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Polar Motion Influences in the Gravity Data Recorded by Superconducting Gravimeters

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Abstract

Gravity data stored in the GGP database (GGP-ISDC) are used to study the small gravity variations caused by polar motion. In a first step the dominant tidal signal and the instrumental drift have to be eliminated from the gravity data. In most cases it is sufficient to model the instrumental drift by polynomials of low degree. The resulting non-tidal gravity variations are split up into their main constituents by fitting two sinusoidal waves with periods of 365.25 days (Annual Wobble) and 432 days (Chandler Wobble). In a similar way the gravity effect of the observed polar motion (IERS-Data) is processed. The ratio between the correspondent amplitudes gives the amplitude factors δ of both wobbles.

In a more sophisticated model an additional annual wave was included, destined to absorb disturbing influences with annual period (e.g. environmental influences of different origin). The amount of these influences and the success of their elimination are very different at the individual stations.

Besides the comparison of the amplitude factors it also was tried to compare the gravity residuals itself. For that purpose the data series recorded at the different stations were transferred to a common reference point (0° E, 45° N). The graph of the stacked data series gives a first impression of the accordance of the data series recorded at the different stations. Since randomly distributed disturbing influences are reduced by the averaging the amplitude factors derived from the mean of the stacked data series are more reliable than the values derived from the data at the individual stations.

In the end 12 data series were included in a common processing. Amplitude factors of 1.183 for the annual and 1.168 for the Chandler wobble result with mean errors less than ± 0.010 (roughly estimated). Although corrections for environmental influences were not included directly, the additionally fitted annual wave reduced the scatter of the amplitude factors in the annual range considerably. In contrast to that the amplitude factor of the Chandler wobble remains nearly unaffected, confirming the assumption that the disturbing environmental influences do not extend into the period range of the Chandler wobble.

Keywords

Superconducting gravimeter; Global Geodynamics Project (GGP); Polar motion; Estimation of parameters; Worldwide stacking

1. Introduction

Superconducting gravimeters are characterized first of all by high sensitivity, low drift and stable calibration. Therefore among others they are especially suited for studies with concern to the global gravity field and its long-term variations (e.g. gravity effect of polar motion). With the intention to benefit from the superb quality of the SG in 1997 the GGP started as a loose cooperation of institutions around the world which operate superconducting gravimeters.

The data in the GGP-data bank (GGP-ISDC) grow continuously. This is the reason why several studies with similar topics are repeated from time to time (Harnisch et al., 1998; Loyer et al., 1999; Boy et al., 2000; Harnisch and Harnisch, 2001; Xu et al., 2004; Ducarme et al., 2006; Harnisch and Harnisch, 2006a). Meantime in the GGP-ISDC gravity data series of more than 10 years are available. From the beginning also auxiliary data, first of all the local groundwater level and precipitation data can be stored in the GGP data bank. However,

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in reality auxiliary data are available not at all stations and not for the complete period of the corresponding gravity data.

In the present study altogether 14 series of gravity data were processed, among them both systems of the three dual sphere gravimeters at Bad Homburg, Moxa and Sutherland. Due to the lack of sufficient auxiliary data and with the aim to get a dataset as homogeneous as possible, the processing was performed completely without additional information on environmental influences. In order to compensate the missing environmental data in the period range of one year an additional annual wave was included destined to absorb as much as possible disturbing influences. In addition a joint consideration of all gravimeters distributed more or less all over the Earth was tried. To this aim all data series were condensed to an averaged dataset, valid at the fictive reference point 45°N, 0°E. Environmental and other disturbing influences on this dataset should be minimized as far as they are randomly distributed. Nevertheless in the future it should be tried to eliminate not only local but also regional disturbing influences directly by adequate corrections as far as possible.

2. Data and Data Processing

All gravity data as well as some additional information used in the present study are downloaded from the GGP-ISDC¹. With concern to the gravity uncorrected minute data were preferred so far as available. The use of corrected minute data is limited to some greater gaps in the data series of Medicina.

Log-files with information about the behavior and the maintenance of the instruments may be helpful during the preprocessing and for the determination of the drift. Unfortunately log-files are not available in all cases and - if they are - often just the crucial events are not listed.

