indo/sp/ useful reprints

H Bray

CSIRO Marine Laboratories
Report 208

Sea-Level Changes around Papua New Guinea, 1984–1987

K. R. Ridgway

1989

CSIRO Marine Laboratories
Report 208

Sea-Level Changes around Papua New Guinea, 1984–1987

K. R. Ridgway

CSIRO
AUSTRALIA

1989

National Library of Australia Cataloguing-in-Publication

Ridgway, K. R. (Ken R.).
Sea-level changes around Papua New Guinea, 1984–1987.

ISSN 0725–4598.
ISBN 0 643 05030 2.

1. Sea level – Papua New Guinea. 2. Sea level – Papua New Guinea – Measurement. I. CSIRO. Marine Laboratories. II. Title. (Series: Report (CSIRO. Marine Laboratories); no. 208).

551.45809953

CSIRO Marine Laboratories Report 208

Sea-level changes around Papua New Guinea, 1984–1987

K. R. Ridgway

CSIRO Division of Oceanography
Marine Laboratories
GPO Box 1538
Hobart, Tas 7001
Australia

Abstract

This report presents sea-level data collected in Papua New Guinea waters in the period 1984–87 as part of the Tropical Ocean Global Atmosphere Program (TOGA) and the Western Equatorial Pacific Ocean Climate Study (WEPOCS). The installation, instrumentation and data-reduction procedures used on the CSIRO sea-level network are described. Time-series plots of twelve-hourly and monthly sea-level, and contour maps of monthly sea-level anomalies for the Western Pacific region are included.

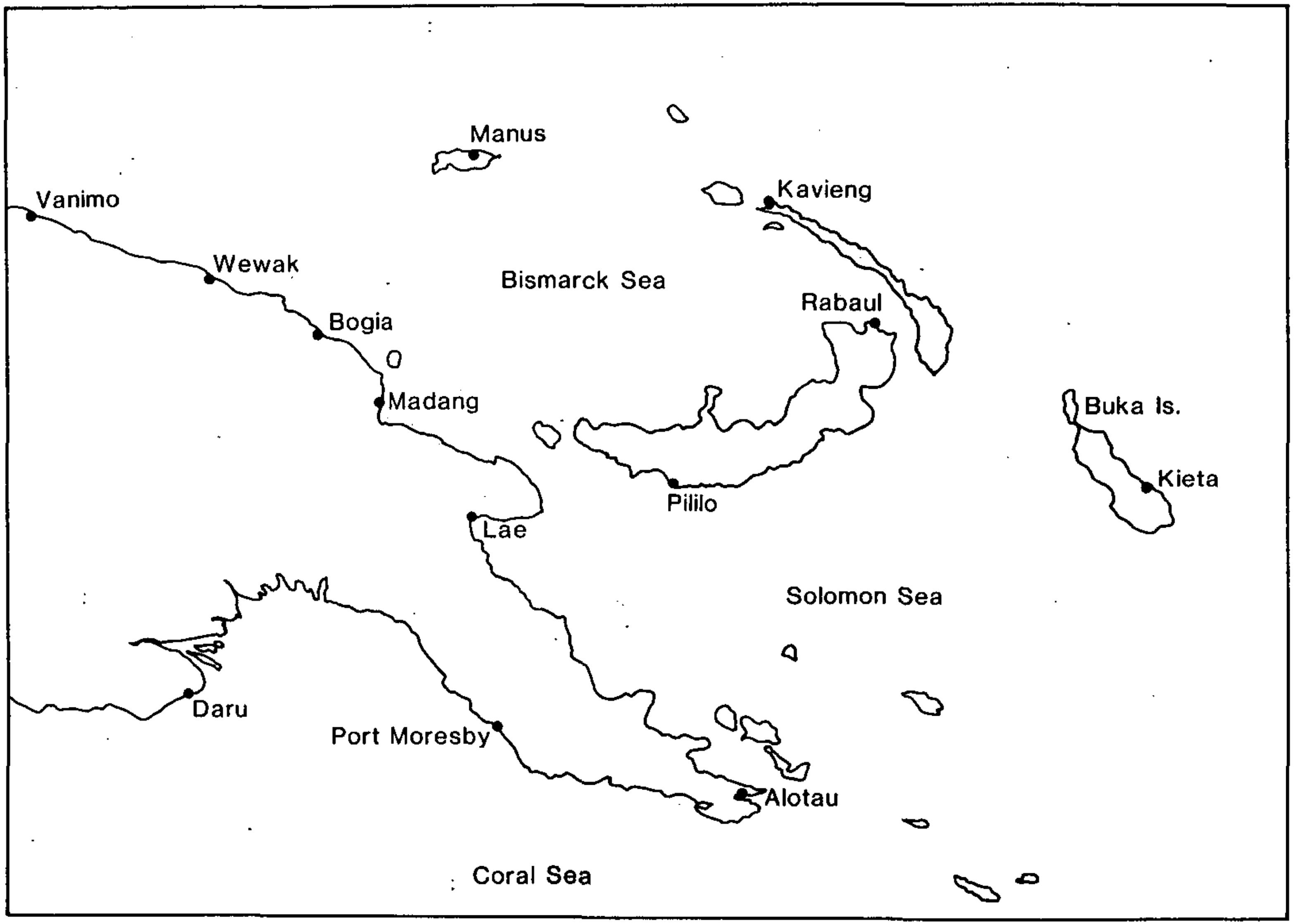

Figure 1: The location of all operating stations referred to in the text.

1. Introduction

The importance of the Western Pacific Ocean region to short-term climatic change is becoming recognised. Within the warm pool encompassing Papua New Guinea and Indonesia are found the highest sea-surface temperatures (SSTs) in the world's oceans. Nicholls (1983) showed that variations in SST correlate closely with other meteorological variables and hence affected the climate of the region. On a global scale, recent evidence indicates that relatively small SST anomalies in this warm region have a major influence on the general circulation of the atmosphere (Palmer and Mansfield 1985).

These findings have stimulated much research activity in the region, including the establishment of XBT lines (Greig et al. 1986), the implementation of oceanographic research cruises, the deployment of current-meter moorings (Lindstrom et al. 1987) and the installation of a sea-level network around Papua New Guinea (Ridgway 1986). All these research initiatives are under the umbrella of the Tropical Ocean Global Atmosphere Program (TOGA). This program was set up to obtain a ten-year set of oceanic and atmospheric data that will provide a new understanding of the important climatic mechanisms, leading to the development of more realistic models. In this report, however, we are concerned with the sea-level data from Papua New Guinean waters over the first three years of the program.

Changes in sea-level show a strong correlation with variations in the heat content of the upper few hundred metres of the adjacent ocean. Observations from both individual and arrays of stations therefore provide a cost-effective means of monitoring such climatic variables as heat content, ocean circulation and sea-surface topography (Wyrtki 1979). A network of stations around the Pacific Ocean has been particularly effective in documenting the response to recent ENSO events. During 1982–83 variations in monthly mean sea-level of as much as 40 cm were recorded over large areas (Wyrtki 1985). The Papua New Guinea stations are a logical extension of the Pacific network into a previously unoccupied area.

The dearth of sea-level data in the Papua New Guinea region has been noted by Done (1983, 1984) in the context of the hydrographic needs of the nation. The vastly improved sea-level observing capability will be of immense value for land and marine surveys, navigation, storm surge and tsunami warning, and port design and construction. Of particular future importance are the implications for the fishing industry in utilising sea-level as an SST index. Seven permanent tide gauges were installed around Papua New Guinea in August–September 1984.

This report describes the gauge design, details the data processing procedures and presents plots of the data collected up to the end of 1987. Between June 1985 and January 1986, the Western Equatorial Pacific Ocean Climate Study (WEPOCS, Lindstrom et al. 1987) deployed five pressure gauges in selected Papua New Guinea sites. These data are also presented in the report, along with that from Rabaul for this period (courtesy of K. Wyrtki) (TOGA sea-level Centre).

This report includes the most comprehensive description of the fluctuations in sea-level around Papua New Guinea yet produced.

2. Data

Until very recently (before 1984), the sea-level was not rigorously monitored in Papua New Guinea. Records were obtained at most ports, but generally only over very short periods (2–30 days) for tidal analysis purposes (Bye and Bye 1976, Arrowsmith et al. 1983, PCTMSL 1987). Longer records, some dating back to World War II (Port Moresby, Lae, Dreger Harbour, Seadler Harbour –Manus Island) form the basis of the predictions for Papua New Guinea in the Australian tide tables (ANTT 1988). In theory, tide gauges were operated at Port Moresby, Vanimo, Madang, Lae and Rabaul on a continuous basis, but in practice a lack of resources and adequate supervision meant that they were out of service most of the time. Unfortunately many of these data have not been archived apart from 2 to 3 years of records from Port Moresby and Lae, and longer records (up to 10 years) at Rabaul and Anewa Bay (Wyrtki and Leslie 1980, Perm. Cttee Tides 1987, Pugh et al. 1987).

This was the rather depressing situation existing in 1984, when CSIRO Division of Oceanography established a network of seven modern, digital tide gauges around the country. Only three of the older gauges were still in operation: at Rabaul, Laing Island (near Bogia) and Samarai Island. Rabaul, unlike the other ports, had, for a short time, three well-maintained operational gauges. The other two station gauges were below acceptable standards of instrumentation, but were regularly monitored. Samarai was of particular interest, as the gauge was home built and in operation for over ten years (Pringle-Jones 1987). Table 1 contains details of all the currently archived sea-level data, of at least four months duration, collected before 1984.

The CSIRO network has now been in operation for over three years and near-continuous data sets are available from most of the sites. In addition to the permanent gauges, five bottom-mounted pressure gauges were deployed as part of WEPOCS at Buka Island, Cape St. George, Pililo, Long Island and Finschhafen; the relevant details are found in Table 2. The locations of all these stations are shown in Fig. 1.

Table 1. Details of the location and period of all sea-level data collected in the Papua New Guinea region (of at least four months' duration) before September 1984. The source refers to a location where the data is archived; this may not be the only organisation with a copy of the data.

Location		Period of record	Source
Alotau		3/71 – 12/71	FIAMS
		4/72 – 2/73	FIAMS
Arawa		8/68 – 10/68	FIAMS
		6/69 – 3/70	FIAMS
		1968 – 1977	TSLC
Daru		6/71 – 3/72	FIAMS
		1985 – 1986	CSIRO
Dreger Harbour (Finschhafen)		6/48 – 6/49	PSMSL
East Cape		2/78 – 5/78	FIAMS
Kavieng		4/64 – 7/64	RAN
		1/65 – 6/65	RAN
Kieta		1/72 – 5/72	FIAMS
Lae		1947	PSMSL
		3/71 – 12/73	FIAMS
Laing Is.		1982 – 1987	CSIRO
Madang		6/78 – 6/79	FIAMS
Magarida		12/72 – 7/73	FIAMS
Oro Bay		12/70 – 3/71	FIAMS
Port Moresby		1939 – 1940	PSMSL
		1957 – 1959	PSMSL
		12/70 – 6/71	FIAMS
		6/76 – 4/79	FIAMS
Rabaul A.		1980	PSMSL
		5/62 – 8/62	RAN
		5/62 – 8/62	RAN
		4/66 – 4/71	FIAMS, PSMSL
Rabaul	A*	1974 – 83	TSLC
	B	1974 – 83	TSLC
	C	1983 – 87	TSLC
Samarai		6/61 – 1/62	RAN
		1976 – 1984	CSIRO
Manus Is (Seadler Harbour)		3/47 – 6/47	USCGS
Uramu Island		5/71 – 2/72	RAN
Vanimo		4/67 – 7/67	RAN
		6/78 – 2/79	FIAMS
Wewak		9/71 – 4/73	FIAMS
		6/76 – 4/77	FIAMS
		4/79 – 8/79	FIAMS

*	A, B, C correspond to three gauges that have operated independently at Rabual.
CSIRO	CSIRO Division of Oceanography
FIAMS	Flinders Institute of Atmospheric and Marine Science
TSLC	TOGA sea-level Centre
PSMSL	Permanent Service for Mean sea-level
RAN	Royal Australian Navy
USCGS	United States Coast and Geodetic Service

Table 2 Location and period of data collected in Papua New Guinea since September 1984. These data form the basis of this report.

Station	Latitude	Longitude	Period of record		
Port Moresby	9°30'S	147°9'E	1.9.84	–	30.6.87
Alotau	10°19S	15°27'E	15.9.84	–	30.4.85
			1.4.87	–	30.9.87
Lae	6°44'S	147°0'E	1.9.84	–	31.8.87
Madang	5°10'S	145°45'E	1.9.84	–	3.8.87
Wewak	3°34'S	143°39'E	1.9.84	–	31.8.87
Manus	2°0'S	147°16'E	4.9.84	–	30.11.86
Kavieng	2°35'S	150°48'E	1.9.84	–	31.8.87
Rabaul	4°12'S	152°11'E	1.9.84	–	31.8.87
Finschhafen	6°35'S	147°51'E	1.7.85	–	9.11.85
Long Island	5°20'S	147°5'E	10.7.85	–	30.4.86
Pililo	6°10'S	149°6'E	3.7.85	–	26.1.86
Buka Island	5°15'S	154°35'E	26.6.85	–	19.1.86
Cape St George	4°52'S	152°51'E	28.6.85	–	19.1.86

3. Installation, instrumentation and methods

The procedures adopted for the program were based on the guidelines laid down by the relevant Australian and international bodies (PCTMSL 1984, IOC 1985).

The stations were located to enable measurements representative of offshore sea-level changes to be obtained, to provide a stable platform for the gauge, to withstand the worst storm conditions and to be protected as much as possible from shipping activity (although ocean-going ships are generally moored nearby).

Simple, field-proven instruments were chosen for deployment in these remote locations. The gauges have a counterbalanced float system in a vertically mounted stilling well made from 30 cm PVC tubing. The inlet is, typically, 15 mm in diameter and has a sump to prevent its being blocked by small debris. The well also has an internal cleaning rod for the inlet. The stilling well acts as a high-frequency filter to remove surface wind waves and swells from the sea-level fluctuations. The recorder units are in an insulated fibreglass housing with ventilation vents on either side.

The observations are digitally logged on a Leopold and Stevens analog-digital recorder (ADR, Model 7001). This has a range of 10 m and a resolution of 1 mm. Timing is controlled by a Stevens solid state timer incorporating a quartz crystal oscillator with an accuracy of 2–4 seconds per day. The timer is programmed to collect samples at 15 minute intervals. They are recorded in a sixteen-bit binary coded decimal format on paper tape and collected and mailed to Hobart every month for processing. These recorders are powered by rechargeable 12 volt dry cell batteries.

Each gauge also has a tide staff, the zero mark of which defines the local datum. This zero reference level is established by connecting the staff to a network of vertical control points (benchmarks), at least three of which, chosen for their visibility and stability, are within a few metres of the tide staff. The local benchmarks are ultimately linked to the appropriate national levelling grid. The first staffs were made from water–resistant timber (Huon pine, Terpentine), the later ones are of laminated fibreglass.

The gauges have worked well, providing dependable long-term data. In addition, they can be maintained by relatively unskilled personnel, who must, however, be meticulous in their attention to detail. The excellent quality of the data produced at the stations is due primarily to the conscientious efforts of the local observers.

The observer's main role is to make daily observations of sea-level from the tide staff and the tide recorder. These, along with the date and time, provide the main check of the datum stability of the tide gauge. Table 3 gives some basic statistics relating to these data. At the end of each month, the paper tape is retrieved and the record reset for the next month's operation. As Papua New Guinea is some 4,000 km from the CSIRO Laboratories in Hobart, the observer generally makes minor repairs and adjustments. Technicians from CSIRO visit each gauge every two years and carry out any maintenance work required.

After the seven sites around Papua New Guinea were chosen, the tide gauge assemblies were built at the workshops of CSIRO in Hobart, Tasmania and installed in August/September 1984.

Table 3 The standard deviation of recorder–visual observations (cm) and the average number of observations per month for each station.

Station	Standard deviation	Observations (average no.)
Port Moresby	1.86	11
Alotau	1.66	10
Lae	1.84	11
Madang	1.55	12
Wewak	2.83	12
Manus	2.02	12
Kavieng	1.54	11

4. Data Processing

The aim of the sea-level processing procedures is to produce a permanent archive of high-quality data, which is then available for research and exchange. The data reduction process follows several stages in moving from the punched paper tape to the archive. The original fifteen minute observations are converted to hourly, twelve-hourly and monthly data files. The procedures are similar to those used at other institutions (Wyrtki et al. 1988).

On receipt of a monthly data tape, the CSIRO officer checks the record for continuity, in conjunction with the operator's check sheet and the previous month's data. The data are then converted to ASCII digital format and transferred to a Vax 11-750 computer via a Leopold and Stevens Translator (model STR–1000). To complete the initial processing stage, the fifteen-minute observations are converted to hourly values, using a simple Gaussian filter. This file forms the basis for quality control, datum and timing adjustments.

Preliminary plots of the observed tides, predicted tide, non-tidal residuals and the observer's comparison checks are then produced. These plots are a major diagnostic tool, as both height and time errors can be detected at this early stage. A sample plot for Port Moresby is given in Fig. 2. The tidal analysis and prediction procedures are those of Foreman (1977).

Datum changes due to geological uplift or settling are a local hazard, but so far observers have not reported any of these at our gauges; only mechanical faults such as float-wire slippage on the drive pulley have occurred. These changes can be readily identified from the residual plots and observer's comparisons and appropriate corrective steps can then be taken. Timing errors due to power failures or human error are easily detected from the residual signal. After these quality control procedures have been followed, the tide staff observations are examined to determine the ADR/tide staff offset.

Data losses caused by power failures, recorder malfunctions (e.g. jammed mechanism, loose pulley screws) may be restored if the period is less than 24 hours. A local harmonic analysis procedure, after Karunaratne (1980), is applied if the gap is less than 12 hours, while for gaps between 12 and less than 24 hours predicted heights are moderated by the observed data surrounding the gap. Data losses of greater than 24 hours duration are considered to be unrecoverable.

At the next level of processing, the record is filtered to remove the tidal signals. This is done with a 10-day Lancos–Cosine filter, which has a cut-off period of 1.7 days (Thompson 1983). This filter is designed to remove all diurnal and semi-diurnal frequencies but to retain lower-frequency tidal signals (Mf and Msf). The data are then decimated to obtain 12-hourly heights, which form the working file for the analysis of sea-level changes. Atmospheric pressure data derived from objective analysis methods (Davidson and McAvaney 1981) are used to correct the data for the inverse barometer effect as they become available. Fig. 3 gives examples of the Port Moresby data in filtered, pressure-corrected and seasonally corrected forms. Monthly means are obtained from simple averages of the hourly data, excluding those months with less than 15 days of data. Seasonal two-harmonic best-fit curves are computed from the monthly means after Wyrtki and Leslie (1980).

5. Results

Tides

The observed tidal signals at each permanent station for July to August 1987 are displayed in Fig. 4. The Port Moresby record stands out from the others: it has a larger tidal range and also a much greater semi-diurnal influence. This is borne out in Fig. 5, which displays the co-tidal plots of the M_2 constituent for the Pacific region (Luther and Wunsch 1974). The amplitude of M_2 increases dramatically as we move west from the south-east tip of the Papua New Guinea mainland. The remaining stations are predominantly diurnal, although Wewak, and to a lesser extent Kavieng, show a small semi-diurnal signal. The amplitude and phase of the major constituents are presented in Appendix Table 1. The extreme tide levels at each station are given in Table 4.

Table 4 Extreme tides and tidal range (metres) for all stations.

Station	Maximum	Minimum	Range
Port Moresby	3.370	0.410	2.960
Alotau	1.520	0.170	1.350
Lae	1.930	0.570	1.360
Madang	1.890	0.540	1.450
Wewak	1.610	0.10	1.600
Manus	1.610	0.0	1.610
Kavieng	1.630	0.160	1.470

Non-tidal residuals

The changes in mean sea-level around the Papua New Guinea coast are included in Figs. 6 and 7. These are actually 12-hourly heights obtained after filtering and decimating the observed sea-levels. The fortnightly constituent, Msf, was found to have significant energy in relation to the non-tidal signals, as indicated by the large peaks at periods of order 14 days appearing in cross-correlation plots. It was therefore removed. Each panel of figures contains six months of data, starting from September 1984. The shorter records from the pressure gauges are plotted together with the nearest permanent stations to allow for more convenient comparison (Fig. 8a–b).

This low-passed record displays a readily observable correlation between adjacent stations (see Madang and Wewak, Fig. 6). Higher-frequency signals (2–3 day period) may be observed in all locations, particularly at Wewak and to a lesser extent at Lae. Fluctuations with 8–10 day period and up to 20 cm amplitude are evident in the Port Moresby data, presumably responding to meteorological forcing. Wiffjels (1986) suggests that these fluctuations are remotely forced by winds along the north Queensland coast. The signal propagates northward along the coast, across Torres Strait and the Gulf of Papua via some form of long period waves. The longer data records now available are being examined for further evidence of these waves and of any other coastally trapped wave activity around the northern Papua New Guinea coast.

Seasonal Variation and Anomalies

These stations have relatively small seasonal signals, with amplitudes of order 5 cm, the smallest being at Lae with only 2.5 cm (Fig. 9). All the relevant statistics, including monthly and annual means, are found in Tables 5 and 6 and Appendix Table 2. Again the format is after Wyrtki and Leslie (1980) *to allow for ready comparison with their* results for the whole Pacific Ocean. The distribution of the parameters in Table 6 shows general agreement with the maps of the corresponding values in Wyrtki and Leslie.

Monthly maps of sea-level anomaly, as given in Table 5, are plotted in Fig. 10. We have included data from adjacent stations in the Western Pacific. The contours are hand drawn because of the limited number of stations and the complicated nature of the Bismarck Archipelago.

Interannual Variations

With nearly four years of data from the stations on the network, we are now in a position to begin a study of interannual variations of sea-level in the region. We present the data in two different ways. Firstly, time-series plots of monthly sea-level anomaly are displayed in Fig. 11. The most prominent feature is a large decrease in sea-level, beginning in October 1986, associated with the 1986/87 ENSO event. The signal is strongest at Honiara and Rabaul but may also be observed at Kavieng, Wewak and Madang from December 1986 to August 1987. However the response at Lae is much smaller and no significant variation from mean conditions occurs at Port Moresby. The dynamical implications of this result are more obvious in Fig. 12 where the monthly anomalies, supplemented by data from IGOSS sea-level Pilot Project (ISLPP), are contoured for the whole Western Pacific region. The data from the Papua New Guinea stations now enable us to resolve the currents through Vitiaz Strait. *In particular, during 1987,* an anomalous northward western boundary current may be observed along the Papua New Guinea mainland. This feature is not present in the ISLPP maps as they do not have these stations (apart from Rabaul). To ensure compatibility between the data sets, the ISLPP anomalies were recalculated using mean sea-levels and mean annual cycles for the 1984–87 period.

Table 5 Observed monthly means (OBS), standard deviations (SD) and monthly means from harmonic analysis (CALC) for the indicated stations (in mm).

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
A. Port Moresby												
OBS	6	39	42	68	38	36	−19	−55	−53	−61	−29	−12
SD	42	3	34	36	35	6	11	39	36	21	27	22
CALC	11	31	49	59	51	23	−16	−49	−62	−54	−33	−10
B. Alotau												
OBS	30	64	63	29	−23	−21	−56	−54	−59	−9	−2	37
SD	15	0	0	20	0	0	0	0	0	15	14	7
CALC	48	59	53	30	−5	−37	−55	−56	−43	−22	2	27
C. Lae												
OBS	−11	21	23	16	22	20	−3	−18	−37	−17	−3	−12
SD	27	10	30	13	38	38	37	45	45	19	30	5
CALC	1	9	18	25	24	13	−5	−20	−26	−22	−13	−5
D. Madang												
OBS	−51	−18	−7	33	61	29	18	2	−23	−7	0	−35
SD	26	25	43	45	37	57	59	60	52	42	28	11
CALC	−41	−32	0	36	52	40	13	−7	−11	−7	−13	−29
E. Wewak												
OBS	−82	−55	14	26	54	44	26	19	−4	17	0	−59
SD	39	75	62	49	49	48	48	42	45	49	14	20
CALC	−72	−54	−6	41	57	43	20	12	15	11	−15	−53
F. Manus												
OBS	−56	−13	41	66	32	9	−14	−10	−14	1	−5	−38
SD	89	64	15	10	16	30	15	13	43	43	23	67
CALC	−44	−12	35	60	45	8	−19	−18	−1	4	−16	−42
G. Kavieng												
OBS	12	8	35	41	20	−1	−33	−36	−28	−10	4	−11
SD	9	78	76	92	81	98	84	80	88	73	31	46
CALC	2	15	32	39	24	−5	−31	−38	−26	−10	−2	−1

Table 6 Amplitude (cm) and phase of the annual and semi-annual components (H1, $\phi 1$, H2, $\phi 2$), ratio of the annual and semi-annual variation (H1/H2), standard deviation of sea-level anomaly (σ), ratio of standard deviation to H1 (σ/H1), standard error of the harmonic analysis (δ) and the ratio of the standard error to H1 (δ/H1).

