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INFORMATIONS for CONTRIBUTORS

Contributors should follow as closely as possible the rules below :

Manuscripts should be typed (single spaced), on one side of plain paper 21 cm x 29,7 cm with a 2 cm margin on the left and right hand sides as well as on the bottom, and with a 3 cm margin at the top (as indicated by the frame drawn on this page).

NOTA : ***The publisher welcomes the manuscripts which have been prepared using WORD 6 for Macintosh and also accepts ASCII files on diskettes 3"5.***

Title of paper. Titles should be carefully worded to include only key words.

Abstract. The abstract of a paper should be informative rather than descriptive. It is not a table of contents. The abstract should be suitable for separate publication and should include all words useful for indexing. Its length should be limited to one typescript page.

Footnotes. Because footnotes are distracting, they should be avoided as much as possible.

Mathematics. For papers with complicated notation, a list of symbols and their definitions should be provided as an appendix. Symbols that must be handwritten should be identified by notes in the margin. Ample space (1.9 cm above and below) should be allowed around equations so that type can be marked for the printer. Where an accent or underscore has been used to designate a special type face (e.g., boldface for vectors, script for transforms, sans serif for tensors), the type should be specified by a note in a margin. Bars cannot be set over superscripts or extended over more than one character. Therefore angle brackets are preferable to accents over characters. Care should be taken to distinguish between the letter O and zero, the letter l and the number one, kappa and k, mu and the letter u, nu and v, eta and n, also subscripts and superscripts should be clearly noted and easily distinguished. Unusual symbols should be avoided.

Acknowledgements. Only significant contributions by professional colleagues, financial support, or institutional sponsorship should be included in acknowledgements.

References. A complete and accurate list of references is of major importance in review papers. All listed references should be cited in text. A complete reference to a periodical gives author (s), title of article, name of journal, volume number, initial and final page numbers (or statement "in press"), and year published. A reference to an article in a book, pages cited, publisher's location, and year published. When a paper presented at a meeting is referenced, the location, dates, and sponsor of the meeting should be given. References to foreign works should indicate whether the original or a translation is cited. Unpublished communications can be referred to in text but should not be listed. Page numbers should be included in reference citations following direct quotations in text. If the same information have been published in more than one place, give the most accessible reference ; e.g. a textbook is preferable to a journal, a journal is preferable to a technical report.

Table. Tables are numbered serially with Arabic numerals, in the order of their citation in text. Each table should have a title, and each column, including the first, should have a heading. Column headings should be arranged to that their relation to the data is clear.

Footnotes for the tables should appear below the final double rule and should be indicated by a, b, c, etc. Each table should be arranged to that their relation to the data is clear.

Illustrations. Original drawings of sharply focused glossy prints should be supplied, with two clear Xerox copies of each for the reviewers. Maximum size for figure copy is (25.4 x 40.6 cm). After reduction to printed page size, the smallest lettering or symbol on a figure should not be less than 0.1 cm high ; the largest should not exceed 0.3 cm. All figures should be cited in text and numbered in the order of citation. Figure legends should be submitted together on one or more sheets, not separately with the figures.

Mailing. Typescripts should be packaged in stout padded or stiff containers ; figure copy should be protected with stiff cardboard.

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BUREAU GRAVIMÉTRIQUE INTERNATIONAL

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BULLETIN D'INFORMATION

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Bulletin d'Information n° 81

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INTERNAL MATTERS

GENERAL INFORMATION

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4. PROVIDING DATA TO B.G.I.

1. HOW TO OBTAIN THE BULLETIN

The Bulletin d'Information of the Bureau Gravimétrique International is issued twice a year, generally at the end of June and end of December.

The Bulletin contains general information on the community, on the Bureau itself. It informs about the data available, about new data sets...

It also contains contributing papers in the field of gravimetry, which are of technical character. More scientifically oriented contributions should better be submitted to appropriate existing journals.

Communications presented at general meeting, workshops, symposia, dealing with gravimetry (e.g. IGC, S.S.G.'s,...) are published in the Bulletin when appropriate - at least by abstract.

Once every four years, an issue contains the National Reports as presented at the International Gravity Commission meeting. Special issues may also appear (once every two years) which contain the full catalogue of the holdings.

About three hundred individuals and institutions presently receive the Bulletin.

You may :

- either request a given bulletin, by its number (80 have been issued as of June 30, 1997 but numbers 2,16, 18,19 are out of print).

- or subscribe for regularly receiving the two bulletins per year (the special issues are obtained at additional cost).

Requests should be sent to:

Mrs. Nicole LESTIEU
CNES/BGI
18, Avenue Edouard Belin
31401 TOULOUSE CEDEX 4 - FRANCE

Bulletins are sent on an exchange basis (free of charge) to individuals, institutions which currently provide informations, data to the Bureau. For other cases, the price of each issue is 75 FF.

2. HOW TO REQUEST DATA

2.1. Stations descriptions Diagrams for Reference, Base Stations (including IGSN 71's)

Request them by number, area, country, city name or any combination of these.

When we have no diagram for a given request, but have the knowledge that it exists in another center, we shall in most cases forward the request to this center or/and tell the inquiring person to contact the center.

Do not wait until the last moment (e.g. when you depart for a cruise) for asking us the information you need: station diagrams can only reach you by mail, in many cases.

2.2. G-Value at Base Stations

Treated as above.

2.3. Mean Anomalies, Mean Geoid Heights, Mean Values of Topography

The geographic area must be specified (polygon). According to the data set required, the request may be forwarded in some cases to the agency which computed the set.

2.4. Gravity Maps

Request them by number (from the catalogue), area, country, type (free-air, Bouguer...), scale, author, or any combination of these.

Whenever available in stock, copies will be sent without extra charges (with respect to usual cost - see § 3.3.2.). If not, two procedures can be used:

- we can make (poor quality) black and white (or ozalide-type) copies at low cost,

- color copies can be made (at high cost) if the user wishes so (after we obtain the authorization of the editor).

The cost will depend on the map, type of work, size, etc... In both cases, the user will also be asked to send his request to the editor of the map before we proceed to copying.

2.5. Gravity Measurements

2.5.1. CD-Roms

The non confidential data, which have been validated by various procedures are available on two CD-ROMs.

The price of these is :

- *800 (Eight hundred) French francs for individual scientists, universities and research laboratories or groups working in geodesy or geophysics.*
- *3000 (Three thousand) French francs for all other users.*

Most essential quantities are given, in a compressed format. The package includes a user's guide and software to retrieve data according to the area, the source code, the country.

2.5.2. Data stored in the general data base

BGI is now using the ORACLE Data Base Management System. One implication is that data are stored in only one format (though different for land and marine data), and that archive files do not exist anymore.

There are two distinct formats for land or sea gravity data, respectively EOL and EOS.

EOL
LAND DATA FORMAT
RECORD DESCRIPTION
126 characters

Col.	1-8	B.G.I. source number	(8 char.)
	9-16	Latitude (unit : 0.00001 degree)	(8 char.)
	17-25	Longitude (unit : 0.00001 degree)	(9 char.)
	26-27	Accuracy of position The site of the gravity measurements is defined in a circle of radius R 0 = no information 1 - R <= 5 Meters 2 = 5 < R <= 20 M (approximately 0'01) 3 = 20 < R <= 100 M 4 = 100 < R <= 200 M (approximately 0'1) 5 = 200 < R <= 500 M 6 = 500 < R <= 1000 M 7 = 1000 < R <= 2000 M (approximately 1') 8 = 2000 < R <= 5000 M 9 = 5000 M < R 10...	(2 char.)
	28-29	System of positioning 0 = no information 1 = topographical map 2 = trigonometric positioning 3 = satellite	(2 char.)
	30	Type of observation 1 = current observation of detail or other observations of a 3rd or 4th order network 2 = observation of a 2nd order national network 3 = observation of a 1st order national network 4 = observation being part of a nation calibration line 5 = coastal ordinary observation (Harbour, Bay, Sea-side...) 6 = harbour base station	(1 char.)
	31-38	Elevation of the station (unit : centimeter)	(8 char.)
	39-40	Elevation type 1 = Land 2 = Subsurface 3 = Lake surface (above sea level) 4 = Lake bottom (above sea level) 5 = Lake bottom (below sea level) 6 = Lake surface (above sea level with lake bottom below sea level) 7 = Lake surface (below sea level) 8 = Lake bottom (surface below sea level) 9 = Ice cap (bottom below sea level) 10 = Ice cap (bottom above sea level) 11 = Ice cap (no information about ice thickness)	(2 char.)
	41-42	Accuracy of elevation 0 = no information 1 = E <= 0.02 M 2 = .02 < E <= 0.1 M 3 = .1 < E <= 1 4 = 1 < E <= 2 5 = 2 < E <= 5 6 = 5 < E <= 10 7 = 10 < E <= 20 8 = 20 < E <= 50 9 = 50 < E <= 100 10 = E superior to 100 M	(2 char.)
	43-44	Determination of the elevation 0 = no information 1 = geometrical levelling (bench mark) 2 = barometrical levelling 3 = trigonometric levelling 4 = data obtained from topographical map 5 = data directly appreciated from the mean sea level 6 = data measured by the depression of the horizon 7 = satellite	(2 char.)
	45-52	Supplemental elevation (unit : centimeter)	(8 char.)
	53-61	**Observed gravity** (unit : microgal)	(9 char.)

