Paper-ID: VGI_199640

The Austrian Gravity Base Net 1995

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VGI – Österreichische Zeitschrift für Vermessung und Geoinformation **84** (3), S. 275–283

1996

BibTEX:

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@ARTICLE{Ruess_VGI_199640,
Title = {The Austrian Gravity Base Net 1995},
Author = {Ruess, Diethard and Gold, Wolfgang},
Journal = {VGI -- {\"O}sterreichische Zeitschrift f{\"u}r Vermessung und
   Geoinformation},
Pages = {275--283},
Number = {3},
Year = {1996},
Volume = {84}
}
```

Acknowledgements

I am very grateful to my colleagues in Berne for their support during my stay at the Astronomical Institute over the past two years. In particular I should like to thank the head of the Institute Prof. Dr. Gerhard Beutler and Dr. Markus Rothacher whose continued assistance was invaluable for the work presented above.

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The Austrian Gravity Base Net 1995

Diethard Ruess, Wolfgang Gold, Vienna

Abstract

The Austrian Gravity Network is one of the tasks of the Federal Office of Metrology and Surveying (BEV) in Vienna. A revision of the old existing network were started 1981. New stations were established and relative measurements were made with LCR gravimeters only. The neighboring networks were connected with the Austrian network. Since 1987 the absolute gravity meter JILAG-6 has been used for observations on 28 stations of the 0. order. Two different national network adjustments and an European adjustment were calculated. The results were compared and contrasted with the absolute observations. The maximum difference is less then 30 μGal, the average difference is less than 1.5 μGal.

Repeated absolute measurements twice a year have been done on a station in the Central Alps of Austria to check the stability of the gravity values. The amplitude of these results is $8 \cdot 10^{-8}$ m/s^2 (8 μGal).

1. Introduction

The Federal Office of Metrology and Surveying in Vienna has a long tradition in determining the gravity. First observations were made 1878 in Vienna with a Repsold Pendulum by Theodor R. v. Oppolzer of the k. k. Gradmessungsbüro. Further measurements were made by Robert D. v. Sterneck. The Vienna Gravity System was established and valid until 1909 when the Potsdam Gravity System was decided by the IAG. In the 50th and 60th relative measurements were possible using the relative gravimeters Nørgaard and Worden. Therefore a base station network was established and derived from the European Calibration Line which crossed Austria between Kufstein and Brenner. At the end of the 70th a lot of these base stations were lost. In 1980 four new absolute gravity stations were established in Austria, measured by I. Marson with the rise and fall apparatus IMGC of Italy [1]. New relative gravimeters were available and a lot of geophysical projects demanded a new homogeneous and practical gravity base network. Since 1987 the JILAG-6 free fall absolute gravimeter (figure 1) has been used for several new absolute stations in Austria [7]. The results of these observations have been introduced in the gravity network.

2. The Austrian Gravity Base Net (ÖSGN = Österreichisches Schwere-Grund-Netz)

A lot of different tasks in geodesy, geophysics and technical applications effect the necessity of a homogeneous distribution of gravity base stations with high accuracy. The mountainous area of Austria causes the number of 236 main stations of the order 0. – 2. The stations of the order Zero are defined as absolute stations. A primary network of further 20 stations (1. order) was established in the area of important junctions in 1981 – 1985 [6]. At least in the 2. order a distribution of one station on each page of the Austrian Map 1:50.000 (1 station/$\approx$520 km^2) was aimed. The final distribution is shown in figure 2. One to three witness stations were es-

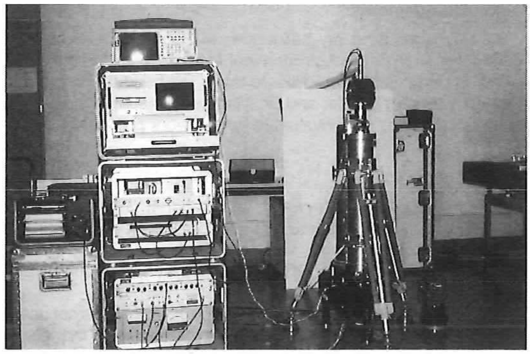

Fig. 1: The absolute gravitymeter JILAG-6

tablished in the surrounding of each main station and somewhere points of 3. order complete the number of about 720 stations (table 1).

