COMMONWEALTH OF AUSTRALIA

Commonwealth Scientific and Industrial Research Organization

Division of Fisheries and Oceanography

REPORT 9

MEAN SEA LEVEL VARIATION ON THE COAST OF NEW SOUTH WALES

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Cronulla, Sydney
1957

CONTENTS

SUMMARY

The effects of atmospheric pressure, wind, currents, and water density on sea level at Sydney have been examined. It was found that an increase in atmospheric pressure tends to decrease sea level, the change in sea level being greater than would be expected if the total pressure on the sea bed remained constant. Jacobs' (1939) explanation for a similar effect on the California coast is believed to apply also at Sydney. This is supported by the existence of a correlation between sea level at Sydney and atmospheric pressure gradient normal to the coast.

It was found that changes in water density in the upper 50 metres a few miles off the coast were too small to have an appreciable effect on sea level. The available data from stations beyond the edge of the continental shelf were too meagre to establish a definite connection between sea level and the density of the upper 600 metres.

Tables giving some details of tide stations on the New South Wales coast, and the differences in observed sea level (relative to the local datum) between each station and Fort Denison, are included as an Appendix.

In citing this report, abbreviate as follows:

C.S.I.R.O. Aust. Div. Fish. Oceanogr. Rep. No. 9.

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I. INTRODUCTION

Mean sea level is obtained by averaging the observed tide heights in a given period, so as to reduce tidal components of astronomic origin as much as possible. The most usual averaging period is one month, and extensive tables of monthly mean sea levels have been published (UGGI 1940, 1950). In general, the monthly means show a marked seasonal effect. On the east Australian coast, for example, sea level is highest in May and lowest in November, the range being about six inches.

The causes of non-astronomic variations in sea level depend on the time scale. Thus secular trends in annual mean sea levels, when established over centuries or at least many decades, are probably of geological origin. At the other extreme are storm surges, which may be of only a few hours' duration and are caused by the strong winds that accompany intense atmospheric depressions. Neither long-term trends nor storm surges will be considered further in this report, which is mainly concerned with variations between these extremes of the time scale.

Although annual and semi-annual tidal components of astronomic origin are recognized theoretically, it is generally agreed that their amplitudes are negligible, especially in mid latitudes (see e.g., Pattullo <u>et al</u>. 1955). The observed changes in monthly mean sea level must therefore have other causes. Previous investigators have found that the observed changes can be accounted for fairly well by variations in atmospheric pressure, and in the density of the upper layers of the ocean. The relation between sea level, atmospheric pressure and water density appears to be such that the total mean pressure at any fixed point on the bottom in sufficiently deep water remains constant. Thus sea level rises when the barometer falls, the ratio of corresponding changes (the "barometer factor") being equal to the ratio of the densities of mercury and sea water (13.2). Sea level also rises when the mean density of a vertical column of sea water decreases.

Pattullo <u>et al</u>. (1955) examined the variations of monthly mean sea level on a global scale, and found that general agreement between observed sea level and the sum of the density and atmospheric pressure effects was widespread. They suggested the term "steric sea level" for the sea level computed from the density (or specific volume), and that conditions be referred to as "isostatic" when the total pressure, due to ocean and atmosphere, at a point on the deep sea floor does not change with time. These convenient terms will be adopted in the following discussion. Variations in steric sea level are very closely equal to variations in dynamic height, when both are calculated from the same reference level.

If isostatic conditions can be established as normal for a particular region, one should be able to obtain the mean density of the upper layers of the sea near the coast from observations of sea level and atmospheric pressure. The mean densities obtained in this way should be of value in supplementing the information obtained by the more usual methods, especially when hydrographic cruises can be made only at infrequent intervals. The investigation reported here was carried out with this end in view. Pattullo <u>et al</u>. (1955) included south-east Australia in their global survey, but considered only the average conditions over many years. Since there is appreciable variation from year to year, it appeared worthwhile to investigate the validity of the isostatic condition in more detail, using values of sea level, steric level and atmospheric pressure that apply to identical periods.

In the following sections, the tidal records from three different tide gauges in the Sydney area have been used. These gauges are at Camp Cove and Fort Denison (both in Port Jackson) and at Cronulla (Port Hacking). The standard deviations of the differences between corresponding monthly means at the three stations are small compared to seasonal changes in monthly mean sea level, so that the records from any of the three gauges may be used to study changes in mean sea level at Sydney. (See Appendix, Table II).

The monthly mean sea levels have been computed as either the mean of three-hourly heights (Port Hacking), or the mean of high and low waters (all other ports). Investigations have shown that the different methods of calculation are of no consequence, since shallow water tidal effects are negligible at the ports considered.

II. THE EFFECT OF ATMOSPHERIC PRESSURE ON SEA LEVEL

Many studies of the effect of atmospheric pressure on sea level have been reported. Close (1918) reviewed earlier work, and gave a number of new determinations of the "barometer factor" relating sea level to atmospheric pressure. In general, he found good agreement with the value of 13.2 to be expected from the isostatic hypothesis. Nomitsu and Okamoto (1927) found that approximately 25 per cent. of the variations in sea level at Japanese tide stations could be explained by means of atmospheric pressure changes, using the factor 13.2. The remaining 75 per cent. was due to changes in water density. Rouch (1944), analysing data collected in the Antarctic in 1908-10, found excellent agreement with the expected barometer factor, especially when differences from the previous day's value were taken for both pressure and sea level. This latter procedure tends to eliminate slow changes in water density.

The dependence of sea level on atmospheric pressure at Sydney has been investigated in two ways. In the first, corresponding daily values of mean sea level and atmospheric pressure were plotted against one another, and the points joined consecutively by straight lines. A number of short periods, in which marked changes of atmospheric pressure occurred, were chosen from the records for the years 1954-56. It was considered that this method of plotting should reduce the effects of slow changes in density. In general, the graphs showed a decrease in sea level with increase in atmospheric pressure, the ratio being in reasonable agreement with the expected barometer factor of 13.2. There were however a few anomalies, and a suggestion that sea level changes sometimes lag behind the corresponding pressure changes by about one or two days. A more detailed analysis would be necessary to confirm the existence of this lag. The daily sea levels used for this investigation were the means of eight tide heights at three-hourly intervals, and consequently contain appreciable astronomic components.

The second method of investigating the effect of pressure on sea level was by using monthly means instead of daily means. Seasonal effects were reduced in this case by plotting all the values for a particular month in one diagram. The effects of relatively long-term changes in annual mean sea level were allowed for by subtracting the appropriate five-year running mean annual sea level from each monthly mean, although these long-term changes are relatively small.

