Application of a least square spectral filter in correcting abnormal meteorological drift of a LaCoste-Romberg Gravimeter

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ABSTRACT

The performance of a least square spectral filter in removing abnormal meteorological drifting earlier reported for a Lacoste-Romberg gravimeter is evaluated. A short (3-days) drift curve of the instrument was compared with tidal data for the location that is derived from theoretical Earth parameters before and after application of the filter. The filter was effective in remove noise registrations above 4 cycles per day in the gravimeter record. A large amplitude disparity at frequencies < 2 cycles per day between the two time series were found after application of the filter. This is attributed to temperature induced creeps in the meter spring, which resulted in phase shifts in the gravimeter series. It is concluded that a combination of "Optimum Operating Procedures" as earlier published and appropriate filtering and phase adjustments may increase gravimeter precision for measurements requiring mGal accuracy. μGal precision data would however require instruments with better temperature compensation. The procedure presented here is suggested for routine assessment of gravimeter precisions prior to field deployment, against the background of scarcity of new gravimeters for fieldwork in Nigeria.

Key words: *Spectral filter, least square, LCR gravimeter, meteorological drift, and synthetic Earth tide.*

1.0 INTRODUCTION

The Lacoste Romberg (LCR) gravimeter is useful in mapping geologic structures of anomalous densities associated with ore and hydrocarbon accumulation (Ojo, 1992). In geodesy, it is useful in the monitoring of elevation changes (Woollard, 1980) and surface deformations (Kiviniemi, 1974); and in geodynamics for monitoring tectonic stresses (Honkassalo, 1975). One of the major advantages in using the Lacoste-Romberg gravimeter for fieldwork is that it records minimal drift when stationary. This facility is reduced as a consequence of aging and mechanical faults, (Osazuwa & Ajakaiye, 1982; Nwofor, 1994; Nwofor & Chineke, 2003). Since the few available LCR gravimeters in Nigeria are mostly very old and as such have lost most of the in-built compensations making them highly susceptible to meteorological effects. There is the need to continue to assess the reliability of the available instruments for various applications. Since synthetic tides of the Earth can be determined to a very high level of precision (such as nano-Gals), via software: (http://www.gik.uni-karlsruhe.de/Forschung/eterna33.htm), one of the problems presently encountered is to measure to this accuracy using instruments. Synthetic Earth tide data can therefore provide a facility for routine investigation of abnormal drifting of a gravimeter. This work introduces this method. It involves the comparison of a short series of ground based gravity tidal observation of a LaCoste-Romberg gravimeter in Jos Nigeria with a synthetic tide derived from wave groups that are based on theoretical Earth parameters. The LCR gravimeter is among the very old ones commonly found in the country whose several compensations were suspect, making it highly susceptible to meteorological influences. "Optimum Operating Principles" for reducing these impacts some of which can interfere in the tidal band, have been studied for the system as reported by Nwofor and Chineke (2003). The present method is an appraisal of the effectiveness a low pass least square filter in reducing these abnormal drifts.

2. 0 METHODS

The gravimeter tide is a 72 hours ground based data beginning at 08,30 hours local time (UTC) on October 10, 1992, obtained with a LaCoste Romberg (LCR) using the optical method. The gravimeter model G.468 was positioned in Jos, Nigeria at a longitude of 8^o 53' E, latitude of 9^o 57' N, elevation of 1159 meters above sea level (Macleod et al., 1971); and about 1000 km from the southern coastline. The gravimeter measures to 1 part in 100 million or 0.01 mGal (1 mGal $=10^{-5}$ ms^{-2}), which suites the limit of sensitivity for the major tides, if instrumental and interference errors are removed. Two major errors are however encountered with the use of the instrument. The first is due to spring response to dial turns which may not be simply accurate and the other due to spring hysteresis. This second error type is easily associated to loading, aging and meteorological effects.

