Compilation of a new Bouguer gravity data base in Austria


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Abstract

All gravity data acquired in Austria by several institutions during the past 50 years have been re-processed in order to get a high accurate data base for interpretation and geoid determination. The paper addresses the problem of data homogenization and quality assessment. Detection of gross coordinate errors has been performed by comparing with high resolution digital terrain models. Erroneous horizontal coordinates have been corrected by digitizing of modern topographic maps and by utilizing the digital cadastre. Another focus is set on the problem of correction errors (mass correction, free air correction) in order to estimate the accuracy of the Bouguer gravity.

Kurzfassung

Alle verfügbaren Schweredaten Österreichs, die in den letzten 50 Jahren an verschiedenen Institutionen entstanden sind, werden neu aufbereitet um einen hochgenauen Datenbestand zu erhalten, der für geophysikalische Interpretationen und für die Geoidbestimmung verwendet werden kann. Der Artikel spricht das Problem der Homogenisierung und der Beurteilung der Daten an. Grobe Koordinatenfehler wurden aus dem Höhenvergleich mit einem hochauflösenden digitalen Geländemodell aufgedeckt. Fehlerhaften Lagekoordinaten wurden durch Digitalisierung moderner topographischer Karten bzw. durch Verwendung der digitalen Katastralmappe verbessert. Weiters wird das Problem der Korrekturfehler angesprochen (Massenkorrektur, Freiluftkorrektur) um die Genauigkeit des Bougerschwerefeldes abzuschätzen.

1. Introduction

Gravity data available in Austria have been acquired during the past 50 years by

- Federal Office of Metrology and Surveying (BEV), Austria
- Institute of Meteorology and Geophysics, University of Vienna, Austria
- Institute of Geophysics, Mining University of Leoben, Austria
- Institute of Geophysics, Technical University of Clausthal, Germany
- OMV AG, Austria,
- Institute of Geophysics, Technical University of Vienna, Austria

In the early beginning, the gravity network design was motivated by the establishment of an orthometric height system in Austria. The first gravity map of Austria was an important by-product (Senftl, 1965). Accordingly, the gravity stations are mainly arranged along levelling lines and consequently often situated within regions of very local anomalies due to the gravity effect of sedimentary valley fillings, for example. While their vertical coordinates were well determined, their horizontal coordinates had to be obtained by topographic map digitization based on maps available in that time. Oil exploration companies built up the first gravity networks of areal character. However, as the target was hydrocarbon exploration, surveying was confined to the Alpine Foreland, the Vienna basin and to parts of the Flysch and Calcareous zone of the Eastern Alps (Zych 1988). For better understanding the crustal structure of the Alps additional gravity profiles were established across the Eastern Alps (Ehrismann et al. 1969, 1973, 1976, Götze et al. 1978) during the late 1960ies and 1970ies. In all these cases, vertical coordinates were derived from precise levelling methods while the horizontal ones were read from topographic maps. Due to limited accessibility, stations were widely missing in rugged mountainous terrain, and gravity had to be interpolated there.

However, Steinhauser et al. (1990) showed that interpolation errors of up to 100 μms^{-2} can occur in the Bouguer anomaly pattern when stations are arranged along profiles exclusively. Therefore, the first areal investigation with a lot of stations even high up mountain flanks and tops has been done during the late 1970ies on the so called Gravimetric Alpine Traverse (Meurers et al. 1987) and by the gravimetric research group of the Technical University of Clausthal (Germany)