	H1	$\phi 1$	H2	$\phi 2$	H1/H2	σ	σ/H1	δ	δ/H1
Port Moresby	58	93	9	142	6.4	29	50	8	14
Alotau	58	42	5	96	11.4	9	16	11	20
Lae	24	100	6	141	4.3	31	130	8	34
Madang	35	159	20	127	1.7	43	124	9	26
Wewak	49	180	28	114	1.8	48	97	11	23
Manus	31	131	32	103	1.0	43	142	8	27
Kavieng	29	72	15	113	1.9	74	253	5	18

6. Concluding Remarks

As mentioned previously, the main objective in establishing the stations was to contribute to the ten-year database of the TOGA program. Results obtained so far suggest that the data have a significance far greater than simply filling a gap in the TOGA sea-level network. For example, the anomalous northward western boundary current shown in the 1986/87 data would not have been observed without the Papua New Guinea stations. Fluctuations in this current may play an important role in ENSO events.

To this end one hopes that the stations will continue to operate after the TOGA decade is over, and that the sites most representative of the region will be included in the Global sea-level Observing System (GLOSS, IOC 1986).

While the stations have generally operated successfully, simple equipment malfunctions have often resulted in extended data losses. To overcome this weakness in the system, it is hoped to install some form of backup sensor/data logging capability to provide suitable redundancy in the data collection. Other developments may include upgrading to near-real time operation with the installation of satellite telemetry at selected locations.

7. Acknowledgements

We wish to thank Neal McQueen, Arthur Banks, Peter Jackson and other members of the CSIRO Marine Laboratories Workshop for constructing the tide gauge structures, installing and maintaining the gauges. The assistance and cooperation of the Papua New Guinea Harbours Board, Fisheries Research Department of Primary Industry, Department of Transport and the Christensen Research Institute have been essential for the success of the program. Finally our thanks to the most important group of people — the tide gauge operators: Capt. Eric Long, Dick Bates, Buck Benney, Augustine Mobiha, Jean Pierret, Greg Fae, Capt. Mike Phillips, Capt. Barry Jones, Anton Yaku, Foe Oii, Emanual Tamba, Tapas Potuka and Noel Mave. The high quality of the data collected in this report is mainly due to their conscientious efforts over several years.

8. References

Arrowsmith, Johns and Muir Pty. Ltd. (1983) Hydrographic surveys and tidal data collection. Papua New Guinea Harbours Board Surveyors Report.

Australian National Tide Tables 1988 (1987) Australian Hydrographic Publication 11, 256 pp.

Bye, J. A. T., and J. Bye (1976) Tidal analyses and various monthly mean sea-levels for the years 1966-1973 in Papua New Guinea. FIAMS Research Report 22, 70 pp.

Davidson, N. E. and B. J. McAvaney (1981) The ANMRC tropical analysis scheme. Australian Meteorological Magazine 29, 155-168.

Done, P. (1983) Hydrography in Papua New Guinea: a current overview. The Australian Surveyor 31 No. 5, 327-337.

Done, P. (1984) Papua New Guinea: a note on sea-level slopes. The Hydrographic Journal 31, 25-27.

Foreman, M. G. G. (1977) Manual for tidal heights analysis and prediction. Pacific Marine Science Report 77–10, Institute of Ocean Sciences.

Greig, M. A., Ridgway, K. R., Vaudrey. D. V., Lambert, D., Foran, D., Hynes, K., and Godfrey, J. S. (1986) MV Nimos sections: thermal profiles of the Coral and Bismarck Seas, June 1983 to July 1984. CSIRO Marine Laboratories Report 173, 49 pp.

IOC (1985) Manual on sea-level measurement and interpretation. IOC Manuals and Guides 14.

IOC (1986) Global sea-level observing system implementation plan 1985–1990. Intergovermental Oceanographic Commission, IOC/INF-663.

Karunaratne, D. A. (1980) An improved method for smoothing and interpolating hourly sea-level data. International Hydrographic Review 57, 135-148.

Lindstrom, E., Lukas, R., Fine, R., Firing, E. Godfrey, J. S., Meyers, G., and Tsuchiya, M. (1987) The Western Equatorial Pacific Ocean Study. Nature 323, 523-526.

Luther and C. Wunsch (1974) Tidal charts of the central Pacific Ocean. Journal of Physical Oceanography 5, 222-230.

Nicholls, N. (1983) The Southern Oscillation and Indonesia sea surface temperature. Monthly Weather Review 112, 426-432.

Palmer, T. N. and Mansfield, D. A. (1985) Response of two atmospheric general circulation models to sea surface temperature anomalies in the tropical east and west Pacific. Nature 310, 483-485.

Permanent Committee on Tides and Mean Sea Level (1984) Recommended operating procedures for tide gauges on the national network. National Mapping Council of Australia, 33 pp.

PCTMSL (1988) Tidal record inventory. Inter-Governmental Advisory Committee on Surveying and Mapping.

Pringle-Jones, J. (1987) Gauging the tide, Air Nuigini Inflight Magazine Paradise 63, 33-34.

Pugh, D. T., Spencer, N. E. and Woodworth, P. L. (1987) Data holdings of the Permanent Service for Mean Sea Level. Birkenhead, PSMSL.

Ridgway, K. R. (1986) sea-level in the tropics, Australian Marine Sciences Association Bulletin 94, 20-22.

Thomson R. O. R. Y. (1983) Low pass filters to suppress inertial and tidal frequencies. Journal of Physical Oceanography 13, 1077-83.

Wijffels, S. E. A. (1986) An analysis of low frequency sea-level variations around the border of the north western Coral Sea, and investigation of the role of coastally trapped waves. Honours Thesis, Flinders University, 90 pp.

Wyrtki, K. (1979) sea-level variations: monitoring the breadth of the Pacific. Transactions of the American Geophysical Union 60, 25-27.

Wyrtki, K. (1985) sea-level fluctuations in the Pacific during the 1982-1983 El Nino. Geophysical Research Letters 12(3), 125-128.

Wyrtki, K. and Leslie, W. G. (1980) The mean annual variation of sea-level in the Pacific Ocean. University of Hawaii, HIG-80-5, 159 pp.

Wyrtki. K., K. Constantine, B. J. Kilonsky, G. Mitchum, B. Miyamoto, T. Murphy, S. Nakahara and P. Caldwell (1988) The Pacific Island sea-level Network, University of Hawaii JIMAR 88-0137, 70 pp.

Appendix

Table 1: Amplitude and phase of the tidal constituents for the TOGA and WEPOCS stations in Fig. 1. The amplitudes are in centimetres and the phases correspond to the Greenwich epoch G

PORT MORESBY			ALOTAU			LAE		
NAME	AMPLITUDE	PHASE	NAME	AMPLITUDE	PHASE	NAME	AMPLITUDE	PHASE
SA	0.0598	77.38	SSA	0.0088	270.20	SA	0.0324	137.32
SSA	0.0192	2.37	MSM	0.0057	55.57	SSA	0.0115	75.36
MSM	0.0079	156.10	MM	0.0122	317.78	MSM	0.0119	22.22
MM	0.0129	353.18	MSF	0.0046	294.43	MM	0.0110	340.65
MSF	0.0011	44.68	MF	0.0176	352.41	MSF	0.0016	291.19
MF	0.0143	27.51	ALP1	0.0004	291.19	MF	0.0175	27.10
ALP1	0.0011	236.21	2Q1	0.0032	338.12	ALP1	0.0003	278.31
2Q1	0.0039	289.31	SIG1	0.0032	8.19	2Q1	0.0013	356.15
SIG1	0.0026	291.61	Q1	0.0246	2.91	SIG1	0.0030	0.58
Q1	0.0250	347.03	RHO1	0.0054	5.92	Q1	0.0222	20.14
RH01	0.0050	338.86	O1	0.1380	25.76	RHO1	0.0049	16.55
O1	0.1435	14.53	TAU1	0.0025	143.95	O1	0.1344	31.53
TAU1	0.0056	127.40	BET1	0.0019	39.79	TAU1	0.0006	28.81
BET1	0.0007	81.74	NO1	0.0109	57.39	BET1	0.0010	79.15
NO1	0.0179	30.27	CHI1	0.0035	42.09	NO1	0.0118	23.42
CHI1	0.0030	54.96	P1	0.0775	46.68	CHI1	0.0027	58.22
PI1	0.0070	18.66	K1	0.2639	49.04	PI1	0.0057	50.98
P1	0.0812	37.44	PHI1	0.0011	62.25	P1	0.0746	49.82
S1	0.0168	100.29	THE1	0.0035	48.07	S1	0.0180	155.56
K1	0.2784	43.51	J1	0.0133	75.48	K1	0.2504	53.25
PSI1	0.0054	4.34	SO1	0.0013	101.39	PSI1	0.0019	51.09
PHI1	0.0043	88.28	OO1	0.0109	97.78	PHI1	0.0026	74.12
THE1	0.0032	75.88	UPS1	0.0015	136.88	THE1	0.0024	56.36
J1	0.0131	54.81	OQ2	0.0016	255.04	J1	0.0116	55.54
SO1	0.0023	161.97	EPS2	0.0036	276.45	SO1	0.0015	92.96
OO1	0.0133	87.88	2N2	0.0073	272.02	OO1	0.0092	95.19
UPS1	0.0026	96.38	MU2	0.0094	293.95	UPS1	0.0012	113.29
OQ2	0.0024	332.06	N2	0.0389	300.56	OQ2	0.0008	18.56
EPS2	0.0079	290.77	NU2	0.0064	299.71	EPS2	0.0014	257.60
2N2	0.0198	319.28	M2	0.0277	9.20	2N2	0.0024	189.99
MU2	0.0378	307.17	MKS2	0.0012	259.90	MU2	0.0025	263.26
N2	0.1620	327.63	LDA2	0.0037	114.16	N2	0.0214	241.04
NU2	0.0292	342.27	L2	0.0114	141.39	NU2	0.0059	231.27
H1	0.0060	230.89	S2	0.0871	219.84	H1	0.0053	339.22
M2	0.4881	349.05	K2	0.0245	213.64	M2	0.0578	156.04
H2	0.0082	23.59	MSN2	0.0023	348.00	H2	0.0020	341.55
MKS2	0.0086	278.68	ETA2	0.0018	254.06	MKS2	0.0043	296.63
LDA2	0.0106	124.54	MO3	0.0020	224.91	LDA2	0.0023	111.67
L2	0.0131	149.47	M3	0.0066	117.27	L2	0.0125	144.96
T2	0.0251	281.62	SO3	0.0010	258.49	T2	0.0112	198.81
S2	0.2880	308.42	MK3	0.0024	242.59	S2	0.1108	184.09
R2	0.0094	329.03	SK3	0.0014	315.77	R2	0.0015	248.47
K2	0.0787	306.76	MN4	0.0025	304.02	K2	0.0297	174.20
MSN2	0.0075	9.07	M4	0.0056	28.91	MSN2	0.0027	29.47
ETA2	0.0076	335.48	NS4	0.0004	72.35	ETA2	0.0008	160.71
MO3	0.0034	174.38	MS4	0.0019	133.10	MO3	0.0015	326.91
M3	0.0061	348.54	MK4	0.0001	107.40	M3	0.0082	97.47
SO3	0.0022	228.57	S4	0.0014	148.08	SO3	0.0050	322.75
MK3	0.0017	210.18	SK4	0.0005	178.12	MK3	0.0002	47.85
SK3	0.0007	230.38	2MK5	0.0004	37.57	SK3	0.0011	23.94
MN4	0.0012	135.97	2SK5	0.0002	53.75	MN4	0.0019	311.73
M4	0.0041	177.95	2MN6	0.0013	136.42	M4	0.0052	17.74
SN4	0.0007	104.96	M6	0.0015	156.25	SN4	0.0023	336.74
MS4	0.0032	176.26	2MS6	0.0026	180.60	MS4	0.0023	60.38
MK4	0.0015	153.37	2MK6	0.0008	203.48	MK4	0.0006	292.61
S4	0.0010	326.34	2SM6	0.0011	187.97	S4	0.0011	183.20
SK4	0.0003	137.65	MSK6	0.0005	202.54	SK4	0.0009	107.43
2MK5	0.0009	321.32	3MK7	0.0002	213.47	2MK5	0.0006	82.12
2SK5	0.0002	10.73	M8			2SK5	0.0002	113.77
2MN6	0.0017	17.29				2MN6	0.0009	31.17
M6	0.0026	27.55				M6	0.0018	62.51
2MS6	0.0038	31.58				2MS6	0.0018	96.29
2MK6	0.0007	26.52				2MK6	0.0004	63.22
2SM6	0.0015	8.02				2SM6	0.0005	17.05
MSK6	0.0007	15.50				MSK6	0.0001	45.48
3MK7	0.0001	272.33				3MK7	0.0002	238.94
M8	0.0001	241.37				M8	0.0001	233.04

MADANG			WEWAK			MANUS		
NAME	AMPLITUDE	PHASE	NAME	AMPLITUDE	PHASE	NAME	AMPLITUDE	PHASE
SA	0.0451	158.84	SA	0.0610	156.79	SA	0.0176	67.19
SSA	0.0172	55.26	SSA	0.0244	42.25	SSA	0.0391	40.35
MSM	0.0054	30.39	MSM	0.0100	61.92	MSM	0.0062	97.47
MM	0.0078	17.80	MM	0.0043	43.88	MM	0.0078	331.81
MSF	0.0076	220.27	MSF	0.0079	225.74	MSF	0.0015	116.70
MF	0.0168	36.02	MF	0.0154	30.69	MF	0.0209	32.36
ALP1	0.0005	75.49	ALP1	0.0009	34.83	ALP1	0.0011	51.69
2Q1	0.0020	43.58	2Q1	0.0028	39.63	2Q1	0.0021	45.40
SIG1	0.0026	28.22	SIG1	0.0044	37.15	SIG1	0.0039	35.53
Q1	0.0257	35.23	Q1	0.0238	43.49	Q1	0.0238	40.09
RH01	0.0060	36.85	RH01	0.0051	32.52	RH01	0.0054	48.08
O1	0.1448	46.12	O1	0.1457	48.18	O1	0.1414	48.79
TAU1	0.0032	77.72	TAU1	0.0102	80.47	TAU1	0.0099	39.20
BET1	0.0014	90.79	BET1	0.0008	32.63	BET1	0.0022	39.65
NO1	0.0173	4.80	NO1	0.0200	9.66	NO1	0.0133	15.55
CHI1	0.0014	95.40	CHI1	0.0028	70.58	CHI1	0.0021	59.80
PI1	0.0050	53.55	PI1	0.0016	115.39	PI1	0.0076	76.32
P1	0.0758	55.30	P1	0.0788	62.84	P1	0.0703	61.27
S1	0.0113	112.61	S1	0.0142	139.60	S1	0.0168	144.07
K1	0.2434	58.60	K1	0.2387	63.33	K1	0.2348	61.48
PSI1	0.0010	213.59	PSI1	0.0006	256.98	PSI1	0.0057	75.79
PHI1	0.0061	80.07	PHI1	0.0028	65.94	PHI1	0.0004	303.32
THE1	0.0036	54.68	THE1	0.0025	56.08	THE1	0.0019	53.82
J1	0.0096	63.48	J1	0.0085	69.03	J1	0.0094	75.57
SO1	0.0019	97.90	SO1	0.0012	173.20	SO1	0.0006	184.19
OO1	0.0091	91.99	OO1	0.0083	97.02	OO1	0.0088	95.63
UPS1	0.0012	98.23	UPS1	0.0009	98.70	UPS1	0.0008	131.22
OQ2	0.0015	155.88	OQ2	0.0007	146.82	OQ2	0.0012	176.13
EPS2	0.0008	174.83	EPS2	0.0007	53.79	EPS2	0.0003	236.78
2N2	0.0083	203.37	2N2	0.0092	221.37	2N2	0.0081	198.35
MU2	0.0017	200.46	MU2	0.0027	269.93	MU2	0.0018	164.64
N2	0.0431	248.93	N2	0.0564	264.91	N2	0.0375	248.32
NU2	0.0077	253.22	NU2	0.0122	265.15	NU2	0.0094	251.15
H1	0.0073	354.25	H1	0.0063	309.34	H1	0.0055	266.25
M2	0.0957	278.79	M2	0.2203	291.58	M2	0.1009	280.38
H2	0.0054	229.14	H2	0.0033	264.62	H2	0.0011	261.46
MKS2	0.0017	295.03	MKS2	0.0011	249.08	MKS2	0.0040	173.40
LDA2	0.0023	90.13	LDA2	0.0032	334.81	LDA2	0.0013	47.55
L2	0.0016	·72.92	L2	0.0050	322.19	L2	0.0010	325.16
T2	0.0049	200.09	T2	0.0038	287.35	T2	0.0018	249.54
S2	0.0586	176.83	S2	0.0207	284.95	S2	0.0459	157.65
R2	0.0026	177.47	R2	0.0012	195.80	R2	0.0017	86.19
K2	0.0168	167.81	K2	0.0041	296.29	K2	0.0121	148.89
MSN2	0.0008	3.85	MSN2	0.0001	165.67	MSN2	0.0024	279.69
ETA2	0.0009	168.09	ETA2	0.0005	156.24	ETA2	0.0010	200.86
MO3	0.0023	211.27	MO3	0.0014	201.48	MO3	0.0017	224.64
M3	0.0085	71.17	M3	0.0057	65.91	M3	0.0058	73.00
SO3	0.0004	306.11	SO3	0.0003	81.56	SO3	0.0013	133.13
MK3	0.0008	118.78	MK3	0.0010	96.21	MK3	0.0015	83.64
SK3	0.0021	104.45	SK3	0.0022	128.62	SK3	0.0011	145.45
MN4	0.0004	184.61	MN4	0.0009	151.03	MN4	0.0006	140.11
M4	0.0008	205.47	M4	0.0023	185.96	M4	0.0018	164.44
SN4	0.0006	226.19	SN4	0.0004	257.78	SN4	0.0007	247.56
MS4	0.0017	268.94	MS4	0.0014	244.84	MS4	0.0013	220.43
MK4	0.0008	235.57	MK4	0.0007	216.11	MK4	0.0006	121.95
S4	0.0010	0.10	S4	0.0009	316.61	S4	0.0004	312.16
SK4	0.0003	323.20	SK4	0.0005	297.52	SK4	0.0005	258.70
2MK5	0.0004	187.83	2MK5	0.0003	247.97	2MK5	0.0002	43.98
2SK5	0.0007	294.70	2SK5	0.0004	281.23	2SK5	0.0003	297.44
2MN6	0.0005	264.77	2MN6	0.0001	191.56	2MN6	0.0003	248.82
M6	0.0004	275.40	M6	0.0002	158.48	M6	0.0004	341.18
2MS6	0.0000	2.80	2MS6	0.0003	42.67	2MS6	0.0004	225.61
2MK6	0.0002	78.67	2MK6	0.0001	244.19	2MK6	0.0000	349.03
2SM6	0.0002	160.37	2SM6	0.0002	211.89	2SM6	0.0002	269.58
MSK6	0.0001	66.14	MSK6	0.0002	246.93	MSK6	0.0001	128.09
3MK7	0.0002	116.49	3MK7	0.0002	40.55	3MK7	0.0004	52.23
M8	0.0001	319.64	M8	0.0002	69.23	M8	0.0004	230.16

KAVIENG			PILILO			LONG ISLAND		
NAME	AMPLITUDE	PHASE	NAME	AMPLITUDE	PHASE	NAME	AMPLITUDE	PHASE
SA	0.0206	125.94	SSA	0.0338	83.81	SSA	0.0543	32.93
SSA	0.0306	36.58	MSM	0.0059	79.33	MSM	0.0014	331.72
MSM	0.0019	341.60	MM	0.0043	40.12	MM	0.0105	28.02
MM	0.0085	342.05	MSF	0.0069	332.08	MSF	0.0022	298.69
MSF	0.0012	43.94	MF	0.0205	39.40	MF	0.0157	42.11
MF	0.0170	28.21	ALP1	0.0005	313.24	ALP1	0.0009	144.35
ALP1	0.0009	60.41	2Q1	0.0011	323.79	2Q1	0.0023	137.69
2Q1	0.0030	52.53	SIG1	0.0023	348.74	SIG1	0.0043	131.61
SIG1	0.0035	37.47	Q1	0.0223	4.42	Q1	0.0252	140.82
Q1	0.0232	37.33	RH01	0.0058	358.70	RH01	0.0054	136.52
RH01	0.0051	57.61	O1	0.1410	23.95	O1	0.1491	151.92
O1	0.1380	43.32	TAU1	0.0027	338.14	TAU1	0.0052	164.76
TAU1	0.0028	21.62	BET1	0.0020	74.08	BET1	0.0016	211.24
BET1	0.0009	85.57	NO1	0.0167	11.96	NO1	0.0134	136.34
NO1	0.0103	21.64	CHI1	0.0023	52.21	CHI1	0.0024	167.61
CHI1	0.0030	22.42	P1	0.0765	45.26	P1	0.0767	174.53
PI1	0.0044	51.09	K1	0.2458	48.33	K1	0.2438	176.45
P1	0.0730	57.98	PHI1	0.0027	74.43	PHI1	0.0039	210.78
S1	0.0066	74.55	THE1	0.0029	50.22	THE1	0.0025	190.52
K1	0.2212	60.22	J1	0.0102	52.58	J1	0.0101	184.96
PSI1	0.0030	309.67	SO1	0.0010	90.29	SO1	0.0002	263.81
PHI1	0.0040	56.96	OO1	0.0103	85.16	OO1	0.0087	217.73
THE1	0.0016	101.11	UPS1	0.0015	95.43	UPS1	0.0008	234.99
J1	0.0096	48.34	OQ2	0.0010	345.92	OQ2	0.0009	340.25
SO1	0.0022	149.84	EPS2	0.0008	233.05	EPS2	0.0008	122.91
OO1	0.0074	91.74	2N2	0.0038	168.08	2N2	0.0060	50.92
UPS1	0.0012	105.52	MU2	0.0046	267.16	MU2	0.0007	164.77
OQ2	0.0012	144.40	N2	0.0228	243.70	N2	0.0380	112.14
EPS2	0.0011	93.87	NU2	0.0050	257.42	NU2	0.0083	126.46
2N2	0.0063	161.38	M2	0.0504	134.04	M2	0.0852	143.98
MU2	0.0052	140.38	MKS2	0.0035	325.42	MKS2	0.0025	155.28
N2	0.0253	198.69	LDA2	0.0028	98.62	LDA2	0.0006	267.63
NU2	0.0034	216.16	L2	0.0092	113.73	L2	0.0011	305.47
H1	0.0017	111.70	S2	0.0894	177.75	S2	0.0429	46.38
M2	0.0841	155.27	K2	0.0287	166.01	K2	0.0153	33.43
H2	0.0044	243.45	MSN2	0.0028	17.35	MSN2	0.0006	232.21
MKS2	0.0010	140.07	ETA2	0.0022	199.94	ETA2	0.0015	72.51
LDA2	0.0029	103.05	MO3	0.0016	290.53	MO3	0.0013	192.68
L2	0.0071	88.12	M3	0.0077	92.10	M3	0.0071	53.85
T2	0.0067	155.59	SO3	0.0002	32.91	SO3	0.0003	3.25
S2	0.1205	156.49	MK3	0.0008	90.85	MK3	0.0016	71.55
R2	0.0046	105.86	SK3	0.0012	249.01	SK3	0.0012	119.76
K2	0.0339	152.31	MN4	0.0014	318.35	MN4	0.0004	122.53
MSN2	0.0013	67.54	M4	0.0059	2.95	M4	0.0010	294.67
ETA2	0.0028	192.87	SN4	0.0003	49.54	SN4	0.0002	262.92
MO3	0.0009	227.04	MS4	0.0015	24.93	MS4	0.0016	340.21
M3	0.0067	67.16	MK4	0.0004	33.70	MK4	0.0010	345.90
SO3	0.0004	201.46	S4	0.0002	203.36	S4	0.0011	106.65
MK3	0.0004	15.51	SK4	0.0003	17.57	SK4	0.0004	97.95
SK3	0.0008	35.11	2MK5	0.0003	51.83	2MK5	0.0002	353.87
MN4	0.0006	232.39	2SK5	0.0002	38.29	2SK5	0.0003	142.49
M4	0.0006	223.85	2MN6	0.0006	55.66	2MN6	0.0001	151.19
SN4	0.0002	302.52	M6	0.0009	63.83	M6	0.0006	259.18
MS4	0.0008	265.43	2MS6	0.0008	86.52	2MS6	0.0001	44.69
MK4	0.0007	201.21	2MK6	0.0003	59.99	2MK6	0.0000	203.61
S4	0.0006	35.31	2SM6	0.0000	186.94	2SM6	0.0002	18.94
SK4	0.0004	322.21	MSK6	0.0001	133.89	MSK6	0.0001	17.57
2MK5	0.0003	128.03	3MK7	0.0001	135.64	3MK7	0.0002	64.95
2SK5	0.0002	178.78	M8	0.0000	260.67	M8	0.0002	332.53
2MN6	0.0004	191.56						
M6	0.0008	183.84						
2MS6	0.0004	208.54						
2MK6	0.0000	271.16						
2SM6	0.0001	260.51						
MSK6	0.0001	76.82						
3MK7	0.0002	191.15						
M8	0.0001	351.19						

