Gravity Monitoring with a Superconducting Gravimeter in Vienna

Bruno Meurers
Institute of Meteorology and Geophysics, University of Vienna
Central Institute of Meteorology and Geodynamics, Vienna

Introduction

Since August 1995 the superconducting gravimeter GWR C025 is operating in the seismic laboratory of the Central Institute of Meteorology and Geodynamics in Vienna (Austria). The laboratory is situated in the basement of the institute's main building where a concrete pillar is founded deeply in Alluvial sediments. The main goal of research is the determination of both tidal and non-tidal gravity variations by combining continuous records with repeated absolute gravity measurements. The latter will be performed by using an upgraded Jila-g type absolute gravimeter. All these investigations will contribute to the Global Geodynamics Project (GGP) started in July 1997.

The SG gravimeter has been set up at a preliminary site and will be moved to its final position at the new Conrad Observatory that will be constructed 60 km SE of Vienna next year. This station is far away from sources of industrial noise in contrast to the actual site which is situated at the margin of Vienna. Nevertheless, the results obtained from a 2 years' observation are of high quality. The instrument exhibits a linear and very small drift of about 30 nms^{-2}/a only. Therefore, it is especially suited to monitor non-periodic and long period gravity variations.

The data acquisition is carried out with CSGI software (Dunn 1995) running on a PC with a QNX operating system. All data samples are triggered by a GPS time signal. The high resolution gravity output channel (HR-GRAV) is read by a HP3457A digital multimeter with 1 Hz sampling rate. The air pressure signal is sampled with 0.1 Hz by a Keithley 2000 digital scanner that also monitors in one minute intervals additional instrumental and environmental parameters like the tide filter output signal, two tilt signals, the neck temperatures at the 11 K and 70 K stage, the room and electronics temperature and the liquid Helium flow rate. Since September 1997 a new gravity card (Warburton 1997) is operating that meets the GGP requirements.

Calibration

The initial calibration has been performed by comparing the filtered gravimeter signal with the synthetic earth tide model of Timmen and Wenzel (1995) including the ocean effects. In 1996 the instrument has been calibrated by comparison with absolute gravity measurements performed by Jila g-6 (Figure 1). The absolute gravity has been observed during 2.5 days. After elimination of outliers, about 9000 single drops could be used for the linear regression analysis. Unfortunately the drop to drop scatter is rather high at the station in Vienna which limits the calibration accuracy. In addition, the observation period is probably too short to get more accurate results (Hinderer et al. 1997, Francis 1997), but further calibrations could not be performed till now because of remaining instrumental problems after servicing and an absolute gravimeter's upgrade. Of course calibrations will be repeated regularly in future.

The initial calibration factor turns out to be correct within the error band, but because of the high seismic noise level the accuracy is not better than 0.7%. Additionally the calibration factor is confirmed by comparing tidal analysis results with those obtained at the same station in 1986 (Figure 2) by analyzing a 6 months observation period of LaCoste-Romberg D-9 (Meurers 1987) equipped with an electronic feedback system SRW-D (Schnüll et al. 1984). The feedback has been calibrated at the precise vertical calibration line in Hannover (Kanngieser et al. 1983). In order to check the temporal stability of the SG's calibration factor several successive and non-overlapping data sets covering a 83 day interval have been investigated. The instrumental time lag being changed since installation of the new gravity circuit card has been considered accordingly. Figure 3 shows the adjusted tidal parameters for the main tidal waves O_1 and M_2. The standard deviation of the amplitude factors amounts for both components 0.0002 only.

