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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 5.1 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 has 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.

BUREAU GRAVIMETRIQUE
INTERNATIONAL

Toulouse

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PART I
INTERNAL MATTERS

GENERAL INFORMATIONS

- 1. HOW TO OBTAIN THE BULLETIN**
- 2. HOW TO REQUEST DATA**
- 3. USUAL SERVICES B.G.I. CAN PROVIDE**
- 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 informations 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 (74 have been issued as of June 30, 1994 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
31055 TOULOUSE CEDEX - 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

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.

<p style="text-align: center;">EOL LAND DATA FORMAT RECORD DESCRIPTION 126 characters</p>
--

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	(2 char.)
		The site of the gravity measurements is defined in a circle of radius R	
		0 = no information	
		1 - $R \leq 5$ Meters	
		2 = $5 < R \leq 20$ M (approximately 0'01)	
		3 = $20 < R \leq 100$ M	
		4 = $100 < R \leq 200$ M (approximately 0'1)	
		5 = $200 < R \leq 500$ M	
		6 = $500 < R \leq 1000$ M	
		7 = $1000 < R \leq 2000$ M (approximately 1')	
		8 = $2000 < R \leq 5000$ M	
		9 = $5000 < R$	
		10...	
	28-29	System of positioning	(2 char.)
		0 = no information	
		1 = topographical map	
		2 = trigonometric positioning	
		3 = satellite	
	30	Type of observation	(1 char.)
		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	
	31-38	Elevation of the station (unit : centimeter)	(8 char.)
	39-40	Elevation type	(2 char.)
		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)	
	41-42	Accuracy of elevation	(2 char.)
		0 = no information	
		1 = $E \leq 0.02$ M	
		2 = $.02 < E \leq 0.1$ M	
		3 = $.1 < E \leq 1$	
		4 = $1 < E \leq 2$	
		5 = $2 < E \leq 5$	
		6 = $5 < E \leq 10$	
		7 = $10 < E \leq 20$	
		8 = $20 < E \leq 50$	
		9 = $50 < E \leq 100$	
		10 = E superior to 100 M	
	43-44	Determination of the elevation	(2 char.)
		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	
	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)	(6 char.)
	Simple Bouguer anomaly with a mean density of 2.67. No terrain correction	
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)	(6 char.)
	<i>computed according to the next mentioned radius & density</i>	
86-87	Information about terrain correction	(2 char.)
	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	
88-91	Density used for terrain correction	(4 char.)
92-93	Accuracy of gravity	(2 char.)
	0 = no information	
	1 = $E \leq 0.01$ mgal	
	2 = $.01 < E \leq 0.05$ mgal	
	3 = $.05 < E \leq 0.1$ mgal	
	4 = $0.1 < E \leq 0.5$ mgal	
	5 = $0.5 < E \leq 1.$ mgal	
	6 = $1. < E \leq 3.$ mgal	
	7 = $3. < E \leq 5.$ mgal	
	8 = $5. < E \leq 10$ mgal	
	9 = $10. < E \leq 15.$ mgal	
	10 = $15. < E \leq 20.$ mgal	
	11 = $20. < E$ mgal	
94-99	Correction of observed gravity (unit : microgal)	(6 char.)
100-105	Reference station	(6 char.)
	<i>This station is the base station (BGI number) to which the concerned station is referred</i>	

106-108	Apparatus used for the measurement of G	(3 char.)
	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)	
	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.)

<p style="text-align: center;">EOS SEA DATA FORMAT RECORD DESCRIPTION 146 characters</p>

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	(2 char.)
		The site of the gravity measurements is defined in a circle of radius R	
		0 = no information	
		1 - $R \leq 5$ Meters	
		2 = $5 < R \leq 20$ M (approximately 0'01)	
		3 = $20 < R \leq 100$ M	
		4 = $100 < R \leq 200$ M (approximately 0'1)	
		5 = $200 < R \leq 500$ M	
		6 = $500 < R \leq 1000$ M	
		7 = $1000 < R \leq 2000$ M (approximately 1')	
		8 = $2000 < R \leq 5000$ M	
		9 = $5000 \text{ M} < R$	
		10...	
	28-29	System of positioning	(2 char.)
		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)	
	30	Type of observation	(1 char.)
		1 = individual observation at sea	
		2 = mean observation at sea obtained from a continuous recording	
	31-38	Elevation of the station (unit : centimeter)	(8 char.)
	39-40	Elevation type	(2 char.)
		1 = ocean surface	
		2 = ocean submerged	
		3 = ocean bottom	
	41-42	Accuracy of elevation	(2 char.)
		0 = no information	
		1 = $E \leq 0.02$ Meter	
		2 = $.02 < E \leq 0.1$ M	
		3 = $.1 < E \leq 1$	
		4 = $1 < E \leq 2$	
		5 = $2 < E \leq 5$	
		6 = $5 < E \leq 10$	
		7 = $10 < E \leq 20$	
		8 = $20 < E \leq 50$	
		9 = $50 < E \leq 100$	
		10 = E superior to 100 Meters	
	43-44	Determination of the elevation	(2 char.)
		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	
	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)	(6 char.)
		Simple Bouguer anomaly with a mean density of 2.67. No terrain correction	
	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) <i>computed according to the next mentioned radius & density</i>	(6 char.)
86-87	Information about terrain correction	(2 char.)
	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)	
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	14 = tc (unknown radius)	
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	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	
88-91	Density used for terrain correction	(4 char.)
92-93	Mathew's zone <i>when the depth is not corrected depth, this information is necessary. For example : zone 50 for the Eastern Mediterranean Sea</i>	(2 char.)
94-95	Accuracy of gravity	(2 char.)
	0 = no information	
	1 = $E \leq 0.01$ mgal	
	2 = $.01 < E \leq 0.05$ mgal	
	3 = $.05 < E \leq 0.1$ mgal	
	4 = $0.1 < E \leq 0.5$ mgal	
	5 = $0.5 < E \leq 1.$ mgal	
	6 = $1. < E \leq 3.$ mgal	
	7 = $3. < E \leq 5.$ mgal	
	8 = $5. < E \leq 10.$ mgal	
	9 = $10. < E \leq 15.$ mgal	
	10 = $15 < E \leq 20.$ mgal	
	11 = $20. < E$ mgal	
96-101	Correction of observed gravity (unit : microgal)	(6 char.)
102-110	Date of observation <i>in Julian day - 2 400 000 (unit : 1/10 000 of day)</i>	(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	(1 char.)
	0 = without restriction	
	1 = with authorization	
	2 = classified	
123	Validity	(1 char.)
	0 = no validation	
	1 = good	
	2 = doubtful	
	3 = lapsed	
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_0), 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 :

$$\gamma_0 = 978031.85 \times [1 + 0.005278895 * \sin^2(\phi) + 0.000023462 * \sin^4(\phi)] , \text{ mgals}$$

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 :

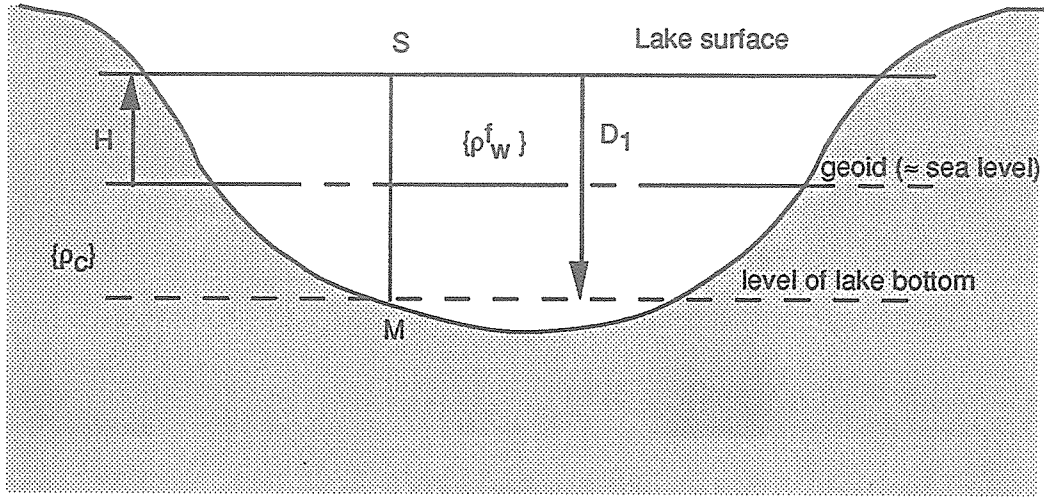
g	: observed value of gravity
γ	: theoretical value of gravity (on the ellipsoid)
Γ	: vertical gradient of gravity (approximated by 0.3086 mgal/meter)
H	: elevation of the physical surface of the land, lake or glacier ($H = 0$ at sea surface), positive upward
D_1	: depth of water, or ice, positive downward
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 ($667.2 \cdot 10^{-13} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$) $\Rightarrow k = 2 \pi G$
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_0 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).

* 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 :



$$g_S = g_M + 2 k \rho_w^f D_1 - \Gamma D_1$$

$$\Rightarrow FA = g_S + \Gamma H - \gamma_o$$

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

$$\begin{aligned} \delta g_s &= g_s - k \rho_w^f D_1 + k \rho_c (D_1 - H) \\ &= g_s - k \rho_w^f [H + (D_1 - H)] + k \rho_c (D_1 - H) \\ &= g_s - k \rho_w^f H + k (\rho_c - \rho_w^f) (D_1 - H) \\ \Rightarrow BO &= \delta g_s + \Gamma H - \gamma_o \end{aligned}$$

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	$FA = g + \Gamma H - \gamma_0$ $BO = FA - k \rho_c H$
2	Land Observation-subsurface	$FA = g + 2 k \rho_c D_2 + \Gamma (H - D_2) - \gamma_0$ $BO = FA - k \rho_c H$
3	Ocean Surface	$FA = g - \gamma_0$ $BO = FA + k (\rho_c - \rho_w^s) D_1$
4	Ocean submerged	$FA = g + (2 k \rho_w^s - \Gamma) D_2 - \gamma_0$ $BO = FA + k (\rho_c - \rho_w^s) D_1$
5	Ocean bottom	$FA = g + (2 k \rho_w^s - \Gamma) D_1 - \gamma_0$ $BO = FA + k (\rho_c - \rho_w^s) D_1$
6	Lake surface above sea level with bottom above sea level	$FA = g + \Gamma H - \gamma_0$ $BO = FA - k \rho_w^f D_1 - k \rho_c (H - D_1)$
7	Lake bottom, above sea level	$FA = g + 2 k \rho_w^f D_1 + \Gamma (H - D_1) - \gamma_0$ $BO = FA - k \rho_w^f D_1 - k \rho_c (H - D_1)$
8	Lake bottom, below sea level	$FA = g + 2 k \rho_w^f D_1 + \Gamma (H - D_1) - \gamma_0$ $BO = FA - k \rho_w^f H + k (\rho_c - \rho_w^f) (D_1 - H)$
9	Lake surface above sea level with bottom below sea level	$FA = g + \Gamma H - \gamma_0$ $BO = FA - k \rho_w^f H + k (\rho_c - \rho_w^f) (D_1 - H)$
A	Lake surface, below sea level (here $H < 0$)	$FA = g + \Gamma H - \gamma_0$ $BO = FA - k \rho_c H + k (\rho_c - \rho_w^f) D_1$
B	Lake bottom, with surface below sea level ($H < 0$)	$FA = g + (2 k \rho_w^f - \Gamma) D_1 + \Gamma H - \gamma_0$ $BO = FA - k \rho_c H + k (\rho_c - \rho_w^f) D_1$
C	Ice cap surface, with bottom below sea level	$FA = g + \Gamma H - \gamma_0$ $BO = FA - k \rho_i H + k (\rho_c - \rho_i) (D_1 - H)$
D	Ice cap surface, with bottom above sea level	$FA = g + \Gamma H - \gamma_0$ $BO = FA - k \rho_i D_1 - k \rho_c (H - D_1)$

2.6 Satellite Altimetry Data

BGI has access to the Geos 3, Seasat and Geosat data bases which are managed by the Groupe de Recherches de Géodésie Spatiale (GRGS). These data are now in the public domain. ERS1 and TOPEX-POSEIDON data are not.

Since January 1, 1987, the following procedure has been applied :

- (a) Requests for satellite altimetry derived geoid heights (N), that is : time (julian date), longitude, latitude, N, are processed by BGI for small areas (smaller than $20^{\circ} \times 20^{\circ}$), and forwarded to GRGS for larger areas.*
- (b) Requests for the full altimeter measurements records are forwarded to GRGS, or NASA in the case of massive request.*

In all cases, the geographical area (polygon) and beginning and end of epoch (if necessary) should be given.

All requests for data must be sent to :

*Mr. Gilles BALMA
Bureau Gravimétrique International
18, Avenue E. Belin - 31055 Toulouse Cedex - France*

*In case of a request made by telephone, it should be followed by a confirmation letter, or telex.
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, formatted (EBCDIC) on labeled 9-track tape (s) with a fixed block size, for large amounts of data, or on diskette in the case of small files. The exact physical format will be indicated in each case.

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 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 tape - 1600 BPI*
 - (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 scales, 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).

. 5F/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 Δ x Δ' 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

..1 F per measurement

. minimum charge : 150 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 the polygon.

3.2.3. Data Screening

. 1 F per screened point

. 250 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

Tape 100 F (+ tape price, if not to be returned)

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

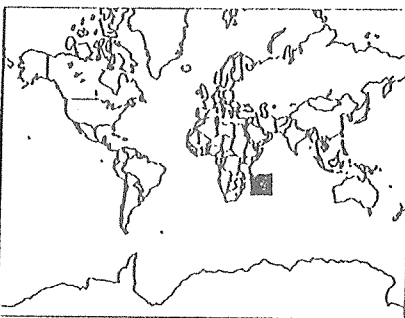
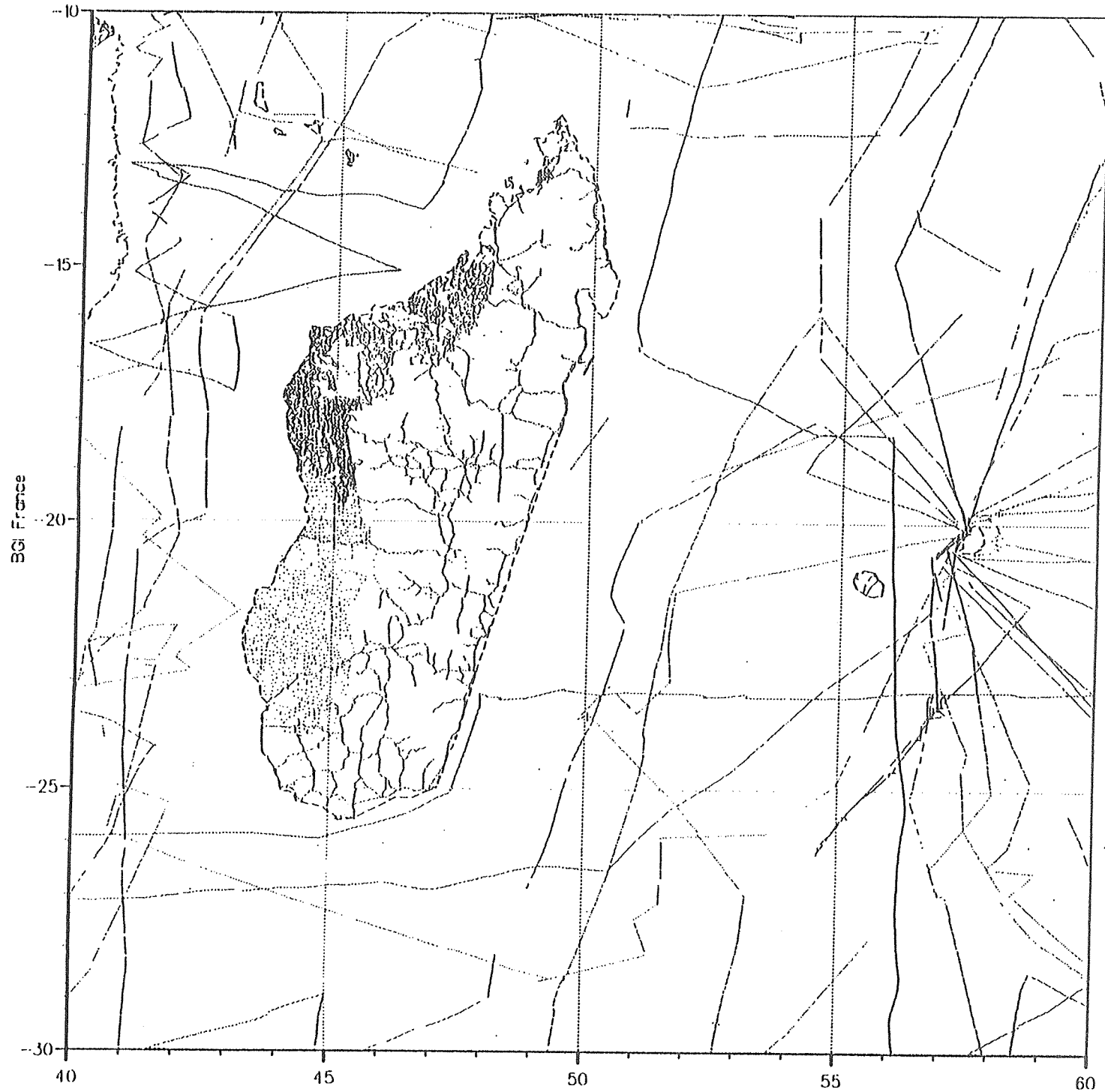
THE UNIFICATION OF THE GRAVITY NETS OF AFRICA

(Vol. 1 and 2)	1979	150 FF
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. Black and white copy of maps : 150 F per copy

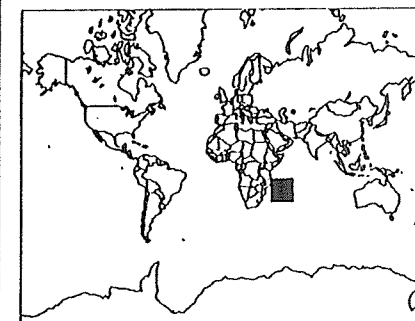
. Colour copy : price according to specifications of request.

Mailing charges will be added for air-mail parcels when "Air-Mail" is requested)
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Map 1. Example of data coverage plot

BGI France	-10	214	102	15	52	8	26	29	184	53	65	26	8	116	138	51	44	52	85		66
		23.3	-38.8	5.6	-25.9	-14.5	-18.3	-27.7	-22.5	-23.9	-27.9	-8.2	-7.2	-5.5	-13.1	-5.8	-3.8	-1.5	-9.2		-13.9
		10.1	42.1	6.2	12.0	1.3	4.3	17.6	26.3	10.3	26.7	37.4	24.0	8.2	11.1	6.0	12.2	23.2	9.1		9.4
			118	39	53	37	41		85		2	13	82	43	29	3	25	68	40		37
			-11.0	-14.1	66.2	-16.6	-26.4		-42.6		77.7	-45.1	-12.9	-7.7	-16.9	-7.8	-2.6	-14.2	-1.7		-21.3
			30.0	12.6	89.8	16.6	3.9		9.9		2.8	4.8	16.3	8.4	4.3	12	13.6	10.5	2.6		5.9
		21	207	51	28	98	74		99	14	111	15	101	26	26	35	58	50	6		16
		-55.9	-41.0	-63.4	93.6	6.4	66.8	-47.1	-58.0	37.9	54.8	-32.7	-17.2	-12.3	-20.4	-23.8	-11.0	-8.6	-6.1		58.7
		5.6	15.9	12.2	114.6	83.8	121.5	3.7	6.1	9.1	17.3	1.7	4.5	6.0	5.9	3.1	13.1	10.1	1.4		4.8
		3	334	170	204	125	84	172	35	155	117	4	72			23	1	49			62
		-47.8	-13.0	-40.3	-39.8	-52.1	-40.1	-38.4	-32.0	29.6	34.3	82.6	-5.9			-0.2	21.7	-4.5			12.4
		1.8	30.1	11.7	8.3	4.7	5.6	8.0	37.7	16.6	15.9	10.5	3.5			6.7	0.0	5.5			54.4
			249	13	88	84	97		87	101	44	60	71			31	11	62	41	3	49
			13.8	-37.0	-28.4	-36.3	-42.4		-13.1	1.2	12.3	47.6	-10.8			-8.6	11.9	3.7		12.3	-39.7
			72.1	3.0	4.0	7.6	5.2		12.8	32.6	16.4	20.2	4.5			4.7	4.2	7.3	11.4	0.4	10.8
	-15	1	220	548	396	151	103	329	617	146	38	47	35			40	6	32	9	68	7
		-45.2	-40.7	-22.3	-63.3	-72.8	-63.1	-12.2	-18.2	-5.0	-36.5	1.3	-27.3			29.0	1.4	8.8	-7.4	-17.7	-33.3
		0.0	42.1	12.7	8.2	25.2	33.0	14.5	10.5	10.3	6.8	28.1	2.4			54.2	1.6	10.7	3.3	17.1	3.0
		102	421	158	176	348	416	407	244	53	117	45	51		16	60	14	73	6	95	31
		-20.1	-51.3	-40.4	-25.6	12.6	-5.2	-26.0	-3.2	50.4	0.3	-15.8	-14.9		-18.2	-14.3	-10.6	4.9	-18.4	-0.0	57.7
		14.1	40.2	16.0	10.6	19.8	15.2	8.9	12.8	19.5	20.4	12.2	11.7		3.6	13.9	16.2	9.3	2.5	19.4	50.5
		22	81	98	136	782	399	83	76	110	66	3	27	79	106	14	116	64	28	98	23
		-9.1	-47.6	-4.4	-18.1	6.1	8.0	-10.4	50.3	35.0	15.9	-43.9	-16.8	-2.1	-2.2	3.4	-7.4	-6.5	-19.8	-2.5	39.5
		13.1	36.5	28.1	12.5	24.4	17.8	22.3	33.1	20.6	19.4	2.1	4.3	6.9	5.6	5.2	10.8	17.9	10.5	41.4	30.2
		47	23	32		725	387	155	202	137	80	13		47	70	167	198	81	59	23	34
		-38.9	-27.4	21.1		-7.6	-9.2	46.4	62.1	23.2	18.5	-47.8		-7.0	-8.0	-0.3	-5.1	-32.7	25.1	36.9	-0.3
		7.4	29.7	12.5		11.8	33.8	12.9	16.1	25.1	32.6	3.0		6.6	6.1	11.8	14.1	13.0	50.0	59.0	25.8
		37	46	38		478	336	115	171	91	2	2	37	73		26	96	114	241	105	66
		-41.2	-45.8	16.8		-20.2	-23.4	40.8	67.2	31.8	56.6	-9.8	-13.3	-8.8		-13.0	-25.8	-59.0	74.2	-14.7	4.5
	-20	8.6	15.1	19.8		10.0	19.7	20.0	18.7	26.5	2.1	1.1	3.7	8.2		5.3	8.9	24.2	105.9	72.2	27.9
		24	96	12	6	151	144	49	104	81		43	12	12	23	24	47	145	366	71	46
		-22.6	-21.2	-29.8	4.3	5.1	-15.8	49.4	49.6	47.0		-21.3	-3.8	-1.7	-3.7	8.8	149.9	-24.2	8.8	-31.9	-0.8
		7.4	14.5	16.2	2.3	28.1	28.3	27.5	22.1	39.1		7.3	8.8	15.2	15.9	23.7	88.1	33.3	71.3	28.5	17.0
		25	67	29	87	166	82	146	176	99		52	48	24	8	1	65	177	212	170	44
		-25.5	-10.5	-16.1	13.8	-2.7	-4.3	26.4	-5.8	46.9		-24.8	2.7	-5.5	-18.5	13.0	281.3	-4.5	-29.4	-2.4	16.5
		6.9	8.9	20.0	11.2	14.8	19.9	16.7	33.8	39.3		5.7	6.2	1.2	4.5	0.0	61.4	53.0	24.2	16.1	9.0
		110	81	30	113	200	166	149	205	13		45	50		1	5	46	170	100	106	108
		6.4	3.3	-20.8	30.0	17.6	41.8	29.4	7.6	75.7		-14.0	-6.0		1.6	-2.8	-14.4	-8.7	-15.0	-0.8	9.4
		27.8	11.5	11.0	12.9	16.0	30.8	19.1	34.6	3.6		1.7	12.3		0.0	1.0	4.6	11.9	24.7	14.4	14.1
		122	33		76	237	118	46	157	145	116	214	157	105	76	97	79	294	166	87	124
		-2.8	3.1		27.0	11.4	31.8	36.0	32.3	-7.5	-2.8	-25.0	7.3	21.2	5.2	11.1	5.2	9.0	-8.6	2.6	-8.0
		10.0	9.1		12.3	23.4	14.8	17.4	29.4	6.2	7.5	13.6	10.6	16.0	3.5	7.2	32.8	9.6	26.1	10.0	14.1
		28	99		28	132	150	139	131		34	17	47	27	27	6	49	173	41	29	
		-3.2	1.2		39.4	50.4	30.0	11.0	27.0		-7.5	-16.5	3.7	3.7	1.6	42.8	3.1	5.9	-21.1	-12.5	
		6.1	15.8		10.6	10.8	9.8	34.3	42.3		4.0	3.6	5.4	3.8	9.3	3.2	14.9	10.7	25.3	17.2	
	-25	109	130	58	58	104	161	123	31	1	45	24	65	50	13	42	70	100	47	26	24
		-8.9	-1.5	3.7	1.2	19.5	11.4	41.3	66.7	-24.9	-12.2	-1.7	-4.4	4.0	13.9	0.5	-8.9	6.4	-3.7	-8.1	-6.5
		9.6	10.3	7.0	14.4	32.7	28.4	41.0	19.1	0.0	6.2	7.3	7.6	7.5	3.2	23.3	3.7	4.0	18.7	2.9	9.6
		37	77	51	49	34	37	30	35	48	71	68	26	21	9	15		105	26	57	13
		-27.9	10.9	2.2	-14.7	-22.2	-7.4	-6.7	-7.5	-20.5	-16.2	-12.2	-7.1	-11.9	-9.7	-17.9		2.1	9.4	-7.7	-18.2
		4.9	23.4	10.5	21.6	21.0	6.9	10.4	5.9	7.6	4.7	5.9	3.7	5.8	1.1	4.5		7.7	22.9	10.1	7.4
		54	74	3		18	20	30	7		3	21	28		25		4	78	24	34	27
		-12.2	-1.1	-5.7		10.3	42.4	59.4	36.5		2.4	-1.7	0.9		-11.6		-8.9	6.7	1.5	-29.5	-0.1
		13.3	14.6	0.5		21.1	10.4	22.8	10.5		1.1	4.3	10.3		4.2		2.6	3.3	3.2	21.5	17.3
		32	34			12	1		14		58	67	19	10	17	6	16	115	29	29	108
		-23.9	-14.1			10.7	6.2		39.6	33.9	14.5	-3.2	-6.9	8.6	-3.2	-12.0	-0.8	-3.5	-3.6	1.2	12.4
		8.2	4.9			4.8	0.0		6.4	16.1	6.7	3.9	11.8	4.4	1.9	5.3	3.1	10.0	19.9	15.2	20.6
			55	31	33	64	9	21	40	3	24			37	11	23		88	56	111	36
			-13.2	3.9	-6.1	16.1	47.1	20.3	11.7	7.7	23.1			16.7	-6.2	-5.6		0.1	0.6	1.4	20.6
	-30		8.3	3.9	16.4	17.5	22.8	17.2	4.6	0.4	12.0			8.0	4.8	3.8		7.2	20.9	17.5	8.7



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

BGI GRAVITY DATA MEAN FREE AIR ANOMALY

1st field : number of points
2nd field : mean value (mgal)
3rd field : Std. Dev. (mgal)

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.

* 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 magnetic 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

INTERNATIONAL ASSOCIATION OF GEODESY INTERNATIONAL GRAVITY COMMISSION

IGINIO MARSON
REPORT presented at the XII Meeting
of the International Gravity Commission

JOINT MEETING OF THE INTERNATIONAL GRAVITY COMMISSION AND THE INTERNATIONAL
COMMISSION FOR THE GEOID

GRAZ, AUSTRIA, 11-17 SEPTEMBER 1994

Introduction.

The International Gravity Commission has supported scientific projects and achieved important results thanks to the work of the members of the Directing Board, the Chairmen and Members of the Working Groups, Chairmen and Members of the few Subcommission which are presently active, Director and Staff Members of the Bureau Gravimétrique International, National Representatives and all the scientists who have contributed to the achievements in gravimetry during the last four years.

In the following report I have tried to summarize the most relevant activities in gravimetry as reported by the national representatives who have submitted reports. These unfortunately do not give complete image of the gravity community since several national reports are still missing. However the picture is of an active scientific community which deals with several branches of gravimetry and tackles the most modern problems of the field.

Important activities have been performed in absolute gravimetry in the last period. For the first time, absolute gravimeters are commercially available. This has increased the number of gravimeters that are available to the community and therefore encouraged the uses of absolute gravimetry in several fields of geodesy and geophysics. Improvements and new developments by scientific institutions have focused on the increase of the reliability of the instruments so to assure the highest accuracy to the users of this tool. Absolute gravimetry is currently employed in the traditional field of geodetic metrology (gravity datum and gravity scale, fundamental networks), in the study of secular and long-term gravity changes, in the assessment of the fluctuations of the mean sea level, in association with space geodetic measurements for the study of crustal deformations (mainly of the vertical component).

The availability of absolute measurements has encouraged several countries to redesign and remeasure the Fundamental Gravity Nets. Most of the Zero Order Reference networks are based on absolute sites. IGC recommends the use of absolute gravimetry for these purposes. The recent political events in former eastern European countries have brought up the need of unifying all the gravity data in a common frame. This is important not only for the problem strictly related to gravimetry, but also, for instance, for the definition of a worldwide geoid for cartographic purposes. Absolute gravimetry offers the easiest and optimal solution. The International Gravity Commission has been approached by DMA and BGI to coordinate an international Project which aims at the establishment of absolute gravity sites in the Central European Countries. The program was initiated at the end of 1993 with the establishment of the first core of the team of absolute gravimeters and gravimetrists and during 1994 the field campaigns have been initiated as well. IGC has encouraged and will encourage the participation in this project of all the absolute teams and all the countries which might be interested.

On a continental scale adjustment of the Unified European Gravity Network has been completed. This is an adjustment of the available national gravity networks of several European countries together with a considerable amount of absolute sites.

Airborne gravimetry is attracting the interest of several scientists as well as of commercial companies. Most important, large scale airborne gravity surveys have been performed in the last years in Switzerland and Greenland with satisfactory results. This tool will become increasingly important in the near future.

Relevant activities have been performed also in the more traditional fields of gravity mapping, both at land and at sea, in microgravimetry for geodetic (crustal deformation) and geophysical (earthquake and volcanic risk, geothermal fields, archeology) fields, in the mathematical development of algorithms for reduction, interpretation and inversion of gravity data and in the geophysical interpretation of gravity data.

Absolute Gravimetry.

This field of gravimetry has witnessed a significative increasing activity during the last four years. Absolute gravity meters are now available from a commercial company and this has considerably increased the number of gravimeters that are available to the scientific community. In addition to these, a few prototypes have been developed,

and others are still in development, by scientific institutions. This has certainly contributed to a wider use of absolute gravimetry in different fields of geodesy and geophysics.

It is worth mentioning the establishment of absolute gravity sites in Antarctica (Italy at Terra Nova Bay, Japan at Syowa - where in 1993 a Superconducting gravity meter was installed as well - and Finland) since it represents the optimal solution to the problem of the definition of the gravity datum in an unsurveyed area, and certainly Antarctica is not an easy area for traditional long range ties.

Secular changes of gravity have been studied at the Geodetic Observatory of Pecny (Czech Republic) by instruments of different types (GABL, JILAG-8 and FG5 107). In addition to this, the Czech Republic is undertaking a project to strengthen their national gravity control net which includes another five absolute sites.

Repeated absolute and relative measurements have been used to establish an absolute gravity baseline between Hannover and Potsdam in Germany. Three absolute sites have been taken as nodal points of a calibration line (200 mgal) in southern Italy.

Absolute gravimetry has been widely applied in several projects for monitoring the fluctuations of the mean sea level in Italy (10 sites), France (2 sites), Germany (11 sites in the Baltic and North Sea), Greece (8 sites), Spain (2 sites) and the Black Sea area (2 sites).

An absolute campaign in South America (Argentina and Uruguay) has been performed by IFE, Germany. New absolute sites have been installed in Buenos Aires, San Juan, Comodoro Rivadavia and Paysandy. Toledo (Montevideo) was reoccupied.

The Geographical Survey Institute has observed six sites using a rise-and-fall gravity meter in Japan, where also a small intercomparison campaign has taken place among Jaeger/BIPM, a JILAG and FG5 instruments.

The gravity datum and gravity scale of Netherlands have been determined by four absolute sites established by IFE, Hannover at Delft, Kootwijk, Westerbork and Epen.

Seven new absolute sites have been established in Finland with the JILAg-5 gravity meter. A co-location of JILAg-105 and FG5-102 and FG5-101 has been performed at Onsla A site.

Four new absolute sites have been measured in Switzerland by BEV, Austria as contribution to the new fundamental gravity network of Switzerland.

Airborne Gravimetry.

There is a great interest in the gravity community in the developments and uses of air- and space-borne gravimetry and gradiometry. The space missions, which include gradiometry and gravimetry, have been subjected to serious delays or cancelled, but important activities in airborne gravimetry have been performed in the recent years.

Interesting experiments on the use of GPS for airborne gravimetry have been performed by the Inst. of geodesy and navigation in Germany.

In Nov. 1992 the Geodetic and Geodynamic Lab of the ETH Zurich in cooperation with La Coste & Romberg has conducted a 6000 km line airborne gravimetric survey covering the whole of Switzerland. The first results show an average difference of 3.4 mgal at the crossing points of lines flown at the same altitude.

Fundamental gravity networks.

The wider use of absolute gravimetry has generated a considerably higher number of fundamental gravity stations, so that several countries have redesigned, and in some cases have also already measured their Fundamental Gravity Nets. Important activities are reported in the upgrading of the gravity datum of the European countries belonging to the former "eastern European block" by means of absolute gravimetry and relative ties to absolute sites.

The national gravimetric network of the Czech Republic has been updated by field measurements and ties to neighbouring countries (Germany, Austria, Hungary and Slovakia). More measurements, specially to tie the new absolute sites are now being performed.

Re-observation of the German Fundamental Gravity Network is being carried out. An important role will be played by the use of the two absolute gravity meters now available in Germany. First and second Order networks in Germany are almost complete.

A new Reference National Network is currently being measured in Italy. The new Net will use the twenty new absolute gravity sites established in Italy during the last three years.

Fundamental and first order gravity nets of Japan have been completed in 1993.

The Hungarian fundamental net, completed in 1989 and based on five absolute gravity stations observed with a GABL gravity meter, has been implemented by three additional absolute sites carried out with JILAG and FG5 gravity meters. The Hungarian network is tied to the Austrian and Slovakian ones.

Gravity measurements at the high precision levelling network of Portugal have been completed in the period 1990-92, in order to establish a first order network to support the observations of the second order network and to cover the fundamental bench marks of the Portuguese high precision levelling network. Two absolute sites at the Azores (Faial and Flores) islands have been measured by the Finnish JILAg meter.

The new Swedish gravity datum is now provided by the Zero Order gravity Net, which includes the absolute site of Martsbo and ties to the absolute sites of Goteborg, Copenhagen and Sodankyla. Measurements on the first and second order net have also been performed.

Measurements for a new and more precise fundamental gravity network in Switzerland were started in 1991. The stations of the network coincide, whenever possible, with benchmarks of the fundamental GPS network of Switzerland. The net includes five absolute gravity stations.

The Turkish Fundamental Gravity Network 1956 has been adjusted in 1991 and the second order network (3940 stations) has been measured.

Microgravimetry.

Traditionally a field of intense activities which last for several years since most microgravity projects are long-term studies. Gravity changes induced by seismicity, volcanism, exploitation of geothermal fields, geodynamics processes are typical fields of interest of this branch of gravimetry. Microgravity mapping for civil engineering, archeology and environmental geophysics has been also reported by several national representatives.

The active tectonics of the Andes is being studied by DGFI (Germany) and Cartografia Nacional de Venezuela. For the earthquake prediction program in North Anatolia, an interdisciplinary Turkish-German project has established microgravity networks in Turkey.

Microgravity surveys for volcanic hazard assessment are reported in Italy (Vesuvio, Vulcano, Etna), Greece (Santorini), Japan (Unzen volcano where gravity changes of up to 100 μgal within about 3 years have been observed), Yellowstone National Park (cooperation between Geophysics Dept. of the University of Utah and ETH Zurich, Switzerland).

The study of gravity change for earthquake predictions projects are being carried out in Greece (Crete), Italy (Friuli, Calabrian Arc), Japan (which carries out an intensive earthquake prediction program where microgravity is widely used: Okushiri Island, Izu Peninsula, Akita-Fukaura....)

The exploitation of geothermal fields induces gravity variations for reasons which range from the variation of water level in the shallow aquifers to the change in density due to the change in temperature or pressure in the reservoir. Microgravity surveys to detect and study these variations have been reported in Italy and Japan.

Microgravity surveys for archeological purposes have been performed in Italy, Greece and Turkey.

The post glacial rebound of Fennoscandia, which is studied by repeated gravity observations along the Fennoscandians Land Uplift Gravity Lines has been continued in 1993 with measurements on the 63 line. The whole series of measurements is now beginning to allow geophysical conclusions.

Land gravimetry and mapping.