The most of the relative measurements were observed by the La Coste & Romberg gravity meters D-9, D-51, G-625. The ÖSGN is connected with the networks of the surrounding states (table 2).

3. Network Adjustments

A first homogeneous adjustment was presented at the XX. IUGG Assembly 1991. Further

ÖSGN				
order	stations	σ[μGal]	determination	instruments
0	28	4–8	absolutely	JILAG-6
1	139	5–10	relatively, directly and jointly	2–4 LCR
2	446	5–15	relatively, jointly	1–3 LCR
3	106	8–20	relatively, directly	1 LCR
0–3	719	4–20	summary	

Table 1: Station groups of the Austrian Gravity Base Network (June 1995) (σ [μGal]: adjusted error of the absolute g-value on a station)

Connection to the surrounding states	time	connections
Italy	1985	2
Switzerland / Liechtenstein	1982–85, 1994	6
Germany	1982–85	19
Czechia	1991, 1995	34
Slovakia	1991	4
Hungary	1992	12
Slovenia	1995	11

Table 2: Gravity network connections with surrounding countries

Austrian Gravity Base Network 1995

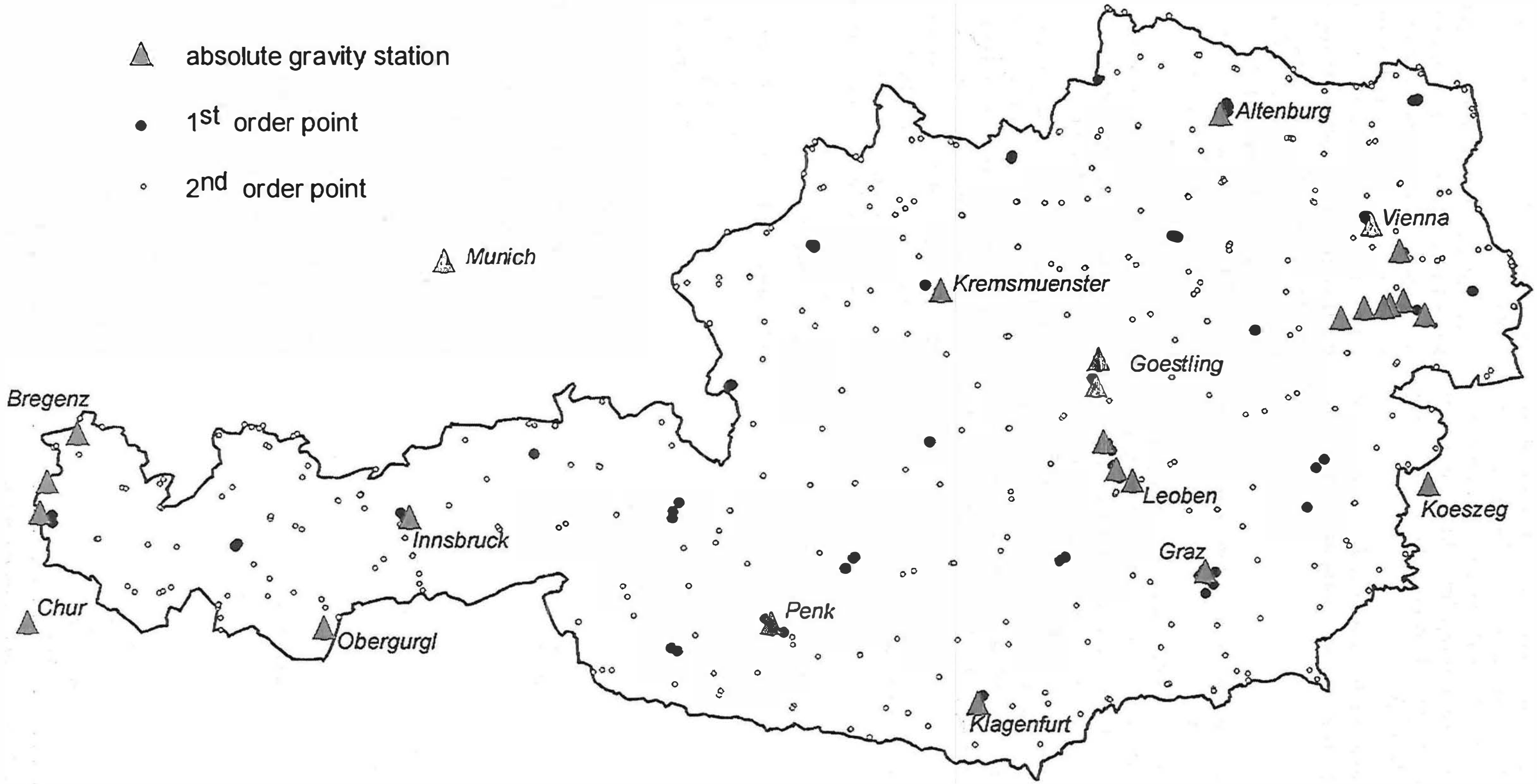

Fig. 2: Distribution of network stations

analyses were done and the main part of the Austrian gravity network is included in the new European Gravity Network. According to the accuracy of the absolute gravity values the mean error of the adjusted values is better than $8 \cdot 10^{-8}$ m/s^2 (8 μGal).