Figures 1 and 2 show the results in the form of scatter diamgrams for the months of January, April, July, and October, for the years 1899-1951. In all cases there is evidence that sea level increases with decreasing atmospheric pressure. In both January and April, however, the barometer factor appears to be significantly greater than the expected value of 13.2. Similar results were obtained by Jacobs (1939) for sea level on the Californian coast. Jacobs suggested that "the departures in atmospheric pressure represent widespread meteorological changes which, themselves, serve to alter the dynamic picture of the ocean." On this view, the connection between pressure and sea level is at least partly an indirect one. Jacobs showed that, particularly in spring and summer, low values of monthly mean sea level occurred when the anticyclone over the North Pacific was best developed, or was displaced towards the coast. The sign of the change in mean sea level was consistent with the effects to be expected from the geostrophic winds associated with the anticyclone. It seems probable from Jacobs' work that the change in sea level for a given change in pressure can be regarded as made up of two parts. The first part is the direct barometric effect, given by the barometer factor of 13.2, and the second part is really a "current-effect" (Section III (b)) due to winds that are correlated with the pressure change. This point will be discussed more fully in Section III (c).

A barometer factor significantly greater than 13.2 has been found for daily values of mean sea level and atmospheric pressure at Fremantle, Western Australia (Bennett 1939), and at other Western Australian ports (Bennett, private communication). The daily levels and pressures for Fremantle for the month of August 1933 show an exceptionally close correlation, with a barometer factor of 22. Jacobs' explanation cannot apply in this case, since there would not be time to establish the necessary currents, and in any case the mechanism suggested could not be expected to result in such a close correlation even under the best circumstances. The factor 22 does not appear to apply at all times at Fremantle, and further investigation is desirable.

III. THE EFFECTS OF WIND AND CURRENT ON SEA LEVEL

Wind can affect sea level in two different ways. Palmen (quoted by Jacobs 1939), refers to these two effects as "Windstau" (wind set-up) and "Stromeffekt," (current-effect).

(a) Wind Set-up

Wind set-up can be considered as a piling-up of water against the shore by a wind that blows normal to the coastline. An on-shore wind causes a rise in sea level, while an offshore

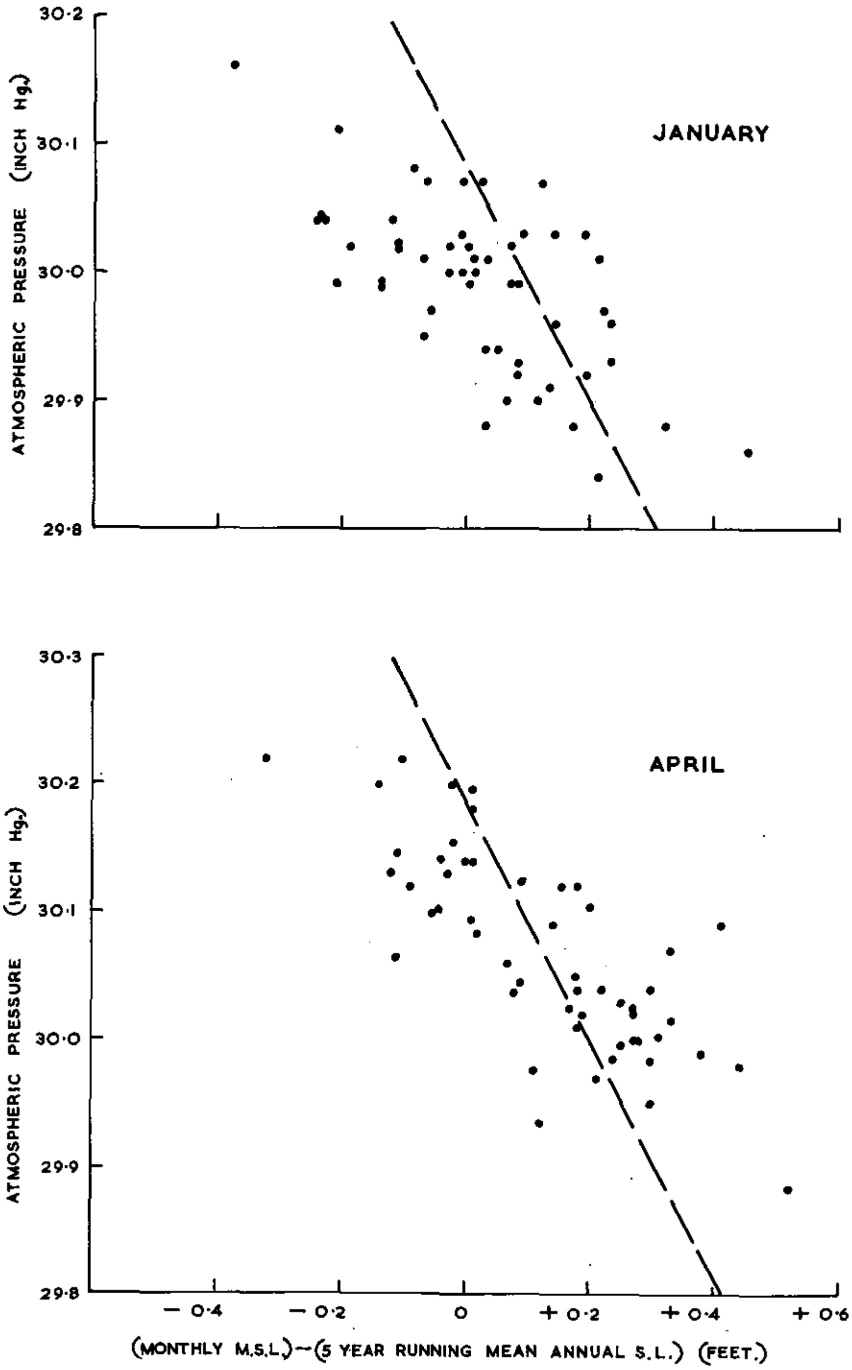

Fig. 1. Monthly mean atmospheric pressure at Sydney plotted against the difference between monthly mean sea level and the 5 year running mean annual sea level, for all months of January (upper) and April (lower) in the period 1899-1951. The dashed lines have a slope corresponding to 13.2 inches of sea level per inch of atmospheric pressure.

