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**BUREAU  
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INTERNATIONAL**

**BULLETIN D'INFORMATION**

**N° 85**

**Janvier 2000**

**18, Avenue Édouard Belin  
31401 TOULOUSE CEDEX 4  
FRANCE**

## INFORMATIONS for CONTRIBUTORS

*Contributors should follow as closely as possible the rules below :*

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

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

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

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

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

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

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

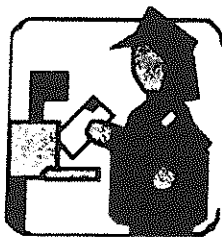
*References. A complete and accurate list of references is of major importance in review papers. All listed references should be cited in text. A complete reference to a periodical gives author (s), title of article, name of journal, volume number, initial and final page numbers (or statement "in press"),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

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

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

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

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



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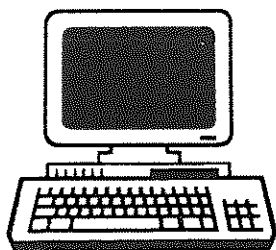
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**BUREAU GRAVIMÉTRIQUE  
INTERNATIONAL**

**Toulouse**

***BULLETIN D'INFORMATION***

***Janvier 2000***

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Bulletin d'information n° 85

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**PART I**  
**INTERNAL MATTERS**



## **GENERAL INFORMATION**

- 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 information on the community, on the Bureau itself. It informs about the data available, about new data sets...*

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

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

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

*About three hundred individuals and institutions presently receive the Bulletin.*

*You may :*

*- either request a given bulletin, by its number (84 have been issued as of June 30, 1999 but numbers 2,16, 18,19 are out of print).*

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

*Requests should be sent to:*

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

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

## **2. HOW TO REQUEST DATA**

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

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

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

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

### **2.2. G-Value at Base Stations**

*Treated as above.*

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

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

### **2.4. Gravity Maps**

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

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

- we can make (poor quality) black and white (or ozalide-type) copies at low cost,*
- color copies can be made (at high cost) if the user wishes so (after we obtain the authorization of the editor).*

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

### **2.5. Gravity Measurements**

#### **2.5.1. CD-Roms**

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

*The price of these is :*

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

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

#### **2.5.2. Data stored in the general data base**

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

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

<p style="text-align: center;"><b>EOL</b>  <b>LAND DATA FORMAT</b>  <b>RECORD DESCRIPTION</b>  <b>126 characters</b></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 <= 5 Meters	
		2 = 5 < R <= 20 M (approximately 0'01)	
		3 = 20 < R <= 100 M	
		4 = 100 < R <= 200 M (approximately 0'1)	
		5 = 200 < R <= 500 M	
		6 = 500 < R <= 1000 M	
		7 = 1000 < R <= 2000 M (approximately 1')	
		8 = 2000 < R <= 5000 M	
		9 = 5000 M < R	
		10...	
	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 <= 0.02 M	
		2 = .02 < E <= 0.1 M	
		3 = .1 < E <= 1	
		4 = 1 < E <= 2	
		5 = 2 < E <= 5	
		6 = 5 < E <= 10	
		7 = 10 < E <= 20	
		8 = 20 < E <= 50	
		9 = 50 < E <= 100	
		10 = E superior to 100 M	

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	<b>Observed gravity</b> (unit : microgal)	(9 char.)
62-67	<b>Free air anomaly</b> (0.01 mgal)	(6 char.)
68-73	<b>Bouguer anomaly</b> (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	<b>Terrain correction</b> (0.01 mgal)	(6 char.)
	<i>computed according to the next mentioned radius &amp; 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	<b>Reference station</b>	(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	<b>Country code (BGI)</b>	(3 char.)
112	<b>Confidentiality</b>	(1 char.)
	0 = without restriction	
	.....1 = with authorization	
	2 = classified	
113	<b>Validity</b>	(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;"><b>EOS</b>  <b>SEA DATA FORMAT</b>  <b>RECORD DESCRIPTION</b>  <b>146 characters</b></p>
---

Col.	1-8	<b>B.G.I.</b> source number	(8 char.)
	9-16	<b>Latitude</b> (unit : 0.00001 degree)	(8 char.)
	17-25	<b>Longitude</b> (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 ≤ 5 Meters	
		2 = 5 < R ≤ 20 M (approximately 0'01)	
		3 = 20 < R ≤ 100 M	
		4 = 100 < R ≤ 200 M (approximately 0'1)	
		5 = 200 < R ≤ 500 M	
		6 = 500 < R ≤ 1000 M	
		7 = 1000 < R ≤ 2000 M (approximately 1')	
		8 = 2000 < R ≤ 5000 M	
		9 = 5000 M < R	
		10...	
	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	<b>Elevation of the station</b> (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 ≤ 0.02 Meter	
		2 = .02 < E ≤ 0.1 M	
		3 = .1 < E ≤ 1	
		4 = 1 < E ≤ 2	
		5 = 2 < E ≤ 5	
		6 = 5 < E ≤ 10	
		7 = 10 < E ≤ 20	
		8 = 20 < E ≤ 50	
		9 = 50 < E ≤ 100	
		10 = E superior to 100 Meters	
	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	<b>Observed gravity</b> (unit : microgal)	(9 char.)
	62-67	<b>Free air anomaly</b> (0.01 mgal)	(6 char.)

68-73	<b>Bouguer anomaly</b> (0.01 mgal)	(6 char.)
	Simple Bouguer anomaly with a mean density of 2.67. No terrain correction	
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77-79	Estimation standard deviation bouguer anomaly (0.1 mgal)	(3 char.)
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	<i>computed according to the next mentioned radius &amp; 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)	
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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	(2 char.)
	<i>when the depth is not corrected depth, this information is necessary. For example : zone 50 for the Eastern Mediterranean Sea</i>	
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	(9 char.)
	<i>in Julian day - 2 400 000 (unit : 1/10 000 of day)</i>	
111-113	Velocity of the ship (0.1 knot)	(3 char.)
114-118	Eötvös correction (0.1 mgal)	(5 char.)
119-121	<b>Country code</b> (BGI)	(3 char.)
122	<b>Confidentiality</b>	(1 char.)
	0 = without restriction	
	1 = with authorization	
	2 = classified	
123	<b>Validity</b>	(1 char.)
	0 = no validation	
	1 = good	
	2 = doubtful	
	3 = lapsed	
124-130	Numbering of the station (original)	(7 char.)
131-136	<b>Sequence number</b>	(6 char.)
137-139	<b>Leg number</b>	(3 char.)
140-145	<b>Reference station</b>	(6 char.)

Whenever given, the theoretical gravity ( $\gamma_0$ ), 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:

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

where  $\phi$  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
$\gamma$	: theoretical value of gravity (on the ellipsoid)
$\Gamma$	: 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 ( $667.2 \cdot 10^{-13} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$ ) $\Rightarrow k = 2 \pi G$
$\rho_c$	: mean density of the Earth's crust (taken as $2670 \text{ kg m}^{-3}$ )
$\rho_w^f$	: density of fresh water ( $1000 \text{ kg m}^{-3}$ )
$\rho_w^s$	: density of salted water ( $1027 \text{ kg m}^{-3}$ )
$\rho_i$	: density of ice ( $917 \text{ kg m}^{-3}$ )
FA	: free-air anomaly
BO	: Bouguer anomaly

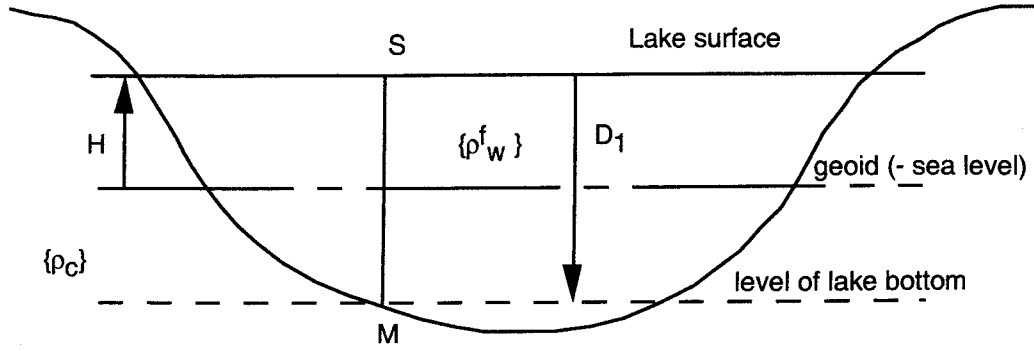
Formulas :

- \* 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  $\gamma_0$  computed on the reference ellipsoid (classical concept). The more modern concept<sup>\*</sup>, 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  $\rho_c$  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	$FA = g + IH - \gamma_0$ $BO = FA - k \rho_c H$
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	$FA = g + IH - \gamma_0$ $BO = FA - k \rho_w^l D_1 - k \rho_c (H - D_1)$
7	Lake bottom, above sea level	$FA = g + 2 k \rho_w^l D_1 + \Gamma (H - D_1) - \gamma_0$ $BO = FA - k \rho_w^l D_1 - k \rho_c (H - D_1)$
8	Lake bottom, below sea level	$FA = g + 2 k \rho_w^l D_1 + \Gamma (H - D_1) - \gamma_0$ $BO = FA - k \rho_w^l H + k (\rho_c - \rho_w^l) (D_1 - H)$
9	Lake surface above sea level with bottom below sea level	$FA = g + IH - \gamma_0$ $BO = FA - k \rho_w^l H + k (\rho_c - \rho_w^l) (D_1 - H)$
A	Lake surface, below sea level (here $H < 0$ )	$FA = g + IH - \gamma_0$ $BO = FA - k \rho_c H + k (\rho_c - \rho_w^l) D_1$
B	Lake bottom, with surface below sea level ( $H < 0$ )	$FA = g + (2 k \rho_w^l - \Gamma) D_1 + \Gamma H - \gamma_0$ $BO = FA - k \rho_c H + k (\rho_c - \rho_w^l) D_1$
C	Ice cap surface, with bottom below sea level	$FA = g + IH - \gamma_0$ $BO = FA - k \rho_i H + k (\rho_c - \rho_i) (D_1 - H)$
D	Ice cap surface, with bottom above sea level	$FA = g + IH - \gamma_0$ $BO = FA - k \rho_i D_1 - k \rho_c (H - D_1)$

*All requests for data must be sent to :*

*Mr. Bernard LANGEILLIER  
Bureau Gravimétrique International  
18, Avenue E. Belin - 31401 Toulouse Cedex 4 - France  
E-mail : [Bernard.Langellier@cnes.fr](mailto:Bernard.Langellier@cnes.fr)*

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

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

### 3. USUAL SERVICES BGI CAN PROVIDE

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

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

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

#### 3.1. Charging Policy for Data Contributors and Scientists

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

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

##### 3.1.1. Digital Data Retrieval

*. on CD-Roms : see 2.5.1.*

*. on one of the following media :*

*\* printout ..... 2 F/100 lines*

*\* diskette..... 25 F per diskette (minimum charge : 50 F-*

*\* magnetic tape ..... 2 F per 100 records*

*+ 100 F per DAT cartridge*

*(if the tape is not to be returned)*

*. minimum charge : 100 F*

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

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

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

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

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

##### 3.1.3. Data Screening

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

*. 5 F/100 points to be screened.*

*. 100 F minimum charge.*

##### 3.1.4. Gridding

*(Interpolation at regular intervals  $\Delta$  in longitude and  $\Delta'$  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  $\Delta$  (1, 2, 5,... mgal), on a given projection :  
10 F/ $\Delta$  per degree square, plus the cost of gridding (see 3.4) after agreement on grid stepsizes. (at any scale, within a maximum map size for : 90 cm x 180 cm).

. 250 F minimum charge

. maximum area : 40° x 40°

### 3.1.6. Computation of Mean Gravity Anomalies

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

. minimum charge : 150 F

. maximum area : 40°x40°

## 3.2. Charging Policy for Other Individuals or Private Companies

### 3.2.1. Digital Data Retrieval

. on CD-Roms : see 2.5.1.

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

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

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

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

### 3.2.3. Data Screening

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

. 500 F minimum charge

### 3.2.4. Gridding

Same as 3.1.4.

### 3.2.5. Contour Maps of Bouguer or Free-Air Anomalies

Same as 3.1.5.

### 3.2.6. Computation of Mean Gravity Anomalies

Same as 3.1.6.

## 3.3. Gravity Maps

The pricing policy is the same for all categories of users

### 3.3.1. Catalogue of all Gravity Maps

Printout : 200 F

DAT cartridge (4 mm) 100 F

### 3.2.2. Maps

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

. Special maps :

#### Mean Altitude Maps

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

#### Maps of Gravity Anomalies

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

#### World Maps of Anomalies (with text)

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

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

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

#### Miscellaneous

##### CATALOGUE OF ALL GRAVITY MAPS

listing	200 FF
tape	300 FF

##### THE UNIFICATION OF THE GRAVITY NETS OF AFRICA

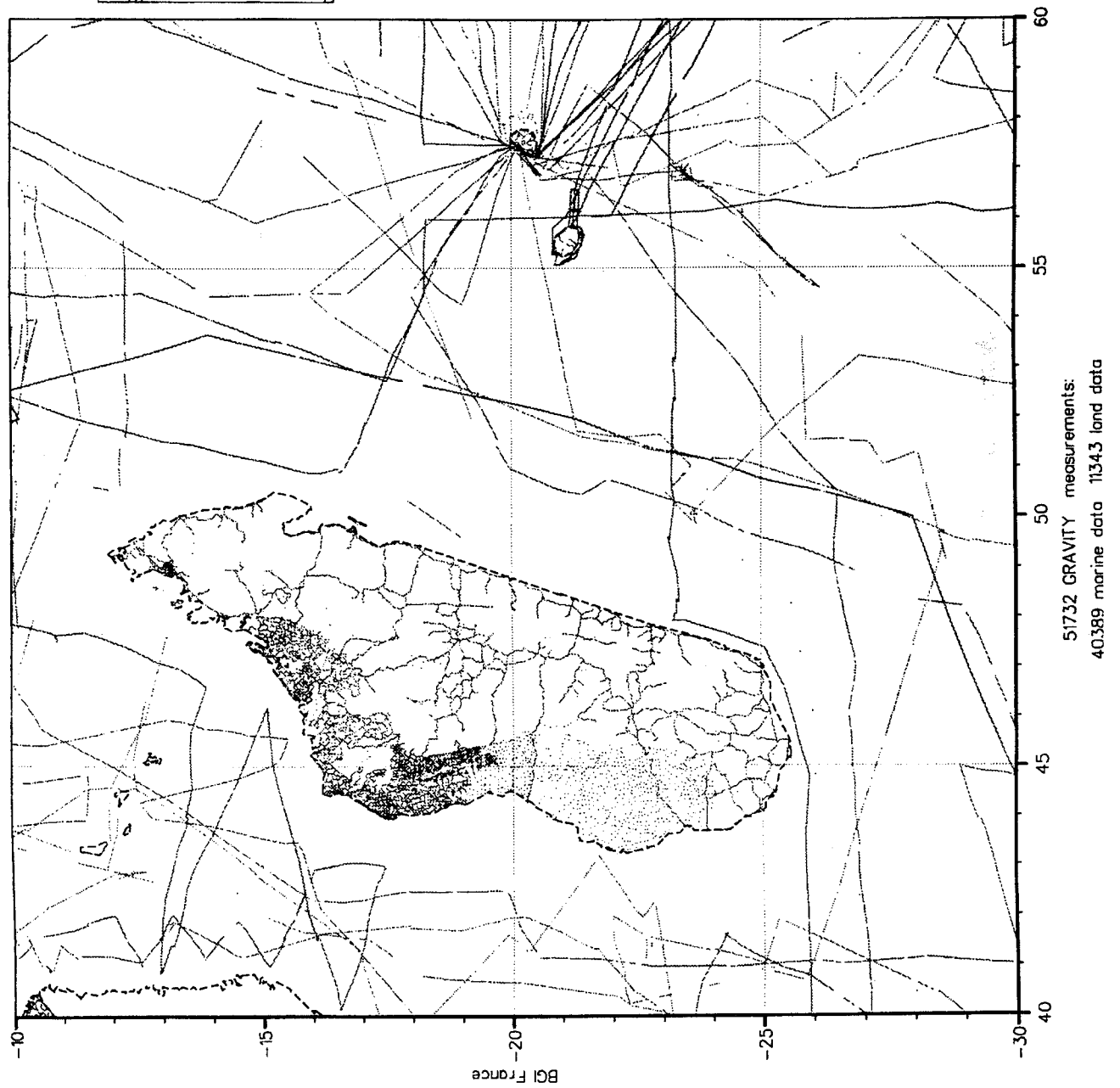
(Vol. 1 and 2)	1979	150 FF
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. Black and white copy of maps : 150 F per copy

. Colour copy : price according to specifications of request.