62-67	**Free air anomaly** (0.01 mgal)	(6 char.)
68-73	**Bouguer anomaly** (0.01 mgal) Simple Bouguer anomaly with a mean density of 2.67. No terrain correction	(6 char.)
74-76	Estimation standard deviation free-air anomaly (0.1 mgal)	(3 char.)
77-79	Estimation standard deviation bouguer anomaly (0.1 mgal)	(3 char.)
80-85	**Terrain correction** (0.01 mgal) *computed according to the next mentioned radius & density*	(6 char.)
86-87	Information about terrain correction 0 = no topographic correction 1 = tc computed for a radius of 5 km (zone H) 2 = tc computed for a radius of 30 km (zone L) 3 = tc computed for a radius of 100 km (zone N) 4 = tc computed for a radius of 167 km (zone 02) 11 = tc computed from 1 km to 167 km 12 = tc computed from 2.3 km to 167 km 13 = tc computed from 5.2 km to 167 km 14 =tc (unknown radius) 15 = tc computed to zone M (58.8 km) 16 = tc computed to zone G (3.5 km) 17 = tc computed to zone K (18.8 km) 25 = tc computed to 48.6 km on a curved Earth 26 = tc computed to 64. km on a curved Earth	(2 char.)
88-91	Density used for terrain correction	(4 char.)
92-93	Accuracy of gravity 0 = no information 1 = E <= 0.01 mgal 2 = .01 < E <= 0.05 mgal 3 = .05 < E <= 0.1 mgal 4 = 0.1 < E <= 0.5 mgal 5 = 0.5 < E <= 1. mgal 6 = 1. < E <= 3. mgal 7 = 3. < E <= 5. mgal 8 = 5. < E <= 10 mgal 9 = 10. < E <= 15. mgal 10 = 15. < E <= 20. mgal 11 = 20. < E mgal	(2 char.)
94-99	Correction of observed gravity (unit : microgal)	(6 char.)
100-105	**Reference station** *This station is the base station (BGI number) to which the concerned station is referred*	(6 char.)
106-108	Apparatus used for the measurement of G 0.. no information 1.. pendulum apparatus before 1960 2.. latest pendulum apparatus (after 1960) 3.. gravimeters for ground measurements in which the variations of G are equilibrated of detected using the following methods : 30 = torsion balance (Thyssen...) 31 = elastic rod 32 = bifilar system 34 = Boliden (Sweden) 4.. Metal spring gravimeters for ground measurements 41 = Frost 42 = Askania (GS-4-9-11-12), Graf 43 = Gulf, Hoyt (helical spring) 44 = North American 45 = Western 47 = Lacoste-Romberg 48 = Lacoste-Romberg, Model D (microgravimeter)	(3 char.)

5.. Quartz spring gravimeter for ground measurements
51 = Norgaard
52 = GAE-3
53 = Worden ordinary
54 = Worden (additional thermostat
55 = Worden worldwide
56 = Cak
57 = Canadian gravity meter, sharpe
58 = GAG-2
59 = SCINTREX CG2
6.. Gravimeters for under water measurements (at the bottom of the sea or of a lake)
60 = Gulf
62 = Western
63 = North American
64 = Lacoste-Romberg

109-111 **Country code** (BGI) (3 char.)

112 **Confidentiality** (1 char.)
0 = without restriction
.....1 = with authorization
2 = classified

113 **Validity** (1 char.)
0 = no validation
1 = good
2 = doubtful
3 = lapsed

114-120 Numbering of the station (original) (7 char.)

121-126 Sequence number (6 char.)

EOS
SEA DATA FORMAT
RECORD DESCRIPTION
146 characters

Col.	1-8	**B.G.I.** source number	(8 char.)
	9-16	**Latitude** (unit : 0.00001 degree)	(8 char.)
	17-25	**Longitude** (unit : 0.00001 degree)	(9 char.)
	26-27	Accuracy of position The site of the gravity measurements is defined in a circle of radius R 0 = no information 1 - R <= 5 Meters 2 = 5 < R <= 20 M (approximately 0'01) 3 = 20 < R <= 100 M 4 = 100 < R <= 200 M (approximately 0'1) 5 = 200 < R <= 500 M 6 = 500 < R <= 1000 M 7 = 1000 < R <= 2000 M (approximately 1') 8 = 2000 < R <= 5000 M 9 = 5000 M < R 10...	(2 char.)
	28-29	System of positioning 0 = no information 1 = Decca 2 = visual observation 3 = radar 4 = loran A 5 = loran C 6 = omega or VLF 7 = satellite 8 = solar/stellar (with sextant)	(2 char.)
	30	Type of observation 1 = individual observation at sea 2 = mean observation at sea obtained from a continuous recording	(1 char.)
	31-38	**Elevation of the station** (unit : centimeter)	(8 char.)
	39-40	Elevation type 1 = ocean surface 2 = ocean submerged 3 = ocean bottom	(2 char.)
	41-42	Accuracy of elevation 0 = no information 1 = E <= 0.02 Meter 2 = .02 < E <= 0.1 M 3 = .1 < E <= 1 4 = 1 < E <= 2 5 = 2 < E <= 5 6 = 5 < E <= 10 7 = 10 < E <= 20 8 = 20 < E <= 50 9 = 50 < E <= 100 10 = E superior to 100 Meters	(2 char.)
	43-44	Determination of the elevation 0 = no information 1 = depth obtained with a cable (meters) 2 = manometer depth 3 = corrected acoustic depth (corrected from Mathew's tables, 1939) 4 = acoustic depth without correction obtained with sound speed 1500 M/sec. (or 820 fathom/sec) 5 = acoustic depth obtained with sound speed 1463 M/sec (800 fathom/sec) 6 = depth interpolated on a magnetic record 7 = depth interpolated on a chart	(2 char.)
	45-52	Supplemental elevation	(8 char.)
	53-61	**Observed gravity** (unit : microgal)	(9 char.)
	62-67	**Free air anomaly** (0.01 mgal)	(6 char.)
	68-73	**Bouguer anomaly** (0.01 mgal) Simple Bouguer anomaly with a mean density of 2.67. No terrain correction	(6 char.)
	74-76	Estimation standard deviation free-air anomaly (0.1 mgal)	(3 char.)

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88-91	Density used for terrain correction	(4 char.)
92-93	Mathew's zone *when the depth is not corrected depth, this information is necessary. For example : zone 50* *for the Eastern Mediterranean Sea*	(2 char.)
94-95	Accuracy of gravity 0 = no information 1 = E <= 0.01 mgal 2 = .01 < E <= 0.05 mgal 3 = .05 < E <= 0.1 mgal 4 = 0.1 < E <= 0.5 mgal 5 = 0.5 < E <= 1. mgal 6 = 1. < E <= 3. mgal 7 = 3. < E <= 5. mgal 8 = 5. < E <= 10. mgal 9 = 10. < E <= 15. mgal 10 = 15 < E <= 20. mgal 11 = 20. < E mgal	(2 char.)
96-101	Correction of observed gravity (unit : microgal)	(6 char.)
102-110	Date of observation *in Julian day - 2 400 000 (unit : 1/10 000 of day)*	(9 char.)
111-113	Velocity of the ship (0.1 knot)	(3 char.)
114-118	Eötvös correction (0.1 mgal)	(5 char.)
119-121	**Country code** (BGI)	(3 char.)
122	**Confidentiality** 0 = without restriction 1 = with authorization 2 = classified	(1 char.)
123	**Validity** 0 = no validation 1 = good 2 = doubtful 3 = lapsed	(1 char.)
124-130	Numbering of the station (original)	(7 char.)
131-136	**Sequence number**	(6 char.)
137-139	**Leg number**	(3 char.)
140-145	**Reference station**	(6 char.)

Whenever given, the theoretical gravity (γ_o)*, free-air anomaly (FA), Bouguer anomaly (BO) are computed in the 1967 geodetic reference system.*

The approximation of the closed form of the 1967 gravity formula is used for theoretical gravity at sea level :

$$\gamma_o = 978031.85 * [\ 1 + 0.005278895 * \sin^2(\phi) + 0.000023462 * \sin^4(\phi)\ ] \text{ , mgals}$$

where ϕ *is the geographic latitude.*

The formulas used in computing FA and BO are summarized below.

Formulas used in computing free-air and Bouguer anomalies

Symbols used :

g *: observed value of gravity*

γ *: theoretical value of gravity (on the ellipsoid)*

Γ *: vertical gradient of gravity (approximated by 0.3086 mgal/meter)*

H *: elevation of the physical surface of the land, lake or glacier* ($H = o$ *at sea surface), positive upward*

D_1 *: depth of water, or ice, positive downward*

D_2 *: depth of a gravimeter measuring in a mine, in a lake, or in an ocean, counted from the surface , positive downward*

G *: gravitational constant* ($667.2\ 10^{-13}\ m^3\ kg^{-1}\ s^{-2}$) $\Rightarrow k = 2\pi G$

ρ_c *: mean density of the Earth's crust (taken as* $2670\ kg\ m^{-3}$*)*

ρ_w^f *: density of fresh water* ($1000\ kg\ m^{-3}$)

ρ_w^s *: density of salted water* ($1027\ kg\ m^{-3}$)

ρ_i *: density of ice* ($917\ kg\ m^{-3}$)

FA : free-air anomaly

BO : Bouguer anomaly

Formulas :

* *FA : The principle is to compare the gravity of the Earth at its surface with the normal gravity, which first requires in some cases to derive the surface value from the measured value. Then, and until now, FA is the difference between this Earth's gravity value reduced to the geoid and the normal gravity* γ_o *computed on the reference ellipsoid (classical concept). The more modern concept* [*], *in which the gravity anomaly is the difference between the gravity at the surface point and the normal (ellipsoidal) gravity on the telluroid corresponding point may be adopted in the future depending on other major changes in the BGI data base and data management system.*

* *BO : The basic principle is to remove from the surface gravity the gravitational attraction of one (or several) infinite plate (s) with density depending on where the plate is with respect to the geoid. The conventional computation of BO assumes that parts below the geoid are to be filled with crustal material of density* ρ_c *and that the parts above the geoid have the density of the existing material (which is removed).*

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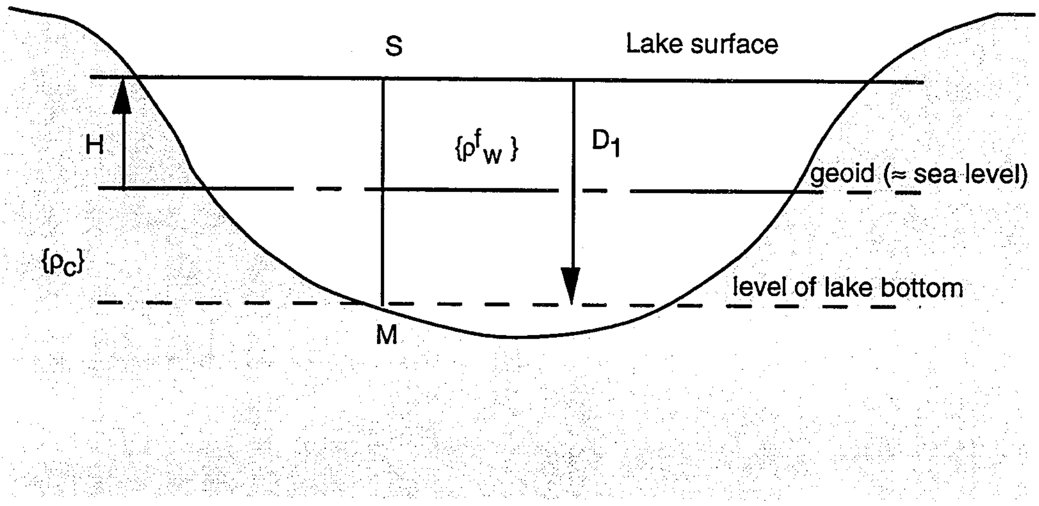
[*] cf. "On the definition and numerical computation of free air gravity anomalies", by H.G. Wenzel. Bulletin d'Information, BGI, n° 64, pp. 23-40, June 1989.

