ASSOCIATION INTERNATIONALE DE GÉODÉSIE

BUREAU GRAVIMETRIQUE INTERNATIONAL

BULLETIN D'INFORMATION

N° 53

DECEMBER 1983

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 type-script 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 the margin. Bars cannot be set over superscripts or extended over more than one character. Therefore angle brackets are preferable to overbars to denote averages, and superscript symbols (such as $*$,', and $\neq$) are preferable to accents over characters. Care should be taken to distinguish between the letter O and zero, the letter l and the number one, kappa and k, mu and the letter u, nu and v, eta and n, also subscripts and superscripts should be clearly noted and easily distinguished. Unusual symbols should be avoided.

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

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, 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 referred to in the text.

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.

B U R E A U   G R A V I M E T R I Q U E

I N T E R N A T I O N A L

Toulouse

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B U L L E T I N   D ' I N F O R M A T I O N

Décembre 1983

N° 53

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Bull. d'Inf. n° 53

PART III : *CONTRIBUTING PAPERS*

ANNOUNCEMENT

FIRST CIRCULAR

INTERNATIONAL SUMMER SCHOOL ON LOCAL GRAVITY FIELD APPROXIMATION

Beijing, China

August 21 - September 4, 1984

The Chinese Society of Geodesy, Photogrammetry and Cartography will organize the International Summer School on Local Gravity Field Approximation in Beijing, the capital of China, from August 21 to September 4, 1984 (called Beijing International Summer School for short).

A. Some famous specialists such as Prof. Dr. H. Moritz (Austria), Prof. Dr. K.P. Schwarz (Canada), Prof. Dr. R. Rummel (The Netherlands), Prof. Dr. E. Grafarend (F.R.G.), Prof. Dr. E. Groten (F.R.G.), Prof. Ning Jinsheng (China), Prof. Xu Houze (China), Dr. G. Hein (F.R.G.), Dr. G. Lachapelle (Canada), Mr. C.C. Tscherning (Denmark) and so on, will be invited to provide lectures in the Summer School.

B. The main lectures are as follows :

1. Mathematical structure of the problem
2. Requirements for reliable local gravity field representations
3. Data types and their spectral properties
4. Least-squares collocation
5. Integration approaches
6. The effect of the earth tide on the local gravity field
7. New numerical techniques
8. The local gravity field in the concept of integrated geodesy

...

C. After the Summer School, a four-day excursion will be organized. The participants may choose one of the following two excursion lines :

1. Beijing - Guilin - Guangzhou (exit from China)
2. Beijing - Hangzhou - Shanghai (exit from China).

D. All the expenses for the participation including registration, travelling, accommodation and others will be borne by each participant himself (see second circular - to come, in detail).

If you are willing to participate to the Beijing International Summer School under the above-mentioned economic condition, please send your application (with your address and telex number) to our Society as soon as possible.

Dr. J.Y. CHEN
Secretary General

Address : Chinese Society of Geodesy,
Photogrammetry & Cartography
Baiwanzhuang, Beijing
The People's Republic of China

Telephone : 8992185

Telex : 22477 CSCEC CN c/o M

SECOND CIRCULAR

International Summer School on Local Gravity Field Approximation (called Beijing Summer School for short) is scheduled to be held in Beijing, the capital of the People's Republic of China, from August 21 to September 4, 1984 under the support of National Bureau of Surveying and Mapping, the People's Republic of China, International Union of Geodesy and Geophysics and International Association of Geodesy.

This circular is intended to give you some detail on the program of the Summer School and to send you an application form.

TIME : *August 21-September 4, 1984*

PLACE : *Beijing, the capital of the People's Republic of China*

ORGANISER : *Chinese Society of Geodesy, Photogrammetry and Cartography*

SPONSOR : *International Union of Geodesy and Geophysics (IUGG)*
International Association of Geodesy (IAG)

SUPPORTING ORGANIZATION :

National Bureau of Surveying and Mapping (NBSM)
The People's Republic of China

LECTURERS :

Prof. Dr. E. Grafarend (FRG)
Prof. Dr. E. Groten (FRG)
Prof. Dr. G. Hein (FRG)
Dr. G. Lachapelle (Canada)
Prof. Dr. H. Moritz (Austria)
Dr. M. Neyman (USSR)
Prof. Ning Jinsheng (China)
Prof. Dr. R. Rummel (Netherlands)
Prof. Dr. K.P. Schwarz (Canada)
Prof. Dr. Sunkel (Austria)
Dr. C.C. Tscherning (Denmark)
Prof. Xu Houze (China)

TOPICS :

1. Theory of local gravity field determination by data combination
2. Data types and their spectral properties
3. Least-squares collocation
4. Integration approaches
5. The effect of the earth tide on the local gravity field
6. New numerical technique
7. The local gravity field in the concept of integrated geodesy
8. From the observational model to gravity parameter approximation
9. Model refinements

...

Lectures and seminars are scheduled at 8 - 12 and 14 - 17 from Monday to Friday. The lecture notes will be provided to participants at the registration desk in the hotel.

ORGANIZER OF LECTURES : Prof. Dr. K.P. SCHWARZ

LANGUAGES : English and Chinese

REGISTRATION FEE :

Participant...........................	150 U.S. Dollars per capita
Accompanying person...................	80 U.S. Dollars per capita

ACCOMODATION :

500 U.S. Dollars per person - includes full board at the hotel where the Summer School takes place (Aug. 21 - Sept. 4, 1984). There are only double rooms with individual bathes in the hotel. If you do not want to share a room, an extra charge of 350 U.S. Dollars will be asked.

SIGHTSEEING AROUND BEIJING

will be arranged for accompanying persons, for which a reasonable amount of transportation fee will be charged. Detailed information will be provided in the next circular.

EXCURSION :

after the Summer School : two excursion lines will be arranged for choosing :

A. Beijing-Guilin-Guangzhou (Sept. 5-8, 1984)
350 U.S. Dollars per person - includes airtickets, all accomodation and tickets for sightseeing

B. Beijing-Hangzhou (Sept. 5-8, 1984)
250 U.S. Dollars per person - includes airtickets, all accomodation and tickets for sightseeing

APPLICATION FORMS :

should be sent to Dr. J.Y. CHEN at the address given in the first circular before the end of February 1984. Due to the limited number of rooms, the number of participants is limited and application will be accepted in the temporal order of reception. Therefore, early application is recommended and the third circular with registration form will be only sent to those who will returned application forms.

Dr. J.Y. CHEN
Secretary General

APPLICATION FORM

1. **Participant**

Surname :

Sex :

Given name :

Date of birth :

Title :

Nationality :

Organization :

Address :

Country :

Telephone :

Telegram :

Telex :

2. **Accompanying Person**

Name :

Date of birth :

Nationality :

☐ I'd like to joint the sightseeing around Beijing

3. **Accomodation**

I'd like to share a room with

4. **Excursion**

I'd like to take part in excursion A ☐

excursion B ☐

cont'd

5. Arrival and Departure

I will arrive in Beijing on August , 1984

by Flight n°

by Train n°

I will depart China from on Sept. 1984

by Flight n°

by Train n°

note : It is recommended to arrive in Beijing not later than August 20, 1984, since the lectures will start early on August 21.

Please return this form at your earliest convenience to :

Dr.J.Y. CHEN
Secretary General
Chinese Society of Geodesy, Photogrammetry & Cartography
Baiwanzhuang, Beijing
The People's Republic of China

Telephone : 8992185, 8992167, 8992229
Telegram : 2424 Beijing China
Telex : 22477 CSCEC CN c/o SM

PART I : *INTERNAL MATTERS*

NEW OFFICERS AND MEMBERS OF IGC, DB/B.G.I. & B.G.I./WG.

The informations below are taken from a circular letter of September 30, 1983 by J. Tanner, and may not be definite. The official version will be published in the next Geodesist's Handbook (to appear at the end of 1984).

1. New officers of the International Gravity Commission

President	:	*J.G. Tanner*
Vice-President	:	*J. Krynski* *H.T. Hsu*
Secretaries	:	*D. Ajakaiye* *C. Morelli*

2. Members of the Bureau Gravimétrique International

Elected	:	*J. Woodside* *I. Nakagawa* *C. Morelli* *J. Krynski*
Ex-officio	:	*W. Torge* *G. Balmino* *C. Tscherning* *J.G. Tanner (Chairman)*

3. Chairmen of the B.G.I. Working Groups

WG. 1 - Collection of gravity data..................	*R.K. McConnell*
WG. 2 - Gravity standards - Networks................	*U. Uotila*
WG. 3 - World gravity maps 1° x 1° and 5° x 5° means.	*J.D. Boulanger*
WG. 4 - Gravity anomaly prediction..................	*L. Wilcox*

EXTRACTING GRAVITY DATA FROM THE B.G.I. DATA BANK

J.F. ISAAC

As explained in Bulletin d'Information N° 50 (pages 122-125), gravity data are stored by B.G.I. in two different forms : the Archive Files and a Compressed Gravity Data File (CGDF). Depending on the kind of informations needed to satisfy a user's request, data will be extracted interactively from the CGDF or by means of a batch process from the archive files. This led us to the definition of two different standard exchange formats for the extracted data.

A) From the Archive files

In order to make easier the data manipulation and to adopt some homogeneity in the data informations within the archive files, the data exchange formats defined by BRGM in 1976 (also given in B.I. n° 50 pages 112-113) are no longer used. Instead of these two formats, a unique full-information format has been defined for both terrestrial and marine measurements. Each gravity point is described by a 160 character record, as detailed in Annex A.

Also, it has to be noted that, due to some reorganization within BRGM all request for data from these archive files should be addressed to the Bureau in Toulouse from January 1, 1984 on.

B) From CGDF

CGDF is disk-resident and contains only the informations needed for the most frequent kinds of retrievals performed at BGI. A standard format has been defined for data extracted from CGDF, each record being 60 character long (annex B). Information such as the g value can be easily recomputed using the formulas given at the end of annex A. Additional information about each source corresponding to the extracted data can be obtained in printed form (see Annex C).

Any data from CGDF have also to be requested to the Bureau in Toulouse.

ANNEX A

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)

Col. 30- 31 Type of observation

A minus sign distinguishes the pendulum observations from the gravimeter ones.

0 = Current observation of detail or other observation of a 3rd 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 national 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 below sea level)
D = Ice cap (bottom above sea level)
E = Transfer data given

33- 39 Elevation of station (0.1 M)

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

Col. 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
2 = Trigonometrical 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 Mathews' 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 Basses/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

Col. 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, Eotvos 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 or base)

This zone will reveals 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

Col. 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 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 or 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 world wide
56 = Cak
57 = Canadian gravity meter, sharpe
58 = GAG-2

6.. Gravimeters for underwater 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

Col. 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

Col. 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 (Heikanen'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 Eotvos correction (0.1 mgal)

Col. 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	Flag (internal use)
150-154	Original source number (ex. D.M.A. Code)
155-160	Sequence number

Note 1 : Theoretical gravity (g0) :
The approximation of the closed form of the gravity formula 1967 is used for theoretical gravity at sea level :
$g0 = 978031.85*(1 + 0.005278895*\sin^2(\phi) + .000023462*\sin^4(\phi))$ mgal

Note 2 : Free air anomaly
To reduce gravity to sea-level, we use the normal gradient of gravity or "free-air" correction : + 0.3086*H mgal ; H is in meters and positive down to the geoid. The free air anomaly is derived from :
g + 0.3086*H-g0

Note 3 : Simple bouguer anomaly
The simple bouguer anomaly is derived from : g + 0.3086*H - 0.1119*H-g0, The term 0.1119*H is the attraction of an infinite flat plate, thickness H and with standard density 2.67 g/cm^3

Note 4 : Formulas used in computing free-air and bouguer anomalies

Elev Type	Situation	Formulas
1	Land Observation	FA = g + 0.3086*H - g0 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 - g0 BO = FA + 0.06886*H (H = depth of ocean positive downward from surface)
4	Ocean submerged	FA = g - 0.2225*D2 - g0 BO = FA + 0.06886*H (D2 = depth of instrument positive downward) (H = depth of ocean positive downward)
5	Ocean bottom	FA = g - 0.2225*D1 - g0 BO = FA + 0.06886*D1 (D1 = depth of ocean positive downward)
6	Lake surface (above sea level)	FA = g + 0.3086*H - g0 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) - g0 BO = FA - 0.04191*D1 - 0.1119*(H-D1)
8	Lake bottom (below sea level)	FA = g + 0.08382*D1 + 0.3086*(H-D1) - g0 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 - g0 BO = FA - 0.04191*H - 0.06999*(H-D1)
A	Lake surface (below sea level)	FA = g + 0.3086*H - g0 BO = FA - 0.1119*H + 0.06999*D1
B	Lake bottom (surface below sea level)	FA = g + 0.3086*H - 0.2248*D1 - g0 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 - g0 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 - g0 BO = FA - 0.03843*D1 - 0.1119*(H-D1) (D1 = depth of ice)

ANNEX B
CGDF RECORD DESCRIPTION
60 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 a mean density of 2.67 - No terrain correction.

Col. 44-45 Estimation standard deviation bouguer anomaly (mgal)

46 System of numbering for the reference station

1 = IGSN 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

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.

ANNEX C
EXAMPLE OF SOURCE DESCRIPTOR

Source number : 2000004

Land data from Africa

Origin D.M.A. 25

Number of stations : 77

Archive : 03007

TITLE
E.C. BULLARD
GRAVITY MEASUREMENTS IN EAST AFRICA
CAMBRIDGE UNIVERSITY
1936

GEOGRAPHICAL EXTENSION	LATITUDE -90 - 90 DEGREES	LONGITUDE -180 - 180 DEGREES
MINIMUM	-9.6000	29.3667
MAXIMUM	4.9333	40.1167

TYP	NB STAT	C C	COUNTRY NAME	NB STAT	REFERENCE	NB STA
1	77	050	ZAIRE	9	4 320	25
		048	UGANDA	12	4 1220	52
		043	SUDAN	2		
		022	KENYA	23		
		045	TANZANIA	31		

ANOMALIES	MINIMUM	MAXIMUM	NB EVAL	MIN EVAL	MAXI EVAL
FREE AIR	-131.9	91.1	77	4	4
BOUGUER	-237.9	-20.4	77	4	4

STATIONS WITH DENSITY # 2.67	0
STATIONS WITH TOPOGRAPHIC CORRECTION	0
STATIONS WITH ISOSTATIC ANOMALY 1	0
STATIONS WITH ISOSTATIC ANOMALY 2	0

PART II

THE 11TH MEETING OF THE

INTERNATIONAL GRAVIMETRIC COMMISSION

HAMBURG 10-13 AUG., 1983

PROGRAM

10 Aug., BGI Working Groups

WG1 : 9.00 ; WG2 : 10.30 ; WG3 : 14.30 ; WG4 : 16.00.

11 Aug., 9.00

1. Activity report on I.G.C. including reports and programs of Sub-Commissions...........	Morelli, Presidents S.C.
2. Reports on B.G.I..........................	Balmino (2)
3. Reports on B.G.I. Working Groups...........	McConnel, Uotila, Boulanger, Wilcox

11 Aug., 14.30

4. Absolute measurements	
4.1. Technical improvements................	Faller et al., Ogier & Sakuma
4.2. Comparison results...................	Boulanger
5. Special meeting of the Sub-Commission for Western Europe	

12 Aug., 9.00

6. Non-tidal gravity variations..............	Boulanger, Xu, Ogier
7. I.G.S.N..................................	Boulanger, Ogier
8. New nets and adjustments. Statistical studies..................................	Goad, Ruess, Ogier, Heineke

12 Aug., 14.30

9. New gravimeter instrumentations & improvements................................	Betz, Boedecker, Becker, Kangieser, Geri, Hipkin, Xu-Jusheng
10. Microgravimmetry.........................	Hsu

13 Aug., 9.00

11. Marine gravity...........................	Almazan, Dehghani, Makris
12. Various items	
13. Proposal and resolutions	
14. Program on the next quadriennal	

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II.1. MINUTES OF WG. 1, WG. 2, WG. 3, WG. 4, AND DIRECTING BOARD AND ACTIVITY REPORT OF I.G.C.

BUREAU GRAVIMETRIQUE INTERNATIONAL (BGI)
WORKING GROUP NO. 1 (WG1)
DATA PROCESSING AND EVALUATION

Meeting of 10 August 1983
Hamburg, Federal Republic of Germany

Attendees:

G. Balmino
J. Faller
I. Marson
R. K. McConnell
C. Morelli
I. Nakagawa
M. Ogier
M. Sarrailh
L. Wilcox

The Convenor of WG1, R. K. McConnell, presided.

McConnell complimented the BGI on Bulletin d'Information No. 50 which provides an excellent and comprehensive description of the BGI data base operations and status.

There being no follow-up actions pending from the May 1982 meeting of WG1 at Tokyo, McConnell requested that Balmino report on the current status at the BGI, identify issues affecting the BGI and ways in which WG1 can provide support, and comment on a July 1982 letter from C. C. Tscherning to the BGI that discusses some aspects of the BGI data base system.

Balmino said he would confine his remarks on BGI activities to items of interest to WG1. Major efforts at the BGI have been directed at setting up a new data base and data management system and collecting new gravity data. The data management system was built up from scratch.

The first effort in setting up the data base consisted of merging DMA data sent during 1979 with the original BGI data. The data merging was done in a kind of brute force way but the results are quite satisfactory. It was assumed that the DMA data was better when no independent evaluation could be made.

Two data bases now exist at the BGI. There is an archival data base that includes all data just as it was received from all sources. Since much identical data has been received from different sources, there is considerable duplication of data within the archival data base. A second file known as the routine data base is derived from the archival data base. It contains the most important data for scientific uses with descriptive flags and key words. There is no duplication in the data base.

McConnell asked which data base is used to satisfy requests for data. Balmino replied that the archival file is usually sent. Wilcox thought it might be better to send the routine data file since the user may not be able to sort out duplication or evaluate the raw data contained in the archival data base. McConnell agreed that the archival data base could be confusing to the users. Balmino replied that users have not complained nor asked for clarifications.

McConnell and Wilcox pointed out that it is not clear from instructions given to date in the Bulletin d'Information that there are two data bases available. McConnell said he plans to visit the BGI in the near future. At this time he will obtain details on the nature of the routine and archival files and report his findings back to the WG1. It is clear that complete information and recommendations to users with respect to the two data bases should be published in the Bulletin. Balmino will publish a clear definition and formats for the two files in the near future, but any recommendations to users will be held pending further WG1 action.

Faller asked about the uncertainty of gravity data held by the BGI. Balmino replied that the data had various accuracy ranging from excellent to poor, and that the DMA data includes accuracy estimates.

Morelli asked whether it is possible to select data suitable for producing Bouger gravity anomaly maps. Balmino said he could do so.

Balmino announced that the BGI has collected some important new gravity data. Data has been obtained for Australia, Finland, Italy, Japan, Canada, the United Kingdon (U.K.), France, and various African territories. The data from Finland was collected from A. Kiviniemi. The Italian data is a 1980 data set. A new complete data set has been obtained for Japan. The material from the U.K. includes the best new data sets and covers about one-third of the territory of the U.K. The data collected from France is the 60% of such data for which digitization has been completed. The remainder of the French data will be digitized in the next year or so. Some marine data has also been collected. This includes Russian cruises in the Pacific and South Atlantic.

A new policy of accepting data having distribution restrictions has been instituted to enable the BGI to have the largest possible data set for mean gravity anomaly computation. To date, restricted distribution data has been received from Canada and Finland. It is hoped that this initial response will encourage people from other countries to contribute data to the BGI.

About 100 personalized circulars have been sent to all national representatives in an attempt to collect additional data. Four types of requests were sent. One type was sent to countries that have contributed a lot of data and requested them to keep in touch with respect to any additional data that may be generated. A second type was sent to countries that have contributed partial data sets. These circulars reiterated the BGI data collection mandate and requested transmission of additional data. The third type was sent to countries that have provided no recent gravity data, and the fourth to countries that have contributed nothing. The third and fourth types were more emphatic with respect to the data request. Attached to the circulars, which were sent in late June and early July, was a list of sources contributed by each country. It was quite a task to assemble these country listings since the data is not stored by country.

In summary, Balmino requested WG1 to publicly emphasize the continuing need for the BGI to collect continental gravity data for geophysical purposes.

With regard to Tscherning's remarks, Balmino thought it might be advisable to modify the BGI data exchange format. There are two possibilities. Either the user can extract only the data he needs from a standard format, or the user can request only the data he needs. Wilcox suggested that the WG1 might look at some details in the data exchange format.

L. E. WILCOX
Recorder

R. K. MCCONNELL
Convenor

BUREAU GRAVIMETRIQUE INTERNATIONAL (BGI)
WORKING GROUP NO. 2 (WG2)
WORLD GRAVITY STANDARDS

Meeting of 10 August 1983
Hamburg, Federal Republic of Germany

Attendees:

G. Balmino
J. D. Boulanger
J. Faller
I. Marson
R. K. McConnell
C. Morelli
I. Nakagawa
M. Ogier
M. Sarrailh
L. Wilcox

C. Morelli presided in the absence of U. Uotila, the Convenor of WG2.

Morelli announced that Uotila was ill and unable to travel to Hamburg. He suggested that WG2 send a cable to Uotila expressing the group's best wishes and sentiments. There was unanimous agreement. Faller was appointed to draft the cable.

Morelli presented Uotila's recommendations for the International Absolute Gravity Basestation Network (IAGBN). The purpose, site selection criteria, and other specifications are published on p. 10-12 of the International Gravity Commission (IGC) Activity Report 1979-82 prepared by C. Morelli. Action proposed with respect to the IAGBN is on page 12 of this report. Suggested locations of permanent sites for absolute gravity measurements are given on page 13.

Marson read a list of additional specifications for absolute gravity base stations to supplement those promulgated by Uotila.

Morelli called attention to comments on Uotila's specifications made by the IGC Subcommission for Western Europe, and to a modification proposed by Ducarme. The latter appears on page 11 of Morelli's IGC Activity Report. It is necessary to emphasize earth tides and indirect effects in establishing the IAGBN. However, Melchior has shown that earth tides can be determined with good accuracy most places in the world. However, there are a number of areas in the world where this is not possible. It is also possible to compute the crustal loading effect provided that points nearby coastlines are avoided.

At Morelli's request, Balmino summarized the scientific requirements for a world wide network of absolute gravity stations (complete text available from BGI).

Faller asked the status of the position paper on absolute gravity that was to be prepared by Torge and Balmino. Balmino thought this item is no longer needed and now probably won't be completed.

It was agreed that sites for the IAGBN must be selected based upon site stability, scientific requirements, and logistics. In some areas of the world, there may have to be some trade offs in using these parameters, for example in the Central Pacific.

Boulanger suggested that it may be necessary to make tidal measurements over a period of time in order to obtain the best accuracy in computing values of absolute gravity. It is also necessary to consider changes in the water table. Gravity variations of 35-100 μgal have been found in Eastern Europe due to water level changes. Morelli agreed that it is clear that all environmental conditions must be studied. The problem of earth tides may be resolved by the report of the special Earth Tides Committee.

Morelli pointed out that we now have Uotila's proposals on the IAGBN, but no comments or reactions have been received from any of the IGC Subcommissions other than the Western European Subcommission. We must now begin the follow-up to agree on site selection and to make the measurements. Many new absolute gravity devices are being developed, and the IGC must plan for use of these plus the existing instruments in the most efficient manner. Completion of the necessary follow-up actions will take some time.

McConnell suggested that the lack of response to Uotila's proposals may be due to people looking at these proposals in light of current economic conditions and wondering how such a global project is going to be funded. Perhaps the plan is too ambitious. Morelli thought that the IAGBN is a long range project that may last some 20 years. In this time economic conditions may improve. If the project is worthwhile and scientifically sound, the necessary funds will be forthcoming.

Boulanger thought it very important to compare absolute gravity devices before making new measurements, and suggested a comparison of all available instruments be made at Sevres during June and July of 1984. Faller said he did not want to have to stay at Sevres for two months to establish earth tide effects - he did not think it was necessary to do so based upon previous experience at this location. Boulanger agreed that accurate tidal corrections can be computed for Sevres, but though tidal corrections would be difficult at some other places in the world.

Faller suggested that use of superconducting gravimeters may not be the best way to monitor earth tides for long periods. He wondered if all such instruments drifted no more than 5 μgal per year. He felt it might be more cost effective to repeat absolute measurements over time.

McConnell made a brief presentation of an African gravity base network. He explained that D. Ajakaiye, Chairman of the African Gravity Committee had asked him to assist in designing a regional African gravity base network based upon specifications established by the African gravity committee.

Meeting of 12 August 1983
Hamburg, Federal Republic of Germany

Attendees:

M. G. Arur
G. Balmino
G. Boedecker
J. D. Boulanger
J. Faller
I. Marson
R. K. McConnell
C. Morelli
I. Nakagawa
C. Poitevin
M. Sarrailh
J. Tanner
L. Wilcox

Morelli presiding.

Morelli requested Boedecker to outline arguments and purposes for the super absolute gravity network (IAGBN).

Boedecker suggested that there are three major purposes for a super net: reference, geodynamics, and instrument testing. For reference purposes, the IAGBN will provide absolute bases for subordinate gravity base networks, and will constitute a zero order geocentric/gravimetric network. In the latter, collocation with space geodetic sites is important. The geodynamic work related to the IAGBN includes studies of the variation of gravity, the earth's rotation rate, motion of the geocenter, motion of the earth's principal axis and polar motion, variations in ellipsoidal flattening, motion of the earth's core, and mass redistribution in the mantle and crust. Some of the geodynamic studies can be aided by combining absolute gravity measurements with measurements made by superconducting gravity meters and space measurements. Instrument testing includes intercomparison of absolute gravity devices and calibration of relative gravity meters. For these last two purposes, the IAGBN sites should be located along convenient traffic lines.

Boedecker emphasized the importance of combining the IAGBN with geometric networks, and suggested that the guideline for keeping IAGBN sites at least 300 km from coastlines be replaced by another rule. By way of illustration, he thought that the Scandanavian uplift is the smallest tectonic feature that should be investigated using a global gravity network.

Morelli suggested that Boedecker's presentation be accepted as a first statement of IAGBN goals and purposes. He pointed out that global problems are being addressed by the current work - local problems can come later.

Balmino suggested that WG2 request specialists to write detailed justifications for each item in Boedecker's presentation.

Boulanger worried about how to handle changes in height. Boedecker said that VLBI stations give three-dimensional coordinates with 2 cm accuracy, and these can be used to control vertical changes.

Faller thought that IAGBN sites need not be restricted to space sites. If changes are noticed at IAGBN sites, a space technique could be installed to check. If there are no changes detected at IAGBN sites there is no problem. Gravity is cheap compared to the space methods.

Boulanger wanted to obtain an understanding of reasons for observed changes in gravity. There was general agreement that these changes will be studied for years into the future.

Boulanger suggested that there should be a geophysical laboratory at each IAGBN site to facilitate studies of reasons for gravity changes. Morelli noted that a special building for absolute gravity has been constructed in Japan, and thought that similar special facilities might be appropriate at selected IAGBN sites. It is logical to establish gravity observatories, just as magnetic, seismic, and astronomical observations have been established.

Tanner thought it best not to introduce too many refinements at the outset of the IAGBN project or it may become prohibitively expensive. We must keep the project cost effective. If it can't be planned simply, it may never be started at all. The project can be done relatively cheaply if some parameters are neglected for the time being. He also pointed out the operational problems that would result if too large a number of stations is included in the IAGBN. He suggested limiting the number of stations to 25-30.

Faller thought 50-100 stations could be handled in a reasonable time span by the number of instruments now available, but more than that number would be unwieldy. About 50-100 absolute measurement sites exist today, and if we could establish this number in the past, such a number should also be practicable in the future.

Morelli pointed out that many years ago, people made absolute measurements with pendulums without any central direction. We want to avoid undirected measurements and direction should be established by some central authority to achieve best use of the falling body instruments that are available. He thought it proper to draft a resolution that gives general direction as to what to do with respect to the IAGBN.

Morelli, Boedecker, and Balmino were appointed to draft the resolution.

The African gravity base net was discussed briefly. However, because no representative of the African gravity working group was present, no action could be taken.

L. E. WILCOX
Recorder

C. MORELLI
Acting Convenor

BUREAU GRAVIMETRIQUE INTERNATIONAL (BGI)
WORKING GROUP NO. 3 (WG3)
APPLICATIONS OF GRAVITY DATA

Meeting of 10 August 1983
Hamburg, Federal Republic of Germany

Attendees

G. Balmino
G. Boedecker
J. D. Boulanger
J. Faller
I. Marson
R. K. McConnell
C. Morelli
I. Nakagawa
M. Ogier
M. Sarrailh
J. Tanner
L. Wilcox

J. D. Boulanger, the Convenor of WG3, presided.

Boulanger reported that the six sheets of the World Gravity Anomaly Map Series (WGAMS) being compiled by the USSR will be completed not later than the latter half of 1984. He stated that it is now impossible to obtain surface gravity data for Eastern Europe, the Soviet Union, and China. Therefore, WGAMS must be published without such data.

WG3 and Lamont collaborated to produce a free-air gravity anomaly map of the southern part of the Atlantic Ocean. The map is in six sheets at a scale of 1:6,000,000, and will be ready for distribution in September 1983.

Work has begun on compilation of Bouguer gravity anomaly maps for the International Geological - Geophysical Atlas of the Pacific and Atlantic Oceans. The maps are at a scale of 1:10,000,000. The four sheets covering the Atlantic Ocean will be ready in December 1983, and the six sheets covering the Pacific Ocean will be ready in 1984. There will also be several other gravity maps prepared for that atlas.

Balmino asked if there is any hope of being able to compile WGAMS over the USSR from measured data. Boulanger said there is no possibility that this can be done and that the WGAMS must be compiled without USSR data.

Wilcox pointed out that a world gravity map prepared by Carl Bowin has now been published. It seems pointless to continue with WGAMS unless it provides a significant improvement over Bowin's map. Without data coverage for the USSR and Eastern Europe, WGAMS does not offer anything new that is not already covered by Bowin's map.

Boulanger said he objects to the Mercator projection used in Bowin's map. WGAMS would be better for geophysical interpretation in that it is the same scale and projection as the international tectonic map of the world - thereby enabling direct comparisons to be made between gravity and structure.

Morelli and Tanner called attention to the Tokyo meeting of WG3. At this time it was decided not to continue WGAMS without data coverage for eastern Europe and the USSR. It was agreed that the major contribution of WGAMS is to provide world gravity anomaly coverage including substantial amounts of gravity data (eastern Europe and USSR) not previously published.

Boulanger indicated that he has made every possible effort to obtain USSR data for publication. But he now has no hopes that such data will be released in the foreseeable future.

Morelli assured Boulanger that the members of WG3 appreciate his efforts to obtain the data and understand the problems he has had. However, it is clear that the value of WGAMS is greatly diminished without gravity data coverage of the USSR.

Tanner agreed that WG3 is faced with an unfortunate situation. He sympathized with Boulanger's position, but felt that the BGI would not look good if WGAMS were to proceed without USSR data. There are too many other good maps - WGAMS would not add anything. There is little to be gained by going ahead.

McConnell agreed with Tanner's position. The major contribution of WGAMS should be to provide coverage of a major landmass (USSR) where no coverage is presently available.

Balmino stated that WGAMS is a failure without USSR coverage. He felt the project should be discontinued.

The consensus of WG3 is that WGAMS be discontinued as an international project sponsored by the BGI. However, Boulanger indicated that WGAMS probably will be completed unilaterally by the USSR.

Balmino recommended a strong push to fill the USSR gravity gap by other means, such as satellite-to-satellite tracking (SST) missions. Faller agreed, and suggested that impending coverage of the USSR by gravity data from STT might be an incentive for release of some surface data.

L. E. WILCOX
Recorder

J. D. BOULANGER
Convenor

BUREAU GRAVIMETRIQUE INTERNATIONAL (BGI)
WORKING GROUP NO. 4 (WG4)
MEAN GRAVITY ANOMALIES

Meeting of 10 August 1983
Hamburg, Federal Republic of Germany

WG4 Members Attending

C. Merry
L. Wilcox

Other Attendees:

G. Balmino
G. Boedecker
J. D. Boulanger
J. Faller
I. Marson
R. K. McConnell
C. Morelli
I. Nakagawa
M. Ogier
M. Sarrailh
J. Tanner

L. Wilcox, the Convenor of WG4, presided.

Due to the small number of WG4 members in attendance, a formal meeting was not held at this time. Programmed business will be handled later by correspondence.

Wilcox announced that he has recommended that the functions of Special Study Group 5.62, Gravity Anomaly Production Techniques, be combined with WG4 for the next four year period. He further recommended that Rapp's June 1983 world mean gravity anomaly data tape be used as a primary guideline for the first approximation to a BGI mean gravity anomaly file.

Balmino noted that Rapp's June 1983 mean anomaly data tape was used in the GRIM-3 global gravity model. This gave a significantly better representation for oceanic areas due to inclusion of SEASAT data.

L. E. WILCOX
Convenor

BUREAU GRAVIMETRIQUE INTERNATIONAL (BGI)
DIRECTING BOARD (DB)

Meeting of 10 August 1983
Hamburg, Federal Republic of Germany

Attendees

G. Balmino
G. Boedecker
J. D. Boulanger
J. Faller
I. Marson
R. K. McConnell
C. Merry
C. Morelli
I. Nakagawa
M. Ogier
M. Sarrailh
J. Tanner
L. Wilcox

C. Morelli presiding.

Morelli requested Balmino to report on BGI activities since the Tokyo meeting of the DB.

Balmino reported that the BGI has moved again - this time only a few hundred meters into new buildings having better office space and equipment. The BGI can now welcome scientists in a more satisfactory way to work with the gravity data.

Balmino showed graphics illustrating the data coverage of the operational data base and the location of newly collected data. All newly collected data has been merged into the data base. The BGI gravity data holdings now include some 2,700,000 points contained in 2,300 sources. Some data has restricted distribution. When such data is requested from the BGI, either the donor is contacted to find out whether the data can be released to the requester, or the requester is referred directly to the donor.

The data management system is performing well. The basic documentation for the data management system probably will be published in the next issue (December 1983) of the Bulletin. Details of the software and users guides will be published in BGI Technical Reports if this information is too bulky for the Bulletin.

The BGI is now issuing Technical Reports describing certain details of BGI operation. To date, six such reports have been issued. Three or four more will appear in the next future. Several more are in preparation.

The format of the archival and routine data bases, set up by Lepretre in 1971, is going to be changed. There will be a common format for land and marine data. Also, some flags will be incorporated into the archival data base.

The services and charges of the BGI have been described on many occasions. For the moment, however, most requests from users are being serviced free of charge. The charging policy is being applied only for certain special services. The free servicing policy may have to be terminated in the future since the BGI is under pressure to make charges for all services, even simple data retrieval.

The BGI has made some attempts to evaluate marine gravity data using satellite altimetry as control. The work, although not yet finished, appears to be inconclusive. The BGI will want to consult with some specialists before publishing this work.

The BGI has been involved in the digitization of bathymetry. Two years ago, the desire was to produce files of bathymetry with a density that depended upon the quality of the material being used. It was decided instead to start the project using the latest GEBCO series maps. One sheet has been digitized to date. The contour lines were digitized using a laser scanner at IGN. Then a raster-vector transfer was performed for this sheet. At this point, the project was temporarily discontinued because of a lack of funds. It is very costly to do the work for the whole series of GEBCO maps. The project probably will be restarted this year with a new schedule that extends the work over a longer period of time. Production of grid values or terrain models may come later after the laser scanning has been completed. The BGI cannot digitize gravity contours for the Mediterranean Sea at this time.

Base station descriptions have been put on microfische. The BGI gets many requests for large blocks of base station data. It is cheaper and more efficient to service such requests using microfische.

Other details of BGI operations have been published in Bulletin d'Information No. 50.

The BGI budget was presented to the DB for its consideration by Balmino. Balmino noted that there were some mistakes in the presentation of the FAGS account in prior years, and that some bookkeeping procedures have been changed to account for this.

After a brief discussion, the DB approved the BGI budget.

Boulanger noted the excellent progress that has occurred at the BGI recently. The organization and systematization of the work has been excellent.

Morelli, speaking for the DB, extended thanks to Balmino and his staff for a job well done.

Boulanger requested that the next meeting of the IGC be held at Toulouse. There was general agreement. Balmino agreed to make the necessary arrangements.

Faller requested that better bindings be put on the Bulletin d'Information. He thought the bindings used recently are too fragile. There was general agreement.

Balmino expressed his thanks to those who have contributed data to the BGI. he also thanked people who have sent contributed papers for publication in the Bulletin. The BGI has now set up specifications for contributed papers.

There being no other new items for consideration by the DB, the meeting was adjourned.

L. E. WILCOX
Recorder

C. MORELLI
Chairman

A C T I V I T Y   R E P O R T   1979-82

by C. Morelli

I N D E X

Foreword

Institutionally, "the purpose of the I.G.C. is to promote scientific investigation of the gravity field of the Earth, its relationship with the Earth's interior and exterior, and its variations with time. Its purpose is to be achieved with the concerted action of its members, through a homogeneous gravimetric coverage of the whole world".

Practically in the latest decade it became the forum for debating all the scientific, technical and organisatory problems connected with Gravimetry. IGSN 71 is a milestone, condensating 20 years of enthousiastic international efforts and cooperation and has open a new area in Gravimetry.

Presently, the scientific community has in the experimental stage :

- absolute gravity - meters of the μgal accuracy, transportable, computerized, able to make a measurement in a few hours ;
- relative gravity - meters stable, compacted, with the same order of accuracy ;
- experimental gravity - meters (superconducting gravimeter) with an accuracy of 10^{-2} μgal ;
- sea - surface gravity - meters with stabilized platforms and positioning systems permitting the 100 μgal accuracy ;
- air - born gravity - meters with adequate positioning approaching the μgal accuracy.

The potential impact of Gravimetry on the environmental Science and control can be therefore enormous : provided that this very expensive effort is properly planed, guided and coordinated ; and that all the connected problems are conveniently studied and solved.

E.g. : the variation of gravity with time as a consequence of tides, loading effects, environmental variations, etc...

This is one of the future tasks for I.G.C.. Another one is the establishment in the years 80's of an International Absolute Gravity Net, for Geophysical Control, and of an Absolute Gravity Super-Net, for Geodetic and Metrology Control.

The results of the studies by the Working Groups of the Bureau Gravimetrique International, "central agency" of IGC, have already open the way. The next decade will permit to IGC to realize the goals.

Also to this purpose, but especially in an effort to enlarge the scientific activities and interests of the I.G.C. to the Developing Countries, the I.G.C. decided in Canberra to set up Sub-Commission (S.C.) for a more capilar actions and cooperation.

1. The Report

The main facts related to the activity of the I.G.C. 1979-81 have been presented in the "Report 1978-1982 to the 10th I.G.C. Meeting (Tokyo 1982)" during the General Meeting of the IAG which was held in Tokyo (7-15 May 1982).

The present report summarizes therefore the main results till May 1982, and complete them for the subsequent year.

For brevity reasons are here omitted following chapters, treated in the above mentioned Tokyo Report but pertinent to "ad hoc" Study Groups :

Theoretical gravimetry (SSG 4.56 , 4.57) ;

New gravimeter instrumentation and improvements. Microgravimetry (SSG 3.37) ;

Earth tides (Commission V) ;

Non-tidal gravity : secular variation (SSG 6.34).

2. Sub-Commissions

Accordingly, the Executive Committee of I.G.C. met in Paris with B.G.I. Directing Board March 25, 1980, and decided to set up following Sub-Commissions and to appoint the coordinators :

North Pacific Region	:	Nakagawa
South-West Pacific Region	:	Reilly
North America	:	Strange
Central and South America	:	Kausel
Africa	:	Ajakaye
Western Europe	:	Boedecker
Eastern Europe and URSS	:	Boulanger
India and Arab Countries	:	Arur

In summaries, their activities have been :

2.1. North Pacific Region (Pr. Nakagawa)

(1) *Area to be covered*

The Sub-Commission for the North Pacific covers the countries which are faced to the Pacific Ocean and located to the North of the Equator. The countries located in the equatorial area could be belonged to both the Sub-Commission for the North Pacific and the Sub-Commission for the South-West Pacific, depending on the wishes of the countries concerned.

(2) *Organization of Sub-Commission*

Membership of the Sub-Commission is envisaged to comprise :

(a) Representatives of member countries of the IAG in the area concerned : namely, People's Republic of China, Indonesia, Japan, Republic of Korea, People's Democratic Republic of Korea, Malaysia, Philippines, Thailand, Viet Nam, USA and USSR.

(b) Representatives of the countries in the area who are not members of the IAG, to be appointed in consultation with the appropriate authorities in the area.

It is suggested that the Bureau of the Sub-Commission consists of a President, a Vice-President and a Secretary. The starting members of the Bureau are suggested to be :

President	: Professor Ichiro NAKAGAWA Geophysical Institute Kyoto University Sakyo-ku, Kyoto 606, JAPAN
Vice President	: To be appointed from the People's Republic of China
Secretary	: Dr. Masatsugu OOE International Latitude Observatory of Mizusawa Mizusawa, Iwate-Ken 023, JAPAN

Since June 1982, the National Committees of member countries of the Sub-Commission have nominated the following geodesists as the representative of the respective country who is engaged in gravimetry :

Japan	: Ichiro NAKAGAWA
Philippines	: Jose Halo ISADA, Philippines Geodetic and Geophysical Institute, 421 Barraca Street, San Nicolas, Manila.

As for the other countries, nomination have not yet been received.

The section of Geodesy of the National Committee for Geodesy and Geophysics of Japan issued "Report on the Gravimetry in Japan during the Period from July 1978 to March 1982" with the joint editing of the Geodetic Society of Japan and submitted it to the General Meeting of the IAG which was held at Tokyo in 1982. The Section of Geodesy of the National Committee for Geodesy and Geophysics of Japan also issued "Report of the Geodetic Works in Japan during the Period from January 1979 to December 1982" with the joint editing of the Geodetic Society of Japan on March 1983. This report contains a chapter on gravimetry and will be submitted to the XVIII General Assembly of the IUGG.

(3) *Report of China (Dr. J.Y. Chen)*

(a) High precision gravity measurement and the development of absolute gravimeter.
In an effort to improve the configuration of national gravity network and increase the accuracy of gravimeter control network, absolute gravity measurement was carried out in China by Chinese and Italian technical staffs in 1981 according to the cultural and scientific cooperative program signed by both sides of Chinese and Italian government. A total of 11 stations have been established. About 100 observations were made in each determination at each station. Mean error in single observation and that in mean value amount to ± 49 and ± 5 μgal respectively, on an average. Taking into account various instrumental errors, the overall error (except error in gravity vertical gradient measurement) amounts to ± 10 μgal on an average. The gravity vertical gradient was determined by LaCoste & Romberg or Worden relative gravimeter. The absolute gravity measurement started from and closed at Beijing gravity station with a closure error of ± 1 μgal.

In the period 1981-1982, high-precision relative gravity measurement was made by using LaCoste & Romberg gravimeter (Model G). A network consisting of several loops was established. Included in this network were all absolute gravity stations and six old gravity stations established in 1950's. As a consequence of network adjustment, observation accuracy was found superior to ± 10 μgal. A comparison of the previously and newly determined gravity values of these six stations revealed that previous values had an error of about ± 200 μgal, but did not manifest systematic character. It is evident that the old gravity network is in need of redetermination.
Another achievement occurring during the reporting period was the success of China self-developed absolute gravimeter. The principle underlying this gravimeter consists in measuring the time elapsed by a freely falling body in a constant distance. Numerition is effected by coincidence method of laser interference fringe and time pulse. Rubidium atomic standard is used as time scale. A mobile absolute gravimeter has been produced. After having undergone testing measurements at 13 gravity stations in Beijing, Quenming, etc..., the gravimeter was transported to Paris, France to make comparison measurement against Sakuma gravimeter of the International Bureau of Metrology. The mean error resulted from the comparison amounts to ± 15 μgal. A comparison of the gravity value of Beijing station determined by this absolute gravimeter and the original value determined in 1957 with reference to Potsdam system indicates that a correction of - 13.6 mgal should be assigned to the old system.

(b) Other works in the field of gravimetry.
According to the requirement of nationwide uniformly distributed gravity measurements, field work has been and continues in progress in some regions with the aim being to determine mean gravity anomalies in ground grid. In the densification of gravity measurements, the density of gravity stations is designed in accord with the size of the grid, the complexity of gravity field, and the requirement on the accuracy in mean gravity anomaly. Thus far, the evaluation of nationwide 1° x 1° mean free-air anomalies and the compilation of nationwide 1/1 000 000 Bouguer anomaly maps have been completed.
Complementary gravity measurement have been made recently along some routes to meet the need of more detailed study on deflection of verticals and height anomaly. Also made have been gravity measurements along national primary levelling lines in order to apply corrections for gravity anomaly to the height differences obtained from levelling. Significant improvement has been achieved in the closure errors of two primary levelling loops in West China by applying corrections for gravity anomaly.

China has taken up ocean gravity measurements in the recent years. Early in 1960's, gravity measurements on the Bohai Sea, the Beibu Bay of the South China Sea and the North Yellow Sea were carried out by relevant agencies for compiling gravity anomaly maps at scale 1/500 000 or 1/1 000 000. In October 1977 and May 1980, gravity measurements over water areas west of 129° E of the East Sea were carried out by using GSS-2 sea gravimeter for compiling gravity anomaly maps at scale 1/1 000 000. Started with 1979, gravity, magnetic and depth measurements over water areas north of 11° N of the South China Sea were carried out and scheduled to be completed in 1983. In the period 1976-1978, four comprehensive explorations over the water areas of the central part Pacific Ocean were made successively by Ship Xiang Yang Hong N.5. During these explorations, GSS-2 sea gravimeter N. 34 was used for gravity measurement and Navy

Navigation Satellite System for positioning. A total of 11 739 points have been determined, the first batch of data of gravity and depth cover exploring lines with a total length of 57 482 km. The precision in gravity measurement is estimated to be less than 3 mgal. These data and the 1° x 1° mean free-air anomalies in the central part of Pacific Ocean have been compared with those of DMA. The average deviation is found to be ± 15-20 mgal. In addition, ZYZY sea gravimeter and ZSM-3 Quartz spring one have been designed and produced by two research agencies devoting to seismology and geology respectively. These gravimeters have been put to use to meet respective needs.

Computation of astro-gravimetric levelling was done during the reporting period. Two kinds of averaging templates were used in succession in the computation of correction term for gravity. Gravity anomalies were obtained through indirect interpolation by using the heights of points concerned. The nationwide astro-gravimetric lines form 94 loops which had been adjusted as a whole by adjustment method of condition of unequal precision observation.
The mean error of unit weight after adjustment amounts to ± 0.95 m. Mean errors of 1 km levelling line of 1st and 2nd order are found to be ± 0.022 m and ± 0.050 m respectively.

2.2. India and Arab Countries

(1) *Introduction*

Constant efforts were continued to collect information regarding activity and program in the field of gravity and related technology from the Countries falls under this S.-C.. Efforts were made to establish contacts with the following Scientists/Executive Heads of the concerned departments in their respective countries :

India	: Various Scientific Institutions
Iraq	: Dr. M.J. ABBAS, Director General, Geological Survey and Mineral investigation, Baghdad
Jordan	: Dr. Issam KHAIRY, General Secretary, Jordan Research Council, Amman
Kuwait	: Dr. M.A. ALSHAMALI, Director, Kuwait Institute of Scientific Research, Kuwait
Lebanon	: Dr. A. ZEHIL, Observatory de Ksara, Ksarapar Zehlo
Saudi Arabia	: Dr. M.S. JOUKHDAR, Ministry of Petroleum and Mineral Resources, Riyadth
Siria	: General A.M. SAFI, Director of Military Survey Department, Damascus
United Arab Republic	: Dr. A. ASHOUR, Academy of Scientific Research & Technology, Cairo

Status Report

This report is intended as a brief review of significant scientific investigation of the gravity field of the Earth, its relationship with the Earth's interior and its variations with time. Review of the results of such investigations made only during the period of 1979-82 have been included in this report.

(2) *India*

Scientific investigations in gravity, particularly concerning to the Commission's program have been briefly given in the ensuring paragraphs.

Detailed account of the Gravimetric Work carried out in the country during the period 1.6.1978 to 31.5.1982 has been reflected in the National Report on the Gravimetric Work done in India by various Organizations and Institutions during the period 1978-82 being presented at the 11th Meeting of the International Gravimetric Commission of International Association of Geodesy to be held at Hamburg in August, 1983.

(3) *Survey of India - Geodetic & Research Branch*

(a) Gravity Anomaly Prediction

Survey of India predicted 1° x 1° mean Free-air anomalies for some blocks by the Uotila method and compared the same with values as computed by the formula $\Delta gm = a+bH$ as reported in the National Report 1975-78. The table given below shows the comparative values.

T A B L E

1°x1° Block No.	Value of anomaly: By using formula $\Delta gm=a+bH$	Value of anomaly: Uotila's method.	Difference Col.2-Col.3
(1)	(2)	(3)	(4)
47G	-50	-44	-6
53F	-35	-33	-2
54G	+ 4	+ 2	+2
64G	-19	-20	+1
64H	- 8	- 6	-2
83C	+90	+43	+47

(b) Gravimetric Deflections and Undulations at Initial Point

Gravimetric Deflections and Undulations at the origin of the Indian Datum on the Geodetic Reference System 1967 by using surface gravity data were determined by Survey of India. The values obtained are :

Meridional component = - 2".01

Prime vertical component = + 4".33 and

Undulation = - 55.7 metres

(4) *Charts of Topography + Compensation (T+C) corrections*

Chart of (T+C) correction for zones 18-1 both on Pratt-Hayford-Hypothesis for depth of compensation D = 113.7 km and Airy Heiskanen Hypothesis for the thickness of Earth crust T = 30 km are under compilation for India and adjacent countries and adjoining sea areas.

(5) *Miscellaneous*

(a) Iraq

Contacts are being pursued.

(b) Jordan

Contacts are being pursued.

(c) Kuwait

We have been able to establish contacts with Director General. Kuwait Institute for Scientific Research KISR and detailed informations are being pursued.

(d) Lebanon

Contacts are being pursued.

(e) Saudi Arabia

Contacts are being pursued.