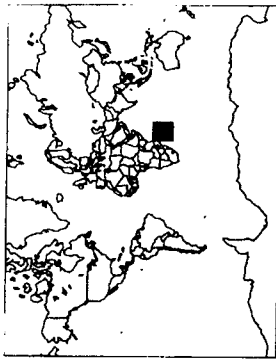
Mailing charges will be added for air-mail parcels when "Air-Mail" is requested)
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Map 1. Example of data coverage plot



E12

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)

E12

214	102	15	52	8	26	29	184	53	65	26	8	116	138	51	44	52	85	66	139	101	421	62	120	13	43	176	263	103	267	872	72	72	232	91	94	37	213	
101	118	39	53	37	41	284	85	426	777	451	163	43	29	3	25	68	40	37	213	21	207	51	28	98	74	32	99	14	111	173	17	45	60	59	238	1	14	587
21	207	51	28	98	74	32	99	14	111	173	17	45	60	59	238	1	14	587	559	410	634	936	64	668	471	580	379	548	327	172	123	204	238	31	101	14	48	
56	159	122	114	638	1215	37	61	91	91	173	17	45	60	59	238	1	14	587	56	159	122	114	638	1215	37	61	91	91	173	17	45	60	59	238	31	101	14	48
3	334	170	204	125	84	172	35	155	117	4	72	72	72	72	72	72	72	72	72	3	334	170	204	125	84	172	35	155	117	4	72	72	72	72	72	72	72	72
478	130	403	398	521	401	384	320	286	343	826	59	35	35	35	35	35	35	35	478	130	403	398	521	401	384	320	286	343	826	59	35	35	35	35	35	35	35	
18	301	117	83	47	56	80	377	166	159	105	35	35	35	35	35	35	35	35	18	301	117	83	47	56	80	377	166	159	105	35	35	35	35	35	35	35	35	
249	13	88	84	97	97	249	87	101	44	60	71	71	71	71	71	71	71	71	249	13	88	84	97	97	249	87	101	44	60	71	71	71	71	71	71	71	71	
721	30	40	76	151	103	329	617	146	38	47	35	35	35	35	35	35	35	35	721	30	40	76	151	103	329	617	146	38	47	35	35	35	35	35	35	35	35	
220	548	396	151	103	329	617	146	38	47	35	35	35	35	35	35	35	35	35	220	548	396	151	103	329	617	146	38	47	35	35	35	35	35	35	35	35	35	
452	407	223	633	728	631	122	182	50	365	13	273	273	273	273	273	273	273	273	452	407	223	633	728	631	122	182	50	365	13	273	273	273	273	273	273	273	273	
00	421	127	82	252	330	145	105	103	68	281	24	24	24	24	24	24	24	24	00	421	127	82	252	330	145	105	103	68	281	24	24	24	24	24	24	24	24	
102	421	158	176	348	486	407	244	53	117	45	51	51	51	51	51	51	51	51	102	421	158	176	348	486	407	244	53	117	45	51	51	51	51	51	51	51	51	
201	513	404	256	126	52	260	32	504	03	158	149	149	149	149	149	149	149	149	201	513	404	256	126	52	260	32	504	03	158	149	149	149	149	149	149	149	149	
141	402	160	106	198	152	89	128	195	204	122	117	117	117	117	117	117	117	117	141	402	160	106	198	152	89	128	195	204	122	117	117	117	117	117	117	117	117	
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91	476	44	181	61	80	104	503	350	159	439	168	168	168	168	168	168	168	168	91	476	44	181	61	80	104	503	350	159	439	168	168	168	168	168	168	168	168	
131	365	281	125	244	178	223	331	206	194	21	43	69	56	52	108	179	105	414	131	365	281	125	244	178	223	331	206	194	21	43	69	56	52	108	179	105	414	
47	23	32	725	725	387	155	202	137	90	13	13	13	13	13	13	13	13	13	47	23	32	725	725	387	155	202	137	90	13	13	13	13	13	13	13	13	13	
389	274	211	74	297	125	118	338	129	161	251	326	30	66	61	118	141	130	500	389	274	211	74	297	125	118	338	129	161	251	326	30	66	61	118	141	130	500	
37	46	38	178	336	115	171	91	2	2	37	73	73	73	73	73	73	73	73	37	46	38	178	336	115	171	91	2	2	37	73	73	73	73	73	73	73	73	
412	458	168	202	234	408	672	318	568	568	98	133	133	133	133	133	133	133	133	412	458	168	202	234	408	672	318	568	568	98	133	133	133	133	133	133	133	133	
86	151	198	100	197	200	167	265	21	11	11	11	11	11	11	11	11	11	11	86	151	198	100	197	200	167	265	21	11	11	11	11	11	11	11	11	11		
24	96	12	6	151	144	49	104	81	81	213	12	12	12	12	12	12	12	12	24	96	12	6	151	144	49	104	81	81	213	12	12	12	12	12	12	12	12	
226	212	298	43	51	158	494	496	470	470	213	12	12	12	12	12	12	12	12	226	212	298	43	51	158	494	496	470	470	213	12	12	12	12	12	12	12	12	
74	145	162	23	281	283	275	221	381	381	73	88	88	88	88	88	88	88	88	74	145	162	23	281	283	275	221	381	381	73	88	88	88	88	88	88	88	88	
255	67	29	87	86	82	146	176	99	99	52	48	24	8	1	65	177	212	170	255	67	29	87	86	82	146	176	99	99	52	48	24	8	1	65	177	212		
255	105	161	138	27	43	264	58	469	469	248	27	55	85	130	2813	45	284	165	255	105	161	138	27	43	264	58	469	469	248	27	55	85	130	2813	45	284		
69	89	200	112	148	199	167	338	393	393	57	62	12	45	00	614	530	242	161	69	89	200	112	148	199	167	338	393	393	57	62	12	45	00	614	530			
110	81	30	113	200	166	149	205	13	13	45	50	50	50	50	50	50	50	50	110	81	30	113	200	166	149	205	13	13	45	50	50	50	50	50	50	50	50	
64	33	208	300	176	418	284	76	757	757	140	60	60	60	60	60	60	60	60	64	33	208	300	176	418	284	76	757	757	140	60	60	60	60	60	60	60		
278	115	110	76	237	118	46	157	145	145	17	123	105	76	97	46	119	247	144	278	115	110	76	237	118	46	157	145	145	17	123	105	76	97	46	119	247		
122	33	110	76	237	118	46	157	145	145	17	123	105	76	97	46	119	247	144	122	33	110	76	237	118	46	157	145	145	17	123	105	76	97	46	119	247		
28	99	28	132	132	150	139	131	34	75	136	106	160	35	72	328	96	261	100	28	99	28	132	132	150	139	131	34	75	136	106	160	35	72	328	96			
32	12	394	504	394	300	110	270	75	75	75	165	37	16	428	31	59	211	125	32	12	394	504	394	300	110	270	75	75	75	165	37	16	428	31	59	211		
61	158	106	108	98	343	423	31	1	45	24	65	50	13	42	70	100	47	26	61	158	106	108	98	343	423	31	1	45	24	65	50	13	42	70	100			
109	130	58	58	104	161	123	31	1	45	24	65	50	13	42	70	100	47	26	109	130	58	58	104	161	123	31	1	45	24	65	50	13	42	70	100			
89	15	37	12	195	144	413	667	249	249	17	123	105	76	97	46	119	247	144	89	15	37	12	195	144	413	667	249	249	17	123	105	76	97	46	119	247		
96	103	70	144	327	284	410	191	0	62	73	76	75	32	233	37	40	187	29	96	103	70	144	327	284	410	191	0	62	73	76	75	32	233	37	40			
37	77	51	49	34	37	30	35	48	71	68	26	21	9	15</																								

## 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*

**PART II**

**DIRECTING BOARD,  
CHANGES AT BGI**





**Minutes of the BGI Directing Board meeting**  
**held at the IUGG 99 in Birmingham**  
**on the 21st July 1999**

Present: I. Marson, M. Vermeer, G. Balmino, J.P. Barriot, W. Torge, P. Paquet, H. Sünkel, F. Sansò, C. Morelli, R. Forsberg, B. Richter, J.E. Faller, P.P. Medvedev, Chief Coker, S. Takemoto, N. Courtier (secretary).

Marson opened the meeting with a warm welcome to Morelli, the first president of the International Gravity Commission (IGC). This is the final BGI Directing Board meeting; the IGC is being merged with the International Geoid Commission (IGeC) to form, what is expected to be called, the International Gravity and Geoid Commission (IGGeC). This natural progression follows from the increasingly close ties between the two commissions and their combined conferences. An interim board will be appointed by the IAG. The new board will review the working groups and national representatives of both commissions.

Balmino presented an updated BGI report and overview of its scientific data, analysis and educational services. The BGI has been operating since 1951 with three full time and two part time members providing, since 1980, an ever increasing volume of gravity data and services to geodesists, geophysicists, industry, instrumental users, metrologists, schools, universities and the military. Much progress has recently been made in the difficult field of marine data validation through the use of gravity derived from satellite altimetry. Land (both relative and absolute), sea and air data are being archived. Recently there has been a large increase in the sea gravity data holdings. Reference and IAGBN station descriptions have been scanned and archived. Some gridded gravity data is available. Data and other information is distributed by CD-ROM and the BGI web server. Under the leadership of its new director, J.P. Barriot, the BGI will continue to collect and distribute gravity data, publish the Bulletin and provide tutorials and educational services. It will expand its data base capabilities and interpretation tools and forge close links with the IGGeC, IGeS and other FAGs services. The new BGI structure will bring additional energy and expertise from its 10 supporting organizations.

The board agreed that it is essential that the IGGeC support and encourage the donation of data to the BGI, possibly by creating a working group to deal specifically with this issue.

All members of the meeting expressed sincere thanks and appreciation to Balmino and Marson, and their best wishes to Barriot and Vermeer for success in their new tasks and responsibilities.

N. Courtier. July 21, 1999.



## CHANGES AT BGI !!!

Important changes have taken , and are going to take place at BGI.

Following the call for proposal issued by the International Gravimetric Commission in 1997, several organisations in France made a joint proposal in mid-1998 to continue hosting and running BGI in this country with, in principle, an enlarged support with respect to the current situation. The proposal was accepted by IGC in the fall of 1998, reviewed and accepted by the Executive Committee of IAG early 1999, blessed and accepted by the FAGS Council in March, and finally approved by the IUGG Council at Birmingham last July during the General Assembly of the Union. The terms of the proposal came into force at the closing of this General Assembly. The reader will find details of the new organisation of BGI in section 13 of the report « *BGI : from 1979 to 1999* » by myself and published in this issue..

In practice there is a transition period, extending until the spring of 2000, to take care of the following :

- taking over of the directorship by my successor, Jean-Pierre Barriot (this has been done);
- signing of a new covenant between the partners for the support of BGI with national means : logistics, man-power, computer facilities, travel money, specific contributions (expertise, software, educational material,...) – the covenant, which I have established, is now being circulated between the relevant French organisations ;
- organisation of the new structure by J.P. Barriot ;
- changes in the BGI staff in Toulouse : Gilles Balma will leave the office at the end of this year (and will not be replaced) ; Denis Toustou will also leave BGI at the end of April 2000, but he will be replaced by Bernard Langellier (from IGN) who is getting acquainted with BGI matters and being trained on the database management system for which he will be responsible ;

All measures are being taken by my successor to ensure a smooth transition. Our hope is that the BGI users will hardly notice the changes although we have no means to guarantee this in absolute !

I would like to thank heartily Denis and Gilles for their dedicated work for BGI since so many years. I think that our community especially owes an immense tribute to Denis who, among other tasks, established the present data base and the BGI server, which are so much used daily. I wish both our colleagues all the best and success in their future activities.

Nicole Lestieu will continue as secretary of the BGI central office in Toulouse, as well as Michel Sarrailh in his position of gravimetrist, computer engineer and living memory of BGI. Thank you to both of them, with whom I have shared so many good things during the past twenty years.

Besides Bernard Langellier, you will very likely come in touch with new people from other French partner organisations, who will participate in BGI works : a warm welcome and good luck to all of them ... and to Jean-Pierre Barriot of course !

Georges Balmino  
(outgoing Director)



# THE BUREAU GRAVIMETRIQUE INTERNATIONAL

from 1979 to 1999

G. Balmino  
Director of B.G.I.  
Secretary General of I.U.G.G.

## 1. INTRODUCTION

In geodesy, gravity values play a great part in the modelling of the Earth gravity field, which is of permanent use for the computation of precise satellite orbits. It is also an essential information for the determination of the geoid, and for the definition of the ocean mean surface used for the study of the global circulation (Balmino et al., 1986). In geophysics, the interpretation of the gravity field anomalies allows to study density variations in the lithosphere or the mantle, with applications in oil and mineral prospecting (Balmino, 1986a).

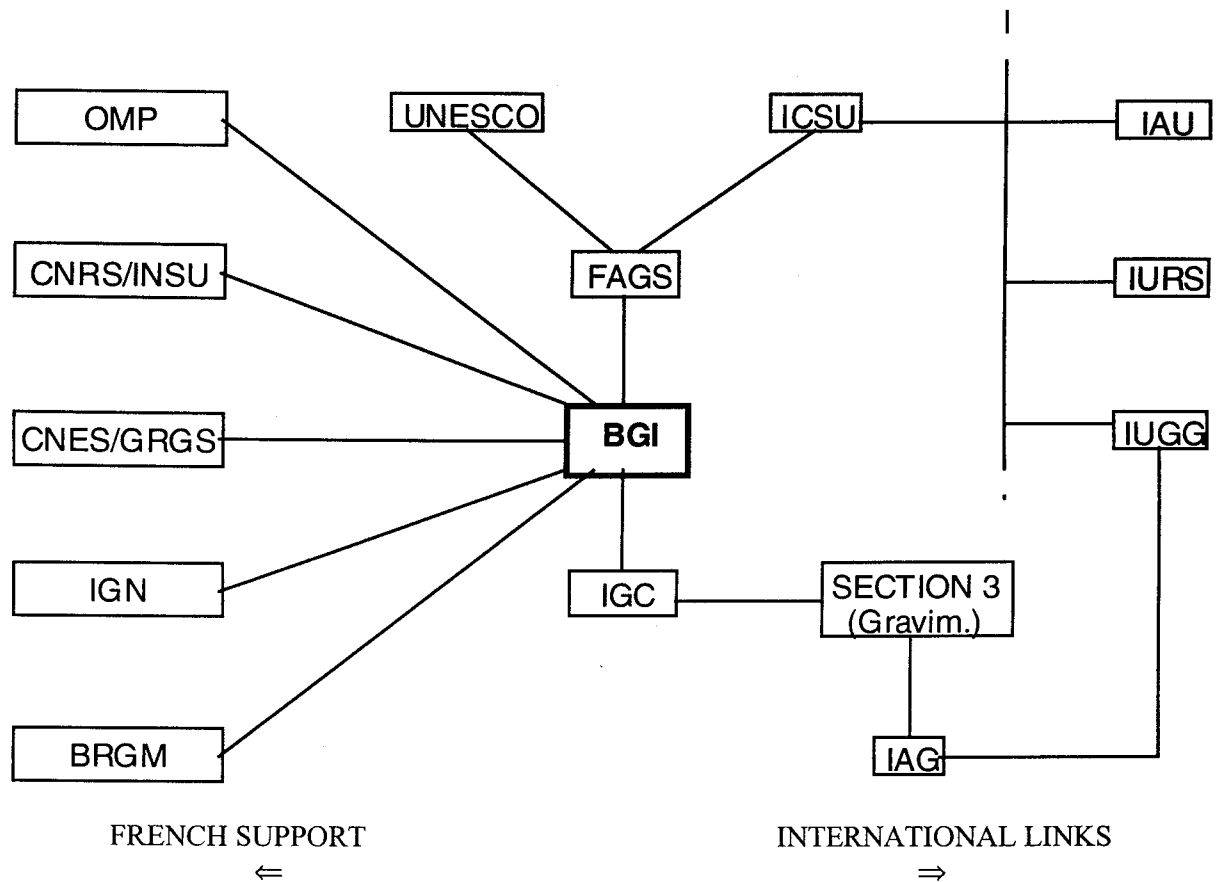
The Bureau Gravimétrique International (BGI) is one of the offices of the Federation of Astronomical and Geophysical Services (FAGS) which operates under the auspices and in part thanks to the financial support of the International Council of Scientific Unions (ICSU) and the United Nations Educational Scientific and Cultural Organisation (UNESCO). Primarily interested in the activities of these services are the International Astronomical Union (IAU), the International Union of Radio-Sciences (IURS), and of course the International Union of Geodesy and Geophysics (IUGG). - see fig. 1 and Melchior (1989). It may also be considered as an executive arm of the International Gravity Commission (IGC) within the International Association of Geodesy (IAG), one of the seven associations of which IUGG is composed.

