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Mean Sea Level at Norfolk Island and Lord Howe Island

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MEAN SEA LEVEL AT NORFOLK ISLAND AND LORD HOWE ISLAND.

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Abstract

Preliminary results of analysis of mean sea level for Norfolk Is. (29°04'S, 167°56'E) are reported, and compared with results of similar analysis for Lord Howe Is. (31°33'S, 159°06'E). The total variance of adjusted mean sea level at Norfolk Is. (55 cm^2) is much less than that at Lord Howe Is. (286 cm^2). Amplitudes of the annual terms are approximately 9 cm and 6 cm at Lord Howe Is. and Norfolk Is., respectively. Positive spikes in mean sea level, due to wave action, were found at both islands, and are correlated, with a time delay of 1 day. These correlated spikes complicate interpretation of the spectra.

INTRODUCTION

Analyses of mean sea level (hereafter referred to as "sea level") at Lord Howe Is. (31°33'S, 159°06'E) have already been reported. Hamon and Stacey (1960) noted the relatively large variations in monthly means, and ascribed them to "steric" level changes (changes due to variations in vertically-averaged density), which in turn were due to movements of currents relative to the island. Hamon (1965) showed monthly means 1957-1964, and compared their range with that of dynamic height (essentially the same as "steric sea level") from oceanographic stations in the area. Earlier (Hamon 1962), the spectra of sea levels at Lord Howe Is. were computed in the range 0-0.5 cycle per day (cpd), with (1/60) cpd resolution, both for the sea levels as observed, and after adjustment for the effects of atmospheric pressure ("adjusted" sea levels). The resolution of the spectrum calculations was extended to (1/384) cpd in Hamon (1968), using data from July 1958 to October 1967.

Boland (in press) compared a histogram of sea level at Lord Howe Is. with that of temperature at 240 m depth (closely related to dynamic height or steric sea level) at 34°S, 154°E. Both histograms are bi-modal, but the bi-modal effect is less marked at Lord Howe Is. than at 154°E. The bi-modality was taken as evidence for strong, narrow currents in both areas, with relatively rapid sideways movement of the current pattern, so that the island or the station position is most often on one side (high dynamic height, high sea level) or the other (low dynamic height, low sea level) of the current.

The present paper concentrates mainly on similar spectral analysis for Norfolk Is. (29°04'S, 167°56'E), but includes a cross spectrum analysis between Lord Howe Is. and Norfolk Is. sea levels. The analyses are regarded as preliminary. They should be repeated after editing of the data to remove at least the largest of the positive spikes found in plots of sea levels at both islands, and using additional data that had not been processed when the analyses reported here were made.