FINSCHHAFEN			CAPE ST. GEORGE			RABAUL		
NAME	AMPLITUDE	PHASE	NAME	AMPLITUDE	PHASE	NAME	AMPLITUDE	PHASE
MM	0.0142	210.61	SSA	0.0559	173.23	SA	0.0289	87.35
MSF	0.0155	226.60	MM	0.0042	210.46	SSA	0.0320	39.65
ALP1	0.0002	173.57	MSF	0.0111	203.14	MSM	0.0052	31.55
2Q1	0.0014	302.58	MF	0.0142	267.22	MM	0.0140	347.14
Q1	0.0195	263.76	ALP1	0.0005	356.30	MSF	0.0034	348.35
O1	0.1248	274.95	2Q1	0.0014	138.68	MF	0.0160	33.00
NO1	0.0122	278.46	Q1	0.0202	194.94	ALP1	0.0003	87.11
K1	0.2204	303.86	1	0.1269	224.15	2Q1	0.0007	114.79
J1	0.0069	318.69	TAU1	0.0031	246.13	SIG1	0.0038	28.60
OO1	0.0085	336.96	BET1	0.0026	234.36	Q1	0.0189	43.83
UPS1	0.0017	354.96	NO1	0.0125	237.79	RH01	0.0020	56.41
EPS2	0.0012	246.78	P1	0.0745	268.40	O1	0.1263	48.58
MU2	0.0029	251.60	K1	0.2445	275.05	TAU1	0.0059	89.50
N2	0.0184	205.40	PHI1	0.0034	297.06	BET1	0.0022	100.88
M2	0.0658	91.32	J1	0.0099	292.74	NO1	0.0112	25.82
L2	0.0074	82.93	SO1	0.0009	347.91	CHI1	0.0028	71.12
S2	0.1068	141.71	OO1	0.0100	340.68	PI1	0.0025	43.68
ETA2	0.0001	100.82	UPS1	0.0012	12.55	P1	0.0715	65.50
MO3	0.0023	18.79	EPS2	0.0001	229.86	S1	0.0100	117.77
M3	0.0089	117.43	MU2	0.0026	351.31	K1	0.2379	69.51
MK3	0.0004	132.82	N2	0.0251	58.49	PSI1	0.0039	0.78
SK3	0.0028	236.58	M2	0.1061	26.60	PHI1	0.0051	102.03
MN4	0.0016	85.10	MKS2	0.0073	155.74	THE1	0.0023	63.23
M4	0.0056	106.51	L2	0.0078	15.23	J1	0.0114	70.74
SN4	0.0014	152.34	S2	0.1087	78.23	SO1	0.0017	182.60
MS4	0.0019	162.49	K2	0.0319	75.81	OO1	0.0095	110.17
S4	0.0013	180.96	MSN2	0.0013	263.00	UPS1	0.0012	120.52
2MK5	0.0009	280.86	ETA2	0.0023	119.05	OQ2	0.0003	172.63
2SK5	0.0010	160.27	MO3	0.0027	224.45	EPS2	0.0021	48.48
2MN6	0.0005	267.81	M3	0.0091	1.17	2N2	0.0057	226.31
M6	0.0017	297.69	SO3	0.0020	325.57	MU2	0.0004	200.79
2MS6	0.0013	314.52	MK3	0.0014	113.61	N2	0.0312	265.54
2SM6	0.0007	138.49	SK3	0.0011	179.20	NU2	0.0054	278.55
3MK7	0.0003	197.36	MN4	0.0032	282.67	H1	0.0027	336.03
M8	0.0009	261.73	M4	0.0074	321.20	M2	0.0453	269.21
			SN4	0.0019	299.01	H2	0.0072	303.75
			MS4	0.0044	7.37	MKS2	0.0010	255.78
			MK4	0.0003	135.35	LDA2	0.0010	128.06
			S4	0.0016	62.10	L2	0.0041	171.38
			SK4	0.0002	79.76	T2	0.0069	225.89
			2MK5	0.0004	27.52	S2	0.0830	197.89
			2SK5	0.0002	110.66	R2	0.0040	185.20
			2MN6	0.0006	79.39	K2	0.0237	185.06
			M6	0.0004	79.91	MSN2	0.0018	344.41
			2MS6	0.0007	174.60	ETA2	0.0019	249.29
			2MK6	0.0003	179.05	MO3	0.0003	283.30
			2SM6	0.0005	319.81	M3	0.0081	128.52
			MSK6	0.0001	197.85	SO3	0.0003	173.45
			3MK7	0.0001	74.41	MK3	0.0013	156.05
			M8	0.0001	80.12	SK3	0.0009	125.40
						MN4	0.0009	24.43
						M4	0.0021	83.03
						SN4	0.0000	227.88
						MS4	0.0002	245.11
						MK4	0.0007	299.36
						S4	0.0008	63.09
						SK4	0.0002	44.46
						2MK5	0.0003	258.44
						2SK5	0.0004	5.89
						2MN6	0.0002	27.69
						M6	0.0004	60.36
						2MS6	0.0004	57.86
						2MK6	0.0001	151.04
						2SM6	0.0003	69.00
						MSK6	0.0002	173.87
						3MK7	0.0002	216.59
						M8	0.0001	281.95

BUKA

NAME	AMPLITUDE	PHASE
SSA	0.0990	151.05
MM	0.0039	123.01
MSF	0.0064	139.31
MF	0.0165	239.41
ALP1	0.0006	295.45
2Q1	0.0007	299.72
Q1	0.0220	299.12
O1	0.1250	319.22
TAY1	0.0019	291.56
BET1	0.0013	312.13
NO1	0.0120	318.61
P1	0.0703	342.41
K1	0.2205	345.49
PHI1	0.0059	22.01
J1	0.0090	357.58
SO1	0.0013	55.29
OO1	0.0087	31.29
UPS1	0.0011	73.68
EPS2	0.0026	177.52
MU2	0.0069	208.30
N2	0.0337	223.15
M2	0.1514	191.26
MKS2	0.0005	113.96
L2	0.0122	164.99
S2	0.1389	216.43
K2	0.0413	208.70
MSN2	0.0040	73.71
ETA2	0.0025	225.61
MO3	0.0019	106.17
M3	0.0069	242.99
SO3	0.0014	116.37
MK3	0.0004	183.93
SK3	0.0015	119.17
MNF	0.0025	180.77
M4	0.0039	241.05
SN4	0.0018	155.54
MS4	0.0026	201.27
MK4	0.0012	225.18
S4	0.0008	209.75
SK4	0.0002	208.72
2MK5	0.0008	62.51
2SK5	0.0003	113.77
2MN6	0.0007	169.47
M6	0.0012	193.46
2MS6	0.0021	223.72
2MK6	0.0007	260.35
2SM6	0.0003	202.78
MSK6	0.0005	216.05
3MK7	0.0003	132.01
M8	0.0008	184.61

Appendix

Table 2: Monthly means of sea-level (in millimetres) and the number of hours of data for all stations from 1984 to 1987,

	January	February	March	April	May	June	July	August	September	October	November	December	Mean
Port Moresby													
	-	-	-	-	-	-	-	1703	1723	1758	1771	1838	1762
1984	0	0	0	0	0	0	0	528	720	744	529	744	3265
	1796	1,871	1849	1853	1921	1878	1830	1783	1815	1798	1819	1798	1832
1985	744	672	744	720	744	409	744	744	720	744	720	744	8449
	1897	1,877	1923	1939	1839	1863	1802	1813	1805	1787	1839	1805	1849
1986	744	672	744	720	744	720	744	744	720	744	720	744	8760
	1828	1,873	1855	1915	1859	1875	1816	1797	1784	1746	1783	1852	1833
1987	744	633	624	720	744	720	744	744	648	609	625	744	8299
													1835
Alotau													
1984	-	-	-	-	-	-	-	-	-	899	906	937	914
	0	0	0	0	0	0	0	0	216	744	720	744	2208
1985	909	958	957	940	-	-	-	-	-	-	-	-	941
	744	672	744	720	81	0	0	0	0	0	0	0	2880
1986	-	-	-	-	-	-	-	-	-	-	-	-	-
	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	-	-	-	900	871	873	838	840	835	870	877	924	869
	0	0	0	537	744	720	707	744	720	744	720	744	6380
													894
Lae													
1984	-	-	-	-	-	-	-	-	1213	1272	1259	1272	1254
	0	0	0	0	0	0	0	0	720	744	720	744	2928
1985	1247	1297	1314	1314	1345	1321	1319	1270	1277	1297	1293	1266	1297
	744	672	744	720	744	720	744	744	720	744	720	744	8760
1986	1318	1321	1342	-	-	1342 -		1325	1306	1259	1327	1280	1313
	744	672	744	321	327	720	296	660	720	744	720	744	6468
1987	1258	1302	1269	1288	1269	1252	1245	1213	1198	1245	1252	1274	1255
	744	672	744	720	744	720	744	744	720	744	720	735	7651
													1285
Madang													
1984	-	-	-	-	-	-	-	-	1293	1340	1327	1324	1321
	0	0	0	0	0	0	0	240	720	744	720	744	2928
1985	1292	1,360	1329	1403	1432	1419	1414	1373	1377	1404	1363	1321	1374
	744	672	744	720	744	720	744	744	720	744	720	744	8760
1986	1345	1,340	1403	1427	1432	1411	1408	1415	1380	1349	1391	1324	1386
	744	672	744	720	744	720	744	744	720	744	720	744	8760
1987	1279	1,300	1302	1322	1341	1288	1285	1272	1262	1285	1323	1297	1295
	744	672	744	720	402	543	744	744	720	744	720	744	8241

	Year	January	February	March	April	May	June	July	August	September	October	November	December	Mean
Wewak														
	1984	-	-	-	-	-	-	-	-	1004	1038	1011	982	1006
		0	0	0	0	0	0	0	72	720	744	720	744	2928
	1985	946	1050	976	1099	1118	1113	1094	1071	1085	1119	1035	974	1056
		744	672	744	720	744	720	744	744	720	744	720	744	8760
	1986	989	983	1099	1068	1107	1091	1073	1074	1028	1022	1030	932	1042
		744	672	744	720	744	720	744	744	720	744	720	744	8760
	1987	880	867		982	1010	1001	984	983	961	984	1031	973	970
		744	619	0	704	744	720	744	744	720	743	720	744	7946
														1024
Manus														
	1984	-	-	-	-	-	-	-	-	1061	1117	1097	1134	1104
		0	0	0	0	0	0	0	0	648	744	720	744	2856
	1985	1132	1,134	1124	1174	1148	1138	1100	1102	1143	1144	1120	1075	1127
		744	672	744	720	676	720	744	744	720	660	720	744	8608
	1986	1072	1,096	1155	1155	1115	1078	1069	1076	1047	1043	1064	972	1078
		744	672	744	720	744	720	744	744	720	744	719	744	8759
	1987	919	956	-	-	-	-	-	-	-	-	-	-	930
		719	299	0	0	0	0	0	0	0	0	0	0	1018
														1099
Kavieng														
	1984	-	-	-	-	-	-	-	-	900	927	916	963	929
		0	0	0	0	0	0	0	0	504	744	720	744	2712
	1985	939	1,002	975	1030	1008	988	950	952	994	994	957	906	974
		744	672	744	720	744	720	744	744	720	744	720	744	8760
	1986	921	958	1033	1019	983		939	924	912	917	940		954
		744	672	744	720	675	134	744	744	720	744	714	235	7221
	1987	-	818	850	829	827	781	767	769	758	792	874	851	812
		228	672	744	720	744	372	744	744	720	744	689	744	7619
														918

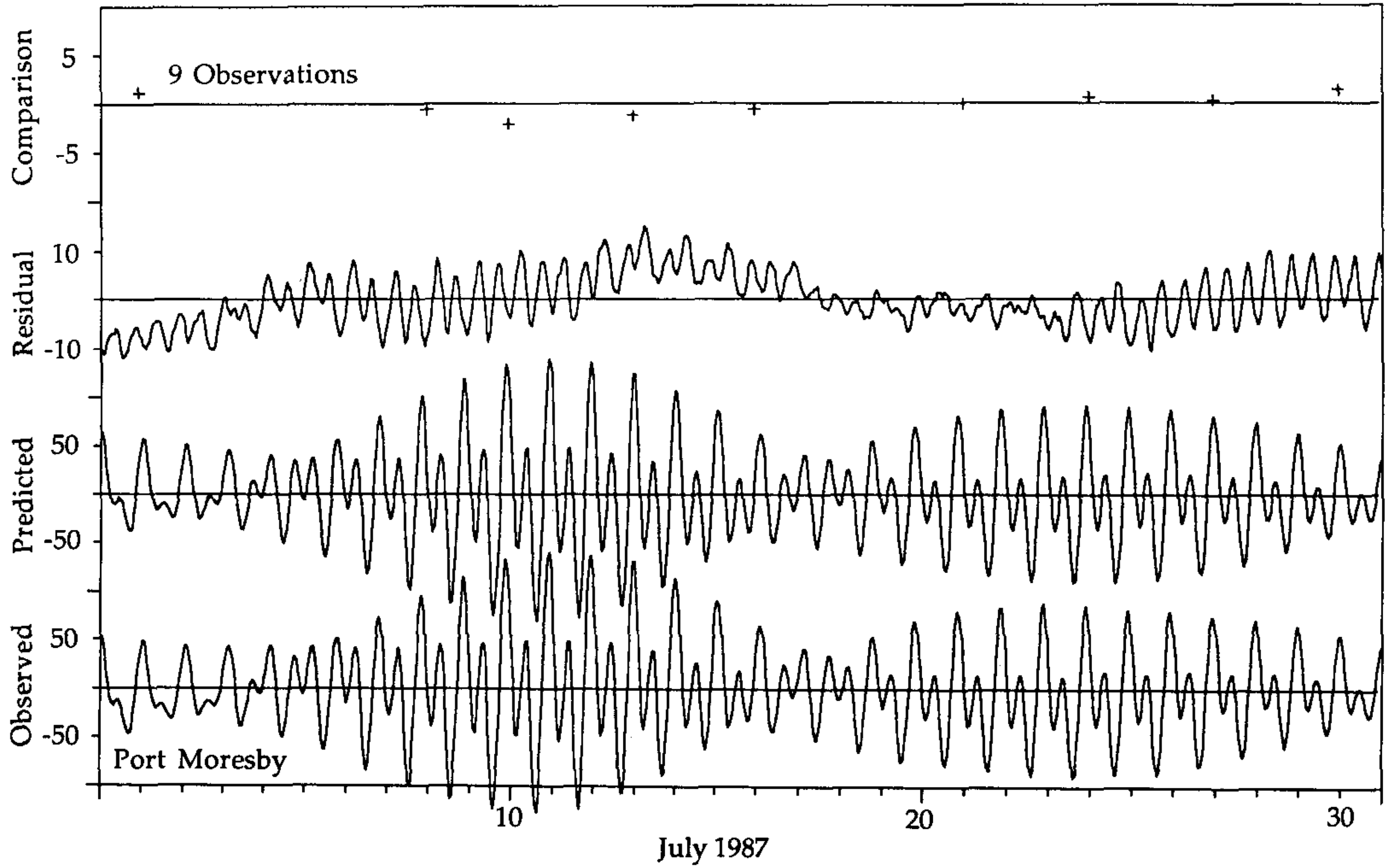

Figure 2: A diagnostic plot for data received from Port Moresby for July 1986. The observed tides, predicted tides, non-tidal residuals, and the observers, comparison checks (all in cm), are displayed.

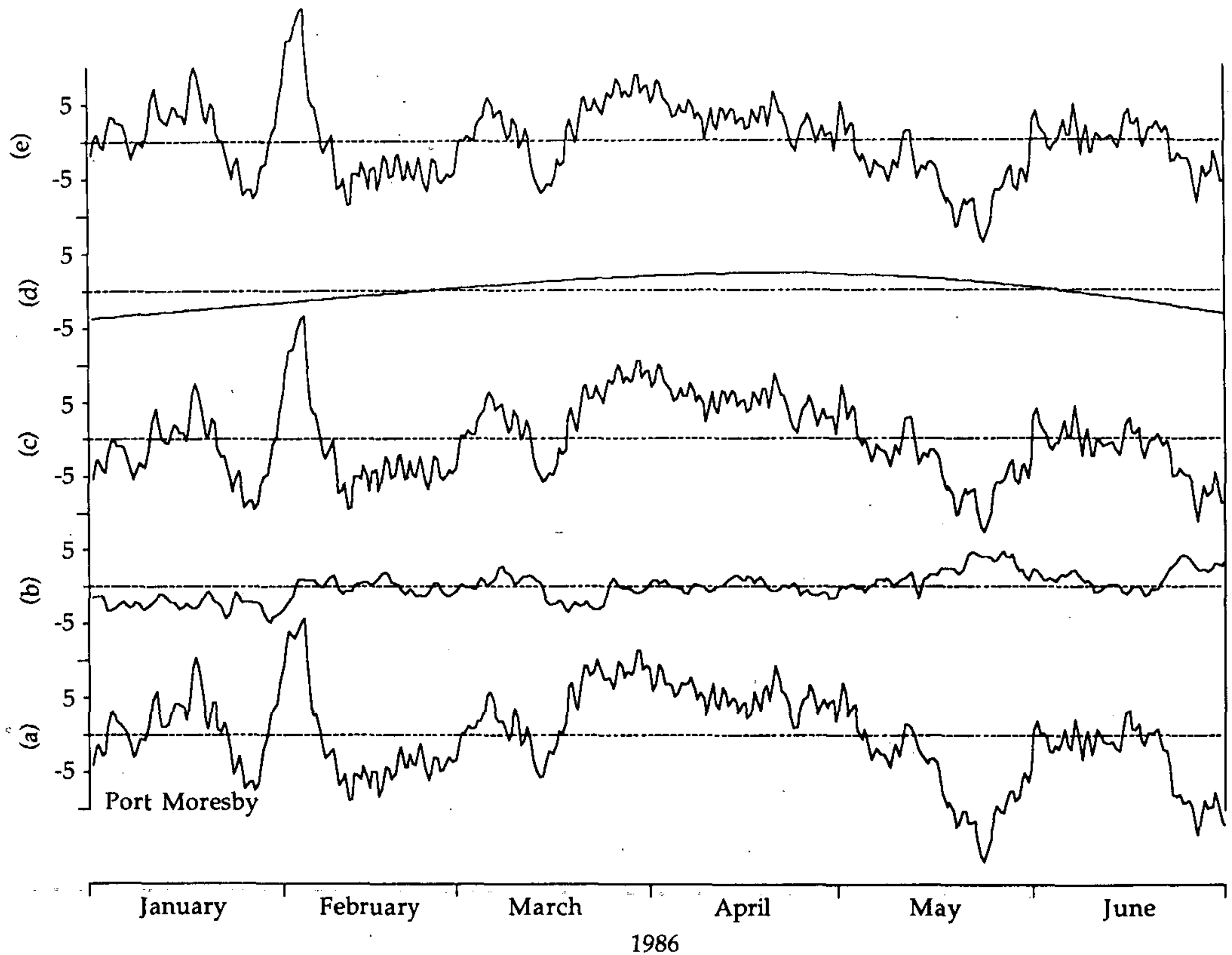

Figure 3: Standard plot for Port Moresby data. Filtered (a), sea-level pressure (b), pressure corrected (c), seasonal correction (d) and seasonally corrected (e) forms are shown. The sea-levels are in cm and the pressure is in mb.

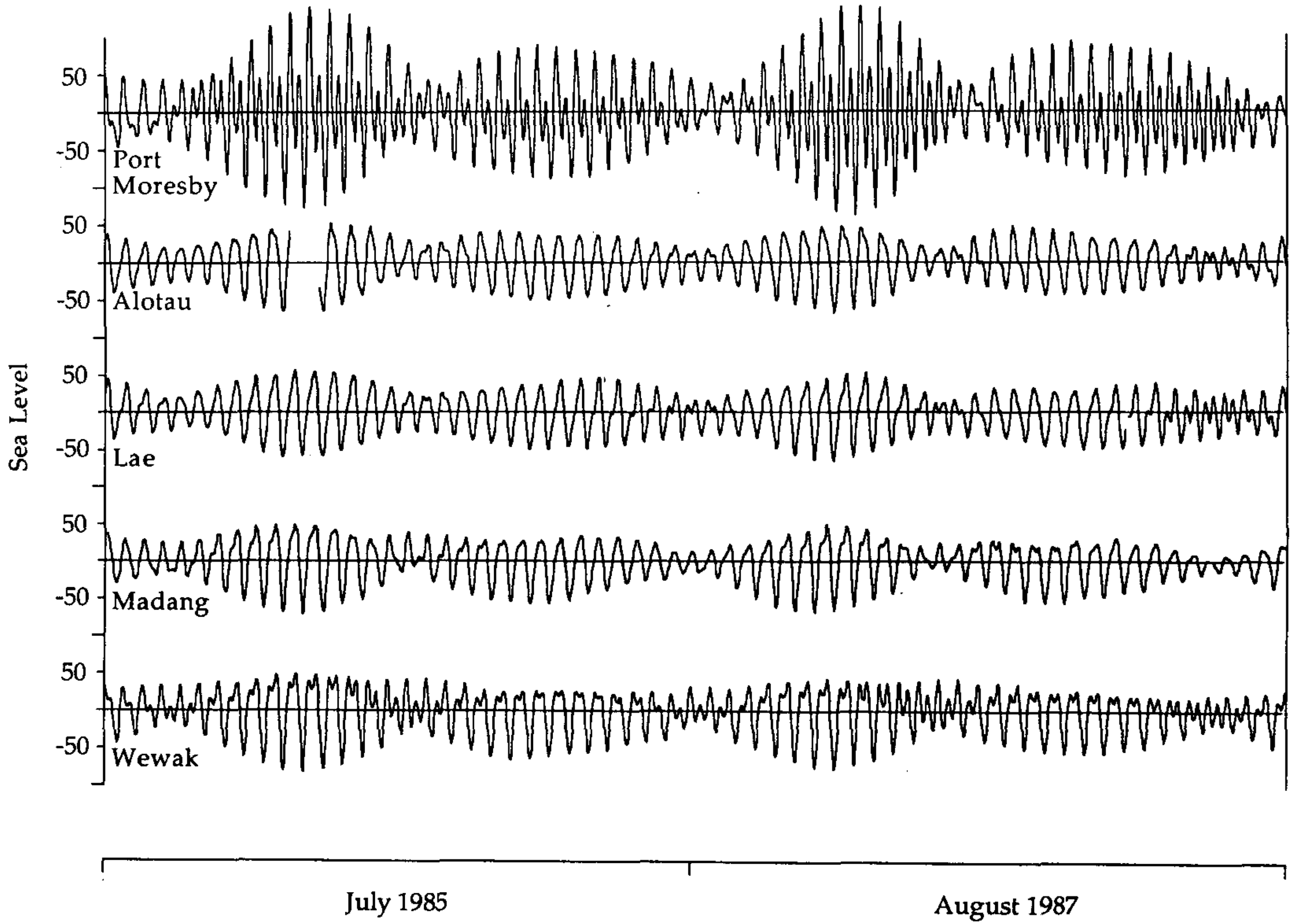

Figure 4: The observed tidal signals (raw data in cm) are shown for all stations for the period July 1985 to August 1987.

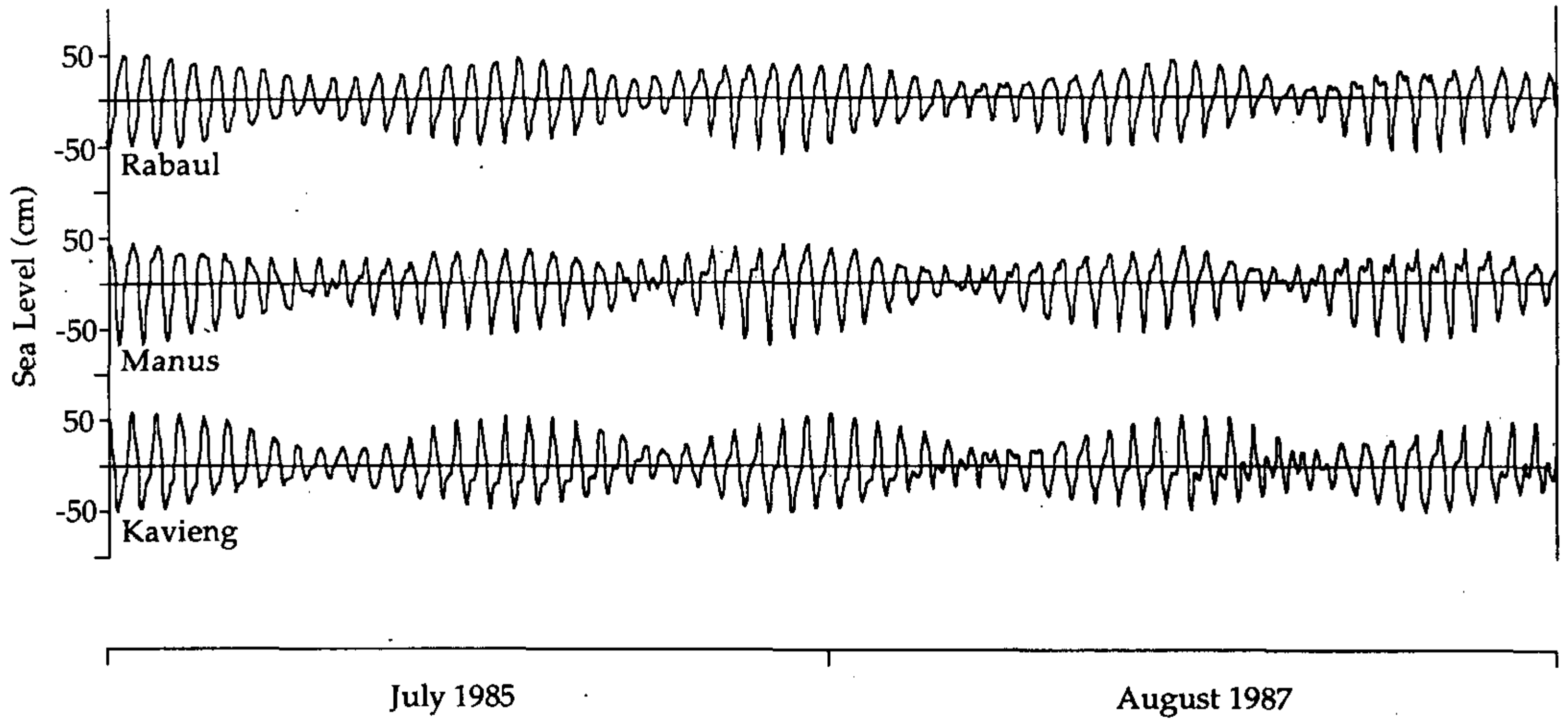

Figure 4 cont.