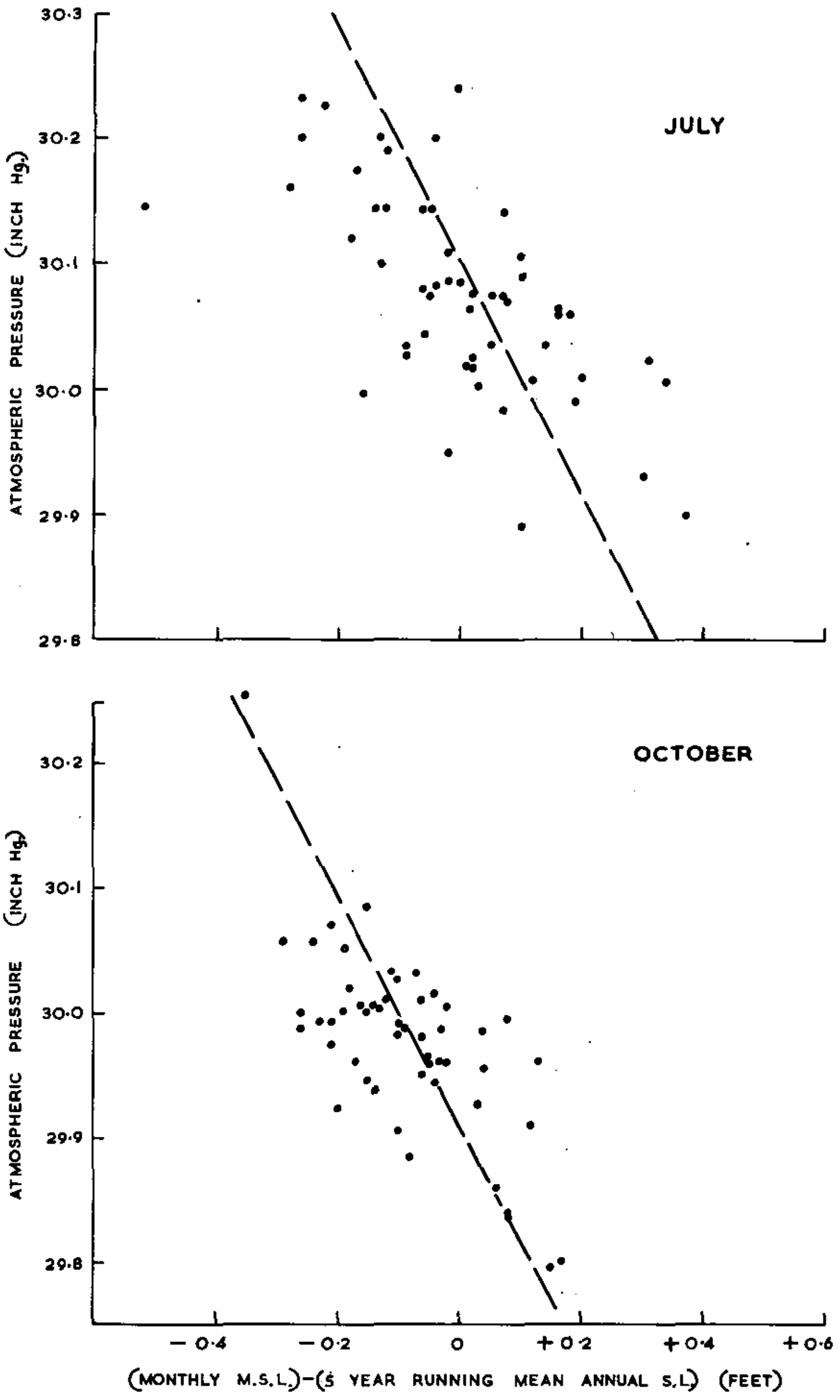

Fig. 2. Monthly mean atmospheric pressure at Sydney plotted against the difference between monthly mean sea level and the 5 year running mean annual sea level, for all months of July (upper) and October (lower) in the period 1899-1951. The dashed lines have a slope corresponding to 13.2 inches of sea level per inch of atmospheric pressure.

wind causes a fall in level.

The magnitude of the effect, for a given wind, depends on the depth of water, being greater for shallow water. This effect has been extensively studied in shallow seas (e.g. the Baltic Sea) and in inland lakes, and has been used to obtain values of the stress exerted by the wind on the surface of the water. To the writer's knowledge, appreciable wind set-up has not been reported for ports on the open coast of continents, where the continental shelf is relatively narrow. Jacobs (1939) could find no correlation between sea level on the Californian coast and the local winds, and Nomitsu and Okamoto (1927) did not find an effect due to wind on the Pacific coast of Japan.

The order of magnitude of the wind set-up to be expected on the east Australian coast can be calculated from the following formula (Proudman 1953, p.143).-

$$3.0 \times 10^{-6} < \frac{gh \sin \theta}{U_a^2} < 4.5 \times 10^{-6}$$

where g is the acceleration due to gravity, h the depth of water, U_a the wind speed and θ the slope of the water surface in the direction of the wind. Taking U_a = 15 m/sec (approx. 30 m.p.h. or Beaufort force 6), h = 150 metres (approximate average depth over the continental shelf), and taking the greater value of the two limits given above, one finds.-

$$\sin \theta = 6.9 \times 10^{-7}$$

Taking the width of the continental shelf as 20 miles, and assuming no disturbance in level at the outer edge of the shelf due to the wind, the change in level on the coast would be 0.9 inch. While strong on-shore or off-shore winds may produce detectable short-term variations in sea level, the effect on monthly means should be much less than one inch, and can be neglected.

(b) Current-effect

The term "current-effect" refers to changes in sea level that accompany currents parallel to the coast, due to the action of Coriolis forces. These changes in sea level can be related to the wind only to the extent that the wind is considered to cause the currents. Whereas wind set-up is due to winds normal to the coast, the current-effect can be expected to depend on winds parallel to the coast. It should be noted however that the currents will depend in a complex way on the wind system over an appreciable area, and that there is no a priori reason to expect a direct connection with local winds.

If steady-state conditions are assumed, and non-linear terms in the equations of motion are neglected, the current-effect on sea level depends only on the surface water velocity and the Coriolis force, according to the equation:-

$$\delta \zeta / L = 2 \omega \sin \emptyset \, v/g$$

where $\delta \zeta$ is the change in height in a distance L across the current, and ω, $\emptyset$, v, and g are respectively the angular velocity of the earth, the latitude, the surface water velocity, and the acceleration of gravity. In the southern hemisphere, sea level increases to the left when facing in the direction of the current. In the latitude of Sydney (34°S), the order of magnitude of the change in level is 0.02 inches per mile for a surface current of 1 knot.