(f) Syria

Status of activities in the country is continued as reflected in previous reports and efforts are being made to procure LaCoste Romberg Gravity-metres in order to commence regular field observations. A program for determination of absolute gravity values of some points in Syrian territory and then to extende these points to the World Stations of absolute gravity is being planned. An International effort in this direction shall be highly appreciated.

(g) Future program

At would be see from this report many individual countries of the Sub-Commission have yet to provide input for this report and further efforts in this direction are continuing. It is possible many of the countries would provide this input in their National Reports for the IUGG General Assembly due to be held at Hamburg in August, 1983 and it is hoped that exchange of the information will promote scientific investigation in this field.

2.3. South-West Pacific Region

Officers :

President	:	Dr. W.I. Reilly, Wellington
Vice President	:	Mr. P. Wellman, Canberra
Secretary	:	Dr. D.J. Woodward, Wellington

The Sub-commission has begun a campaign to check the status of the gravity stations within its region which are part of the IGSN 71 network. This is being done in the first instance by making enquires of the people listed on the station information sheets or of other geophysicists, geologists and surveyors in the locality.

A circular letter has been sent to the relevant people in many of the Pacific Islands advising them of the willingness to help them with any gravity projects they may undertake.

The principal activity of the Sub-commission has been to establish contact with the appropriate authorities, in the region, and to attempt to check on the current status of gravity base stations established in the past. So far, there have been responses concerning Western Samoa, Vanuatu, Solomon Islands, Kiribati, Fiji, Niuguri, as well as Australia and New Zealand. The question of the proposed International Absolute Gravity Station Network is being dealt with by Australia, as it has the only possible sites.

2.4. Western Europe (Dr. Boedecker)

In accordance with the by-laws of the IAG the Sub-commission Western Europe (SCWE) comprises one or two members from 20 countries :

Austria	: D. Ruess and P. Steinhauser
Belgium	: B. Ducarme and C. Poitevin
Denmark	: O.B. Andersen
Finland	: A. Kiviniemi
France	: M. Ogier
Germany (R.F.A.)	: G. Boedecker
Iceland	: G. Palmason
Ireland	: T. Murpy
Israel	: A. Ginzburg
Italy	: I. Marson and M. Pampaloni
Luxemburg	: J. Flick
Netherlands	: G. Strang Van Hees
Norway	: A. Midtsundstad
Portugal	: M.M.R. Lisboa
Spain	: R. Parra Maldonado
Sweden	: L. Pettersson
Switzerland	: H.G. Kale
Turkey	: H. Balkan
United Kingdom	: R.G. Hipkin and R. McQuillin
Yugoslavia	: K. Colic

The Executive Board consists of the president and two secretaries : G. Boedecker, München, I. Marson, Trieste, and G. Strang Van Hees, Delft. The major means for communication within the SCWE represent the circular letters.

On the basis of the terms of reference (Morelli, c.f. IGC-report 1978-82, Tokyo 1982) the following future activities of the SCWE were defined in 1980 :

1. Regional data collection and preprocessing,
2. Regional base nets for the control and updating of IGSN 71,
3. Harbour gravity stations,
4. Absolute gravity measurements,
5. Support for precise gravity measurements on profiles of constant gravity,
6. Control and further improvement of regional gravity meter calibration lines.

In one way or the other all of these aims were brought forward. Regional data collection and preprocessing - which was a peculiar argument for establishing the subcommissions - was not that important for our SCWE, because the BGI resides within Europe and has a long experience with European gravity data. The most important activities will be listed in the sequel.

(1) *Catalogue of Coastal Gravimetric Stations*

Sea gravimetry still is an important tool for the evaluation of detailed structures of the gravity field complementary to the global gravity field determination by various satellite methods. One precondition for homogeneous results from marine gravimetry is a homogeneous set of appropriate reference stations on land. To this end the SCWE initiated the compilation of a catalogue of coastal gravimetric stations. Belgium, Denmark, France, the Federal Republic of Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden and the United Kingdom contributed 150 station descriptions comprising sketch, map cutout, verbal description as also coordinates. The gravity values refer to IGSN 71, slight modifications because of national gravity network adjustments and varying treatment of the Honkasalo correction are indicated in the catalogue. Neglecting these minor effects, the gravity values should be homogeneous within 0.1 to 0.2 mgal, which is satisfying for sea gravimetry. The catalogue was issued in 1982 and can be obtained from the Bureau of the SCWE.

(2) *New Unified European Gravity Network*

Regional gravity network maintenance is defined a central task of the sub-commissions. In the past decade, several European countries carried out numerous absolute and relative gravity measurements for national or regional nets. These measurements shall be utilized for the establishment of a European gravity base network of improved accuracy, homogeneity and station density distribution as compared to IGSN 71. The role of this net as a reference to subordinate regional nets and for geophysical and metrological purposes is to be improved. Via the connection with the projected International Absolute Gravity Basestation Network IAGBN it will serve for investigations concerning the variation of gravity with time.

The major requirements for this project are :

1. the availability of original data from the member countries, and,
2. a sufficient number of links between the national nets.

A first survey by means of a questionnaire circulated in 1982 showed, that probably Belgium, Denmark, France, Germany, Italy, the Netherlands, Norway, Sweden and the United Kingdom will participate in this joint cooperation by providing data. The computations will be performed in Trieste, Delft and Bruxelles. The average station density will be of the order of 1 station per 10 000 square km. The procedure of station selection in subnets with higher density (e.g. UK) as also data formats, adjustment models are currently under discussion. These problems will be treated on the occasion of a SCWE meeting in Hamburg 1983.

(3) *International Absolute Gravity Basestation Network IAGBN*

According to the guidelines for the site selection criteria of IAGBN stations communicated in 1982, three European stations were nominated : Wettzell, Germany (49N, 13E) ; Sodankylae, Finland (67N, 27E) ; Madrid, Spain (40N, 3W). In the light of recent developments as to the existing instruments and new arguments concerning the loading effect, a few additional stations came into the discussion : Paris, France, Frankfurt, Germany, Bruxelles, Belgium ; one station in Switzerland.

The SCWE is ready to offer more approved absolute station sites as soon as the general design criteria for the IAGBN are defined. In particular, a selection out of the existing about 25 absolute stations in Europe can be offered for intercomparison and calibration purposes.

2.5. U.R.S.S. and Eastern Europe (Pr. Boulanger)

(Summary of a 29 page report distributed at the meeting)

There was no answer to the circular letter sent by the President of the Sub-commission (Pr. Boulanger) to countries of the sub-commission for nominating representatives. A second circular brought two answers, from GDR and CSSR.

(1) *USSR*

- Absolute gravity measurements were performed with the GABL instrument (USSR Acad. of Sc.) in Australia (5 sites), Papua-New Guinea (1 site), Singapore (3 sites), Finland (2 sites), GDR (3 sites in Potsdam). These allowed some control of IGSN 71.
- Standardization (calibration) of gravimeters has been given a particular attention, for both land and marine instruments. It is performed by tilt technique at standard polygons located in various regions of the country and at special stands in laboratories.
- Gravity tides recording is continued by means of Askania gravimeters with photo-electric and capacitive pickups and by gravimeters constructed by the Academy of Sciences. Results possibly show some variations of the tidal factor (up to 20 %) - the influence of the oceans was estimated from Schwidersky's maps. Theoretical studies on Earth tides, Earth rotation and nutation were performed (tides of an elastic asymetric Earth, effects of large scale inhomogeneities, effects of oceans and elasticity on the free and induced nutation).
- Non-tidal gravity variations were analyzed from absolute measurement series. Correlation was established between gravity changes and Earth's rotation fluctuations. Also, relations with hydrological events and earthquakes were studied.
- Many cruises of the research vessels of the Ac. of Sc. yielded about 20 000 new marine measurements which are in WDC B2 and BGI. The Faye gravity map (scale 1/6 000 000) for the South Atlantic was produced in cooperation with the Lamont Geological Observatory (USA).
- The compilation of the WGAMS is continued : 6 sheets completed (excluding USSR and Eastern countries territories).
- Theoretical studies on the behaviour of the lithosphere were done.
- A list of 32 references was attached to the full report.

(2) *GDR*

- Absolute measurements in Potsdam were performed with the aid of the USSR Ac. of Sc. (see above).
- Relative measurements were done, especially over a W-E profile running inside GDR in the Southern part of the North-German-Polish degressive and crossing the Central German main fault, with the participation of Pr. Kiviniemi (Finland) - 5 references given.
- Geodetic investigations of the gravity field were performed : effects of free air mean value errors on (ξ,η) and ξ (height anomaly) ; representation of the geopotential by point masses ; numerical analysis of gravity anomalies and topographic heights ; formulation of a mixed boundary value problem (gravity + altimetry) ; correlations between temporal gravity variations, levelling results and recent crustal movements ; new form for the

solution of Molodenski b.v.p. was found, very useful for numerical calculations ; contributions to the inverse gravimetric problems and to the gravity fields of the Moon and Planets ; elaboration of a data base management system for gravity data (BESYGRAV) - 30 references given.

. Geophysical interpretations of the gravity field : correlative studies of the gravity, geomagnetic and geoelectric fields and geodynamic concepts lead to an interpretation of some Middle European gravity anomalies (correction with the formation of rift zones in the North Atlantic Ocean). Also several special methods were developed for the evaluation of local and regional gravity anomalies with respect to the generating density distributions - 20 references given.

(3) CSSR

. Studies on non-tidal variations of gravity were done ; in connection, attention was given to the problem of gravimeter scale calibration (non linearity).

. Gravity corrections : ground water level, atmosphere, were derived. Also a harmonic development of the Earth-tide potential is proposed for tidal corrections. Further thoughts to the so-called Honkasalo-term yielded some conclusions to how defining the isolated and zero geoids.

. Analysis of the accuracy of gravimetric measurements were carried out.

. Some new results in the theory of the direct and indirect gravimetric problem were obtained. Investigations were conducted for Csechoslovakia and Central Europe.

. For the optimization of the Earth crust profiles with the use of gravity data, the collocation method was used. The effect of irregularities of the shape of the core-mantle boundary on the measured gravity was also studied.

. A stochastical model of the Earth's gravity field was built (Earth approximated by a Lyapunov surface).

. A list of 50 references was attached to the full report.

2.6. From the Report of the Commission for Geodesy in Africa (R. O. Coker)

The Gravity Network Committee of the Commission for Geodesy in Africa is presently exploring the possibility of working on a continental network of 100-200 stations. The project is planned for 3 years and the present estimate is that the project will cost about 500,000 U.S. dollars for 100 stations. The Gravity Division, Earth Physics Branch, Ottawa Canada has indicated the desire to provide help in the reduction etc... of the project. This is a very important project both for scientific and economic purposes. The Commission for Geodesy in Africa would therefore appreciate the support of the International Association of Geodesy and its relevant Commissions in the implementation of this project.

Not received :

2.7. North America (Dr. Strange)

2.8. Central and South America (Dr. Kausel)

Joint report for North, Central and South America presented by K. McConnel

There has been little activity of the part of the North American Sub-Commission since most of the functions of such an organization are adequately carried out by existing Agencies. Therefore occasional contact such as takes place at General Assemblies appears sufficient.

At the Santiago meeting of the Pan American Institute of Geography and History in March, 1982 the SILAG (Latin American Gravity Information System) Data Base and associated software was transferred from the Earth Physics Branch (EPB), Ottawa, Canada to the University of Chile in Santiago. At the same time, the chairmanship of SILAG and the Gravity Sub-Commission for South America was taken over by Dr. Edgar Kausel, chairman of the Geophysics Department, University of Chile, from J.G. Tanner of EPB. Since the objectives of SILAG and the Gravity Sub-Commission are similar, it is intended that both function from a single Headquarters.

The Data Base presently installed in Santiago contains the digital data and descriptions for the Latin American Gravity Standardization Net 1977 (LAGSN77). Personnel operating the Data Base have been trained in USA and operation of the data reduction and adjustment software provided by EPB and have a mandate to update LAGSN77 as required, to distribute data and information relative to gravity standards in South and Central Americas and to provide advice and assistance in planning gravity standardization projects in these areas.

3. Absolute Gravimetry

Several absolute gravity meters have been used in field campaigns and some of the results are matter of discussion.

The I.M.G.C. apparatus has been used to establish seven absolute sites in Switzerland (1978, 1980), four in Austria (1981), six in the U.S.A. (1980), two in Italy (1979, 1981) and eleven in the People's Republic of China.

The JILA instrument has observed 12 sites in the U.S.A., while the USSR absolute gravimeter has measured the gravity acceleration in five sites in Australia, and one in New Guinea.

Finally the AFGL and JILA (USA), the USSR and the JAEGER-BIPM gravity meters have been employed in 1981 for a comparison campaign in Sevres. On april 1982 also the I.M.G.C. (Italy) absolute instrument was taken to Paris for the same purpose.

The results of the campaign, together with those of repeated absolute measurements made in the U.S.A. either with the same instrument or with different ones (AFGL, IMGC and JILA), have produced data which in most cases agreed within the limits of given error terms, but at some sites they differed by as much as 100 μgal (Uotila U., Bull. Inf. BGI n. 51). These differences, probably due to unresolved sources of systematic errors, mainly induced by the environment, must be investigated.

4. International Absolute Gravity Basestation Network (IAGBN)

The exceptional advancement in accuracy (± 1 μgal in the latest years) for the absolute measurements is now giving practical possibilities to the Absolute Net proposed by J.J. Levallois in 1971.

The studies by the B.G.I. W.G. n. 2 (Pr. Uotila) and by the International Center for Earth Tides, Uccle (Pr. Melchior) are summarized in the appendix to the report.

5. IGSN 71

5.1. New ties

Ogier (1980) realized in 1978-79 ties between France and the European adjacent countries in order to define with accuracy the connection between the French and the European gravity networks. An attempt was made to give a more accurate relative value of the gravity at Toulouse Observatory which with Sevres A was the Basic Station of the French gravity system.

The gravity has been measured in both IGSN 71 and absolute stations in order to investigate the accuracy of the used gravity-meter.

A new gravity value has been computed for Toulouse but with an accuracy not greater than 0.03 mgal because of the errors in the calibration measurements. The new value is as following :

980 427.74 mgal, raw LaCoste & Romberg values, exactly the same as the IGSN 71 one,

980 427.48 mgal, which is the adjusted value in regard of the italian absolute measurements.

5.2. Gravity measurements in Kenya

A new catalogue of gravity data from Kenya has been prepared and is briefly described by Swain and Khan (1978). New Bouguer anomaly maps have also been compiled and a copy was presented.

5.3. North Africa Gravity Traverse

Brown et al. (1980) report on a military expedition across the Sahara Desert in 1975 which provided an opportunity to obtain gravity data where there were previously few measurements. The expedition crossed northern Africa from the Atlantic Ocean to the Red Sea ; 608 gravity measurements were made with a LaCoste Romberg geodetic gravimeter. Apart from filling a gap in world gravity data, the traverse revealed a large negative Bouguer anomaly associated with the Jebel Marra volcanic complex and provided a profile of the negative Bouguer anomaly as the Red Sea is approached. Comparison with the U.S. Defense Mapping Agency Aerospace Center (DMAAC) Bouguer gravity anomaly map of Africa lends confidence to the gravity prediction methods used by the DMAAC.

6. New Nets and Adjustments

6.1. Switzerland

A calibration line for gravimeters has been established in 1980 in Switzerland (Klingele, Kahle, 1981). Between Interlaken and Jungfraujoch (604.7 mgal ; absolute stations), 5 stations have been measured with 3 LaCoste - Romberg gravity meters. A preliminary adjustment (Fischer, 1981) indicates for the 3 instruments the some accuracy, but sensible differences in the scale factors.

6.2. Brazilian Fundamental Net

A new gravimetric Fundamental Net of 145 stations has been established in Brazil from 1976 to 1979 with two LaCoste & Romberg gravimeters mod G.

Escobar (1980) reports on the adjustment performed in the IGSN 71 system utilizing 1500 ties, with the aid of an IBM/370 computer. Accuracy is better than 20 μgal.

6.3. Gravity Network in Greenland

The Danish Geodetic Institute has since 1976 established c. 400 LaCoste & Romberg gravity stations in Greenland, primarily in northern Greenland in connection with the major geodetic survey recently carried out. The principal aim of the gravity surveys was to provide a regional gravity coverage in northern and north-eastern Greenland in addition to the establishment of a fundamental network of gravity reference stations and tying in older gravity networks.

The LaCoste & Romberg gravity network have been connected to IGSN-stations in Denmark, Iceland, Canada (Alert) and Norway. The adjustment of the measurements indicated systematic scale errors in the LaCoste & Romberg calibration tables and the old gravity networks of 0.5 and 3 %, respectively, assuming the IGSN-scale to be correct. Due to the relatively low priority of the gravity measurements the structure of the gravity network is often suboptimal, necessitating assumptions of constant instrument drifts during longer periods. This combined with the rough arctic environment causes the standard deviation of a single measurement to become 30 - 50 μgal, somewhat larger than precision measurements in e.g. Europe, but satisfactory especially taking the huge area and the large gravity differences into account.

Forsberg (1981) outlines the gravity survey operations and adjustment method, and gives a brief account of the experiences using LaCoste & Romberg gravimeters in the Arctic by helicopters transportation.

APPENDIX TO I.G.C. REPORT

INTERNATIONAL ABSOLUTE GRAVITY BASESTATION NETWORK

PURPOSE

The absolute sites will be used to provide stable locations for the continued testing of absolute gravity devices, to monitor possible changes in gravity as a function of time, etc... and to form a strong network of absolute stations for definition of the International Gravity Standardization Datum.

SITE SELECTION CRITERIA

1. General Location

1.1. Geology

Site to be located on stable crystalline rock, preferably Precambrian or Paleozoic in age. The preferred location of maximum stability is the continental shield area of Precambrian rocks. The next preferred locations are on discordant plutons such as batholiths. The stations shall be at least 50 kilometers from active fault systems.

1.2. Seismic Hazard

Sites shall not be located high seismic risk area. They shall be located areas comparable to zones 0 to 2 of the seismic risk map of the U.S.A..

1.3. Geography

Site shall be located approximately 300 kilometers from the ocean and 80 kilometers from other bodies of water larger than 2,000 square kilometers.

1.4. Solid Earth tides

Can be computed (e.g. by the International Centre of Earth Tides, Uccle) with a precision of 1 µgal or even better.

1.5. Indirect effects due to the oceanic tides (gravitational attraction and loading effect)

Are less sure. Presently the best tidal oceanic maps are those of Schwiderski.

The Intern. Centre for Earth Tides (Pr. Melchior) has calculated and published in the Bull. Inf. Marées Terr. 89 the amplitude of the M2 oceanic attraction and loading effect on the basis of Schwiderski's map for M2, the main tidal component. The equal loading attraction lines are given for peak to peak values of M2 (in µgal) ; one can estimate that the other main semi-diurnal waves (S_2, N_2, K_2) contribute for an additional 50 % of these amplitudes. The effect of diurnal waves in usually less than 1 µgal.

This seems to be valid at a distance of 100 km from the coasts - may be less, but surely not less than 50 km. Near to coasts the variations cannot be controlled with such computations. Measurements must be made with tidal gravimeters at the coastal places where absolute measurements are planned (duration of measurements should be six months).

As an example for a very coastal station like Nosy Bé in Madagascar the calculated M2 effect was 15.8 µgal peak to peak but the measured effect is 39.40 µgal. For such a place the total effect including all the main oceanic tidal components is 84 µgal according to direct measurements.

As another example, the indirects effects in the center of Spain still reach for M2 10 µgal peak to peak and 5 µgal in Brussels which is much closer to the sea.

The important point is therefore to be sure that the predictions based upon oceanic tides models fit properly the observed attraction and loading effects.

Dr. B. Ducarme proposes to change consequently IGC recommendation as follows :

"Places where tidal gravity measurements reconfirm indirect effects computations based upon Schwiderski oceanic models are optimum."

2. Other General Specifics

2.1. Irregular Noise

Irregular noise level should be low, preferably no greater than five (5) microgal when measured by a gravity meter at peak periods.

2.2. Electromagnetic Interference

The site shall not be located near devices that generate electromagnetic interference with absolute or relative gravity measuring instruments.

2.3. Access to Site

Access to the site should be relatively easy, without excessive cost and available to international measuring teams with their absolute gravity measuring devices.

Air connections should be easy : that is, it should be possible to reach each site using regularly scheduled flights.

2.4. Excentres

Excentres shall be established at acceptable sit's in the vicinity of the absolute station. When the absolute station is not located on bedrock, excentres should be established preferably on bedrock and the height difference of excentre stations with respect to the absolute site be determined by high precision levelling.

2.5. VLBI (or other similar) Stations

Consideration should be given to location of some sites in the vicinity of stations where high accuracy geocentric positions can be determined.

2.6. Superconducting Gravimeters

It should be interesting to connect regularly, by absolute measurements, places where superconducting gravimeters are continuously operated in order to check their instrumental drift.

3. Additional Local Specifics

3.1. Build Stability

A stable, permanent building will be chosen for the measurements. The building should be over ten years old preferably, in order to ensure that settling has already occured. The building should be far enough away from disturbances caused by railroad or vehicular traffic.

3.2. Room Selection

The room chosen will be in the lowest level of the building to ensure maximum stability. It should not be near heavy machinery, power transformers or other equipment that would cause vibrations or an electromagnetic field. The room should have at least 2 x 3 meters of space to accommodate the equipment. There should be additional room to allow easy access by the personnel conducting the measurements and to allow dissipation of heat generated by the equipment.

3.2.1. *Measuring surface*

The surface on which the absolute apparatus sits shall be bare concrete, terrazo, marble, or other similar hard floor covering.

3.2.2. *Temperature*

The room chosen for the measurements should not have external temperature or temperature variation that would adversely affect instrument performance. A climatically controlled room is preferred.

The ideal temperature for the room is 18 to 24 degrees of Celsius with only a two (2) degrees of Celsius variation during measurements.

In order to avoid air currents, ventilation outlets and air ducts must not be located adjacent to the apparatus or must be blocked off. Furnace rooms should not be used because of excessive heat. Attention must be paid to the year round temperature of the room, not just the temperature during one season.

3.2.3. *Lighting*

The room must have provision for maintaining semidarkness during absolute observations to accommodate absolute instruments with external laser sources.

3.2.4. *Electric Power Requirement*

Two kilowatts of power are generally required. This normally requires two separate circuits to supply the necessary power. Two 20-ampere circuit breakers will be adequate. A thorough analysis must be made of the electrical panel of the selected building as one or two separate circuits may have to be added.

ACTION PROPOSED

This informations has been sent prior to May 1982 to the Presidents of the I.G.C. Sub-Commissions, asking them to suggest a number of sites in their area using the criteria set up above. The Sub-Commissions should specify the sites and give a brief description related to items listed in the site selection criteria. They should have sent their selections to the President of W.G. 2 (Pr. Uotila) within April 30, 1982.

Having received no reply, a April 12, 1983 Pr. Uotila decided to select a tentative list of possible absolute sites around the world.

The sites have been selected mainly using available information about ocean loading effect in the form of maps.

This information has been sent April 28, 1983 to the appropriate Sub-Commissions for their recommendations. The S.C. should recommend suitable sites from the list. But since the stations which are marked by an asterisk on the list have been selected tentatively without detailed knowledge, there might be cases, where sites, which are not included to the list, might be preferable and should be selected.

The S.C.'s action is essential.

Suggested locations of permanent sites for absolute gravity measurements.

Africa:

Group 1:

1. Cairo, Egypt	30°03'N	31°15'E*
2. Aswan, Egypt	24 05 N	32 56 E
3. Abu Simbel, Egypt	22 19 N	31 38 E
4. Hurghada, Egypt	27 17 N	33 47 E
5. Luxor, Egypt	25 41 N	32 24 E

Group 2:

1. Bamoko, Mali	12°40'N	7°59'W*
2. Ouagadougou, Upper Volta	12 20 N	1 40 W
3. Niamey, Niger	13 32 N	2 05 E
4. Adrar, Algeria	27 51 N	0 19 W

Group 3:

1. Ndjamena, Chad	12°10'N	14°59'E
2. Khartoum, Sudan	15 36 N	32 32 E*

Far East:

1.a. Delhi, India	28°35'N	77°12'E*
b. Jodhpur, India	26 16 N	73 03 E
2.a. Xian, China	34 16 N	108 54 E*
b. Lanzhou, China	36 01 N	103 45 E
c. Yinchuan, China	38 30 N	106 19 E
d. Chengdu, China	30 37 N	104 06 E
e. Beijing, China	39 55 N	116 25 E

Australia:

1. Darwin	12°23'S	130°44'E
2. Tennant Creek	19 31 S	134 15 E
3. Alice Springs	23 42 S	133 52 E*

Western Europe:

1. Paris, France	48°50'N	2°20'E*
2. Wettzell, Germany	49 N	13 E*
3. Frankfurt, Germany	50 10 N	8 40 E
4. Bruxelles, Belgium	50 50 N	4 20 E

USSR:

1. Moscow	55°45'N	37°40'E*
2. Novosibirsk	55 N	83 E*
3. Khabarovsk	49 N	135 E*

North America:

1. Mt Evans, Colorado, USA	39°40'N	105°35'W*
2. Ironton, Missouri, USA	37 30 N	90 40 W*
3. Ft. Davis, Texas, USA	30 45 N	104 00 W*
4. Ottawa, Canada	45 25 N	75 40 W
5. International Falls, USA	48 40 N	93 30 W*
6. Calgary, Canada	51 00 N	114 10 W*

South America:

1. La Paz, Bolivia	16°30'S	68°10'W*
2. Tucuman, Argentina	26 48 S	65 12 W
3. Santiago Del Estero, Arg.	27 48 S	64 15 W
4. Cordoba, Argentina	31 25 S	64 10 W*
5. Buenos Aires, Argentina	34 40 S	58 30 W
6. Asuncion, Paraguay	25 15 S	57 40 W*
7. Curitiba, Brazil	25 25 S	49 15 W

II.2. REPORTS AND PAPERS PRESENTED AT I.G.C.

SUMMARY OF THE I.G.C. MEETING :
PAPERS PRESENTED AND ACTIVITIES OF THE SESSIONS

Eleventh Meeting of the
International Gravity Commission (IGC)

Geomatikum, University of Hamburg
Hamburg, Federal Republic of Germany

11-13 August 1983

Meeting of 11 August 1983 at 0900

C. Morelli presiding

Morelli noted that W. Torge and U. Uotila were ill and unable to attend the IGC meeting. He announced that a telegram had been sent to Uotila and that Torge had been contacted by telephone. The best wishes of all were passed on in both instances.

1. Welcome

J. Makris, speaking on behalf of the Institute of Geophysics and the University of Hamburg, welcomed the delegates to Hamburg and the IGC meeting. He offered to provide any help and assistance to the delegates, and hoped for a very successful meeting. He passed on regrets from W. Torge who was unable to welcome the delegates in person due to illness.

Morelli, speaking on behalf of all attendees at the IGC meeting, thanked Makris for his help in organizing the meeting.

2. Report of the IGC

C. Morelli reported.

Morelli called attention to the printed Activity Report of the IGC that summarizes the activities of the Commission since the Tokyo meeting of the IGC in May, 1982.

Two items, held over from the Tokyo meeting, are of special interest. The first is the new network of world wide absolute gravity measurements, called the International Absolute Gravity Base Station Network (IAGBN). The philosophy and technical aspects of the IAGBN must be carefully considered before the actual work is begun. The second item pertains to the new absolute gravity instruments now being constructed, for example, the six devices being assembled by Faller. The IGC must develop a suitable program so that these instruments will be used in a way that provides maximum benefits to science.

Another important topic pertains to investigations of environmental conditions and their effects on absolute gravity instruments and measurements.

Also, vast areas of the world are not yet covered by surface gravity measurements. Gravity measurements are urgently needed in many land areas.

To date, all of the work accomplished by the Commission has been done through international cooperation. A prime example is IGSN71 - which is a monument in gravimetry. International cooperation is needed now more than ever if the gravimetric problems of today are to be solved. The impetus and scientific needs are apparent. Money to carry out the projects must be found.

It took 20 years to develop the IGSN. The establishment of the new absolute world gravity network may take just as long a time. Morelli expressed confidence that if the appropriate programs are prepared and planned properly, the necessary support will become available, and the work will be accomplished in a number of years.

Finally, the Bureau Gravimetrique International (GBI) is now in good shape. In a couple of years, G. Balmino has reorganized and revitalized the BGI.

3. Reports of the Subcommissions

Morelli reported that in order to resolve today's gravimetric problems more efficiently, the IGC has established a number of regional subcommissions. These subcommissions represent the IGC locally and can bring regional problems to the attention of the IGC. Morelli called upon the presidents of the subcommissions to give their initial reports.

North American Subcommission

K. McConnell spoke for the North American Subcommission in the abscence of the President, W. Strange.

In Correspondence to McConnell, Strange reported that the North American Subcommission has not actually begun to function. Strange feels that the role of the Subcommission in North America is being carried out by existing groups and agencies. He also points out that there are only a few countries in North America, and feels that a North American Subcommission may not be needed at this time.

Tanner added that an absolute gravity network for North America is in the initial planning stages. A mid continent calibration line has been established within the U.S. This line may be extended and others established.

South American Subcommission

In the abscence of the President, Kaussel, K. McConnell spoke for the South American Subcommission.

McConnell reported that important gravity projects are in progress in Latin America. The Latin American Gravity Information System (SILAG) has been working for a number of years with the Inter American Geodetic Survey (IAGS) and Latin American agencies within the aegis of the Geophysical Commission of the Pan American Institute of Geography and History (PAIGH) to develop a gravity data base and gravity reference system for South America.

The Latin American Gravity Standardization Network of 1977 (LAGSN77) has been completed. This provides a gravity reference system for South America.

Following completion of the LAGSN77, a home was sought for the SILAG gravity data base. In 1981, the University of Chile agreed to take over and manage the gravity data base. The transfer of the gravity data base from Ottawa to Santiago is in progress. Further discussions within SILAG are needed to define abilities and funds needed, and services to be provided by the Latin American gravity data center.

During the General Assembly of the PAIGH at Santiago in the spring of 1982, it was proposed that SILAG and the South American Subcommission function from the same office with Kaussel as chairman. There has not been much additional contact with Kaussel since then.

Giesecke was selected President of the PAIGH Geophysical Commission for the period 1982-85. SILAG is one of three working groups within the Geophysical Commission.

India and Arab Countries Subcommission.

M.G. Arur, the President of the Subcommission, spoke.

Arur's main tasks have been to establish contacts with the various contries included in the Subcommission, and to develop information on the activities of these countries. To date, contacts have been established with Iraq, Jordan, Kuwait, Lebanon, Saudi Arabia, the United Arab Republic, and Syria. Most responses so far have been somewhat sketchy.

Syria is attempting to obtain a LaCoste and Romberg gravimeter to do gravity surveys within the country. Possibly the IGC can assist.

India has established a 15 km gravity net and has produced $1^{o}x1^{o}$ mean gravity anomaly values. About one half of the country is covered by this work. All gravity data has been adjusted to the IGSN71. Some gravimetric undulation and deflection computations have also been done using surface gravity data and the GEM-10 gravity model and a gravimetric geiod is being produced. Compensation correction charts for zones 18-1 have been prepared for India. The collocation methods have not yet been applied. Appropriate software is needed.

Western Pacific Subcommission.

J. Nakagawa, the President of the Subcommission, reported.

Nakagawa has made initial efforts to organize the Western Pacific Subcommission. Circular letters have been sent to member countries asking that representatives to the Subcommission be nominated. Some countries have responded; others have not. He will continue his efforts to establish a working Subcommission.

Western European Subcommission

The President of the Subcommission, G. Boedecker, spoke.

The European Subcommission has been set up to include one or two members from each of about 20 countries. There is an executive board consisting of three members. The main function of one member of this board is to maintain the European base station network. The second member concentrates on supporting the BGI with respect to gravity data collection. The third member supports any other activities of the IGC and BGI.

The work of the Subcommission has been concentrated in the area of base station maintenance. A catalog of marine base stations has been compiled and published. This catalog includes some 150 stations distributed along the coastlines of Europe from northern Norway to Portugal and Italy. The accuracy of these base stations is 1-2 mgal which is sufficient for marine gravity control.

The main future work of the Subcommission will be a new adjustment to produce a unified European gravity base network. The adjustment probably will incorporate all existing absolute measurements in Europe. The Subcommission also will assist in the world wide absolute basenet project. Also, under discussion is possible support for marine gravity nets in the North and Mediterranean Seas.

USSR and Eastern European Subcommission

The President of the Subcommission, J.D. Boulanger, reported.

All Eastern European countries have been invited to participate in the activities of the Subcommission. To date, Czechoslovakia and East Germany have responded favorably.

The USSR has continued to put in absolute gravity measurements to enable calibration of gravimeters. A calibration line extending from the northern part of the USSR to Sofia, Bulgaria, has been established.

Non tidal gravity variations have been studied extensively. It is Boulanger's opinion that any secular changes in gravity are very small, certainly less than 0.12 µgal per year. A high precision gravity net established in Eastern Germany also suggests that gravity changes are very small.

The USSR has continued marine gravity measurements. About 20,000 points in the Atlantic and Pacific Ocean have been transmitted to the BGI.

There has been a considerable amount of work in geophysical intrepretation of the gravity field.

Subcommissions not reporting: Southern Pacific, Africa.

4. Report of the Bureau Gravimetrique International (BGI)

G. Balmino provided a report on the activities of the BGI. Complete details of Balmino's report may be found in "Activity Report of the BGI (December 1979 - July 1983)" which was distributed at the IGC meeting. Additional copies are available from the BGI.

Other information on BGI activities may be found in BGI Bulletin d' Information No. 50, and in Balmino's report to the Directing Board of the BGI on 10 August 1983.

Discussion of report:

Morelli asked Balmino to state what assistance can be provided to the BGI by the IGC and its Subcommissions. Balmino replied that the BGI would like to have reports on new gravity survey activities and on the availability of gravity data sets. The BGI also needs assistance in keeping track of gravity base and reference stations.

C. Merry said that the main gravity work in South Africa is the performance of detailed gravity surveys in various parts of the country. Also, assistance has been provided to the International Center for Earth Tides by making earth tide measurements at various sites. There are, at present, no plans for absolute gravity measurements in South Africa. However, there is a desire for such measurements to be made at some time in the future. Merry encouraged Balmino's work in comparing marine gravity data to satellite altimetry produced data.

M.G. Arur said there is great interest in India to have absolute measurements made within the country. He would like instruments to be loaned and people trained so that the Indians can make the measurements themselves. He also requested assistance in contacting gravimetrists from the Arab countries.

Technical Paper: "The Surface Gravity Data Available for Improvement of the Global Knowledge of the Geopotential," by G. Balmino.

Speaker: G. Balmino

The main conclusion of Balmino's paper is that ten years may elapse before data from satellite-to-satellite tracking (SST) will fill in the gaps where surface gravity data is currently available. In the meantime, gravimetry will suffer from the existance of "black holes" where no data is available. Mean values are satisfactory for scientific work, and the release of mean gravity anomalies for $1^{\circ}x1^{\circ}$ surface areas cannot hurt the national interests of any country.

Discussion of paper:

Morelli emphasized the main point of Balmino's paper. One quarter of the land area of the world is without gravity data. Mean gravity anomaly values are scientifically useful, and it is difficult to understand why at least mean gravity values cannot be released.

Swenson said one of two conditions may exist: either no data exists, or the existing data is classified. He felt that all countries should furnish at least $1^{\circ}x1^{\circ}$ mean gravity values.

Morelli suggested a resolution be formulated to state the position of the IGC with respect to free release of at least $1^{\circ}x1^{\circ}$ mean gravity anomaly data. He asked if any attendee was opposed to such a resolution. There was no dissent. Balmino was appointed to draft the resolution.

5. BGI Working Group (WG) Reports

WG1
R.K. McConnell, the Convenor of WG1, reported.

WG1 provides advice and assistance to the BGI in various aspects of data base maintenance, operations, and evaluation. Based upon Balmino's report to WG1 on 10 August 1983, BGI data base operations are in excellent condition. Only one or two items need WG1 input at this time. For example, the nature of the two different types of gravity data bases maintained by the BGI needs to be clarified. The archival data base contains raw data just as it was received by the BGI. The routine data base is the result of merging of all sources. Balmino will clarify the nature of these two data bases in the BGI Bulletin d' Information. Also, as a result of a critique received by the BGI from C.C. Tscherning, certain changes in data exchange formats and bibliographic formats may be made.

The WG1 is also pleased with the success to date of data collected on a restricted distribution basis, and encourages continuation of this policy.

WG2
C. Morelli commented briefly in the absence of the Convenor, U. Uotila.

WG2 is considering proposals for the new world wide absolute gravity base network and plans to meet again to continue its consideration of this project.

WG3
J.D. Boulanger reported.

The most important work of WG3 for the past 3-4 years has been the World Gravity Anomaly Map Series (WGAMS). Many sheets of this series are nearly complete. The map is very important to assist in geological and geophysical interpretations of gravity on a world wide basis. However, it is not possible to obtain surface gravity data coverage for Eastern Europe, the USSR, and China for use in compiling WGAMS. Since the major contribution of WGAMS was to have been to provide first time gravity anomaly coverage of these areas, WG3 has decided to discontinue WGAMS as an international project. However, the project probably will be continued within the USSR where the map will be completed without coverage of Eastern Europe, the USSR, and China.

Working in cooperation with Lamont, WG3 has completed a gravity anomaly map of the South Atlantic Ocean. WG3 is also involved in providing a number of gravity maps for inclusion in a Geological and geophysical atlas of the Atlantic and Pacific Oceans.

WG4
L.E. Wilcox reported.

The accomplishments and current work program for WG4, as reported at the Tokyo meeting of WG4, were reiterated.

Meeting of 11 August 1983 at 1430

C. Morelli, Presiding

6. Absolute Measurements:

Technical Paper: "The JILA Portable Absolute Gravity Apparatus", by J.E. Faller, Y.G. Guo, T.M. Niebauer, and R.L. Rinker.

Speaker: J.E. Faller

Faller described the changes and improvements that have been made in the newest version of his absolute gravity apparatus.

As a final statement for the future, Faller said he believes that today absolute gravity measurements are more accurate and cost effective than relative gravity measurements. He believes the scientific community can look foward to the time when absolute gravity will completely replace relative gravity.

Discussion of paper:

W. Grosse - Brauckmann noted that error bars shown by Faller for absolute measurements using the absolute apparatus appeared to be increasing in length with time and questioned the long term stability of the instrument. He also asked what the price of Faller's instrument would be if it was manufactured in quantity.

Faller replied that the laser used in the measurements for which the error bars were shown aged with time causing the wave length to become more uncertain with time. He felt the laser contributed more error than it should have or will do in later measurements. With respect to price, Faller is currently constructing six greatly improved copies of his currently operational instrument. Five of these six instruments will be sold at cost, approximately, $100,000 to the following agencies: EPB (Canada), University of Hannover, National Geodetic Survey, Institute of Metrology and Geology (Vienna), and Finnish Geodetic Institute. The sixth copy will be retained for research and development purposes. If any more are to be constructed, the fabrication will have to be done commercially and the cost probably will be within the range $100,000 to $200,000. Faller's estimate of the internal error of the new version is $\pm$ 3 µgal.

Technical Paper: "Measures Absolutes Pesanteur en France" (Absolute Gravity Measurements in France), by M. Ogier and A. Sakuma.

Speakers: M. Ogier and A. Sakuma

Ogier described the absolute instrument and observational techniques, showed the location and gravity values for the new absolute measurements in France, and discussed accuracies attained in the measurements and other aspects of the French absolute gravity measurement campaign.

Sakuma described the improvements made on the older Italian apparatus to develop the new commercial apparatus used for the French measurements. The maximum systematic error in the new instrument is 3 µgal. He noted that the absolute measurement at Orleans was made at two different times during the year (February and July), and that a difference of 2.1 µgal was noted between the measurements made at these two different times. During the same period, the water table level at the Orleans station changed 50cm. This phenomenon illustrates the environmental problems that affect absolute gravity at the microgal level.

Discussion of Paper:

Faller asked about the magnitude of gravity changes at Sevres over the past year.

Sakuma replied that extensive excavation and construction work took place at Sevres recently. The drift of gravity readings at the Sevres site during construction work was 29 µgal. There also may be water table level changes at Sevres.

Several attendees expressed the opinion that Sevres may not be the best site for comparison of absolute gravity devices in light of the gravity changes that have taken place there.

Technical Paper: "Results of Comparison of Absolute Gravimeters, Sevres, 1981" by J.D. Boulanger, G.P. Arnautov, and S.N. Scheglov.

Speaker: J.D. Boulanger

The complete text of this paper was published in BGI Bulletin d' Information No. 52.

Boulanger observed that problems in dealing with the vertical gradient of gravity may be one of the primary causes of differnces between the absolute measurements made by different instruments at Sevres in 1981.

Boulanger recommended another comparison of all absolute gravity measuring devices be made before starting work on the new absolute world gravity network. He suggested Sevres as the site and June or July of 1984 as the time.

Boulanger feels that it is now possible to measure absolute gravity with a precision of 1-2 µgal at any time at any place. The problems arise when the measurement is later transferred to the floor or other location so that it can be used. To make a valid transfer, many factors must be considered. He recommended a special study group be established to study these factors and the problems of calculating usable absolute gravity.

Discussion of paper:

Faller questioned claims of 1 µgal accuracy in determining vertical gradients using gravimeters. He said he has never seen an error budget for relative measurements, and that statistical precision is quoted without regard to a systematic error budget. Differences of 10-20 µgal have been noted between absolute and relative gravity gradient determinations at Boulder. He reiterated his opinion that absolute measurements are more accurate than relative measurements.

Boulanger said he gets practically the same result comparing gravimeter and absolute measurements of the gradient. The two agree to about 2 µgal. He requested that Sakuma measure all points on the micronet at Sevres with his instrument prior to the next intercomparison of absolute instruments there. He suggested that the absolute gravity value be referred to the effective height of the instrument rather than to the floor - this practice will minimize error sources.

Marson showed differences in the vertical gradient as determined by Faller in the U.S. over a period of many years. The range of the differences was 0 to 29 µgal. The Italians have been similar experiences in Europe. Thus, data reduction is a problem.

Morelli mentioned that the design accuracy of La Coste and Romberg Model G meters is 10 µgal, and Model D meters is 7 µgal. With good calibration and careful observations, it should be possible to measure gravity differences with an accuracy of a few microgals. Still, side-by-side intercomparisons of absolute instruments is made difficult by vertical gradient and environmental problems. We must decide how to transfer absolute measurements. This involves a careful determination of vertical gradient. Sites for new absolute measurements must be selected very carefully. They must be very stable.

Becker reported finding discrepancies of 8-10 µgal when determining gravity differences on the micro net at Sevres using different gravimeters. The solution is to use several gravimeters and average the measurements. The gravity difference between A3 and A6 at Sevres agreed at the 2-3 µgal level when the average of three D meters was compared to the average of three G meters.

Boulanger reported significant differences in gravity measured on the pier at A3 in Sevres that depend upon where on the pier the measurement is taken.

Morelli felt that Sevres may not be an optimum site for absolute instrument intercomparisons.

Meeting of 12 August 1983 at 0900

7. Tidal and Non-Tidal Gravity Variations

Technical Paper: "On Non-Tidal Gravity Variations," by J.D. Boulanger, G.P. Arnautov, and S.N. Scheglov.

Speaker: J.D. Boulanger

Boulanger remarked that it is difficult to separate measurement error from gravity changes due to environmental factors. Absolute measurements taken by several instruments at Sevres and sites in the USSR suggest a secular change in gravity during the period 1969-72, but no change since then. In the Baikal area, gravity descreased by 20 ugal during the period 1971-82. This decrease may be correlated with height changes, but is more likely related to water level changes. Boulanger showed several examples of gravity changes related to water level changes, but there was also at least one situation when the water level changed but gravity did not. He emphasized the difficulty of analyzing temporal gravity changes.

Technical Paper: "Tidal Correction of Precision Gravity Measurement in China," by H.T. Hsu.

Speaker: H.T. Hsu

Tidal corrections for absolute gravity measurements in China were determined from a combination of theoretical computations and actual tidal gravity measurements. The standard error of the tidal corrections is ± 2 µgal.

Discussion of paper:

Ducarme presented the results of tidal determinations in Europe at stations located at varying distances from the ocean. He noted that loading effects are larger in Spain than near the North Sea Coast. He suggested that super net stations can be placed closer to the sea if the tides can be computed accurately.

Technical Paper: "Variations de la Pesanteur non Liees a la Maree Luni-Solaire" (Variations in Gravity not Related to Luni-Solar Tides), by M. Ogier and A. Sakuma

Speaker: M. Ogier

A linear correlation between gravity changes and barometric pressure variations was computed at Orleans and Toulouse. A slightly different relationship was found at the two sites. The dispersion in absolute measurements was reduced by a factor of two after making a barometric correction.

Discussion of paper:

Ducarme asked what normal or reference pressure level was used.

Sakuma replied that a normal sea level value was defined, then the height of the station above sea level was taken into account.

Ducarme stated that a standard atmospheric reference system is needed if atmospheric corrections are to be made to gravity measurements. He feels that the atmostpheric-gravity relationship depends upon gravity not only at the site but also regionally. The atmospheric correction should be computed in a manner similar to that used for the terrain correction in order to take regional factors into account.

Sakuma said atmospheric effects must be corrected for if maximum accuracy is to be attained.

8. I.G.S.N.

Technical Paper: "Control of IGSN71 System", by J.D. Boulanger, G.P. Arnautov, and S.N. Scheglov

Speaker: J.D. Boulanger

Boulanger wondered about the precision of IGSN71 and whether it is affected by systematic errors. At Port Moresby and Hobart, differences between new absolute measurements and IGSN71 values of 140 and 111 µgal, respectively, have been found. When differences between absolute measurements and IGSN71 values are plotted as a function of latitude, a slight systematic effect of 16.5 ± 5 µgal/gal is noted.

Discussion of Paper:

McConnell said that scale variations of this magnitude in IGSN71 are not unexpected. However, these errors are still within the stated error limits of IGSN71.

Technical Paper: "Integration du Reseau Gravimetrique Francais RGF83 dans le Reseau International IGSN71" (Integration of the French Gravity Network RGF83 into the International Network IGSN71), by M. Ogier.

Speaker: M. Ogier

Ogier concluded that comparison of absolute gravity values within France and adjacent countries to IGSN71 values show all differences to be within 0.1 mgal. There is no indication of any scale error if the absolute measurement at Torino is omitted.

9. Statistical Studies

Technical Paper: "Gravity Empirical Covariance Values for the Continental United States," by C.C. Goad, C.C. Tscherning, and M.M Chin.

Speaker: C. C. Goad

Goad described a least squares collocation program that fits a local first order systematic surface to terrain corrected gravity data over 30 min x 30 min areas. The program has a variety of uses and applications.

Discussion of paper:

Merry asked whether a separate covariance function was determined for each 30 min x 30 min area and if the problem was isotropic.

Goad replied that separate covariance functions are determined, and that with terrain corrected gravity data, a condition of isotropy is being approached.

Arur asked about the uncertainty of the heights used in the solution.

[illegible] said the accuracy of the heights is at the 50m level.

10. New Nets and Adjustments

Technical Paper: "The Austrian Gravity Base Net," by D. Ruess.

The new Austrian gravity base net includes 4 absolute measurements made by the Italian apparatus, and 24 first order and 224 second order stations made by relative measurements. Station sites were selected on the basis of stability, durability, and accessability. Two La Coste and Romberg instruments were used for the relative measurements.

Technical Paper: "The French Gravity Base Network", by M. Ogier.

Speaker: M. Ogier

The French first order gravity base network has been completed. The net, which is tied to absolute measurements and contains 32 stations, was established using two La Coste and Romberg gravimeters. A calibration line of 12 stations also has been established. The second order network is still in work.

Technical Paper: "A New Precise Gravity Network in Lower Saxony", by U. Heineke

Speaker: U. Heineke

A first order gravity network of 68 stations has been established by the Land Survey Office of Lower Saxony. The net, which incorporates two absolute measurements made by the Italian apparatus, was established using four La Coste and Romberg gravimeters (two Model G and two Model D). Seven stations of the German gravity base net were introduced into the variance/covariance matrix. The root mean square error of the gravity values in the new net is ± 8 µgal.

11. New Gravimetric Instrumentations and Improvements

Technical Paper: "Instrumental Investigations and Improvements of the Calibration Function a of LCR Gravimeter Model D", by H. Beetz, B. Richter, and D. Wolf

Speaker: H. Beetz

A La Coste and Romberg Model D gravimeter has been encased in a thermostated aluminum container to minimize effects of external temperature changes. Electronic tilt meters are monitored continuously during measurements. Electronic readout is recorded during each measurement to document reading and give an indication of noise at each station. The measurement process, thereby, is made as impersonal as possible. For meter D-21, a periodic error on the order of 5 µgal was determined by calibration at Darmstadt. After applying the periodic error equation to measurements, residuals between individual and mean measured differences at Sevres are reduced to 1-2 µgal.

Meeting of 12 August 1983 at 1400

S. Krynski, presiding

Technical Paper: "Inertial Gravimetry," by G. Boedecker

Speaker: G. Boedecker

Boedecker described the principles of inertial surveying and explained how gravity is obtained from inertial measurements. Today's inertial gravity measurements have an accuracy of 1-2 mgal. In the near future, improved instruments should yield accuracies of 0.1-0.5 arc seconds for deflection of the vertical and 1 mgal or less for gravity. Inertial surveying provides a very fast method of measuring data.

Technical Paper: "Investigation of Non-Linear Calibration Terms for La Coste-Romberg Model D Gravity Meters", by E. Kanngieser, R. Roder, and H. G. Wenzel

Speaker: R. Roder

Three model D LCR gravimeters were calibrated over the Cuxhaven-Harz calibration line. A third degree polynomial was used to represent the empirical calibration curve. Some empirical calibration curves are strikingly different than the manufacturer's calibration, there being non-linear effects of up to 30 μgal. Empirical calibration improves the accuracy of the D meters tested by about 30 percent.