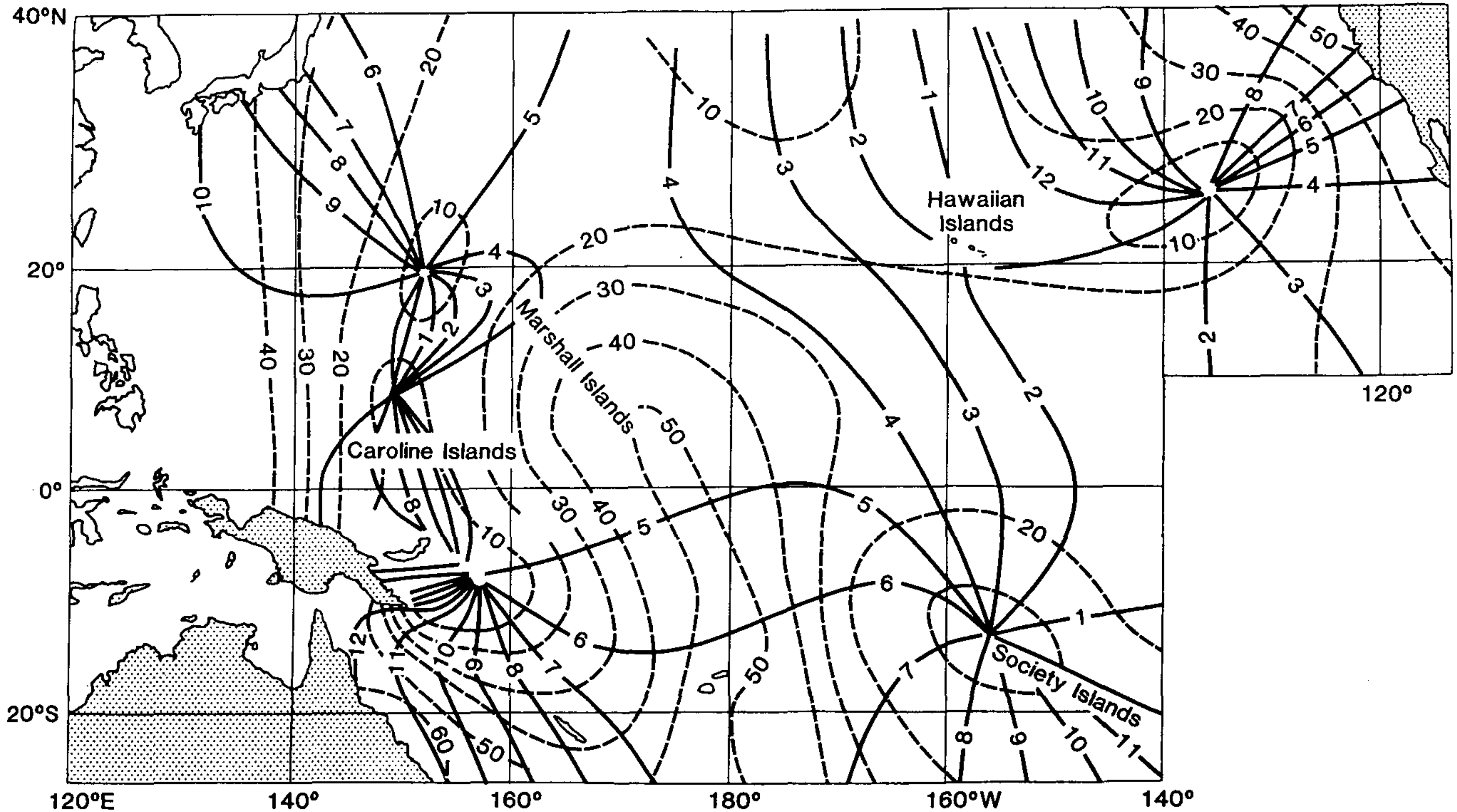

Figure 5: M2 cotidal chart. Solid curves represent equal Greenwich epoch G, in solar hours, and dashed curves are equal amplitude, H, in centimetres (after Luther and Wunsch 1975).

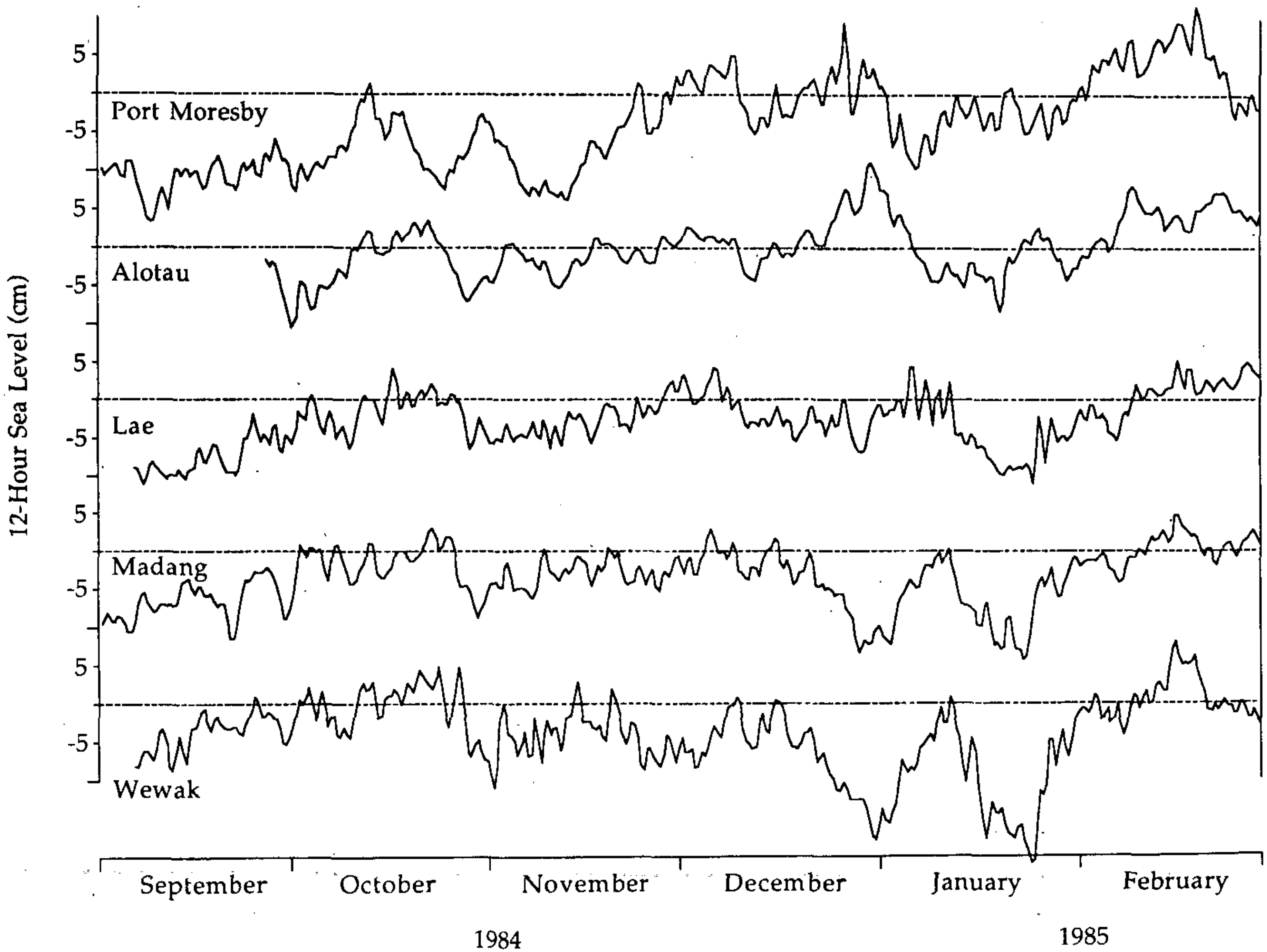

Figure 6: Time series of 12-hourly sea-levels, obtained after filtering and decimating the observed hourly sea-levels, for Port Moresby, Alotua, Lae, Madang and Wewak. Each panel of plots contains six months of data, starting from September 1984.

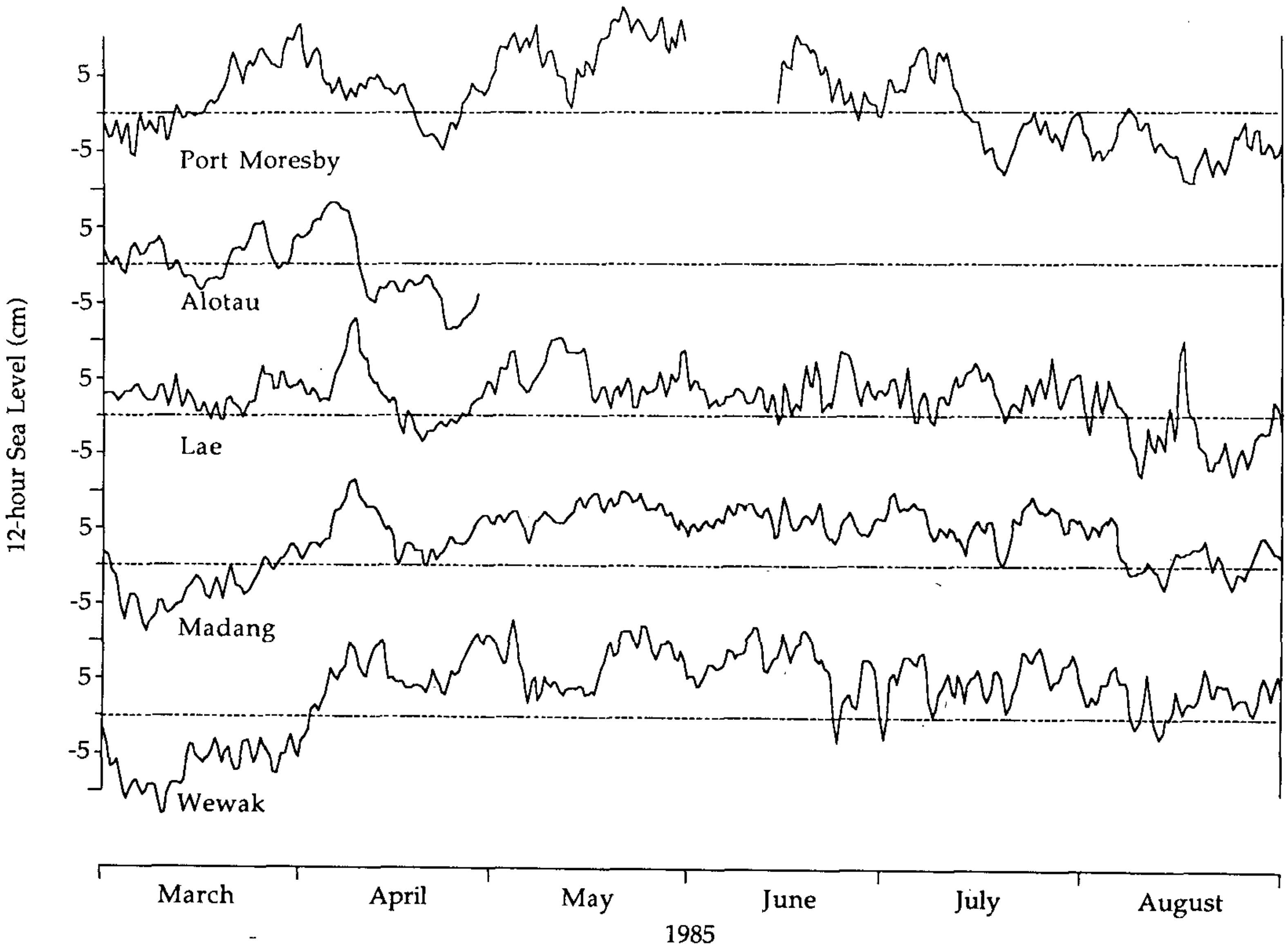

Figure 6 cont.

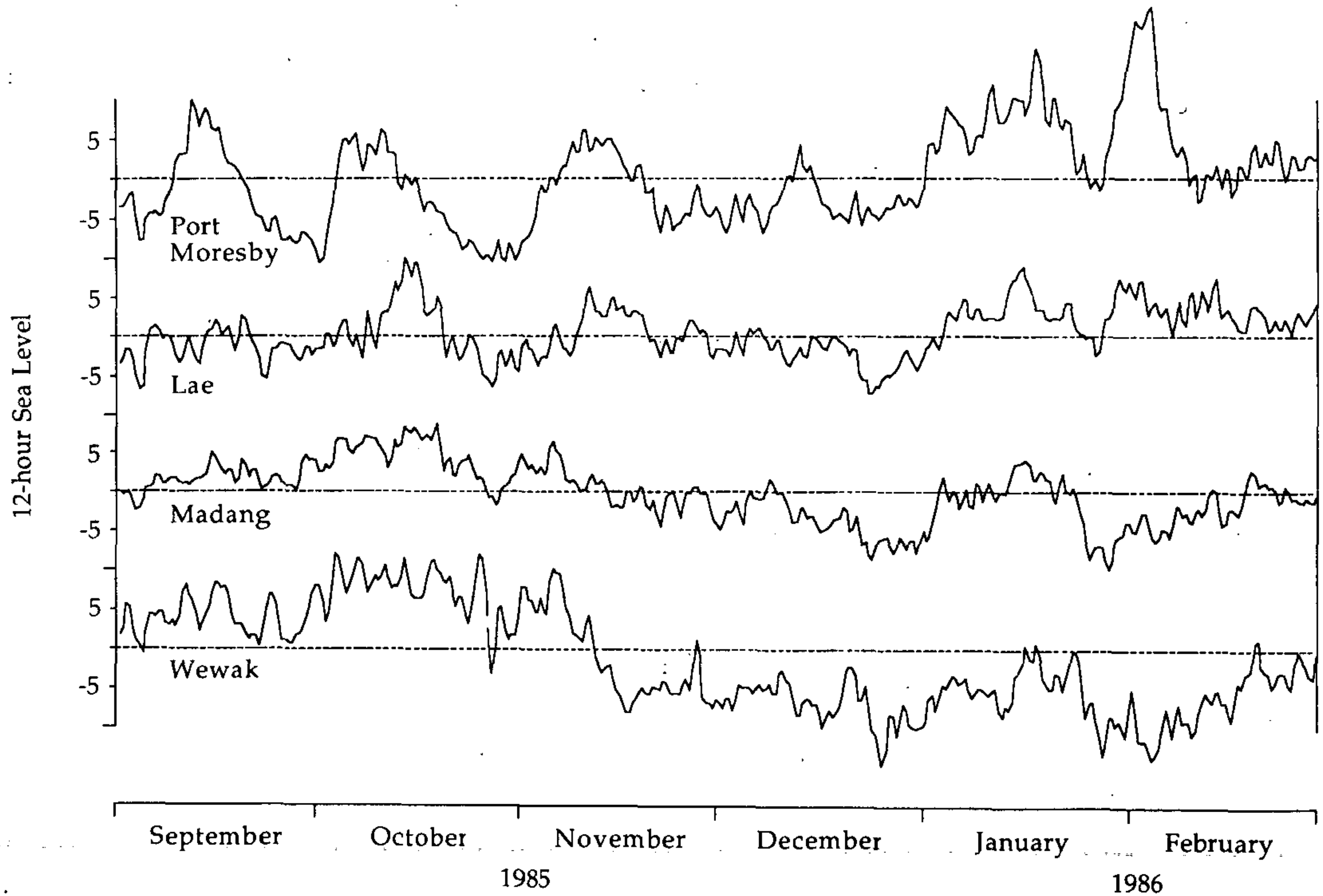

Figure 6 cont.

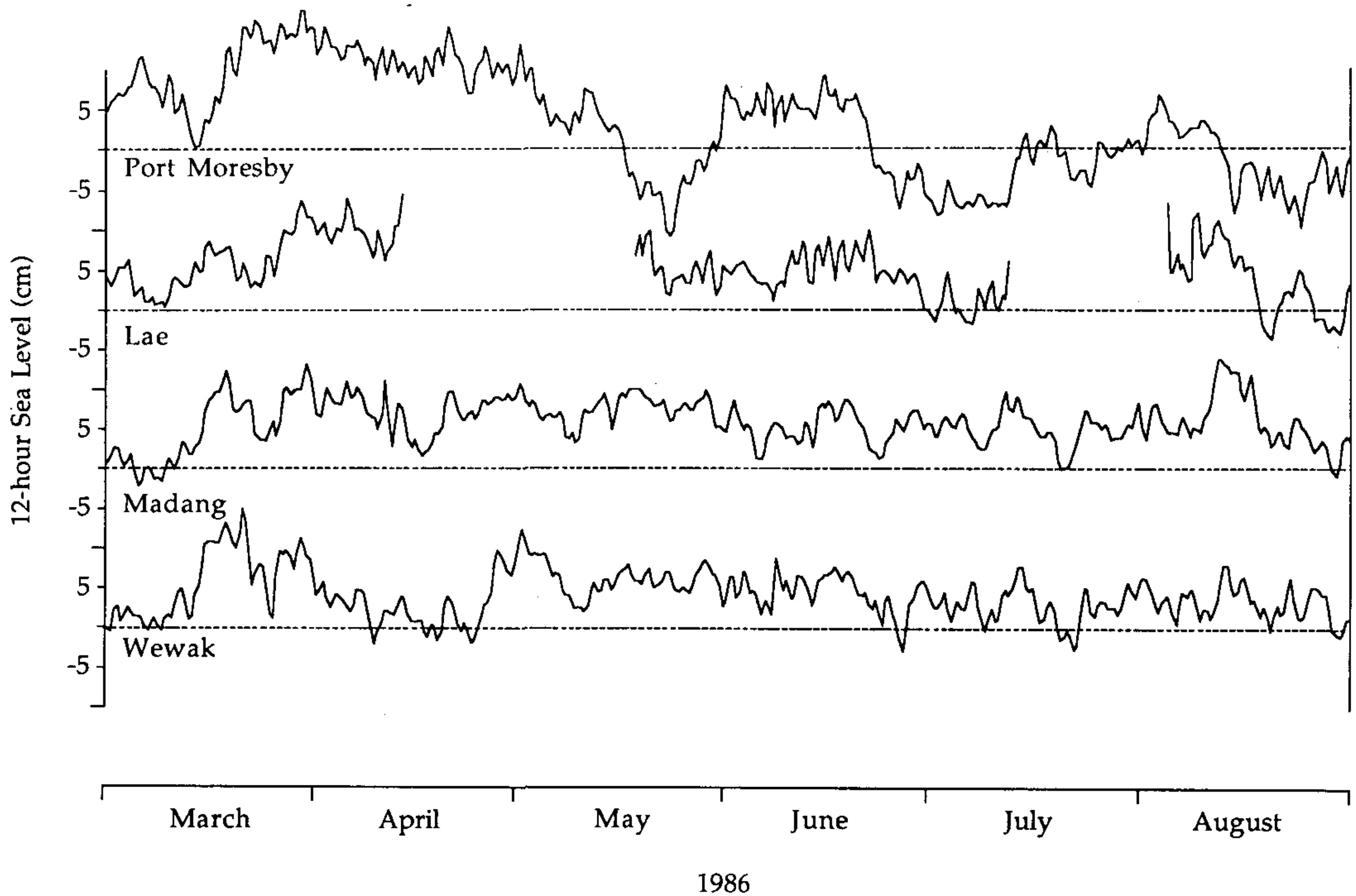

Figure 6 cont.

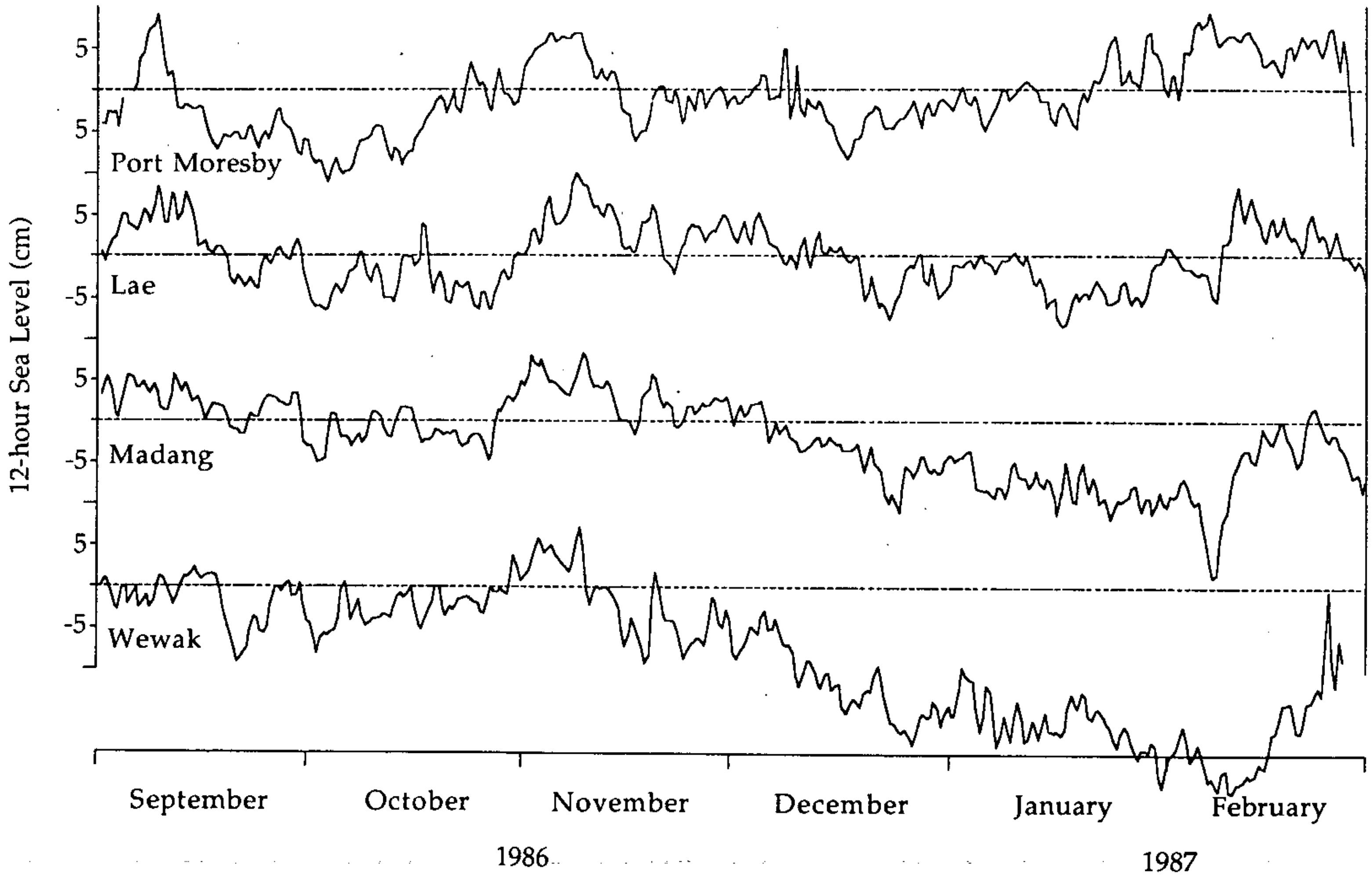

Figure 6 cont.