The solutions of the three different types of network adjustments are compared and presented.

3.1. Iterative Solution of the Austrian Gravitynetwork (ISAG)

At the same time when the measurements in the new gravity network were started the values of the base stations were needed for different other gravity projects. Therefore it was necessary to make a first partially network adjustment. The distribution of the measured network connections was very inhomogeneous until 1985. Therefore it was not possible to use modern adjustment computing models using matrix algorithms.

iterative adjustment of the OESGN

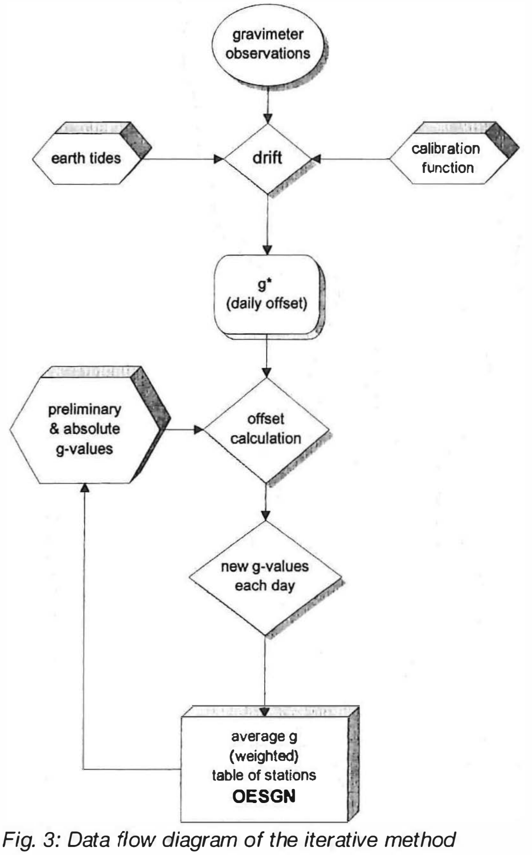

Fig. 3: Data flow diagram of the iterative method

Therefore a method was developed which allows to calculate new station values for each measuring cycle beginning on well known starting points. The Gaussian law of propagation of errors was used straight. The new values on each station were given by the weighted mean of the results of the certain cycles and then used for a new turn of calculation. This procedure is a modification of the technique of Anér and Lichte "The adjustment of a trigonometric elevation network" [12]. The data flow diagram is shown in figure 3.

The first step used was to calculate the g-values by the daily observation cycles, beginning at the absolute stations.

1) calculation of relative g-values using the calibration function of the certain instrument and correction of tidal and drift effects ⇒ g-values of each daily station + unknown offset
2) calculation of the unknown offsets by using absolute stations and preliminary values
3) recalculation of the station – values
4) computing the average value by using all results of 3)
5) back to 2)

Introduced data:	3826	relative observations
	107	absolute observations which give the datum
	27	foreign network values

3.2. ANAG (ANalyse AusGleich)

This adjustment system is a modified version of the 3D network adjustment program system ANAG which is used in the BEV to adjust control points [13]. The part of the adjustment of the heights was befitted for the gravity network adjustment.