12. Microgravimetry

Technical Paper: "Partial Analysis of Gravity Measurements on the Fennoscandian Gravity Lines", by M. Becker and E. Groten

Speaker: M. Becker

Becker provided a detailed analysis of the drift and calibration characteristics of the gravimeters used in the campaign. Results of the campaign suggest that the change in gravity in the vicinity of Vaasa is about 1.5 μgal per year. The change decreases with increasing distance from Vaasa. Scatter at some stations suggests local disturbances.

Discussion of paper:

Kiviniemi said the Finnish opinion about gravity changes on the Fennoscandian uplift is in agreement with Becker's results. The gravity change rate at Vaasa is very stable.

Technical Paper: "Gravity and Elevation Changes in the Travale Geothermal Field Within 1979/1982", by G. Geri, I. Marson, A. Rossi, and B. Toro.

Speaker: I. Marson

Microgravity surveys have been conducted in Italy in different areas for different purposes. Three micro gravity nets were established for seismic analysis. No changes due to seismic conditions were observed; rather observed changes were ascribed to local environmental conditions. Microgravity nets have also been used to measure uplift. This is much less expensive than leveling. Microgravity surveys in volcanic areas have been undertaken within the last few years. Several examples of gravity changes related to uplift or subsidence in such areas were shown. Marson concluded it is impossible to measure subsidence or uplift using gravity alone because internal mass changes also affect gravity. However, one may be able to use gravity to interpolate between level lines.

Technical Paper: "Gravity Meter Drift and Microgravimetry", by R.G. Hipkin and D. Lyness

Speaker: R.G. Hipkin

Hipkin gave examples of gravimeter reading scatter with time over short gravity ranges to demonstrate that non-linear drift is a reality.

Meeting of 13 August 1983 at 0900

C. Morelli presiding

13. Marine Gravimetry

Discussion of KSS-30 Sea Gravity Meter

Dehghani reported that the University of Hamburg has owned a KSS-30 sea gravity meter for about one year. The KSS-30 meter consists of a GSS-30 gravity sensor (non-astatized), KT-30 stabilization (gyro table), and data handling equipment. The gravity sensor is highly compensated to minimize outside effects such as motion, pressure and temperature changes, etc. The factory states the dynamic accuracy (RMS) of the system to be 0.5 mgal in calm seas, 1.0 mgal in rough seas, 1.5 mgal in very rough seas, and 2.5 mgal during turns. The drift is less than 3 mgal per month. In actual sea tests by the University of Hamburg, the meter appeared to be yielding accuracies better than the factory's claims.

Makris reported that the University of Hamburg began working with the KSS-30 meter in December of 1982. Four surveys have been completed. In cooperation with the U.S. Geological Survey (USGS), a test survey was run in the Gulf of Mexico to compare results of measurements made by the KSS-30 meter and two La Coste and Romberg meters of the USGS. Two operational surveys using the KSS-30 meter have been run in the North Sea and one in the Strait of Gilbraltar. In the Gulf of Mexico survey, about 10,000 stations were taken. The mean value of the KSS-30 cross over differences was 0.67 mgal. The maximum difference was 2.41 mgal, the minimum was 0.4 mgal. All but four of the differences were less than 0.6 mgal. These results are very good considering that the survey was conducted during bad weather aboard a small ship that was strongly affected by winds and rough sea. A simple Bouguer anomaly map, 5 mgal contour interval, was drawn using the KSS-30 output. The gravity field depicted by the map is rather smooth. A Bouguer gravity anomaly map with 5 mgal contour interval was also drawn from the output of the La Coste and Romberg meters. This map depicts many high frequency anomalies not found on the KSS-30 map. These high frequency anomalies are thought to be mistakes caused by ship vibration, winds, and rough sea. The data analysis and comparison from the Gulf of Mexico survey is continuing.

Balmino asked how well positions were determined in the Gulf of Mexico survey, the size of the short wave length anomalies appearing in the map prepared from the La Coste and Romberg gravimeter output, and the grid spacing used for contouring.

Makris replied that position was determined to better than ± 10m by trilateration to three beacons. The Eotvos correction appears to have been accurately computed because the cross over differences are so small. The short wave length anomalies are about 5-10 km in size and 20 to 30+ mgal in amplitude. Since the bathymetry is very smooth, Makris doesn't believe these are valid anomalies. The grid spacing used for contouring was 500m. x 500m. The profile spacing was 7 miles. All meters were calibrated at the same harbor base station.

McConnell remarked that the KSS-30 has been tested in Canada over a very small area under ideal conditions. The cross over differences in this test were 0.1 to 0.2 mgal.

Technical Paper: "Marine Gravity and Magnetic Measurements in the Area of the Strait of Gilbraltar," by J.L. Almazan, G.A. Dehghani, J. Makris, G. Navacerrada, and R. Parra.

Speaker, J. Makris

Makris presented a preliminary report on interpretation of the Strait of Gilbraltar survey. The sea gravity data will be combined with land data for Spain and Morocco. More seismic profiles will be run next year and the interpretation will be completed when all data is available. Makris recommended establishment of a marine gravity group to study standards, instruments, navigation, and other marine survey problems.

14. Structural Interpretation

Technical Paper: "On the Manifestation of the Deep Crustal Structure in the Anomalous Gravity Field of Central Europe," by V. Vyskocil.

Speaker: V. Vyskocil

Vyskocil has computed correlation coefficients for the depth of the crust-mantle boundary (Moho) vs Bouguer anomaly relationship in Central Europe. He has found the correlation to be very good in the Alps and Capathians. The correlation is weaker in other parts of Europe and is practically nil in Central Germany (e.g., Bohemian Massif). He concludes that the correlation is good in regions that are young geologically and poor in regions that are geologically old.

Discussion of paper:

Hipkin said that a British study has reached the same conclusions as those in Vyskocil's paper. There is no correlation in old regions, but a strong correlation in young regions. The lack of correlation in old regions suggests that the compensation is confined to the upper parts of the crust.

15. Resolutions

Resolution No. 1: Release of Land Gravity Data

Presented by G. Balmino.

The International Gravity Commission, recognizing that the study of many geophysical phenomena in the 100-1000 km range of wave length is severly handicapped by large gaps in the surface gravity coverage especially over land.

- urges all countries to release as much as they can of their land gravity measurements to the scientific community via the Bureau Gravimetrique International; if release of more detailed data is not possible, all countries are urged to release $1^{o}x1^{o}$ mean values of free-air gravity anomalies and elevations which are of fundamental importance for global scientific pursuits -at this resolution, there can in no case by any conflict with national interests.

Resolution No. 1 was adopted with three abstentions but no negative votes.

(Recorder's note: Resolution No. 1, as originally presented, was somewhat more emphatic than the version given above that eventually was adopted. The final version was prepared by softening the original text in accordance with points raised in the following discussion of the original version)

Discussion of Resolution No 1:

The Chinese representatives stated that land gravity data within China is controlled and classified by high Chinese authorities. Resolution No. 1 can be passed on to the proper Chinese authorities, but it probably will not be effective in securing release of the data. Moreover, the Chinese authorities may misunderstand the resolution and consider it to be interference in Chinese internal affairs. A higher degree of cooperation between west and east may help in solving this and similar problems in the future. For example, La Coste and Romberg gravimeters cannot now be exported to China. A resolution will not correct this situation either. East-west cooperation is of great importance.

Morelli said that Resolution No. 1 was written to express the scientific needs for world wide surface gravity coverage. It is not intended to have political overtones. It is general knowledge that overall global knowledge of $1^{o}x1^{o}$ mean gravity anomalies will be of great value to science, and release of such data cannot prejudice any national interests. Since such data will be obtained in time from the methods of satellite geodesy, there can be no harm done in the long run if such data is made available now. The resolution is not directed at any country or group of countries. It merely expresses the wishes of the scientific community to the world as a whole.

Balmino agreed that the resolution is not intended to be political in nature. It merely emphasizes the need for $1^\circ x 1^\circ$ mean gravity anomalies for computation of accurate and truly representative models of the global geopotential. The quality of the best models available today is rather poor mostly because measured gravity data is unavailable for a large portion of the earth's land surface. There are many phenomena in the wave lengths defined by $1^\circ x 1^\circ$ mean gravity data that cannot be studied. Satellite-to-satellite tracking in the low-low mode will provide the necessary data - but not for a number of years. In the immediate future, only release of $1^\circ x 1^\circ$ mean surface gravity data will help.

Morelli noted that it is the duty of the IGC to assist the BGI in collection of gravity data of value to important scientific tasks. The resolution is completely in line with this duty.

Makris suggested that the minimum grid spacing of point gravity data needed for applications be written into the resolution. Balmino replied he purposely didn't want to make the resolution very precise. Rather, it should just state: "Release what you can."

Hipkin thought the resolution satisfactorily separates the $1^\circ x 1^\circ$ requirement from any further requirements. If desired, another resolution emphasizing the need for point data can be proposed at a later date.

Faller suggested that the resolution does three things. It points out a specific scientific problem that cannot be addressed using currently available data, it recognizes that some may not wish to release all gravity data at the present time, and it states that $1^\circ x 1^\circ$ data is sufficient to address the immediate scientific problem. The overall statement is made rather nicely, and with a little softening and some phrase changes, no one should object to its passage.

Arur said whether or not gravity data will be released depends upon the perceptions of the authorities in each country that control such data. The IGC is not a proper forum to rule on national interest with respect to release of gravity data. Just urge the countries to release gravity data for scientific purposes.

Hipkin said that the scientific desire is to obtain acceptable gravity coverage over the continents for scientific purposes such as that stated in the resolution. One cannot derive detailed geodetic data, such as deflection of the vertical components, from $1^\circ x 1^\circ$ mean gravity data. Perhaps the information contained in the resolution could be documented in some sort of a publication instead.

Boulanger said he agrees that it is necessary to collect world wide gravity data to solve global scientific problems. But he is able to do only that which is possible. It is not now possible to obtain any surface gravity data within the USSR. The resolution will not help in getting this data released. If there is anything that can be done in the near future to get the data, he will do it.

Morelli thought that the resolution might not be a good idea if it is going to cause misunderstandings. The idea of a publication, as suggested by Hipkin, may have merit.

Balmino said it is a fact that there are big gaps in the surface gravity data coverage, and that data is urgently needed to eliminate these gaps. These facts need to be pointed out. Passing a resolution is a gentle way to ask for the data and make the facts known. He agreed to rewrite and soften the resolution if that would help.

Wenzel agreed with Balmino. The resolution may be of benefit in convincing some countries to release gravity data.

Morelli asked Balmino and Hipkin to redraft the resolution. The redrafted resolution was adopted without further discussion or dissent.

Resolution No. 2: Standard Gravity Correction System

Presented by C. Poitevin

The International Gravity Commission

- recognizing the high level of accuracy of both absolute and relative gravity measurements recently attained;

- considering the necessity to adopt standard corrections to gravity observations in order to allow intercomparison between instruments at different epochs of time;

- recommends:

(1) that the tidal correction applied to gravity observations must follow the final recommendations of the Standard Earth Tide Committee as presented at the XVIII IUGG General Assembly, Hamburg, 1983;

(2) that the atmospheric pressure correction refer to a common Standard Atmosphere, the sensitivity coefficient being 0.4 microgal/millibar if not determined by special investigations; the value used must be published together with the results; the closed formula for computation of this Standard Atmosphere will be published in a future issue of the Bulletin d' Information of the Bureau Gravimetrique International with the corresponding numerical tables and the programming code;

(3) that the gravity gradient corrections must be published with the adopted local gradient and/or the adopted height difference so that the original values can be recovered.

Resolution No. 2 was adopted unanimously

Resolution No. 3: International Absolute Gravity Base Station Network (IAGBN)

Presented by G. Boedecker

- recognizing that the microgal level of accuracy has been successfully reached by most of the modern absolute apparatuses and by the best gravity meters properly handled and studied with respect to the computation of the environmental effects, thus making possible the establishment of absolute gravity reference points for the different needs of science and for practical applications;

- knowing that approximately ten absolute apparatuses will be operating within the year with an equivalent number in preparation;

- and knowing also that without a common and rational global program, any worldwide absolute gravity project cannot optimize benefits in relation to time and cost;

considers its duty to be the preparation of a program in which the use of absolute measurements and their characteristics be properly exploited according to scientific objectives;

- and recommends to the Executive Council of the International Association of Geodesy the establishment of a Special Study Group to define the purposes (e.g., global reference system, monitoring earth figure changes, intercomparison and calibration of instruments, geodynamic control, etc.), scientific requirements and specifications of a world wide network of absolute stations, wherever possible in coordination with global geometric reference stations, and for the management of its realization and maintenance in agreement with interested countries and bodies.

Resolution No. 3 was adopted unanimously.

16. IGC Program for Next Quadriennium

Morelli thought the most important program for the next four years is development of the world wide super net of absolute stations. The intercomparison of absolute instruments is subordinate to this purpose. The second project, also very important, is to fill gaps in continents with base networks and detailed gravity data. The proposed African gravity project is noteworthy in this context. The third major project area is the problems of marine gravimetry.

Tanner noted that the IGC has been very concerned with the problems and results of microgravimetry. There are needs and uses for these types of investigations. However, it may be appropriate also to discuss needs and uses for gravity data. He suggested that, at the next meeting of the IGC, some time be devoted to gravity applications that involve seismic, magnetic, and other types of data. Papers with gravity interpretations will give the IGC more of a real world framework.

Faller fully supported Tanner's suggestions.

17. Election of Officers

The following persons were elected to office.

IGC Vice Presidents: S. Krynski, H.T. Hsu
IGC Secretaries: D. Ajakaiye, C. Morelli

(Recorder's note: The President of the IGC is J.G. Tanner. He was elected by the IAG)

Presidents of IGC Subcommissions

N. Pacific: I Nakagawa
SW Pacific: Reilley
N. America: C. Goad
S. America; Vacant - to be appointed when PAIGH selects the next chairman of SILAG
Africa: D. Ajakaiye
W. Europe: G. Boedecker
E. Europe/USSR: J. Boulanger
India/Arab Countries: M.G. Arur

Director of BGI: G. Balmino

Directing Board of BGI (elected members)*

I. Nakagawa
J. Woodside
C. Morelli
R. K. McConnell

*Ex officio members of BGI Directing Board are the President IGC, J. G. Tanner (Chairman), the Secretary IGC, D. Ajakaiye, the President of IAG Section 3, W. Torge, and the Secretary of IAG Section 3, C. Tscherning.

18. Closing

In closing, Morelli thanked everyone for the excellent cooperation and support given to him during his term as President of the IGC. He offered his best wishes for continued success and progress of the IGC in the future.

Tanner noted the tremendous progress made by the IGC during Morelli's Presidency. Much of the success of the programs of the IGC are due to Morelli's hard work. He suggested a vote of thanks to Morelli. There was sustained and vigorous round of applause.

L. E. WILCOX
Recorder

C. MORELLI
President

ACTIVITY REPORT OF BGI (Dec 1979-July 1983)

The Bureau Gravimétrique International (BGI), one of the services of FAGS, operates within the framework of this federation as the central agency of the International Gravity Commission to collect and distribute gravity data.

Since its settlement in the Space Center in Toulouse, BGI is supported by five french organizations :

. CNES/GRGS (Centre National d'Etudes Spatiales / Groupe de Recherches de Géodésie Spatiale) in Toulouse,

. IGN (Institut Géographique National) in Paris,

. BRGM (Bureau de Recherches Géologiques et Minières) in Orléans ; which hosts the archive files and perform data retrieval for many users,

. CNRS (Centre National de Recherche Scientifique),

. UPS (Université Paul Sabatier) where the BGI central offices are located since July 1982, precisely in the building of the Observatoire du Pic-du-Midi-Toulouse.

In this 43 months time period, BGI put most of its efforts in the automation of many tasks related to the data preprocessing, analysis, the management of gravity maps, and in the elaboration of a new data base and data management system.

We give below a summary of the major tasks accomplished.

Finally, we present the status of our FAGS account, keeping in mind that most of the support (manpower, computing time, etc...) comes from the above mentionned organizations (appendix 1 gives an idea of the amount of this support excluding the salaries - 7 persons in Toulouse, 2 persons in Orléans).

1. Completion of the Data Base and Data Base System

It is now a completely computerized system, composed of :

. an archive data bank (on magnetic tapes), managed by an index file (disk resident),

. a routine data base, on disk, comprising : the file of the gravity measurements (2 680 000 points as of Nov. 1, 1982) in compressed format, a source description file, a country file, a file of reference stations and a file of maps (main characteristics of maps own by BGI),

. these files can communicate by means of pointers activated by various software programs for interrogating the files or validating and retrieving data.

Other data sets pertain to this data base : mean anomalies, satellite altimetry derived geoid heights, mean values of topographic elevations, to help in the data processing and interpretation.

2. Data Collection

New data sets have been collected and merged with the base, after the merging of the two main bases which BGI had (before 1980) was performed, namely the original BGI data base and the DMA data sets. The new data have been provided mostly by Australia, Finland, Canada, Italy, Japan, United Kingdom, France, plus some african territories prospected by the Office de la Recherche Scientifique et Technique d'Outre-Mer (ORSTOM) ; marine data were also collected, such as several soviet cruises. Modalities to exchange data and to obtain data from BGI were then redefined.

3. Services

BGI has been developping some methods and algorithms to make the user task easier. These methods are described in Technical Notes published after the completion of series of tests to validate each piece of software. As of March 1983, six technical notes have been published.

4. Inversion of Altimetry Derived Geoid Heights

Two software programs have been developped to transform gridded geoid heights into free air gravity anomalies, according to the following methods : (i) inverse Stokes operator in regionalized form (and with respect to a reference field expanded in spherical harmonics) ; (ii) 2-D Fourier transforms in plane approximation. Results derived from Seasat altimeter measurements over the Walvis ridge (South Atlantic) have been obtained, and compare favorably with russian maps of free air anomalies over this area.

This technique is now to be applied to the validation of some cruises of marine gravity data.

5. Digitization of the Worldwide Bathymetry

BGI made satisfactory tests of digitizing the contour lines of the GEBCO (new series) maps of the Earth bathymetry, by means of the laser scanner of the Institut Géographique National. The main steps of such a work for each map are :

(a) automatic numerization of the contour lines with the scanner,

(b) inter-active correction of the digitized level curves,

(c) computation of analytical terrain models,

(d) production of a regular grid of bathymetry values,

(e) constitution of a data base which would allow future updating.

The purpose of such an operation is to help geodesists and geophysicists in the validation and analysis of marine data.

Unfortunately, this operation is now stopped due to lack of funding, but it is hoped that it can be resumed in 1984, which would allow its completion by mid-1985 approximately.

6. Scientific Meetings

- BGI participated in and helped organizing the workshop of SSG 3.37 and 3.40 which were held in Paris in Oct. 1981, and in the intercomparison in Sèvres (BIPM) of four absolute gravimeters. Papers of these workshops were published in B.I. n° 49.
- BGI presented the complete report of its activities at the last meeting of the International Association of Geodesy held in Tokyo, in May 1982.

7. Bibliography

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8. FAGS Account Summaries for 1980, 1981, 1982

FAGS-BGI Account

Statement of Income and Expenditure
for the Year ended 31 December 1980

I. INCOME		
I.1. Allocation from Unesco Subvention to ICSU	3 000.	Dollars
I.2. Unesco Contract (s)		
I.3. Grant from ICSU		
I.4. Contribution from National Members (*)		
I.5. Special Contributions (*)		
I.6. Special Grants (*)		
I.7. Sales of Publications	733.74	Dollars
I.8. Bank Interest and Gain on Exchange		
I.9. Miscellaneous Income	421.31	Dollars
	4 155.05	Dollars
II. EXPENDITURE		
A) Routine Meetings		
A1. Bureau	133.58	Dollars
A2. Executive Committee		
B) Publications	1 162.86	Dollars
C) Scientific Activities		
C1. General Assembly		
C2. Conferences		
C3. Symposia/Colloquia/Working Groups		
C4. Representation at Meetings	139.31	Dollars
C5. Data Gathering/Processing	941.01	Dollars
C6. Research		
C7. Grants to Individuals/Organizations (*)	431.96	Dollars
C8. Other		
D) Administrative Expenses		
D1. Salaries, Related Charges		
D2. Office Equipment	696.58	Dollars
D3. Audit Fees		
D4. General Office Expenses		
D4.a. Heating, lighting, supplies		
D4.b. Postage, Telegrams, telephone	247.58	Dollars
D4.c. Stationery	1 369.43	Dollars
D4.d. Office charges, etc	630.25	Dollars
D4.e. Bank charges	4.46	Dollars
loss on exchange	52.01	Dollars
	5 808.58	Dollars
Excess of Income over Expenditure		
or Excess of Expenditure over Income	- 1 653.53	Dollars
Accumulated Balance at 1 January 1980	- 1 485.	Dollars
Accumulated Balance at 31 December 1980	- 3 138.53	Dollars

FAGS-BGI ACCOUNT

Statement of Income and Expenditure for the Year ended 31 December 1981

I. INCOME

I.1. Allocation from Unesco Subvention to ICSU............	3 500. Dollars
I.2. Unesco Contract (s)	
I.3. Grant from ICSU	
I.4. Contribution from National Members (*)	
I.5. Special Contributions (*)	
I.6. Special Grants (*)	
I.7. Sales of Publications..................................	338.31 Dollars
I.8. Bank Interest and Gain on Exchange	
I.9. Miscellaneous Income..................................	780.56 Dollars
	4 618.87 Dollars

II. EXPENDITURE

A) Routine Meetings	
A1. Bureau..	444.11 Dollars
A2. Executive Committee	
B) Publications..	82.72 Dollars
C) Scientific Activities	
C1. General Assembly	
C2. Conferences...	190.65 Dollars
C3. Symposia/Colloquia/Working Groups.....................	774.35 Dollars
C4. Representation at Meetings............................	134.31 Dollars
C5. Data Gathering/Processing.............................	707.03 Dollars
C6. Research..	41.68 Dollars
C7. Grants to Individuals/Organizations (*)...............	184.48 Dollars
C8. Other...	5.64 Dollars
D) Administrative Expenses	
D1. Salaries, Related Charges	
D2. Office Equipment......................................	1 212.09 Dollars
D3. Audit Fees	
D4. General Office Expenses	
D4.a. Heating, lighting, supplies	
D4.b. Postage, telegrams, telephone.....................	215.73 Dollars
D4.c. Stationery..	493.73 Dollars
D4.d. Office charges, etc...............................	88.17 Dollars
D4.e. Bank charges, loss on exchange....................	1.87 Dollars
	4 576.56 Dollars
Excess of Income over Expenditure.........................	42.31 Dollars
or Excess of Expenditure over Income	
Accumulated Balance at 1 January 1981.....................	1 002.42 Dollars
Accumulated Balance at 31 December 1981...................	1 044.73 Dollars

(*) Detailed list should be attached to Financial Statement

FAGS-BGI ACCOUNT

Statement of Income and Expenditure for the Year Ended 31 December 1982

I. INCOME

Grant from ICSU Fund	
Allocation from Unesco Subvention to ICSU.................	4 300. Dollars
Unesco Contract (s)	
Contributions from National Members	
Contributions from Scientific Members	
Special Contributions	
Special Grants/Contracts	
Sales of Publications, royalties..........................	423.03 Dollars
Sales of Scientific Materials.............................	118.83 Dollars
Bank interest and gain on exchange	
Other Income..	235.71 Dollars
	5 077.57 Dollars

II. EXPENDITURE

a. Scientific Activities	
General Assembly	
Conferences...	61.66 Dollars
Symposia/Colloquia/Working Groups.........................	253.58 Dollars
Representation at Scientific Meetings	
Data Gatherings/Processing................................	271.92 Dollars
Research Projects...	70.29 Dollars
Grants to Individuals/Organizations.......................	312.93 Dollars
Other	
b. Routine Meetings	
Bureau / Executive Committee..............................	365.31 Dollars
Other	
c. Publications...	179.62 Dollars
d. Administrative Expenses	
Salaries, Related Charges	
General Office Expenses : rental, heating, lighting, supplies, postage, telephone, telegrams, stationery etc...	3 254.82 Dollars
Office Equipment..	406.50 Dollars
Audit Fees	
Bank Charges and Loss on Exchange.........................	3.08 Dollars
	5 179.71 Dollars
Excess of Expenditure over Income.........................	- 102.14 Dollars
Accumulated Balance at 1 January 1982.....................	1 096.53 Dollars
Accumulated Balance at 31 December 1982...................	994.39 Dollars

- APPENDIX 1 -

ESTIMATION OF THE ANNUAL BUDGET OF BGI EXCLUDING THE PERSONNAL SALARIES

(French francs)

Locaux :

. Actuels : 150 m^2 + pourcentage des locaux communs avec OPMT (escaliers, couloirs, sanitaires...)

. Nécessaires : 170 m^2 en immeuble indépendant coût annuel locatif (incluant charges, chauffage électricité).................................. 50 kF*

Matériel :

. Location terminal type ORDO 80 (lecteur + imprimante 600 l/mn + console).. 40 kF*□

. Fournitures (imprimante) papier-ruban.......................... 10 kF*□

. Contrats d'entretien du matériel informatique BGI + machine à écrire
Tektro 4014 + "hard-copy" ; console SECAPA + imprimante ; console ADM5 + imprimante ; console ADM3A ; machine à écrire ; perfo IBM.. 20 kF*⊙

Edition :

. Photo-copies (Copie-service NASHUA)........................... 20 kF*+

. Impression : Bulletin d'Information (2 x 200 ex.).............. 50 kF*+

. Rapports techniques, thèses stagiaires........................ 10 kF+

Fournitures de Bureau :

. Evaluation forfaitaire (d'après 1981 et 1982)................. 10 kF*+

Courrier :

. Essentiellement : envoi bi-annuel du B.I. et de catalogues..... 10 kF*

. Envoi bandes magnétiques et cartes............................ 5 kF*

. Courrier général.. 1 kF*

Téléphone :

. Estimation forfaitaire (7 personnes au BGI, env. 200 correspondants).. 25 kF*

Télex :

. Estimation forfaitaire (location + coût)....................... 15 kF*

Heures de Calcul :

. 120 h. équivalentes CDC-CY.750 sur centre de calcul du CNES, au prix du ticket modérateur i.e. 2 000 F/heure.................. 240 kF*

. location de la ligne (proximité 1 km).......................... 40 kF*□

Missions :

. Estimation (d'après 1981 et 1982) ; missions soit strictement BGI, soit liées aux activités scientifiques GRGS............... 50 kF*+⊙

Vacations :

. Estimation (d'après 1981 et 1982)............................. 10 kF+⊙

Investissements - Remplacements de matériel :

. Microfiches - Lecteur, support
. Matériel cartothèque (meubles à cartes, réglettes) .... 10 kF*+
. Machine à écrire

TOTAL.. 616 kF

Légende des Symboles *, +, ⊙ :

Ces symboles correspondent à la source actuelle de financement :

* CNES (Centre Spatiale de Toulouse)

\+ Budget BGI propre (ICSU-UNESCO-CNFGG, éventuellement contrats)

⊙ CNRS, ATP,...

Symbole □ : Partie commune avec OPMT.

THE SURFACE GRAVITY DATA AVAILABLE FOR IMPROVEMENT OF THE GLOBAL KNOWLEDGE OF THE GEOPOTENTIAL

G. Balmino

Bureau Gravimétrique International, Toulouse, France

Abstract. The best way of using surface gravity data to improve our global knowledge of the geopotential is to make use of mean values of free-air gravity anomalies which yield observation equations for spherical harmonic coefficients of the field to be usually combined in the least squares sense with equations derived from the analysis of satellite orbit perturbations, after appropriate weighting. Although the latter equations serve mainly to control the long wavelength behaviour of the gravity field model, it is an experienced fact that the whole set of coefficients can be badly affected by large gaps in the surface data coverage. That is why as complete as possible data sets of mean values of free air anomalies computed either from gravimeter measurements, or from satellite altimetry derived geoid heights, or even predicted - usually by topo-isostatic models, are of so great interest. Such data sets are generally 1° x 1° mean values and may be used directly or in a two step process in which they are first used to derived mean values over larger areas, e.g. 5° x 5°.

The best 1° x 1° data set presently available is the one computed at Ohio State University by Prof. Rapp and his team (Rapp, Jan. 1983) which includes newer data than the previous sets already derived by the same research group, especially mean values derived from Seasat altimetry observations. Unfortunately, there are still over six thousand anomalies which are predicted ; in most cases, this is due to classification exerted by various countries which do so for preserving (not well understood) national interests. It is widely recognized that mean values of gravity at a resolution of 100 km, or even 50 km, can serve geophysical interests only, and that is why it is strongly recommended that all countries deliver freely a set of mean values of free air gravity anomalies over their territory for the benefit of the scientific community.

INTRODUCTION

The assessment of accuracy of global Earth gravity field models is of fundamental importance for refine studies of the long and medium wavelength behaviour of the Earth crust, for validating models of deep internal processes such as thermal convection and for a better understanding of the ocean dynamics as mapped by satellite altimetry. Comparisons between recent solutions of the field in spherical harmonics, solutions which combined satellite perturbation analysis and observation equations derived from mean values of surface gravity and from satellite altimetry data, clearly show that they are probably inadequate to represent the geoid, or the gravity, over areas where gravity data were not available. This is a fact we wish to emphasize in this paper, for which the only remedy is to make all efforts towards the completion of a worldwide set of mean values of gravity, preferably 1° x 1° means, derived from existing gravity measurements made by all organizations in all countries.

PRESENT SITUATION

Satellite tracking data accumulated since the beginning of the space age, that is optical, interferometric, doppler and laser measurements, have been analyzed by various groups to derive observation equations for spherical harmonic coefficients of the Earth's gravity field expansion, by processing either long arcs of data of 10 to 40 days (or sometimes more for determining the zonal harmonics) or much shorter ones (2 to 5 days, typically) in the recent years, yielding satellite only solutions, such as GEM 9 (Lerch et al., 1979). To these data are generally added equations for all considered harmonics derived from surface data, namely 1° x 1° mean values of free air gravity anomalies either computed from real measurements or from satellite altimetry derived geoid heights (from the Geos 3 and Seasat spacecrafts), which are processed as such or in the form of smoothed 5° x 5° area means.

In an Earth fixed-coordinate system $\{x_i\}$ centered at the Earth center of mass, with the x_3 axis coinciding with the principal axis of minimum inertia, the gravitational potential is expressed in spherical coordinates r : radius vector, ϕ : latitude, λ : longitude (positive eastward) as :

$$U(r,\phi,\lambda) = \frac{GM}{r}\left[1 + \sum_{\ell=2}^{\infty}\sum_{m=o}^{\ell}\left(\frac{R}{r}\right)^{\ell}(\bar{C}_{\ell m}\cos m\lambda + \bar{S}_{\ell m}\sin m\lambda)\,\bar{P}_{\ell m}(\sin\phi)\right] \quad (1)$$

where GM : product of the gravitational constant (G) by the Earth mass (M),

R : reference length value, usually equal to the semi-major axis of a reference ellipsoid

$\bar{P}_{\ell m}(x)$: fully normalized Legendre functions (and polynomials when m = o) such that

$$\frac{1}{4\pi}\iint_{\text{unit sphere}} \bar{P}^2_{\ell m}(\sin\phi)\begin{Bmatrix}\cos^2 m\lambda\\ \sin^2 m\lambda\end{Bmatrix} d\sigma = 1$$

$\bar{C}_{\ell o}$: zonal harmonic coefficients

$\bar{C}_{\ell m}, \bar{S}_{\ell m}, m > 0$: tesseral harmonic coefficients

For our planet, $\overline{C}_{20} \simeq -5.10^{-4}$, while higher degree coefficients appear to decrease in magnitude according to $10^{-5}/\ell^2$ (Kaula's "rule").

The coefficients $\overline{C}_{\ell m}$, $\overline{S}_{\ell m}$ are then determined, up to a maximum degree and order L :

(a) from the analysis of satellite orbit perturbations : this is a classical inverse problem in celestial mechanics, in which some force parameters are computed from the knowledge of the orbit tracked from Earth stations. In this problem, it is known that a given mean trajectory is mostly sensitive to some classes of harmonics and that, given a certain tracking accuracy, only a finite number of linear combinations of coefficients can be determined ; furthermore many different orbits of varied inclinations are necessary to then separate these coefficients.

One technique consists in directly inverting the equations of motion of several Earth satellites through a two step differential correction procedure in which orbit parameters are first eliminated and where the tracking station coordinates appear to be supplementary unknowns to the problem (they may be part of a global solution or determined independently from different approaches). Besides this, one generally makes use of other characteristics of the response of an orbit to some coefficients, that is to say : (I) the zonal harmonics which are responsible for the dominant secular changes in the angular elements (for the even degree terms) and for large long period perturbations with frequencies $\dot{\omega}$, $2\dot{\omega}$, $3\dot{\omega}$... (ω being the argument of perigee) ; (II) some classes of tesseral harmonics coefficients corresponding to cases when a given satellite orbit is in shallow resonance with the Earth rotation, these harmonics being usually of order 11, 12, 13, 14 or 15 for geodetic satellites. Therefore, special methods have been developped for all these terms, which use a multi-stage filtering technique yielding expansions of residuals in the orbital elements of a satellite in terms of the coefficients to which the trajectory is sensitive.

We can summarize all the equations derived from the satellite orbit approach in the form of a normal system such as :

$$N_S \, \Delta H = b_S \qquad (2)$$

in which N_S is the normal matrix, ΔH is the vector of all corrections to selected harmonics (up to degree and order L) with respect to initial values $H^\circ = \{\overline{C}_{\ell m}{}^\circ, \overline{S}_{\ell m}{}^\circ\}$.

Low order coefficients can be reliably estimated as they result in perturbations with periods that exceed a few hours and which can be well sampled from tracking stations of a global network, but the higher-degree coefficients become increasingly difficult to estimate because of the $(R/r)^\ell$ attenuating factor and the fact that $r - R \gtrsim 600$ km (at least for all processed orbit - due to the atmosphere). To illustrate this situation, figure 1 indicates the approximate limits of the sensitivity of satellite to the potential for different accuracies : 10 m (typical for optical observations), 1 m (old laser and classical Doppler systems), 0,20 m (actual laser stations) ; the shaded regions between the lines indicate those coefficients that cannot be estimated ; the coefficients below A_x can be determined from short period perturbation analyses while those above A'_x follow from shallow resonance studies (for a tracking accuracy equal to x meters).

(b) from the analysis of surface data :

It is clear that it is necessary to complement the satellite orbit analysis informations by other data in order to obtain a global model complete up to a certain degree and order $\ell_{max} = m_{max} = L$. Such data presently consist in surface free-air gravity anomalies, Δg, which are related to U through the well-known equation (Heiskanen & Moritz, 1967) :

$$\Delta g = -\frac{\partial T}{\partial r} - \frac{2T}{r} \qquad (3)$$

in spherical approximation, where T, the disturbing potential, equals U minus U^*, the gravitational potential of a selected reference ellipsoid (expressed as a spherical harmonic expansion involving only $\overline{C}^*_{2n,o}$ terms). This equation yields :

$$\Delta g(r,\phi,\lambda) = \frac{GM}{r^2} \sum_{\ell=2}^{\infty} (\ell-1) \left(\frac{R}{r}\right)^{\ell} \left[(\overline{C}_{\ell,o} - \overline{C}^*_{\ell,o}) \, \overline{P}_{\ell,o} (\sin\phi) + \sum_{m=1}^{\ell} (\overline{C}_{\ell m} \cos m\lambda + \overline{S}_{\ell m} \sin m\lambda) \, \overline{P}_{\ell m} (\sin\phi) \right] \qquad (4)$$

where the point (r,ϕ,λ) lies on the reference ellipsoid, that is with $r \simeq R\,(1 - f \sin^2\phi)$, f being the flattening of this ellipsoid and R its mean semi-major axis.

Equation (4) is used for residual mean values of gravity (with respect to the initial field of coefficients $\bar{C}^{o}_{\ell m}$, $\bar{S}^{o}_{\ell m}$) over spherical rectangles $\Delta\phi \times \Delta\lambda$.

In some global combined solutions such as SE III (Gaposchkin, 1971), SE IV.6 (Gaposchkin, 1980), the GEM 2k solutions - e.g. GEM 10B (Lerch et al., 1981), mean values over 5° x 5° blocks or 5° x 5° "equal area blocks" have been first computed from existing sets of mean 1° x 1° values of Δg and then used in equations such as (4), whereas the last GRIM models - GRIM 3 (Reigber et al., 1983a), GRIM 3B (Reigber et al., 1983b) have made use directly of 1° x 1° values, a process which is reported by the authors to be less smoothing, although more demanding in computing time and which require greater care for the weighting. Finally, the observation equations yield a normal system :

$$N_g \; \Delta H = b_g \qquad (5)$$

which is added to system (2) after some multiplying factor has been applied, an empirical procedure which was proved to be necessary but which requires many trial solutions.

Although great attention have been given by all the groups deriving gravity field models, to many questions pertaining to the analysis of data, to numerical algorithms, to the weighting of the data, etc..., it is a fact that still large discrepancies exist and that, although some models appear to be better presently at orbit fitting or in representing some parts of the oceanic geoid, they are still unsatisfactory for many theoreticians. As far as the general behaviour of the differences between any two models is concerned, we can give a measure of the disagreement by means of the geoid undulation differences by degree δN_ℓ, computed as :

$$\delta N_\ell = R \left[\sum_{m=o}^{\ell} (\delta\bar{C}^2_{\ell m} + \delta\bar{S}^2_{\ell m}) \right]^{1/2} \qquad (6)$$

where the $\delta\bar{C}$'s and $\delta\bar{S}$'s stand for the individual differences in the coefficients of the two considered models. Figure 2 and 3 illustrate the fact for the models GEM 10B and GEM L2 (Lerch et al., 1982) and for GRIM 3 and GEM 10B, successively.

Local divergences between models are even more clearly shown by free-air gravity anomaly differences in some parts of the world where the gravity data themselves were almost non existant (often predicted for sake of coverage completeness, therefore having variances as large as 500 or 1 000 $mgal^2$) and where shorter wavelength gravity variations are very unreliable. Figure 4 shows what we call "the worst case" over a large part of Asia, for the models GEM 10B and GRIM 3. It must be noted that both models made use of Rapp Oct. 1979 1° x 1° data set which consisted in : 25 001 values computed by collocation from measured point values or sometimes predicted through topo-isostatic models (land areas mostly), 27 916 values determined by collocation from the Geos 3 satellite altimetry derived geoid heights (for most oceanic areas between latitudes 65°N and 65°S) ; the coverage of these data is shown on figure 5 where the distinction is made between computed and predicted values.

THE RAPP JANUARY 1983 1° x 1° DATA SET

R. Rapp group at Ohio State University has been working in the field of compiling and computing global sets of 1° x 1° mean gravity anomaly values for a decade, works which have been of great value to all other groups which undertake the computation of global combined models of the geopotential. The last file of such 1° x 1° data was presented and released in January 1983 and its author gave all its characteristics. Table 1, taken from R. Rapp communication, summarizes some of them. To these purely terrestrial data of 44 513 values, either computed from real measurements or predicted, of which the coverage is shown on figure 6 (the dark areas correspond to predicted values), we can add the gravity anomalies derived from Seasat geoid altimetry informations which are 37 905 in numbers, their location being shown on figure 7. Although most recent combined models are still using these anomalies in combination with the others for producing equations such as eq. 5, we do not recommend to do so in the future since 1° x 1° values located near the coasts have used altimetry informations and terrestrial gravity measurements ; satellite altimetry derived geoid heights should be used as such without transformation.

A merged set of anomalies can then be derived for geopotential model calculators usage, such as the one shown on figure 8 which contains 56 849 values of which the signal distribution is displayed on figure 9, a merging performed by DGFI (Reigber & Bosch, 1983, private communication) in which most of the original oceanic anomalies have been replaced by the Seasat derived ones.

Figure 8 shows in particular that the 1983 situation is not very much better than the 1979 case for some land areas namely Alaska, South America, Greenland, most of Africa, Middle East, USSR, China, and Antarctica, the reasons being the same that is : (I) the difficulties which still exist in making gravity measurements in some areas of our planet (high mountains, deserts,...) ; (II) the classification exerted by some countries even on the 1° x 1° mean values.

WHAT TO DO IN THE NEAR FUTURE ?

It is unfortunately recognized that many geophysical studies of phenomena in the 100-1 000 km range of wavelength are very much handicaped by large gaps in the surface gravity coverage which exist mostly overlands. A quick look at table 2, which gives an overview of questions which still need further studies and of the required accuracy in term of gravity anomalies, geoid heights or other parameters, show that problems such as isostasy in continental areas, small scale convection, could be very much clarified if a better gravity data set (mostly better in term of coverage) was at the disposal of the geophysicists.

We want to make clear that, within one or two decades, new types of global satellite experiments will yield a fast, complete and direct mapping of the gravity field variations down to a resolution of 200 or 100 km and with an accuracy of a few milligals ; these projects are satellite to satellite tracking projects such as GRAVSAT (Pisacane et al., 1981) or GRM (Geopotential Research Mission), and satellite gradiometry such as GRADIO (Balmino et al., 1983).

In the mean time and considering that gravity over the oceans is much better known now, the only progress may only come from new data sets covering land areas. It is striking to see the difference in the coverage over various countries as exhibited by figures 10 and 11, a disproportion which is responsible for many artefacts which certainly affect all global models as we already explained it. That is why, in the framework of its activities, the Bureau Gravimétrique International has issued a circular sent to representatives of the IUGG National Committees of several countries, asking for additional gravity data, either measured point values or at least 1° x 1° mean values (an example of such circular is given in appendix). It must be noted that delivering a set of 1° x 1° values is in no case at all in conflict with military or other civilian national objectives ; as it is well known, such studies actually require the knowledge of gravity for two reasons :

- calibration of inertial navigation systems which can only be made through precise gravimeter measurements at the instrumentation location,
- derivation of deviation of the vertical at and around some specific points, a procedure which needs much finer data sets with a resolution of 10 km or better in order to be of some usage.

In short, 1° x 1° values cannot serve any of the two above mentionned purposes and their delivery can in no case affect any national interest. In the contrary, all countries, organizations and individuals will benefit from this since a better knowledge of the global Earth gravity field is at the crossroads of all geophysical disciplines in the broad sense and of all economic applications which make use of satellite and especially satellite geodesy techniques.

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ASSOCIATION INTERNATIONALE DE GEODESIE

BUREAU GRAVIMETRIQUE INTERNATIONAL

Toulouse, le July 25, 1983

REF. :

EXAMPLE OF CIRCULAR

SUMMARY OF GRAVITY DATA IN YOUR COUNTRY, PROVIDED TO B.G.I.

This personal circular aims at informing you of the inventory of gravity measurements performed over the territory of your country and which are present in the data base of the Bureau Gravimétrique International.

Please note that the coding operations which we performed prior to this inventory were based on automated comparisons with a digital file of country boundaries and therefore that a few mistakes may have occured.

We are giving below a list of data sources with their characteristics.

We recognized your contribution to our data collection program, but we are unaware of better surveys or recent gravity campaigns which have been performed by various organizations over your territory.

In consequence, and according to the mandate which has been given to us by the Federation of Astronomical and Geophysical Services, may we urge you to deliver all pertinent informations to the Bureau. May we remind you on this occasion that it was agreed at the general meeting of IAG, Tokyo, May 1982, that BGI could host data which may have some restrictions of distribution (see Bulletin d'Information n° 50, pp 5-7).

The B.G.I. Staff

Adresse : CENTRE NATIONAL D'ETUDES SPATIALES / GROUPE DE RECHERCHES DE GEODESIE SPATIALE
18, avenue Edouard-Belin - 31055 TOULOUSE CEDEX (FRANCE)
Tél. : (61) 53.11.12 - Ext. 50.72
Télex CNEST B 531 081 F

Table 1a. Rapp Jan. 83 gravity file characteristics

History	Major improvements
1. Data sets developped since 1972 on the basis	1. Addition of 12 new sources
2. All data to be intercompared where possible	2. More uniform treatment of accuracy estimates
3. Past fields	3. Selection of data in ocean areas based on comparison with Geos 3 and Seasat implied gravity anomalies
	4. Data selection in land areas aided by comparisons with residuals in a high degree combination solution

Name	Number of anomalies
June 72	23355
Sept 73	29789
1 - July 75	36149
Aug 76	38406
June 78	39405
* Oct 79	41973
→ Jan 83	44513

Table 1b. Rapp Jan. 83 file. Problem anomalies in continental and oceanic areas

Continental areas

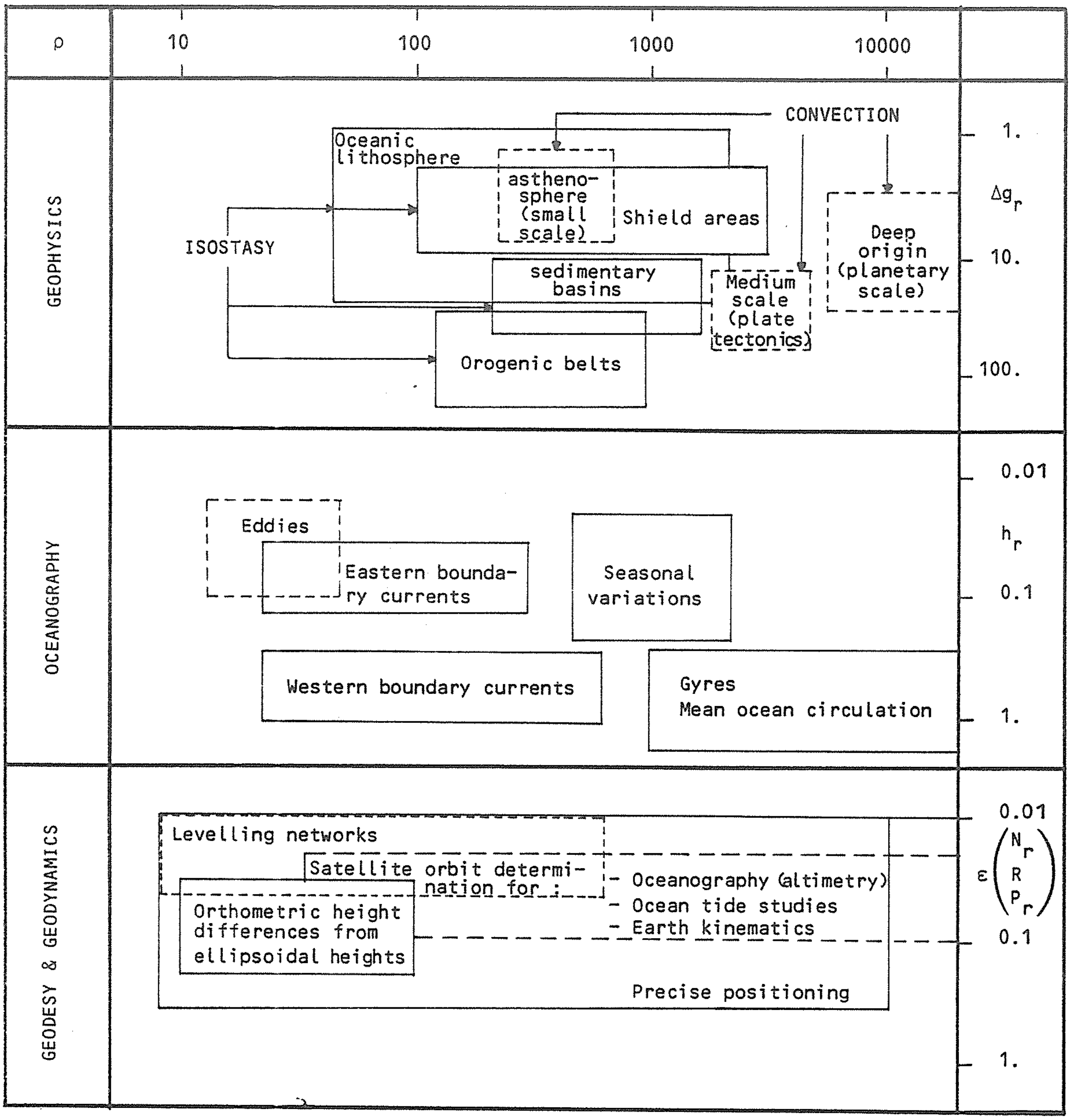
NW CORNER	AREA	ELEVATION	MGALS NEW	MGALS OLD	DIFFERENCES
27° 94	NE INDIA	580 M	-28	-254	227
-33° 291	ARGENTINA	843	-42	127	-168
6° 45	ETHIOPIA	394	-10	120	-129
28° 94	NE INDIA	239	-57	-171	115
-84° 159	ANTARCTIC	2100	-36	120	-155

Oceanic areas

NW CORNER	AREA	DEPTH	MGALS NEW	MGALS OLD	MGALS DIFFERENCE	MGALS SEASAT
13° 257°	OFF MEXICO	-3200M	6±17	149±97	-142	7± 4
-28° 183°	KERMADEC RIDGE	-5500	-60±10	-181±97	122	-74±17
-67° 34°	SOUTH OF AFRICA	-3528	-20±16	117±30	-136	-47± 7

Table 2

Magnitude of various quantities related to Earth gravity perturbations at different resolutions



Caption : ρ : resolution, or half wavelength of phenomenon (km)

Δ : relative variation of gravity anomaly (mgal)

h_r : relative variation of sea surface height (m)

$\varepsilon(N_r)$: accuracy of geoid height relative variation (m) ; $N_r \simeq 3.25\ 10^{-4}\ \rho\ \Delta g_r$

$\varepsilon(R)$: accuracy of satellite orbit radial component (m)

$\varepsilon(P_r)$: accuracy of relative geodetic positioning (m)

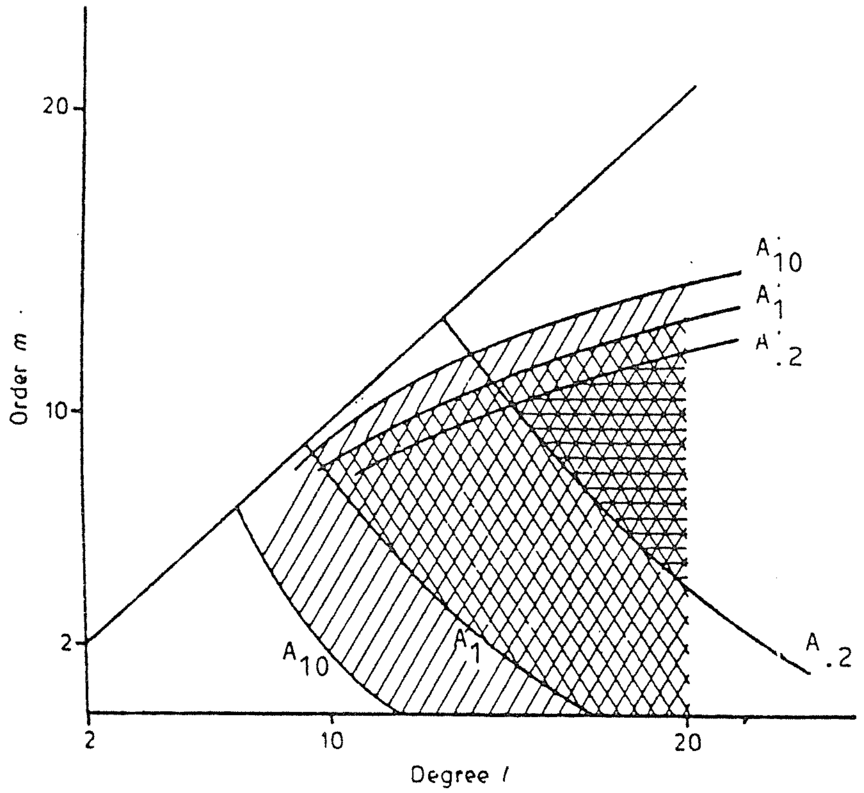


Fig. 1. Schematic representation of the non-zonal coefficients that cannot be determined from satellite orbit perturbation analyses. The coefficients of degree and order ℓ, m lying in the shaded area between the lines A_x and A_x' cannot be determined if the tracking accuracy is lower than x meters.