The idea of a service for gravity data and related matters originated during the 1951 IUGG General Assembly in Brussels and BGI was created in 1953. Its offices have been located in France since the beginning, when pioneer works were being done by the first directors : Reverend Father Lejay from the Society of Jesus, Academician Tardy, and then Professor Levallois.

The central office is in Toulouse (France) since 1980, in the premises of the Observatoire Midi-Pyrénées (OMP) of which it is one of the services. The other french supporting organisations are : the Centre National d'Etudes Spatiales (CNES), the Institut Géographique National (IGN), the Centre National de la Recherche Scientifique (CNRS) - via the Institut National des Sciences de l'Univers (INSU), and the Bureau de Recherches Géologiques et Minières (BRGM). There exists a covenant between these agencies to guarantee their support to BGI. The organisation of BGI at the French level is going to change beginning of 2000, following the re-structuration of the service (see chapter 13).

BGI has a Directing Board composed of nine voting members (comprising the IGC president, two vice-presidents, the section III chairperson, the BGI director, plus four elected members), and non voting members : the chairpersons of the IGC-BGI working groups ; the secretary (ies) of the Board ; three ex-officio members (the Geoid Commission president, the Director of the International Geoid service and a FAGS representative). Names of members are given in Chapter 12. The Directing Board meets once every year in principle.

Fig. 1. Links of BGI with international and national (french) bodies



List of Acronyms :

BGI	Bureau Gravimétrique International
BRGM	Bureau de Recherches Géologiques et Minières
CNES/GRGS	Centre National d'Etudes Spatiales/Groupe de Recherches en Géodésie Spatiale
CNRS/INSU	Centre National de la Recherche Scientifique/Institut National des Sciences de l'Univers
FAGS	Federation of Astronomical and Geophysical Services
IAG	International Association of Geodesy
IAU	International Astronomical Union
ICSU	International Council of Scientific Unions
IGC	International Gravimetric Commission
IGN	Institut Géographique National
IUGG	International Union of Geodesy and Geophysics
IURS	International Union of Radio Science
OMP	Observatoire Midi-Pyrénées
UNESCO	United Nations Educational, Scientific and Cultural Organisations

## **2. OBJECTIVES AND TERMS OF REFERENCE**

The main task of BGI is to collect, on a world-wide basis, all existing gravity measurements and pertinent information about the gravity field of the Earth, to compile them and store them in a computerized data base in order to redistribute them on request to a large variety of users for scientific purposes. The data consist of : gravimeter observations (mainly location - three co-ordinates, gravity value, corrections, anomalies ...), mean free-air gravity values, gravity maps, reference station descriptions, publications dealing with the Earth's gravity. BGI also has access through one of his host agencies to satellite altimetry derived geoid heights (presently from Geos 3, Seasat, Geosat, ERS1 and 2, Topex/Poseidon) ; spherical harmonic coefficients of current global geopotential models ; mean topographic heights. These data are sometimes used internally for data validation and geophysical analysis.

The data collection activities are especially conducted in the framework of large regional projects, in order to densify the world data coverage, and BGI has put emphasis on the validation of received measurements, so as to improve the quality of the delivered information.

Three working groups of the International Gravimetric Commission are presently helping BGI in different tasks :

- WG2 : World Gravity Standards (chairman : G. Boedecker). This group is now in charge, and probably for a long time, of the deployment of the International Absolute Gravity Base Station Network (IAGBN)
- WG6 : Intercomparison of Absolute Gravimeters. For a long time under the responsibility of late Prof. Boulanger, the activity is now chaired by L. Robertsson and controlled by this group which continues to organise comparisons of instruments about every four years at the Bureau International des Poids et Mesures (B.I.P.M.) in Sèvres, near Paris ; the last campaign took place in November-December 1998.
- WG7 : Global Gravity Monitoring Network (chairman : B. Richter). Newly established, this group has a large variety of problems to deal with, due to the growing use of superconducting gravimeters.

Other working groups (WG1, WG3, WG4, WG5, WG8) terminated their mandates and were naturally dismantled. A special mention goes to WG1 which dealt with data processing : our Canadian colleagues, who have chaired this group from the beginning, have provided invaluable help to the Bureau.

## **3. SERVICE ACTIVITIES : GENERAL INFORMATION**

### **3.1. Providing Data to BGI**

All kinds of gravity data can be sent to BGI, with or without restrictions of redistribution to be specified by the contributors, sometimes in the form of a protocol of usage.

Essential quantities and information for gravity data submission are :

a) 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

b) Measured (observed) gravity, corrected to eliminate the periodic gravitational effects of the Sun and the Moon, and the instrumental drift.

c) 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 : IGSN71, or IAGBN.

A specific form has been included in the BGI Bulletin d'Information of June 1999, which gravity campaign operators are kindly asked to return for each reference station used. This will help BGI update its reference station file.

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. The same applies to air-borne gravity data. Additional information are optional, but welcome.

### **3.2. Getting Data and Services from BGI**

The most frequent service BGI can provide is data retrieval over a limited area. Data have been sent on tapes or diskettes (even on printouts in the past), or nowadays transferred electronically. Data coverage plots may also be provided, usually over 20° x 20° areas or over any area at the user's request. Cases of massive data retrieval requests may be considered ; they are studied and may be processed in a specific way, but the users are encouraged to acquire them from the BGI CD-Roms (see 4.4).

Other services include :

- data screening,
- provision of gravity base station information (on micro-fiches, sometimes rushed by fax ; recently they have been made available on the BGI server),
- data evaluation and gridding,
- computation of mean values (simple means ; computation by collocation available on request),
- contouring,
- supply of maps, or information on existing maps (catalogue available in printed form and on tape),
- bibliographical information.

The cost of the services have been established in view of the categories of users-mostly contributors of measurements and scientists, and also considering the large amount of support of our host organisations. The charging policy is explained in detail in the Bulletin d'Information. Some of the services may be provided free of charge upon request, to data contributors, individuals working in universities, such as students, and generally to any person who can contribute to our activities on a data or documentation exchange basis.

### **3.3. The Publications**

BGI issues a Bulletin d'Information twice a year (generally in June and December). It is sent to about 350 subscribers. 84 issues have been published so far. The Bulletin contains :

- . general information in the field, news about the Bureau itself, recent additions to our holdings,
- . contributing papers in gravimetry,
- . communications at meetings dealing with gravimetry (e.g. IGC meeting).



Every four years, an issue (which may be an additional one) contains the National Reports of Activities in Gravimetry.

Besides, the full catalogue of the holdings has been issued every two years. It usually came in two volumes : one with the coverage plots of the measured gravity points in the form of maps covering  $20^\circ \times 20^\circ$  areas (fig. 2), the other as a set of tables of statistics per square degree (number of points, mean free-air value and its r.m.s.) corresponding to each map of the first volume (fig. 3). These catalogues will not be updated because there has been no request for them in the last four years (due to the distribution of data on CD-ROMs and via Internet).

BGI has also prepared and published a brochure publicising its role and activities (distributed at the IUGG General Assemblies, also on other occasions), and realised (with IGN Space Company) a Spot image map with contours of Bouguer gravity anomalies.

Scientific and technical papers are also written, on an irregular basis, on problems, software, study results and various applications dealt with at the Bureau ; they are published in journals or proceedings of meetings at which they are presented.

## **4. DATA BASES AND RELATED ACTIVITIES**

### **4.1. The Gravity Data Base :**

The first computerised data base was established in 1976 with the help of BRGM, of IGN and of the Institut de Physique du Globe in Paris (where BGI was located at that time). A great deal of effort was put, between 1980 and 1982, at building up an entirely new data bank and management system on one of the CNES main frames (CDC Cybers). This resulted in a quite sophisticated system, entirely specific to gravity data, but very difficult to maintain. Along the years, after having suffered from computer changes and staff turn-over, also facing difficulties in upgrading the software (for instance to speed up the merging operations which had to be done more and more frequently with the increase of the data volume), B.G.I. decided to change its strategy in data base maintenance.

Instead of putting more efforts from BGI staff and following the availability of the ORACLE software on a main frame at CNES, it was decided in early 1991 and after extensive satisfactory testing to discontinue the usage of the old software and to switch to ORACLE. A first version was operational in the fall of 1991. Attention was exerted to ensure no interruption in the services ; for this purpose, the two software with two different data bases have been run and used in parallel up to early 1992 until not a single failure appears with the new system. This is described by Toustou (1992). To-day, the ORACLE (V7) is still in use and operates on an IBM-9672 R14. Access to the data base is possible via UNIX work-stations, or via the server which has been opened mid-1997. New pieces of software are written from time to time to perform new functions required by the archiving of special data sets and by their validation.

### **4.2. Data Collection**

The data base content, as concerns actual measurements, undergone an extraordinary increase. It contains as little as 800 000 measurements in 1979. Then several sets of land data were regularly added ; the contribution of NIMA (National Imaging and Mapping Agency, ex-DMA ; USA) is worth mentioning. This was, in the 80's, a very slow process due to the characteristics of the old software, until the new system was perfectly working.

Large data sets of marine data were received in 1993 from NGDC (National Geophysical Data Center, Boulder, USA) in the context of the European Geoid Project, and then BGI acquired the totality of the NGDC data on CD-ROMs. These were merged in the data base in 1994 and 1995 after some editing.

Fig. 2. Example of data coverage plot

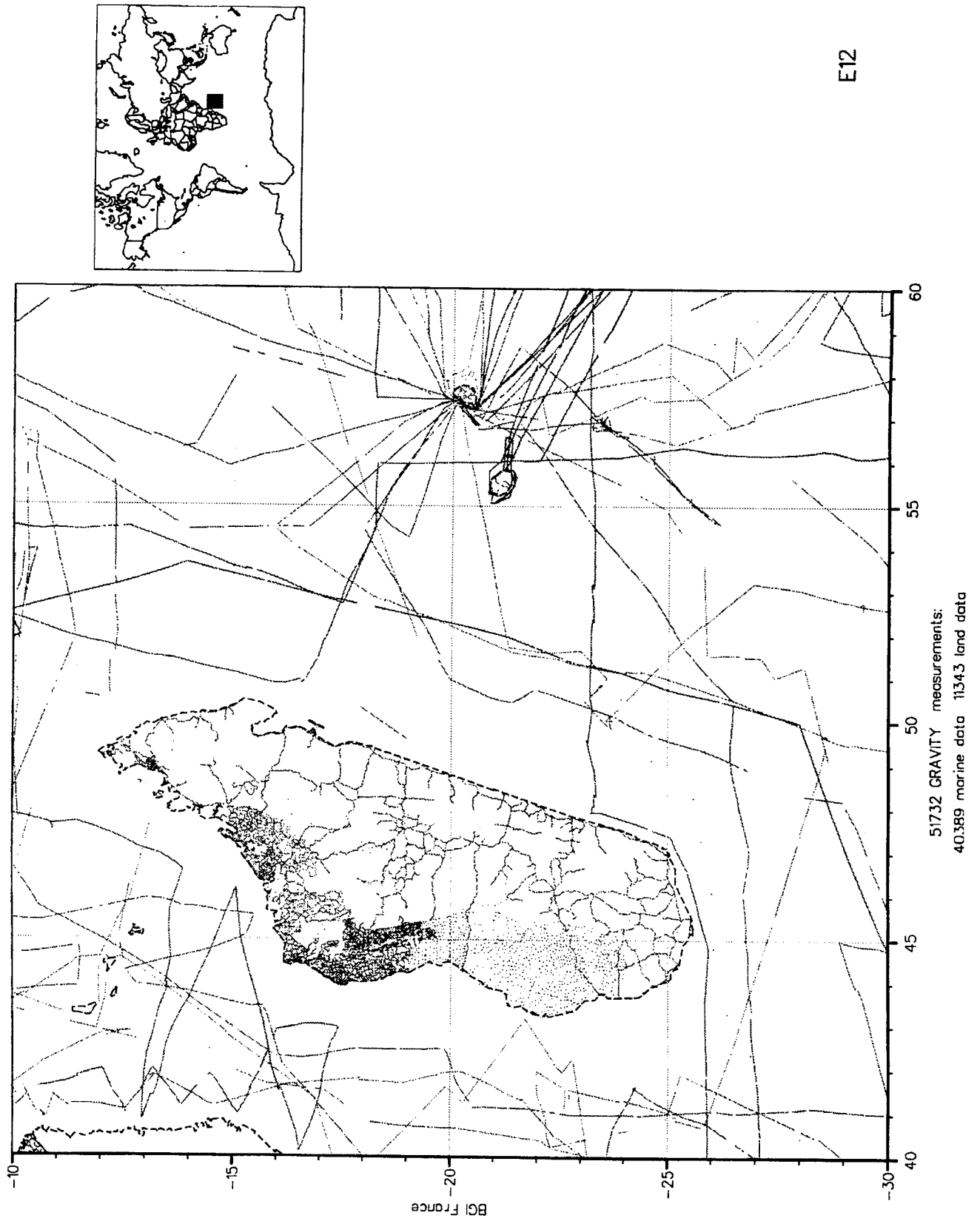
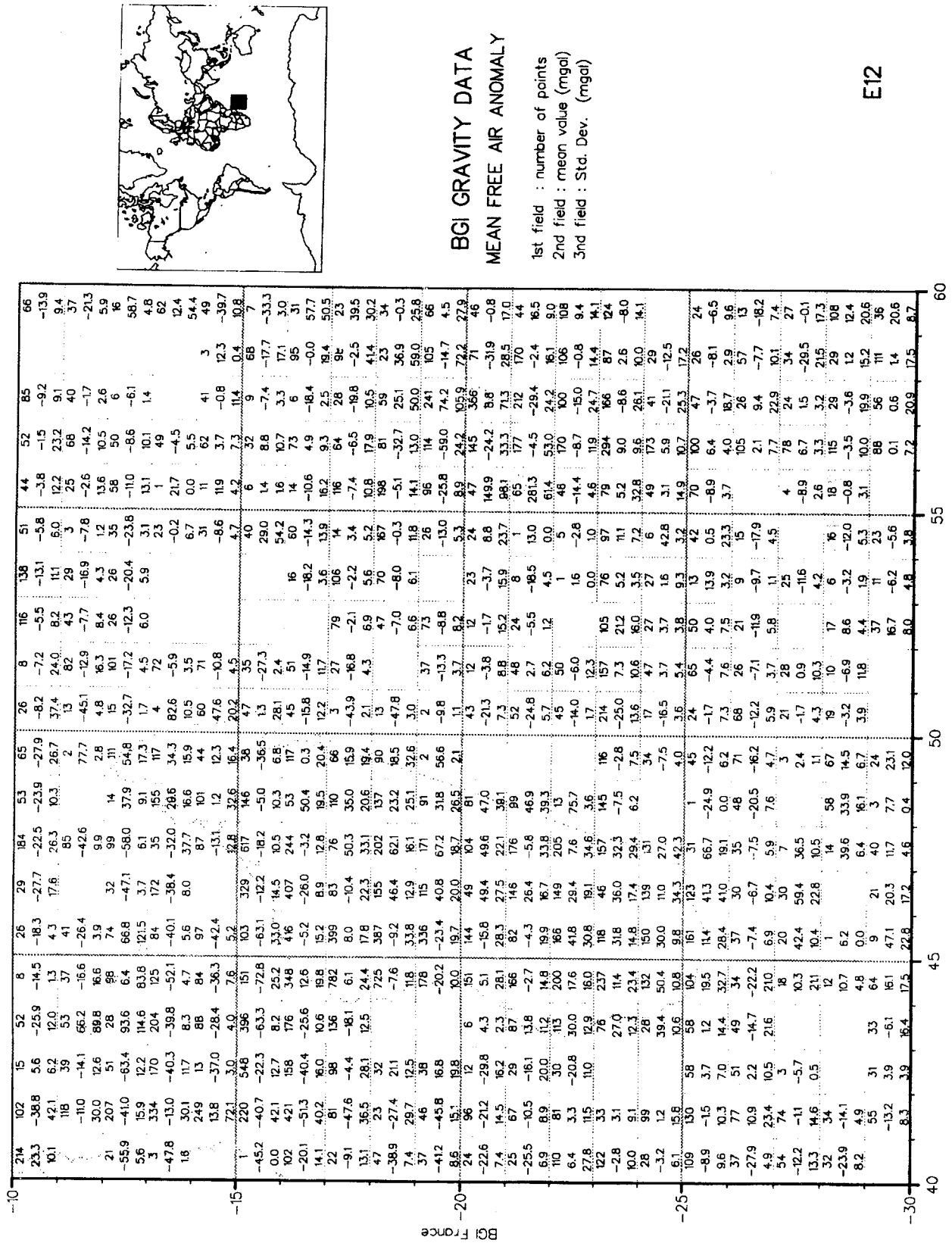


Fig. 3. Example of detailed index (Data coverage corresponding to Fig. 2)



In addition, efforts were permanently exerted in trying to get data from the Eastern (then ex-Eastern) countries prior to and then following the important geopolitical changes of the early 90's. In most cases, gridded values of free-air gravity and topography were obtained such as in Poland (5' x 5'), Hungary (5' x 7.5'), Rumania (5' x 5').