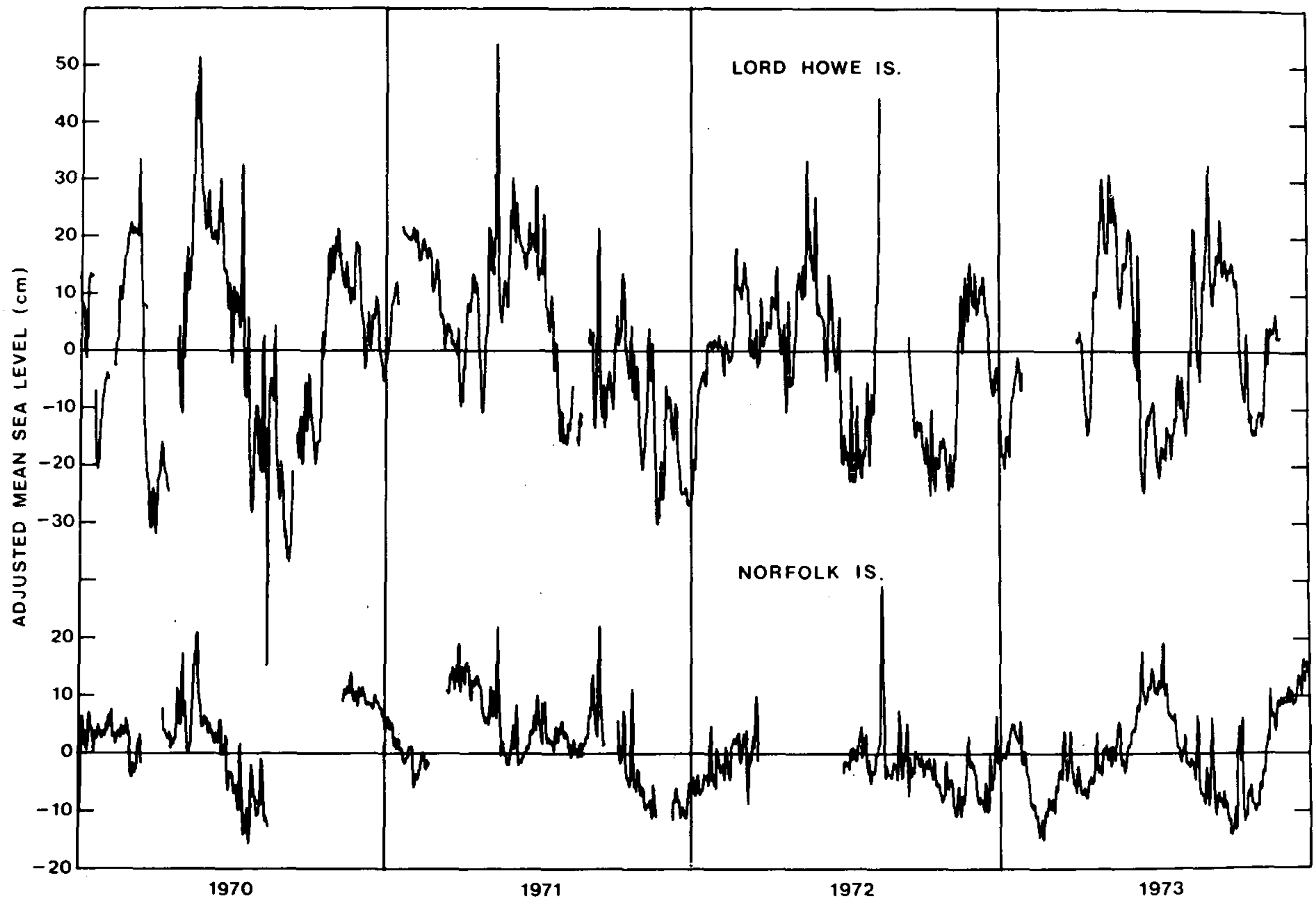

Fig. 1. Adjusted mean sea level at Lord Howe Is. and Norfolk Is., at 1 day intervals, 1970-1973. Each graph is the deviation from the long-term mean.

DATA

Sea levels at 0.5 day intervals were computed from hourly tide heights, using Munk's filter (filter weights and frequency response in the tidal bands are given in Hamon (1977)). Mean atmospheric pressures were computed from 3-hourly values, using a grouping of the Munk filter weights, so that both sea level and pressure series would be subject to similar attenuations in the band of interest (0-0.5 cpd). Half-day sea levels for both islands were computed for 1200 and 2400 Universal Time (U.T.). Half-day pressures for Lord Howe Is. are at the same times, but for Norfolk Is. they are at 1030 and 2230 U.T. This 1.5 hour displacement should have negligible effect on the results. Series of half-day-mean "adjusted" sea levels were formed for each station by adding corresponding sea level and atmospheric pressure, with the usual hydrostatic response factor of 1 cm decrease in sea level for 1 mb increase in atmospheric pressure.

The tide gauge at Lord Howe Is. was attached to a jetty in the lagoon on the south-west side of the island. Plots of the 0.5 day sea levels showed a number of positive spikes, of duration 2-3 d. and heights estimated to be up to 40 cm above background. These spikes are due to impounding of water in the lagoon due to waves or swell breaking over the reef. Similar positive spikes appear in plots of Norfolk Is. sea level. The gauge at Norfolk Is. is also mounted on a jetty, and although there is no lagoon, the position is very exposed and wave-induced set-up can be expected. For the Lord Howe Is. gauge, on average about 4 positive spikes per year were found with amplitudes greater than 10 cm. It was estimated that these spikes contribute only about 5% to the total sea level variance. The spikes at Norfolk Is. generally have smaller amplitudes. Most of them are definitely correlated in time with the spikes at Lord Howe Is., with a time delay of about 1 day.

Data from Norfolk Is. used in this study are for the period February 1969-November 1976. Data from Lord Howe Is. are for September 1958 to November 1973. Operation of the Lord Howe Is. gauge was discontinued in October 1977. Due to the exposed and remote locations, there are many gaps in both sea level series.