The gravimeter tidal record is superimposed on the linear drift, which agrees in value with the normal specification (0.0079 mGals/hour) (figure 1). The amplitudes h of the gravimeter series were then obtained by fitting a linear trend d to the gravimeter readings G according to the equation

$$h = G - d \qquad (1)$$

Fig. 1a

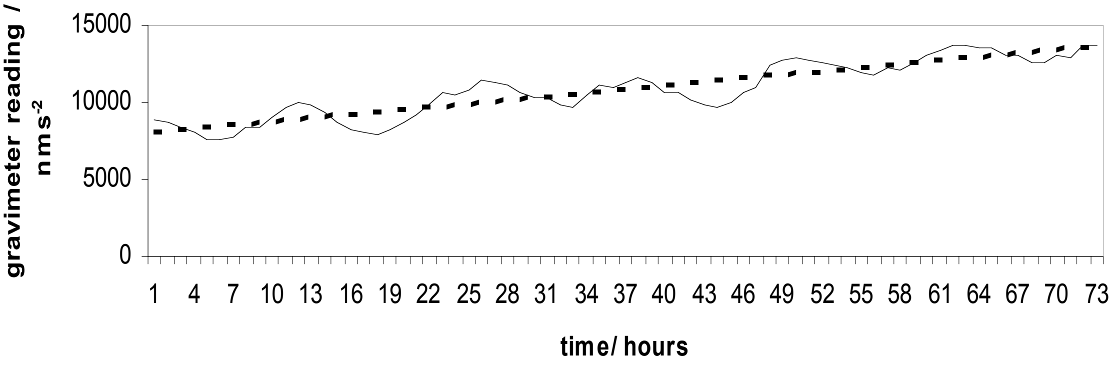

Fig 1b

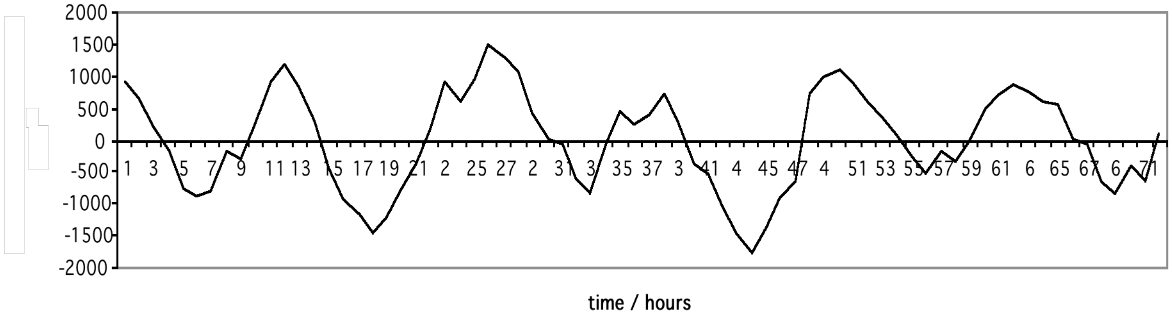

Figure 1: (a) Observed gravimeter drift (solid lines) with fitted linear trend (dashed lines)

(b) Gravimeter drift corrected for linear trend trend

The gravimeter data has a high signal to noise ratio, and therefore required appropriate filtering. Some criteria for choosing frequencies to be removed have been explained by Mishra and Rao (1997). In their work, temporal variations in the gravity field recorded at a station were classified into six major types; very large period (100 – 10000 years); large period (10 – 100 years); medium period (days – years); short period (hours – days); shorter period (hours) and shortest period (seconds – minutes). In the present case the noise registrations are obviously shorter period events, which are found to be mainly meteorological i.e. changes in atmospheric pressure (Durcame et al., 1999) and perhaps fluctuations in the tropical temperatures (Nwofor 1994, Nwofor and Chineke, 2003).

We applied a low pass least square filter at a cut off frequency of 4 cycles per day in other to preserve signals in the tidal band. The filter is implemented in the model tide programme Tsoft (Van Camp &

Vauterin, (2005)) which was also used to compute the synthetic tide for the station using a wave group table.