For example, if a measurement g_M is taken at the bottom of a lake, with the bottom being below sea level, we have :



$$g_s = g_M + 2\,k\,\rho^f_w\,D_1\; - \Gamma D_1$$
$$\Rightarrow FA = g_s + \Gamma H - \gamma_o$$

Removing the (actual or virtual) topographic masses as said above, we find :

$$\begin{aligned}\delta g_s &= g_s - k\,\rho^f_w\,D_1 + k\,\rho_c(D_1 - H)\\ &= g_s - k\,\rho^f_w\,[H + (D_1 - H)] + k\,\rho_c\,(D_1 - H)\\ &= g_s - k\,\rho^f_w\,H + k\,(\rho_c - \rho^f_w)(D_1 - H)\end{aligned}$$

$$\Rightarrow \quad BO = \delta g_s + \Gamma\,H - \gamma_o$$

The table below covers most frequent cases. It is an update of the list of formulas published before.

It may be noted that, although some formulas look different, they give the same results. For instance BO (C) and BO (D) are identical since :

$$\begin{aligned}-k\,\rho_i H + k(\rho_c - \rho_i)(D_1 - H) &\equiv -k\,\rho_i(H - D_1 + D_1) - k(\rho_c - \rho_i)(H - D_1)\\ &\equiv -k\,\rho_i\,D_1 - k\,\rho_c(H - D_1)\end{aligned}$$

Similarly, BO (6), BO (7) and BO (8) are identical.

Elev. Type	Situation	Formulas
1	Land Observation-surface	$FA = g + \Gamma H - \gamma_o$ $BO = FA - k\rho_c H$
2	Land Observation-subsurface	$FA = g + 2k\rho_c D_2 + \Gamma(H - D_2) - \gamma_o$ $BO = FA - k\rho_c H$
3	Ocean Surface	$FA = g - \gamma_o$ $BO = FA + k(\rho_c - \rho_w^s) D_1$
4	Ocean submerged	$FA = g + (2k\rho_w^s - \Gamma) D_2 - \gamma_o$ $BO = FA + k(\rho_c - \rho_w^s) D_1$
5	Ocean bottom	$FA = g + (2k\rho_w^s - \Gamma) D_1 - \gamma_o$ $BO = FA + k(\rho_c - \rho_w^s) D_1$
6	Lake surface above sea level with bottom above sea level	$FA = g + \Gamma H - \gamma_o$ $BO = FA - k\rho_w^f D_1 - k\rho_c(H - D_1)$
7	Lake bottom, above sea level	$FA = g + 2k\rho_w^f D_1 + \Gamma(H - D_1) - \gamma_o$ $BO = FA - k\rho_w^f D_1 - k\rho_c(H - D_1)$
8	Lake bottom, below sea level	$FA = g + 2k\rho_w^f D_1 + \Gamma(H - D_1) - \gamma_o$ $BO = FA - k\rho_w^f H + k(\rho_c - \rho_w^f)(D_1 - H)$
9	Lake surface above sea level with bottom below sea level	$FA = g + \Gamma H - \gamma_o$ $BO = FA - k\rho_w^f H + k(\rho_c - \rho_w^f)(D_1 - H)$
A	Lake surface, below sea level (here $H <$ o)	$FA = g + \Gamma H - \gamma_o$ $BO = FA - k\rho_c H + k(\rho_c - \rho_w^f) D_1$
B	Lake bottom, with surface below sea level ($H <$o)	$FA = g + (2k\rho_w^f - \Gamma) D_1 + \Gamma H - \gamma_o$ $BO = FA - k\rho_c H + k(\rho_c - \rho_w^f) D_1$
C	Ice cap surface, with bottom below sea level	$FA = g + \Gamma H - \gamma_o$ $BO = FA - k\rho_i H + k(\rho_c - \rho_i)(D_1 - H)$
D	Ice cap surface, with bottom above sea level	$FA = g + \Gamma H - \gamma_o$ $BO = FA - k\rho_i D_1 - k\rho_c(H - D_1)$

All requests for data must be sent to :

Mr. Gilles BALMA
Bureau Gravimétrique International
18, Avenue E. Belin - 31401 Toulouse Cedex 4 - France
E-mail : Gilles.Balma@cnes.fr

In case of a request made by telephone, it should be followed by a confirmation letter, or fax.
Except in particular case (massive data retrieval, holidays...) requests are satisfied within one month following the reception of the written confirmation, or information are given concerning the problems encountered.

If not specified, the data will be written as tarfiles on DAT cartridge (4 mm). for large amounts of data, or on diskette in the case of small files. The exact physical format will be indicated in each case. Also a FTP anonymous service is available on our computer center.

3. USUAL SERVICES BGI CAN PROVIDE

The list below is not restrictive and other services (massive retrieval, special evaluation and products...) may be provided upon request.

The costs of the services listed below are a revision of the charging policy established in 1981 (and revised in 1989) in view of the categories of users : (1) contributors of measurements and scientists, (2) other individuals and private companies.

The prices given below are in French Francs. They have been effective on January 1, 1992 and may be revised periodically.

3.1. Charging Policy for Data Contributors and Scientists

For these users and until further notice, - and within the limitation of our in house budget, we shall only charge the incremental cost of the services provided. In all other cases, a different charging policy might be applied.

However, and at the discretion of the Director of B.G.I., some of the services listed below may be provided free of charge upon request, to major data contributors, individuals working in universities, especially students ...

3.1.1. Digital Data Retrieval

. on CD-Roms : see 2.5.1.
. on one of the following media :
** printout .... 2 F/100 lines*
** diskette....................... 25 F per diskette (minimum charge : 50 F-*
** magnetic tape .... 2 F per 100 records*
+ 100 F per DAT cartridge
(if the tape is not to be returned)

. minimum charge : 100 F

. maximum number of points : 100 000 ; massive data retrieval (in one or several batches) will be processed and charged on a case by case basis.

3.1.2. Data Coverage Plots : in Black and White, with Detailed Indices

. 20°x20° blocks, as shown on the next pages (maps 1 and 2) : 400 F each set.

. For any specified area (rectangular configurations delimited by meridians and parallels) : 1 F per degree square : 100 F minimum charge (at any scale, within a maximum plot size of : 90 cm x 180 cm).

. For area inside polygon : same prices as above, counting the area of the minimum rectangle comprising the polygon.

3.1.3. Data Screening

(Selection of one point per specified unit area, in decimal degrees of latitude and longitude, i.e. selection of first data point encountered in each mesh area).

. 5 F/100 points to be screened.

. 100 F minimum charge.

3.1.4. Gridding

(Interpolation at regular intervals Δ in longitude and Δ' in latitude - in decimal degrees) :

. 10 F/($\Delta\Delta'$) per degree square

. minimum charge : 150 F

. maximum area : 40° x 40°

3.1.5. Contour Maps of Bouguer or Free-Air Anomalies

At a specified contour interval Δ (1, 2, 5,... mgal), on a given projection :
10 F/Δ per degree square, plus the cost of gridding (see 3.4) after agreement on grid stepsizes. (at any scale, within a maximum map size for : 90 cm x 180 cm).

. 250 F minimum charge

. maximum area : 40° x 40°

3.1.6. Computation of Mean Gravity Anomalies

(Free-air, Bouguer, isostatic) over $\Delta x \Delta'$ area : 10F/$\Delta\Delta'$ per degree square.

. minimum charge : 150 F

. maximum area : 40°x40°

3.2. Charging Policy for Other Individuals or Private Companies

3.2.1. Digital Data Retrieval

. on CD-Roms : see 2.5.1.

. 1 F per measurement for non commercial use (guaranteed by signed agreement), 5 F per measurement in other cases (direct or indirect commercial use - e.g. in case of use for gridding and/or maps to be sold or distributed by the buyer in any project with commercial application). Minimum charge : 500 F

3.2.2. Data Coverage Plots, in Black and White, with Detailed Indices

. 2 F per degree square ; 100 F minimum charge. (maximum plot size = 90 cm x 180 cm)

. For area inside polygon : same price as above, counting the area of the smallest rectangle comprising ihe polygon.

3.2.3. Data Screening

. 1 F per screened point for non commercial use (guaranteed by signed agreement), 5 F per screened point in other cases (cf. 3.2.1.).

. 500 F minimum charge

3.2.4. Gridding

Same as 3.1.4.

3.2.5. Contour Maps of Bouguer or Free-Air Anomalies

Same as 3.1.5.

3.2.6. Computation of Mean Gravity Anomalies

Same as 3.1.6.

3.3. Gravity Maps

The pricing policy is the same for all categories of users

3.3.1. Catalogue of all Gravity Maps

Printout : 200 F
DAT cartrdige (4 mm) 100 F

3.2.2. Maps

. Gravity anomaly maps (excluding those listed below) : 100 F each

. Special maps :

Mean Altitude Maps

FRANCE	(1: 600 000)	1948	6 sheets	65 FF the set
WESTERN EUROPE	(1:2 000 000)	1948	1 sheet	55 FF
NORTH AFRICA	(1:2 000 000)	1950	2 sheets	60 FF the set
MADAGASCAR	(1:1 000 000)	1955	3 sheets	55 FF the set
MADAGASCAR	(1:2 000 000)	1956	1 sheet	60 FF

Maps of Gravity Anomalies

NORTHERN FRANCE	Isostatic anomalies	(1:1 000 000)	1954	55 FF
SOUTHERN FRANCE	Isostatic anomalies Airy 50	(1:1 000 000)	1954	55 FF
EUROPE-NORTH AFRICA	Mean Free air anomalies	(1:1 000 000)	1973	90 FF

World Maps of Anomalies (with text)

PARIS-AMSTERDAM	Bouguer anomalies	(1:1 000 000)	1959-60	65 FF
BERLIN-VIENNA	Bouguer anomalies	(1:1 000 000)	1962-63	55 FF
BUDAPEST-OSLO	Bouguer anomalies	(1:1 000 000)	1964-65	65 FF
LAGHOUAT-RABAT	Bouguer anomalies	(1:1 000 000)	1970	65 FF
EUROPE-AFRICA	Bouguer Anomalies	(1:10 000 000)	1975	180 FF with text 120 FF without text
EUROPE-AFRICA	Bouguer anomalies-Airy 30	(1:10 000 000)	1962	65 FF

Charts of Recent Sea Gravity Tracks and Surveys (1:36 000 000)