As it was pointed out many times, and especially on the occasion of international meetings (e.g. Balmino, 1983), some countries still do not provide any gravity data to BGI. Whether this is due to military regulations or a policy which intends to protect some national economic interests, we feel that it does much harm to these countries which, in turn, cannot pretend receiving data from the bureau or from similar organisations, and with which scientists will be discouraged to cooperate in the long run.

In 1993, the former Soviet Union released to BGI a set of 1° x 1° averaged values of free-air anomalies (and topographic heights) ; a paper was published in EOS (Makedonskii et al., 1994). China did the same in 1995 (J.Y. Chen and G. Balmino, 1996). Later both Russia and China provided higher resolution grids of gravity values in the context of privately sponsored projects, but these grids are not yet in the public domain (cf. Chapter 6).

Airborne gravity starts to be collected. BGI received the first set of gridded and downward – continued values of free air anomalies over Greenland in 1996 (R. Forsberg, private communication). Then, the airborne gravity data collected by E. Klingelé from ETH (Zurich) were transferred to BGI in late 1996 and have been analysed. A new format is under preparation for archiving this type of measurement. Presently, a simple format, taylored to the ETH data file, is used. Another data set is expected in the near future, which will consist of the airborne measurements over the entire French Alps (one of the Geo-France 3-D campaigns).

Catalogues of coverage per 20 x 20 degrees area and statistics per degree square (number of points, mean value, standard deviation) have been regularly issued every two years but their production and publication will be discontinued in the future for reasons already given in section 3.3.

As of to-day the BGI data base contains about 12.7 million non classified points (2.2 millions over land, and 10.5 millions over the oceans).

Figure 4 shows the data distribution, including the areas for which grid values are available (as the only piece of information sometimes, e.g. over most of Siberia, China). Other data, subject to restriction clauses for distribution, are not shown. Table 1 summarizes all gridded value sets (free-air, Bouguer, isostatic anomalies ; geoid heights, digital terrain models) which were deposited at BGI as open files and which can be retrieved from the server.

#### **4.3. Data Validation**

A great deal of effort have been directed at validating data for several years.

Firstly, several land data validation software were intercompared (on the occasion of a dedicated workshop in 1989) some of them developed by BGI - such as SYSTEVAL and DIVA/VERSET (Toustou et al., 1989), others having been provided by working group members or associates. From 1990 onward, the in-house software has been used to validate all BGI land data on a one by one source basis (example on fig. 5) ; inter-source comparisons software (adjustments using overlapping parts) was then developed. In 1994 was undertaken the conversion of DIVA/VERSET on a Sun-Sparc 2 workstation using the SUNPHIGS library. Finally, in 1997, important modifications took place and the software was converted under JAVA so as to allow future portability and easier upgrading.

In parallel, plans were made to install similar software for the validation of marine data especially to solve for cross-over minimisation parameters. A program (SEAGRA) for performing this task, was received from H.G. Wenzel. It was installed, upgraded ; in particular, the decomposition of each cruise into legs was implemented in an automatic mode in late 1991. A complete tool in its first version became quickly

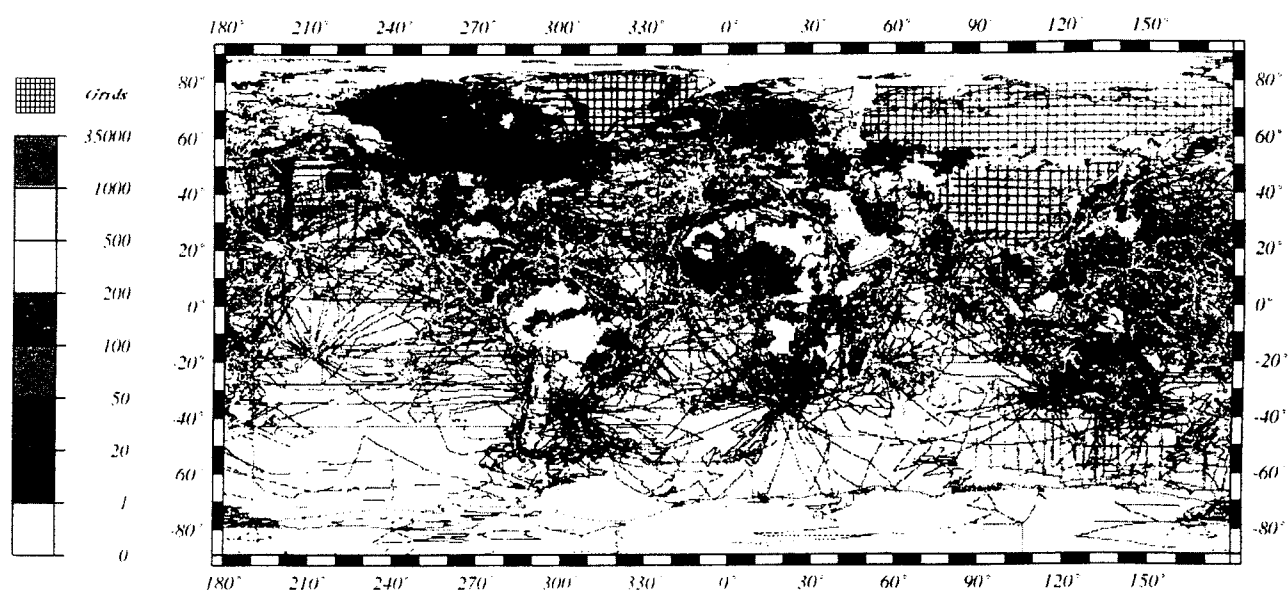


Fig. 4. Distribution of data in the BGI database

Table 1. Gridded value sets deposited at BGI

Area	Grids available on BGI server	
	Type	Resolution
Ex-USSR	Free-air, Isostat. Anom., Topo	1° x 1°
CHINA	Free-air, Bouguer, Geoïd	1° x 1° et 0.5° x 0.5°
GREENLAND	Free-air	1° x 1° et 0.5° x 0.5°
Ex-CZESCHOSLOVAKIA	Free-air, Bouguer, Topo, Topo Corr.	7.5' x 5'
HUNGARY	Free-air, Topo	7.5' x 5'
NETHERLANDS	Free-air, Topo	5' x 3'
POLAND	Free-air, Free-air rms, Topo	5' x 5'
ROMANIA	Bouguer, Topo	7.5' x 5'
Southern Baltic Sea	Free-air	1' x 1'
All oceans derived from altimetry (Hwang)	Free-air	2' x 2'
All oceans derived from altimetry (Sandwell)	Free-air	2' x 2'
Polar zones derived from altimetry (BGI)	Free-air	5' x 5'
Global (NIMA-GSFC-OSU)	Free-air (surf. mes. + altim.)	30' x 30'
Mean Sea Surface (CLS)	Geoïd + ocean circul. (Geosat, ERS1/2, T/P)	3.75' x 3.75'

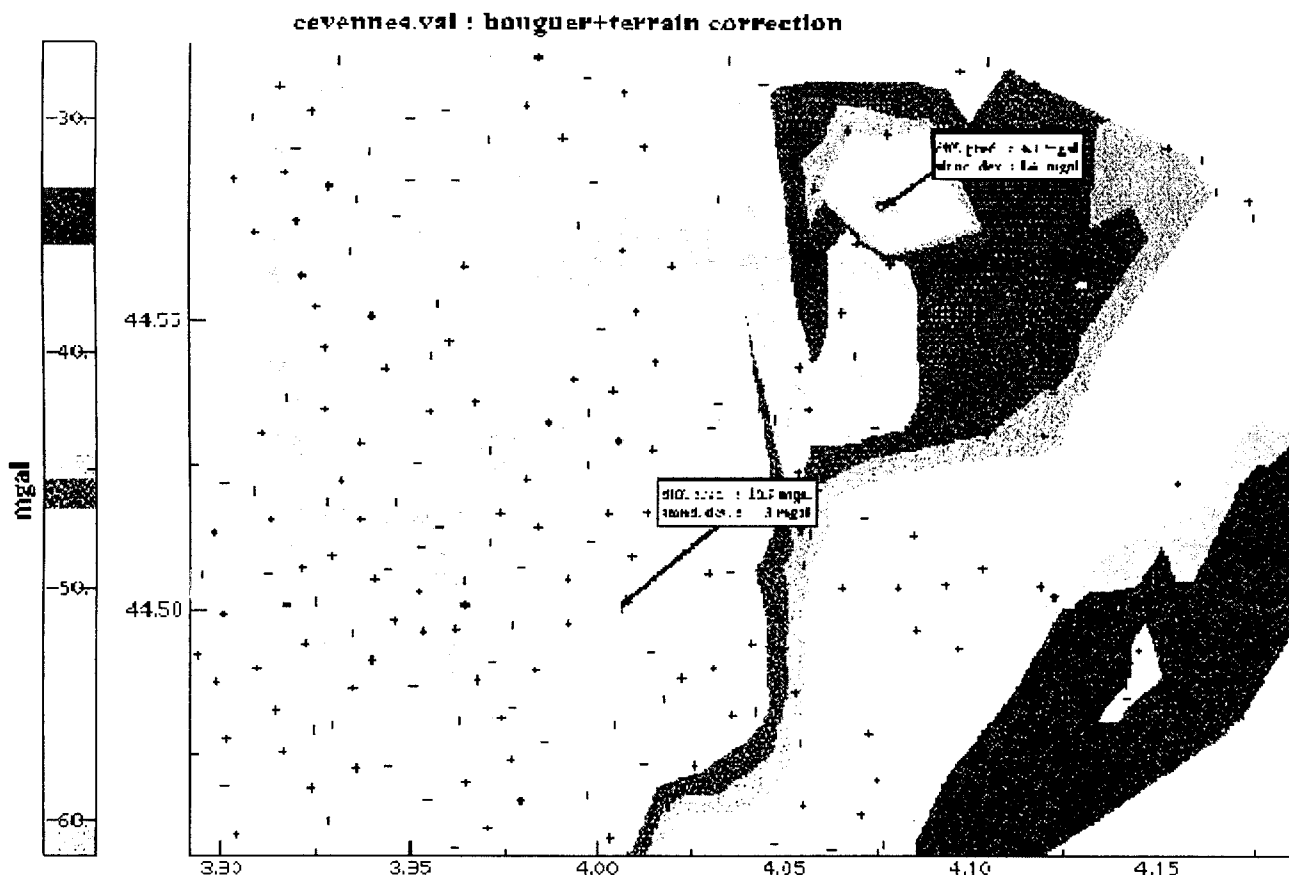


Fig. 5. Bouguer anomaly map with two measurement predicted "doubtful"

available and was presented at another workshop organised on these topics (Oct. 1992). The software was several times upgraded and extensively used in the context of a thesis (Adjaout, 1996) by which BGI acquired expertise in this area of gravimetry (Adjaout et al., 1997).

The SEAVVALID software, an interactive graphic tool enabling the fast editing of marine data by simultaneously looking at the measurement, the Eötvös correction, the bathymetry and the ship navigation, was also developed in this time period and is currently used in preprocessing marine data. No global inter-cruise validation has been performed (by looking at and minimizing the cross-over differences), only regional ones over a few specific areas (e.g. Adjaout and Sarrailh, 1997). It is easier and faster to adjust most marine data on the free air gravity field derived from satellite altimetry data, the cross-over adjustments being limited to specific cases. Software has been under development in 1997 and 1998 for performing the adjustment of sea measurements (by cruise, or by leg – according to some criteria) with respect to the satellite altimetry derived field (after adequate filtering of ship data), and it is now close to operational status.

The final product of a validation session is the set of data with erroneous measurements being flagged, and maps of free-air and/or Bouguer anomalies (such as on fig. 6).

#### 4.4. The BGI data on CD-Rom

Following the advises of the Directing Board in October 1992, the project of producing a CD-Rom with all BGI non confidential data was studied and undertaken. The main characteristics of such a product were defined. Software was developed in view of being provided with the data base. A first version with land data only and a poster paper presented an experimental product to the inter-commission assembly of IGeS and ICG in Sept. 1994 (Graz, Austria). Some selected users were asked to test the product.

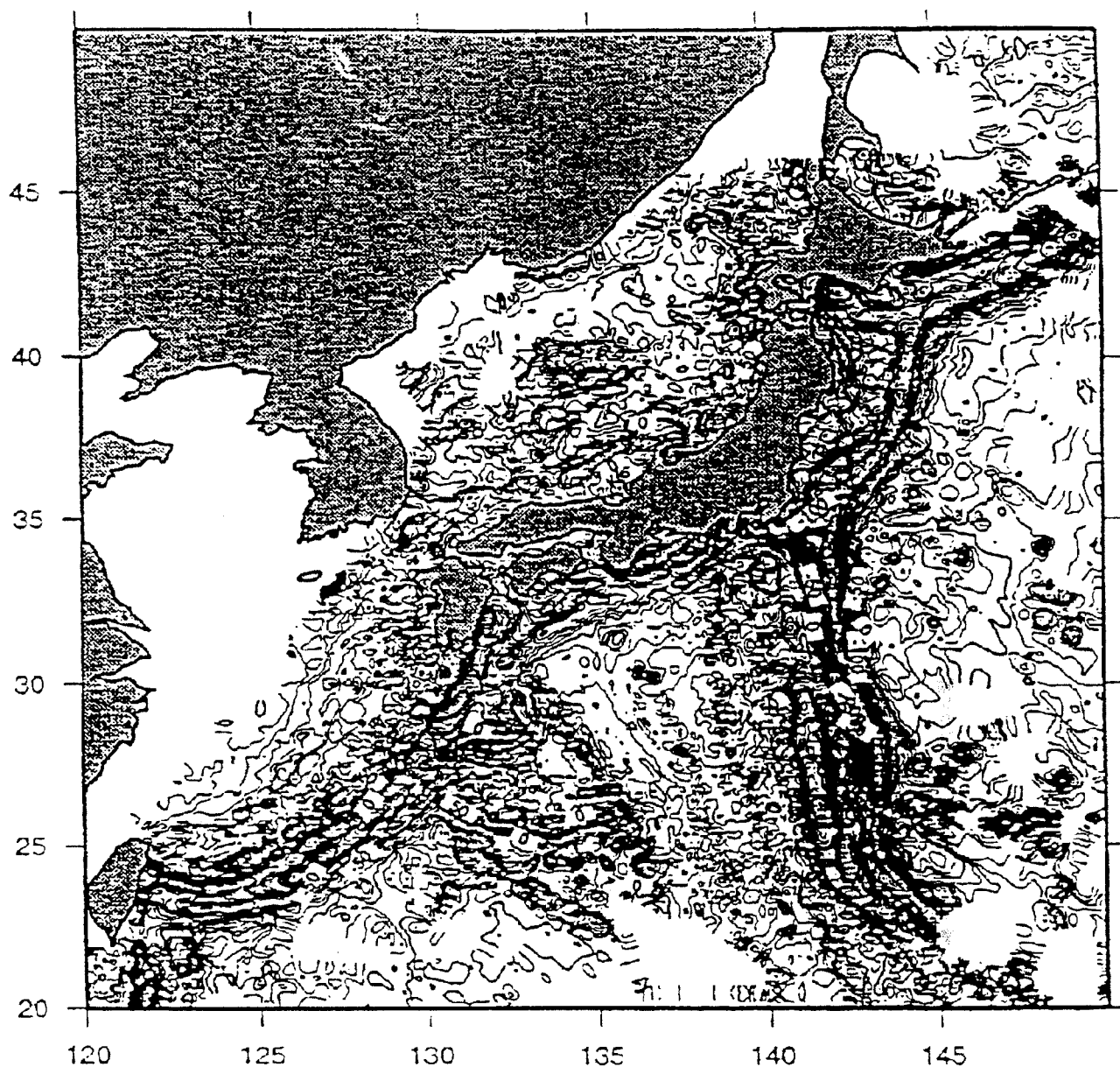


Fig. 6. Example of 5' x 5' free-air anomaly map (10 mgal contour), from ship measurements

The distribution of open file data in this form is now fully operational. The current version comes in two CDs (one with land data and miscellaneous files, sources, countries, pointers,... ; and one with marine data), the software is distributed on diskette. It allows an easy access to the data by type (land/sea), by source, by country, by geographic area or by combination of several of these criteria. It operates on any Unix workstation. A PC version (which had a very vicious bug which could not be removed) has been replaced by a JAVA version which should be 100 % portable (tests are still being made as we write this report).