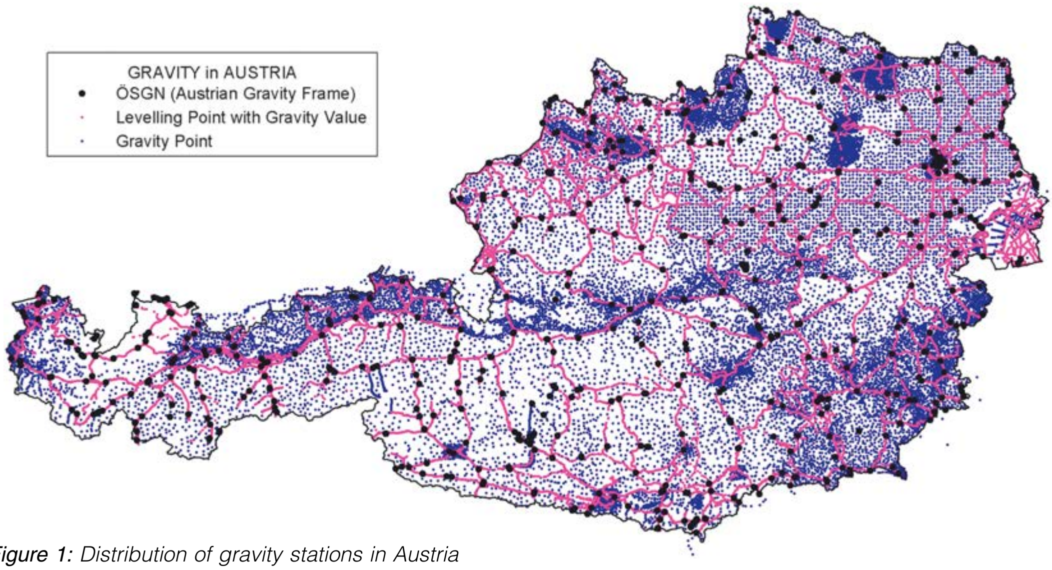

Figure 1: Distribution of gravity stations in Austria

(e.g. Götze et al. 1979, Schmidt 1985) in the adjoining central part of the Eastern Alps. The westernmost and the south-east part of Austria were surveyed by the Mining University of Leoben (Posch and Walach 1990, Walach 1990, Walach and Winter 1994). The first Bouguer gravity map of entire Austria since Senftl's (1965) work has been compiled about 15 years ago (Kraiger and Kühtreiber 1992, Kraiger 1993). In that time wide areas, especially along the Alpine crest, were not or poorly covered by gravity stations, and no high resolution digital terrain models could be utilized for precise mass corrections. The gaps remaining especially along the crest of the Eastern Alps have been filled since 1990 in cooperation of the Institute of Meteorology and Geophysics (University of Vienna), the Central Institute for Meteorology and Geodynamics (Vienna) and the Department of Physical Geodesy of TU Graz by applying GPS techniques and helicopter transportation in otherwise un-accessible mountainous regions. Presently the gravity map is supported by 54000 stations (Fig. 1). The average station interval is less than 3 km even in the high mountains resulting to an average station density of 1 station/9 km^2 or higher.

2. Data processing

During the past 50 years both data acquisition and processing methods have been continually improved. Depending on the origin, the available gravity data refers to different datum and exhibits different quality and accuracy. Additionally, digital terrain models of high spatial resolution (<50 m) have been established and could be used for more accurate mass corrections (Graf 1996). Therefore, data homogenization is required.

3. Gravity datum and calibration

The industrial data (OMV) was tied to an own gravity base net. Compared to the Austrian gravity base net (AGBN/OeSGN), which is supported by absolute gravity observations (Ruess and Gold 1995, Ruess 2001, 2002), the OMV base net has not only an offset but also a slightly different scale due to limited calibration accuracy. Therefore, both scale factor and offset had to be determined by least squares adjustment of numerous ties between the OMV base net and AGBN (Meurers 1992a). The gravimeter calibration was controlled by observations at the Hochkar Calibration Line in Austria which is constraint by absolute gravity measurements (Meurers and Ruess 2001). Finally the gravity of all stations was transformed to the absolute gravity datum established by Ruess (2002).

