Gravimetric Tide observation at Lake Nasser Region, Aswan, Egypt

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ABSTRACT

The LaCoste and Romberg gravimeter D-218 of the National Research Institute of Astronomy and Geophysics (NRIAG) was installed in the tidal gravity station in the ground floor of the main building of the Seismological Centre at Sahari, close to Lake Nasser, Aswan, Egypt. Two years of continuous gravity observations (from October 2002 to December 2004) were available to conduct the current study. The main objectives of this study are to determine the real response of the crust to the tidal forces and, in consequence, to increase the accuracy of the geodetic observations, which were initiated due to the continuous seismological activities in this region, and, in addition, to shed more light on the effect of variation of the Lake level to the surrounding crust. The analysis of tidal gravity observations at Aswan tidal station shows discrepancies between the observed tidal parameters and the synthetic tidal parameters. These discrepancies may be due to variations of lake level, which are seen in the variable load of the lake and the change of underground water level. The residuals are generally quite high: They cover about 300 nm/s². The amplitude spectrum shows a noise level in the diurnal band of 16 nm/s² and 9 nm/s² in the semidiurnal band, but no distinct tidal lines.

1. Introduction

The main objective of geodetic and geophysical activities, which have been initiated in Lake Nasser region after the occurrence of November 1981 earthquake and the continued seismic activities, is to understand the seismic mechanism in this region, to study recent crustal movements around active faults responsible for the seismological activities and to evaluate a possible relation between variation of water level in the lake and seismicity. The results of gravity and GPS observations around Lake Nasser showed that the annual gravity variation around the lake is in the order of tens of microgals; on the other hand, the crustal deformation around the lake is in the order of few millimetres. Thus, to study such small phenomena, higher accuracy in both gravity and GPS are needed. Consequently, accurate determination of gravity variations and local site deformations due to Earth tides are necessary. A tidal gravity station was decided to be installed close to Lake Nasser to determine the response of the crust to tidal forces, to study the effect of the loading of the lake, and to increase the accuracy of geodetic and geophysical observations in the area. Beside gravity also tilt measurements are suitable for monitoring effects of lake level changes to the crust: Jentzsch and Koß (1997) used borehole tilt measurements to observe tilts associated with the change of the level of the artificial reservoir Blå SjØ in southern Norway. This monitoring was conducted to evaluate both the tidal parameters and the long-term drift and to test the correlation of temporal variations to water level variations. In addition, a comparison of long-period measurements was carried out in southern Finland. The results from the two clinometric stations Metsähovi and Lohja, Finland (Weise et al., 1999), showed that continuous tilt measurements are suitable not only for the investigation of small-scale but also for regional-scale crustal dynamics. However, to benefit from the high sensitivity of tilt and strain measurements, observations have to be carried out inside deep tunnels or boreholes. Thus, because gravity measurements can be carried out on or near the surface, it was decided to install a tidal gravity station at Lake Nasser (Hassan et al., 2007).

2. Objectives of Aswan Tidal Gravity Station

Recent crustal deformation studies around Lake Nasser area demand accurate corrections for tidal forces. Zahran (2005) showed that even when using high accurate Earth and ocean tide models, tidal observation is needed, if high precision observations are to be obtained. Moreover, variations of the water level of the lake deform the crust and as a result, affect the geodetic observations, which are mostly located very close to the lake. Thus, evaluation of the effect of the water level variation of the lake is strongly needed. Finally, continuous gravity observations can also shed some light on the response of Lake Nasser to seismic activities in this region. Generally, the objectives of Aswan tidal gravity station can be summarized in the following points:

a. Continuous gravity observations to determine the elastic parameters of the Earth's crust and, thus, to increase the accuracy of geodetic observations in the region;
b. Determination of the variation of the elastic response of the Earth's crust as a result of the variable load of the lake;
c. Evaluation of the effect of the load of the lake, as seen from continuous gravity observations.