Regional and local gravity data for geophysical purposes have been acquired in Finland (33165 stations in regional gravity measurements, 46000 in profile measurements and 43650 stations for local systematic measurements).

The Bouguer anomaly maps 1:50000 and 1:250000 of Germany have been compiled in 1992 and 1993/94, respectively.

A new Bouguer anomaly map 1:500000 of Italy, based on something like 300.000 land gravity sites has been compiled and published.

3560 gravity stations were measured in various area of Greece: 1174 in Igoumenitsa, 1315 in Kastoria, 292 in Skolis and 979 in Grevena. A new Gravity Anomaly Map of Greece has been recompiled and will be published in 1994. The gravity data bank of Greece, comprising some 22000 gravity stations, has been also completed.

Local gravity surveys for different purposes have been performed in Japan. Among them, Hokkaido district (more than 8000 gravity sites), geothermal areas of Okushi-to and Nikorikawa caldera, South-Western Japan (13000 new gravity sites which brings the data base up to 26000 gravity observations), Lake Biwa and many others.

A gravity survey made on the ice of the Bothnian Sea in 1994 by the Geological Survey of Sweden and the Geodetic Institute of Finland is particularly worth of mention.

In the frame of a systematic gravity mapping of Switzerland at a scale of 1:100000 the Geophysical Institute of the Univ. of Lausanne has measured some 5500 new points.

About 70000 gravity data have been screened in order to compute the Bouguer Anomaly Map of Turkey at the scales 1:100000, 1:500000, 1:2000000.

Marine gravimetry.

A detailed gravimetric survey has been performed in the German bay (North Sea) by IFE, Hannover on an area of about 100 km x 100 km.

In the framework of the Italian project for scientific research in Antarctica, marine gravity surveys on an area of about 1000 km x 1000 km on the Ross Sea, has been performed by OGS, Trieste, Italy.

A significant number of gravity stations were carried out mainly in the marine area north of Crete, in the Cretan Sea. The relative Bouguer anomaly map has been published.

Geological Survey of Japan, Hydrographic Department of Japan, Ocean Research Institute of the Univ. of Tokyo have been involved in several important projects for the measurement of marine gravity data as part of the geological mapping program of the continental margin around the Japanese islands.

The gravity project on the North sea initiated by Netherlands in 1986 has been completed in 1992 by a survey on the Waddenzee and the Ljsselmeer.

**Minutes of the Directing Board of the Bureau Gravimétrique International
held on 10th September 1994 in Graz, Austria, at the Graz University of Technology**

Present : Marson (Chair), Balmino, Boedecker, Courtier, Faller, Forsberg, Groten, Klingele, Mäkinen, Poitevin, Sünkel, Wenzel. Guest: Professor Torge.

1) New members of the Directing Board

It was agreed that the Director of the International Geoid Service be an ex-officio member of the board.

Tscherning wishes to retire from the board. A proposal will be made to the commission that he be replaced by Forsberg.

2) Report of the Director of the BGI (Balmino)

2.1) Balmino presented the BGI Activity Report January 1, 1993 to August 31, 1994.

The most striking fact is the increase of marine measurements (about 9 million points) in the data base, which results from the merging with the NGDC marine data (after validation).

2.2) The current status of the CD-ROM is an 'alpha' release for UNIX systems containing only land gravity data. The full release of land and marine point data, on 2 CDs for both UNIX and DOS, will be made before 1995. Restricted data will show only as XY coordinates with an indication of how to obtain the full information.

The board agreed that the price of the CD-ROM should be based on the cost of data bases of comparable size and quality. There should be a special reduced price for customers who participate fully in providing data to the BGI.

3) IGC Activities (Marson)

3.1) In response to a request from DMA and BGI to establish a common gravity datum for former Eastern European countries the IGC has initiated a project to coordinate the supply of absolute gravity measurements. Five absolute meters are currently involved and field campaigns are underway.

3.2) Many national reports have not been received. The format and media for these reports were discussed. It was agreed that they should be reduced to less than three pages and be available for retrieval/update on FTP/MOSAIC. Marson will send details of the new format to national representatives.

3.3) A questionnaire on the 'present and future activities in gravimetry' has been designed and distributed to 200 people. A second distribution will be made to ensure the responses represent a complete cross section of the community. Final results will be distributed prior to the Boulder assembly in 1995.

4) Reports from Working Group Chairmen

4.1) WG1 - Data Processing

This working group has fulfilled its objectives and is now closed.

4.2) WG2 - World Gravity Standards (Boedecker)

The United European Gravity Network (UEGN) now consists of 15000 observations from 11 countries. Data and station descriptions for the 500 points used in the final adjustment will be sent to the BGI.

The catalog of IAGBN-A (global control sites) and IAGBN-B (other absolute sites) has been updated. It contains extended documentation for the 'A' stations and single line data for the 'B' stations.

The catalog is available in hard copy but is not ready for distribution in computer form as standard formats for data and site descriptions are not yet in common use. Once these standards are established (two to three years time) it is hoped that the BGI will take over the collection of data.

Absolute gravity measurements should be collocated with other geophysically meaningful observations (SSG's, GPS, VLBI, etc) or vice versa. It is desirable to have geometric control at all IAGBN-A sites.

The trend to control relative networks by absolute measurements instead of the IGSN will necessitate more work on reference systems.

The task of WG2 is 70% complete and it is important to complete the formats and standards for data exchange. It was agreed that WG2 should continue for another four-year term.

4.3) WG5 - Monitoring of Non-tidal Gravity Variations (Poitevin)

4.3.1) A successful workshop was held in Walferdange in 1994 with 60 present and 41 participants. The proceedings will be published and widely distributed prior to the Boulder IUGG assembly in 1995.

It is important to repeat absolute measurements until consistent results are obtained. One measurement every five years is inadequate. Environmental effects must be carefully monitored.

One or two sites per continent with collocated absolute and superconducting gravimeters with geometric control and environmental monitoring would help to determine global gravity change.

4.3.2) Links between WG5, the work in Commission V on the Monitoring of Tidal Gravity Variations, and the Global Geodynamics Project (GGP) were discussed.

The overlap between the two working groups from the Commissions is such that they could be combined into a single group reporting to both Commissions. Marson will contact Hsu.

The GGP is an inter union group, active and worthwhile, and should be officially recognized by the IAG. The GGP investigations into the Chandler wobble and the nearly diurnal free wobble will be of direct benefit to the IAG.

The board felt the title "Global Geodynamics" is too encompassing and should be modified to more correctly represent the project. Marson will discuss this with the GGP group prior to recommending the introduction of an IAG resolution.

4.4) WG6 - Intercomparisons of absolute meters (Marson)

The Fourth International Intercomparison of Absolute Meters and a workshop were held in Sèvres in 1994. Results and proceedings will be published in a special edition of Metrologia on gravimetry.

Another intercomparison should be held in Sèvres in 1998 and should include laser, clock and barometer calibrations.

Because of the increasing number of absolute gravimeters (now 30 + worldwide) not all will be able to participate at Sèvres. Secondary continental intercomparison campaigns should follow the main intercomparison. Possible sites : N. America - Table Mountain, Europe - Helsinki, Asia - Beijing.

Marson will contact Becker regarding the future of relative measurements at Sèvres.

5) Subcommissions

No activity reports have been received from the three subcommissions (North Pacific - Nakagawa, North America - Moose, Western Europe - Ruess).

6) Preparations for the Graz IGC assembly

Discussed.

7) IUGG General Assembly and related topics (Wenzel)

Sessions at the Boulder 1995 assembly that may be particularly relevant:

IAG Symposia :

- Trends in Precise Terrestrial, Airborne and Spaceborne Applications.
- Geodesy in Southeast Asia.
- Global Gravity Field and its Temporal Variations.

IAG Joint Symposia :

- Earth Rotation : An Interdisciplinary Approach to Earth System Science.
- Crustal Deformation Along Plate Boundaries.
- Geodetic, Remote Sensing and Seismic Methods for Monitoring of Volcanic Activities.

IAG Inter-Section Symposia :

- Airborne Gravity Field Determination.

IAG Section III Business :

- Business Session : Report of Section, Commissions, Data Services, Special Study Groups.

Abstracts must be submitted to the Local Organizing Committee (A.G.U.) by 1st February 1995. -

Terms and extensions for special study groups must be reviewed in 1995.

Elections will be held for officers of the IAG. Nominations should reach the nominating committee before 31st January 1995.

8) Next Meeting

The next meeting of the Directing Board will be held during the first week of the 1995 Boulder Assembly.

GRAVITY and GEOID

**Joint Symposium
of the
International Gravity Commission
and the
International Geoid Commission**

Graz, Sep. 11 - 17, 1994

Organized by

H. Sünkel

**Mathematical Geodesy and Geoinformatics
Graz University of Technology**

ADOPTED RESOLUTIONS

Resolution 1

Recognizing the effort to coordinate the measurement of gravity using a network of existing and future superconducting gravimeters supplemented by periodic measurements with absolute gravimeters, IGC supports the establishment of a 6-years observation period in the framework of the "Global Geodynamics Projects (GGP)" for a global monitoring of the gravity field.

Resolution 2

Considering the need for a homogeneous global gravity coverage and realizing that airborne gravimetry provides very efficient means to fill the large data gaps still existing,

1. IGC/ICG proposes an international cooperative program for the determination of the gravity field in Antarctica and encourages its members to participate in this effort.
2. IGC/ICG strongly supports the further development of airborne gravity techniques with the goal of resolving wavelengths of the gravity spectrum below 200 km with an rms error of 10^{-5}m/s^2 (1 mGal) or better.

Resolution 3

Recognizing the importance of the work done by the International Geoid Service in providing data and scientific advice to geoid determination projects, we thank

1. the IGeS and its sponsors for having quickly set up an efficient operation and
2. its sponsors, the National Italian Research Council, the Istituto Geografico Militare and the Politecnico di Milano for their valuable support

and urge these sponsoring agencies to provide support such that a permanent base for the activities of IGeS can be maintained.

Resolution 4

Recognizing the importance of a high-precision geoid for both scientific and operational applications, and that the European geoid is serving as a prototype for similar continent-wide

computations, we thank the German authorities and Institut für Erdmessung (Hannover) for its support in these tests and urge continued support to be provided to allow continuation of this project to completion.

Resolution 5

The International Gravity Commission and the International Commission for the Geoid

Considering

that the global Earth gravity field models are not yet accurate enough to provide for a centimeter level geoid over distances of a few hundred kilometers as required for instance in oceanography to enable better modelling of the ocean circulation in relation with climatic and environmental studies,

Considering also

that, although there has been some recent progress in the availability of gravity information over some countries, and despite some improvement in the high resolution measurement of the Earth gravity field over limited areas by airborne gravimetry techniques, performing the full mapping of gravity over the Earth's surface seems unrealistic by these methods,

Strongly recommend

that the space agencies of the world reconsider the development of a dedicated satellite mission for improving our knowledge of our planet's gravity field in a global and homogeneous way, and give it the highest possible priority in their mission planning.

<p>PART II</p> <p>CONTRIBUTING PAPERS</p>

WORLDWIDE SYNTHETIC GRAVITY TIDE PARAMETERS AVAILABLE ON INTERNET

by

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and

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Abstract

This is to inform you that a set of synthetic (model) gravity tide parameters (amplitude factors and phase leads) for the waves MF, Q1, O1, P1, K1, N2, M2, S2, and K2 in a 1° x 1° worldwide grid has been computed in 26995 gridpoints located on land and is available to public domain on INTERNET electronic network together with program ETGTAB to compute gravity tides from tidal potential developments:

address: 129.13.100.201

login: ftp

password: ftp

directory: pub

files:	wparm.txt	7.128 kB	manual file,
	wload.dat	5173.950 kB	grid of ocean tide contributions,
	wparm.dat	4737.990 kB	grid of gravity tide parameters,
	etgtab.txt	8.181 kB	manual file for program etgtab,
	etgtab.for	133.133 kB	FORTTRAN source code of program etgtab,
	etgtab2.exe	127.434 kB	executable program etgtab, 80286/287 pc,
	etgtab3.exe	277.270 kB	executable program etgtab, 80386/387 pc,
	etgtab.bas	91.138 kB	plotprogram in MS-QuickBasic,
	etgtab.inp	1.345 kB	input file for program etgtab,
	etgtab.out	22.584 kB	output file for program etgtab,
	etgtab.prn	12.152 kB	print file of program etgtab,
	etcpot.dat	112.982 kB	tidal potential catalogues.

The files wload.dat and wparm.dat have been compressed under UNIX operation system (wload.dat.Z: 1681.930 kB and wparm.dat.Z: 1397.799 kB) in order to speed up the file transfer. They have to be uncompressed after transfer to your computer ("uncompress wload.dat" and "uncompress wparm.dat").

1 Description of the computations

The computations have originally been performed in order to supply gravimetric earth tide parameters for the adjustment of the Unified European Gravity Network 1994 (UEGN 1994, Boedecker et al. 1994). Because it has been found that the data set was useful for the adjustment of the UEGN network, synthetic gravity tide parameters could also be useful for other gravity surveys around the world and therefore the computations have been repeated for a worldwide grid and the data sets have been made available to public domain. We will give in the following a short summary of the computations and comparisons with observations; a more complete description will be given in Timmen and Wenzel (1994).

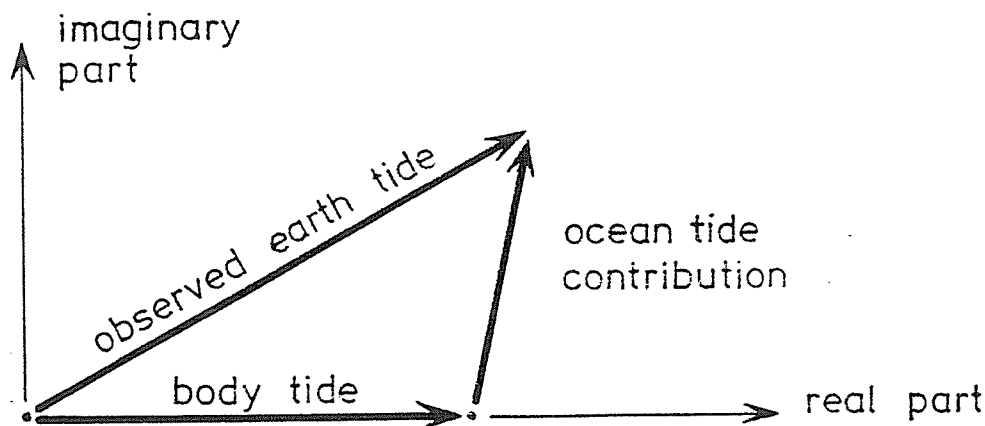


Figure 1: Schematics of the computations of synthetic gravity tides.

The procedure may be summarized by

1. Computing ocean tide contribution to tidal gravity (gravitation and load) in a worldwide regular grid (land area only) from Schwiderski's $1^\circ \times 1^\circ$ ocean tide model (Schwiderski 1980), using program LOADF of D.C. Agnew. There has been used the Green's function (Farrell 1972) for the Gutenberg-Bullen Earth model; mass conservation has been established for the ocean tide model by subtracting a uniform sheet of water from all the $1^\circ \times 1^\circ$ cells (e.g. Knopoff et al. 1989). To reduce gridding effects, the coast lines in the neighbourhood of the computation point were taken from $5' \times 5'$ topographic model ETOPO5.
2. Computing body tide amplitude factors from the Wahr-Dehant model of an ocean-free, elastic, rotating, isotropic, ellipsoidal Earth with liquid outer core (Wahr 1981, Dehant 1987).
3. Computing the tidal gravity parameters (amplitude factors and phase leads) from body tide amplitudes plus ocean tide contribution (see Fig. 1) divided by rigid earth tide amplitudes from Tamura's (1987) tidal potential. Because Schwiderski's ocean tide model contains the waves MF, Q1, O1, P1, K1, N2, M2, S2, and K2 only, we were able to compute tidal parameters for these waves only. Because the body tide amplitude factors and the ocean tide contribution is smooth over the frequency, we assume constant amplitude factors and phase leads over small frequency bands e.g. around the major waves. This corresponds to the assumption that the ocean tide contribution is proportional to the body tide amplitude for neighboured waves. It has to be noted, that the body tide amplitudes are zero at specific latitudes for the different waves (about 36° for MF, at the poles and at the equator for diurnal waves, and at the poles for semidiurnal waves). Therefore, the corresponding synthetic gravity tide amplitude factors may have arbitrarily high values around these latitudes.

The advantage of computing the tidal parameters in a regular grid is that the user of the grid does not have to carry out the time-consuming ocean load computation and that the final set of computed tidal parameters may be used for different local, regional or continental gravity networks. In general, it is easy to interpolate for any observation station the tidal parameters (there may be problems with stations located on very small islands, because the grid is defined mainly for the continental area).

The computation procedure has been splitted up into different steps:

1. Defining a worldwide regular grid (mainly on land) with $1^\circ \times 1^\circ$ spacing. The basis for the land/sea decision was a $1^\circ \times 1^\circ$ mean elevation file (BGI 1986). The grid has been defined by selecting all mean elevations larger than -500 m. This procedure should provide a grid which covers and surrounds the continents and also small islands in order to enable the interpolation of tidal parameters for all gravity stations located on land by the user. The height of the grid points was set

equal to the mean $1^\circ \times 1^\circ$ elevation if it was greater than zero, and it was set to zero for negative mean elevations. The total number of selected grid points was 26995.

2. Computing ocean tide gravitation and load from Schwiderski's $1^\circ \times 1^\circ$ ocean tide models for the tidal waves MF, Q1, O1, P1, K1, N2, M2, S2, and K2 using program LOADF of D.C. Agnew. This computation step was rather time-consuming (about 100 sec per point on an IBM-AT compatible 486 DX4 100 Mc processor) and took in total over one month CPU time. The ocean tide contributions at the 26995 grid points are provided with file wload.dat; a description of the contents and format is provided with file wparm.txt. As an example, the ocean tide contribution to gravity tides due to wave M2 at Europe is given in Fig. 2.
3. Computing earth tide parameters from rigid earth amplitudes using the Tamura (1987) tidal potential, Wahr-Dehant body tide amplitude factors, and Schwiderski's ocean tide amplitude and phase leads. To the 9 wave groups from Schwiderski's model, there have been added wave group M3 (body tide only). These parameters are given in file wparm.dat. There exists 3 records for each gridpoint (see Tab. 1). As an example, contour line plots of the M2 gravity tide amplitude factors and phase leads for Europe are given in Fig. 3 and 4. For the computation of gravity tide corrections, one has to add wave M0S0 using amplitude factor 1.000 and phase lead 0.000 according to IAG standards (Rapp 1983).

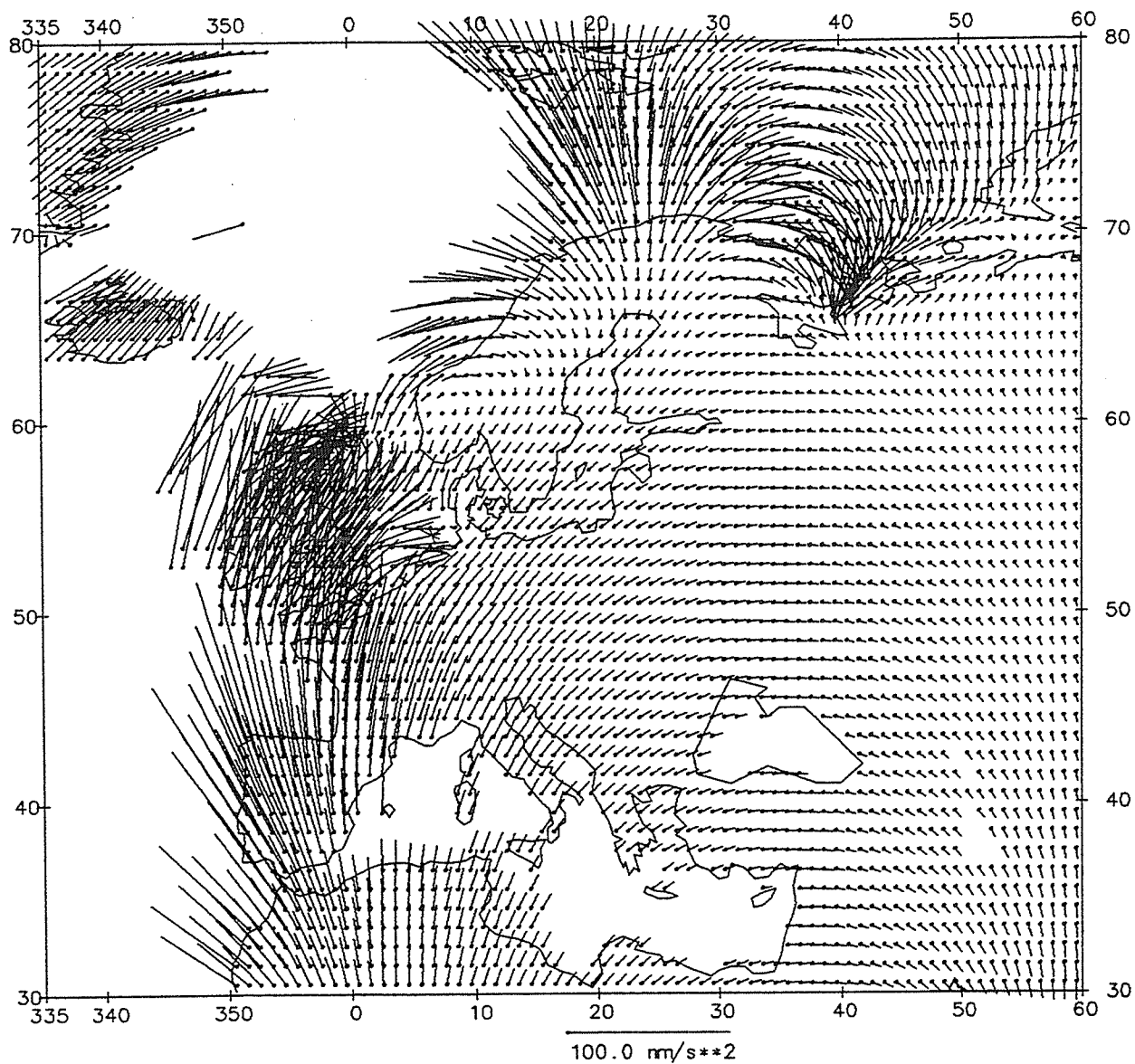


Figure 2: Ocean tide contribution to M2 gravity tide parameters at Europe. A horizontal vector pointing to the right means zero phase lead. A vertical vector pointing upwards means 90° phase lead.

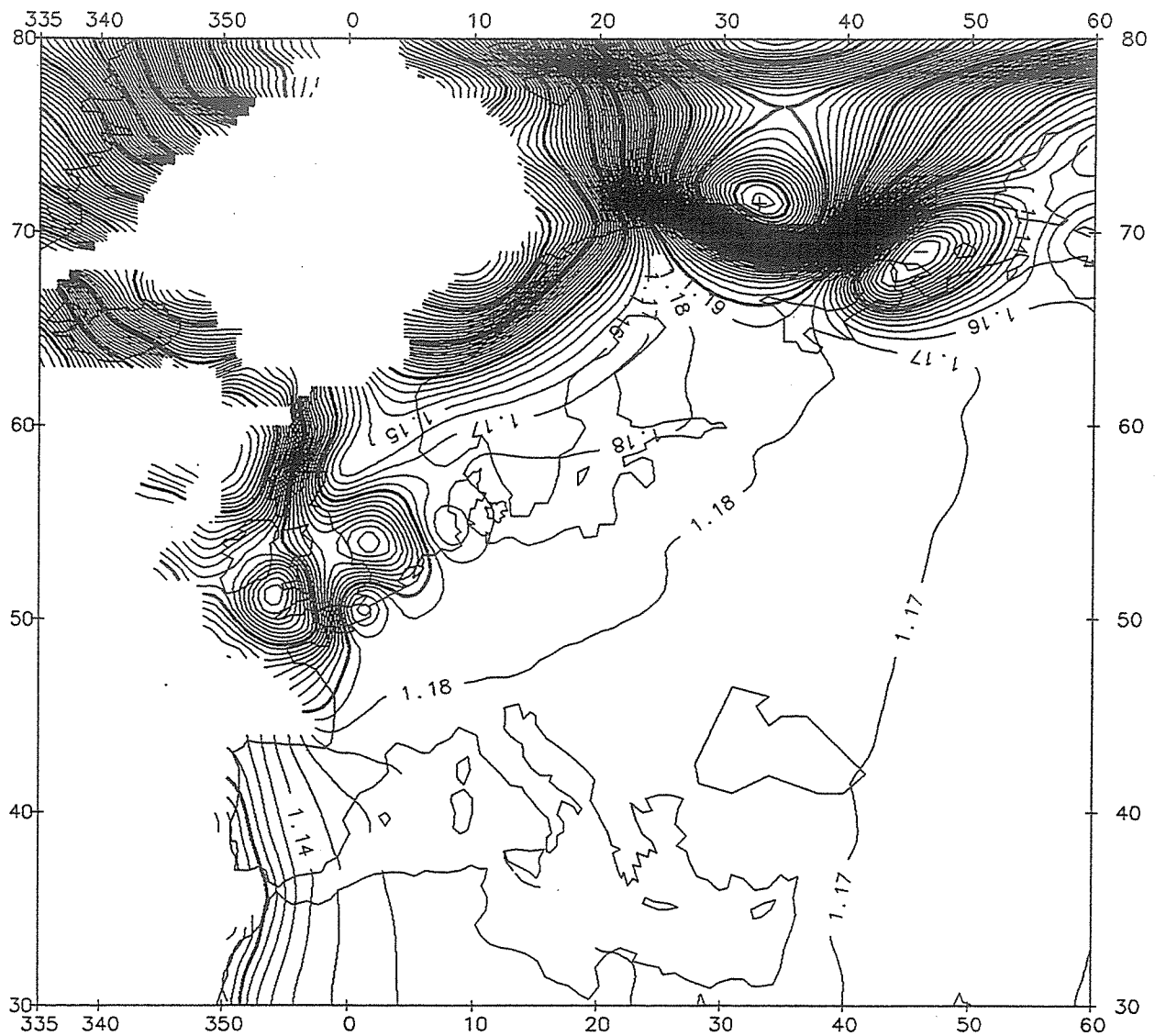


Figure 3: M2 gravity tide amplitude factors for Europe

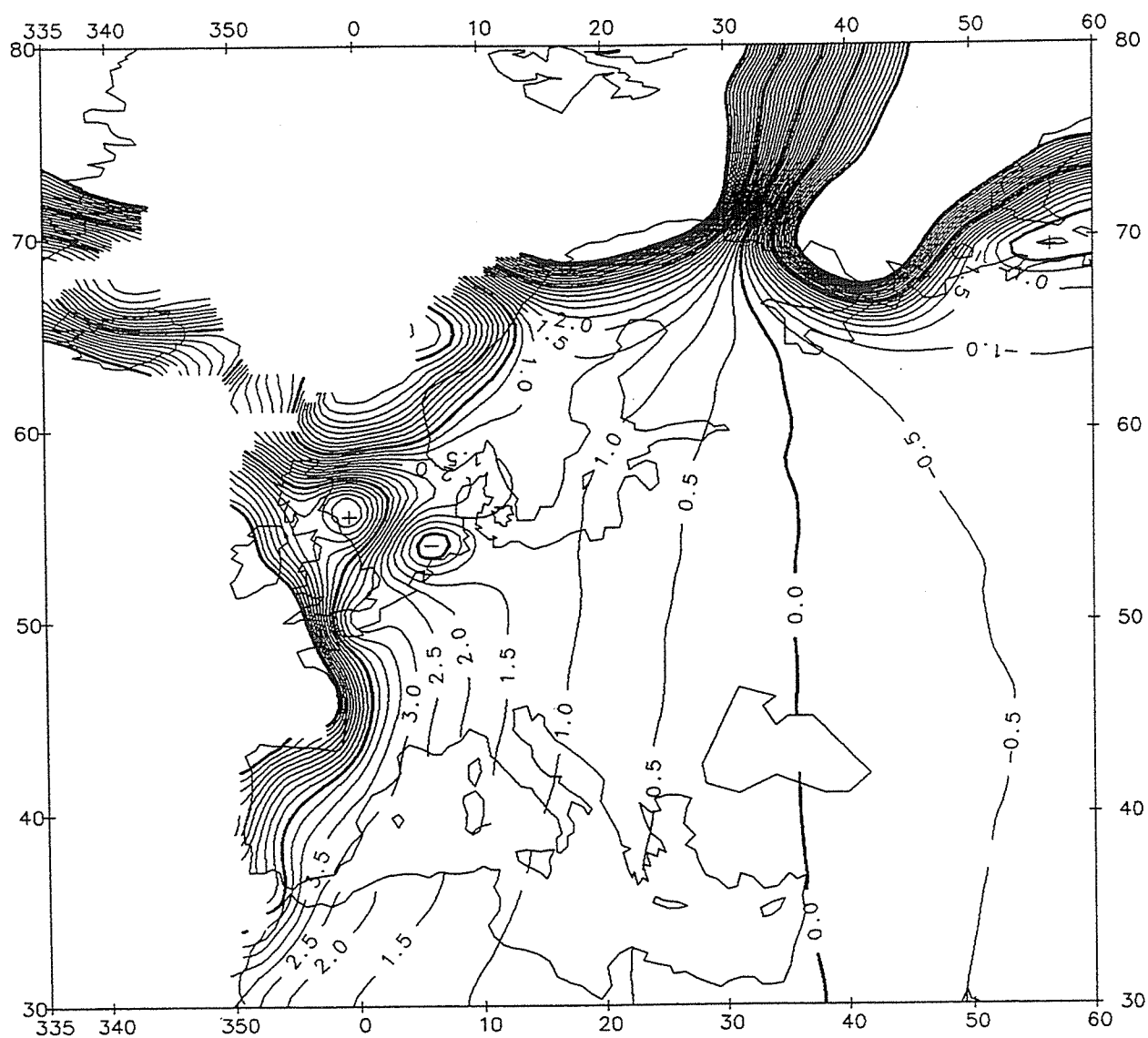


Figure 4: M2 gravity tide phase leads in degree for Europe

Table 1: Extract of file wparm.dat for one gridpoint

54.5	34.5	214.0							
1.1694	1.1493	1.1496	1.1457	1.1303	1.1748	1.1779	1.1703	1.1658	1.0687
-0.143	0.079	0.156	0.100	0.037	0.415	0.100	-0.291	-0.326	0.000

The first row contains latitude in degree, longitude in degree, elevation in meter.

The second row contains amplitude factors for waves MF, Q1, O1, P1, K1, N2, M2, S2, K2, M3.

The third row contains phase leads in degree for waves MF, Q1, O1, P1, K1, N2, M2, S2, K2, M3.

2 Comparison of synthetic and observed gravity tide parameters

The accuracy and reliability of the synthetic gravity tide parameters has been estimated by comparison with observed gravity tide parameters. We have selected from our own data base of gravity tide observations a few stations (Chur, Zürich, Schiltach, Bad Homburg, Hannover, Karlsruhe, Potsdam, Strasbourg, Wettzell) observed in central Europe with carefully calibrated feedback LaCoste and Romberg gravimeters or superconducting gravimeters and compared the observed and the synthetic gravity tide parameters at these stations. The rms discrepancies of the amplitude factors (0.0015 at O1 and 0.0023 at wave M2) and of the phase leads (0.05° at wave O1 and 0.16° at wave M2) are in the range of the noise level of the observations mainly due to calibration uncertainties.

For a global check of our synthetic gravity tide parameters, we have used the data base DB92 of the International Center of Earth Tides, which contains 331 stations at which gravimetric earth tide parameters have been observed (Melchior 1994). The majority of these stations (143) is located in Europe. After some initial comparisons of our synthetic gravity tide parameters with the data base DB92, we have selected only those observations with an internal consistency factor q_1 (as taken from DB92) greater than 10.0 for our comparisons. There exist 31 of such stations in Europe, but only 7 stations with q_1 greater 10 outside Europe. In Tab. 2 and Tab. 3 are given the statistical parameters of the comparison of observed gravity tide parameters from DB92 with synthetic gravity tide parameters for European stations and for stations outside Europe. In Europe, the synthetic and the observed gravity tide parameters agree well at the main waves O1 and M2 with rms deviations of 0.79 % and 0.87 % for the amplitude factors and 0.24° and 0.48° for the phase leads. Outside Europe, the rms differences are 2.04 % and 1.09 % for the amplitude factors and 1.16° and 0.38° for the phase leads of waves O1 and M2 resp. The larger differences outside Europe are partly due to lower observation accuracies and partly due to larger errors of the ocean tide model. The larger differences for the smaller waves in Europe and outside Europe are most probably due to larger errors in the observations.

Table 2: Differences of observed gravity tide parameters from DB92 data base minus synthetic gravity tide parameters. European stations with internal consistency factor q_1 greater 10.0 selected from DB92.

wave	samples	mean	amplitude factor			phase lead			
			min.	max.	rms	mean [°]	min. [°]	max. [°]	rms [°]
Q1	30	0.0006	-0.0271	0.0526	0.0165	-0.24	-1.39	0.97	0.56
O1	31	0.0061	-0.0115	0.0177	0.0079	-0.12	-0.93	0.21	0.24
P1	22	0.0019	-0.0171	0.0184	0.0083	-0.16	-0.96	0.63	0.39
K1	31	0.0094	-0.0051	0.0232	0.0077	0.01	-0.83	0.42	0.24
N2	31	0.0018	-0.0409	0.0323	0.0137	0.10	-2.65	2.68	0.95
M2	31	0.0030	-0.0326	0.0160	0.0087	-0.15	-1.48	0.82	0.48
S2	31	0.0065	-0.0412	0.0236	0.0119	-0.12	-2.07	1.80	0.65
K2	21	0.0191	-0.0169	0.0788	0.0250	0.05	-1.53	1.33	0.67

Table 3: Differences of observed gravity tide parameters from DB92 data base minus synthetic gravity tide parameters. Stations outside Europe with internal consistency factor q_1 greater 10.0 selected from DB92.

wave	samples	mean	amplitude factor			phase lead			
			min.	max.	rms	mean [°]	min. [°]	max. [°]	rms [°]
Q1	7	0.0179	-0.0254	0.0703	0.0286	-0.20	-2.85	3.49	1.75
O1	7	0.0128	-0.0213	0.0477	0.0204	-0.22	-2.28	2.00	1.16
P1	7	0.0085	-0.0081	0.0259	0.0112	0.04	-0.47	1.68	0.69
K1	7	0.0086	-0.0179	0.0256	0.0128	-0.06	-1.00	1.52	0.73
N2	7	0.0063	-0.0161	0.0181	0.0108	-0.33	-0.74	0.87	0.52
M2	7	0.0072	-0.0158	0.0214	0.0109	-0.40	-0.99	0.23	0.38
S2	7	0.0103	-0.0144	0.0263	0.0121	-0.23	-1.23	0.32	0.48
K2	7	0.0018	-0.0269	0.0161	0.0147	-0.46	-1.41	0.45	0.63

3 Conclusion

We have shown that for continental areas the synthetic gravity tide parameters show very small discrepancies to the observed parameters, whereas on islands or close to the oceans there exist larger discrepancies most probably due to the insufficient spatial resolution of the ocean tide model and thus due to larger errors of the synthetic grid. Nevertheless, we conclude that the presented synthetic gravity tide parameters are valuable data to compute gravity tide corrections for the reduction of gravity observations.

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Absolute Gravity Measurements at Syowa Station during the Japanese Antarctic Research Expedition

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Abstract: Syowa Station was included in an International Absolute Gravity Basestation Network (IAGBN), and the Gravity Observation Hut (GOH) with a base for installing an absolute gravimeter (1.5 m x 2.5 m) was constructed in February 1991 at a location of 69°00'27.04"S in latitude, 39°35'06.37"E in longitude and 21.492 m height above sea level. The ad hoc Working Group for Syowa Station Absolute Gravimetry proceeded to integrate the measurement program as part of the Japanese Antarctic Research Expedition (JARE). JARE members from the Geographical Survey Institute (GSI) performed gravity measurements employing a symmetrical free rise-and-fall Sakuma-type transportable absolute gravimeter (GSI gravimeter) in January 4-28, 1992 (JARE-33), while those from the National Astronomical Observatory, Mizusawa (NAOM) performed gravity measurements employing a NAOM2 gravimeter of a free-fall method and an absolute gravimeter with a rotating vacuum pipe (AGRVP gravimeter) of a free-fall method in December 27, 1992 - February 5, 1993 (JARE-34). The gravity values measured were corrected for the five effects of light travel time, earth tides, polar motion, atmospheric pressure variations and derivative of gravity along the plumb line, following the recommendations from the IAG/IUGG resolution, and the results are described in this report according to the IAG/IUGG standards. The mean values finally obtained after data processing are 982 524 252 μ gals from 834 falls with the GSI gravimeter, 982 524 152 μ gals from 276 falls with the NAOM2 gravimeter and 982 524 113 μ gals from 43 falls with the AGRVP gravimeter, respectively. After some discussion in the summary and concluding remarks, the Working Group adopted the value by the GSI gravimeter as a working standard at Syowa Station in January 1992.

1. Introduction

At the 19th General Assembly of the International Association of Geodesy (IAG) held at Vancouver, Canada in 1987, the establishment of an International Absolute Gravity Basestation Network (IAGBN) was recommended. The objectives of the IAGBN are (1) to monitor global secular gravity changes, (2) to calibrate instrumental scale factors and metrology for relative gravimeters, (3) to refine and maintain an International Gravity Standardization Network to an accuracy of better than $\pm 10 \mu$ gals (1μ gal = 10^{-8} m/s^2), and (4) to supply gravity values to the Bureau Gravimétrique International (BGI) [e.g., Boedecker and Fritzer, 1986]. A total of 36 subset A stations was nominated (Figure 1), considering geographical distribution on the Earth, crustal age, tectonic circumstances, mantle convection pattern, predicted secular gravity change, collocation to geocentric coordinates determined with a space geodesy

technique, distribution of Earth tides observatories, gravity effect of M2 ocean loading, and seismic hazards.