Also some environmental data, e.g. local groundwater or precipitation may be found in the category "auxiliary data", but not for all stations and not for the whole period of the gravity data series. Therefore and with regard to the principle to handle all data series in the same manner corrections of environmental influences have not been applied.

Altogether the complete data series from 11 gravimeters at 11 different stations were processed, among them those of both systems of the three dual sphere gravimeters at Bad Homburg (BH), Moxa (MO) and Sutherland (SU). The involved stations are listed in Table 1, column 1.

The own processing of the uncorrected minute data aims at a detailed overview over the different corrections, esp. the step corrections and their influence on the long-term drift. The preprocessing and the tidal analysis were done with the ETERNA 3.30 package (author H.-G. Wenzel), completed by some additional programs (e. g. for the correction of steps). As a basic rule of the preprocessing for long-term purposes the drift of the data series has to be maintained as far as possible and not to be falsified (e.g. by improper adaptive drift algorithms, false step corrections).

For the tidal analysis the program ANALYZE (author H.-G. Wenzel) was used together with a tidal model with 23 wave groups up to Sa. Besides the local air pressure the gravity effect of the polar motion was included into the tidal analysis as a second additional channel. In this way the polar motion should not affect the estimation of the tidal parameters in the long-periodic range. Moreover the tidal parameters of Sa and Ssa resulting from the tidal analysis may be falsified by environmental influences. Therefore they were replaced by the theoretical values $\delta = 1.16$ and $\kappa = 0$ to avoid an overcompensation in the long-periodic range. In the short-periodic range the tidal parameters include also the ocean tidal effects in this period range. Using the set of tidal parameters and the admittance factor of the local air pressure resulting in this way the tides and the gravity effect of the air pressure were removed from the recorded gravity data. The resulting non-tidal residual gravity should contain the full information on the polar motion.

¹ <http://ggp.gfz-potsdam.de/>, <http://isdc.gfz-potsdam.de/>, <http://www.eas.slu.edu/GGP/ggphome.html>

3. Drift Elimination

Thanks to the high stability of the superconducting gravimeters in the majority of cases the instrumental drift may be modeled by polynomials of low degree, i.e. by a straight line or a parabola of second degree. In principle absolute gravity measurements could support the drift estimation and the proof of their reliability. However, up to now only few absolute gravity data are available for this purpose. With regard to the different accuracies of the absolute and the superconducting gravimeters already in the normal case frequently repeated absolute measurements would be required for a successful and reliable estimation of the drift. This is valid all the more when the drift of the gravimeter is nonlinear and disturbed.

Fig. 1a.

There are two other methods to estimate and eliminate the drift of a gravimeter, especially if the drift is very anomalous. The moving mean is a highly adaptive procedure. However, if long-term phenomena have to be preserved, a sufficient long averaging period has to be chosen (clearly longer than e.g. the period of the Chandler wobble) and according to this the data series is shortened at both ends. In other cases (e.g. data series from the lower system of the gravimeter GWR CD030 at Bad Homburg) the only way may be to split up the data series in several sections and to approximate the drift in each of these sections by simple polynomials. But once more it has to be pointed out that the more complex the drift model the less reliable is the estimation and elimination of the instrumental drift. In extreme situations it can be necessary to reject the whole data set.

As an example of moderate long-term linear drift Fig. 1a shows the drift behavior of the gravimeter GWR C031 at Canberra during the ten years from 1997 to 2007. As a contrasting example the gravimeter GWR C026 at Strasbourg is characterized by a clear nonlinear drift (Fig. 1b). While for the data series of the GWR C031 at Canberra a linear drift model may be used, the gravimeter GWR C026 at Strasbourg needs a more flexible drift approximation e.g. a polynomial of 5th degree. For the data series of the GWR C026 also a low pass filtering with the moving mean was tried (operator length 750 days). The result is very similar to the fit of a polynomial of 5th degree. The difference between both methods is less than 10 nm s^{-2} , but the low pass filtered data series is shortened by 375 days at each end.

