ASSOCIATION INTERNATIONALE DE GEODESIE

BUREAU
GRAVIMETRIQUE
INTERNATIONAL

BULLETIN D'INFORMATION

N° 66

Juin 1990

18, Avenue Edouard Belin
31055 TOULOUSE CEDEX
FRANCE

INFORMATIONS FOR CONTRIBUTORS

Contributors should follow as closely as possible the rules below :

Manuscripts should be typed (double-spaced) in Prestige-Elite characters (IBM-type), 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).

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.

Table of contents. Long papers may include a table of contents following the abstract.

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. All characters that are available on standard typewriters should be typed in equations as well as test. 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 0 and zero, the letter l and the number one, kappa and k, mu and the letter u, nu and v, eta and n, also subscripts and superscripts should be clearly noted and easily distinguished. Unusual symbols should be avoided.

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

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 Unpublished communications can be referred to in text but should not be listed.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

Tables. 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.

Address :

BUREAU GRAVIMETRIQUE INTERNATIONAL

18, Avenue Edouard Belin

31055 TOULOUSE CEDEX

FRANCE

Phone :

(33) 61.33.28.89
(33) 61.33.29.80

Telex :

530776 F OBSTLSE

or

7400298

Fax :

(33) 61.25.30.98

BUREAU GRAVIMETRIQUE INTERNATIONAL

Toulouse

BULLETIN D'INFORMATION

Juin 1990

N° 66

Publié pour le Conseil International des
Unions Scientifiques avec l'aide financière
de l'UNESCO
Subvention UNESCO 1990 DG/2.1/414/50

Table of Contents

Bull. d'Inf. n° 66

OBITUARY

Suzanne CORON
(1917-1989)

Suzanne Coron figure familière de la section de Gravimétrie de l'Association Internationale de Géodésie est décédée à Paris le 23 Décembre 1989.

Née en 1917, près de Lyon, elle se destina de bonne heure à l'enseignement scientifique et passa sa licence es-sciences.

Elle débuta dans l'enseignement, mais le deuxième conflit mondial venait d'éclater.

Le R.P. Lejay, gravimétriste très connu, rappelé de l'Observatoire de Zikawei qu'il dirigeait, fut accueilli à l'Observatoire de St Génis Laval près de Lyon. Ayant besoin d'assistants pour les calculs de réductions, il fit appel à des jeunes licenciés parmi lesquels **S. Coron**, dont il sera désormais le mentor et l'étoile. Directeur de Recherches au CNRS (1945), membre de l'Académie des Sciences (1946) il la fit entrer au CNRS.

Elle participera avec lui à plusieurs campagnes en France et en Afrique du Nord, ce qui l'amènera à des études de la croûte terrestre. Elle passera sa thèse de doctorat en 1953, intitulée "Contribution à l'étude du champ de pesanteur en France".

Entre temps, le R.P. Lejay qui vient de créer le Bureau Gravimétrique International (1953), avec l'aval de l'Association Géodésique Internationale, l'y appelle comme collaboratrice. Il installe le Bureau dans ses propres locaux, où il va prendre son développement.

Ce fut pour **S. Coron** la période la plus brillante et la plus heureuse de sa carrière.

De collaboratrice technique au Centre National de la Recherche Scientifique (1949-1952), elle avait été nommée attachée de recherches (1952-1955), puis chargée de recherches (1955-1966), enfin promue physicien adjoint à l'Institut de Physique du Globe de Paris. Elle procède à ses études, s'organise au B.G.I., participe à des campagnes de mesures gravimétriques, en particulier effectue des plongées avec le bathyscaphe à - 2000 m de profondeur en Méditerranée.

Experte et compétente dans l'étude des liaisons et des réseaux internationaux, disposant d'une bonne documentation bien étudiée, minutieuse, aimant son travail, elle s'était fait connaître des gravimétristes, en France d'abord où elle était chargée de travaux pratiques à l'Université, au Comité National de Géodésie et Géophysique, dont elle devint secrétaire pour la section de gravimétrie.

Au point de vue international, elle était depuis 1953 responsable scientifique du Bureau Gravimétrique International, elle fut secrétaire de la section de gravimétrie de l'A.I.G. (1954-1967) déléguée aux assemblées générales et participait à de nombreux symposia.

Elle s'activait particulièrement lors des réunions de la Commission Gravimétrique Internationale qui se tenait à Paris, au B.G.I., qu'elle préparait avec soin et minutie : c'étaient les rendez-vous des gravimétristes internationaux ; on y examinait les questions relatives aux progrès théoriques ou instrumentaux, à l'unification d'un réseau mondial, aux mesures en mer, etc... Le rôle du B.G.I. était, à l'époque, un rôle d'ingénieur-conseil, d'informateur, un lieu de rencontres internationales : **S. Coron** s'y livrait avec foi et bonheur.

Malheureusement, lorsque l'A.I.G. décida de créer une banque de données gravimétriques internationale au B.G.I., ce dernier, malgré toute sa bonne volonté, ne put faire face faute de moyens. Création privée, l'absence à peu près totale de toute structure administrative officielle, ne permettait pas de les augmenter.

Le Comité National Français de Géodésie et Géophysique dut alors se résoudre à rechercher un nouvel organisme d'accueil doté des moyens et des compétences nécessaires pour continuer la tâche. Le B.G.I. fut transféré.

Ce fut certainement un crève-coeur pour **S. Coron**. Très indépendante, elle ne chercha pas à s'intégrer à la nouvelle équipe. Elle poursuivit à titre personnel un certain nombre de campagnes gravimétriques, assista à quelques symposiums et finalement prit sa retraite, où elle n'admettait que quelques intimes.

Elle est décédée le 23 décembre 1989 après une longue maladie. Ses amis américains l'avaient affectueusement surnommée "**Miss Milligal**". C'est probablement sous ce nom qu'elle aurait aimé que l'on conserve son souvenir.

J.J. Levallois

Part I

INTERNAL MATTER

GENERAL INFORMATIONS

1. HOW TO OBTAIN THE BULLETIN
2. HOW TO REQUEST DATA
3. USUAL SERVICES B.G.I. CAN PROVIDE
4. PROVIDING DATA TO B.G.I.

1. HOW TO OBTAIN THE BULLETIN

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

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

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

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

Once every four years, a special issue contrains (solely) the National Reports as presented at the International Gravity Commission meeting. Other 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 (65 have been issued as December 1, 1989, but numbers 2, 16, 18, 19 are out of print).*
- *or subscribe for regularly receiving the two bulletins per year plus the special issues.*

Requests should be sent to :

Mrs. Nicole ROMMENS
CNES/BGI
18, Avenue Edouard Belin
31055 TOULOUSE CEDEX - FRANCE

Bulletins are sent on an exchange basis (free of charge) for individuals, institutions which currently provide informations, data to the Bureau. For other cases, the price of each number is as follows :

- 65 French Francs without map,

- 75 French Francs with map.

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 reach you by mail only !

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 charges. 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

They can be requested :

(a) either from the CGDF (Compressed Gravity Data File). the list and format of the informations provided are the following :

CGDF RECORD DESCRIPTION

70 CHARACTERS

Col. 1	*Classification code - 0 if not classified*
2- 8	*B.G.I. source number*
9- 15	*Latitude (unit = 1/10 000 degree)*
16- 23	*Longitude (unit = 1/10 000 degree)*
24	*Elevation type* *1 = Land* *2 = Subsurface* *3 = Ocean surface* *4 = Ocean submerged* *5 = Ocean Bottom* *6 = Lake surface (above sea level)* *7 = Lake bottom (above sea level)* *8 = Lake bottom (below sea level)* *9 = Lake surface (above sea level with lake bottom below sea level)* *A = Lake surface (below sea level)* *B = Lake bottom (surface below sea level)* *C = Ice cap (bottom below sea level)* *D = Ice cap (bottom above sea level)* *E = Transfer data given*
25- 31	*Elevation of the station (0.1 M)* *This field will contain depth of ocean positive downward) if col. 24 contains 3, 4 or 5.*
32- 36	*Free air anomaly (0.1 mgal)*
37- 38	*Estimation standard deviation free air anomaly (mgal)*

39-43	*Bouguer anomaly (0.1 mgal)* *Simple Bouguer anomaly with mean density of 2.67 - N_o terrain correction*
44-45	*Estimation standard deviation Bouguer anomaly (mgal)*
46	*System of numbering for the reference station* *1 = IGNS 71* *2 = BGI* *3 = country* *4 = DMA*
47-53	*Reference station*
54-56	*Country code*
57	*1 : measurement at sea with no depth given* *0 : otherwise*
Col. 58	*Information about terrain correction* *0 = no information* *1 = terrain correction exists in the archive file*
59	*Information about density* *0 = no information or 2.67* *1 = density ≠ 2.67 given in the archive file*
60	*Information about isostatic anomaly* *0 = no information* *1 = information exists but is not stored in the archive file* *2 = information exists and is included in the archive file.*
61	*Validity* *0 = no validation* *1 = good* *2 = doubtful* *3 = lapsed*
62-70	*Station number in the data base.*

(b) *or from the Archive file. The list and format of the informations provided are the following :*

ARCHIVE FILES

RECORD DESCRIPTION

160 CHARACTERS

Col. 1-7	*B.G.I. source number*
8-12	*Block number* *Col. 8-10 = 10 square degree* *Col. 11-12 = 1 square degree*
13-19	*Latitude (Unit : 1/10 000 degree)*
20-27	*Longitude (unit : 1/10 000 degree) (- 180 to + 180 degree)*
28	*Accuracy of position* *The site of the gravity measurement is defined in a circle of radius R* *0 = no information on the accuracy* *1 = R <= 20 M (approximately 0'01)* *2 = 20 < R <= 100* *3 = 100 < R <= 200 (approximately 0'1)* *4 = 200 < R <= 500* *5 = 500 < R <= 1000* *6 = 1000 < R <= 2000 (approximately 1')* *7 = 2000 < R <= 5000* *8 = 5000 < R* *9 ...*

29 — System of position

0 = unknown
1 = Decca
2 = visual observation
3 = radar
4 = loran A
5 = loran C
6 = omega or VLF
7 = satellite
9 = solar/stellar (with sextant)

30-31 — Type of observation

A minus sign distinguishes the pendulum observations from the gravimeter ones.
0 = current observation of detail or other observations of a 3 rd or 4th order network
1 = observation of a 2nd order national network
2 = observation of a 1st order national network
3 = observation being part of a nation calibration line
4 = individual observation at sea
5 = mean observation at sea obtained from a continuous recording
6 = coastal ordinary observation (Harbour, Bay, Sea-side...)
7 = harbour base station

32 — Elevation type

1 = Land
2 = Subsurface
3 = Ocean surface
4 = Ocean submerged
5 = Ocean bottom
6 = Lake surface (above sea level)
7 = Lake bottom (above sea level)
8 = Lake bottom (below sea level)
9 = Lake surface (above sea level with lake bottom below sea level)
A = Lake surface (below sea level)
B = Lake bottom (surface below sea level)
C = Ice cap (bottom above sea level)
D = Ice cap (bottom above sea level)
E = Transfer data given

33-39 — Elevation of the station (0.1 M)

This field will contain depth of ocean (positive downward) if col. 32 contains 3, 4 or 5

40 — Accuracy of elevation (E)

0 = unknown
1 = E < = 0.1 M
2 = 1 < E < = 1
3 = 1 < E < = 2
4 = 2 < E < = 5
5 = 5 < E < = 10
6 = 10 < E < = 20
7 = 20 < E < = 50
8 = 50 < E < = 100
9 = E superior to 100 M

41-42 — Determination of the elevation

= no information
0 = geometrical levelling (bench mark)
1 = barometrical levelling
3 = data obtained from topographical map
4 = data directly appreciated from the mean sea level
5 = data measured by the depression of the horizon (marine)

Type of depth (if Col. 32 contains 3, 4 or 5)
1 = depth obtained with a cable (meters)
2 = manometer depth
4 = corrected acoustic depth (corrected from Mathew's tables, 1939)
5 = acoustic depth without correction obtained with

	sound speed 1500 M/sec. (or 820 Brasses/sec) *6 = acoustic depth obtained with sound speed 800 Brasses/sec (or 1463 M/sec)* *9 = depth interpolated on a magnetic record* *10 = depth interpolated on a chart*
43-44	*Mathews' zone* *When the depth is not corrected depth, this information is necessary.* *For example : zone 50 for the Eastern Mediterranean Sea*
45-51	*Supplemental elevation* *Depth of instrument, lake or ice, positive downward from surface*
52-59	*Observed gravity (0.01 mgal)*
60	*Information about gravity* *1 = gravity with only instrumental correction* *2 = corrected gravity (instrumental and Eotvos correction* *3 = corrected gravity (instrumental, Eötvös and cross-coupling correction)* *4 = corrected gravity and compensated by cross-over profiles*
61	*Accuracy of gravity (e)* *When all systematic corrections have been applied* *0 = E < = 0.05* *1 = .05 < E < = 0.1* *2 = 0.1 < E < = 0.5* *3 = 0.5 < E < = 1.* *4 = 1. < E < = 3.* *5 = 3. < E < = 5.* *6 = 5. < E < = 10.* *7 = 10. < E < = 15.* *8 = 15. < E < = 20.* *9 = 20. < E*
62	*System of numbering for the reference station* *This parameter indicates the adopted system for the numbering of the reference station* *1 = for numbering adopted by IGSN 71* *2 = BGI* *3 = Country* *4 = DMA*
63-69	*Reference station* *This station is the base station to which the concerned station is referred*
70-76	*Calibration information (station of base)* *This zone will reveal the scale of the gravity network in which the station concerned was observed, and allow us to make the necessary corrections to get an homogeneous system*
77-81	*Free air anomaly (0.1 mgal)*
82-86	*Bouguer anomaly (0.1 mgal)* *Simple bouguer anomaly with a mean density of 2.67 - No terrain correction*
87-88	*Estimation standard deviation free air anomaly (mgal)*
89-90	*Estimation standard deviation bouguer anomaly (mgal)*
91-92	*Information about terrain correction* *Horizontal plate without bullard's term* *0 = no topographic correction* *1 = CT computed for a radius of 5 km (zone H)* *2 = CT 30 km (zone L)* *3 = CT 100 km (zone N)* *4 = CT 167 km (zone 02)* *11 = CT computed from 1 km to 167 km* *12 = CT 2.5 167* *13 = CT 5.2 167*
93-96	*Density used for terrain correction*
97-100	*Terrain correction (0.1 mgal)* *Computed according to the previously mentioned radius (col. 91-92) & density (col. 93-96)*

101-103	*Apparatus used for the measurements of G* *0.. pendulum apparatus constructed before 1932* *1.. recent pendulum apparatus (1930-1960)* *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* *4.. Metal spring gravimeters for ground measurements* *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* *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* *7.. Gravimeters for measurements on the sea surface or at small depth (submarines..)* *70 = Graf-Askania* *72 = Lacoste-Romberg* *73 = Lacoste-Romberg (on a platform)* *74 = Gal and Gal-F (used in submarines) Gal-M* *75 = AMG (USSR)* *76 = TSSG (Tokyo Surface Ship Gravity meter)* *77 = GSI sea gravity meter*
104	*Conditions of apparatus used* *1 = 1 gravimeter only (no precision)* *2 = 2 gravimeters (no precision)* *3 = 1 gravimeter only (without cross-coupling correction)* *4 = 2 gravimeters (influenced by the cross-coupling effect) with the same orientation* *5 = 2 gravimeters (influenced by the cross-coupling effect) in opposition* *6 = 1 gravimeter (compensated for the cross-coupling effect)* *7 = 1 gravimeter non subject to cross-coupling effect* *8 = 3 gravimeters*
105	*Information about isostatic anomaly* *0 = no information* *1 = information exists but is not stored in the data bank* *2 = information exists and is included in the data bank*
106-107	*Type of the isostatic anomaly* *0.. Pratt-Hayford hypothese* *01 = 50 km including indirect effect (Lejay's tables)* *02 = 56.9 km* *03 = 56.9 km including indirect effect*

04 = 80 km including indirect effect
05 = 96 km
06 = 113.7 km
07 = 113.7 km including indirect effect
1.. Airy hypotheses (equality of masses or pressures)
10 = T = 20 km (Heiskanen's tables, 1931)
11 = T = 20 km including indirect effect (Heiskanen's tables 1938 or Lejay's)
12 = T = 30 km (Heiskanen's tables, 1931)
13 = T = 30 km including indirect effect
14 = T = 40 km
15 = T = 40 km including indirect effect
16 = T = 60 km
17 = T = 60 km including indirect effect
6......
65 = Vening Meinesz hypothesis "modified Bouguer anomaly" (Vening Meinesz, 1948)