The facilities of the French Space Agency computing center in Toulouse are used to press the CDs. BGI however continues to distribute gravity data over specific areas on request (but up to the capacity of one high density diskette in compressed format).

#### 4.5. Other data files

- Absolute stations and measurements :  
The data transferred from WG2 to BGI in 1996 have been homogenized, edited and put on the BGI server, except some sets which need further analysis and additional information.
- Other reference stations :  
The status of IGSN 71\* reference gravity stations has been a problem. A situation was established in 1989-1990, with the help of some sub-commissions of IGC. About 1200 stations (out of 1850) still existed at that time, the others having been destroyed (generally when reconstructing buildings ...). The other reference stations (e.g. the ACIC\* file) are updated from time to time. Their description sketches are on microfiches and numerical values (code number, site co-ordinates, g-value, microfiche number) are in a computer file (like for the IGSN71 network) ; there are about 9000 reference stations (1220 in IGSN71\*, 5200 in ACIC, 320 in WHOI\*, 800 in LAGSN77\*, 1500 in various national networks).  
In the last years, BGI undertook the digitization of the reference station schemes and description. After some positive tests in 1997, the systematic work began in 1998. The schemes consist of diagrams or/and picture or/and description. As of to-day IGSN71, LAGSN77 and ACIC station schemes have all been put on the server. It remains to include schemes for some national networks. It should be completed in late 1999.
- Maps :  
BGI also archives gravity maps of various types and scales, from different origins. A map file and a catalogue (print-out and computer form) exist, which contain references of ~ 3100 maps. Software to extract information from the file exist. Nowadays, only a few new maps are added each year.
- Bibliography  
Compiling bibliographical references of all publications received at the Bureau and dealing with gravimetry or closely related subjects has been an historical task. The digitisation of these references started with the current material in 1980 when the office was moved from Paris to Toulouse.  
The digitization of the old bibliography (prior to 1980) was undertaken in 1990. This was a huge work which was performed by the BGI secretary, with an additional temporary help. It was completed in 1991. The corresponding data base is resident on the main frame (where resides the gravity base), and is managed by means of the ORACLE software, too.  
Compilation continues and references (about 8500 as of today) regularly accumulate. They have been completed by references of all articles published in the Bulletin d'Information since the beginning. A file is available on diskette. It is planned to put the reference file on the W3 server.

#### 4.6. Requests

The Bureau has satisfied over two thousand requests for data (of any type) since 1982 - when we start counting them, with sharp increases in 1986 and 1991 (fig. 7). This activity presently employs one person more than half-time.

### 5. SPECIAL PROJECTS OR EVENTS

We give below an account of important works which BGI did in parallel to its service duties at the request of some organisations or individuals, also of some marking events which took place during the last two decades.

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\* IGSN : International Gravity Standardization Net 1971, ACIC : Aeronautical Chart and Information Center  
WHOI : Woods Hole Oceanographic Institution, LAGSN77 : Latin American Gravity Standardization Net 1977



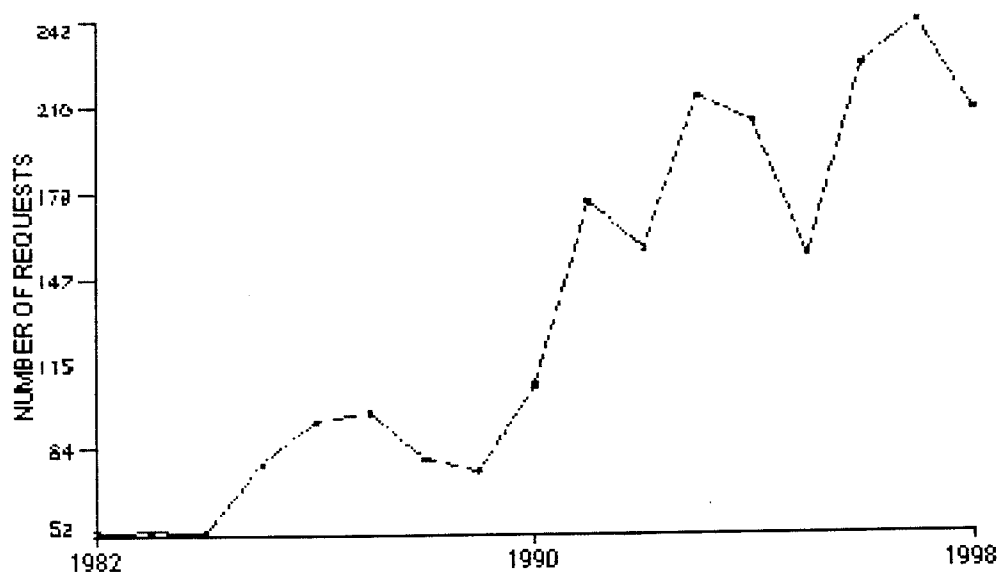


Fig. 7. Number of requests to BGI per year since 1982

### 5.1. Contributions to Gravity Maps

- 10° x 10° maps (A0 format) displaying marine gravity data, cruises location and gravity values themselves were made at BGI for the following areas :

- . North Atlantic Ocean (in 1984).

- . Whole Pacific Ocean (in 1985).

This important work was done at the request of late Professor Boulanger, from the Soviet Geophysical Committee (Boulanger chaired WG3 at that time) to complete their Geological-Geophysical Atlas (finally published with the help of UNESCO in 1992). Subsequent interpretation work was performed in cooperation with Russian scientists (Kogan et al., 1985).

- Gravity Maps over the Mediterranean Area :

At the request of the UNESCO/IBCM project, conducted by the International Oceanographic Commission, BGI compiled a first series of 10 maps of Bouguer Gravity anomalies (scale 1:1 000 000) from existing measurements plus additional values which were gridded from maps, and a second series which is mostly based on the maps by Morelli. Maps were all of A0 size.

A 3' x 5' grid was produced as an intermediate product.

- 5' x 5' Gravity Map of the World :

The Bureau and WG1 members (at the Geological Survey of Canada, GSC) prepared a 5' x 5' gravity map of the whole world. BGI produced the part of the basic grid over land areas (Bouguer anomalies) while GSC prepared the oceanic part (free air). It was published in 1991.

### 5.2. Use of Satellite Altimetry

Satellite altimetry derived geoid heights have been used on several occasions in various research activities in co-operation with several groups in the BGI supporting French agencies.

- A combined Geos 3 and Seasat altimetric geoid (derived from an adjusted mean sea surface and a model of the mean ocean circulation) was especially produced and used to derive a quasi-global oceanic set of 15' x 15' free-air gravity anomalies by the inverse-Stokes operator method (Balmino et al., 1987).
- Combinations of satellite derived data with measured gravity were also done over the North-Algerian Marge, the Aegeen trench, and around the Reunion Island. Deviations of the vertical were also computed from these data.
- Simultaneous use of GEOSAT, ERS1 and TOPEX POSEIDON altimetry derived geoid heights to compute mean gravity anomalies in the North Atlantic, North Sea, and in parts of the Pacific and Indian Oceans in the context of large regional projects (cf. Chapter 6). Algorithms and software realizing this

method suitable for global validation of the marine data at BGI (cf. 4.3.).

- Arctic and peri-Antarctic gravity field : a special effort was made in 1996 for deriving suitable « pseudo-geoid » height data over sea-ice from the raw measurements (coming every 1/20.th of a second) of the ERS1 35-day and 168-day repeat missions.

High resolution gravity field grids have been derived which are, as expected, more noisy than over open ocean areas. A paper was presented at the Gra-Geo-Mar-96 symposium and gave interim results. The final grids were obtained early 1997 and published in the symposium proceedings (Sarrailh et al., 1997). They were merged in 1999 with a new global grid of gravity values obtained by inverting (at BGI) a detailed 3.75' x 3.75' mean sea surface derived from the ensemble of GEOSAT, ERS1 (oceanographic and geodetic cycles), and TOPEX-POSEIDON missions (Fig. 8).

### **5.3. Geoid Computations**

At the time the International Service for the Geoid did not exist, a number of requests were made to BGI to help in the computation of the geoid over limited areas (Balmino, 1986 b). These determinations were made using the classical Stokes integral (regularised at origin and with respect to a high degree spherical harmonic model of the geopotential), sometimes also by the collocation method (Balmino, 1982 and 1986 c). For example :

- the geoid over and around Madagascar was computed from a combination of gravity and Seasat altimetry data, and from a 180 x 180 spherical harmonics reference field (Rakotoary, 1986).
- the gravimetric geoid over the straight of Gibraltar and over most Morocco was determined in the context of the fixed link project and at the request of the Morocco government (Balmino et al., 1989). Geoid heights were in good agreement (20 to 45 cm) with satellite Doppler and survey derived quantities at control points.
- in the framework of a geophysical project supported by ICSU, BGI computed a gravimetric geoid over Jordania, based on a 360 x 360 reference field provided by the Ohio State University and on gravity measurements specifically available for the project.
- a 3' x 5' gravimetric geoid over France has been in preparation for many years. The project involves about 400 000 gravity measurements over France (provided by BRGM) and about 100 000 in neighbouring countries and oceanic areas. After an attempt (Deloménie, 1987) which showed some defects in the methodology (no terrain corrections had been applied) but also in the data (there were still large gaps and data were poorly validated), the activity was frozen for some time due to manpower constraints and other priorities. It started again in 1992 (Balma et al., 1992) with a complete analysis of the various stages and of the operational questions (including existing software) and continued in collaboration with IGN, which resulted in a Ph.D. dissertation (Jiang, 1996) and several papers (e.g. Duquenne et al., 1995). This work has been pursued by Duquenne at ESGT (with the GRAVSOF software provided by our Danish colleagues) and very good results have been recently obtained (Duquenne, 1998).

### **5.4. Participation in the ICL/CC5 Activities**

The Co-ordinating Committee Number 5 of the International Committee for the Lithosphere asked for the help of BGI to compile an index of all centers archiving gravity, topographic, magnetic, seismic, and other data. This was achieved in 1988 and resulted in a catalogue published by CC5.

The Director of the Bureau represented the International Gravity Commission on CC5 from 1985 to 1995.

*Free-Air Gravity Anomalies from CLS-SHOM Mean Sea Surface  
and ERS1 Altimetric Data over Ice (BGI and GRGS, 1999)*



Fig. 8. BGI 3.75' x 3.75' gravity anomaly grid over the oceans (1999)

## **5.5. Participation in RGIA**

The Bureau contributed to the activities in the project : "Réseau Géodésique Intégré sur l'Afrique" (Integrated Geodetic Network in Africa), in which the establishment of new gravity networks, the making of absolute measurements, and questions of data densification were discussed (1989 to 1994).

## **5.6. Activities Related to Digital Terrain Models**

- Digitisation of the worldwide bathymetry :

BGI was engaged in the digitisation of the GEBCO 5th Edition Bathymetric Charts between 1982 and 1991, with the help of the GEBCO Sub-Committee on Digital Bathymetry, the Canadian Hydrographic Service and the Institut Géographique National.

The main steps involved in such a work were :

- (a) automatic numerization of the contours (by a scanner) - performed at IGN, France.
- (b) interactive correction of the digitised level curves.
- (c) constitution of a data base for future updating of the GEBCO maps.
- (d) computation of analytical terrain models and production of grid values.

Step (b) was the BGI responsibility and was by far the most difficult and demanding in manpower and software. It was completely reanalyzed in 1984 after it was discovered that the previously developed package was very incomplete and inadequate. A new and quite sophisticated software was then developed and proved to be very efficient operationally.

Five maps were digitised (5-13, 5-14, 5-15, 5-16, 5-18) in 1986 and 1987. One person was assigned in 1987 by IGN to work full time on it. BGI completed the Northern Europe sheet (5-01) in 1987, the North Atlantic (5-04), Central Atlantic (5-08), and North Polar sheet (5-17) in 1988. The course of this effort was interrupted in 1989 for priority reasons and restarted in October 1990. Then the two sheets for the North and Central Indian oceans (5-05 and 5-09) were produced in 1991. The contribution of the Bureau and IGN to the project therefore consists in eleven files (out of eighteen) and terminated in 1992. There remains the software which could be used for other similar applications (Toustou, 1985).

- A new DTM project :

The International Geoid Service (IGeS) and BGI need a data base of DTMs for a variety of uses, but obviously with major applications in geodesy and geophysics.

A project to undertake the activity jointly was envisaged but was not put to realization due to manpower limitations. Meanwhile a limited DTM base around the Western Mediterranean, in relationship with other projects over this area, was set up.

BGI has still in mind to carry on such endeavour which would consist in :

- . collecting existing (gridded) DTMs, probably with variable resolution.
- . creating DTMs from the BGI gravity data base (height information).
- . comparing these two types of DTMs.
- . providing the best possible grids over limited areas.

### **5.7. The release of 1° x 1° gravity data by Russia**

In 1993, a catalog of 1° x 1° averaged free-air gravity anomalies over the whole former Soviet Union (FSU) was placed at BGI as an open file (named MGK93 catalog) by the International Scientific Environmental Center of the Russian Academy of Sciences. A protocol of usage of these data was established and a paper describing the file appeared in EOS (Makedonskii et al., 1994). A subsequent paper discussing the tectonic and lithospheric strength of northern Eurasia, and based on this data set, was published in 1995 (Kogan et al.).

### **5.8. The release of 1° x 1° gravity data by China**

The National Bureau of Surveying and Mapping (Beijing, China) released files of 1° x 1° averaged free-air, Bouguer anomalies and geoid heights, to BGI in March 1995. These data have been evaluated (compared to actual global gravity field models) and have been reported in the Bulletin d'Information (Balmino et al., 1996).

## **6. PARTICIPATION OF BGI IN SPECIAL REGIONAL GRAVITY PROJECTS**

Some of the BGI activities reported above were very much triggered by the advent of large regional gravity projects undertaken in the U.K. with private support. The participation of BGI in these programs extended from 1986 to 1995. It is thanks to them and to the additional financial support which come to BGI that some new investigations were conducted, new software developed and interesting scientific results obtained.

### **6.1. African Gravity Project (AGP)**

This first project was formulated in 1985 by geophysicists D. Fairhead of the University of Leeds (U.K.) and A. Watts of Lamont Doherty Geological Observatory. The goal was the compilation of all available private and public domain gravity data for Africa to derive a map of the gravity field of the African continent and its continental margins. The project was managed by the University of Leeds Industrial Services (ULIS) and sponsored by 16 oil companies. The Bureau participated in 1986-87 by bringing its data base over that region. It is now also responsible for the archival of all the AGP data and received in addition the files of the produced grid values of free-air, Bouguer anomalies and elevations at 5' resolution both in longitude and latitude, for internal use in validating future acquisitions of data from Africa. Maps are being sold by GETECH (see 6.3.) since early 1991 and the grids are in the public domain in 1998.

### **6.2. South American Gravity Project (SAGP)**

BGI was involved with the same group at the Leeds University in their South American gravity compilation project on the same basis as the African project in 1985-88. In addition, BGI brought its expertise and validated the initial data set (about 70 000 gravity observations) over this continent. The project terminated in June 1991, but final products were produced later, in the course of 1992 : 5' x 5' of free air and Bouguer anomalies, and of topography ; atlas of maps. BGI is a depository of these products which are used internally, but are not freely available - except over local areas in the context of special studies or for lower resolution data sets (e.g. 30' x 30' obtained by the Ohio State University).

### **6.3. Gravity Projects in Asia and Europe (SEAGP, WEEGP)**

D. Fairhead transformed his group at the Leeds University into GETECH (Geophysical Exploration TECHnology) while making new plans in 1991 for projects similar to the previous ones, in South-East Asia (SEAGP) and in Europe, including the ex-Eastern countries and ex-USSR, up to Ural (WEEGP). BGI was also involved in these activities. Both projects started in mid 1991. Of special interest was WEEGP since it tried in some way to combine the efforts with those of the Sub-Commission for the Geoid in Europe (of the International Commission for the Geoid). Great emphasis was put on WEEGP due to the new situation in this part of the world ; specifically, Russia provided gridded data at the resolution of 4 km x 4 km.