CRUISES prior to	1970	65 FF
CRUISES	1970-1975	65 FF
CRUISES	1975-1977	65 FF

Miscellaneous

CATALOGUE OF ALL GRAVITY MAPS

listing	200 FF
tape	300 FF

THE UNIFICATION OF THE GRAVITY NETS OF AFRICA

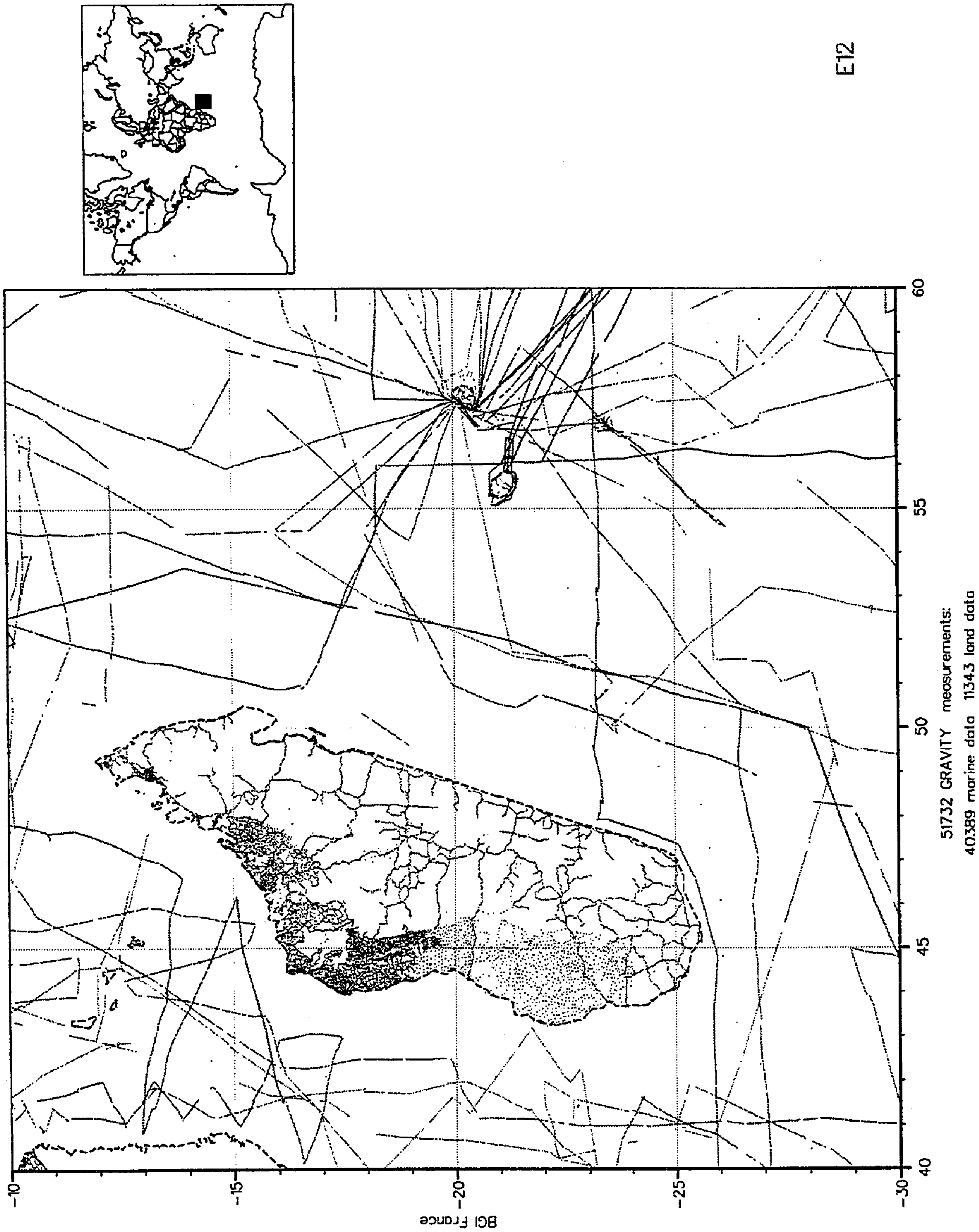
(Vol. 1 and 2)	1979	150 FF

. Black and white copy of maps : 150 F per copy

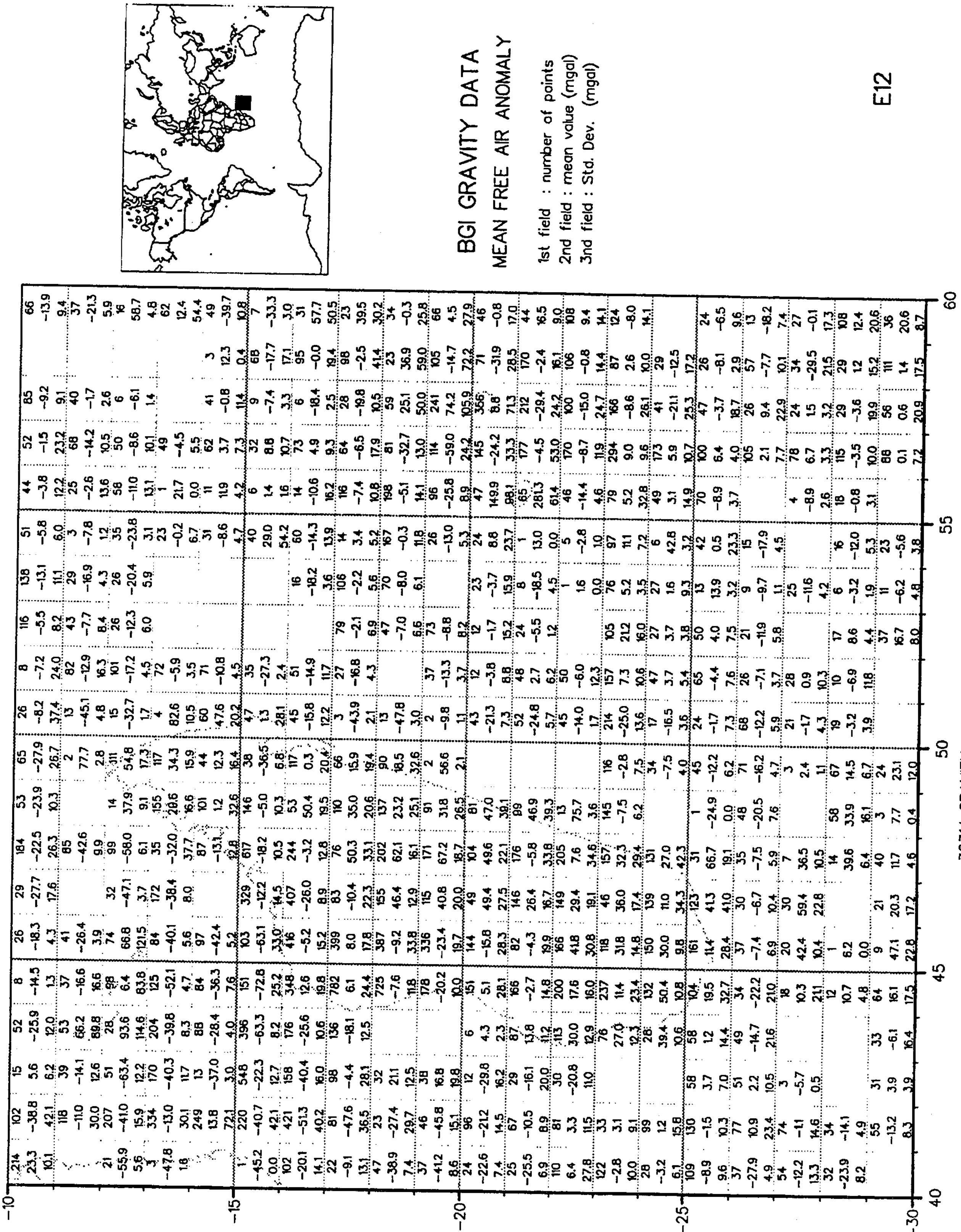
. Colour copy : price according to specifications of request.

Mailing charges will be added for air-mail parcels when "Air-Mail" is requested)

Map 1. Example of data coverage plot



Map 2. Example of detailed index (Data coverage corresponding to Map 1)



4. PROVIDING DATA TO B.G.I.

4.1. Essential Quantities and Information for Gravity Data Submission

1. Position of the site :

- *latitude, longitude (to the best possible accuracy),*
- *elevation or depth :*
  - *. for land data : elevation of the site (on the physical surface of the Earth)* *
  - *. for water stations : water depth.*

2. Measured (observed) gravity, corrected to eliminate the periodic gravitational effects of the Sun and Moon, and the instrument drift **

3. Reference (base) station (s) used. For each reference station (a site occupied in the survey where a previously determined gravity value is available and used to help establish datum and scale for the survey), give name, reference station number (if known), brief description of location of site, and the reference gravity value used for that station. Give the datum of the reference value ; example : IGSN 71.

4.2. Optional Information

The information listed below would be useful, if available. However, none of this information is mandatory.

. Instrumental accuracy :

- *identify gravimeter (s) used in the survey. Give manufacturer, model, and serial number, calibration factor (s) used, and method of determining the calibration factor (s).*

- *give estimate of the accuracy of measured (observed) gravity. Explain how accuracy value was determined.*

. Positioning accuracy :

- *identify method used to determine the position of each gravity measurement site.*

- *estimate accuracy of gravity station positions. Explain how estimate was obtained.*

- *identify the method used to determine the elevation of each gravity measurement site.*

- *estimate accuracy of elevation. Explain how estimate was obtained. Provide supplementary information, for elevation with respect to the Earth's surface or for water depth, when appropriate.*

. Miscellaneous information :

- *general description of the survey.*
  date of survey : organization and/or party conducting survey.
- *if appropriate : name of ship, identification of cruise.*
- *if possible, Eötvös correction for marine data.*

. Terrain correction

Please provide brief description of method used, specify : radius of area included in computation, rock density factor used and whether or not Bullard's term (curvature correction) has been applied.

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* Give supplementary elevation data for measurements made on towers, on upper floor of buildings, inside of mines or tunnels, atop glacial ice. When applicable, specify whether gravity value applied to actual measurement site or it has been reduced to the Earth's physical surface (surface topography or water surface)
Also give depth of actual measurement site below the water surface for underwater measurements.

** For marine gravity stations, gravity value should be corrected to eliminate effects of ship motion, or this effect should be provided and clearly explained.

. Isostatic gravity

Please specify type of isostatic anomaly computed.
Example : Airy-Heiskanen, T = 30 km.