108-112	*Isostatic anomaly a (0.1 mgal)*
113-114	*Type of the isostatic anomaly B*
115-119	*Isostatic anomaly B*
120-122	*Velocity of the ship (0.1 knot)*
123-127	*Eötvös correction (0.1 mgal)*
128-131	*Year of observation*
132-133	*Month*
134-135	*Day*
136-137	*Hour*
138-139	*Minute*
140-145	*Numbering of the station (original)*
146-148	*Country code (B.G.I.)*
149	*Validity*
150-154	*Original source number (ex. DMA code)*
155-160	*Sequence number*

Whenever given, the theoretical gravity (gO), 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 :

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

where ϕ *is the geographic latitude.*

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

Formulas used in computing free-air and Bouguer anomalies

Elev Type	Situation	Formulas
1	Land Observation	FA = g + 0.3086*H - gO BO = FA - 0.1119*H
2	Subsurface	FA = g + 0.2238*D2 + 0.3086*(H-D2) BO = FA - 0.1119*H
3	Ocean surface	FA = g - gO BO = FA + 0.06886*H (H = depth of ocean positive downward from surface)
4	Ocean submerged	FA = g - gO BO = FA + 0.06886*H (D2 = depth of instrument positive downward) (H = depth of ocean positive downward)
5	Ocean bottom	FA = g + 0.3086*H - gO BO = FA + 0.06886*D1 (D1 = depth of ocean positive downward)
6	Lake surface (above sea level)	FA = g + 0.3086*H - gO BO = FA - 0.04191*D1 - 0.1119*(H-D1) (D1 = depth of lake positive downward)
7	Lake bottom (above sea level)	FA = g + 0.08382*D1 + 0.3086*(H-D1) - gO BO = FA - 0.04191*D1 - 0.1119*(H-D1)
8	Lake bottom (below sea level)	FA = g + 0.08382*D1 + 0.3086*(H-D1) - gO BO = FA - 0.04191*D1 - 0.06999*(H-D1)
9	Lake surface (above sea level with bottom below sea level)	FA = g + 0.3086*H - gO BO = FA - 0.04191*H - 0.06999*(H-D1)
A	Lake surface (below sea level)	FA = g + 0.3086*H - gO BO = FA - 0.1119*H + 0.06999*D1
B	Lake bottom (surface below sea level)	FA = g + 0.3086*H - 0.2248*D1 - gO BO = FA - 0.1119*H + 0.06999*D1 (D1 = depth of lake positive downward)
C	Ice cap (bottom below sea level)	FA = g + 0.3086*H - gO BO = FA - 0.03843*H - 0.07347*(H-D1) (D1 = depth of ice positive downward)
D	Ice cap (bottom above sea level)	FA = g + 0.3086*H - gO BO = FA - 0.03843*D1 - 0.1119*(H-D1) (D1 = depth of ice)

2.6. Satellite Altimetry Data

BGI has access to the Geos 3 and Seasat data base which is managed by the Groupe de Recherches de Géodésie Spatiale (GRGS). These data are now in the public domain.

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

(a) *Requests for satellite altimetry derived geoid heights (N), that is : time (julian date), longitude, latitude, N, are processed by B.G.I.*

(b) *Requests for the full altimeter measurement records are forwarded to GRGS, or NASA in the case of massive request.*

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

All requests for data must be sent to :

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

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

If not specified, the data will be written, formatted (EBCDIC) on unlabeled 9-track tape (s) with a fixed block size. The exact physical format will be indicated in each case.

3. USUAL SERVICES B.G.I. 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 are effective January 1, 1989 and will be revised periodically.

3.1. Charging Policy for Data Contributors and Scientists

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

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

3.1.1. Digital Data Retrieval

. on one of the following media :
** printout.................. 2 F/100 lines*
** magnetic tape............. 2 F per 100 records*
+ 100 F per tape - 1600 BPI
(if the tape is not to be returned)

. minimum charge : 100 F.

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

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

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

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

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

3.1.3. Data Screening

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

. 5 F/100 points to be screened.

. 100 F minimum charge.

3.1.4. Gridding

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

. 10 F/ΔΔ' per degree square

. minimum charge : 150 F

. maximum area : 40°x 40°

3.1.5. Contour Maps of Bouguer or Free-Air Anomalies

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

. 250 F minimum charge

. maximum area : 40°x 40°

3.1.6. Computation of Mean Gravity Anomalies

(Free-air, Bouguer, isostatic) over ΔxΔ' area : 10 F/ΔΔ' per degree square.

. minimum charge : 150 F

. maximum area : 40°x 40°

3.2. Charging Policy for Other Individuals or Private Companies

3.2.1. Digital Data Retrieval

. 1 F per measurement

. minimum charge : 150 F

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

- *2 F per degree square ; 100 F minimum charge. (maximum plot size = 90 cm x 180 cm)*
- *For area inside polygon : same price as above, counting the area of the smallest rectangle comprising in the polygon.*

3.2.3. Data Screening

. 1 F per screened point

. 250 F minimum charge

3.2.4. Gridding

Same as 2.1.4.

3.2.5. Contour Maps of Bouguer or Free-Air Anomalies

Same as 2.1.5.

3.2.6. Computation of Mean Gravity Anomalies

Same as 2.1.6.

3.3. Gravity Maps

The pricing policy is the same for all categories of users.

3.3.1. Catalogue of all Gravity Maps

printout : 200 F

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

3.3.2. Maps

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

. Special maps :

Mean Altitude Maps

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

Maps of Gravity Anomalies

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

World Maps of Anomalies (with text)

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

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

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

Miscellaneous

CATALOGUE OF ALL GRAVITY MAPS
listing *200 FF*
tape *300 FF*

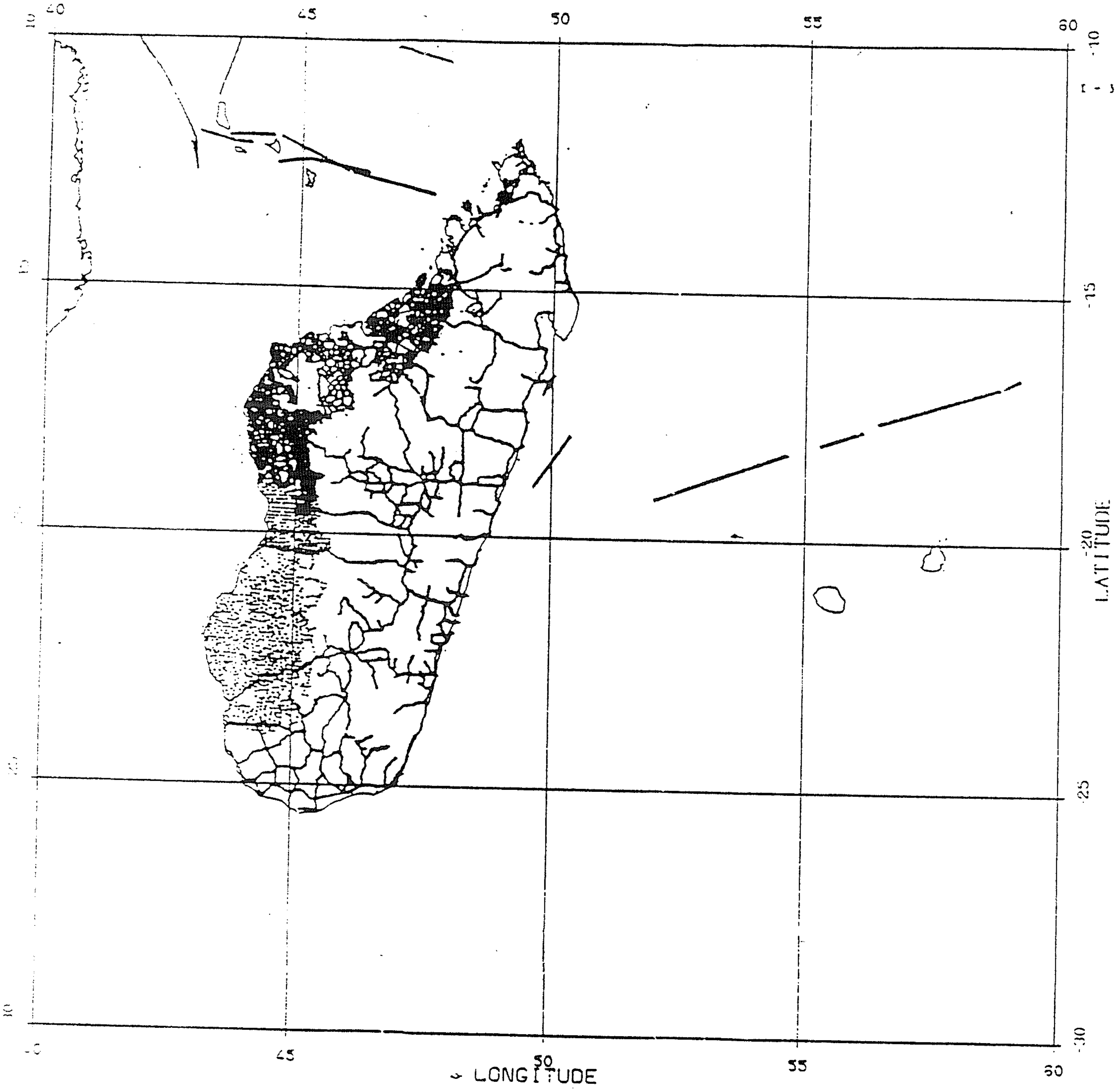
THE UNIFICATION OF THE GRAVITY NETS
OF AFRICA (Vol. 1 and 2) 1979 150 FF

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

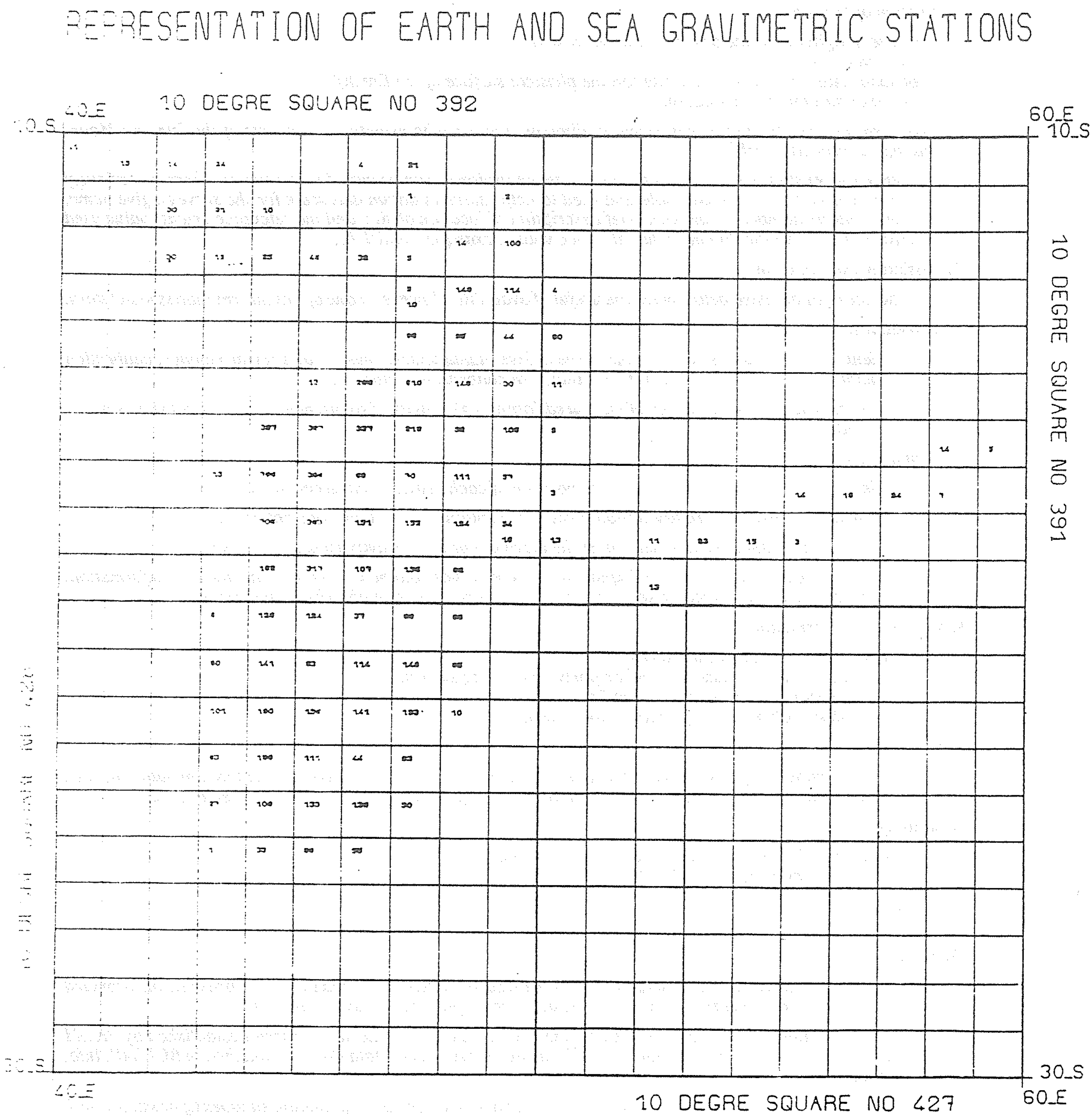
. Colour copy : price according to specifications of request.

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

Map 1. Example of data coverage plot



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



4. PROVIDING DATA TO B.G.I.

4.1. Essential Quantities and Information for Gravity Data Submission

1. *Position of the site :*

   - latitude, longitude (to the best possible accuracy),
   - elevation or depth :
   . for land data : elevation of the site (on the physical surface of the Earth)[1]
   . for water stations : water depth.

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

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.

. 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, 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 unlabeled tapes (if possible), with no password, and formated records of possibly fixed length and a fixed blocksize, too. Tapes are returned whenever specified, as soon as they are copied.

---

1 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 wheter 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.

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

Part II

CONTRIBUTING PAPERS

ADJUSTMENT OF THE FIRST ORDER GRAVITY NET IN THE IBERIAN PENINSULA

M.J. Sevilla, A.J. Gil and P. Romero.

Instituto de Astronomia y Geodesia. (UCM - CSIC)
Facultad de Ciencias Matemáticas
Universidad Complutense
28040 Madrid. Spain

ABSTRACT

In this paper we present the first adjustment of the Iberian First Order Gravity Net accomplished with the gravimetric data of Spain and Portugal. Several adjustment models and a statistical analysis of the results are included. With precise systematic effects corrections we achieved a standard deviation of 22 mGal.

1. Introduction

The Spanish first order gravity net was established in 1973 with the measurements made by combined groups from the IGN (Instituto Geográfico Nacional, Spain) and the DMATC (Defense Mapping Agency Topographic Center, USA).The Portuguese first order gravity net was established in 1973 with the contribution of the IGC (Instituto Geografico e Cadastral, Portugal).The connections between Spain and Portugal were made in two observations campaigns in 1973 and 1976. The gravity data were processed by DMATC separately and reported to IGN and IGC respectively, but no global adjustment was accomplished.

Recently these results have been revised to obtain a data bank of gravity anomalies to be used in the gravimetric geoid determination. As result of this analysis possible errors in the first computations and the lack of a statistical analysis have been detected.

In order to obtain a global Iberian First Order Gravity Net with the statistical analysis of data and results, we have dealed with the Spanish and Portuguese gravity data, to perform with all data together a new unified adjustment of the resulting gravity network that will be called IFOGNET.