4. Linear Regression

The simplest way to estimate the amplitude factor for the influence of polar motion on the recorded gravity data is a linear regression between the respective data series of both effects. The regression coefficient represents the amplitude factor of the total effect of polar motion; a separation of the both main constituents is not possible in this way.

The amplitude factors resulting for the different stations scatter considerably. Numerical values are given in Table 1, column 3. Any dependency on the geographical position of the respective station cannot be recognized. First of all the differences depend on the local conditions around the gravimeter, esp. on the environmental influences which in the current processing are neglected up to now. Also type and operation time of the gravimeter and the state of its maintenance may influence the quality of the results. The weighted mean over the 14 data sets yields $\delta(\text{total}) = 1.13 \pm 0.05$.

Fig. 1b.

5. Separation of the Annual and the Chandler Wobble

Ducarme et al. (2006) published a spectrum of the y-component of the polar motion which is based on a data set, covering the period from 1899.7 to 1992.0 (Vondrak et al., 1998). In this spectrum clearly are to be recognized the narrow peak around 365.25 days (annual wobble)

and the more extended spectral band around 435 days (Chandler wobble). Jochmann (2003) discusses possible variations of the Chandler period with the result that the order of magnitude of such variations is below the detection limit defined by the length of the data series presently available. Variations of the Chandler period found out at times probably should be misunderstood phase variations in the excitation mechanism of the Chandler wobble.

With respect to these few remarks concerning the frequency of the Chandler wobble and its stability two sinusoidal waves with periods of 365.25 and 432 days were fit to the non-tidal drift-free gravity residuals derived from the gravity series (GGP-Data). In the same manner also the gravity variations derived theoretically from the astronomically observed polar motion are treated (IERS-Data²). Very carefully it has to be considered that both data series included in the common processing extend exactly over the same time span. The ratio of the amplitudes of the respective sinusoidal functions yields the amplitude factors which describe the elastic behavior of the Earth in the period range of the annual and the Chandler wobble.

An essential constraint of this very simple model is the fact that it is not possible to discern between contributions coming from environmental influences in the annual range and the annual wobble of the polar motion to be studied. Therefore the results with concern to the annual wobble are irrelevant. However, if it can be assumed that the environmental influences don't extend into the period range of the Chandler wobble, at least the estimated amplitude factor for the Chandler wobble should be a valid result.

The amplitude factors resulting from the fit of two sinusoidal waves with fixed frequencies are compiled in Table 1, columns 5 and 6. Beneath each column the weighted mean values 1.11 ± 0.14 for the annual wobble (AW) and 1.15 ± 0.02 for the Chandler wobble (CW) are given. The weights were taken inversely proportional to the mean errors resulting from the fit of the sinusoidal waves at each station. As to be expected the values for the annual wobble scatter over a considerably larger range (extreme values 0.3 and 3.0) than the values resulting for the Chandler wobble (extreme values 0.95 and 1.57). The same fact is expressed by the errors of the weighted means (± 0.14 for the AW, ± 0.02 for the CW). The comparatively good agreement of the mean values itself has to be considered as a random result.

Table 1

Together with the δ -factors the phase shift between the non-tidal residual gravity and the gravity effect of polar motion was estimated. Every time when the scatter of the results was small the phase shift is near zero. Phase shifts which significantly differ from zero give additional hints on uncorrected environmental influences.

6. Environmental Influences and Ocean Loading

Among the different environmental influences only the air pressure near the gravimeter and its temporal variations are included regularly in the tidal analyses. Other environmental influences have to be considered separately. This concerns first of all the local soil moisture, groundwater level and precipitation (Harnisch and Harnisch, 2006b) as well as the spatial distribution of the air density and its variations in the regional scale. The success of such corrections depends on the station and its environment, appropriate models (stochastic, deterministic) and last but not least on the availability of data and their quality (disturbing influences, parameters of models). The data series recorded 1995-1998 at Boulder is an example for the influence of precipitation and its correction (Harnisch and Harnisch, 2001). The data series recorded by the dual sphere gravimeter CD030 at Bad Homburg was successfully corrected for groundwater influences. Corrections were derived from different groundwater gauges in different distances (Harnisch et al., 2006). At Wettzell corrections as well for groundwater influences as also for precipitation are essential for a useful processing

² <http://www.iers.org/MainDisp.csl?pid=36-9>

of the recorded gravity data (Harnisch and Harnisch, 2002).