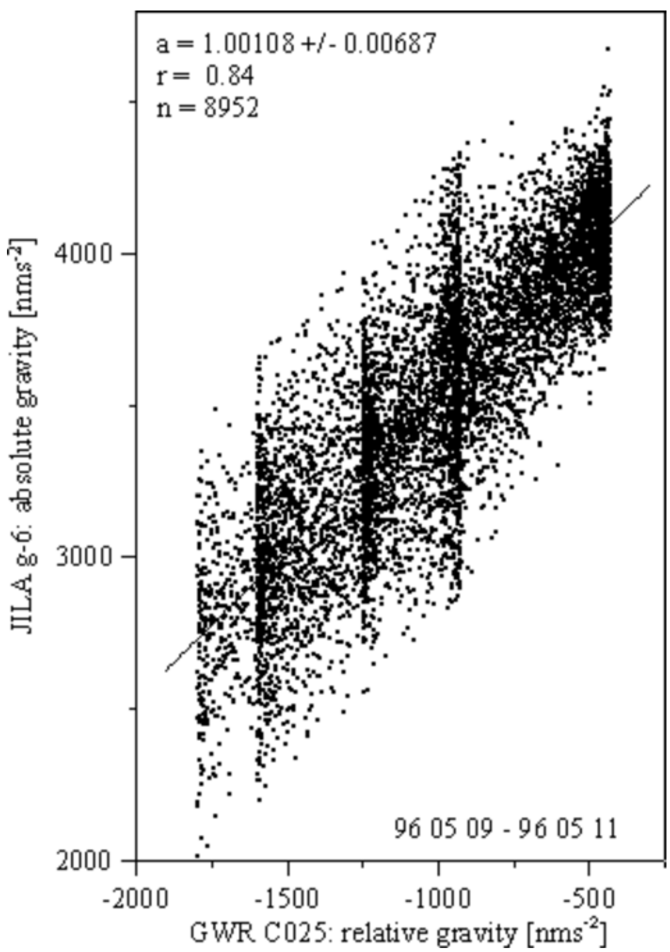

Fig. 1: Linear regression analysis of absolute gravity data (Jila g-6) and relative gravity obtained from GWR C025 (a = regression coefficient, r = correlation coefficient, n = number of samples).

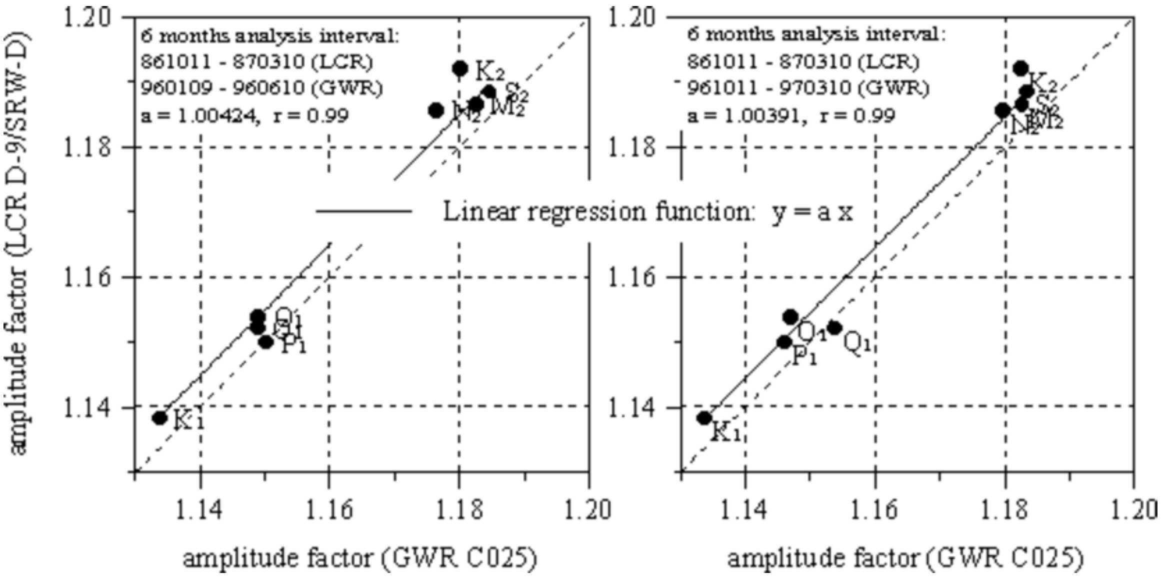

Fig. 2: Comparison of tidal parameters obtained by analyzing 6 months' observation periods from data of LCR D-9 (equipped with electronic feedback system SRW-D) and GWR C025. The regression analysis (a = regression coefficient, r = correlation coefficient) yields same results for independent GWR time series proving the time stability of the calibration factor.