3. Description of the Station

The tidal gravity station is located at the ground floor of the main building of the Seismological Centre at Sahari, Aswan, which is a few tens of meters away from Lake Nasser. The station coordinates are 24.100° N and 32.600° E, and elevation is 117.00m. The Aswan tidal gravity station consists of two rooms: one for the gravimeter (measuring room), and the other one for recording (registration room). In the measuring room (Fig. 1), a wooden box chamber was designed that consists of double walls of wood and an insulation material between the double walls to keep the sensor (gravimeter) isolated from the surroundings. A pillar of the size 0.5 m x 0.5 m, connected to the bedrock, was established inside the measuring room, which is separated from the construction of the building. The gravimeter used is the LaCoste-Romberg meter D-218 with electrostatic feedback. Test of temperature stability in the sensor room shows that acceptable stability exists; the change is less than 1°C per day. The recording room contains a multi-channel A/D-converter to provide the feedback output to the computer (Fig. 2). Data are logged at high resolution with sampling interval of 5 seconds.

The recording room contains a multi-channel A/D-converter to provide the feedback output to the computer (Fig. 2). Data are logged at high resolution with sampling interval of 5 seconds. The quartz clock in the computer was compared to a GPS clock. A drift of 1.5 minutes per month was found in the quartz clock. Thus, this deviation was corrected every two weeks. The digital multimeter provides ten channels, of which only three are used, two of them for the cross and long levels of the gravimeter to monitor the stability of the meter, and the third one for the feedback output voltage, which reflects the changes of gravity. The resolution of this multimeter is based on a 28 bit A/D converter, that provides the resolution and the dynamic range (1µV to 20 V) needed to cover smaller changes as well as the drift. All data are stored on the hard disk, using a program that was designed under Q basic.

4. Calibration of the Gravimeter D-218

The calibration factors for both the spring of the sensor and the feedback plays an important role for the accuracy of the analysis of tidal records and consequently the accuracy of the separated tidal parameters. Spring calibration of the gravimeter has been carried out by comparing the gravity difference between two gravity stations with known absolute values located close to the Aswan tidal station. The used stations, Sahari and Aswan have a distance of about 15 km and a gravity difference of about 42 mGal.

Figure 1: Gravimeter D-218 in the measuring room of Aswan station.

Figure 2: Registration room of Aswan tidal gravity station.

The calibration factor of the gravimeter has been determined by comparing the observed gravity difference of the gravimeter and the difference between the absolute gravity values. The optimum calibration factor was estimated by a linear fit between the observed calibration factor and the number of readings. The optimum calibration factor is 0.72560±0.01280. The comparison of the observed calibration factor with the one provided by the manufacturer of 0.72815 shows that the disagreement of both factors is not significant. Thus, as this factor of the manufacturer lies well inside the error bars, it has been decided to keep this value. Calibration of the feedback was done by comparing the fine dial reading of the gravimeter with the feedback output. The calibration factor for feedback was found to be -0.887±0.01309 mvolt /dial. This factor converts the output voltage to reading dial.

5. Recording of Data

The data logged were stored in a computer using software developed by the first author, which was designed under Q-basic. Data were logged in a high resolution sampling interval of 5 seconds. The data were stored in files, each of one hour capacity. The ETERNA format used was described by Wenzel (1994). It was adopted for the exchange of high precision and high rate Earth tide data by the working group on High Precision Tidal Data Processing at its meeting in Bonn 1994 (comp. Jentzsch, 1995). This format was used in the tidal analysis. The recording of tidal gravity data started at the end of 2002 and is still going on. The feedback of the D–218 gravimeter returns the beam of the gravimeter to the reading line continuously, also after the occurrence of any earthquake. The changes in air pressure and temperature affect the quality of the recorded data. Besides, the data contain some gaps due to power failure. The raw data, with all noise and local perturbations, are shown in Fig. 3. The data contain, in general, a high drift of about 1,500 nm/s^2 per month in average. The high drift is probably due to the high noise level in the station, and the environmental effects. Because the station is located in a region of seismic activity, therefore, any seismic activity is clearly observed in the raw data. However, a period of two years (from 2003 to 2004) was selected for the tidal analysis, because in this period no big gaps in the data occurred and the noise in the raw data is not so high. Because of the response time of the feedback system there was no additional anti-aliasing filter.