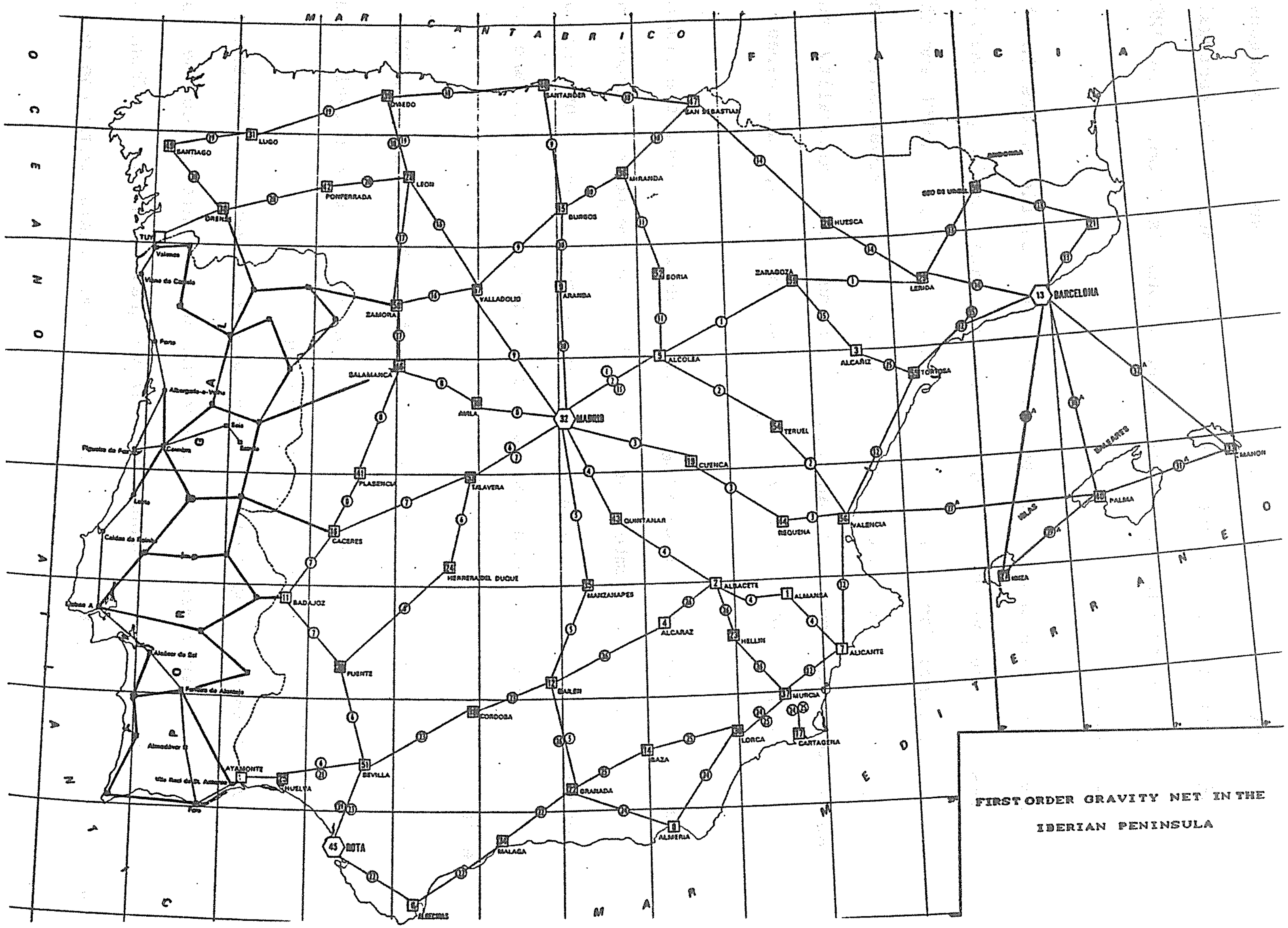
Since 6 to 13 of may 1989, two absolute gravity measurements have been done in Spain, one in Madrid, Instituto de Astronomia y Geodesia (IAG), and the other one in the Geodynamic Station of the IAG not far from Madrid. These observations were made under the direction of Dr. J. Makinen and Dr. R. Vieira using the absolute gravimeter JILAG-5 of the Finnish Geodetic Institute of Helsinki. Although, in the future, these results are going to be check with other absolute measurememts, we could introduce an absolute reference in IFOGNET.

2. **Observation Data**

Following the projected gravity survey plans, observations of IFOGNET were made in ladder sequence ABCDDCBA, and in some cases with additional measurements in rest stations.

Eight Lacoste&Romberg gravimeters model G (n. 41, 59,69, 86, 103, 115, 301, 307) were used making consecutive measurements with groups of them in every station. For each gravimeter two visual readings were noted with the time, but without data of atmospheric pressure, air temperature, height and orientation of the gravimeter. Transport of gravimeters was made by car in the Peninsula, and by aircraft in Baleares Islands connections.

Station coordinates were taken off from the available cartography, heights are of different classes (indicated with a code) caming from



FIRST ORDER GRAVITY NET IN THE IBERIAN PENINSULA precision levelling to map interpolation.

Figure 2.1 shows the IFOGNET, stations are marked with squares, every itinerary with a circle and IGSN 71 stations with hexagons.

IFOGNET consists of 136 stations (79 in Spain and 57 in Portugal) distributed in 67 trips. Number of observations is 1906, with 1283 repeated stations.

We have made a pre-processing data to detect possible errors in the coordinates, in the heights of stations, in times or in gravimetric readings. As control for this analysis we make use of the drift and its mean square error, a chronological control of observations, the regression between free air anomalies and heights, centrality and dispersion measures of gravity values and anomalies, and repeated observations.

As results of this pre-processing we get information about the number of stations involved, number of trips in the network, number of gravimeters participating, number of measurements done, number of revisiting stations and redundancies and a check of stations are all connected.

2.1 Transformation of dial readings to milligals. Calibration factor.

Let m be a dial reading and l the corresponding milligal value obtained by means of the calibration function .

For LaCoste&Romberg gravimeters manufacturer gives the calibration table for each gravimeter. By interpolation in this table we can determine from m the corresponding relative gravity value z. Then, we must transform the z value to a real scale in milligals using the scale factor.

For short rank of measurements, the scale factor can be modelated with a lineal term and two or three periodical terms , |5|, |10|, |21|.

$$l^m = f_0 + f(1+\Delta f)z + \sum_{j=1}^{2} a_j \cos(\nu_j z + \varphi_j).$$

Knowing the factors in this formula we can get the milligals value. Really, we only know the f value (manufacturer gives f=1 and Δf=0) which can have been modified by calibration in a calibration line (with absolute gravity measurements). This procedure enables us to determine some periodic coefficients too.

After all, we have two values for the observable l

l^m theoretical value of observation according to the scale model,

l^c calculated value with a provisional scale factor,

$$l^c = f\, z, \qquad (1)$$

being related by,

$$l^m = f_0 + f\,(1+\Delta f)\, z + \sum_{j=1}^{2} a_j \cos(\nu_j z + \varphi_j)$$

$$= f_0 + l^c + \Delta f\, l^c + \sum_{j=1}^{2} a_j \cos(\nu_j z + \varphi_j)$$

and without periodic part

$$l^e = f_0 + l^c + \Delta f\, l^c. \qquad (2)$$

3. Systematic effects. Corrections.

Precise gravity observations must be corrected of all known systematic effects of different kind: Earth tides, polar motion, vertical gradient of the gravity (height of gravimeter above the bench mark), temperature variations, air pressure, influence of the atmospheric pressure on the gravimeter, variations of the groundwater level, changes in the magnetic azimuth, variations in the battery voltage, microsismic effects, long period movements of the crust, mechanic vibrations, etc.

The modelation and evaluation of some of these effects are complicated, and the local effects are difficult to study. Nevertheless for absolute gravimetry some of them have been investigated |4|, |5|, |22|. Corrections for absolute measurements which can be applied to relative measurements too, are reviewed in |3|. The more important effects that can be corrected are:

3.1 Earth tides.

At present several precise methods for computing the vertical component of earth tides are available |6|, |7|, |9|, |19|, |20|, |28|, |29| . In our work we have used the Cartwright-Tayler-Edden development supplemented by the International Center of Earth Tides with 505 tidal constituents, which provides a precision of 0.1 μGal.

As in Spain we have the data of an Earth tides net with 19 stations well distributed |24|, see figure 3.1, the δ and κ parameters of the wave groups O1,P1,K1,N2,M2,S2 and M3 have been interpolated from the results obtained in the harmonic analysis of tide observations; the other waves have been modified by the factors calculated from the Molodensky I model |25|.

The direct constant part of the tidal gravity effect has been considered following the resolutions of the International Association of Geodesy, |3|,

$$\delta g = -4.83 + 15.73 \sin^2\psi - 1.59 \sin^4\psi \qquad \mu\text{Gal},$$

ψ being the geocentric latitud.

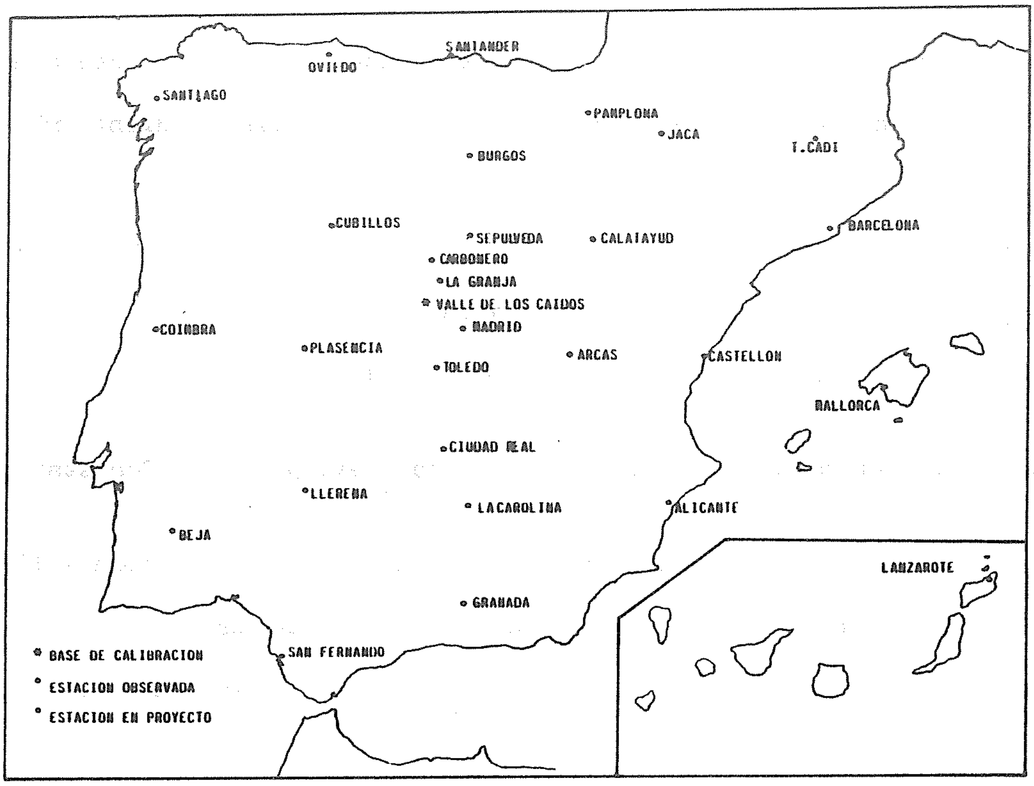


FIGURE 3.1 SPANISH EARTH TIDES NETWORK

3.2 Polar Motion

Another temporal variation in the observed gravity is due to the variation of the Earth rotation axis. To correct this effect we use the Wahr formula |26|,

$$\delta g = 1.164\ 10^{8}\ \omega^{2}\ a\ 2\ \sin\varphi\ \cos\varphi\ (x\ \cos\lambda - y\ \sin\lambda) \quad \mu Gal,$$

where x and y are the pole coordinates in the IERS system, ω is the angular velocity of rotation of the Earth, $\omega = 7292115\ 10^{-11}$ rad s^{-1}, a is the semimayor axis, a = 6378136 m and φ, λ are the coordinates of the station. (As for observations of 1973 and 1976 concerned we have taken the CIO System).

3.3 Vertical Gradient

This correction is to refer the gravity measurement to the bench mark of the station. We use the formula for the vertical gradient of the normal gravity,

$$\delta g = 0.3086\ h \quad \mu Gal,$$

h being the height of the instrument in mm.

Other systematic effects are analized in |5|.

4. Observational data values and approximate gravity values for stations

Approximate gravity values for the stations of the net, which will be used in the adjustment, are calculated from dial readings.

Corrected and adjusted in mean results are classified with the following procedure.

First, dial readings m are converted to his value in milligal l^c by interpolating in the calibration tables supplied by manufacturer and the available value of the scale factor. Then, values l^c (3) are the initial values of observations. By other hand, observation times, usually given in date, hour and minute are transformated in fraction of year, to get a continuos series of Universal Time values.

With these times and other data, corrections given in section 3 are calculated and applied to the (l^c) values.

All these corrections are represented by c_s.

Thus, we have two kinds of observations, the calculated ones (numerical values), from (1),

$$l = l^c + c_s,$$

and the modelated ones, from (2)

$$l^s = f_0 + l^c + \Delta f\ l^c + c_s\ . \qquad (3)$$

4.1 Modelling of gravimeter drift

For short ties, drift of LaCoste&Romberg gravimeters can be considered as a lineal function of time. More complicated models used to obtain the estimated values do not show significative differences with the lineal model |14|. Then, we write,

$$D(t) = D_0 + d\,t, \qquad (4)$$

where D_0 is the accumulative drift up to $t = 0$, (the same for a series of measurements), and d the rate of the drift, taken the same for each gravimeter and each trip, t is the time elapsed from the initial time.

Then, a gravimetric observation at time t is modelled by adding to expression (3) the model (4),

$$l^d = f_0 + l^c + \Delta f\, l^c + c_s + D_0 + d\,t\,.$$

This expression will be taken into account for the design of the network adjustment model.

Nevertheless, in order to calculate well approximate gravity values in the observation stations, we need to know a numerical value of observation itself, which means that we need a numerical value of parameters D_0 and d if we want to consider the drift. In this case iteration procedure in the adjustment can be avoided.

Under the hypothesis that gravimeter drift is the time variation of corrected measurements made in the same station, we can determine d by least squares adjustment of measurements made with the same gravimeter in the same station and belonging to the same trip in t and t' times respectively |16|.

4.2 Removing the static drift

It has been proved that gravimeters work in different way in rest or during transport, |8| , |18|. In the first case, for instance during the night in a trip, we always have a measurement before rest (end of transport) and other measurement before the next transport (end of rest). In the second case the measurements are made between stations and the behavior of gravimeter must be controled.

To obtain the drift we consider the variations when the gravimeter is operating or in transport only. Therefore, we remove of the measurements the static drift, calculated with the data of the begining and the end of rest, subtracting their effect from the next to the final observed values, the same thing is done with the corresponding time tag.

4.3 Calculating the gravity

Let G_1 be the reference gravity of the initial station of the trip, l_1 the observation in this station P_1 in time t_1, l_j the observation in station P_j in time t_j, and d the rate of the drift in the trip, then the approximated gravity in station P_j, j=2,...n is given by,

$$g_j^0 = G_1 + l_j - l_1 - (t_j - t_1)\, d \;,$$

and its corresponding mean square error by,

$$m_j = \sigma_d\,(t_j - t_1)\;.$$

σ_d being the standard deviation.

As references values in the initial stations of the trips we take the IGSN 71 gravity values; when the initial station do not belong to IGSN 71 we take the result of a previous calcul through another trip linked

If we get several values of gravity in a station due to redundancy of observations, to get a single value we take the arithmetic mean, and the same is done if we have measurements of different gravimeters. The resulting values of this procedure will be taken as approximate values of gravity in the network adjustment.

5. Adjustment Models

With the establishment of the International Gravity Standardization Network IGSN 71 and the moderns National Base Networks, several mathematical models for adjustment of gravimetric networks have been developed, |1|, |4|, |8|, |10|, |11|, |12|, |14|, |18|, |23|, |27|, |30|.

Two fundamental models with different options to study the influence of the parameters can be considered: the model of observation equations and the mixed model. In the first the observables are differences of observed gravity between two consecutive stations in the same trip for every used gravimeter, and in the second they are observed gravities in each station.

5.1 Model of observation equations.

Following |17| we can establish the model of observation equation in the form

$$s_q - s_p + \delta g_p - \delta g_q + d_k\,(t_j - t_i) + \Delta f_l\,(l_j^c - l_i^c) - \left[(l_i - l_j) - (g_p^0 - g_q^0)\right] = v_r\,, \qquad (5)$$

with,

s_p, s_q systematic parameters , $p,q = 1,\dots,n_e$,

$\delta g_p, \delta g_q$ correcting parameters to the approximate values of gravity in stations $p,q = 1,\dots,n_e$,

d_k parameters of drift, one parameter for each gravimeter and each trip, $k = 1,\dots,n_{gi}$,

$t_j - t_i$ time interval of measurement,

Δf_l parameter for correction calibration factor , $l = 1,\dots,n_g$,

$l_j^c - l_i^c$ differences of raw observations,

$l_i - l_j$ difference of observations corrected for known systematic effects,

$g_p^0 - g_q^0$ difference of approximate gravity values,

v_r residuals, $r=1,\dots,m$,

n_e number of stations,

n_g number of gravimeters,

n_i number of trips,

n_{gi} $= n_g n_i$,

m number of observed differences of gravity.