The observation equation is given by:

$$v_{ij} = gd_j - gd_i + [(g_j - g_i) - \Delta g_{ij}]$$

Δg_{ij} observations
g_j, g_i preliminary g-values
gd_j, gd_i unknowns

Used data in the adjustment: 2439 Δg values
769 stations

The Δg values were computed by using the adjustments of the daily observations (drift & tide corrected). It is the same data set as in 3.1. 1).

The absolute g-values are included by using the fixed g-values and a pseudo-difference of

Austrian Gravity Base Network 1995 (30% sample)

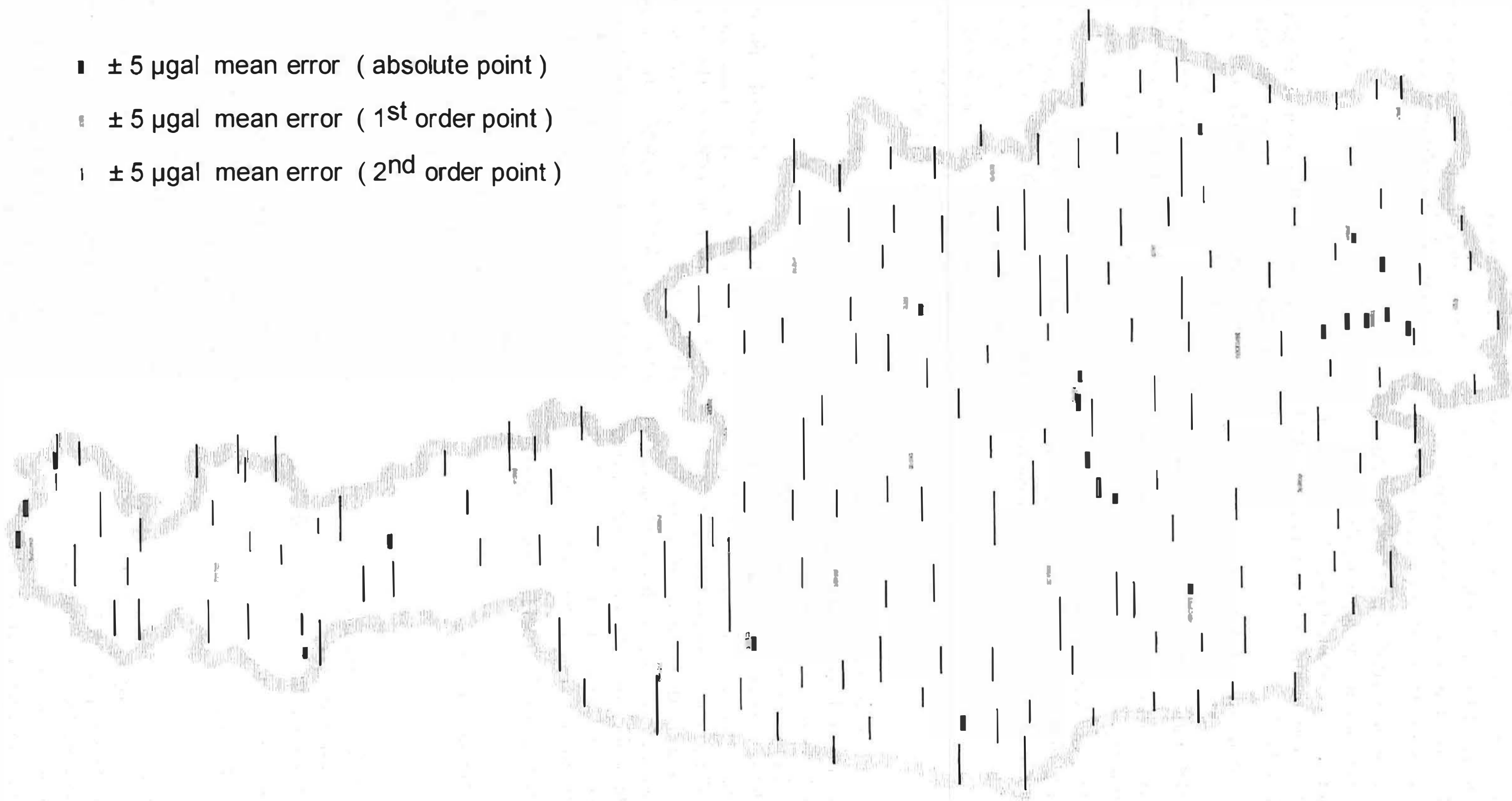

Fig. 4: Error bars of results of ANAG

zero to an identical relative station. The rectification's of these zero-differences corresponds to the rectification's of the absolute values. The accuracy of the absolute measurements are used for the weight of the pseudo-difference 0.