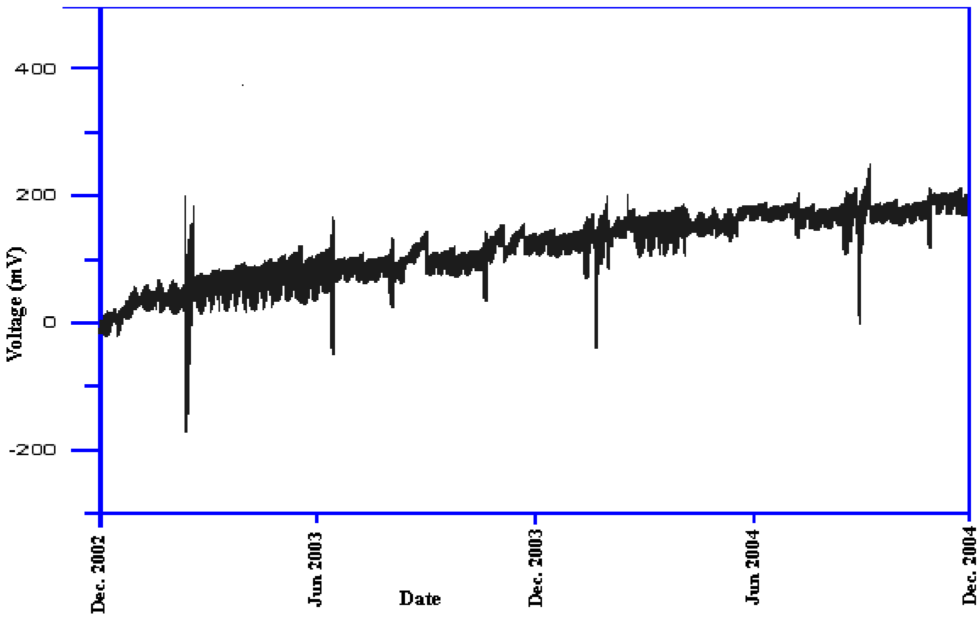

Figure 3: Raw data recorded by D-218 LaCoste & Romberg gravimeter at Aswan station during the period of study (from 2002 to 2004).

6. Analysis of Aswan Tidal Gravity data

The period of two years from October 2002 to December 2004 was selected for the tidal analysis. The analysis of data consisted of two main steps, the pre-processing and analysis. In the first step the 5 second data files for each day were combined into one single file per day, and then, all files were combined into one file. The data were numerically filtered and sampled at 1 min interval. Afterwards, the 1 min data were calibrated and de-tided (synthetic tidal gravity, computed using a-priori tidal parameters). Fig. 4 shows the synthetic tide gravity variation at Aswan station through the studied period. For the pre-processing of high rate Earth tide data the programs DECIMATE,

DETIDE, DESPIKE and PREGRED of Wenzel's package were used. The data pre-processing was carried out using a remove-restore technique. At first, all well-known signals were removed with program DETIDE. With program DESPIKE, the residual signal (the Earth tide sensor drift) was automatically cleaned (de-stepped, de-spiked, and de-gapped) and the known signals were added back to the cleaned residual signal. The interrupted data, such as earthquakes or micro-seismic waves, were deleted, gaps filled and steps corrected automatically. The corrected one minute samples were finally numerically filtered and decimated to 5 min sampling interval and again decimated to one hour sampling interval, using the program DECIMATE. The hourly samples have been used for tidal analysis. Fig.5 shows the pre-processed hourly samples of the recording period. It can be noticed that there is a non-linear drift in the observed hourly data, the linear drift being removed by the processing.
The analysis was carried out using the program ANALYZE of the ETERNA 3.3 package (Wenzel, 1996a, 1997), where the Hartmann and Wenzel (1995a, b) tidal potential catalogue was used. In addition a numerical digital high-pass filtering was applied in order to eliminate the long periodic drift of the instrument.