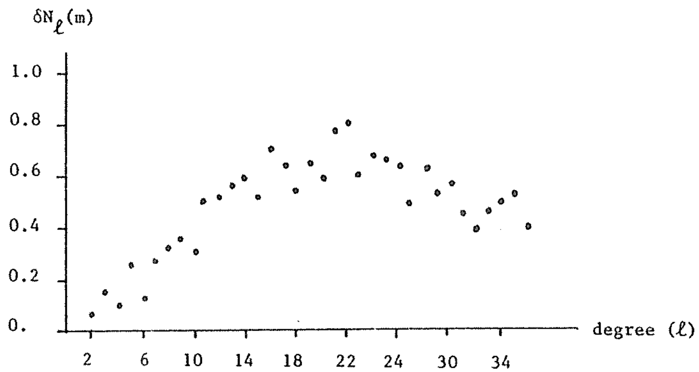


Fig. 2. Geoid undulation differences by degree : GEM 10B-GEM L2

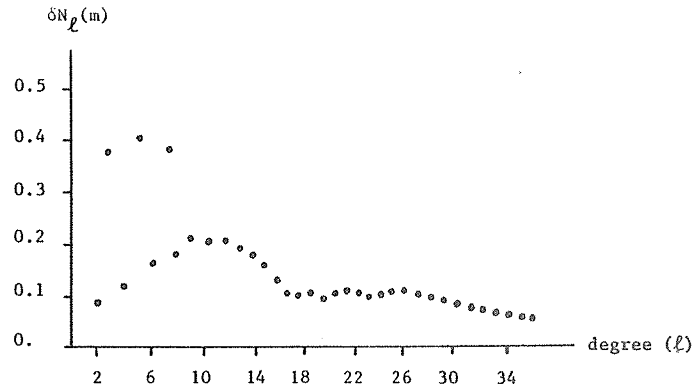


Fig. 3. Geoid undulation differences by degree : GRIM 3 - GEM 10B

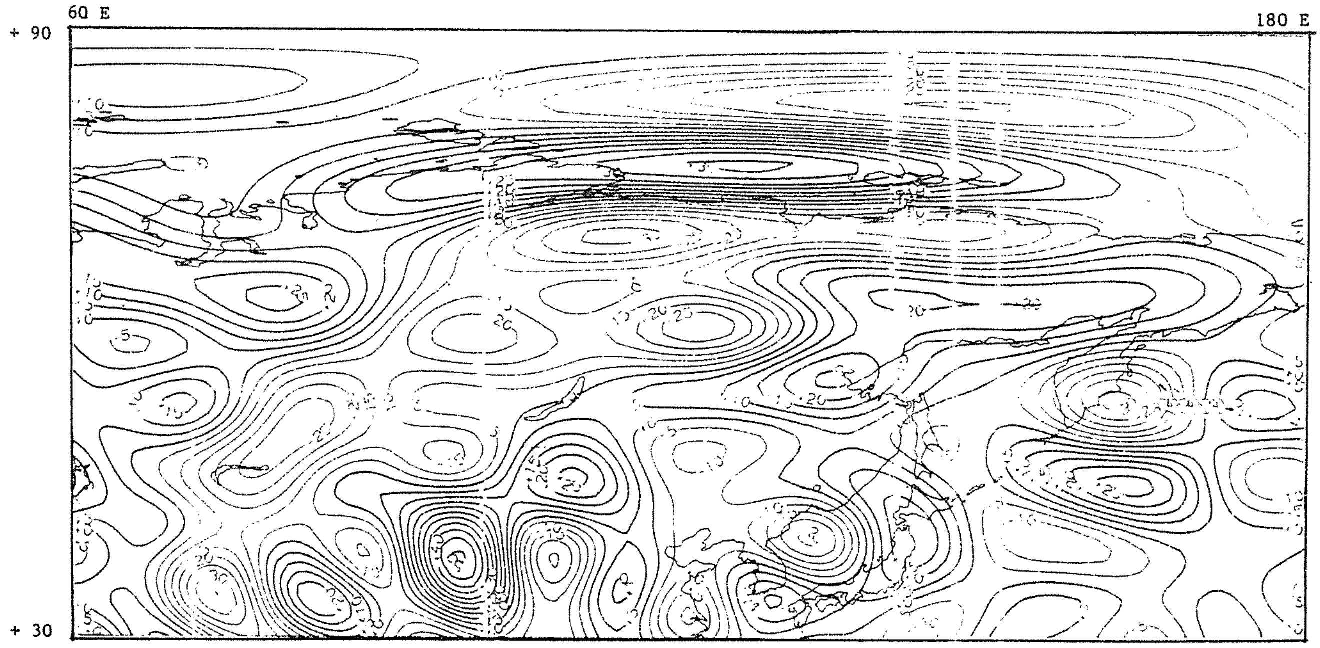


Fig. 4. Gravity anomaly differences between GRIM 3 and GEM 10B : the worst case.

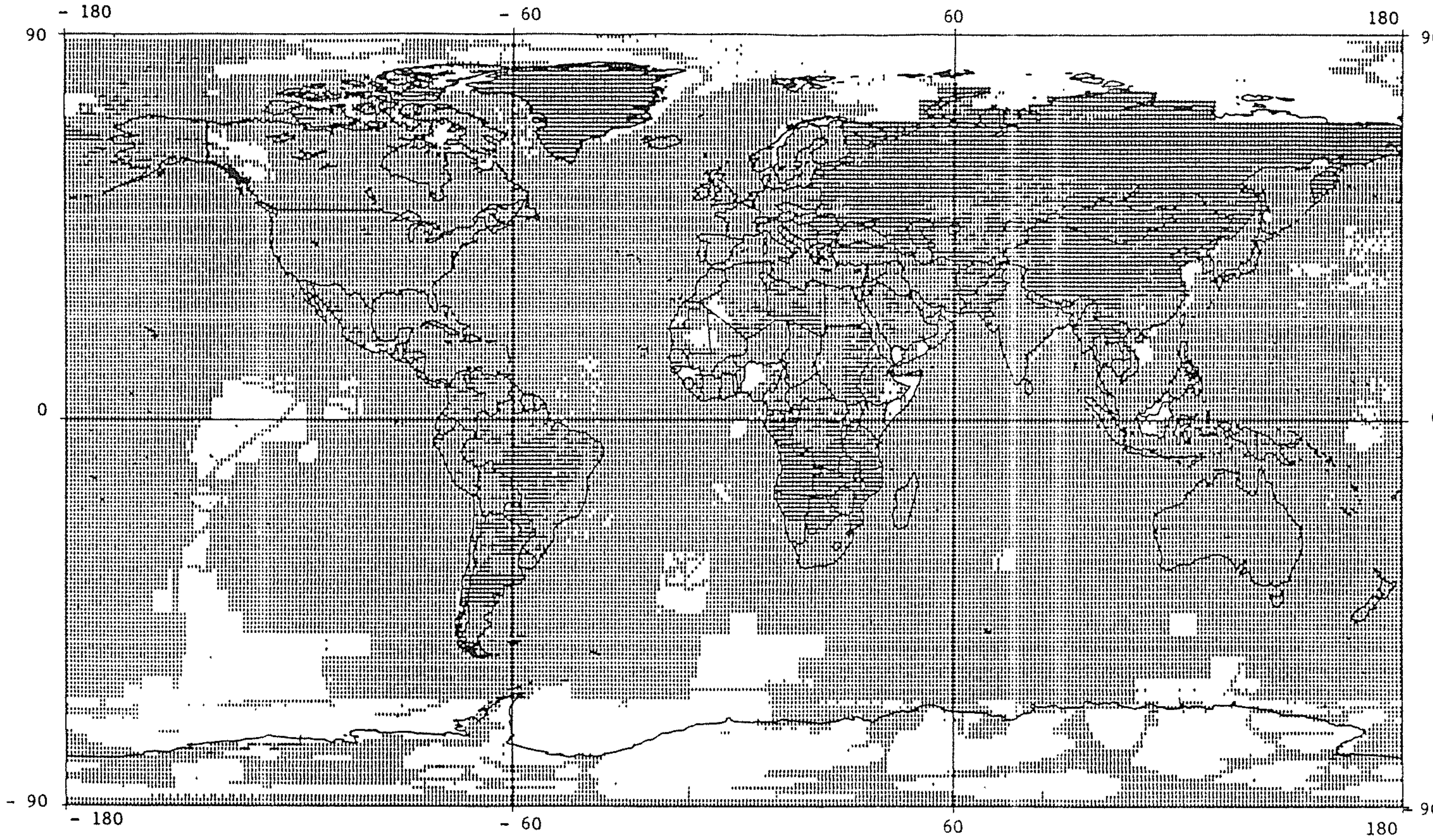


Fig. 5. Coverage of Rapp Oct. 1979 merged file (surface gravity + gravity means derived from Geos 3 altimetry)

| : computed + : predicted

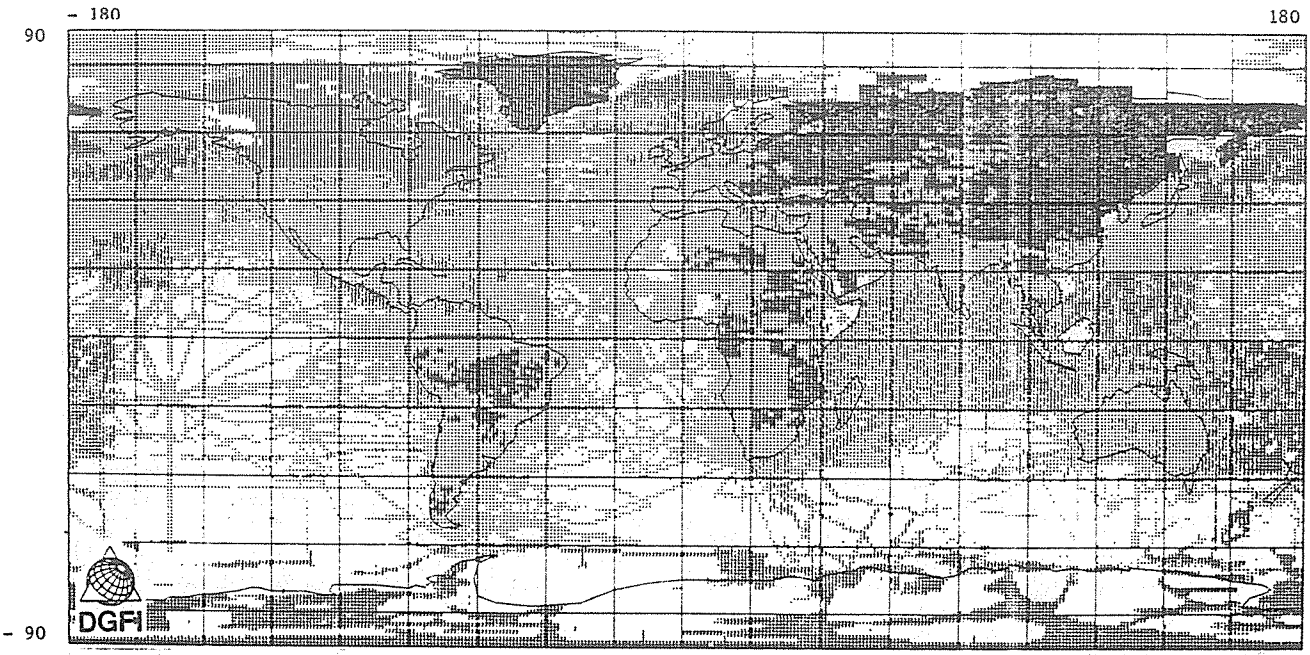


Fig. 6. Distribution of the terrestrial gravity data in Rapp Jan. 1983 file
The darkest areas are those where 1° x 1° data are predicted.

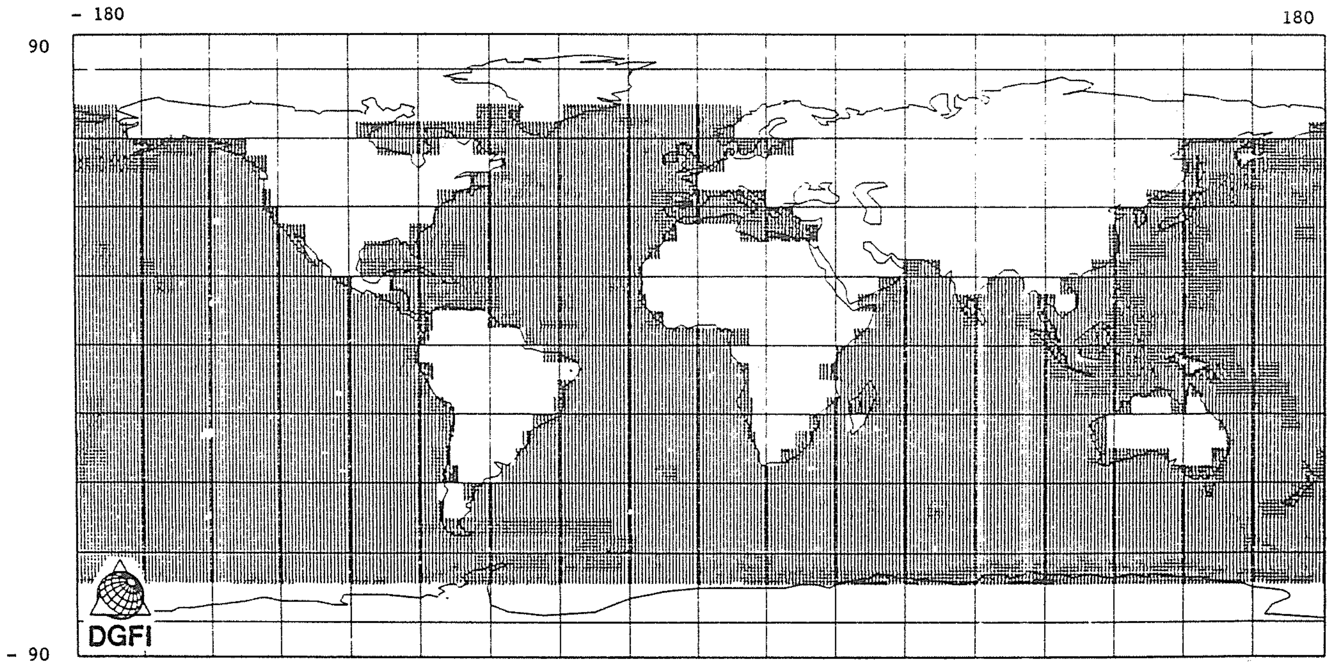


Fig. 7. The 1° x 1° gravity anomalies computed from Seasat altimetry derived geoid heights
In most places, the standard error is ⩽ 5 mgals.

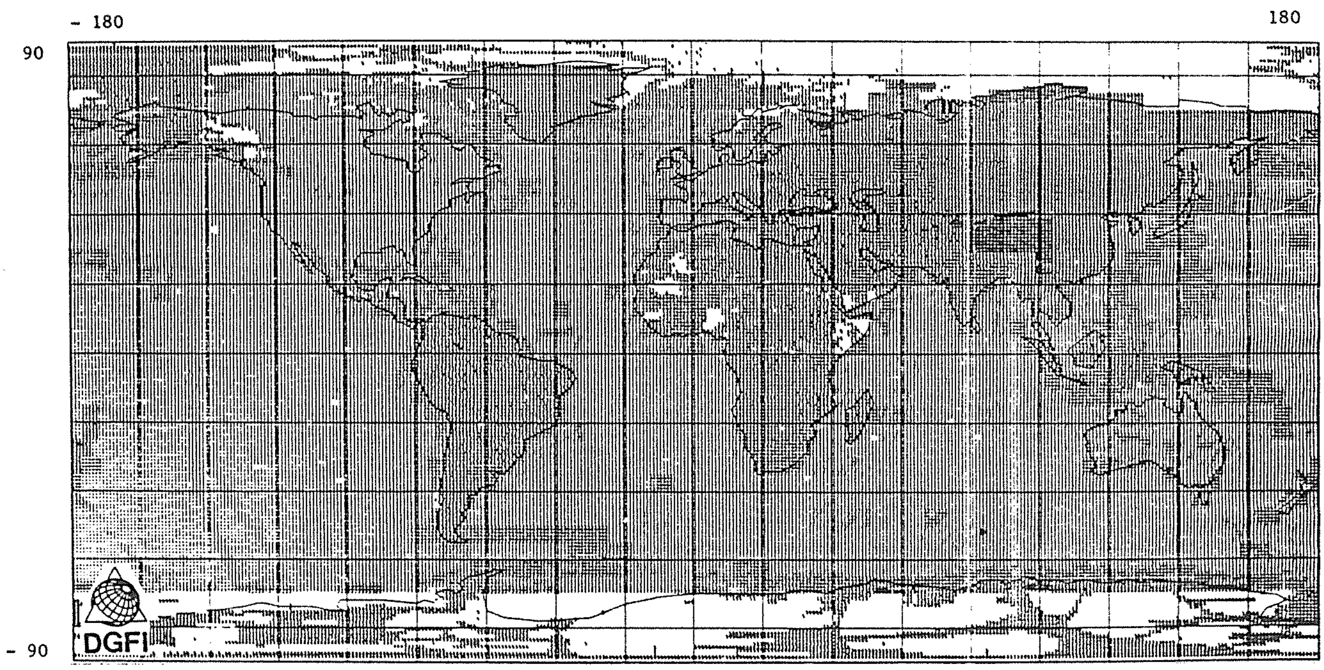


Fig. 8. Coverage of the 1° x 1° gravity data (terrestrial + Seasat) merged at DGFI
The darker the area, the larger is the standard deviation.

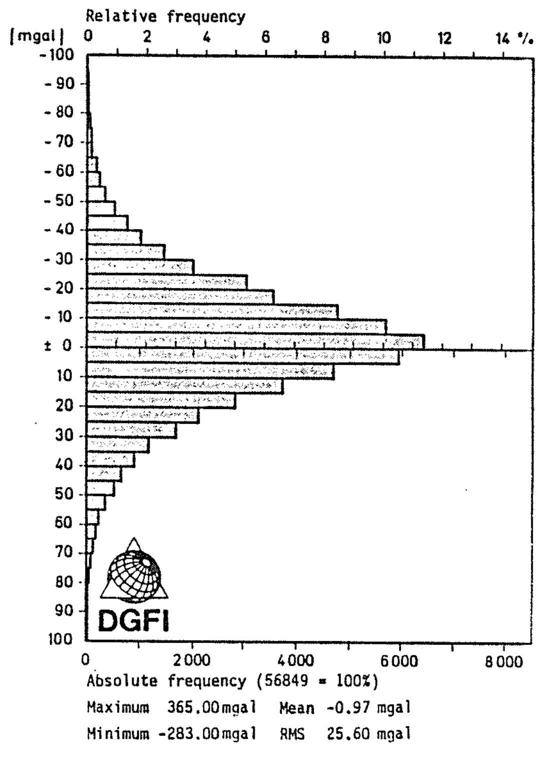


Fig. 9. Signal distribution of 1° x 1° mean gravity anomalies
(merged data Rapp 1/83 + Seasat).

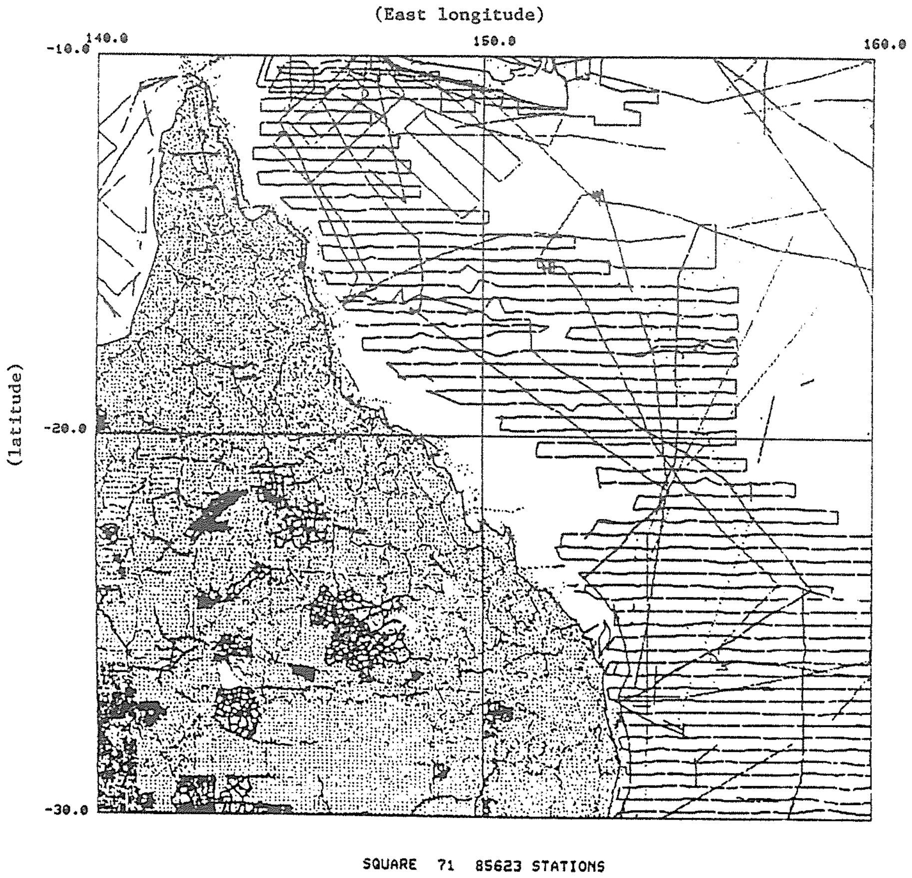


Fig. 10. First example of gravity measurements coverage.

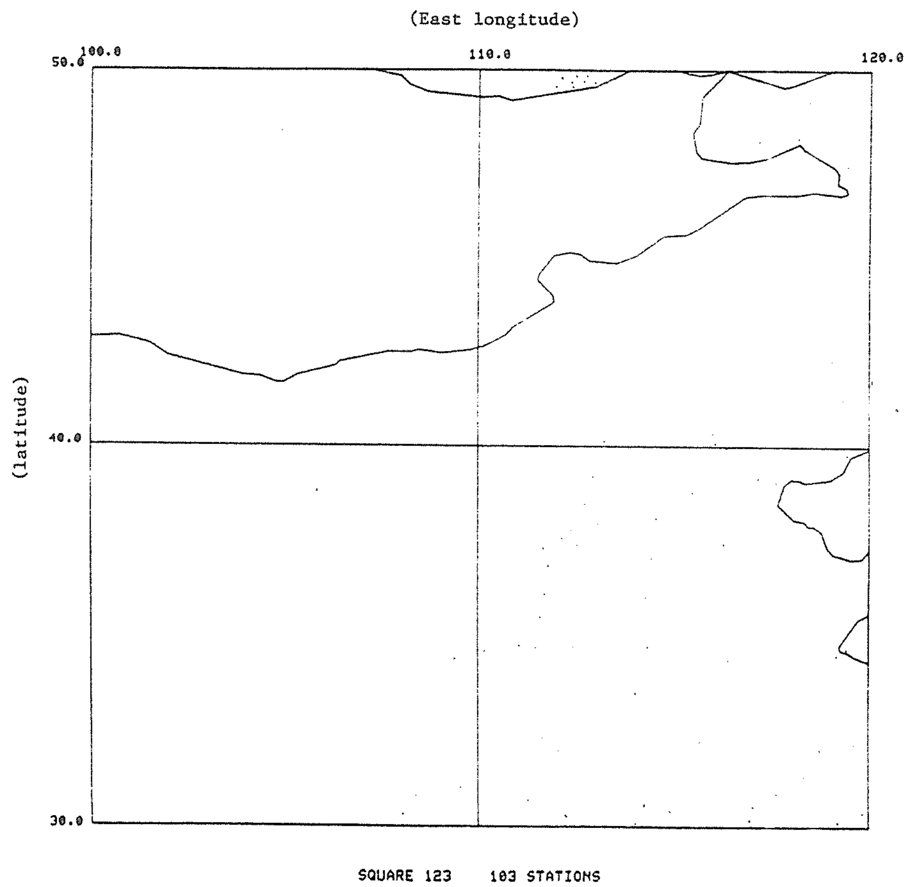


Fig. 11. Second example of gravity measurements coverage

Report

ON THE ACTIVITY OF WG. 3 DB IGB

(1980-1983)

In the time period from the beginning of 1980 till July 1983 the major task of WG. 3 DB IBG was the collection of gravimetric data, their systematisation for compilation of gravimetric maps covering large territories. This activity was based of close cooperation between the International Gravimetric Bureau (Toulouse), WDC A (USA) and WDC B2 (Moscow). Pr. J.D. Boulanger was Coordinator of work on map compilation.

During this time interval, WG. 3 met twice, in October 1981 in Paris and in Tokyo in May 1982, and discussed current matters.

The following work was done in the interim period by WG. 3 :

1. Compilation was continued of the "Gravimetric map of the World" in scale 1/15 000 000 on 10 sheets on the topographic basis of the "Tectonic map of the World". The map is compiled from actually measured gravity values in Bouguer reduction ($\delta = 2.67\ g.cm^{-3}$) for land and in Faye reduction for aquatories. The section is 20 mgal. The major compilers of the Map are : the Soviet Geophysical Committee of the USSR Academy of Sciences (J.D. Boulanger and N.B. Sazhina) and Drs. L. Wilcox and O. Williams, USA.

   The International Gravimetric Bureau renders much help in that work by making available a large amount of data. Without the IGB support this work could not have been done at all.

   By distribution of responsabilities the Soviet Union compiles sheets 3, 4, 5, 8, 9 and 10 ; in the USA sheets 1, 2, 6 and 7 are compiled. At the meeting of map compilers in October 1981 in Paris, Dr. L. Wilcox asked J.D. Boulanger to undertake additionally the compilation of sheet 1 of the Map, to which J.D. Boulanger agreed.

   During this period of great importance was collection of materials. Machine-readable data of the IGB were used, as also various gravimetric maps, catalogues, and materials published in scientific journals, Proceedings of conferences, symposia, meetings.

   At present in the Soviet Union sheets 3, 4, 5, 8, 9, 10 and 1 are in work Sheets 8, 9, 10 are practically finished, but are continuously supplemented and corrected by new data. In the USA much is done for compilation of sheets 2, 6, 7. These are near completion.

   The difficulty of work in the Soviet Union is enhanced by the fact that a great amount of it in map compilation is done by hand, because for the larger part of the territory it is impossible to use the computer due to the mosaic nature of data. Therefore, for a considerable part of the territory it is first necessary to make maps in larger scale (for land : 1/5 000 000 ; for the ocean : 1/5 000 000 - 1/10 000 000) and only after that incorporate them into the Gravimetric Map of the World.

   Judging by the actual state of work we may hope that the compilation of the original map models could be finished in 1984.

2. Work has been started to compile maps of gravity anomalies in the Bouguer reduction for International Geological-Geophysical Atlases of the Pacific and Atlantic Oceans using measured gravity values. The scale of the basic map is 1/10 000 000, the section is 10-20 mgal. Compilation of maps of the Atlantic Ocean is planned to be finished in 1984 and those of the Pacific in 1985. These maps shall be a part of the indicated Atlases and used for final correction of the "Gravimetric Map of the World".

3. The maps of gravity anomalies for the two continents, South America /1/ and Africa /2/, are soon to be published. Both maps are in scale 1/5 000 000 on 10 sheets each. The maps are compiled in two variants : first in Bouguer reduction ($\delta = 2.67\ g.cm^{-3}$) and second in Bouguer reduction for land and in Faye reduction for aquatories.

4. The map of gravity anomalies of the southern part of the Atlantic Ocean /3/ was published with WG. 3 participation ; it was compiled in scientific cooperation by specialists of the Lamont Geological Observatory, USA, and of the Institute of Physics of the Earth, USSR, Academy of Sciences.

All the indicated maps, when published, could be sent on request to the scientific organizations which submit its data to the International Gravimetric Bureau. Requests are sent to : WDC B2, Molodezhnaya 3, Moscow 117 296, USSR.

In conclusion, I have the pleasant duty to thank all WG. 3 members who helped to collect the necessary gravimetric data and who gave valuable advice when discussing the scientific contents of the maps and technique of their compilation. I am especially grateful to Dr. S. Coron, Mr. O. Wilson, and Dr. G. Balmino for the great contribution to the collection of materials.

Moscow, April 1983

J.D. Boulanger
Convenor, WG. 3, IAG

LIST OF MAPS

1. Gravimetric map of South America. Scale 1/5 000 000. On 10 sheets. Ministry of Geology. All-Union Institute of Geology in Foreign Countries. 1983.
2. Gravimetric Map of Africa. Scale 1/5 000 000. On 20 sheets. Ministry of Geology of the USSR. All-Union Institute of Geology in Foreign Countries. 1983.
3. Gravity anomalies in free-air over the Atlantic Ocean (southern part). Scale 1/5 000 000 on the equator. On 6 sheets. Gunio, Ministry of Defence of the USSR, 1983.

THE JILA PORTABLE ABSOLUTE GRAVITY APPARATUS

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ABSTRACT

At the Joint Institute for Laboratory Astrophysics, we have developed a new and highly portable absolute gravity apparatus based on the principles of free-fall laser interferometry. A primary concern over the past several years has been the detection, understanding, and elimination of systematic errors. In the Spring of 1982, we used this instrument to carry out a survey at twelve sites in the United States. Over a period of eight weeks, the instrument was driven a distance of nearly 20,000 km to sites in California, New Mexico, Colorado, Wyoming, Maryland, and Massachusetts. The time required to carry out a measurement at each location was typically one day. Over the next several years, our intention is to see absolute gravity measurements become both usable and used in the field. To this end, and in the context of cooperative research programs with a number of scientific institutes throughout the world, we are building additional instruments (incorporating further refinements) which are to be used for geodetic, geophysical, geological, and tectonic studies. With these new instruments we expect to improve (perhaps by a factor of two) on the 6-10 μgal accuracy of our present instrument. Today one can make absolute gravity measurements as accurately as — possibly even more accurately than — one can make relative measurements. Given reasonable success with the new instruments in the field, the last years of this century should see absolute gravity measurement mature both as a new geodetic data type and as a useful geophysical tool.

— — — —

A new, highly accurate, and highly portable absolute gravity apparatus has been designed and developed at the Joint Institute for Laboratory Astrophysics (JILA). In building this new instrument, particular attention was paid to those aspects affecting its field performance. The result, we believe, is a viable and exciting new geophysical tool. The instrument is very small; it can be transported in a small van, and requires about an hour for assembly. A high rate of data acquisition is available: a new drop (measurement) can be made every 2 sec. In developing this instrument, a concerted effort was made to detect and eliminate systematic errors. The results of extensive tests with a prototype apparatus (which served as the basis for Mark Zumberge's Ph.D. thesis [1] and in part as the basis for Bob Rinker's Ph.D. thesis [2]) indicate that the achieved accuracy for g is between six and ten parts in 10^9. We are now in the process of building six new instruments (based

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†Guest worker, National Bureau of Standards, on leave from the National Institute of Metrology in Beiging, China.

‡Staff Member, Defense Mapping Agency, Cheyenne, Wyoming.

on this prototype) in which we are making a number of modifications aimed at further enhancing the instrument's field usability. We also expect to improve the accuracy obtained with these instruments to between 3 and 5 μgal. These new instruments, therefore, should provide a sensitivity to vertical motions (e.g., of the Earth's crust) which are as small as 1 or 2 cm.

The principle of the instrument's operation has been discussed in a number of publications [3-7], and is similar to that on which other free-fall gravity instruments have been based [8-27]. We review here the method and in particular our present approach.

Our new apparatus is based on the principles of free-fall laser interferometry (see Fig. 1). In this method one arm of a Michelson interferometer is terminated by a corner cube retroreflector which is allowed to be freely accelerated by the Earth's gravity. The times of occurrence of certain interferometer fringes are measured and then used to determine the acceleration of the falling object. A stabilized laser, the light source, provides the length standard, while an atomic frequency standard provides the time standard.

Two aspects of our new instrument account for its ability to achieve high accuracy without sacrificing small size and, hence, portability. First, a new dropping mechanism has been developed which eliminates several sources of systematic error and makes possible a rapid rate of data acquisition since it minimizes the resetting time required between drops. Second, a new type of long-period isolation device [2,28] is used to greatly decrease the instrument's sensitivity to ground vibrations. This avoids the large drop-to-drop scatter that would otherwise result from our comparatively short dropping length (20 cm) — a consequence of the instrument's small size.

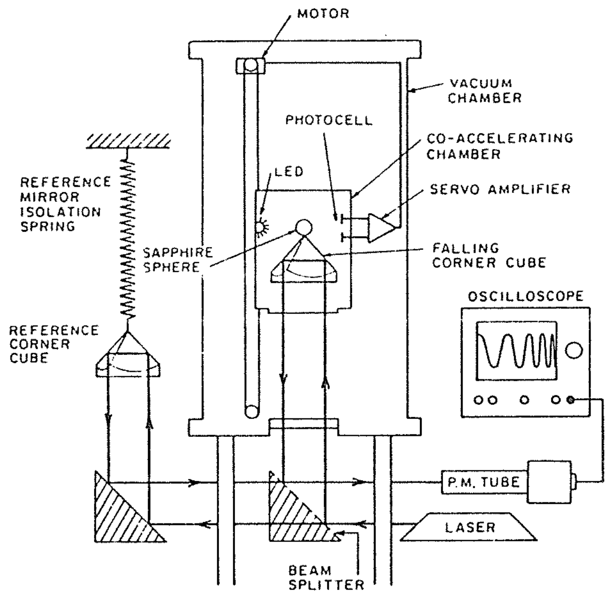

Fig. 1. Schematic of absolute gravity apparatus.

In the free fall method, air drag makes it impossible to approach any reasonable accuracy without dropping the corner cube in a vacuum. In the JILA instrument, the dropped object is contained in a servo-controlled motor-driven drag-free evacuated dropping chamber which moves inside the main vacuum system. This dropping chamber effects the release and then tracks the falling object — without touching it — during the measurement, and at the end of the measurement gently arrests the dropped object's free fall. The result is that the object falls <u>with</u> the residual gas molecules rather than <u>through</u> them.

Figure 2 is a schematic representation of our prototype dropping chamber. The dropped object rests in kinematic mounts in a chamber that can be driven along vertical guide rails by a thin stainless steel belt which is connected to a dc motor. The position of the dropped object relative to this drag-free chamber is measured by focusing light from a light-emitting diode, through a lens attached to the dropped object, onto a position-sensitive photodetector. The error signal thus derived controls the motor that accelerates the chamber downward which results in the dropped object freely floating inside. Near the bottom of the drop, the chamber is first servoed to gently arrest the dropped

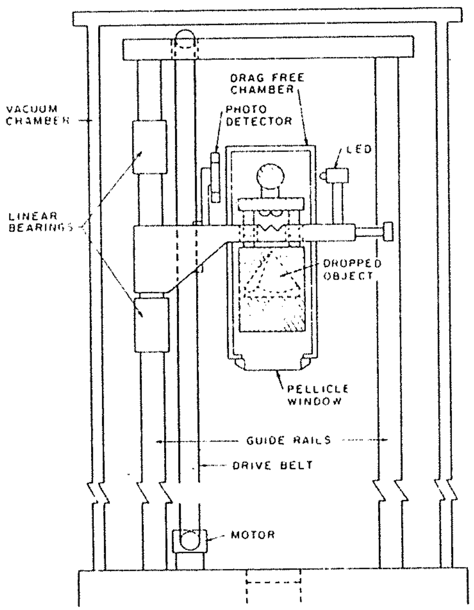

Fig. 2. Schematic of dropping system.

object's fall, and then used to return the dropped object to the top of the track for the next measurement. This rapid turnaround capability is primarily responsible for the system's ability to acquire data at a very high rate.

The falling chamber also serves to remove other nongravitational forces. It provides an electrically conducting shell to completely surround the dropped object so that external electrostatic fields do not affect the measurement. Also, the purely mechanical character of the release makes it unnecessary to have any sort of magnetic support or release mechanism that might subsequently result in an unwanted magnetic force.

If one is to achieve a few parts in 10^9 accuracy in g, an effective method must be found to isolate either the entire system or the reference cube (hung vertically so that vertical motion of the base shortens both arms equally). The need for this isolation stems from the fact that, during a measurement, the dropped cube is completely isolated during its free fall from the Earth's micro-seismic motion and other man-made noise. The reference corner cube (in the other arm of the interferometer), however, is not. In the past, astable spring systems have been used such as those employed in commercially available long-period vertical seismographs. These systems, however, are somewhat awkward to adjust and suffer from internal (violin-string) modes in the main system spring.

We electronically terminate a tractable length of spring (i.e., 30 cm) so that it behaves exactly as if it were, for example, 1 km long. The mass on the end oscillates up and down with a period of 60 sec (ν = 0.017 Hz) and therefore is isolated for all periods shorter than this. To understand this electronically generated "super spring," imagine you have a 1 kg mass hanging on the end of a weak coil spring which extends 1 km vertically. This mass will oscillate up and down (with a period of 60 sec) and as it does, the coils of the spring will oscillate up and down also. The coils very near the mass will have an amplitude nearly equal to the amplitude of the mass and the coils that are far away from the mass will have an amplitude less than that of the mass. In fact the coils near the top will scarcely move at all. Now if one were to grasp the spring 30 cm above the mass and move that point on the spring just as it moved when the lower portion was in free oscillation, the motion of the mass would remain unchanged. Having done this, one could then cut off the top of the spring and be left with a 30 cm long spring that has the same resonance frequency, and behaves in all ways exactly as a spring 1 km long. In our "super spring" we use a servo system to generate such a virtual point of suspension.

Figure 3 is a schematic drawing of this system. The two side springs supply the force to support a bracket on which a mass is attached by a central spring; this bracket is free to move in a vertical direction. The light from the LED is focused by the sapphire ball onto a split photodiode. The outputs from the two halves of this diode are amplified and differenced, producing an analog signal that is proportional to the displacement of the weight. This signal is processed by a servocompensated amplifier which drives a loud speaker voice coil. This coil then supplies the needed force on the bracket to cause it to track the motion of the bottom weight. Since the top of the spring is attached to the bracket, the top moves with nearly the same amplitude as the bottom. The degree of tracking is determined by the gain setting of the servo system and this in turn sets the effective length of the spring and thereby the achieved period. While we can easily achieve periods in the range of 10 to 100 sec, we normally use a period of about 50 sec.

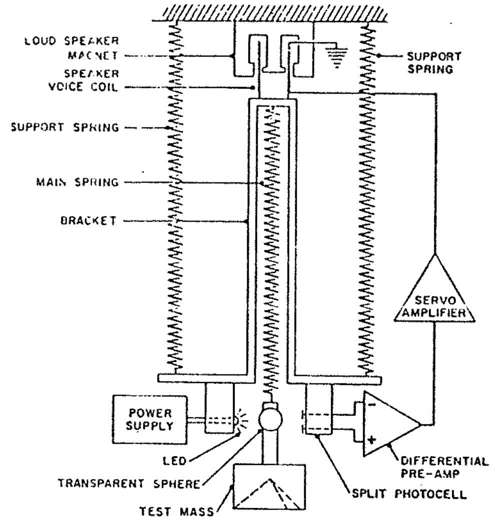

Fig. 3. The "super spring."

In order to test the super spring concept, we constructed a "shake table" on which we could place the spring. The table surface, driven by a system of levers and a speaker magnet-voice coil system, is constrained so as to tilt less than one arcsecond for vertical motions of the order of 5×10^{-3} cm. A LED photodiode position detector was used to monitor the table motion. The isolation measurements were made using a spectrum analyzer whose internal noise source was used to drive the table. The output from the table's position detector and the position of the test mass with respect to the floor ("inertial space") were applied to the two inputs of the spectrum analyzer which computed the transfer function. Figure 4 is an example of such a

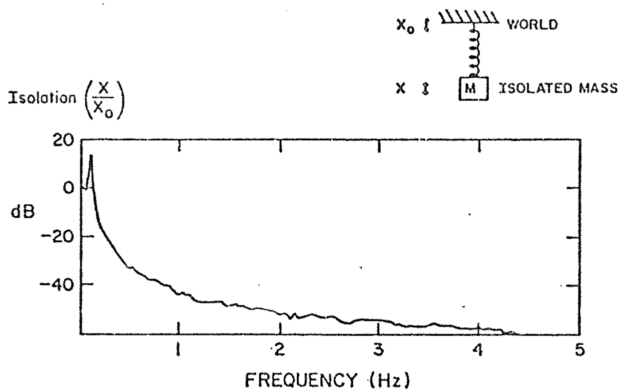

Fig. 4. Transfer function obtained during "shake table" testing of super spring.

transfer function. This particular one was taken with the spring period set at 12 sec (shorter than usual so that the 1/12 Hz resonance can be seen).

Further evidence that the spring does indeed isolate is obtained when the test mass is used to hold the reference corner cube in the gravimeter. Figure 5 shows two histograms of 150 "g" measurements each. The use of the spring is seen to reduce the scatter by a factor of 20.

Figure 6 is a photograph of our prototype apparatus. The dropping mechanism is inside a vacuum chamber which is supported by three folding legs. Beneath this is a base that supports the long-period isolation spring and contains the associated optical components that comprise the interferometer. The electronics fit nicely in two packing cases.

Figure 7 illustrates results from two days of continuous operation at about 70% of the maximum possible data acquisition rate. The tidal effects of

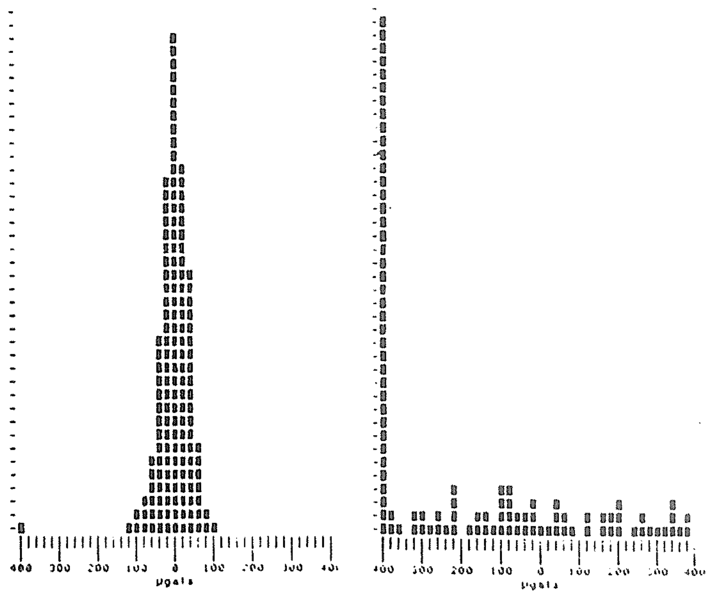

Fig. 5. Histogram of measurements of the gravitational acceleration of g with and without super spring isolated reference corner cube.

the sun and moon can easily be seen. The solid line is the theoretical tides calculated without the inclusion of any ocean loading effects (which are small in Boulder). If we subtract the theoretical tides, we obtain an rms deviation of about 6 μgal for the means of sets of 150 drops. Removal of the theoretical variation due to changes in barometric pressure did not reduce the rms deviation. No attempt was made to correct for other meterological effects.

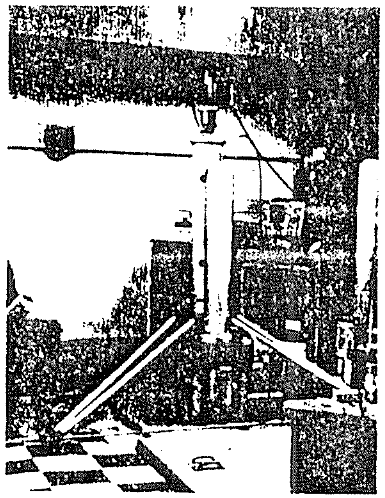

Fig. 6. Photograph of apparatus.

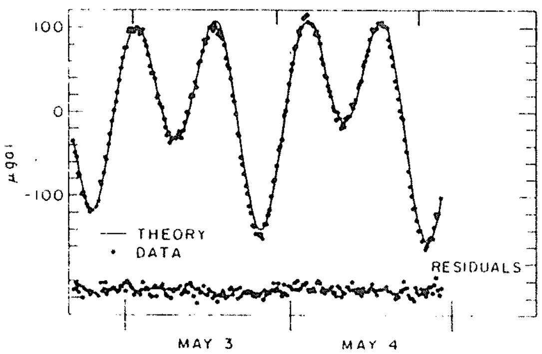

Fig. 7. Gravity tide.

The fundamental problem in measurements of this sort is the recognition and elimination of systematic error sources. Table 1 gives a concise summary of the sources of error that we have recognized and considered to date.

High repeatability of a measurement (e.g., the precision) is unfortunately not always an indication of the accuracy; it is, however, a necessary condition. A rather detailed discussion of the question of accuracy has been published elsewhere [1,6]. For a year-long period, during which many tests and evaluations were made involving both disassembly of and modifications to the instrument (including a trip with the instrument to Paris to participate in an international intercomparison of gravity meters), the rms deviation in g as measured in our JILA laboratory amounted to about 10 μgal (Fig. 8). We are unable to attribute this variation to any specific effect, although we suspect that some part of it may be related to changes in ground water content around and under our sub-basement laboratory.

Table 1. Known systematic errors

Source	Error
Differential Pressure	1.0 μgal
Differential Temperature	1.0
Magnetic Field Gradient	0.5
Electrostatics	1.2
Attraction of Apparatus	0.5
Vertical Reference	0.8
Optical Path Changes	2.8
Laser Wavelength	1.0
Rotation	1.0
Translation	1.0
Floor Recoil	1.0
Phase Shift	1.0
Frequency Standard	0.5
rss Total	4.2 μgal

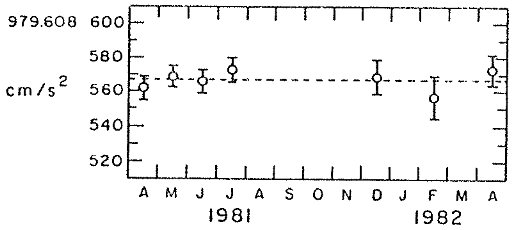

Fig. 8. Absolute gravity measurements at JILA over a one-year period. One vertical division is 10^{-7} m/sec^2 (10 μgal).

In 1982 we completed an absolute gravity survey at twelve sites in the U.S. Eight sites had been previously occupied by other absolute instruments and four were new sites chosen because they were near locations in which other measurements relevant to the study of geodynamics have been made. Over a period of eight weeks, the instrument was driven a total distance of nearly 20,000 km to sites in California, New Mexico, Colorado, Wyoming, Maryland and Massachusetts. A measurement accuracy of around 1×10^{-7} m/sec^2 (10 μgal) is believed to have been obtained at all but one of these sites. At one site, floor motions as well as other unfavorable characteristics of the surroundings resulted in a measurement uncertainty at least an order of magnitude larger than obtained elsewhere.

At most of the twelve sites, the entire operation of unloading, assembling the instrument, acquiring the data, disassembling and reloading required less than one day. The vacuum chamber was pumped continuously, even during transport in a small truck. This eliminated the pump-down time that would otherwise have been necessary preceding each measurement. At three sites, mechanical problems inside the dropping chamber required some attention, and as a result the vacuum was lost. This usually meant an overnight delay — to achieve a good vacuum — after the problem was corrected.

When no difficulties were encountered, the operation proceeded smoothly and rapidly. The time needed to get the instrument set up and running was two hours. Although gravity data were available immediately following the instrument's assembly, they were generally rejected because of known instrumental biases that can result from temperature transients. To insure quality gravity measurements the instrument had to remain passive for an hour or so after its initial setup and testing. During this time, the laser, the long-period isolator, and the pressure in the vacuum chamber equilibrated with the new temperature environment.

The period over which actual measurements were taken varied among the sites from several hours to as long as one day. Since a data set of 150 drops can be taken in ten minutes, the statistical uncertainty is outweighed by systematic effects after a few hours of measurements. Disassembly and reloading required approximately one hour, as did the transfer of the absolute value from the measurement height to the floor using a relative gravimeter. Eight of the twelve sites had been previously occupied by the Air Force Geophysics Laboratory (before the occurrence of that instrument's gravity offset) or the Istituto de Metrologia "G. Colonnetti" absolute gravimeters. Five of these sites were occupied by all three absolute gravimeters. Details of the results obtained are given elsewhere [29]. Since the reported accuracy from all three instruments is typically 1×10^{-7} m/sec^2 (10 μgal), most of the intercomparisons should agree to about 1.4×10^{-7} m/sec^2 (14 μgal). This is true at some sites, but not at others. Some of the differences could be due to real gravity changes, because simultaneous measurements were not made. The method of transferring the measured values to a common reference height of one meter could also contribute slightly to the differences. It is more likely, however, that the discrepancies are due to unrecognized systematic errors in one or more of the instruments. Clearly, further observations and more intercomparisons are needed.