The Least Square Spectral Filter (LSSF) is found to be particularly suitable for the data series. This is because the Discrete Fourier Transform (DFT), which is an alternative (Scales, 1997), may not be suitable for analyzing data with gaps in the series (Vanicek, 1971), and is generally not convenient for short data series since it assumes signals to be limited in both time and frequency (Ozaktas et al., 1996). Algorithms for implementing the DFT such as The Fast Fourier Transform (FFT) are equally inappropriate, as these do not estimate DFT with high accuracy (Becker and Morrison, 1996). Unlike the DFT and FFT, the LSSF, models short periodicities that contain periodic or systematic signals, which may contain either random or systematic errors or both (Vanicek, 1971). The performance of this filter in removing the interference effects in the gravimeter data is deduced from comparison of the spectral series for the gravimeter drift contaminated with noise (figure 2a), the filtered gravimeter tides (figure 2b) and the synthetic tide (Figure 2c). The outputs of the filter for figures 2b and 2c are similar. Noise registrations, above the white noise threshold are minimized by application of the filter.

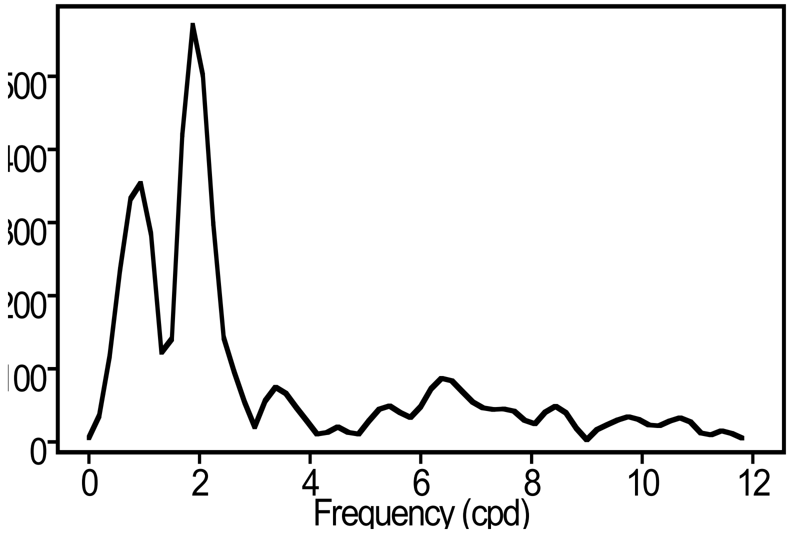

Figure 2 a: Spectrum of gravimeter drift before application of the LSSF showing high frequency noise registrations