5.2 Control equations

The control of a gravimetric net is best achieved if absolute sites are avalaible. These stations, which give the gravimetric reference to the network, can be considered as fixed stations or weighted reference stations (at present, absolute measurements made in the same station with different instruments give significative discrepances). Absolute base points are of great importance because the quality of a gravity network depends on the accuracy and distribution of absolute base points.

For the other reference stations (IGSN 71), according to the suggested procedure |13| for readjusting existing sub-nets, we can introduce the gravity as weighted observations in the observation equations. Thus, for each fixed station we applied the condition $\delta g_F=0$, and for each weighted station we add the equation,

$$\delta g_R = v_R \,, \qquad R = 1,2,\ldots\, m_R \,, \tag{6}$$

which is more or less weighted depending how close the network will be fitted to these m_R points. For large weight the network is fit to these points, and for small weight the network is less deformed and some corrections to reference gravity values come out.

In any case, except in the free network adjustment, a reference station (fixed or weighted) will be necessary to avoid the rank deficiency in origin in the design matrix.

For the IFOGNET, as at the moment we do not dispose of absolute definitive gravity values, we have taken the following IGSN 71 stations

Madrid C (g = 979955.61),

Barcelona J (g = 980306.23),

Lisboa A (g = 980075.73).

with a small weight to avoid the deformation of the network and to allow some corrections to the IGSN 71 values. This overdetermined criterion solves the problem of the origin , does not overreach any IGSN 71 station and allows to fix the scale more precisely by impossing conditions to a reference gravimeter.

5.3 Reference Gravimeter

The approximate values of correction calibration factor Δf of all gravimeters are taken equal to zero. If we want to fix the scale of the network by a particular gravimeter we must use the condition $\Delta f=0$ for this gravimeter. It is not necessary the reference gravimeter has been used in all stations of the network. Weighted equations for all scales can be also added in the form,

$$\Delta f_G = v_G \ , \qquad G = 1, \ldots . \ m_G \ , \tag{7}$$

with a weight more or less large according to the closeness to each m_G gravimeter scale we want the scale of the network remains.

If we have only considered a fix or reference station, except in the free network adjustment, a reference scale factor (fixed or weighted) will be necessary to avoid the rank deficiency in scale in the design matrix.

If we take at least two reference stations, the scale of the network is given by the gravity of these stations, and the scale factors of all gravimeters can be determined in the adjustment. Particularly, if these two stations are absolute sites we treat with a real calibration of instrument.

Nevertheless, it is possible to use a hybrid approach consisting of taking two or more reference stations weakly weighted and a scale factor strongly weighted. Then we can fix the origin with IGSN 71 stations and the scale with a good gravimeter which behaviour have been tested.

This hybrid approach has been applied in the computation of the final results of the IFOGNET, taking the three reference weakly weighted stations cited above jointly the scale factor of gravimeter number 115 strongly weighted.

The use of differences of gravity as observations presents the following advantages: the parameter D_0 of drift is missing, we have removed as many parameters as trip by gravimeter number, also the factor f_0 disappears, in equal number as gravimeters; and static drifts are removed.

5.4 Matricial Formulation

The adjustment model of observation equations according to (5), (6) and (7) can be written in the form,

$$A\,\underline{x} - \underline{t} = \underline{v} \quad , \tag{8}$$

where A is the design matrix

The parameter vector $\underline{x}$ is,

$$\underline{x} = (s_1,\ldots s_{n_e}, \delta g_1,\ldots \delta g_{n_e}, d_1,\ldots d_{n_{gi}}, \Delta f_1,\ldots \Delta f_{n_g})^T ,$$

and the constants of observations vector $\underline{t}$ is,

$$\underline{t} = \left[[l_i - l_j - g_p^0 + g_q^0]_1, \ldots\ldots, [l_i - l_j - g_p^0 + g_q^0]_m, \ldots 0, \ldots\ldots 0 \right] ,$$

with dimensions,

$$\dim \underline{x} = (2\,n_e + n_{gi} + n_g \;,\; 1),$$

$$\dim \underline{t} = (m + m_R + m_G \;,\; 1).$$

Regular network

In this case matrix A is a full rank regular matrix and the number of degrees of freedom is equal to the number of equations minus the number of unknowns. It is necessary at least to have fixed one station and one gravimeter or to add one equation of type (6) and another of type (7).

Free network

In this case we can have a deficiency of rank equal to 1 or 2. If we have fixed the scale with a gravimeter to solve the mathematical model we add the inner constrain,

$$\sum_{k=1}^{n_e} \delta g_k = 0,$$

in the second case, if the scale has not been fixed, we also add the equation,

$$\sum_{k=1}^{n_e} \delta g_c \, g_i^0 = 0.$$

The free adjustment has some advantages, as we do not take any privileged station (or gravimeter) all gravity data are corrected. This kind of adjustment will be used to study the precision of different observation groups, and to detect outliers.

5.5 Stochastic model

Taking as observables gravity differences the apriori covariance matrix for one gravimeter is |4|,

$$\sum_{l_i - l_j} = \sigma_0^2 \begin{bmatrix} 2 & -1 & \ldots & 0 \\ -1 & 2 & -1 \ldots & 0 \\ \ldots & \ldots & \ldots & \ldots \\ 0 & \ldots & -1 & 2 \end{bmatrix},$$

σ_o^2 being the apriori variance. This correlation has influence in the estimated variances for the adjusted gravity values. However, due to it is a small value in practice it is not considered |4|, |10|, |21|, |23|. So, we take as weighting matrix the diagonal matrix $P = \sigma_0^2 \, \Sigma^{-1} = Q^{-1}$, being Q the cofactor matrix.

By individual free adjustments of measurements of each gravimeter and several surveying areas also, we have got the results given in Table I

TABLE I

I	II	III	IV	V	VI	VII	VIII	IX	X	XI
41	204	0	0	20	16.8	45.6084	14	35	15	16
59	145	5	3	30	40.8	34.3908	34	93	37	38
69	202	1	1	20	18.7	43.9071	15	38	17	18
86	145	4	2	30	65.3	35.4518	55	135	59	62
103	146	2	1	30	23.8	34.8936	24	70	26	25
115	208	0	0	20	15.2	47.3163	12	24	14	14
301	200	3	1	20	26.4	46.0214	22	53	23	26

I NUMBER OF GRAVIMETER, II NUMBER OF OBSERVATIONS, III NUMBER OF REJECTED OBSERVATIONS, IV ITERATION NUMBER, V APRIORI STANDARD DEVIATION, VI APOSTERIORI STANDARD DEVIATION, VII TRACE OF THE COFACTOR MATRIX OF PARAMETERS, VIII MAXIMUN STANDARD DEVIATION OF PARAMETERS, IX MAXIMUM RESIDUAL, X MAXIMUM STANDARD DEVIATION OF RESIDUALS, XI MAXIMUM STANDARD DEVIATION OF OBSERVATIONS. (UNITS ARE μGAL.).

In the results for the individual adjustments of Table I, gravimeters numbers 41, 69, 115 and 301 correspond to the Spanish gravimetric network, and gravimeter 59, 86 and 103 to the Portuguese net. Gravimeter number 307 was only used in two itineraries with four observations.

As there is not any gravimeter used in both gravimetric networks, and on account of that the best results are those of gravimeter 115 used in Spain, we have considered the greatest weight for this gravimeter, and for the best portuguese gravimeter and the second spanish one we have adopted the same weight. For gravimeter 307 as no individual adjustment could be made and due to its little effect we have adopted an unit weight factor.

Therefore, to homogenize the network we have adopted the following weight factors

F_B 41 = 1.42 ⇒ 0.821, F_B 59 = 0.54 ⇒ 0.340,

F_B 69 = 1.14 ⇒ 0.659, F_B 86 = 0.21 ⇒ 0.132,

F_B 115 = 1.73 ⇒ 1.000, F_B 103 = 1.59 ⇒ 0.821,

F_B 301 = 0.57 ⇒ 0.329, F_B 307 = 1.00 ⇒ 1.000.

and a apriori variance of unit weight of σ_0^2 = 24 μgal.

For reference stations, weight is about 1 and for scale factors about 25000.

5.6 Estimated values

The least squares solution of the mathematical model (8) is given by,

$$\underline{\hat{x}} = (A^t PA)^{-1} A^t P \underline{t} ,$$

the residuals are obtained as,

$$\underline{\hat{v}} = A \underline{\hat{x}} - \underline{t} = \left[A^t (A^t PA)^{-1} A^t P - I\right] \underline{t} . \qquad (9)$$

The variance of unit weight is,

$$\hat{\sigma}_0^2 = \frac{(\underline{\hat{v}}^t P \underline{\hat{v}})}{f} ,$$

where f = m-rank(A) is the number of degrees of freedom of adjustment. And the covariance matrix are,

$$\sum_{\underline{\hat{x}\hat{x}}} = \hat{\sigma}_0^2 Q_{\underline{\hat{x}\hat{x}}} = \hat{\sigma}_0^2 (A^t PA)^{-1},$$

for parameters,

$$\sum_{\underline{\hat{v}\hat{v}}} = \hat{\sigma}_0^2 Q_{\underline{\hat{v}\hat{v}}} = \hat{\sigma}_0^2 \left[Q - A (A^t PA)^{-1} A^t \right], \qquad (10)$$

for residuals, and,

$$\sum_{\hat{l}_i \hat{l}_j} = \hat{\sigma}_0^2 Q_{\Delta\hat{l}\Delta\hat{l}} = \hat{\sigma}_0^2 \left[A (A^t PA)^{-1} A^t\right],$$

for observations. $Q_{\underline{\hat{x}\hat{x}}}$, $Q_{\underline{\hat{v}\hat{v}}}$, $Q_{\Delta\hat{l}\Delta\hat{l}}$ are the corresponding cofactor matrix.

The estimated values of the final adjustment are shown in Section 8.

6. Statistical Analysis

The statistical analysis of adjustment results is made by appliying the following tests |17|.

6.1 X^2- test of normality of residuals

We applied this test to the vector $\hat{\underline{v}}$ with a classification of 10 intervals at a significance level of $\alpha = 0.05$.

For the final results of IFOGNET we have

```
COMPUTED VALUE = 23.363
CHI VALUE      = 27.593
```

6.2 F-test of the variance of unit weight

We define,

$$y = \max \left[\frac{\hat{\sigma}_0^2}{\sigma_0^2} , \frac{\sigma_0^2}{\hat{\sigma}_0^2} \right] ,$$

the null hypotesis

$$H_0 : \hat{\sigma}_0^2 = \sigma_0^2 ,$$

is rejected if

$$y > F_{f,\infty,\alpha} ,$$

where F is the value of the F-distribution with f and ∞ degrees of freedom at a significance level α.

For the final results of IFOGNET we have

APRIORI VARIANCE	= 0.00058
APOSTERIORI VARIANCE	= 0.00050
Y-STATISTIC VALUE	= 0.863
$F_{1084,\infty,0.05}$	= 1.075

6.3 t-test for systematic errors

We define the statistic,

$$y = \frac{\hat{W}_m}{\sigma_{\hat{W}_m}},$$

where $\hat{W}_m$ is the mean value of the standardized residuals and $\sigma_{\hat{W}_m}$ their mean square error, then the hypothesis,

H_0: there are not systematic errors (E [v]=0)

is rejected if,

$$y > t_{m-1,\alpha}.$$

with t being the Student-distribution with m-1 degrees of freedom.

For the final results of IFOGNET we have

Y-STATISTIC VALUE = 0.093

$t_{1437,0.05}$ = 1.962

6.4 Pope test to detect outliers

We applied this test to the standardized residuals,

$$\hat{v}_i = \hat{v}_i \,/\, \hat{\sigma}_{\hat{v}_i}, \qquad (11)$$

where $\hat{v}_i$ are the residuals given by (9) and $\hat{\sigma}_{\hat{v}_i}$ the variance of $\hat{v}_i$ taken off from $\Sigma_{\hat{v}\hat{v}}$ (10). If

$$|\hat{v}_c| \geq \tau_{m-n+1,\alpha/2},$$

τ being the Tau-distribution |15|, the corresponding observation (two consecutive gravimeter readings) is rejected, and must be investigated for possible errors. If it is not locate the error cause, alternatively each gravimeter reading is eliminated, if H_0 is in both cases rejected, the two measurements are eliminated.

In the IFOGNET adjustment 22 observations have been rejected.

6.5 Reliability parameters

Following theory of Baarda |2|, we compute the reliability parameters,

Baarda coefficient,

$$q_B = q_{\hat{l}} / q_l , \tag{12}$$

External local reliability for parameters,

$$r_x = \sqrt{\frac{q_B}{1-q_B}} \; 3.44 , \tag{13}$$

Internal local reliability for observations,

$$r_T = \sqrt{\frac{1}{1-q_B}} \; 3.44 , \tag{14}$$

Minimum error detectable,

$$\Delta m = r_T \, \sigma_0 \, q_l^{1/2} , \tag{15}$$

Effect of the minimum error detectable on a residual,

$$\Delta v = (1 - q_B) \, \Delta m , \tag{16}$$

where q_l is the diagonal element of the apriori cofactor matrix of observations Q and $q_{\hat{l}}$ the aposteriori corresponding element of $Q_{\Delta\hat{l}}$.

The reliability parameters give us information about the possibility to detect outliers. Following Baarda tables, in ordinary cases (A0 = 0.001, B0 = 20, $\lambda_0^{1/2}$ = 3.44) for good controled observations, $0.6 < q_B < 0.9$, $5 < r_x < 12$, $6.5 < r_t < 13$. For lower values, observations (or parameters) are very well controled. This can be used not only for control but to get a optimum design criteria of the network.

6.6 Extreme values

For the control of the different estimate vectors in the adjustment process the following values are computed: sume of elements, mean value, standard deviation, maximun value and its position, minimum value and its position, number of zeros.

For the final results of IFOGNET adjustment see Section 8 .

6.7 Different models comparison

Several mathematical models of adjustment have been considered to study the influence of different parameters.

Using the same set of observations (acepted in the statistical analysis of section 6), the same stations, the same datum and the same unit of weight, sixteen different models with different number of unknowns have been adjusted. Followimg the conclusions get in |17| we use a model like (5) without s_p and s_q parameters.