Syowa Station was included in the IAGBN, together with another McMurdo Station from the Antarctic area. Syowa Station is the only one A station where Japan is responsible for its maintenance. Thus under the auspices of the Geodetic Society of Japan (President: I. Nakagawa), National Institute of Polar Research (NIPR), Geographical Survey Institute (GSI) and National Astronomical Observatory, Mizusawa (NAOM) organized an ad'hoc Working Group to proceed the installation of facilities and to integrate the measurement program as part of the Japanese Antarctic Research Expedition (JARE).

2. Station documentation

As Part of the "Synthetic Observations and Monitoring of Dynamic Behavior of the Earth's Crust" in the IVth Programme of JARE, the construction of the Gravity Observation Hut (GOH) and sending of specialists as JARE-members were endorsed. This endorsement was timely because Syowa Station has been arranged for an observatory for global geodesy in Antarctica [e.g., Shibuya, 1993]. In February 1991, GOH (Photo 1) was constructed by JARE-32 near the 11m S- and X-bands parabola antenna. Figure 2 shows an example of site log sheet for the IAGBN Syowa Station (code 0417), and supplementary explanations will be given below considering the "Absolute Gravity Observation Documentation Standards" by Boedecker [1991].

Syowa Station is constructed on a small East Ongul Island (about 2 km diameter) at the mouth of Lützow-Holm Bay, East Antarctica. Similar to other facilities of Syowa Station, the GOH was settled on the granitic gneiss bedrock of 700 m.y. metamorphic age. There are no sedimentary covers, so that there is no ground water effect. The GOH has a concrete base of 2.5 m by 1.5 m to set up an absolute gravimeter. A marble plate of 1.0 m by 1.4 m is placed at the center of the concrete base. At the center of the marble plate, a brass disk of 8 cm diameter (see Photo 2) is buried to define the IAGBN station. It is possible to stand a levelling staff on this brass disk. There was and will be neither significant influence to the gravimeter installation nor secular changes to the floor-base.

The floor of the GOH is detached from the grounded concrete base with 5 cm spacing, so that vibration of the hut walls under high winds was designed to be suppressed. The shorter side of the GOH (6 m length) runs to WSW-ENE, while wind direction prevails NNE.

The GOH is supplied with a 100 V (50 Hz) two-phase electric power and a 220 V (50 Hz) three-phase one. Although the capacity and the frequency stability of the main power system are enough during the winter period (after February 20), there are many programs to use high electric consumption during the summer season (from mid December to mid February) and time sharing of the programs is sometimes required to have stabilized electric powers. The electric grounding of the GOH is maintained at present, but this depends on yearly sea ice conditions because the earth-line into sea may be cut incidentally across the tide crack line. The GOH is air-conditioned with room-temperature kept at $12^{\circ} \pm 5^{\circ}$ C at ground level. This stability may not be enough and several gravimeters may require additional furnace with a fan to have warmer environments.

To east and south of the Island, there is a 650 m deep sub-sea fjord (Ongul Strait) of about 3 km width, which is running parallel to the continental coast (Soya Coast). To north, the Island faces to the vast Southern Indian Ocean. Throughout 35 years' history of JARE, there were several seasons when packed sea ice surrounding the East Ongul Island totally disappeared (in 1983 and 1987). When ocean waves directly struck the Island, the ground noise level attained 10-30 mkines ($(1-3) \times 10^{-4}$ m/s) in the frequency bands of 0.05-1 Hz. This high ocean wave conditions sometimes lasted five months, for example from March to July of 1983. Another cause of high ground noises is the passage of low pressure mass; blizzards raise ground noise level to 10 mkines in the frequency bands of 0.5-20 Hz for a week. Under calm weather conditions, ground noise is usually below 10-20 μ kines ($(1-2) \times 10^{-7}$ m/s).

At Syowa Station, the WGS84 coordinates of the SCAR GPS site (see Figure 2) are obtained in Kanao and Shibuya [1994] as

$$\begin{aligned}\phi_G &= 69^{\circ}00'24.697''\text{S}, \\ \lambda_G &= 39^{\circ}35'06.299''\text{E}, \\ H_G &= 38.71 \text{ m},\end{aligned}\tag{1}$$

where H_G is the ellipsoidal height. Since the IAGBN station marker is offset 26 m to 95° from the SCAR GPS site, its WGS84 coordinates can be determined as

$$\phi = 69^{\circ}00'27.035'' \pm 0.03''S, \quad (2)$$

$$\lambda = 39^{\circ}35'06.372'' \pm 0.10''E$$

As for the elevation of the IAGBN station marker, JARE-32 (S. Nakajima) made the first-order levelling survey from the BM 1040 marker (height datum point near TOH in Figure 2) and the elevation h above sea level of the cross point in the brass disk was obtained as

$$h = 21.492 \pm 0.001 \text{ m} \quad (3)$$

3. Gravity measurements with Geographical Survey Institute (GSI) gravimeter

During the Period of January 4 - 28, 1992, JARE-33 members (S. Fujiwara and K. Watanabe from GSI and Y. Fukuda from Ocean Research Institute, University of Tokyo) made gravity measurements employing a symmetrical free rise-and-fall Sakuma-type transportable absolute gravimeter (GSI absolute gravimeter ; see Sakuma [1984] and Murakami [1989]). The outline of the gravity measurements and their results are given by Fujiwara and Watanabe [1992], and Fujiwara *et al.* [1994].

The followings are additional information which were not included in the above reports:

Type/status of the instrument: GA60.BIPM-JAEGER/GSI.1991.9

Frequency standard: Rubidium vapor frequency standard
(Rb1008B, NEC)

Light source: Iodine stabilized He-Ne laser (NN-1, Nikon)

Absorption line/wave length: i line/632.991 399 nm

Material/weight of falling object; Aluminium corner cube/60 g

Drift rate: None

There was neither change of falling object nor malfunctioning of the frequency standard/light source. The gravity measurements were performed at the place indicated in Figure 3 (just above the IAGBN station: see also Photo 3), where the mean maximum height of the falling object was about 1.2 m above the station marker. Following the recommendations from the IAG/IUGG resolution [Boedecker, 1988], gravity values measured were corrected for the following five effects:

- (1) Light travel time correction was based on $c = 299\,792\,458 \text{ m/s}$.
- (2) Earth tides correction was applied to each measurement value using the tidal parameters obtained by Ogawa *et al.* [1991] and applying the calculation program by Tamura [1987]. The correction value was $+0.64 \mu\text{gal}$ larger than that based on the constant δ -factor of 1.164 and zero phase lag. The direct constant part of the tidal gravity effect was removed from the measured gravity data using the formula

$$\delta g (M_0S_0) = -4.83 + 15.73 \sin^2 \psi - 1.59 \sin^4 \psi \quad (\mu\text{gals}) \quad (4)$$

with the geocentric latitude ψ of $69.0^{\circ}S$. The applied correction was $+7.7 \mu\text{gals}$ (add with sign to the measured value). After the IAG resolutions Nos. 9 and 16, Honkasalo correction (Honkasalo, 1964; about $57.0 \mu\text{gals}$ at Syowa Station) was not included.

- (3) Correction for polar motion was made after

$$\delta g = 1.164 \times 10^8 \omega^2 a^2 \sin \phi \cos \phi (x \cos \lambda - y \sin \lambda) \quad (\mu\text{gals}) \quad (5)$$

where coordinate values (x, y) were referenced to IERS1992. January, $\omega = 7\,292\,115 \times 10^{-11} \text{ rad/s}$, $a = 6\,378\,136 \text{ m}$ and (ϕ, λ) were taken from Eq. (2). The applied correction was $+0.25 \mu\text{gal}$.

- (4) Atmospheric pressure variation correction was applied using the formula

$$\delta g = \alpha (P_a - P_n) \quad (\mu\text{gals}) \quad (6)$$

where the pressure admittance value of $-0.32 \mu\text{gal/hPa}$ [Ogawa *et al.*, 1991] was adopted for α , and the normal pressure value P_n of 986.7 hPa was adopted from the average of the 30 years' (1957-1987) air pressure variations [Japan Meteorological Agency, 1994]. P_a of the actual measured air

pressure was monitored from the air pressure transducer attached to the absolute gravimeter for each measurement. This resulted in correction value of +1.3 μgals on an average.

- (5) In order to reduce the measured gravity values to the height of the station marker, derivative of gravity along the plumb line was estimated using four LaCoste & Romberg gravimeters [G-515, G-583, G-590 and D-73]. Gravity measurements were repeatedly carried out at the height of the IAGBN station marker and 1.2 m above the marker along the plumb line, and 40 derivatives were obtained. An average value of $0.334 \pm 0.001 \text{ mgal/m}$ was adopted for height correction. It is noted that the horizontal gradient was insignificant; 5 $\mu\text{gals/m}$ for EW direction (west high) and 1 $\mu\text{gal/m}$ for NS direction (north high), respectively.

The final results obtained are as follows:

Number of effective data: 834

A: Gravity value at the primary reference point at an elevation of 0.800 m above the marker: Not available

B: Gravity value obtained at the measurement reference point defined as a result of the measurement evaluation (1.2 m): $9.825\,238\,51 \times 10^8 \mu\text{gals}$

C: Obtained gravity value reduced to the height of station marker (cross point) at the base: $9.825\,242\,52 \times 10^8 \mu\text{gals}$

Standard deviation of a single measurement: 30 μgals

Histogram of the gravity values measured is illustrated in Figure 4(a).

We apologize that the value in Fujiwara and Watanabe [1992] is incomplete because $\delta g (M_0S_0)$ is not corrected for, and that in Fujiwara *et al.* [1994] is also incomplete because Honkasalo correction was included as opposed to their description and $\delta g (M_0S_0)$ is not corrected for.

4. Gravity measurements with National Astronomical Observatory, Mizusawa (NAOM) gravimeters

T. Tsubokawa and H. Hanada from National Astronomical Observatory, Mizusawa (NAOM) participated in JARE-34 and performed gravity measurements employing the NAOM absolute gravimeters. T. Tsubokawa installed the NAOM2 gravimeter (No. 2 absolute gravimeter of NAOM; for details see Tsubokawa and Hanada, 1986) of a free-fall method on the northern side of the base (see Photo 4), while H. Hanada placed the AGRVP gravimeter (an absolute gravimeter with a rotating vacuum pipe, for details see Hanada *et al.*, 1987) of a free-fall method on the southern side of the base (see also Photo 4), as illustrated in Figure 3.

4.1. Gravity measurements with the NAOM2 gravimeter

Absolute gravity measurements employing the NAOM2 gravimeter were performed from December 27, 1992 to January 26, 1993.

The instrumentation specification is summarized as follows:

Type/status of the instrument: NAOM2.1992.10

Frequency standard: Rubidium vapor frequency standard (Rb3100N; NEC)

Light source: Iodine stabilized He-Ne laser (NN-1, Nikon)

Absorption line/wave length; i line/632.991 399 nm

Material/weight of falling object: BK7-glass corner cube with titanium case/35 g

Drift rate: None

The outline of the gravity measurements and their results for a full paper are in preparation, while a summary abstract is available in Tsubokawa and Hanada [1994], although correction for $\delta g (M_0S_0)$ is not included in this abstract. There were no problems in the frequency standard/light source, but there appeared malfunctioning in the catcher of the falling object, and finally the corner cube prism in the falling object was broken on January 26, 1993. Thus only the data obtained before this problem (December 27, 1992 - January 26, 1993) were adopted for later analysis.

As for the correction items, methods of (1) light travel time correction, (2) Earth tides correction and (3) polar motion correction were the same as those were applied to the GSI gravity measurements, though Earth tides correction was calculated based on the program by Nakai [1979]. As for item (4) of atmospheric pressure variation correction, the admittance value of -0.32 $\mu\text{gal/hPa}$ was adopted in Eq.

(6), which is the same as that was applied to the GSI gravity measurements. However, for the standard normal pressure,

$$P_n = 1010.6708 \text{ hPa} \quad (6')$$

at a height of $h = 21.492 \text{ m}$ was adopted instead of the 30 years' average. Height correction was made using the measured derivative value of 0.334 mgal/m by Fujiwara and Watanabe [1992].

The final results obtained are as follows:

Number of effective data: 276

A: Gravity value at the primary reference point at an elevation of 0.800 m above the marker: Not available

B: Gravity value obtained at the measurement reference point defined as a result of the measurement evaluation (0.98 m): $9.825\,238\,25 \times 10^8 \text{ } \mu\text{gals}$

C: Obtained value reduced to the height of station marker at the base: $9.825\,241\,52 \times 10^8 \text{ } \mu\text{gals}$

Standard deviation of a single measurement: $40 \text{ } \mu\text{gals}$

Histogram of the gravity values measured is illustrated in Figure 4(b).

4.2. Gravity measurements with the AGRVP gravimeter

Absolute gravity measurements employing the AGRVP gravimeter were performed from December 29, 1992 to February 5, 1993. The detail of the gravity measurements and their results are given by Hanada and Tsubokawa [1994]. The instrumentation specification is summarized as follows:

Type/status of the instrument: AGRVP.1992.10

-Frequency standard: Rubidium vapor frequency standard (Rb3100N, NEC)

Light source: Stabilized He-Ne laser (SP-117A, Spectra Physics) calibrated by the iodine stabilized laser

Absorption line/wave length: i line/ $632.991\,399 \text{ nm}$

Material/weight of falling object: BK7-glass corner cube with stainless-steel case/ 45 g

Drift rate: None

The function of the AGRVP gravimeter at Syowa Station was found to have several problems. Supply current for the ion pump which is attached to the vacuum pipe was not stable, and the pump often generated electrical noises, which in turn induced an uncontrollable motion of the motor and mistrigger of the transient recorder. There appeared a bug in the computer program, which brought about normal solution only once in about ten falls. The number of data obtained during the Period from December 28, 1992 to February 5, 1993 was 374, but Hanada and Tsubokawa [1994] adopted a group of smaller data number (subset A of 43 data) which was obtained in the initial stage from January 3 to 10 and the last stage from February 4 to 5. One of the reasons for accepting data set of smaller number is that the ruby sphere attached to the top of the falling object broke on January 10, and its replacement and adjustment were made again on February 4. Slight misalignment of the corner cube after replacement may have resulted in biased measurements during the intermediate stage, and then, those data were not used for later analysis.

As for the correction of five effects, the same methods that were applied to the NAOM2 gravity measurements were adopted, and the final results obtained are as follows:

Number of effective data: 43

A: gravity value at the primary reference point at an elevation of 0.800 m above the marker: Not available

B: gravity value obtained at the measurement reference point defined as a result of the measurement evaluation (0.82 m): $9.825\,238\,39 \times 10^8 \text{ } \mu\text{gals}$

C: Obtained value reduced to the height of station marker at the base: $9.825\,241\,13 \times 10^8 \text{ } \mu\text{gals}$

Standard deviation of a single measurement: $40 \text{ } \mu\text{gals}$

Histogram of the gravity values measured is illustrated in Figure 4 (c).

5. Summary and concluding remarks

A comparison of the final results obtained by the three kinds of absolute gravimeters mentioned above is given in Table 1a. The GSI result gave the largest value, while the NAOM2 result was about 100 μ gals smaller than the GSI one, and the AGRVP result gave the smallest value with a discrepancy of 139 μ gals from the GSI one. As for the AGRVP result, Hanada and Tsubokawa [1994] reported the result $C = 9.825\,243\,45 \times 10^8$ μ gals for subset B of larger data number (304 data) with the standard deviation of 65 μ gals for a single measurement, although the result is only for reference and not included in Table 1a.

In order to reexamine the above tendency, comparison measurements of the three gravimeters with almost unchanged status (GA60.BIPM-JAEGER/GSI.1991.9, NAOM2.1992.10, AGRVP.1992.10) were executed at the Gravity Observatory of GSI, Tsukuba, Japan. Table 1b gives a summary of the final results after correcting for five effects according to the same formulas which were applied to the Syowa data. It is noted that $\delta g (M_0S_0)$ is negligible (0.22 μ gal) at latitude 36.1°N of Tsukuba. The sequence of the final results obtained at Tsukuba is very similar to that obtained at Syowa Station. The largest GSI value had an offset of 55 μ gals against the intermediate NAOM2 value, and the discrepancy was somewhat smaller than that at Syowa Station (100 μ gals difference). The value obtained by the AGRVP gravimeter was rather small (158 μ gals offset) as compared with that by the GSI gravimeter. Since possible inconsistency among existing absolute gravimeters is believed to be 40-50 μ gals [Boulanger *et al.*, 1991], repeated gravity measurements and intercomparison with another gravimeter are required in a future expedition.

The general trend of smaller S.D. values (30 - 40 μ gals) obtained at Syowa Station than those obtained at Tsukuba (50 - 340 μ gals) may be due to lower ground noise levels by the absence of ground water effect and very low seismic tremor activity around Syowa Station.

Since the metrology of absolute gravimeters is still in progress, and also since gravity measurements were made during current progressing stage, the Working Group did neither discuss nor endorse the superiority of a certain gravimeter with a certain metrology. However, the IAGBN station has to contribute not only to monitor secular gravity change but also to calibrate the relative gravimeters employed for regional survey in the JARE research area, so that the definition of the station value at a certain epoch is definitely required. From the following considerations, the Working Group agreed to accept the gravity value obtained by the GSI gravimeter as a working standard in January 1992.

(1) The GSI gravimeter was calibrated at Tsukuba before cargoing to Syowa Station and after return to Tsukuba, which showed insignificant change (14 μ gals difference; 979 951 233 μ gals in July 1991 and 979 951 247 μ gals in October 1992) of the measured mean values. On the other hand, unfortunate malfunctioning occurred to both of the NAOM gravimeters at Syowa Station and status of the instruments in the calibration procedures after return could not exactly be the same as those before shipment.

(2) Total number of effective data in the GSI gravity measurements is the largest with Gaussian distribution and with reasonable standard deviation of a single measurement.

(3) The GSI gravimeter was installed just above the station marker, while the NAOM gravimeters were placed offset as illustrated in Figure 3.

(4) GSI can maintain the IAGBN station as an institutional basis because participation to JARE is systematically endorsed every year.

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Fig. 1. IAGBN network. Although there are three stations of subset B in Japan (Esashi, Tsukuba and Kyoto), Syowa Station is the only one station of subset A where Japan is responsible for its maintenance.

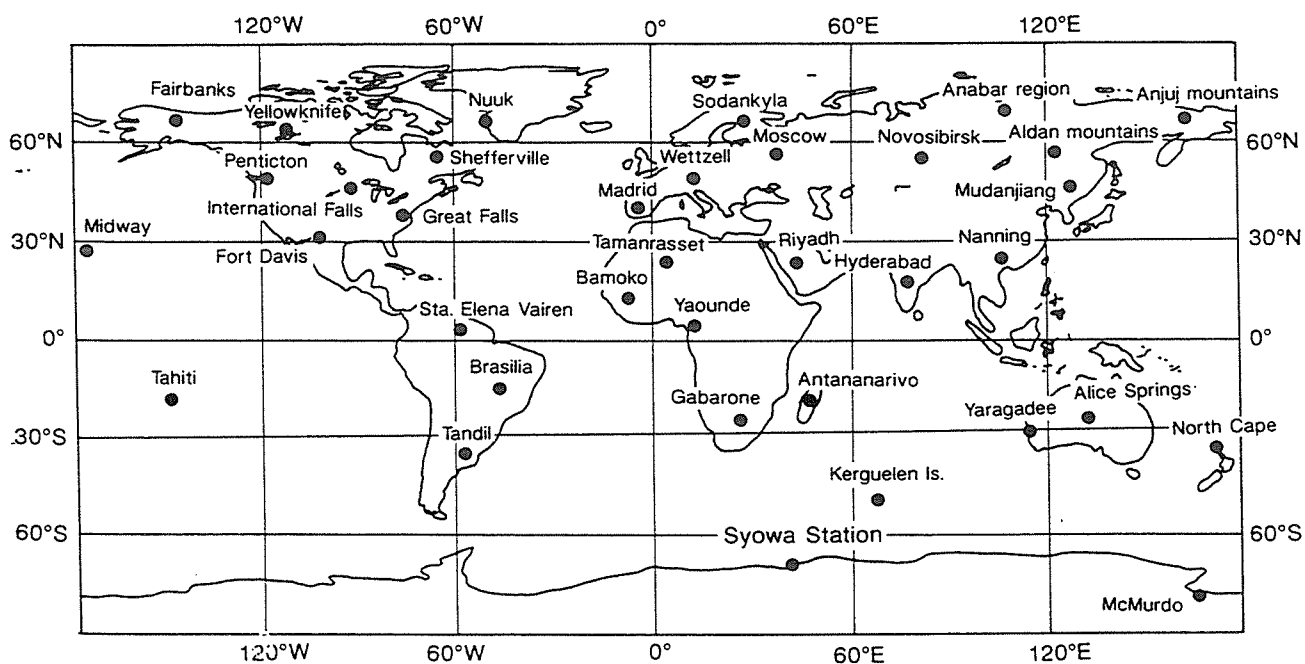


Fig. 2. IAGBN data log sheet for Syowa Station.

International Absolute Gravity Basestation Network (IAGBN)

Station Location: Syowa Station

Country: Antarctica

$\varphi = 69^{\circ}00'27.04''S$

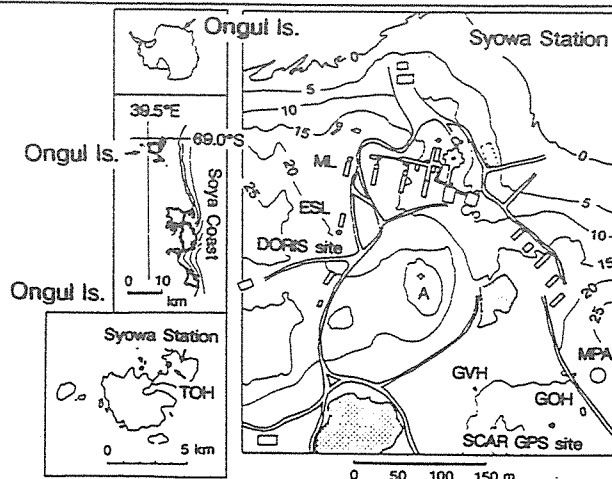
$\lambda = 39^{\circ}35'06.37''E$

$H = 21.492 \text{ m}$

$g = 982524.25 \times 10^{-5} \text{ m/s}^2$

Overview / Access / Outside View / Topo Map

The IAGBN station is located in the Gravity Observation Hut (GOH) of Syowa Station, East Ongul Island, Antarctica. Access to Syowa Station can be done only by the icebreaker "Shirase", which transports the members and goods of the Japanese Antarctic Research Expedition (JARE).



Remarks / Station Identity / Contact

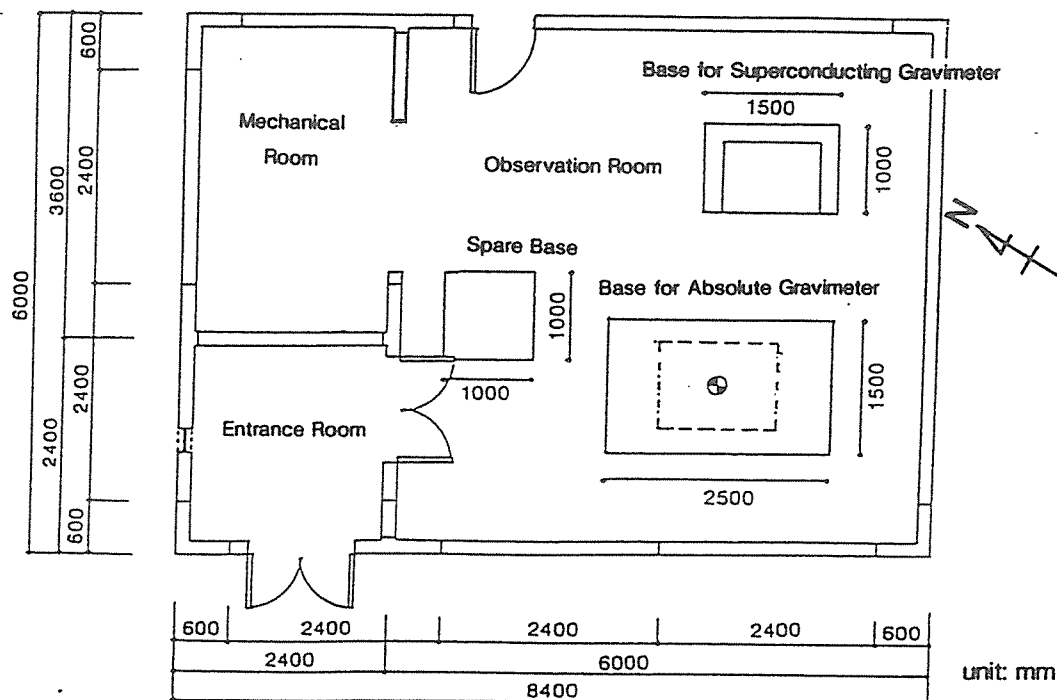
The Gravity Observation Hut (GOH) was constructed in February 1991 by JARE-32. As for inside of the GOH, a plane figure is drawn below. A marble plate of 1.0 m x 1.4 m is placed within the base for installing an absolute gravimeter. At the center of the plate, a brass disk of 8 cm diameter is buried. Station marker is IAGBN(A) SYOWA STATION JARE32 1991.

Station contact: Earth Sciences Division, National Institute of Polar Research, Kaga 1-9-10, Itabashi-ku, Tokyo 173, JAPAN

Tel: 81-3-3962-4789, Telefax: 81-3-3962-5741

Detailed Sketch (North? Station Marker?) / Photograph

The IAGBN station marker (brass disk) is located at the center of the marble plate within the concrete base of 2.5 m by 1.5 m.



Date / Author 21 June 1994 (revised), Kazuo Shibuya, NIPR

Fig. 3. Location of three absolute gravimeters occupied on a base in the Gravity Observation Hut, Syowa Station.

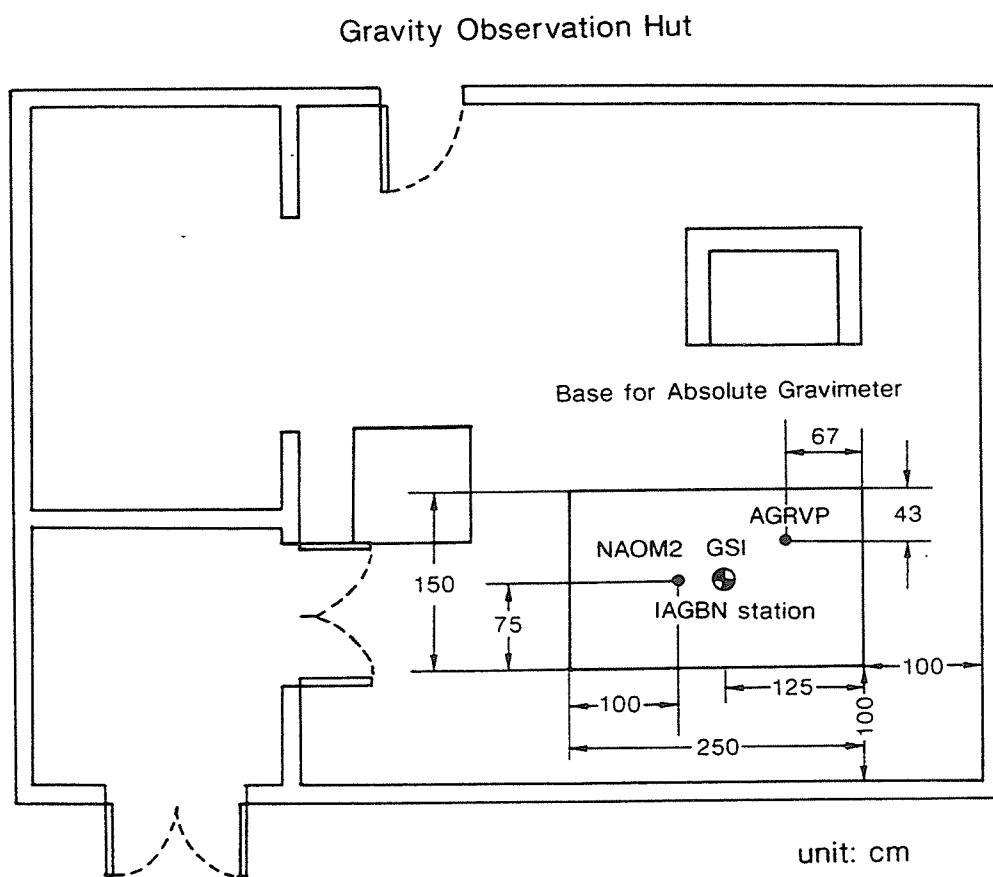


Fig. 4. Histogram of the gravity measurements for (a) the GSI gravimeter, (b) the NAOM2 gravimeter and (c) the AGRVP gravimeter. N means total number of effective falls. Note that three ordinates are not normalized.

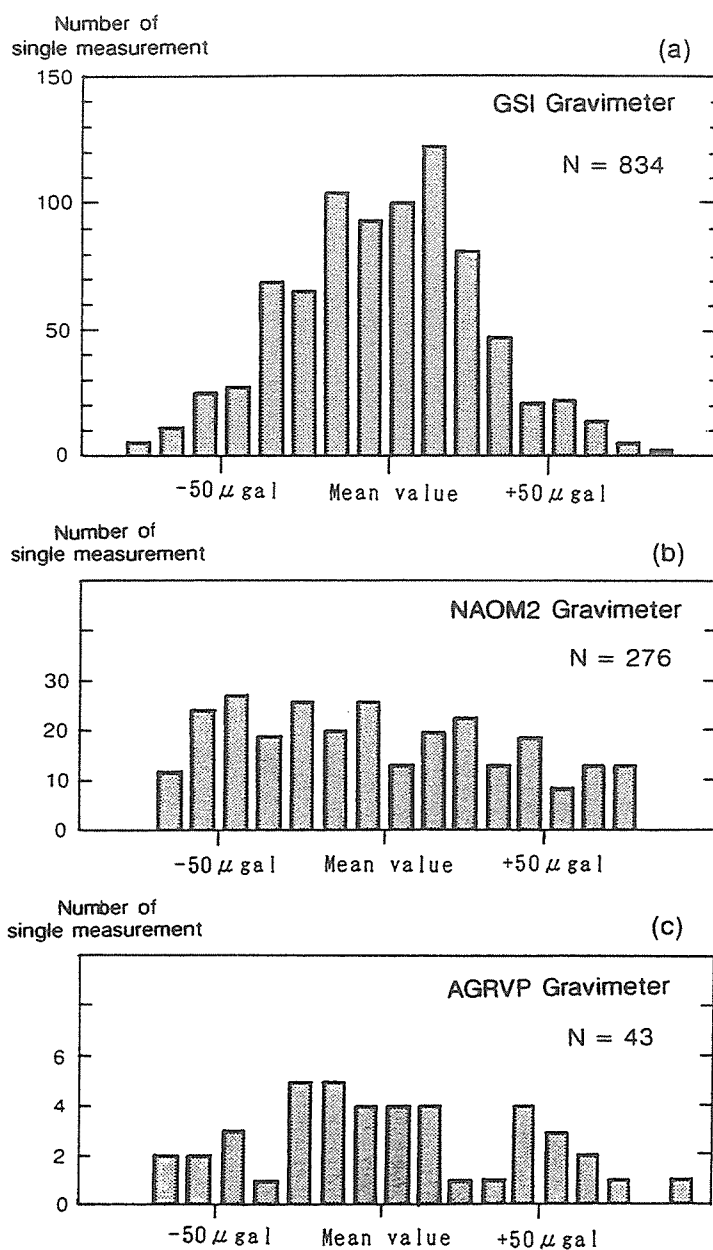


Photo 1. Outside view of the Gravity Observation Hut. Behind radome is for the 11 m multi-purpose S- and X-bands parabola antenna.

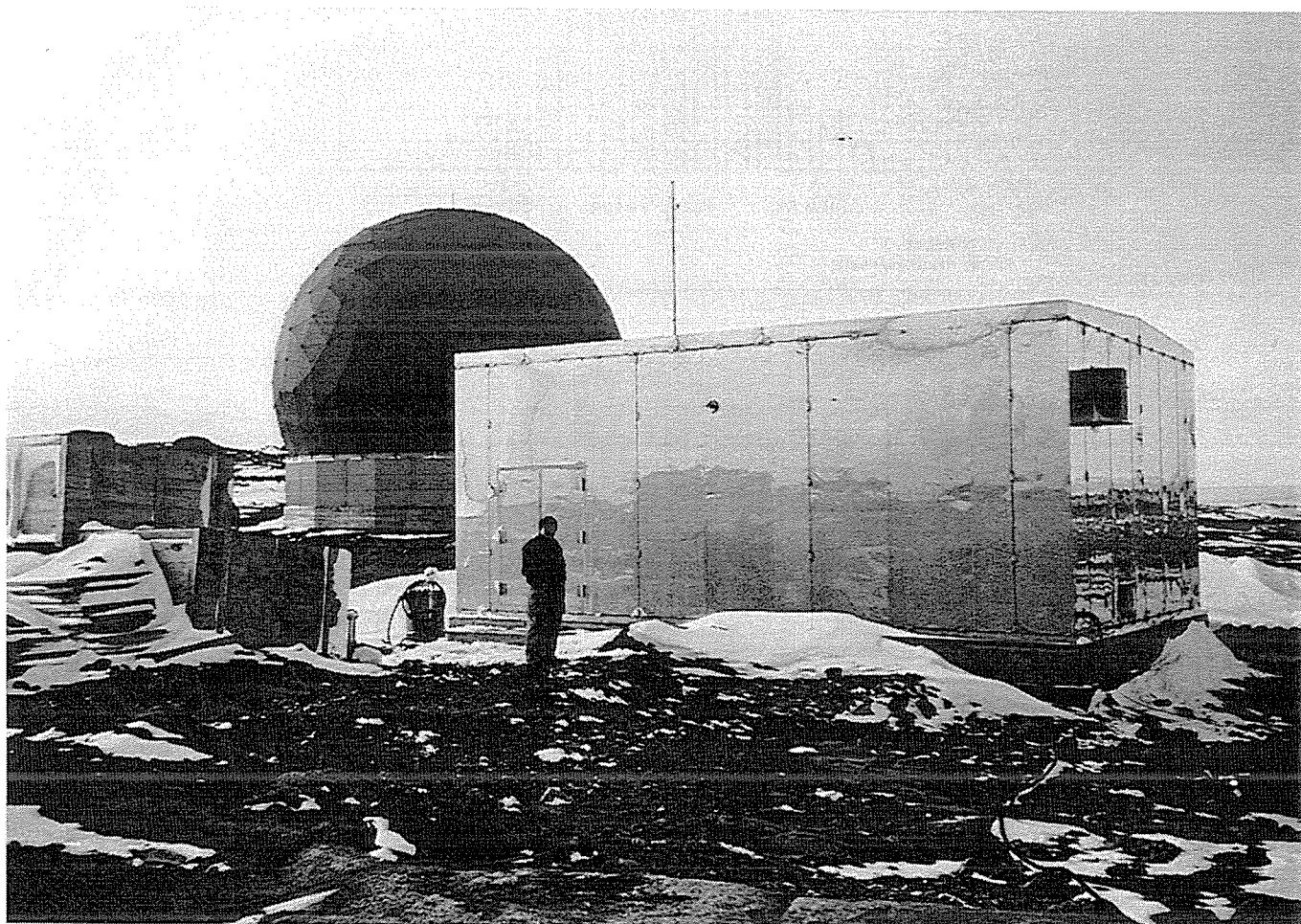


Photo 2. IAGBN station marker for Syowa Station.



Photo 3. Gravity measurements with the GSI gravimeter by JARE-33.



Photo 4. Gravity measurements with the NAOM2 gravimeter (right) and the AGRVP gravimeter (left) by JARE-34.