Now that we have a successfully working, field-usable instrument — an instrument that exploits available technology as well as incorporates our own research from the past 25 years — we plan to insure that this new type of gravity instrument is widely used and field tested in as many different geophysical settings as possible. To this end, we are in the process of building six new instruments (see Fig. 9). One of these will remain at JILA and will be used chiefly for continued research and development. The other five are being built for and in connection with cooperative scientific programs which we are establishing with the Division of Gravity, Earth Physics Branch, Department of Energy, Mines, and Resources in Ottawa, Canada; the Institute of Earth Measurement in Hannover, W. Germany; the National Geodetic Survey in Washington, DC; the Institute for Meteorology and Geophysics in Vienna, Austria; and the Finnish Geodetic Institute in Helsinki. In addition (in the context of a protocol agreement between the NBS and the National Institute for Metrology in Beiging, China), we are helping NIM to build a copy of our new instrument in China. We are making a number of significant changes in the prototype design to either improve the instrumental accuracy or enhance the instrument's field performance. In particular, the process of transforming a "theses" instrument to one which can be used and maintained in a routine fashion involves some effort. For example, a multitude of hand-wired circuit boards have been condensed (in

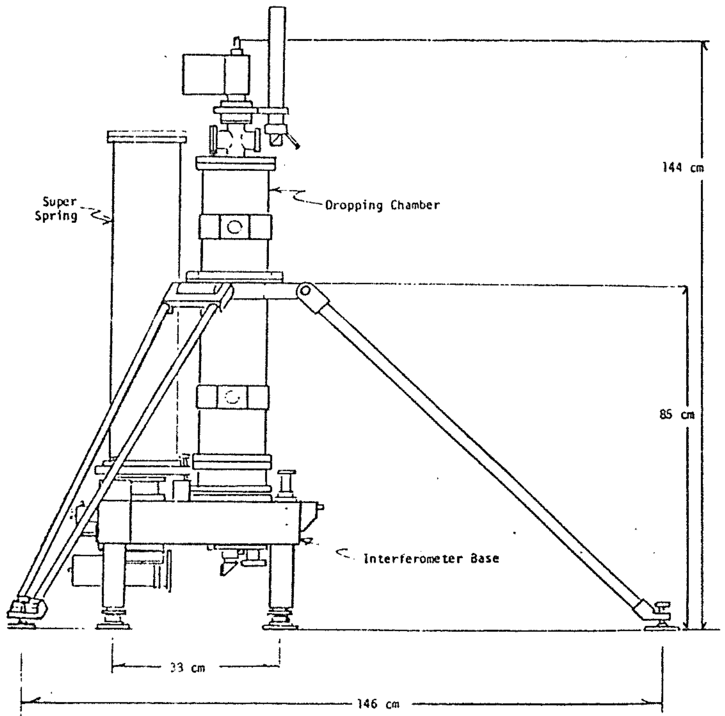

Fig. 9. Line drawing of new JILA instruments.

space) and transformed to printed circuit boards. Set-screw-maintained shaft couplings (our experience has been that they always eventually work loose) have been replaced with collet-type couplings which are considerably more difficult — and therefore more expensive — to fabricate but which we believe will prove much more satisfactory in terms of long-term and field reliability. We have redesigned and rearranged the optical system so that it is easier to work on, and much faster to align the laser beam vertically in the free-fall arm of the interferometer. What once took about 15 minutes to accomplish when setting up the instrument can now be done in much less time. We have also recognized the rapidly changing computer technology and have configured the system to take advantage of one of the most recent machines, replacing an older style computer (and its somewhat slower performance) that was used in the prototype instrument. In fabricating the new instruments, the design philosophy has been to produce individual components from single pieces of metal rather than to fabricate them out of several pieces — thus increasing both their rigidity and their mechanical integrity.

Certain changes have also been made that decrease the scatter and/or increase the achieved accuracy. For example, to reduce the drop-to-drop scatter, we have substantially increased the tightness of the servo-lock on the position of release at the top, and by so doing reduced the starting height uncertainty to the order of a small fraction of a millimeter. Perhaps the most fundamental change has been the elimination of the pellical window from the bottom of the drag-free chamber; its "shielding" function has been replaced by collimating tubes (see Fig. 10) which will serve to restrict (to an acceptable level) the number of molecules that make a direct vacuum-wall-to-the-dropped-object uninterrupted transit. The reason for this is clear if you look at the error budget that we developed for the prototype instrument. You will note that it contains one dominant term — the path-difference error associated with the pellicle's (inevitable) wedge and the coupling of this wedge into the free-fall path length as the carriage accelerates downward and experiences small but nonetheless real sidewise and systematic displacements due to the imperfect straightness of the guide rod. By replacing this wedge with appropriately sized open tubes, we can completely eliminate this single dominant systematic error term and thereby reduce our error budget from the present 4.2 μgal to 3 μgal. (The single tube seen at the top makes possible a fairly simple locking mechanism to cage the dropped object during transit.)

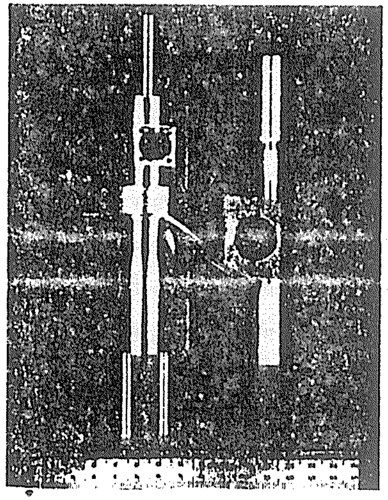

Fig. 10. New, drag-free chamber.

We have not (and indeed in the space available could not have) mentioned all of the various refinements we are incorporating into these new instruments; nevertheless we have tried to give some idea of the types of changes we are making and the motivations for them. Even our new instruments, we feel, should still be thought of as laboratory (and field) prototypes rather than as commercial instruments, even though — to the best of our abilities and based on our experiences with the prototype JILA absolute gravimeter — we are trying to correct and improve both performance and field adaptability. Any "next group" of instruments — if there is sufficient interest — would, however, need to be made commercially.

What about the future for absolute gravity measurements? In 1963, one of us (JEF), attended his first IUGG meeting (in Berkeley) and talked about his recently completed Ph.D. thesis, "An Absolute Interferometric Determination of the Acceleration of Gravity," a measurement which was good to 7 parts in 10^7 and which used white light fringes in connection with optical interferometry. After his talk, he remembers walking up to Dr. LaCoste and asking him if he thought that absolute gravity instruments would someday be used — at least for some purposes — instead of relative gravimeters. Dr. LaCoste replied that at least for the time being, he wasn't worried. Twenty years later, what answer might be given to the same question at this Hamburg IUGG meeting?

Today, gravimeters are being increasingly used as reconnaissance tools in geodynamic research. Because gravity data are sensitive to both vertical height and the subsurface mass distribution, they can provide a powerful and unique type of information. Vertical crustal movements — which have characteristic rates of centimeters per year — will require a precision of 3-10 μgal (1 μgal = 10^{-6} cm/sec^{-2}) in order for gravity measurements to be useful on time scales of one or two years. Because even the best portable spring-type gravimeters have serious difficulties with tares and long-term drifts at this level of sensitivity, the value of absolute gravimeters with accuracies of several μgal for this type of work is obvious. Today one can make absolute measurements as accurately — possibly even more accurately — than one can make relative measurements. Further, although absolute instruments are more complicated to operate, the time required to make a measurement at a particular site is comparable to that for a relative instrument when one includes the back-and-forth ties that must be made when using a relative gravimeter. And although the size of an absolute instrument is considerably larger than that of a relative gravity meter, perhaps the important thing to note is that either one can easily fit into a small truck or van.

While there remains work yet to be done, one should not fail to be impressed with the extraordinary progress that has been made over the past several decades by workers in the field. Today's answer to the question posed in 1963 must surely be that if today's easily portable new instruments prove to be usable and reliable in the field without sacrificing their laboratory-obtained levels of accuracy, then, given continued interest and support, the last 20 years of this century should see absolute gravity mature as a useful adjunct to, and in some cases a replacement for, relative gravity both as a new geodetic data type and a useful geophysical tool.

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MESURES ABSOLUES DE PESANTEUR EN FRANCE

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RESUME

Le Bureau de Recherches Géologiques et Minières a réalisé conjointement avec le Bureau National de Métrologie et en association avec le Bureau International des Poids et Mesures, une campagne de mesures absolues en France de février à août 1983.

Huit mesures absolues dont 5 implantées en de nouvelles stations ont été réalisées avec une précision de 3 à 8 microGal. Ce travail a été réalisé dans le but essentiel de caler le nouveau réseau gravimétrique français. Il a permis néanmoins de faire des observations scientifiques de première importante et en particulier de mettre en évidence une corrélation très nette entre la variation de la valeur de la pesanteur et les variations de pression atmosphérique.

Une nouvelle série de mesures est en cours de réalisation au centre scientifique du B.R.G.M. à Orléans afin d'étudier les variations de la valeur de la pesanteur en fonction des battements de la nappe phréatique.

SUMMARY

The B.R.G.M. in joint venture with the B.I.P.M. and the french Bureau National de Métrologie has undertaken a national absolute gravity campain during the February-July period.

Eight absolute gravity measurement located at five new station (Orléans, Toulouse, Marseille, Dijon and Nancy) have been performed. These stations including Sèvres-B.I.P.M. are the fundamental base-stations of the new french gravity network.

The accuracy obtained for the differents stations runs from 3 to 8 microGal. These accuracy allows us to perform some scientific observations. The main result is a strong correlation between the gravity and barometric variations.

Another set of experiments is in progress on the pillar of B.R.G.M. scientific office in Orléans in order to define the influences of the water table variations on the absolute gravity measurements.

1. INTRODUCTION

Les travaux réalisés conjointement par le B.R.G.M. et le B.I.P.M. ont été effectués à l'aide du gravimètre absolu transportable GA60 N° 2 construit par les établissements JAEGER à Paris et appartenant au B.I.P.M.

Le but de cette campagne était double. Pour le B.I.P.M. d'une part il s'agissait de qualifier l'appareil au cours d'une campagne de plusieurs mois afin de mettre à l'épreuve sa robustesse, sa maniabilité et sa transportabilité, et d'implanter non loin des bureaux centraux du B.I.P.M. des stations satellites devant permettre l'étude comparative des variations séculaires de la pesanteur.

Pour le B.R.G.M. le but était d'implanter des stations absolues destinées à permettre le calage des nouveaux réseaux relatifs réalisés de 1980 à 1983. Le choix s'est donc porté sur une station qui peut être considérée comme un dédoublement de Sèvres (Orléans), deux stations méridionales (Toulouse et Marseille) et deux stations proches de Paris, mais suffisamment éloignées des mers pour atténuer au maximum le "loading effect" (Dijon et Nancy).

2. CARACTERISTIQUES DES STATIONS

Les travaux préliminaires ont été réalisés par le B.R.G.M. qui a étudié 25 sites d'implantation possible à travers le France avant d'en retenir finalement 5.

Après une définition du site idéal et de l'étude des caractéristiques du site primaire à Sèvres, nous avons défini un certain nombre de conditions à respecter :

- contexte géologique stable ;
- distance aux océans ou à la Manche supérieure à 100 km ;
- agitation microsismique faible ;
- faibles perturbations du champ magnétique ;
- accessibilité permanente ;
- éventuellement présence d'un pilier.

Ces critères définis avant ceux du Working Group I (I.A.B.G.N.) de la Commission Gravimétrique Internationale sont en désaccord sur plusieurs points avec ceux de la commission et en particulier sur la distance aux océans et la nature du socle géologique cristallin.

En ce qui concerne la distance aux océans, la limite de 300 km fixée nous semble irréaliste et beaucoup de stations déjà réalisées ne répondent pas à ce critère voir sont situées en bordure de mer. En fait, il faut considérer deux facteurs l'un à l'échelle locale, l'autre régionale. Le premier est l'effet direct du battement des marées océaniques, c'est-à-dire l'attraction de la masse d'eau supplémentaire et l'effet de charge locale. Si l'on se réfère aux travaux de T. BAKER l'influence de l'effet de charge locale ne serait plus que de 2,66 microGal à 2 km de la mer. Quant à l'attraction directe des masses d'eau s'il est difficile à quantifier elle sera de toute façon négligeable dès que l'on s'éloigne à plusieurs dizaines de kilomètres à l'intérieur des terres.

Tout autre est le problème posé par l'effet de charge à l'échelle régionale qui varie si l'on se réfère aux travaux de DUCARME et MELCHIOR sur une beaucoup plus grande échelle, et là point n'est question de se référer à une distance précise.

Pour notre part, nous avons considéré qu'une distance minimum de 100 km aux océans était largement suffisante pour l'établissement de stations absolues destinées au calage des réseaux gravimétriques relatifs. Néanmoins, certaines stations (Orléans) devant être à l'avenir réutilisées, il importe dans ce cas d'effectuer un calcul plus précis de la composante M2.

En ce qui concerne la nature cristalline du socle, l'esprit de la commission était de s'affranchir des phénomènes de battement de la nappe qui peut avoir une influence de plusieurs à une dizaine de microGal en fonction de l'amplitude du battement et de la profondeur du niveau hydrostatique. C'est un problème réel qui ne nous a pas échappé et que l'on doit analyser cas par cas.

* Orléans : battement mesuré en permanence depuis 3 ans, un forage étant situé à 50 m environ de la station absolue.

* Toulouse : nappe à 40 m environ, battement inconnu.

* Marseille : pas de nappe, la station étant située sur un massif calcaire à régime karstique. Par contre, faible marée de la méditerranée à 3,5 km.

* Dijon : c'est la plus mauvaise configuration, nappe superficielle avec des battements importants.

* Nancy : pas de nappe, la station étant située sur un massif calcaire à régime karstique. C'est probablement du point de vue hydrogéologique la station la moins perturbée.

3. GRADIENTS GRAVIMETRIQUES ET CORRECTIONS LUNI-SOLAIRES

Le gradient vertical ayant été déterminé préalablement à l'emplacement exact de la mesure absolue, il n'a pas été nécessaire de mesurer un gradient horizontal.

Le gradient vertical a été mesuré à l'aide du gravimètre Lacoste et Romberg modèle D 24 par une série d'aller-retour entre deux stations situées rigoureusement à l'aplomb l'une de l'autre et espacées d'environ 1,60 m. La dénivellée de chaque liaison a été déterminée en mesurant la hauteur de la face supérieure de l'appareil au sol à chaque déplacement de l'appareil.

Le tableau 1 en annexe présente les résultats avec pour chaque station :

- le nombre d'observations ;
- la dénivellée moyenne ;
- la valeur du gradient vertical en nm/s^{-2} ;
- l'écart quadratique moyen (σ).

Après la réalisation des mesures absolues on a pu vérifier que le σ sur le gradient vertical était toujours égal au moins à la moitié du σ du g absolu sauf pour Dijon où les deux σ sont du même ordre de grandeur. La réduction au sol des mesures absolues de pesanteur (réalisée à une hauteur de 1,125 m) n'amènera donc pas de perte de précision sensible sur la valeur de g au sol adoptée sauf pour Dijon.

Les corrections luni-solaires ont été calculées par C. POITEVIN au Centre International d'Etudes des Marées terrestres à Bruxelles. Les valeurs fournies incluant le terme constant MOSO (ou correction de Honkasalo), celle-ci a été retranchée au moment de la réduction finale de la valeur de g au niveau du sol.

4. RESULTATS DES MESURES ABSOLUES (cf. localisation fig. 1)

Nous ne reviendrons pas sur le principe du gravimètre absolu GA60 Jaeger présenté plus en détail dans une autre communication à cette commission. Nous ne ferons qu'insister sur les facilités de transport (un seul véhicule type Renault C35 suffisant malgré les nombreux accessoires annexes, y compris groupe de pompage et climatiseur transportable), et la rapidité de mise en oeuvre : dans tous les cas le démontage, le transport, le remontage et les premières mesures test ont pu être réalisés dans une seule -mais longue- journée.

Les mesures ont été réalisées entre janvier et août 1983 selon le calendrier suivant :

- janvier 1983 : dernières mesures contrôle à Sèvres ;
- 1 au 8 février : Orléans ;
- mars : légères modifications de détail de l'appareil ;
- 16 au 20 avril : Toulouse ;
- 21 au 26 avril : Marseille ;
- 27 avril au 3 mai : Dijon ;

- 4 mai au 10 mai : Nancy ;
- 11 mai : retour à Sèvres, mesure de fermeture ;
- 21 juillet-1er août : retour à Orléans pour comparaison avec les résultats de février.

4.1. Orléans

Station située au B.R.G.M.(Centre scientifique d'Orléans La Source) dans les sous-sols du département Géophysique (cave pesanteur). Un pilier isolé du bâtiment a été spécialement construit environ 2 ans avant la première mesure. Un forage d'étude géophysique dans lequel le niveau hydrostatique est mesuré chaque semaine a été placé à 50 m environ de la station. La salle est climatisée, la température et la pression sont enregistrées en permanence.

Cette station est mise à la disposition de la communauté scientifique internationale comme station satellite de Sèvres.

Bruit microséismique faible, agitation magnétique 10 à 30 nanoTeslas.

Coordonnées : latitude : 47° 54' Nord
longitude : 1° 54' Est
altitude : 110 m environ.

Les résultats (tableau 2) ont été définis à partir de 21 séries de mesures totalisant 353 tirs retenus. Les mesures brutes affectées des corrections luni-solaires présentant une dispersion relativement grande nous avons recherché et mis en évidence une corrélation des variations de g avec la pression barométrique (cf. communication à la section "Non tidal gravity variations").

Suite à la mise en évidence de ce coefficient (de - 4,78 nm/s/s par mBar) nous avons appporté pour chaque tir, une correction de pression atmosphérique.

Le g final est donc la valeur obtenue après avoir apporté à la valeur de g brute les corrections luni-solaires, barométriques et éventuellement lorsque la déviation de la trajectoire pendant le tir est supérieure à 0,1 mm, la correction d'Oetvös.

La figure 2 donne la dispersion des résultats finaux toutes corrections incluses.

$$g_{sol} = 980.818,821.10^{-5} \text{ m/s/s.}$$

4.2. Toulouse

La station est située dans l'ancien observatoire de Toulouse et du Pic du Midi de Bigorre au centre de la ville à environ 400 m à l'Est de la gare de Matabiau.

La station appartient maintenant à la ville de Toulouse à laquelle il faut s'adresser pour obtenir l'autorisation d'accès.

La station est située dans une cave sur un pilier au ras du sol. Salle non climatisée, bruit microséismique très faible, agitation magnétique 1 à 10 nanoTeslas.

Coordonnées : latitude : 43° 36' 45" Nord
longitude : 1° 27' 41" Est
altitude : 176 m environ.

Les résultats (tableau 3) ont été définis à partir de 7 séries de mesures totalisant 82 tirs retenus. Comme pour Orléans il a été nécessaire d'apporter une correction barométrique. Cette correction a été calculée dans ce cas à - 4,4 nm/s/s par mBar.

La figure 3 donne la dispersion des résultats finaux toutes corrections incluses.

$$g_{sol} = 980.427,678.10^{-5} \text{ m/s/s}$$

4.3. Marseille

La station est située dans une cave du B.R.G.M.-Service géologique régional à Lumigny à environ 10 km au Sud-Est de Marseille.

Salle non climatisée, bruit microsismique faible à nul, agitation magnétique très faible (2-3 nanoTeslas). La station est située à 3,5 km de la Méditerranée et 30 km de l'étang de Berre.

Coordonnées : latitude : 43° 12' Nord
longitude : 5° 24' Est
altitude : 120 m environ.

Les résultats (tableau 4) ont été définis à partir de 7 séries de mesures totalisant 70 tirs. Là encore il a été appliqué une correction barométrique de - 4 nm/s/s par mBar. Cependant, cette correction est assez approximative eu égard à l'amplitude des variations barométriques observées (3 mBar). Les variations n'ayant pas dépassé ± 1,5 mBar par rapport à la pression normale, la valeur de la pesanteur moyenne avec ou sans correction barométrique est identique.

La figure 4 donne la dispersion des résultats finaux non compris la correction barométrique.

$$g_{sol} = 980.456,091.10^{-5} \text{ m/s/s.}$$

4.4. Dijon

La station est située dans une cave du B.R.G.M.-Service géologique régional Bourgogne, au sous-sol de la Caisse d'Epargne de Dijon.

Salle non climatisée, très humide et soumise à de fortes variations de température. Bruit microsismique nul mais environnement magnétique fortement perturbé (10-40 nanoTeslas) par les émetteurs radio de la Gendarmerie Nationale proche du site.

Coordonnées : latitude : 47° 23' Nord
longitude : 5° 01' Est
altitude : 247 m.

Les résultats (tableau 5) ont été définis à partir de 7 séries de mesures totalisant 52 tirs retenus. Là encore un coefficient de corrélation barométrique a été estimé (- 3 nm/s/s par mBar), mais comme à Marseille, la faiblesse des écarts barométriques le rend peu fiable. D'autre part, la faible valeur du coeficient rend les corrections souvent négligeables (maximum 1,8 µGal, généralement inférieur à 1 µGal), si bien que la valeur de la pesanteur moyenne avec ou sans correction barométrique est pratiquement identique.

La figure 5 donne la dispersion des résultats finaux non compris la correction barométrique.

$$g_{sol} = 980.745,648.10^{-5} \text{ m/s/s.}$$

4.5. Nancy

La station est située dans les sous-sol du B.R.G.M.-Service géologique régional de Lorraine à Vendeuvres au Sud de Nancy.

Salle magasin très vaste, non climatisée mais température très stable (18-19° C), bruit microsismique très faible, environnement magnétique très calme (1-2 nanoTeslas).

Coordonnées : latitude : 43° 41' Nord
longitude : 6° 10' Est
altitude : 217 m.

Les résultats (tableau 6) ont été définis à partir de 5 séries de mesures totalisant 49 tirs. Dans cette station, contrairement aux précédentes, il n'a pas été possible de mettre en évidence de coefficient de corrélation pesanteur-pression atmosphérique.

La figure 6 donne la dispersion des résultats finaux.

$$g_{sol} = 980.845,736.10^{-5} \text{ m/s/s.}$$

5. PRECISION DES RESULTATS OBTENUS

Il faut distinguer trois types d'erreur :

- les erreurs systématiques ;
- la précision sur la mesure proprement dite et sur les différentes correctiòns apportées ;
- l'incertitude liée à la réduction au niveau du sol.

Nous ne parlerons pas des erreurs systématiques qui seront discutées en détail dans la communication de A. SAKUMA et nous en viendront directement aux suivantes.

5.1. Précision instrumentale et précision sur les corrections

Les mesures de g fournies par l'ordinateur du gravimètre absolu sont inutilisables en elles-mêmes et nécessitent l'application d'au moins une, parfois deux ou trois corrections.

* La correction luni-solaire (CLS) est de toute la plus importante et celle qui est systématiquement appliquée. Sa précision est estimée (GERSTENECKER, 1977) à 10 nm/s/s, précision qui peut être améliorée par une observation marégraphique de longue durée de chaque station. Cette observation n'ayant été réalisée sur aucune des stations absolues françaises on adoptera comme précision liée aux CLS : 10 nm/s/s.

* Correction d'Oetvös : cette correction nécessaire lors de la détermination de la gravité par des objets mobiles, est appliquée uniquement lorsque des déviations de la trajectoire supérieure à 0,1 mm sont constatées. Elle a été rarement appliquée dans notre étude et le coefficient utilisé est de 5 nm/s/s par dixième de millimètre de déviation (± selon la direction de la déviation).

On peutconsidérer l'erreur entrainée par cette correction comme nulle.

* Corrections barométriques : cette correction a été appliquée uniquement pour les stations d'Orléans et Toulouse mesurées pendant de fortes dépressions barométriques pour ramener les valeurs observées à la pression normale.

La précision de cette correction est fonction de la précision du coefficient utilisé et de l'amplitude de la dépression. Pour Toulouse où le phénomène a été observé avec la plus grande ampleur le coefficient a été déterminé avec une précision de 1 nm/s/s soit pour une dépression de 11 Bar, une erreur de 11 nm/s/s pour 17 tirs seulement sur 82. Pour les autres tirs, l'erreur est de l'ordre de 1,6 nm/s/s. On aura donc en moyenne 4 nm/s/s.

5.2. Incertitude sur la réduction au sol

Elle est fonction de l'incertitude sur la détermination du gradient vertical aux stations. Le tableau 1 où étaient présentés les résultats des déterminations du gradient vertical donne également la précision, pour un dénivelé de 1 m, sur le gradient vertical de chaque station.

5.3. Précision finale

Le tableau 7 donne les précisions finales pour chacune des station Dans ce tableau où toutes les valeurs sont exprimées en nm/s/s, les symboles ont la signification suivante :

σi : précision instrumentale liée au gravimètre absolue ;
σCLS : incertitude sur les corrections luni-solaires ;
$\sigma BARO$: incertitude liée à la correction barométrique ;
σGV : précision sur la réduction des mesures au niveau du sol ;
$\sigma Total$: préicison finale sur la valeur de g au niveau du sol.

L'analyse des précisions finales pour chaque station et des moyennes globales montre que nous sommes désormais capable de déterminer la valeur absolue de la pesanteur en une station avec une précision moyenne instrumentale de 4 microGal e.q.m. A ce niveau d'observation se pose le problème de la précision des corrections apportées aux mesures brutes pour obtenir une valeur utilisable au niveau du sol, près de la moitié de l'incertitude sur la valeur finale étant en effet liée à ces corrections.

On peut sans avoir recours à de nouvelles mesures absolues de pesanteur, améliorer les résultats que nous venons de présenter :

- en procédant à une nouvelle détermination du gradient de la pesanteur à l'aide de plusieurs appareils, une multiplication des liaisons et en augmentant la dénivellée entre les deux stations ;

- en procédant pendant plusieurs mois à des enregistrements de matées terrestres dont l'analyse permettra de déterminer avec précision les composantes O1, K1, N2, M2, S2, M3 et MF des marées terrestres et d'arriver à une précision de quelques nm/s/s sur la correction de marée.

6. CONCLUSIONS

Le gravimètre absolu transportable GA60 JAEGER a permis d'atteindre sur les cinq stations françaises une précision moyenne de 4,4 microGal inespérée il y a seulement deux années. La facilité de mise en oeuvre absolument remarquable, la fiabilité à toute épreuve (plus de 2400 tirs sans la moindre panne) et la grande tolérance aux variations de température en font un appareil parfaitement adapté à un usage itinérant.

La précision de cet appareil nous a permis d'implanter cinq stations gravimétriques absolues de référence et d'entreprendre conjointement avec le B.I.P.M. un programme d'étude des variations de la pesanteur non liées aux marées luni-solaires dontles premiers résultats positifs sont présentés à cette commission.

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TABLEAU 1

Détermination du gradient vertical sur les sites de mesures absolues

Site	Nbre d'observations	Dénivellée moyenne (m)	Gradient vertical (nm/s^{-2})	σ (nm/s^{-2})
ORLEANS	37	1,615	2720	17
TOULOUSE	14	1,667	2940	22
MARSEILLE	17	1,699	2780	19
DIJON	20	1,663	2770	28
NANCY	16	1,691	2910	18

TABLEAU 2

Résultats des mesures absolues à Orléans, février et juillet 1983

Séries	Nbre de tirs	g moyen brut	P. atmosp. (mBar)	Correct. P. atmo. $nm/s^{-2}/mBar$	g corrigé
FEVRIER 1983					
1	18	980.818,5403	983	- 81	980.818,5322
2	28	5436	978	- 105	5331
3	15	5416	983	- 81	5335
4	16	5400	985	- 72	5328
5	27	5419	985	- 72	5347
6	12	5433	989	- 53	5380
7	18	5374	991	- 43	5331
Nbre total : 134				moyenne :	980.818,5339
JUILLET 1983					
2	7	980.818,5350	1000	0	980.818,5350
4	10	5327	999	- 5	5322
6	9	5378	998	- 10	5368
9	9	5324	998	- 10	5314
10	10	5335	1000	0	5335
11	8	5329	1002	+ 10	5339
12	11	5325	1001	+ 5	5330
13	24	5331	1003	+ 15	5346
16	25	5311	1010	+ 48	5359
17	37	5334	1008	+ 38	5372
18	15	5319	1004	+ 19	5338
19	19	5311	998	- 10	5301
20	17	5336	998	- 10	5326
21	18	5365	995	- 24	5341
Nbre total : 219				moyenne :	980.818,5338

Valeur de g moyenne sur 353 tirs :

$g = 980.818,5339.10^{-5}$ m/s/s

Honkasalo : - 191 nm/s/s

Réduction au sol : + 3060 nm/s/s

$g_{sol} = 980.818,821.10^{-5}$ m/s/s

TABLEAU 3

Résultats des mesures absolues à Toulouse, avril 1983

Tirs retenus	g brut	Corrections luni-sol.	Oetvös	Barom.	g final
18 avril 1983 : 13 h 18 à 14 h 17					
1	980.427,2759	+ 828	0	- 55	980.427,3532
2	2927	842	- 60	- 55	3654
3	2866	880	- 60	- 55	3631
4	2759	924	0	- 55	3628
5	2552	972	0	- 55	3479
6	2829	985	- 30	- 55	3729
7	2518	1046	- 40	- 55	3469
8	2566	1075	- 15	- 55	3571
9	2612	1085	0	- 55	3642
18 avril 1983 : 15 h 19 à 15 h 56					
10	980.427,2374	+ 1209	0	- 53	980.427,3530
11	2523	1216		- 53	3686
12	2361	1220	+ 30	- 53	3558
13	2413	1220		- 53	3580
14	2571	1220	- 15	- 53	3723
15	2340	1218		- 53	3505
16	2493	1218		- 53	3658
17	2462	1214		- 53	3623
19 avril 1983 : 2 h 57 à 5 h 11					
18	980.427,4091	- 510	0	- 5	980.427,3576
19	4015	511		- 5	3499
20	4119	511		- 5	3603
21	4173	511		- 5	3657
22	4170	511		- 5	3654
23	4137	511		- 5	3621
24	4187	514		- 5	3668
25	4157	514		- 5	3638
26	4096	515		- 5	3576
27	4149	521		- 5	3623
28	4200	522		- 5	3673
29	3993	524		- 5	3464
19 avril 1983 : 7 h 58 à 10 h 02					
30	980.427,4037	- 546	0	- 6	980.427,3485
31	4099	529		- 6	3564
32	4214	519		- 6	3689
33	4104	486		- 6	3612
34	3984	454		- 6	3524
35	4110	448		- 6	3656
36	4039	403		- 6	3630
37	4014	382		- 6	3626
38	4004	326		- 6	3672

TABLEAU 3 (suite)

Tirs retenus	g brut	Corrections luni-sol.	Oetvös	Barom.	g final
19 avril 1983 : 17 h 07 à 18 h 37					
39	980.427,2499	+ 1102	0	- 2	980.427,3599
40	2496	1099		- 2	3593
41	2520	1094		- 2	3612
42	2513	1093		- 2	3604
43	2466	1092		- 2	3556
44	2459	1088		- 2	3545
45	2608	1075		- 2	3681
46	2500	1071		- 2	3569
47	2499	1062		- 2	3559
48	2644	1059		- 2	3701
49	2487	1042		- 5	3524
50	2549	1033		- 5	3576
51	2421	1022		- 5	3438
52	2563	1015		- 5	3573
53	2575	1003		- 5	3573
54	2604	996		- 5	3595
55	2730	979		- 5	3704
56	2588	971		- 5	3554
57	2666	953		- 5	3614
58	2694	944		- 5	3633
20 avril 1983 : 3 h 55 à 5 h 01					
59	980.427,4134	- 580	0	- 4	980.427,3550
60	4160	576		- 4	3580
61	4194	573		- 4	3617
62	4160	570		- 4	3586
63	4226	566		- 4	3656
64	4242	563		- 4	3675
65	4118	560		- 4	3554
66	4146	557		- 4	3585
67	4237	543		- 4	3690
68	4074	540		- 4	3530
69	4161	536		- 4	3621
70	4158	535		- 4	3619
71	4132	531		- 4	3597
72	4072	528		- 4	3540
73	4133	525		- 4	3604
74	4131	523		- 4	3604
20 avril 1983 : 9 h 47 à 10 h 19					
75	980.427,3945	- 351	0	- 6	980.427,3588
76	3982	347		- 6	3629
77	3969	345		- 6	3618
78	3953	336		- 6	3611
79	3957	333		- 6	3618
80	3939	331		- 6	3602
81	3920	327		- 6	3587
82	3976	324		- 6	3646

g mesuré moyen : 980.427,3600 mm/s/s
Honkasalo : - 128
réduction au sol : + 3308

980.427,6780 mm/s/s

g_{sol} = 980.427,678.10^{-5} m/s/s

TABLEAU 4

Résultats des mesures absolues à Marseille, avril 1983

Tirs retenus	gbrut	Corrections luni.sol.	Corrections Oetvös	g final
24 avril 1983 : 4 h 39 à 6 h 18				
1	980.455,8632	- 764	- 4	980.455,7864
2	8707	731	- 4	7972
3	8641	706	- 4	7931
4	8588	615	- 4	7969
5	8468	482	- 4	7981
6	9321	393	- 4	7924
24 avril 1983 : 14 h 54 à 15 h 38				
7	980.455,8434	- 526	0	980.445,7908
8	8449	536	0	7913
9	8463	553	- 5	7885
10	8537	563	- 4	7970
11	8459	576	- 4	7879
12	8371	577	- 4	7790
13	8556	596	- 4	7956
14	8612	608	- 3	8001
15	8515	615	- 3	7894
16	8640	625	- 3	8012
17	8579	633	- 3	7943
18	8502	639	- 3	7860
24 avril 1983 : 20 h 49 à 21 h 26				
19	980.455,7388	+ 435	- 4	980.445,7819
20	7480	471	- 4	7947
21	7413	479	- 4	7930
22	7363	494	- 4	7854
23	7450	508	- 4	7954
24	7422	516	- 4	7934
26	7342	535	- 4	7873
27	7313	546	- 4	7855
28	7217	554	- 4	7767
25 avril 1983 : 10 h 10 à 13 h 57				
29	980.455,7208	+ 784		980.445,7992
30	7034	764		7798
31	7178	745		7923
32	7201	729		7930
33	7143	713		7856
34	7338	693		8031
35	7127	663		7790
36	7388	594		7982
37	7152	533		7685
38	7224	443		7667
39	7951	154		8106

TABLEAU 4 (suite)

Tirs retenus	g brut	Corrections luni-sol.	Corrections Oetvös	g final
25 avril 1983 : 14 h 52 à 15 h 20				
40	980.455,8234	- 339		980.445,7895
41	8252	381		7871
42	8238	405		7833
43	8320	455		7865
26 avril 1983 : 3 h 02 à 4 h 46				
44	980.455,8588	- 654		980.445,7934
45	8683	665		8018
46	8514	690		7824
47	8646	700		7946
48	8670	718		7952
49	7877	738		8050
50	8543	748		7795
51	8710	772		7938
52	8718	799		7919
53	8710	808		7902
54	8592	814		7782
55	8847	817		8030
56	8771	829		7942
57	8723	830		7893
27 avril 1983 : 7 h 11 à 11 h 34				
58	980.455,6787	+ 1053		980.445,7840
59	6892	1065		7957
60	6822	1083		7905
61	6713	1092		7805
62	6700	1096		7796
63	6819	1100		7919
64	6836	1099		7935
65	6846	1097		7943
66	6818	1096		7914
67	6888	1096		7984
68	6764	1095		7859
69	6856	1092		7948
70	6892	1091		7983

g mesuré moyen : 980.455,7906 mm/s/s
Honkasalo : - 123
Réduction au sol : + 3128

980.456,0911 mm/s/s

g_{sol} = 980.456,091.10^{-5} m/s/s

TABLEAU 5

Résultats des mesures absolues à Dijon, avril 1983

Tirs retenus	g brut	Correction luni-sol.	g final
29 avril 1983 : 13 h 15 à 15 h 33			
1	980.745,2330	+ 1270	980.745,3600
2	2532	1047	3579
3	2603	1003	3606
4	2583	969	3552
5	2704	913	3617
6	2793	717	3510
29 avril 1983 : 19 h 29 à 19 h 41			
7	980.745,3996	- 500	980.745,3496
8	4060	512	3548
9	4049	516	3533
10	4091	521	3570
11	4095	525	3570
30 avril 1983 : 7 h 27 à 8 h 01			
12	980.745,3959	- 371	980.745,3588
13	3939	359	3580
14	3916	347	3569
15	3879	334	3545
16	3873	324	3549
17	3821	301	3520
18	3799	296	3513
19	3798	266	3532
30 avril 1983 : 8 h 47 à 9 h 16			
20	980.745,3550	- 11	980.745,3539
21	3514	39	3553
22	3386	76	3452
23	3414	118	3532
24	3356	167	3523
30 avril 1983 : 13 h 21 à 14 h 18			
25	980.745,2291	+ 1244	980.745,3595
26	2267	1243	3510
27	2325	1237	3562
28	2326	1230	3556
29	2335	1227	3562
30	2376	1222	3592
31	2362	1212	3574
30 avril 1983 : 23 h 01 à 0 h 48			
32	980.745,3971	- 401	980.745,3570
33	3921	395	3526
34	3951	389	3562
35	3902	384	3518
36	3966	382	3584
37	3846	374	3472
38	3989	371	3618
39	3843	350	3493
40	3958	353	3605
41	3930	352	3578

TABLEAU 5 (suite)

Tirs retenus	g brut	Correction luni-sol.	g final
1er mai 1983 : 9 h 15 à 10 h 00			
42	980.745,3552	+ 11	980.745,3563
43	3463	25	3488
44	3540	40	3580
45	3503	91	3594
46	3441	108	3549
47	3426	123	3549
48	3412	158	3570
49	3402	165	3567
50	3325	227	3552
51	3308	238	3546
52	3294	258	3552

g mesuré moyen	:	980.745,3553 mm/s/s
Honkasalo	:	- 187
Réduction au au sol	:	+ 3116
		980.745,6482 mm/s/s

$g_{sol} = 980.745,648.10^{-5}$ m/s/s.

TABLEAU 6

Résultats des mesures absolues à Nancy, Mai 1983

Tirs retenus	g brut	Correction (CLS)	g final
8 mai 1983 : 4 h 24 à 6 h 22			
1	980.845,4711	- 509	980.845,4208
2	4892	489	4403
3	4727	475	4252
4	4706	458	4248
5	4719	437	4282
6	4808	426	4382
7	4639	412	4227
8	4582	367	4215
9	4643	332	4311
10	4438	248	4190
11	4607	229	4378
12	4349	207	4142
13	4441	180	4261
14	4528	158	4370
15	4433	143	4290
16	4560	129	4431
17	4409	113	4296
8 mai 1983 : 15 h 35 à 17 h 00			
18	980.845,4576	- 259	980.845,4314
19	4501	254	4247
20	4468	212	4256
21	4564	192	4372
22	4541	185	4356
23	4531	171	4360
24	4351	164	4185
25	4384	160	4224
26	4413	138	4275
9 mai 1983 : 4 h 37 à 5 h 46			
27	980.845,4756	- 467	980.845,4286
28	4590	404	4186
29	4688	390	4298
30	4720	376	4344
31	4731	367	4364
32	4571	292	4279
33	4611	275	4336
9 mai 1983 : 9 h 05 à 9 h 47			
34	980.845,3737	+ 530	980.845,4237
35	3806	538	4344
36	3694	544	4238
37	3774	560	4334
38	3850	565	4315
39	3771	571	4342

TABLEAU 6 (suite)

Tirs retenus	g brut	Correction (CLS)	g final
10 mai 1983 : 5 h 16 à 6 h 10			
40	980.845,4720	- 456	980.845,4264
41	4610	420	4190
42	4785	402	4383
43	4753	370	4383
44	4665	350	4315
45	4736	332	4404
46	4578	302	4276
47	4452	287	4165
48	4636	272	4364
49	4431	209	4222

g moyen mesuré : $980.845,4293.10^{-5}$ m/s/s
Honkasalo : - 209 nm/s/s
Réduction au sol : + 3274 nm/s/s

$g_{sol} = 980.845,736.10^{-5}$ m/s/s

TABLEAU 7

Précision sur la détermination de la valeur réduite de la pesanteur (en nm/s/s)

Stations	σ_i	σ_{CLS}	σ_{BARO}	σ_{GV}	σ_{TOTAL}
ORLEANS	67	10	4	16	70
TOULOUSE	33	10	4	25	43
MARSEILLE	52	10	3	21	57
DIJON	24	10	0	23	35
NANCY	43	10	0	23	50
moyenne	44	10	2	22	51

Erreurs abosules : $\frac{\sigma}{\sqrt{n-2}}$

	σ_i	n	e.a
Orléans	67	353	3,6
Toulouse	37	82	3,7
Marseille	52	70	6,3
Dijon	24	52	3,4
Nancy	43	49	6,3

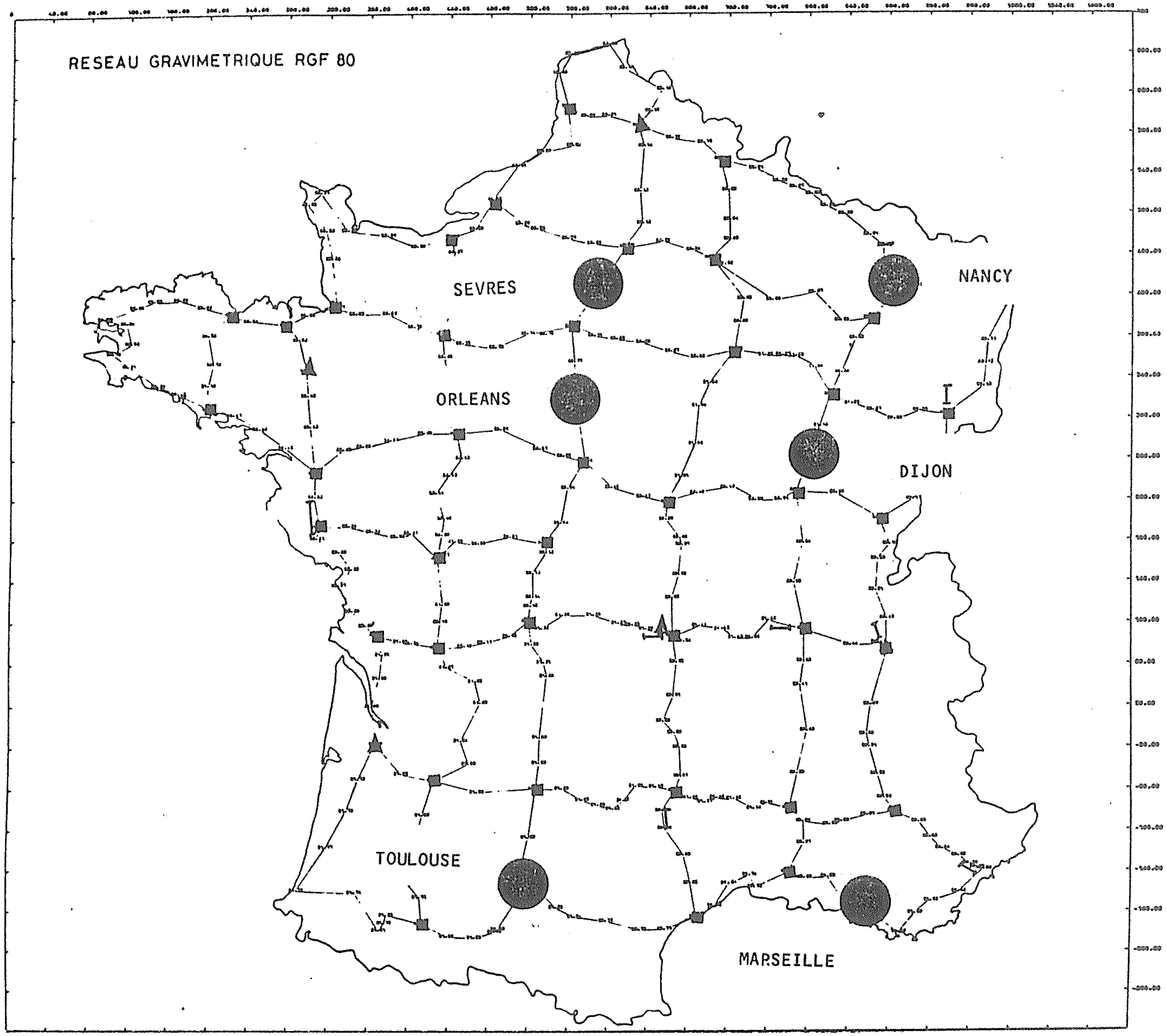


Figure 1 - Localisation des stations absolues

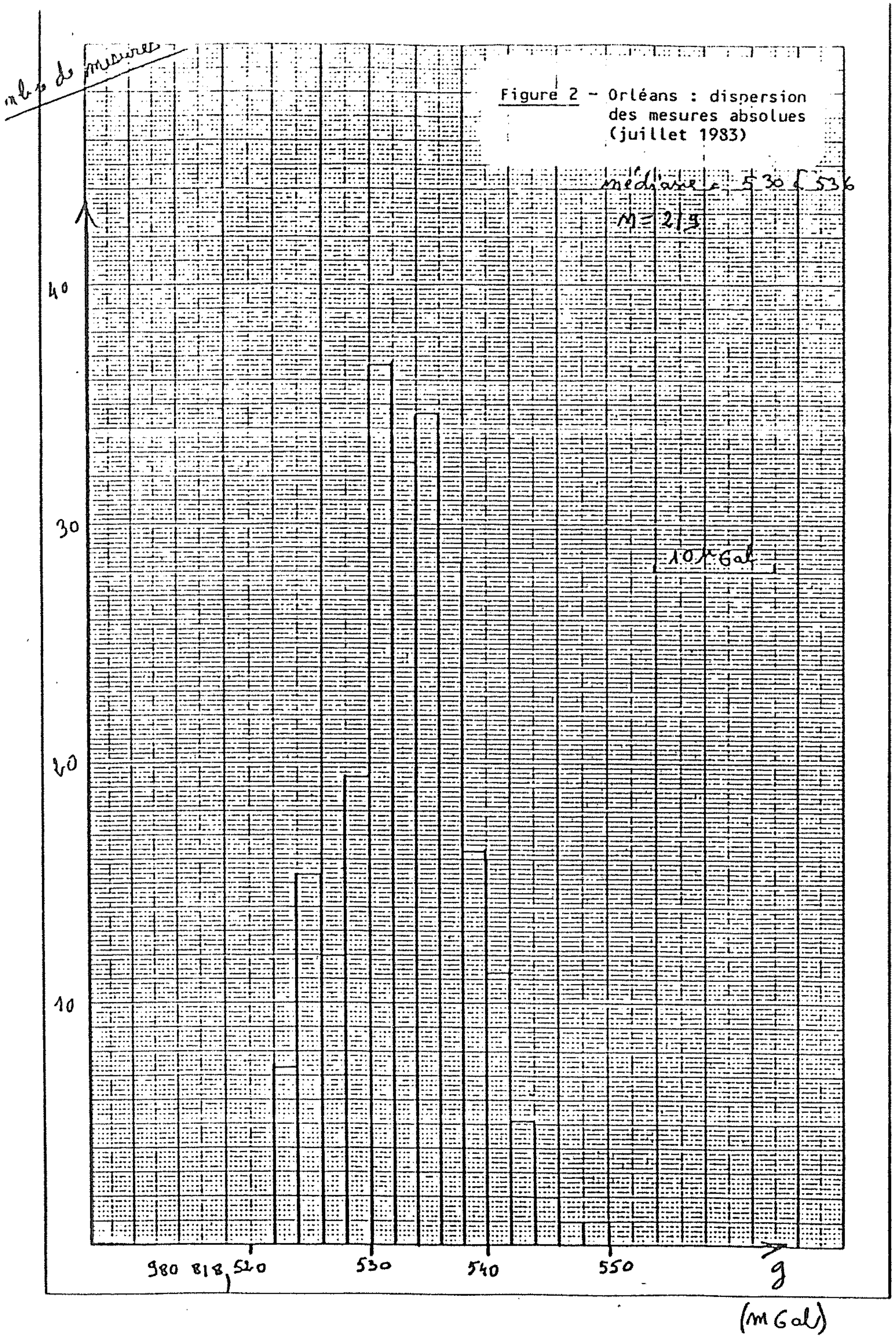


Figure 2 - Orléans : dispersion des mesures absolues (juillet 1983)

