International Hydrographic Review, Monaco, LVII (1), January 1980.

PROCESSING OF TIDAL RECORDS AT HOUT BAY HARBOUR

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ABSTRACT

Twenty-two years of tidal records at Hout Bay Harbour in South Africa have been digitized and analysed in order to seek long-term variations in mean sea level. After accounting for a local movement of the tide gauge, a rise in sea level of approximately 1 mm per year has been detected. This agrees well with global estimates of the eustatic rise in sea level.

INTRODUCTION

In recent years geodesists have shown an increasing interest in the land/sea interface, both from the point of view of providing data for oceanographic use, and for the purpose of better determining the position of the basic vertical reference surface, the geoid. Investigations have concentrated on the rise (or fall) of sea level with respect to the land (MATHER, 1974), and on the North/South slope of sea level with respect to the geoid (FISCHER, 1977).

For both these applications, long term tide gauge records are of great importance. South Africa is one of many countries where these records are lacking, or are badly fragmented. Although tide gauges were installed at two South African ports in the 1880s (FINLAY, 1893), the records of these and other early gauges are either no longer available or are considered too unreliable to be of any use. Since 1958, when the Hydrographer to the South African Navy took over the maintenance of most of the tide gauges in South African waters, more consistent data have become available.

In addition to the data available from the Navy, another source of mean sea level information is the tide gauge operated by the Survey Department of the University of Cape Town at Hout Bay Harbour. This gauge has been in operation at this fishing harbour, 20 km from Cape Town, since late 1955. However, it is only recently that the Department has been in a position to process the analogue records. The analysis described in this paper concentrates on the detection of long-term variations (in the geodetic sense) in mean sea level.

THE TIDE GAUGE

The gauge was manufactured in the departmental workshop, and is a conventional stilling well, float, and drum recorder type. For the period late 1955 to mid 1977 it was mounted on a jetty consisting of a metal framework with a wood beam deck. In 1977, after repeated damage to the stilling well by refuelling trawlers, it was moved to a quieter portion of the harbour. Only the data acquired up to mid 1977 have been used in this study.

In 1977, both the old and new sites were connected by precise levelling to a number of benchmarks in the vicinity, and the gauge was calibrated using the van de Casteele test (MERRY, 1977). To the author's knowledge, no calibrations were carried out previously, and the gauge has been connected once, in 1967, to a neighbouring benchmark (TAYLOR, 1979).

METHOD OF ANALYSIS

Before any analysis could take place, a certain amount of preprocessing of the tidal data was necessary. With close to 22 years of weekly records (all on unlined paper), and a limited amount of funds, an automated digitising process had to be used. Digitising took place using a Summagraphics tablet, linked to a Tektronix mini-computer. The mini-computer was used to scale the data and to check for gross errors in date or time, and in datum. With a complete lack of calibration records, and a knowledge that the float cable had been replaced on several occasions (at unspecified dates), establishment of a reliable datum was difficult. In this case, the weekly measurements of the depth of the water surface below the base of the gauge, made at the time of changing the paper, were used. These depths are of a low accuracy, and result in height discontinuities of the order of 5 cm between adjacent weekly records. However, these errors are of a random nature in the long term, and should not significantly affect this analysis.

The result of the digitising process is a set of half-hourly tidal heights, correctly scaled, and related to a common datum. At this stage, additional filtering of gross errors was carried out, by fitting a polynomial successively to 120-day segments of the data, and then identifying residual outliers.

This least squares fitted polynomial allowed for a datum shift, linear trend, and for the two predominant tidal constituents, M_2 and S_2. Outliers were compared against adjacent values, and where necessary rejected or corrected. Major causes of rejection were pen or float jams, illegible records, and incompatible data, leading to almost 30 % of the original data being rejected at this stage.

The next step in the preprocessing was the interpolation of half-hourly values for all gaps not exceeding 1.5 days. For this purpose, the polynomial described in the previous paragraph was used again. Tests using real data indicated that the Root Mean Square (RMS) error in the daily mean level, applying this interpolation, would be 0.03 m. The daily mean levels were computed from the observed and predicted half-hourly values, using a simple arithmetic mean, where sufficient data were available. If sufficient (i.e. at least 46) values were not available, no daily mean was computed.

The resultant set of daily mean values is not continuous, and has many gaps in it. Monthly mean levels, based on this set, are shown in figure 1. The large gap in 1965/66 was due to the use of the incorrect type of paper, which resulted in most of the records for this period being illegible. In 1971/72, the problems appear to be chiefly mechanical, and there are several months for which no records are available at all.

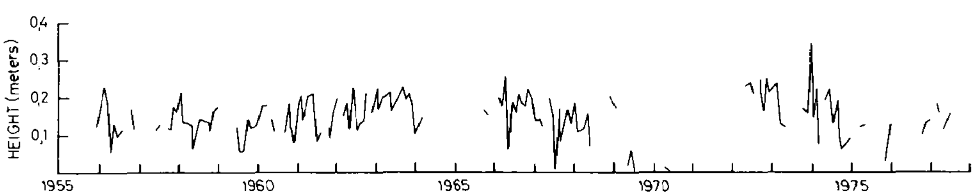

FIG. 1. — Monthly mean sea levels – Hout Bay Harbour.

A spectral analysis has been carried out on the daily mean levels, to determine the long period tidal constituents and the linear trend in mean sea level. The method of analysis is that due to VANÍČEK (VANÍČEK, 1971), and which is documented as a computer program in WELLS and VANÍČEK, 1978. Details are given in the referenced papers, but conceptually the method can be considered as successively performing a least squares fit to a time series, f(t), for a single frequency at a time, within a predefined frequency band.