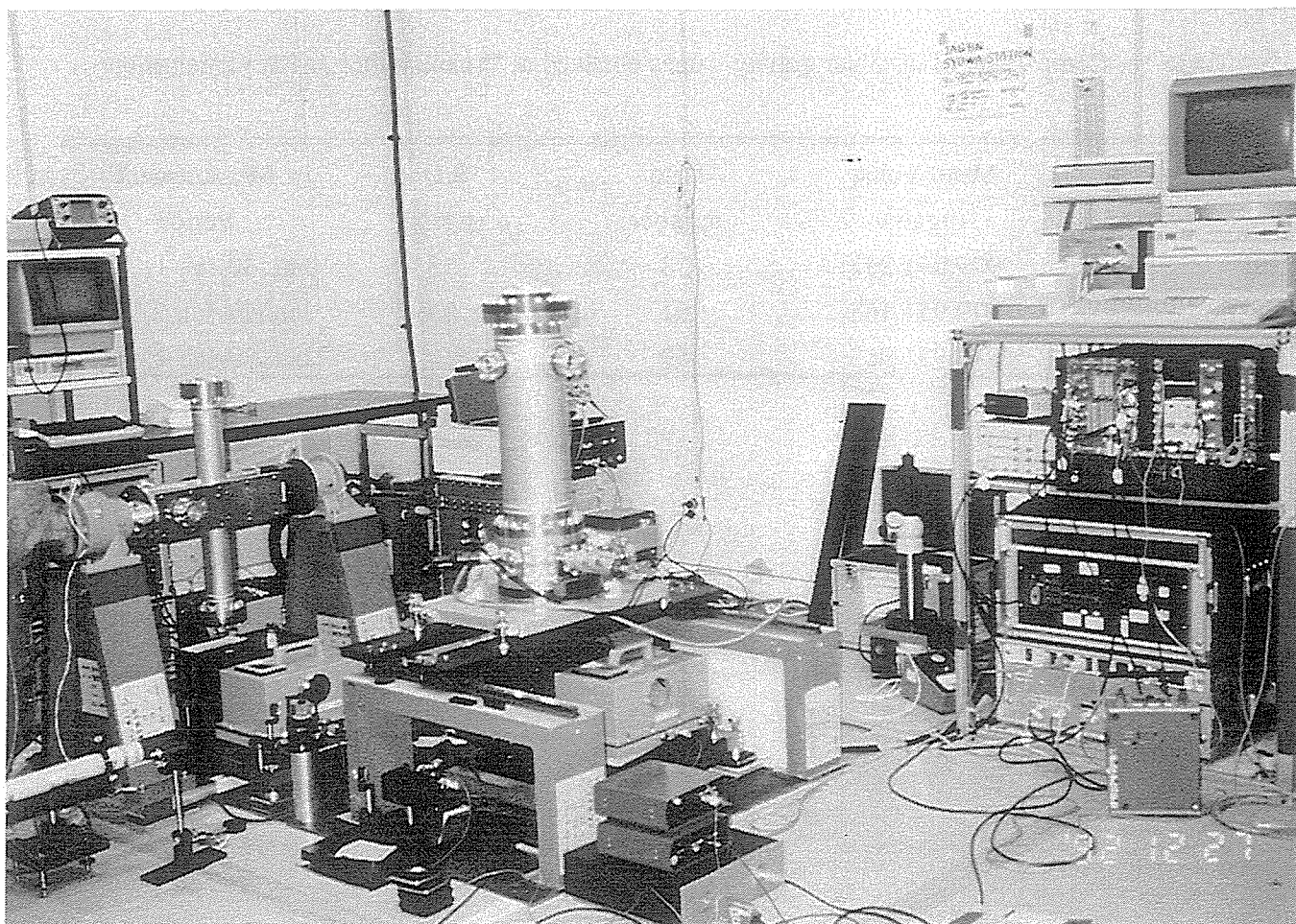


Table 1a. Comparison of absolute gravity values obtained at Syowa Station

Gravimeter	Mean Value (μ gals)	Date number	S.D. (μ gals)	Measurement Period
GSI	982,524,252	834	30	Jan. 4-28, 1992
NAOM2	982,524,152	276	40	Dec. 27, 1992 - Jan. 26, 1993
AGRVP	982,524,113	43	40	Jan. 3-10 and Feb. 4-5, 1993

Table 1b. Comparison of absolute gravity values obtained at Tsukuba after JARE participation

Gravimeter	Mean Value (μ gals)	Date number	S.D. (μ gals)	Measurement Period
GSI	979,951,252	58	53	Jan. 30-Jul. 1, 1992
NAOM2	979,951,168	61	85	Jun. 29-Jul. 2, 1993
AGRVP	979,951,063	69	336	Jan. 29-Jul. 2, 1993

The National Geophysical Data Center's Gravity Program

Michael A. Chinnery, Allen M. Hittelman, George F. Sharman,
Ron W. Buhmann, Dan Metzger and David Dater

The National Geophysical Data Center's (NGDC) Gravity Program represents an ongoing activity of the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA). In addition to its national role, NGDC operates on behalf of the International Council of Scientific Unions (ICSU) the World Data Centers - A for Solid Earth Geophysics and Marine Geology and Geophysics, with missions to collect and distribute data associated with the Earth's potential field, including: gravity, magnetics, and topography for use by scientists internationally.

The Gravity Program at NGDC has a *data management* focus and is divided into two component efforts: "land and satellite-derived data" and "shipborne geophysical data." Diverse categories of gravity data are managed, such as: station records (in both land and marine environments), absolute measurements, representations of the Earth's field in grid formats, and geoid determination.

NGDC functions as an intermediary between data producers and data users. Data come from numerous national and international sources, including government agencies, academic institutions and commercial sources. U.S. government agencies are the primary contributors to the National Geophysical Data Center; they include the Defense Mapping Agency, NOAA, and the U.S. Geological Survey. Several dozen other contributors exist in government, academia, and commercial organizations (nationally and internationally). Data contributed to the NGDC Gravity Program include: station and shipborne observations, anomalies (Bouguer, free-air, and isostatic), satellite altimetry, sets of coefficients, deflections of the vertical, and geoid models. Often correlative data such as terrain or magnetics is available. NGDC assimilates these data by performing standard quality control, documentation, inventory, and archival procedures. Computers at the Data Center are fully networked and include IBM-compatibles, UNIX machines, and Macintoshes.

NGDC has developed some specialized software to validate, document, inventory, and access data. These software products are in the public domain and available over Internet (either on-line or by special arrangement). Of special interest is a library of programs called FREEFORM which has: (1) platform-independent format description language which facilitates input and output of data (such as translations of data to and from ASCII to binary), (2) utilities that compute histograms of each field within a data file, (3) utilities that convert multiple representations of latitude-longitude to standard notations, and (4) conversion functions to generate standard formats (such as HDF). GEODAS, a data management system for inventorying, documenting and accessing trackline data (shipborne and airborne), has gained world-wide acceptability.

NGDC maintains a modern computer facility and provides data in almost any format specified by a data customer. These data are available on an exchange basis or at nominal costs (~\$300). For convenience and cost savings considerations, CD-ROM (with access software) have become our most popular products. In the last 200 requests for gravity data, 95 % requested CD-ROMs. These CD-ROMs are typically snapshots of our data base updated every year or so; however, we can make a custom CD at any time.

<p>PART III</p> <p>NATIONAL REPORTS</p>

Austrian Report on Gravity Activities for the Period 1990-1994

IGC 1994, Graz

Abbreviations :

BEV	Bundesamt für Eich- und Vermessungswesen, Wien (Federal Office of Metrology and Surveying, Vienna)
ML	Monanistic University of Leoben
UW	University of Vienna, Institute of Meteorolgy and Geophysics
ZAMG	Central Institute of Meteorology and Geodynamics, Vienna.
TW	Technical University of Vienna, Institute of Theoretical Geodesy and Geophysics
TG	Technical University of Graz, Institute of Theoretical Geodesy, Inst. of Applied Geodesy and Photogrammetry, Inst. of Physical Geodesy.

1) Absolute measurements (JILAG-6 free fall absolute gravimeter) :

BEV, UW, ZAMG : Continuing measurements in Obergurgl (Tyrol) and Vienna. Project in investigation of gravity variations in the southern Vienna Basin (5 stations). Observations in Germany (1), Hungary (4), Slovakia (4), Czechia (1), Switzerland (5). Participation at the comparison in Sèvres 1994.

2) Austrian Gravity Base Net:

HW, ML: Net connections to Hungary.

BEV: Net connections to Czechia, Slovakia, Switzerland; adjustment. Connections to the absolute stations, control measurements.

3) Regional measurements:

BEV: Continuing measurements along the precise levelling lines for calculation of geopotential units and ortometric heights.

UW: Continuing measurements in the central Alps (1 station / 10 km²)

ML: Continuing measurements in Styria, Carinthia, Upperaustria, Vorarlberg.

4) Local measurements :

BEV, UW, TW: Tests and calibrations along the Hochkar Calibration Line (LCR, Scintrex).

BEV, UW, ZAMG: Investigations on recent gravity changing with absolute and relative gravity measurements in the southern Vienna Basin.

ML: Gravimetric investigations in topographic deformations by mining.

TW: Investigations in engineering projects.

5) Theoretical studies and gravity field investigations:

UW: Investigations in determing and analysing the gravity field in high mountain areas onhand the eastern alps.

TG: Investigations in a new bouguermep of Austria.

ML: Local bouguer maps of Vorarlberg, Linz Basin, Leoben, Styria.

BEV: Development of a practical way for interpolations of gravity values along levelling lines to get geopotential units and precise orthometric heights by using a detailed digital topographic model.

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NATIONAL REPORT ON GRAVIMETRY IN CZECH REPUBLIC FOR 1990-1994

Edited by Petr Holota¹ and Ludmila Kubácková²

PREFACE

This report outlines Czech activities in gravimetry for the period 1990 to 1994. It has been prepared for submission to the International Association of Geodesy (IAG) on the occasion of the Joint Meeting of the International Gravimetric Commission (IGC) and the International Commission on the Geoid (ICG) in Graz, Austria, September 11-17, 1994. It is issued on behalf of the Czech National Committee of Geodesy and Geophysics.

Since the last report there have been some important structural changes in the way that IAG matters were administrated within the former Czechoslovakia. The International Union of Geodesy and Geophysics (IUGG) membership of the former Czechoslovakia has been divided between two succession states, the Czech Republic and the Slovak Republic. Correspondingly all formal IUGG/IAG matters are now dealt separately via the Czech National Committee of Geodesy and Geophysics and the Slovak National Committee of Geodesy and Geophysics.

Another important, and extremely useful, geodetic event that took place during the quadrennium to which this report refers was the holding of the First Continental Workshop on the Geoid in Europe, Prague, May 11-14, 1992. The workshop was organized jointly by the IAG - Subcommittee for the Geoid in Europe and the Research Institute of Geodesy, Topography and Cartography, Prague - Zdíby, under the sponsorship of the International Association of Geodesy and the Czechoslovak Committee for Geodesy and Geophysics. The workshop attracted 70 scientific delegates from 21 countries. It is fully documented in the proceedings which appeared as a joint edition of the IAG - Subcommittee for the Geoid in Europe and the Research Institute of Geodesy, Topography and Cartography, Prague - Zdíby, in Prague, 1992.

This national report results from a co-operation of the Czech National Committee of Geodesy and Geophysics, and its Geodesy Subcommittee with a number of institutions in the Czech Republic. Special thanks are due to:

Astronomical Institute, Academy of Sciences of the Czech Republic;

Geophysical Institute, Academy of Sciences of the Czech Republic;

Department of Geophysics, Faculty of Mathematics and Physics, Charles University;

Department of Higher Geodesy, Faculty of Civil Engineering, Czech Technical University;

Topographic Service of the Army of the Czech Republic;

Research Institute of Geodesy, Topography and Cartography, Prague - Zdíby;

Geodetic Institute, Prague

for their numerous contributions which made it possible to compile this report. The dedicated work of many authors and individuals which is equally as important is also gratefully acknowledged.

Prague, July, 1994

Editors

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1. Gravimetric Networks and Measurements

The national gravimetric network was updated by field measurements with the use of Sharp and Worden gravimeters, see [69]. Moreover, interconnections to neighbouring countries were accomplished with Germany, Austria, Hungary and Slovakia within international projects. An attention was also paid to the calibration of instruments used and to the methodology of measurements, see [11], [26] and [10]. On the basis of the agreement between the Defense Mapping Agency and the Topographic Service, Ministry of Defense, Czech Republic a long term loan of two LaCoste & Romberg gravimeters was offered to the Czech National Geodetic Survey. These instruments are now being used to remeasure the gravity calibration baselines, some lines of national gravity network and to tie the absolute stations with the national gravity network.

2. Absolute Measurements

Geodetic Observatory Pecny was incorporated into the research project of investigations of gravity field time variations. Within this project three absolute gravity measurements were performed at the observatory by means of the Russian ballistic gravimeter GABL already in 1978 -1986. The fourth measurement was carried out in February 1992 with the Austrian gravimeter JILAG - 8. Finally, in 1993 a group from the Defense Mapping Agency, USA, completed this series of absolute measurements by means of the gravimeter Axis FG5 No. 107. All the results obtained so far display a similar periodicity as that at the station Potsdam (Germany). The amplitude reaches ca $30 \cdot 10^{-8} \text{ ms}^{-2}$ (i.e. $30 \mu\text{gal}$) and the period is ca 11.5 years, see [67] and [68].

To strengthen the national gravity control and to homogenize it with the gravity control of neighbouring countries a project of the national absolute gravity station network was elaborated in 1992. Besides the fundamental gravity station Pecny, where repeated absolute gravity measurements have been performed, it comprises five other stations which meet the technical standards for the IAGBSN stations. Two of them are situated at the end points of the latitude gravity calibration baseline. In September 1993 the realization of this project was started by the absolute gravity measurements at the station Polom performed by the DMA group with the gravimeter Axis FG5 No. 107. Based on mutual agreements between the International Gravity Commission, Federal Office of Metrology and Surveying (BEV Wien) and the Czech Office of Surveying and Cadastre, the absolute measurements will continue in 1994 by observations of three other national absolute stations. Further suggestions for absolute gravimetric measurements were discussed e.g. in [49].

3. Reductions and the Normal Field

Some problems of reductions of gravimetric measurements were also treated. A more precise normal gravity formula was derived in [54] and [55]. Here the numerical constants necessary to compute the normal gravity for the following gravity systems were deduced: Helmert 1901-9, Cassinis 1930, system 1987, 1975, 1980, 1983. It was shown that an exact computation using Helmert's formula is not possible, and that deviations of about 10^{-5} ms^{-2} (1 mGal) have to be expected. An attempt was also made to give a new definition of the normal gravity field which would contain the constant part of the direct tidal effect of the Moon and the Sun. Consequences for definition of heights were discussed in [74]. Finally, in connection with the conversion to the system WGS-84 a proposal was made to modernize the definition of the Bouguer anomaly in the Czech Republic and to simplify the computation of the Bullard term at the same time, see [59] and [62].

4. Conversions

Within the conversion of geodetic systems a transformation of the astro-geodetic as well as gravimetric (quasi-)geoid of the Czech Republic into the geocentric systems WGS - 84 and EUREF- 89 was successfully accomplished, see [14]. In addition geopotential differences were computed in this connection, see [2]. Theoretically and methodologically the solution of these problems was supported e.g. by [60].

5. Quasigeoid, Geoid and Gravity Field Modelling

A considerable activity was devoted to the theoretical as well as practical problems related to the quasigeoid and geoid determinations. In 1992 the First continental workshop on the geoid in Europe was held in Prague, organized jointly by the IAG - Subcommission for the Geoid in Europe and the Research Institute of Geodesy, Topography and Cartography, Prague - Zdiby, under the sponsorship of the International Association of Geodesy and the Czechoslovak Committee for Geodesy and Geophysics, see [25], [22], [71] - [73] and [1]. The oral and poster presentations were grouped in 6 topics:

- . Present status of European geoid,
- . Local and national geoid studies,
- . Problems, practical needs and proposals,
- . The geoid and geophysical research,
- . Specifications for a precise European reference geoid,
- . Theory and methods.

In addition to regular sessions a panel discussion on the specifications for a precise European reference geoid and a business meeting of the IAG - Subcommission for the Geoid in Europe were held on this occasion.

In the reporting period the (quasi-)geoid for the territory of the Czech and the Slovak Republics was computed and treated particularly in [65], [66] and [13]. For the European territory the results of a gravimetric geoid computation can be found in [12]. Studies of mathematical methods for determination of the figure and external gravity field of the Earth were based on the theory of boundary-value problems of mathematical physics and the central role of the Molodensky problem. The results were published in [16] - [21], [23] and [24].

Global gravity field modelling problems based on spherical harmonic expansions were discussed in [27], [30], [31] and [33]. Here the use of surface gravity data was also an essential part of the respective considerations together with methods for computation of

the global geoid. In regional dimension the geoid determination problem was examined in [32], [40] - [45] and [70]. The Stokes-Helmert approach was discussed in this connection together with the role of inverse problems.

6. Solid Earth and Gravimetry

Closely related topographic masses compensation problems and some compensation models were investigated in [29], [35] - [39] and [15]. Particularly, a global model of the Mohorovicic discontinuity was obtained in [8]. Some interesting, but regionally oriented comments on this topic can be found in [9]. Problems related to the Earth's interior and its dynamics were also approached. Earth's density models were discussed in [57]. Here the Clairaut theorem was taken as an important starting point. Love numbers for a non-spherical Earth were discussed in [34] and [28]. With the use of Runcorn's hypothesis on the existence of convection flows an attempt was made to deduce from the Earth's gravity field a distribution of forces between the lithosphere and asthenosphere, see [56], [58] and [61]. Local studies of the stress field were accomplished in [52] and [53]. Finally, various applications of gravity as e.g. in prospection, monitoring and prediction were treated in [46] - [48] and [50]. Here also tilt observations were applied, see [63] and [64].

7. Scale Factor, Altimetry and Space Applications

Results of a systematic long-term investigation on the gravity field and dynamics of the Earth were published in [6]. They were used practically as well as methodologically in the determination of the geopotential scale factor from satellite altimetry, see [3], [7] and [51]. Finally, the methods developed for the investigation of the Earth, its gravity field and dynamics were extended to the domain of planetology and applied within the project of Phobos' explorations, see [4] and [5].

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NATIONAL REPORT ON GRAVIMETRY IN FINLAND 1991-1994

The 14th Meeting of the International Gravity Commission

Graz,
11. -17. September 1994

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Introduction.

The National report on gravimetry in 1987-1991 is presented in the publication Geodetic operations in Finland 1987-1991 and in the paper National Report on Gravimetry in Finland 1987-1991, compiled by A. Kiviniemi and presented in the XX General Assembly of IUGG in Vienna, August 1991. The present report covers the period May 1991- August 1994.

1. Densification of the national gravity network.

The densification of the existing national gravity network with a density of one point per $5 \times 5 \text{ km}^2$ has been continued so that there will be two points per square kilometer. During the reporting period 1411 new points have been measured in the area around the point $\phi = 61^\circ 5' \text{ N}$, $\lambda = 22^\circ \text{ E}$.

2. Gravity measurements on the ice of the Bothnian Sea.

The gravity measurements on the Bothnian Sea which started in 1985 have been suspended due to the mild winters since 1987. In March 1994 the ice was thick enough for a resumption. In cooperation with the Geological Survey of Sweden and the Swedish National Land Survey altogether 183 new points were measured in the area of $150 \times 150 \text{ km}^2$ around the point $\phi = 63^\circ \text{ N}$, $\lambda = 21^\circ \text{ E}$. The LaCoste-Romberg gravimeter of SGS no. 788 with full damping was used. For the first time, positioning was made by a GPS on the transporting helicopter and the water depth was measured using a transportable echo sounding device. The point spacing was 5 km in longitude and 10 km in latitude.

3. Measurements in Antarctica.

Gravimetric survey has been continued in Western Queen Maud land during the austral summer 1991-1992. The measurements were made in the surroundings of the Finnish Antarctic station Aboa, located at the nunatak Basen, $\phi = 73^\circ 03' \text{ S}$, $\lambda = 13^\circ 24' \text{ W}$. This second expedition used a LaCoste-Romberg gravimeter G-600 at 261 new points in the surroundings of Aboa. In addition 32 points were measured on Basen for computing the gravimetric deflection of the vertical. In January 1994 the absolute gravimeter JILA-5 of the Finnish Geodetic Institute was used in Antarctic in the Aboa station. About 25 000 drops were made during ten days. Observations were made on the concrete pillar cast by the 1990-1991 expedition. The pillar and the hut around it lie on rocky ground.

4. Measurements on land uplift gravity lines.

The measurement on the land uplift gravity line of 63° N has been repeated as follows:

1991	Vaasa-Kramfors,	2 gravimeters
	Vaasa-Äänekoski-Joensuu,	1 gravimeter
1993	Vägstranda-Joensuu (whole line),	2 gravimeters.

In 1991 the measurement was made by the Finnish team only while in 1993 also the Geographical Survey of Norway with 4 gravimeters and the National Land Survey of Sweden with 2 gravimeters participated in the campaign so that altogether 8 gravimeters were used.

5. Absolute gravity measurements.

Since the year 1987 absolute gravity measurements have been carried out with the JILA-5 instrument. During the reporting period the following stations have been measured:

Ilmala	Finland
Vaasa	"
Sodankylä	"
Metsähovi	"
Furuögrund	Sweden
Mårtsbo	"
Gothenburg	"
Onsala	"

Ny Ålesund	Svalbard, Norway
Tromsø	Norway
Stavanger	..
Trysil	..
Strasbourg	France
Luxembourg	Luxembourg
Brussels	Belgium
Membach	..
Clausthal	Germany
Horta	Azores, Portugal
Flores	..
V. de los Caidos	Spain
Madrid	..
Aboa	Antarctic
Paarl	Rep.of South-Africa
Pretoria	..
Vilnius	Lithuania
Panevėžys	..
Klaipėda	..

The absolute gravity values for the eight Chinese stations, measured in 1990 have been computed and published.

6. Superconducting gravimeter.

During 1993-1994 a new gravimetric laboratory was built in the Metsähovi research station. Inside the building there are two separate laboratory rooms, in the first one stands a pillar for the superconducting gravimeter as well as a pillar on floor level for the absolute gravity meter, while in the other laboratory room stand two additional pillars, also suited for absolute gravity measurements. The superconducting gravimeter TT70/20 has been installed in August 1994 and has run smoothly since then.

7. Gravimetric measurements on the postglacial fault in Pasmajärvi, North Finland.

These measurements started in 1987 and have been repeated twice during the reporting time, in 1991 and 1993 using the LCR-gravimeters nos. G-55 and G-600. The measured gravity difference is 1400 μgal and no significant change in the gravity has been found in relation to a reference station, at 14 km distance from the point under investigation.

8. Gravimetric works in the Baltic States and in Poland.

The Finnish Geodetic Institute has measured in 1992 a first order gravity network consisting of 5 points in Estonia. Two La-Coste Romberg gravimeters nos. G-55 and G-600 were used and a tie to the Finnish reference point in Metsähovi was established. Three absolute gravity points have been measured in Lithuania in July 1994 as mentioned above and preparations for similar measurements have been done for Estonia, Latvia and Poland.

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GRAVITY INVESTIGATIONS OF THE GEOLOGICAL SURVEY OF FINLAND

1991-1993

by
Seppo Elo

At the Geological Survey of Finland, gravity measurements are applied together with other geophysical methods (1) to studying bedrock, (2) to exploration and investigation of ores and mineral deposits, and (3) to investigations of Quaternary deposits. In addition to our own data, the data registers of the Finnish Geodetic Institute, and those compiled in international projects (for example, Nord-Kalott and Mid-Norden Projects) are utilised.

In bedrock research, gravity measurements are used in studying, e.g. suture, shear and fault zones; fragmentation of upper crust into blocks of different composition and metamorphic grade; igneous intrusions, mafic sills and dyke swarms; stratigraphic cross-sections; greenstone belts; Proterozoic metasedimentary and metavolcanic cover with windows into basement; Meso and Neo-Proterozoic sedimentary basins; and meteorite impact structures. Gravity data is also important in providing additional constraints for interpretation of deep seismic and electromagnetic soundings of earth's crust and upper mantle. In exploration, the current major applications are in the search for large kaolin deposits and ore-bearing mafic and ultramafic intrusions. The gravity measurements supplement other methods in estimating the thickness of Quaternary deposits when planning the use of and assessing groundwater and gravel resources.

In the three-year period 1991-1993 the Geological Survey continued gravity mapping in the following way:

-Regional gravity measurements:	33165 stations (5285 km ²)
-Profile measurements:	46000 stations (988 km)
-Local systematic measurements:	43650 stations (71 km ²)

The state of the regional gravity mapping (one to six stations per sq. km) by the Geological Survey of Finland is shown in Appendix 1 (Blue: measured in 1972-1992; Yellow: measured in 1993; Red: planned for 1994; Green: measured by the Finnish Geodetic Institute).

In regional surveys, the GPS Satellite system was adopted for horizontal positioning of gravity stations, and new electronic handheld barometers were purchased for vertical positioning. The performance of new Scintrex CG3 automatic gravimeter and new electronic barometers were tested (Elo, 1993a).

Contoured and coloured maps of Bouguer anomaly and its derivatives were produced in a routine manner. Second vertical derivative, horizontal gradient and shaded relief maps of Bouguer anomaly were made in order to improve qualitative interpretation. Besides paper maps, digital maps together with a program to view these are available. The digital maps are stored in Tagged Image File Format (TIFF). By means of the supplied viewing program one can rapidly and easily manage a large and versatile volume of maps. Moreover, one can prepare one's own vector data file to be superposed on any of the maps. The system works on MS-DOS microcomputers with Super Vga graphics capabilities. Fig. 1 is an example of a shaded relief map of Bouguer anomaly.

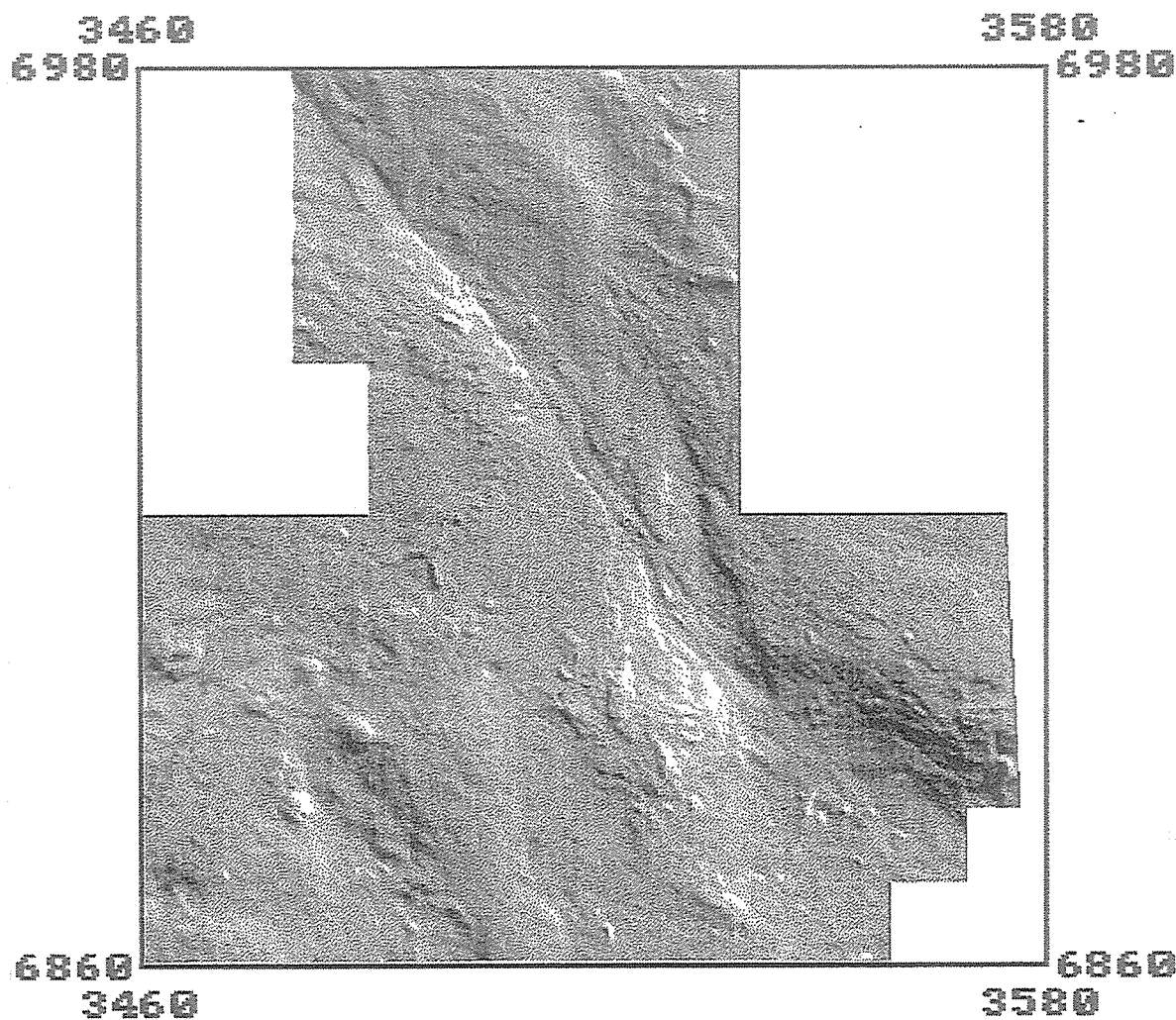


Figure 1. A shaded relief map of Bouguer anomaly, illumination from Northeast.

In cooperation with the Finnish Geodetic Institute, gravity anomaly maps with some geological explanations were published in the Atlas of Finland and in the Geochemical Atlas of Finland, Part 2. (Elo, 1992 a & b).

Terrain corrections including the effect of Earth's curvature was studied in the proprietary case of South American West Coast gravity data of Suomen Malmi Company (Elo, 1992c).

Two- and three-dimensional modelling programs including ones made at the Geological Survey and three commercial packages are currently used in quantitative interpretation. Fig. 2 is an example of the output of a code by S. Elo designed to display the ground and bedrock surface reliefs along a profile.

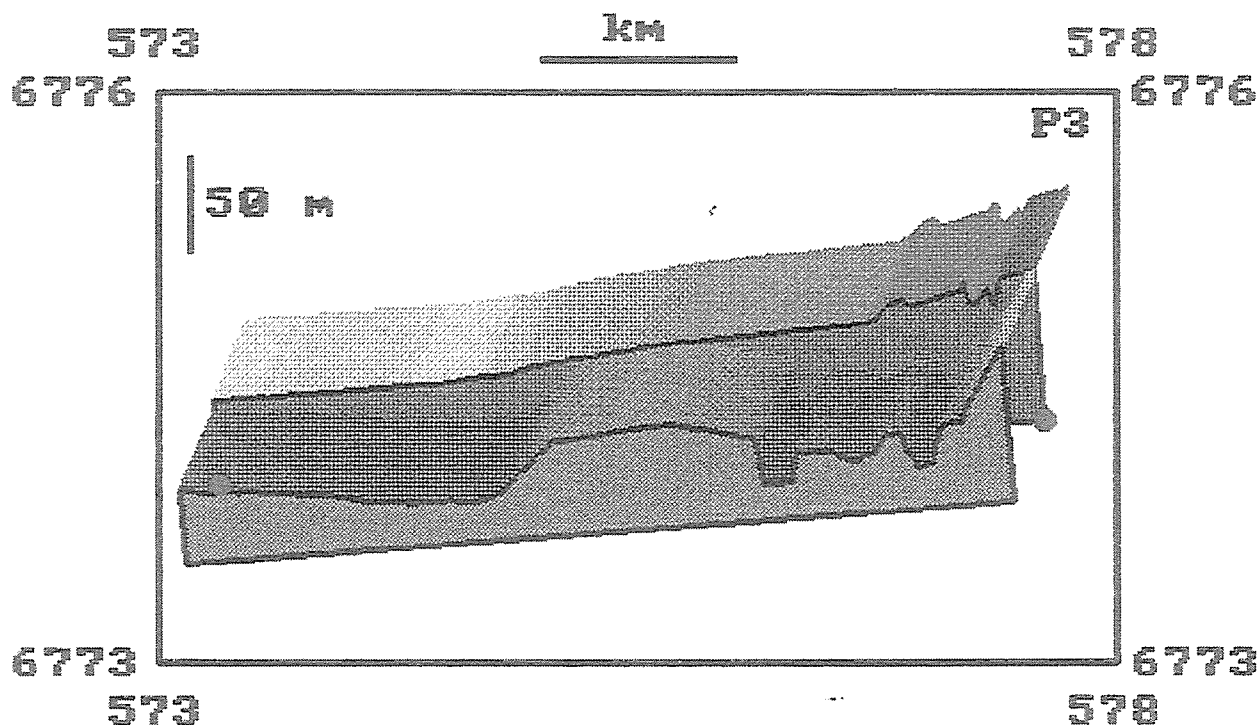


Figure 2. Ground and bedrock surface relief: an illustration of the result of gravity modelling of a Bouguer anomaly profile in south-western Finland.

Ruotoistenmäki (1992a & 1993) demonstrated the use of advanced algorithms to calculate potential field anomalies of bodies having an arbitrary shape and continuously varying density contrast.

Elo (1992d) prepared a micro-computer program SDFGM (Surface Density from Gravity Measurements) that implements Nettleton's method on MS-DOS microcomputers.

Interpretations of gravity data associated with deep fracture zones in the Kandalaksha-Kuusamo-Puolanka area were published (Ruotoistenmäki 1992 b & c, Elo 1992 e & f).

A geophysical study (including gravity) of the crustal and upper mantle structure in the Wiborg Rapakivi area, southeastern Finland, was published (Elo and Korja, 1993).

Several papers dealing with gravity anomalies and rock densities associated with proven or probable meteorite impact structures were published (Elo, Jokinen, and Soininen, 1992; Elo, Kivekäs, Kujala, Lahti, and Pihlaja, 1992; Kukkonen, Kivekäs, and Paananen, 1992; and Elo, Kuivasaari, Lehtinen, Sarapää, and Uutela, 1993).

The use of gravity measurements to estimate the thickness of Quaternary deposits was demonstrated in southwestern Finland (e.g. Elo ja Kurimo, 1993; Elo, Kurimo, Mattsson, Niemelä ja Salmi, 1993).

Two tutorial texts (in Finnish) on gravity methods found public delivery (Elo 1993 b & c).

Several papers describing the regional petrophysical mapping programme of the Geological Survey and some of its results were published (e.g. Airo and Loukola-Ruskeeniemi, 1991; Puranen, 1991; Säävuori, Korhonen, and Pennanen, 1991; Korhonen, Säävuori, Wennerström, Kivekäs, Hongisto, and Lähde, 1993; and Kivekäs, 1993). The petrophysical programme, which includes measurement of rock densities, provides necessary constraints for geological and integrated interpretation of gravity data.

The Mid-Norden project is currently compiling gravity anomaly maps of middle latitudes of Finland, Norway of Sweden, and preparing regional interpretations. The results will be published in 1995 and 1996.

The section EU2 of the Global Geotransect traverses Finland in southwest-northeast direction from Mesoproterozoic Åland Rapakivi to Archean Kuhmo region and involves integrated modelling (including gravity) of crustal and upper mantle structures. Publications will be prepared by the end of 1996 and subsequently printed.

The widespread adoption of microcomputers in geosciences a few years ago increased dramatically the conventional processing and interpretation of geophysical data, but perhaps delayed the development of more advanced graphical systems for data integration,

and calculation & optimisation of three-dimensional models for more realistic representation of complex geological structures, until microcomputers currently in use will be replaced by more efficient ones.

One hopes that the future will bring to gravity investigations (1) continuous improvement in data coverage, (2) inexpensive availability of state-of-the-art GPS positioning techniques, (3) replacement of non-digital gravimeters by automatic digital ones that provide improved control of accuracy (4) incorporation of profound understanding of geological and geochemical processes into interpretation of geophysical data, (5) advanced computer systems of geophysical modelling, and (6) even numerical modelling of relevant geological processes themselves.

Altogether, during the three year period 1991-1993, the geological applications of gravity measurements have become more versatile and widespread, and prospects for future application are exciting enough.

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APPENDIX

GTK

Alueelliset

painovoimamittaukset

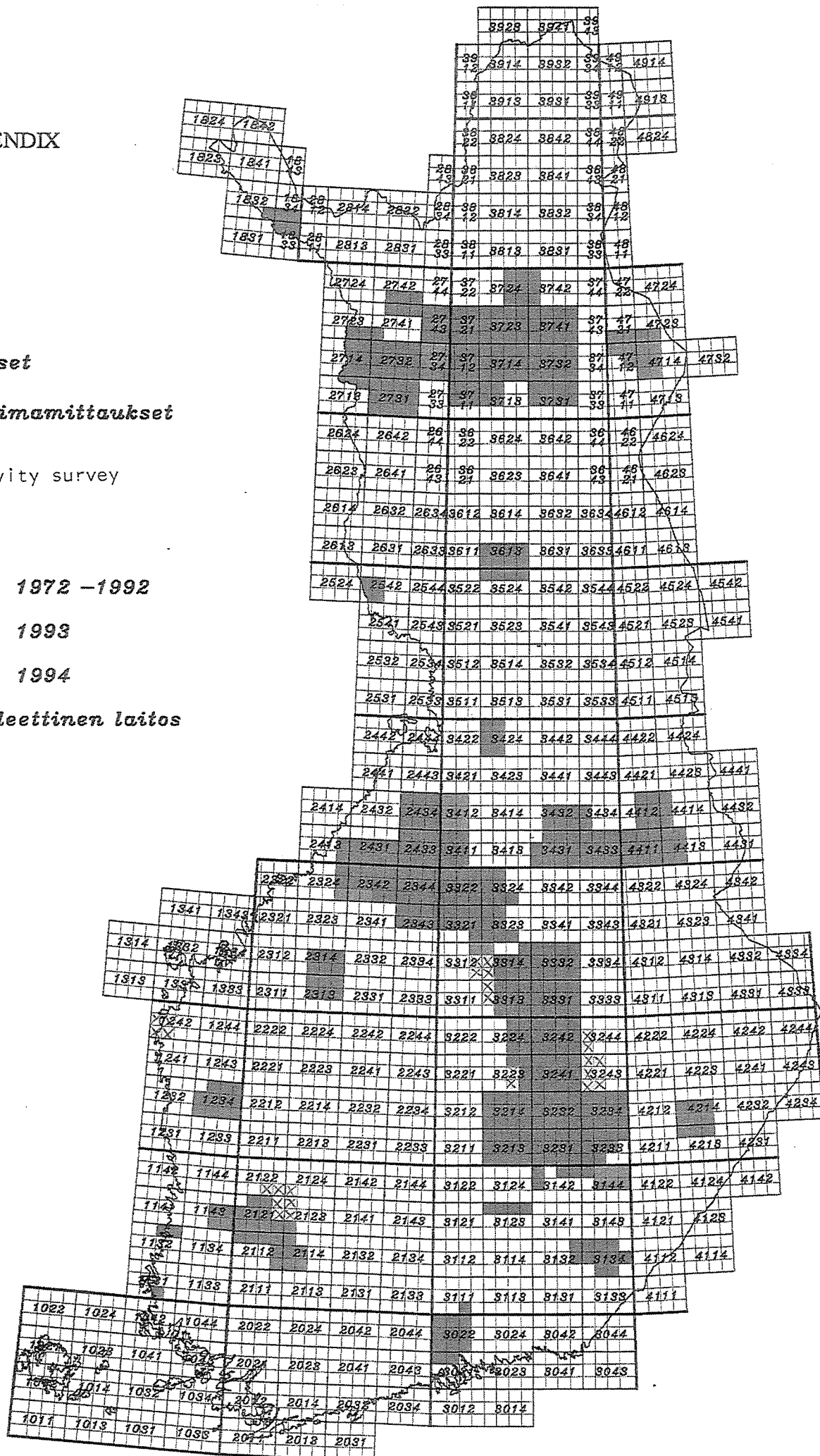
Local gravity survey

■ GTK 1972 -1992

⊗ GTK 1993

■ GTK 1994

■ Geodeettinen laitos



Report to IGC

Federal Republic of Germany (Activities 1990-1994)

It is well known that the new Absolute Gravimeter FG 5 which was built for IfaG in collaboration with NGS and other institutions yields repeatability of about $\pm 1.2 \mu\text{Gal}$; first detailed results were published in EOS and other periodicals.