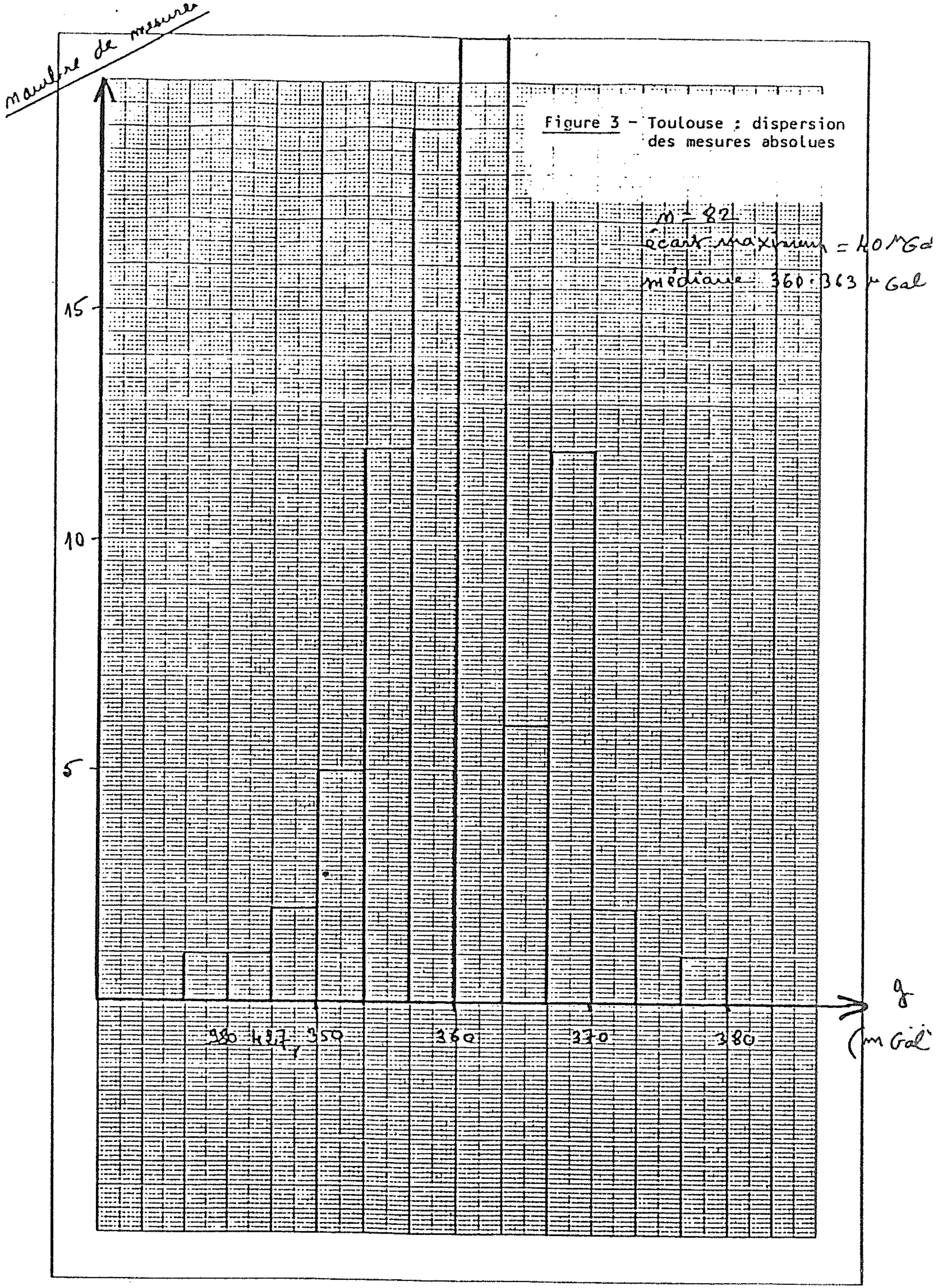


Figure 3 - Toulouse : dispersion des mesures absolues

Figure 4 - Marseille : dispersion des mesures absolues

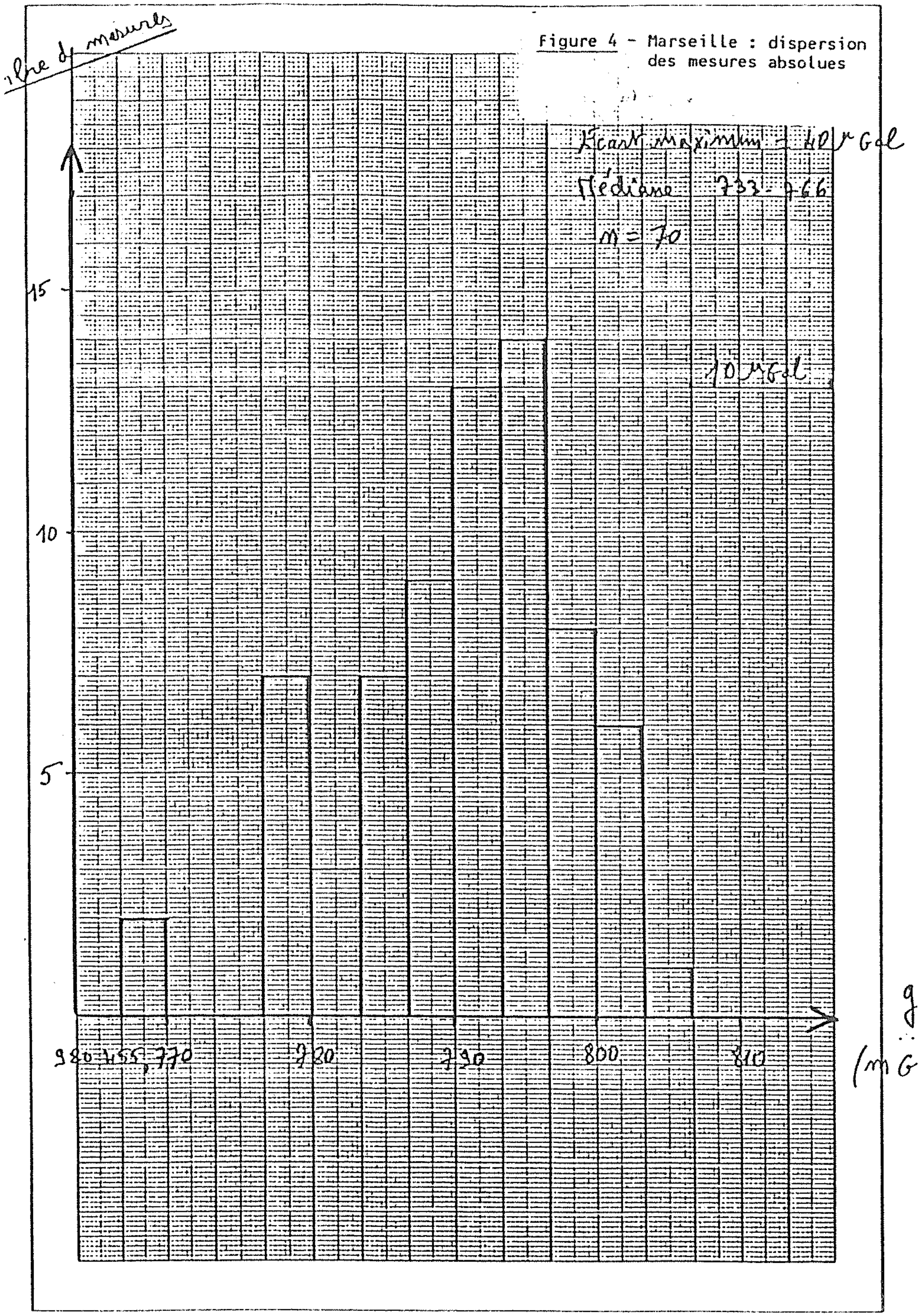


Figure 5 - Dijon : dispersion des mesures absolues

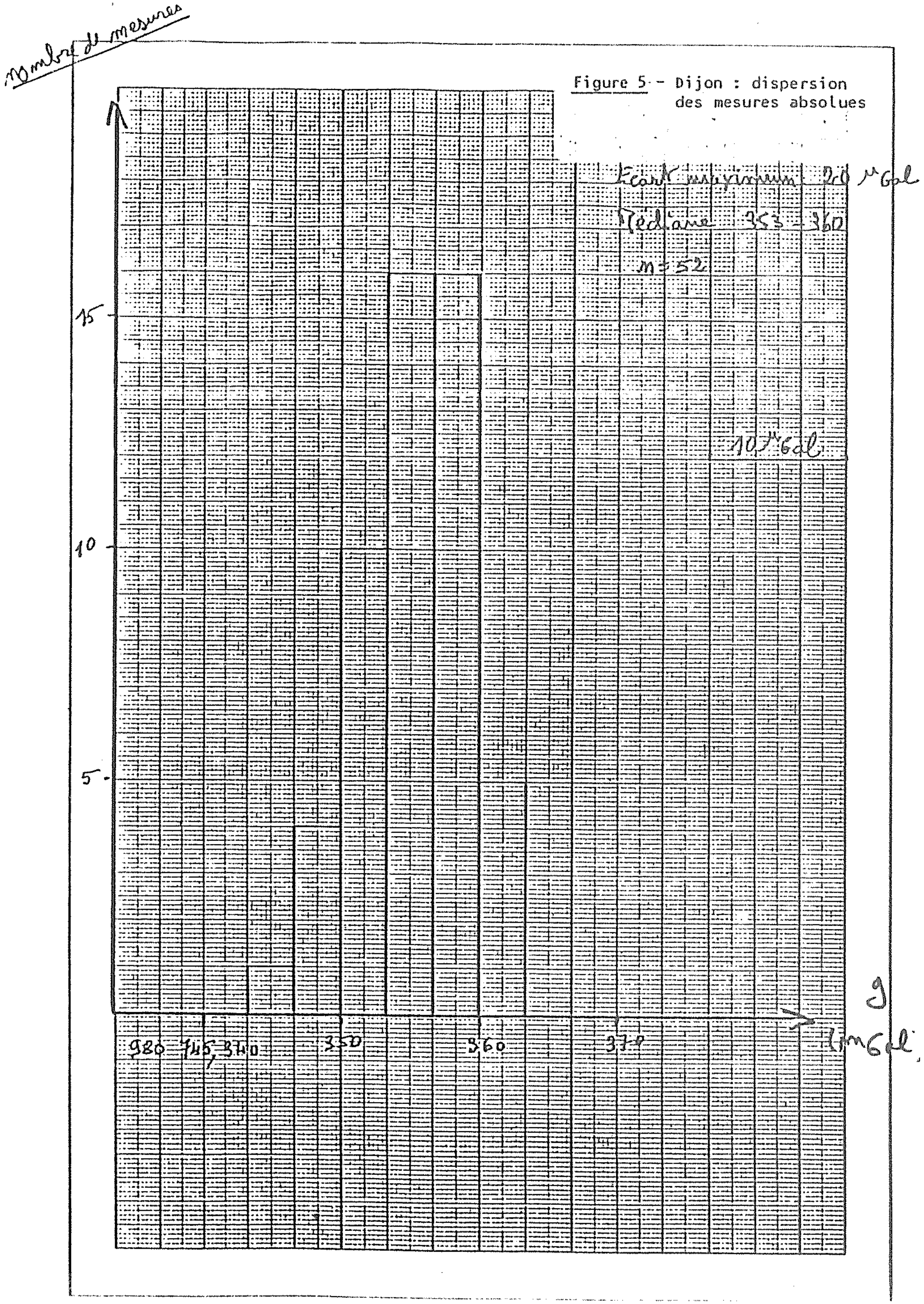
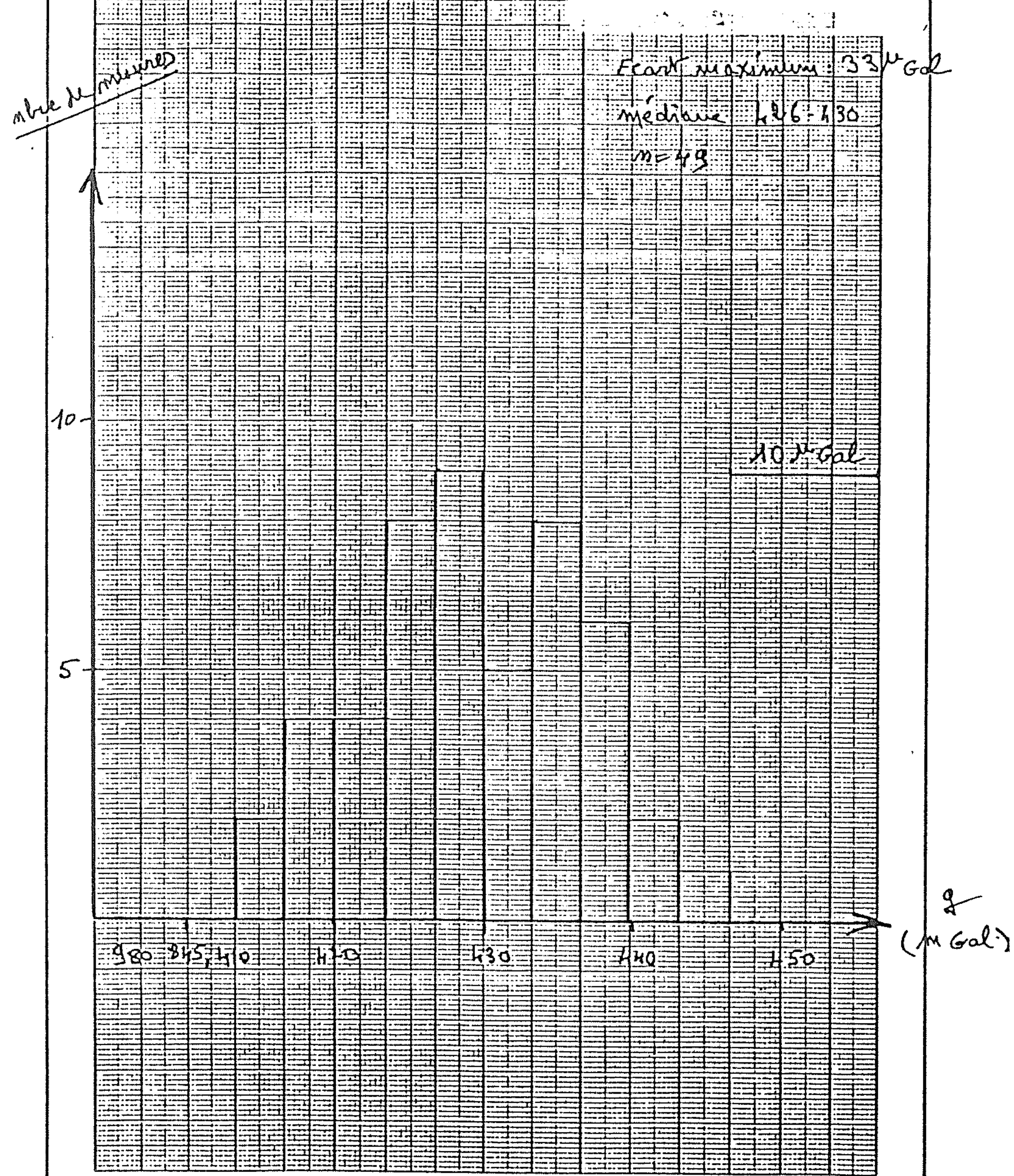


Figure 6 - Nancy : dispersion des mesures absolues



An Industrialized Absolute Gravimeter : Type GA 60
A description of the instrument
and its trial use in the French Gravity Net

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1. Introduction. The first transportable absolute gravimeter using the symmetrical free rise and fall method was developed in 1974 at the Istituto di Metrologia "G. Colonnetti" (IMGC), Torino, after a long technical collaboration with the BIPM Sèvres [1]. Following the successful results obtained by this prototype [2], the BIPM was approached by several laboratories concerning the possibility of developing a second generation apparatus of the IMGC prototype in an industrialized version.

After long discussions between BIPM and the Aviation Division of the French firm "JAEGER S.A.", our proposals were accepted, and during 1980-81 two exemples of the first commercial absolute gravimeter were manufactured [3]. One is in operation at the Geographical Survey Institute, Tsukuba, Japan, the other is at BIPM and is being used for a large number of studies in metrology and in geophysics.

This paper describe briefly several features of this gravimeter including the results of gravity determinations made made since February 1983 on five new absolute stations in the French Gravity Net.

2. Apparatus. A general view and the opto-mechanical composition of the gravimeter are shown respectively in Fig. 1 and Fig. 2. This new absolute gravimeter, like its predecessor, employs the method of the symmetric free rise and fall of a cube corner reflector (mirror) ; the method which is known to be the most accurate and advantageous [4] for absolute gravimetry.

It is novel, however, in using a new data processing system which we call the "multiple station" method. This is explained schematically in Fig. 3 where it is compared with the "two station" method which has been used in the IMGC prototype and elsewhere. A cube corner reflector (70 g) is projected vertically about 40 cm by a catapulte in the vacuum cylinder (< 0.01 Pa). During the free rise and fall, the position of the cube corner is observed continuously by means of an iodine-stabilized laser interferometer using a sub-nanosecond (< 0.1 ns) time digitizer.

The large amount of data obtained, a total of about 1300 measured relative positions and times, is used in the least squares adjustment of the best trajectory from which the following is deduced : a value of gravity at a well-defined height, the value of the vertical gradient of gravity throughout the trajectory, the proportional factor that links deceleration force (due to residual pressure) to the velocity of the falling object and the residual vibration of the interferometer, represented in a graphical form in Fig. 4. All of the data recording and computation is carried out by a microprocessor integral with the gravimeter. The print-out of the results follows about two minutes after each launch.

The gravimeter : GA 60, No. 2 at BIPM is normally kept in a "Stand by" condition in an air-conditioned room (20 °C ± 1 °C) ; the vacuum cylinder is continuously pumped by an ion pump and even during transportation of the gravimeter, the vacuum is maintained in the vacuum cylinder and in the interferometer ; the vertical and horizontal alignments of the apparatus and optical beams are also maintained with sufficient accuracy and monitored before and after of each set of gravity measurements. Thus, gravity measurements can be started after a warm-up period of only 10 minutes after the "Switch-on" of the gravimeter ; this wait of 10 minutes is required for the warm up of the iodine stabilized laser and for the locking of the Rubidium Atomic Frequency Standard. After transporting the gravimeter to another location about half a day is required for the preparation and assembling in readiness for operation. About two hours are required for disassembling of the instrument by two operators During operation 20 measurements of "g" can be made by a semi-automatic procedure over a period of one hour. Because of the high accuracy and good repeatability of the measurements (< 1 part in 10^8), there is no need to make a large number of measurements. Normally, at one station, a total of about 100 made over one or two days, composed of 8-10 sets of 12 measurements at different phases of the earth tide are sufficient to give a standard deviation of less than 1 part in 10^8 of "g".

3. New absolute stations. Since February 1983, the GA 60, No. 2 of BIPM has been employed to establish an absolute gravity net in France. Presently five new absolute stations have been created ; in Orléans, Toulouse, Marseille, Dijon and in Nancy. At the Toulouse station (IGSN : 18031), the IGSN value of gravity was found too high by about 500 nm.s^{-2} (50 µgal) with respect to our absolute measurement.

Results of this first expedition of the GA 60, No. 2, are summarized in Table 1 (in French). There are two things worth noting here, the first is that the drift of "g" due to atmospheric pressure change has been clearly observed and the second is that, probably for the first time at the Orléans station, a reasonable correlation is identified between the level change of the underground water table and the drift of gravity (of the order of a few micro gal). During this expedition, which lasted several months, the GA 60, No. 2 was always in a fully operational condition, there were no instrumental troubles with the exception of one minor incident at the Dijon station, where the underground room was not air-conditioned and a high humidity was observed. Water condensation occured around the iodine laser absorption cell (maintained at 15 °C by a Peltier effect coder) and caused difficulties in the stabilization of the laser wavelength. During operation the GA 60 has scarcely any need of maintenance or repair, the catapult and catcher of the projectile and resetting mechanism for launching of the cube corner have been operated about 2500 times without degrading the quality of the free rise and fall.

In parallel with the "g" measurements, we are also carrying out studies of the posssible sources of systematic error in the measured gravity. These studies have made now good progress and at present we estimate that the maximum systematic error of this GA 60, No. 2 is unlikely to be more than ± 3 parts in 10^9 (± 3 µgal), of which the main component stems from an incomplete knowledge of the correction of the obliquity of the laser beam. The results of these studies together with a more detailed description of the instrument, the data reduction and the various sources of uncertainty in the final value for "g" will be published later.

4. Conclusion. The first commercially available absolute gravimeter type GA 60 has been demonstrated. Its successful use in a trial expedition over five stations has shown that absolute gravimetry has now entered a now phase open to all who are interested in a large field of studies and applications in metrology, geodesy and geophysics.

5. Acknowledgements. The design, construction and commissioning of an instrument such as this transportable absolute gravimeter has, of course, been the work of many people. In particular I would like to acknowledge the cooperation of Messrs. Dutitre, Colas and Gain of JAEGER S.A. during the whole of the project, Messrs. Ogier and Lescop of the BRGM who undertook most of the work during the setting up of the five stations of the French Gravity Net and the following members of the BIPM staff : P. Carré and J. Hostache for the development of the mathematical and computational methods for data handling, J.-M. Chartier for help with the iodine stabilized laser J. Hamon for help in the adjustment of the interferometer and J. Dias for assistance throughout the project.

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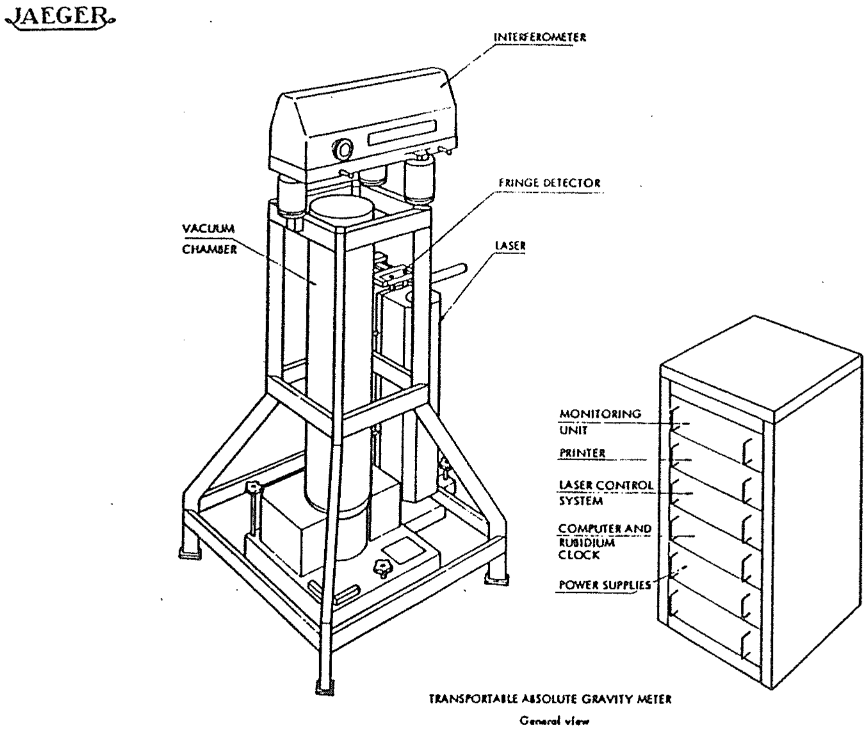


Figure 1

Fig. 2

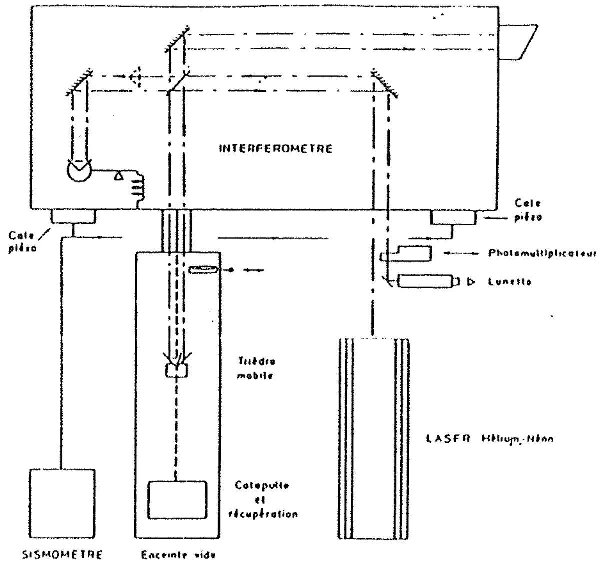
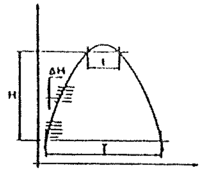


Fig. 3



$e = \frac{1}{2} g t^2$

1°/ 2 stations

$g = \frac{8H}{T^2 - t^2}$

2°/ multiples stations

ΔH = 1mm environ

GRAVIMETRE

ABSOLU TRANSPORTABLE

Exactitude $\frac{\Delta g}{g} = 1 \times 10^{-8}$

GRAVIMETRE ABSOLU TRANSPORTABLE 'GA 60' BIPM JAEGER

CONDITIONS DE TIR CORRECTES

DATE : 1983-07-25   05 h 55 min 04 s   T.U. BRGM ORLEANS LA SOURCE

TIR NUMERO 1989

NOMBRE DE MESURES   MONTEE 570   DESCENTE 742

COTE DU POINT DE REFERENCE
0,062 m AU-DESSOUS DU SOMMET DE LA TRAJECTOIRE
1,032 m AU-DESSUS DU PLAN DE BASE

PREMIERE APPROXIMATION

DIST. DE LA PREM. STAT. AU SOMMET	0,369103683 m
ACCELERATION DUE A LA PESANTEUR	9,808105446 m.s-2

VALEURS AJUSTEES SUR 1138 MESURES (ET ECARTS-TYPES)
(MESURES RETENUES : 1 A 569 ET 572 A 1140)

DIST. DE LA PREM. STAT. AU SOMMET	0,369103681 m (0,000000000)
DECALAGE RESIDUEL	-0,000000009 m (0,000000001)
GRADIENT	0,000003697 s-2 (0,000000420)
COEFFICIENT DE TRAINEE MOYEN	0,000001119 s-1 (0,000000022)
ACCELERATION DUE A LA PESANTEUR	9,808105364 m.s-2 (0,000000007)

ECART MAXIMAL : 7,8 nm
MINIMAL : -7,2 nm

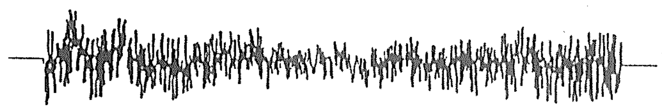


Fig. 4

TABLE 1

Résumé de mesures absolues de "g", accélération due à la pesanteur. Unité : $nm.s^{-2}$ (0,1 μGal)

Station	Période	"g" (moyenne au niveau du gravimètre) [1]	σ [2]	Δg/PA [3]	PA [4] mb	Δg/ΔZ [5]	Nbre de mesures	MOSO [6]	Niveau souterrain de l'eau
Toulouse [7] Ancien OBS	16-20 avril 1983	980 427 347 9	± 47	- 5	988	2 940 ± 22	74	128	-
Marseille BRGM"A"	24-26 avril 1983	980 455 778 1	± 65	- 4	995	2 780 ± 19	71	123	-
Dijon BRGM"A"	29 avril-03 mai 1983	980 745 336 5	± 34	- 3	980	2 770 ± 20	52	187	-
Nancy BRGM"A"	06-10 mai 1983	980 845 409 0	± 53	0	970	2 910 ± 14	46	209	-
Orléans [8] BRGM"A"	03-08 février 1983	980 818 518 3	± 81	- 3	1000	2 720 ± 14	133	191	- 15,06 m
	24-31 juillet 1983	514 9	± 51	- 3	1000	2 720 ± 14	218	191	- 15,36 m
SEVRES [9] BIPM"A"	avril 1983	980 925 610 9	± 82	- 3	1006	2 980 ± 20	> 50	211	-
	mai-juin 1983	612 3	± 79	- 3	1006	2 980 ± 20	> 50	211	-

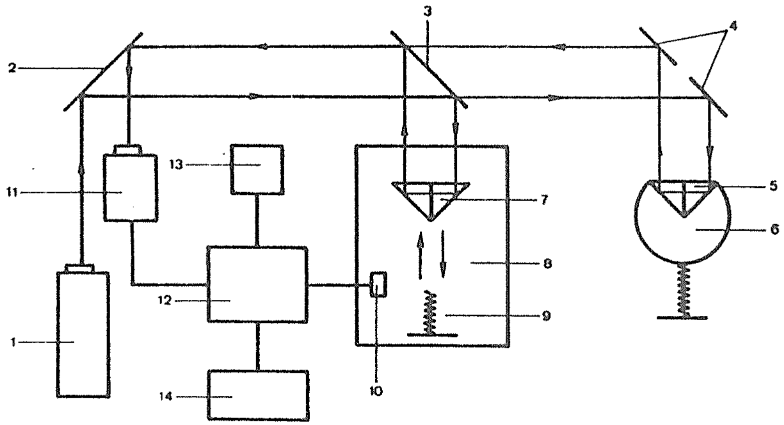
1) Altitude par rapport au sol du gravimètre absolu utilisé (Type BIPM-JAEGER GA-60 N° 2) : 1,125 m. Ces valeurs moyennes de g ne contiennent pas les termes constants de marée MOSO (correction de Honkasalo) dont les valeurs sont indiquées en 6).
2) Ecart-type d'une mesure après application des corrections des marées gravimétriques établit par le Centre International des Marées Terrestres à Uccle (Belgique).
3) Coefficients de dérive de g due à la variation de la pression atmosphérique, décelés par le gravimètre absolu. Unité : $nm.s^{-2}/mBar$ (pour la station de Nancy ce coefficient n'était pas décelable).
4) Pression atmosphérique aux lieux de mesure de g admise comme "Normale" correspondant aux valeurs moyennes de g.
5) Gradient vertical de la pesanteur déterminé par Mr Ogier (sauf à Sèvres). Unité : 10^{-9} s^{-2}.
6) Correction des termes constants de la marée gravimétrique.
7) Station "PILIER" 18031 A IGSN 71.
8) Seule station parmi les six où le niveau souterrain de l'eau est actuellement mesurable.
9) Station instable : diminution de g importante à cause des travaux de bâtiment très près de cette station.

This gravity meter has been developed by JAEGER Aviation Division on the basis of studies and experiments carried out by the Bureau International des Poids et Mesures (BIPM) in Sevres, France.

GENERAL

The equipment has an accuracy of better than 1×10^{-7} ms^{-2} and measures the gravitational acceleration at a point well defined with respect to the body of the instrument. A moving body describes an upward and downward vertical trajectory; g is calculated in accordance with the "multiple station" method.

GENERAL DESCRIPTION AND OPERATION



Block diagram

1- Laser source
2- Mirror
3- Semi-transparent beam splitter
4- Mirror
5- Fixed reference corner cube
6- Long-period seismometer
7- Moving corner cube
8- Vacuum chamber
9- Launching device
10- Pressure sensor
11- Fringe detector
12- Microprocessor computer
13- Clock
14- Printer

The equipment, which is transportable, consists of :

- a vacuum chamber in which the moving body is launched vertically;
- a coherent light source made up of an iodine-stabilized He-Ne laser;
- an interferometer containing a long-period seismometer upon which is mounted the fixed reference corner cube; the interferometer is stabilized by piezo-electric blocks;
- a fringe detector and counter;
- a microprocessor computing unit for data acquisition and the calculation of g;
- a high-stability rubidium clock;
- and a printer.

The moving corner cube is launched vertically upward which modifies the optical paths in the Michelson interferometer. The change in path length is observed by a fringe counting system.

The "multiple station" method consists of recording the instants of the moving body's upward and downward passage (using a timer controlled by the clock) at a great number of equidistant stations (defined by the fringe counter). This is followed by computer adjustment of the various parameters involved in the equation of motion; the principal ones being : the value of g at a well defined point, the gradient of g throughout the trajectory and the proportional factor that links deceleration force (due to residual pressure) to the velocity of the moving body.

DATA

Accuracy : 1.10^{-7} ms^{-2}

Total weight of all assembled components : 400 kg

Weight of the heaviest individual component : 95 kg

Overall dimensions of the gravity meter itself : height : 1.95 m
width : 0.9 m) at ground
depth : 0.9 m) level

APPLICATIONS

Realisation of a world network of reference stations.

Calibration of relative gravity meters.

Tectonic studies and geological prospection.

Participation in earthquake prediction studies.

Secular g variation studies.

RESULTS OF COMPARISON OF ABSOLUTE GRAVIMETERS, SEVRES, 1981

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By the initiative of SSG 3.37 and 3.40 of IAG, in October 1981, in Sèvres, the comparison was made of three absolute gravimeters : two from the USA and one GABL gravimeter from the USSR. Later, in April 1982, at the same site measurements were made by the Italian instrument and Jaeger gravimeter. As reported by A. Sakuma, in Sèvres after 1977, gravity changes had the character of noise with the amplitude of about 7 mgal. Therefore, for comparison a possibility was rendered to use measurements of the Italian instrument made in 1977 and 1978, of GABL gravimeter in 1979 and of the Chinese instrument in 1980.

Since through technical reasons the instruments were installed on different pillars, a micronet was established for their comparison which connected all the points into one system. Relative measurements were made by 6 gravimeters LCR with the average error of ± 2 mcgal. The vertical gradients were measured with the same precision.

The instruments were compared in two variants : when all absolute determinations by all instruments were accepted independently (n = 12) and when only those measurements were taken into account which were made in 1981 and 1982 (n = 4). For point A3 the results were :

1. n = 12 ; g = 980 925 913 ± 2.5 ; m = ± 8.6
2. n = 4 ; g = 980 925 912 ± 4.0 ; m = ± 8.1

We can consider it established, that on the average the accuracy of up-to-date absolute determinations has the error of about ± 8 mcgal. The Hammond instrument (USA) revealed a systematic error of 50 mcgal.

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ON NON-TIDAL GRAVITY VARIATIONS

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Absolute gravity measurements taken by various absolute gravimeters in 1972 to 1982 at sites in Sèvres, Potsdam, Moscow, Novosibirsk were adjusted to site A3 in Sèvres.

Data obtained permit to conclude that no cosiderable gravity variations occurred during this time interval at the above mentioned sites. Variations of g measured by different instruments are of noise character with amplitude of about ± 10 mcgal, which well agrees with average error for absolute gravity measured by one instrument. This error was obtained from the calibration of absolute gravimeters in 1981, in Sèvres.

ON THE SUBJECT OF NON-TIDAL CHANGES OF GRAVITY

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The study of non-tidal measurements of gravity is one of the major problems of modern gravimetry closely associated with solution of fundamental problems of global geodynamics. There is a considerable amount of published information on repeated gravity determinations. But owing to insufficient metrological basis the larger part of measurements is incompatible. Moreover, their authors often identify the obtained divergences in measurements with time gravity changes. Therefore, every new result indicating gravity change or its stability in time should be carefully justified in the first place from the view point of metrological basis of the accomplished measurements.

In the end of the 60-s great progress was achieved in the field of experimental gravimetry. Principally new instruments were constructed, i.e., absolute ballistic gravimeters with rather high accuracy. These instruments allowed to start the study of non-tidal gravity changes on an essentially new basis of independent measurements of absolute gravity values.

In the Soviet Union the research started in 1972 and still continues. During that period the Soviet instrument GABL has several times carried out repeated gravity determinations at points Ledovo (Moscow), Novosibirsk, Potsdam and Sèvres.

Owing to the high accuracy of measurements of differences between points conducted by the GABL gravimeter, it became possible to reduce all these measurements to the point Sèvres A3. Moreover, using published data, all available absolute determinations carried out by other instruments in Sèvres, were reduced to that point [1,2,3,4,5,6] .

Table 1 shows the assumed values of Δg used for reduction of all measurements to point A3 and their average errors. Table 2 shows g values reduced to point Sèvres A3.

Fig. 1 demonstrates results of these determinations. This plot implies that in the time period from 1966 to 1973 a clear change in gravity value was observed from the measurements made by the stationary gravimeter of Prof. A.Sakuma. Starting from 1973 such clear picture was not observed. Measurement results in the time interval from 1972 to 1982 can be approximated by a straight line whose tilt to the axis of abscissas is characterised by the value:

$$\alpha = + 1{,}0 \pm 0{,}4 \text{ mcgal/y.}$$

In this case the error of weight unit was $\pm$ 9,3 mcgal.

Consequently, the tilt of the straight line was rather small and was determined without reliability. The obtained sum of measurements, therefore, can be considered as the sum of equally accurate determinations with only accidental errors. In this case the error of one g determination by one instrument shall be

$$\mu = \pm 9{,}9 \text{ mcgal.}$$

In 1981 in Sèvres a comparison of 5 absolute gravimeters was carried out [7] . The results of this work showed that the error of the absolute value of gravity determination by one instrument was equal to:

$$m = \pm 8{,}0 \text{ mcgal,}$$

i.e., fairly close to error μ by value.

It therefore follows that during the period of time 1972-1982 at points located on the Eurasian continent along the distance of 5 000 km notable gravity changes of secular character were not observed.

This conclusion is confirmed by the fact that the average gravity value obtained from five determinations of absolute gravimeters during their comparison in 1981 for point A3 is g = 980 925 914 $\pm$ 3,6 mcgal [7] and in good correlation with the average value g = 980 925 912 $\pm$ 1,3 mcgal (Table 2). The difference between these two values is

$$\Delta = 2 \pm 3{,}9 \text{ mcgal.}$$

Since from the sum of all observations a tendency is traced towards the increase of gravity of the order of 1 mcgal/y, these observations should be continued with all possible attempts to increase their accuracy.

J.D.Boulanger
G.P.Arnautov
S.N.Scheglov

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Table 1

Values of reduction to station Sèvres A3

Stations	Δ g	M(Δ g)
	mcgal	mcgal
Sèvres A - Sèvres A2	+ 312	± ?
Sèvres A3 - Sèvres A	- 79	± 2
Sèvres A3 - Sèvres A5	- 660	± 3
Sèvres A3 - Sèvres A6	- 688	± 2
Sèvres A3 - Novosibirsk	-	± 5
Sèvres A3 - Ledovo	- 625 408	± 5
Sèvres A3 - Potsdam	- 335 470	± 7

Table 2

Absolute gravity values at point Sèvres A3

Ser. no.	Date Month Year	Instru-ment	Station	g	M(g)
1	2	3	4	5	6
				mcgal	mcgal
1	.11.1966	1*	Sèvres A2	980 925 892	± 30
2	.09.1967	1	- " -	869	10
3	.05.1968	1	- " -	862	22
4	.10.1968	1	- " -	859	18
5	.06.1969	1	- " -	859	7
6	.08.1969	1	- " -	855	5
7	.11.1969	1	- " -	862	8
8	.12.1969	1	- " -	865	5
9	.01.1970	1	- " -	867	7
10	.02.1970	1	- " -	857	10
11	.09.1970	1	- " -	864	4
12	.10.1970	1	- " -	852	4
13	.11.1970	1	- " -	892	9
14	.12.1970	1	- " -	887	5
15	.02.1971	1	- " -	882	8
16	.06.1971	1	- " -	878	9
17	.1971	2	Sèvres A	881	41
18	.07.1971	1	Sèvres A2	886	7
19	.08.1971	1	- " -	883	6
20	.09.1971	1	- " -	888	6
21	.01.1972	1	- " -	914	7
22	.02.1972	1	- " -	909	9
23	.03.1972	1	- " -	902	8
24	.04.1972	1	- " -	910	6
25	.05.1972	1	- " -	901	6
26	13-14.05.1972	6	Novosibirsk	928	30
27	.06.1972	1	Sèvres A2	903	7
28	18.10.1972	6	Novosibirsk	905	30
29	16.11.1972	6	Novosibirsk	980 925 886	± 30
30	.03.1973	1	Sèvres A2	897	8
31	.04.1973	1	- " -	901	7
32	.06.1973	1	- " -	899	7
33	.09.1973	1	- " -	901	7
34	5-6.10.1973	6	Novosibirsk	905	30
35	20.10.1973	6	- " -	910	30
36	5-6.10.1975	6	Ledovo	937	29
37	4.11.1975	6	- " -	933	29
38	.05.1976	3	Sèvres A3	900	10
39	.06.1976	3	- " -	910	10
40	.1976	1	Sèvres A	911	7
41	2-5.07.1976	6	Ledovo	912	17
42	13-16.07.1976	6	Potsdam	920	17
43	25-26.07.1976	6	Ledovo	921	17
44	8.12.1976	6	- " -	908	17
45	27.12.1976	6	- " -	913	17
46	.01.1977	3	Sèvres A3	904	10
47	.03.1977	3	- " -	914	10
48	30.03- 4.04. 1977	6	Novosibirsk	921	20
49	28-29.05.1977	6	- " -	915	16
50	8.06.1977	6	- " -	919	17
51	29-30.08.1977	6	Ledovo	911	17
52	12-20.09.1977	6	Sèvres A3	920	16
53	30.09.1977	6	Ledovo	906	17
54	3.02.1978	6	Novosibirsk	903	15
55	7-8.08.1978	6	- " -	922	17
56	24.08- 1.09. 1978	6	Ledovo	903	16
57	25.09- 1.10. 1978	6	Potsdam	898	15
58	17.11.1978	6	Ledovo	906	17
59	27-28.03.1979	6	Novosibirsk	912	20
60	4-8.04.1979	6	Ledovo	918	16
61	8-9.06.1979	6	- " -	922	16

1	2	3	4	5	6
62	26-29.06.1979	6	Novosibirsk	980 925 913	± 18
63	19-28.11.1979	6	- " -	931	16
64	3-6.12.1979	6	- " -	915	15
65	11.01.1980	6	- " -	919	13
66	.04.1980	5	Sèvres A3	928	16
67	25.05.1980	6	Novosibirsk	916	16
68	4-6.06.1980	6	Ledovo	902	13
69	3-6.08.1980	6	- " -	909	13
70	11-14.09.1980	6	Potsdam	926	11
71	21.04.1981	6	Ledovo	916	11
72	16-17.10.1981	6	- " -	909	11
73	23-25.10.1981	2	Sèvres A5	903	5
74	23-30.10.1981	6	Sèvres A6	921	8
75	5.11.1981	6	Sèvres A3	920	9
76	10.02.1982	6	Ledovo	917	10
77	.03.1982	4	Sèvres A	918	8
78	16-17.04.1982	3	Sèvres A3	908	5
			Average**	980 925 912	
				m = ± 9,9	
				M = ± 1,3	

* 1 Stationary instrument of A.Sakuma
2 Instrument of J.Faller
3 Italian instrument
4 Instrument of Jaeger co.
5 Chinese instrument
6 GABL

** Averaged over epoch Jan. 1972 to Apr. 1982.

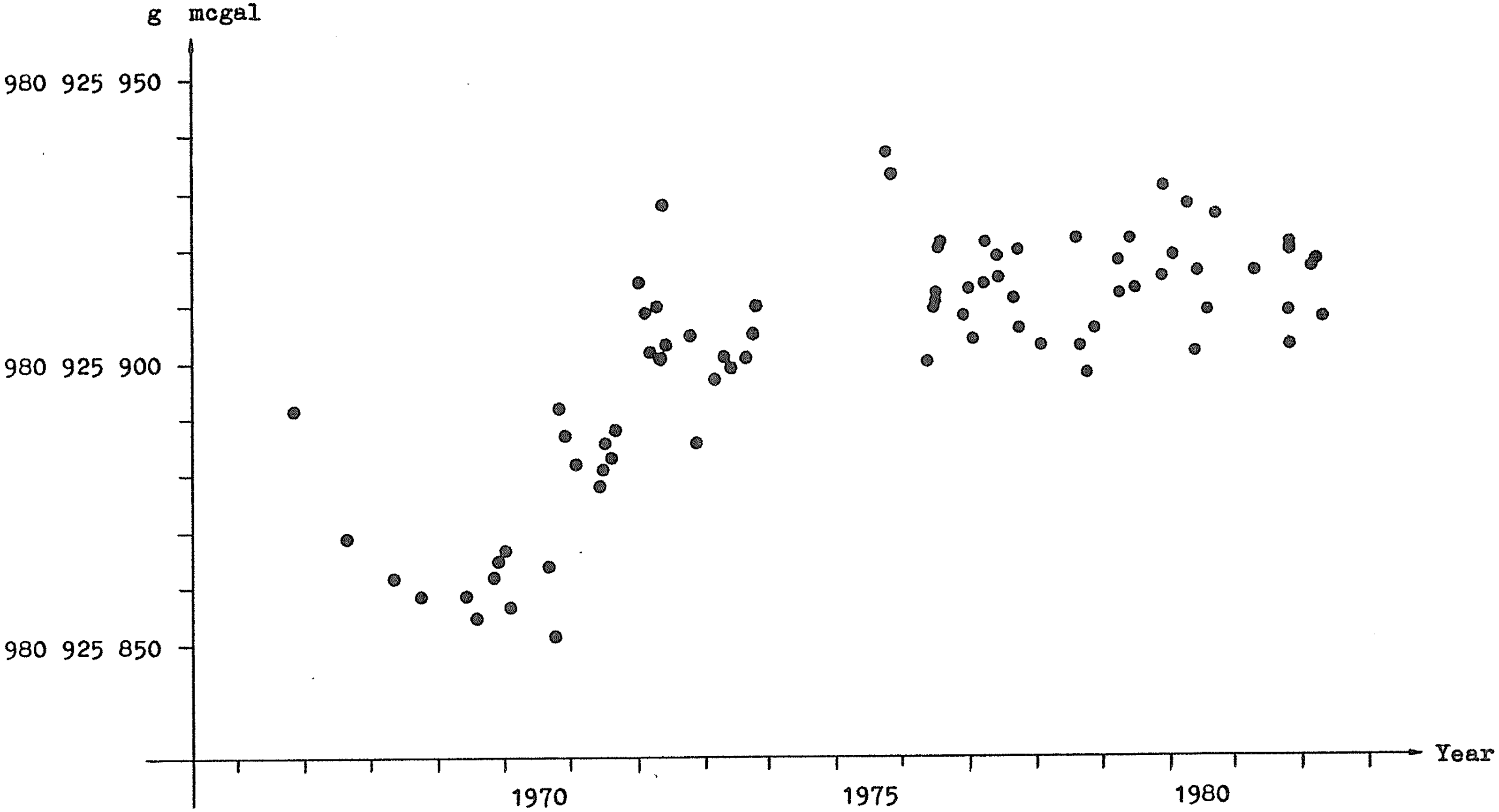

Fig. 1

Comment on the

INTERNATIONAL ABSOLUTE GRAVITY BASESTATION NETWORK IAGBN

G. Boedecker

It is felt, that, before establishing the sites for the IAGBN stations, the purposes of such a net shoul be recalled from which requirements as to station distribution and other characteristics can be derived.

Common to all purposes are requirements as to good geological, hydrological and building stability, safety against destruction, good access and measuring conditions as defined by UOTILA, and even global distribution. Furthermore, the reduction of the instantaneous observed gravity to a time-independant value because of tidal and atmospheric effects has to be assured. If a permanent earth tide station exists at the location of an IAGBN station, the respective recordings are to be used for reduction ; in this case further restrictions are obsolete. If not, it should be checked by tidal recordings over a short duration and trial computations, that the reductions can be predicted with an accuracy less than 3 μgal. If this is also not possible, the predicted loading tide at the station has to be less than 3 μgal.

In excess to the above general requirements, specifications have to be derived from special aims of the net summarized in the table (it is clear, that the aims are strongly correlated).

It is important, that the full spectrum of the dynamic behaviour of the earth be considered. A model can only be established, if the different effects can be identified and this is only possible in combination of different methods. In the ideal case, all of the IAGBN station would be collocated with earth tide and space geodetic stations. Because this might be a non feasible aim, each IAGBN station should be (or become) identical with an earth tide or a space geodetic station.

Before the BGI-WG II has proposed its IAGBN, several other authors dealt with this topic. Levallois (1971) suggested 20 to 30 continental stations. Pariisky (1978) listed 27 possible sites and Mather/Larden (1978) performed a study on various effects on the basis of 54 proposed stations.

NASA (1979) published a future network of VLBI and laser sites for global study of plate motion ; this net was complemented and/or replaced in a letter of D. Smith (1983) to Pr. Uotila. Drewes (1982) proposed an optimal global set for plate motion investigations. In the projects MERIT (Wilkins, ed., 1980) and POPSAT (Reigber et al., 1982) the rotation vector of the Earth shall be investigated. The IAG resolved at its XVIIth General Assembly, "that gravity also be measured with high accuracy at such points" (Worldwide Reference Network, Res. N° 13). These projects have to be taken into account for possible station collocation as also the worldwide earth tide station net, especially those equiped with superconducting devices.

Aims	Specific requirements
1. Reference	
1.1. Basis for subordinate gravity nets	Regard to regional net structure
1.2. Zero order geometric/gravimetric net (Bender 1981)	Collocation with space geodetic sites
2. Geodynamics	
2.1. Tectonic activity* { . uplift . lithospheric plate motions	Combination with superconducting g-meter, with space geodetic and astrometric sites (2.1.–2.3.)
2.2. Earth's rotation rate (length of day) (Lambeck, 1973 ; Lindinger, 1976)	
2.3. Motion of the geocentre, motion of principal axis of greatest moment of inertia, polar motion, ellipsoidal flattening variation (Stolz, 1976 ; Mather/Larden, 1978 ; Lambeck, 1973)	
2.4. Motion of the earth's (eccentric) core (Barta, 1978)	
2.5. Mass redistribution in mantle and crust (Mather/Larden, 1978 ; Pariiskij, 1978)	Numerous stations
3. Instrument testing	
3.1. Intercomparison of absolute instruments	Convenient traffic lines (3.1.–3.2.)
3.2. Calibration of relative gravity meters	

* originally : 2.1. Variation of G... but this is better done by Space Techniques.

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RESULTS OF SEA GRAVITY MEASUREMENTS AND CHARACTERISTICS OF GRAVITY ANOMALY DISTRIBUTION IN THE EAST CHINA SEA

Xu Jusheng, Liu Suowang, Zhu Zhongfen
and Liu Guangquan

During a period of 1977 and 1979, the sea gravity measurements were twice carried out in the East China Sea and its neighbourhood by use of ZYZY-type Sea Gravity Meter developed by Seismological Institute of State Seismological Bureau of China.

In the first measurement, the measuring region is located at 26°.5 to 34° (N), 124° to 129° (E). In the second measurement, the gravity measuring section across Ryukyu Trench is more than 1100 km long.

Ship's position has been determined by the methods of satellite navigational system and LORAN (A) navigational system, the accuracy of positioning is less than 1 knot. The sounding accuracy is 2% of water depth.

ZYZY-type sea gravity meter is installed on a gyro-stabilized platform. There is a C-C computer in the meter. The accuracy of sea gravity measurement (including the errors of the meter and the positioning) is about 4 mGal.

A method of "compressed mass plane" is used for inversion of crustal thickness and the density difference of boundary 0.6 g/cm^3 is adopted.

On basis of two sea gravity measuring results the authors have compiled 7 basic maps of free air gravity anomaly, Bouguer gravity anomaly, crustal thickness and synthetical gravity measuring section across Ryukyu Trench etc. and have divided the measuring region into five areas:

a) The area of east sea continental shelf;
b) The area of Okinawa trough;
c) The area of Ryukyu island arc;
d) The area of Ryukyu trench;
e) The area of Daito ridge;

Characteristics of the gravity anomaly distribution and the crustal structure in each area are respectively dealt with in the paper.

The authors are of opinion that the crustal structure of the continental shelf of East Sea belongs to standard continental crust and showing definite entirety and uniformity. The crustal structure of the Okinawa trough is a kind of transitional crust from the continental crust to the oceanic crust and it is in a state of non-isostasy. The crustal structure of Ryukyu trench belongs to standard oceanic crust.