RESULTS

(i) Variance and Annual Cycles

Figure 1 shows graphs of adjusted sea level at both islands for 1970-1973, at 1 day intervals (every second value of the data series). Several of the main features of sea level records at the two islands can be seen by inspection of Fig. 1. The most noticeable feature is that the variance at Lord Howe Is. is much larger than at Norfolk Is. The estimated variances (standard deviations) are 287 cm^2 (16.9 cm) for Lord Howe Is., and 55 cm^2 (7.4 cm) for Norfolk Is. The standard deviation for Lord Howe Is. agrees well with the standard deviation in dynamic height in the East Australian Current of 18 dyn. cm (Wyrtki 1975). The positive spikes due to local effects of waves or swell, and their correlation at the two islands, can be seen in Fig. 1. It is also clear from Fig. 1 that longer-term variations in sea level at the two islands do not appear to be correlated; this point will be discussed in a later section. Finally, no annual variation stands out in the sea level graph for either island. Separate estimates of the amplitude of the annual component of adjusted sea level, based on all available data, gave 9 cm for Lord Howe Is. and 6 cm for Norfolk Is. Based on these estimates, the annual component accounts for 33% of the total variance at Norfolk Is., but only 14% at Lord Howe Is.

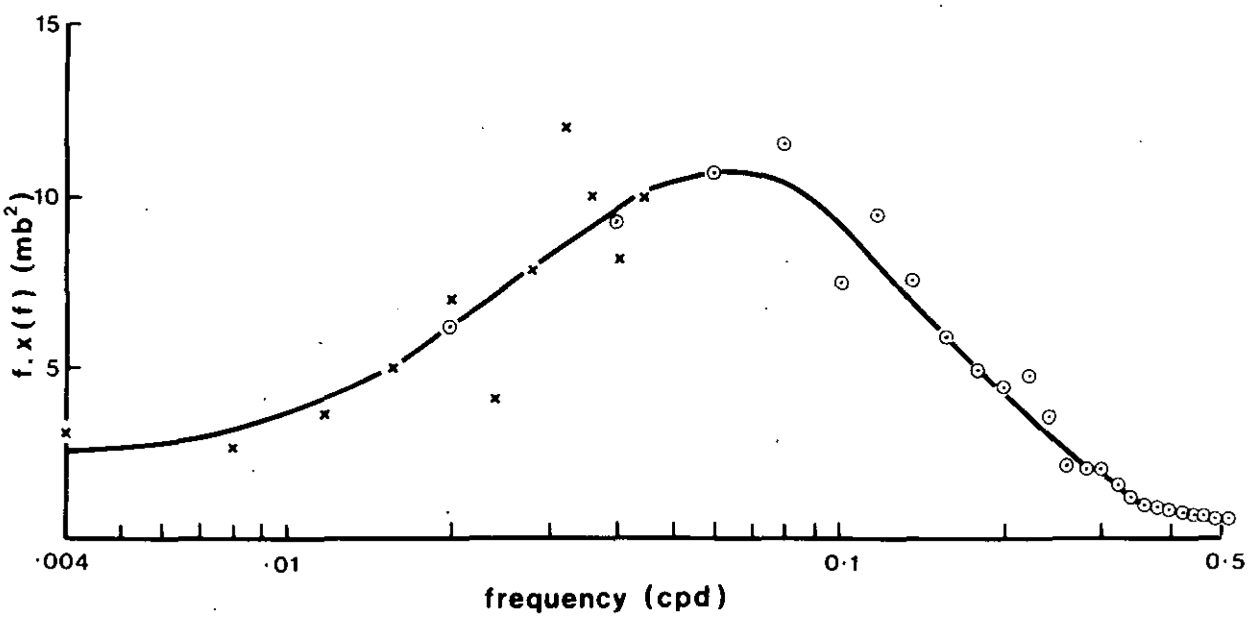

Fig. 2. Spectrum of atmospheric pressure at Norfolk Is. The product of frequency (f) and spectral energy density (X(f)) has been plotted as a function of log f. ⊙ 0.02 cpd resolution, 95% confidence factors 0.76 and 1.4. x 0.004 cpd resolution, 95% confidence factors 0.54 and 2.3. The spectrum has been corrected for filtering.

