma Wan, Ko Lau Wan, Lok On Pai, Tai O, Tsim Bei Tsui and Waglan Island (which will be referred to as CMW, KLW, LOP, TAO, TBT and WAG respectively in the following discussions).

(b) to see if the harmonic constants so derived can give better tidal predictions for these locations than the time/height adjustment method hitherto used.

2. ANALYSIS

Selected tide records were analysed, and the results of the analyses are given in Table 1. The harmonic series are able to explain about 90% of the observed variance. The residual variance can be attributed to random variations in meteorological conditions. The harmonic constants derived for each location are given in Tables 2-7. The frequencies of the harmonic constituents are given in Table 8. (For the sake of brevity, only the set with the best hindcasting performance is presented for each location)

2.1 Annual tidal variation at Tai O

For Tai O, attempts to include tide data before November 1987 in the analysis were met with difficulties, as data sparsity in these months makes the least square matrix singular. As a result only about ten months of data were analysed for Tai O and SA (the annual variation) cannot be determined. The constituent is therefore omitted from Table 5.

2.2 Sea Level Anomaly in 1982/83

The amplitudes of SA and SSA for the six locations are compared in Table 9. Those for Quarry Bay (QUB) and Tai Po Kau (TPK) are also listed for comparison*. The amplitude of SSA is twice as large as that of SA for Waglan Island while for the other locations the amplitude of SSA is roughly only half that of SA. A comparison of the monthly mean sea level variation of Waglan Island during the period April 1982 - September 1983 with the 19 years average monthly variation in 1970-1988 (Fig. 2) suggests that the spectral anomaly is a reflection of the large dip in sea levels in July and August 1982 which appears as a large amplitude oscillation with a period of half year. A similar anomaly was also recorded at Quarry Bay (Fig. 3). This sea level anomaly is in fact a reflection of a large scale sea level drop in the western Pacific associated with the intense El Nino event in 1982/83 (Wyrtki, 1985). As a result, the amplitudes and phases of SA and SSA for this period are not representative of the normal tidal variations and were not used in tidal predictions for Waglan.

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* The harmonic constants for QUB and TPK given in the report were obtained from analysis of the tides at these locations for the periods 1969-87 and 1977-81 respectively.

3. TIDAL CHARACTERISTICS OF HONG KONG WATERS

A mixture of tidal pattern is experienced in Hong Kong. On most days, there are two high waters and two low waters per day. However, there are often a few days in each month when only one pair of extreme waters are observed. These diurnal tides usual occur around the first or last quarter on days when the Moon is near its northermost or southernmost position. This type of mixed tides with predominantly semi-diurnal characteristics is in fact common to the coastal waters of Guangdong from Daya Bay to the Leizhou Peninsula (Ding, 1986). Locally, tide records at various locations in Hong Kong display a gradual change in tidal range and in times of extreme waters from southeast to northwest across the territories. In a tidal cycle, WAG is usually the first to experience the high/low water and TBT is always the last. The mean delay is about 1 hour 45 minutes for high water and around 2 hours 30 minutes for low water. The tidal range is largest at TBT and smallest at WAG. The mean tidal range at TBT is 1.41 m and that for WAG is only 0.97 m. This distribution is in line with that observed over the south China coast. The diagram of the average maximum range of tide given in the "Sea Pilot - China Coast" published by the China Navigation Press (1976) shows a local minimum of tidal range to the south of Shanwei and a maximum at Zhangjiang with the steepest gradient in the northwest direction.

3.1 Astronomical Constituents

The amplitudes and phase lags of the major diurnal constituents (O1, P1 and K1) and semidiurnal constituents (N2, M2 and S2) are plotted in Fig. 4(a)-(1). The ratios of amplitudes of the diurnal constituents to those of the semi-diurnal ones, $(A_{K1}+A_{O1})/(A_{S2}+A_{M2})$ for all the eight locations are calculated to be in the range 0.88 to 1.32. These ratios are typical for locations with mainly semi-diurnal mixed tides (Pugh, 1987). These charts show a gradual rise of amplitude and an increase in phase lag from the east or southeast to the northwest. This agrees with the observations that the mean diurnal range of tides increases towards the northwest and that extreme waters occur in the eastern waters before those in the western waters.

Yu (1984) showed that tides in the South China Sea is mainly driven by tidal waves propagating westwards from the Pacific through the Bashi and Balintang Channel. The tidal waves were progressing from east to west in the vicinity of Hong Kong. The phase angles calculated for the major constituents (O1, P1, K1, N2, M2 and S2) agree in general with Yu's finding. The additional phase lags of LOP and TBT compared with TAO suggest that tidal waves responsible for the tides at these two locations travels round the southwest tip of the Lantau Island before reaching them. The shallowness of Deep Bay conceivably also introduces additional phase lag by impeding the propagation of the tidal wave.

3.2 Shallow Water Constituents

Table 10 gives the amplitudes of the more significant shallow water constitutents at the six tide gauge sites relative to the amplitude of M2 (the principal lunar diurnal constituent) for the same locations. Those for QUB and TPK are also listed for comparison. The relative amplitudes of those constituents which represent the influence of shallow water effects are largest at TPK, KLW, TBT and WAG. There are significant constributions from higher harmonics with frequencies about 4 cycles/day (viz. MN4, M4 and MS4) and

6 cycles/day (viz. M6 and and 2MS6) in the tidal spectra of TPK and KLW whereas in TBT the amplitudes are larger for the constituents with frequencies 1-3 cycles/day. Pugh (1987) has shown that the quaterdiurnal and hexadiurnal tidal constituents are the main contributing factors for double high waters observed in shallow water. It is therefore understandable why double high waters are not observed at TBT which is a located in waters with depth less than 4 m. The large amplitudes of OP2, MKS2, 2SK2 and SK3 observed in tides at Waglan Island are discussed in the following two sections.

3.3 Meteorological tides

The relatively large amplitudes of OP2, MKS2 and 2SK2 in the tidal spectrum of WAG as shown in Table 10, are in fact due to the seasonal modulation of the principal lunar constituent M2 and the principal solar constituent S2. The frequencies (f) of these shallow water constituents coincide with the following meteorological tides (Fang and Wang, 1986),

$$f(OP2) = f(M2) - f(SSA)$$
$$f(MKS2) = f(M2) + f(SSA)$$
$$f(2SK2) = f(S2) - f(SSA)$$

The enhanced amplitudes of these constituents indicate that the tides at Waglan Island are more susceptible to seasonal influence when compared with other locations in or near the harbour.

3.4 The Terdiurnal Oscillation

The large amplitude of SK3 (c.f. other deep-water locations) is another interesting feature of the tidal spectrum of Waglan Island. The period of this constituent is 7.993 hours representing a terdiurnal oscillation with a seasonal phase reversal between summer and winter. The maxima occur at around midnight, 8 a.m. and 4 p.m. on vernal equinoxs, and around 8 p.m., 4 a.m. and noon on autumnal equinoxs. This terdiurnal oscillation was also reported in deep sea tidal measurements in Atlantic Ocean (Cartwright et al, 1986). This phenomenon is believed to be the response of the ocean to the atmospheric tidal motion which is known to have a terdiurnal component with notable seasonal reversal in phase from summer to winter (Chapman and Lindzen, 1970).

4. PREDICTION

Tides at the six locations were hindcast with the harmonic constants derived in the previous section, and then compared with the observed data. The standard deviations of their differences (residues) are presented in Table 11. This statistic is the root mean error of the tidal prediction when the mean water level for the period is perfectly predicted. It measures the ability of the harmonic method to simulate the tidal variation.

To remove the anomalous contributions due to the 1982/83 El Nino event on the tidal harmonic series for WAG, the amplitudes and phases of SA and SSA of that location were replaced by those of the KLW before computing the predictions.

As the phase and amplitude of SA for TAO cannot be determined from the ten months of data, the annual tidal variation there was assumed to be the same as that at LOP. The amplitude and phase of SA of LOP were included in the set of harmonic constants of TAO to enable the simulation of the complete annual variation at the latter location.

Table 11 also compares the performance of the harmonic method with that of the time/height adjustment method in tidal prediction. It can be seen that the harmonic method is able to provide better predictions at the six location. In particular, the average deviation at TBT was about 5 cm less than that generated by the time/height adjustment method. The merit of the harmonic method can also be seen in Fig. 5 on which observed tides at Ko Lau Wan on two arbitrarily chosen days are plotted against the corresponding predicted tides obtained using the two different methods. Only the harmonic method is able to simulate the feature of double high water which is characteristic of the tides at KLW.

5. CONCLUSION

Tidal records of Chi Ma Wan, Ko Lau Wan, Lok On Pai, Tai O, Tsim Bei Tsui and Waglan Island were analysed with the harmonic method. The spectral characteristics of the tides at these locations were studied. It was found that sea level anomalies associated with intense El Nino events could cause appreciable errors in the determination of the annual and semi-annual tidal components (SA and SSA) when the tide record analysed is short. The study also revealed that the tide at Waglan are more susceptible to the seasonal variation of meteorological conditions than other locations and that the tides there displayed a measureable response to the terdiurnal variation in atmospheric pressure. Tidal hindcasts were made using the harmonic constants extracted for the six locations. It was demonstrated that the harmonic method was able to generate more accurate tidal prediction than the time/height adjustment method. The method has been used to generate the tidal predictions for the six locations since the 1991 tide tables.

6. ACKNOWLEDGEMENT

The author wishes to thank Miss Y.C. Leung of the Royal Observatory for her effort in re-coding the tidal analysis program to improve the efficiency and in preparing numerous tidal predictions using various sets of harmonic constants.