SEAGP faced insuperable problems with India : Indian authorities did not disclose any recent gravity data. China made available to the project 15' x 15', then 5' x 5' gridded free-air anomalies.

In both projects, BGI task has been : (i) to validate extensive sets of land data ; (ii) derive free-air gravity anomalies from satellite altimetry measurements (cf. 5.2.).

#### **6.4. North and Central Asia Gravity Project (NCAGP)**

This is the last large project, of the kind of the others, to which BGI participated in 1994-95 in the continuation of its cooperation with GETECH.

The role of BGI was especially to study methods and derive algorithms and software for recovering gravity anomalies from satellite altimetry data over sea ice over the Arctic region. The ERS1 raw data (at 1/20 sec. sampling) were used, which was a very heavy work and very demanding in computer time. The work terminated at the end of 1995.

This is from there that BGI undertook a similar activity around the Antarctic, and also completed the computations over the remaining part of the Arctic (not covered in NCAGP) – see also section 5.2. Results were published later (Sarrailh et al., 1997). As an example, Fig. 9 shows the gravity anomaly field in the Canadian Arctic derived in this manner.

### **7. THE BGI SERVER**

#### **7.1. The Static page on W3**

In 1996, BGI established a home page on WWW. Collection and selection of ad'hoc material, design work, formatting of all information, were performed by BGI personal. Static information only were available and could be found at :

<http://www.obs-mip.fr/uggi/bgi.html>

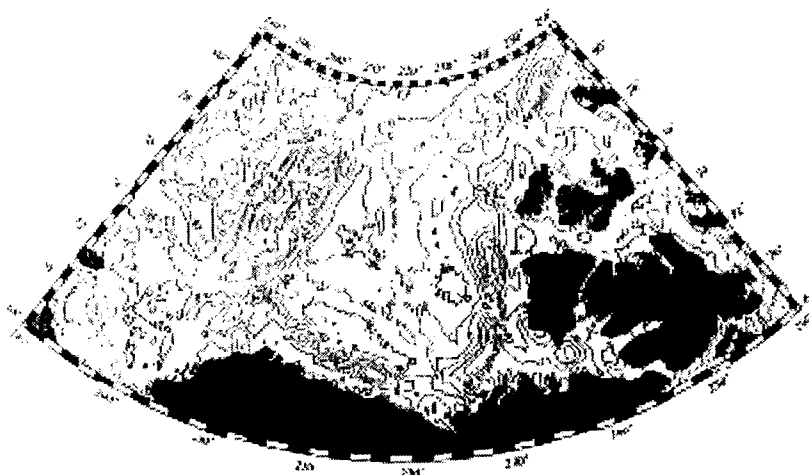
(it was, and is still, resident on the server « obs-mip.fr » of OMP)

#### **7.2. The Server**

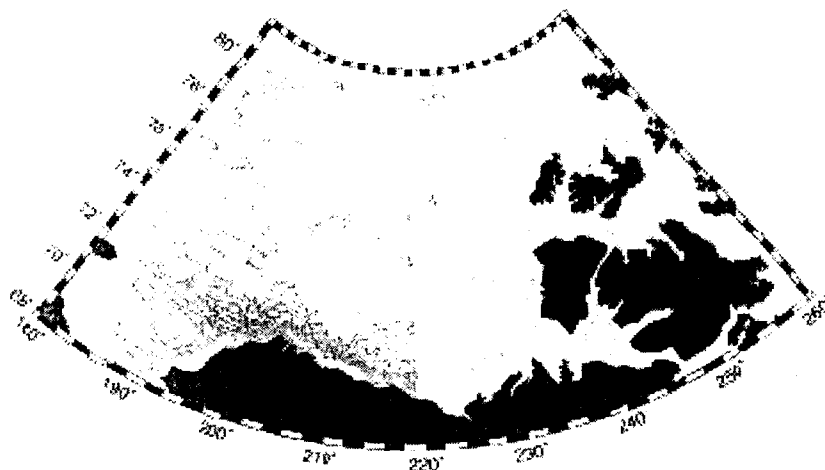
Studies started, in early 1996, of a server which would allow direct consultation of open file data in the base and dialogues with BGI (e.g. by semi-automatic e-mailing). Operations took time due to security rules at the computer center in Toulouse with which the system had naturally to comply. The architecture design (Fig. 10), analysis of interfaces with the data base, software writing, implementation and testing were performed by BGI and additional experienced CNES personal. The server opened in July 1997. The URL is :

<http://bgi.cnes.fr:8110/>

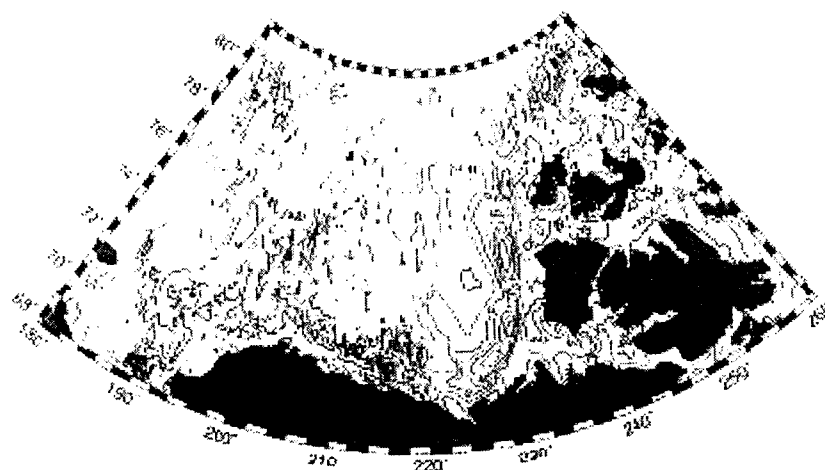
The users can visualize the coverage of open file gravity data by type : land, marine, reference stations, grids ; by country ; by geographic area ; by any combination of these. They can also ask for data retrieving, but they cannot do it themselves yet (this capability is one of the mid-term plans).



**Fig. 9a**



**Fig. 9b**



**Fig. 9c**

- Fig. 9 a) Free air anomaly map from WAP altimetric data. (Contour interval : 20 milligals)  
 b) Coverage of the surface gravity measurements over Canadian Arctic Ocean  
 c) Free air anomaly map from surface gravity measurements. (Contour interval : 20 milligals)

# WWW server

<http://bgi.cnes.fr:8110/>

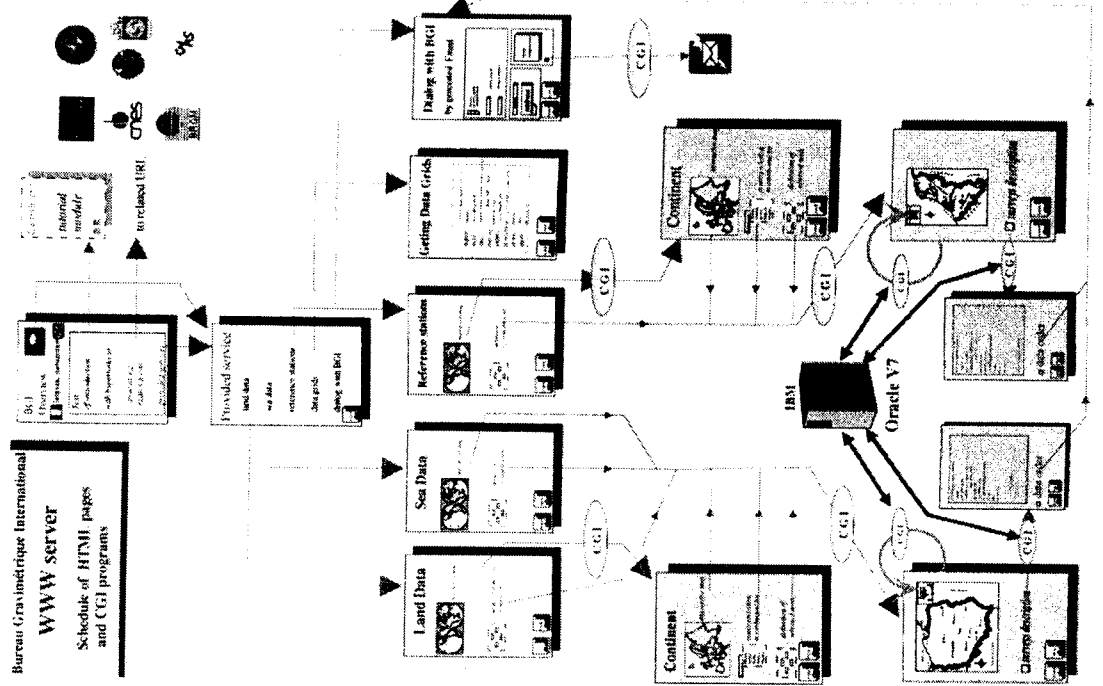
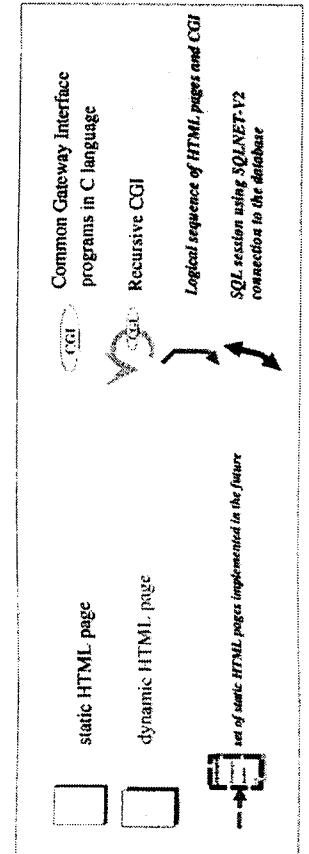
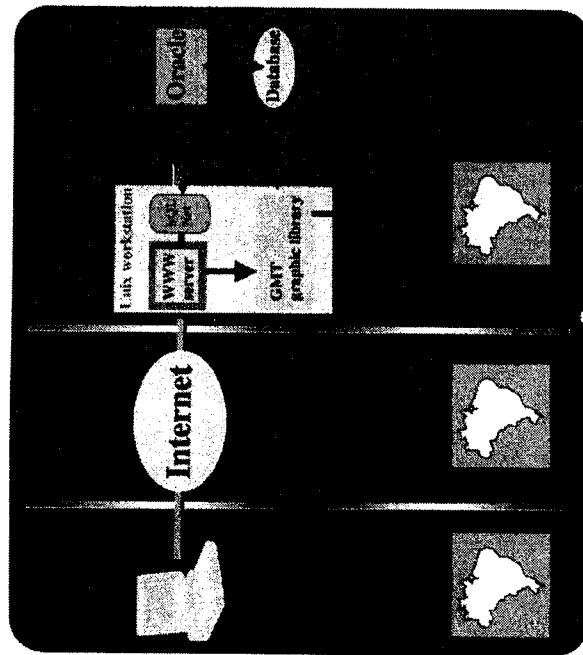


Figure 10



## 8. MEETINGS

One of BGI's role is obviously to foster all programs aimed at improving our knowledge of the geopotential (Balmino, 1988, 1989 ; Balmino et al., 1995).

Besides organising or co-organising the meetings of IGC, which take place every four years (1986 and 1990 in Toulouse, France ; 1994 in Graz, Austria ; 1998 in Trieste, Italy - these two times jointly with the International Commission for the Geoid), BGI tries to be present on the world geodetical and geophysical scene : IUGG and IAG general assemblies, symposia and workshops. It is not our intention to list them all here ; restricting ourselves to the recent years and to the most specialized meetings, let us quote the following :

- European Geoid Workshop (Prague, May 1992), with one paper.
- WEEGP-SEAGP Workshop (Toulouse, Oct. 1992), with four papers.
- Workshop on Marine Gravity Data validation (Toulouse, Oct. 1992) with 3 technical papers by BGI staff, including a report on a test case distributed for comparison to participants (proceedings appeared in Bulletin d'Information n°71).
- WEEGP final meeting (Leeds, April 1994) with two papers and one poster
- SEAGP final meeting (Houston, Aug. 1994) with one paper
- GraGeoMar Symposium (Tokyo, Oct. 1996) with one paper and one poster
- Special session « IAG Services », IAG Scientific Assembly (Rio de Janeiro, 1997) with one paper and poster
- Western Pacific Geophysical Conference (Taiwan, July 1998) with one paper and poster
- Geospectra (Dusseldorf, June 1999) with two posters (in a stand shared with the IERS and IGS).

## 9. EDUCATIONAL ACTIVITIES

As part of the educational efforts of IAG, BGI undertook the realization of tutorials which can be accessed via the server. On the date of this report, the following exist or are in preparation :

T1 : Gravitation, Gravimetry, Satellite Geodesy and Geophysics (In French, English summary ; G. Balmino)

T2 : The Earth's Gravity Field and Geoid. Principles, Present and Prospects (in French, English summary ; G. Balmino)

T3 : Modern Concepts, Concerns and Satellite Projects in the Determination and Use of the Earth's Gravity Field (in English, French summary ; G. Balmino, R. Sabadini, C.C. Tscherning, P. Woodworth)

T4 : Direct Measurements of the Earth's Gravity Field : Gravimetry (in French, English summary ; M. Sarrailh, G. Balmino)

T5 : Geodetic Satellite Orbits in the Earth's Gravity Field (in English, French summary ; G. Balmino)

T6 : Manual of Practical Gravimetry (in French, English summary ; E. Hurtebis) – in preparation

T7 : Errors in Marine Gravity Measurements (in French, English summary ; M.F. Lequentrec-Lalancette).

Besides, and in the framework of the relationships of some of its staff members with other French research groups and Universities, BGI has been training students every year in the following areas : data validation procedures, computational methods (determination of gravity, geoid, etc... from spherical harmonic models;

numerical works with the integral equations of physical geodesy) ; interpretation of gravity data (inverse problems, linear programming techniques...) ; use of satellite altimetry measurements ; contribution of surface data to global gravity field models ; graphics.

## 10. FUTURE ACTIVITIES

Continuation of data collection, archiving and service activities.

Emphasis on :

- validation of marine data by means of satellite altimetry derived gravity field.
- archival of absolute measurements.
- archival of airborne gravity measurements.
- CD-ROM regular updates, and distribution.
- Expansion of the server capabilities.
- Increase the number of tutorials (and translate all of them into French or English, as appropriate).
- Digital Terrain Models collection and archiving.

## 11. THE BGI STAFF

The permanent staff of the Bureau is composed of the following, as of July 1, 1999 :

G. Balmino	Director, CNES	: part time
N. Lestieu	Secretary, CNRS	: part time
G. Balma	Technician, IGN	: full time
M. Sarrailh	Engineer, CNES	: full time
D. Toustou	Analyst & Surveyor, IGN	: full time

... plus part time contribution from M. Barriot, Secretary (CNRS) to the IUGG Secretary General.