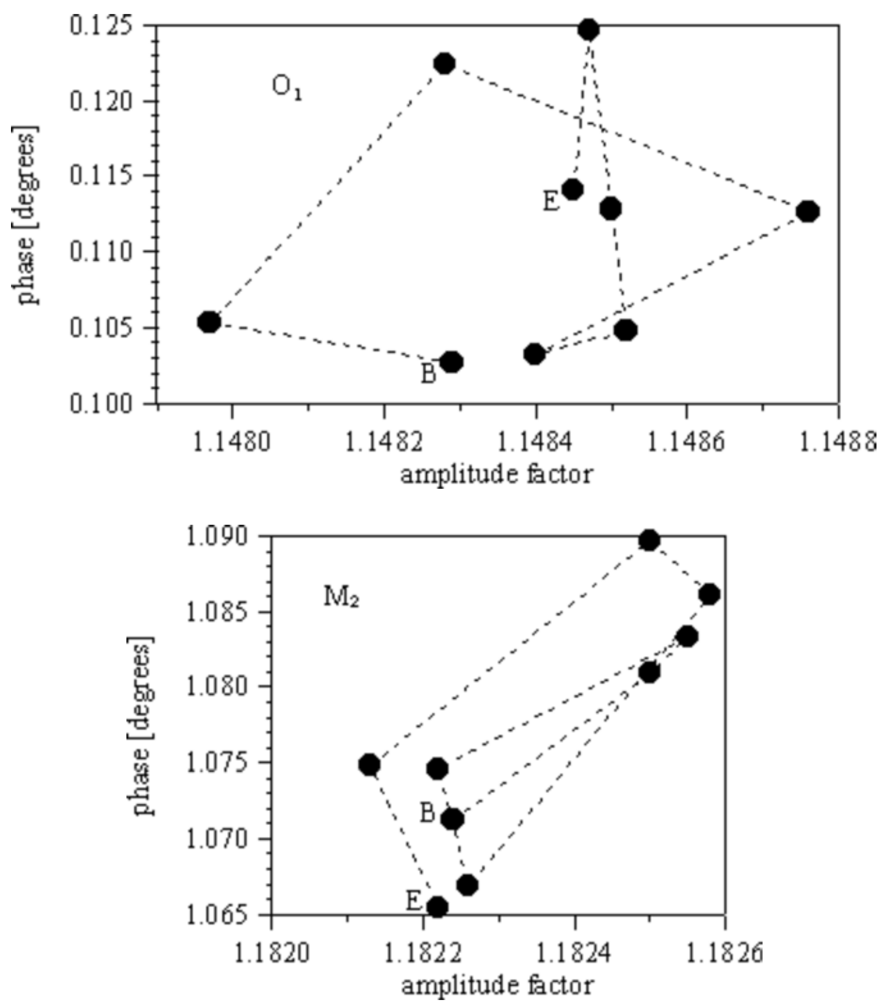

Fig. 3: Tidal parameters (O_1 and M_2) obtained by analyzing successive non-overlapping intervals of 83 days each. B: first observation period, E: last interval, the only one with the new gravity card installed.

Frequency transfer function

During the installation of the new gravity circuit card in September 1997 the frequency transfer function of the complete recording system has been determined for both the original and the new gravity card by applying the step response method. The step response data have been analyzed by Wenzel's (1994) program ETSTEP using discrete Fourier transform of their time derivative.

Because of the improved filter characteristics of the new card the results are much more sensitive to the microseismic noise than those of the old gravity card. This is a severe problem at noisy stations like Vienna. In order to reduce the random noise contribution the data of up to 10 single steps have been averaged after detiding. Figure 4 shows the differentiated step response functions of about ten single steps and their average for two experiments performed with the old and the new card respectively. Averaging is obviously effective. However, small amplitude disturbances still remain in the case of the new card. Therefore the desired accuracy of 10 ms could not be obtained because of the high noise level at the station in Vienna. Table 1 compares the results of time lag determination and the errors within the tidal band. The statistical evaluation was done in two different ways. First a mean time lag has been calculated using the results from all single steps in upward and downward direction respectively. Afterwards the averaged step response data has been analyzed separately for each step direction. Table 1 shows that the final average values of the time lag do not depend on the evaluation method. The transfer function seems to be well determined which is confirmed by the tidal analysis results. Both the amplitude factors and phases did not change significantly since the new gravity card has been installed. This is shown in Figure 3 where the symbol E marks the results obtained with the new configuration.