7. Results

I. General information about the adjustment

NUMBER OF STATIONS......................	136
NUMBER OF FIXED STATIONS................	0
NUMBER OF FIXED SCALES..................	0
NUMBER OF WEIGHTED REFERENCE STATIONS...	3
NUMBER OF WEIGHTED REFERENCE SCALES.....	1
NUMBER OF GRAVIMETERS..................	8
NUMBER OF TRIPS.........................	210
NUMBER OF THE REFERENCE GRAVIMETER......	0
NUMBER OF SYSTEMATIC UNKNOWNS...........	0
NUMBER OF STATION UNKNOWNS..............	136
NUMBER OF DRIFT UNKNOWNS................	210
NUMBER OF SCALE UNKNOWNS................	8
NUMBER OF NORMALITATION UNKNOWNS........	0
TOTAL NUMBER OF UNKNOWNS	354
TOTAL NUMBER OF OBSERVATIONS............	1438

II. table of observations (Only one trip)

STATION NUMBER	STATION NAME	DATE		TIME	ROW DATA	EARTH TIDE	POLE	FINE DATA
41 102								
1032	MADRID C	3	573	8.175	3592.84551	-0.01250	-0.00180	3592.83122
1035	MANZANARES B	3	573	12.658	3540.64496	0.17940	-0.00180	3540.82255
1012	BAILEN B	3	573	16.033	3523.91675	0.03850	-0.00177	3523.95349
1022	GRANADA B	3	573	20.167	3290.43430	-0.09610	-0.00177	3290.33644
1022	GRANADA B	4	573	7.850	3290.42387	-0.06180	-0.00177	3290.36030
1012	BAILEN B	4	573	11.383	3523.84839	0.13560	-0.00178	3523.98221
1035	MANZANARES B	4	573	14.733	3540.72114	0.14940	-0.00182	3540.86872
1032	MADRID C	4	573	18.575	3592.91962	-0.04600	-0.00182	3592.87180

COMPENSACION DE LA RED GRAVIMETRICA IBERICA DE PRIMER ORDEN

NUM	ESTACION	GRAVEDAD INICIAL	CORRECCION	GRAV. COMPENSADA	E.M.C.
1	1C01 ALMANSA B	979880.570	0.090	979880.660	0.019384
2	1002 ALBACETE B	979885.940	0.069	979886.009	0.018586
3	1003 ALCANIZ	980145.110	0.063	980145.173	0.016581
4	1004 ALCARAZ B	979809.510	0.076	979809.586	0.020836
5	1005 ALCOLEA B	979952.850	0.071	979952.921	0.015943
6	1006 ALGECIRAS B	979750.990	0.106	979751.096	0.023292
7	1007 ALICANTE B	980026.500	0.066	980026.566	0.016581
8	1008 ALMERIA B	979904.300	0.094	979904.394	0.019464
9	1009 ARANDA B	980070.730	0.062	980070.792	0.015990
10	1010 AVILA B	979923.480	0.071	979923.551	0.017465
11	1011 BADAJOZ B	980037.670	0.064	980037.734	0.016307
12	1C12 BAILEN B	979886.680	0.092	979886.772	0.018454
13	1013 BARCELONA J	980306.230	-0.001	980306.229	0.016824
14	1113 BARCELONA AP	980305.740	0.032	980305.772	0.016975
15	1213 BARCELONA UNIV	980297.780	0.038	980297.818	0.017089
16	1313 BARCELONA NHO	980313.690	0.044	980313.734	0.019775
17	1014 BAZA B	979655.960	0.154	979656.114	0.025533
18	1015 BURGOS B	980140.390	0.037	980140.427	0.015734
19	1016 CACERES B	979999.780	0.062	979999.842	0.016045
20	1017 CARTAGENA B	980018.160	0.071	980018.231	0.018383
21	1018 CORDOBA B	979935.160	0.086	979935.246	0.018554
22	1C19 CUENCA B	979881.460	0.144	979881.604	0.018465
23	1020 FUENTE B	979912.980	0.074	979913.054	0.017993
24	1021 GERONA B	980330.860	0.025	980330.885	0.019210
25	1022 GRANADA B	979653.050	0.121	979653.171	0.024896
26	1023 HELLIN B	979877.200	0.086	979877.286	0.019645
27	1024 HERRERA B	979986.350	0.057	979986.407	0.017065
28	1025 HUELVA B	979970.390	0.089	979970.479	0.018980
29	1026 HUESCA B	980214.490	0.037	980214.527	0.017298
30	1027 IBIZA B	980127.210	0.053	980127.263	0.016596
31	1C28 LEON B	980159.180	0.051	980159.231	0.016119
32	1029 LERIDA B	980250.630	0.034	980250.664	0.016823
33	1030 LORCA B	979878.710	0.081	979878.791	0.019412
34	1031 LUGO B	980346.490	0.047	980346.537	0.020661
35	1032 MADRID C	979955.610	0.053	979955.663	0.015385
36	1132 MADRID A NP 26	979966.560	0.033	979966.593	0.022077
37	1232 MADRID N	979981.340	0.009	979981.349	0.027254
38	1332 MADRID M	979992.480	0.013	979992.493	0.031240
39	1033 MAHON B	980229.260	0.049	980229.309	0.017166
40	1034 MALAGA B	979900.170	0.080	979900.250	0.019795

COMPENSACION DE LA RED GRAVIMETRICA IBERICA DE PRIMER ORDEN

NUM	ESTACION	GRAVEDAD INICIAL	CORRECCION	GRAV. COMPENSADA	E.M.C.
41	1035 MANZANARES B	979903.560	0.085	979903.645	0.017989
42	1036 MIRANDA B	980251.600	0.031	980251.631	0.017308
43	1037 MURCIA B	979993.850	0.069	979993.919	0.017365
44	1038 ORENSE B	980313.000	0.033	980313.033	0.019799
45	1039 OVIEDO B	980415.740	0.020	980415.760	0.021001
46	1040 MALLORCA J	980163.100	-0.087	980163.013	0.015878
47	1140 MALLORCA K	980161.580	0.084	980161.664	0.018454
48	1041 PLASENCIA B	980055.740	0.053	980055.793	0.016541
49	1042 PONFERRADA B	980218.690	0.059	980218.749	0.018156
50	1043 QUINTANAR B	979928.330	0.090	979928.420	0.017589
51	1044 REQUENA B	979934.340	0.112	979934.452	0.017840
52	1045 ROTA B	979849.630	0.103	979849.733	0.020447
53	1145 ROTA K	979851.310	-0.117	979851.193	0.022484
54	1046 SALAMANCA B	980046.600	0.057	980046.657	0.015874
55	1047 S SEBASTIAN B	980439.190	0.014	980439.204	0.021528
56	1048 SANTANDER B	980497.330	0.000	980497.330	0.023193
57	1049 SANTIAGO B	980401.090	0.019	980401.109	0.022108
58	1050 SEO DE URGEL B	980135.690	0.042	980135.732	0.017149
59	1051 SEVILLA B	979937.230	0.085	979937.315	0.018221
60	1052 SORIA B	980028.560	0.041	980028.601	0.016552
61	1053 TALAVERA B	980029.950	0.078	980030.028	0.015342
62	1054 TERUEL B	979905.800	0.091	979905.891	0.017954
63	1055 TORTOSA B	980217.030	0.057	980217.087	0.016188
64	1056 VALENCIA B	980113.410	0.078	980113.488	0.015226
65	1057 VALLADOLID B	980097.300	0.047	980097.347	0.015326
66	1058 ZAMORA B	980139.550	0.052	980139.602	0.015779
67	1059 ZARAGOZA B	980223.200	0.050	980223.250	0.016469
68	1060 ADUANA NAP	980037.110	0.057	980037.167	0.019606
69	1160 PORTUGAL NP 47	980037.220	0.063	980037.283	0.019597
70	1061 DERIVA 1	980428.700	0.018	980428.718	0.022860
71	1062 AYAMONTE B	979979.540	0.079	979979.619	0.021091
72	1063 VILA REAL NP	979977.420	0.083	979977.503	0.025731
73	1064 GUINZO DE LIMIA	980180.500	0.022	980180.522	0.023257
74	1065 LA CA IZA	980246.050	0.024	980246.074	0.021825
75	1066 PONTEVEDRA B EST	980378.610	1.822	980380.432	0.024529
76	1067 PORRINO B	980356.630	0.883	980357.513	0.022705
77	1068 TUY	980354.020	0.012	980354.032	0.024674
78	1069 VERIN B	980206.050	0.018	980206.068	0.027714
79	1070 VIGO B CATEDRAL	980375.650	1.975	980377.625	0.024980
80	2001 ALBERGARIA VELHA	980241.000	-0.026	980240.974	0.019575

COMPENSACION DE LA RED GRAVIMETRICA IBERICA DE PRIMER ORDEN

NUM	ESTACION	GRAVEDAD INICIAL	CORRECCION	GRAV. COMPENSADA	E.M.C.
81	2101 ALBERGARIA VEL	980241.020	-0.083	980240.937	0.020400
82	2002 ALCACER DO SAL	980058.450	-0.003	980058.447	0.017649
83	2102 ALCACER DO SAL G	980060.910	0.048	980060.958	0.023619
84	2003 ALMODOVAR	979936.010	0.040	979936.050	0.021534
85	2004 AMARELEJA	980000.180	0.020	980000.200	0.021388
86	2104 AMARELEJA G	980002.020	-0.046	980001.974	0.024786
87	2005 BARCA D ALBA	980192.170	-0.082	980192.088	0.020924
88	2006 BEJA	979984.930	0.030	979984.960	0.020875
89	2007 BRAGA	980269.290	-0.097	980269.193	0.022377
90	2008 BRAGANCA	980169.170	-0.053	980169.117	0.017020
91	2009 CALDAS DA RAINHA	980134.630	0.000	980134.630	0.016621
92	2010 CASTELO BRANCO	980058.380	-0.077	980058.303	0.016261
93	2011 COIMBRA	980209.680	-0.047	980209.633	0.017997
94	2111 COIMBRA G	980209.600	-0.041	980209.559	0.023176
95	2012 CHAVES	980196.220	-0.062	980196.158	0.017274
96	2112 CHAVES G	980195.960	-0.058	980195.902	0.019741
97	2212 CHAVES FRONT	980205.000	-0.049	980204.951	0.022273
98	2312 CHAVES B	980204.940	0.018	980204.958	0.031431
99	2013 ELVAS	980006.530	-0.077	980006.453	0.017561
100	2014 EVORA	980006.000	-0.025	980005.975	0.018464
101	2114 EVORA G	980012.460	-0.049	980012.411	0.023473
102	2015 FARO J	979961.450	-0.038	979961.412	0.021913
103	2115 FARO G	979956.030	0.070	979956.100	0.025621
104	2016 FERREIRA ALENTEJ	980005.110	0.010	980005.120	0.019711
105	2017 GUARDA	979974.840	-0.072	979974.768	0.019029
106	2018 LEIRIA	980152.370	-0.012	980152.358	0.017054
107	2019 LISBOA A	980075.730	-0.052	980075.678	0.015538
108	2020 MIRANDA DOURO	980113.040	-0.067	980112.973	0.020171
109	2120 MIRANDA DOURO G	980113.060	-0.072	980112.988	0.022504
110	2021 MIRANDELA	980216.780	-0.076	980216.704	0.020749
111	2022 MOGADOURO	980109.470	-0.062	980109.408	0.019465
112	2023 MONCAO	980337.640	-0.067	980337.573	0.025255
113	2024 ODEMIRA	980006.170	0.025	980006.195	0.021866
114	2025 PONTE DE SOR	980079.170	-0.058	980079.112	0.018784
115	2026 PORTALEGRE	980001.590	-0.072	980001.518	0.018315
116	2027 PORTO	980265.450	-0.094	980265.356	0.019919
117	2127 PORTO J	980291.800	-0.128	980291.672	0.021726
118	2028 S GREGORIO	980302.000	-0.062	980301.938	0.025901
119	2029 SANTAREM	980088.080	-0.065	980088.015	0.016844
120	2030 SANTIAGO CACEM	979998.270	0.012	979998.282	0.020420

COMPENSACION DE LA RED GRAVIMETRICA IBERICA DE PRIMER ORDEN

NUM	ESTACION	GRAVEDAD INICIAL	CORRECCION	GRAV. COMPENSADA	E.M.C.
121	2130 SANTIAGO CACEM G	979998.010	0.011	979998.021	0.023325
122	2031 SERTA	980110.130	-0.074	980110.056	0.016938
123	2131 SERTA G	980113.460	-0.056	980113.404	0.021775
124	2032 VALENCA B	980348.330	-0.086	980348.244	0.024277
125	2132 VALENCA C	980352.690	0.010	980352.700	0.024758
126	2232 VALENCA D	980348.250	0.008	980348.258	0.028725
127	2033 VIANA DO CASTELO	980357.600	-0.077	980357.523	0.024070
128	2034 VILA BOIM G	979986.090	-0.119	979985.971	0.022243
129	2035 VILA DO BISPO	980001.040	0.043	980001.083	0.022927
130	2036 VILA REAL	980162.430	-0.071	980162.359	0.016995
131	2037 V R SANTO ANTON	979977.440	0.047	979977.487	0.022362
132	2137 V R S ANTONIO G	979978.020	0.030	979978.050	0.025680
133	2038 VISEU	980108.620	-0.047	980108.573	0.016986
134	2039 ESTRELA	979757.940	-0.079	979757.861	0.027179
135	2040 FIGUEIRA DA FOZ	980202.120	-0.084	980202.036	0.018680
136	2041 SEIA	980065.080	-0.073	980065.007	0.020611

ITINERARIO	GRAVIMETRO	DERIVA	E.M.C.
101	L&R 115	0.009797	0.010451
102	L&R 41	-0.000945	0.002639
102	L&R 69	0.001363	0.002953
102	L&R 115	-0.000196	0.002391
102	L&R 301	0.009919	0.004301
103	L&R 41	-0.000373	0.002415
103	L&R 69	-0.001832	0.002688
103	L&R 115	0.002660	0.002182
103	L&R 301	-0.001567	0.002288
104	L&R 41	-0.000318	0.002645
104	L&R 69	-0.001895	0.002874
104	L&R 115	0.004131	0.002345
104	L&R 301	-0.003019	0.004053
105	L&R 41	0.000339	0.002396
105	L&R 69	0.001266	0.002657
105	L&R 115	0.001513	0.002159
105	L&R 301	-0.002938	0.003499
106	L&R 41	-0.000558	0.003359
106	L&R 69	-0.000862	0.003750
106	L&R 115	0.001470	0.003047
106	L&R 301	0.001352	0.005322
107	L&R 41	-0.002671	0.002695
107	L&R 69	-0.003437	0.003026
107	L&R 115	0.001932	0.002463
107	L&R 301	0.002970	0.004278
108	L&R 41	0.000202	0.002453
108	L&R 69	-0.000262	0.002703
108	L&R 115	0.001914	0.002196
108	L&R 301	-0.000004	0.003850
109	L&R 41	-0.002774	0.002547
109	L&R 69	-0.000309	0.002802
109	L&R 115	0.001345	0.002285
109	L&R 301	-0.002050	0.003993
110	L&R 41	-0.000269	0.003016
110	L&R 69	-0.000376	0.003253
110	L&R 115	0.003344	0.002656
110	L&R 301	0.000439	0.002389
111	L&R 41	0.001224	0.002648
111	L&R 69	-0.000063	0.002950
111	L&R 115	0.003913	0.002404
111	L&R 301	-0.000992	0.004190
112	L&R 41	-0.000279	0.002996
112	L&R 69	-0.000842	0.003309
112	L&R 115	0.001244	0.002701
112	L&R 301	-0.001314	0.004703
113	L&R 41	-0.000213	0.006239
113	L&R 69	-0.000017	0.006982
113	L&R 115	0.001999	0.005668
113	L&R 301	-0.002018	0.009899
114	L&R 41	-0.002688	0.002565
114	L&R 69	-0.002835	0.002861
114	L&R 115	0.000965	0.002322
114	L&R 301	-0.000704	0.004075
115	L&R 41	-0.003593	0.002426
115	L&R 69	0.001973	0.002699
115	L&R 115	0.000724	0.002183
115	L&R 301	0.000436	0.003897
116	L&R 41	-0.001803	0.002323
116	L&R 69	-0.000447	0.002575
116	L&R 115	0.000509	0.002098
116	L&R 301	-0.000530	0.003809
117	L&R 41	0.014468	0.008279
117	L&R 69	0.005544	0.009679
117	L&R 115	0.009965	0.007597
117	L&R 301	0.009183	0.013003
118	L&R 41	-0.001902	0.002549
118	L&R 69	-0.002888	0.002843
118	L&R 115	0.002337	0.002292
118	L&R 301	-0.001057	0.004010
119	L&R 41	-0.000217	0.001995
119	L&R 69	-0.000728	0.002226
119	L&R 115	0.001633	0.001816
119	L&R 301	0.001303	0.002718
120	L&R 41	-0.000736	0.002391
120	L&R 69	-0.001193	0.002659
120	L&R 115	0.002331	0.002131
120	L&R 301	-0.000173	0.003266
121	L&R 41	-0.002124	0.002832
121	L&R 69	0.000456	0.003162
121	L&R 115	0.000254	0.002564
121	L&R 301	-0.001439	0.004487
122	L&R 41	-0.004976	0.004488
122	L&R 69	-0.000538	0.004996
122	L&R 115	-0.001566	0.004065
122	L&R 301	0.001299	0.007051
123	L&R 41	-0.001927	0.005050
123	L&R 69	-0.000580	0.005634
123	L&R 115	-0.000786	0.004600
123	L&R 301	0.000411	0.008071
124	L&R 41	-0.002640	0.003954
124	L&R 301	0.003602	0.006274
124	L&R 69	0.000718	0.004574
124	L&R 115	0.004140	0.003712
125	L&R 41	-0.002859	0.002597
125	L&R 69	-0.000664	0.002895
125	L&R 115	0.000354	0.002367
125	L&R 301	0.004354	0.004128
126	L&R 41	0.000025	0.003076
126	L&R 69	0.000235	0.003420
126	L&R 115	0.004643	0.002783