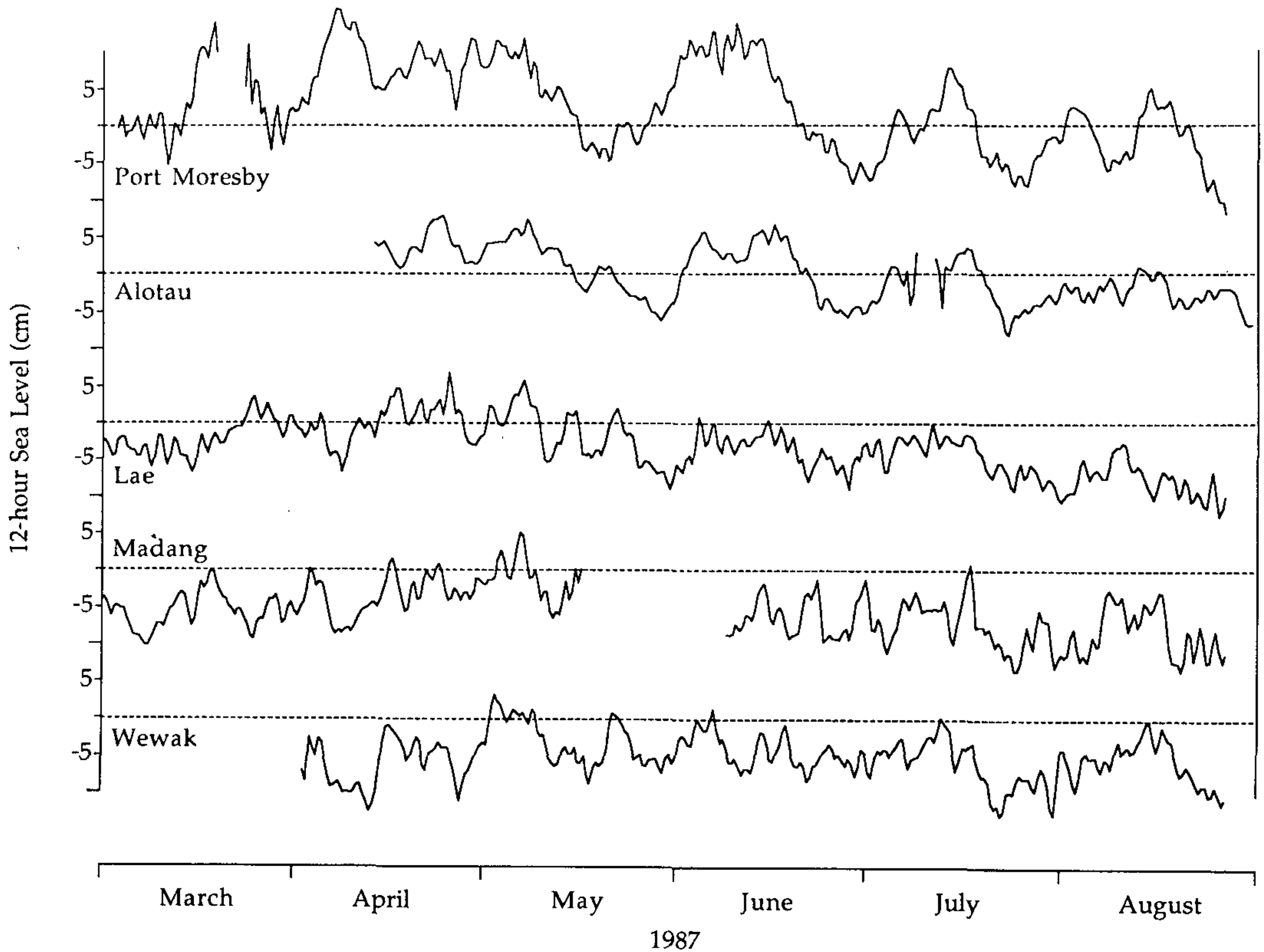

Figure 6 cont.

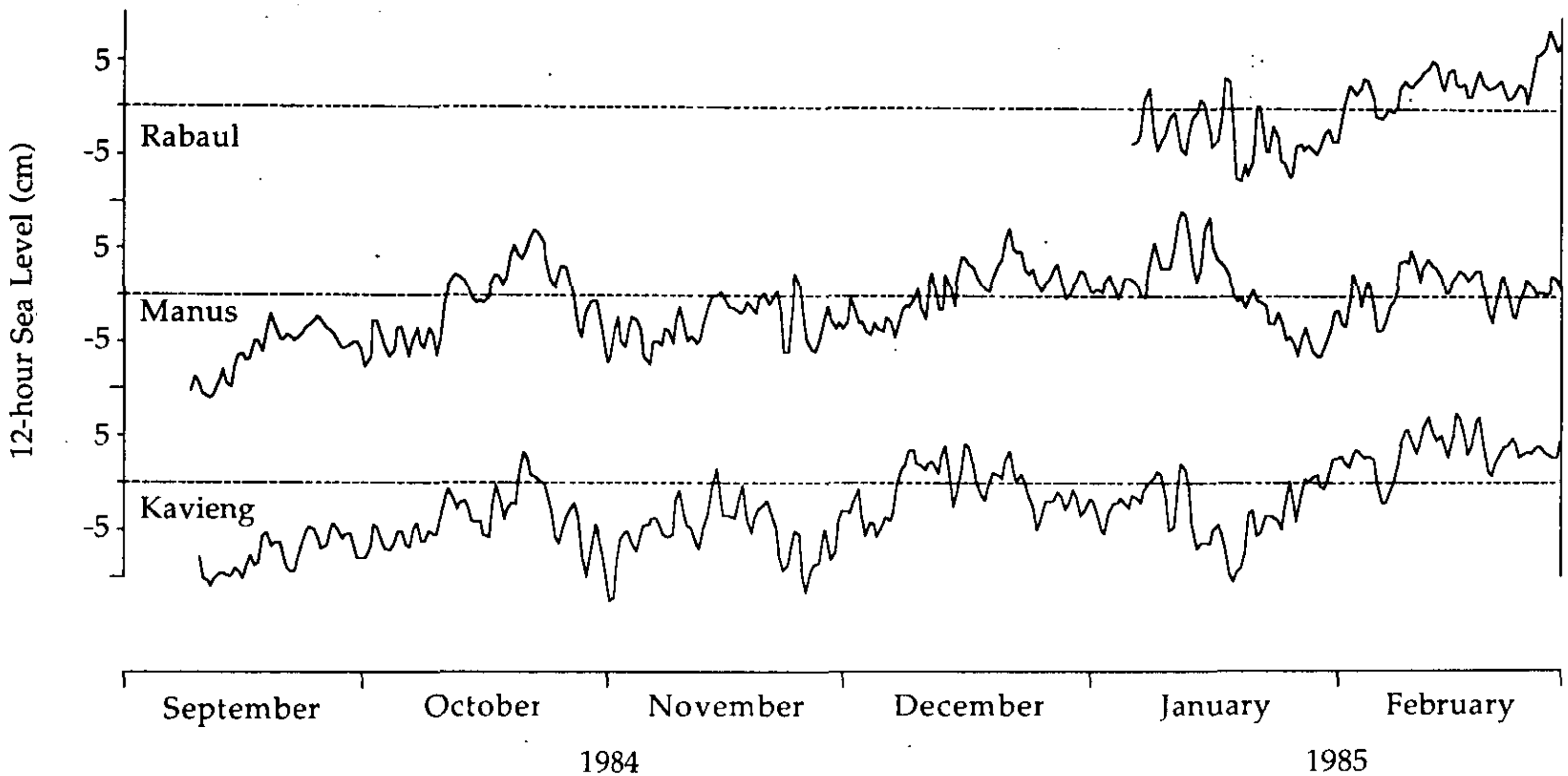

Figure 7: As for Fig. 6 for stations Manus, Kavieng and Rabaul.

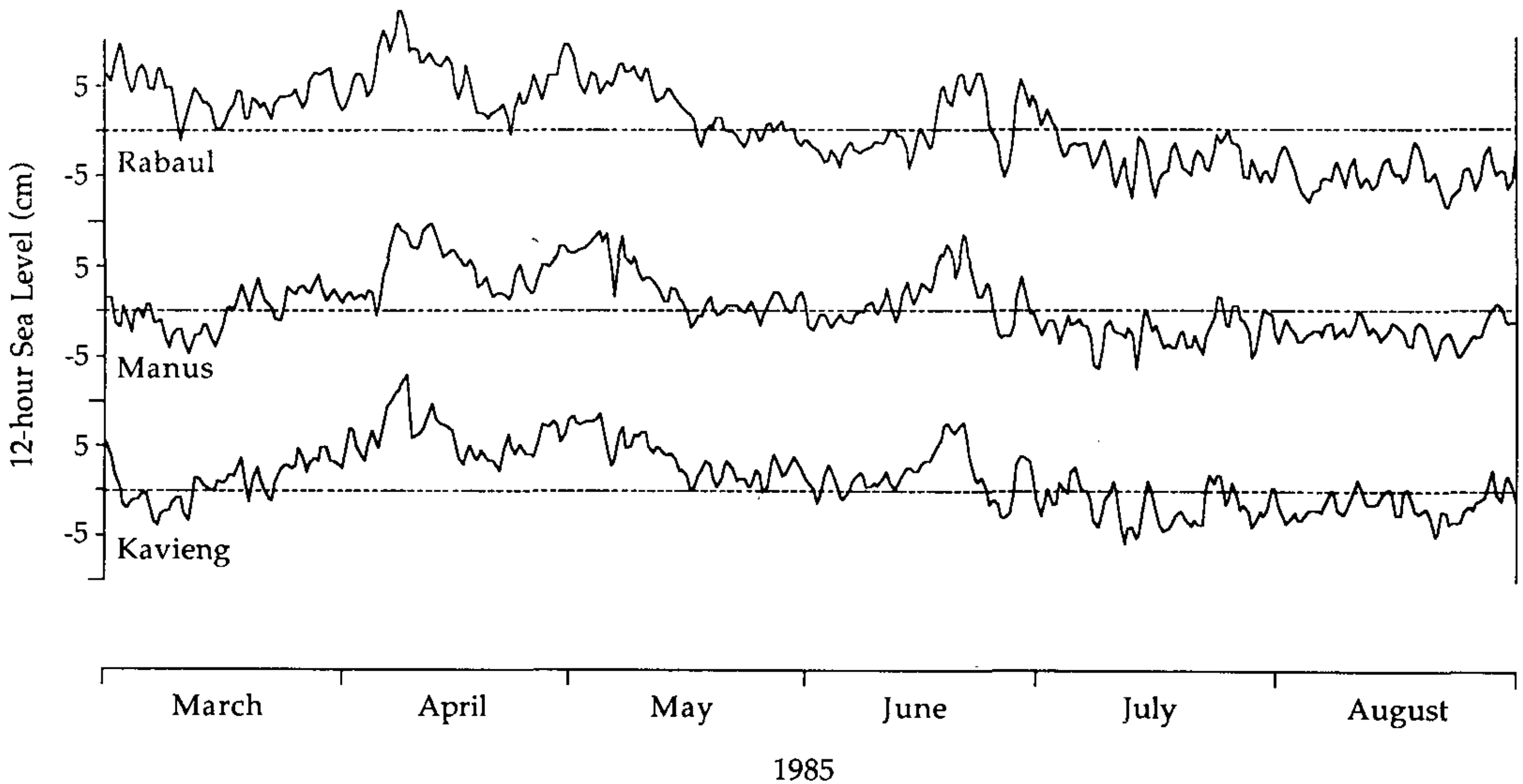

Figure 7 cont.

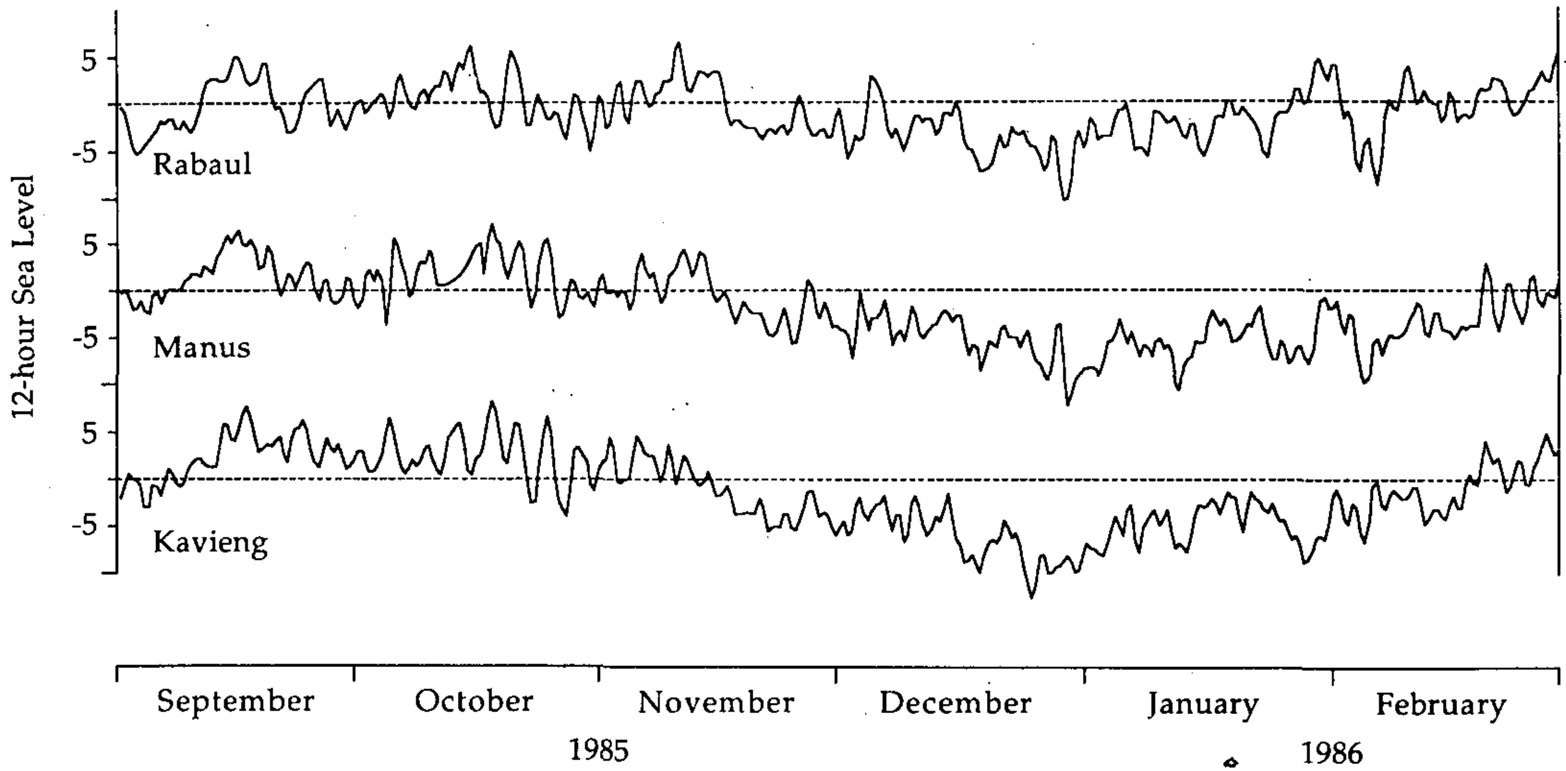

Figure 7 cont.

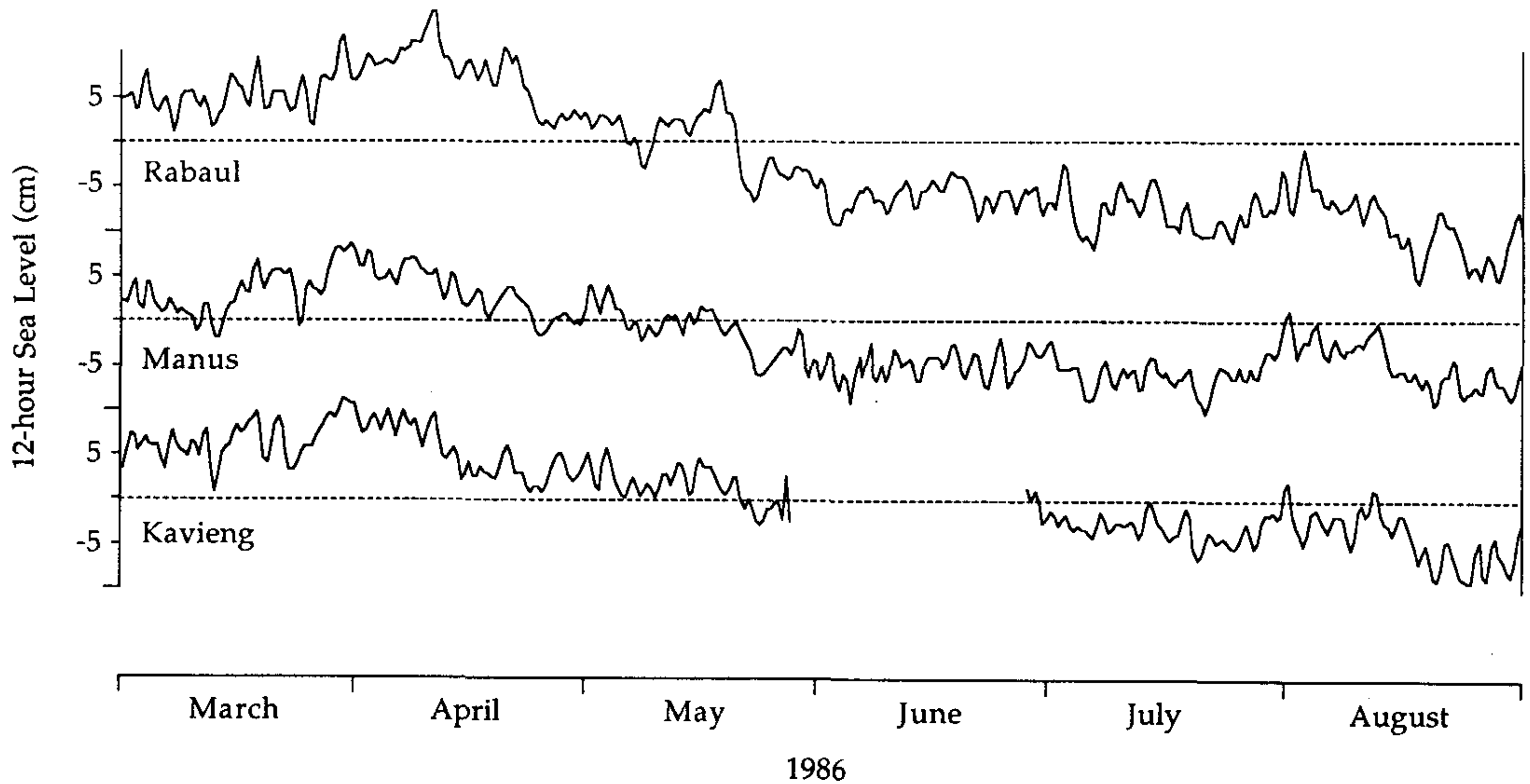

Figure 7 cont.

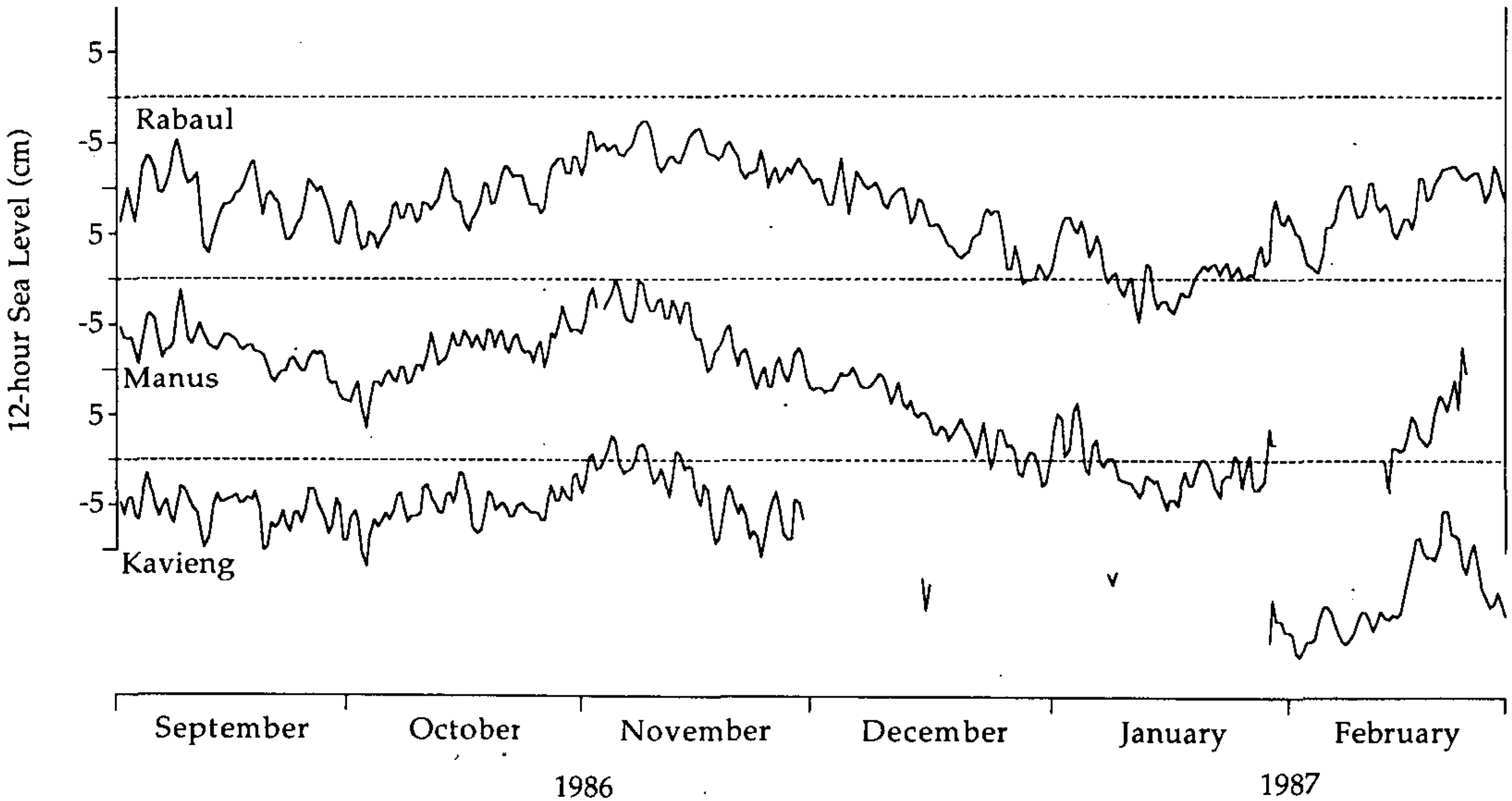

Figure 7 cont.

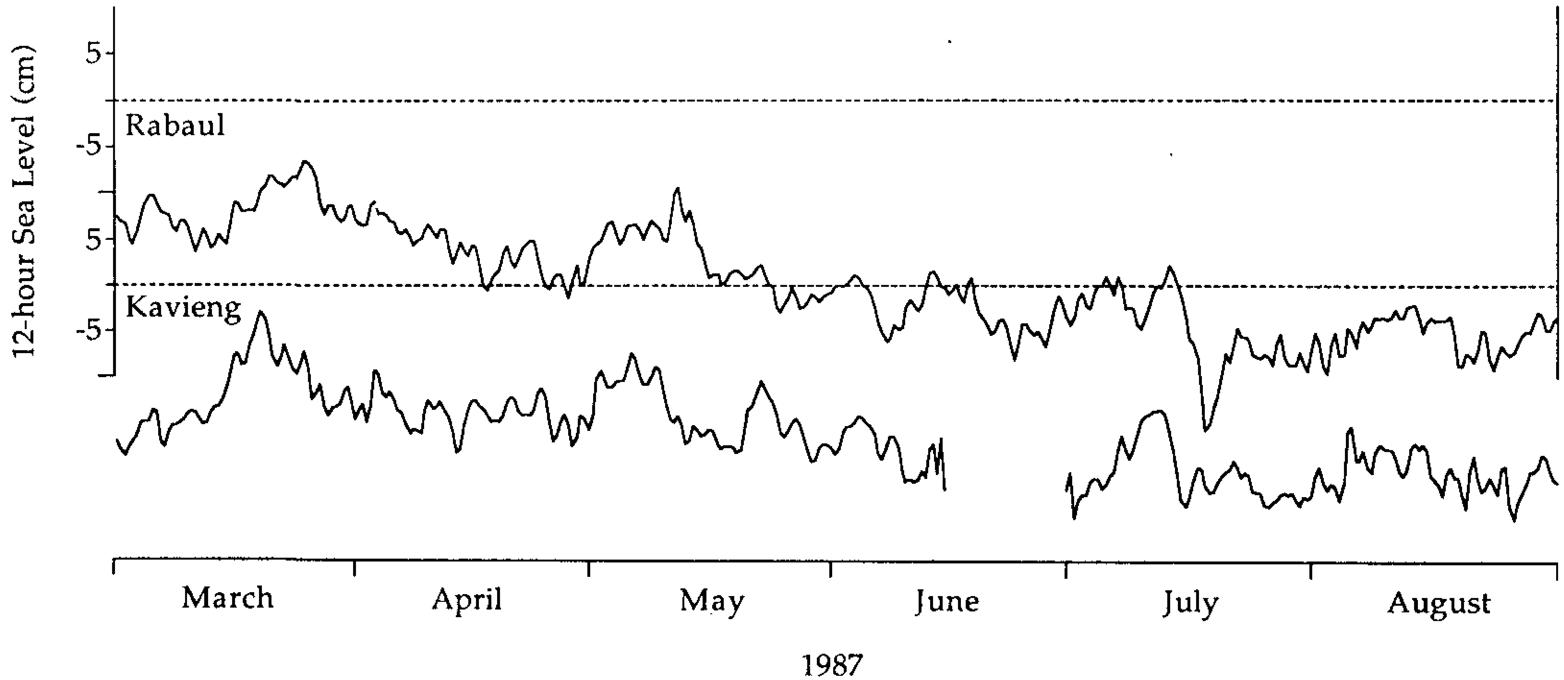

Figure 7 cont.