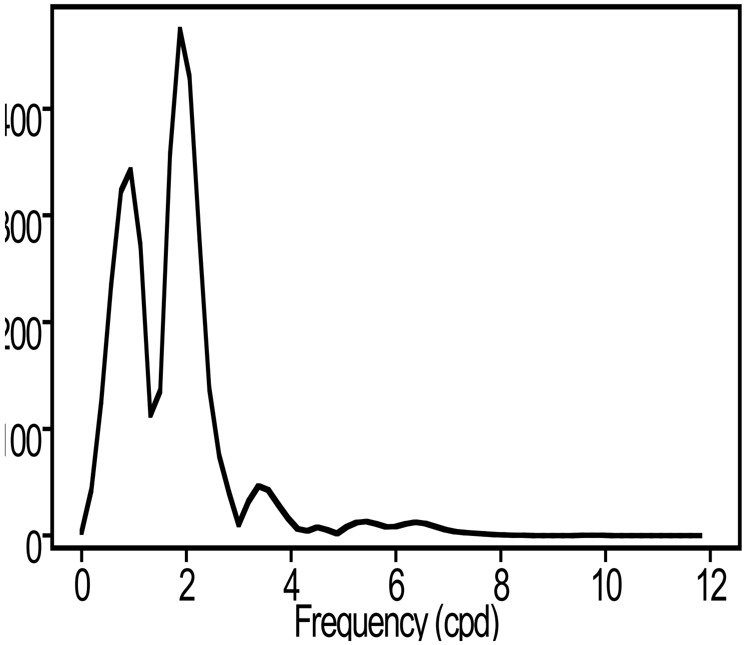

Figure 2b: Spectrum of gravimeter drift after application of the LSSSF

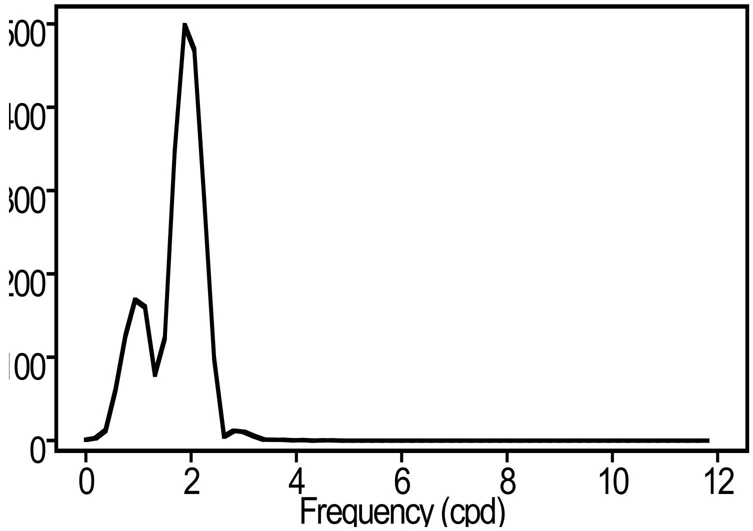

Figure2c: Spectrum of the synthetic tide

3.0 DATA ANALYSIS AND DISCUSSIONS

A rough comparison of some of the properties of the gravimeter and synthetic tide series is carried out in *table 1* to test the assumption of linearity in the propagation of the two tides. The properties are the periodicity, and the amplitude and phase evolution ratios in the two data series. Where the ratios are evaluated for the i^{th} crest to the preceding (ith – 1) crest. For the amplitudes these are given as

$$\frac{h_i}{h_{i-1}};\frac{H_i}{H_{i-1}} \tag{2}$$

Where *h* and *H* stand for the amplitudes of the gravimeter and synthetic tides respectively. And for the phases as

$$\frac{\Phi_{hi}}{\Phi_{hi-1}};\frac{\Phi_{Hi}}{\Phi_{Hi-1}} \tag{3}$$

Where Φ_h and Φ_H are the phases for the gravimeter and synthetic tides respectively. With Φ_H - $\Phi_{h\text{ defined}}$ as the phase shift and *h /H,* the amplification. (Amplitude increase of gravimeter series over the synthetic series).

The amplitudes and phase evolution of the series have been evaluated using the highest and the lowest points of the envelopes in the filtered data and the shift is assessed from the correlation. (Figure 3)

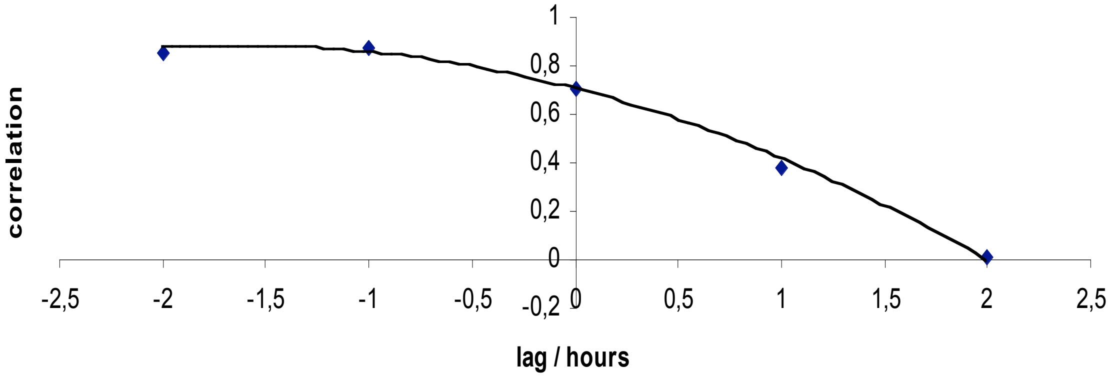

Figure 3: Correlation between gravimeter and synthetic tides for different time lags(hours)