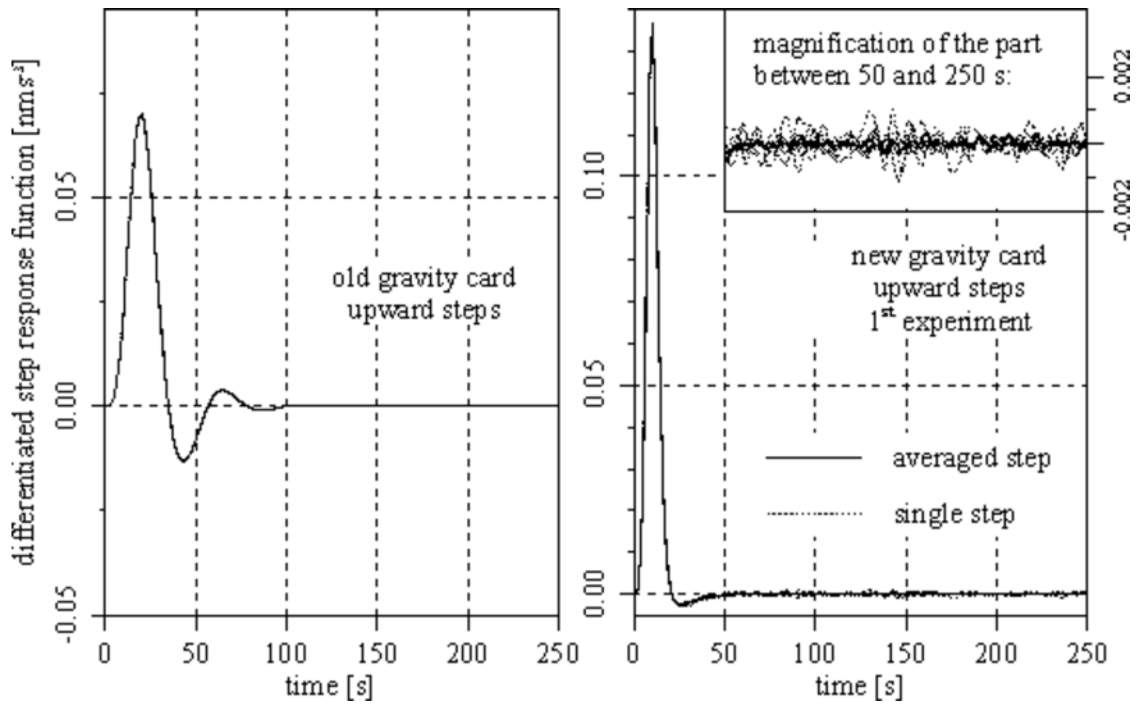

Fig. 4: Step response of the recording system with the old (left) and the new (right) gravity circuit card. Small disturbances remain after averaging the step response data in case of the new card (see details at the top of the graph).

old gravity card					mean
step direction	upward	downward			
number of single steps	10	10			
single step statistics: average standard deviation mean error	 17.005 ± 0.041 ± 0.013	 16.994 ± 0.039 ± 0.012			 16.999 ± 0.039 ± 0.009
averaged steps standard deviation	17.005	16.999			17.002 ± 0.004
new gravity card					**mean**
step direction	upward	downward	upward	downward	
number of single steps	10	9	9	10	
single step statistics: average standard deviation mean error	 9.401 ± 0.102 ± 0.032	 9.374 ± 0.204 ± 0.068	 9.366 ± 0.081 ± 0.027	 9.267 ± 0.034 ± 0.010	 9.349 ± 0.126 ± 0.020
averaged steps standard deviation	9.402	9.374	9.366	9.255	9.349 ± 0.065

Tab. 1 : Time lag [s] of the recording in the tidal band

Tidal analysis and residual determination

Preprocessing and tidal analysis of the raw data sampled with 1s interval has been performed by applying the ETERNA v3.3 software package of Wenzel (1996) and the programming module GSOFT of Vauterin (1997). Only a few big disturbances caused by earthquakes had to be removed manually. Also, two manual offset corrections were necessary in order to remove two steps caused by a power supply interruption (190 nms^{-2}) and the exchange of the gravity card (-16 nms^{-2}) respectively. These step corrections have been determined precisely by adjusting low degree polynomials to small portions of the raw data separately for both sides of the step. Further, despiking and destepping has been performed automatically applying thresholds of 2 and 5 nms^{-2} respectively for spike and step detection. Intensive test calculations with different despiking and destepping limits show adjusted tidal parameter to be almost independent on the thresholds applied. This justifies the application of automatic preprocessing. Within the more than 2 years long observation period only three small steps (< 40 nms^{-2}) have been removed by this automatic procedure.