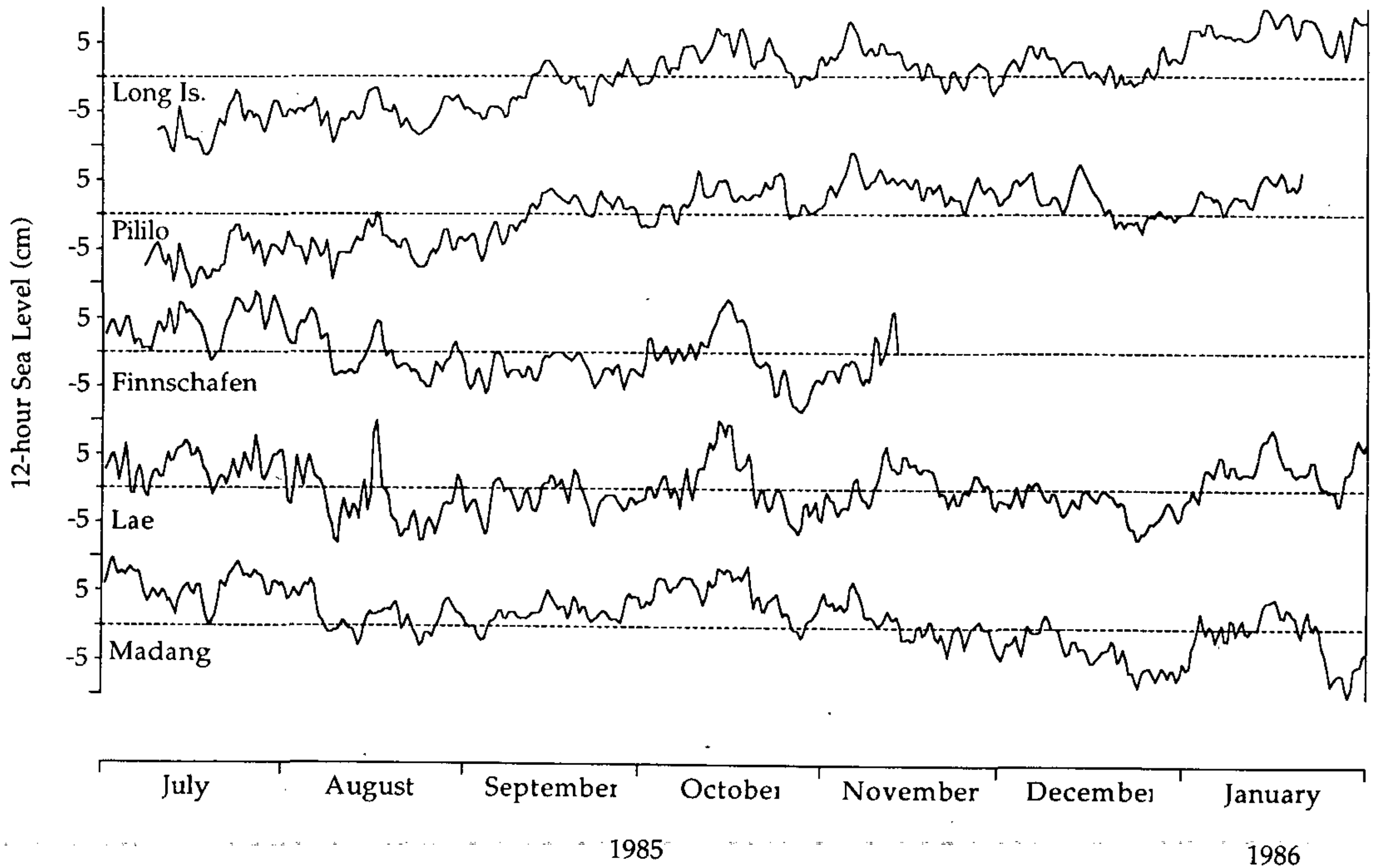

Figure 8: Time series for sea-level data obtained from the pressure recorders at Finschhafen, Long Island and Pililo for the period July 1985 to January 1986. Adjacent records from permanent gauges at Lae and Madang are also plotted for comparison.

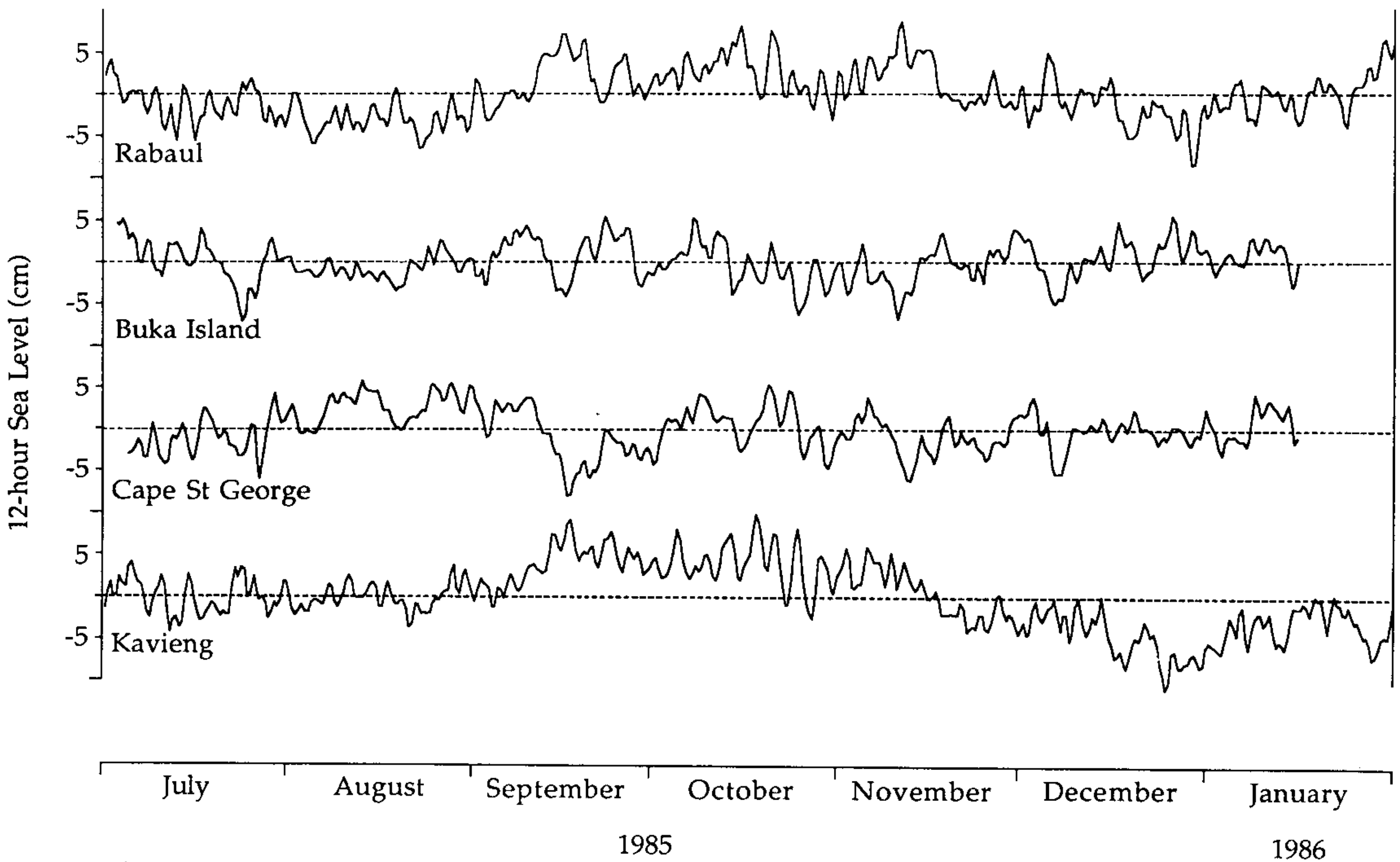

Figure 9: As for Fig. 8 for stations Buka, Cape St. George, Rabaul and Kavieng.

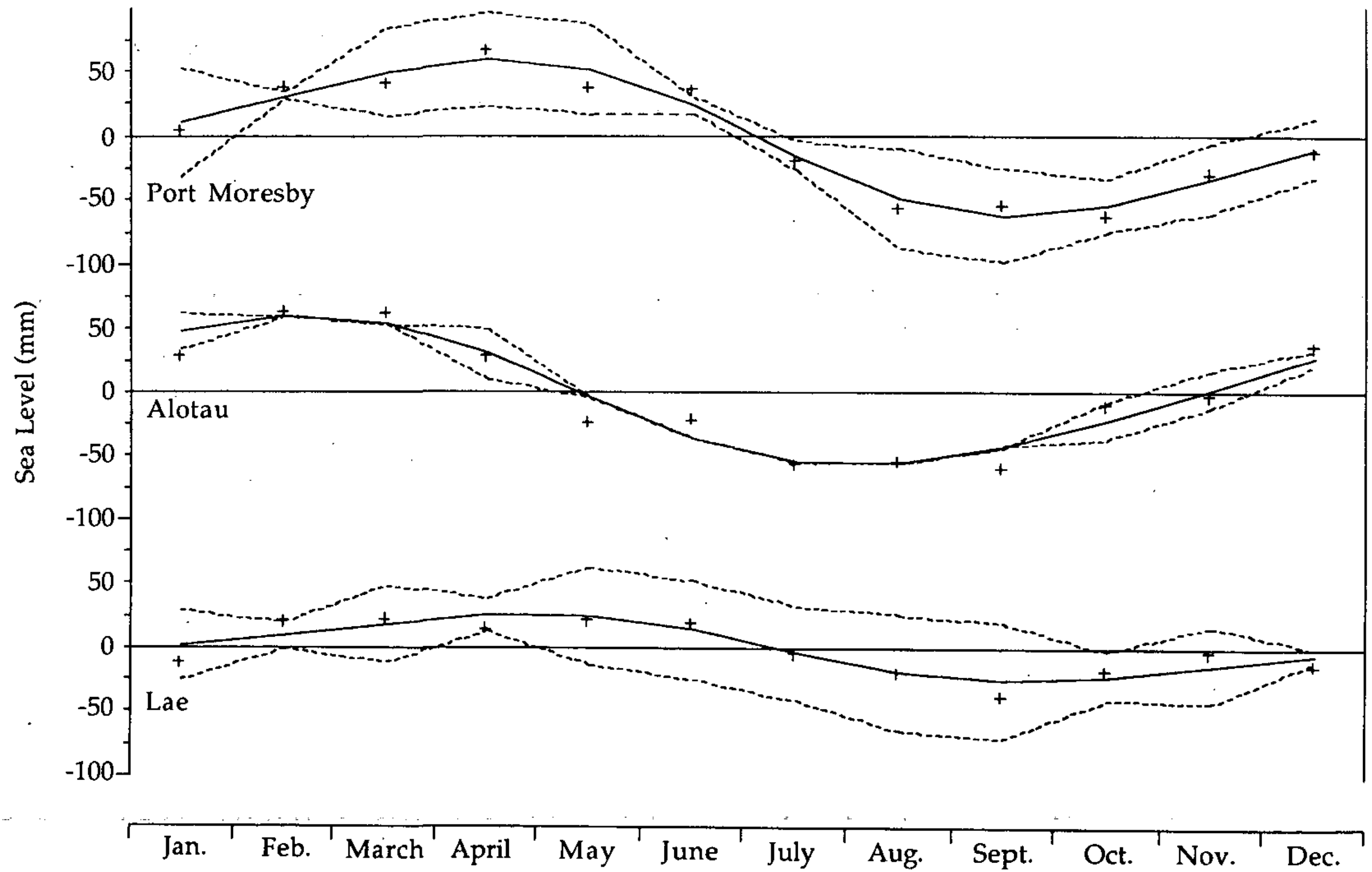

Figure 10: The seasonal cycle of sea-level at each station, as determined from a two-harmonic best fit to the whole data record. The full line is the seasonal cycle, the dotted lines trace out the standard deviation of the monthly means,

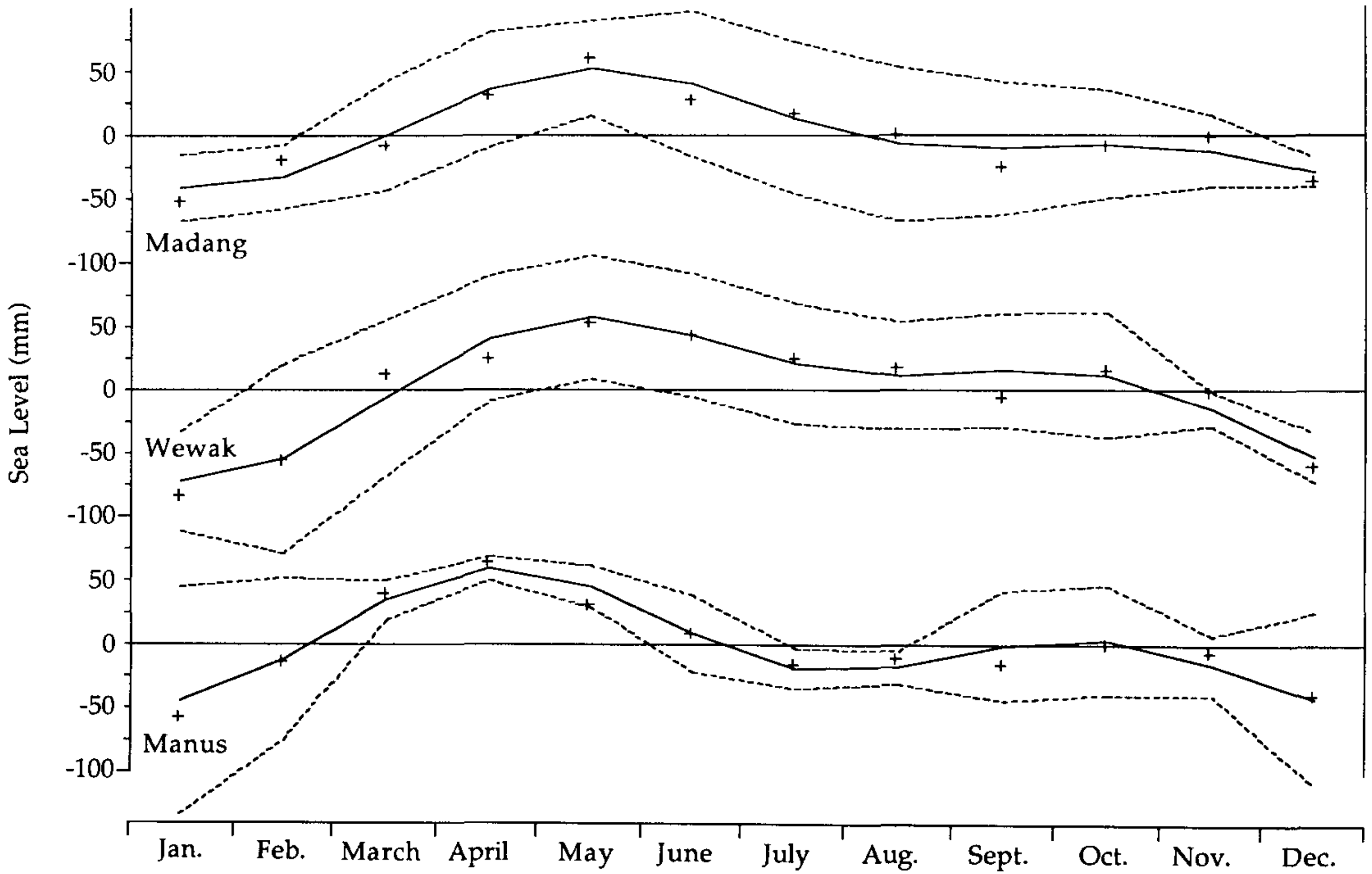

Figure 10 cont.

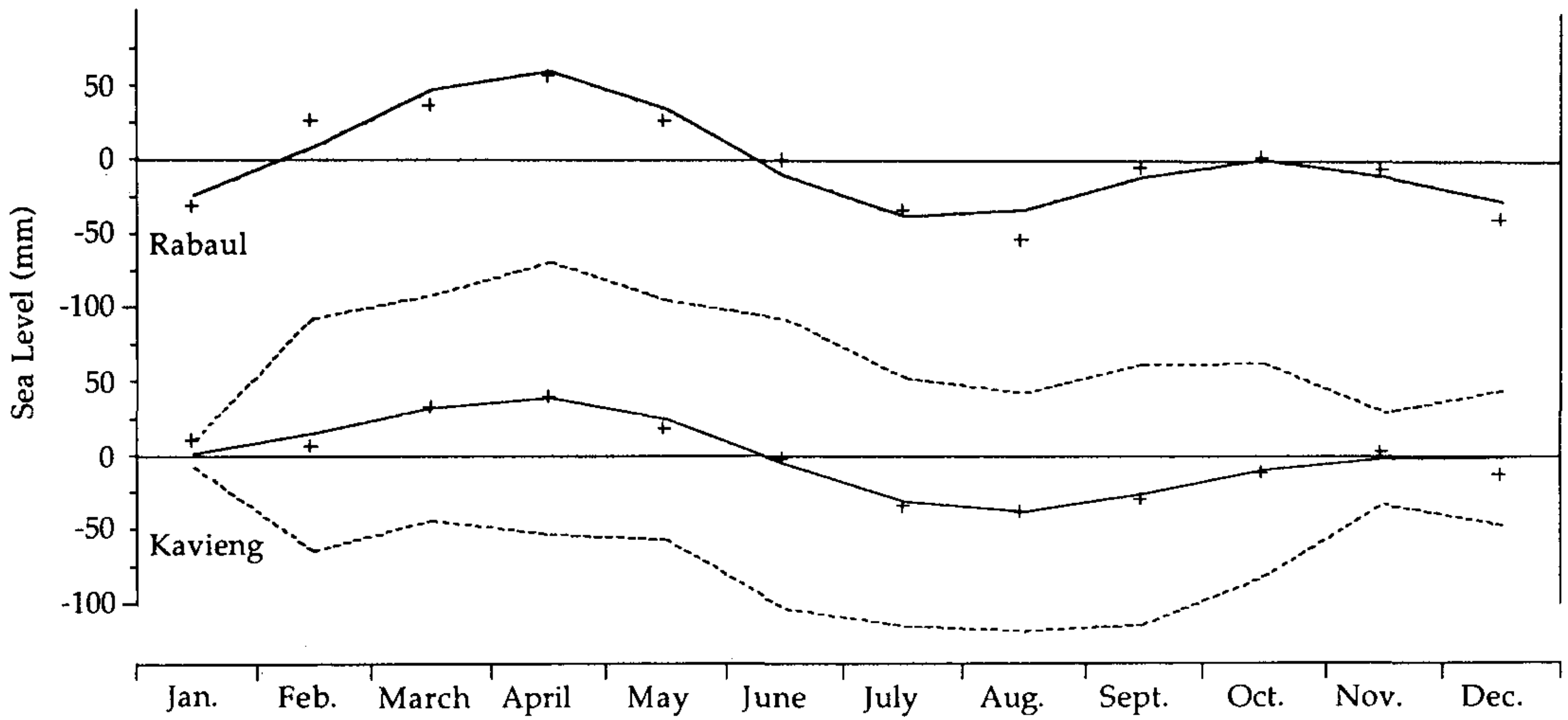

Figure 10 cont.

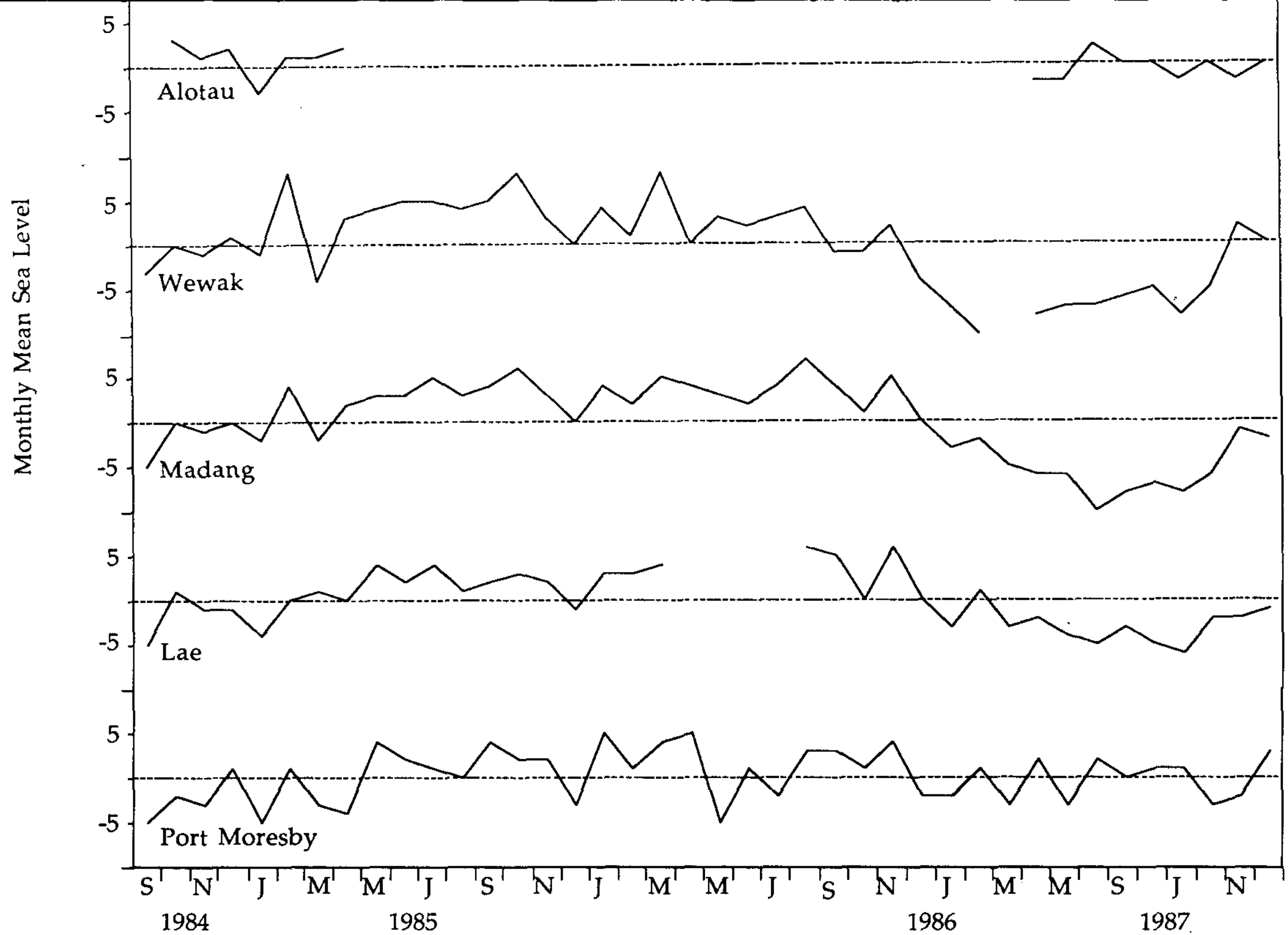

Figure 11: Time series of the monthly anomalies of sea-level (cm) from September 1984 to December 1987. Each monthly anomaly is derived by subtracting from the individual monthly mean, the mean sea-level (MSL) for the whole period and the mean annual cycle as given in Fig. 9.

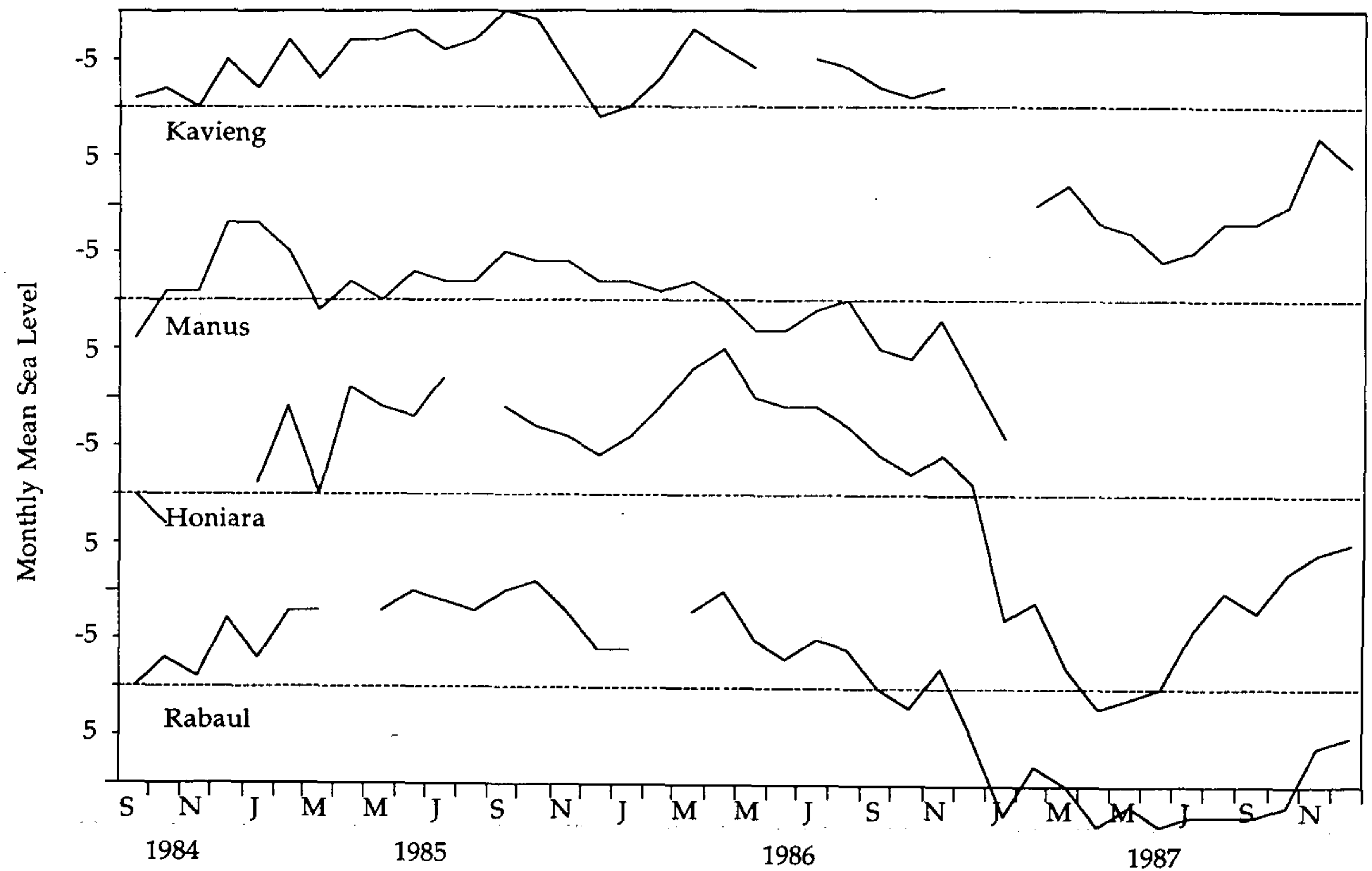

Figure 11 cont.