VARIATIONS DE LA PESANTEUR NON LIEES A LA MAREE LUNI-SOLAIRE

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RESUME

La réalisation de janvier à juillet 1983 de 8 mesures absolues en 6 stations françaises a été l'occasion de faire un certain nombre d'observations sur les variations de la pesanteur non liées à la marée luni-solaire.

La précision instrumentale du gravimètre absolu GA60 construit par JAEGER permettant la mesure de g avec une précision (e.q.m.) de 4 microGal, nous avons pu mettre en évidence et calculer précisément pour deux stations absolues, une corrélation entre les variations relatives de la pesanteur et de la pression atmosphérique . Les coefficients obtenus sont de :

- 4,28 et 4,78 nm/s/s par mBar pour Orléans.
- 4,40 nm/s/s par mBar pour Toulouse.

De plus, deux mesures de g absolu réalisées à Orléans à 6 mois d'intervalle (février et juillet 1983) n'ont pas permis de mettre en évidence de modification de la valeur de g en liaison à une baisse de 30 cm du niveau piézométrique.

SUMMARY

The measurement in France from 1983 January to July of 8 absolute gravity values in 6 stations let us to make some investigations for non-tidal gravity variations.

The instrumental accuracy of the absolute gravitymeter GA60 from JAEGER being of 4 microGal (r.m.s.), we can find and determine with accuracy for two stations a correlation between gravity changes and barometric pressure variations. The computed coefficients were :

- 4,28 et 4,78 nm/s/s per mBar for Orléans ;
- 4,4 nm/s/s per mBar for Toulouse.

In addition, two measurements performed in Orléans at 6 months interval (1983 February-July) don't show any gravity change despite a 0,3 m change of the water table.

1. INTRODUCTION

Le programme de réalisation de mesures absolues de pesanteur en France réalisé de janvier à juillet 1983 a été l'occasion de faire un certain nombre d'observations relatives aux variations de la pesanteur non liées aux marées luni-solaires.

Huit mesures ont été réalisées en 6 stations : Sèvres (2), Orléans (2), Toulouse, Marseille, Dijon et Nancy. La première mesure à Orléans (février 1983) et celle de Toulouse ayant été réalisées pendant une dépression barométrique, et la seconde mesure à Orléans durant un anticyclone, nous avons pu étudier l'influence de la variation de la pression atmosphérique sur la valeur de g.

Les deux mesures réalisées à Orléans à six mois d'intervalle ne nous ont pas permis de mettre en évidence de variation de g liée au changement de niveau de la nappe phréatique.

2. INFLUENCE DES VARIATIONS DE PRESSION ATMOSPHERIQUE SUR LA VALEUR DE g

2.1. Orléans (Février et juillet 1983)

L'établissement d'un premier histogramme donnant une dispersion de la valeur de g importante, nous avons regroupé les tirs en séries horaires dont les valeurs moyennes ont été reportées sur un diagramme en fonction de la pression atmosphérique.

Ce plot (fig. 1) met bien en évidence une étroite corrélation entre valeur de g et pression barométrique mesurée. La détermination graphique du coefficient de corrélation donne une diminution de g de 40 microGal pour une augmentation de la pression atmosphérique de 70 mm de mercure d'où un coefficient de corrélation de 5,7 nm/s/s par mm de mercure, soit - 4,28 nm/s/s par mBar.

Les mesures s'étant poursuivies en février après la fin de la dépression et ayant repris en juillet pendant un anticyclone, nous avons réalisé une seconde détermination du coefficient de corrélation, mais en tenant compte cette fois des 21 séries de valeurs disponibles (tableau 1).

Les résultats donnent un coefficient de corrélation de - 4,78 mm/s^{-2}/mBar (fig. 2). C'est cette dernière valeur qui a été utilisée pour la réduction finale de la valeur de g. La figure 3 donne la dispersion des résultats à Orléans après application de la correction barométrique.

2.2. Toulouse (18 et 19 avril 1983)

Le même type d'observations que pour Orléans a été réalisé à Toulouse. Nous avons regroupé de la même manière les observations en séries horaires, tracé un diagramme g = f(PA), calculé de coefficient de corrélation graphiquement (fig. 4) et mathématiquement (tableau 2).

Les résultats sont très comparables à ceux obtenus pour Orléans : - 5 nm/s/s par mBar mathématiquement et - 4,40 nm/s/s par mBar graphiquement cette dernière valeur étant identique au premier coefficient d'Orléans.

L'écart entre résultat mathétiquement et résultat graphique peut s'expliquer par l'influence des valeurs de pesanteur et de pression de référence dans le cas de la résolution mathématique.

La figure 5 donne la répartition des écarts pour la station de Toulouse après correction barométrique, dont la dispersion est réduite de près de moitié.

Cette corrélation est la conséquence de la superposition de trois facteurs : marées atmosphériques, variation de la masse de la colonne d'air en fonction de sa température et effet de charge atmosphérique sur la croute terrestre, les deux premiers facteurs étant inséparables l'un de l'autre.

Théoriquement, lorsque la pression atmosphérique augmente de 1 mBar, la valeur de g devrait diminuer de 0,43 microGal. En pratique, l'augmentation de la pression atmosphérique se traduit également par une déformation de la terre (effet de charge), qui diminue légèrement l'altitude et donc entraine une faible augmentation de g. Ces deux phénomènes jouant en sens inverse, les coefficients de corrélation observés seront plus faibles et compris entre - 0,1 et - 0,4 microGal/mBar (tableau 3).

Deux déterminations graphiques des coefficients de corrélation donnant - 0,44 et 0,43 microGal soit la valeur théorique, nous sommes tentés d'en déduire que ces déterminations sont plus valables que les moyennes arithmétiques simples et que l'effet observé correspond à l'attraction pure de la masse d'air, l'effet de charge étant négligeable voir nul.

3. VARIATIONS A LONG TERME DE LA PESANTEUR A ORLEANS

L'influence des variations barométriques étant éliminées par l'application d'un coefficient de correction, il devient possible d'étudier l'influence des fluctuations du niveau hydrostatique sur la valeur de g en un point comme cela a été avancé pour expliquer les variations de la pesanteur à Sèvres (fig. 6).

Le site d'Orléans est tout indiqué pour ce type d'étude car un forage d'investigation géophysique est situé à 50 m environ du pilier gravimétrique. Depuis trois ans le niveau de l'eau est relevé toutes les semaines et permet ainsi d'étudier le comportement de la nappe (fig. 7). Les battements sont de l'ordre de 1 m à 1,50 m selon les années et se caractérisent par un minimum assez constant à - 16 m en septembre, et un maximum variable suivant les années en fonction de la recharge à la fin de l'hiver ou au printemps entre 15 m et 14,5 m.

La comparaison du niveau de la nappe entre février et juillet montre une baisse de 30 cm ce qui est très peu mais pourrait néanmoins se traduire dans l'hypothèse d'une porosité de 10 % et une profondeur de 15 m, par une diminution de la valeur de g de 4 nm/s/s. On n'observe pas une telle diminution, l'écart observé (- 1 nm/s/s) n'est pas suffisamment important, eu égard à la précision, pour être significatif.

Ces travaux vont donc être poursuivis par des mesures pendant les périodes de minimum (septembre) et de maximum (printemps) là où le battement du niveau piézométrique est le plus important et où l'on peut espérer des anomalies de pesanteur comprises entre 10 et 20 nm/s/s.

4. CONCLUSIONS

La réalisation entre janvier et juillet 1983 de 8 mesures absolues de pesanteur sur 6 sites, nous a permis de mettre en évidence une corrélation très nette de la valeur de g avec les variations de la pression atmosphérique. Trois coefficients de corrélation ont pu être calculés :

- 4,28 et - 4,78 $nm/s^2/mBar$ pour Orléans ;
- 4,40 $nm/s^2/mBar$ pour Toulouse.

Par contre, les tentatives pour relier les variations de g avec les fluctuations du niveau hydrostatique se sont révélées dans un premier temps négatives en raison de la trop faible baisse du niveau hydrostatique.

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TABLEAU 1

Résultats des mesures absolues à Orléans, février et juillet 1983

Séries	Nbre de	g moyen brut	P. atmosp. (mBar)	Correct. P. atmo. $nm/s^2/mBar$	g corrigé
FEVRIER 1983					
1	18	980.818,5403	983	- 81	980.818,5322
2	28	5436	978	- 105	5331
3	15	5416	983	- 81	5335
4	16	5400	985	- 72	5328
5	27	5419	985	- 72	5347
6	12	5433	989	- 53	5380
7	18	5374	991	- 43	5331
Nbre total : 134				moyenne :	980.818,5339
JUILLET 1983					
2	7	980.818,5350	1000	0	980.818,5350
4	10	5327	999	- 5	5322
6	9	5378	998	- 10	5368
9	9	5324	998	- 10	5314
10	10	5335	1000	0	5335
11	8	5329	1002	+ 10	5339
12	11	5325	1001	+ 5	5330
13	24	5331	1003	+ 15	5346
16	25	5311	1010	+ 48	5359
17	37	5334	1008	+ 38	5372
18	15	5319	1004	+ 19	5338
19	19	5311	998	- 10	5301
20	17	5336	998	- 10	5326
21	18	5365	995	- 24	5341
Nbre total : 219				moyenne :	980.818,5338

Valeur de g moyenne sur 353 tirs :

$g = 980.818,5339.10^{-5}$ m/s/s

Honkasalo : - 0,0191

Réduction au sol : + 0,3060

$g_{sol} = 980.818,821.10^{-5}$ m/s/s

TABLEAU 2

Détermination du coefficient de corrélation gravimétrie-pression atmosphérique.

Les valeurs de Δg et ΔPA sont exprimées par rapport aux valeurs du 18 avril 15 h T.U. prises comme référence.

Série	Δg (μGal)	ΔPA (mBar)	Coefficient (μGal/mBar)
8 et 9	- 3,9	+ 7,1	- 0,55
10	- 6,7	+ 11,8	- 0,57
11	- 5,7	+ 10,4	- 0,55
12	- 4,7	+ 10,8	- 0,44

Valeur moyenne : - 0,53 μGal/mBar.

TABLEAU 3

Coefficients de correction de l'influence des masses atmosphériques.

Auteur	Coefficient r (10^{-8} m.s^{-2}/mBar)	Laboratoire	Méthode
LECOLAZET 1968	- 0,12	Strasbourg	marée terrestre
BREIN 1970	- 0,36	Frankfurt	" "
HONKASALO 1971	- 0,52	Helsinki	" "
BREIN 1972	- 0,22 à - 0,37	Frankfurt	" "
NAKAI 1975	- 0,43	Japon	" "
VARGA 1975	- 0,38	Budapest	" "
VARGA 1975	- 0,34	Budapest	théorie
WENZEL 1976	- 0,25	Allemagne	estimation
BREIN 1977	- 0,26	Finlande	marée terrestre
WARTBURTON 1977	- 0,66 - 0,21	Californie	" "
WARTBURTON 1977	- 0,36	Californie	théorie
WARTBURTON 1977	- 0,30	Californie	marée terrestre
BREIN 1977	- 0,10 - 0,40	Allemagne	" "
ELSTNER 1978	- 0,50	Allemagne orientale	théorie

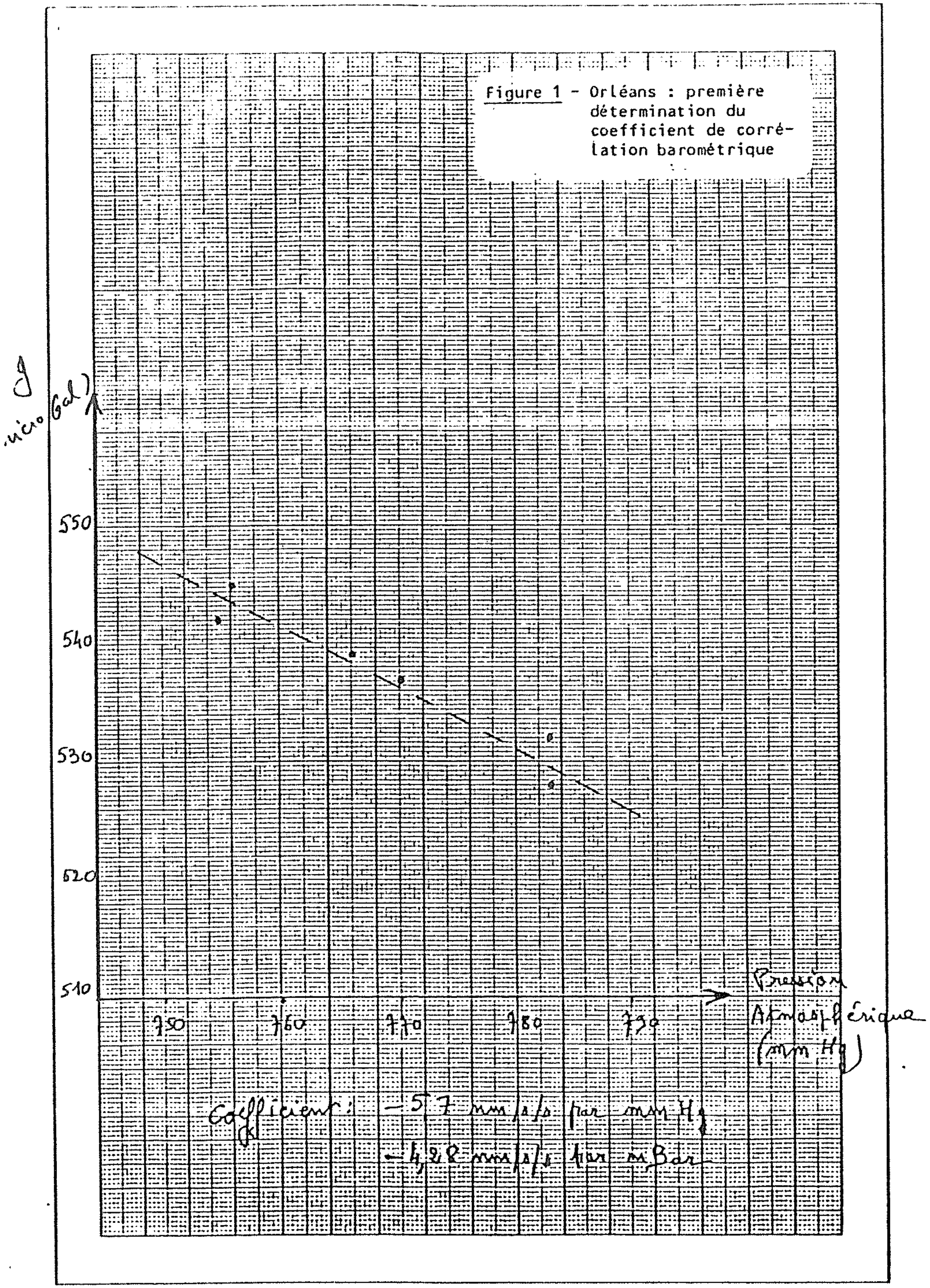

Figure 1 - Orléans : première détermination du coefficient de corrélation barométrique

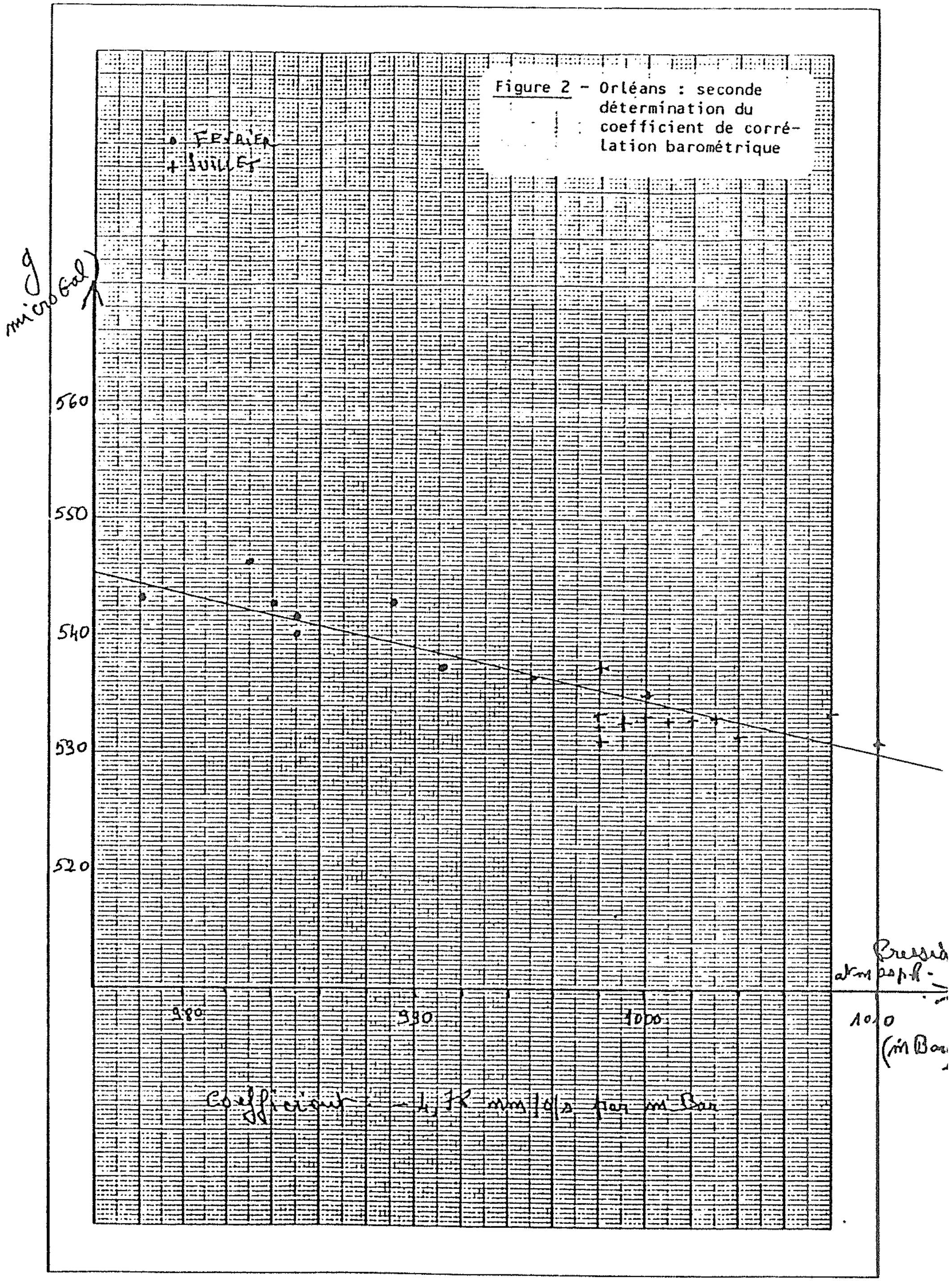

Figure 2 - Orléans : seconde détermination du coefficient de corrélation barométrique

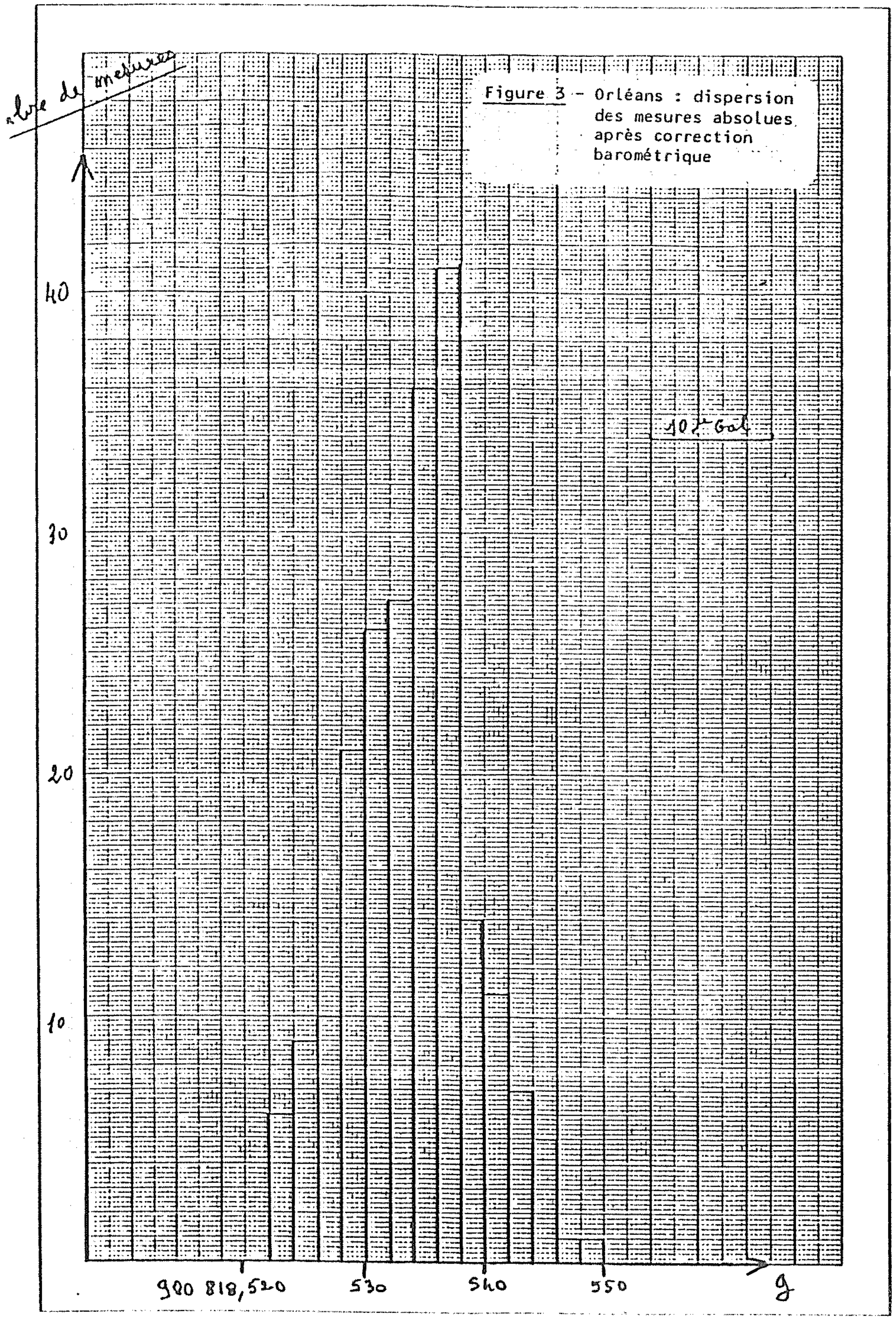

Figure 3 - Orléans : dispersion des mesures absolues après correction barométrique

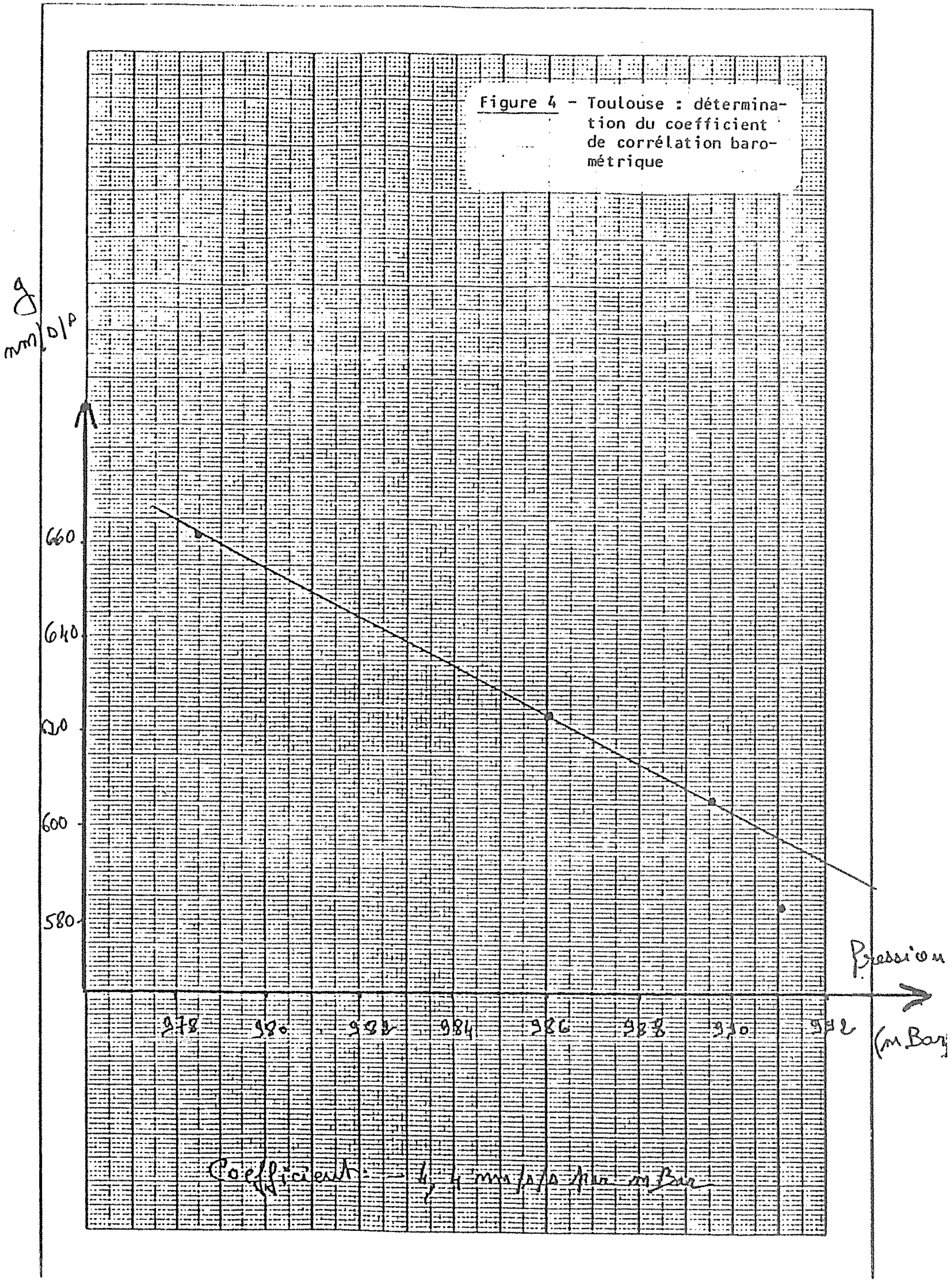

Figure 4 - Toulouse : détermination du coefficient de corrélation barométrique

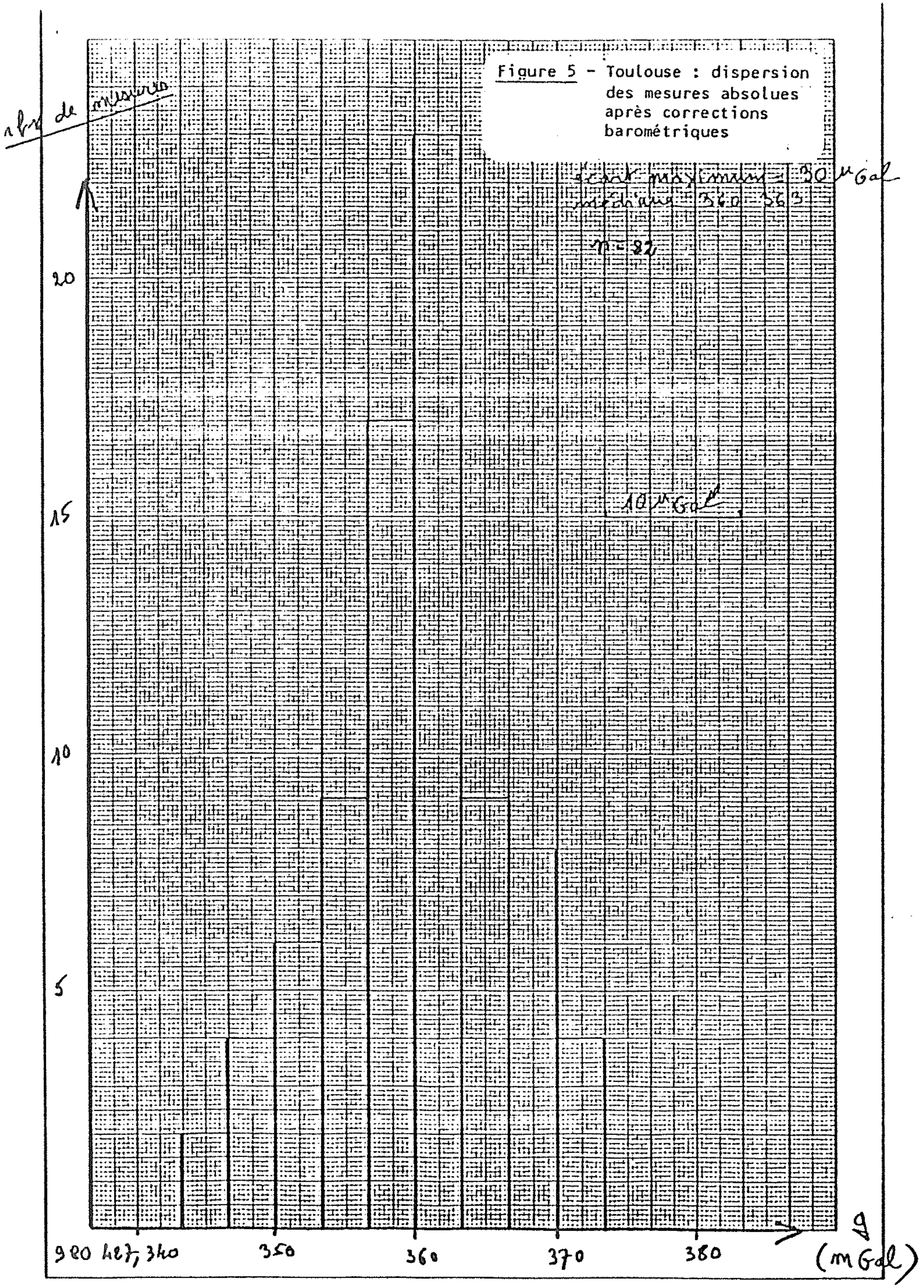

Figure 5 - Toulouse : dispersion des mesures absolues après corrections barométriques

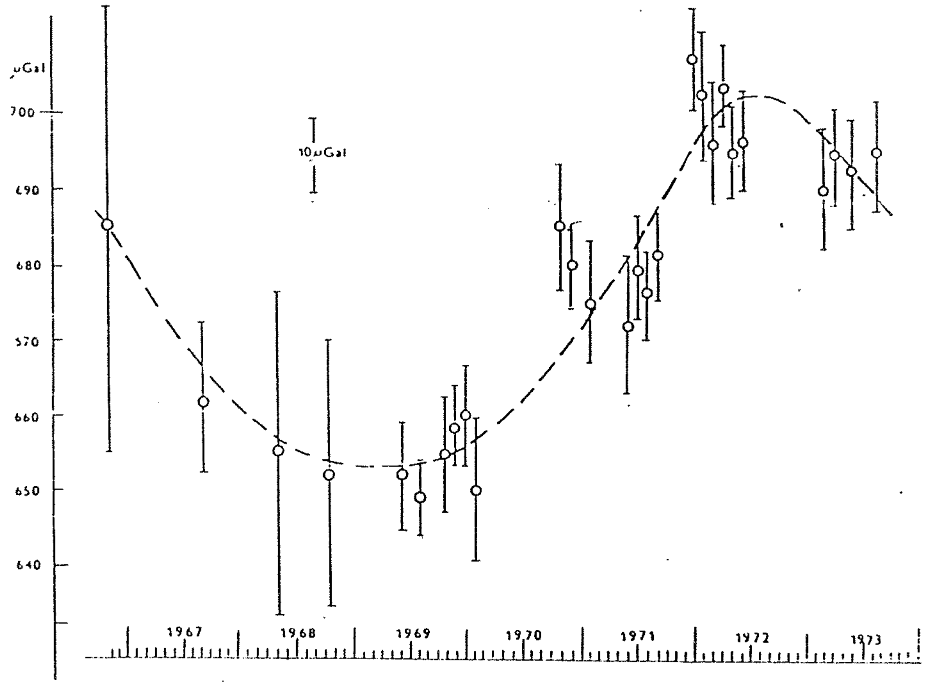

Figure 6 - Sèvres : variations de la valeur de g entre 1967 et 1973

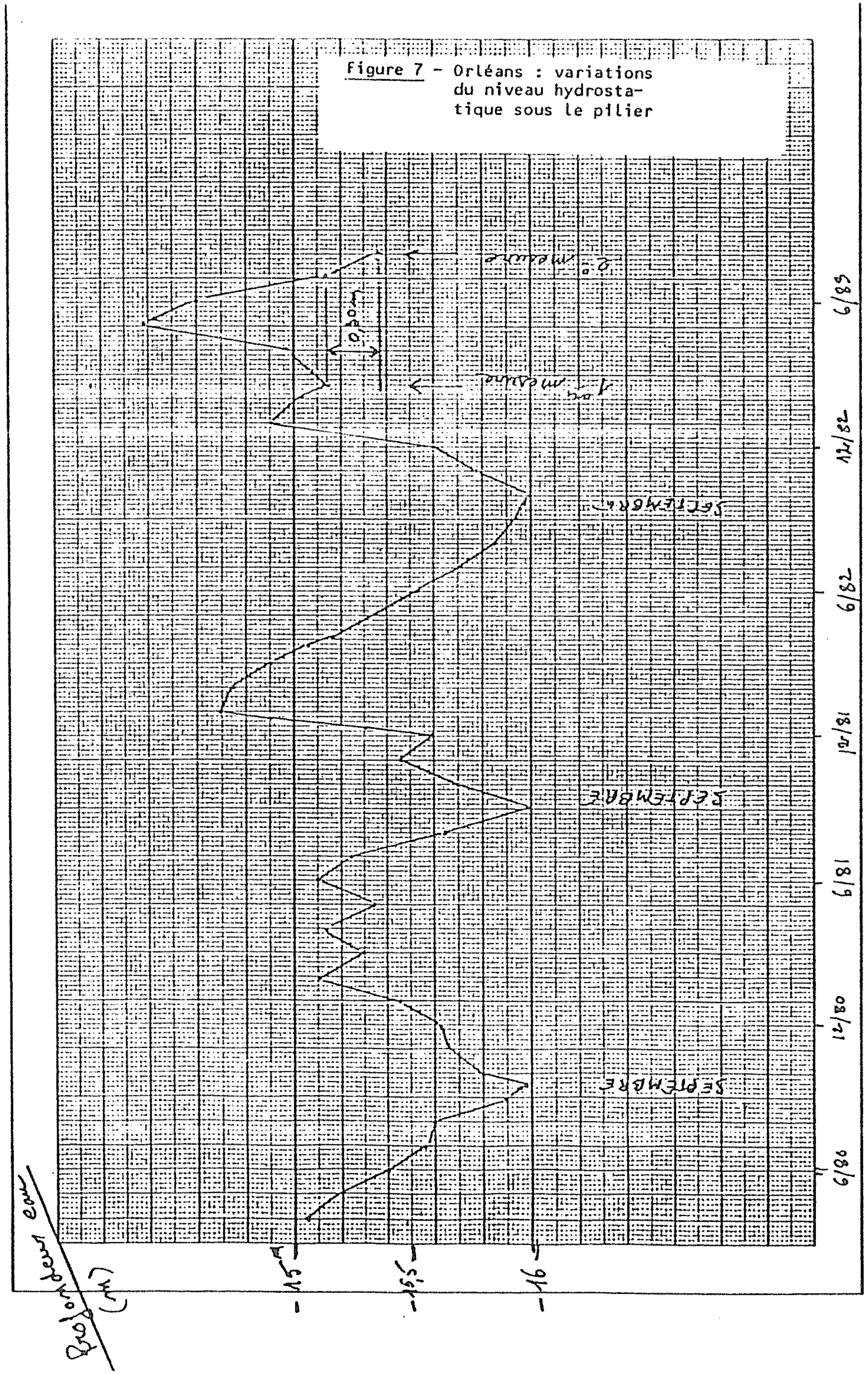

figure 7 - Orléans : variations du niveau hydrostatique sous le pilier

Check of IGSN-71 System

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The Soviet ballistic GABL gravimeter made absolute gravity determinations at 10 points IGSN-71 located within latitudes 60°N - 43°S.

The measurements established that IGSN-71 has the systematic error + 16,5 ± 3,5 mcgal/gal, depending on the gravity value.

If this systematic error is not taken into consideration, then the accuracy of IGSN-71 points is characterised by the error ± 40 mcgal.

The errors at some points reach 140 mcgal. The errors of Δg determinations, by IGSN-71 catalogue data, may amout to 0,25 mgal.

Check of IGSN-71 System

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In 1971 a considerable contribution has been made to the creation of means for global study of the gravity field of the Earth. By using the data of absolute determinations, obtained in Sèvres by stationary ballistic gravimeter of Prof. A.Sakuma, the results of measurements made by portable absolute gravimeter of J.Faller, and the data of a large number of ties carried out by relative instruments, a group of scientists headet by Prof. C.Morelli processed these materials and set up the International Gravity Standardisation Net IGSN-71.

The mean square errors of IGSN-71 points, obtained from joint equation of absolute and relative determinations, allowed to suppose that their value may range from ± 20 to ± 50 mcgal. Later it was found, however, that individual IGSN-71 points do not completely correlate to the results of both relative and absolute determinations.

It was therefore suggested to conduct control measurements at IGSN-71 points by new and more accurate instruments, in the first place by absolute gravimeters.

These control measurements were carried out in Europe [1] and the USA [2] .

In the middle of the seventies the absolute ballistic GABL gravimeter was constructed in the Soviet Union [3] . This instrument was elaborated mainly for the study of global instability of the Earth's gravity field. With this purpose in view the GABL gravimeter was used to make repeated measurements on the territory of the Soviet Union and in other countries. The intention was to set up a reliable initial epoch of study of non-tidal gravity changes in the widest latitude range possible.

Normally the GABL measurements were carried out either exactly at IGSN-71 points, or at short distances from them. This provided control of 10 IGSN-71 points from 60°N to 43°S. The points were located in Europe, Singapore, Australia.

The results of these determinations were published earlier. Here we shall only present final result of GABL measurements and compare them with the data published in [4]. Table 1 gives their summary. All g values have Honkasalo correction.

The tie between IGSN-71 points and the installation points of GABL was usually repeatedly made by a group of LCR gravimeters. Accuracy evaluation of such ties is deduced from Δg agreement between instruments.

Table 1 shows that the discrepancy $\Delta = g_{GABL} - g_{IGSN}$ reaches rather high values in Hobart and Port Moresby. Unreliability of these points was estabilished earlier when the standard basis Port Moresby-Hobart was set up by relative instruments. Therefore these two points shall be disregarded in the evaluation of accuracy.

Fig. 1 shows Δ differences as numerical values of a certain function from g value. If this function is approximated by the straight line, then its tilt angle shall be: $K = + 16{,}5 \pm 3{,}5$ mcgal/gal i.e., the points of IGSN-71 system have the systematic error depending on g value. Over the Earth's globe this error in g differences may reach about 0,12 mgal.

When determining K all Δ values were considered equally accurate. In this case the error of the weight unit μ was equal to only $\pm$ 14 mcgal, whicc is the evidence of small accidental errors in gravity determinations at IGSN-71 points and of fairly high accuracy of GABL measurements.

If we consider Δ as accidental error, then the mean error of determination of IGSN-71 point can be found by formula:

$$M_{IGSN} = \pm \sqrt{\frac{\sum \Delta^2 - \sum M^2_{GABL}}{n}} = \pm 38 \text{ mcgal}$$

Comparison of M_{IGSN} error with the error of weight unit μ provides sound confirmation of the presence of the systematic effect K.

Therefore, the following conclusions can be derived from these data:

1. The IGSN-71 system has the systematic error which depends on g value equal to $+ 16{,}5 \pm 3{,}5$ mcgal/gal.

2. On the average the accuracy of gravity value at IGSN-71 points is characterised by mean square error of the order $\pm$ 40 mcgal.

3. The errors at some points reach 140 mcgal, whereas in Δg they may be 250 mcgal and more.

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Table 1

Check of IGSN-71 System

Points	Catalog. number	System IGSN-71: g	System IGSN-71: Reduction to the GABL point	System IGSN-71: g at the GABL point	g measured by gravimeter GABL	Difference Δ
		mcgal	mcgal	mcgal	mcgal	mcgal
Helsinki	25004 A	981 900 499 ± 19	+ 16 500 ± 5	981 916 999 ± 20	981 917 071 ± 11	+ 72 ± 23
Potsdam	21523 A	981 261 339 ± 17	0 ± 0	981 261 339 ± 17	981 261 385 ± 9	+ 46 ± 19
Sèvres A3		980 925 865 ± 14	0 ± 0	980 925 865 ± 14	980 925 914 ± 4	+ 49 ± 14
Hobart	49027 K	980 435 465 ± 77	− 17 775 ± 31	980 417 690 ± 83	980 417 830 ± 14	(+140 ± 84)
Sydney	45331 A	979 671 862 ± 21	− 34 274 ± 3	979 637 588 ± 21	979 637 619 ± 15	+ 31 ± 26
Perth	45715 P	979 386 286 ± 24	+ 17 351 ± 2	979 403 637 ± 24	979 403 694 ± 14	+ 57 ± 28
Alise Springs	41933 J	978 639 408 ± 44	− 8 609 ± 3	978 630 799 ± 44	978 630 800 ± 14	+ 1 ± 46
Darwin	38320 L	978 300 640 ± 30	+ 305 ± 2	978 300 945 ± 30	978 300 959 ± 14	+ 14 ± 33
Port Moresby	34697 J	978 198 363 ± 65	+ 3 990 ± 21	978 202 353 ± 68	978 202 242 ± 14	(−111 ± 69)
Singapore	02613 A	978 066 716 ± 25	+ 3 262 ± ?	978 069 978 ± 25	978 069 984 ± 10	+ 6 ± 27
Singapore	02613 B	978 066 076 ± 26	+ 3 914 ± ?	978 069 990 ± 26	978 069 984 ± 10	− 6 ± 28

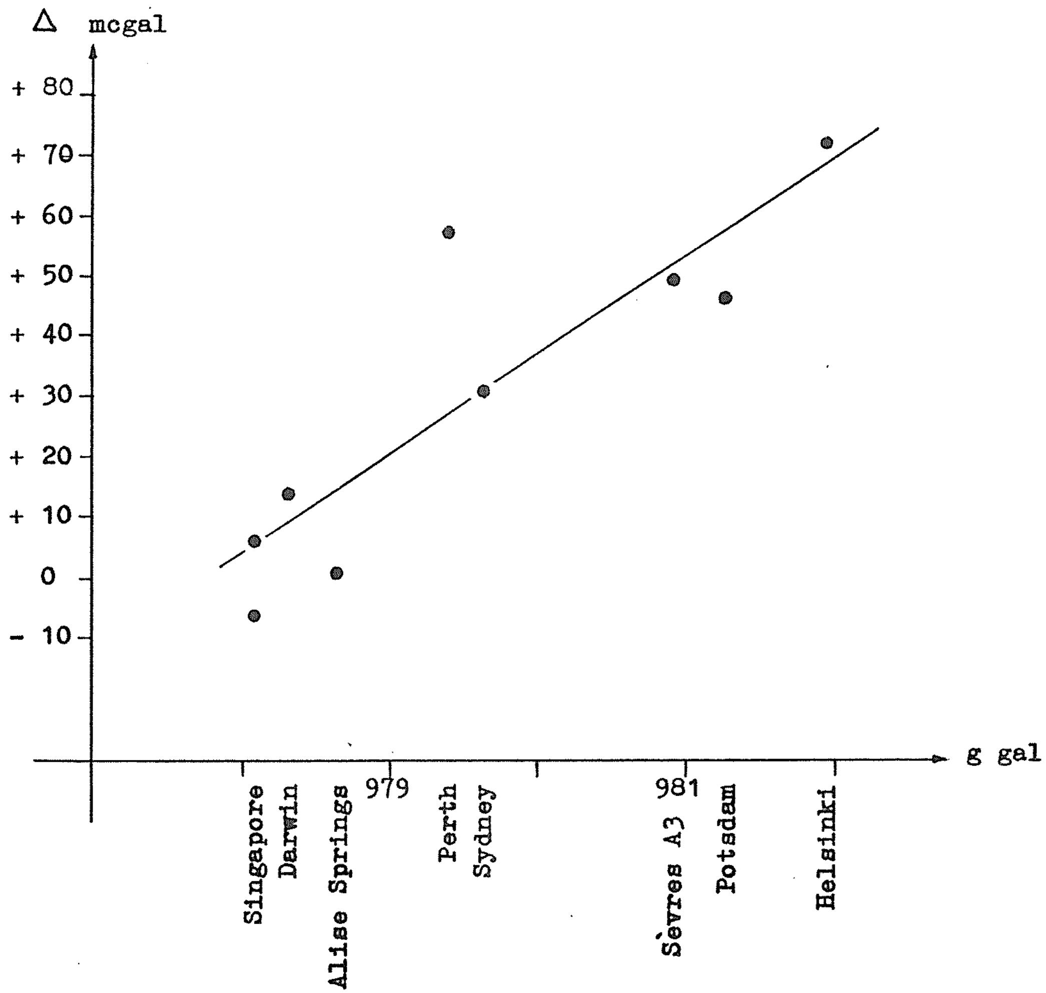
Δ mcgal
+ 80
+ 70
+ 60
+ 50
+ 40
+ 30
+ 20
+ 10
0
- 10
g gal
979
981
Singapore
Darwin
Alise Springs
Perth
Sydney
Sèvres A3
Potsdam
Helsinki

Fig. 1

INTEGRATION DU RESEAU GRAVIMETRIQUE FRANCAIS RGF 83 DANS LE RESEAU INTERNATIONAL IGSN 71

M. OGIER

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R E S U M E

La réalisation de 1980 à 1983 du nouveau réseau gravimétrique français RGF 83, a été pour nous l'occasion de remesurer l'ensemble des stations IGSN 71 françaises encore réoccupables ainsi que quelques stations européennes proches. Nous avons ainsi pu étudier les divergences existant entre notre nouveau réseau calé sur des mesures absolues de pesanteur et le système international unifié IGSN 71.

Nous avons pu ainsi mettre en évidence :

1) une relation linéaire entre l'écart ($g_{CNR}-g_{RGF\ 83}$) et la valeur de la pesanteur aux stations ;

2) l'absence de corrélation entre l'écart ($g_{IGSN\ 71}-g_{RGF\ 83}$) et la valeur de la pesanteur pour les stations françaises.

Ces deux conclusions nous amènent à mettre en doute les variations périodiques de l'écart $g_{absolu}-g_{IGSN\ 71}$ et la valeur de la pesanteur définie par L. CANIZZO et al. (1978), celle-ci n'ayant pas été retrouvée. sur le réseau RGF 83 pourtant situé aux mêmes latitudes gravimétriques.

En outre, nous n'avons pas retrouvé sur la station de Toulouse l'écart systématique de + 50 microGal entre valeur absolue et système IGSN 71 annoncé par le professeur Y. BOULANGER (1983), nos mesures ayant donné un écart de - 71 microGal.

SUMMARY

Measurements were performed between 1980-1983, during the establishment of the new french gravity net, on all the French IGSN 71 stations still available and some european ones.

The results clearly show :

1) a linear correlation between the difference ($g_{CNR}-g_{RGF\ 83}$) and the value of the gravity field ;

2) the lack of correlation between the difference ($g_{IGSN\ 71}-g_{RGF\ 83}$) and the value of the gravity field.

These observations let us to ask on the validity of the periodic variation of ($g_{absolute}-g_{IGSN\ 71}$) versus the gravity field as shown by L. CANIZZO et al. (1978).

In addition we have not found the + 50 microGal systematic difference between asolute and IGSN 71 values, our data showing a difference of - 71 microGal for Toulouse.

1. INTRODUCTION

Après la réalisation en 1980-83 du nouveau réseau gravimétrique français, il était indispensable de placer ces résultats dans le réseau gravimétrique unifié IGSN 71.

Ce calage a pu être effectué, d'une part en mesurant toutes les stations IGSN 71 encore utilisables et en les calculant dans le nouveau réseau français RGF 83, et d'autre part en intégrant dans notre réseau les résultats des liaisons internationales réalisées en 1978 (M. OGIER, 1980).

2. CALAGE DES RESULTATS 1978 SUR LE RESEAU RGF 83

Le calage des mesures de la campagne 1978 a été effectué sur le réseau RGF 83. Les résultats sont présentés dans le tableau 1 où l'on trouvera successivement :

- le nom de la station;
- le Δg mesuré ;
- les valeurs de g 1978 calées sur Sèvres A, avec pour Sèvres la valeur de 980.925,946 prise pour le réseau RGF 83 ;
- les valeurs de g calées sur les stations RGF 83 encadrées. La station d'Arras n'a pas été prise en compte, la station ayant été détruite entre 1978 et 1982 ;
- l'écart g 1978 - g RGF 83.

Les conclusions de ce calage sont de deux ordres :

1) il n'est pas possible de définir un coefficient d'étalonnage Lacoste et Romberg par rapport aux mesures absolues de pesanteur réalisées en France (fig. 1) ;

2) les liaisons relatives de 1978 et leur calage sur le réseau RGF 83 ne permettent pas de retrouver les valeurs absolues de Bruxelles, Wiesbaden et Turin, l'écart variant linéairement du Nord vers le Sud (fig. 2) :

Bruxelles	+ $11,0.10^{-7}$	m/s/s
Wiesbaden	+ $4,7.10^{-7}$	m/s/s
Sèvres	0	(référence)
Turin	- $18,6.10^{-7}$	m/s/s

3. COMPARAISON STATIONS ABSOLUES IGSN 71

3.1. Stations absolues C.N.R.

La comparaison des mesures absolues de pesanteur réalisées en 1976 et 1977 en Europe avec les stations IGSN 71 avait conduit L. CANNIZO, G. CERUTTI et I. MARSON (1978) à définir une erreur périodique dans le système IGSN 71 (fig. 3 et tableau 2).

Nous avions retrouvé à l'époque cet écart entre nos mesures et les valeurs absolues entre Bruxelles et Turin (fig. 4 pratiquement identique à la figure 2), comme les latitudes de travail étaient comparables, nous avions défini un étalonnage afin de rapporter nos observations en France et de définir une nouvelle valeur de g plus précise à Toulouse.