Assuming a relatively narrow current parallel to the coast, the above equation gives only the difference in sea level between the coast and the offshore edge of the current. Since the sea level in the open sea cannot be taken as constant, one cannot expect a direct relation between observed sea level at one coastal station and the current parallel to the coast. The position is improved if sea levels at an island on the other side of the current are also available. In this way Iselin (1940); Wertheim (1954); and Stommel (1954) have used sea level differences between Key West and Havana, and between Bermuda and Charleston, to study variations in the strength of the Gulf Stream. Since total mass transport is usually the quantity of interest, an additional assumption of proportionality between mass transport and surface current has to be made in these studies.

The above equation expresses a balance between the Coriolis force, which is at right angles to the water velocity, and the component of gravity parallel to the sea surface. The equation does not hold when other forces are available to balance the Coriolis force. Thus the familiar "Ekman spiral" type of wind drift in the open sea does not require a slope of the sea surface, since the Coriolis force on an element of water is assumed to be balanced by the nett frictional force on the element.

If conditions are isostatic in the deep water near the coast, then sea level on the coast depends only on the vertical density structure near the coast (neglecting atmospheric pressure effects). It follows that changes in sea level at the coast depend on the current only to the extent that the current is accompanied by changes in density structure along its inshore edge.

(c) Correlation between Sea Level at Sydney and Atmospheric Pressure Gradient Normal to the Coast

If the explanation suggested by Jacobs (Section II) for the increased value of the barometer factor is to hold also for Sydney, there should be a correlation between sea level at Sydney and some measure of the atmospheric pressure system over the Tasman Sea. Of the pressure data readily available, the monthly mean pressure difference between Sydney and Lord Howe Island seemed the most suitable. Figure 3 shows the sea levels (corrected to an atmospheric pressure of 30.00 in. Hg.) and the pressure differences for the period 1942-54, and Figure 4 shows the average values for each month over the same period of years.

It is clear from Figure 4 that there is a close agreement in shape and in phase between the two average curves. Figure 3 shows further that when either quantity varies only slightly for a period of several months, the other also varies only slightly (e.g. the periods March 1942 - March 1943, and March 1951 - December 1952). There is however appreciable difference in shape of the two curves in individual years, e.g. 1943 and 1944.

Figures 3 and 4 strongly suggest that changes in mean sea levels at Sydney are associated with winds in the western part of the Tasman Sea, since the pressure difference between Sydney and Lord Howe Island is a measure of the average geostrophic wind at right angles to the line joining them. This average wind makes an angle of about 25° with the direction of the coastline, and it is assumed that it is the component parallel to the coast that is effective. When the pressure at Sydney is greater than that at Lord Howe Island, the wind component will be from the south. This will transport surface water towards the coast, and will result in a field of mass which in turn will be associated with a gradient current in the direction of the wind, and also with an increased sea level on the coast. The increase in sea level for a positive difference in pressure between Sydney and Lord Howe Island agrees with observation (Figs. 3 and 4).

Detailed agreement between sea level and pressure difference is not to be expected since, as already mentioned, the current along the coast may be influenced by winds over a large area, and there is in any case no unique relationship between current and sea level.

Pattullo <u>et al</u>. (1955) mention that the effect of wind on sea level is likely to be larger than the pressure effect, and of opposite sign. The explanation for the opposite sign is presumably as follows. A high mean pressure will, on the average, correspond to an anticyclone centred at the station in question. The winds associated with this anticyclone will cause surface water to be displaced towards its centre, thereby raising sea level at the station, whereas the direct pressure effect is a lowering of sea level. Cases in which the effects of winds and pressure are of the same sign, as on the south-east coast of Australia and the coast of California, can be explained by assuming that pressure systems tend to reach maximum development when their centres are some distance offshore. A high pressure at a coastal station might then be associated with an even higher pressure at the offshore centre of the pressure system. The direction of the geostrophic winds would be such as to transport surface water away from the coast, and lower sea level at the coast.

Scatter diagrams in which mean monthly pressures at Sydney were plotted against pressure differences between Sydney and Lord Howe Island for all months of January and November 1932-1953, confirmed that there is a tendency for high pressures at Sydney to be correlated with an even higher pressure at Lord Howe Island. No similar correlation was apparent for July.

IV. THE RELATION BETWEEN MEAN SEA LEVEL AND STERIC SEA LEVEL

Three attempts have been made to relate the observed sea level at Sydney to steric sea levels. In each case, the observed sea levels have first been corrected to a fixed atmospheric pressure of 30.00 in. Hg., using a barometer factor of 13.2.

(a) Port Hacking Station - Monthly Means

This station is about 3 miles offshore, and was occupied at intervals of between one and two weeks. The data used are for the period 1950-54, (C.S.I.R.O. Aust. 1951(c), 1953(a), 1953(b), 1954, 1956). The mean density (σ_t) of the water column between 5 and 55 metres depth was calculated for each date. Monthly means were then calculated by averaging