Table 2 summarizes the analysis results based on the Tamura (1987) tidal potential. The noise estimate of the amplitude spectrum is less than 0.03 nms^{-2} in the diurnal and less than 0.02 nms^{-2} in the semidiurnal band. The pressure admittance factor results to -3.538±0.005 nms^{-2}/hPa.

The procedure of residual calculation starts with subtraction of the tidal effect from the hourly data applying the same tidal parameters and the same model as obtained by and adopted for tidal analysis. For these computations the tidal prediction program supplied by the ETERNA package has been used. The air pressure effect is removed using the admittance factor mentioned above.

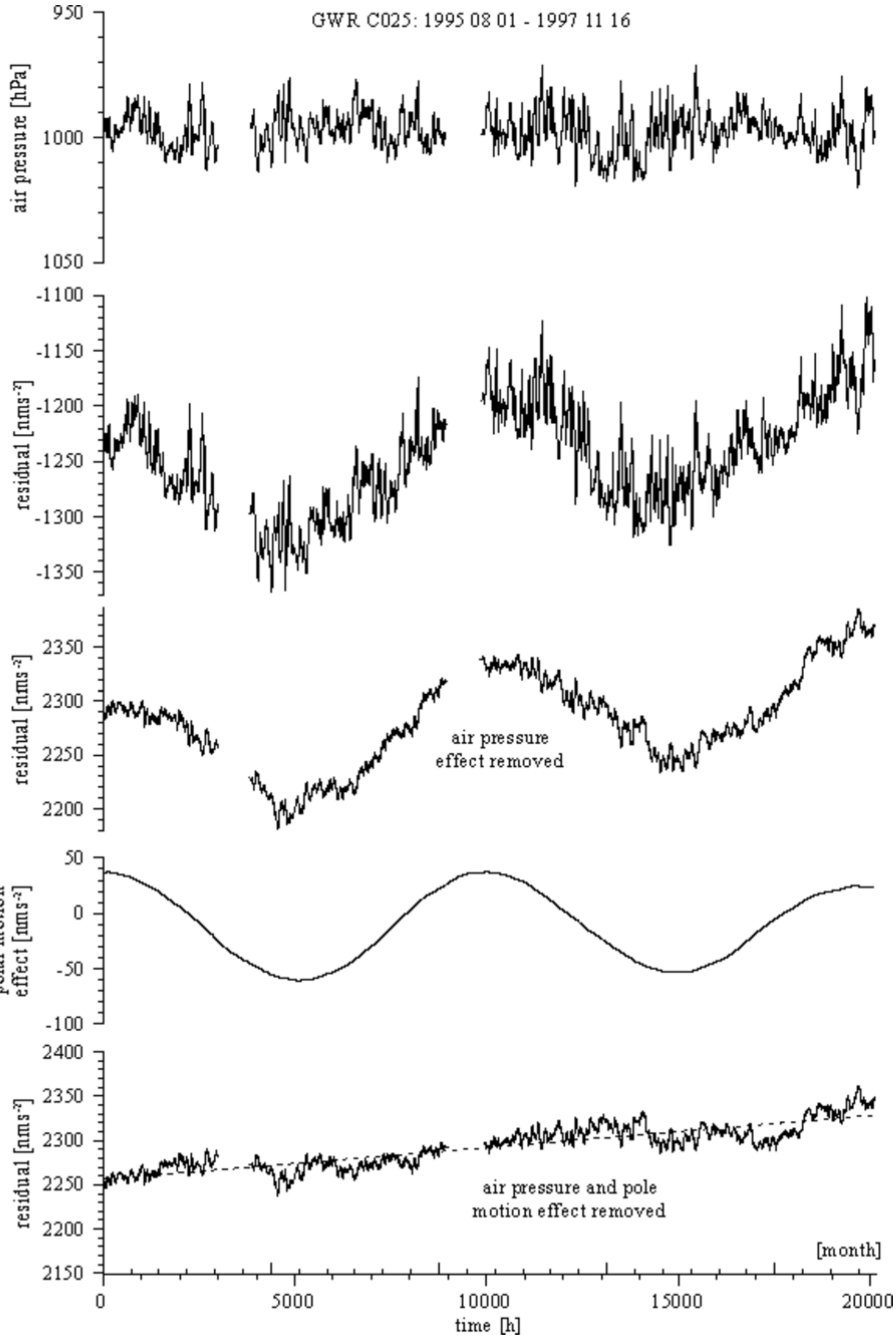

Fig. 5: Residuals after subtracting the gravity effect of the adjusted tidal model, the air pressure contribution assuming a frequency independent admittance factor and the pole motion effect.