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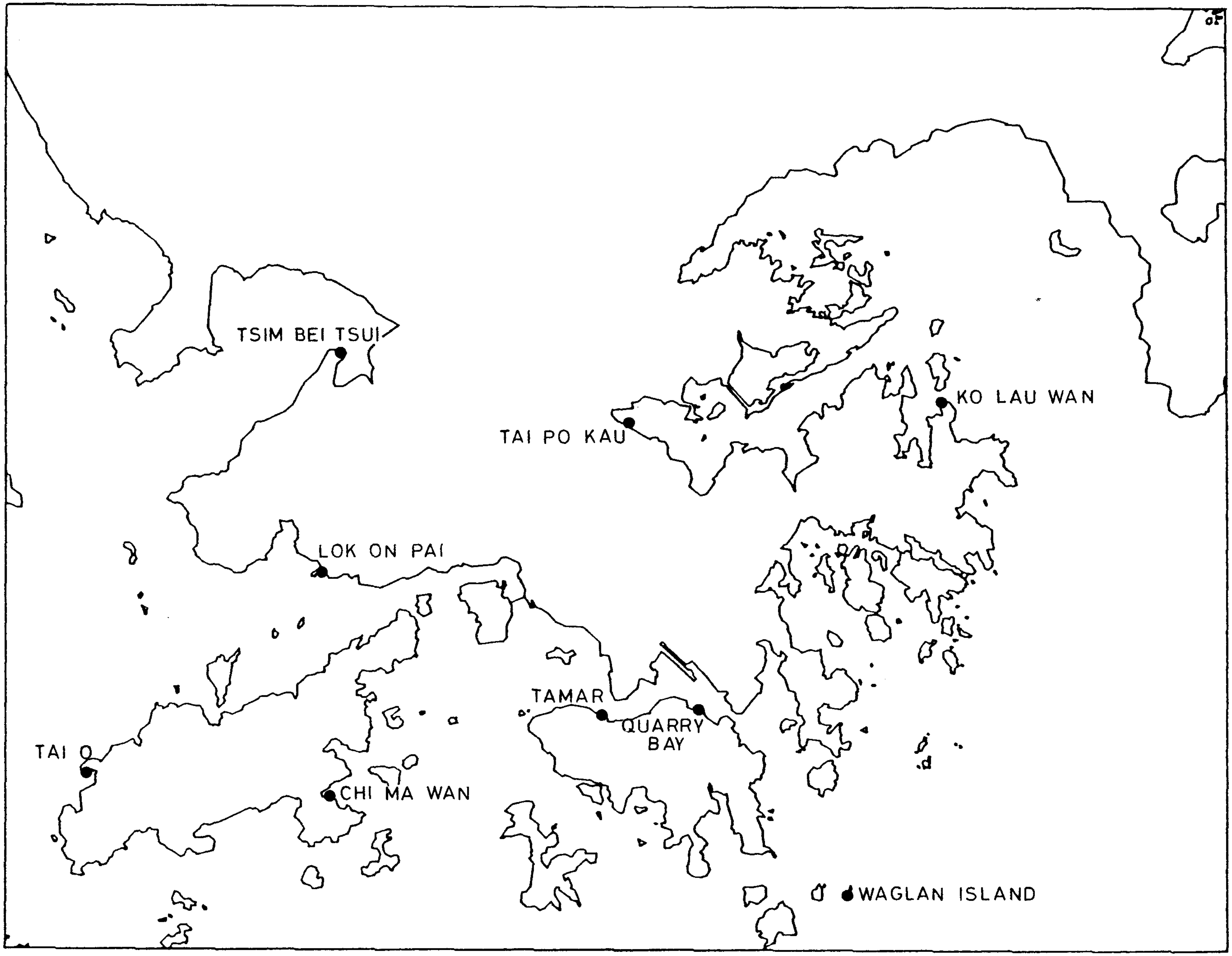
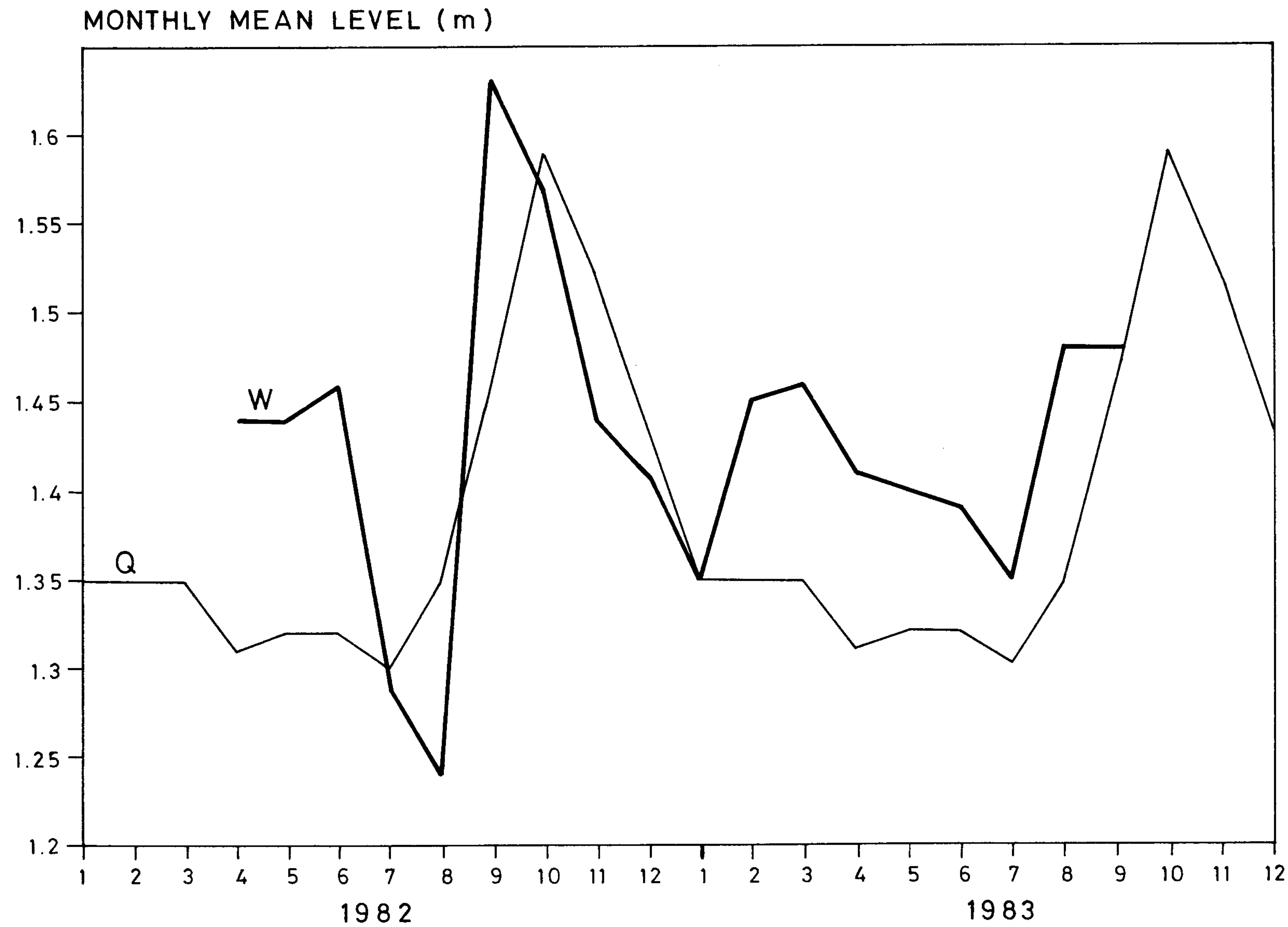


FIGURE 1 TIDE GAUGE NETWORK IN HONG KONG AS ON 1 JAN 1990



(Q) Quarry Bay 19-year average monthly mean sea level
(W) Waglan Island monthly mean sea level during 1982-1983

FIGURE 2 MONTHLY MEAN LEVELS OF WAGLAN ISLAND DURING APRIL 1982 - SEPTEMBER 1983

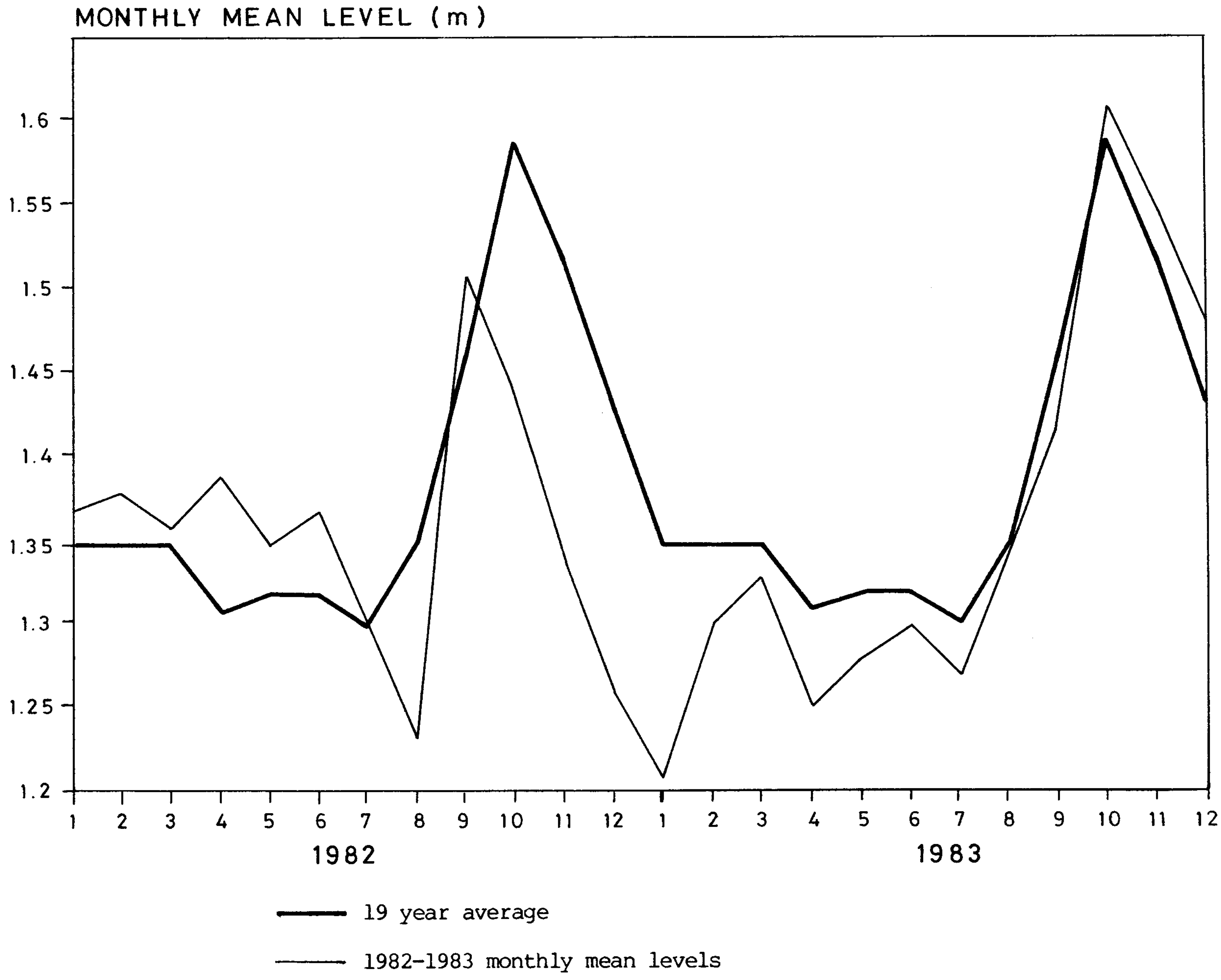


FIGURE 3 MONTHLY MEAN LEVELS AT QUARRY BAY DURING 1982-1983

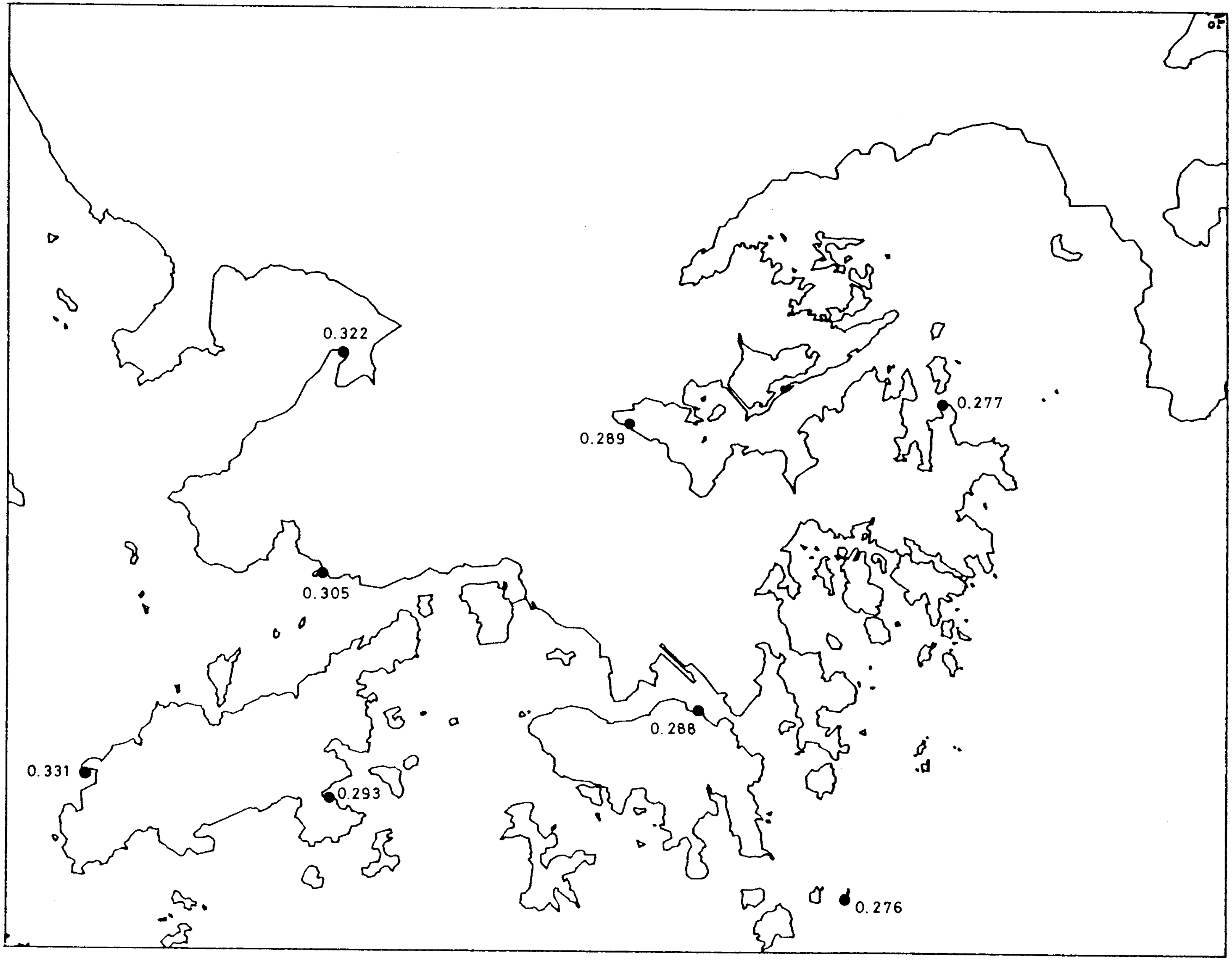


FIGURE 4(a) AMPLITUDE (m) of O1 (0.9295 cycle/day)