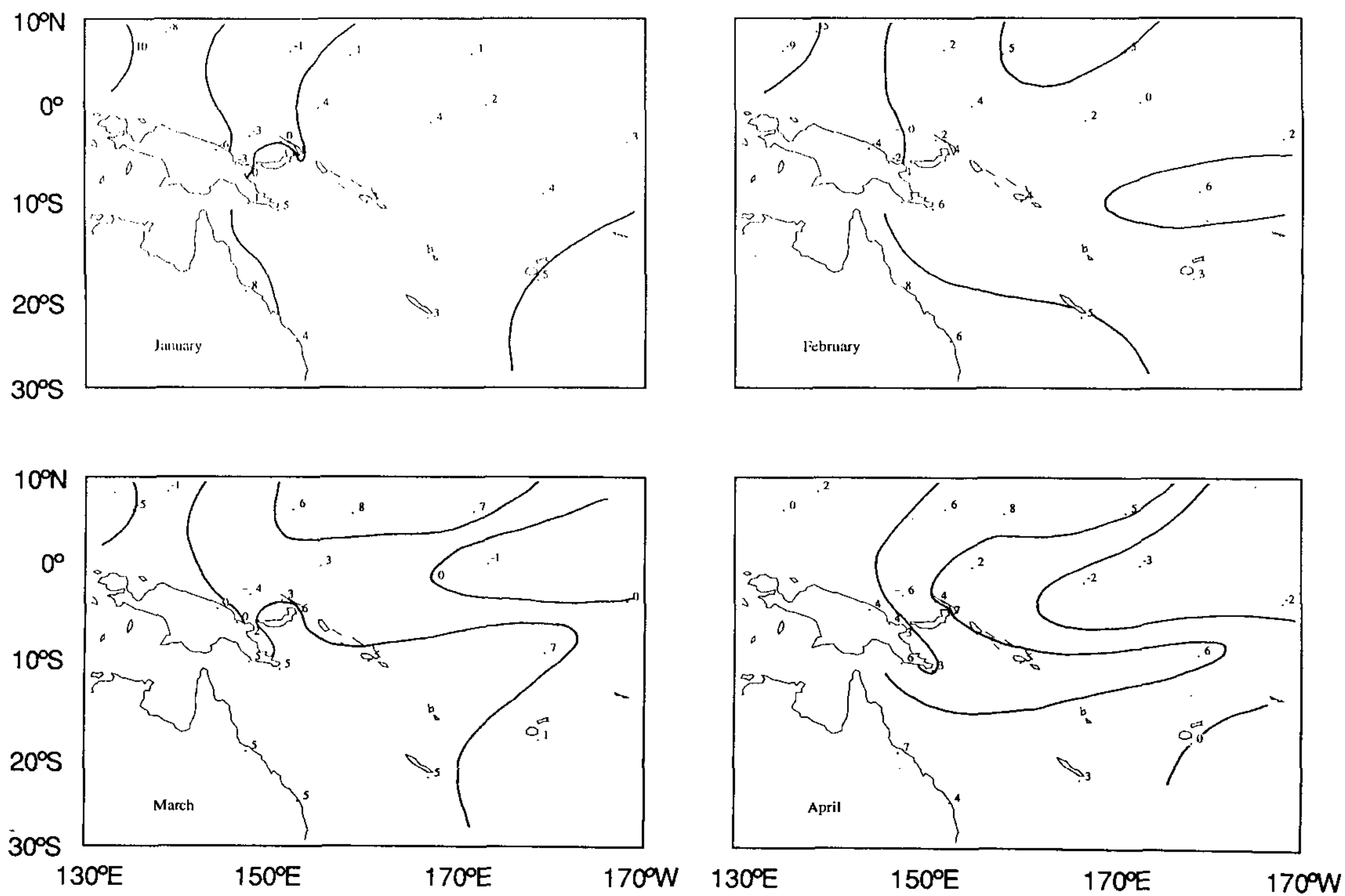

Figure 12: Maps of the monthly sea-level deviations (cm) from the two harmonic best fit curve given in Fig. 9. The Papua New Guinea stations have been supplemented with data from adjacent Pacific Ocean stations.

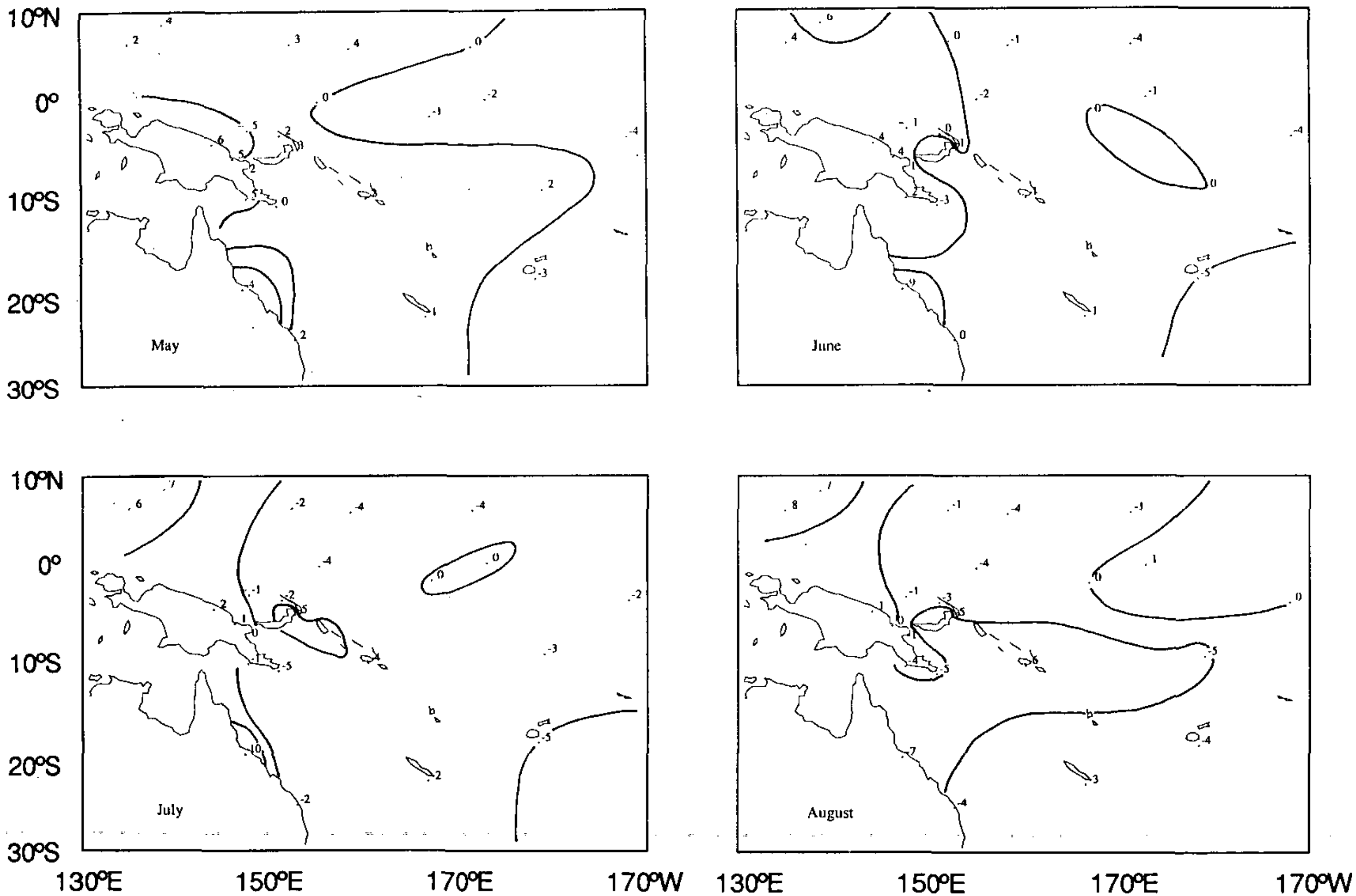

Figure 12 cont.

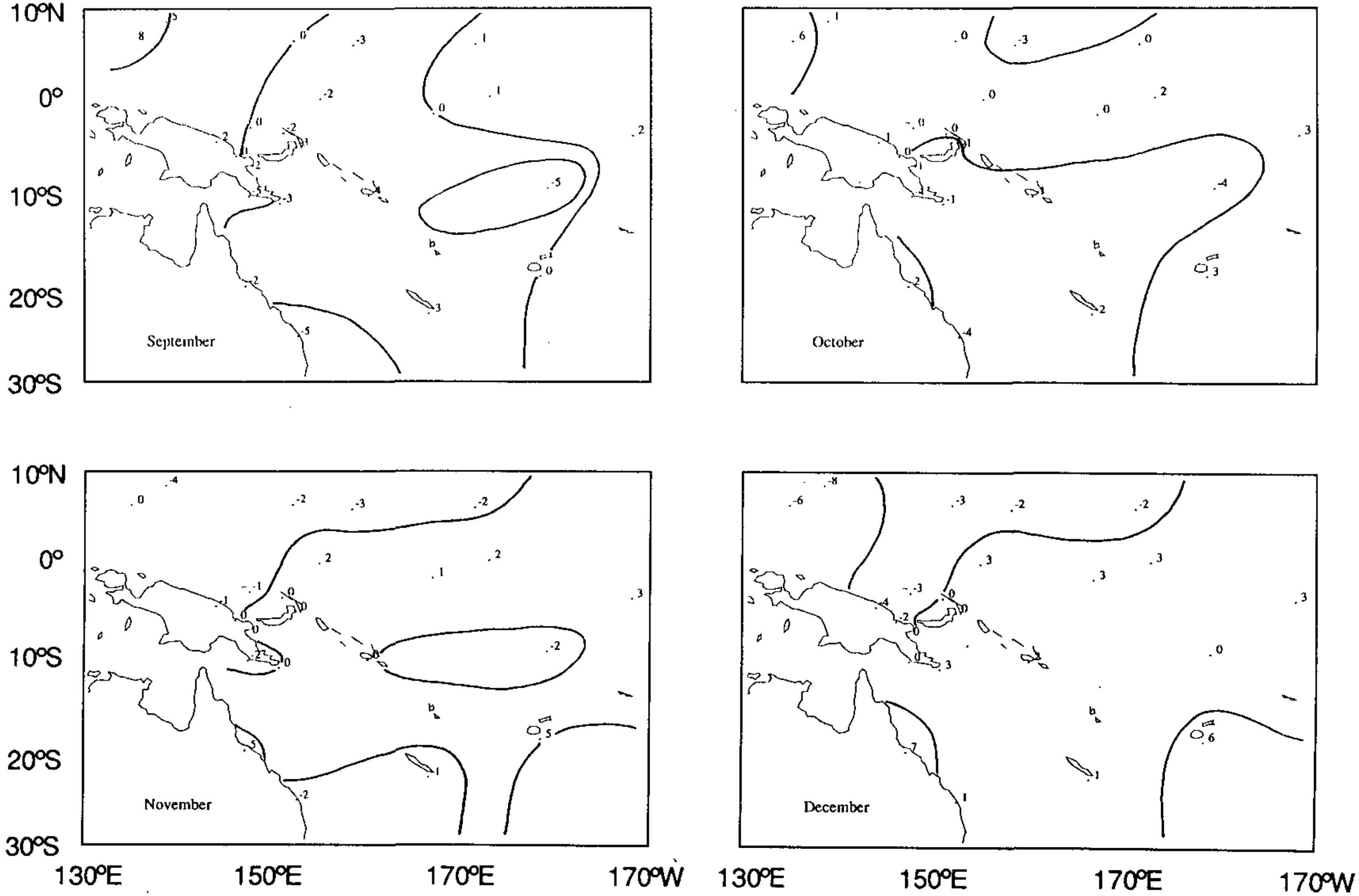

Figure 12 cont.

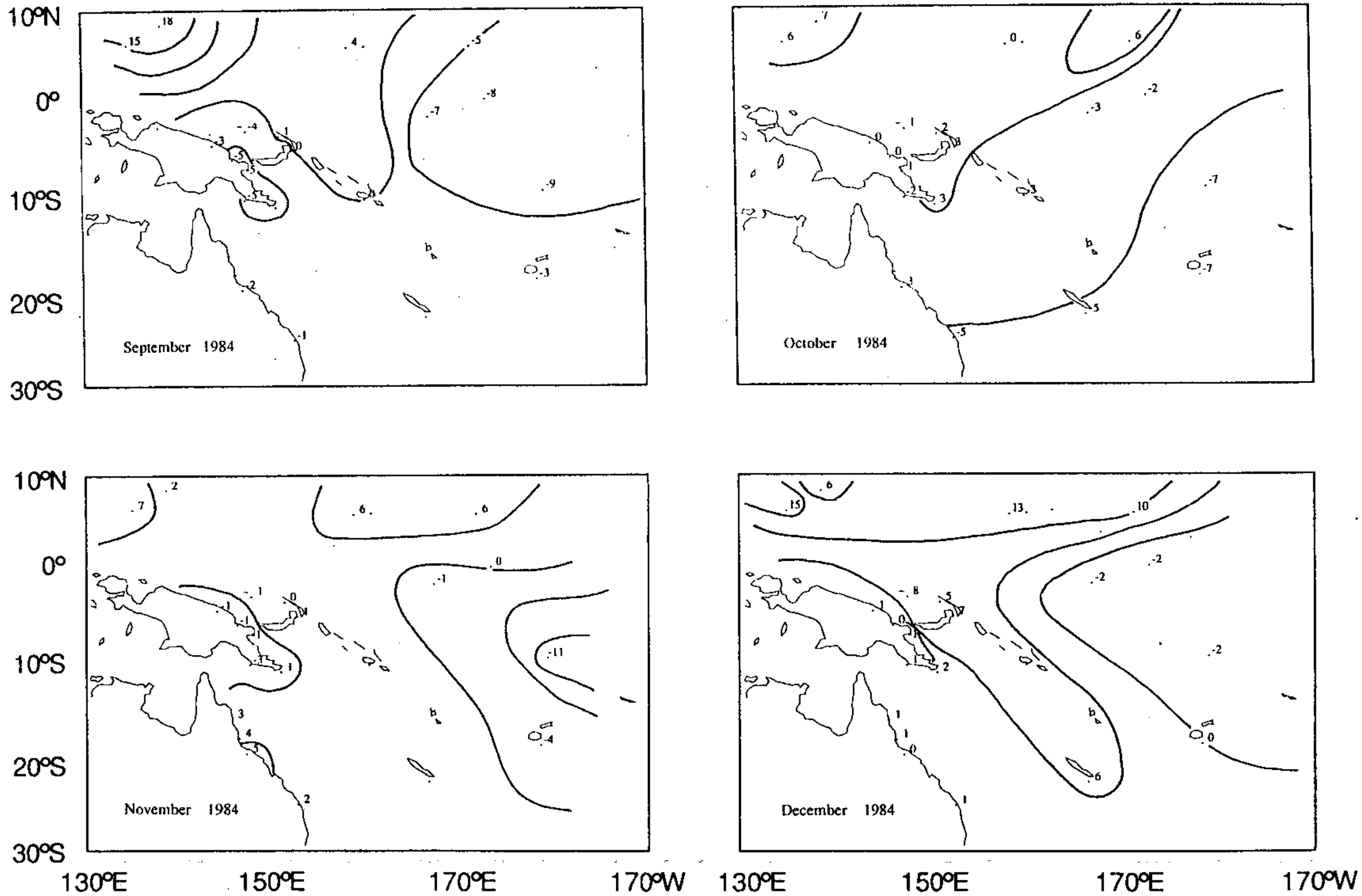

Figure 13: Maps of the monthly sea-level anomalies (cm) as calculated for the Western Pacific region (30° S–10° N, 130° E–170° W). The Papua New Guinea stations have been supplemented with data from adjacent Pacific Ocean stations

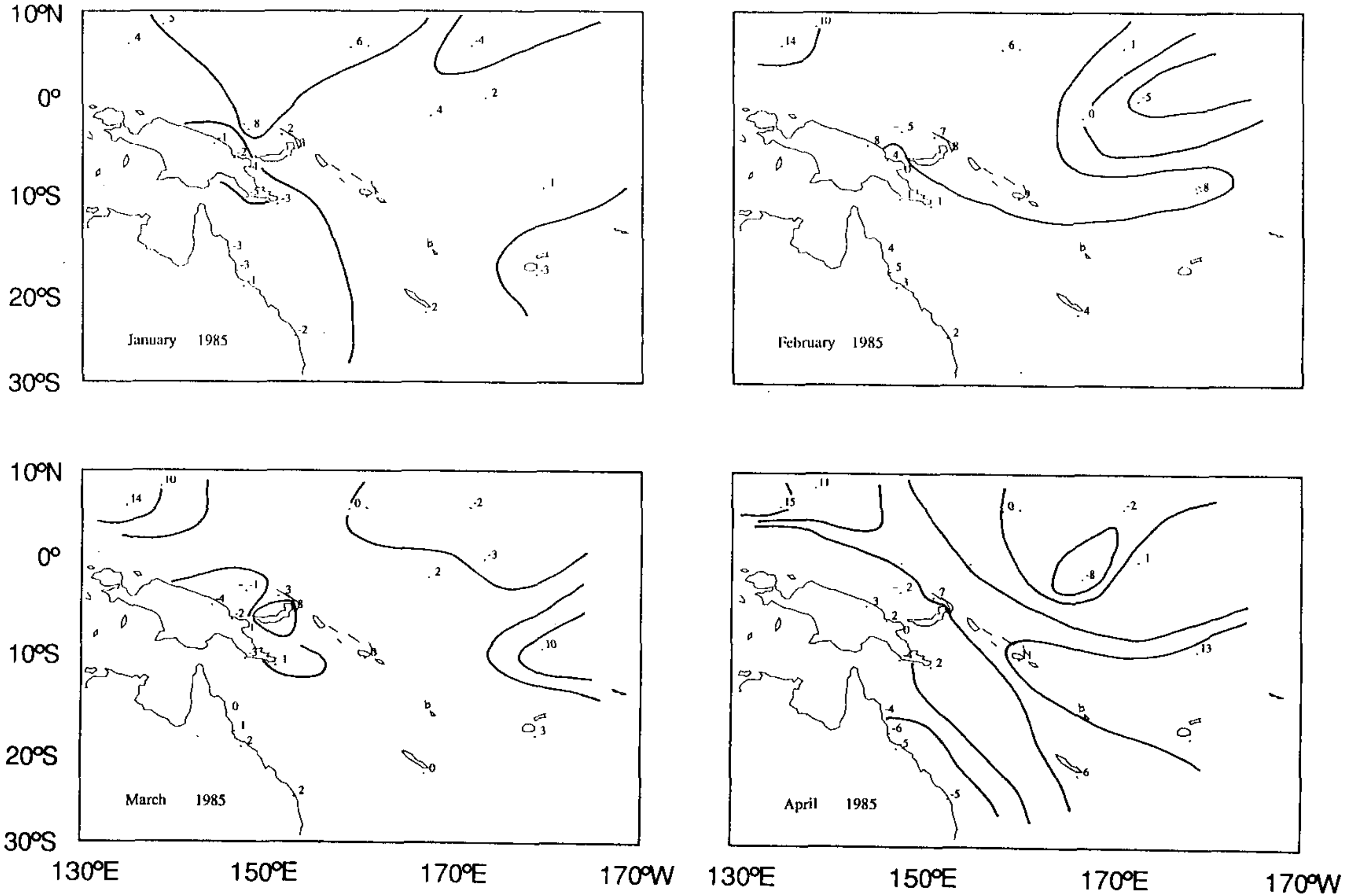

Figure 13 cont.

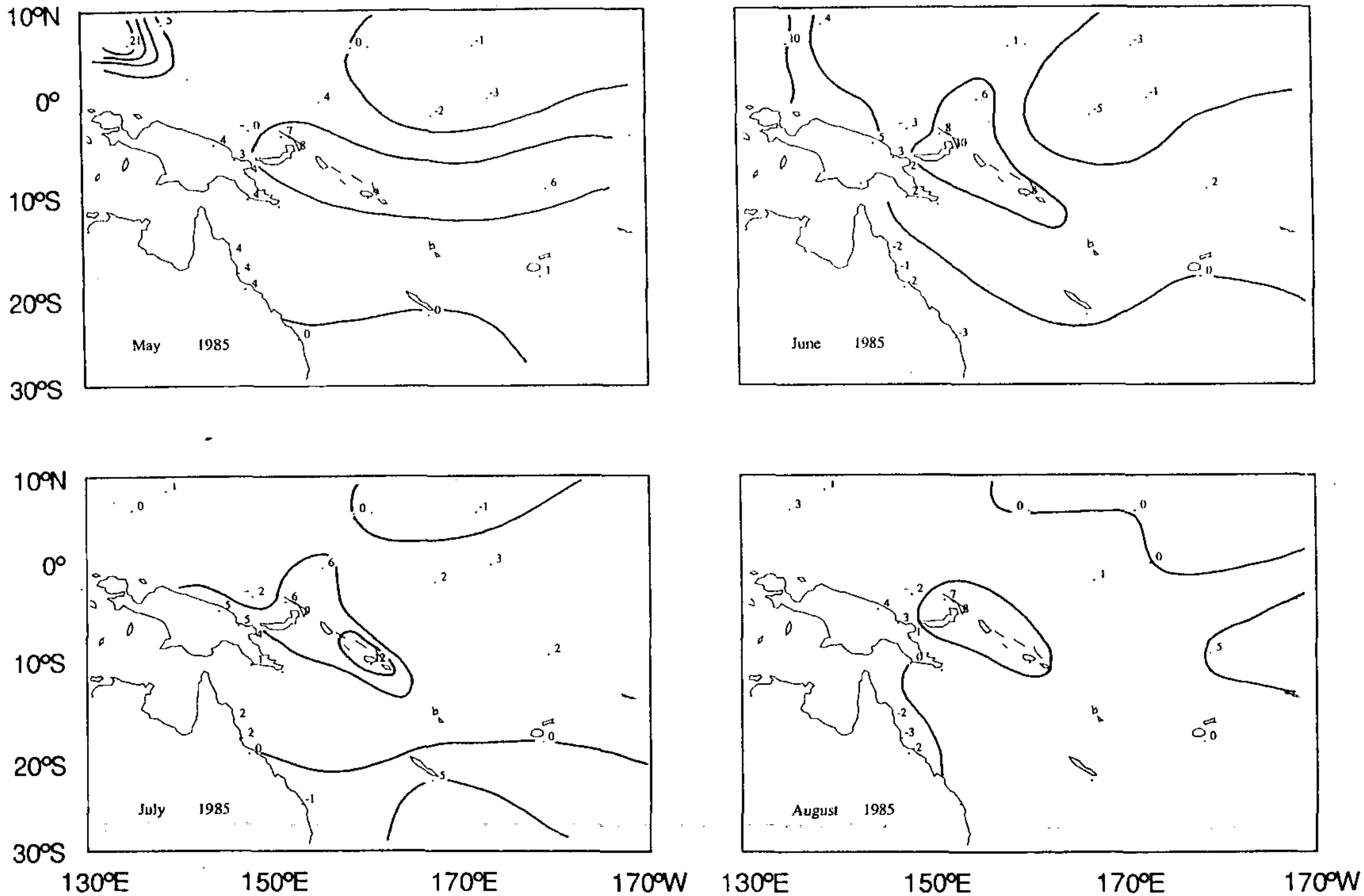

Figure 13 cont.