4. Correcting erroneous coordinates

Horizontal coordinates have been obtained in many cases by topographic map digitization based on those maps which were available when the stations have been established. Mostly maps with a scale of 1:50000 have been used for that purpose. Therefore, generally the coordinate accuracy is estimated as ±25 m in x- and y-direction, but even higher errors can occur occasionally. However, apart from these random

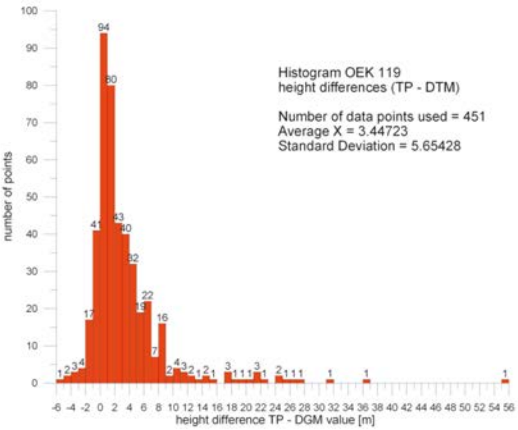

Figure 2: *Histogram of the differences between the elevations of geodetic benchmarks (TP) and their corresponding interpolated DTM heights within a mountainous area (Austrian map sheet 119).*

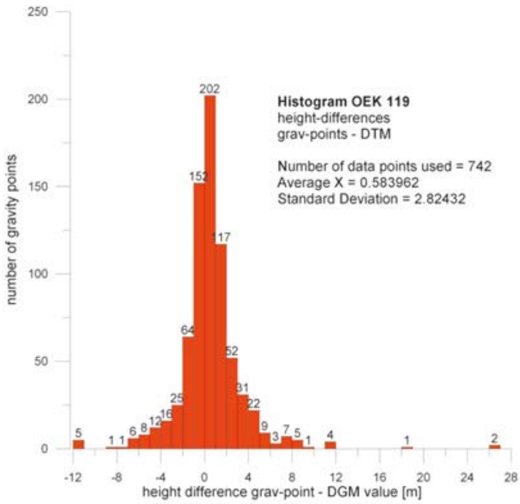

Figure 3: *Histogram of the differences between the elevations of all gravity stations and their corresponding interpolated DTM heights within the same area as investigated in Fig. 2 (Austrian map sheet 119).*

errors, the low quality of some older maps causes even systematic errors. In order to check gross coordinate errors we compared the station heights with those obtained by interpolating a high resolution digital terrain model (DTM) with 50 m spacing. This method of course works well only where interpolation does not seriously smooth out the true topography. Fig. 2 demonstrates the capability of this method by applying the procedure on geodetic benchmarks in Austria which typically exhibit coordinate errors of less than 10 cm. Fig. 2 shows the histogram of the differences between the elevations of the geodetic benchmarks (H_{TP}) and those of the DTM (H_{DTM}) on the Austrian map sheet 119 (Inn valley, Tyrol). Large differences belong to benchmarks situated on extreme terrain (steep rugged rock or peaks), where gravity stations normally are not established. In Fig. 3 the actual situation for all gravity stations within the same area is displayed. Large discrepancies potentially point to errors of horizontal or vertical coordinates, which have to be checked and re-evaluated if necessary.

Figure 4: *Example of a digital cadastre map (DKM) used for fixing the horizontal position of the gravity stations.*

Erroneous coordinates have been corrected by making use of modern topographic maps, orthophoto maps and by utilizing the digital cadastre, based on the original gravity station descriptions or sketches. An example of a digital cadastre map (DKM) used for fixing the horizontal position of the gravity stations is shown in Fig 4.

5. Bouguer gravity determination

Normal gravity at the gravity stations has been calculated by applying a Taylor series expansion to the 2^{nd} order both in elevation and geometrical flattening (Wenzel 1985) based on the Geodetic Reference System 1980 (Moritz 1984). Atmospheric corrections according to Wenzel (1985) were performed. The height system used corresponds to orthometric rather than to ellipsoidal heights. The expected geophysical indirect effect varies between 8.5 and 10 mGal[1)] in Austria (Vajda et al. 2006).