. Description of geological setting of each site

4.3. Formats

Actually, any format is acceptable as soon as the essential quantities listed in 4.1. are present, and provided that the contributor gives satisfactory explanations in order to interpret his data properly.

The contributor may use the EOL and/or EOS formats as described above, or if he wishes so, the BGI Official Data Exchange Format established by BRGM in 1976 : "Progress Report for the Creation of a Worldwide Gravimetric Data Bank", published in BGI Bull. Info, n° 39, and recalled in Bulletin n° 50 (pages 112-113).

If magnetifc tapes are used, contributors are kindly asked to use 1600 bpi, unlabelled tapes (if possible), with no password, and formatted records of possibly fixed length and a fixed blocksize, too. Tapes are returned whenever specified, as soon as they are copied

PART II

Contributing Papers

Relative gravity measurements with a SCINTREX CG3-M in the gravimeter calibration systems Hannover and Hornisgrinde

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Abstract

From January to June 1994 the manufacturer SCINTREX provided its CG3-M gravimeter No. 124 to the Institut für Erdmessung (IfE), University of Hannover, for testing purposes. Regional gravity surveys as well as microgravimetric measurements were carried out during this period, including measurements in the *gravimeter calibration systems Hannover* and *Hornisgrinde* and the determination of gravity gradients. The instrument has been tested under different conditions regarding gravimeter transport and network design.

1. The gravimeter calibration system Hannover

Most of the surveys with the SCINTREX CG3-M were carried out in the *gravimeter calibration system Hannover.* This was established between 1976 and 1982 for the determination of calibration functions for LaCoste&Romberg (LCR) gravimeters with 0.01 $\mu m/s^2$ accuracy (KANNGIESSER et. al. 1983). The calibration system serves for the analysis of polynomial and periodic calibration terms, with the intent of improving the manufacturer's calibration tables which usually provide accuracies of 10^{-3} to 10^{-4} only.

Relative gravity measurements were performed in the following two parts of the Hannover calibration system:

a) The *vertical calibration line Hannover* with a total gravity range of 220 $\mu m/s^2$ was established in the staircase of a 19-storied Hannover University building. It consists of 41 stations with 0.2, 2 or 10 $\mu m/s^2$ gravity difference. The station-to-station transport of the instrument can be done manually.

b) The *Cuxhaven–Harz calibration line* consists of 34 stations with ~90 $\mu m/s^2$ gravity difference, leading to a total gravity range of 3070 $\mu m/s^2$ (Fig. 1). The stations are made up of concrete piers with a surface of 45x45 cm^2 and a depth of 80 cm, which is below the freezing depth.

Over 13000 relative ties measured with 47 LaCoste&Romberg instruments and 12 absolute gravity determinations were included in the adjustment of the calibration system. The estimated mean standard deviations for the adjusted gravity differences are 0.02 $\mu m/s^2$ for the Cuxhaven–Harz line and 0.01 $\mu m/s^2$ for the vertical calibration line Hannover.

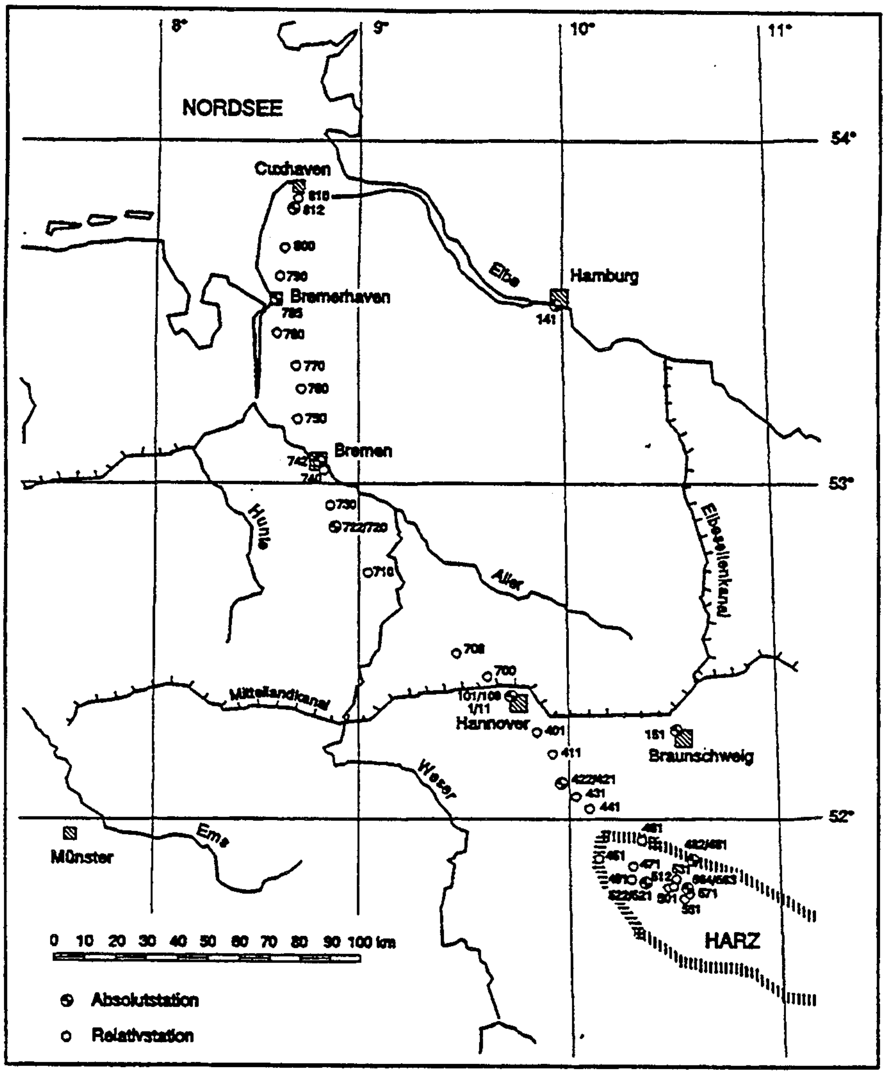

Figure 1: The gravimeter calibration system Hannover, station distribution (RÖDER 1994).

2. Regional surveys with SCINTREX CG3-M

2.1 Measurements

Two different regional surveys have been carried out in the Hannover calibration system:

a) Detailed regional survey using 12 points of the Cuxhaven-Harz line covering almost the whole gravity range ($\sim 3000\ \mu m/s^2$) with individual gravity differences between 70 and 850 $\mu m/s^2$. The measurements were done using the step method (A-B-A-B-C-B-C-D...) with additional overlapping connections. Each tie between neighbouring stations was measured 3-5 times. Two registrations with a ReadTime (RT) of 60s and a Cycle Time (CT) of 75s were carried out for each station occupation. As no systematic difference between the two readings could be found, the average of both values was used for the further computations.

b) Besides the detailed regional survey described in a), an additional quick survey using the profile method (A-B-C-D-C-B-A) was performed in the southern part of the Cuxhaven–Harz line (10 stations were occupied two times, leading to 20 measured gravity differences Δg). The whole procedure took only one day. Every point in this area that had been observed during the regional investigation described in a) was reoccupied. According to the later season (late in April), also the point 571 which was still covered by snow during the regional survey (early in March) could be observed.

In order to check the gravimeter calibration within a different gravity range, an additional regional survey was carried out in an area with well known reference gravity values. Corresponding to the Hannover calibration system in the northern part of Germany, the *gravimeter calibration line Hornisgrinde/Black Forest* covers the gravity range of the southern parts of Germany. It was established by the University of Karlsruhe and consists of 21 stations with a mean standard deviation of 0.02 – 0.03 $\mu m/s^2$ for the adjusted gravity differences. The total gravity range is ~2000 $\mu m/s^2$ with average gravity differences of 100 $\mu m/s^2$ (LINDNER et al. 1996). The measurements done on the Hornisgrinde calibration line were similar to those in the Harz-mountains. 10 points were observed applying the step method (3 ties between neighbouring stations with additional long connections, gravity differences between 80 and 400 $\mu m/s^2$).

2.2 Results

The adjustment of the relative measurements was carried out using the program system GRAV (WENZEL 1993) which can evaluate gravity differences and absolute gravity measurements in a combined solution employing the least squares method. In this case the reference gravity values of the calibration system stations were introduced as absolute gravity measurements with standard deviations of 14 nm/s^2 for the calibration adjustment. We did not use the built in online routine for the reduction of tidal influences but a set of precise tidal parameters which are available from long-term registrations (TIMMEN and WENZEL 1994). Table 1 shows some statistics of the performed measurements, the precision of the instrument for a single measured gravity difference ($s_{\Delta g}$) and the derived scale factors. Polynomial calibration terms of higher degree were not found. The comparison of the results from the two different calibration systems leads to a significant

Calibration system	Range [m/s²]	no. of stations	no. of Δg	$s_{\Delta g}$ [nm/s²]	Scale factor F_s
Hannover	9.8108–9.8119	9	51	91.	1.000194 ±0.000032
	9.8127–9.8138	3			
Hornisgrinde	9.8069–9.8089	10	35	86.	0.999905 ±0.000026

Tab.1: Network statistics and scale factors for SCINTREX CG3-M No. 124, derived on different calibration lines.

difference of $\approx 3\cdot 10^{-4}$, showing that a gravity range dependence of the CG3-M scale factor has to be considered for precise measurements. As a similar difference in the scale factor could be derived from the analysis of parallel measurements with the LCR-G079 gravimeter of IfE, a possible systematic difference between the two calibration systems also has to be taken into account.

In a second evaluation step the calibration measurements in the Hannover system were adjusted without any constraints from the reference gravity values of the calibration system (free net adjustment). The scale factor derived from the calibration adjustment ($F_s=1.000194$) was applied a-priori. The resulting differences between the adjusted and the reference gravity values are plotted in Fig. 2. Although this evaluation step is not completely independent of the first step described above, the differences still give an idea of the achievable accuracy. They have a root mean square (rms) of 23 nm/s^2, which corresponds with the accuracy limit of the Hannover calibration line (see 1.). The standard deviation for a single observation in this adjustment is $s_{\Delta g}=87$ nm/s^2, which is only 4 nm/s^2 less than in the calibration analysis (Tab. 1). This indicates clearly that there are no systematic differences between the calibrated SCINTREX CG3-M results and the Hannover calibration system. The adjustment of the calibrated profile measurements (2.1 (b)) led to a slightly worse $s_{\Delta g}$ of 99 nm/s^2 and and an rms of 89 nm/s^2 for the differences between the CG3-M results and the calibration line reference values. According to the simple network design and the fast measurement method, these values are still good results compared to other gravimeters.