A working group is actively preparing the reobservation of the German Fundamental Gravity Network where absolute gravimeters will play a dominant role and a number of selected relative gravimeters will be used for secondary purposes. Detailed procedures are under consideration for measurement and adjustment which will take place in the next years.

The exchange of gravity anomalies for scientific purposes obviously poses problems in the free way how the U.S., France and the other countries are handling this problem. A solution is considered in several national committees. It is hoped that free exchange is no longer made difficult by some institutions.

The gravimetric network along the Bocono-Fault in the Venezuelan Andes region was reobserved by DGFI/I and Cartografia Nacional de Venezuela for the fifth time since 1978 in December 1992. Fifty-eight stations over an area of about 700 km in length and about 100 km in width were each occupied at least twice by three LaCoste and Romberg model G gravimeters. The adjusted gravity values relative to a reference station some 150 km off the investigation area (Maracaibo) show r.m.s. errors from ± 0.08 to $\pm 0.012 \mu\text{ms}^{-2}$ (± 8 to $\pm 12 \mu\text{Gal}$).

The comparison of all five observation epochs (2/78, 10/81, 2/85, 9/88, 12/92) was done by a functional fit per station, including a linear (secular) and an annual periodic (seasonal) term. The seasonal variations show amplitudes up to $0.50 \mu\text{ms}^{-2}$ ($50 \mu\text{Gal}$) which can be explained by ground-water changes during rainy and dry tropical seasons. Secular gravity changes are much smaller (max. $0.06 \mu\text{ms}^{-2}/\text{year}$) and have a general tendency to gravity decrease (fig. 1) which would indicate a recent uplift of the Andean region relative to the reference station Maracaibo.

The question, whether the reference station itself is varying in gravity (e.g. subsidence of the Maracaibo Basin) has to be controlled by absolute gravity observations. A first absolute gravimetric survey of stations Maracaibo and Mérida (in the center of the Andes network) was done by the Institut für Erdmessung, Universität Hannover in 1988 and will be repeated in the near future.

The NLfB Hannover reports :

In consequence of the German re-unification NLfB has become responsible for geophysical research in the eastern German provinces on behalf of the relevant Geological Surveys. Thus gravity surveys at several places have been performed in these provinces too, in addition to analogous activities in the western provinces as before. Connections have been established between existing eastern and western base nets to serve homogenization of the data sets.

The Center Sheet of the Bouguer gravity anomaly map 1:500.000 of the Federal Republic of Germany has been published (PLAUMANN 1991).

The Technische Universität Berlin reports:

After establishing first order stations in the western part of Berlin, this region has been covered with a second order network of 26 points with an accuracy better than $\pm 10 \mu\text{gal}$ (Hirsch, 1988). Considering the new situation (after the fall of the wall in Germany) this network was extended to the eastern part of the City of Berlin in 1992/93 and additional measurements were carried out in the whole region. All measurements were made with LCR-Gravimeters. A report about this network will be prepared.

In 1991 we participated in the measurements of the West-East profile in Eastern Germany in the same manner as in 1990 with one observer and two LCR-Gravimeters.

Within the interdisciplinary Turkish-German project on Earthquake prediction in the North Anatolian fault zone some gravimetric networks were established (Aksoy et al., 1988; Demirel and Gerstenecker, 1990). A small geodetic-control-net near Gerede (Bolu) was observed several times in the last ten years (Aksoy, Bautsch, 1992). Since 1990 this net was connected by yearly measurements with the gravimetric profile near Yenicaga.

One LCR-Gravimeter was installed for recording gravimetric earth tides in Potsdam (1991/92) and in Berggieshübel (Sachsen) in the year 1993.

IfEN (formerly the Institute of Astronomical and Physical Geodesy) of the University FAF Munich reports:

Airborne Gravimetry using GPS

-Evaluation of an airborne gravity system by the Institute of Geodesy and Navigation

An airborne scalar gravity system was built up in 1990 for aerogeophysics and exploration industry consisting of a Bodenseewerk KSS-31 air-sea gravity meter, a GPS receiver (for differential GPS), an inertial navigation system, pressure barometer, a laser

altimeter and a central data registration and processing unit. In total 42 hours were flown on a Dornier 128 aircraft. The flight characteristics were: approx 180 km/h, average altitude 150 m above ground, profiles and a dense grid area in northern Germany. The analysis of the collected airborne data was carried out in 1991-93 using a software system developed at IfEN including gravity and GPS low-pass filtering.

It could be proven by ground gravity measurements that differential GPS could determine the vertical disturbing accelerations with an accuracy of 2-4 mGal over wavelength of 1-3 km.

Hein et al.. (1991) Evaluation of an Airborne Gravity System Final Report IfEN, University FAF Munich.

Institut für Erdmessung (University of Hannover) reports:

1. Instrumental investigations and developments

Since 1993 a broad band seismometer is employed simultaneously to the absolute gravity observations. This serves for considering the microseismic disturbances inherent in the time/distance measurements of free fall experiments. A reliable data rejection is now possible which replaces mainly the statistical gross error detection. An extension of the adjustment procedure for absolute gravity observations by additional seismic measurements is still under investigation. For station selections during the reconnaissances the seismometer has already proved to be a valuable tool.

In August 1991 parallel experiments were performed with the absolute gravimeters JILAG-3 (IFE) and JILAG-5 (Finnish Geodetic Institute) at the IFE reference station Clausthal (Harz Mountains). The investigations were conducted by Prof. J.E. Faller, constructor of the JILA instruments (Joint Institute for Laboratory Astrophysics, Boulder, USA). The source of a systematic gravity discrepancy between the gravimeters of about $0.10 \mu\text{ms}^{-2}$ was located in the individual functioning of the dropping chambers.

In 1993/94 a new feedback system has been developed at IFE which allows the determination of the 35.47 and 70.94 (resp. 36.67 and 73.33) Counter Unit periodical errors of the mechanical system of LCR relative gravimeters. With this system the periodical calibration terms can be determined within the gravity range of the planned network and without any need for Calibration line measurements.

2. Regional surveys in Germany

By repeated absolute and relative gravity measurements in and between Hannover and Potsdam in 1990, an absolute gravity baseline was established, which serves as reference for future geodynamic investigations in the German coastal regions (TORGE et al. 1990, REHREN et al., 1994).

In cooperation with the State Geodetic Survey of Nordrhein-Westfalen the German Gravity Base Network 1976 (DSGN76) station Aachen and the lower order point Espelkamp were occupied by JILAG-3 in 1991. The data will contribute to a long-term control of an assumed uplift of the Eiffel Mountains.

Two repeated absolute measurements were performed in DSGN76, resp. DSGN94 (under construction): Wettzell in 1992 with $0.15 \mu\text{ms}^{-2}$ discrepancy to 1989, and Karlsruhe in 1993 with $0.01 \mu\text{ms}^{-2}$ discrepancy to 1988.

In 1993 an IFE-project started to control vertical mass movements by gravimetry at a number (11) of German tide gauges (Baltic Sea and North Sea). In the frame of a broad sea level change research program the German Ministry for Research and Technology (BMFT) supports the project. After two absolute gravimetric campaigns (1994, 1996) a "zero" gravity reference epoch will be provided for long-term gravity control, repetition surveys should be performed at 10 to 20 years time interval.

In order to improve the tidal and air pressure reductions for relative and absolute gravity measurements in northern Germany, IFE performed relative gravity registrations in Hannover (1992, 6 months, 4 LCR gravimeters, e.g. TIMMEN and WENZEL 1994), Rostock (1993, 4 months, 2 LCR gravimeters), and Aurich (1993/94, 4 months, 3 LCR gravimeters). Three additional gravimetric earth tide stations in the North Sea and Baltic Sea area are planned.

3. Projects of international character

Geodynamic research projects were worldwide continued by IFE in order to monitor vertical movements of the earth's surface and/or subsurface mass shifts. The gravimetric control systems are generally combined with geodetic networks to allow a common interpretation of the results. Some regional gravity nets were densified and strengthened by LCR relative gravity measurements between the absolute stations; national and international gravity net points were included, whenever possible (e.g. TORGE 1991). Besides the geodynamic purposes, the surveys also serve for improvement of national fundamental networks, and contribute to the International Absolute Gravity Basestation Network. Three IAGBN set stations were occupied by the JILAG-3 absolute gravimeter (Beijing/China 2 determinations, 1990 and 1992, Wettzell, 1992).

In the collision zone of the Indian and Eurasian plates, the State Seismological Bureau (SSB) of China established the Western Yunnan Earthquake Prediction Study Area. IFE is employed in this test area within the frame of a long-term cooperation program with the SSB Institute of Seismology (ISSSB) Wuhan. A control system was established by JILAG-3 absolute gravity measurements in 1990 (4 stations) and reobserved in 1992 (+ 1 new station). Several LCR gravimeters mostly equipped with electronic feedback systems were employed for connecting the absolute stations and interpolating of additional stations (24 stations, 6 identical with GPS points). Two local networks were connected to the regional net: a microgravity net (loop of 11 points, $10 \times 8 \text{ km}^2$) crossed by several faults, and a vertical gravity gradient line (12 points, 18 km) crossing the Red River Fault. The two campaigns also included absolute measurements at gravity twin stations in Kunming (1990, 1992), in Wuhan (1990) and in Beijing (1990, 1992). Gravity changes up to more than $0.2 \mu\text{ms}^{-2}$ have been found in the local networks and between the twin stations in Kunming.

Within its Absolute Gravimetry Program in South America, IFE carried out a third campaign in 1991 which was concentrated on Argentina and Uruguay. New absolute stations were installed in Buenos Aires, San Juan (Central Andes Geodynamics Network, BECKER et al. 1993), Comodoro Rivadavia, and Paysandy, Toledo (Montevideo) was reoccupied. The results for the new absolute points in Buenos Aires (site change in 1991 because of groundwater problems) agree within $0.04 \mu\text{ms}^{-2}$ with the 1989 absolute station determination. For Toledo the 1989 value was confirmed within $0.01 \mu\text{ms}^{-2}$.

In a joint project with the Faculteit der Geodesie, Technische Universiteit Delft, absolute and relative gravity measurements were carried out to improve the national base network of the Netherlands. Four absolute determinations were performed: at the fundamental satellite observation station Kootwijk (1991, 1993, $0.17 \mu\text{ms}^{-2}$ discrepancy), at the VLBI-station Westerborg (1991), and in the underground observatory Epen (1993, based on rock). The stations are connected to 3 DSGN76 (German gravity base network) stations in a relative network.

4. Sea gravimetry

Within the frame of an IfE project to exactly (± 1 cm) determine the height of the island of Helgoland (about 60 km from the coast line) with respect to the German height system, a gravimetric detailed survey has been performed in the German Bay (North Sea), in 1992/93. The height transfer is performed by GPS measurements from benchmarks located near tide gauges, and by a local geoid calculation.

The gravimetric survey consists of two sea gravimetric surveys (Bodenseewerk Gss sea gravimeter, GPS navigation, 2800 nm in an area of more than $100 \times 100 \text{ km}^2$), and a survey in the tidal flat areas (164 stations) with station distance 3 to 4 km. Including older gravity measurements, the average profile distance has been reduced to about 2 to 5 nm, with 1 km gravity sampling along the profiles. The r.m.s. cross-over discrepancies after adjustment are between 0.5 and 1.5 mgal.

The project was supported by Deutsches Amt für Seeschifffahrt und Hydrographie, Hamburg, Institut für Geophysik, Universität Hamburg, and Alfred-Wegener-Institut für Polar-und Meeresforschung, Bremerhaven.

5. Gravity Field Data Bases

At the Institut für Erdmessung (IfE), University of Hannover, global and regional gravity field data bases were established for the purpose of calculating an improved European geoid (DENKER and TORGE 1993, TORGE 1992). In this project the Institut für Erdmessung serves as a computing center as requested by the IAG Geoid Subcommittee for Europe (Chairman Dr. Vermeer).

The data sets stored in the data bases are mainly point and mean gravity values and digital terrain models. At present the gravity data base includes about 1,500,000 gravity stations with the majority of data coming from Bureau Gravimétrique International, Toulouse. For each observation station the horizontal and vertical position, station name, free-air and Bouguer anomaly, topographic correction, as well as some additional informations are stored.

For the precise calculation of terrain effects a high resolution terrain data base was established. About 600,000,000 original data values were provided to IfE. The resolution of the original data grids varies between 30 m and 8000 m. The original grids were transformed to a common reference system (WGS) and then merged to a grid with a block size of $7.5'' \times 7.5''$ as well as multiples of this grid size. At present high resolution models (30...500 m block size) are available for most parts of central, northern, southern and western Europe, while such data are still lacking for large parts of eastern Europe.

The Arbeitsgemeinschaft der Vermessungsverwaltungen der Länder der Bundesrepublik Deutschland (AdV) reports:

Gravity networks:

The First Order Network (1 point/ 1000 km^2) has everywhere in Germany, the Second Order Network (1 point/ 100 km^2) has almost everywhere been completed. In the Third Order Network (1 point/ 5 km^2) is presently under investigation in most of the "Länder"; in the eastern part of Germany most administrations dispose of completed gravity networks. In all stations coordinates, elevation (height) and gravity are available in a uniform format.

The Landesvermessungsamt Rheinland-Pfalz reports :

Gravity Networks: Since 1990 in the Eifel area (1 point/ 4 km^2) a Third Order densification was carried out.

Gravity anomalies: Since 1991 Bouguer anomaly maps 1 : 50 000, in particular, and since 1993/94 a Bouguer map 1: 250 000 in cooperation with Prof. Jacoby/Univ. of Mainz was compiled.

The Landesvermessungsamt Baden-Württemberg reports :

Gravity Networks: Whereas in the First Order Network (1976-1985) accuracies of ± 8 microgal were achieved, in the Second order (1982-1986) ± 5 microgal and in the Third Order (1987-1990) ± 3 to 10 microgal were obtained. Since 1991 gravity measurements along First and Second Order Levelling lines were carried out.

Gravity anomalies: Unrefined Bouguer anomalies for 2500 stations for First to Third Order were evaluated. All gravity data are now stored in a data bank.

GFZ, Potsdam reports:

Comparative tidal gravimetry were performed at Potsdam with the following LaCoste Romberg instruments:

No. ET 16	(TH Darmstadt)	VIII.1991-IV.1991
No.G 318F	(Technical University Berlin)	IV.1991-VI.1993
No.G 156F	(University of Karlsruhe)	XII.1991-III.1992
No.G 249F	(University of Karlsruhe)	XII.1991-III.1992

Since June 1992 the Superconducting Gravimeter TT70 No. 018 is installed at the Potsdam Absolute Site. After reduction of influences of air pressure and groundwater level variations and of the polar motion effect a quasi linear drift rate of

$$29 \text{ nm/s}^2/\text{year}$$

was estimated during the first 15 months of the record.

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APPENDIX

The Bayerische Kommission für die Internationale Erdmessung reports:

About 15000 relative and absolute gravimetric observations at 500 stations in 11 countries with 50 instruments have been earth tide corrected and adjusted to yield the 'Unified European Gravity Network 1994' (e.g. Boedecker 1993)- A paper on UEGN 94 bei G. Boedecker, I. Marson and H.G. Wenzel will be presented to the IGC Meeting 1994.

Based on a 1000x1000 DTM with 50 m resolution and using FFT techniques, Boedecker (1990) showed e.g. that for gravimetric terrain corrections in mountainous areas the usual linear approximation produces errors of more than 5 mGal.

For the 'International Absolute Gravity Basestation Network' stations, a catalogue is under work, a preliminary version was presented to the IAG General Meeting Beijing 1993.

Institute of Physical Geodesy (IPG), Darmstadt Reports:

The following gravity field approximation and representation reports were published; they were elaborated in cooperation with SFB 228, particularly Prof. Grafarend; see also list of references (Grafarend, 1990).

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REPORT OF GRAVITY ACTIVITIES IN GREECE FOR THE PERIOD 1990-94

by

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Introduction

The activities related to gravity research, performed by various Institutions of Greece (with the exception of the Hellenic Army Geographical Service (HAGS)), are described in the following. The HAGS publishes special reports describing its annual activities, and as a consequence there will not be any section referred to it. Analytically, the Institutions which have shown some gravity research work in Greece are the following:

1. Geodesy Laboratory, National Technical University, Athens, GR. Dionysos Satellite Observatory

1.1. Absolute Gravity Measurements

Absolute gravity measurements were carried out at eight stations in Greece in cooperation with the Universities of Bologna and Torino, during the Sea Level Fluctuations (S.E.L.F.) project, within the period from September '93 until November '93. The absolute gravity stations are situated at the following places: Dionysos (Attica), Roumeli (Crete), Kattavia (Rodoss), Khrisokellaria (Peloponissos), Askites (Thrace), Karitsa (Epirus), Siros and Katakolo (Peloponnese). The first six stations are very near to the corresponding S.L.R. stations.

Relative gravity measurements are going to be also carried out in cooperation with the Hellenic Army Geographical Service (HAGS), in order to connect the Absolute gravity stations with the National Gravity Network and with the S.L.R. stations.

1.2. Tidal Gravity Recording

LaCoste & Romberg G-63 gravity meter was used to study Earth tides for the broader area of Athens by Milas (1992a, 1992b). The gravimetric factors and phase differences for each group of tidal waves were determined, together with the tidal residuals corresponding to the local sea tidal effects.

2. Public Oil Corporation of Greece

3560 gravity stations were measured in various areas of Greece; that is 1174 in Igoumenitsa area (NW Greece), 1315 in Kastoria area (Northern Greece), 292 in Skolis area (Northern Greece), and 979 in Grevena area (Central Greece). The measurements were carried out in four measuring periods during 1990-1992.

3. Department of Geophysics - Thessaloniki University.

Two Gravity Data Collection projects were carried out:

- (i) In the area of Ancient Evros. The target of the project was the detection of subsurface (archaeological) tombs.
- (ii) In the area of Ancient Thessaly (Central Greece), where Nettleton traverses were carried out for density determination of geological formations and used for the study of the crustal structure of the Karditsa Basin.

The rest of the activities of the Geophysical Laboratory of the University of Thessaloniki are dealing with the development of inversion algorithms and interpretation of gravity data. In more details:

- (i) Development of a space-domain deconvolution algorithm for the inversion of gravimetric and magnetic data. (Tsokas and Papazachos (1993)).
- (ii) Calculation of the structure of the Crust and the upper Mantle in the Aegean Area with the use of the Bouguer Anomalies map of the Area.
- (iii) Local studies concerning the Basin of Thessaly the Mygdonian Basin and the Island of Milos.

4. National Marine Research Center

A significant number of gravity stations were carried out mainly in the marine area north of Crete, in the Cretan Sea. These gravity observations were processed and a Bouguer gravity anomaly map of the area was compiled. Detailed analysis of this work is presented by Pavlakis (1992).

5. Department of Geophysics & Geothermy, University of Athens

5.1 Microgravimetry

Remeasurements were carried out in two of the microgravimetric networks, which had been established by the Department of Geophysics & Geothermy:

- (i) In Santorini Island for volcanic hazard assessment (Lagios et al., 1992; Lagios, 1993) and,
- (ii) In Crete for earthquake prediction studies (Lagios et al., 1991, 1992)

5.2 Conventional Gravimetry

A new Gravity Anomaly Map of Greece has been recompiled (Lagios et al., 1988) and will be published by the Institute of Geology and Mining Exploration by the end of 1994.

262 gravity observations were made in Sperchios Basin (Central Greece). The observations were processed and a Bouguer gravity anomaly map of the area was compiled. Detailed analysis of this work is presented by Apostolopoulos (1993).

A Gravity Data Bank of Greece has been compiled (Lagios et al., 1994) in cooperation with Edinburgh University. In this data bank 22,000 gravity values are included.

5.3 Gravity Related Research

An Isostatic study of Greece (Chailas et al. 1993) is in progress, based on the data of the forementioned gravity data bank. A preliminary isostatic anomaly map of Greece has been calculated (Airy isostatic model, mean depth of compensation 25.5 km), and presented (filtered version for wavelengths >200 km) (Chailas et al., 1993).

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Hungarian National Report

for the Workshop of International Gravity Commission
Graz, Austria, 1994.
Gravimetric Research in Hungary
between 1990 - 94.

Compiled by
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Eötvös Loránd Geophysical Institute of the Geological Survey of Hungary

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H-1145

1. Hungarian Gravity Base Network (MGH-80)

The observations of the new Hungarian Gravity Base Network had been completed in 1989 and the measurements were adjusted in 1990. The scale of the network is based on five absolute gravity stations observed by GABL gravimeters. The network consists of 16 first order (established on airports) and 310 second order gravity points. The r.m.s. error of the adjusted network is $\pm 160 \text{ nms}^{-2}$. In the framework of modernisation of the network three more absolute points were established and reobservations were carried out on earlier absolute points with JILAG and AXIS instruments.

The scale constants of relative gravimeters used for geodetic gravimetry are regularly checked on the national calibration line. The gravity range of the calibration line is $200 \cdot 10^{-5} \text{ ms}^{-2}$ which covers about 80 % of the total gravity difference existing in the territory of the country. The calibration line consists of three absolute and ten relative points. In 1993 the line was recalibrated by 6 LCR gravimeters. The r.m.s. error of the calibration line is less than $\pm 100 \text{ nms}^{-2}$.

The Hungarian Gravity Base Network is tied to the Austrian and Slovakian gravity networks along the whole range of common borders. The location map of the absolute and first order gravity points of the network are presented on Fig.1.

Hungary is participating in the international campaign to establish an absolute gravity network in Central Europe.

Between 1991-93 gravity measurements were carried out on the points of GPS geodynamic network established in earlier years. 24 points of the network were observed and tied to the nearest (within 30 km distance) absolute or first order gravity base point.

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HIGH ORDER GRAVITY POINTS OF HUNGARY

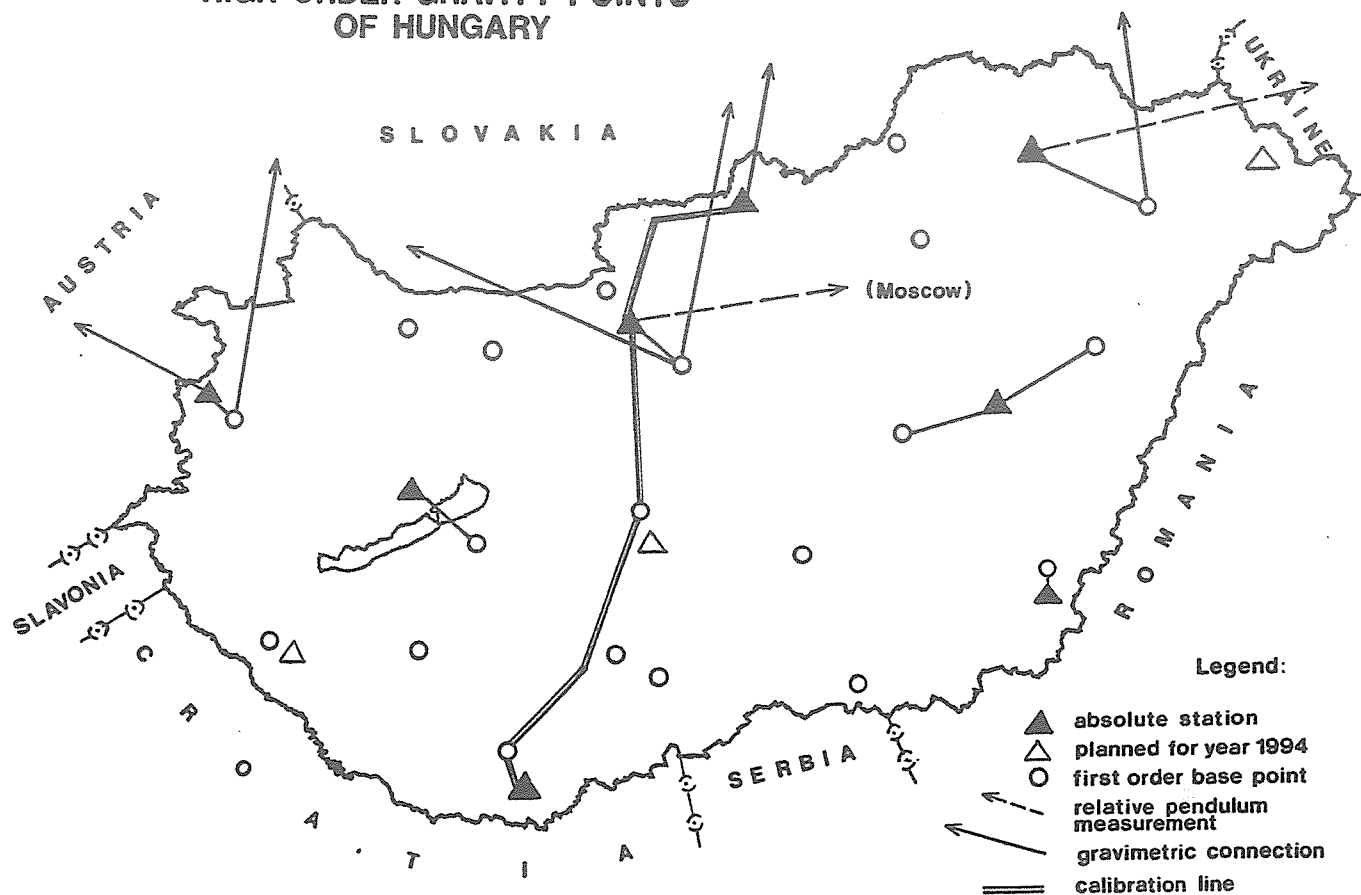


Fig. 1.

BLOCK DIAGRAM OF THE ABSOLUTE CALIBRATION SYSTEM

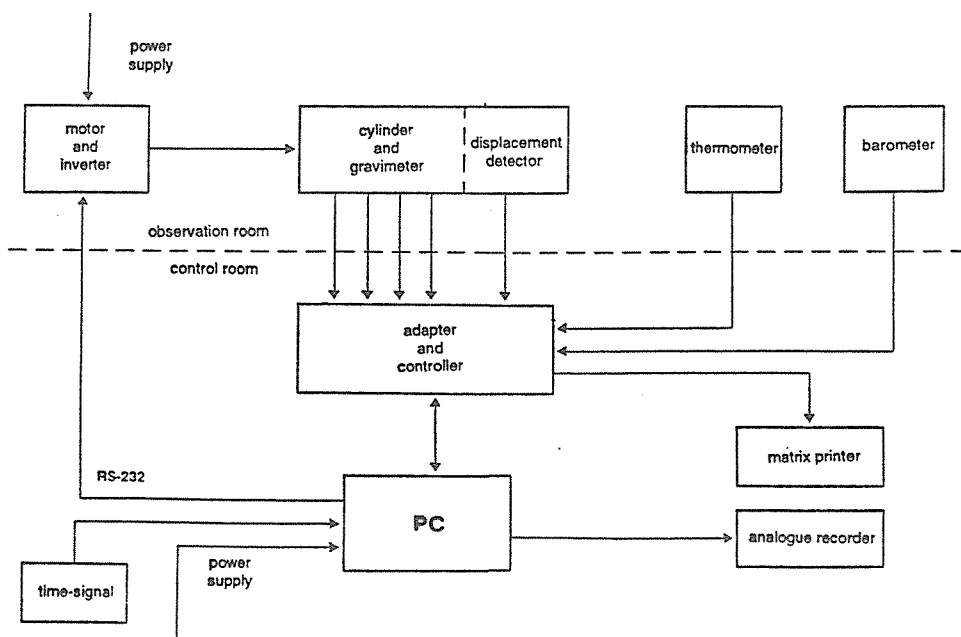


Fig. 2.

2. Instrumental and Methodological Research

An absolute calibration method has been developed for the calibration of Earth-tide registering LCR gravimeters within the framework of Special Study Group 3.133 of IAG. The range of calibration is about 1100 nms^{-2} and the calibration can be performed by a relative accuracy of several thousands. The procedure is automatic and can be controlled by a computer. The block diagram of the calibration is presented on Fig.2. To carry out one series of calibration takes about 8-12 hours.

To improve the accuracy of the LCR-G type gravimeters of ELGI a broad-band electronic feedback system has been developed and constructed. The linear operation interval of the system is $\pm 5\text{-}6 \cdot 10^{-5} \text{ ms}^{-2}$.

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Csapó, G.: Calibration of an Extended Range Feedback System Constructed for LCR Gravimeters. Geodézia és Kartográfia, 1991/5. Budapest, 1991. (in Hungarian).

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3. Theoretical Research

On the Representation of the Earth's Gravity Field

For the representation of the gravity field Geodesy and Geophysics use the gravity vector and the gravity potential. In the definition of these terms there are two different usual ways, a kinematic and a dynamic one. The first fits to a geometric, the second to a physical way of thinking. In the kinematic system gravity is defined as acceleration vector and the gravity potential has no physical meaning. In the dynamic system gravity is defined as specific force (i.e. the gravity intensity) and the gravity potential has consequently the dimension of specific work done. Both ways can be used but a mixture of them (such as gravity as acceleration and gravity potential as work done) used very often in Geodesy is inconsistent. There are some advantages of the physical system and it is suggested to use it with proper units consequently and generally in Geodesy, and in other geosciences as well.

References:

Bíró, P. (1990): What is "gravity" in fact ? Gravity, Gradiometry and Gravimetry Ed: R. Rummel & R.G. Hipkin, IAG Symposia 103, Series Editor I.I. Mueller, Springer, New York 1990, pp-8.

Bíró, P. (1993): On the representation of the earth's gravity field. Allgemeine Vermessungs-Nachrichten, International Edition, pp. 14-20.

Global Topographic - Isostatic Crust Models

The topographic-isostatic potential of the earth's crust can be computed easily using average crustal density parameters, and a numerical dataset of mean continental and oceanic heights. In lack of detailed data for density, crustal thickness and isostatic compensation, a least squares estimation is suggested to determine global horizontal variation of crustal parameters.

These variations can be determined using a minimum principle to yield a minimum variance high frequency residual geoid. The basic mathematical tool for the determination of such parameter functions is the Clebsch-Gordan product-sum conversion formula of spherical harmonics.

Computer programs were developed based on the above mentioned mathematical algorithm to determine optimal linear topographic-isostatic crust models. Previous calculations detected significant global density variations within the crust with respect to the simple Airy model of uniform crustal parameters. The results would perhaps provide us a better insight on the global isostatic behaviour of the crust.

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Völgyesi, L. - Tóth, Gy. (1992): Optimal Topographic - Isostatic Crust Models for Global Geopotential Interpretation. Periodica Polytechnica Civ. Eng. Vol. 36, No. 2, pp 207-241.

Supplement

Cooperating institutions in the field of gravimetry:

1. Defence Mapping Agency, USA
2. Bundesamt für Eich- und Vermessungswesen (Vienna)
3. Institute for Meteorology and Geophysics of the University of Vienna
4. Institute of Surveying and Mapping (Prague)
5. Institute of Geodesy, Cartography and Remote Sensing (Budapest)
6. Ágoston Tóth Mapping Institute of the Hungarian Defence Forces (Budapest)
7. Institute of Surveying and Mapping (Bratislava)
8. Department of Geodesy, Technical University of Budapest
9. Geodetical and Geophysical Research Institute of Hungarian Academy of Scientific (Sopron).

NATIONAL REPORT ON GRAVIMETRY IN ITALY 1990/1994

I. MARSON

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Absolute Gravimetry.

An extended project which includes the establishment and periodic reobservation of absolute gravity at VLBI and SLR sites in Italy has been carried under the sponsorship of the Italian Space Agency (ASI). The VLBI sites of Medicina, Matera and Noto and the SLR sites of Trieste, Padova, Trapani, Lampedusa and Cagliari have been observed with the absolute gravity meter of IMGC (Ist. di Metrologia G. Colonnetti, CNR, Torino) and the measurement have been repeated once during the last four years. The results show precisions of the order of 1 mgal, accuracy of the order of 3 mgal confirmed by the repetitions which do not exceed 5 mgal with the exception of Matera where a gravity change of 21 mgal, due to significant water table variation, has been observed.

In the framework of the SELF Project (Sea Level fluctuations and geophysical interpretation), supported by the Commission of the European Community, new absolute sites in Italy (Padova, Genova, Napoli, Catania), France (Grasse and Marseille) and Greece (Dionysos, Karitsa, Kattavia, Katakolo, Siros, Xrisokellaria, Roumeli and Askites) have been observed with the IMGC instrument.

The Italian Agency for Volcanic Risk has sponsored a program where absolute gravimetry is used, together with relative gravimetry, terrestrial and space geodesy, to monitor the volcanic areas of Vesuvio, Vulcano, Mt. Etna and Pantelleria.

Finally it is certainly worth mentioning that the IMGC absolute gravity meter has established the first absolute gravity station in Antarctic (Dec. 1990/Jan. 1991, Terranova Bay).

From the instrumental point of view, significant implementations have been made on the IMGC instrument, mainly by improving the launching mechanism, which have allowed a significative improvement of the precision of the instrument itself, which is nowadays of the order of 1 mgal. At the University of Trieste it has been completed the construction of a new rise-and-fall absolute gravity meter which peculiarly features a launching mechanism of a different design with respect to the IMGC one and an interferometer based on the principle of multiple reflections. It uses an iodine stabilized laser (Winters Optics) and the counting electronics by AXIS, which allows for post-processing of the data (of high importance to achieve results of high accuracy) and for an easy interchange of the data. Due to some unexpected problems with the laser and the counting electronics, the instrument has not been fully tested yet.

New Fundamental Gravity Net of Italy.

The first fundamental gravity net of Italy has been observed in the '50ies. It covers homogeneously the Italian peninsula and Sicily. In 1977 a Reference Gravity Net, essentially based on the newly established absolute sites of Torino, Roma, Napoli and Catania, has been measured. In this occasion part of the 1950 Net and part of the IGSN71 sites in Italy have been reobserved as well and a new gravity net has been computed. The 1977 First Order Gravity Net is essentially based on new measurements on old sites. The time history of the network is therefore preserved, but the quality of several sites has to be considered as poor because the relative benchmarks have been chosen in a rather different condition of urbanization and traffic than the present one. Today, the Italian territory is covered in a rather homogeneous way by twenty absolute sites. Therefore a project to establish a Reference Gravity Network by connecting the absolute sites with something like ten relative gravity meters has been initiated (Fig. 1).

Microgravimetry.

The Italian activities in microgravimetry are related with the studies of gravity changes induced by the exploitation of geothermal fields, volcanic and seismic activity, geodynamics and environmental geophysics. Gravity changes induced by the exploitation of geothermal fields for the production of electrical energy are routinely studied in all the fields currently exploited by ENEL (National Agency for the Electrical Energy) in Tuscany and Latium. As already mentioned above, the program for monitoring the volcanic risk periodically observes the microgravity nets installed on the Vesuvio, Vulcano and Mt. Etna volcanoes. The seismic area of Friuli, northern Italy, is interested by geodetic (GPS and levelling) and gravity networks. The first microgravity network was measured in 1977, less than one year after the 1976 earthquake. The net, based on benchmarks of the first order levelling lines measured by IGMI (Italian Military Geographical Institute) is rather extended and covers the most part of the Friuli region. In 1993 IGMI has reobserved the Friuli first order levelling lines and the Friuli gravity net has been reobserved as well. In 1991 another microgravity net was installed in the area interested at most by the 1976 earthquake, and it has been reobserved in 1993 (in a joint project between DINMA, Univ. of Trieste and Inst. f. Physikalische Geodasie, Univ. of Darmstadt). The distribution of the observed gravity changes, even if of small amplitude, appears to be in a rather good agreement with the distribution of the main tectonic features present in the studied area. Finally, it is worth mentioning microgravity observations for geodynamical purposes made on two WE transects in central Italy. Microgravity has been also employed in archeological researches with good achievements in several circumstances.

Regional and local mapping.