1) 1 mGal = 10^{-5} m/s^2

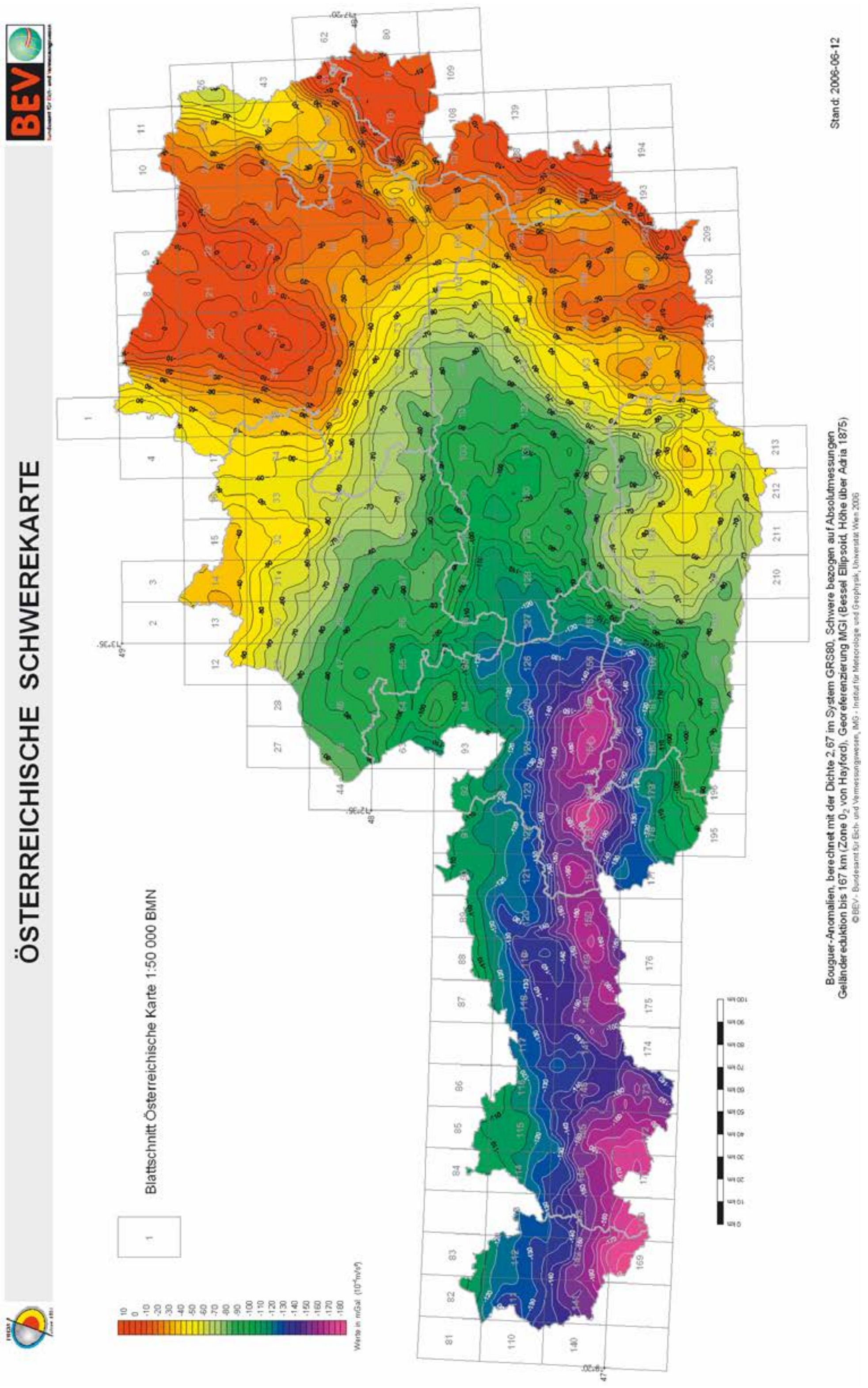

Figure 5: Bouguer gravity map of Austria. Absolute gravity datum, GRS 1980, mass corrections: spherical, Hayford zone O2, density 2670 kg/m³.