The examples mentioned above are more or less important in the short-periodic and local range. In the long-term range the consideration of the local air pressure near the gravimeter has to be completed (or replaced) by the three-dimensional distribution of the air density and its changes in the regional and global scale (Simon, 2003; Simon 2006; Simon et al., 2006; Neumeyer et al., 2004; Neumeyer and Stöber, 2006).

After the launch of the CHAMP and GRACE satellites the GGP-network of superconducting gravimeters was used for the calibration of the satellite data by comparison with gravity data measured at the Earth's surface (Neumeyer et al., 2006; Hinderer and Crossley 2004). The models of the global water storage developed in this context (e.g. Döll et al., 2003; Güntner et al., 2007) can also be used for the validation and correction of the long-term drift behavior of the superconducting gravimeters. At first sight the graphs of the non-tidal residual gravity, the variations of the groundwater level and the fitted annual wave at the one hand and the gravity effect of the global water storage on the other hand look very similar.

Besides the local hydrology also all influences of the oceans were neglected. In the short-periodic range therefore e.g. the data series recorded at Concepcion could not be processed adequately as it was done in an earlier study (Wilmes et al., 2006). Similarly long-term influences cannot be excluded completely. But with concern to the ocean loading influences it can be hoped that they also are absorbed – at least partly – by the additional fitted annual wave. The excellent agreement between the averaged graph of the non-tidal residual gravity and the gravity effect of polar motion in Fig. 4 seems to confirm this hope.

7. Fit of an Additional Annual Wave

As already mentioned in section 5, the simple fit of two sinusoidal waves with fixed frequencies gives no chance to separate disturbing environmental influences with annual period from the annual wobble of the polar motion. A possible way to do this is the fit of an additional annual wave which absorbs the disturbing influences in the period range of one year. However, this is an experimental approach which gives no total assurance that the polar motion signal remains unaffected. The additional annual wave corresponds to the term $A(t)$ used by Ducarme et al. (2006) in the general theoretical discussion of the non-tidal residual gravity.

The additional annual wave has to be split up from the non-tidal gravity residuals before the remaining main part is analyzed with regard to the gravity effect of both wobbles of the polar motion. Practically the regression model is used (see section 4), completed by the annual wave with initially unknown amplitude and phase. Amplitude and phase of the additional annual wave, the regression coefficient of polar motion and an offset were estimated by a stepwise search following a least square criterion.

Fig. 2.

As an example in the upper frame of Fig. 2 the non-tidal gravity residuals derived from the upper system of the dual sphere gravimeter CD030 at Bad Homburg are presented. When the additional annual wave (shown in the middle frame) is subtracted from the non-tidal gravity residuals the plot in the lower frame results. Clearly it is to be seen that the consideration of the additionally fitted annual wave contributes to a better matching of the gravity residuals to the gravity effect of polar motion.

Table 2

The amplitudes of the fitted annual waves determined for all data sets under consideration are very different. Accordingly the influence on the δ -factors of the AW and the CW is also different at the individual stations. In Table 2 three characteristic examples are shown with

small, middle and large amplitude of the disturbing annual wave (col. 5) and small, middle and large influences on the δ -factors of the annual wobble respectively. Before the additional annual wave was subtracted the δ -factors of the total effect and the AW at the three stations are very different (col. 2 and 3). The subtraction of the additional annual wave reduces the differences considerably (col. 6 and 7). In contrast the scatter of the corresponding values of the CW is small, as well before as also after the additional annual wave has been subtracted (col. 4 and 8). In this way again it is emphasized that the disturbing environmental influences with annual period don't affect the δ -factor of the CW.

The individual δ -factors of all the 14 data series included in the study are compiled in Table 1, col. 7 and 8 together with the corresponding weighted mean values. As may be seen from columns 5 and 7 the δ -factors of the annual wobble in all cases move towards the theoretical value 1.16 after the additional annual wave has been removed. While the error of the δ -factor of the CW remains nearly unaffected, the corresponding error of the annual wobble decreases considerably.