(ii) Effect of Atmospheric Pressure

An in-phase barometer factor b(f) was estimated as a function of frequency for Norfolk Is.,

$$b(f) = C_{12}(f)/X_{22}(f)$$

where $C_{12}(f)$ is the co-spectrum between sea level and pressure, and $X_{22}(f)$ is the pressure spectrum. The result agreed well with the expected value of -1 cm/mb (the inverse barometer effect) for frequencies up to 0.1 cpd. Somewhat lower (absolute) values were found between 0.1 and 0.5 cpd. The squared coherence between sea level and pressure was $\geqslant 0.25$ for frequencies less than 0.25 cpd. The phase showed an almost linear increase with frequency in the range 0-0.2 cpd, consistent with sea level lagging pressure by 0.3 day. A lag of 0.4 day, of the same sign, had been found earlier (Hamon 1966) for Lord Howe Is., and was confirmed with data from a different epoch during the present study. These lags might be due only to the wave-induced spikes in sea level, which would be expected to be correlated with atmospheric pressure, at least for locally-generated waves.

The spectrum of atmospheric pressure at Norfolk Is. (Fig. 2) shows that most of the pressure variance is in the frequency band 0.02-0.2 cpd (50-5 day period). There is no evidence of separate summer and winter peaks, as was found at Lord Howe Is., Coffs Harbour and Sydney (Hamon 1962).

Although not of direct oceanographic interest, the cross spectrum between pressures at Lord Howe Is. and Norfolk Is. was computed. It showed a linear phase change up to about 0.3 cpd, equivalent to pressure at Lord Howe Is. leading pressure at Norfolk Is. by 0.7 day.

(iii) Spectrum of Sea Level at Norfolk Island

Figure 3 shows the spectrum of adjusted sea level at Norfolk Is., 0.004-0.5 cpd, corrected for filter effects. The variance in the "atmospheric pressure band" (0.02-0.2

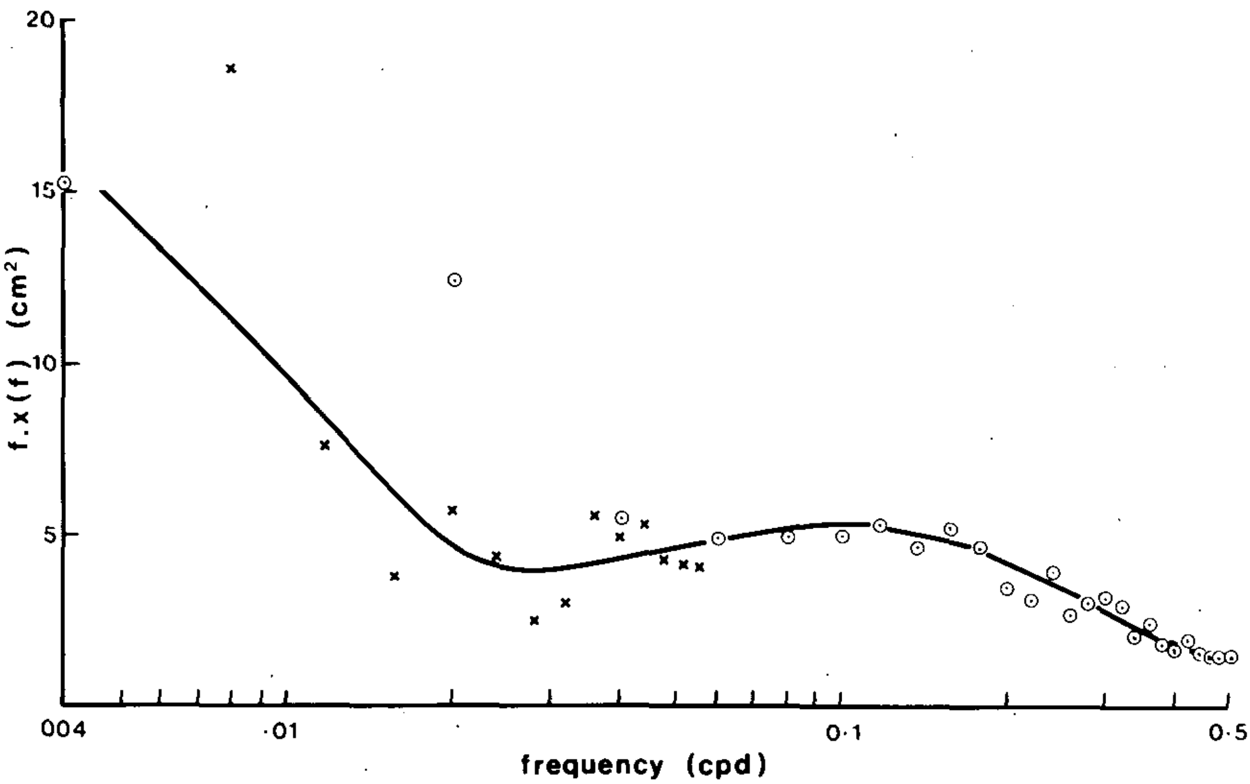

Fig. 3. Spectrum of adjusted mean sea level at Norfolk Is., corrected for filtering. Confidence factors as for Fig. 2.

cpd) is small (~10 cm^2). At lower frequencies the spectrum rises, but the record is not long enough to resolve any low frequency peak of the type that was just resolvable at Lord Howe Is. (Hamon 1968).