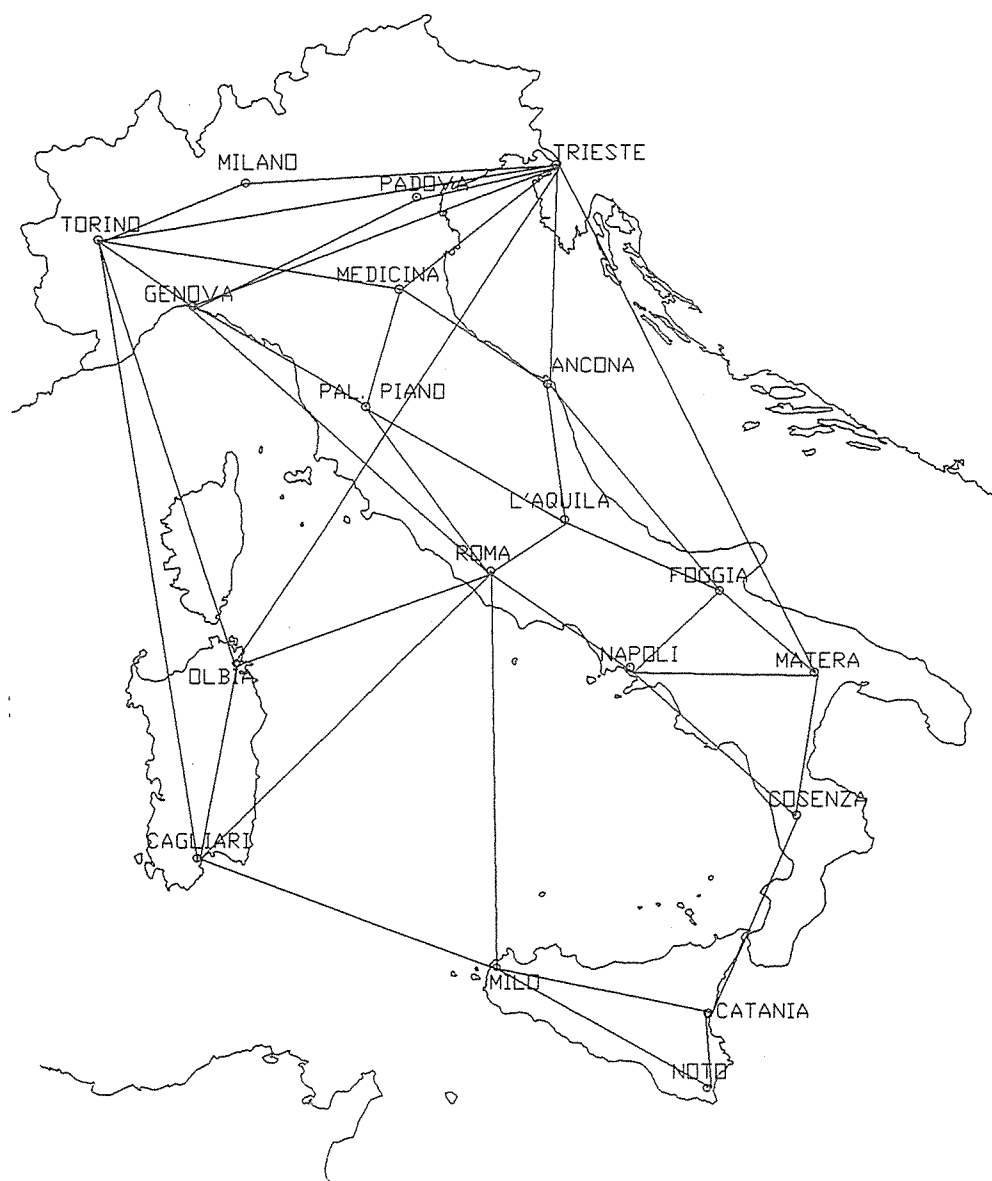
The Italian territory has been covered, in the course of the years, by some 300.000 land gravity stations which have been used to produce, in a joint effort of CNR (National Council of Research), AGIP and the Italian Geological Survey, a new Bouguer Gravity Map of Italy at a scale of 1:500.000. Acquisition of new gravity data has been limited to very local projects. It is worth mentioning the gravity profiles acquired on the Central Alps and on the Central and Southern Apennines (about 1 station/km) together with the shooting of seismic reflection profiles for the exploration of the deep crust of the Earth (CROP Project). This

provides important information for the integrated interpretation and inversion of geophysical data where algorithms for automatic interpretation of gravity and gravity gradiometric data as well as for upward continuation of gravimetric data in rugged topography (developed in a joint cooperation between ETH, Zurich and DINMA, Univ. of Trieste) can be tested and fruitfully used.

The Italian Project for Scientific Research in Antarctica has supported the acquisition, by OGS Trieste, of marine gravity data (surface) in the Ross Sea which cover an area of about 1000 km x 1000 km. The data, which significantly increase the Antarctic gravity data bank, have been used to produce the Bouguer gravity map of the Ross Sea, for geophysical interpretation and to compute a local geoid.

Experiment on the "Fifth Force".

An experiment for the detection of the so called "fifth force" is currently carried out at the Barsimone lake, near Bologna. A superconducting gravity meter is used to study the gravity changes induced by the changes of the mass of the water of the artificial lake. Besides the use of a gravity meter in studies of fundamental physics, the experiment has allowed to study the problem of calibrating a superconducting gravity meter which has been tackled with the construction of a properly designed "calibration ring" of known mass and by comparison with the data acquired with the IMGC absolute gravity meter.



Report on the Gravimetry in Japan during the Period from April 1990 to March 1994

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May 30, 1994

Report on the Gravimetry in Japan
during the Period from April 1990 to March 1994

Foreword

This document is the quadrennial report of gravimetric works made in Japan during the period from April 1990 to March 1994. It is to be submitted to the International Gravity Commission of the International Association of Geodesy at the Joint Meeting with the International Commission on Geoid, to be held in Graz, Austria from September 11 to 17, 1994. A few of works and publications not included in the previous report to the 13th meeting are also supplemented. It summarizes gravimetric works such as international and domestic connections of gravity networks, absolute and relative gravity measurements, tidal and non-tidal gravity changes, gravity surveys in Japan and foreign countries, data handling and mapping, geophysical interpretation of gravity data, theoretical researches of gravity field, etc. Complete references of the related articles are found in the bibliography.

The report was made by compiling manuscripts of various Research Institutes and University research groups. The editors are grateful to Drs. Y. Ehara, Y. Ganeko, Y. Hagiwara, T. Hashimoto, K. Kaminuma, M. Komazawa, Y. Kono, M. Kosuga, M. Mishina, H. Murakami, M. Murakami, I. Nakagawa, S. Nakai, K. Nakamura, J. Nishida, I. Ohno, M. Ooe, M. Satomura, J. Segawa, R. Shichi, S. Takemoto, T. Yabuki, A. Yamamoto and A. Yoshida.

Editors: Shuhei Okubo and Yoichi Fukuda.

1 International and Domestic Gravimetric Connections

The Geographical Survey Institute finished the first round of fundamental and first order gravity measurements at about 300 gravity stations in 1993. The series of the survey started in 1984 to improve the gravity standardization network of Japan including 13 absolute gravity sites.

International gravimetric connection along the route of Japan-Singapore-Indonesia was carried out by Disaster Prevention Research Institute (DPRI) of Kyoto University, in cooperation with Earthquake Research Institute of the University of Tokyo during the period from October to November, 1993. Two LaCoste & Romberg gravimeters (model-G) were employed in this investigation. In Singapore, gravity measurements were performed at ten gravity stations with kind help of the Survey Department of Singapore (SDS). The ten stations consist of three IGSN 71 stations, one absolute gravity point, two benchmarks of SDS, one point at Singapore airport internationally connected by BAKOSURTANAL (National Agency for Surveying and Mapping of Indonesia) and three temporally established stations. In Indonesia, three temporal gravity stations were established at Jakarta airport, one in the city center of Jakarta and one in Bandung. Gravimetric connection was performed along the route of Jakarta-Bogor-Bandung at eight gravity stations. They are composed of three stations of BAKOSURTANAL, two stations of Geological Survey of Indonesia whose gravity values are linked to IGSN 71, one GPS site and three temporal stations. Another gravimetric connection was performed along a calibration line from Bandung to Subang in Indonesia. The calibration line has a gravity difference of 276 mgal along a 50 km long route. In this investigation three GPS sites were gravimetrically connected to the calibration line under the cooperation of DPRI, ERI, BAKOSURTANAL and Bandung Institute of Technology (ITB). In addition to this gravimetric connection, gravity measurements were performed at eight GPS sites which were constructed in West Java by DPRI in cooperation with ITB. The results will contribute to improving accuracy of gravity measurements in Indonesia.

2 Absolute Gravimetry

The Geographical Survey Institute (GSI) carried out absolute gravity measurement at 6 sites using a rise-and-fall absolute gravity meter (Sakuma type) during the period concerned (Kuroishi and Murakami, 1991; Kuroishi et al., 1992). Newly occupied sites are Kushiro, Kochi and Kanazawa, whereas reoccupied are Kyoto, Kanoya and Matsue. Throughout those measurements standard deviation for mean value is 3 to 6 microgals and standard deviation for a single shot is 30 to 80 microgals.

The GSI introduced a new absolute gravity meter (FG5) manufactured by AXIS company of USA in December 1992. The GSI and National Astronomical Observatory Mizusawa (NAOM) conducted a joint measurement of absolute gravity meters for the purpose of the validating the consistency of the absolute methodology in June 1993. The GSI and NOAA of USA jointly compared their absolute gravity instruments (a rise-and-fall gravity meter, a JILA meter and two FG5's) in February 1991 and March 1993. The GSI

team visited Bureau International des Poids et Mesures (BIPM) in France with the rise-and-fall gravity meter (Sakuma-type) and the FG5 to participate in the fourth campaign for intercomparison of absolute gravimeters in March 1994.

NAOM participated in the third International Comparison of Absolute Gravimeters held at BIPM in 1989 with the NAOM2 absolute gravimeter developed by itself. The result from the NAOM2 was in good agreement with the mean value of those from the other absolute gravimeters (Tsubokawa et al., 1990; Boulanger et al., 1991; Becker et al., 1991).

NAOM developed an absolute gravimeter with a rotating vacuum pipe and has succeeded in the measurements with a drop-to-drop scatter of 19 microgals in 1989. NAOM succeeded in the continuous measurements for a week in 1991 (Hanada et al., 1990, 1992).

NAOM evaluated the data obtained by the free rise-and-fall type absolute gravimeter at Mizusawa and found that the gravity values remained almost unchanged during the period from 1983 to 1985. (Suzuki and Hanada, 1993).

NAOM designed an interferometer with two retroreflectors and two beam splitters and showed that it is possible to attain a sensitivity of $5.78 \times 10^{-13} \text{ s}^{-2}$ when a gravity gradiometer employs this interferometer (Hanada, 1992b).

Department of Geophysics, Kyoto University has started developing a small-size portable absolute gravity meter (Takemoto et al., 1992). A prototype was designed using a rise-and-fall technique to have a resolving power of 100 microgals.

3 Gravimetry in Antarctica

The 32-nd Japanese Antarctic Research Expedition (JARE) built an observation hut in 1990 at Station Syowa, Antarctica (69°S, 39°E) to establish a class A station in the International Absolute Gravity Basestation Network (IAGBN); the station has a code IAGBN No. 0417. The first absolute gravity measurement was conducted by the Geographical Survey Institute (GSI) in January 1992 using a transportable Sakuma-type gravimeter (Fujiwara and Watanabe, 1992; Fujiwara et al., 1993). The GSI obtained following results after correcting Earth tides, barometric effect and the pole tide:

Number of measurements: 834

Gravity value: $982,524.187 \pm 0.001 \text{ mgal}$

Standard deviation of a single measurement: 0.030 mgal

Gravity gradient: 0.334 mgal/m.

The second measurement was made by National Astronomical Observatory of Mizusawa (NAOM) from December 1992 to February 1993 by using 2 types of absolute gravimeters: the NAOM2 and an absolute gravimeter with a rotating vacuum pipe. The NAOM2 yielded following results after correcting Earth tides, barometric effect and the pole tide (Tsubokawa and Hanada, 1993; Hanada and Tsubokawa, 1994):

Number of measurements: 276

Gravity value: $982,524.142 \pm 0.002 \text{ mgal}$

Standard deviation of a single measurement: 0.040 mgal

Gravity gradient: 0.334 mgal/m.

Tidal gravity was observed at Station Syowa and Station Asuka (71.5°S, 24.1°E) in 1987 by the 28-th JARE. LaCoste & Romberg gravimeters (model-G) with electrostatic feedback amplifiers were used in this work (Ogawa et al., 1990, 1991). They estimated the δ -factors at the two stations, which is a little larger than that predicted by Wahr. This may be because the ice sheet is more easily to yield to the tidal force.

JARE installed a GWR superconducting gravity meter (SCG; model TT-70, #016) at Station Syowa in 1993 to observe the Earth tides and the core oscillations. This is a joint work among NAOM, the National Institute of Polar Research (NIPR) and the other scientists related to the Study of the Earth's Deep Interior (SEDI). Continuous observations of tidal gravity has been made there together with a LaCoste & Romberg gravimeter (model-D) and a three-component Streckeisen seismometer (Sato et al., 1993).

Since it is impossible to transport liquid helium at will from outside the Antarctica, a nitrogen liquefier and a helium liquefier were installed at Station Syowa to meet SCG's demand on cryogenics liquid. The gravity signals from the SCG are digitized every 2 seconds with an A/D converter of 7.5 digits. Stable recording of tidal data in 7.5 digit and mode data (Mode signal) in 20 to 100 nanogal noise level were achieved 5 months after the levitation procedure by overcoming maintenance troubles: software bugs in data acquisition systems, tilt compensation lock-off, scanner break-down and so on. Preliminary analyses of 1 year's tidal data clearly show long-period tides with a maximum amplitude of about 40 microgals besides the diurnal and semi-diurnal tides. After reduction of the long-period tides, the apparent instrumental drift is about -15 microgals for a period of 220 days. Recording of mode signals shows high quality registration of Earth's free oscillations caused by large earthquakes such as Off Southwest Hokkaido Earthquake ($M = 7.8$, 12 July 1993) and Mariana Islands Earthquake ($M = 8.0$, 8 August 1993).

4 Tidal Gravity Changes and Free Oscillations

Core modes of Earth's free oscillation were investigated by using the low-frequency seismic signals from the superconducting gravimeter (SCG; model TT-70, #007) installed at Esashi Earth Tides Station of National Astronomical Observatory, Mizusawa (Imanishi et al., 1992a, 1992b). The amplitudes of the core modes at the surface of the Earth are far smaller than those of ordinary normal modes and may be on the order of 10 nanogals or less for an earthquake of $M \approx 8$. This value, however, is well above the minimum recording level of the SCG. Core modes were searched for in a 5-day SCG record at Esashi, Japan, when Macquarie Ridge Earthquake occurred on 23 May 1989 ($M = 8.2$). Analyses by Sompi method showed four well-resolved core modes 3S3 (1.439 mHz), 3S5 (2.265 mHz), 6S2 (2.441 mHz) and 7S3 (3.122 mHz) whose eigenfrequencies are consistent with the theoretical estimation using the earth model 1066A. A test observation was carried out by using a three component long-period accelerometer in a vault at Esashi Earth Tides Station for comparison with a LaCoste & Romberg gravimeter and the SCG.

The Ocean Research Institute, University of Tokyo installed a SCG (model TT-70, #011) in 1989 at the Geophysical Research Facility at Kakioka, Ibaraki Prefecture, which belongs to the Faculty of Science, University of Tokyo. The objective is to investigate time variations of gravity due to the Earth tides, free oscillations of the Earth, polar motion, free core nutation, and so forth. This

meter has been working well so far, providing data on Earth tides, core undertones and the Chandler wobble (Fukuda, 1990a; Fukuda et al., 1991). Seama et al. (1993) found a clear signal of gravity change caused by the Chandler wobble in the 3-year record of the SCG. They also discussed the core resonance mode of the free core nutation and suggested a possible influence of the unstable oceanic tides on the gravity signals. Shi et al. (1993) dealt with the effect from the atmospheric pressure on the gravity changes. They computed the residual gravity changes by removing Earth tides and the barometric effect. The residuals are considered to include the effect from the oceanic response to the pressure changes as well as the changes of the groundwater level. It was found that the residuals became smaller when they assume 'Inverted Barometer' for the oceanic response to barometric change.

Continuous observations of gravity changes are being carried out by using two SCG's (model TT70, #008 and #009) at Kyoto University since July 1988 (Higashi et al., 1991). The two meters are oriented perpendicular to each other in the same observation room. Simultaneous observations of the two SCG's for about a year were subject to the Bayesian Tidal Analysis Program. The results for the two gravity meters were in excellent agreement with each other not only in δ -factors but also in phase lag (Higashi et al., 1992).

Faculty of Science, Kyoto University continued observation of tidal gravity change at Shizuoka using a LaCoste & Romberg gravimeter (model-D) (Faculty of Science, Kyoto University, 1993). Data from January 1990 to March 1992 were subject to the tidal analyses. No distinguished change of tidal factors was revealed during the period.

The Geographical Survey Institute has been monitoring Earth tides using a LaCoste & Romberg gravimeter (model-G) at Kanozan Geodetic Observatory in Kanto District.

5 Non-tidal Gravity Changes

5.1 Gravity Change Associated with Crustal Deformation and Seismic Activity

In July 1993, Off Southwest Hokkaido Earthquake occurred near Okushiri Island, which tolled more than 200 human lives. Hokkaido University established two observation routes, the Matsumae-Taisei route and the Setana-Soubetsu route, for precise gravity measurements near aftershock regions of this earthquake. The former route is running from the south to the north on the coast of Japan Sea in southern Hokkaido while the latter from the west to the east. Hokkaido University performed a precise gravity measurement also on the Okushiri Island.

Just after the earthquake, the Geographical Survey Institute (GSI) carried out gravity surveying on Okushiri Island and Oshima Peninsula in order to detect a gravity change associated with the coseismic crustal movement.

Precise gravity measurement was carried out in 1991 by the Tohoku University along the leveling route from Akita to Fukaura, on the coast of the Japan Sea. The rate of the gravity change was nearly equal to that of through 1982 to 1986.

Crustal movements on and around the Izu Peninsula were quite active during the period concerned. The biggest event was an earthquake swarm in June 1989 followed by a submarine eruption off Ito city in July 1989. Also in January 1993 and May 1993 occurred earthquake swarms. The GSI conducted gravity measurements on the Izu Peninsula and its vicinity in October 1990 and May 1993 to detect gravity changes associated with the volcanic activities in this region.

The Meteorological Research Institute carried out precise gravity measurements 5 times during the period from July, 1989 to February, 1994 (partly reported by Koizumi et al., 1989) to monitor volcanic activities and earthquake swarms on the east coast of the Izu Peninsula.

Earthquake Research Institute of the University of Tokyo detected significant gravity change due to the 1989 earthquake swarm and the submarine eruption, off Ito. Simultaneous inversion of gravity, leveling and EDM data shows almost zero density of cavity filling matter associated with the event (Okubo et al., 1991a). The analysis clearly favors dry tensile crack opening due to regional stress for the event of July 1989. Okubo et al. (1991a) concluded rather small-scale magma intrusion confined to an area just around Teishi knoll, rejecting the possibility of magma intrusion as a principal driving force of opening cracks in this event.

A probability has been pointed out that a great earthquake might occur in a near future in the Tokai region, Central Japan. The GSI monitors gravity at Omaezaki located in the southernmost of the Tokai District using LaCoste & Romberg gravimeters (model-G) to detect precursory gravity change for the expected earthquake. The data are transmitted to the headquarters of the GSI via a telemetry system.

National Astronomical Observatory Mizusawa (NAOM) carried out absolute gravity measurements with the NAOM2 absolute gravimeter at Omaezaki. Absolute gravimetry there, however, detected no significant gravity change so far (Tsubokawa et al., 1992). NAOM, Nagoya University and Kyoto University have made cooperative precise gravity measurements with LaCoste & Romberg gravimeters (model-G) in a seismic risk zone of Tokai District every year since 1981. The precise gravity network consists of two routes: (a) Omaezaki-Ogasa-Kakegawa-Mori-Haruno-Tatsuyama-Sakuma-Misakubo, and (b) Mikkabi-Hosoe-Hamamatsu-Hamaoka-Omaezaki-Yaizu-Shizuoka. Two more routes: (c) Inuyama-Nagoya-Okazaki-Mikkabi-Hosoe-Hamamatsu-Kakegawa and (d) Hosoe-Inasa-Tenryu-Tatsuyama-Sakuma are supplemented by School of Science, Nagoya University. These four routes are visited at least once or twice a year by double or more of going and returning trips. They detected a gradual gravity increase up to 1 microgal/year at Omaezaki, the southernmost of the district, relative to Kakegawa, 25 km northwest of Omaezaki. On the other hand, the first order leveling on the same route by the GSI revealed subsidence at Omaezaki at a rate of as large as 5 mm/year, which means tilting of the ground toward Omaezaki. The gravity is thus changing with the Bouguer gradient -0.2 mgal/m. In north of Kakegawa where no frequent leveling data were available, the gravity changes suggested the same tilting (Nakai et al., 1990). These gravity and elevation changes have continued as of June 1993, when fast (rapid) static GPS technique was introduced to monitor displacements at the gravity stations. Combined use of gravimetry and the fast static GPS is expected to yield deeper insight into the physical process of the ongoing crustal movement.

Kyoto University performed precise gravity measurements in the Kii Peninsula every two years since 1971. Since 1988, the tip of the Peninsula has been directly connected to the reference gravity station in Kyoto every year. No significant gravity change has been observed in this area during the last ten years.

A cooperative team from NAOM, Hokkaido University, Hirosaki University, Akita University, Tohoku University, University of Tokyo, Shizuoka University, Nagoya University, Kyoto University, Kanazawa University and Mizusawa high school continued experimental observations of precise gravimetry with LaCoste & Romberg gravimeters (model-G and model-D) since 1988 in and around the Kuji Underground Fluid Oil Storage, Northeastern Japan. The Oil Storage has a 1.75 million kiloliters cavity in granitic

basement rocks. The group conducted gravity measurements and leveling survey in 1992, and detected gravity changes associated with the excavation of the storage. The amount of the gravity change is comparable to that expected from the volume of the cavity.

5.2 Gravity Change Associated with Volcanic Activity

An university team from Hokkaido University, Tohoku University, the University of Tokyo, Kyoto University, Kyushu University and Kagoshima University has repeated precise gravity measurements at Unzen Volcano since November, 1990, immediately after the commencement of its eruption (Geophysical Party, 1992; Faculty of Science, Tohoku University et al., 1991, 1992a, 1992b, 1992c). Remarkable gravity increases amounting to 100 microgals were observed around the crater during the period from November 1990 to December 1993. The pattern of the temporal gravity change is correlated with the activity of high-frequency earthquakes in shallow depths and the bulging of the summit area. The gravity increase may be caused by accumulation of magma beneath the volcano.

Kyoto University, Hokkaido University and University of Tokyo carried out precise gravity measurements over Aso Volcano in 1992 for the first time since the last measurements in 1981. Four LaCoste & Romberg gravimeters (model-G) were employed for the measurements. The results showed gravity increase of several tens microgals during the last 11 years around the central crater. On the other hands, precise leveling along the same route as the gravity measurements did not show subsidence larger than 1 cm toward the crater.

5.3 Gravity Changes Associated with Groundwater Level

National Astronomical Observatory Mizusawa (NAOM) found a good correlation between the gravity measured by the absolute gravimeter NAOM1 and groundwater level at Mizusawa. Hanada et al. (1990) estimated the regression coefficient to be about 16 microgals/m.

Beppu Geophysical Research Laboratory (BGRL), Kyoto University has conducted precise gravity measurements in Beppu geothermal area since 1993. The main purpose of the measurements is to detect gravity changes associated with annual variation of the groundwater level; the annual variation is evident in continuous monitoring at some wells since the amplitude is larger than 10 meter. 11 gravity stations were newly established in the area, and the measurements have been repeated almost every one month using a LaCoste & Romberg gravimeter (model-G). A preliminary analysis shows a good correlation between gravity values and groundwater levels. The regression coefficient, however, was 2.5 to 5.0 microgals/meter, a smaller value than expected. It implies 6 to 12 % as effective porosity of subsurface rocks.

Ehara et al. (1994) carried out gravity monitoring of geothermal reservoirs at Takigami, Central Kyushu, Japan, where a hot water dominated geothermal system is well developed. Before a new 25 MW geothermal power plant starts its operation in 1996, a short period test of production and reinjection was performed from November 1991 to February 1992. Ehara et al. (1994) repeated gravity surveying every one to three months for two years including the test period to observe gravity changes of up to 150 microgals. Most of such large changes are ascribed to seasonal variations of shallow groundwater level. After correcting the seasonal effect, they detected gravity increase of up to 30 microgals in the reinjection area. This change can be well understood by supposing that the reinjected water resides for a while beneath the reinjected area. Gravity decreases of up to 40 microgals were also detected in and eastward of the production area, which became less evident by the end of March 1992, a month and a half after the test was finished.

6 Gravity Surveys in Japan

The Geographical Survey Institute conducted a gravity survey with a dense coverage (1 obs./km²) at Boso area to analyze the underground structure (Akiyama et al., 1992).

Geological Survey of Japan (GSJ) has conducted gravity surveys in order to study the brief feature of gravity anomalies in the Abukuma Mountains at 1,586 stations (Murata et al., 1992) and the Kitakami Mountains at about 2,500 stations during the period from 1987 to 1992. The 532 gravity data of the Kanto Mountains obtained during the period from 1985 to 1987 were also published (Komazawa et al., 1994). To achieve more homogeneous coverage of gravity measurements, c.a. 2,500 gravity points in a part of Hokkaido, Kinki and Kyushu Districts have been supplemented since 1992.

GSJ carried out a gravity survey over the Izu Islands in 1990 for investigation of volcanic activity and subsurface structure. The total number of the points amounted to about 350 on To-shima, Mikura-jima, Hachijo-jima and Aoga-shima Islands.

GSJ conducted gravity surveys for search of hot springs and geothermal resources at c.a. 650 gravity stations in Tanegashima Island and at about 120 stations in Kushima city, Kyushu.

New Energy Development Organization (NEDO) conducted gravity surveys for research and development of geothermal resources at 362 points in Okushi-to and at 403 points in and around Nigorikawa Caldera in Hokkaido District.

Hokkaido University has extensively performed a dense gravity survey in Hokkaido District since 1986 and more than 8,000 data were newly stored. They observed a steep horizontal gravity gradient across the Tokachi Central Fault System (TCFS). The gravity data were inverted for a shallow crustal structure together with the result of long-period microtremors. It turns out that the bottom of the late Tertiary to Quaternary sediments in the western part of the TCFS reaches a depth of 2,000 m, while the top of the basement of the eastern part is only 500 m deep (Yamamoto and Matsushima, 1991). In southern Hokkaido, Hokkaido University observed a large gradient of Bouguer anomaly exceeding 5 mgal/km along Oshima-Ohno fault, the western margin of Hakodate Plain. A sharp gradient boundary was also observed in the eastern margin of Hakodate Plain. This gradient anomaly belt crosses Funka Bay to the north leading to a high Bouguer anomaly belt near Hakodate-Kuromatsunai depression. The gravity anomaly is consistent with the subsurface structure revealed by explosion seismology except thickness of the basement at Hakodate Plain; explosion experiments were done in 1990 and 1991 along an east to the west profile from Matsumae Peninsula to Kameta Peninsula.

Hirosaki University has carried out gravity surveys at two volcanoes, Iwaki Volcano and Akita-Komagatake Volcano in northeastern Japan, to clarify the subsurface density structures. The surveys were performed at about 350 points for Iwaki Volcano, and at about 200 points for Akita-Komagatake. Bouguer anomalies thus obtained suggest some characteristics on the density structures of active volcanoes.

A gravity survey was carried out by Tohoku University at 230 points in the focal area of the 1962 Northern Miyagi Earthquake ($M = 6.5$). Adding the data surveyed by GSI, the distribution of Bouguer anomalies were mapped in detail. Good spatial correlation was pointed out between the distribution of gravity anomalies and that of microearthquake epicenters.

Earthquake Research Institute of the University of Tokyo (ERI) carried out gravity surveying at about 320 points around the Matsumoto Bonchi Toen Fault (MBTF), Central Japan (Okubo et al., 1990, 1991b); MBTF is located in the middle part of the Itoigawa-Shizuoka geotectonic line. They used Translocation GPS (Global Positioning System) to determine 3-dimensional coordinates of gravity points (Okubo et al., 1991c). Improved Bouguer gravity anomaly there reconfirms a steep horizontal gravity gradient there, which clearly indicates the existence of a dipping slab along the MBTF. The gravity data suggest thrusting fault motion along the MBTF because the density perturbation due to repeated faulting on the MBTF successfully explains the observed gravity low (Okubo et al., 1990, 1991b).

ERI carried out gravity measurements around the Kozu-Matsuda fault, Kanto, Japan (Okubo et al., 1992). Improved Bouguer anomaly data confirm the existence of a low-angle dipping slab beneath the Ashigara Plain and suggest thrusting fault motion on it. They concluded that the Ashigara Plain is a sedimentary basin with Oiso Hill as an accretional prism (Okubo et al., 1992).

Fujimoto et al. (1990) made an extensive gravity survey around the Yatsugatake volcanic chain neighboring the Fossa Magna Tectonic Line using a LaCoste & Romberg gravimeter (G-124).

Satomura et al. (1990) carried out gravity measurements in the Tokusa Basin, Western Japan, in order to find the most suitable point to drill and to get core samples for paleoenvironmental study. The results predicted that the sediment may be as much as 200 m thick at the center of the Basin.

Mio and Satomura (1993) carried out gravity measurements and investigated the relation between gravity anomalies and earthquake disaster in the central and western parts of Shizuoka Prefecture, Central Japan. They found a good spatial correlation between the area of a negative residual gravity anomaly and that where the 1944 Tonankai Earthquake caused severe damage.

Kanazawa University carried out gravity measurements in the following areas during 1990 and 1993: (1) Iki, Tsushima and Goto-Netto Islands in north and northwestern Kyushu District, (2) islands in central part of Seto-naikai (Seto inland sea), (3) Ogasawara (Bonin) Islands, and (4) Nemuro Peninsula in eastern part of the Hokkaido District.

School of Science, Nagoya University has been conducting a gravity survey in Southwestern Japan since 1978. During the period concerned, 13,000 of new measurements are added to its gravity database, which now stores about 26,000 gravity data. The database covers a quarter of whole area of the Japanese Islands including Chubu, Kinki, Shikoku, Chugoku Districts and a part of Kyushu District in Southwestern Japan.

Precise gravity surveys were carried out in Yoshioka and Tottori Hot Springs areas, Tottori Prefecture by the Department of Geophysics, Kyoto University in cooperation with Tottori University and Tottori Prefecture Office. The purposes of the surveys were to clarify the underground structure and a current origin of hot springs and also to find out a new source of hot springs in the future. In addition to the data of gravity surveys, geological and topographical surveys as well as radioactive and electric prospecting were available.

Beppu Geophysical Research Laboratory, Kyoto University (BGRL) conducted underwater gravity measurements in the Beppu Bay area, Northeast Kyushu, to study several distinctive tectonic boundaries intersecting there (Yusa et al., 1992). Complementary land gravity measurements around the bay have also been made since 1989 under the cooperation with BGRL and Department of Geophysics, Kyoto University. Both underwater and land gravity data were recompiled by means of the least squares prediction (an optimum prediction method) to make a gridded data set of Bouguer gravity anomalies. A preliminary 2-dimensional analysis showed a subsurface density structure composed of 4 layers: upper and lower sedimentary layers, the Ryoke formation and the Sanbagawa formation (Fukuda et al., 1994).

Department of Geology and Mineralogy, Kyoto University compiled the gravity data around Lake Biwa, Shiga Prefecture (Nishida et al., 1990). The gravity data at 2,331 points revealed large-scale negative anomalies in the center of northern Lake Biwa. Nishida et al. (1990) pointed out that these gravity lows cannot be explained by the thick sediments of Lake Biwa. Small-scale negative anomalies are also found in the Ohmi basin, southeastern part of Lake Biwa. These small anomalies give the information on the basin structures around Lake Biwa.

Nishida et al. (1991) reported the result of gravity survey of 216 points around the Takayama region of Ikoma City, Nara Prefecture. They estimated the vertical displacement of Miyakata fault, a parallel fault of Ikoma fault.

Department of Geology and Mineralogy, Kyoto University carried out the gravity survey (253 points) in the central part of Nara basin, northern part of Nara Prefecture, Western Japan.

Ehime University carried out land gravity survey using a LaCoste & Romberg gravimeter (G-691) in Shikoku, Chugoku and Kyushu Districts; they are located in and around the western area of the Seto Inland Sea, Southwestern Japan. The number of measured gravity stations amounts to 740. Sea surface gravity measurements in the area were made in 1991 with a TSSG gravity meter on a research vessel "Tansei-maru" of the Ocean Research Institute, the University of Tokyo. Marine and land gravity data were merged to produce a Bouguer anomaly map. The map shows a significant gravity low anomaly belt from Beppu bay to off Matsuyama along the Median Tectonic Line, which indicates a graben structure along this belt.

Kochi University has conducted the gravity survey in the southern Shikoku District, Japan since 1989. Gravity measurements were carried out at more than 1400 points during the period from December 1990 to January 1994 (Murakami et al., 1991; Nagoya University et al., 1993).

7 Marine Gravimetry

Geological Survey of Japan has been conducting marine gravity surveys since 1974 using the survey vessel, "Hakurei-Marui", which was equipped with a LaCoste & Romberg straight-line air-sea gravimeter (SL-2). The cruises of the ship during the period from 1991 to 1993 are listed in Table 1. Gravity surveys were conducted as a part of the geological mapping program of the continental margin around Japanese Islands. The results were published in cruise reports and free-air and Bouguer anomaly maps have also been published as appendices of the "Marine Geology Map Series" in a scale of 1:200,000 (Geological Survey of Japan, 1993a, 1993b, 1994).

The Hydrographic Department of Japan (JHD) carried out marine gravity surveys using two survey vessels "Meiyo" (620 gross tons) and "Takuyo" (2,600 gross tons) during the period from 1990 to 1994. These vessels are equipped with the sea gravimeter Bodenseewerk KSS-30. The gravimeter on Meiyo, which was launched in 1990, was moved from survey vessel "Shoyo" in 1990. The cruises from April 1990 through March 1994 are listed in Tables 2 and 3. The preliminary reports of the cruises are presented in the publications of JHD (Hydrographic Department, Maritime Safety Agency, 1990, 1991a, 1991b, 1992a, 1992b, 1992c, 1992d, 1993a, 1993b, 1994a, 1994b, 1994c). The gravity data were analyzed by Kasuga et al. (1992), Okino and Kato (1992) and Ueda (1994).

Marine gravity surveys have been conducted by the Ocean Research Institute of the University of Tokyo (ORI) and National Institute of Polar Research (NIPR) in the framework of Japanese Antarctic Research Expedition since 1980. NIPR-ORI (model-2) is the gravity survey system which is installed on board Japanese Antarctic icebreaker "Shirase". Purposes and procedure for the gravity measurements are described by Fukuda et al. (1993a).

ORI conducted four cruises boarding the research vessel "Hakuho Maru" from 1990 to 1994. Throughout these cruises gravity measurements were conducted using the NIPR-ORI gravimeter. The surveyed areas are: Izu-Ogasawara, Shikoku Basin and Kashima Offing (Segawa, 1990), Japan Trench and Izu-Ogasawara Ridge (Kobayashi, 1991), Mariana Region and Ayu Trough (Segawa, 1992), Western Kuril Trench and Eastern Nankai Trough (Kobayashi, 1993).

In the geophysical study of the sea, data collection and compilation are as important as the measurements. Tamaki et al. (1992) developed a computer system called MAGMAT, which can be used for mapping world-wide marine geophysical data including gravity, magnetics, bathymetry and heat flow at any place in any scale.

Table 1: Cruise for marine gravimetry by the Geological Survey of Japan during the period from 1991 to 1993.

Cruise ID	Cruise period	Surveyed Area
GH91	June-July 1991	Off Yamagata and off Niigata
GH92	June-July 1992	Eastern border of Central Japan Sea
GH93	June-July 1993	Eastern border of Central Japan Sea

Table 2: Cruises of "Meiyo" for sea gravity surveys conducted by the Hydrographic Department of Japan during the period from April 1990 to March 1994.

Cruise ID	Cruise Period	Surveyed Area
91ZN	Jan. 1991	Nankai Trough, Zenisu Ridge
91HY	Feb. 1991	Offing of Iyo and Hyuga Nada
91BO	Mar. 1991	Sagami Trough, East Offing of Boso
91MF	May 1991	Offing of Miyagi and Fukushima, II
91UN	June 1991	Shimabara Bay and Tachibana Bay
91MI	Aug.-Sept. 1991	Vicinity of Mikura Seamount
92EN	Jan. 1992	Offing of Ensyu-Nada
92NI	Mar. 1992	Nankai Trough, West Offing of Niiijima
92NK	Aug.-Sept. 1992	Nankai Trough
92IZ	Nov.-Dec. 1992	North of Izu-Ogasawara Trench
93HY	Jan.-Feb. 1993	Offing of Iyo Hyuga-Nada
93KO	Feb.-Mar. 1993	Around of Kozu-Sima
93TO	Apr. 1993	Japan Trench, Offing of Tokachi
93AY	May-June 1993	Offing of Akita and Yamagata
93OK	July 1993	Offing of Southwest Hokkaido, Vicinity of Okusiri
94EN	Jan. 1994	Offing of Ensyu Nada, II
94IR	Feb.-Mar. 1994	Offing of North-Northwest Iriomote-Sima

Table 3: Cruises of "Takuyo" for sea gravity survey conducted by the Hydrographic Department of Japan during the period from 1990 to 1994.