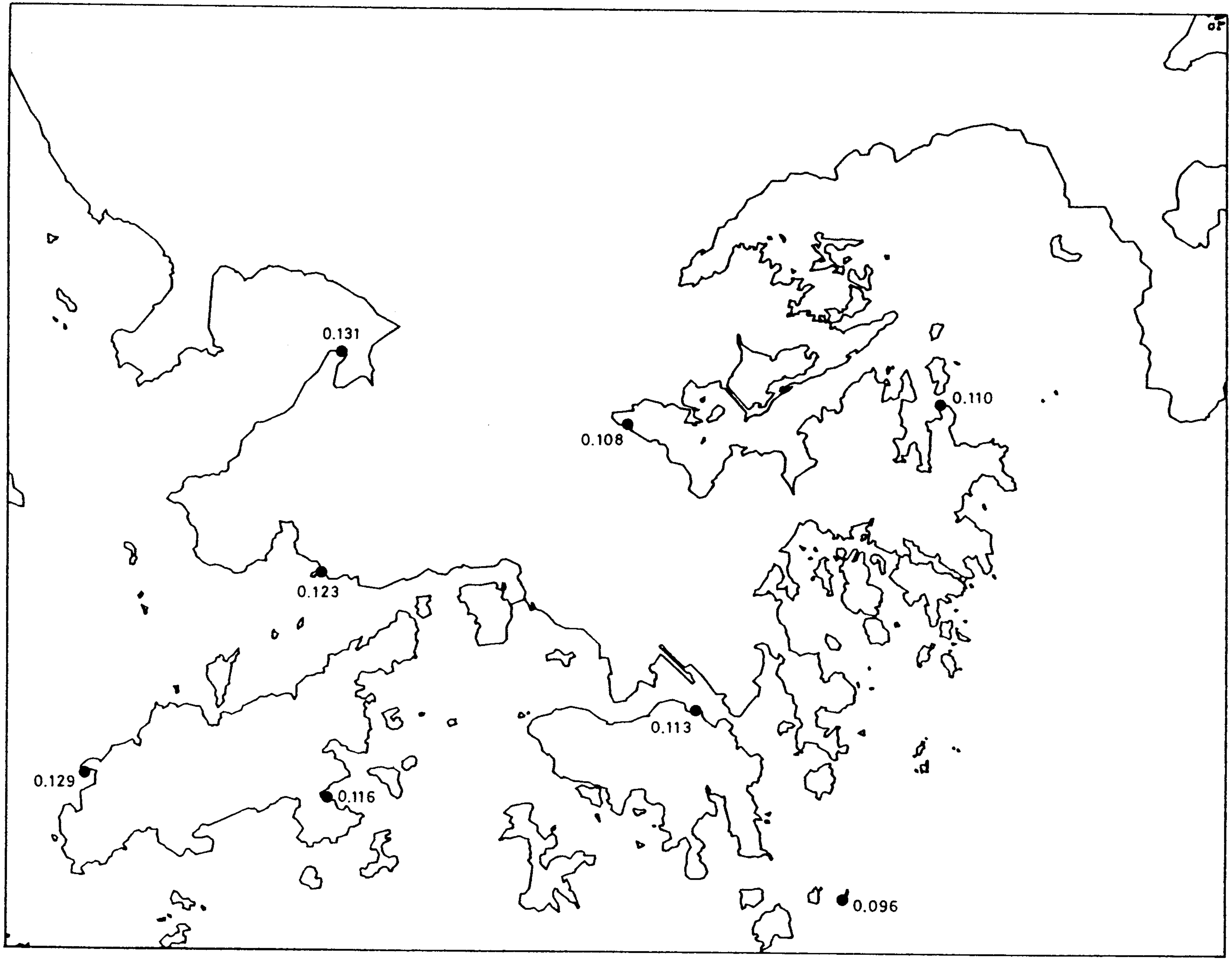


FIGURE 4(b) AMPLITUDE (m) of P1 (0.997 cycle/day)

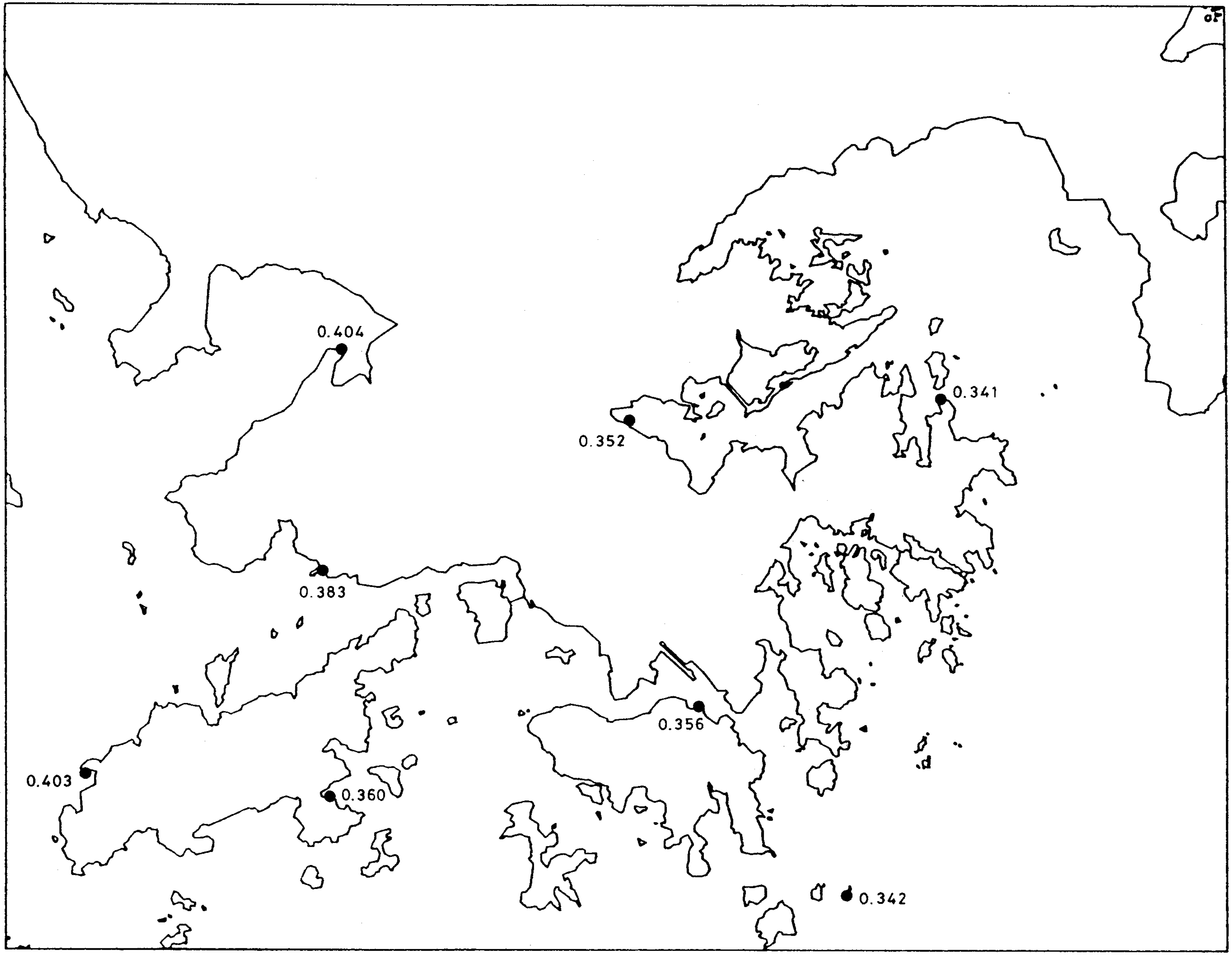


FIGURE 4(c) AMPLITUDE (m) of K1 (1.003 cycles/day)

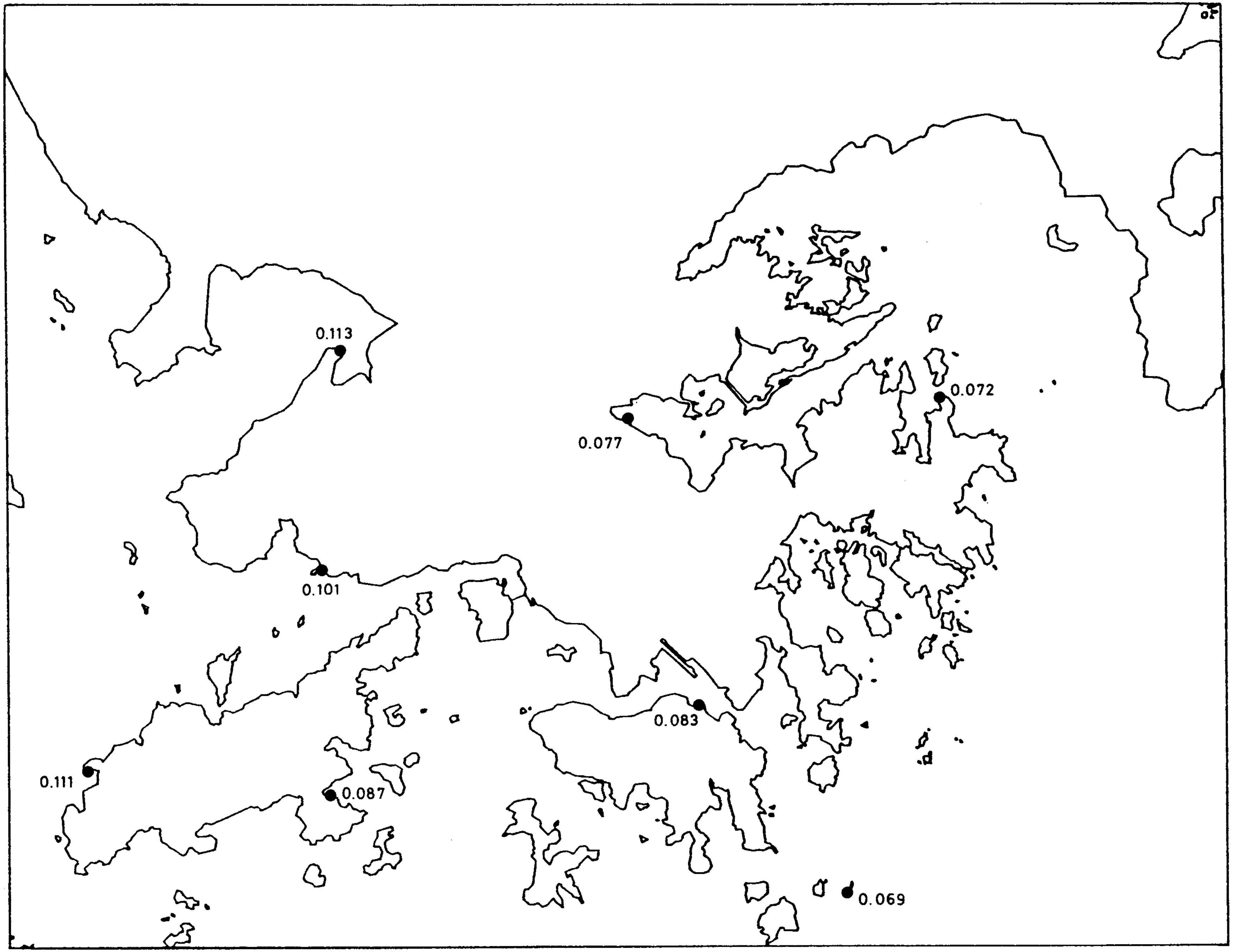


FIGURE 4(d) AMPLITUDE (m) of N2 (1.860 cycles/day)