## 12. DIRECTING BOARD

The membership of the BGI Directing Board, as of July 1, 1999 is the following

Voting Members :	I. Marson	(Italy)	IGC President
	G. Boedecker	(Germany)	IGC Vice-Prt + Chairman WG2
	J. Makinen	(Finland)	IGC Vice-President
	G. Balmino	(France)	BGI Director
	R. Forsberg	(Denmark)	Section III President
	J.E. Faller	(USA)	elected
	E. Groten	(FRG)	elected
	P.P. Medvedev	(Russia)	elected
	S. Takemoto	(Japan)	elected

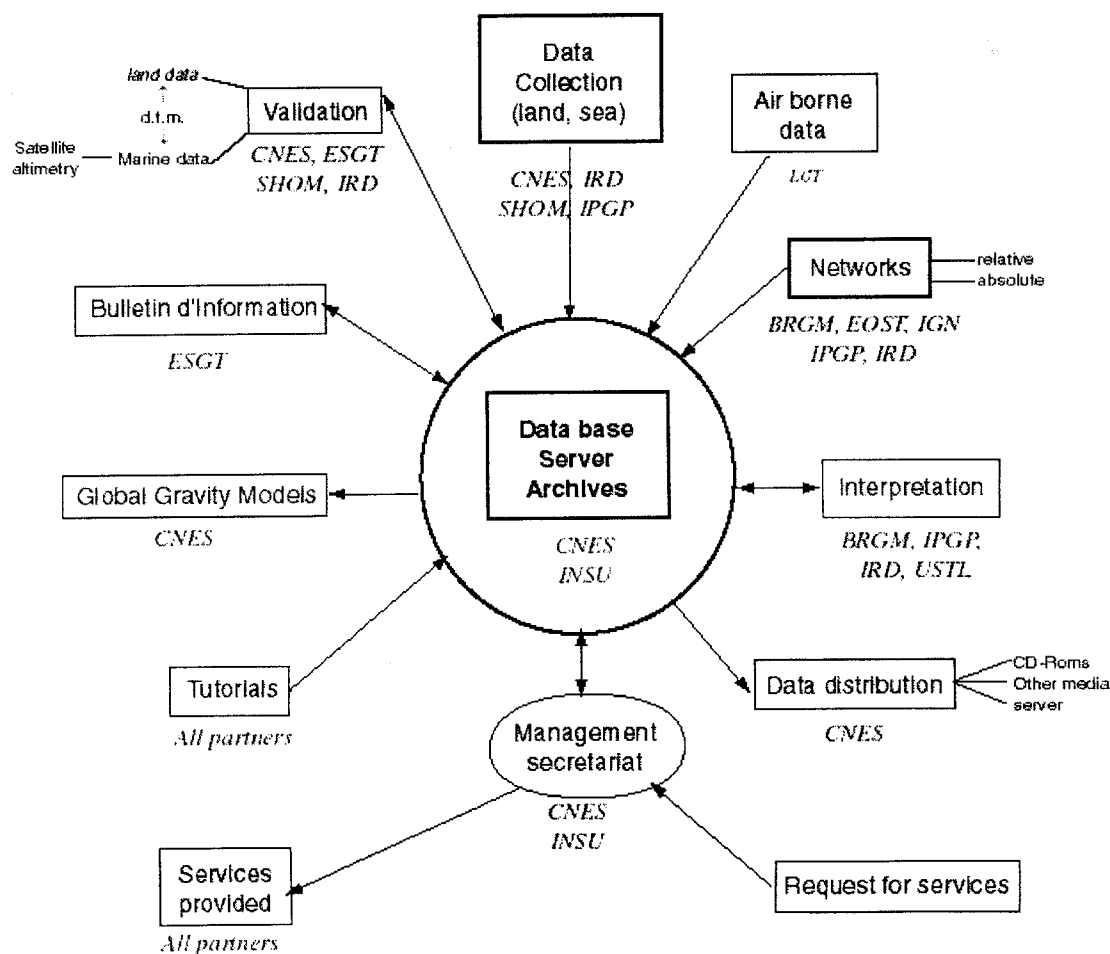
Non-voting Members :	L. Robertsson	(France)	WG6 Chairman
	B. Richter	(Germany)	WG7 Chairman
	M. Becker	(Germany)	WG8 Chairman
	N. Courtier	(Canada)	Secretary
	E. Klingelé	(Switzerland)	Secretary
Ex-Officio Members :	H. Sünkel	(Austria)	Geoid Com., Prdt.
	F. Sanso	(Italy)	IGeS Director
	P. Paquet	(Belgium)	FAGS Repres.

### 13. BGI IN FRANCE AFTER YEAR 2000

The present Director has served for five periods (in IUGG terminology), that is twenty years and had to be succeeded.

IGC issued in 1997 a call for proposal for taking over the BGI activities. Only one proposal, sent by the French National Committee for Geodesy and Geophysics in the summer of 1998, was made to continue operating BGI in France, with a different and enlarged structure involving ten partners instead of four-since 1979 (these four are part of the new structure). The diagram below (Fig. 11) shows the new organisation and distribution of responsibilities between the partners

Fig. 11. Functional diagram of the French proposal



The future Director of BGI, to be formally confirmed at the 22<sup>nd</sup> General Assembly of IUGG which will take place in Birmingham, UK (July 18-30, 1999) will be Dr. Jean-Pierre BARRIOT (from the Space Center and GRGS group in Toulouse). While taking over the directorship, the new structure will be formed and ought to be operational (with a formal covenant binding the partners over a four year cycle-renewable) on January 1, 2000.

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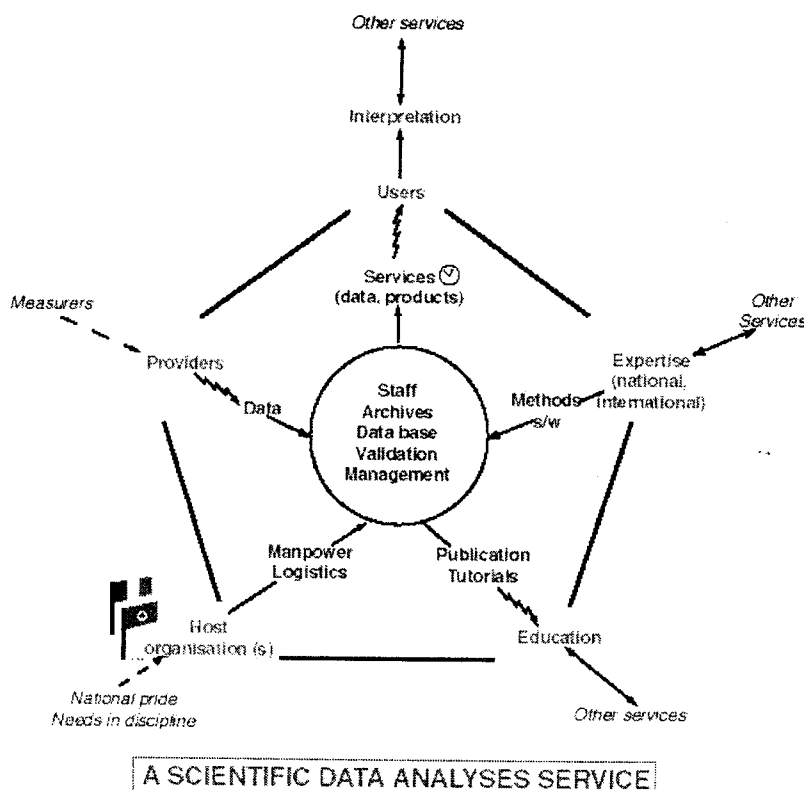
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## POSTSCRIPT

*On the eve of terminating a twenty year mandate at the head of BGI, I would like to give my thoughts on this service - some of which may apply to similar ones (see fig. below).*



*In two decades, the challenge has changed from the difficulty of setting up, maintaining and securing a data base, to making it user friendly, reachable by a growing number of persons and with much shorter response time. Users have also become more demanding on the amount of information, on the quality of the data and their presentation, and on the services which may come with their distribution.*

*In the BGI case, the size of the data base is no longer a problem, the validation of measurements is still a concern. Some applications, such as centimeter geoid computations with high resolution, require higher and higher accuracy of the data which makes their validation more and more difficult. Ultimately, one has to perform sophisticated transformations, up to refined interpretation, to assess the actual quality of a data set. This is most often very rewarding to scientifically oriented minds but it should not, by the time and energy it requests, overshadow the main duties of the service.*

*Keeping the balance has been difficult : Science is part of BGI - it is the incentive to people who work for it, but the pressure of the users should be dealt with first. That is why the proposal which is presented aims at bringing more energy and additional means so as to run the service in a smoother and better way, although not in a simpler context. We are still at the dawn of a revolution in computers and information transfer technology and my successor will need this rejuvenated BGI to challenge this.*

*This is not intended to sound like my swan-song ; only a strong desire to witness new accomplishments under a new leadership.*

*In leaving the stage, I would finally like to thank heartily my colleagues at BGI for their dedicated work and friendliness : Nicole Lestieu, our enthusiastic and efficient secretary ; Gilles Balma with whom almost all BGI users have been in contact ; Michel Sarrailh and Denis Toustou without whom the data base, the server and all the software would not exist.*

*I am happy to pass the fame to my successor. I wish him all the best and long life to BGI !*

G. B.  
July 1, 1999

*Acta est fabula*



**PART III**

**CONTRIBUTING PAPERS**



# RESULTS OF RELATIVE GRAVIMETER MEASUREMENTS AT THE ICAG97 INTERCOMPARISON

M. Becker, G. Berrino, A.G. Camacho, R. Falk, O. Francis, C. Gagnon,  
C. Gerstenecker, J. Liard, G. Läufer, B. Meurers, F.-J. Navarro, I. Nowak, F. Rehren,  
U. Riccardi, B. Richter, M. van Ruymbeke, K. Schmidt, M. Schnüll, D. Stizza,  
J.E. Friederich, P. Vauterin, H. Wilmes

## ABSTRACT

In Sèvres the fifth International Absolute Gravimeter Intercomparison was conducted in November 1997. In order to support the absolute measurements, the BGI Working Group 8: "Relative Networks at Absolute Gravimeter Comparison ICAG97" conducted a relative gravimeter campaign as well. Twelve LaCoste and Romberg and one Scintrex gravimeters measured the connections between absolute points and vertical gravity gradients at each point. In addition the calibration baseline installed in 1994 was re-measured as well to check or provide calibration factors for all gravimeters. The results show that the accuracy for single instruments is in the range of 3 to 8  $\mu\text{Gal}$ <sup>1</sup> for a gravity difference, for both the Scintrex and the LaCoste gravimeters. The campaign was also used to intercompare different ways of calibrating the gravimeter electrostatic feedback systems. The calibration platform of BKG, Frankfurt, was installed in Sèvres and the results can be compared to that of the calibration line. This paper gives results for the 1997 campaign.

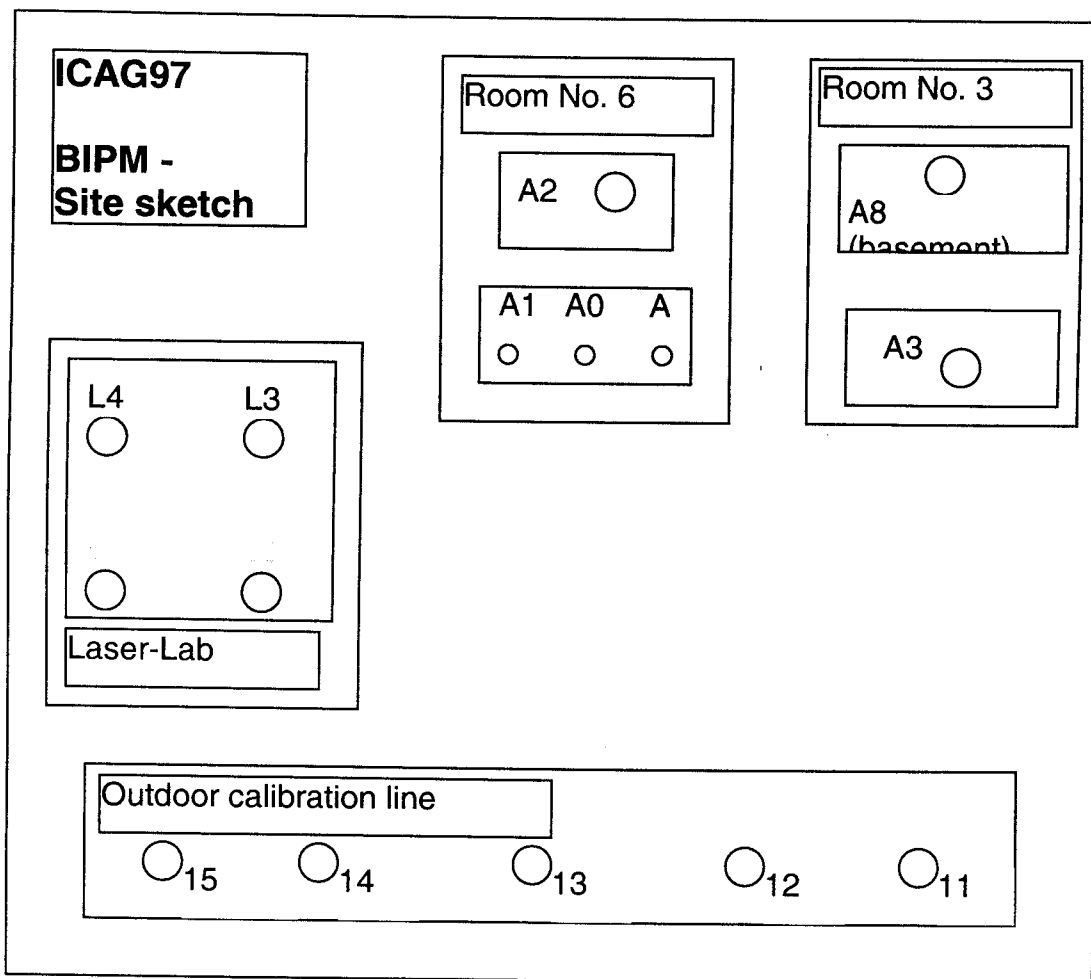
## INTRODUCTION

Since 1981, campaigns for the intercomparison of absolute gravimeters (ICAG) have been organized in Paris-Sèvres at the Bureau International des Poids et Mesures (BIPM). In support, working group 8 of the Bureau Gravimétrique International (BGI) entitled "Relative Networks at Absolute Gravimeter Comparison" was formed to conduct relative measurements for the determination of gravity differences and vertical gravity gradients between and above the pillars occupied by absolute gravimeters. These activities follow those of the former special study groups on relative gravimetry by the International Association of Geodesy and are well documented in publications, see (Becker and Groten, 1983, Boulanger et al, 1983, Becker 1985, Becker et al. 1989, Boulanger et al, 1986, Becker et al. 1995). Generally a joint workshop is held to discuss the latest developments in instrumental design and gravimetry in general.

The 1997 intercomparison ICAG97 had quite a large number of participating groups with 7 FG5, 4 JILAG and 4 other type of gravimeters (Robertsson et al, in press). The observation strategy for the absolute instruments was changed so as to have each absolute instrument on the same two pillars in order to determine instrumental biases and also to be independent of ties measured by relative gravimeters to a certain extent. So, contrary to the previous comparisons, the absolute instruments did not observe in parallel, but sequentially. The change of strategy was thought to be necessary because of the increased accuracy and precision of the absolute instruments. However, due to time limitations, this could not be realized strictly and also points A3, A8 and L4 were used by some groups.

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<sup>1</sup>For convenience the unit  $1 \mu\text{gal} = 1 \cdot 10^{-8} \text{ m/s}^2$  is used.



**Fig. 1.** Sites used for relative gravimetry in ICAG97.

The set of points chosen for relative measurements and given in the next section in detail was selected to include some points used in ICAG94 and also the outside calibration line in order to allow comparisons to previous campaigns. In order to generate data for further investigations of the calibration of relative gravimeters with feedback systems the calibration platform of BKG (Richter et al, 1995) was again installed at BIPM with some improvements as compared to 1994. The complete list of observations recorded on the platform is given in the appendix. The data is not used in this evaluation, but is available for interested people and further studies.

In addition to the relative measurements at ICAG97, O. Francis (Francis, 1998, pers. comm.) made available data of a Scintrex CG-3M microGal gravimeter S265 gathered in 1997 at BIPM. This turned out to enable the connection to some of the additional points, but on the other hand caused some problems in the combination with the LaCoste & Romberg instruments as the reference height of all levels of observation was different and no common height level was used. This led to rather large height reductions for the Scintrex and is the main reason why results for this gravimeter are given separately at its reference heights in addition to the combined adjustment where it was used as well.

## THE GRAVITY NET

The majority of the relative gravimeters measured on sites 9008 (Sèvres A, not to be confused with A0 used in 1994 and labeled 108 in this paper), 9208 (A2), 9308 (A3), 949608 (L3), 949708 (L4) and the outside calibration line stations, see Fig. 1. The ties between the absolute sites were measured at a height of 0.9 m corresponding to the average value of the reference height for some absolute gravimeter measurements. Additional points were measured by the Scintrex S265 of ROB (Francis, pers. comm.).

In addition, the vertical gravity gradient, which is known to be non-linear inside the BIPM buildings, was measured between the heights of 0.05m, 0.9m and 1.3m (the latter being the reference height of the FG5 instruments). Table A1 in the appendix gives a list of instruments used.

Observations were made separately for the network ties, the gradients at each point and the calibration line. The height of the gravity sensor was brought close to the reference heights given above. However, the Scintrex CG-3M has quite a different sensor height, which is normally about 0.26 m above the floor. Therefore both network and gradient measurements had to be reduced to the reference height in an iterative procedure using the newly determined gradients at each point, the height reduction being up to 50  $\mu\text{Gal}$ . So a separate single adjustment for the Scintrex CG-3M was made using reference heights near the sensor heights during the measurements (0.26 m, 0.66 m and 1.56 m). These results give additional information about the local gravity field (Table 7).