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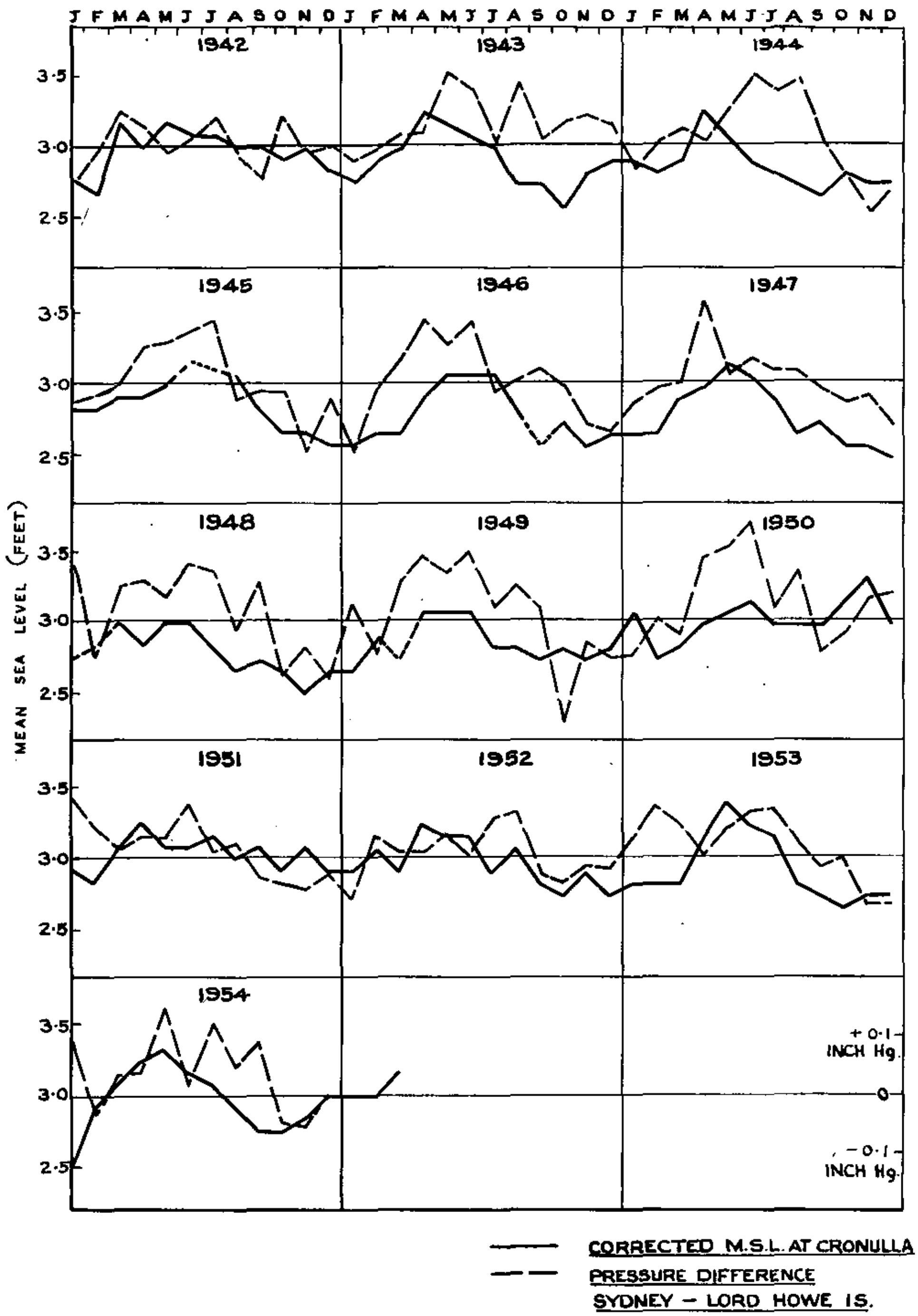

Fig. 3. Monthly mean sea levels at Sydney (corrected to an atmospheric pressure of 30.00 in. Hg.), and differences between monthly mean atmospheric pressures at Sydney and Lord Howe Island, for the period of 1942-1954.

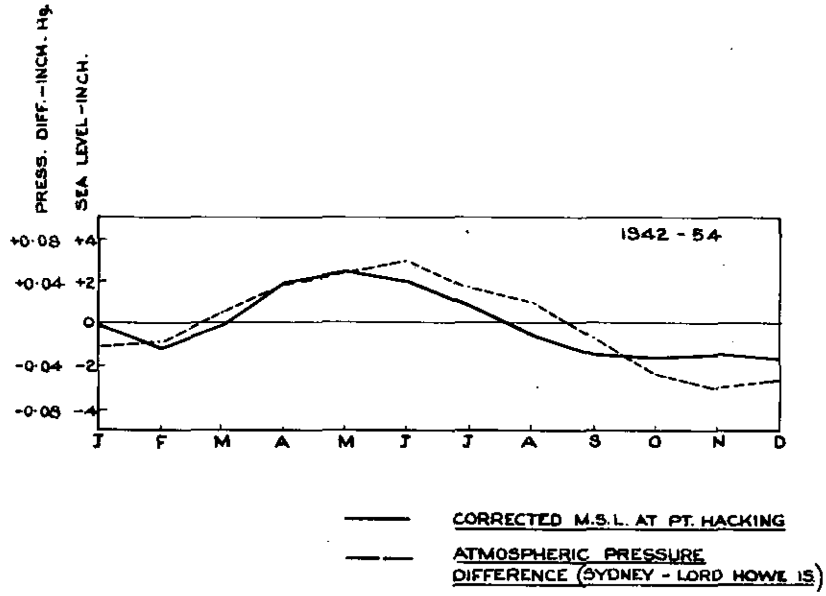

Fig. 4. The average seasonal variations in mean sea level at Sydney, and in the differences between monthly mean atmospheric pressures at Sydney and Lord Howe Island, for the period 1942-1954.

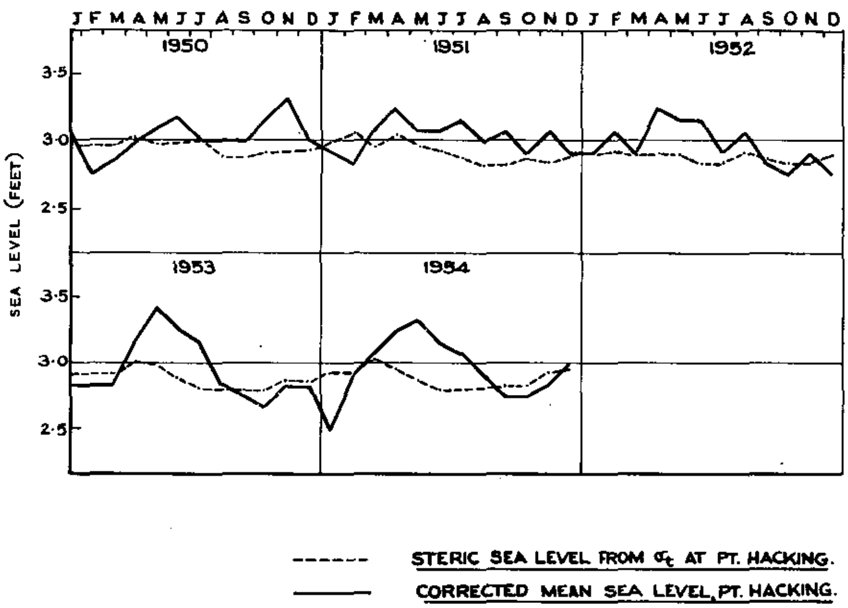

Fig. 5. Observed and steric monthly mean sea levels at Port Hacking 1950-1954.

the values in each calendar month. These monthly means were converted to steric sea levels by means of the relation (approximately valid for a column of water 50 metres deep).-

1 unit of σ_t = 2 inches change in sea level.