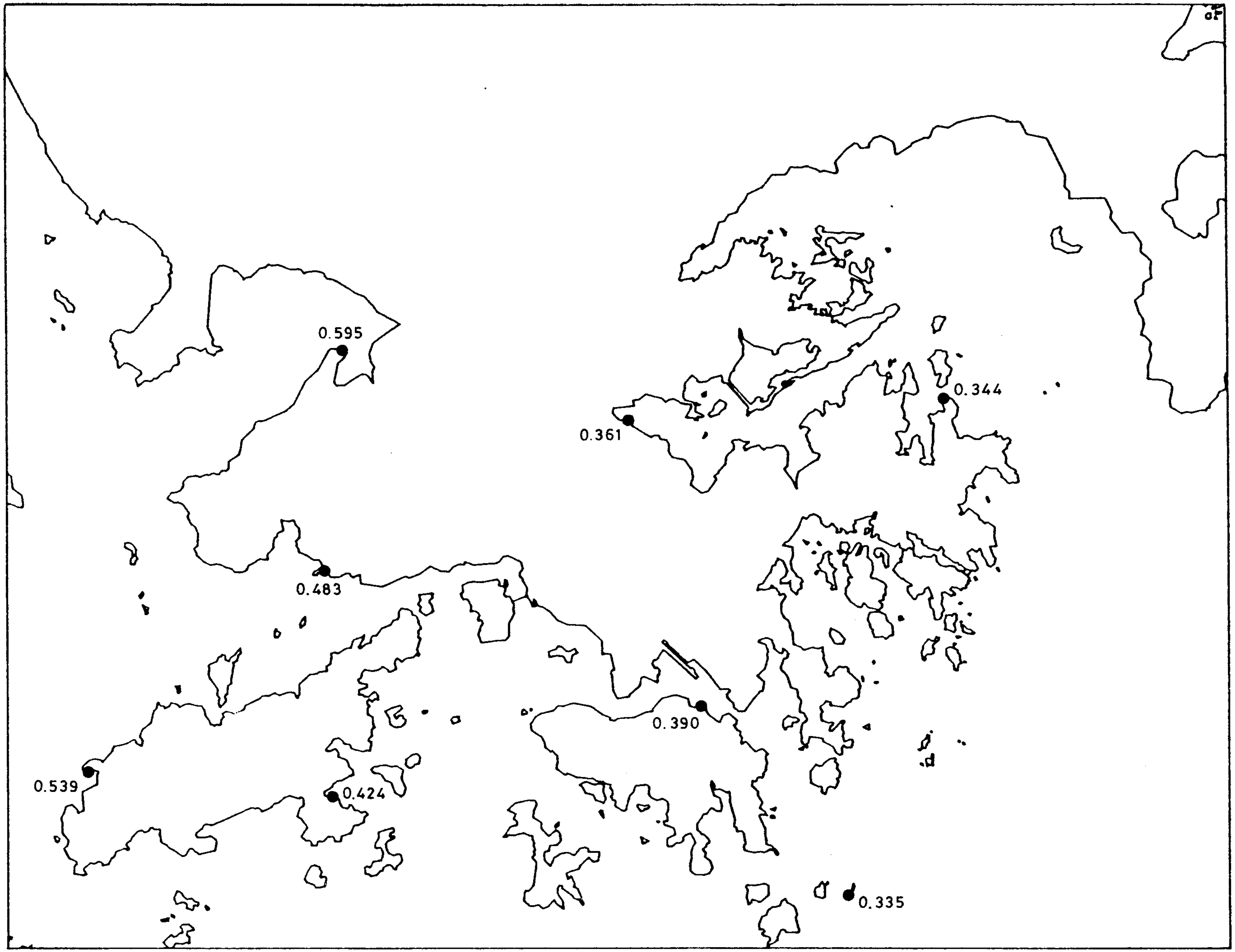


FIGURE 4(e) AMPLITUDE (m) of M2 (1.932 cycles/day)

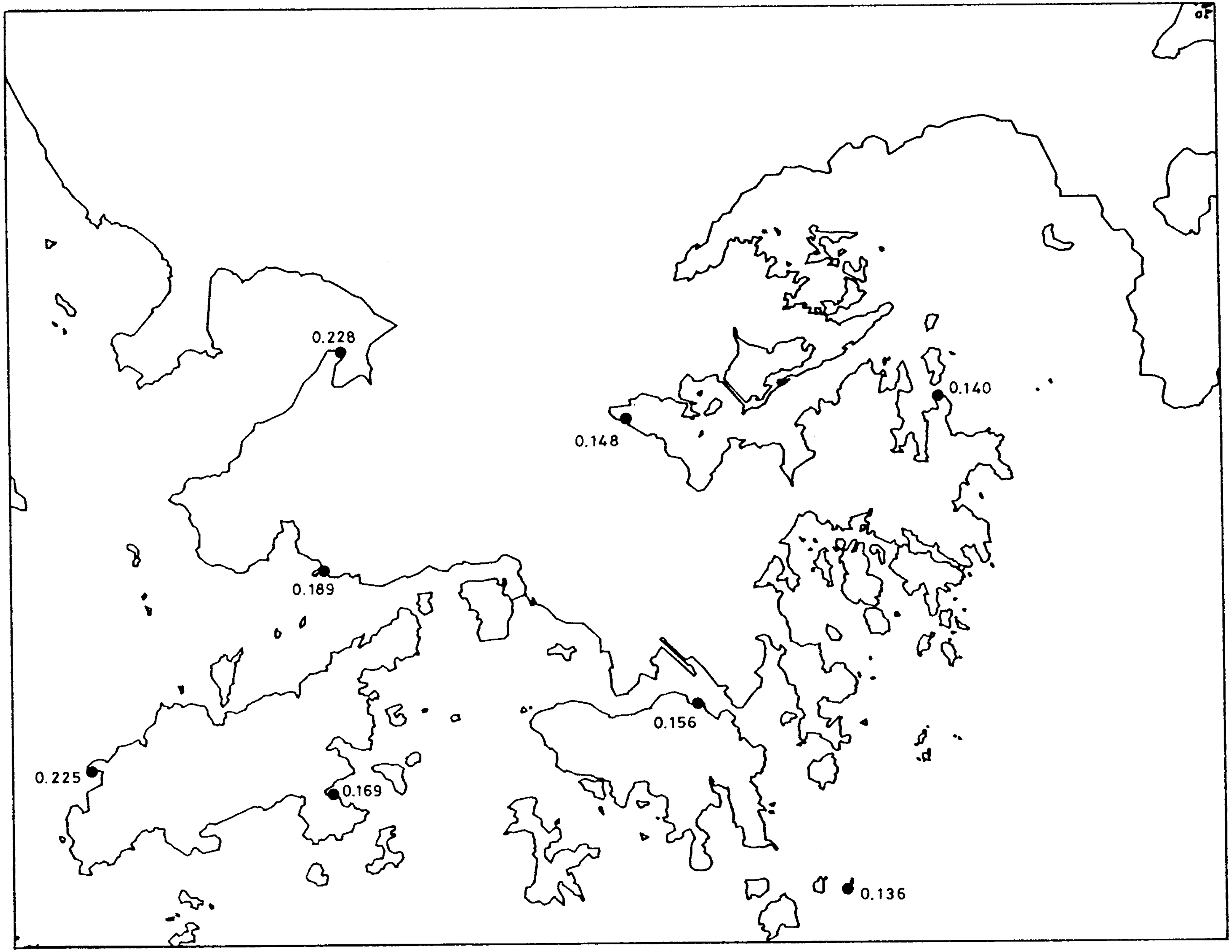


FIGURE 4(f) AMPLITUDE (m) of S2 (2.000 cycles/day)

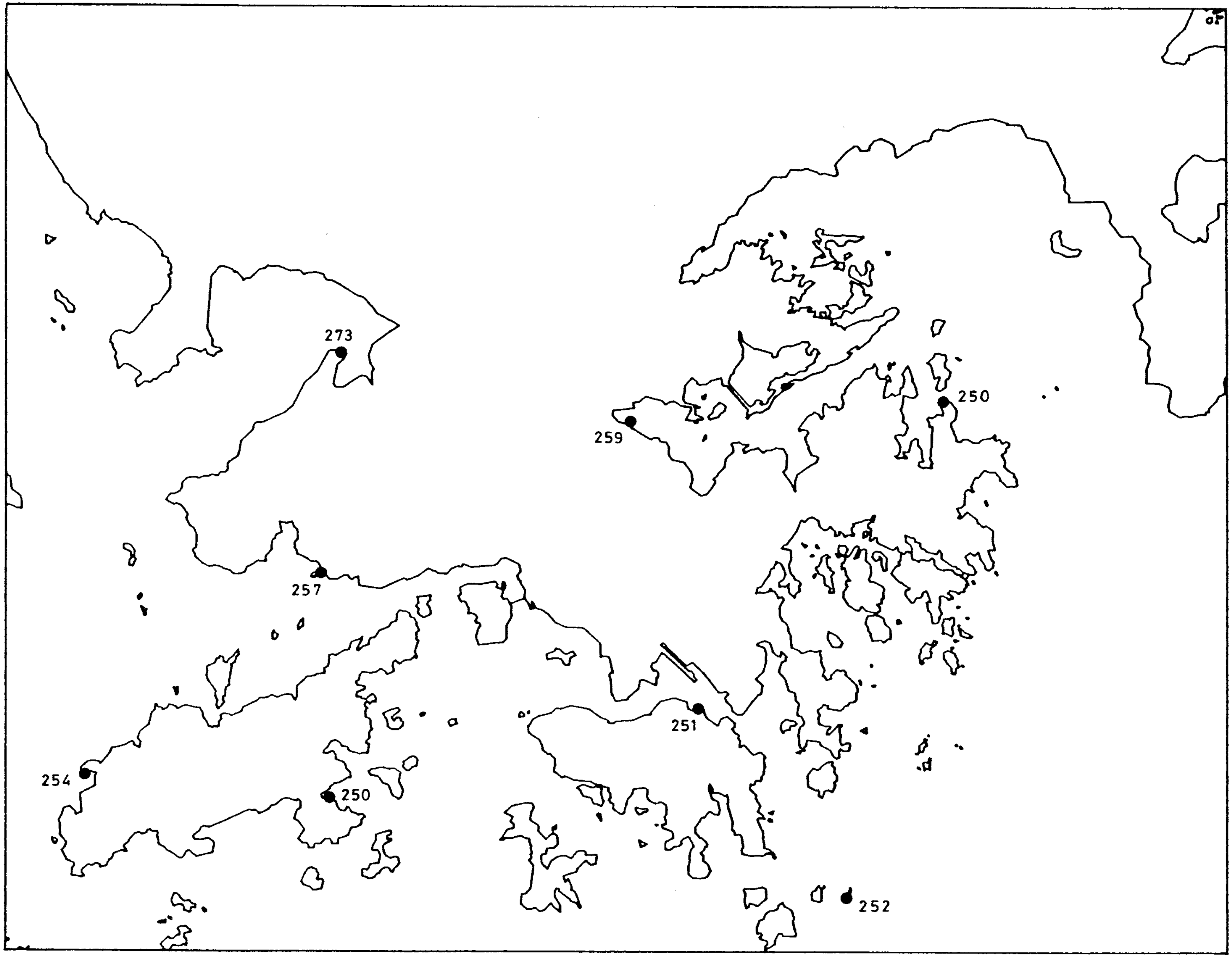


FIGURE 4(g) PHASE LAG OF O1 (0.9295 cycle/day)