(iv) Cross Spectrum between Adjusted Sea Levels at Lord Howe Island and Norfolk Island

Figure 4 shows the squared coherence and phase as functions of frequency, from the cross spectrum between adjusted sea levels at Lord Howe Is. and Norfolk Is. Although the squared coherence is small, it is significant at the 95% level from 0.04 to about 0.4 cpd. The significance is supported by the non-randomness of the phase. The linear phase diagram indicates a constant time delay, with Lord Howe Is. leading Norfolk Is. by 1.0 day.

Physical interpretation of Fig. 4 is complicated by the spikes due to impounding of water or wave set-up (Fig. 1). The occurrence of these at the two islands is highly correlated, and with a lag of order 1 day, in the sense consistent with the phase in Fig. 4. But, if the coherence and phase were due only to the spikes, one would expect coherence to increase appreciably with increasing frequency, since the spectrum of the spikes can be expected to be much flatter than that of sea level.

Figure 4 does not show any significant coherence at 0 or 0.02 cpd. This was confirmed by an additional analysis with resolution 0.004 cpd. We conclude that the dynamically-interesting variations in sea level, in the range 0-0.02 cpd, are not coherent at the two islands. This confirms the qualitative inference from Fig. 1.

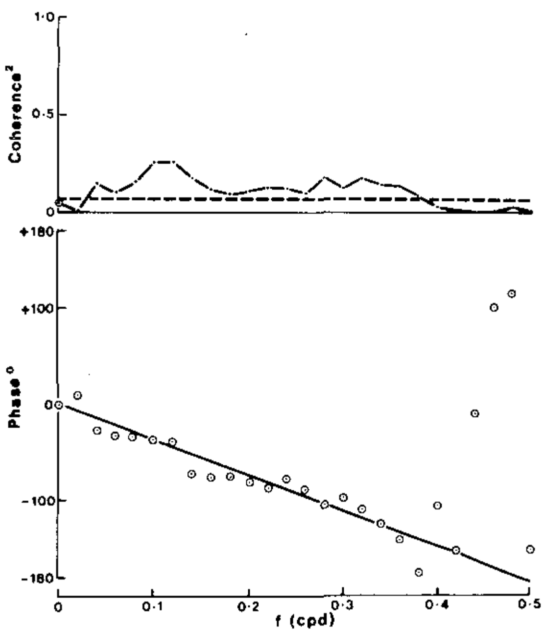

Fig. 4. Coherence-squared and phase as functions of frequency, from cross spectrum between adjusted mean sea levels at Lord Howe and Norfolk Islands. The 95% confidence level for coherence-squared is indicated as a dashed line.

DISCUSSION

The lack of coherence at low frequencies (0-0.02 cpd) between adjusted sea levels at Lord Howe and Norfolk Islands was to be expected, since most of the variance at Lord Howe Is. is due to variations in the East Australian Current and its eddies. A typical length scale for this system (diameter of an eddy) is 300 km, which is small compared to the separation between the two islands (900 km).

The much reduced total variance at Norfolk Is. shows that the strong variable currents between Lord Howe Is. and the east Australian coast do not extend as far east as Norfolk Is.

At Norfolk Is., 40% of the total variance of adjusted sea levels is in the frequency band 0-0.004 cpd, i.e. periods greater than 250 days, but an appreciable part of this is due to the annual term. The corresponding figure for Lord Howe Is. is 18%. Until the Norfolk Is. spectrum can be re-computed with seasonal effects removed, and with a longer data base we cannot draw meaningful conclusions about very low frequency behaviour. At this stage, we note only that appreciable variability with time scales of several years has been reported (Wyrtki 1977) for the equatorial Pacific, based on sea level and other data. Donguy and Henin (1977) have discussed the difference in monthly mean sea level between Auckland (New Zealand) and Noumea (New Caledonia) for 1967-1974, in relation to surface circulation. Again, there is appreciable variation with time scales of more than a year.

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