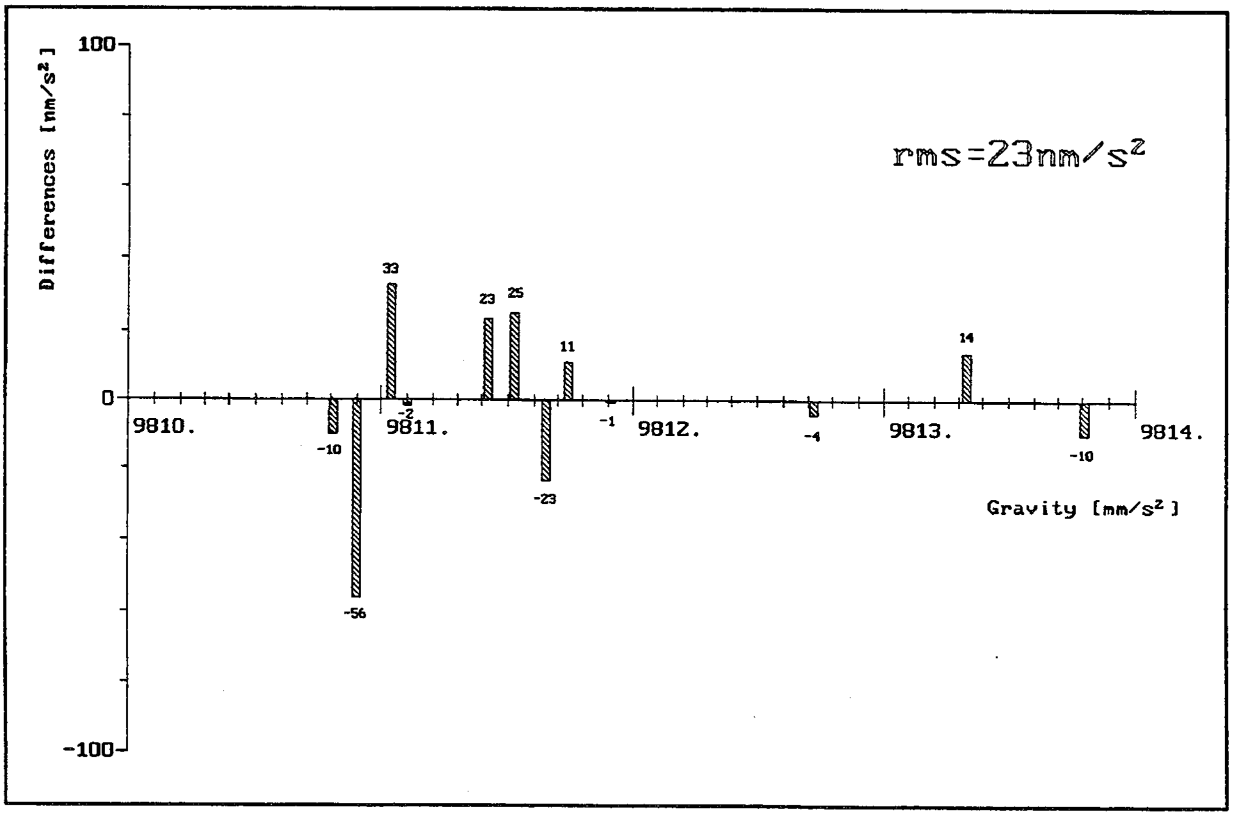

Figure 2: SCINTREX CG3-M No. 124 versus gravimeter calibration system Hannover (scale factor $F_s=1.000194$ applied).

3. Microgravimetric Measurements

3.1 High precision local gravity network

The linear calibration factor was used for the adjustment of a detailed gravity survey of a local gravity net consisting of ten points of the *vertical calibration line Hannover*. The measured gravity differences were between 10 μm/s² and 160 μm/s², with a total observed gravity range of 174 μm/s². As the stations are all located in one building, the gravimeter could be transported by hand, no car transport was needed. The gravity differences between neighbouring stations were measured 5 times (step method) with additional 15 overlapping ties. Two readings (ReadTime 50s, CycleTime 60s) were carried out for each station occupation. No systematic difference was found between the two readings, so that the average value was used for further computations. The adjustment statistics are shown in Tab. 2. Due to the short distances between the gravity stations and the shock preventing transport method the standard deviation for a single measured gravity difference could be reduced to 45 nm/s², which is comparable to the precision of an average LaCoste&Romberg relative gravimeter equipped with an SRW-feedback system (RÖDER et al. 1988).

max. gravity difference [μm/s²]	no. of stations	no. of Δg	r.m.s$_{(CG3\text{-}M-ref.)}$ [nm/s²]	$s_{\Delta g}$ [nm/s²]
174.	13	88	25.	45.

Tab. 2: CG3-M results on the Hannover vertical calibration line.

3.2 Determination of gravity gradients

The determination of *vertical gravity gradients* gets more and more important, because the combination of instruments with different reference heights strongly needs a highly precise centering of the measured gravity values to a common reference. In the field of absolute gravimetry, for example, the reference height of the new FG5 (Faller Gravimeter 5) differs about 0.5m from the reference height of the so far used JILA (Joint Institute for Laboratory Astrophysics) Gravimeters. In relative gravimetry, for example, the reference height of the SCINTREX CG3-M departs from the height of the often used LaCoste&Romberg gravimeters by about 20 cm.

Vertical gradients were observed on selected points of the *gravimeter calibration line Hornisgrinde*. Together with the Scintrex CG3-M, two LaCoste&Romberg gravimeters (LCR-G079F, LCR-D014F) with implemented SRW-feedback systems (RÖDER et al. 1988) were employed. The vertical gradient was determined with the help of a tripod of 1m height. As the same tripod was used for both instrument types the resulting gradients refer to different reference heights above the pier surface (LCR: 0.05m-1.05m, SCINTREX:

0.25m-1.25m). Having this in mind the resulting gradients of the two gravimeter types are in good agreement (max. diff. = 61 n/s², Tab. 3). The precision of the CG3-M is comparable to the result from the Hannover vertical calibration line ($s_{\Delta g}$=46 nm/s²). The precision of the LCR-G079F ($s_{\Delta g}$=37 nm/s²) is not reached, whereas the results of the LCR-D014F are much worse ($s_{\Delta g}$=76 nm/s²).

Station no.	SCINTREX CG3-M [n/s²]	LCR-D014F,G079F [n/s²]	Difference [n/s²]
4	-2844.	-2843.	-1.
9	-2742.	-2681.	-61.
15	-3130.	-3160.	30.
18	-2636.	-2648.	12.

Tab. 3: Determination of vertical gradients on selected stations of the Hornisgrinde calibration line.

Since the stations of the Hannover vertical calibration line are located quite near to walls, a detectable *horizontal gravity gradient* can be expected there. Two calibration line points (185,190) in the cellar of the high-rise building were selected. A grid of 60x60 cm² area and 20 cm point distance was observed employing the step method (5 ties between neighbouring points). A standard deviation of 60 nm/s² for a single measured gravity difference resulted from these observations. The interpolation of a smooth gravity field didn't succeed on point 185, on point 190 additional measurements were necessary to obtain a plausible result (measurements with the LCR-G079F led to a reasonable gravity structure on both stations). Apparently, the CG3-M is hardly able to resolve gravity differences <4-5 nm/s² with the applied reading and measurement methods.

4. Instrumental drift

The large drift is considered as one major disadvantage of quartz-based gravimeters. The software of the Scintrex CG3-M allows the online reduction of an a-priori determined drift, leading to residual longterm drift components of less than 0.2 μm/s². It is recommended to check the drift in regular intervals of one month. We did 6 special drift checks from Febuary to June 1994 and used a 14-days tidal registration to obtain information about variations of the drift parameter with time. The initial linear drift of 2.52 μm/s² in February 1994 increased to 3.34 μm/s² at the end of June 1994, showing clearly the need for the recommended drift check in monthly intervals.

Summary

The SCINTREX CG3-M has been tested for a variety of high precision gravimetric applications in the Hannover calibration system and on the Hornisgrinde calibration line. For regional surveys with a total range of ~3000 $\mu m/s^2$ and gravity differences up to 850 $\mu m/s^2$, a standard deviation of 87 nm/s^2 for a single measured gravity difference was found. The comparison of the manufacturer calibration with the calibration systems led to linear calibration factors of 1.000194 (Hannover) resp. 0.999905 (Hornisgrinde). These variations have to be taken into account for high precise measurements over long distances or in different gravity ranges. After application of the derived linear calibration factor, the residual discrepancies between the CG3-M results and the reference values of the Hannover calibration system are reduced to 23 nm/s^2 (r.m.s), which is at the accuracy limit of the reference gravity values. For microgravimetric measurements with hand transport of the gravimeter the achieved precision was 45 nm/s^2 for a single measured gravity difference. These results show the excellent capabalities of the SCINTREX CG3-M for its use in high precision gravimetric networks.

REFERENCES

KANNGIESSER, E., K. KUMMER, W. TORGE, H.-G. WENZEL (1983): Das Gravimeter-Eichsystem Hannover. Wiss. Arb. d. Fachrichtung Verm.wesen der Univ. Hannover, Nr. 120, Hannover.

LINDNER, K., H. MÄLZER, H.-G. WENZEL (1996): The Hornisgrinde gravimeter calibration line. In preparation.

RÖDER, R.H., M. SCHNÜLL, H.-G. WENZEL (1988): SRW feedback for LaCoste&Romberg gravimeters with extended range. Bull. d'Inf., Bur. Grav. Int., No. 62, 46-50, Toulouse.

RÖDER, R.H. (1994): Zum Einsatz des Absolutgravimeters JILAG-3 in Präzisionsschwerenetzen. Wiss. Arb. d. Fachrichtung Verm.wesen der Univ. Hannover, Nr. 205, Dissertation am Institut für Erdmessung, Universität Hannover.

TIMMEN, L., H.-G. WENZEL (1994): Improved gravimetric earth tide parameters for station Hannover. Bull. d'Inf. Marées Terrestres, No. 119, 8834-8846, Bruxelles.

WENZEL, H.-G. (1993): Programmsystem GRAV, Version 1.5, Programm Manual, Geod. Inst. Univ. Karlsruhe, März 1993.

A New Gravity Base Net in the Emirate of Dubai

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W. Torge[2], F. Rehren[2], M. Schnüll[2]

Abstract

Within the framework of the "Geodetic Project for Precise Mapping" the Planning & Surveying Department of Dubai Municipality and the Institut für Erdmessung (IfE) of the University of Hannover established a gravity base net with an accuracy of a few 0.01 $\mu m/s^2$ in the Emirate of Dubai. In a two weeks measurement campaign in November 1994, three absolute gravity determinations with IfE's JILAG-3 absolute gravimeter were carried out on specially established stations. Further six stations of the national geodetic network of Dubai were connected to the new absolute datum employing 3 LaCoste&Romberg model D and G relative gravimeters.