The errors of the preliminary (daily) adjustments are used for the weight of the g-differences by eliminating the extremes ($5 \leq \sigma \leq 30$). An error proportional to the g-differences (2 μGal / 100 mGal) is used.

Therefore the extremes of the errors are:

$$1.2 \leq \sigma \leq 8.5$$

and the used weights are: $0.0013 \leq p \leq 0.069$

The error bars of the results of the adjustment are shown in figure 4.

The absolute stations in Austria measured in 1987 – 1994 with the JILAG-6 give the datum of the adjustment, additionally the station Munich of the DSGN 80 was used.

3.3. UEGN

The Austrian observations of the 0. and 1. order observations and some important parts of 2. order measurements are included in the adjustment of the Unified European Gravity Network UEGN [1]. All the superior parts of the most western European countries are included. For this adjustment all the row – data of the field observations were used. These data were evaluated using a unified algorithm of drift calculation and corrected with the newest earth tide model. Therefore inconsistencies due to different national computing algorithms were avoided.

The dispositions of the rectification equations are:

on absolute measurements:

$$v_i = g_j - g_i$$

with

v_i *residuals of the observations*
g_j *estimated station value*
g_i *observed value (earth tide corrected)*

on relative measurements:

$$v_i = g_j + o_l + z_j f_g + t_j d_l + r_j$$

with

v_i, g_j *as above*
o_l *unknown offset of a measuring cycle*
z_j *observed value (reading)*
f_g *calibration factor of the instrument*
t_j *time of observation*
d_l *linear drift coefficient in a cycle*
r_j *gravimeter reading # i, earth tide corrected, calibrated*

The datum of the adjustment corresponds to the 123 used absolute measurements.

4. Comparisons with the absolute stations

The results of the 3 different kinds of network adjustments were compared with the given absolute values (table 3). The mean errors are very close together. The higher mean value of the UEGN error – results is caused by a smaller number of used relative observations. Therefore the big difference of 44 μGal in the UEGN at Mannswörth is declared by only a few week relative connections to the other stations on one hand and by not using the absolute value on the other hand. Also further 5 absolute values are not introduced in the UEGN. The average residuals of the different adjustments lay between −1.7 (UEGN) and + 0.6 (ANAG). So a good agreement could be found in all three types of adjustments.

5. Comparisons with further network stations

The results of the different adjustment routines were compared on 47 significant base stations and presented in table 4. The extremes in the discrepancies are −27 and + 32 and will be found in the row UEGN – ANAG. The maximum discrepancies between ANAG and ISAG is −13 and +18. The reason of the smaller disagreements is caused be the greater number of used observations.

The gravity niveau of the UEGN fits very good to the results of ISAG (~ 0.5 μGal). The niveau of ANAG seems to be higher by about 1.5 μGal than the results of ISAG.

6. Checks on stability of absolute gravity observations

The long term stability of gravity can only be checked by repeated absolute observations. In Austria this was possible only on few stations. The most frequented absolute stations are Obergurgl and Vienna. Repeated measurements are also planned in geodynamic sensitive zones.