Table 1*: Comparison of period, amplitude and phase evolution ratios of the gravimeter and synthetic tides.*

	Gravimetric tide	Synthetic tide	Discrepancy
Average period (hours)	1180	11.80	0
Average amplitude evolution ratios	0.980	1.000	0.02
Average phase evolution ratios	1.04	1.05	0.01

The amplitude and phase ratios for the two series are close from Table 1. Hence there is a marked linearity in the evolution of the two tides. Based on this established linearity we determined the lag in hours by calculating the cross correlation coefficients at different adjusted values of the time lag, taking the point of maximum correlation to imply zero lag (based on the linearity test) between the two tides (with the synthetic tide taken as reference), i.e. we correlated *H (t)* and *h (t + lag)*. Figure 3 is a plot of the correlations calculated for different lags. Since the data points were sampled at 1-hour intervals, a second-order polynomial ($0.0676\ t^2 + 0.288t + 0.7011$), where t is the lag/ hours, which fitted the correlation curve properly, enables a more precise determination of the points of maximum correlation (at the turning point of the curve). This we found to be at a time lag of about 1.4 hours. Indicating that the gravimeter tide propagates with a time lag of about 1.4 hours behind the synthetic tide. This of course introduces a phase lag of $-\Omega\, t_0$, ($\sim 43^0$) for the gravimeter series with respect to the synthetic tide, where Ω is the frequency ($\Omega = 2\pi/T$; T = period in hours) and t_0 the time lag. The amplitude variations given by the residuals (*h-H)* are also remarkable. They are higher by over 50% when the time lags in the tides are not corrected (Figure 4), than when they are adjusted for lag even only slightly (figure 5). Figure 5 is a lag-adjustment of only 1 hour, since data was sampled at 1-hour intervals. This is less than the optimum lag-shift by 0.4 hours, but shows the effect of the shift in reducing the residual amplitudes.