Cruise Period	Surveyed area
Apr.-June 1990	Oki-Daito Ridge
Sep.-Nov.1990	North of Oki-no-Tori Sima
Nov.1990-Jan.1991	Northern End of West Mariana Basin
Feb.-Mar.1991	Round Cruise in the Philippine Sea
Apr.-May 1991 and Sept.-Oct.1991	Eastern Part of Ogasawara Plateau
Oct.-Nov.1991	Northeast of Ogasawara Plateau
Feb.-Mar.1992	Round Cruise in the Palau Trench
Jan.1992 and July.1992	Southern Part of Izu-Ogasawara Trench
Aug.-Oct.1992	North of East End of Ogasawara Plateau
Oct.1992-Jan.1993	East End of Ogasawara Plateau
Feb.-Mar.1993	Round Cruise in the Yap Trench
Apr.-Oct.1993	South of Minami-Io-Sima
Oct.1993-Dec.1994	East of Oki-no-tori-Sima
Feb.-Mar.1994	Round Cruise in the Philippine Sea

8 Data Handling and Gravity/Geoid Maps

Geological Survey of Japan (GSJ) published a detailed complete Bouguer anomaly map of Akita District, Yamagata District, Niigata District and Joetsu District by processing about 60 thousands of data in the gravity mapping program of Japanese Islands (Hiroshima et al., 1990, 1991, 1993, 1994).

GSJ created a map of Bouguer anomaly with terrain-correction in and adjacent Japanese Islands (25°N-47°N, 115°E-150°E) in a scale of 1:5 millions by using about 300 thousand land gravity data, about 900 thousand shipborne gravity data and satellite altimeter data in area where little surface observation data exist (Komazawa et al., 1992a, 1992b). Shipborne gravity data are checked and processed by using upward continuation filter considering bathymetry in order to remove noise and irregular short-wavelength components.

Shichi and Yamamoto (1991) created a gravity database to cover the Southwestern Japan by collecting gravity data from more than 20 institutions and organizations. The number of compiled gravity data amounted up to 80,881 in total with net points. The database is characterized by its overall accuracy of 1 mgal or better as well as a uniformly distributed dense coverage. Shichi and Yamamoto (1991) reported the compilation process of gravity data in Southwest Japan and a problem on the accuracy of gravity data. Using the present gravity database, Shichi et al. (1992) analyzed gravity anomaly around Mt. Ontake Volcano. On its southern foot occurred the 1984 Western Nagano Prefecture Earthquake with magnitude 6.8. A steep gradient belt of Bouguer anomaly was outstanding just along the seismic fault.

Noro and Shichi (1994) published gridded gravity data created from the gravity database by Shichi and Yamamoto (1994), source data of gravity anomaly maps, gravity analyzing programs, and so on in a CD-ROM format.

The database of gravity in southwestern Japan compiled by Shichi and Yamamoto (1994) enables producing a pair of very fine gravity anomaly relief maps (1:1 million and 1:2 million scale sizes) and a 1:700,000 scale of large sized precise Bouguer anomaly map contoured at 0.5 mgal interval. The former were published from the Geographical Survey Institute (Geographical Survey Institute, 1993) and the latter from GSJ (Gravity Research Group in Southwest Japan, 1994; Murata et al., 1994). An excellent correlation can be seen in the maps between known active faults or tectonic boundaries and distributions of Bouguer anomalies even on a local scale. Many linear structures with sharp gravity changes are observed both in the Chugoku and in the Shikoku areas. Some structures which do not correspond to known active faults or geological boundaries might indicate the existence of hidden faults or tectonic structures (Yamamoto and Shichi, 1994).

Four maps of free-air gravity anomalies are published in the series of the basic map of the Sea (Map Nos. 6424G, 6601SGM, 6602SGM, 6302G) by the Hydrographic Department of Japan (JHD). In particular, map 6302G, which covers vast area of southern waters of Japan, was produced by compiling both large amount of data sets collected by JHD from 1983 until 1993 and those provided by Japan Oceanographic Data Center (Kasuga et al., 1994).

Gravity data around Station "Syowa", East Antarctica (68°S-78°S, 25°E-55°E) was re-compiled to produce three-dimensional maps of free-air and Bouguer anomalies (Nagao and Kaminuma, 1991; Nagao et al., 1991). Gravity values referred to the Potsdam System are transformed into the IGSN71 System, and accuracy of the gravity values was evaluated.

Kaminuma et al. (1991) published a map of Antarctic Geoscience Transect which includes long profiles of gravity anomalies across the Antarctic continent over to the surrounding seas.

Nakakuki et al. (1991) published a summarized map of free-air gravity anomalies of the Philippine Sea. Yang et al. (1992) compiled gravity across the Mariana Ridge and Trench using surface gravity data and satellite altimeter data to obtain a significant lowering of density in the lithosphere beneath the Mariana Ridge/Trough.

Kono and Furuse (1990) reported digital compilation of gravity data over the Japanese Islands, not only on land but also in marine areas at the IAG General Meeting 1989 in Edinburgh. Data points are over 500 thousands and anomaly map scale is 1:1 Million with a contour interval of 2 mgal.

Tanaka and Kono applied an adaptive filter to gravity anomaly studies; the adaptive filter is popular now in electronic communication theory.

Kudo and Kono (1993, 1994) employed the shaded relief map technique to illustrate gravity anomaly over the Japanese Islands where dense and homogeneous gravity data are available (Kono and Furuse, 1990). This method yields pictures which clearly illustrate undulation of gravity anomaly over the islands and helps one find out linearments in gravity anomaly.

The most reliable gravity mapping around Japan was made by Fukuda (1990b) using both surface gravity data and satellite altimeter data. The formal errors in free-air gravity anomalies estimated by the Least Squares Collocation were less than 10 mgal. A similar method was applied to the estimation of gravity anomalies in Antarctica (Fukuda et al., 1992).

A set of geoid maps in and around Japan have been published based on the geoid data from Ocean Research Institute, University of Tokyo (Fukuda et al., 1993b). The maps were intended to provide a practical material in the use of geoid data such as a case of planning the GPS surveys and so on. Thus they were plotted using Lambert's conformal conic projection with the scale of 1:1,000,000, following the bathymetric charts of the same scale published by the Hydrographic Department, Maritime Safety Agency of Japan.

9 Gravity Data Analysis

Komazawa et al. (1991) analyzed gravity data in and around Aso caldera, Southwestern Japan, to estimate the basement structure. They found that the caldera is composed of not one but of several depressions. Its ring-shaped steep gradient at the basement allows them to classify the caldera as a piston-cylinder type caldera (Valles type).

Murata (1993) applied an ABIC method to estimate surface rock densities from gravity data in Kyushu. The estimated densities are consistent with the surface geology in the area. The ABIC method is thus very useful to obtain true Bouguer anomalies because it yields accurate estimate on surface density.

Tohoku University, Hirosaki University and Geological Survey of Japan, found a close correlation between the Bouguer anomaly and the distribution of epicenters of earthquake swarms. They also pointed out that the source area of big earthquake (disastrous earthquake) was laid from the area of low anomaly through that of high anomaly.

Gravity anomalies and geoidal undulations around Stations Syowa, Antarctica, (60°S - 80°S, 20°E - 50°E) have been newly estimated using both satellite altimeter data and surface gravity data. Fukuda et al. (1990) employed the Least Squares Collocation to process the two data sets simultaneously with exact estimates on formal errors. Some problems on the simultaneous use of the different kinds of gravity field data for the determination of the gravity field around Antarctica are discussed by Fukuda et al. (1992). The regional geoid obtained by satellite altimetry data can be used to detect the relationship between the deformation of the plate and the sub-bottom structure (Matsumoto and Kaminuma, 1993). Several GEOSAT tracks across the circum-Antarctic ridges were examined to investigate the characteristics of geoid anomaly and to detect the sub-bottom structure.

Doi et al. (1991) discussed the elastic part of the atmospheric pressure effects on gravity changes by analyzing the data of a superconducting gravity meter installed at Kyoto University. They first computed residual gravity change by removing the gravimetric tides, linear instrumental drift and atmospheric mass attractions from the raw data. The residuals thus obtained were compared with elastic effect estimated by using the atmospheric pressure distribution within an angular distance of 20 degrees and a load Green's function. The residuals were in good agreement with the computed elastic effects except for some discrepancies at short periods. The observed elastic effect is approximately an average of elastic effects estimated for two extreme cases: (1) a non-inverted barometer model where ocean bottom responds perfectly to the atmospheric loading and (2) a perfect inverted barometer model where ocean bottom does not respond to the atmospheric loading at all. This result may be ascribed to (i) some non-zero response of the ocean bottom to the atmospheric pressure, (ii) the deviation of structure beneath the observation station from the mean Earth's structural model, (iii) the truncation error of integration and so on.

Doi (1992) estimated a load Green's function for gravity by using the gravity changes associated with the time-varying atmospheric pressure loads. To be more precise, parameters corresponding to discretized load Green's function were estimated by the non-negative least squares method. He obtained a parameter for the nearest region consistent with the theoretically predicted one. The other parameters, however, could not be well determined because of noises included in gravity changes associated with atmospheric pressure variations. For example, groundwater will be a major source of observational noise. Reduction of such noises and a potent method of inversion are required for the improvement of the analysis.

10 Geoid and Theoretical Study of Gravity Field

Estimation of Geoid has remarkably advanced since the advent of satellite radar altimetry. Following SEASAT and GEOSAT, the TOPEX/Poseidon satellite has been providing 2cm altitude data since 1992. Segawa and his colleagues applied to NASA for providing TOPEX/Poseidon data in 1986. They were processing the data mainly to determine gravity and geoid around Japan and the East Antarctica (Segawa, 1990; Segawa et al., 1991).

Kuroishi at the Geographical Survey Institute computed geoid undulation around Japan mainly using land and marine gravity data in 1993.

Fukuda (1990b) determined a geoid in and around Japan (20°N - 50°N and 120°E - 150°E) within rms errors of 20 cm using both satellite altimeter data and surface gravity data. Geoid heights and their formal errors at the center of 5' x 5' blocks are evaluated by use of the Least Squares Collocation.

To clarify the effects of the data selection, Fukuda (1990b) computed geoids for the following data sets: (1) surface gravity data only, (2) altimeter data only, (3) all the surface gravity data supplemented partially by altimeter data where the gravity data are not available and (4) vice versa. Strictly speaking, the second case did not present the geoid but the sea surface height. The sea surface dynamic topography should be thus detected by comparing results for the first and the second cases. Its detection, however, was still difficult because the gravimetric geoid is only poorly determined (Fukuda and Segawa, 1991). From the comparison between each result and its formal error estimate, the third case is considered to be the most reliable.

The main drawback of the Least Squares Collocation is that a large set of linear equations must be solved. One approach to overcome this difficulty is to divide the matrix into small pieces by a multi-step collocation. A test computation was successfully carried out to estimate a very detailed local geoid in an area of 24°N - 26°N and 133°E - 137°E (Fukuda, 1991). Using dense gravity data with a 5' x 5' reference geoid, an accurate geoid of 1'x1' grids was obtained with formal errors better than 5 cm.

Since the GPS survey directly determines the height of the Earth's surface from a reference ellipsoid, its combination with ordinary leveling and/or gravity measurements provides us several kinds of the gravity field quantities such as gravity anomaly, gravity disturbance and geoid height. Although these quantities are equal in the sense to represent a gravity field, it is meaningful to investigate the most practical ways of treating the data. Fukuda (1993) presented a proper formulation to use the Least Squares

Collocation as a mean to deal with GPS, leveling and gravity data for a local problem. He also investigated the degree variances of the gravity field in Japan to discuss the error estimates of the combined measurements, and concluded that the combined use of GPS and gravity data is quite efficient for both gravity surveys and height determinations.

GPS/leveling geoid undulation was determined at 37 stations in Chugoku, Shikoku and northern Kyushu Districts of the Southwestern Japan (Yabuta, 1993; Fujimori et al., 1993). Since the measurement area was widely extended, five reference stations with accurate global coordinates were used in GPS measurements. The estimated geoid height were almost consistent with the previous works, such as the JHD geoid and the ORI-89 geoid. Yabuta (1993) discussed a large-scale upheaval of the geoid in the Kii Peninsula, the southern Kinki District. He showed that the upheaval was strongly influenced by topography and that isostatic equilibrium did not exist in that region. He presented a crustal structure model in the region to explain the observed geoid undulation and gravity anomaly as well.

Shibuya et al. (1990, 1991) determined the geoid height at Breid Bay of Antarctica by the combined observation of satellite Doppler positioning, GPS measurement, and ocean tide observation. Their method is appropriate for dense installation of geoid height control stations along the circum-Antarctic coast.

The Hydrographic Department of Japan (JHD) investigated sea bottom topographies by inspecting the ERS-1 altimetry data (Ganeko et al., 1993) because sea surface closely approximates the geoid on which sea mounts, ridges and trenches have profound effects. The satellite altimetry is thus a very effective way to observe the gravity field in oceanic areas.

JHD continued satellite laser ranging (SLR) observation of remote sensing satellites and geodetic satellites at the Simosato Hydrographic Observatory (Hydrographic Department, Japan Maritime Safety Agency, 1991c, 1992e, 1993c, 1994d). The SLR observation of remote sensing satellites such as ERS-1 and TOPEX/Poseidon contributes to producing reliable altimetry data by providing essential data to determine their accurate orbits. Moreover, the observation of the motions of geodetic satellites such as Lageos and Ajisai contributes to the improvement of global gravity field.

Okubo (1991, 1992) derived expressions in closed form which give the gravity potential changes raised by point dislocations and by faulting on a finite rectangular plane buried in a half space. They enable us to evaluate coseismic changes in surface gravity and geoid height. Numerical simulation shows that the geoid changes its height by 1 to 10 cm after a great earthquake. Even a moderate earthquake of moment 10^{19} N.m causes a gravity change of up to 500 microgal.

Okubo (1993) found intriguing reciprocity relations between the static deformation excited by a point dislocation in a SNREI (spherically symmetric, non-rotating, perfectly elastic and isotropic) earth and those generated by external forces, such as tidal force, surface loading and surface shear forces. Coseismic potential change can be written in terms of the tidal deformation field. The relations greatly reduce the effort to compute the coseismic crustal deformation in a spherically symmetric earth.

Sun (1992) and Sun and Okubo (1993) studied the potential and gravity changes caused by dislocations in spherically symmetric earth models. The results for a homogeneous sphere agree very well with those predicted by the flat-earth theory (Okubo, 1991) as long as epicentral distance is smaller than 1 degree. The far-field results indicate no larger than 10 percent difference when epicentral distance is less than 10 degrees. Calculations for a radially heterogeneous earth model (Model 1066A) yielded results similar to those for a homogeneous sphere as a whole. In some cases, however, the difference between the two becomes significant. For example, the locations of the nodal lines of the gravity change differ significantly between the two models. This indicates that stratified structures can cause significant effects on the deformation field.

National Astronomical Observatory Mizusawa (NAOM) investigated the detectability of the non-Newtonian gravity considering uncertainty in the density of the Earth, lateral heterogeneity, and undulation in the figure of the Earth. Hanada (1991, 1992a, 1992b) showed that it is possible to detect the non-Newtonian gravity by measuring gravity gradient with the sensitivity of $10^{-13}/s^2$ if the coefficient is larger than 10^{-6} .

Hagiwara (1990) derived mathematical formulas of the non-Newtonian attraction force of simply-shaped bodies.

Hagiwara and Kotake (1994) developed general formulas for the transformation from spherical harmonics to spheroidal ones, and those for its inverse transformation. They applied the formulas to the Earth's gravity potential field to obtain the power spectrum of difference between geoidal height expressed by spherical harmonics and that expressed by spheroidal ones. They conclude that the second-degree harmonic term of the difference results in an error of ± 10 cm on the geoidal height, and the terms lower than the 11th degree in that of the order of ± 1 cm.

Hagiwara and Kotake (1993) applied the two-dimensional Walsh analysis with the sequence spectrum up to degrees $m = n = 32$ to gravity field data of Suwa Basin, Central Japan. They demonstrated that the original data can be reproduced within errors of ± 1 mgal by truncating higher degrees of $m + n > 32$ from the spectrum. A pattern recognition procedure using the spectrum yields a horizontal dislocation to be 15 km, which is consistent with the geological result of 12 km.

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NATIONAL REPORT OF THE NETHERLANDS ON GRAVITY AND GEOID 1990-1994.

Introduction.

Study of the gravity field of the Earth has been a major task of Geodesy. The geoid is the equipotential surface of the Earth at mean sea level. Its determination requires the gravity field available all over the Earth.

In recent years the geometric shape of the Earth, continents and ocean surface, became measurable with an unprecedented precision, due to the enormous progress of space methods.

The geoid is the reference surface for height measurements. With modern space techniques like GPS positioning, it is possible to determine the topographic heights. A necessary condition is that the geoid must be available with a very high precision.

For the connection of the height datums and horizontal datum points in the different continents it is also necessary to know the gravity field and the geoid.

Gravity measurements.

Characteristic for the data collection in The Netherlands is the position near the sea. The collection of sea gravity data is necessary.

Gravity measurements are divided into four steps:

- Absolute gravity measurements on four points.
- Relative gravity measurements, first order net of about 40 points.
- Relative gravity measurements, second order net with point distance of 2 km.
- Gravity measurements at sea.

Absolute gravity.

To determine the scale and absolute level of the Netherlands gravity net it is necessary to determine three or four absolute gravity points. These measurements give also a reliable connection to the international gravity network. Secondly, repeated measurements give us an insight in the change of gravity during the time. This is important in connection with the study of land subsidence and sea level change.

Measuring absolute gravity demands very special instruments, using the free fall method. In the Netherlands such an instrument is not available, therefore the Institute for Earth Measurements in Hannover was asked to execute these measurements.

In 1991 three stations were measured: Delft, Kootwijk, Westerbork and in 1993: Epen (Limburg) and Kootwijk again.

Relative gravity measurements are carried out by LaCoste Romberg spring gravimeters. A contract was agreed with the Survey department of Rijkswaterstaat (RWS) to set up a common gravity network. The measurements were mainly done by the RWS (1e and 2e order network). The Faculty of Geodetic Engineering took part in the first order measurements and carried out the computation and adjustment of the measurements.

For measurements at sea the Faculty of Geodetic Engineering has the disposal of a sea gravity meter. On the North Sea a dense network of gravity measurements has been carried out in 1986. In 1992 this work at sea was completed by a survey on the Waddenzee and the IJsselmeer. The RWS supplied a ship for this purpose. The measurements were successful and a good completion to the land-gravity measurements.

Geoid computation.

As mentioned before geoid computation is necessary for several purposes, both scientific and practical. To compute the geoid with a precision of one cm is a big problem.

Accurate gravity measurements are needed all over the Earth. For the long wave structure of the gravity field the gravity model OSU91 is used (Rapp, 1991). This is a model in terms of spherical harmonics up to degree 360, equivalent to a resolution of $1^\circ \times 1^\circ$ gravity values. In Europe the data are completed by a $10 \times 10 \text{ km}^2$ dataset provided by the University of Hannover. In The Netherlands the gravity field should be the most detailed. The gravity campaign will provide us with a point density of one point per 5 km^2 . The sea gravity campaigns completes the picture.

If the measurements are available it is still possible to use different methods of computation, each having its own advantages, disadvantages and approximations. A main topic of research is the comparison of the methods, improvement and renewal, estimation of all kinds of small error sources, and computation of the final precision.

Strang van Hees also developed a method to compute the geoid with use of FFT on the sphere. This method is very fast and accurate and is even used to compute the geoid in the USA (see report in EOS 1992). Later this method is modified by Haagmans, Van Gelderen and De Min making it still faster and without any approximations.

De Min gave an inventory and estimation of many sources of errors in the geoid computation process. He also compared the Stokes' numerical integration method with collocation which gave a deeper insight in the background of the differences.

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NATIONAL REPORT ON GRAVITY AND GEOID WORK IN NORWAY 1990-94

Joint Symposium of the International Gravity Commission and
the International Geoid Commission, Graz, Sept. 11-17, 1994

Erik Roland and Dag Solheim
Norwegian Mapping Authority

GEODYNAMICS

POST-GLACIAL REBOUND STUDIES

For post-glacial rebound studies Finnish Geodetic Institute (FGI), National Oceanographic and Atmospheric Administration (NOAA), Institute of Applied Geodesy (IfAG) and Norwegian Mapping Authority carried out absolute gravity measurements with the JILA-5 (FGI), FG5-101 (IfAG), and FG5-102 (NOAA) gravimeters in 1991-93 at the geodetic laboratories in Ny-Ålesund on Spitsbergen, Tromsø, Trondheim and Stavanger in Norway, Onsala and Furuögrund in Sweden and Metsähovi in Finland. The stations are collocated with space geodetic systems as permanent GPS, permanent/mobile VLBI and SLR.

A Norwegian team reobserved the Fennoscandian land uplift gravity line Vågstranda-Joensuu at 63°N with four LaCoste and Romberg gravimeters in 1993.

EARTH TIDE

A LaCoste and Romberg gravimeter equipped with SRW feedback system from Hannover and GPS time receiver was installed for Earth tide recordings in Trondheim autumn 1993. Data collected from a six months period of observations is now being processed.

THE BLÅSJO PROJECT

The Blåsjø Project was a multidisciplinary approach towards the monitoring of possible environmental effects on the artificial infilling of more than one billion (10^9) metric tons of water, as part of the Ulla-Forre hydroelectric power project. The monitoring, which lasted for many years, was limited to earth science parameters which presumably could be affected by the infilling of water, and has included geodetic, gravity, tilt and seismicity measurements, as well as theoretical subsidence modelling. A number of scientific institutions in Norway and abroad was involved in this program.

The results are published in Norwegian Mapping Authority's Geodetic Publications 1992:1.

GRAVITY

REGIONAL GRAVITY SURVEYS

Regional surveying along levelling lines were carried out the Trøndelag area in 1991 and 1992. A total of 579 stations (benchmarks) were observed and adjusted.

BASE STATION NETWORK

Old IGSN71 base stations have been tied to the new absolute gravity stations to compute a new gravity values in a new absolute datum.

GRAVITY CALIBRATION LINE

Two absolute gravity measurements were carried out with the FG5 102 gravimeter in the vicinity of our main office in Hønefoss to establish a calibration line for relative gravimeters covering a difference in gravity of 96.5 milligal.

BOUGUER GRAVITY ANOMALY MAP

In collaboration with Norges Geologiske Undersøkelse (Geological Survey of Norway) Norwegian Mapping Authority has published a new Bouguer anomaly map in 1992 in scale 1:1 000 000 and contour interval 3 milligal. From a total number of 123 000 stations a selected data set of 97 700 stations has been interpolated to a square grid of 1.5 x 1.5 km using the minimum curvature method.

MEASUREMENTS IN PRESSURE TEST LABORATORIES

Norwegian Mapping Authority has carried out measurements to compute the gravity values in ten pressure test laboratories owned by private companies. The laboratories calibrate instruments for use in the oil extraction in the North Sea.

GEOID

A new and improved gravity dataset for Norway has been compiled. Then land gravity dataset now includes measurements made by NGU, Norges Geologiske Understokelse, and data from other sources compiled by NGU. In addition we have identified and deleted several errors in our data base. These errors were typically of order 15 mgal due to an erroneous "Potsdam-correction". At sea we have readjusted our old sea-gravity measurements from 1970-71. Comparisons with other sea-gravimetry and internal reports suggested that there might be a bias-error of order 5-10 mgal in these data. We used the line organized dataset made by the private company Amarok. This dataset was then separated into more than 80 separate subsets of connected lines. Each of these subsets were then subject to several cross-over comparisons with other sea-gravimetry and profile-interpolation (GEOGRID, Forsberg). Based upon these results we identified separate biases for each subset.

TERRAIN CORRECTIONS

New terrain corrections have been computed based upon a 100 m x 100 m digital terrain-model for the inner zone (< 5 km) and a 1 km x 1 km model for the outer zone using Forsbergs to program.

REPORT OF THE GRAVITY ACTIVITIES IN PORTUGAL

for the period of 1990 - 1994

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1 - INTRODUCTION:

The present report covers the gravity activities carried out in Portugal in the period 1990-1994. As responsible for the gravimetric network, the "Instituto Português de Cartografia e Cadastro" continues to work in the establishment of the gravimetric points in the first order levelling marks and also in the densification in this network. In cooperation with other institutions the Astronomic Observatory of the University of Porto conducted the establishment of 2 absolute gravity stations in the "Açores" archipelago.

2 - GRAVITY IN THE HIGH PRECISION LEVELLING NETWORK

* Purpose:

- the coverage of the fundamental bench marks of the Portuguese high precision levelling network;
- to establish a first order gravity network to support the observations of the second order network.

* Equipment: for the first order surveys, the stations were observed simultaneously with 2 gravity meters LaCoste & Romberg.

Fundamental bench marks observed (map A):

Before 1990: 112

Between 1990-1992: 163

3 - DENSIFICATION OF THE GRAVITY NETWORK

* Purpose:

- the total coverage of the country with one gravimetric point each 25 km² for the computation of an Iberic Geoid Model; this project is being carried out in cooperation with the University of Madrid and is foreseen to be concluded by the end of 1996.

* Equipment: before 1990, 2 gravity meters were used; for 1993, and following years the observations were (will be) performed with one gravity meter.

Second order gravity stations observed (map B):

Before 1990 - 503 in the south of Portugal

In 1993 - 276 stations.

4 - ABSOLUTE GRAVITY

In July of 1992, the Astronomic Observatory of the University of Porto in cooperation with the Finnish Geodetic Institute and the Institute of Astronomical and Physical Geodesy, University FAF Munich, established 2 absolute gravity stations in "Açores" islands: "Faial" and "Flores".

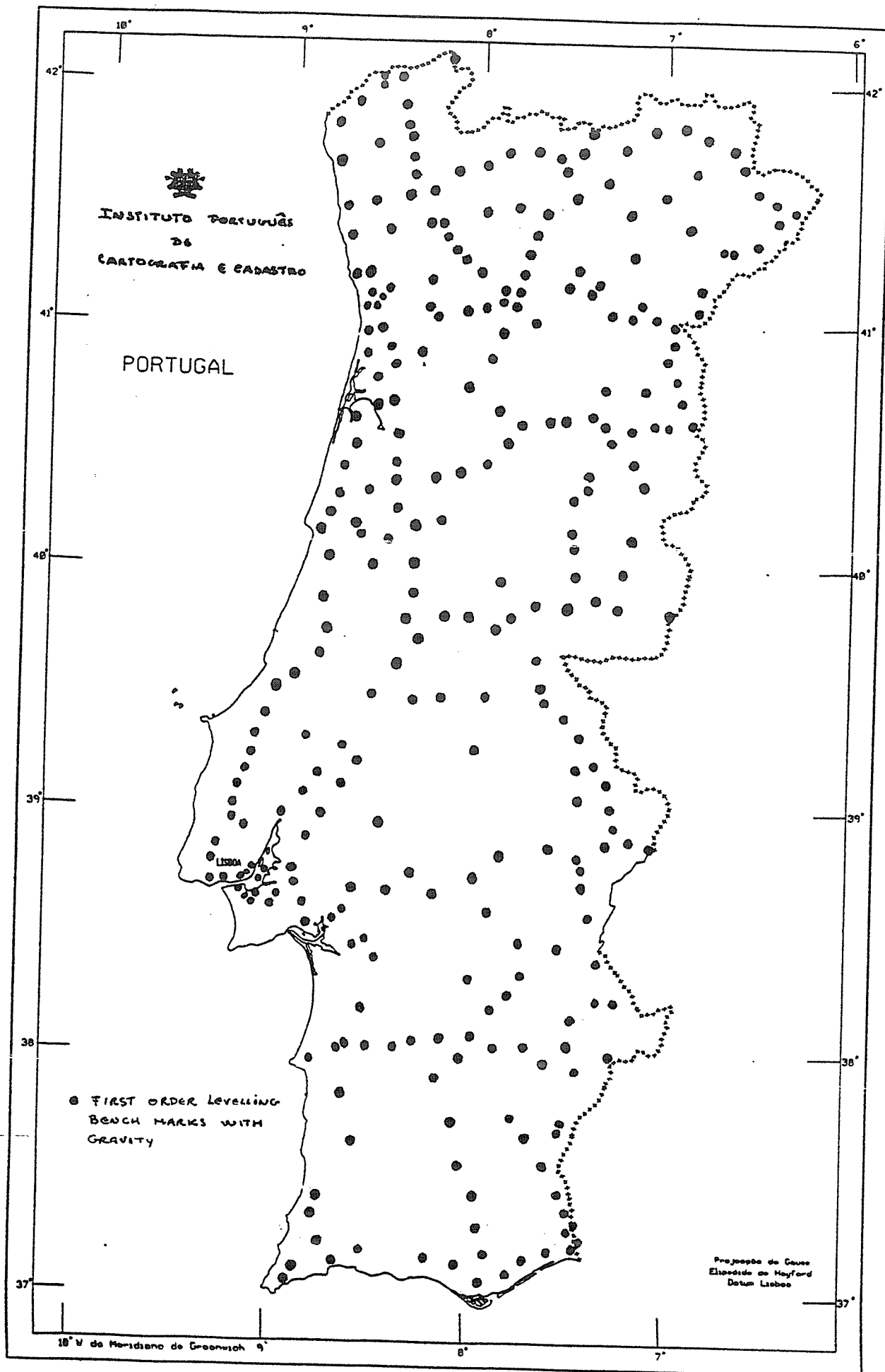
There were also observed 83 relative gravity stations in the islands of:

"S. Miguel"	- 16 stations;
"Santa Maria"	- 7 stations;
"Terceira"	- 11 stations;
"Graciosa"	- 8 stations;
"S. Jorge"	- 10 stations;
"Pico"	- 10 stations;
"Faial"	- 9 stations;
"Flores"	- 7 stations;
"Corvo"	- 5 stations.

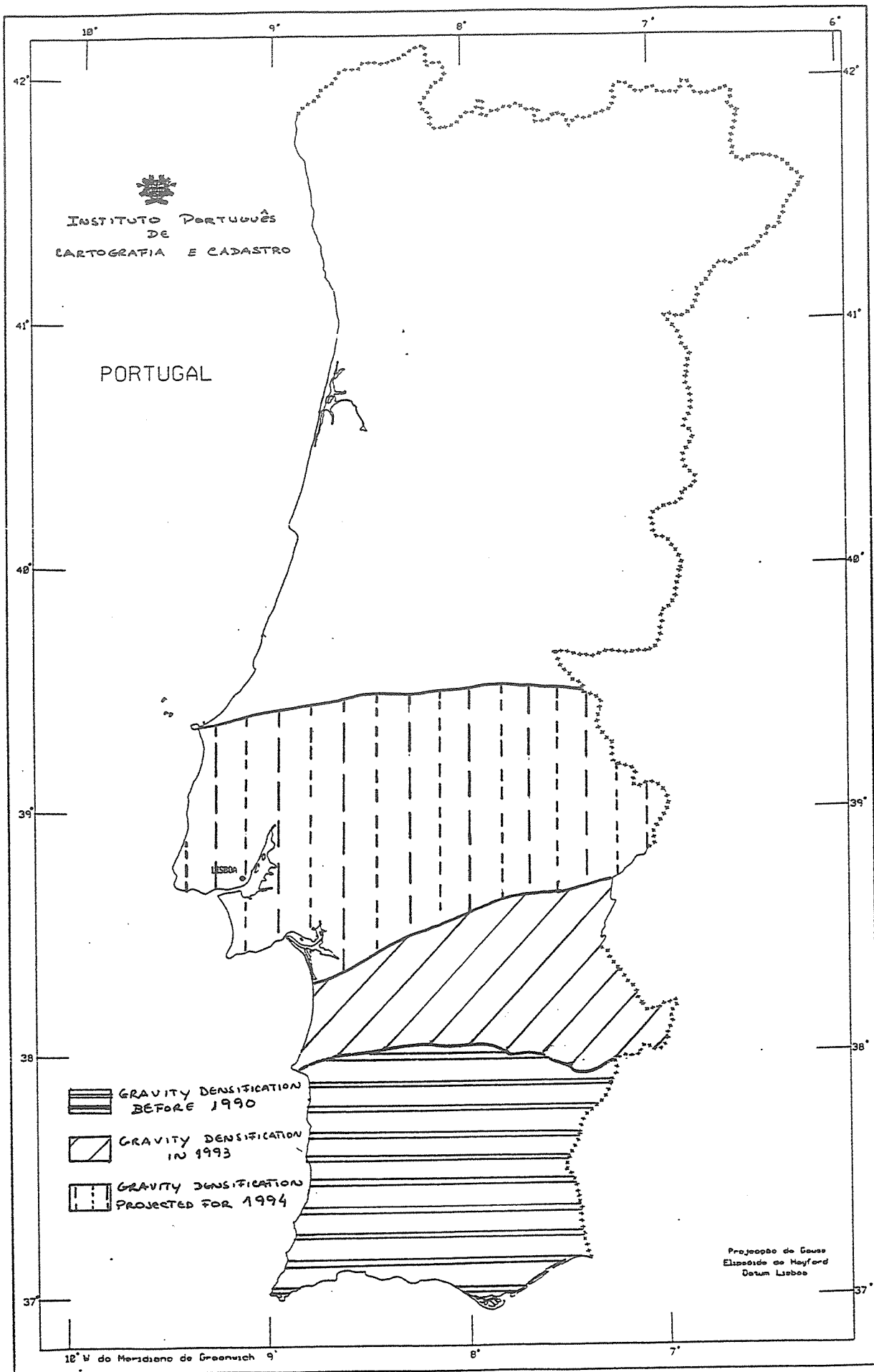
All these stations were observed with 2 gravity meters LaCoste & Romberg.

5 - OTHER CAMPAIGNS

There is also a gravity survey prepared for August/September of 1994, in "Madeira", "Porto Santo" and "Desertas" islands, with the participation of the 512 STRE (Specialist Team Royal Engineers) of the Military Survey of the United Kingdom. Since 1990 until 1994, some other gravity stations over regional or areas have been also established to support other geodetic and geophysical projects, as well as private organisations or local authorities requirements.



MAP A



MAP B

SLOVAK REPUBLIC
NATIONAL COMMITTEE OF GEODESY AND GEOPHYSICS
NATIONAL REPORT ON GRAVIMETRY
for 1990-1994

In the last 4 years the activities concerning gravimetry were focused to the following topics:

1. gravity modelling of the lithosphere in the Eastern Alpine - Western Carpathian - Pannonian Basin region; [1], [8], [11], [10], [79], [97], [94], [30], [80], [3], [7], [9], [25], [26], [27], [78], [4], [28], [12], [29], [5], [2], [6]
2. computation of the mechanical parameters of the lithosphere beneath the Pannonian Basin; [13]
3. study of the mechanical stresses of the rocks surrounding the tidal station of the Geophysical Institute of the Slovak Academy of Sciences at Vyhne; [23], [18], [35], [96], [24], [36], [15], [22], [16], [17], [21], [14]
4. theoretical models for gravity anomalies caused by thermoelastic deformations in the vicinity of magmatic bodies; cite3, [32], [33], [34], [81], [20]
5. density modelling of the Earth; [93], [95], [90], [92]
6. inverse problem of gravimetry for a spherical planetary body; [91], [86], [88], [87], [82], [83]
7. problems of optimum processing geophysical and geodetical data, including deformation measurements; [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76], [77], [37], [38], [39], [40]
8. local quasigeoid and its accuracy; [85]
9. GPS measurements; [84]
10. international gravimetric measurements
11. computation of the tidal gravity corrections; [19]

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National report on Gravimetry in Sweden 1990/94

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* ABSOLUTE MEASUREMENTS

Seven absolute gravity measurements have been performed, four of them by the Finnish Geodetic Institute.

In 1992 the new station Furuögrund A was measured; it belongs to the geodetic mini-observatory established there (20 km North of Skellefteå) the year before. The instrument used was the Finnish absolute gravimeter JILAG-5. In 1993 the same station was measured with the FG5 102 absolute gravimeter of NOAA (National Oceanographic and Atmospheric Administration, USA). The station has been connected to the Swedish fundamental gravity network by relative measurements with LCR gravimeters.

In 1993 the station Göteborg A was moved to Onsala A, using absolute measurements at both stations with the Finnish instrument, together with relative measurements with four LCR gravimeters. In this year Onsala A also was measured with FG5 102 by NOAA and with FG5 101 by IfAG (Institut für Angewandte Geodäsie, Frankfurt a.M.).

The same year also Martsbo A was measured with the Finnish instrument.

* RELATIVE MEASUREMENTS

- The Fennoscandian Land Uplift Gravity Lines

During this period, measurements have been carried out on one of the four Land Uplift Gravity Lines which have been established for studying secular variations in gravity in Fennoscandia. The observations were made 1993 on the 63° line (Vagstranda - Joensuu) using eight LCR-gravimeters from Norway, Sweden and Finland. From Sweden the National Land Survey participated with LCR G-54 and LCR G-290.

The observations have recently been computed. The whole series of measurements is now beginning to allow geophysical conclusions.

- The Swedish Zero Order Gravity Net

The net consists of 24 outdoor stations (each of them with one reserve station) plus the absolute station Martsbo. An adjustment that include connections to the absolute stations Göteborg, Copenhagen and Sodankylä gave a new Swedish gravity datum; RG 82. The gravity values of the stations are now also available in IGSN-71.

- First Order Gravity Net

In the new first order gravity net 35 stations have been established and measured (in southern Lapland and in the area Karlstad - Stockholm). When the net is completed it will consist of about 200 stations.

- Gravity measurements on the ice of the Bothnian Sea

In cooperation between the National Land Survey, the Geological Survey of Sweden and the Geodetic Institute in Finland gravity measurements have been made on the ice of the Bothnian Sea (186 stations 1994; no measurements 1990 - 1993 because of lack of ice).

- Second Order Gravity Net

National Land Survey: about 1200 points have been measured in the ordinary second order net (5 x 5 km net).