1. Absolute gravity determinations

1.1 The JILAG-3 absolute gravimeter system

The JILAG-3 gravimeter was developed by Prof. J. E. Faller and co-workers at the Joint Institute for Laboratory Astrophysics (JILA), Boulder, Colorado, U.S.A. (FALLER et al. 1983). It is operated by IfE since 1986 and has been used for more than 140 gravity determinations worldwide. As the instrument as well as the measurement and evaluation method employed at IfE is well documented (TORGE 1993, RÖDER 1994, TIMMEN 1994), we here only summarize the main features.

The JILAG-3 gravimeter is a transportable free-fall apparatus, including a Michelson interferometer with a frequency stabilized laser serving for distance measurements to the dropped object and a Rubidium frequency standard for the corresponding measurements of time.

The beam of the frequency stabilized laser is splitted into a measurement and a reference beam. The reference laser beam is directly led to a "fixed" reference corner cube reflector, whereas the measurement beam is reflected by the dropped object (falling corner cube reflector). After reflection the two laser beams are superimposed, leading to interferences

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which are detected by a photodiode. The falling height in the JILA instruments is 0.25 m, corresponding to a falling time of 0.22s. Per drop approximately 800000 interference fringes occur. Every 4000th fringe is preselected leading to 200 fringe counts which are used to determine the single drop gravity value.

1.2 Applied reductions

The online adjustment of the 200 position-time observations per drop is done employing an IBM-compatible AT386 personal computer. The derived gravity value is corrected for the finite velocity of light, as well as for the temperature dependence and long term drift of the laser frequency.
Air pressure reduction is applied using the standard regression model

$$\delta g_{air} = 3\ (p-p_n)_{(hPa)}\ nm/s^2,$$

as proposed by the International Association of Geodesy (IAG) in 1983, introducing the observed airpressure p and the normal air pressure p_n, defined after DIN 5450 which is practically identical with the U.S. standard atmosphere 1962:

$$p_n = 1013.25\left(\frac{1-0.0065\,H_{(m)}}{288.15}\right)^{5.2559}\ hPa.$$

During online computation, the effect of *polar motion* is reduced using predicted pole coordinates. For the postprocessing of the JILAG-3 raw-data observed pole coordinates, given by the weekly delivered Bulletin A of the International Earth Rotation Service (IERS), have been used.
For the reduction of gravity changes due to *earth tides*, a set of synthetic earth tide parameters, interpolated from a worldwide 1°x1° grid by [TIMMEN and WENZEL 1994] has been used. This grid was computed from body tide amplitude factors using the Wahr-Dehant model of an ocean-free, elastic, rotating, isotropic and ellipsoidal Earth with liquid outer core, and from ocean tide gravitation and load derived from a 1° x 1° ocean tide model.
The absolute gravity values were centered *from* the JILAG-3 *reference height (≈0.80 m) to floor level* using the vertical gravity gradient γ, which was determined using two LCR-gravimeters with built-in SRW-feedback system (LCR-G298F, LCR-G709F), see [RÖDER et al., 1988]. Assuming a neglectable non-linear behaviour of γ near the ground, the vertical gradient can be easily derived by measuring the gravity difference between the ground point and a corresponding point on a tripod in 1 m height. The vertical gradients on the three Dubai absolute stations with the corresponding

Station	Vertical gradient γ [$\mu ms^{-2}/m$]	Standard deviation [$\mu ms^{-2}/m$]
ET 145	-3.220	0.010
ET 34	-2.971	0.013
ET 152G	-2.885	0.012

Tab. 1: Vertical gradients and related adjustment accuracies on the Dubai absolute stations.

adjustment accuracy are shown in Table 1. From numerous gradient determinations throughout the last years, the absolute accuracy of the derived gradients is estimated to be 0.02 - 0.03 $\mu m/s^2$.

1.3 Station selection

The gravity base network consists of 9 gravity stations. Absolute gravity determinations were carried out on 3 specially constructed stations, two of them in desert area and one in the mountaineous region of the Wadi Hatta. The other 6 stations are points of the national geodetic network of Dubai and have been tied to the absolute datum by relative measurements with 3 LCR-gravimeters (Fig. 1).

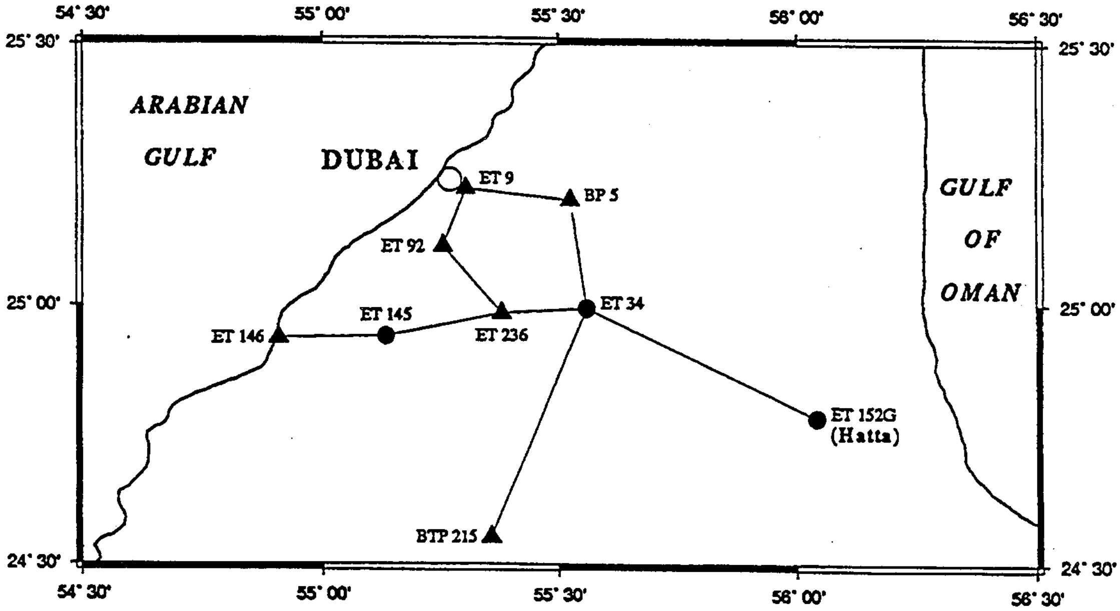

Figure 1: Gravity Base Net Dubai, Network Sketch (• absolute stations, ▲ relative stations tied to the absolute reference).

1.4 Site construction

Because most parts of Dubai are uninhabited desert areas, special sites were established in order to meet the high standards of absolute gravity determinations. A concrete pier of 75x75 cm^2 surface and 80 cm depth was constructed separately from the surrounding concrete floor of the stations. This enables the best possible protection of the instrument's interferometerbase from microseismic disturbances, produced by the dropping chamber during the individual drop experiments. Each pier was surrounded by an aluminium cabin of about 3x3x3 m^3. The cabin was air conditioned in order to protect the instrument against temperatures higher than 25°C, which regularly occur during daytime in desert areas. Electric power for the air-conditioning as well as for the instrument was supplied by a portable generator, which was about 200 m away and worked non-stop to power the gravity station until the disassembly of the instrument.

1.5 Results

Epoch	g [μm/s^2]
941108	9811157.294
941219	9811157.333

Tab. 2: Results of JILAG-3 calibration measurements in Clausthal before and after the Dubai campaign.

Before and after the Dubai field campaign, the instrumental stability of JILAG-3 was controlled on the IfE absolute reference station in Clausthal (Harz mountains / Germany). These two gravity determinations agree within 0.04 μm/s^2 (Tab. 2), indicating that no instrumental changes occured during the Dubai measurements. The results of the Dubai measurements are stored at the Planning & Surveying Department of Dubai Municipality. The precision (standard deviations of adjusted gravity values) of the gravity values is 0.02 to 0.03 μm/s^2, which is within the magnitude of other absolute gravity determinations with JILAG-3 or other absolute gravitymeters. Although the construction of the three sites is the same, significant differences in the "drop-to-drop"-scatter were found (Fig. 2,3), which are supposed to becaused by the environment (the station ET 145 with the largest scatter is located on sand and has the shortest distance to the coast-line).

2. Relative Measurements

In addition to the 3 absolute gravity determinations, 6 further stations of the national geodetic network of Dubai were connected to the new absolute datum, employing two of IfE's LaCoste&Romberg (LCR) model G gravimeters (G298, G709) and one LCR model D gravimeter (D191) of Dubai Municipality.

The feedback-systems of the two LCR model G gravimeters were calibrated before and after the Dubai campaign on the Hannover vertical calibration line. The manufacturer calibration of the LCR-D191 has been checked in the Hannover calibration system in October 1993. Measurements were carried out on the Cuxhaven-Harz calibration line (gravity range ~3000 μm/s^2) as well as on the Hannover vertical calibration line (gravity range ~200 μm/s^2). The adjustment of these observations led to an improvement of the manufacturer calibration in the order of 5×10^{-4}.

For the LCR model G gravimeters, the calibration functions have been found to be gravity range-dependent. The calibration functions determined in the Wuhan(China) calibration system [RÖDER 1994] have been applied a-priori, as the gravity range of this system is close to the Dubai gravity range.

3. Combined absolute/relative adjustment

The combined adjustment of the absolute and relative measurements was carried out using the program system GRAV [WENZEL 1993], kindly provided by Prof. H.G. Wenzel, Geodetic Institute, University of Karlsruhe.

As the calibration functions of LCR gravimeters have been found to be gravity range-dependent, the relative measurements between the absolute stations were used to derive linear calibration factors, fitted to the Dubai gravity range by least squares adjustment.