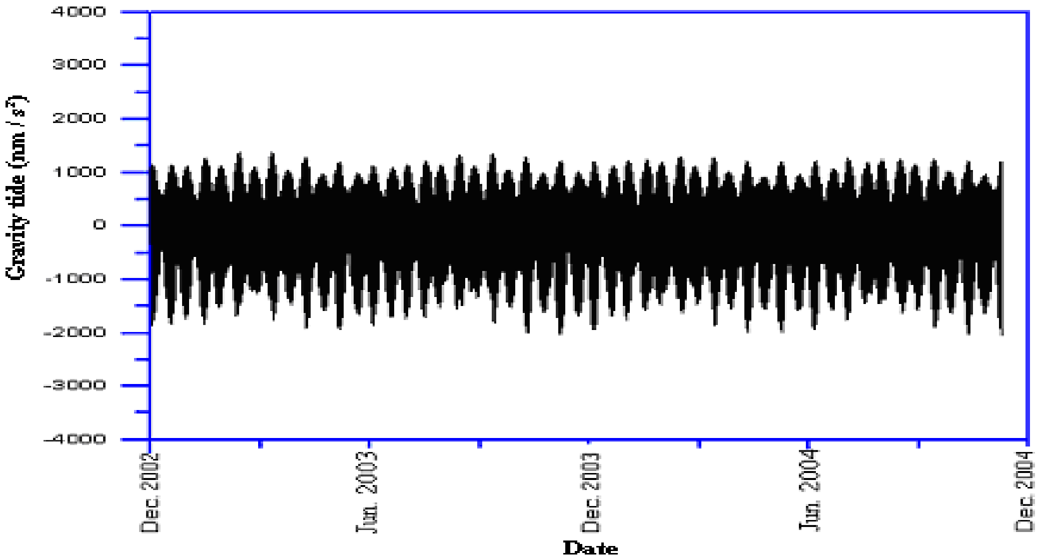

Figure 4: Synthetic tidal gravity for a rigid Earth model computed at Aswan station (from 2002 to 2004).

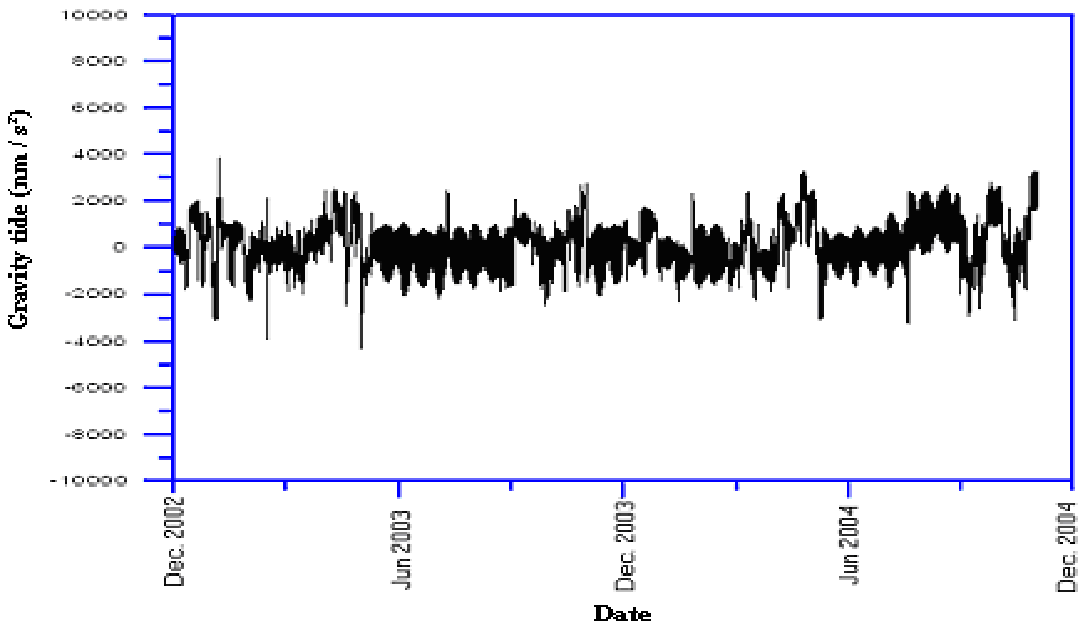

Figure 5: Pre-processed hourly data of gravity tide, observed at Aswan.