The final residuals result from removing the pole motion effect based on IERS data calculated without taking an amplitude factor into account. The residuals are characterized by a very small and linear drift of about 30 nms^{-2}/a. Even immediately after instrumental set up there is no exponential drift behavior. Figure 5 demonstrates the different steps and the result of residual calculation.

The residuals are clearly correlated with the air pressure because of the dependency of the pressure admittance function on frequency. Figure 6 presents in more detail the hourly residuals after removing a linear drift and the air pressure effect calculated with the frequency independent pressure admittance factor derived from tidal analysis. A distinct anti-correlation can be observed proving the assumed admittance factor to be too high in the frequency range below 1 cpd. This anti-correlation is clearly visible also in the long period components fitted by high degree polynomials. A frequency dependent pressure admittance function (Figure 7) has been calculated by applying standard methods (e.g. Neumeyer and Pflug 1997).

wave group	amplitude [nms^{-2}]	amplitude factor	standard deviation	phase lead [deg]	standard deviation
Q1	67.6720	1.14498	0.00027	−0.1121	0.0134
O1	354.5094	1.14842	0.00005	+0.1121	0.0027
M1	28.0418	1.15505	0.00055	+0.1028	0.0275
P1	164.7970	1.14733	0.00010	+0.1462	0.0051
S1	3.7412	1.10145	0.00611	+9.5364	0.3163
K1	492.4439	1.13429	0.00004	+0.1927	0.0019
PSI1	4.3145	1.27027	0.00433	+0.9492	0.1952
PHI1	7.2635	1.17492	0.00234	+0.0098	0.1141
J1	28.0220	1.15427	0.00073	+0.0536	0.0362
OO1	15.2927	1.15124	0.00170	+0.2662	0.0845
2N2	11.8813	1.16629	0.00060	+1.8057	0.0297
N2	75.2188	1.17914	0.00012	+1.5424	0.0060
M2	393.9436	1.18236	0.00002	+1.0775	0.0011
L2	11.0831	1.17686	0.00057	+0.2576	0.0278
S2	182.8325	1.17945	0.00005	+0.0879	0.0026
K2	49.7444	1.18044	0.00024	+0.2992	0.0117
M3M6	4.6693	1.07046	0.00084	+0.1563	0.0450

Tab. 2: Tidal parameters obtained by analyzing the GWR C025 data between 1995 08 01 and 1997 11 16.

Performance control

The performance of the SG gravimeter was permanently controlled by monitoring some additional instrumental and environmental parameters like the electronics and room temperature, the temperatures at the 11 K and 70 K stages and the liquid Helium loss rate. The corresponding time series were compared with the hourly residuals in order to detect instrumental effects in the gravity signal. No significant correlation could be found.