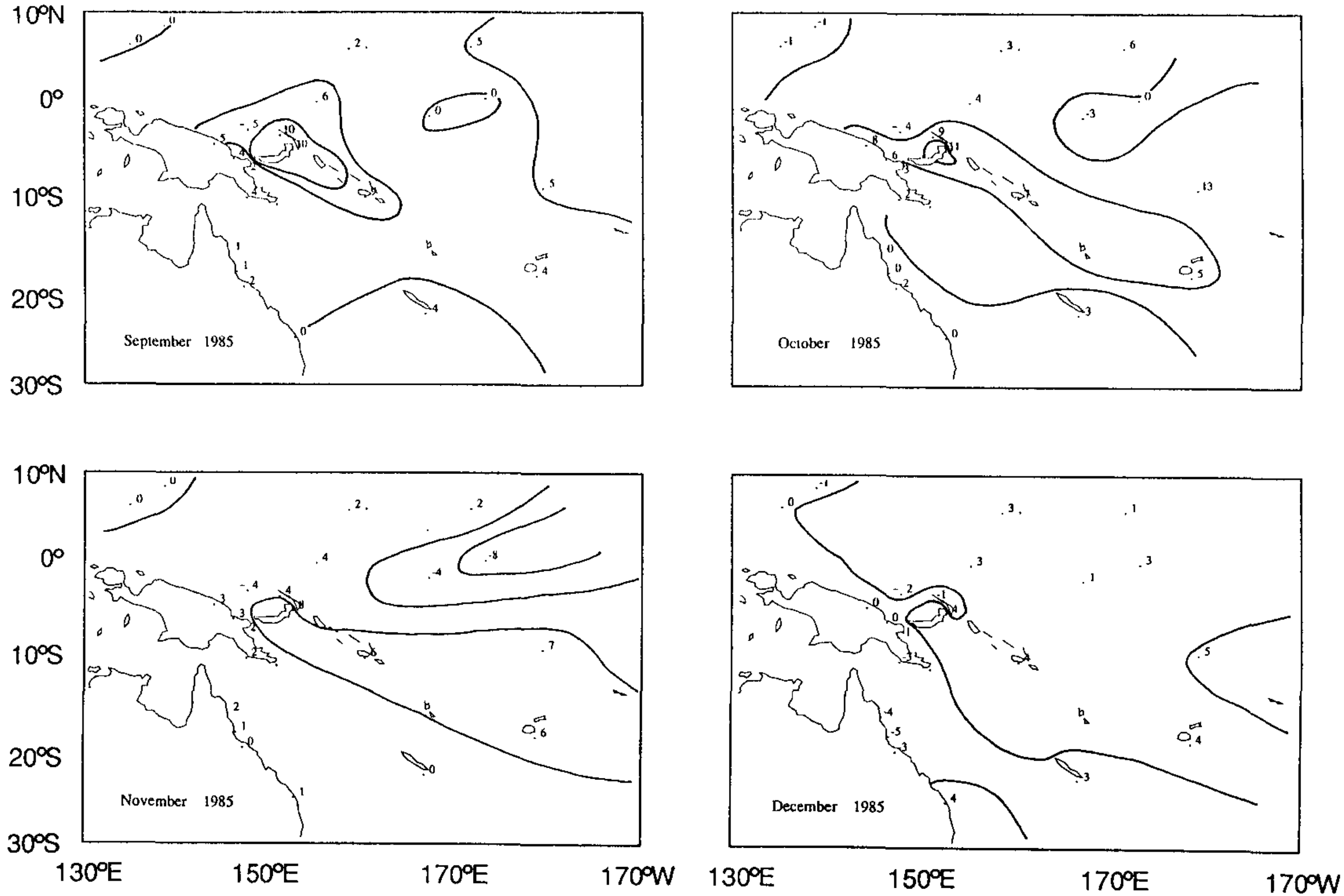

Figure 13 cont.

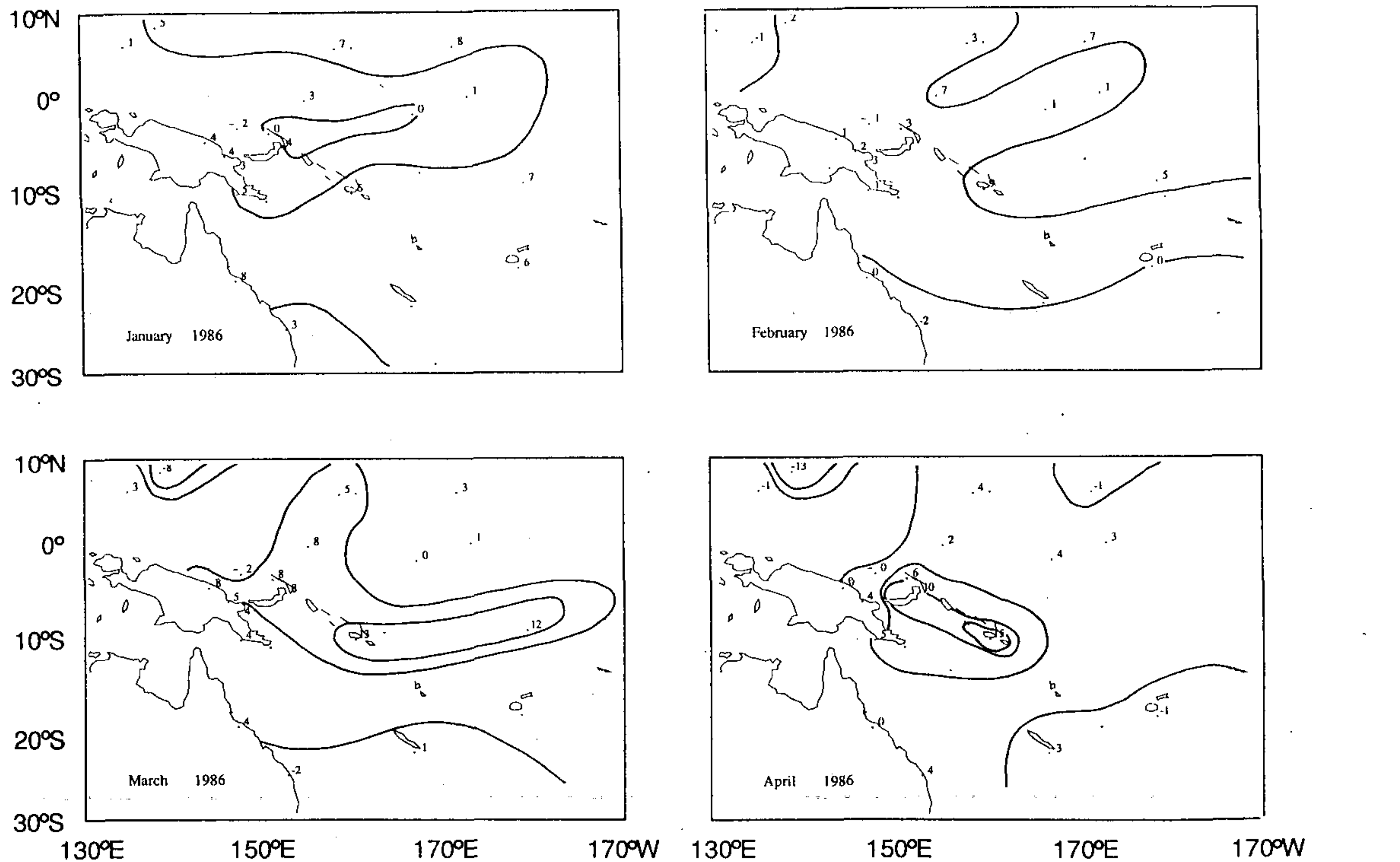

Figure 13 cont.

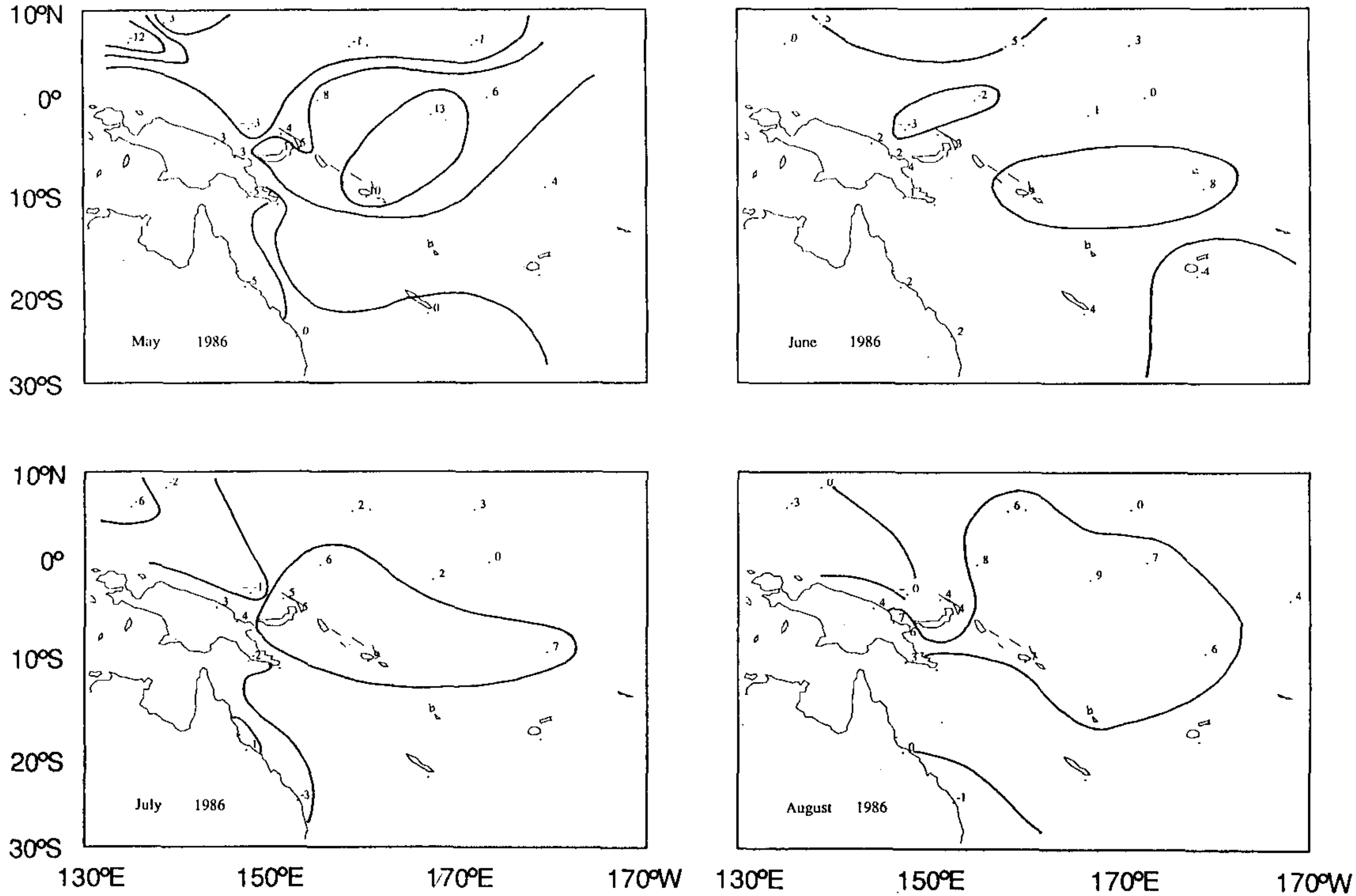

Figure 13 cont.

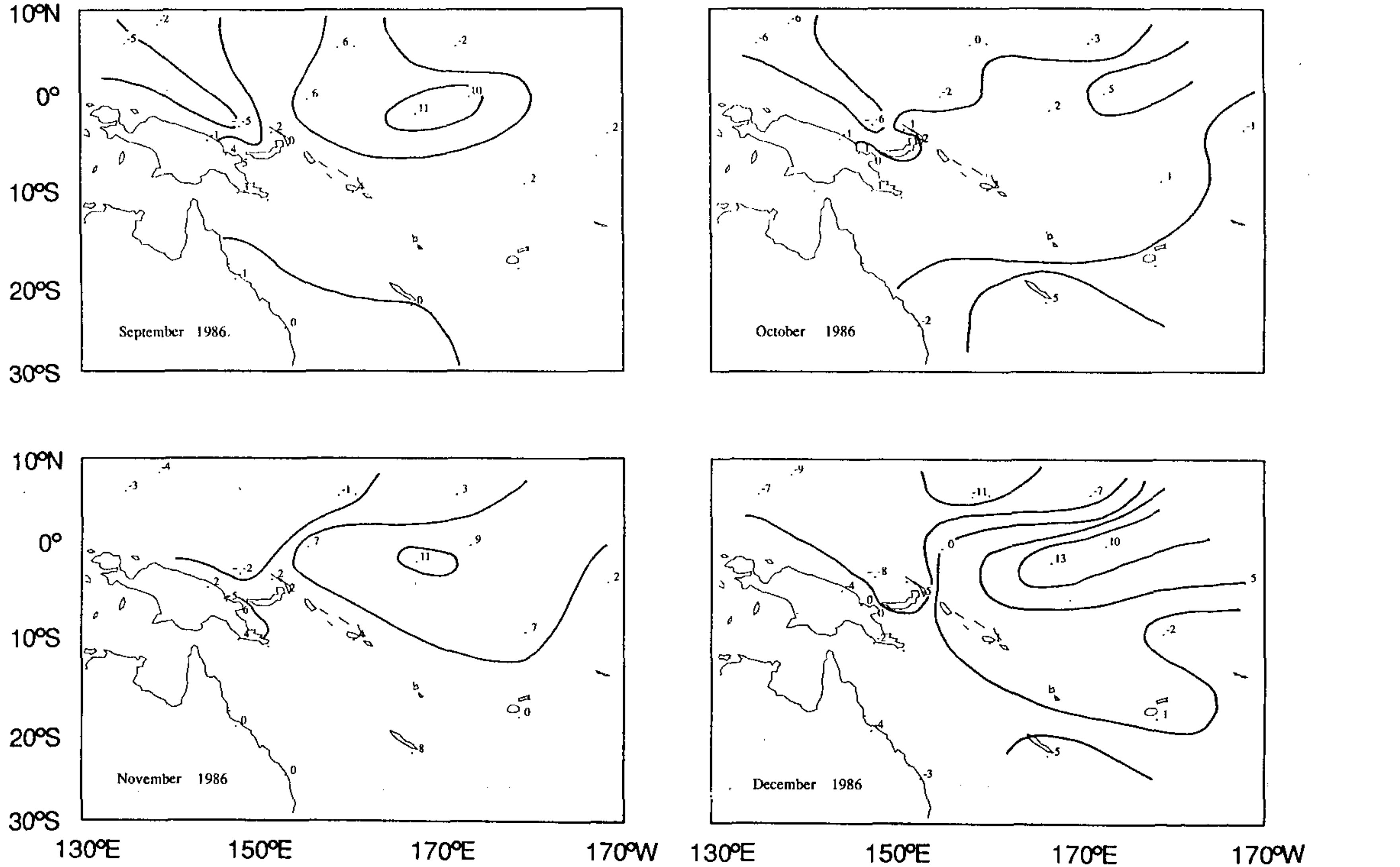

Figure 13 cont.

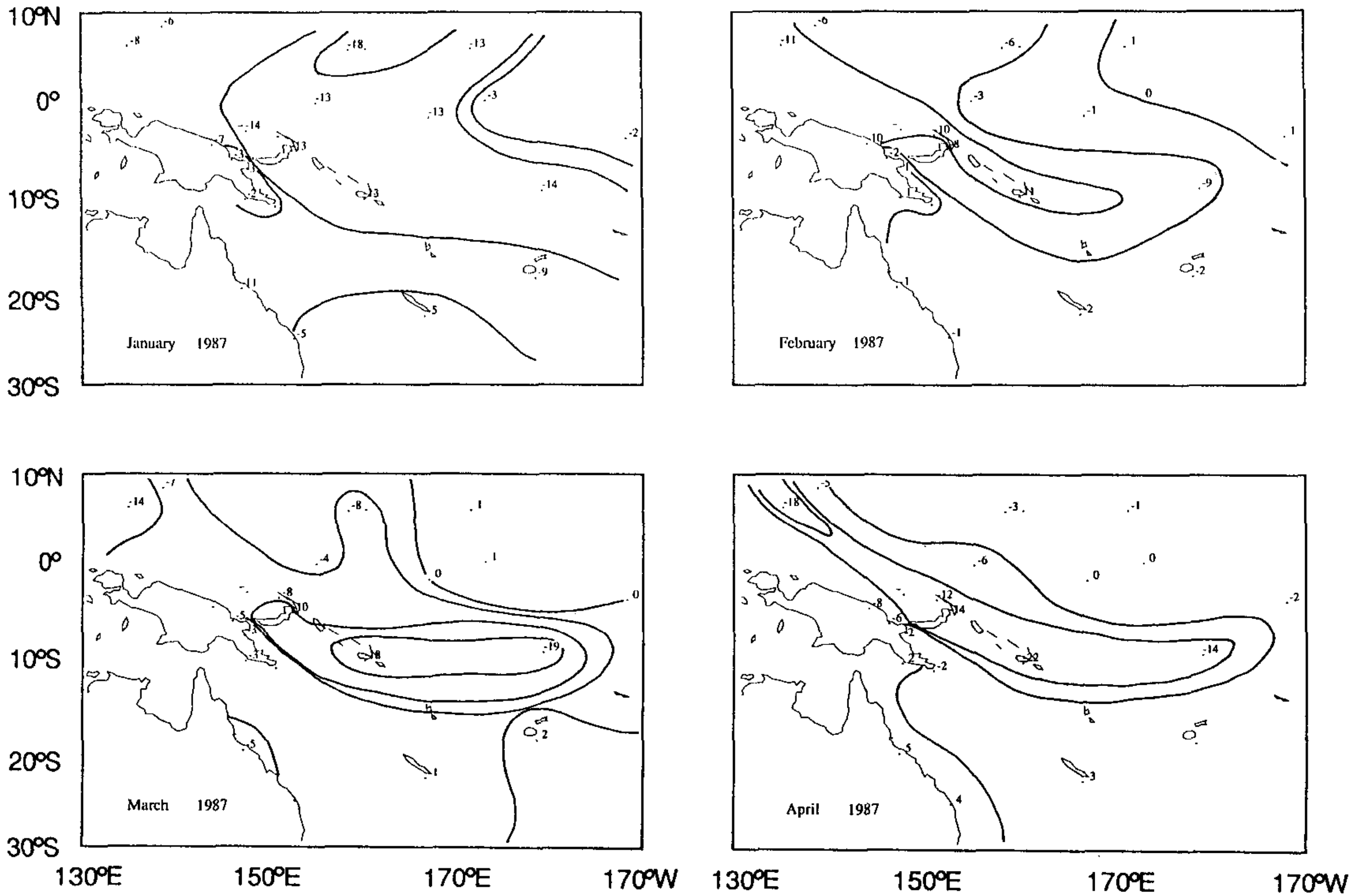

Figure 13 cont.

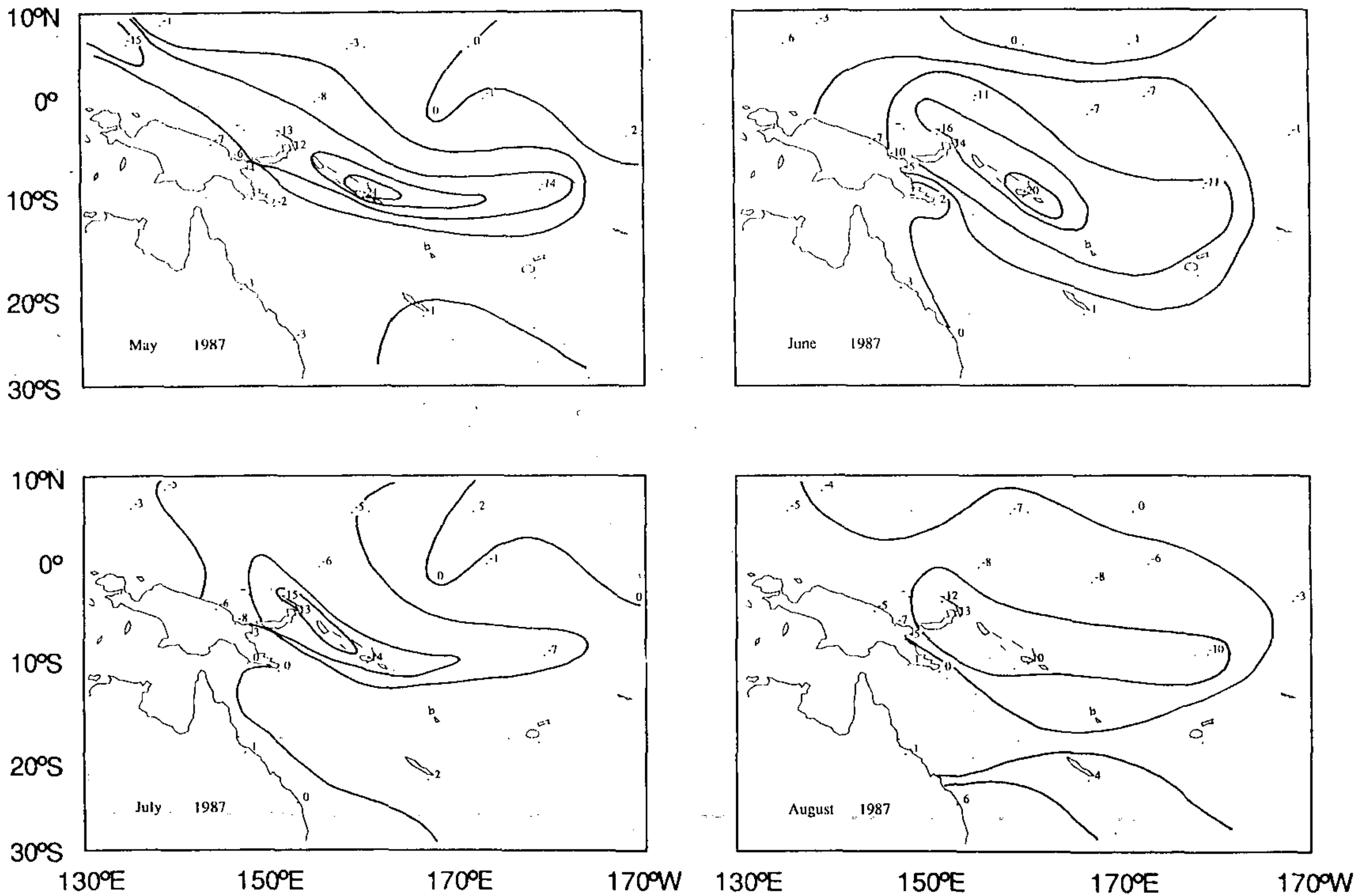

Figure 13 cont.

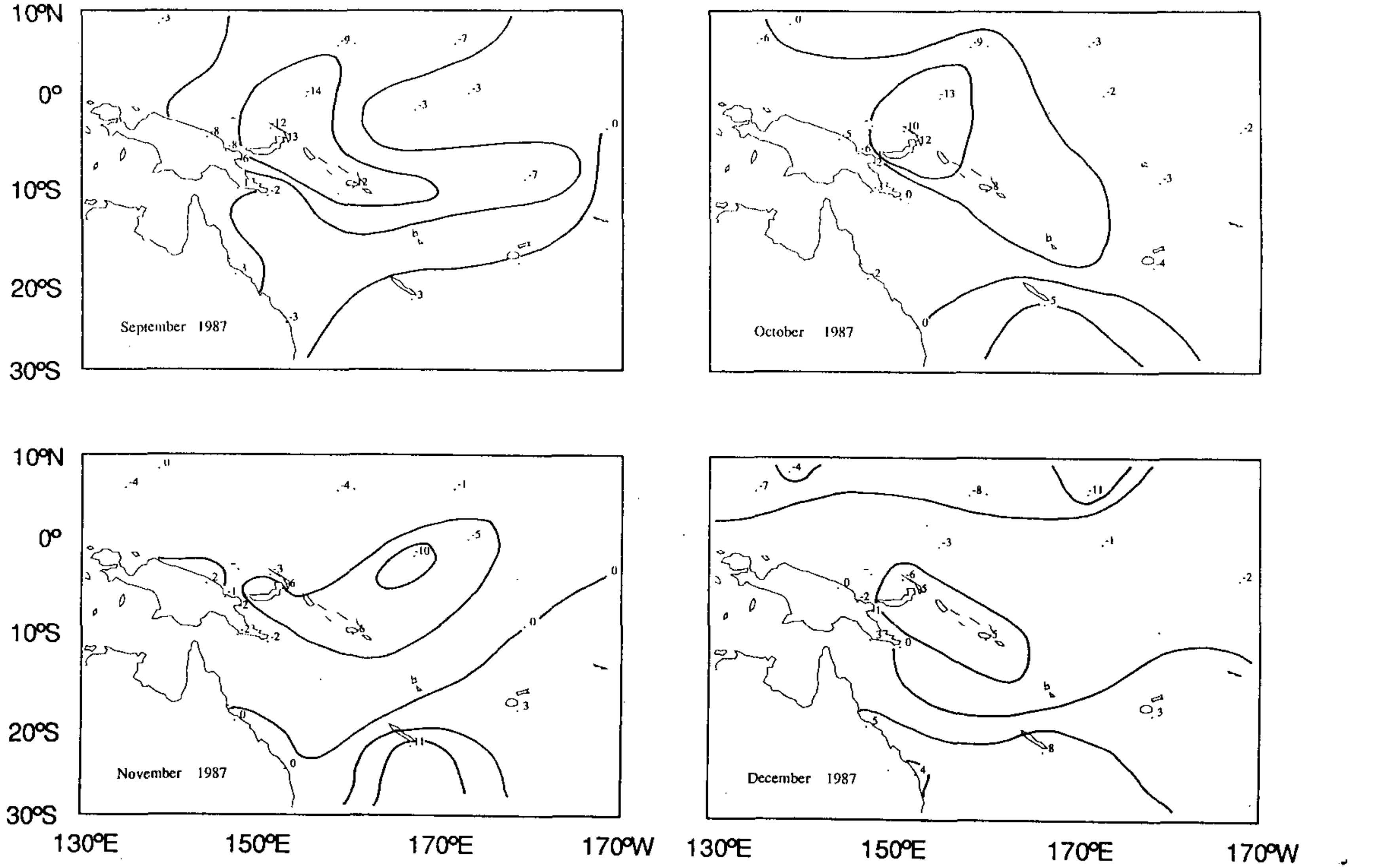

Figure 13 cont.

CSIRO Marine Laboratories
comprise

Division of Oceanography
Division of Fisheries

Headquarters
Castray Esplanade, Hobart, Tasmania
GPO Box 1538, Hobart, Tas 7001, Australia

Queensland Laboratory
133 Middle Street, Cleveland, Qld
PO Box 120, Cleveland, Qld 4163

Western Australian Laboratory
Leach Street, Marmion, WA
PO Box 20, North Beach, WA 6020

CSIRO
AUSTRALIA

ISBN 0 643 05030 2