7. Results of Tidal Gravity Data

The adjusted tidal parameters, using ETERNA 3.3, are given in Tab. 1. It can be noticed from the table that most waves of the diurnal wave group show an amplification factor close to one and much less than the global amplification factor, i. e., 1.16. In contrary, most of the semidiurnal wave group amplification factors are close to the global value. Almost all wave groups have a phase shift close to zero. Generally, smaller standard deviations in the amplification factors are accompanied by small standard deviations in the phase shift, with smaller standard deviations in the semidiurnal band, especially for wave groups of large amplitudes as M2, both in amplification factor and phase shift.

The highest standard deviation has been obtained for K1 and S2, in phase shift. This could be due to the strong air pressure variation and the high solar variation in a tropic area like Aswan during the day. On the other hand, the high standard deviation of the phase shift may be due to an error in the quartz clock.

Table 1: Adjusted tidal parameters of Aswan tidal gravity station.

Wave	from (cpd)	to (cpd)	Amplitude nm / s^2	Amplif. factor	Stand. dev.	Phase shift (degree)	Stand. dev. (degree)
Mf	0.054748	0.501690	38.7448	1.0611	0.0152	0.536	0.378
Q1	0.501370	0.911390	41.8379	1.1070	0.0138	-0.187	0.089
O1	0.911391	0.947991	232.1882	1.1498	0.0115	-0.376	0.119
M1	0.947992	0.981854	5.2569	1.1601	0.0225	-0.724	0.853
K1	0.981855	1.880264	297.5135	0.9906	0.0395	-2.886	1.987
N2	1.880265	1.914128	72.5071	1.1620	0.0215	-1.136	1.158
M2	1.914129	1.950419	476.7849	1.1647	0.0102	2.065	0.023
S2	1.984283	2.451943	227.3244	1.0256	0.0410	2.809	2.854
M3	2.451944	7.000000	9.5189	1.1205	0.0342	0.312	1.538

8. Discussion of Tidal Analysis Results

Evaluation of the quality of observed tidal gravity data was conducted by comparing the observed with theoretical tidal parameters. Thus, the gravity tide parameters were calculated using synthetic tide gravity parameters (Zahran et al., 2005). The synthetic tidal parameters were estimated using the Dehant (1987) rigid Earth model and CSR3.0 ocean tide model (Eanes, 1994). The computations were carried out using the SPOTL-program (Agnew, 1996) at the coordinates of Aswan tidal station. The comparison between observed and predicted tidal parameters at Aswan station is shown in Tab. 2. The analysis of tidal gravity observations at Aswan tidal station shows discrepancies between the observed and synthetic tidal parameters. As can be seen from Tab. 2, there is a low agreement in K1and M3, whereas O1and M1 show a good agreement, and a better agreement in N2 and M2. It can be seen also from Tab. 2 that a very low agreement in phase shift is obtained in K1, N2, M3 and S2, whereas Mf, O1 and M1 show little agreement. A better agreement in phase shift can be only obtained in M2 and Q1. The high discrepancies cannot be related to ocean tidal loading, as the large distance between Aswan tidal station and the shore provides a very small ocean loading effect, only. However, these high discrepancies may be due to the variable loading of the lake level variation or the atmospheric loading, which were not considered during the analysis of data. The high phase standard deviations could be due to the error in quartz clock during recording the data.

Table 2: Comparison between observed and predicted tidal parameters at Aswan station.