The fitted polynomial T(t) is given by:

$$T(t) = c_1 + c_2 \cos \omega t + c_3 \sin \omega t$$

The Euclidean norm of a function, x(t), is denoted by $||x||$, where $||x||^2 = \Sigma x_i x_i$. The spectrum of a particular frequency is then given by:

$$s(\omega) = 1 - ||f - T||^2 / ||f||^2$$

with a range between 0 and 1.

The least squares spectral analysis has the advantage that it can deal with unequally spaced data (including gaps), and that the effect of known frequencies can be removed without producing a shift in the spectrum (TAYLOR & HAMILTON, 1972).

RESULTS

Although the main purpose of the analysis was to detect long-term variations in mean sea level, the spectral analysis program was also used to find the predominant short-term tidal constituents, for application in the interpolation procedure. For this purpose, several segments of half-hourly values were selected for analysis. As expected, the predominant constituents were M_2 and S_2, with weaker contributions from the N_2 and K_1 constituents.

Investigation of the lower frequencies, using the daily mean levels, indicated that most of the signal was hidden by noise. Weak contributions were noticeable from Mf, MSf, Mm, Ssa and Sa. With regard to longer periods, no evidence of the nodal tide (18.6-year cycle) was present, but weak peaks were detectable at 5.3 years and 8.9 years (see figure 2). The origin of the 5.3-year frequency is unknown and the peak is probably fictitious. The 8.9 year peak could be due to p or 2 N or both. However, it is to be expected that all these long-period (> 14 days) constituents would be weakly determined, as their theoretical amplitudes are near zero at the latitude of Hout Bay (approx. 34° S) (LISITZIN, 1974).

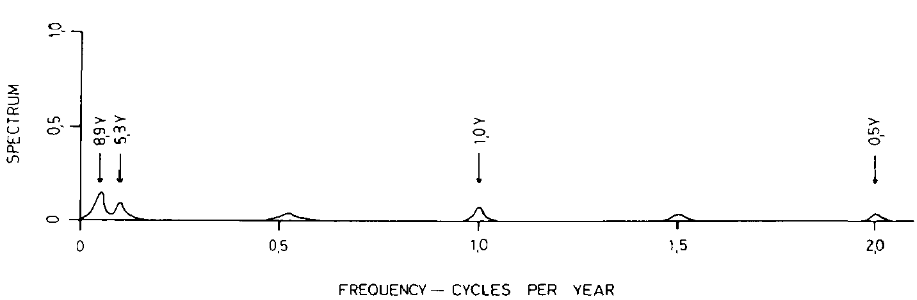

FIG. 2. — Spectrum of sea level – Hout Bay Harbour.

It has been assumed that over the period of observation (21.7 years) any change in mean sea level could be modelled by a linear trend. Visual inspection of the data confirms that no more complex trend is evident. An initial determination of the linear trend, using a least squares fitted straight line with the daily mean sea levels, yielded a slope insignificantly different from zero (that is, no rise or fall in sea level). This apparently contradicted provisional results for other South African seaports (MOES & ZWAMBORN, 1973) which indicated a general rise in sea level, and a further investigation of the stability of the tide gauge datum was carried out. A comparison of the 1967 and 1977 levellings showed that the entire gauge and its supporting wooden beam had risen by 1.5 cm with respect to the adjacent benchmarks. This was confirmed by a noticeable jump in the daily mean sea levels in February 1969, and an explanatory note on the corresponding record: "stilling well slipped out".

This shift in the gauge was treated in two ways. In the first case, only data observed prior to February 1969 were analysed, resulting in a linear trend in mean sea level of + 0.9 mm/year. In the second case, allowance was made for an additional datum shift, at the break, in the least squares fit. In this case, a linear trend of + 1.2 mm/year was obtained. Both these linear trends have a standard deviation of 0.5 mm/year. Although this standard deviation may appear rather high, it must be remembered that this includes the effects of any unmodelled systematic contributions to mean sea level (for example, meteorological effects).

CONCLUSIONS

It is apparent that great care in the maintenance and operation of a tide gauge is necessary in order to obtain reliable data for the purpose of the detection of long-term trends in mean sea level. The Hout Bay gauge was not originally designed for this purpose, as indicated by its installation on a wooden jetty. A lack of regular calibration and levelling data required a modification of the procedure for relating the observations to a fixed datum, which has resulted in some loss of accuracy.

However, stringent editing and checking (which resulted in the rejection of 30 % of the raw data) has enabled a consistent set of daily mean sea levels to be calculated. Analysis of these levels indicates a rise of about 1 mm/year in mean sea level for the period 1955-1977. This agrees well with the values obtained by a number of authors for eustatic rise in sea level. (For a summary, see Lisitzin, 1974.)

A number of improvements could be made in the methods outlined in this paper. For example, the method of calculating the daily mean sea level could be improved by the use of filters, and further interpolation is possible. Tide gauges also exist at the nearby harbours of Table Bay and Simon's Bay, and the rise in sea level at Hout Bay could be confirmed by analysis of the records from these ports.

ACKNOWLEDGEMENTS

I wish to express my appreciation to Drs. D. E. Wells and P. Vaníček for permission to use their program for spectral analysis.

This research was jointly funded by the University of Cape Town and the South African Council for Scientific and Industrial Research.

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