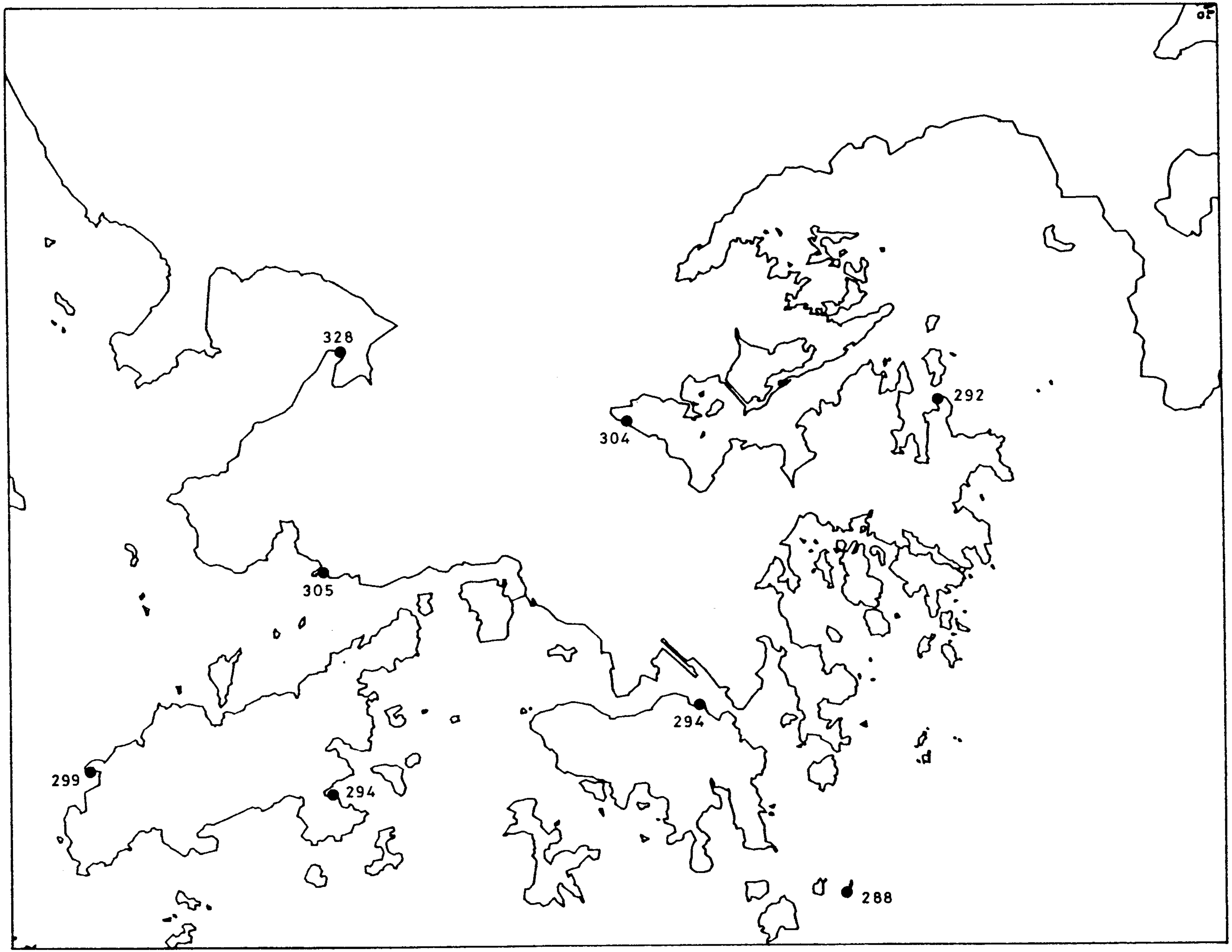


FIGURE 4(h) PHASE LAG OF P1 (0.997 cycle/day)

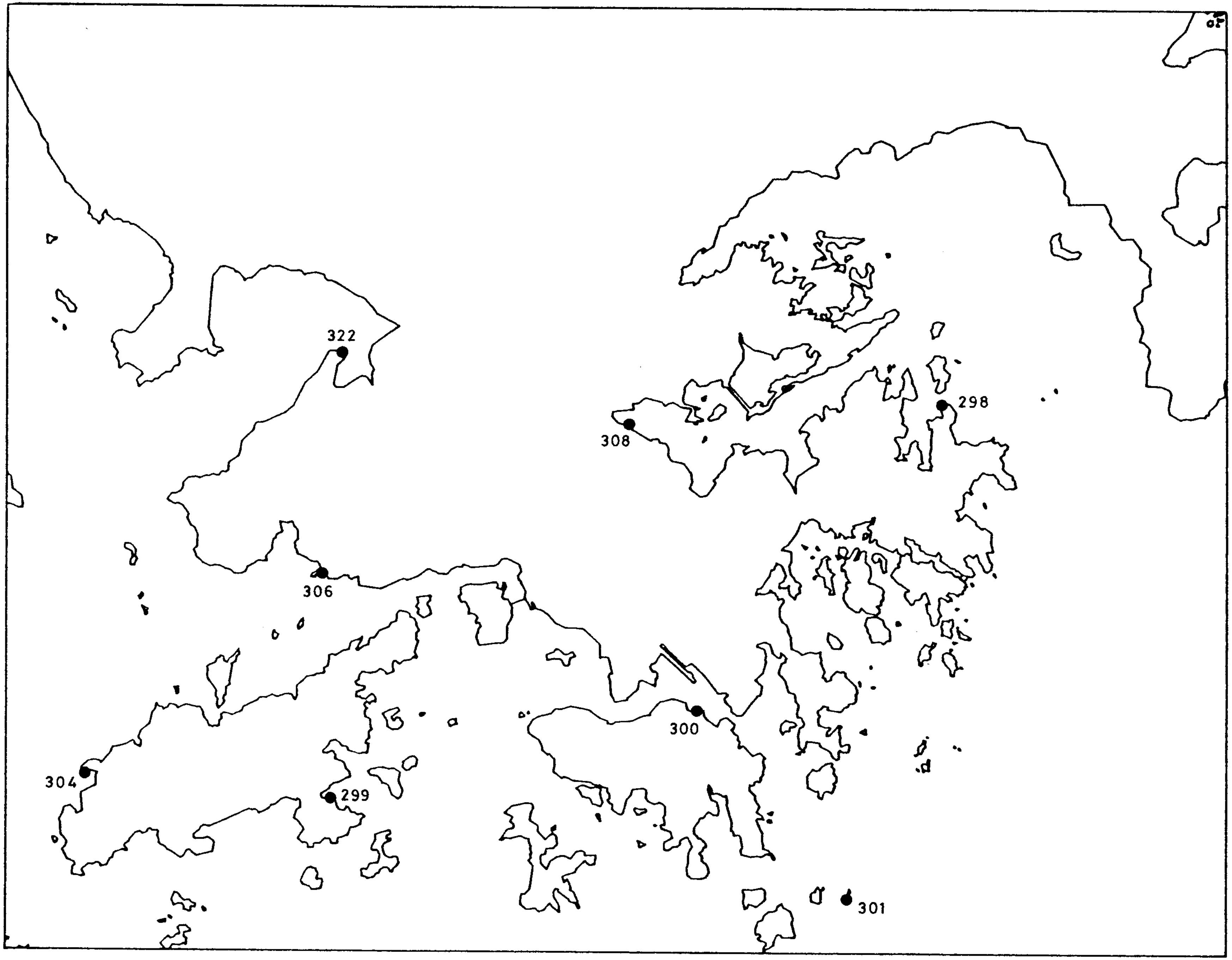


FIGURE 4(i) PHASE LAG OF K1 (1.003 cycles/day)

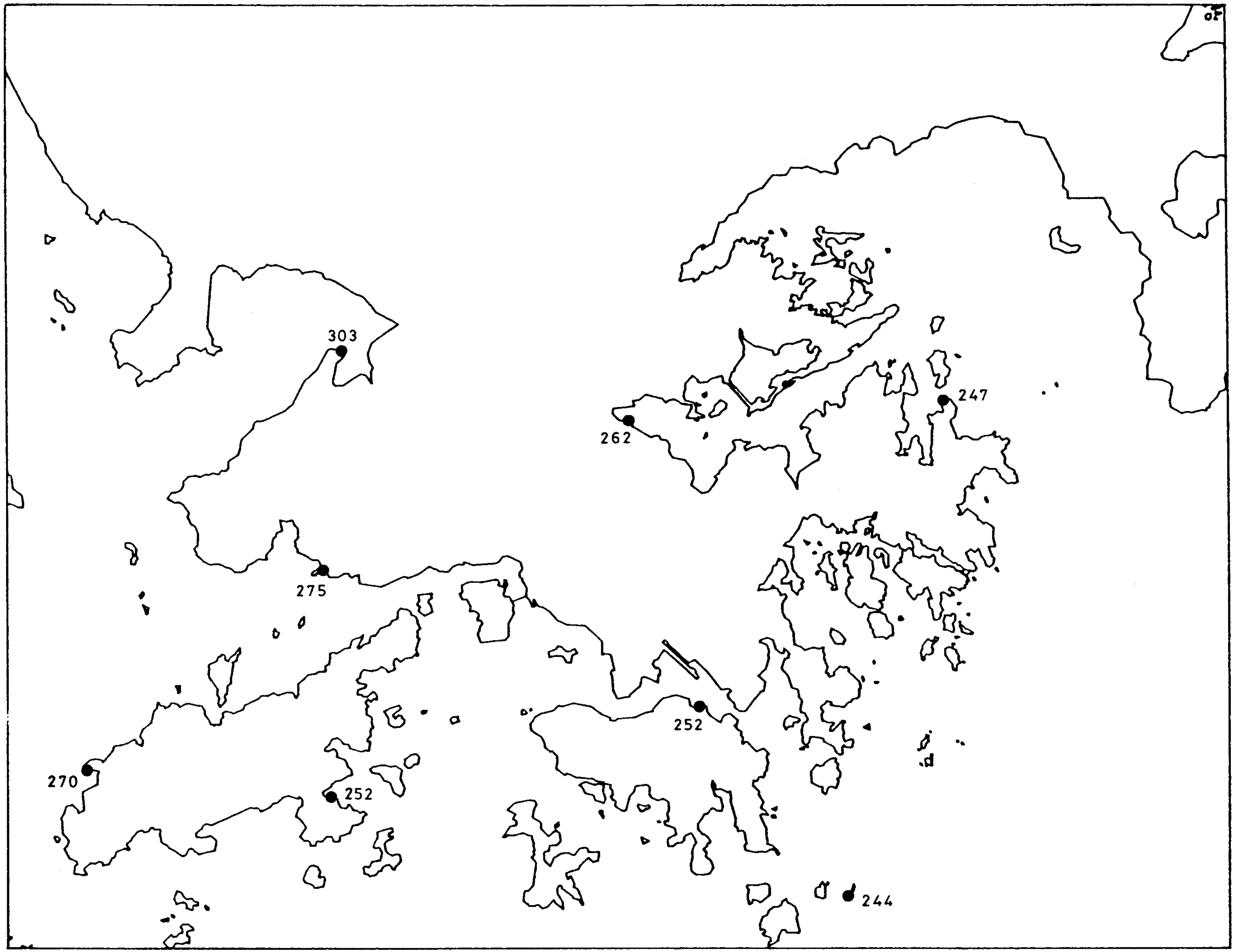


FIGURE 4(j) PHASE LAG OF N2 (1.860 cycles/day)