Wave	Ampl. fact. (predicted)	Ampl. fact (observed)	Ampl. fact (discrepancies)	Pha. Shif. (predicted)	Pha. Shif. (observed)	Pha. Shif. (discrepancies)
Mf	1.1411	1.0611	0.0800	0.210	0.536	-0.033
Q1	1.1564	1.1070	0.0494	-0.247	-0.187	0.061
O1	1.1562	1.1498	0.0064	0.080	- 0.376	0.456
M1	1.1507	1.1601	-0.0194	0.343	0.724	-0.381
K1	1.1352	0.9906	0.1446	-0.207	-2.885	2.678
N2	1.1599	1.1620	-0.0021	2.543	-1.136	3.679
M2	1.1599	1.1647	-0.0048	2.033	2.065	-0.032
S2	1.1599	1.0256	0.1343	0.627	2.809	-2.182
M3	1.1019	1.1205	0.1414	1.700	0.312	1.388

9. Gravity Residuals and Conclusions

The tidal gravity residuals are given in Fig. 6. The residuals have a general range of about 300 nm/s². In some periods, this range reaches 500 nm/s², and in other periods reaches to 750 nm/s². Significant anomalies can be recognized in some periods in the residual gravity. There is a modulation in time, indicating that the tidal gravity factors are not stable, that can be associated to instrumental or environmental factors. The residual gravity signals observed at Aswan show seasonal periods. The amplitude spectrum of residual gravity is very important to prove if the tidal waves are completely separated or not. The ANALYZE program allows the computations of the Fourier amplitude spectrum of the residuals. The Fourier amplitude spectrum of the residuals can be seen in Fig. 7. It shows a noise level in the diurnal band of 16 nm/s² and in the semidiurnal band of 9 nm/s². The significant energy in the residual spectrum may be due to the timing problem of the quartz clock, and air pressure variation, which were not considered during registration and analysis. Besides, the high energy in the diurnal band may be due to the variation of water level in the lake.

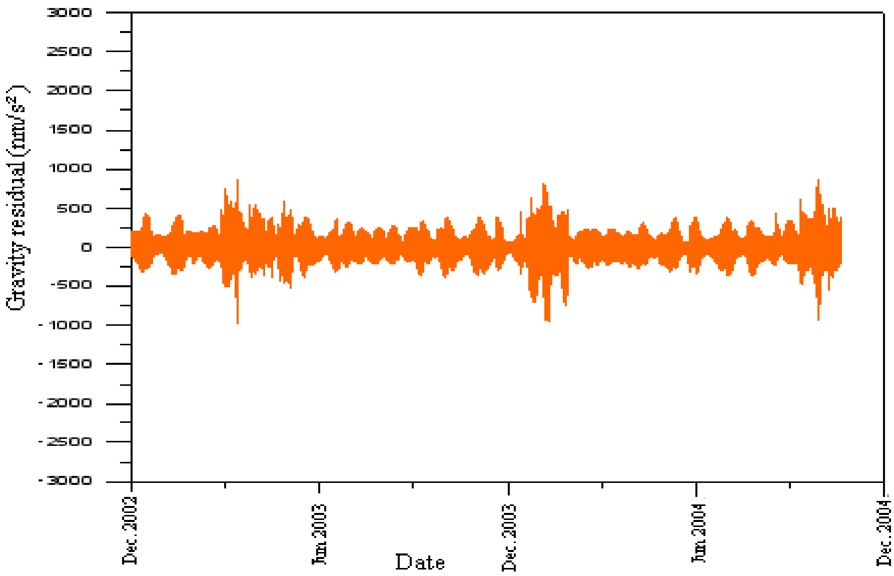

Figure 6: Residuals of gravity tides, observed with gravimeter D-218 at Aswan station (from 2002 to 2004).