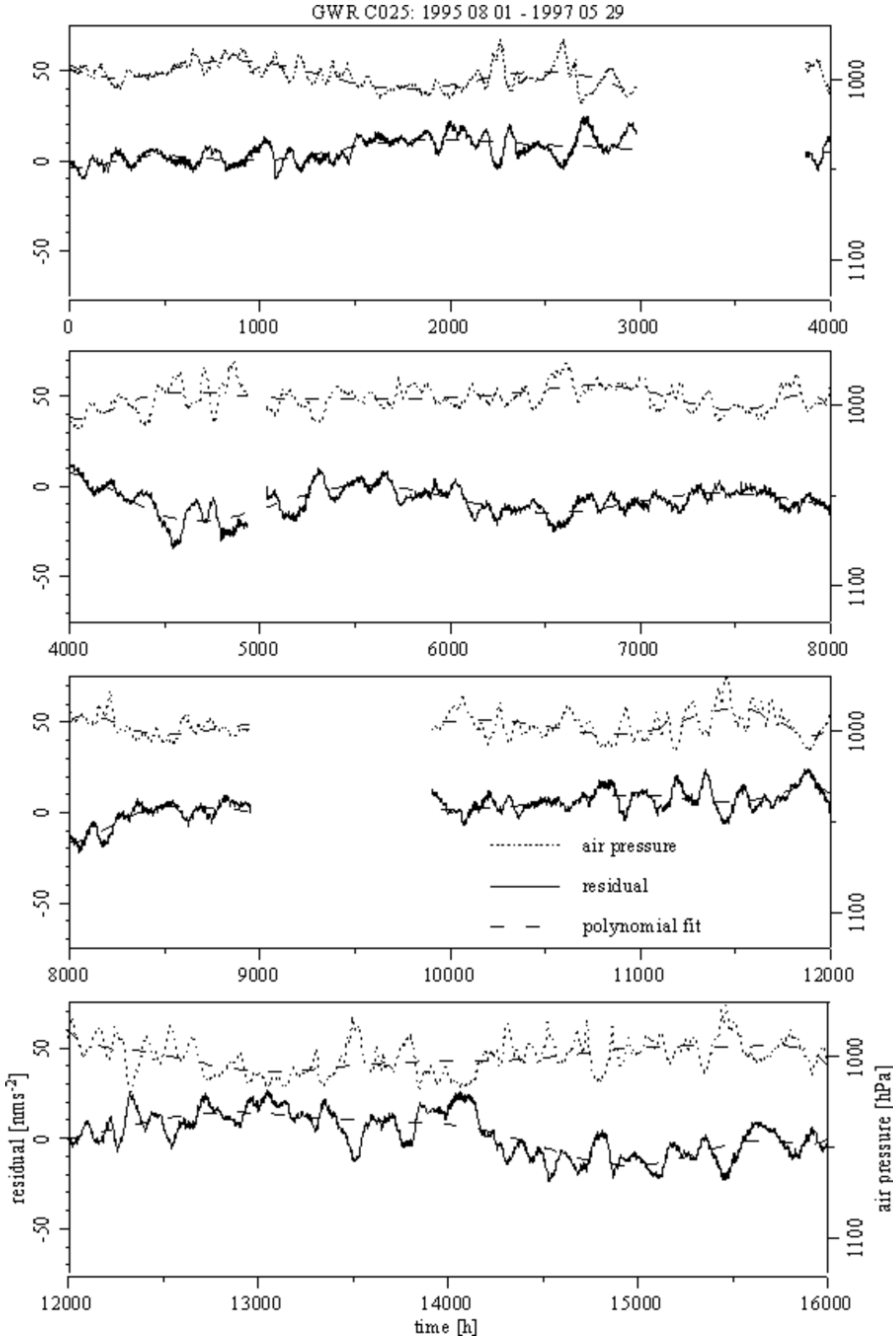

Fig. 6: Comparison of the trend reduced residuals with the observed air pressure showing the frequency dependency of the air pressure admittance function. Air pressure and residuals are distinctly anti-correlated in the frequency band < 1 cpd.