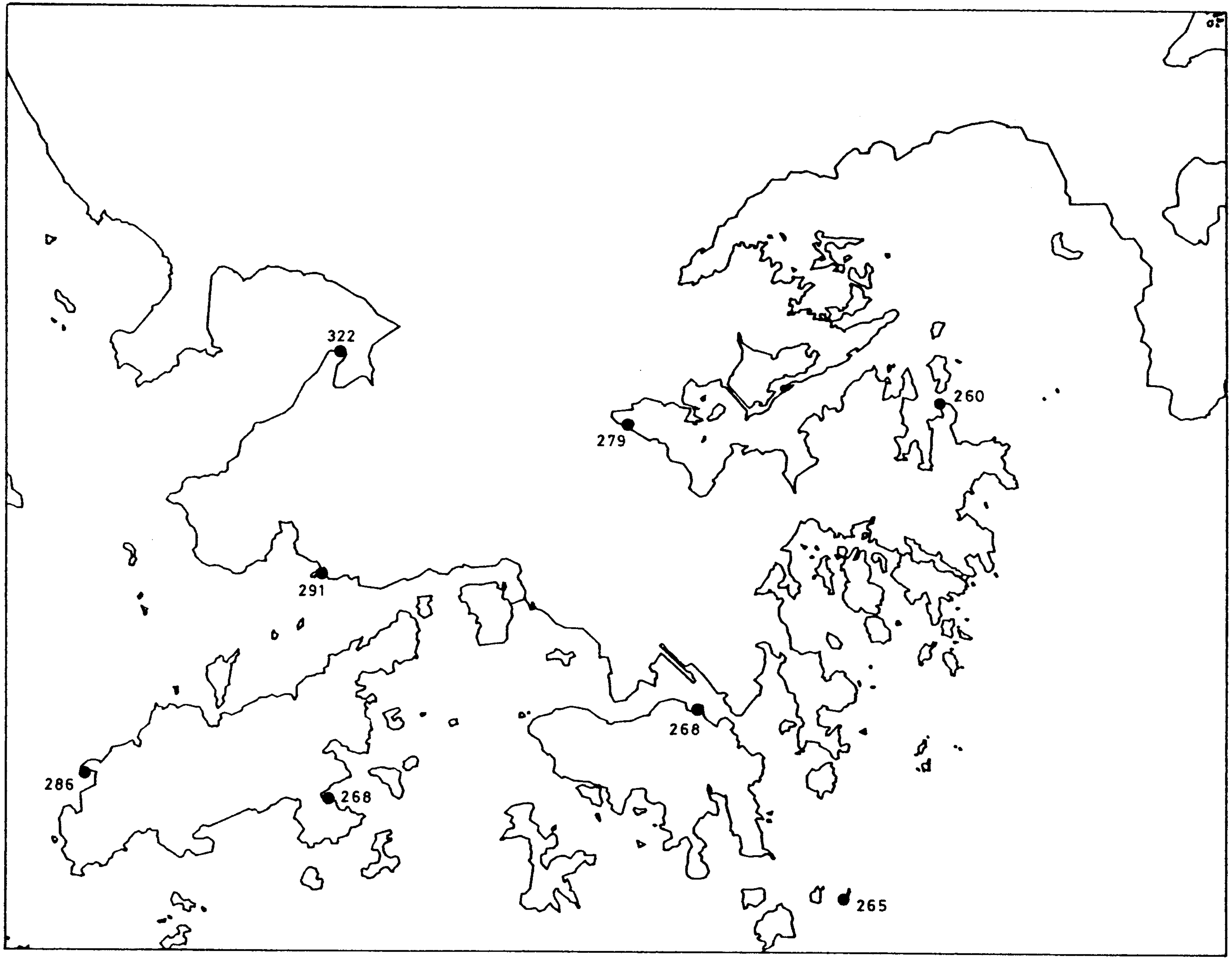


FIGURE 4(k) PHASE LAG OF M2 (1.932 cycles/day)

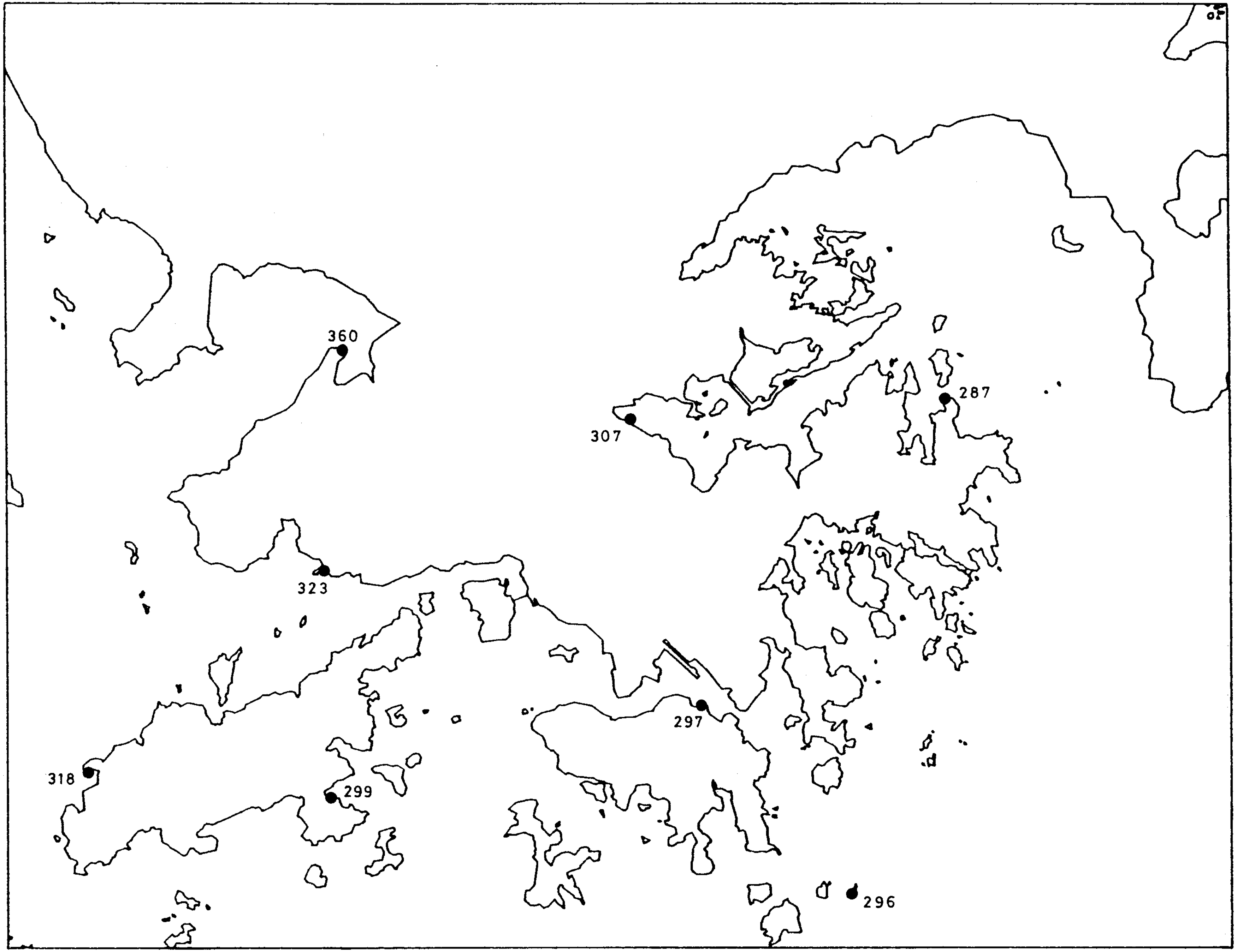


FIGURE 4(1) PHASE LAG OF S2 (2.000 cycles/day)

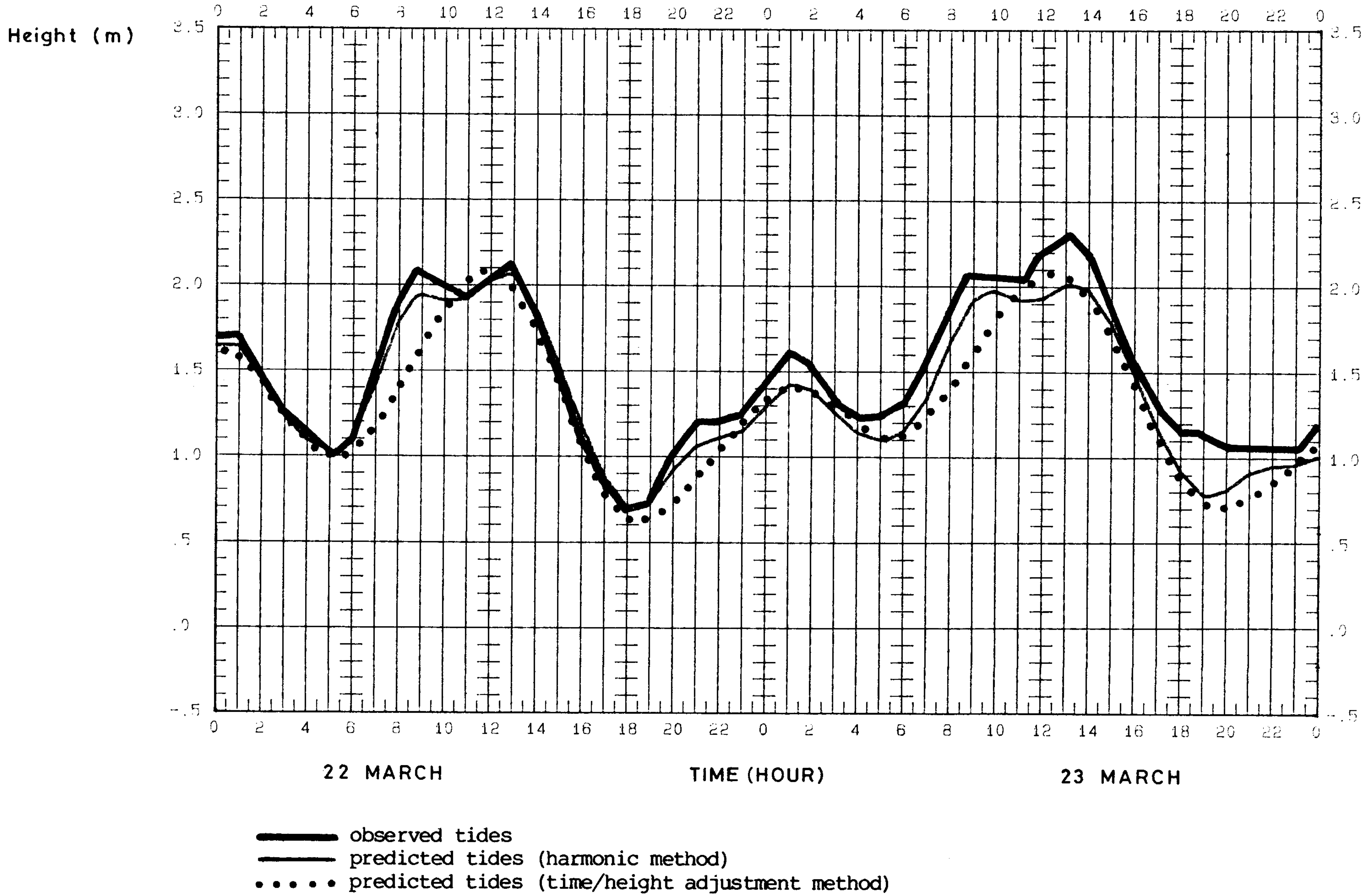


Fig. 5 Observed and predicted tides at Ko Lau Wan on 22 and 23 March, 1988

TABLE 1 TIDE RECORDS ANALYSED BY THE HARMONIC METHOD

Location	Period analysed	No. of hourly data	Data Availability (%)	r.m.s. residue of regression (m)	variance explained (%)
Chi Ma Wan	1.1.1968 - 23.10.1972* 1.11.1973 - 28.2.1979	40707 42995	96 92	0.142 0.170	93 88
Ko Lau Wan	1.3.1988 - 31.7.1989*	11131	88	0.164	89
Lok On Pai	1.1.1983 - 31.12.1987 1.1.1984 - 31.12.1988*	42535 42592	97 97	0.130 0.133	95 95
Tai O	5.11.1987 - 30.8.1988	7069	98	0.177	92
Tsim Bei Tsui	1.11.1980 - 31.7.1984* 1.5.1985 - 31.12.1988	36199 28129	90 87	0.183 0.212	92 88
Waglan	13.4.1982 - 8.9.1983*	11674	86	0.158	88

* Harmonic constants derived from these records are shown in Tables 2-7

TABLE 2 HARMONIC CONSTANTS DERIVED FROM TIDES AT CHI MA WAN

NAME	AMPLITUDE (M)	PHASE (DEG)
Z0	1.4682	0.00
SA	0.1098	294.28
SSA	0.0409	51.80
MSM	0.0096	117.54
MM	0.0083	238.91
MSF	0.0106	39.66
MF	0.0140	340.64
ALP1	0.0010	177.44
2Q1	0.0071	206.98
SIG1	0.0061	236.76
Q1	0.0535	227.08
RHO1	0.0113	228.15
O1	0.2929	250.49
TAU1	0.0069	27.16
BET1	0.0026	284.35
NO1	0.0153	301.04
CHI1	0.0041	273.32
PI1	0.0059	295.00
P1	0.1163	293.92
S1	0.0060	308.64
K1	0.3600	299.23
PSI1	0.0031	197.48
PHI1	0.0033	311.24
THE1	0.0040	338.23
J1	0.0147	324.70
SO1	0.0030	222.44
OO1	0.0058	20.21
UPS1	0.0003	101.10
ST36	0.0005	224.20
2NS2	0.0005	29.38
ST37	0.0020	270.84
OQ2	0.0014	170.51
EPS2	0.0048	189.53
2N2	0.0132	237.10
MU2	0.0206	215.89
SNK2	0.0012	215.47
N2	0.0870	251.73
NU2	0.0158	261.02
OP2	0.0040	91.27
H1	0.0082	291.25
M2	0.4237	267.76
H2	0.0034	201.84
MKS2	0.0009	51.68
LDA2	0.0026	309.73
L2	0.0092	302.06
2SK2	0.0008	44.32
T2	0.0095	286.84
S2	0.1686	299.04
R2	0.0050	104.31