ITINERARIO	GRAVIMETRO	DERIVA	E.M.C.	ITINERARIO	GRAVIMETRO	DERIVA	E.M.C.
126	L&R 301	0.004968	0.004804	209	L&R 103	0.001577	0.006484
127	L&R 41	0.000695	0.003144	210	L&R 59	-0.002556	0.008590
127	L&R 69	-0.000670	0.003520	210	L&R 86	0.023280	0.013805
127	L&R 115	-0.000835	0.002852	210	L&R 103	0.003424	0.005617
127	L&R 301	0.007337	0.004972	211	L&R 59	0.031091	0.017035
128	L&R 41	-0.000811	0.002702	212	L&R 59	-0.001227	0.007861
128	L&R 69	0.001974	0.003013	212	L&R 86	-0.017654	0.012672
128	L&R 115	0.000825	0.002435	212	L&R 103	0.001873	0.005077
128	L&R 301	0.006930	0.004269	213	L&R 59	-0.004712	0.007250
129	L&R 41	-0.000709	0.002708	213	L&R 86	-0.009798	0.011738
129	L&R 69	-0.000008	0.003042	213	L&R 103	-0.001849	0.003372
129	L&R 115	0.000810	0.002465	214	L&R 59	-0.002455	0.006592
129	L&R 301	0.002419	0.004278	214	L&R 86	-0.000727	0.010548
130	L&R 41	-0.007844	0.004923	214	L&R 103	0.000804	0.004207
130	L&R 69	0.004231	0.005488	215	L&R 86	-0.018936	0.017123
130	L&R 115	-0.001507	0.004432	215	L&R 103	0.010766	0.007202
130	L&R 301	-0.011563	0.007705	216	L&R 59	0.006562	0.007813
131	L&R 41	-0.006855	0.009099	216	L&R 86	0.008899	0.011360
131	L&R 69	-0.002558	0.010381	216	L&R 103	-0.000686	0.005023
131	L&R 115	0.000806	0.008053	217	L&R 59	-0.008137	0.007868
131	L&R 301	-0.010708	0.013979	217	L&R 86	0.000374	0.012619
132	L&R 41	0.004923	0.010129	217	L&R 103	0.003568	0.005133
132	L&R 69	-0.003411	0.011136	218	L&R 59	0.007713	0.006362
132	L&R 115	0.000296	0.009366	218	L&R 86	0.015287	0.009925
201	L&R 59	0.019807	0.007946	218	L&R 103	0.001198	0.005183
201	L&R 86	0.008428	0.012568	219	L&R 59	-0.005029	0.018865
201	L&R 103	0.012281	0.004969	219	L&R 86	0.022355	0.025238
202	L&R 59	-0.000570	0.006994	219	L&R 103	0.005474	0.013461
202	L&R 86	-0.001950	0.011219	220	L&R 59	-0.007389	0.007209
202	L&R 103	-0.000771	0.004519	220	L&R 86	-0.002611	0.011757
203	L&R 59	0.000756	0.007318	220	L&R 103	-0.004141	0.004651
203	L&R 86	-0.003542	0.012162	221	L&R 59	0.004869	0.006998
203	L&R 103	0.002193	0.004884	221	L&R 86	-0.002627	0.009499
204	L&R 59	0.003136	0.006692	221	L&R 103	0.005591	0.003855
204	L&R 86	0.017665	0.010590	301	L&R 59	-0.003683	0.042281
204	L&R 103	0.013900	0.004497	301	L&R 103	-0.001674	0.026668
205	L&R 59	0.002050	0.007860	301	L&R 301	0.023494	0.041906
205	L&R 86	-0.006040	0.012574	301	L&R 307	0.006424	0.024196
205	L&R 103	-0.001849	0.005652	302	L&R 59	0.004007	0.007230
206	L&R 59	-0.007452	0.008341	302	L&R 103	-0.000348	0.004669
206	L&R 86	-0.000594	0.013389	302	L&R 301	0.008373	0.007487
206	L&R 103	-0.002543	0.005371	302	L&R 307	0.000202	0.004346
207	L&R 59	-0.002179	0.008066	303	L&R 103	-0.000779	0.005013
207	L&R 86	-0.035408	0.012765	303	L&R 301	0.017999	0.007919
207	L&R 103	-0.004060	0.005139	304	L&R 59	0.002723	0.004606
208	L&R 59	0.002267	0.008188	304	L&R 103	-0.006955	0.003356
208	L&R 86	-0.003317	0.012948	304	L&R 301	0.007330	0.005360
208	L&R 103	0.004794	0.005310	304	L&R 307	-0.000886	0.003066
209	L&R 59	-0.005979	0.009964	305	L&R 41	-0.001707	0.007005
209	L&R 86	-0.000511	0.010468	305	L&R 301	-0.003091	0.006925

ITINERARIO	GRAVIMETRO	DERIVA	E.M.C.
306	L&R 41	-0.005007	0.008954
306	L&R 301	-0.012405	0.014026
307	L&R 41	-0.001333	0.003287
307	L&R 301	-0.001884	0.005180
501	L&R 41	-0.003273	0.002966
501	L&R 86	0.002071	0.011616
501	L&R 115	0.006592	0.001482
502	L&R 41	0.000004	0.001604
502	L&R 86	0.003433	0.008180
502	L&R 115	0.002089	0.002958

COMPENSACION DE LA RED GRAVIMETRICA IBERICA DE PRIMER ORDEN

GRAVIMETRO	COEF. LINEAL FACTOR ESCALA	E.M.C.	CTE NORMALIZACION	E.M.C.
L&R 41	-0.00018042	0.000044	S/C	---
L&R 69	-0.00017387	0.000045	S/C	---
L&R 115	0.00002396	0.000041	S/C	---
L&R 301	-0.00014112	0.000048	S/C	---
L&R 59	0.00041156	0.000087	S/C	---
L&R 86	0.00005417	0.000092	S/C	---
L&R 103	-0.00044352	0.000078	S/C	---
L&R 307	-0.00015663	0.000136	S/C	---

COMPENSACION DE LA RED GRAVIMETRICA IBERICA DE PRIMER ORDEN

ERRORES MEDIOS CUADRATICOS DE LAS OBSERVACIONES HOJA 1

N.OBS	NPE	NPV	DIFERENCIA GRAVEDAD OBSERVADA	DIFERENCIA GRAVEDAD COMPENSADA	DIFERENCIA	PESO DE LA OBSERVACION	E.M.C. DE LA OBSERVACION
1	1032	1132	10.9210	10.9230	-C.0020	41.6667	0.0184
2	1132	1232	14.7430	14.7416	0.0014	41.6667	0.0184
3	1232	1332	11.1366	11.1360	C.0006	41.6667	0.0178
4	1332	1232	-11.1534	-11.1540	C.0006	41.6667	0.0178
5	1232	1132	-14.7637	-14.7651	0.0014	41.6667	0.0184
6	1132	1032	-10.9347	-10.9328	-0.0020	41.6667	0.0184
7	1032	1035	-52.0087	-51.9940	-0.0146	37.7538	0.0141
8	1035	1012	-16.8691	-16.8659	-0.0031	37.7538	0.0120
9	1012	1022	-233.6170	-233.5945	-0.0225	37.7538	0.0127
10	1022	1012	233.6219	233.5970	0.0249	37.7538	0.0115
11	1012	1035	16.8865	16.8944	-C.0079	37.7538	0.0118
12	1035	1032	52.0031	51.9750	0.0281	37.7538	0.0130
13	1032	1035	-52.0665	-52.1000	0.0335	33.8245	0.0147
14	1035	1012	-16.8236	-16.7668	-0.0568	33.8245	0.0134
15	1012	1022	-233.6948	-233.7422	0.0473	33.8245	0.0137
16	1022	1012	233.6842	233.7313	-0.0471	33.8245	0.0125
17	1012	1035	16.8603	16.8497	0.0105	33.8245	0.0126
18	1035	1032	52.0200	52.0182	0.0018	33.8245	0.0141
19	1032	1035	-52.0220	-52.0280	C.0059	41.6667	0.0127
20	1035	1012	-16.8943	-16.9174	0.0231	41.6667	0.0120
21	1012	1022	-233.5892	-233.5833	-C.0058	41.6667	0.0113
22	1022	1012	233.6056	233.6147	-0.0091	41.6667	0.0111
23	1012	1035	16.8712	16.8698	0.0014	41.6667	0.0113
24	1035	1032	52.0336	52.0496	-0.0160	41.6667	0.0121
25	1032	1035	-52.1133	-52.1617	0.0484	23.8994	0.0188
26	1035	1012	-16.9612	-17.0074	0.0462	23.8994	0.0191
27	1012	1022	-233.6441	-233.6195	-0.0246	23.8994	0.0169
28	1022	1012	233.5827	233.5654	0.0172	23.8994	0.0169
29	1012	1035	16.9321	17.0240	-0.0919	23.8994	0.0170
30	1035	1032	51.9988	52.0081	-0.0094	23.8994	0.0176
31	1032	1019	-74.0745	-74.0781	0.0036	37.7538	0.0128
32	1019	1044	52.8684	52.8775	-C.0090	37.7538	0.0121
33	1044	1056	179.0414	179.0136	0.0278	37.7538	0.0114
34	1056	1040	49.5536	49.5723	-0.0187	37.7538	0.0104
35	1040	1140	-1.3562	-1.3635	0.0073	37.7538	0.0099
36	1140	1040	1.3296	1.3095	0.0200	37.7538	0.0096
37	1040	1056	-49.5505	-49.5682	0.0177	37.7538	0.0100
38	1056	1044	-179.0496	-179.0322	-C.0174	37.7538	0.0107
39	1044	1019	-52.8501	-52.8437	-0.0064	37.7538	0.0121
40	1019	1032	74.0780	74.0818	-0.0037	37.7538	0.0144

COMPENSACION DE LA RED GRAVIMETRICA IBERICA DE PRIMER ORDEN

ERRORES MEDIOS CUADRATICOS DE LOS RESIDUALES HOJA 1

NO	NPE	NPV	RESIDUO SIN PON	E.M.C. DEL RESIDUO	RESIDUO TIPIFICADO	EMD	ESR	QB	RX	RT	FLE
1	1032	1132	0.0020	0.0127	0.1550	0.15	0.05	0.68	4.99	6.06	0.68
2	1132	1232	-0.0014	0.0126	-0.1120	0.15	0.05	0.68	5.05	6.11	0.68
3	1232	1332	-0.0006	0.0134	-0.0453	0.14	0.05	0.64	4.58	5.73	0.64
4	1332	1232	-0.0006	0.0134	-0.0453	0.14	0.05	0.64	4.58	5.73	0.64
5	1232	1132	-0.0014	0.0126	-0.1120	0.15	0.05	0.68	5.05	6.11	0.68
6	1132	1032	0.0020	0.0127	0.1550	0.15	0.05	0.68	4.99	6.06	0.68
7	1032	1035	0.0146	0.0202	0.7262	0.11	0.07	0.33	2.41	4.20	0.40
8	1035	1012	0.0031	0.0215	0.1458	0.10	0.08	0.24	1.91	3.94	0.29
9	1012	1022	0.0225	0.0211	1.0680	0.11	0.08	0.27	2.07	4.01	0.32
10	1022	1012	-0.0249	0.0217	-1.1453	0.10	0.08	0.22	1.82	3.89	0.27
11	1012	1035	0.0079	0.0216	0.3674	0.10	0.08	0.23	1.88	3.92	0.28
12	1035	1032	-0.0281	0.0209	-1.3448	0.11	0.08	0.28	2.14	4.05	0.34
13	1032	1035	-0.0335	0.0232	-1.4466	0.12	0.09	0.29	2.19	4.08	0.44
14	1035	1012	0.0568	0.0240	2.3696	0.12	0.09	0.24	1.93	3.94	0.36
15	1012	1022	-0.0473	0.0238	-1.9905	0.12	0.09	0.25	1.99	3.97	0.38
16	1022	1012	0.0471	0.0244	1.9264	0.11	0.09	0.21	1.77	3.87	0.32
17	1012	1035	-0.0105	0.0244	-0.4315	0.11	0.09	0.21	1.78	3.87	0.32
18	1035	1032	-0.0018	0.0236	-0.0777	0.12	0.09	0.26	2.05	4.00	0.40
19	1032	1035	-0.0059	0.0183	-0.3247	0.10	0.07	0.33	2.39	4.19	0.33
20	1035	1012	-0.0231	0.0188	-1.2303	0.10	0.07	0.29	2.20	4.08	0.29
21	1012	1022	0.0058	0.0192	0.3038	0.10	0.07	0.26	2.03	4.00	0.26
22	1022	1012	0.0091	0.0193	0.4707	0.10	0.07	0.25	1.98	3.97	0.25
23	1012	1035	-0.0014	0.0192	-0.0719	0.10	0.07	0.26	2.02	3.99	0.26
24	1035	1032	0.0160	0.0187	0.8538	0.10	0.07	0.29	2.22	4.09	0.29
25	1032	1035	-0.0484	0.0340	-1.4238	0.16	0.13	0.23	1.90	3.93	0.71
26	1035	1012	-0.0462	0.0338	-1.3635	0.17	0.13	0.24	1.94	3.95	0.74
27	1012	1022	0.0246	0.0350	0.7023	0.16	0.13	0.19	1.66	3.82	0.57
28	1022	1012	-0.0172	0.0350	-0.4922	0.16	0.13	0.19	1.66	3.82	0.57
29	1012	1035	0.0919	0.0350	2.6293	0.16	0.13	0.19	1.67	3.83	0.58
30	1035	1032	0.0094	0.0347	0.2706	0.16	0.13	0.20	1.75	3.86	0.62
31	1032	1019	-0.0036	0.0210	-0.1726	0.11	0.08	0.27	2.10	4.03	0.33
32	1019	1044	0.0090	0.0214	0.4218	0.10	0.08	0.24	1.94	3.95	0.29
33	1044	1056	-0.0278	0.0218	-1.2740	0.10	0.08	0.22	1.81	3.89	0.26
34	1056	1040	0.0187	0.0223	0.8392	0.10	0.08	0.18	1.61	3.80	0.22
35	1040	1140	-0.0073	0.0225	-0.3248	0.10	0.08	0.16	1.50	3.75	0.20
36	1140	1040	-0.0200	0.0227	-0.8842	0.10	0.08	0.15	1.46	3.74	0.19
37	1040	1056	-0.0177	0.0225	-0.7876	0.10	0.08	0.17	1.53	3.77	0.20
38	1056	1044	0.0174	0.0222	0.7842	0.10	0.08	0.19	1.65	3.82	0.23
39	1044	1019	0.0064	0.0214	0.3008	0.10	0.08	0.24	1.95	3.95	0.30
40	1019	1032	0.0037	0.0200	0.1872	0.11	0.07	0.34	2.47	4.24	0.41

VI Stochastic characteristics of the adjustment

VARIANCE FACTOR	0.9291
SUM OF WEIGHTED RESIDUALS	1.6990
SUM OF RESIDUALS	- 0.1135
SUM OF SQUARES OF WEIGHTED RESIDUALS	935.7858
SUM OF SQUARES OF RESIDUALS	1.6201
APOSTERIORI STANDARD DEVIATION	0.0223
TRACE OF THE PARAMETERS COFACTOR MATRIX ...	113.3858
MEAN STANDARD DEVIATION OF PARAMETERS	0.0204
NUMBER OF DEGREES OF FREEDOM	1084
TAU-VALUE	4.3330

VII. Extreme values

	SUM	MEAN VALUE	STANDARD DEVIATION	MAXIMUM (Num)	MINIMUM (Num)
CORRECTIONS TO OBSERVATIONS	0.114	0.000	0.034	0.211 (969)	-0.168 (1040)
M.S.E. OF OBSERVATIONS	21.718	0.015	0.006	0.052 (1014)	0.006 (456)
RESIDUALS	-0.114	-0.000	0.034	0.168 (1040)	-0.219 (969)
M.S.E. OF RESIDUALS	41.442	0.029	0.012	0.061 (1398)	0.008 (1365)
STANDARDIZED RESIDUALS	3.529	0.003	1.004	3.370 (976)	-3.578 (969)
INTERNAL LOCAL RELIABILITY	5797.5	4.032	0.548	10.155 (1365)	3.486 (1398)
EXTERNAL LOCAL RELIABILITY	2852.8	1.984	0.886	9.555 (1365)	0.562 (1398)

INTERNAL MEAN RELIABILITY OF THE NET 0.24
EXTERNAL MEAN RELIABILITY OF THE NET 0.53

References

|1| **Arabelos, D., J. M. Karrinti, and L. N. Mavridis**: Establishment of a first Order Gravity Network in Northern Greece; Deutches Geodatisches Kommission Reihe B, Heft 252/II, p. 69-78, München, 1982.

|2| **Baarda, W.**: A testing procedure for use in geodetic networks; Neth. Geod. Comm. Pub. on Geodesy. New Series 2, n. 5, Delft, 1968.

|3| **Boedecker, G.**: International Absolute Gravity Basestation Network (IAGBN) Absolute Gravity Observations Data Processing Standards and Station Documentation; Bureau Gravimétrique International. Bulletin d'information n. 63, p. 51-57, Toulouse 1988.

|4| **Boedecker, G. and Ch. Poitevin**: Unified European Gravity Network UEGN, Status Report; Bureau Gravimétrique International. Bulletin d'information, n. 59, p. 133-143,Toulouse, 1986.

|5| **Boedecker, G. and B. Richter**: The new gravity base net 1976 of the Federal Republic of Germany (DGSN 76); Bulletin. Géodésique. n. 55, p. 250-266, 1981.