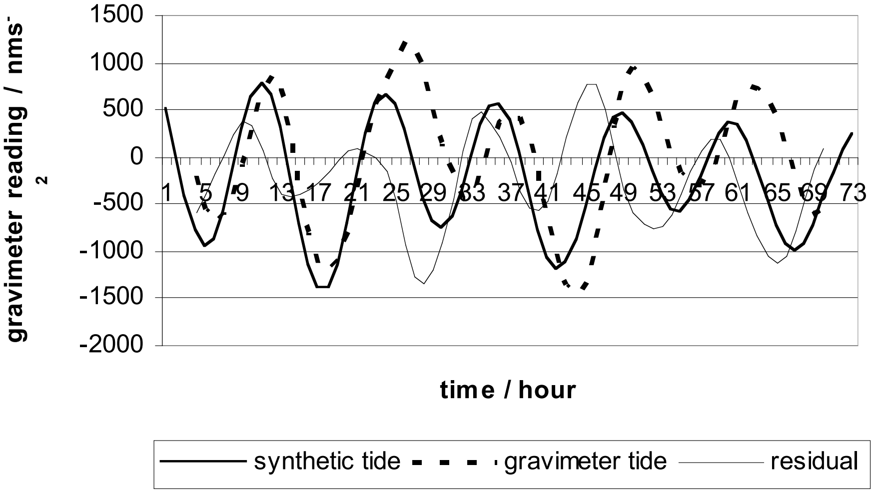

Figure 4: Comparison of gravimeter record with the synthetic tide

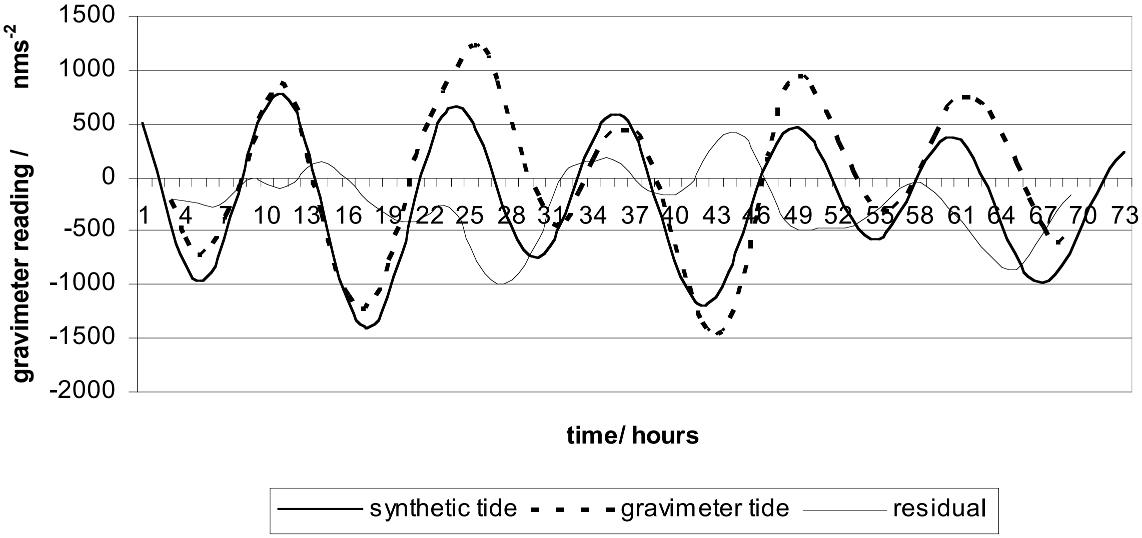

Figure 5: The two time series corrected for time lag by 1 hour and the residuals

3.1 Comments on the Amplitude Disparity

The amplification in the gravimeter data with respect to the synthetic tide has an average value of 0.65. Examination of the spectra for the gravimeter and synthetic tides (fig 4 & 5) indicates that the observed tide has more energy than the synthetic tide in all the frequencies represented. The broadening in the tidal band in the gravimeter spectrum especially between 2 and 4 cycles/day may imply at first sight that more wave groups are contained in the gravimeter series but this is most unlikely. Rather a meteorological artifact, most likely temperature is a strong factor that increased the gravimeter spectral response in the tidal band. A temperature-induced systematic response of the spring is by far the closest periodic signal that can fit this behavior. It shows evidence of growth with time.

3.2 Comments on the Phase Lag

Astatised spring gravimeters such as the LCR gravimeter are known to record appreciable amplitude damping and instrumental phase shift between the gravity sensor and the recording unit (Melchior, 1983; Torge, 1989). For short-time (< 1 day) tidal spectrum, Torge (1989) has reported damping factors of 0.995 for the semidiurnal (m^2) tidal wave and 1^0 and more for the phase lag. This is much lower than the value we observed. The observed maximum cross correlation at lag 1.04 hr indicates a hysteresis response of the gravimeter. A temperature based systematic error component is therefore the most likely explanation for this creeping behavior.

4.0 CONCLUSIONS

The drift patterns of an old LCR gravimeter have been studied at a location in Nigeria to ascertain the reliability of applying a LSSF for reducing abnormal drifting. Our results show a phase lag of the gravimeter record as compared to an appropriate synthetic data due to instrumental response to temperature changes. These resulted in very spurious signals that may limit the use of the instrument for high precision work and tidal studies. Since surveying and static gravity observations require accuracies of ~ 1mGal, this study implies that a LaCoste Romberg gravimeter that looses its temperature compensation may be used under controlled conditions and with appropriate temperature modeling for monitoring static gravity. It is however apparent that such precautions are over simplifications, when the instrument is to be applied for monitoring geodynamic phenomena requiring higher precision (μGal). For this second use there would be need for instruments with better temperature compensations, perhaps new ones. The method adopted here is a fast way of to test the LCR gravimeter response prior to field deployment. It does not represent a study of tidal phenomena owing to the short period of the time series used.

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