In Obergurgl (Ötztal in Tyrol) repeated absolute observations have been made twice a year since 1987 every spring and autumn with the JILAG-6 instrument [11]. The goal of these measurements

Comparison between 3 different adjustments of the Austrian Gravity Base Net

ÖSGN UEGN	Name	ABS	±	ISAG	±	ANAG	±	UEGN	±	ISAG-ABS	ANAG-ABS	UEGN-ABS
0-021-00 1764	Altenburg-O	867386	6	867383	5	867381	4.3	867371	5	–3	–5	–15
0-021-01 1851*	Altenburg-W	868930	5	868935	5	868929	4.9	868927	9	5	–1	–3
0-050-00 1769	Kremsmünster	741249	15	741259	5	741273	4.5	741260	5	10	24	11
0-059-00 1772	Wien	849543	2	549544	5	849544	3.9	849542	3	1	0	–1
0-059-10 1863*	Mannswörth	837769	7	837760	5	837756	5.9	837725	12	–9	–13	–44
0-071-00 1775	Göstling	681846	6	681845	5	681852	4.4	681841	5	–1	6	–5
0-076-00 1778	Hirtenberg	813033	3	813033	5	813034	5.6	813036	6	0	1	3
0-076-01 1854*	Tattendorf	810686	3	810686	5	810688	6.4	810694	9	0	2	8
0-077-00 1780	Seibersdorf	829677	5	829675	5	829675	5.5	829675	5	–2	–2	–2
0-077-01 1857*	Unterwalters	822607	4	822607	5	822604	6.4	822603	7	0	–3	–4
0-077-02 1859*	Ebreichsdorf	818014	4	818015	5	818019	5.5	818024	8	1	5	10
0-078-00 1784	Kaisereiche	795426	4	795430	5	795435	5.8	795429	7	4	9	3
0-082-10 1785	Bregenz	650100	7	650104	5	650103	6.4	650111	7	4	3	11
0-101-00 1789	Hochkar	484653	4	484652	5	484657	6.5	484646	8	–1	4	–7
0-101-50 1790	Präbichl	513094	9	513096	6	513097	6.3	513095	6	2	3	1
0-111-10 1861*	Koblach	612425	6	612418	5	612414	6.4	612396	15	–7	–11	–29
0-118-00 1796	Innsbruck	546559	6	546570	5	546568	5.7	564580	7	11	9	21
0-132-10 1800	Trofaiach	616484	8	616483	5	616482	7.5	616482	8	–1	–2	–2
0-133-10 1802	Leoben	648195	8	648190	5	648191	3.9	648203	6	–5	–4	8
0-140-00 1805	Tisis	588321	7	588331	11	588335	6.4	588323	7	10	14	2
0-164-00 1813	Graz	715514	4	715511	5	714513	4.1	714512	8	–3	–1	–2
0-173-00 1814	Obergurgl 1	239926	4	239923	5	239922	4.5	239922	5	–3	–4	–4
0-173-01 1815	Obergurgl 2	239890	2	239891	5	239892	3.9	239892	3	1	2	2
0-181-00 1819	Penk	467787	8	467780	5	467782	5.5	467796	6	–7	–5	9
0-202-00 1822	Klagenfurt	620236	9	620229	6	620234	6.0	620227	9	–7	–2	–9
0D18/0 1243	München	723137	7	723109	9	723124	7.3	723131	4	–28	–13	–6
0U KOESZ 1837	Köszeg	784708	5	784706	5	—	—	784705	15	–2		–3
	mean values		5.8		5.4		5.5		7.2	–1.1	0,6	–1.7
1851*	absolute value not used in UEGN											

Table 3: Comparisons of 27 used absolute stations and the different adjustment results

Results of adjustments (main stations) 980 ... ... [μGal]							differences		
ÖSGN Number	ISAG	σ	ANAG	σ	UEGN	σ	ANAG-ISAG	UEGN-ISAG	UEGN-ANAG
1-016-00	776.237	5	776.243	7	776.232	8	5	–5	–11
1-025-00	882.229	5	882.236	5	882.221	8	7	–8	–15
1-047-00	740.110	5	740.118	6	740.118	7	8	8	0
1-050-02	740.394	5	740.402	6	740.406	7	8	12	4
1-054-00	855.361	5	855.374	6	855.365	7	13	4	–9
1-055-01	861.618	5	861.625	8	861.615	9	7	–3	–10
1-059-00	849.546	5	849.550	4	849.539	5	4	–7	–11
1-059-10	837.662	7	837.665	6	837.641	12	3	–21	–24
1-061-00	851.691	5	851.700	5	851.686	8	9	–5	–14
1-071-00	683.147	5	683.154	4	683.142	5	7	–5	–12
1-074-00	711.440	5	711.449	10	711.425	8	9	–15	–24