The results are shown in Figure 5, together with the corresponding corrected sea levels. It is clear from Figure 5 that the density changes in the upper 50 metres of inshore water are too small to have an appreciable effect on sea level. This conclusion may be contrasted with those of La Fond (1939), who found that the density changes in the upper 75 metres five miles off La Jolla, California, accounted for most of the observed sea level change, and Doniol (1956), who found similar conditions off Dakar (West Africa).

(b) Offshore Station - Daily Means

During the period 1938 - 1955, a station at latitude 34° 05'S longitude 151°35'E, (approximately 20 miles east of Sydney, and just beyond the edge of the continental shelf) was occupied 25 times, and hydrographic measurements were made to a depth of 600 metres or more (C.S.I.R.O. Aust. 1951(a), 1951(b)). The steric sea levels were calculated for each occasion from the σ_t values by numerical integration, using the formula

$$S = 3.28 \left\{ 1.7 - 10^{-3} \int_0^{600} (\sigma_t - 24.00)\, dh \right\} \text{ ft.}$$

where h is the depth in metres, and S the steric sea level referred to an arbitrary zero.

The corresponding observed sea levels for the particular days on which the station was occupied were obtained from the tidal records for Camp Cove (just inside Port Jackson) by Doodson's method (Doodson and Warburg 1941, p.111). The sea levels were corrected to an atmospheric pressure of 30.00 in. Hg., using the mean of the 9 a.m. and 3 p.m. pressures at Sydney Weather Bureau.

The corrected sea levels so obtained are plotted against the corresponding steric sea levels in Figure 6. If the isostatic condition were fulfilled, the points should be grouped about a straight line with 45° slope. The scatter of the points in Figure 6 is so great that no useful conclusion can be drawn as to whether the isostatic condition is fulfilled or not.

A number of reasons can be suggested for the large scatter in Figure 6. Probably the most important is that the steric levels are in effect single observations, which make no allowance for horizontal variation, or short period changes in mean density due to internal waves.

(c) Offshore Stations - Monthly Means

Since the variations in monthly mean sea levels at ports within a few hundred miles north or south of Sydney are closely correlated (Fig. 7), it should be satisfactory to use all the density observations taken just off the edge of the continental shelf within the latitude limits of say 30°S to 38°S, to calculate steric sea levels. Such calculations have been made for all cases in which two or more stations were occupied in one month. A comparison of the mean steric sea levels in the latitude ranges 30-32°S, 32-36°S, and 36-38°S, indicated that the steric sea level decreases with increase in latitude at a mean rate of 0.065 ft. per degree of latitude. A correction to a standard latitude of 34°S was made on this basis. The steric levels within each month were then averaged, and the averages plotted against the mean sea level at Fort Denison for the same month, corrected to a pressure of 30.00 in. Hg. (Fig. 8). The station numbers, dates, and mean sea levels are given in Table 1. Unfortunately, the different seasons are not uniformly represented, since only two values fall in the period February to July, compared with sixteen in the period August to January. The results must again be regarded as inconclusive.

ACKNOWLEDGMENTS

The writer gratefully acknowledges the assistance of officers of the Maritime Services Board, Public Works Department, and Sydney Weather Bureau in making their records available.

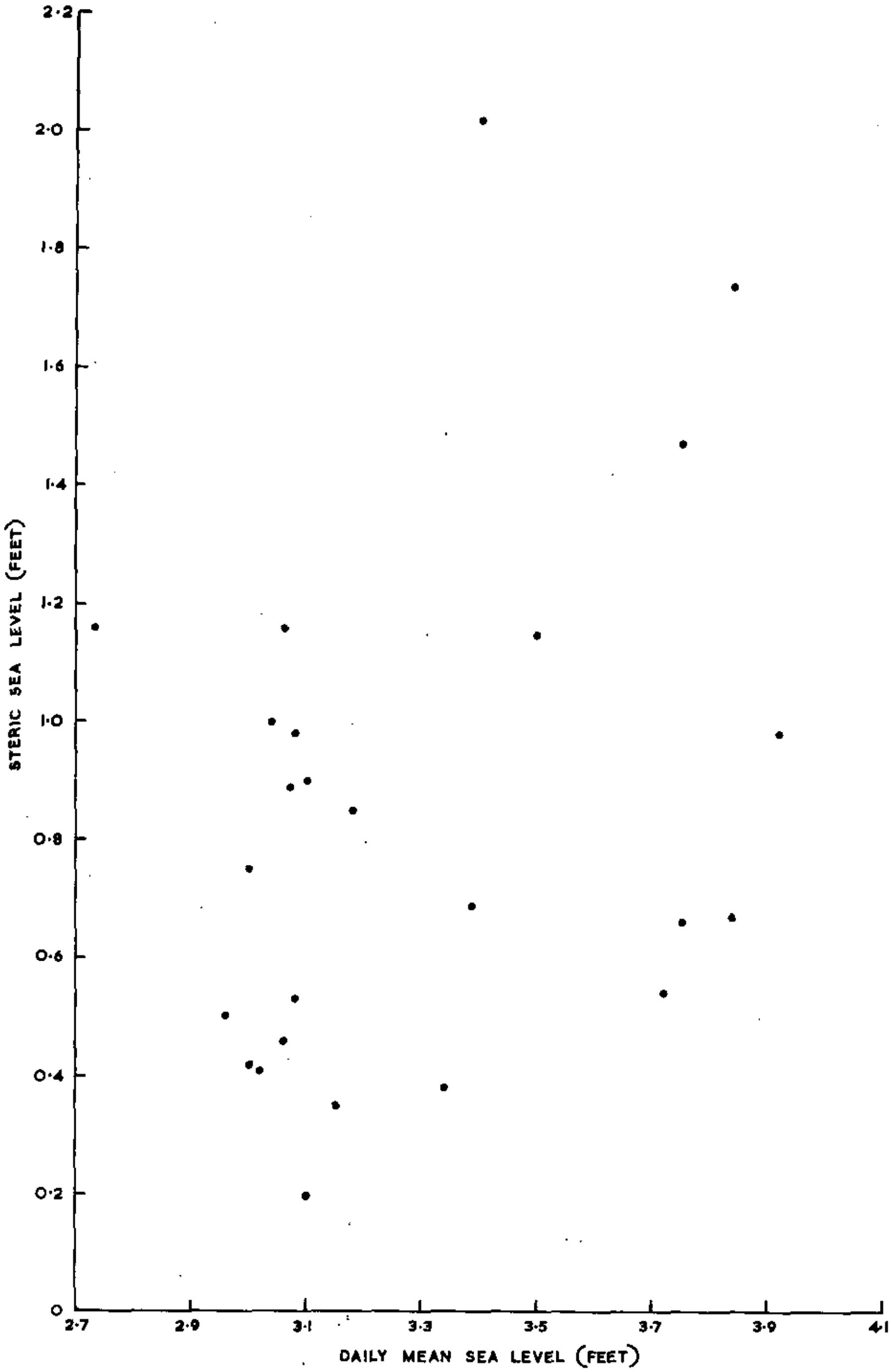

Fig. 6. Daily mean sea level at Camp Cove plotted against steric sea level 20 miles east of Sydney, for 26 days in the period 1938-1955.