The complete mass correction was calculated by using modern and high accurate mass correction methods (Meurers et al. 2001). We applied a spherical mass correction (167 km radius, Hayford zone O2) assuming constant density of 2670 kgm^{-3}. This value is close to the mean surface rock density in the investigated area. The truncation of the mass correction area beyond 167 km is justified as it generates only a very small height dependant effect (Meurers 1992b). Based on a digital terrain model (Graf 1996) with high spatial resolution (50 m spacing), the topography close to the gravity stations (< 1000 m) was approximated by a polyhedral surface, which is able to cope with rugged terrain and allows for exact determination of the corresponding gravity effect (Götze and Lahmeyer 1988). Additionally the gravity effect of lakes has been corrected, which is an important issue in high mountainous areas (Steinhauser et al. 1990).

Fig. 5 shows the new Bouguer gravity map of Austria as coloured map in 10 mGal intervals. The geo-reference (coordinates) is based on the national Austrian system (MGI).

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References

[1] *Ehrismann, W., Rosenbach, O., Steinhauser, P., 1969*: Untersuchungen zur Korrelation zwischen Freiluftanomalie und Stationshöhe im Hochgebirge. ÖZ f. Verm. u. Photogr., Jgg.57, 183-191, Wien.

[2] *Ehrismann, W., Leppich, W., Lettau, O., Rosenbach, O. and Steinhauser, P., 1973*: Gravimetrische Detail-Untersuchungen in den westlichen Hohen Tauern. Z.f.Geoph., 39, 115-130.

[3] *Ehrismann, W., Götze, H.J., Leppich, W., Lettau, O., Rosenbach, O., Schöler, W., Steinhauser, P., 1976*: Gravimetrische Feldmessungen und Modellrechnungen des Krimmler Achentales und Obersulzbachtales. Geologische Rundschau 65, 767-778.

[4] *Götze, H.J., Lahmeyer, B., 1988*: Application of three-dimensional interactive modeling in gravity and magnetics. Geophysics, 53, 1096-1108.

[5] *Götze, H.J., Rosenbach, O., Schöler, W., 1978*: Gravimetric measurements on three N-S profiles through the Eastern Alps – Observational results and preliminary modeling. In: Alps, Apennines, Hellenides. Inter-Union Comm. on Geodynamics, Scient. Rep., 38, 44-49, Stuttgart.

[6] *Götze, H.J., Rosenbach, O., Schöler, W., 1979*: Gravimetrische Untersuchungen in den östlichen Zentralalpen. Geol. Rdsch., 68, 1, 61-82.

[7] *Graf J., 1996*: Das digitale Geländemodell für Geoidberechnungen und Schwerereduktionen in Österreich. Proceed. 7. intern. meeting on Alpine Gravimetry. Österr. Beitr. Met. Geoph., 14, 121-136, ZAMG, Wien.

[8] *Kraiger G., 1993*: Die neue Schwerekarte von Österreich (Bouguer-Isanomalien). 6. Int. Alpengrav. Koll., Leoben 1993, Österr. Beitr. Met. Geoph., 8, 39-53.

[9] *Kraiger G. Kühtreiber, N., 1992*: Preliminary Results of a New Bouguer Map of Austria. Geodesy and Physics of the Earth: Geodetic Contributions to Geodynamics. 7th International Symposium "Geodesy and Physics of the Earth, Symposium No. 112, Berlin, Springer, 1992, p.133.

[10] *Meurers, B., 1992a*: Bearbeitung der Schweredaten der OMV-AG. Unveröff. Firmenbericht. OMV-AG Wien.