|6| **Cartwright, D. E. and A. C. Edden**: Corrected Tables of Tidal Harmonics; Geophy. J. R. Astr. Soc. 33, p. 253-264, 1973.

|7| **Cartwright, D. E. and R. J. Tayler**: New Computations of the Tide Generating Potential; Geophy. J. R. Astr. Soc. 23, p. 45-74, 1971.

|8| **Haller, L. A. and M. Ekman**: The fundamental Gravity Network of Sweden; Bureau Gravimétrique International. Bulletin d'information, n. 63, p. 75-92 ,Toulouse, 1988

|9| **Heikkinen, M.**: On the Tide-generating Forces; Pub. of the Finnish Geodetic Institute, n. 85. Helsinki 1978.

|10| **Krieg, L. A.**: Mathematical modelling of the behavior of the LaCoste & Romberg "G" Gravity Meter for use in gravity network adjustments and data analysis; Rep. of the Deparment of Geodetic Science and Surveying n. 321, The Ohio State University, Columbus, 1981.

|11| **Marson, I. and C. Morelli**: First Order Gravity net in Italy; Boll. Geodesia. e Sc. Affini, p. 659-689, 1978.

|12| **McConnel, R. K. and C. Gantar**: Adjustments and analysis of Data for IGSN 71; Appendix IV to the International Gravity Standardization Net 1971 (IGSN 71), by Morelli, Gantar, Honkasalo, McConnell, Tanner, Szabo, Uotila and Whalen, Special Publication n. 4, International Association of Geodesy, Paris, 1974.

|13| International Gravity Standardization Net 1971 (IGSN 71), by Morelli, Gantar, Honkasalo, McConnell, Tanner, Szabo, Uotila and Whalen, Special Publication n. 4, International Association of Geodesy, Paris, 1974.

|14| **Nakagawa, I., S. Nakai, R. Shichi, H. Tajima, S. Izutuya, Y. Kono, T. Higashi, H. Fujimoto, M. Murakami, K. Tajima and M. Funaki**: Precise Calibration of Scale Values of LaCoste & Romberg Gravimeters and International Gravimetric Connections along the CircumPacific Zone; Geophysical Institute, Kyoto Univ. Japan, 1983.

|15| **Pope, A. J.**: The statistics of residuals and the rejection of outliers; NOAA TR-NOS 65, NGS1, 1976

|16| **Sevilla, M. J.**: Cálculo automático de anomalías gravimétricas; III Asamblea Nacional de Geodesia y Geofísica. Comunicaciones, pp. 95-106, I.G.N. Madrid, 1976.

|17| **Sevilla, M.J.,A.J. Gil, P. Romero** : Adjustment of the first order gravity net in Spain. II Hotine Marussi Symposium on Mathematical Geodesy. Pisa 1989.

|18| **Suzuki, H.**: Establishment of the Gravimetric Network in Japan;Bull. of the Geographical Survey Institute, vol. XX, part 1, Tokyo, 1974.

|19| **Tamura, Y.**: A computer Programm for calculating the Tide Generating Force; Pub. of the International Latitude Observatory, 16 200 Misuzawa, Japan, 1982.

|20| **Tamura, Y.**: A Harmonic Development of the Tide Generating Potential; Bull. d'informations de Marees Terrestres n. 99, p. 6813-6855, 1987.

|21| **Torge, W.**: Fundamentos, métodos y problemas de la gravimetría; V Curso de Geodesia Superior, Instituto de Astronomía y Geodesia, pp.1-83, Madrid, 1989.

|22| **Torge, W., R. M. Röder, M. Schnüll, H. G. Wenzel and J. E. Faller**: First results with the Transportable Absolute Gravity Meter JILAG-3; Bulletin Géodédique. n. 61, p. 161-176, 1987.

|23| **Uotila, U. A.**: Adjustments and analysis of Data for IGSN 71; Appendix II to the International Gravity Standardization Net 1971 (IGSN 71), by Morelli, Gantar, Honkasalo, McConnell, Tanner, Szabo, Uotila and Whalen, Special Publication n. 4, International Association of Geodesy, Paris, 1974.

|24| **Vieira, R.,J. M. Torroja and C. Toro:** A general discussion about the normalization of gravimeters in the Iberian gravity tide profile; Proceedings Tenth International Symposium on Earth Tides pp. 165-175. Madrid, 1986.

|25| **Vieira, R. and A. G. Camacho:** Corrección de las medidas gravimétricas por efecto de marea obtenida a partir de las observaciones efectuadas en la red Ibérica de mareas gravimétricas; Revista de Geofísica n. 44, pp. 119-128, Madrid, 1988.

|26| **Wahr, J. M.**: Deformation Induced by Polar Motion, JGR 90/B11, p. 9363-9368, 1985.

|27| **Whalen, C. T.**: Adjustments and analysis of Data for IGSN 71; Appendix III to the International Gravity Standardization Net 1971 (IGSN 71), by Morelli, Gantar, Honkasalo, McConnell, Tanner, Szabo, Uotila and Whalen, Special Publication n. 4, International Association of Geodesy, Paris, 1974.

|28| **Xi Qin Wen:** A new complete developement of the tide generating potential for the epoch J 2000.0. Bull. Inf. Marés Terrestres, 99, p. 6786-6812. 1987

|29| **Xi Qin Wen:** The precisionn of the development of the tidal generating potential and some explanatory notes. Meeting of working Group on "High Precision Tidal Data Processing", Bonn, 1988.

|30| **Xingli, S., H. Houtze and H. Zhangwei**: On the adjustment of National Gravity Fundamental Network in China, Bureau Gravimétrique International. Bulletin d'information no. 59, p. 129-132, Toulouse 1986.

REDUCTION OF THE SYSTEMATIC ERRORS CAUSED BY FLOOR-GRAVIMETER SYSTEM RESPONSE USING JILAG-4

G. Peter, F.J. Klopping, K.A. Berstis, and B. Bernard
National Geodetic Survey, Charting and Geodetic Services,
NOS, NOAA, Rockville, MD 20852

Abstract: Mathematical and mechanical filtering methods are being used by the U. S. National Geodetic Survey (NGS) to reduce the systematic errors caused by the floor-gravimeter system response. The application of the mathematical filter to absolute gravity data collected during the past 3 years (using the JILAG#4 absolute gravimeter) resulted in a 2 to 5 μGal average correction to the station gravity values. These corrections reduced the scatter (standard deviation) of the repeat observations about the mean station values to less than 3 μGal. The use of various mechanical filtering techniques during current station occupations has reduced the amplitude and decay time of the systematic noise by three-fold, which decreased the corrections that remained for the mathematical filter to capture normally to less than 2 μGal.

In the JILA-type absolute gravimeters (*Zumberge,* 1981, *Zumberge et al.,* 1982, *Faller et al.,* 1983, *Niebauer et al.,* 1986, and *Niebauer,* 1987) the release of the corner cube retroreflector from its resting position by the downward drive of its holding cart transmits a mechanical impulse to the floor. This impulse creates systematic variations in the optical path length between the two arms of the interferometer, which affects the measured positions of the falling corner-cube retroreflector, causing errors in the computed gravity.

The position errors of the retroreflector (least squares residuals) are computed and displayed for each of the 170 distance positions measured along a drop taken with JILAG#4 (*Peter et al.,* 1989). As these residuals are summed after each new drop for each respective distance position, they produce a typical, systematic "floor-gravimeter system response" (noise) signal, such as shown in Figure 1.

From spectral analysis of this noise signal it was found that it can be modeled by several decaying sinusoids in the 10 to 120 Hz range. The frequencies of the sinusoids are identified from the power spectra of the least squares residuals, and after their amplitudes, phases, and decay times are determined, they are removed iteratively from the time-distance data. The corrections to the gravity measurement are obtained from the least squares fitting of the corrected time-distance arrays (*Klopping et al.,* in press). A heavy line illustrates in Figure 1 the residuals left after the removal of the six dominant sinusoids representing the systematic noise in that data.

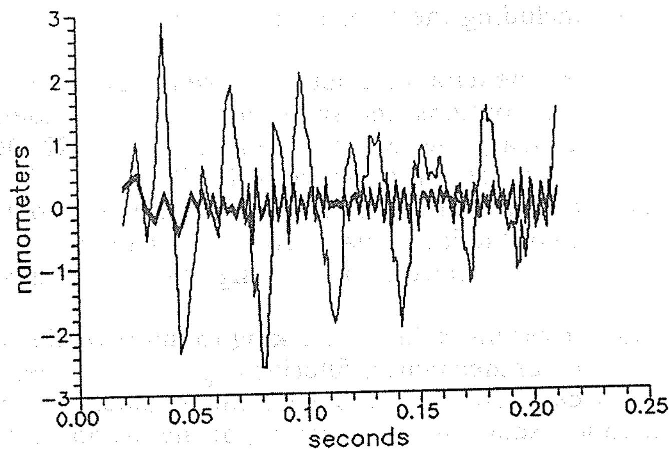


Figure 1. Comparison of the cumulative least squares residuals before (thin line) and after (thick line) the application of the mathematical filter.

It has been found that this systematic signal has generally site dependent characteristics which, nevertheless, can change if the instrument-floor system rigidity changes during or between site occupations. In order to have corrections that can accurately take into account the changes of this signal, the original controller of the gravimeter has been upgraded to be able to retain in the computer memory the time data for each distance position for each drop during a station occupation. With this capability achieved, we have been removing the system response and obtaining a gravity correction for each drop since December 1989.

For the old data, however, the time data required for the determination of the corrections are only available in the two 100-drop time-distance data sets, which were collected at the beginning and at the end of the station occupations. Usually, the averages of the corrections obtained from these two drop sets were used to correct the station gravity values. In those cases when a distinct step-like change in the character of the system response was noted, the corrections were extrapolated forward and backward to correct each drop set with its applicable system response. This was possible, because the plot of the cumulative residuals is available for inspection for each drop set (even though the original time measurements were not retained in computer memory for all sets).

To test the reliability of the corrections derived from only two drop sets at a given site, corrections were computed at four sites from 24 drop sets at each site (each containing 250 drops). These were compared to the correction obtained for the respective sites using all drops (6000). This analysis indicated that in more than 85% of the cases the corrections derived by the two methods were within 2 μGal of each other, which justifies the use of the limited data (beginning and ending drop sets) for correcting gravity station values (*Klopping et al.,* in press).

Some examples of the improvement of the scatter of the individual station gravity values about the station mean (or average where only two observations are listed), following the application of the system response corrections are shown in Table 1. The listed gravity values are the result of 2-day-long station occupations, during which 12 to 24 drop sets (250 drops each) were collected. The gravity values were corrected for all environmental effects, and the observations have been transferred to the floor mark. The measure of the scatter is the standard deviations listed. The uncertainties of each individual station gravity values are not shown; these were defined in *Peter et al.* (1989), and for the stations listed in Table 1 they are between 4 and 6 μGal (including the floor transfer error).

Because time data were not available to compute and show the system response corrections for all the occupations, the six occupations at Golden, CO (GOLDEN AA 979 571 132.1 μGal; $\sigma = \pm 1.2$ μGal), the five at Herndon, VA (HERNDON AA 980 094 796.2 μGal; $\sigma = \pm 0.8$ μGal), and the four at Gaithersburg, MD (WASHINGTON AA 980 103 261.0 μGal; $\sigma = \pm 0.4$ μGal), were not listed in Table 1. Based on the available corrections used and the small scatter (the σ values) of the individual gravity values about the station mean, further reoccupations of these sites are not expected to cause significant changes (>1 μGal) in their mean.

Another recent NGS undertaking to improve absolute gravity results involved the adoption of a number of mechanical filtering approaches. These were designed to reduce the effects of both the background and the equipment generated noise. Interferometer isolation, dropping chamber isolation, and damping of the dropping chamber legs were part of this effort.

To isolate the interferometer base from the floor, a set of approximately 3-mm thick, high-performance thermoplastic vibration isolation/damping pads were placed under the interferometer feet. In the technical specifications of this material a loss factor of 1 is listed for the 10 to 100 Hz frequencies (the range where the systematic floor-gravimeter response is at maximum), at the usual operating temperatures of 10 to 30°C. Additionally, a very rigid, three-layer, honey-combed aluminum platform was built from approximately 2 cm square, 3 mm thick aluminum box sections (separated by roughly 0.5 cm thick aluminum sheets) to put under

Table 1. Examples showing changes of the mean station gravity values and the reduction of the gravity differences among repeated station occupations, using the system response correction. The instrument was raised approximately 2-cm, and the observations were repeated at the sites marked with (*).

DATE	GRAVITY (BEFORE)	CORRECTION	GRAVITY (AFTER)
BYRD AA			
05/87 -	979 779 286.4 μGal	-5.6 μGal	= 979 779 280.8 μGal
04/88 -	979 779 281.4 μGal	-1.0 μGal	= 979 779 280.4 μGal
Means:	979 779 283.9 μGal		979 779 280.6 μGal
Standard deviations:	±2.5 μGal		±0.2 μGal
GREAT FALLS PARK AA			
05/87 -	980 113 812.1 μGal	-2.8 μGal	= 980 113 809.3 μGal
06/87 -	980 113 809.5 μGal	-1.9 μGal	= 980 113 807.6 μGal
04/88 -	980 113 809.9 μGal	-2.2 μGal	= 980 113 807.7 μGal
05/89 -	980 113 808.1 μGal	0.9 μGal	= 980 113 809.0 μGal
02/90 -	980 113 809.5 μGal	-0.6 μGal	= 980 113 808.9 μGal
Means:	980 113 809.8 μGal		980 113 808.5 μGal
Standard deviations:	±1.3 μGal		±0.7 μGal
BLACKSBURG AA			
07/87 -	979 715 437.0 μGal	-8.2 μGal	= 979 715 428.8 μGal
05/88 -	979 715 432.1 μGal	-4.2 μGal	= 979 715 427.9 μGal
05/88 -	979 715 424.3 μGal	2.8 μGal	= 979 715 427.1 μGal*
04/89 -	979 715 440.5 μGal	-9.0 μGal	= 979 715 431.5 μGal
Means:	979 715 433.5 μGal		979 715 428.8 μGal
Standard deviations:	±6.1 μGal		±1.7 μGal
CHARLOTTE AA			
05/88 -	979 728 644.1 μGal	-2.3 μGal	= 979 728 641.8 μGal
01/89 -	979 728 640.2 μGal	+0.3 μGal	= 979 728 640.5 μGal
Means:	979 728 642.2 μGal		979 728 641.2 μGal
Standard deviations:	±2.0 μGal		±0.7 μGal
BERGEN PARK AA			
10/87 -	979 469 129.8 μGal	-2.8 μGal	= 979 469 127.0 μGal
09/88 -	979 469 129.8 μGal	-2.2 μGal	= 979 469 127.6 μGal
Means:	979 469 129.8 μGal		979 469 127.3 μGal
Standard deviations:	±0.0 μGal		±0.3 μGal
McDONALD AB			
01/89 -	978 820 084.7 μGal	-1.4 μGal	= 978 820 083.3 μGal
01/89 -	978 820 089.4 μGal	-3.6 μGal	= 978 820 085.8 μGal *
Means:	978 820 087.1 μGal		978 820 084.6 μGal
Standard deviations:	±2.4 μGal		±1.3 μGal

the interferometer. The triangular shaped platform is approximately 130 cm on its sides, 8 cm thick, and weighs 90 kg. The isolation of the platform from the floor was provided also by a column of shock dampening materials.

To reduce the transfer of the impulse and vibrations from the dropping chamber to the floor, a 2-cm thick aluminum pad in combination with the isolation and damping pads (described above) were used under the feet of the dropping chamber tripod. The vibrations of the tripod legs were further reduced by forcing three flexible polyethylene-foam braces between the dropping chamber housing and the legs. The "v" grooves on the top of the tripod feet (into which the ball of the tripod legs are placed) were aligned radially with the center of the dropping chamber, and were lubricated to facilitate further energy dissipation.