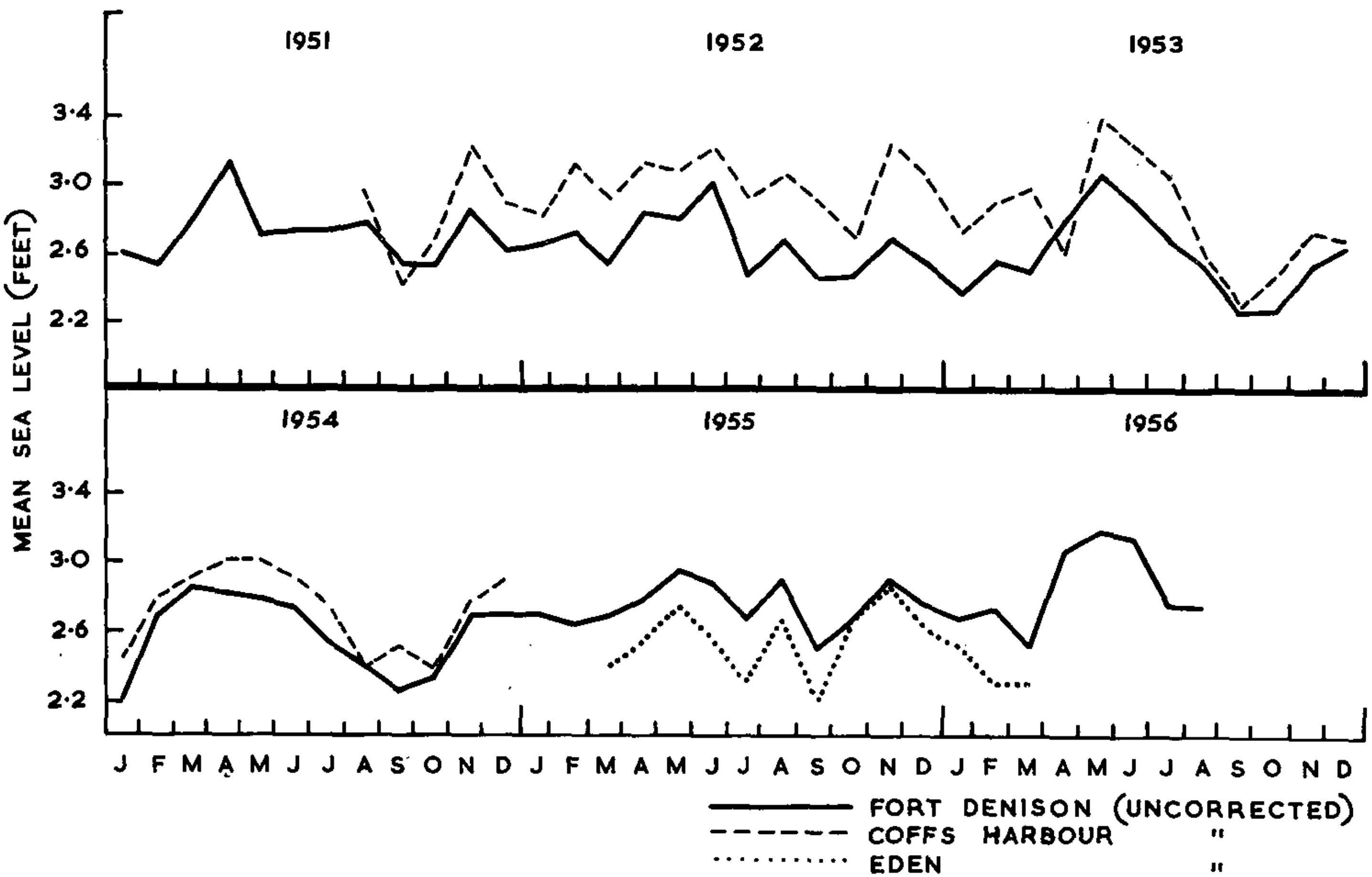

Fig. 7. Monthly mean sea levels at three ports on the New South Wales coast for the period 1951-1956.