	<i>Owner-apriori</i>		<i>ICAG97</i>		
Gravimeter	Linear	Quadratic	Linear	msd	Remarks
D028F	1.21511	-	1.21314	$\pm 0.0018$	not used
D038F	-1.24440	-0.0007240	-1.18074	$\pm 0.0033$	
G115F	-1.06947	-	-1.06049	$\pm 0.0014$	
G258F	-1.04176	-0.0033000	-	-	not significant
S265F	1.00000	-	0.99825	$\pm 0.0005$	not used
G298F	1.07527	-0.0005697	-	-	fixed
G402F	-0.01509	-	-	-	not significant
G487F	-2.93590	-	-	-	not significant
G625F	1.08248	0.0224484	1.08100	$\pm 0.0003$	not used
G665F	1.01673	-	-	-	not significant
G709F	1.00793	-0.0003807	-	-	not significant

**Table 1.** Calibration factors of the feedback systems applied before the final combined adjustment.

Point	Gravimeter	298	28	38	115	258	265	402	487	625	665	709	62	737
No.	Name													
1	A0						13							
108	A0						3							
120	A0						3							
9000	A	6	6	7	6	6	25	5		6	3	6	6	2
9008	A	6	6	7	6	6	6	6		6	3	6	6	3
9012	A	3	3	3	3	3	6	3		2	3	2	3	
9100	A1						11							
9108	A1						3							
9112	A1						3							
9200	A2	6	6	6	6	6	11	6		3	3	5	6	2
9208	A2	7	6	6	6	6	3	6		5	3	5	6	
9212	A2	3	3	3	3	3	3	3			3	3	3	2
9300	A3	6	6	6	5	6	11	3		7		6	6	2
9308	A3	6	6	6	6	6	3	3		7	6	3	6	
9312	A3	3	3	3	3	3	3	3		3		3	3	3
9800	A8						10							
9808	A8						3							
9812	A8						3							
949600	L3	6	3	7	6	6	20		3	6	3	5	6	5
9496 8	L3	6	3	6	6	6	6			6	3	2	6	3
949612	L3	3	3	4	3	3	6		2	2	3	3	3	3
949700	L4	6	3	3		4	14			7	3	6	6	5
949708	L4	6	3	6	3	5	3			6	6	6	6	3
949712	L4	3	3			4	3			4	3	3	3	3
948011	cal. line	3	3	3	3	3	4			3	6	3	3	
948012	cal. line	3	3		2		3			3		3	3	
948013	cal. line	3	3	3	2	3	3			4		3	3	
948014	cal. line	3	2	3	2	3	3			3	2	2	3	
948015	cal. line	3	3	3	3	3	3			3	4	3	3	

**Table 2.** Observations from all gravimeters at each point.

## ADJUSTMENT RESULTS FOR ICAG97

The basic ideas and methods of observations and data analysis are described in (Becker et al., 1995). Tidal corrections were applied using the observed factors as determined by the ROB from recordings in Sèvres. Height corrections were applied as described above so that all values refer to the reference heights.

For the determination of a uniform scale value a line observed by G298F of IFE was calibrated on the Hannover - Harz calibration line (Kanngieser et.al, 1983) after the campaign (Schmidt, pers. comm., 1998). The factor of this instrument was kept fixed in the adjustment and for all other instruments corrections to the factors given by the owners for their feedbacks were determined. Only the linear term was adjusted, the quadratic term was not changed. As can be seen in Tab. 1 for some gravimeters significant improvements could be achieved. For some other instruments there

were indications of changes, however, due to the small gravity range covered and the formal errors they were considered to be non-significant and henceforth not used.

The adjustment was made based on the weights determined for single instruments and it can be clearly seen from Tab. 3, that there is a large variation in instrumental precision among the gravimeters. The errors of the adjusted gravity values are in the order of 2 to 9  $\mu\text{Gal}$ . This is somewhat inferior compared to the results of ICAG 94 and led to a wide range of weights.

<b>Gravimeter</b>	<b>Obs.(Raw)</b>	<b>Obs.(Adjust.)</b>	<b>msd</b>	<b>msd(dg)</b>	<b>msd(obs)</b>	<b>DoF</b>	<b>Weight</b>
D028F	77	77	$\pm 8.6$	$\pm 10.8$	$\pm 5.7$	43	0.1
D038F	85	85	$\pm 9.4$	$\pm 13.7$	$\pm 6.7$	47	0.1
D062	90	90	$\pm 2.2$	$\pm 3.1$	$\pm 1.5$	48	not used
G115F	74	74	$\pm 4.6$	$\pm 5.0$	$\pm 2.6$	50	0.5
G258F	85	85	$\pm 6.0$	$\pm 9.0$	$\pm 4.1$	46	0.3
S265F	191	191	$\pm 3.3$	$\pm 3.9$	$\pm 1.9$	134	0.9
G298F	91	91	$\pm 3.0$	$\pm 4.3$	$\pm 2.1$	48	1.1
G402F	73	38	$\pm 6.2$	$\pm 8.7$	$\pm 4.4$	19	0.3
G487F	33	5	$\pm 2.4$	$\pm 2.4$	$\pm 2.2$	2	1.7
G625F	86	86	$\pm 3.3$	$\pm 3.6$	$\pm 1.9$	57	0.9
G665F	57	57	$\pm 6.4$	$\pm 6.7$	$\pm 3.4$	41	0.2
G709F	84	78	$\pm 5.8$	$\pm 9.6$	$\pm 4.3$	34	0.3
G737	92	52	$\pm 4.7$	$\pm 7.4$	$\pm 3.6$	22	not used
<b>Combined</b>		<b>867</b>	<b><math>\pm 2.6</math></b>	<b><math>\pm 2.1</math></b>	<b><math>\pm 1.4</math></b>	<b>647</b>	<b>-</b>

**Table 3.** Statistics of single instrument adjustment, ICAG97 and weights for combined adjustment.

The final results can be taken from Tab. 3 and Tab.4. Formal error are in the order of 1-3  $\mu\text{Gal}$  for the adjusted gravity differences. About 900 readings were adjusted. The non-feedback instruments were not included to the combined adjustment because no information on periodic error corrections was available. Again it must be noted that the overall precision is worse than in ICAG94. As mentioned before, the Scintrex S265 is adjusted separately in addition and the results are given in Tab. 5. They refer to the approximate sensor heights of the Scintrex at each point and each height level as given in the table.

## VERTICAL GRAVITY GRADIENTS

Vertical gradients can be obtained by using the gravity differences at the three different heights. Tab. 6 and 7 show the values computed by use of the results of the combined adjustment and by the Scintrex only adjustment.

Besides the well known fact that the gradient is considerably different at the different sites, a more or less systematic increase of the vertical gradient with increasing height could be determined. Up to now, function was fitted to the gradients, although a quadratic curve fit may be used for modeling. Vertical gradients converted to  $\mu\text{Gal/m}$  are obtained with an accuracy of 1 to 3  $\mu\text{Gal/m}$  for the intervals from 5 to 90 and from 5 to 130 cm height, and with 2 to 5  $\mu\text{Gal/m}$  for the interval

between 90 and 130 cm. The nonlinearities in the gradient are also obvious when comparing the results of the Scintrex measured over different height-intervals to those of the combined adjustment.

<b>Point</b>	<b>Height in cm</b>	<b>Gravity values in <math>\mu\text{Gal}</math></b>	<b>Mean square deviation (msd) in <math>\mu\text{Gal}</math></b>
1	5	26017.0	$\pm 1.5$
108	90	25737.6	$\pm 2.5$
120	130	25616.2	$\pm 2.5$
9000	5	26000.8	$\pm 0.9$
9008	90	25734.4	$\pm 0.9$
9012	130	25615.0	$\pm 1.2$
9100	5	25991.3	$\pm 1.5$
9108	90	25727.4	$\pm 2.5$
9112	130	25612.1	$\pm 2.6$
9200	5	26006.9	$\pm 0.9$
9208	90	25743.3	fixed
9212	130	25625.2	$\pm 1.3$
9300	5	25924.4	$\pm 1.0$
9308	90	25676.9	$\pm 0.9$
9312	130	25562.4	$\pm 1.4$
949600	5	26884.2	$\pm 1.1$
949608	90	26651.1	$\pm 1.0$
949612	130	26542.8	$\pm 1.3$
949700	5	26902.0	$\pm 1.2$
949708	90	26669.3	$\pm 1.0$
949712	130	26559.1	$\pm 1.5$
9800	5	26556.4	$\pm 2.1$
9808	90	26342.1	$\pm 2.9$
9812	130	26244.3	$\pm 2.9$
948011	5	26390.8	$\pm 1.1$
948012	5	21491.2	$\pm 1.7$
948013	5	27279.7	fixed
948014	5	28258.6	$\pm 1.2$
948015	5	29503.5	$\pm 1.3$

**Table 4.** Results of combined adjustment, ICAG97, 11 gravimeters, scale of G298 fixed.



<b>Point</b>	<b>Height in cm</b>	<b>Gravity values in <math>\mu\text{Gal}</math></b>	<b>Mean square deviation in <math>\mu\text{Gal}</math></b>
1	26	25123.5	$\pm 2.5$
108	66	24997.2	$\pm 3.2$
120	156	24725.8	$\pm 3.2$
9000	26	25122.6	$\pm 2.6$
9008	66	24996.8	$\pm 3.0$
9012	156	24725.8	$\pm 3.0$
9100	26	25113.5	$\pm 2.6$
9108	66	24987.8	$\pm 3.3$
9112	156	24718.3	$\pm 3.3$
9200	26	25126.9	$\pm 2.0$
9208	66	25000.0	fixed
9212	156	24731.7	$\pm 2.3$
9300	26	25050.8	$\pm 2.6$
9308	66	24932.8	$\pm 3.3$
9312	156	24677.5	$\pm 3.3$
949600	26	26013.1	$\pm 3.1$
949608	66	25901.8	$\pm 3.4$
949612	156	25655.4	$\pm 3.4$
949700	26	26031.5	$\pm 3.1$
949708	66	25923.2	$\pm 3.7$
949712	156	25672.5	$\pm 3.7$
9800	26	25691.9	$\pm 3.2$
9808	66	25590.4	$\pm 3.8$
9812	156	25368.5	$\pm 3.8$
948011	26	26383.4	$\pm 3.1$
948012	26	21486.5	$\pm 3.3$
948013	26	27279.7	fixed
948014	26	28258.4	$\pm 3.3$
948015	26	29511.5	$\pm 3.3$

**Table 5.** Results Scintrex SC-3M 265 with reference heights near the sensor.

<i>Point</i>	<i>Gravity Difference (μGal)</i>		<i>Gravity Difference (μGal)</i>		<i>Vertical Gradient (μGal/m)</i>		
	<i>dg(0.05-0.90)</i>	<i>msd</i>	<i>dg(0.05-1.30)</i>	<i>msd</i>	<i>0.05 to 0.9</i>	<i>0.05 to 1.3</i>	<i>0.9 to 1.3</i>
1	279.5	±2.0	400.9	±2.1	328.8	320.7	303.5
9000	266.4	±0.8	385.8	±0.9	313.4	308.7	298.6
9100	263.9	±2.0	379.1	±2.1	310.5	303.3	288.1
9200	263.6	±0.9	381.7	±1.1	310.1	305.4	295.3
9300	247.4	±0.9	361.9	±1.3	291.1	289.5	286.2
949600	233.0	±0.8	341.4	±0.9	274.2	273.1	270.9
949700	232.6	±1.0	342.8	±1.1	273.7	274.3	275.5
9800	214.2	±2.0	312.0	±2.1	252.0	249.6	244.4

**Table 6.** Vertical gravity differences and gradients of combined adjustment.

<i>Point</i>	<i>Gravity Difference (μGal)</i>		<i>Vertical Gradient (μGal/m)</i>		
	<i>dg(0.26-0.66)</i>	<i>dg(0.26-1.56)</i>	<i>0.26 to 0.66</i>	<i>0.26 to 1.56</i>	<i>0.66 to 1.56</i>
1	126.3	397.7	315.7	305.9	301.6
9000	125.8	396.8	314.5	305.2	301.1
9100	125.7	395.2	314.3	304.0	299.4
9200	126.9	395.2	317.3	304.0	298.1
9300	118.0	373.3	295.0	287.2	283.7
949600	111.3	357.7	278.2	275.2	273.8
949700	108.3	359.0	270.8	276.2	278.6
9800	101.5	323.4	253.8	248.8	246.6

**Table 7.** Vertical gravity differences and gradients of single adjustment of gravimeter Scintrex-CG3M (265) using reference heights near the position of the sensor.

## COMPARISON TO RESULTS OF EARLIER RELATIVE MEASUREMENTS.

ICAG 94 and ICAG97 results are compared in Tab. 8. Gravity differences at the sites A0 (108) and A (9008) can not be directly compared, the difference was measured only by the Scintrex in 1997 and is therefore determined only very weakly. On the primary points of the network, the differences are in the order of 1 μGal at each height level and within the error limits of the adjustment. In the connection over the 1 mGal difference to the Laser-Lab, there seems to be a real change of about 4 to 8 μGal. The results of ICAG97 agree better with the differences determined by absolute instruments between Laser-Lab and point A. This seems to indicate a possible error in the ICAG 94 results for this difference.

The outdoor calibration line was not maintained or monumented in any way, so that larger discrepancies to 1994 occur. They are not related to a scale problem and probably due to point identification and height reference identification at some sites. Furthermore, real gravity changes may occur in the sites situated in the slopes of the hill where BIPM is located.

The gradient comparison gives quite an ambiguous picture. At some sites, like A2, A3, A8 and L3, the gradient seems to be stable. At others, like L4 and especially A0, there are large differences with respect to 1994 results. At A0, there is certainly a problem in the usage of the Scintrex data and this has to be investigated further. The gradients determined in ICAG94 for A0 and the ones determined in ICAG97 at A are rather close and fit better than those of A0 in '94 and '97. At L4, the difference occurs at the level of 90 cm and it is not clear what happened here.

## CONCLUSIONS

Gravity differences and vertical gravity gradients could be determined with a formal accuracy of about 2  $\mu\text{Gal}$  during ICAG97 and are listed for further reference in Table 4.

Further comparisons with the results of the absolute measurements and the investigation of the larger discrepancies to 1994 have to be initiated in order to understand the errors and uncertainties in the relative measurements. The increased accuracy of absolute instruments may ask for a much

<i>Point</i>	<i>ICAG 1997</i>	<i>ICAG 1994</i>	<i>1997-1994</i>	<i>Remarks</i>
1	26017.0	26003.1	13.9	only Scintrex
108	25737.6	25739.3	-1.7	only Scintrex
130	25616.2	25621.5	-5.3	only Scintrex
9200	26006.9	26005.0	1.9	
9208	25743.3	25743.3	0.0	fixed
9212	25625.2	25623.9	1.3	
9300	25924.4	25926.3	-1.9	
9308	25676.9	25677.1	-0.2	
9312	25562.4	25563.3	-0.9	
949600	26884.2	26888.9	-4.7	
949608	26651.1	26656.8	-5.7	
949612	26542.8	26547.1	-4.3	
949700	26902.0	26910.5	-8.5	
949708	26669.3	26673.9	-4.6	
949712	26559.1	26564.7	-5.6	
9800	26556.4	26555.5	0.8	only Scintrex
9808	26342.1	26340.4	1.7	only Scintrex
9812	26244.3	26243.5	0.8	only Scintrex
948011	26390.8	26393.0	-2.2	
948012	21491.2	21505.6	-14.4	
948013	27279.7	27279.7	0.0	fixed
948014	28258.6	28267.9	-9.3	
948015	29503.5	29517.5	-14.0	

**Table 8.** Comparison to ICAG 94 (all values in  $\mu\text{Gal}$ ).

<i>Year</i>	<i>dg/dh</i>	<i>msd</i>	<i>Source</i>
1977	273	$\pm 3.0$	Cannizzo et. al. ,1978
1980	273	$\pm 7.0$	Sakuma
1981	284	$\pm 1.6$	ICAG 81(exz.)
1981	294	$\pm 2.5$	ICAG 81 (red.)
1984	275	$\pm 1.9$	Ogier, 1986
1985	295	$\pm 1.2$	ICAG 85
1985	296	$\pm 4.6$	Ogier, 1986
1986	295	$\pm 1.2$	Röder and Wenzel, 1986
1989	297	$\pm 0.7$	ICAG 89
1994	293	$\pm 1.5$	ICAG 94
1997	291	$\pm 1.0$	ICAG 97

**Table 9** Change in vertical gravity gradient at A3 in time, all values in  $\mu\text{Gal}/\text{m}$ .

stronger effort in the relative campaigns. The concept of assembling an as large as possible number of gravimeters in order to minimize systematic errors may have to be replaced by a strategy to select a few, very well performing and very well calibrated instruments in order to get the utmost precision. Then a more comprehensive network measurement with observations at more than 3 height levels and possibly horizontal gradients at the pillars would be required to determine the complicated and nonlinear local gravity field at the BIPM to a sub-microGal level. Then relative ties will still be of value to absolute gravity determinations in future comparisons.

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