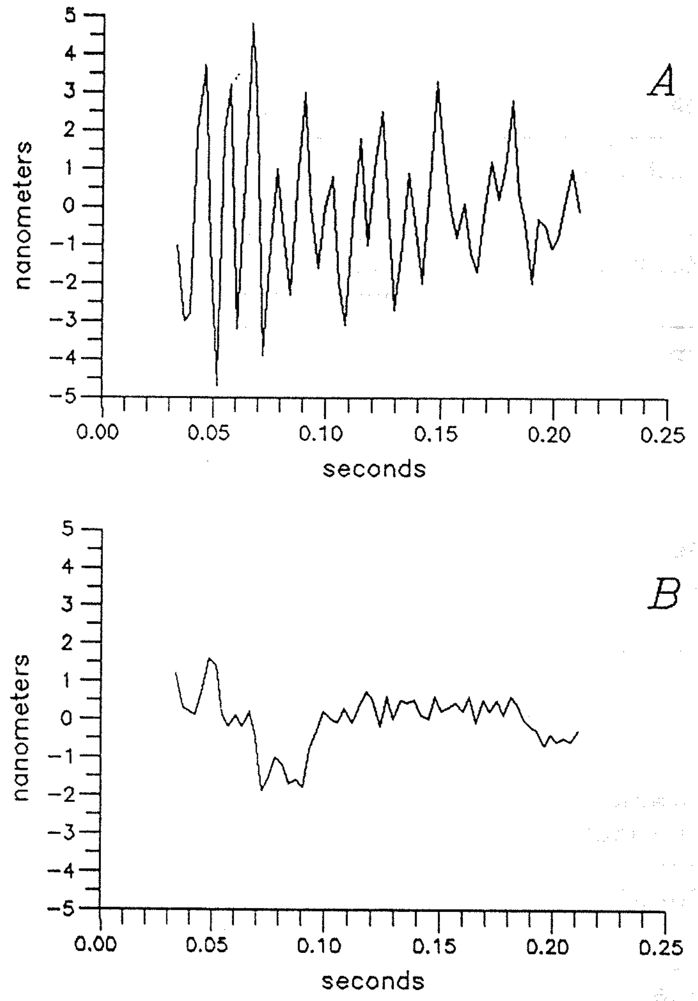


Figure 2. Floor-gravimeter system response signal in the least squares residuals without (a) and with (b) the use of mechanical damping materials.

The reduction of the systematic noise in the least squares residuals with these mechanical noise reduction schemes in place is illustrated in Figure 2. At several recent station occupations we have been able to achieve a noise reduction level that is similar to that shown in Figure 2, without the use of the platform. The platform will serve as a backup at sites where the system response noise is exceptionally large due to the weakness of the floor. The value of these shock dampening devices is further validated by the fact that since their use the system response corrections computed by mathematical filtering has been reduced to a value usually less than 2 μGal.

Niebauer (1987) measured the dropping chamber vibrations and floor recoil in the JILA laboratory, and discussed the systematic errors of the JILA gravimeter in detail. For his observations in the JILA laboratory he estimated an error of 0.7 μGal due to the air-vacuum interface modulation, and an error of 1.0 μGal due to the systematic tilts of the interferometer base. Our analysis of more than 6000 drops at JILA gave a combined floor-gravimeter system response correction of 2.2 μGal, which is within a factor of two of the *Niebauer* (1987) error estimate.

In the process of computing the system response corrections for about 50% of our gravity station occupations, thus far we have found corrections in the 2 to 5 μGal range quite common even at sites where the gravity station is located on bedrock. Corrections as large as 9 and 17 μGal were also obtained. Using synthetic gravity data, created by adding 1-nanometer amplitude sine waves to a perfect acceleration parabola (Figure 3) and least squares fitting the resulting data (*Klopping et al.*, in press), also indicates that errors larger than 20 μGal could occur due to the commonly observed, 10 to 30 Hz range, systematic oscillations. These results support *Niebauer's* (1987) suggestion that in addition to instrumental bias and environmental effects, different response to systematic floor oscillations could also be responsible for some of the previous gravity differences obtained by different instruments occupying the same site.

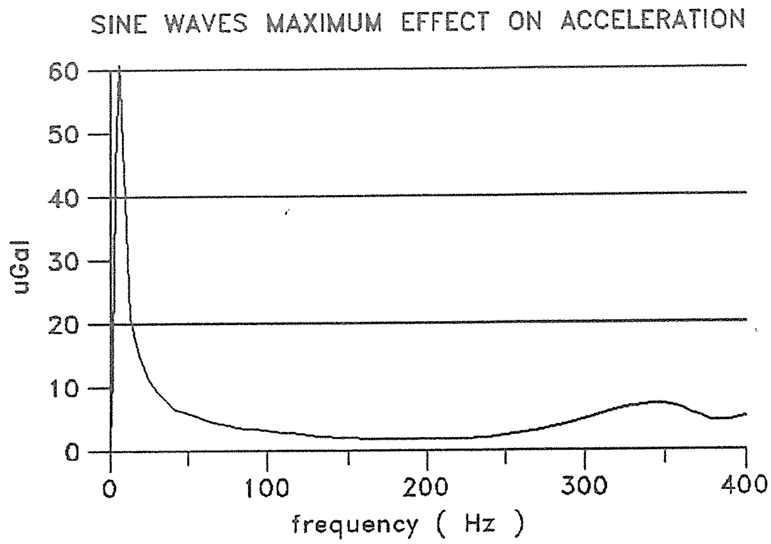


Figure 3. Effect of systematic noise on a 0.2 second long gravity acceleration measurement. Frequencies (0 to 400 Hz; phases varied to obtain max. effect) were added one at a time.

The mathematical filtering program and technical details of the damping materials are available by writing to the authors.

REFERENCES

Faller, J.E., Y.G. Guo, J. Gschwind, T.M. Niebauer, R.C. Rinker, and J. Xue, The JILA portable absolute gravity apparatus, *Bur. Grav. Int., Bull. d'Inf., 53,* 87-97, 1983.

Klopping,, F.J., G. Peter, D.S. Robertson, K.A. Berstis, R.E. Moose, and W.E. Carter, Improvements in absolute gravity observations, *J. Geophys. Res.* (in press).

Niebauer, T.M., New absolute gravity instruments for physics and geophysics, *Ph.D. Dissertation, Univ. of Colorado, Boulder,* 155 pp., 1987.

Niebauer, T.M., J.K. Hoskins, and J.E. Faller, Absolute gravity: A reconnaissance tool for studying vertical crustal motions, *J. Geophys. Res., 91,* 9145-9149, 1986.

Peter, G., R.E. Moose, C.W. Wessells, J.E. Faller, and T.M. Niebauer, High-precision absolute gravity observations in the United States, *J. Geophys. Res., 94,* 5659-5674, 1989.

Zumberge, M.A., A portable apparatus for absolute measurements of the Earth's gravity, *Ph.D. Dissertation, Univ. of Colorado, Boulder,* 134 pp., 1981.

Zumberge, M.A., R.L. Rinker, and J.E. Faller, A portable apparatus for absolute measurements of the Earth's gravity, *Metrologia, 18,* 145-152, 1982.

SOFTWARE REVIEW

A POWERFUL COMMERCIAL SOFTWARE FOR GRAVITY DATA VALIDATION ON A MICRO-COMPUTER : SURFER

C. Poitevin
Centre de Géophysique Interne
Observatoire Royal de Belgique
Avenue Circulaire 3
B-1180 Bruxelles
BELGIUM

During the workshop "Gravity Data Validation" held at the Bureau Gravimétrique International (BGI) in Toulouse on October 17-19, 1989, the efficiency of the new validation tools available now at BGI was shown. More than 10.000 lines of FORTRAN code have been written by the BGI staff. This software is running on a CDC-Cyber mainframe equipped with a Tektronix high resolution graphic colour terminal and a thermic colour printer. Other participants to the workshop presented also their sophisticated tools for gravity data validation developed on powerful mainframes too.

As everybody doesn't necessarily have access to such powerful software - and hardware at his office, I explained how I am performing gravity data validation "at home", how it is possible to perform this task on a PS/2 or PC compatible by using a low cost (US$ 499) commercial integrated software : SURFER. As a result, I was asked to make a review of this package.

In order to be reasonably short, in spite of the wider capabilities of SURFER, I will restrict the explanations to its use for gravity data validation. A few other features useful for gravimetry will be mentioned too.

More details should normally be available from the maker :

Golden Software, Inc.
807 14th Street P.O. Box 281
Golden, Colorado 80 402 U.S.A.
Tel : (303) 279-1021
1-800-333-1021 (toll free)
Fax : 303-279-0909

The tested version of SURFER is version 4.14 dated 1989. The minimum hardware requirements are an IBM PC, XT, AT, PS/2 or compatible with at least 320 kb of RAM, DOS 2.0 or higher, at least one double-sided disk drive and... a printer or a plotter. Though graphics card is not necessary, it is more advisable not to work in a blindly way and to take advantage of the power of the package.

I ran it on a Zenith 386 with co-processor 387, VGA screen and HP-7550A plotter, on a Zenith Supersports 286 with CGA-LCD screen, on a Sperry micro-IT (286) with co-processor 287, EGA screen and NEC 7 + Pro-printer and on a PS/2 50 (286) with co-processor 287, VGA screen and IBM Pro-printer X24 : the different experiences were successful. Most of the screen, printer and plotter drivers are included in the package. Golden Software proposes new drivers for output devices at the price of US$ 10 or if necessary you can - as written in the advertising - contact them. A hard disk is highly recommended for fast processing : SURFER will only occupy 1.35 Mb including the demo files, it is really not too much regarding the possibiities of this software. The same recommendation applies for the math co-processor which will be used automatically if present. In fact most of the devices are automatically recognized by the software in such a way that the installation is very easy and very fast. Just copy the files on the chosen directory, run the install program to select your printer or plotter. You are ready to start !

There is no need at this stage to read the extensive Reference Manual, even the reading of the "Getting Started and Tutorial" booklet is not really necessary. Simply type SURFER then press the ENTER Key. You are now under the SURFER umbrella, a self-explanatory menu driven program allowing more than 100 options. At any step, you can use the help key (F1) for a full screen of explanation and examples for the selected options.

SURFER proposes six main programs you can access separately if you wish : GRID, TOPO, SURF, VIEW, PLOT and UTIL.

Enter the data - up to 14000 rows and up to 26 columns - from an ASCII free format data file, Lotus 1-2-3 file or in the GRID's worksheet from the keyboard. Compute on the data by column using arithmetic, trigonometric and logarithmic functions, random number... Bessel functions... taking into account that only seven digits of precision will be displayed correctly in the work sheet. Choose which columns will be the X, Y and Z components. Then GRID interpolates a regularly spaced matrix (in binary or ASCII format) from irregularly spaced data on the basis of either the inverse distance, the minimum curvature or the Kriging method. For each method a sub-menu allows the user to adjust parameters for the interpolation. In this part of the program the help of a math co-processor is appreciable. The computation time can grow up from minutes to hours depending on the hardware configuration, the computation method, the number of input data points and the number of expected gridded points. For instance, on a PS/2 50 (80286) with co-processor (80287) for about 600 points, to generate a 30 x 25 grid takes around 3 minutes by the kriging method, the most time consuming one. Once the grid file is created, you can smooth the matrix, blank some parts of it and create a new grid by mathematically combining corres-ponding elements of two grids according to your own specified function.

Now select TOPO or SURF, then press the F2 key.

In a few seconds or less, thanks to the default parameters included in the program, you will see on the screen a first look of the 2D-contour map or the 3D-surface representation of your data depending on your choice, TOPO or SURF respectively. Now it's a game to go through the multiple options of the software to adjust the size, change colours, add legends, etc... to customize the drawing. But the most important option for gravity data validation is the POST option. This option allows to display with symbols and labels the (X,Y) locations of the original data points or other data sets. TOPO and SURF allow ten blocks in a posting file. It means it is possible to assign to each block different symbols, colours, etc... to, for instance, the base stations and the detail stations of a network or to different networks you want to merge together ; etc...

Using the POST options on the original data set and provided the grid interval suits well to the mean distance between stations, it's a pleasure to see peaks appearing on the screen with the label of the "erroneous" data. To improve the legibility, zoom on the interesting parts of the networks by using some artfulness of the drawing options (explained in the Reference Manual !). Now it is a question of experience and feeling : is a peak a peak or an error ?... In case of doubt, the option "residuals" of the UTIL program is able to produce a file of residuals (Z[obs] - Z[comp]) and a log file giving the mean and the standard deviation of the residuals.

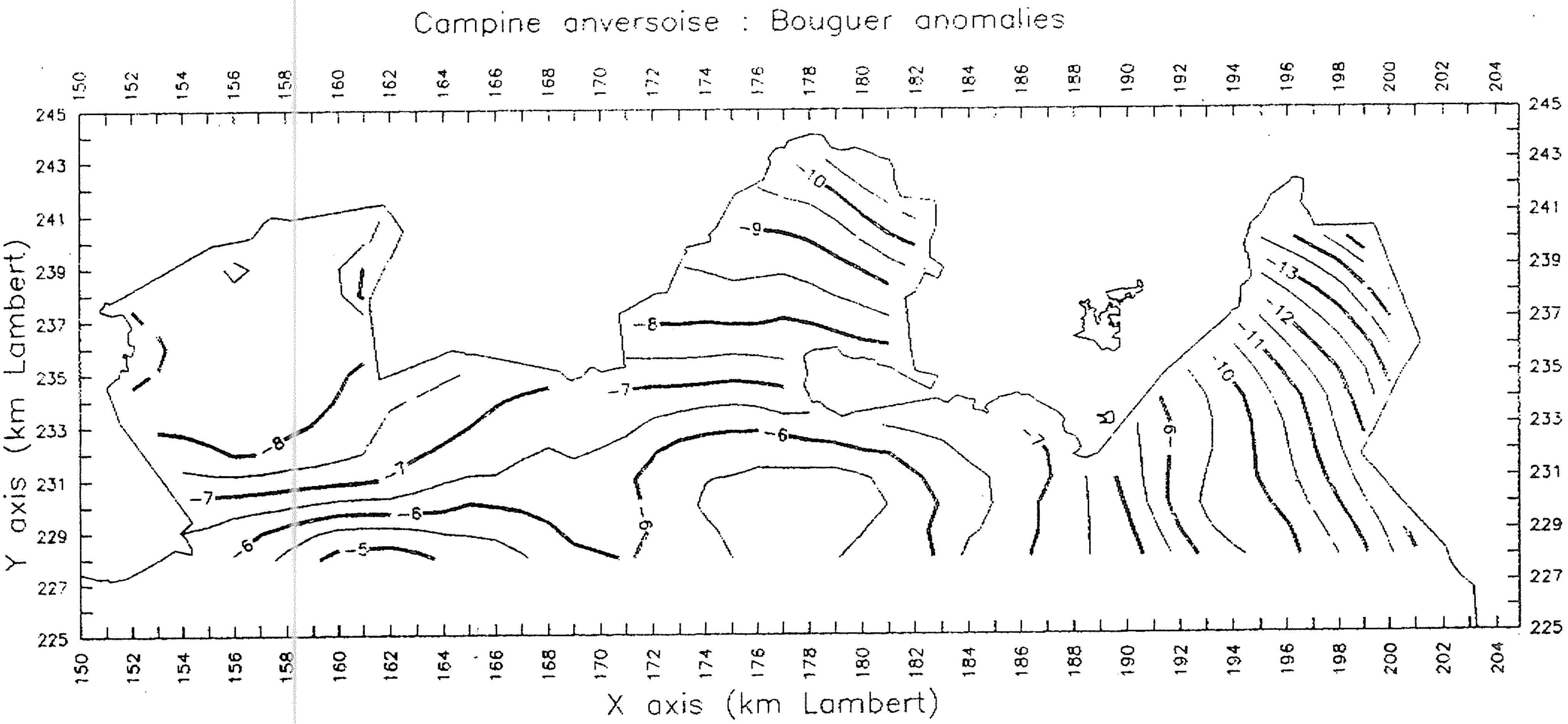
The output option produces a plot file that can be used by the PLOT program to draw on a plotter or a printer ; in this case the plot file is optimized for the installed printer. It is possible to scale again the drawing with PLOT or to produce panel sections that may be attached to each other to form a plot of any size.

The VIEW program shows the plot as it will appear on the output device. It works as a debugger for the plot files with some more capabilities as for instance a very useful zoom command and the possibility to digitize in user's coordinates any point on the viewing screen with the graphics pointer.

Once the bad data are detected, you will have to cancel them in the original file and start again all the process from the GRID program. There is no true interactivity in the SURFER package ; on the counterpart you can create a batch file to avoid entering the same parameters on each pass. May be the next improvemed version of the package will have interactive capabilities ?

Another feature of the software that can be useful for gravimetry is the slice option of the UTIL program. It allows to create a cross-section file across a grid that can be used by the GRAPHER package (2D), another product of Golden Software, Inc. But this is another story !

Just to have an idea of what SURFER is able to do in a 30 mn session have a look to figure 1 : a map of gravity anomalies in a northern area of Belgium. Better and different graphs can be found in the advertising of the maker but it is not my intention to describe them all.



63

FIGURE 1 : CARTE DES ANOMALIES DE BOUGUER (EN MGALS).