NAME	AMPLITUDE (M)	PHASE (DEG)
K2	0.0475	297.76
MSN2	0.0007	241.24
ETA2	0.0035	311.62
2SM2	0.0008	297.31
SKM2	0.0007	318.32
MO3	0.0092	4.26
M3	0.0133	347.40
SO3	0.0070	22.17
MK3	0.0143	37.56
SK3	0.0059	101.88
ST8	0.0013	0.20
N4	0.0021	277.50
3MS4	0.0028	93.02
MN4	0.0136	314.33
ST40	0.0004	217.04
M4	0.0355	340.71
SN4	0.0028	357.01
MS4	0.0209	27.56
MK4	0.0069	39.95
S4	0.0023	23.07
SK4	0.0012	98.68
2MK5	0.0020	237.59
MSK5	0.0011	11.10
2SK5	0.0006	7.33
2MN6	0.0024	118.82
ST41	0.0012	45.75
M6	0.0045	155.56
2MS6	0.0037	206.26
2MK6	0.0013	175.02
2SM6	0.0020	282.70
MSK6	0.0007	196.38
3MK7	0.0005	199.80
ST18	0.0006	54.09
3MN8	0.0007	41.87
M8	0.0007	82.78
ST20	0.0004	124.18
3MS8	0.0008	132.21
3MK8	0.0010	152.08
ST22	0.0006	152.70
ST23	0.0000	59.92
ST24	0.0008	163.69
M10	0.0023	210.28
ST29	0.0022	234.36
ST30	0.0043	266.48
ST31	0.0011	303.74
ST32	0.0023	325.38
M12	0.0003	213.66
ST34	0.0005	330.60

TABLE 3 HARMONIC CONSTANTS DERIVED FROM TIDES AT KO LAU WAN

NAME	AMPLITUDE (M)	PHASE (DEG)
Z0	1.4572	0.00
SA	0.1249	315.26
SSA	0.0630	38.29
MSM	0.0144	17.92
MM	0.0099	235.94
MSF	0.0468	52.64
MF	0.0093	61.82
ALP1	0.0036	239.38
2Q1	0.0048	220.26
SIG1	0.0069	220.16
Q1	0.0572	227.86
RHO1	0.0118	224.62
O1	0.2768	250.05
TAU1	0.0069	3.42
BET1	0.0033	267.26
NO1	0.0182	275.41
CHI1	0.0050	264.05
PI1	0.0064	301.70
P1	0.1098	292.10
S1	0.0082	307.04
K1	0.3409	297.87
PSI1	0.0064	162.70
PHI1	0.0045	10.46
THE1	0.0053	305.40
J1	0.0137	324.27
SO1	0.0024	191.50
OO1	0.0068	12.88
UPS1	0.0016	34.24
ST36	0.0013	172.49
2NS2	0.0007	243.79
ST37	0.0006	289.08
OQ2	0.0008	154.85
EPS2	0.0046	189.54
2N2	0.0135	213.05
MU2	0.0195	214.15
SNK2	0.0017	160.09
N2	0.0721	246.68
NU2	0.0102	257.83
OP2	0.0038	76.20
H1	0.0064	252.77
M2	0.3439	260.31
H2	0.0033	53.47
MKS2	0.0036	2.10
LDA2	0.0022	284.62
L2	0.0058	238.20
2SK2	0.0009	80.01
T2	0.0079	270.03
S2	0.1401	287.45
R2	0.0024	131.38

NAME	AMPLITUDE (M)	PHASE (DEG)
K2	0.0394	286.27
MSN2	0.0018	298.90
ETA2	0.0030	281.40
2SM2	0.0028	49.40
SKM2	0.0015	4.57
MO3	0.0171	1.33
M3	0.0165	327.96
SO3	0.0100	33.89
MK3	0.0192	37.11
SK3	0.0108	87.44
ST8	0.0055	354.67
N4	0.0062	309.62
3MS4	0.0097	75.22
MN4	0.0283	258.97
ST40	0.0060	118.54
M4	0.0817	295.78
SN4	0.0034	270.83
MS4	0.0479	357.04
MK4	0.0099	1.18
S4	0.0000	304.04
SK4	0.0024	37.54
2MK5	0.0058	216.47
MSK5	0.0037	254.56
2SK5	0.0002	123.00
2MN6	0.0149	93.13
ST41	0.0012	8.66
M6	0.0268	128.70
2MS6	0.0240	183.28
2MK6	0.0070	173.88
2SM6	0.0060	229.99
MSK6	0.0039	220.85
3MK7	0.0024	287.85
ST18	0.0005	274.05
3MN8	0.0003	97.35
M8	0.0008	68.53
ST20	0.0009	84.59
3MS8	0.0001	270.87
3MK8	0.0010	355.01
ST22	0.0004	60.25
ST23	0.0005	31.91
ST24	0.0003	27.33
M10	0.0010	311.29
ST29	0.0008	325.67
ST30	0.0012	350.45
ST31	0.0001	211.17
ST32	0.0008	65.39
M12	0.0004	103.03
ST34	0.0008	31.91

TABLE 4 HARMONIC CONSTANTS DERIVED FROM TIDES AT LOK ON PAI

NAME	AMPLITUDE (M)	PHASE (DEG)
Z0	1.3426	0.00
SA	0.0880	279.20
SSA	0.0525	70.77
MSM	0.0059	20.89
MM	0.0067	28.69
MSF	0.0204	82.54
MF	0.0062	71.15
ALP1	0.0028	278.04
2Q1	0.0071	231.21
SIG1	0.0066	284.50
Q1	0.0564	236.68
RHO1	0.0110	232.85
O1	0.3053	257.32
TAU1	0.0172	54.34
BET1	0.0046	261.43
NO1	0.0252	262.39
CHI1	0.0051	281.14
PI1	0.0101	295.81
P1	0.1226	304.56
S1	0.0143	339.01
K1	0.3830	306.28
PSI1	0.0083	188.73
PHI1	0.0044	303.04
THE1	0.0034	326.61
J1	0.0124	333.11
SO1	0.0050	148.60
OO1	0.0073	22.65
UPS1	0.0009	94.37
ST36	0.0006	256.48
2NS2	0.0009	205.46
ST37	0.0034	345.05
OQ2	0.0014	221.93
EPS2	0.0041	215.57
2N2	0.0151	249.28
MU2	0.0206	246.03
SNK2	0.0013	225.76
N2	0.1005	275.48
NU2	0.0143	278.80
OP2	0.0075	113.69
GAM2	0.0009	134.73
H1	0.0172	322.02
M2	0.4825	290.68
H2	0.0093	165.50
MKS2	0.0026	336.81
LDA2	0.0036	283.84
L2	0.0095	285.97
2SK2	0.0022	347.75
T2	0.0091	290.26
S2	0.1890	323.34

NAME	AMPLITUDE (M)	PHASE (DEG)
R2	0.0015	122.23
K2	0.0555	323.53
MSN2	0.0008	169.23
ETA2	0.0043	359.77
2SM2	0.0024	116.47
SKM2	0.0020	63.86
MO3	0.0048	41.91
M3	0.0139	24.12
SO3	0.0061	76.49
MK3	0.0127	80.08
SK3	0.0069	146.61
ST8	0.0008	96.06
N4	0.0014	330.05
3MS4	0.0021	133.09
MN4	0.0072	1.41
ST40	0.0005	247.48
M4	0.0210	32.91
SN4	0.0015	74.19
MS4	0.0133	87.85
MK4	0.0050	85.16
S4	0.0018	134.44
SK4	0.0016	128.53
2MK5	0.0017	343.45
MSK5	0.0012	67.00
2SK5	0.0003	34.55
2MN6	0.0014	212.57
ST41	0.0009	106.36
M6	0.0023	253.08
2MS6	0.0017	321.34
2MK6	0.0006	170.92
2SM6	0.0008	20.13
MSK6	0.0006	193.39
3MK7	0.0002	327.94
ST18	0.0001	48.06
3MN8	0.0005	62.01
M8	0.0004	97.13
ST20	0.0005	156.70
3MS8	0.0008	155.69
3MK8	0.0005	154.19
ST22	0.0003	190.51
ST23	0.0005	188.55
ST24	0.0006	226.89
M10	0.0017	227.97
ST29	0.0020	251.83
ST30	0.0035	276.71
ST31	0.0004	333.46
ST32	0.0017	353.83
M12	0.0004	310.20
ST34	0.0006	318.17

TABLE 5 HARMONIC CONSTANTS DERIVED FROM TIDES AT TAI O

NAME	AMPLITUDE (M)	PHASE (DEG)
Z0	1.3397	0.00
SSA	0.0405	132.06
MSM	0.0375	107.47
MM	0.0043	334.73
MSF	0.0186	65.25
MF	0.0319	20.65
ALP1	0.0034	224.98
2Q1	0.0101	220.43
SIG1	0.0043	243.97
Q1	0.0637	227.81
RHO1	0.0140	225.56
O1	0.3313	254.15
TAU1	0.0058	32.07
BET1	0.0011	279.63
NO1	0.0201	284.22
CHI1	0.0093	298.80
P1	0.1287	299.25
K1	0.4027	304.08
PHI1	0.0070	207.35
THE1	0.0094	322.09
J1	0.0167	330.00
SO1	0.0035	275.05
OO1	0.0060	11.79
UPS1	0.0004	93.46
ST36	0.0006	169.00
2NS2	0.0031	240.61
ST37	0.0046	331.41
OQ2	0.0028	266.43
EPS2	0.0071	233.65
2N2	0.0190	242.66
MU2	0.0279	239.48
SNK2	0.0049	259.81
N2	0.1113	269.89
NU2	0.0216	269.50
OP2	0.0081	132.08
M2	0.5385	286.27
MKS2	0.0030	97.87
LDA2	0.0031	288.01
L2	0.0069	268.40
2SK2	0.0066	50.39
S2	0.2249	318.23
K2	0.0565	318.47
MSN2	0.0021	35.93
ETA2	0.0038	297.56
2SM2	0.0024	87.89

NAME	AMPLITUDE (M)	PHASE (DEG)
SKM2	0.0029	64.00
MO3	0.0007	282.16
M3	0.0181	32.10
SO3	0.0064	348.38
MK3	0.0113	10.12
SK3	0.0035	98.99
ST8	0.0022	162.05
N4	0.0030	273.58
3MS4	0.0021	302.58
MN4	0.0165	357.55
ST40	0.0041	335.38
M4	0.0443	26.09
SN4	0.0051	34.67
MS4	0.0232	66.61
MK4	0.0066	55.60
S4	0.0016	90.22
SK4	0.0025	72.96
2MK5	0.0032	17.19
MSK5	0.0025	50.62
2SK5	0.0006	26.05
2MN6	0.0025	192.60
ST41	0.0012	107.51
M6	0.0045	211.35
2MS6	0.0027	262.58
2MK6	0.0016	250.53
2SM6	0.0012	352.56
MSK6	0.0009	226.82
3MK7	0.0016	152.40
ST18	0.0006	220.95
3MN8	0.0008	158.13
M8	0.0002	159.57
ST20	0.0004	90.82
3MS8	0.0003	99.88
3MK8	0.0006	305.20
ST22	0.0002	257.01
ST23	0.0003	2.99
ST24	0.0005	284.05
M10	0.0010	334.62
ST29	0.0012	46.83
ST30	0.0003	103.04
ST31	0.0003	141.09
ST32	0.0007	98.21
M12	0.0005	329.40
ST34	0.0007	171.85