[11] *Meurers, B., 1992b*: Untersuchungen zur Bestimmung und Analyse des Schwerefeldes im Hochgebirge am Beispiel der Ostalpen. Österr. Beitr. zu Met. u. Geoph., 6, 146. ZAMG Publ.Nr. 343, Wien.

[12] *Meurers, B., Ruess, D., 2001*: Gravity Measurements at the Hochkar Calibration Line (HCL). Proceed. 8. intern. meeting on Alpine Gravimetry. Österr. Beitr. Met. Geoph., 26, 209-216, ZAMG, Wien.

[13] *Meurers, B., Ruess, D., Graf, J., 2001*: A Program System for High Precise Bouguer Gravity Determination. Proceed. 8th intern. meeting on Alpine Gravimetry, Leoben 2000, Österr. Beitr. Met. Geoph., 26, 217-226,ZAMG, Wien.

[14] *Meurers, B., Ruess, D., Steinhauser, P., 1987*: The Gravimetric Alpine Traverse, in Geodynamics of the Eastern Alps, Flügel H. and Faupl P. (Eds), Deuticke, 334-344, Vienna 1987, ISBN 3-7005-4528-2.

[15] *Moritz, H., 1984*: Geodetic reference system 1980. Bull. Geod., 54, 3, 395-405.

[16] *Posch, E., Walach, G., 1989*: Das Bouguerschwerefeld in Vorarlberg und im Bereich der Übergangszone zwischen West- und Ostalpen. 5. Int. Alpengrav. Koll., Graz 1989, Österr. Beitr. Met. Geoph., 2, 147-151.

[17] *Ruess, D., 200*: Absolute Schweremessungen in Österreich seit 1987. In: Hammerl, Ch., Lenhardt, W., Steinacker, R., Steinhauser, P., (eds.), 2001: Die Zentralanstalt für Meteorologie und Geodynamik 1851 - 2001, 150 Jahre Meteorologie und Geophysik in Österreich, 590 – 607, Leykam, Graz 2001, ISBN 3-7011-7437-7.

[18] *Ruess, D., 2002*: Der Beitrag Österreichs an UNIGRACE – Unification of Gravity Systems of Central and Eastern European Countries. VGI, 3+4/2002, 129-139, Wien.

[19] *Ruess, D., Gold, W., 1996*: The Austrian Gravity Base Net 1995 stabilized by Absolute Gravity Measurements and Connected to the European Network Adjustment. VGI, 3/96, 275-283.

[20] *Senftl, E., 1965*: Bouguer – Isoanomalienkarte von Österreich, 1:1.000.000, BEV-Wien.

[21] *Schmidt, S., 1985*: Untersuchungen zum regionalen Verlauf des Vertikalgradienten der Schwere im Hochgebirge. Ph.D. thesis, TU Clausthal.

[22] *Steinhauser, P., Meurers, B., Ruess, D., 1990*: Gravity investigations in mountainous areas. Exploration Geophysics, 21, 161-168.

[23] *Walach, G., 1990*: The Gravity Field in Southern Austria. Mitt. Geodät. Inst. TU Graz, 67, 135–140.

[24] *Walach, G., Winter, P., 1994*: Bouguer Anomaly Map of Styria. „Gravity and Geoid", Proc. Joint Symposium IUGG.

[25] *Wenzel, F., 1985*: Hochauflösende Kugelfunktionsmodelle für das Gravitationspotential der Erde. Wiss. Arb. Fachr. Vermessungswesen Univ. Hannover, Nr. 137.

[26] *Vajda, P., Vanicek, P., Meurers, B., 2006*: A new physical foundation for anomalous gravity. Stud. Geophys. Geod., 50, 189-216.

[27] *Zych, D., 1988*: 30 Jahre Gravimetermessungen der ÖMV Aktiengesellschaft in Österreich und ihre geologisch-geophysikalische Interpretation. Arch. f. Lagerst.forsch. Geol. B.-A., 9, 155-175.

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