1-076-00	812.618	5	812.620	5	812.625	6	2	7	5
1-076-01	810.347	5	810.350	5	810.352	7	3	5	2
1-077-00	829.410	5	829.413	8	829.414	7	3	4	1
1-077-10	837.967	5	837.976	5	837.970	7	9	3	–6
1-082-10	650.190	5	650.186	7	650.183	13	–4	–7	–3
1-093-00	670.597	5	670.603	6	670.609	6	6	12	6
1-097-00	570.794	5	570.797	7	570.808	9	3	14	11
1-101-10	641.992	5	642.010	6	642.007	9	18	15	–3
1-101-30	484.808	5	484.818	7	484.813	12	10	5	–5
1-111-10	612.404	5	612.398	7	612.381	13	–6	–23	–17
1-118-00	546.254	5	546.249	6	546.265	7	–5	11	16
1-120-00	608.969	5	608.972	7	608.968	8	3	–1	–4
1-123-00	523.939	5	523.945	7	523.944	9	6	5	–1
1-132-10	616.462	10	616.463	9	616.436	7	1	–26	–27
1-133-10	647.553	5	647.556	4	647.560	8	3	7	4
1-136-00	711.940	5	711.937	8	711.936	8	–3	–4	–1
1-140-00	588.184	5	588.176	7	588.172	6	–8	–12	–4
1-141-00	489.751	5	489.738	10	489.760	8	–13	9	22
1-144-00	476.672	5	476.667	8	476.685	6	–5	13	18
1-157-00	466.156	5	466.167	7	466.171	10	11	15	4
1-161-00	581.868	5	581.868	8	581.875	8	0	7	7
1-173-00	239.914	5	239.916	5	239.910	6	2	–4	–6
1-179-00	522.487	5	522.483	7	522.490	11	–4	3	7
1-190-08	707.132	8	707.142	8	707.124	12	–12	–8	–18
1-202-01	622.405	5	622.403	6	622.404	10	–2	–1	1
2-001-00	825.997	5	825.987	2	825.978	9	–10	–19	–9
2-005-00	818.525	5	818.520	9	818.503	17	–5	–22	–17
2-100-00	643.555	5	643.569	5	643.560	8	14	5	–9
2-107-00	776.278	5	776.276	7	776.276	10	–2	–2	0
2-111-00	623.737	5	623.734	7	623.740	9	–3	3	6
2-116-10	562.679	5	562.676	6	562.693	11	–3	14	17
2-145-00	516.210	5	516.203	8	516.235	6	–7	25	32
2-146-00	490.001	5	489.992	8	490.007	7	–9	6	15
2-173-00	344.982	5	344.974	9	344.970	8	–8	–12	–4
2-201-00	577.692	5	577.685	9	577.693	6	–7	1	8
2-205-00	647.433	5	647.434	7	647.440	12	1	7	6
mean values		5		7		9	1,3	0,4	–1,1

Table 4: Comparisons on a sample of 47 main base stations of the ÖSGN

is the investigation in slow changing gravity in the area of the Central Alps. Possible reasons are the changing of the air pressure in wide surroundings and the seasonal changing in the hydrological equilibrium. This effects will also cause different loading of the earthcrust and its response in deformations [14]. The graph of the observation – series is shown in figure 5. An evidence of a correlation to the effects mentioned above is not yet produced. Also the uplift of the Alps (1mm/y) calculated with levelling data [3] does not expect increasing of the gravity. Possible explanations may be found in changing of the water budget in this area. Further investigations will be done.

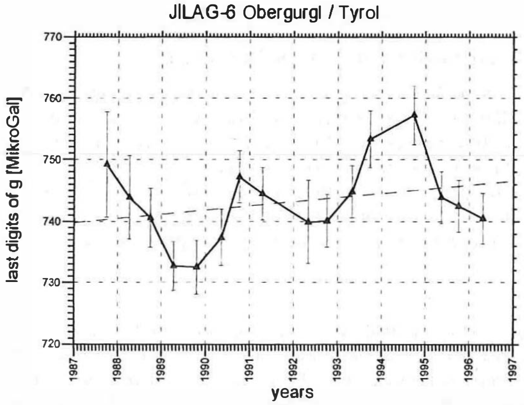

Fig. 5: Repeated absolute gravity measurements in the Central Alps.

7. Conclusion

It was shown that three different methods of adjustments of the Austrian Gravity Base Network (ÖSGN) give the same results within the accuracy of the adjusted values. The accuracy of gravity at the stations is better than $8 \cdot 10^{-8}$ m/s^2 (8 μGal). Therefore a high precision base network is available in Austria for all tasks in Gravity.

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