Fig. 3.

8. Worldwide Stacking of Non-Tidal Residual Gravity

The gravity effect of polar motion and consequently also the non-tidal gravity residuals, derived from the observed gravity variations depend on the geographical position of the observation site. Therefore only the ratio δ of both quantities may be assumed to be constant all around the world and only these ratios estimated from the data series at the different stations may be compared.

If the series of gravity data are to be compared directly they at first must be transferred to a common reference point. To this aim the formula (1) may be used describing the dependency of the gravity effect of polar motion on the geographical coordinates (Schweydar, 1917, p.102).

$$p(t) = \Omega^2 r [x(t) \cos \lambda + y(t) \sin \lambda] \sin 2 \varphi \quad (1)$$

This formula assumes a rigid Earth. For comparisons with really recorded gravity data the theoretical values have to be multiplied by the factor $\delta = 1.16$.

Another more practical way is the use of the data series of the gravity effect of polar motion derived at each station theoretically from the observed polar motion (IERS-Data) using formula (1). It is only necessary to compute an additional data set for the fictive reference point, e.g. a point with the coordinates 45°N, 0°E. Following the relation

$$g_{ref}(t) = g_{obs}(t) - [p_{obs}(t) - p_{ref}(t)] \quad (2)$$

with $g_{ref}(t)$, $g_{obs}(t)$ = non-tidal gravity residuals at the reference and at the observation point, $p_{ref}(t)$, $p_{obs}(t)$ = gravity effect of polar motion (IERS-Data) at the reference and at the observation point the data series recorded at the different stations were transferred to the reference point. The formula (1) cited above remains in the background.

As an example Fig. 3 shows the situation for the European station Membach, the Australian station Canberra and the reference point 45°N, 0°E. In the upper frame the non-tidal gravity residuals at both stations are presented. The graphs of both data series differ significantly. The frame beneath shows the corresponding plots of the gravity effect of polar motion at both stations together with the plot for the reference point. As may be seen in the third frame the difference to the reference point is very small at Membach. In contrast at Canberra far from the reference point it is clearly greater and varies strongly over the time. Also the phases are quite different.

Fig. 4.

In order to transfer the gravity residuals from both stations under consideration to the reference point the difference between the theoretical gravity effect of polar motion (IERS-Data) at both stations and the reference point has to be subtracted from the gravity residuals at the respective station. The result is shown in the lowermost frame of Fig. 3. Now the graphs of the gravity residuals at both stations agree comparatively well. The remaining deviations may be uncorrected parts of disturbing influences of different origin as well as influences of inaccuracies and errors during the recording and processing of the data series.

In the same manner as it was done with the data from the stations Membach and Canberra the data series of all the other stations may be transferred to the reference point. A very simple kind of stacking is to be seen in the upper frame of Fig 4. There the graphs of all data series form a more or less homogeneous stripe. The width of this stripe depends on the deviations of the graphs of the single data series against each other. In this way a very simple visual valuation of the quality of the data series is possible.

In order to stack all data series numerically at first they have to be transferred to the reference point and combined in a single data file. After that step by step all gravity values which refer to the same time are averaged using the simple arithmetic or the weighted mean. The averaged data form a new "averaged" dataset which may be handled in the same manner as the original data at the different stations. The stacking procedure may be applied as well on the data of the total non-tidal residual gravity at the single stations as also on the series after the disturbing annual wave has been subtracted. In Table 1 the amplitude factors derived for each of the single data series are compiled as well for the total effect (col. 5 and 6) as also for the corrected data series after the fitted additional annual waves have been subtracted (col. 7 and 8, see sections 5 and 7). Below each column the correspondent weighted mean values are given, based on weights inversely proportional to the mean errors resulting from the fitting of the two sinusoidal waves.

In Table 1 below col. 5 and 6 and col. 7 and 8 respectively results were presented from the fit of the two sinusoidal functions to all the four versions of stacks (with and without consideration of the fitted additional annual wave, arithmetic or weighted mean). The δ -factors of the annual wobble depend on whether the disturbing annual wave was subtracted or not. The δ -factors of the Chandler wobble are much less influenced by the elimination of the disturbing annual wave than those of the annual wobble. This is the same as already described in concern with the single stations.