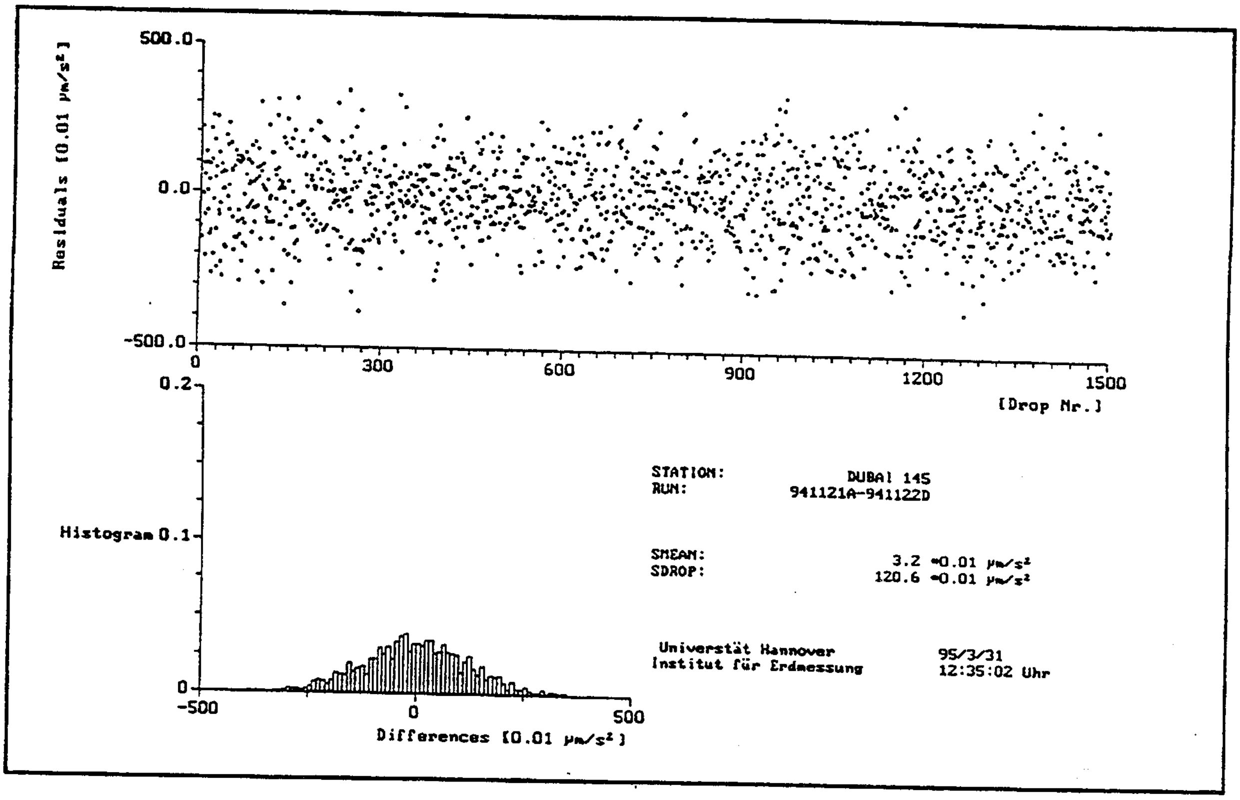

Figure 2: JILAG-3 absolute gravity measurements 1994. Drop-to-drop scatter on ET 145.

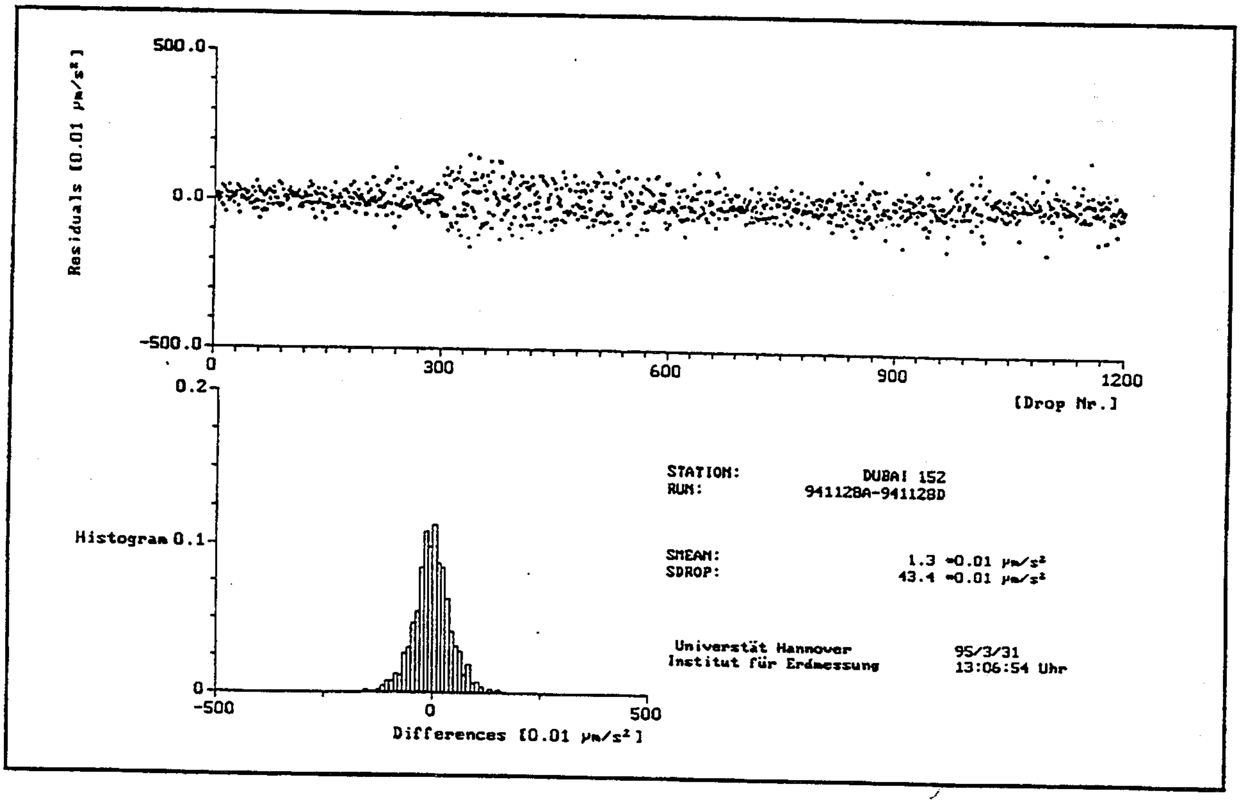

Figure 3: JILAG-3 absolute gravity measurements. Drop-to-drop scatter on ET 152G.

These linear factors were introduced in the subsequent combined adjustment of the absolute and relative gravity observations. The absolute gravity determinations have been introduced into the stochastic model with an accuracy of 0.07 $\mu m/s^2$ (which includes unmodelled systematic effects), which has proved to be a realistic value for the overall accuracy of JILAG-3 measurements. The a-priori standard deviation for an individual gravity difference measured with one LCR-gravimeter was introduced with 0.2 $\mu m/s^2$. The adjustment has been made in an iterative manner with respect to the variance estimations. The resulting precision estimates of the final solution, together with the number of measured ties with each gravimeter, are listed in Tab. 3. The higher accuracy of the feedback (F) mode is clearly to be seen.

Gravimeter	No. of Differences	Standard Deviation of single difference [$\mu m/s^2$]
LCR-D191	27	0.23
LCR-G298	25	0.13
LCR-G709	21	0.13
LCR-G298F	31	0.05
LCR-G709F	29	0.04

Tab. 3: Statistics of the employed LCR relative gravimeters as derived from the combined adjustment.

The accuracy (standard deviation) for the adjusted gravity values ranges between 0.04 (station ET34) and 0.09 $\mu m/s^2$ with an average of 0.06 $\mu m/s^2$, indicating a good homogeneity of the gravity network. The largest standard deviation (0.09 $\mu m/s^2$) is estimated for the point BTP 215 in the South of Dubai. There are mainly two factors that limit the accuracy achievable for this station. First of all, the point cannot be easily reached (~20 km transportation on desert track) which increases the residual drift uncertainties. In addition, the gravity value of this point is not covered by the absolute gravity observations, which leads to an extrapolation of the gravimeter calibration functions, with corresponding uncertainties. From the accuracy figures given above we can state that the new gravity base net is excellently suited for later use at geodetic, geophysical and GIS applications.

4. Conclusions

A fundamental gravity network has been established in the Emirate of Dubai. Three absolute gravity determinations were carried out with a precision (standard deviation of adjusted gravity values) of 0.02 to 0.03 $\mu m/s^2$ and an absolute accuracy of 0.07 $\mu m/s^2$ (including non-modelled systematic errors of instrumental and environmental type). These data provide the first absolute gravity control of this kind not only in the Arabian Peninsula, but in the whole western and southern parts of Asia. Additional six stations of the national geodetic network of Dubai have been connected to this absolute datum, by relative measurements using three LCR gravimeters. The accuracy of the final gravity values is estimated to be better than 0.1 $\mu m/s^2$ at each station. The network consequently can serve as a reliable base for further densification measurements and for long term control of gravity changes. The results of this first gravity survey also indicate a strong gravity anomaly. The height difference of about +200 m between ET 34 and ET 152G is accompanied by a gravity increase of +345 $\mu m/s^2$. If we apply the average Bouguer-factor of $\delta g/\delta H = -2\ \mu m s^{-2}/m$, a gravity difference of $\approx -400\ \mu m/s^2$ should be expected, which indicates a strong anomaly of about 750 $\mu m/s^2$ in the mountaineous Hatta region.

References

FALLER, J.E., GUO, Y.G., GSCHWIND, J., NIEBAUER, T.M., RINKER, R.L., XUE, J.: The JILA portable absolute gravity apparatus. Bulletin d'Information, Bureau Gravimetrique International, No. 53, p. 87-97, Toulouse, 1983.

RÖDER, R.H., SCHNÜLL, M., WENZEL, H.G.: SRW feedback for LaCoste&Romberg gravimeters with extended range. Bulletin d'Information, Bureau Gravimetrique International, Toulouse, No. 62, p. 46-50, 1988.

RÖDER, R.H.: Zum Einsatz des Absolutgravimeters JILAG-3 in Präzisionsschwerenetzen. Wiss. Arb. der Fachrichtung Vermessungswesen der Universität Hannover, Nr. 205, Hannover, 1994.

TIMMEN, L.: Untersuchungen zur Modellbildung bei der Auswertung absoluter Schweremessungen. Wiss. Arb. der Fachrichtung Vermessungswesen der Universität Hannover, Nr. 204, Hannover, 1994.

TIMMEN, L., WENZEL, H.G.: Worldwide Synthetic Gravity Tide Parameters. Paper presented at the Joint Symposium of the International Gravity Commission and the International Commission on the Geoid, Graz, September 1994.

TORGE, W.: Gravimetry and Tectonics. In: J. Kakkuri (ed.), Geodesy and Geophysics, Publ. of the Finnish Geodetic Institute, No. 115, p. 131-172, Helsinki, 1993.

WENZEL, H.G.: Programmsystem GRAV, Version 1.5. Programm Manual, Geodätisches Institut, Karlsruhe, 1993.