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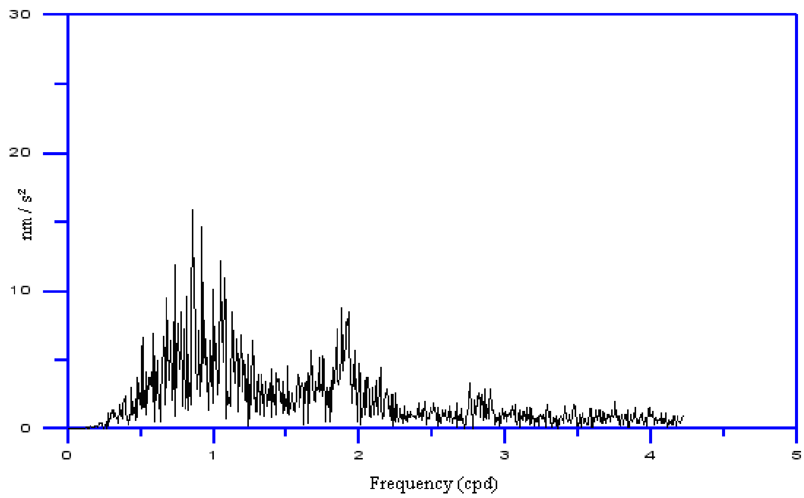

Figure 7: Fourier amplitude spectrum of residual gravity tide at Aswan station.

References

Agnew, D. C., 1996. SPOTL: Some programs for ocean - tide loading. Scripps Institution of Oceanography. SIO Reference Series 96-8.

Dehant, V., 1987. Tidal parameters for an inelastic Earth. PEPI, Vol. pp. 97-116.

Eanes, J., 1994. Diurnal and semidiurnal tides from TOPEX/POSEIDON altimetry (Abstract). Eos Trans. AGU, vol. 75(No. 16), Spring Meet. Suppl., 108p.

Hartmann, T. and Wenzel, H. G., 1995a. The HW95 tidal potential catalogue. Geophys. Res. Lett., vol. 22, pp. 3553-3556.

Hartmann, T. and Wenzel, H. G., 1995b. Catalogue HW95 of the tidal potential Bull. Inf. Marèes Terrestres, vol. 123, pp. 9278-9301.
Hassan, R. M., 2007. Tidal gravity observations at Nasser Lake area, Aswan, Egypt. Dissertation, Geophysics Department, Faculty of Science, Cairo University, 147 pp**.**
Jentzsch, G., 1995. Report of the Working Group on 'High Precision Tidal Data Processing'. Proc. 12th Int. Symp. Earth Tides, Beijing, August 1993, Science Press, Beijing, 1924.
Jentzsch, G. and Koß, S., 1997. Interpretation of long-period tilt records at Blå Sjø, Southern Norway, with respect to the variations of the lake level. Phys. Chem. Earth, vol. 22, pp. 25 – 31.
Weise, A., Jentzsch, G., Kiviniemi, A. and Kääriäinen, J., 1999. Comparison of long period tilt measurements: Results from the two clinomatic stations Metsähovi and Lohjia / Finland. J. of Geodynamics, vol. 27, pp. 237 – 257.
Wenzel, H. G., 1994. PRETERNA a preprocessor for digitally recorded tidal data. Bull. d'Inf. Marèes Terr., vol. 118, pp. 8722 – 8734.
Wenzel, H. G., 1996a. The nanogals software: Earth tide data processing package ETERNA 3.30. Bulletin d'Inf. Marèes Terr., vol. 124, pp. 9425 9439.
Wenzel, H. G., 1997. Analysis of the Earth tide observations In: Wilhelm, H.,W. Zürn and H. -G. Wenzel (Eds),Tidal Phenomena. Lecture Notes in Earth Sciences, Springer Verlag, Berlin, Germany, pp. 59-75.
Zahran, K. H., Jentzsch, G. and Seeber, G., 2005. World – wide synthetic tide parameters for gravity and vertical and horizontal displacements. J. Geod., vol. 79, pp. 293-299.
Zahran, K. H., 2005. Benefit of tidal observations to gravity and GPS networks. Egyptian Geophys. Soc. Journal, vol. 3, No. 1, pp 89-98.