In the upper frame of Fig. 4 the graph of the averaged dataset (weighted mean) is added to the graphs of the residual gravity at the 12 stations under consideration, transferred to the reference point. In the lower frame the averaged dataset is directly compared with the gravity effect of polar motion at the reference point. The agreement of both graphs is excellent.

As may be seen from the lower frame of Fig. 4 the period between July 2000 and June 2005 is characterized on the one hand by large amplitudes of the polar motion and on the other hand by an excellent agreement of the theoretical gravity effect of polar motion and the averaged dataset derived from the stacking of the 12 data series. During this period due to the large amplitudes the influence of disturbing effects is comparatively low. On the other hand nearly all data series under consideration contribute to the stacking result. Therefore an additional estimation of the amplitude factors of both wobbles of the polar motion was done, based on a subset of the averaged data series confined to the period between July 2000 and June 2005. The resulting values 1.183 for the annual and 1.168 for the Chandler wobble are considered to be the most reliable values of the amplitude factors of the annual and the Chandler wobble. The correspondent errors are less than ± 0.01 .

The final result obtained by the stacking procedure is near the theoretically expected value of 1.16 (Dehant et al., 1999). The error of ± 0.01 should be a reasonable estimate, valid from the present-day perspective. It is to be assumed, that future investigations on the basis of further grown data series and refined correction methods will bring more reliable and precise results.

9. Results

Altogether 15 series with gravity data were downloaded from the GGP data bank (GGP-ISDC) and processed. In the end 3 of these data series had to be rejected due to serious problems with the modeling of the drift.

Despite the long and very accurate series of recorded gravity data the accuracy and reliability of the estimated δ -factors of both constituents of the polar motion are limited due to the lack of data and models to eliminate the influence of environmental effects.

In addition to the gravity effect of polar motion an annual wave was fit to the non-tidal residual gravity. In this way the lack of environmental data could be compensated, at least partly.

The elimination of the additional annual wave strongly influences the δ -factor of the annual wobble while the δ -factor of the Chandler wobble remains nearly unaffected.

The stacking of several data series recorded at stations spread all over the Earth reduces disturbing environmental influences as far as they are randomly distributed.

The accuracy and reliability of the results could be enhanced when the processing was confined to a subset of the data series with large polar motion signal and a large number of gravimeters contributing to the stack.

The final results derived from the subset 2000 - 2005 are $\delta(AW) = 1.183$ for the annual wobble and $\delta(CW) = 1.168$ for the Chandler wobble. The correspondent errors are less than ± 0.01 .

In the future work the continuously growing gravity data series shall contribute to enhance the accuracy and the reliability of the estimated δ -factors in the period range of the annual and of the Chandler wobble. Moreover refined methods and algorithms for the correction of disturbing environmental influences (e.g. 3D air pressure variations, global water storage, ocean pole tide) shall replace step by step the formally fitted additional annual wave by specific corrections.

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Figure Captions

Fig. 1a. Canberra, gravimeter GWR C031. Upper Frame: Non-tidal gravity residuals and linear drift. Lower Frame: Non-tidal gravity residuals, linear drift subtracted.

Fig. 1b. Strasbourg, gravimeter GWR C026. Upper Frame: Non-tidal gravity residuals and drift polynomials up to the 5th degree. Lower Frame: Non-tidal gravity residuals, drift polynomial of 5th degree subtracted.

Fig. 2. Bad Homburg, upper system of the dual sphere gravimeter CD030: Non-tidal gravity residuals and the additionally fitted annual wave. Upper Frame: Gravity effect of polar motion and non-tidal gravity residuals. Middle Frame: Additional annual wave. Lower Frame: Gravity effect of polar motion and non-tidal gravity residuals after subtraction of the additional annual wave.

Fig. 3. Canberra, gravimeter C031 and Membach, gravimeter C021. Data series referred to the reference point 45°N , 0°E . Upper Frame: Non-tidal gravity residuals at the respective station. Second Frame: Gravity variations at the respective station derived from the observed polar motion (IERS-Data). Third Frame: Difference between the gravity variations at the station under consideration and the reference point. Lower Frame: Non-tidal gravity residuals, referred to the reference point.