TABLE 6 HARMONIC CONSTANTS DERIVED FROM TIDES AT TSIM BEI TSUI

NAME	AMPLITUDE (M)	PHASE (DEG)
Z0	1.4115	0.00
SA	0.0762	274.73
SSA	0.0416	86.45
MSM	0.0182	59.48
MM	0.0221	32.70
MSF	0.0225	106.99
MF	0.0145	243.11
ALP1	0.0070	332.46
2Q1	0.0055	223.45
SIG1	0.0197	324.04
Q1	0.0562	256.39
RHO1	0.0090	236.50
O1	0.3222	273.46
TAU1	0.0250	64.84
BET1	0.0083	262.94
NO1	0.0172	314.03
CHI1	0.0024	249.42
PI1	0.0101	345.12
P1	0.1311	327.94
S1	0.0202	9.70
K1	0.4035	321.90
PSI1	0.0082	134.06
PHI1	0.0056	325.03
THE1	0.0044	349.84
J1	0.0147	8.50
SO1	0.0204	114.81
OO1	0.0163	36.95
UPS1	0.0021	92.63
ST36	0.0027	281.51
2NS2	0.0033	332.25
ST37	0.0043	346.97
OQ2	0.0020	190.47
EPS2	0.0041	66.27
2N2	0.0162	282.51
MU2	0.0111	335.89
SNK2	0.0061	302.13
N2	0.1129	302.77
NU2	0.0189	300.58
OP2	0.0292	127.36
GAM2	0.0174	87.50
H1	0.0179	263.52
M2	0.5954	322.00
H2	0.0392	126.90
MKS2	0.0140	28.08
LDA2	0.0105	316.56
L2	0.0201	325.88
2SK2	0.0073	16.96
T2	0.0140	9.39
S2	0.2275	359.91

NAME	AMPLITUDE (M)	PHASE (DEG)
R2	0.0065	15.84
K2	0.0937	2.60
MSN2	0.0063	156.86
ETA2	0.0058	63.84
2SM2	0.0109	174.92
SKM2	0.0072	61.16
MO3	0.0318	126.51
M3	0.0187	101.30
SO3	0.0250	184.18
MK3	0.0339	173.83
SK3	0.0234	232.23
ST8	0.0047	191.60
N4	0.0043	113.67
3MS4	0.0115	221.71
MN4	0.0139	105.88
ST40	0.0035	82.02
M4	0.0512	146.14
SN4	0.0036	194.32
MS4	0.0349	205.49
MK4	0.0159	184.94
S4	0.0043	280.88
SK4	0.0083	245.91
2MK5	0.0041	80.88
MSK5	0.0037	118.47
2SK5	0.0016	154.72
2MN6	0.0033	304.30
ST41	0.0038	233.13
M6	0.0064	22.26
2MS6	0.0073	101.20
2MK6	0.0012	320.19
2SM6	0.0029	185.73
MSK6	0.0013	27.31
3MK7	0.0015	54.00
ST18	0.0005	245.42
3MN8	0.0010	322.46
M8	0.0014	313.83
ST20	0.0011	354.08
3MS8	0.0016	15.97
3MK8	0.0018	137.08
ST22	0.0002	238.70
ST23	0.0016	55.92
ST24	0.0023	189.17
M10	0.0006	181.40
ST29	0.0010	233.44
ST30	0.0009	230.57
ST31	0.0002	12.38
ST32	0.0005	311.72
M12	0.0002	76.50
ST34	0.0003	59.21

TABLE 7 HARMONIC CONSTANTS DERIVED FROM TIDES AT WAGLAN ISLAND

NAME	AMPLITUDE (M)	PHASE (DEG)
Z0	1.4339	0.00
SA	0.0419	291.23
SSA	0.0844	37.85
MSM	0.0233	120.87
MM	0.0219	59.98
MSF	0.0244	129.81
MF	0.0019	62.99
ALP1	0.0030	226.51
2Q1	0.0084	203.04
SIG1	0.0080	255.46
Q1	0.0509	230.30
RHO1	0.0118	228.01
O1	0.2756	252.40
TAU1	0.0113	303.65
BET1	0.0082	293.93
NO1	0.0083	259.06
CHI1	0.0060	281.63
PI1	0.0197	5.17
P1	0.0958	287.76
S1	0.0226	331.40
K1	0.3418	300.87
PSI1	0.0093	169.85
PHI1	0.0091	127.31
THE1	0.0003	233.34
J1	0.0193	321.10
SO1	0.0022	85.47
OO1	0.0043	28.69
UPS1	0.0003	182.61
ST36	0.0008	204.43
2NS2	0.0005	211.25
ST37	0.0015	208.79
OQ2	0.0017	284.32
EPS2	0.0042	233.54
2N2	0.0067	196.73
MU2	0.0153	239.55
SNK2	0.0079	327.86
N2	0.0692	243.55
NU2	0.0123	242.69
OP2	0.0378	148.48
H1	0.0231	125.61
M2	0.3345	265.19
H2	0.0193	178.04
MKS2	0.0194	69.60
LDA2	0.0093	325.72
L2	0.0046	238.97
2SK2	0.0189	6.44
T2	0.0166	305.37
S2	0.1355	296.34
R2	0.0058	18.26

NAME	AMPLITUDE (M)	PHASE (DEG)
K2	0.0344	295.92
MSN2	0.0034	60.88
ETA2	0.0032	256.12
2SM2	0.0018	199.12
SKM2	0.0043	330.06
MO3	0.0095	339.79
M3	0.0167	334.80
SO3	0.0058	14.92
MK3	0.0120	56.66
SK3	0.0099	106.44
ST8	0.0029	28.51
N4	0.0018	215.09
3MS4	0.0055	80.49
MN4	0.0137	263.15
ST40	0.0101	72.31
M4	0.0363	307.55
SN4	0.0036	272.88
MS4	0.0222	17.11
MK4	0.0030	340.47
S4	0.0016	70.92
SK4	0.0009	91.21
2MK5	0.0033	230.10
MSK5	0.0025	282.43
2SK5	0.0004	358.28
2MN6	0.0025	99.24
ST41	0.0003	110.44
M6	0.0054	141.85
2MS6	0.0051	185.73
2MK6	0.0009	178.11
2SM6	0.0013	249.89
MSK6	0.0010	218.18
3MK7	0.0008	250.30
ST18	0.0004	121.24
3MN8	0.0004	204.37
M8	0.0001	198.44
ST20	0.0002	355.24
3MS8	0.0002	333.61
3MK8	0.0003	228.95
ST22	0.0002	10.31
ST23	0.0001	108.25
ST24	0.0001	30.07
M10	0.0009	173.96
ST29	0.0009	169.56
ST30	0.0018	227.52
ST31	0.0008	242.90
ST32	0.0003	266.10
M12	0.0003	354.12
ST34	0.0003	185.03

TABLE 8 FREQUENCIES OF TIDAL CONSTITUENTS

NAME	FREQUENCY (CYCLE/HR)
Z0	0.00000000
SA	0.00011407
SSA	0.00022816
MSM	0.00130978
MM	0.00151215
MSF	0.00282193
MF	0.00305009
ALP1	0.03439657
2Q1	0.03570635
SIG1	0.03590872
Q1	0.03721850
RHO1	0.03742087
O1	0.03873065
TAU1	0.03895881
BET1	0.04004044
NO1	0.04026859
CHI1	0.04047097
PI1	0.04143851
P1	0.04155259
S1	0.04166667
K1	0.04178075
PSI1	0.04189482
PHI1	0.04200891
THE1	0.04309053
J1	0.04329290
SO1	0.04460268
OO1	0.04483084
UPS1	0.04634299
ST36	0.07335538
2NS2	0.07466516
ST37	0.07486754
OQ2	0.07597495
EPS2	0.07617732
2N2	0.07748710
MU2	0.07768947
SNK2	0.07877109
N2	0.07899925
NU2	0.07920162
OP2	0.08028324
H1	0.08039733
M2	0.08051140
H2	0.08062547
MKS2	0.08073956
LDA2	0.08182118
L2	0.08202355
2SK2	0.08310517
T2	0.08321926
S2	0.08333333
R2	0.08344741

NAME	FREQUENCY (CYCLE/HR)
K2	0.08356149
MSN2	0.08484549
ETA2	0.08507364
2SM2	0.08615527
SKM2	0.08638343
MO3	0.11924206
M3	0.12076710
SO3	0.12206399
MK3	0.12229215
SK3	0.12511408
ST8	0.15668872
N4	0.15799850
3MS4	0.15820087
MN4	0.15951065
ST40	0.16079464
M4	0.16102280
SN4	0.16233258
MS4	0.16384473
MK4	0.16407289
S4	0.16666667
SK4	0.16689483
2MK5	0.20280355
MSK5	0.20562548
2SK5	0.20844741
2MN6	0.24002205
ST41	0.24130604
M6	0.24153420
2MS6	0.24435613
2MK6	0.24458429
2SM6	0.24717807
MSK6	0.24740623
3MK7	0.28331495
ST18	0.31902130
3MN8	0.32053345
M8	0.32204560
ST20	0.32335538
3MS8	0.32486754
3MK8	0.32509569
ST22	0.32640548
ST23	0.32768947
ST24	0.32791763
M10	0.40255700
ST29	0.40386678
ST30	0.40537894
ST31	0.40691688
ST32	0.40820087
M12	0.48306840
ST34	0.48589034

TABLE 9 AMPLITUDES OF SA AND SSA

Locations	Amplitude (m)		Ratio
	SA	SSA	SA/SSA
CMW	0.110	0.041	2.7
KLW	0.125	0.063	2.0
LOP	0.088	0.053	1.7
QUB	0.107	0.063	1.7
TAO	-	0.041	-
TBT	0.076	0.042	1.8
TPK	0.127	0.71	1.8
WAG	0.042	0.084	0.5

TABLE 10

AMPLITUDE OF SHALLOW WATER CONSTITUENTS RELATIVE TO M2 AT VARIOUS STATIONS

constituent	CMW	KLW	LOP	QUB	TAO	TBT	TPK	WAG
SO1	0.007	0.007	0.010	0.010	0.006	0.034	0.010	0.007
OP2	0.009	0.011	0.015	0.010	0.015	0.049	0.019	0.113
MKS2	0.002	0.010	0.005	0.006	0.006	0.023	0.003	0.058
2SK2	0.002	0.003	0.005	0.002	0.012	0.012	0.007	0.056
2SM2	0.002	0.008	0.005	0.002	0.004	0.018	0.007	0.005
MO3	0.022	0.050	0.010	0.021	0.001	0.053	0.032	0.028
SO3	0.016	0.029	0.013	0.019	0.012	0.042	0.031	0.017
MK3	0.034	0.056	0.026	0.034	0.021	0.057	0.043	0.036
SK3	0.014	0.032	0.014	0.017	0.006	0.039	0.027	0.030
3MS4	0.007	0.028	0.004	0.011	0.004	0.019	0.027	0.017
MN4	0.032	0.082	0.015	0.032	0.031	0.023	0.076	0.041
ST40	0.001	0.017	0.001	0.006	0.008	0.006	0.024	0.030
M4	0.084	0.238	0.044	0.089	0.082	0.086	0.207	0.109
MS4	0.049	0.139	0.028	0.053	0.043	0.059	0.131	0.066
MK4	0.016	0.029	0.010	0.018	0.012	0.027	0.024	0.009
2MN6	0.006	0.043	0.003	0.005	0.005	0.006	0.045	0.007
M6	0.011	0.078	0.005	0.009	0.008	0.011	0.077	0.016
2MS6	0.009	0.070	0.004	0.009	0.005	0.012	0.073	0.015

(constituents with amplitude less than 0.01 of that of M2 at all locations are not shown)

TABLE 11 STANDARD DEVIATION OF THE RESIDUES IN HOURLY TIDAL PREDICTIONS

Location	Year	Number of observed data	STANDARD DEVIATION OF RESIDUES (M)	
			Harmonic method	Time/height adjustment
CMW	1980 1984	7820 6571	0.18 0.16	0.19 0.17
KLW	1983 1984	5671 5272	0.15 0.15	0.17 0.17
LOP	1982 1983	8540 8633	0.14 0.13	0.16 0.15
TAO	1989	4823	0.17	0.20
TBT	1987 1988	7714 8434	0.18 0.18	0.22 0.23
WAG	1987 1988	3810 3188	0.20 0.24	0.23 0.27

Note : Harmonic constants used in these predictions were listed in Table 2-7.
(except SA and SSA of Waglan Island, and SA of Tai O)