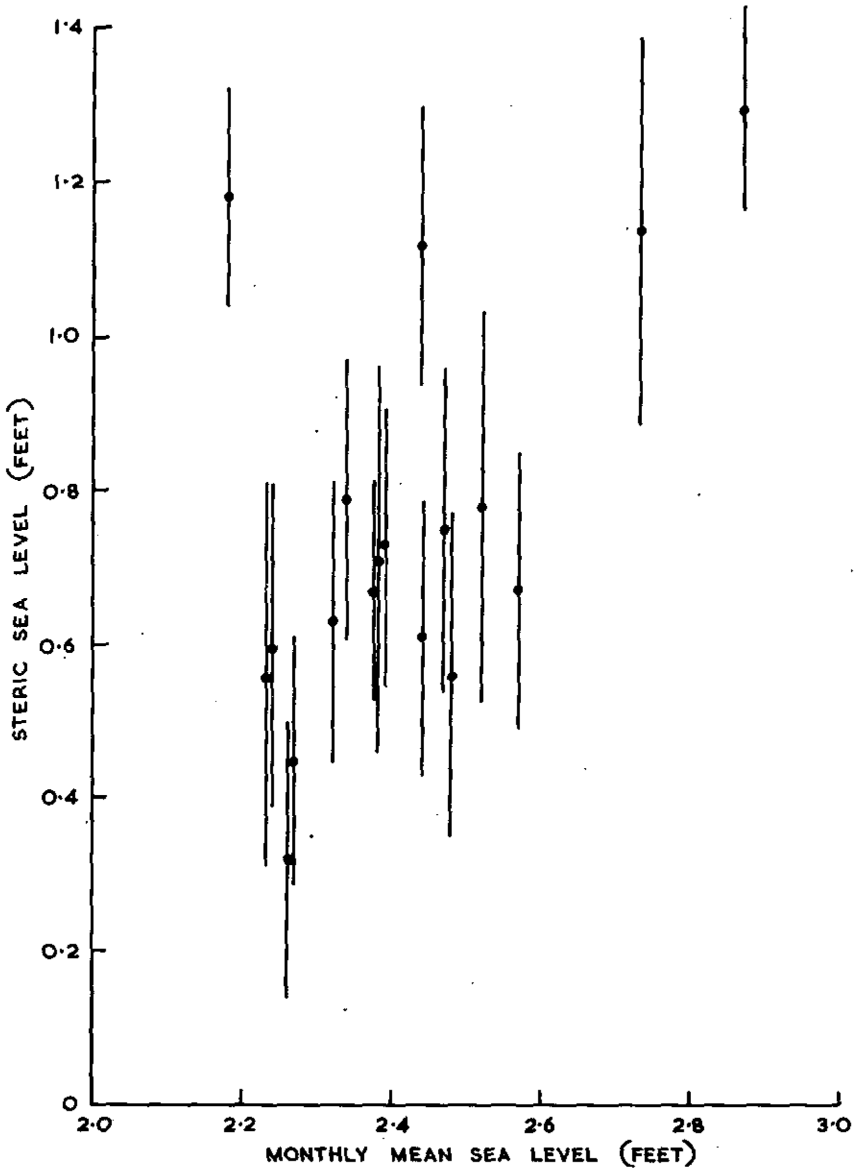

Fig. 8. Monthly mean steric sea levels off the New South Wales coast plotted against the corresponding monthly mean sea levels at Fort Denison, corrected to an atmospheric pressure of 30.00 in. Hg. The length of the vertical line through each point is twice the standard error of the particular mean steric sea level. This standard error was calculated from a pooled estimate of the standard deviation of an individual steric sea level (0.36 ft), and the number of stations in each month.

TABLE I

MONTHLY STERIC AND OBSERVED SEA LEVELS

Year	Month	Station number and day of month (in brackets)	Mean Steric Sea Level (ft)	Mean Observed* Sea Level (ft)
1938	Sept.	39(23), 41(26), 45(29)	0.75	2.47
	Oct.	48(11), 49(12), 52(13)	0.56	2.48
	Nov.	63(2), 65(11), 67 (13), 69 (18), 76(28)	0.45	2.27
	Dec.	96(12), 102(14), 104(15), 106(17)	0.67	2.57
1939	Jan.	1(5), 36(23), 41(25), 43(25)	0.79	2.34
	May	124(1), 127(3), 129 (3), 132(5), 138 (16), 140(29), 142(30), 144(31)	1.30	2.87
	July	200(16), 203(18)	1.14	2.73
	Aug.	205(4), 212(25)	0.71	2.38
	Sept.	214(3), 215(5), 217(6), 221(16)	0.61	2.44
	Oct.	223(2), 224(4), 227(6), 256(26)	0.32	2.27
	Nov.	266(1), 302(15), 309(23)	0.60	2.24
	Dec.	346(26), 349(27)	0.78	2.52
1940	Jan.	2(9), 3(11), 7(14), 9(28)	0.73	2.39
	Aug.	67(3), 73(5), 79(6), 84(8), 93(12), 95(12), 100(20), 106(21)	0.67	2.38
1941	Jan.	4(1), 10(5), 20(8), 26(9), 29(11), 42(18), 66(31)	1.18	2.18
	Nov.	78(16), 82(27)	0.56	2.24
	Dec.	83(2), 85(16), 88(19), 89(21)	0.63	2.32
1942	Jan.	1(2), 6(4), 9(5), 17(11)	1.12	2.44

*Corrected to an atmospheric pressure of 30.00 in. Hg.

APPENDIX

TABLE I

TIDAL RECORDS FOR N.S.W.

Location	Dates	Maintaining Authority	Mean* Sea Level	Notes
Fort Denison	Since 1897	Maritime Services Board of N.S.W.	H	
Camp Cove (Port Jackson)	Since July 1942	" "	H	Some months incomplete
Coff's Harbour	Since Aug. 1951	Public Works Dept. Bridge St., Sydney	H	Gauge faulty in 1955 and 1956
Newcastle	Since Jan. 1928	" "	H	Influenced by river discharge
Eden	Feb. - Nov. 1954 Apr. 1955 - Mar. 1956	" "	H	Unreliable during 1954
Ballina	1928-1939	" "	H	Influenced by river discharge
Yamba	1928-1937	" "	H	" "
Port Hacking	Since Jan. 1942	Division of Fisheries & Oceanography C.S.I.R.O., Cronulla	T	Gauge re-sited in August 1956

* H : Mean half-tide level, obtained by adding the heights of all high and low waters and taking an average.

T : Mean of three-hourly heights throughout each month. Weekly means are also available.

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APPENDIX

TABLE II

DIFFERENCES BETWEEN TIDE GAUGES ON THE N.S.W. COAST

(1)	(2)	(3)	(4)	(5)	(6)
Location	Period Analysed	Number of Months (n)	Mean Difference in Height (ft)	Standard Error of the Mean (ft)	Standard Deviation of Differences (ft)
Camp Cove	Jan.51-Dec.52	24	0.44	0.01	0.04
Port Hacking	" "	24	0.28	0.01	0.06
Coff's Harbour	Feb.52-Mar.53	14	0.39	0.03	0.10
"	Aug.53-Dec.54	16	0.13	0.02	0.10
"	Aug.51-Dec.54	41	0.23	0.03	0.17
Eden	Mar.55-Mar.56	13	-0.21	0.03	0.10

Column (4) of Table II gives the mean of (monthly mean sea level at gauge in column (1)) - (corresponding monthly mean sea level at Ft. Denison), for the periods shown in Column (2). Column (6) gives the standard deviations (s) of the differences between corresponding monthly means for the same periods. Column (5) gives the standard error of the means given in column (4), calculated as $s/\sqrt{n}$, where n is the number of months.

The large difference between the means for Coff's Harbour for the two periods Feb. 1952-March 1953 and Aug. 1953-Dec. 1954 suggests the possibility of an error in the records during one of these periods, or of an alteration in the datum between March and August 1953.

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