Fig. 4. Superposition of the graphs of 12 stacked data series. Upper Frame: Non-tidal gravity residuals, referred to the reference point 45°N , 0°E , weighted mean of these 12 data series. Lower Frame: Weighted mean of the 12 data series and gravity effect of polar motion at the reference point.

Table 1
Results of different variants of the processing of the non-tidal gravity variations

Station	Time Period	$\delta(\text{PM})$	$\delta(\text{PM})$	$\delta(\text{AW})$	$\delta(\text{CW})$	$\delta(\text{AW})$	$\delta(\text{CW})$
		Residual Gravity	Res.Grav. - AW	Residual Gravity		Residual Gravity - Annual Wave	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Bad Homburg 1 (BH1)	2002-2007	0.75	1.00	0.28	1.11	0.77	1.11
Bad Homburg 2 (BH2)	2002-2007	0.72	1.07	0.29	1.10	1.09	1.10
Cantley (CA)	2000-2004	1.68	1.33	2.93	1.30	1.40	1.30
Canberra (CB)	1997-2007	1.18	1.08	1.33	1.11	1.10	1.11
Membach (MB)	1996-2007	1.37	1.14	1.86	1.14	1.15	1.14
Medicina (MC)	1997-2007	1.13	1.11	1.11	1.12	1.11	1.12
Metsahovi (ME)	1994-2007	1.30	1.69	0.45	1.57	1.73	1.57
Moxa 1 (MO1)	2000-2007	1.11	1.07	1.27	1.08	1.07	1.08
Moxa 2 (MO2)	2000-2007	1.13	1.07	1.31	1.09	1.07	1.08
Strasbourg (ST)	1997-2007	1.44	1.24	1.98	1.27	1.27	1.26
Sutherland 1 (SU1)	2000-2006	1.08	1.16	0.84	1.22	1.16	1.19
Sutherland 2 (SU2)	2000-2006	1.07	1.14	0.88	1.17	1.14	1.17
Concepcion (TC)	2002-2008	0.78	0.66	1.19	0.95	0.94	0.98
Vienna (VI)	1995-2006	1.24	1.21	1.29	1.19	1.21	1.19
Weighted Mean		1.13 ± 0.05	1.13 ± 0.03	1.11 ± 0.14	1.15 ± 0.02	1.12 ± 0.03	1.15 ± 0.02
Stack, Period 1996-2007 arithmetic mean				1.23	1.10	1.18	1.12
Stack, Period 1996-2007 weighted mean				1.28	1.13	1.19	1.12
Stack, Period 2000-2005 arithmetic mean				1.117	1.174	1.194	1.154
Stack, Period 2000-2005 weighted mean				1.242	1.150	1.183	1.168
<p><i>Column 3:</i> Amplitude factor δ of the total gravity effect of polar motion. Result of linear regression (section 4). <i>Column 4:</i> same as column 3, additional annual wave subtracted (section 7). <i>Columns 5 and 6:</i> δ of the annual and the Chandler wobble, estimated by fitting of two sinusoidal waves (section 5). <i>Columns 7 and 8:</i> same as columns 5 and 6, additional annual wave subtracted (section 5). Below of the columns weighted means over all stations involved and the results of the processing of the stacked series (section 8).</p>							

Table 2

Amplitude factors (δ -factors) of the gravity effect of polar motion. Disturbing influences of different origin considered by fitting of an additional annual wave. 3 examples.

	Total residual gravity			Amplitude Annual Wave	Annual Wave Subtracted		
	δ (PM) (1)	δ (AW) (2)	δ (CW) (3)	(4)	δ (PM) (5)	δ (AW) (6)	δ (CW) (7)
Canberra	1.18	1.33	1.11	5.299	1.08	1.10	1.11
Membach	1.37	1.86	1.14	11.839	1.14	1.15	1.14
Cantley	1.68	2.93	1.30	28.894	1.33	1.40	1.30
	PM Total gravity effect of polar motion			AW Annual Wobble	CW Chandler Wobble		

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