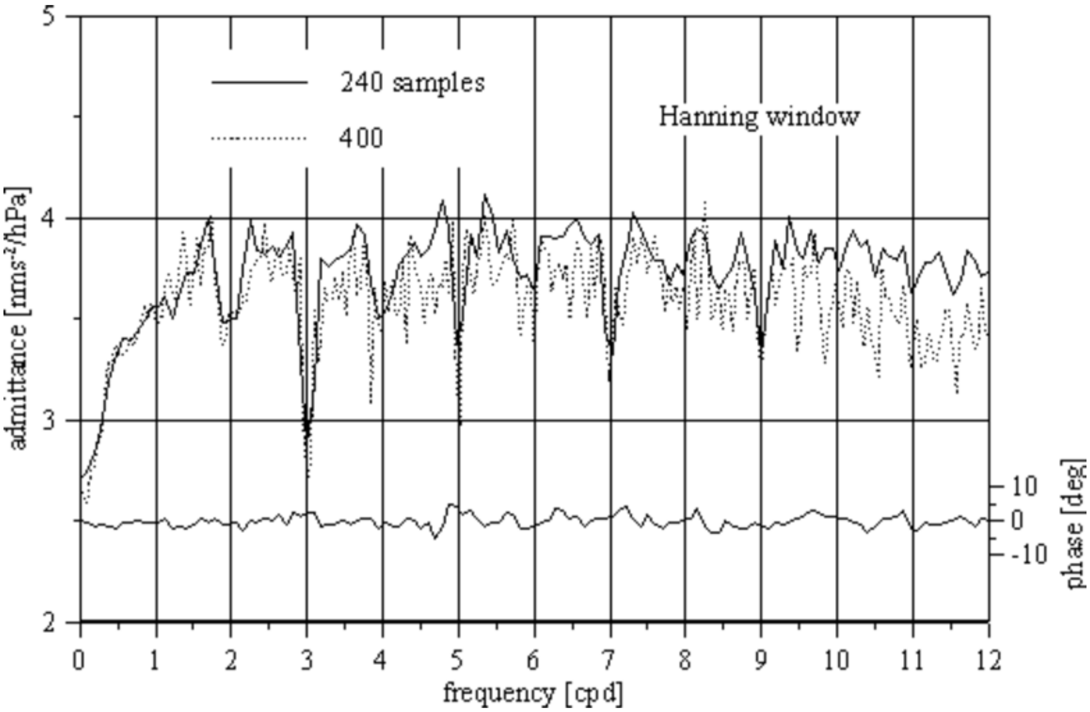

Fig. 7: Air pressure admittance function obtained by averaging over the whole observation period. The method of Neumeyer and Pflug (1997) has been applied.

Additionally the differences between the signals of the GWR air pressure sensor and an external high quality sensor implemented in a semi-automatic climate monitoring station (TAWES) at the site in Vienna have been investigated. A distinct correlation with the room temperature could be observed proving the GWR air pressure sensor being not accurate and stable enough. The differences are of the order of 1-2 hPa. These instabilities consequently introduce errors of about 3-6 nms^{-2} when removing the air pressure effect for residual determination.

Conclusion

The GWR C025 superconducting gravimeter has proven to be an excellent instrument for monitoring tidal and non-tidal gravity variations. The drift behavior is almost linear with a small drift rate of 30 nms^{-2}. Analyzing successive and independent time series of about 3 month period shows the high temporal stability of the instrument. The residuals can be explained mainly by air pressure effects that remain when a frequency independent admittance factor obtained from tidal analysis is applied for air pressure correction. In spite of the high noise level at the station in Vienna the frequency transfer function of the complete recording system could be determined successfully by the step response method for both the original and the new gravity card recommended for GGP. The interpretation of non tidal phenomena will be supported by combining the continuous record with regularly performed absolute gravity measurements.

References

Dunn, B., 1995: CSGI software reference manual. Dept. Earth Sciences, University of Western Ontario, Canada.

Francis, O., 1997: Calibration of the C021 superconducting gravimeter in Membach (Belgium) using absolute gravity measurements. 13th International Symposium on Earth Tides, Brussels.

Hinderer, J., Amalvict, M., Francis, O. and Maekinen, J., 1997: On the calibration of superconducting gravimeters with the help of absolute gravimeters. 13th International Symposium on Earth Tides, Brussels.

Kanngieser, E., Kummer, K., Torge, W. and Wenzel, H.G., 1983: Das Gravimeter-Eichsystem Hannover. Wiss. Arb. Fachrichtung Vermessungswesen, Univ. Hannover, 120.

Meurers, B., 1987: Comparison of Earth Tide Observations in Vienna. Bulletin d'Informations Mareés Terrestres, 100, 6942-6953.

Neumeyer, J. and Pflug, H., 1997: ADMITT - a program for determination of the atmospheric pressure admittance. Bulletin d'Informations Mareés Terrestres, 127, 9851-9855.

Schnüll, M., R.H. Röder and H.-G. Wenzel, 1984: An improved electronic feedback for LaCoste-Romberg gravity meters. BGI, Bulletin d'Information, 55, 27-36.

Tamura, Y., 1987: A harmonic development of the tide-generating potential. Bulletin d'Informations Mareés Terrestres, 99, 6813-6855.

Timmen, L. and Wenzel, H.G., 1995: Worldwide synthetic gravity tide parameters. In: Sünkel, H., Marson, I., (eds): Gravity and Geoid. IAG Symposium 113, Springer Verlag, 92-101.

Vauterin, P., 1997: Graphical interactive software for the analysis of earth tide information. 13th International Symposium on Earth Tides, Brussels.

Warburton, R., 1997: GWR developments. 1st GGP Workshop, 21 July 1997, Brussels.

Wenzel, H.-G., 1994: Accurate instrumental phase lag determination for feedback gravimeters. Bulletin d'Informations, Marees Terrestres, 118, 8735-8752.

Wenzel, H.-G., 1996: The nanogal software: Earth tide data processing package ETERNA 3.30. Bulletin d'Informations Mareés Terrestres, vol. 124, 9425-9439.

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