The Geological Survey of Sweden makes gravity mapping for both regional and detailed geological investigations. Until now approximately 50 % of the Swedish area has been covered by gravity measurements at a grid interval of 2 km or better.

During the period 1990/94 the measurements have been concentrated to the Skellefte ore district in the north and to the central and southern part of Sweden. About 8000 new observations have been made. The data base now contains approximately 120000 observations, including measurements by other organizations.

* GRAVITY DATA BASE ACTIVITIES

In 1994 about 2400 new measurements were delivered from the National Land Survey to the data base of NKG (Nordic Geodetic Commission) in Copenhagen for computing a new version of the Nordic Geoid.

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Gravimetric Activities in Switzerland 1991-1994

Gravity reference networks

Gravity Measurements along re-measured first order levelling lines

In the last years gravity values have been determined simultaneously with the re-levelling of the Swiss National Levelling Network in order to correctly reduce the levelling measurements. In the period extending from 1991 to mid 1994, gravity measurements using LaCoste and Romberg gravity meters have been carried out on the following levelling lines (see also Map).

1991:	Liestal - Olten - Aarburg	(Line A)
	Delémont - Porentruy - Boncourt	(Line B)
	Delle	
1992:	St. Maurice - Martigny - Sion	(Line C)
	Zürich - Winterthur - Frauenfeld	(Line D)
	Stein - Frick - Brugg	(Line E)
1993:	Loeche - Sierre - Sion	(Line F)
	St. Maurice - Aigle - Roche - Les Grangettes	(Line G)
	Roche - Chillon	(Line K)
	Roche - St. Gingolph	
	Luzern - Zug - Sattel	
1994:	Zürich - Baden	(Line I)
	Frauenfeld - Steckborn	(Line J)

Gravity values have been computed on the basis of the absolute gravity value in Zürich and also linked to the Swiss National Gravity Network. The measured stations are fully documented and will be included in the new national levelling documents.

Swiss Absolute Gravity Network

In June 1994 four new absolute gravity stations (Lausanne, Basel, Monte Ceneri) were measured and two old stations were remeasured by means of a absolute gravity meter JLA 3. The measurement were done by "Austrian Bundesamt für Eich und Vermessungswesen" for the Swiss Geodetic Commission.

New fundamental gravity network of Switzerland

During 1953 and 1957, a fundamental gravity network of Switzerland was established. Measurements for a newer and precise gravity network were started in 1991. The stations of the new network were chosen coincident with the LV'95 network, the fundamental GPS network of Switzerland with about 100 stations. Unfortunately, a lot of the GPS stations have quite a poor setup for the gravity instrument, so about 20 additional points coincident with first order levelling points with good setup were chosen. Further, five absolute gravity stations were measured by the Austrian BEV in 1994, two on existing points and three new ones. The relative connection from the absolute stations to and within the relative gravity networks were measured with two or three LaCoste & Romberg G gravimeters. For 1995, it is planned to make connection measurements to neighboured countries absolute stations.

Regional and local mapping

Regional gravimetry (gravity mapping)

In the frame of a systematic gravity mapping of Switzerland at a scale of 1/100 000, the geophysical institute of the University of Lausanne, on behalf of the Swiss Geophysical Commission (SGPK) has measured around 5500 new gravity points. These stations will enable the SGPK to publish in 1994 the first seven 1/100 000 maps and to prepare more four of the eighteen which compose the full coverage of Switzerland.

Apart from this systematic gravity mapping, two very detailed surveys were carried out by the geophysical institute of the ETH Zürich for glaciological purposes. The number of stations measured for these two surveys is approximately 200.

Airborne gravimetry

During November 1992 the Geodetic and Geodynamic Lab of ETH Zurich in collaboration with LaCoste and Romberg Gravimeter Inc. Austin Texas conducted a 6000 km line airborne gravimetric survey covering the whole Switzerland. For this project LaCoste and Romberg Inc. specially modified one of their Marine gravimeter in order to fit the requirement of an airborne survey. The system was mounted on a Twin Otter DeHavilland aircraft owned by the Eidgenössische Vermessungsdirektion. The aircraft was also equipped with two GPS receivers for positioning purposes and one GPS receiver for navigation.

The flight line were oriented 70°E with a line spacing of 12 km. Four crossing line were also flown for equalization purposes (see figure). A full automatic data processing system was developed for the computation of vertical accelerations Eötvös and altitude

corrections and Bouguer anomaly computations. The first results show a difference of g of 3.4 mgal at the crossing points of lines flown at the same altitude.

Interpretation and Analysis

Automatic interpretation of gravity gradiometric data

The magnetic and gravity fields produced by a given homogeneous source are related through Poisson's equation. Starting from this consideration, it is shown that some 2D interpretation tools, widely applied in the analysis of aeromagnetic data, can also be used for the interpretation of gravity gradiometric data in 3 dimensions (vertical gradient). The procedures developed deal specifically with the Werner deconvolution, analytic signal and Euler's equation methods. After a short outline of the mathematical development, synthesized examples have been used to discuss the efficiency and limits of these interpretation methods. These tools could be applied directly to airborne gravity gradiometric data as well as ground gravity surveys after transformation of the Bouguer anomalies into vertical gradient anomalies.

Upward continuation of gravimetric data in rugged topography

The problem of upward continuation of potential field data measured on rugged topography has been tackled by several authors. Its importance lies in the fact that gravity data, and to a certain extent also magnetic and aeromagnetic data, are not measured on a plane, whereas all algorithms for signal analysis and inversion are designed to work with data reduced to a plane surface. On the other hand, the need of properly prepared gravity and magnetic data does not permit careless solution of this problem. The method developed is based on the principle of equivalent-sources. In this method the equivalent-source layer has a specific geometry and depth. Therefore, only the density distribution has to be inverted. The upward continuation is performed by means of a stepwise forward computation procedure which minimizes edge effects. The method provides a well-conditioned system of linear equations and is, therefore, quite stable and produces high-quality results (errors less than 0.04 % using the whole grid to invert for the density distribution) even in the case of very rough topography, which is its main advantage.

Program for calculating gravitational effects of bodies

In order to calculate the gravitational potential, acceleration and gravity gradients a program, called POTENZ, was developed. The formulas used within the program calculate the exact effects (no approximation) of constant density, flat faced bodies.

Geodynamics

Microgravimetric measurements in the Yellowstone National Park

In a work together with the Geophysics Department of the University of Utah microgravimetric measurements in the Yellowstone National Park were performed (partly) by members of the ETH Zürich in 1987, 1991 and 1993.

The Yellowstone caldera is situated in the middle of the Yellowstone National Park in the north west of Wyoming, USA. It is an active silicic volcanic system that exhibits very high heat flow (exceeding 1500 mWm^{-2}), widespread earthquake activity and high rates of modern crustal deformation. From 1923 to 1984, the caldera experienced up to 0.8 m of uplift, measured by precise levelling, followed by a subsidence until 1993 of up to 15 cm. To assess the temporal variations of the gravity field, a 200+ station precise gravity network was established in 1977 over the entire Yellowstone Plateau that was coincident with the levelling network. The gravity network was reobserved in 1983, 1987, 1991 and 1993 with a repeatability of $\pm 12 \mu\text{gal}$. Additional reobservations emphasized two caldera-crossing lines in 1979, 1986, 1988, 1989, and 1990 with a average precision of $\pm 10 \mu\text{gal}$. Levelling measurements over the whole park were carried out in 1977 and 1987. Along one caldera crossing line, annual levelling measurements took place from 1987 to 1993. In 1987, a GPS network of about 40 points along the levelling lines as well as in the backcountry areas was established and also used for gravity stations.

Theoretical work

Gravimetric tests of the Newtonian Law

Since 1989 the IGP of the ETH Zürich is conducting microgravimetric measurements in a dam of an electrical power plant at two stations separated by 90 m height. The measurements are performed mostly during spring when the variations of the water level are maximum. A good knowledge of the artificial take enable the computation of the theoretical value of the vertical component of the attraction on both stations. The comparison between computed and measured gravity enables the computation of the value of the universal gravity constant. This experience will continue until sufficiently large set of data will be available for statistical test. These measurements were repeated in 1991, 1992 and 1994.

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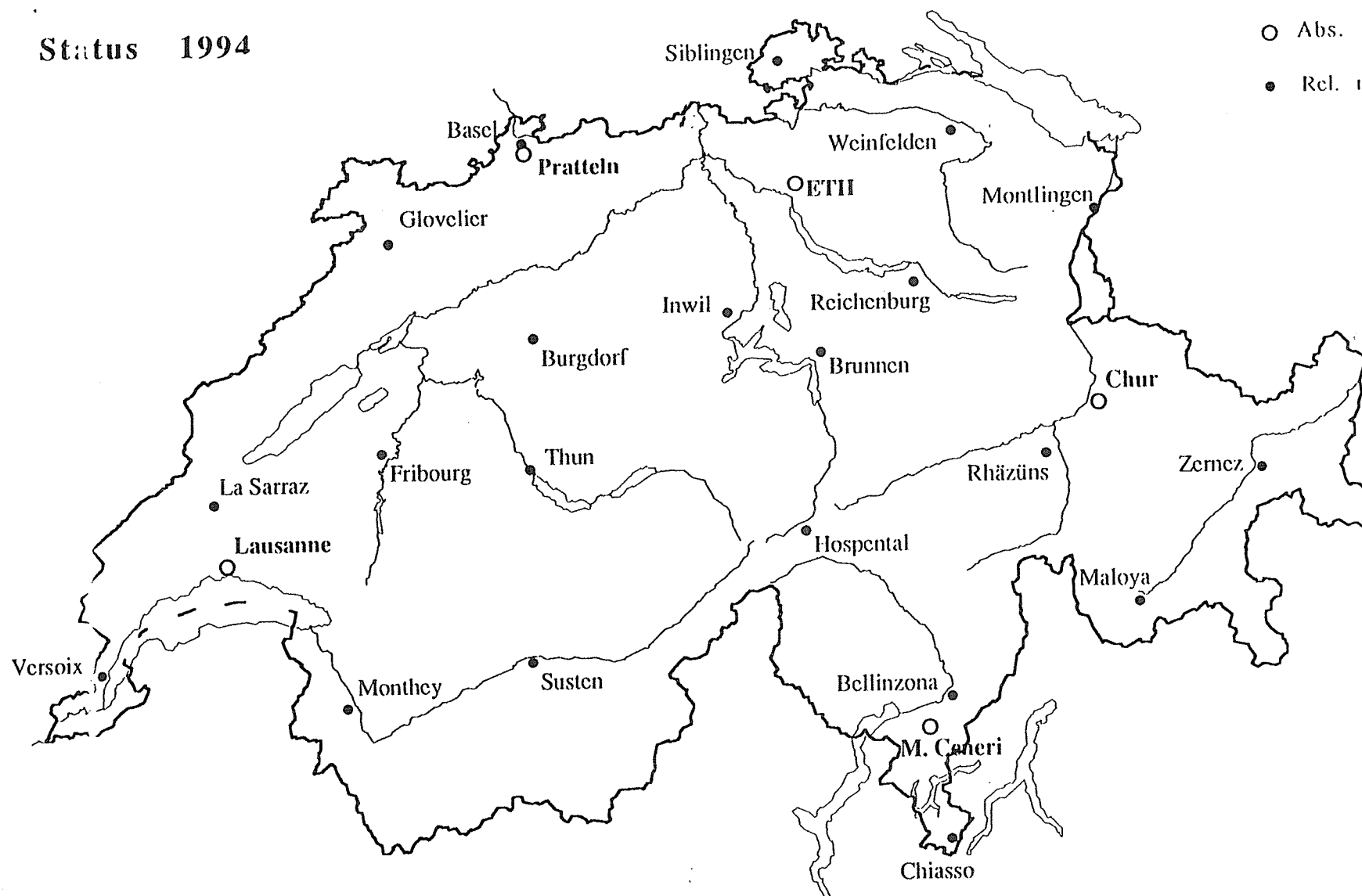
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NEW FUNDAMENTAL GRAVITY NETWORK OF SWITZERLAND

Status 1994

Legende

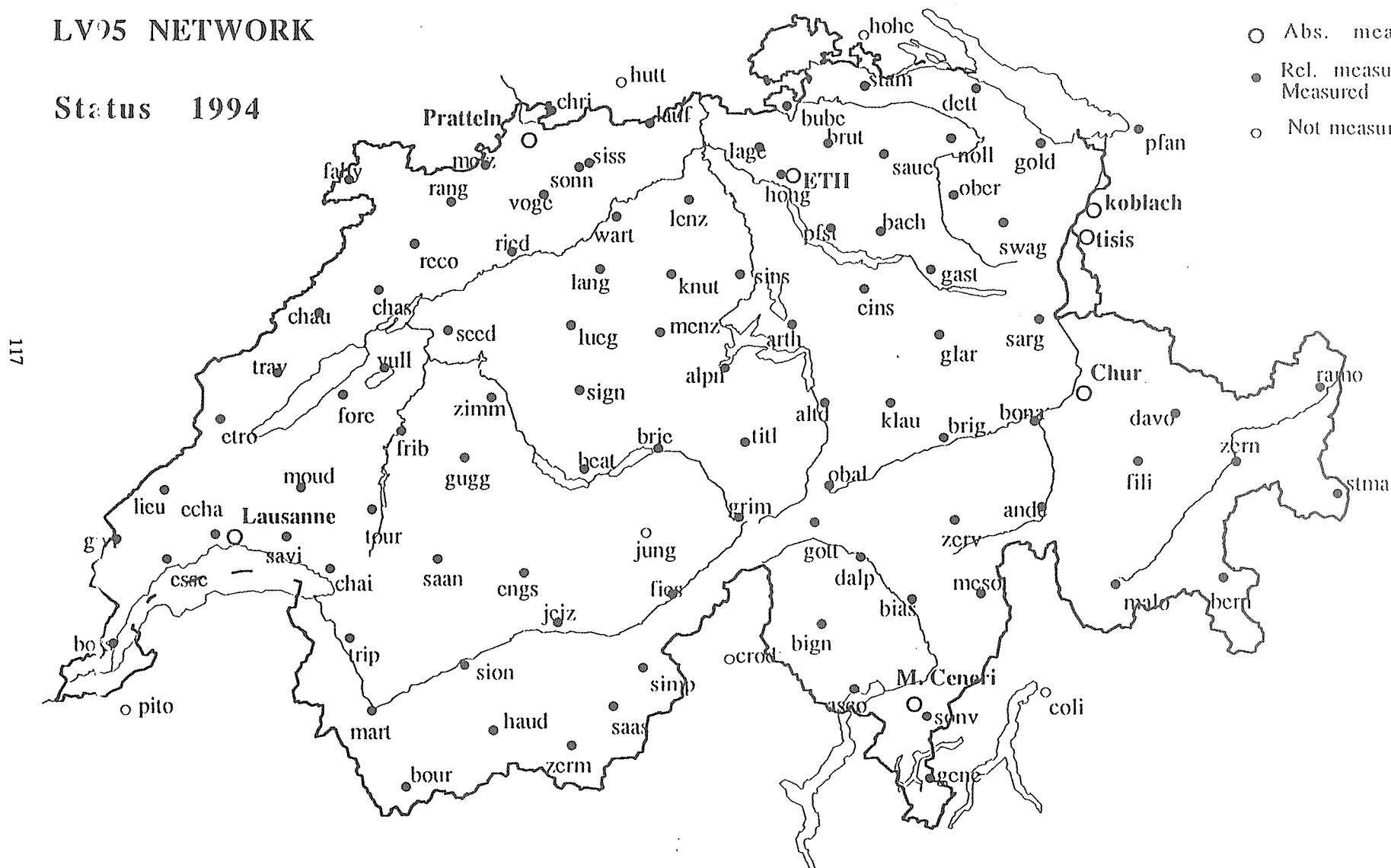
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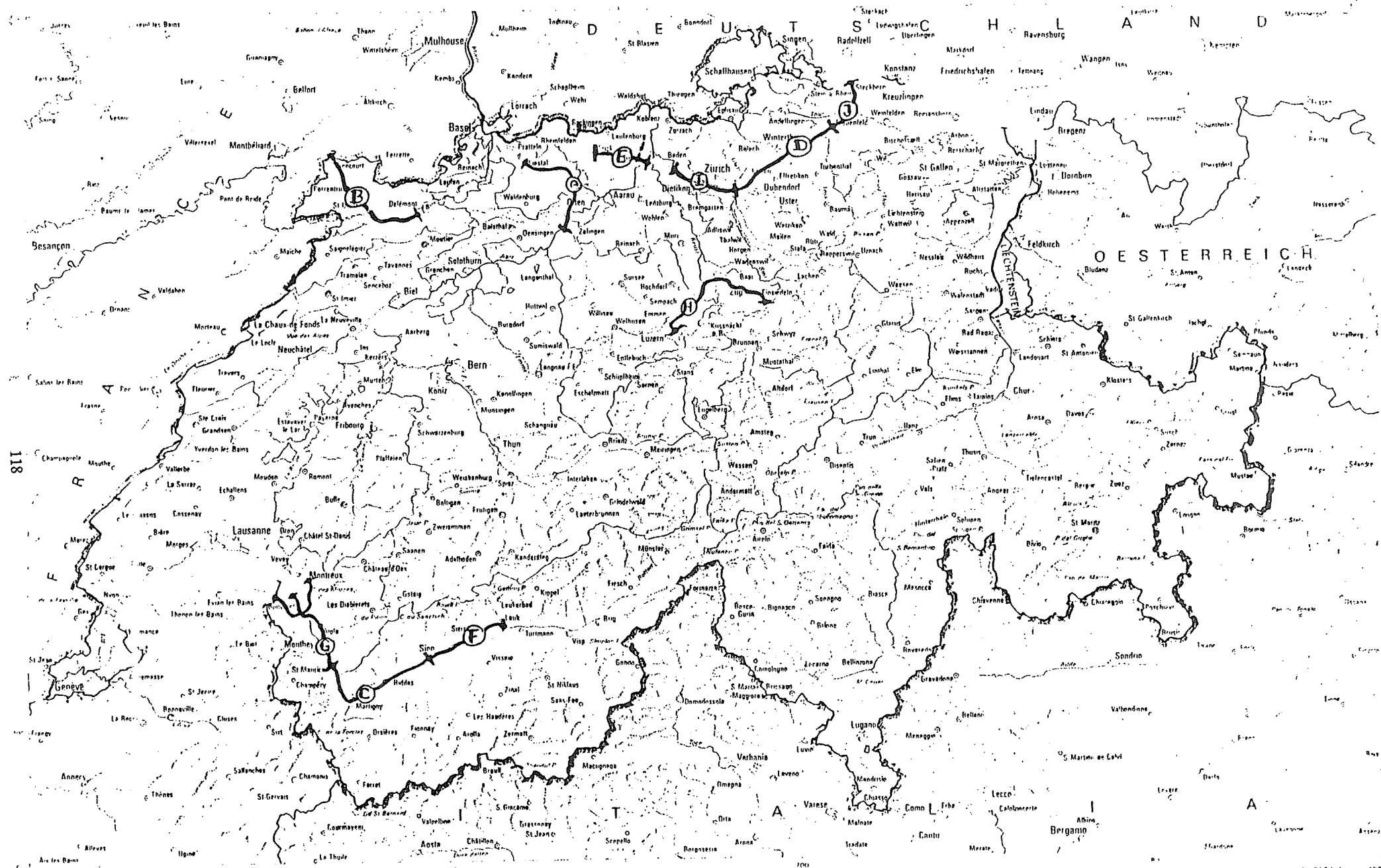


LV95 NETWORK

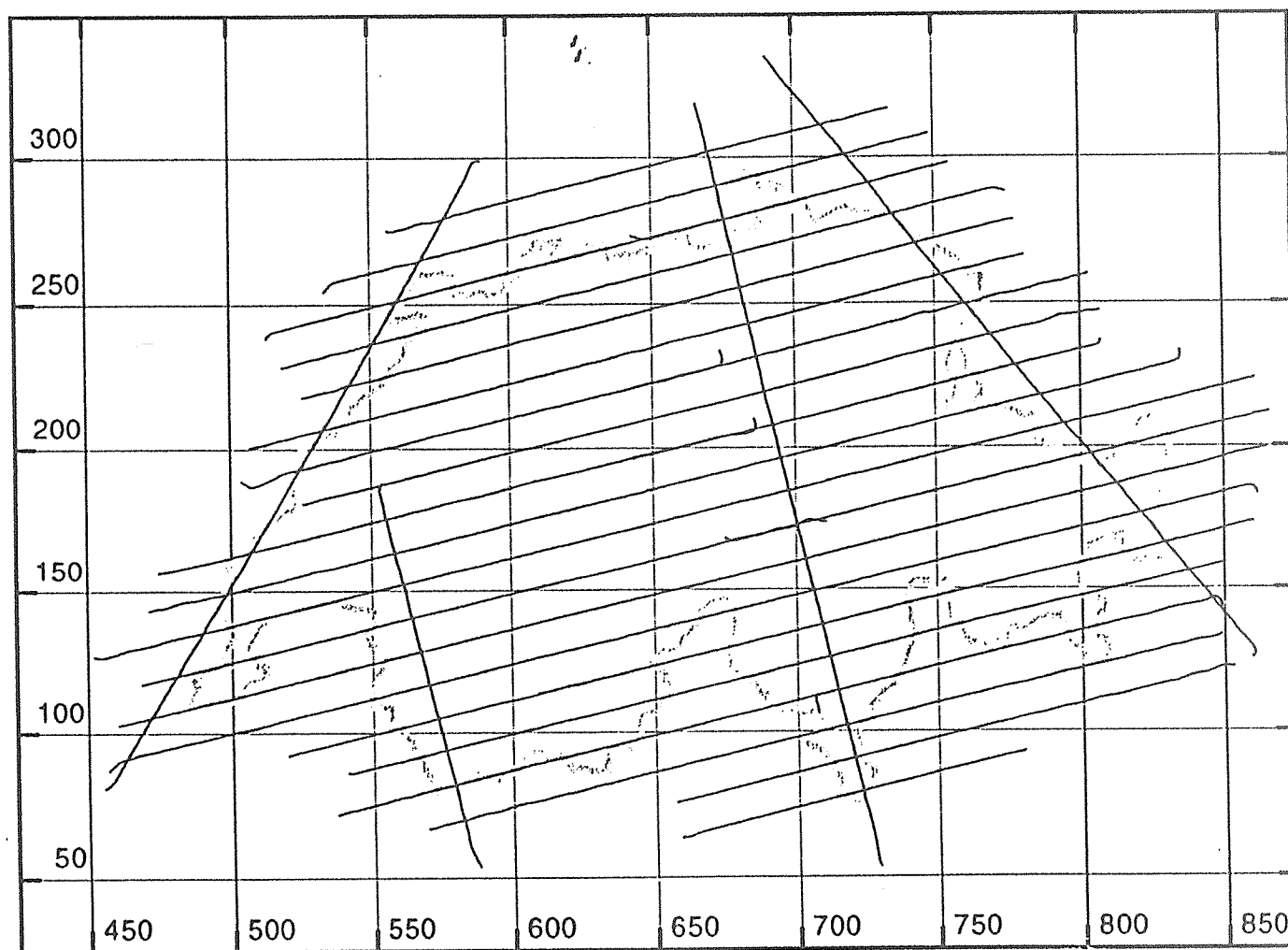
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- Rel. measurements
Measured
- Not measured Stationen





Gravity measurements along levelling lines



Airborne gravity survey of Switzerland
Flight lines

GRAVIMETRIC WORKS IN TURKEY FOR THE PERIOD 1990-1994

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1. INTRODUCTION

Institutions and Universities which carry out the gravimetric works in Turkey are listed below:

- General Command of Mapping (GCM), Ankara
- General Directorate of Mineral Research and Exploration (MRE), Ankara
- Turkish Petroleum Corporation (TPC), Ankara
- Earthquake Research Department (ERD), Ankara
- Geodesy Department of Istanbul Technical University (ITU), Istanbul.
- Geodesy Department of Yildiz Technical University (YTU), Istanbul.
- Kandilli Observatory of Bosphorous University (BU), Istanbul.

Gravimetric works conducted during the period 1990-1994 can be split into two headings in terms of geodetic and geodynamic-prospecting aspects.

2. GRAVIMETRIC WORKS FOR GEODETIC PURPOSES

The gravity observations, related to the first order gravity network of 24 stations, carried out between 1956 and 1960 by GCM with two Norgard gravimeters are reduced and adjusted in 1991. Then Turkish Fundamental Gravity Network-1956 (TTGA-56) has been established. In the adjustment, the gravity value of the TTGA-56 Ankara station on modified Potsdam Datum (close to IGSN 71) is taken fixed (Figure 1). Accuracies of the gravity values after the adjustment are found to range between ± 0.07 mgal and ± 0.19 mgal (Ayhan et al. 1992).

To densify TTGA-56, the second order gravity network which is comprised of 3940 gravity stations on the 79 routes of totally 18000 km along the highways connecting the first order gravity stations has been established and are being evaluated presently. This being the case, editing the gravity data are still going on. It is also planned to connect the available densification network composed of about 70 000 points to the first and second order gravity networks upon completing the on-going works which aims at determining the appropriate model to tie the second order gravity network to the first order one (Ayhan et al, 1993).

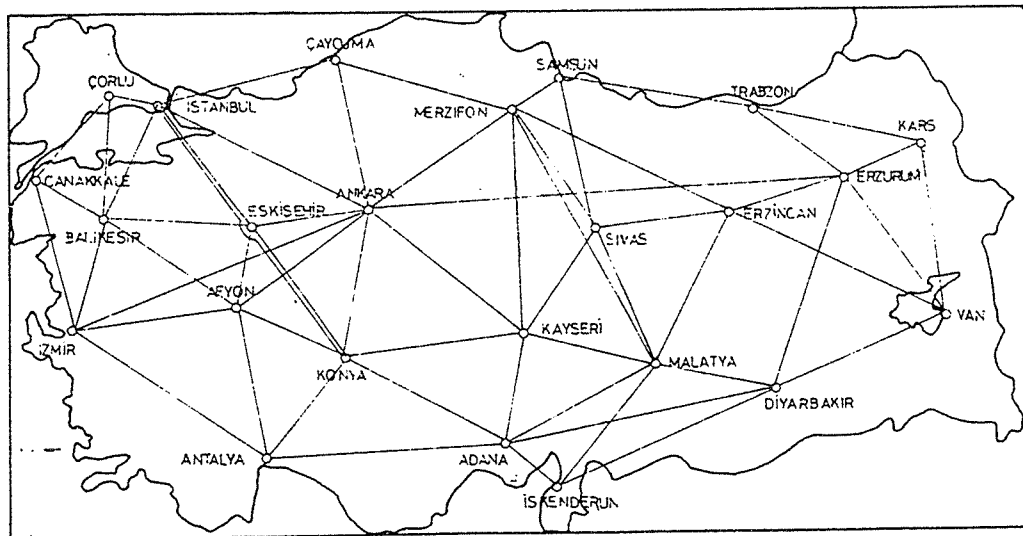


Fig. 1. Turkish Fundamental Gravity Network-1956

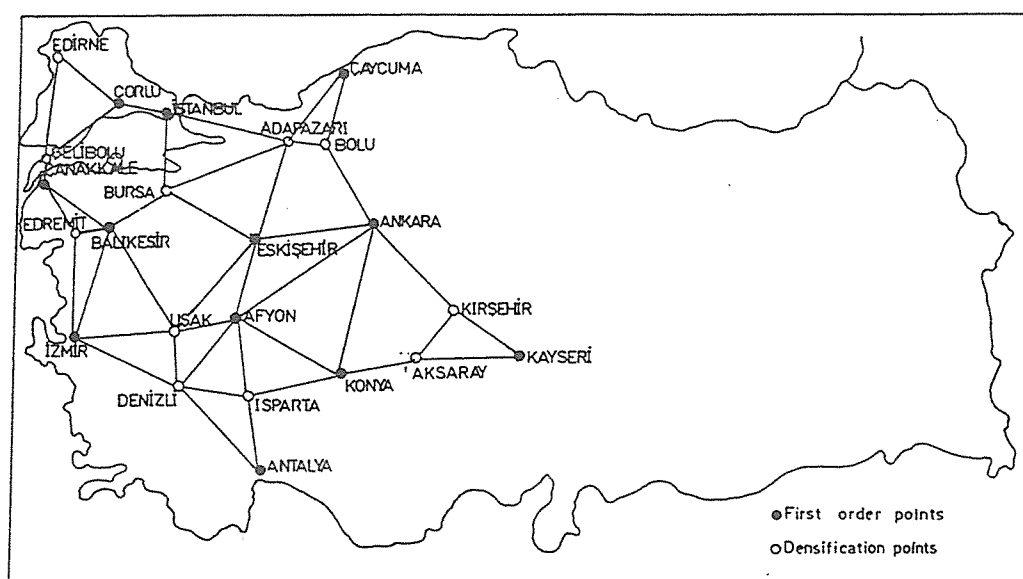
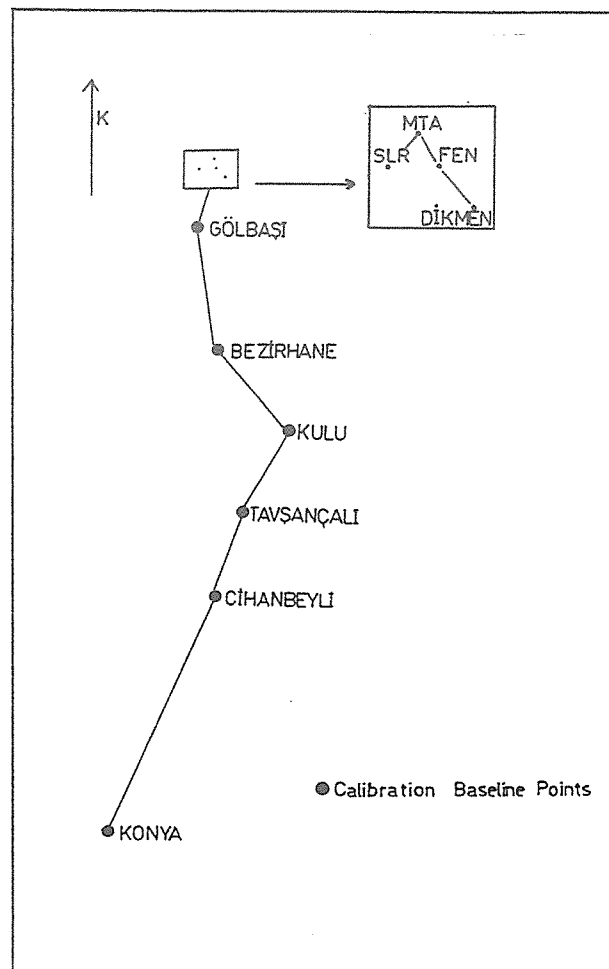
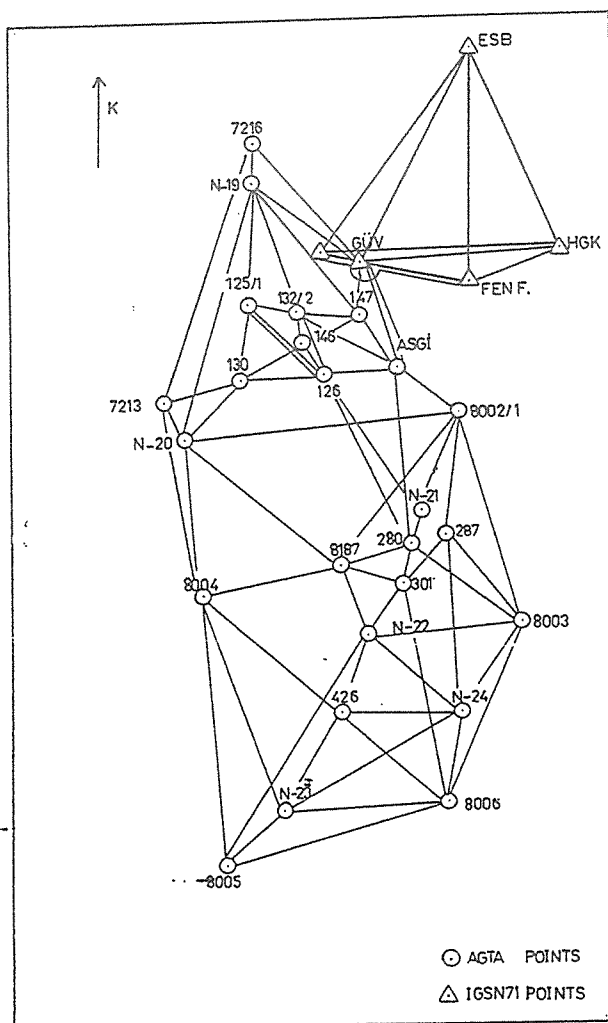


Fig.4. Reobservation plan of the first order gravity network.

Within the frame of the agreement signed in September 1992 by GCM and MRE, in order to better determine the gravity datum connection observations are carried out in Summer 1993 between three IGSN 71 stations in Ankara and TTGA-56 Ankara station (also an IGSN 71 point) using a LaCoste & Romberg Model D gravimeter provided by MRE and evaluation of these observations are still going on (Figure 2). The preliminary results of this evaluation indicated that the difference between IGSN-71 and Potsdam Datum is 15.6 mgal rather than 14 mgal. The establishment and measurement of a new gravity calibration baseline of 10 points between Ankara and Konya which aims at standardizing the calibration of gravimeters are also completed (Figure 3). The distance between the end points of the calibration baseline is about 250 km with a gravity difference of 213.9 mGal. GCM planned also remeasurement of the first order gravity network in order to increase the present accuracy of this network.

The western part of the first order network with the addition of some densification points will be remeasured in Summer 1994 with two Lacoste & Romberg D Gravimeters (Figure 4).

Ankara GPS Test Network (AGTA) which is established to be used in geodetic researches is improved in the sense of integrated geodesy by addition of the gravity observations conducted in 1993 according to the survey plan given in Figure-2, along with all kinds of terrestrial (Angle, distance, levelling), TRANSIT Doppler and NAVSTAR GPS observations carried out previously

Works are still going on to carry out absolute gravity measurements in order to determine Turkish National Gravity Datum.

3. GRAVIMETRIC WORKS FOR GEODYNAMIC AND PROSPECTING PURPOSES

Repeated gravity observations were carried out along the western part of the North Anatolian Fault Zone (NAFZ). In 1992, The Earthquake Research Institute (ERI), Tokyo, Japan and BU have established a high precision gravity network consisting of 35 stations between Iznik and Adapazari. Two Lacoste & Romberg gravimeters were used. The maximal gravity difference is about 230 μ gal, the mean point accuracy 50 nm/s² (Okubo et al, 1993). Since 1988, a gravity network of 25 stations between Adapazari and Bolu has been observed by ERI, YTU and the Technical University Darmstadt, FRG within the joint Turkish-German earthquake research project. Maximum gravity difference is about 330 mGal, and mean point accuracy is about 40 nm/s². Meanwhile 8 field campaigns have been carried out. Only LaCoste & Romberg gravimeter models G and D were used. Data were logged, reduced and stored in the field. Until now only local gravity changes have been found. Significant seasonal changes were also detected which correlate well with groundwater level changes and precipitation. Main regional gravity changes seem to be caused by temporal changes of the calibration functions of the used LaCoste & Romberg gravimeters (Demirel and Gerstenecker, 1989; Demirel and Gerstenecker, 1990; Akin et al., 1990; Akin et al., 1991; Akin et al., 1992).

BU, YTU and Technical University Darmstadt/FRG have carried out high precision observations in Hagia Sophia Museum, Istanbul. The purpose of the measurements is the exploration of subsurface foundations and cavities. The results are integrated in a building information system, which is designed to administrate all collected data of Hagia Sophia. First analysis of Bouguer anomalies shows large anomalies at the southwest corner of Hagia Sophia which cannot be explained by the visible masses of pillars and walls. Further observations including gravity gradients measurements are necessary and shall be carried out in fall 1994 (Atzbacher et al, 1994).

MRE has facilitated the works aiming at screening a total of 70000 gravity observations from various errors, along with gravimetric works carried out for geothermal purposes, prospecting for iron, etc. Bouguer gravity anomaly maps are also prepared using the mentioned data at scales 1/100000, 1/500000, 1/2000000.

Works are still going on jointly by GCM and MRE to update the files of gravity and Digital Terrain Model (DTM) with the addition of the sea gravity and bathymetry respectively. Test applications to prepare Turkish isostatic anomaly maps at different scales are also completed.

Within the frame of the protocol signed in 1993 between MRE and ITU, the studies for preparation of Bouguer anomaly maps of CANKIRI test region to display the general geological structure and to determine the mean crustal thickness by spectral analysis are almost completed.

TPC has carried out during the period 1990 - 1994 gravity measurements at 34000 points throughout Turkey for petroleum explorations with LaCoste & Romberg gravimeters. The evaluation of the mentioned gravity values are completed and Bouguer anomaly maps are prepared.

4. CONCLUSIONS

Works were carried on between 1990 and 1994 in order to re-adjust the first and the second order gravity networks and TTGA-56 was established during this period by reducing and adjusting the gravity observations of the first order gravity network on the modified Potsdam Gravity Datum. Observations were carried out between TTGA-56 Ankara station and three IGSN 71 stations in Ankara to solve the datum problem. In addition to these, a gravity calibration baseline was established between Ankara and Konya. It is planned, considering the low accuracy of TTGA-56 points, to remeasure first order gravity network in 1994 and the following years with LaCoste & Romberg G gravimeters. Besides, the attempts on making absolute gravity observations to define National Gravity Datum are still going on. The periodic gravity observations and evaluation of the gravimetric nets established to determine the vertical crustal movements on the western part of the North Anatolian Fault Zone will be continued.

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