En fait, les résultats de nos mesures absolues n'ont pas confirmé cette corrélation qui aurait dû se retrouver en France. Nous sommes donc amenés à formuler deux hypothèses :

- l'erreur périodique dans le réseau IGSN 71 est un phénomène propre à l'Europe centrale et qui ne se retrouve pas sur l'ensemble du réseau ;
- l'écart est lié non au réseau IGSN 71, mais aux mesures absolues CNR dont la dispersion des résultats est près de dix fois supérieure aux stations B.I.P.M./B.R.G.M.

3.2. Stations absolues B.I.P.M./B.R.G.M.

Les tableaux 3 et 4 et la figure 5 montrent les variations de g RGF 83-g IGSN 71 en fonction de g pour les stations IGSN 71 françaises calées sur le réseau RGF 83.

On voit cette fois-ci que la dispersion est aléatoire et qu'aucune corrélation ne peut être mise en évidence, confirmant par là même les hypothèses faites ci-dessus.

Le tableau 3 donne la liste des écarts. L'écart moyen pour les 14 stations françaises reprises est de 3.10^{-7} m/s/s, ce qui prouve l'excellente qualité du réseau IGSN 71 en France comme nous l'avions signalé dès 1980.

3.3. Erreur périodique dans le système IGSN 71

Cette hypothèse présentée par L. CANIZZO et al. (1978) paraissait séduisante et considérant les difficultés d'un ajustement du réseau mondial, nous y avions adhéré en 1980 et l'avions transposé aux latitudes gravimétriques françaises.

Force nous est maintenant de reconnaître que les choses ne sont pas aussi simples et que l'erreur périodique est loin d'être prouvée puisqu'elle ne se retrouve pas en France. Mieux l'existence d'une relation linéaire entre la valeur de g et l'écart g CNR-g RGF 83 est assez troublant. De toute évidence les deux séries de mesures absolues ne sont pas en accord et il faudra une étude comparative poussée des méthodes de mesure et de calcul pour définir quelle est la meilleure méthode de travail.

On peut néanmoins déjà mettre sérieusement en doute la périodicité défendue par L. CANIZZO. En effet, si l'on se reporte à la figure 5, les stations françaises du réseau IGSN 71 devraient venir s'aligner avec les stations européennes (représentées par des triangles), ce qui est loin d'être le cas.

4. CONCLUSIONS

La réalisation de stations internationales et l'intégration dans le système RGF 83 des données fournies par les liaisons internationales de 1978 (M. OGIER, 1980) a permis de mettre en évidence :

1) une relation linéaire entre l'écart g CNR-g RGF 83 et la valeur de g ;

2) l'absence de corrélation entre l'écart g IGSN 71-g RGF 83 et la valeur de g pour les stations françaises, les stations européennes elles s'intégrent bien dans le nuage fourni par les points des stations françaises ;

3) de mettre en doute la relation périodique entre g CNR-g IGSN 71 définie par L. CANIZZO, celle-ci n'ayant pas été retrouvée sur le réseau français pourtant situé aux mêmes latitudes gravimétriques.

LISTE DES TABLEAUX

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TABLEAU 1

Calage de la campagne 1978 sur le réseau RGF 83

Stations	Valeurs absolues C.N.R.	Δg	G LR	g RGF 83	Ecart (10^{-7} m/s/s)
SEVRES A	980.925,970		980.925,946	980.925,946	
		+ 127,333			
ARRAS A			981.053,279	981.053,279	
		+ 63,883			
BRUXELLES A	981.117,272		981.117,162	981.117,162	
		- 70,431			
KETTENIS			981.046,731	981.046,731	
		- 9,931			
WIESBADEN	981.036,847		981.036,800	981.036,800	
		- 95,366			
KARLSRUHE (DSGN)			980.941,434	980.941,434	
		- 9,577			
SAVERNE			931,857	931,865	- 0,8
		- 99,061			
STUTTGART J			932,796	832,804	- 0,8
		- 35,225			
ENSISHEIM A			797,571	797,586	- 1,5
		- 92,856			
ZURICH			704,715	704,730	- 1,5
		+ 73,362			
ALTKIRCH B			778,077	778,076	+ 0,1
		- 507,222			
MONT BLANC A			270,855	270,854	+ 0,1
		+ 263,602			
TURIN	980.534,237		534,457	534,457	
		- 6,977			
LE BOURGET			527,480	527,446	env. 3,4
		+ 6,977			
TURIN CNR			534,457	534,423	env. 3,4
		- 27,774			
FOURQUES B			506,683	506,708	- 2,5
		- 177,693			
LE PERTHUS A			328,990	329,015	- 2,5
		+ 98,729			
TOULOUSE pilier			980.427,719	980.427,679	+ 4,0
		+ 389,780			
ORLEANS Ø			817,499	817,459	+ 4,0
		+ 108,428			
SEVRES A			925,927	925,887	
		ε = - 0,019	925,946		

TABLEAU 2

Valeurs comparées IGSN 71 Europe

Stations	g RGF 83	g CNR	g IGSN 71	
SEVRES	980.925,946	980.925,970	980.925,94	- 3
BRUXELLES	981.117,162	981.117,272	981.117,32	+ 5
WIESBADEN	981.036,800	981.036,847		
KARLSRUHE	980.942,087	980.942,136	980.942,00	- 14
STUTTGART	980.832,804	980.832,843	980.832,81	- 3
ZURICH	980.704,730	980.704,762	980.704,69	- 7
GENEVE	980.574,506	980.574,538	980.574,44	- 10
TURIN	980.434,457	980.534,237		
TOULOUSE	980.427,679	980.427,506	980.427,74	+ 23

TABLEAU 3

Comparaison valeurs RGF 83 et IGSN 71 : stations françaises.

Stations	Valeurs RGF 83 (10^{-5} m/s/s)	Valeurs IGSN* (10^{-5} m/s/s)	Ecarts (10^{-7} m/s/s)
LE BOURGET K	980.935,312	980.935,31	0
PARIS A	928,565	928,62	+ 5,5
SEVRES A	925,946	925,94	0
CHARTRES	871,724	871,66	- 6
CHATEAURENAULT	818,583	818,56	- 2
CHATELLERAULT	767,100	767,13	+ 3
POITIERS	726,887	726,81	- 8
BERGERAC	568,518	568,50	- 2
AGEN	519,367	519,37	0
MONTAUBAN	491,467	491,50	+ 3
TOULOUSE pilier	427,679	427,75	+ 7
CAPENS	387,997	388,00	0
SAINT GAUDENS	328,802	328,81	+ 1
BAGNERE DE BIGORRE	272,222	272,25	+ 3

*Listing fourni par la banque B.G.I.

Ecart moyen : $0,03.10^{-5}$ m/s/s.

Tableau 4

Comparaison valeurs RGF 83 et IGSN 71 : station européennes.

Stations	g absolu C.N.R.	Valeurs RGF 83	Valeurs IGSN 71	Ecarts
BRUXELLES	981.117,272	981.117,162	981.117,32	+ 16
KETTENIS		981.046,731		
WIESBADEN	981.036,847	981.036,800	-	
KARLSRUHE (IGSN)		980.942,087	942,00	- 9
SEVRES A	980.925,970	980.925,946	925,94	- 1
STUTTGART J		980.832,804	832,81	+ 1
ZURICH-GEBENSDORF		980.704,730	704,69	- 4
GENEVE		980.574,506	574,44	- 7
TURIN	980.534,237	980.534,457	-	

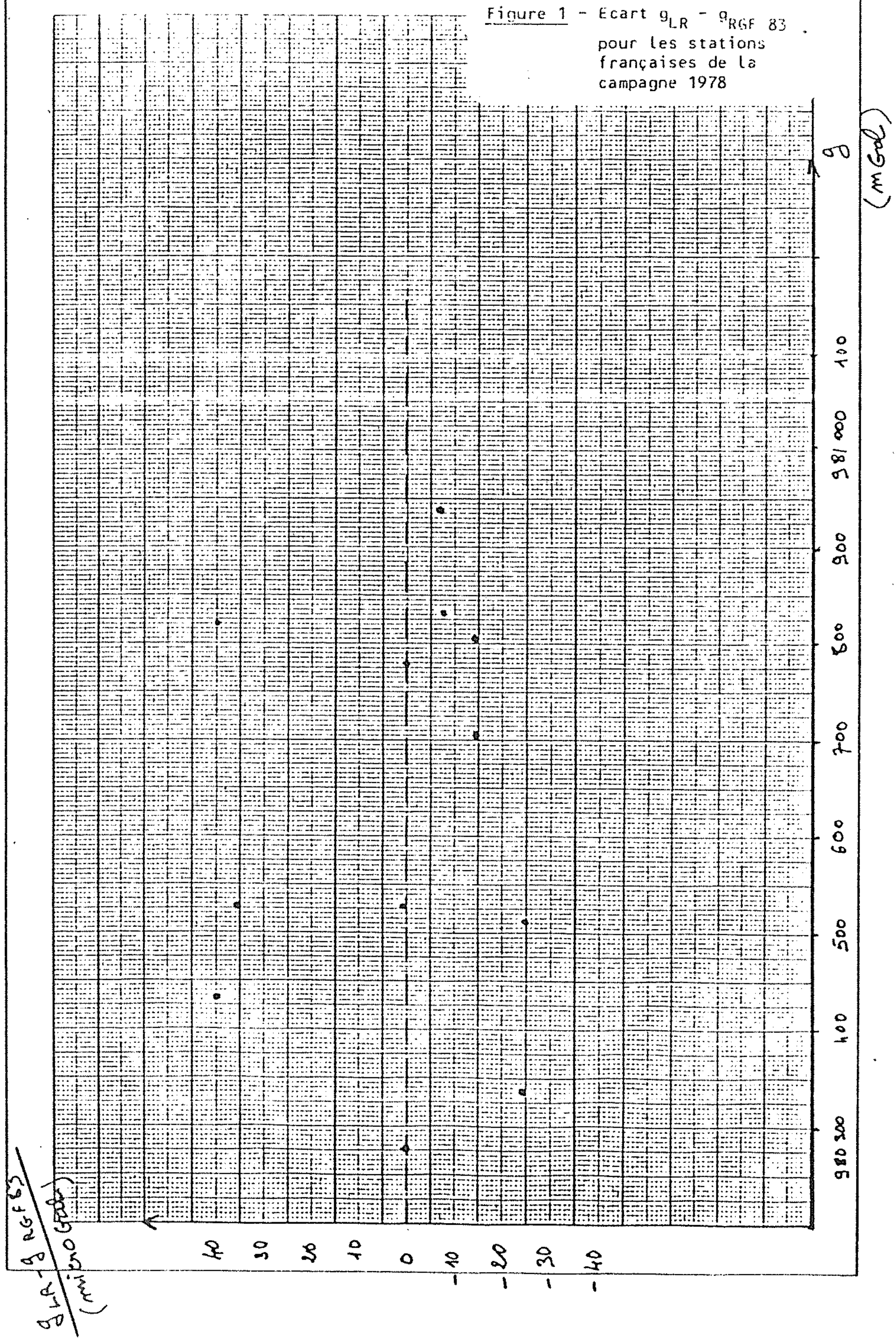

Figure 1 - Ecart g_{LR} - $g_{RGF\ 83}$ pour les stations françaises de la campagne 1978

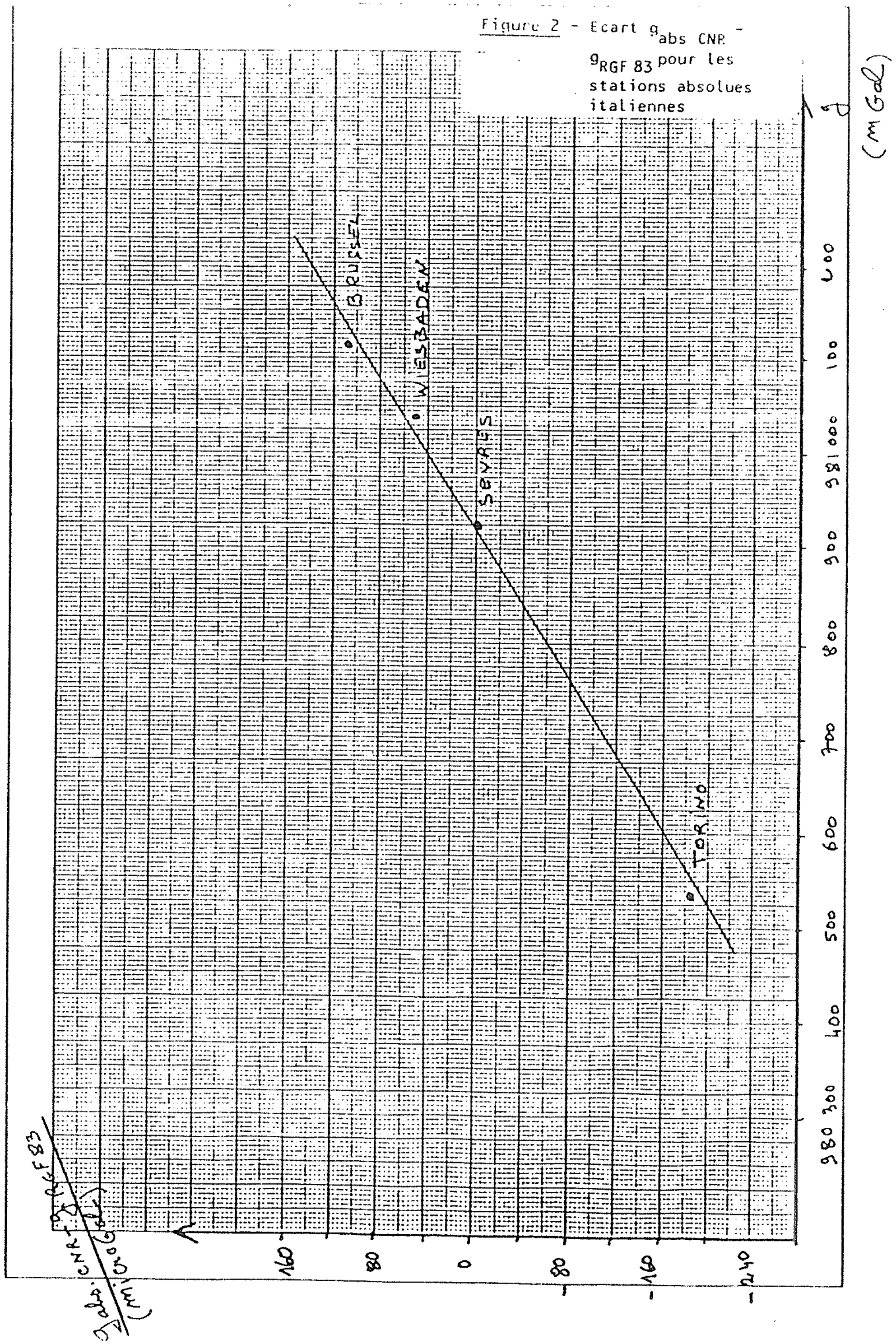

Figure 2 - Ecart $g_{abs\ CNR}$ - $g_{RGF\ 83}$ pour les stations absolues italiennes

Figure 3 - Erreur périodique dans le système IGSN 71 (L. CANNIZZO et al.)

L. CANNIZZO, G. CERUTTI and I. MARSON

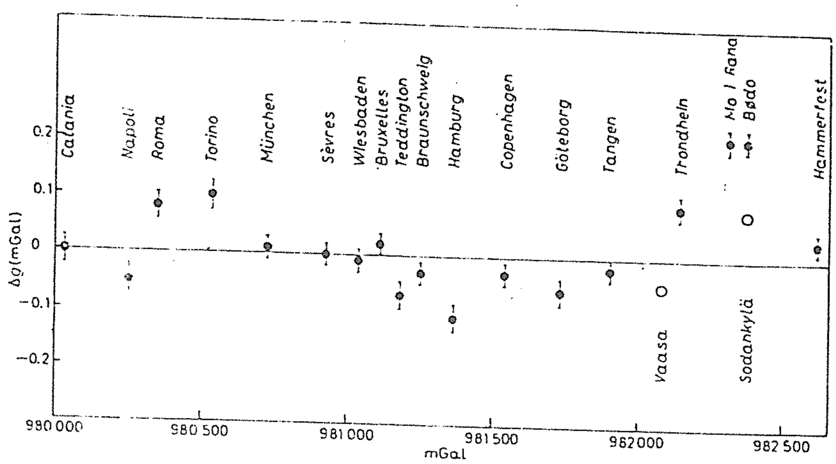

Fig. 6. - Gravity difference ($g_{IGSN\,71} - g_{abs}$) with indication of the standard deviation: • with reference to IGSN 71, o with reference to Finnish net.

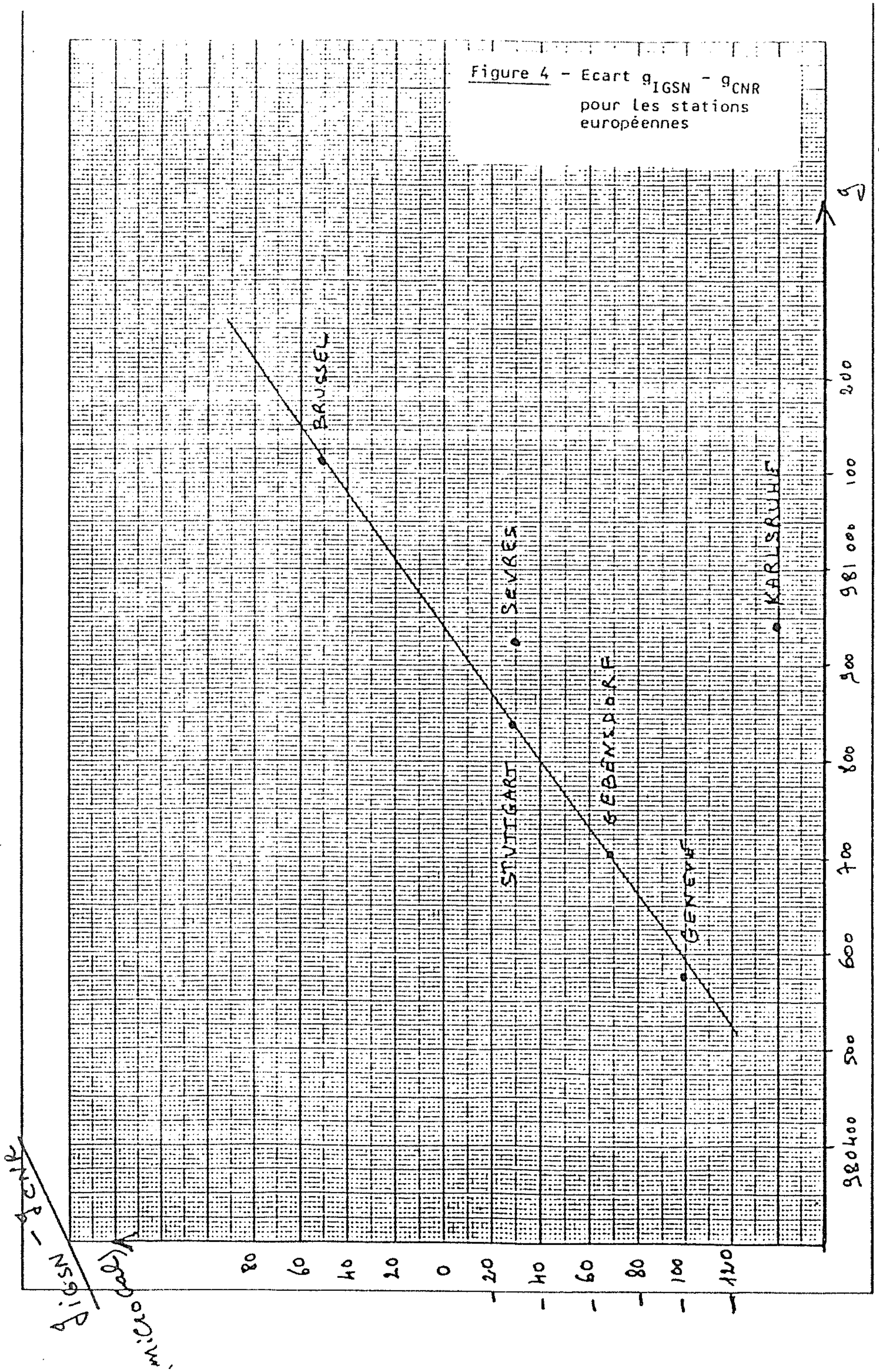

Figure 4 - Ecart $g_{IGSN} - g_{CNR}$ pour les stations européennes

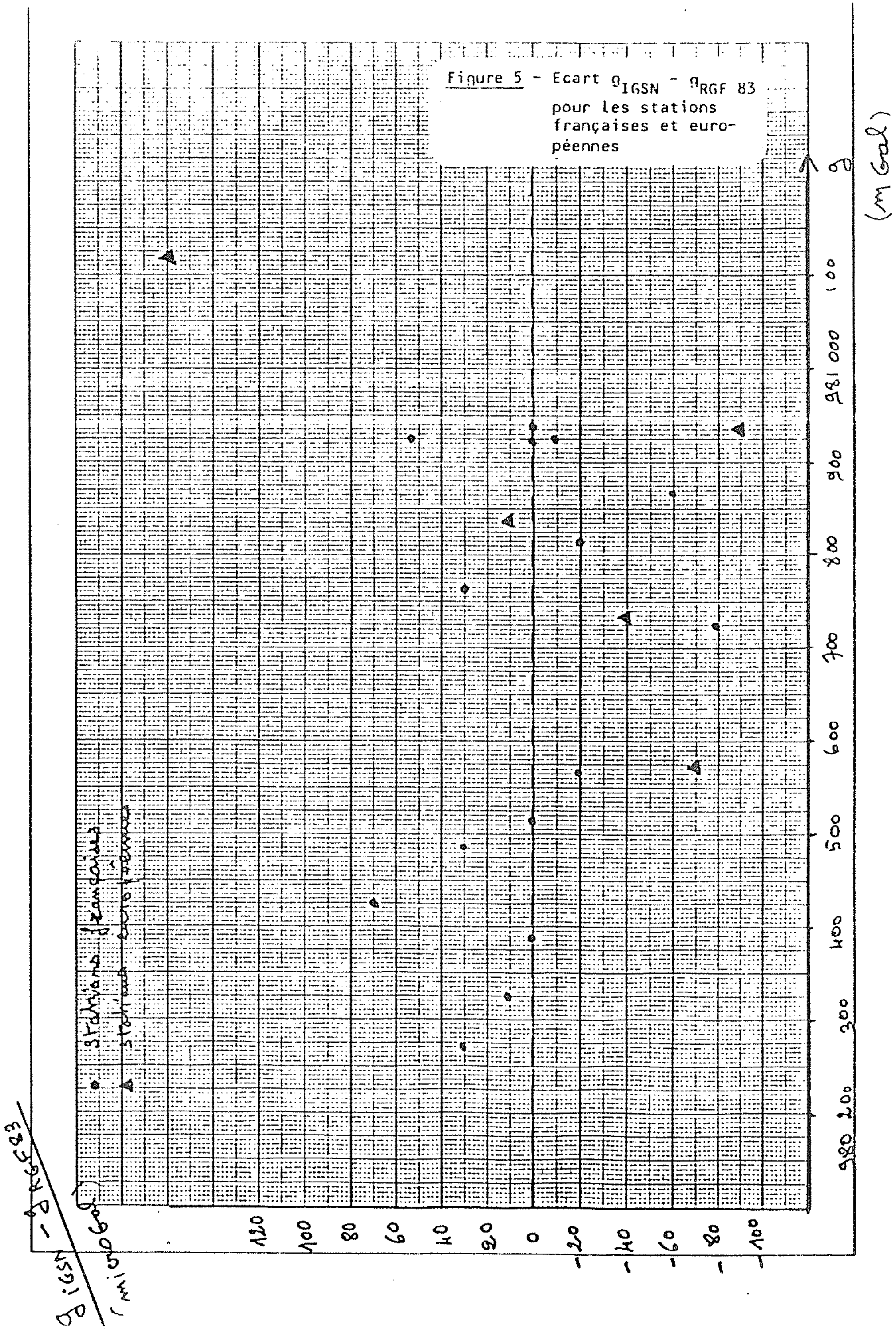

Figure 5 - Ecart $g_{IGSN} - g_{RGF\ 83}$ pour les stations françaises et européennes

LE NOUVEAU RESEAU GRAVIMETRIQUE FRANCAIS

M. OGIER

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RESUME

De 1980 à 1983 le B.R.G.M. a procédé avec la collaboration du Bureau National de Métrologie français à une refonte complète du réseau gravimétrique français.

Le nouveau réseau dont les résultats sont calés sur six stations absolues de pesanteur (Sèvres, Orléans, Toulouse, Marseille, Dijon et Nancy) comporte :

- 52 stations de premier ordre (précision 17 microGal) et 112 satellites ;
- 280 stations de deuxième ordre (précision 34 microGal) ;
- 1800 stations de troisième ordre (80 à 600 microGal selon la nature des stations) ;
- 1080 stations de quatrième ordre (80 à 127 microGal) ;
- 12 bases d'étalonnage (17 microGal) ;
- 15 stations portuaires (estimées à 124 microGal) ;
- 12 stations internationales (16 microGal) ;
- 5 stations aéroportuaires (34 microGal).

Ces données ont été complétées par une reprise des stations IGSN 71 françaises encore réoccupables ainsi que de 6 stations européennes afin de comparer ce nouveau réseau au réseau international.

1. INTRODUCTION

Entre 1980 et 1983 le B.R.G.M. a entrepris avec l'appui financier du Bureau National de Métrologie français une refonte complète du réseau de bases gravimétriques dont beaucoup vieilles de près de 30 ans étaient devenues inutilisables.

Les travaux ont consisté successivement :

- à établir un nouveau réseau de second ordre quadrillant la France d'une maille régulière d'axes le long desquels les stations sont espacées de 30 km en moyenne ;

- à mesurer avec une grande précision les points nodaux du réseau précédent créant ainsi un réseau de premier ordre ;

- à effectuer 5 mesures absolues de pesanteur à Orléans, Toulouse, Marseille, Dijon et Nancy afin de caler avec précision les réseaux précédents ;

- à recompenser sur la base de ces résultats l'ensemble de l'ancien réseau de second ordre relégué au niveau d'un troisième ordre ;

- à recréer par la même occasion une série de bases d'étalonnage ainsi que des stations portuaires et internationales.

2. STATIONS ABSOLUES

Nous ne ferons ici que résumer les principaux résultats, pour plus de détails on se reportera à la communication "Mesures absolues de pesanteur en France" présentée à la même commission.

Huit mesures absolues ont été réalisées entre janvier et août 1983 : 2 à Sèvres, 2 à Orléans puis une à Toulouse, Marseille, Dijon et Nancy.

Les mesures ont été réalisées avec une précision instrumentale de 24 à 67 nm/s/s (moyenne 44) et une précision de la valeur réduite au sol (toutes corrections incluses) de 37 à 70 nm/s/s (moyenne 51). La réalisation d'une telle précision nous a permis d'entreprendre des études sur les variations de la pesanteur non liées aux marées luni-solaires. Dès cette année, il a été possible de mettre en évidence une corrélation très nette sur deux stations des variations de la pesanteur en fonction de l'évolution de la pression atmosphérique :

Toulouse - 4,4 nm/s/s par mBar ;
Orléans - 4,3 et 4,8 nm/s/s par mBar.

3. RESEAU DE PREMIER ORDRE

Ce réseau a été mesuré entre septembre et décembre 1982 avec 4 gravimètres Lacoste et Romberg modèle G mis en oeuvre simultanément par deux opérateurs :

G 126 et G 140 appartenant à la Defence Mapping Agency* (U.S.A.) ;
G 225 de l'Université de Montpellier* (France) ;
G 588 du B.R.G.M.

Les travaux ont consisté en la réalisation de 52 stations de premier ordre et 112 stations satellites représentant 231 liaisons (2022 mesures). En outre, pour garantir la stabilité des stations, celles-ci ont été matérialisées par une plaque de fonte de 10 cm de diamètre et 1 cm d'épaisseur scellée dans le sol.

* Nous tenons à remercier ici la D.M.A. et l'Université de Montpellier qui en mettant leurs appareils à notre disposition, ont rendu possible la réalisation de ce travail.

Toutes ces stations ont été localisées aux noeuds de mailles du réseau de second ordre et un des satellites est constitué par la station de deuxième ordre.

Le comportement de chaque appareil a été suivi avec précision pendant toute la durée de la campagne en calculant la dérive diurne et la dérive à longs termes lors des retours périodiques en une station. Les caractéristiques observées sont les suivantes.

Appareils	Dérive diurne moyenne (en microGal/jour)	Dérive à longs termes
G 126	24	Dérive très irrégulière
G 140	15	Dérive forte mais régulière
G 225	28	Dérive très faible
G 588	20	Dérive régulière, moyenne

* Résultats

La comparaison des résultats entre valeurs absolues et Δg Lacoste et Romberg bruts moyens (tableau 1) montre qu'il n'existe pas de décalage systématique entre les deux systèmes, comme nous en avions mis en évidence entre Bruxelles et Wiesbaden. En effet, pour Orléans-Toulouse (391 mGal) nous observons un écart de 0,052 mGal alors que pour Toulouse-Marseille (28 mGal) nous avons un écart de 0,08 mGal et Sèvres-Orléans (107 mGal) nous obtenons 0,132 mGal.

Ces écarts qui peuvent sembler élevés à première vue pour un réseau de premier ordre, sont en fait dus à ce que la comparaison porte sur des valeurs brutes, c'est-à-dire contenant l'intégralité des données sans aucun tri préalable ni élimination d'aucune liaison (sauf panne de chauffe bien évidemment).

Puisqu'aucun "coefficient d'étalonnage" n'a pu être mis en évidence, le calage des mesures de premier ordre sur les mesures absolues va être réalisé directement. On va d'abord pour chaque liaison éliminer les Δg aberrants, calculer la moyenne, les écarts à la moyenne, puis éliminer les valeurs dont l'écart à la moyenne reste anormalement élevé. On calcule alors la somme des Δg retenus et l'écart ϵ par rapport au Δg absolu. La valeur de ϵ est généralement inférieure à 5 microGal.

* Contrôles

La précision des résultats est ensuite contrôlée par le calcul de la fermeture des mailles. Le tableau 2 donne les écarts à la fermeture pour les 32 mailles constituant le réseau.

Deux mailles seulement présentent une fermeture supérieure à 10 microGal, la plupart étant égale à zéro. La moyenne pour l'ensemble de la France est de 2 microGal.

Une autre méthode pour contrôler le calage des données consiste à calculer la somme des Δg entre les deux extrémités Nord et Sud du réseau par différents cheminements calés sur des stations absolues différentes. Les résultats (tableau 3) donnent les résultats obtenus pour cinq cheminements entre Nancy et Marseille (Δg absolu 389,548 mGal). Cette méthode confirme les résultats de la précédente, aucun écart ne dépasse 11 microGal.

* Précision

Fermetures et cheminements nous permettent de contrôler l'homogénéité des calages, mais ne nous donnent pas la précision effective du réseau.

Pour calculer la précision, nous avons déterminé pour chaque liaison utile l'écart quadratique moyen pour les Δg effectivement utilisés dans les calculs. Les résultats (fig. 2 et tableau 4) montrent que les e.q.m. sont regroupés en deux familles à 6-10 et 14-22 microGal avec une seule valeur anormale à 34 microGal.

L'écart quadratique moyen global correspondant aux 48 stations et 231 liaisons (tableau 5) est de 16 microGal. La précision finale du réseau de premier ordre sera donc :

$$\sigma = \sqrt{\sigma_{MA}^2 + \sigma_{P\emptyset}^2}$$

avec $\sigma_{MA} = \sigma$ sur les mesures absolues. $\sigma_{P\emptyset} = \sigma$ sur les mesures de Premier ordre

$\sigma = 17$ microGal

4. RESEAU DE SECOND ORDRE

Ce réseau a été mesuré en 1980 et 1981 à l'aide d'un seul gravimètre Lacoste et Romberg, soit le G 225 de l'université de Montpellier (1980), soit le G 588 du B.R.G.M. (1981).

Les travaux ont comporté l'implantation de 280 stations principales et 60 stations satellites représentant 748 liaisons et 1496 mesures.

A partir de la campagne 1981, nous avons décidé pour faciliter le repérage de la station sur le terrain, de la matérialiser par un clou enfoncé dans le bitume ou le ciment.

Ces stations constituent une série de segments (78 pour la France continentale et deux pour la Corse) le long desquels les stations sont espacées en moyenne de 30 km.

Les mesures ont été réalisées par boucles se refermant sur elles-mêmes tous les jours ou tous les deux jours de façon à minimiser au maximum l'effet de la dérive des gravimètres. Toutes les boucles présentant une dérive supérieure à 70 microGal en 12 h ont été remesurées.

* Résultats

Le calage du réseau de second ordre sur les mesures absolues a été réalisé par l'intermédiaire des stations de premier ordre situées aux intersections des différents segments de second ordre. La différence (E) pour chaque segment entre valeur du second ordre provisoire (en mGal Lacoste et Romberg) et valeur du premier ordre est toujours très faible et généralement inférieure à 50 microGal (tableau 6). Seuls les 5 segments présentent un écart (E) supérieur à 100 microGal : ces segments seront remesurés dans leur intégralité.

Le calage entre les deux réseaux a été effectué en répartissant uniformément l'écart sur toutes les liaisons du segment au prorata du nombre de stations (cf. tableau 6).

* Précision

Etant donné qu'il n'a été effectué en général qu'une seule mesure par liaison, il n'est pas possible de calculer un écart quadratique moyen pour les stations de second ordre. Par contre, il existe une manière sûre d'estimer la précision de ces liaisons, c'est d'étudier les écarts entre mesures du premier ordre et du second ordre pour tous les segments.

Pour les 78 segments composant le réseau, l'écart moyen (tableau 3) est de 37 microGal. Si l'on excepte les 5 segments anormaux qui seront repris en 1984, l'écart moyen n'est plus que de 30 microGal.

Si l'on considère que la précision sur le réseau de premier ordre est de 17 microGal, la précision estimée du réseau de second ordre sera dans le premier cas de 41 microGal et dans le second de 34 microGal.

5. RESEAUX DE TROISIEME ET QUATRIEME ORDRES

Il s'agit des anciens réseaux B.R.G.M. et C.G.G. calculés dans des systèmes gravimétriques variables.

Le réseau de troisième ordre comporte 1800 stations B.R.G.M. ou C.G.G. déjà calculées dans le système de la carte gravimétrique de la France (C.g.F.) et contrôlées.

Le réseau de quatrième ordre comporte 1080 stations d'origines diverses, calculées dans des systèmes divers et dont les formules de conversion restent parfois à définir. Pour des raisons de commodité ces stations seront d'abord converties individuellement dans le système C.g.F. avant d'être reconverties en bloc dans le système RGF 83.

Les travaux d'établissement de ces deux réseaux sont en cours et devraient être achevés courant 1984.

6. BASES D'ETALONNAGE

Douze bases d'étalonnage ont été implantés en 1982 et 1983. Ces bases sont destinées à étalonner les appareils relatifs type WORDEN ou autres, Lacoste et Romberg modèle D et contrôler périodiquement les modèles G.

Ces bases sont toutes matérialisées par une plaque de fonte portant l'indication :

BNM-BRGM
Réseau gravimétrique
Base d'étalonnage

Les mesures ont été réalisées en plusieurs campagnes à l'aide d'un gravimètre (G 558 mai-juin 1983) de deux (G 225 et G 588 septembre 1982) ou de quatre gravimètres (G 126, G 140, G 225 et G 588 octobre-décembre 1982).

Les travaux ont comporté l'implantation de douze bases d'étalonnage (23 stations) représentant 245 liaisons (353 mesures).

Les mesures ont été réalisées par une série d'aller-retour successifs (jusqu'à 19) entre les deux stations avec selon les cas 1, 2, 3, ou 4 gravimètres.

* Résultats

Les bases ont été réparties sur l'ensemble du territoire de façon à permettre un accès rapide à tout un chacun :

Alpes : GRASSE-ST VALLIER
LE BOURGET-MONT DU CHAT

Centre : AUBUSSON-LETRADE
VALENCAY-BAUDRES

Massif Central : TARARE-VIOLAY
PUY DE DOMES-ORCINES
CLERMONT-ORCINES
MILLAU-ENGAYRESQUE

Ouest : LA BOISSIERE-ROCHESERVIERE

Paris : MARLY-CROISSY

Pyrénées : GAN-BEL AIR (Pau)

Vosges : BALLON D'ALSACE-LEPUY GY

Le tableau 7 en annexe donne les principaux résultats avec successivement pour chaque station :

- la localisation ;
- la longueur ;
- nombre de liaisons effectivement utilisées dans les calculs
- le Δg moyen entre les deux stations ;
- l'écart quadratique moyen (sigma) ;
- l'erreur relative.

Ces nouvelles bases d'étalonnage permettent désormais de calibrer les gravimètres avec un précision d'autant plus grande que le Δg de la base utilisée sera élevé. A cet égard les meilleurs résultats seront obtenus entre LE BOURGET et le MONT DU CHAT (273 mGal) ou CLERMONT FERRAND et le PUY DE DOME (230 mGal). Inversement la base de MARLY-CROISSY eu égard à son faible Δg (28 mGal) doit être réservée au gravimètres utilisés en microgravimétrie.

7. STATIONS PORTUAIRES

Nous ne reviendrons pas sur ce réseau dont les résultats ont déjà été publiés dans le catalogue des bases portuaires européennes. Nous présenterons simplement en annexe (tableau 8) les résultats de ces stations calées cette fois-ci sur les mesures absolues réalisées en 1983 et sur IGSN 71.

En complément à ces 15 nouvelles stations, nous avons ajouté 5 anciennes stations S.H.O.M. (Calais, Bordeaux, Arcachon, Dieppe et St Malo) non matérialisées mais qui permettent d'effectuer dès calages (moins précis) dans des ports non couverts par notre réseau.

A noter enfin que la station de Nice présente une valeur différente de la valeur publiée ; ce n'est pas une erreur, la station ayant dû être déplacée en 1983.

8. STATIONS INTERNATIONALES ET AEROPORTUAIRES

Onze stations internationales ainsi que 4 stations aéroportuaires ont été créées ou intégrées dans notre nouveau réseau afin de permettre le calage sur les différents réseaux européens et le réseau international unifié.

En outre, les résultats de notre campagne internationale 1978 sur diverses stations absolues et IGSN 71 en Europe ont été intégrés afin de pouvoir effectuer les calages IGSN 71-RGF 83 (cf. communication à la section IGSN 71).

9. CONCLUSIONS

Les travaux que nous venons de présenter ont permis de doter la France d'un nouveau réseau de bases gravimétriques de précision homogène et couvrant l'ensemble du territoire.

Ce réseau toujours menacé de destruction sera désormais contrôlé périodiquement au niveau des stations absolues, d'étalonnage, de premier et second ordre afin de restaurer au fur et à mesure les bases détruites.

L'e.q.m. global pour ces divers réseaux est de :

- 5 microGal pour les 6 stations absolues ;
- 17 microGal pour les 52 stations de premier ordre ;
- 34 microGal pour les 280 stations de deuxième ordre ;
- sup. à 100 microGal pour les 2880 stations de troisième ordre et quatrième ordre ;
- 124 microGal pour les 15 stations portuaires nouvelles ;
- 16 microGal pour les 7 nouvelles stations internationales ;
- 17 microGal pour les 12 bases d'étalonnage.

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TABLEAU 1

Ecarts entre valeurs absolues et valeurs Lacoste et Romberg brutes moyennes.

Stations	g absolu	Δg absolu	Δg L & R	Ecarts
SEVRES A (Aller)	980.925,946			
		- 107,122	- 106,990	+ 0,132
ORLEANS	818,824			
		- 391,145	- 391,093	+ 0,052
TOULOUSE	427,679			
		+ 28,412	+ 28,495	+ 0,08
MARSEILLE	456,091			
		+ 289,576	+ 289,368	- 0,203
DIJON	745,667			
		+ 100,069	+ 100,082	+ 0,013
NANCY	845,736			
		+ 80,212	+ 80,120	- 0,092
SEVRES A (Retour)	925,948			
ORLEANS	818,824			
		- 73,157	- 73,193	- 0,036
DIJON	745,667			

TABLEAU 2

Réseau de premier ordre : écarts à la fermeture des mailles.

Maille	Localisation	Ecarts à la fermeture (en 10^{-7} m/s/s)
1	Flandres	0
2	Basse Normandie	0,6
3	Aisne	0
4	Ardennes	0
5	Cotentin	0
6	Haute Normandie	0
7	Brie	0,4
8	Champagne	0
9	Alsace-Lorraine	- 1,4
10	Bretagne	0
11	Maine	0
12	Tourraine	- 0,5
13	Orléannais	0
14	Bourgogne	1,6
15	Franche Comté	- 0,4
16	Vendée	0,5
17	Poitou	0
18	Manche	0
19	Bourbonnais	0
20	Bresse	0
21	Charente Maritime	0
22	Charente	0
23	Bordelais	0
24	Périgord	0
25	Limousin	0
26	Auvergne	0
27	Rhône Alpes	0
28	Landes	0
29	Aquitaine	0,5
30	Languedoc	- 0,2
31	Gard	0,4
32	Provence	0

Moyenne : $0,2.10^{-7}$ m/s/s

TABLEAU 3

Comparaison des cheminements.

Cheminements	$\Sigma\ \Delta g$ (en 10^{-7} m/s/s)	Ecarts (en 10^{-7} m/s/s)
Nancy-Belfort-Sisteron-Marseille	389,557	- 0,9
Nancy-Langres-Arles-Marseille	389,539	+ 0,9
Nancy-La Capelle-Vias-Marseille	389,559	- 1,1
Nancy-Arrras-Toulouse-Marseille	389,557	- 0,9
Nancy-Montreuil-Tarbes-Marseille	389,551	- 0,3
Nancy-Dinan-Bayonne-Marseille	389,556	- 0,8
Nancy-St Brieuc-Auray-Bayonne-Marseille	389,556	- 0,8

TABLEAU 4

e.q.m. individuels (en 10^{-8} m/s/s).

Theillay	15	Chateau Lavallière	17
Argenton	11	La Roche sur Yon	22
Clermont	15	Pont St Esprit	21
Nevers	21	Champagnole	22
Limoges	26	La Capelle en T.	15
Lyon	21	La Canourgue	8
Chambéry	25	Tarbes	7
Sisteron	17	Bayonne	17
Nantes	13	Bordeaux	11
Beaune	10	Marmande	20
Sophia	18	Cahors	6
Arles	25	Saintes	9
Tournus	18	Angoulême	21
Belfort	20	Lusignan	6
Allain	10	Auray	7
Langres	21	St Brieuc	8
Troyes	8	Dinan	3
Ablis	8	Rennes	14
Senlis	9	Pontaubault	3
Reims	10	Alençon	21
Chalons	10	Pont L'Evêque	1
Arras	11	Yvetot	34
Agde	10	Montreuil	2
Lille	5		

TABLEAU 5

Calcul de l'écart quadratique moyen global.

Boucle de calcul	Nbre de stations	Σe^2	Σn	σ individuels (en 10^{-7} m/s/s)
F2	5	13.387	46	0,017
F3	3	4.608	10	0,021
F4	4	8.256	19	0,021
F6	2	5.216	12	0,021
F7	2	3.563	15	0,015
F8	1	113	2	0,008
F9	6	3.183	27	0,011
F10	2	541	7	0,009
F11	5	4.399	24	0,014
F12	3	2.033	10	0,014
F13	3	6.874	22	0,018
F14	6	3.253	19	0,013
F15	4	7.015	15	0,022
F16	1	423	4	0,010
TOTAL	47	62.864	231	

$$\text{e.q.m. global} = \sqrt{\frac{\Sigma_t\, e^2}{\Sigma_t\, n}}$$

e.q.m. global = $0{,}016.10^{-5}$ m/s/s

TABLEAU 6

Calage second ordre-premier ordre.

Segments	Δg 2ème ordre	Δg 1er ordre	Ecarts 10^{-7} m/s/s	Répartition 10^{-7} m/s/s
1	63,597	63,591	0,6	0,3
2	- 29,828	- 29,748	8	1,6
3	- 33,857	- 33,845	1,2	0,4
4	- 95,767	- 95,847	8	2,0
5	- 31,005	- 30,993	1,2	0,2
6				
7	- 23,182	- 23,221	3,9	1,0
8	76,402	76,427	2,5	0,6
9	39,783	39,790	0,7	0,2
10	- 84,704	- 84,627	7,7	1,9
11	165,988	165,797	0,9	0,1
12	- 63,909	- 63,913	0,4	0,1
13	- 63,552	- 63,582	3,0	0,7
14	127,446	127,495	4,9	1,2
15	3,547	3,504	4,3	0,9
16	87,770	87,815	4,5	2,3
17	5,168	5,183	1,5	0,8
18	- 2,264	- 2,186	7,8	1,3
19	66,782	66,779	0,3	0,1
20	- 94,098	- 98,031	6,7	1,3
21	76,221	76,184	3,7	1,2
22	- 11,321	- 11,268	5,3	1,1
23	82,500	82,527	2,7	0,3
24	4,910	4,925	1,5	1,5
25	- 63,420	- 63,409	1,1	0,1
26	63,405	63,409	0,4	0,1
27	- 75,231	- 75,221	1,0	0,3
28	122,009	122,030	2,2	0,4
29	16,621	16,600	2,1	1,0
30	31,191	31,225	3,4	0,7
31	51,608	51,620	1,2	0,2
32	- 24,395	- 24,397	0,2	0,1
33	- 32,727	- 32,640	8,7	2,2
34	87,814	87,764	5,0	1,7
35	- 46,167	- 46,175	0,8	0,3
36	131,746	131,753	0,7	0,1
37	- 8,858	- 8,881	2,3	0,5
38	46,588	46,587	0,1	0,0
39	- 92,151	- 42,115	3,6	1,8
40	127,472	127,450	2,2	0,7
41	- 36,539	- 36,569	3,0	1,5
42	- 46,795	- 46,792	0,3	0,1
43	114,454	114,586	13,2	2,2
44	27,268	27,299	3,1	0,1
45	54,657	54,647	1,0	0,3
46	- 123,497	- 123,495	0,2	0,0
47	- 36,519	- 36,519	0	0,0
48	168,637	168,486	15,1	2,5
49	57,631	57,619	1,2	0,2

TABLEAU 6 (suite)

Segments	Δg 2ème ordre	Δg 1er ordre	Ecarts 10^{-7} m/s/s	Répartition 10^{-7} m/s/s
50	101,936	101,986	5,0	1,7
51	- 97,886	- 97,998	11,2	5,6
52	107,727	107,869	14,2	2,8
53	- 78,505	- 78,479	2,6	0,4
54	- 12,340	- 12,383	0,3	1,4
55	44,042	44,070	2,8	0,7
56	- 52,220	- 52,126	9,4	2,4
57	- 102,795	- 102,798	0,3	0,1
58	- 22,865	- 22,866	0,1	0,0
59	113,313	113,280	3,3	0,6
60	- 6,792	- 6,733	0,1	0,0
61	67,828	67,887	5,9	1,0
62	- 118,778	- 118,618	16,0	2,0
63	149,998	149,986	1,2	0,2
64	102,949	102,860	8,9	1,3
65	104,726	104,745	1,9	0,4
66	- 154,001	- 154,038	3,7	0,7
67	180,810	160,785	2,5	0,4
68	- 105,271	- 105,297	2,6	0,7
69	- 113,436	- 113,410	2,6	0,4
70	195,816	195,841	2,5	0,5
71	80,788	80,733	5,5	0,7
72	108,622	108,658	3,6	0,5
73	41,526	41,608	8,2	1,4
74	- 51,581	- 51,568	1,3	0,3
75	37,399	37,406	0,7	0,1
76	13,885	13,886	0,1	0,0
77	- 36,627	- 36,682	5,5	0,6
78	- 103,557	- 103,470	8,7	1,2

TABLEAU 7

Bases d'étalonnage : Tableau récapitulatif

Nom de la base d'étalonnage	Localisation	Longueur (en km)	Liaisons utiles	Δg moyen 10^{-5} m/s/s	Sigma 10^{-8} m/s/s	Erreur relative %
AUBUSSON	Creuse	32	16	80,937	23	0,03
PAU	Pyrénées Atlantiques	11	15	50,625	14	0,03
BALLON D'ALSACE	Territoire de Belfort	14	14	131,642	27	0,02
GRASSE	Alpes Maritimes	14	11	103,699	33	0,03
LA ROCHE S/YON	Vendée	45	24	76,001	15	0,02
CHAMBERY	Savoie	14	12	273,025	35	0,01
MILLAU	Aveyron	23	23	80,451	14	0,02
PUY DE DOME	Puy de Dôme	8	16	154,408	11	0,01
TARARE	Rhône	11	11	98,288	13	0,01
CLERMONT FERRAND	Puy de Dôme	7	16	76,028	8	0,01
VALENCAY	Indre	12	13	42,707	7	0,02
MARLY	Yvelines	5	12	27,972	8	0,03

TABLEAU 8

Stations portuaires : Tableau récapitulatif

Bases	g(CGF)	g(IGSN 71)	g(RGF 83)	e_T	N°
Dunkerque	981.164,97	981.150,79	981.150,651	0,15	4211
Boulogne	981.136,74	981,122,53	981,122,446	0,18	4212
Le Havre	981.026,85	981.012,51	981.012,448	0,16	4213
Cherbourg	981.043,28	981.028,95	981.028,888	0,15	4214
Brest	980.954,12	980.939,69	980.939,711	0,17	4215
Lorient	980.872,37	980.857,84	980.857,856	0,12	4216
St Nazaire	980.846,12	980.831,56	980.831,579	0,15	4217
La Pallice	980.735,83	980.721,13	980.721,137	0,14	4218
Le Verdon	980.662,28	980.647,50	980.647,493	0,12	4219
Bayonne	980.476,36	980.461,35	980.461,327	0,13	4220
Port Vendres	980.442,62	980.427,58	980.427,580	0,1	4221
Sète	980.510,62	980.495,65	980.495,681	0,07	4222
Marseille	980.497,84	980.482,86	980.482,737	0,08	4223
Toulon	980.494,31	980.479,32	980.479,284	0,07	4224
Nice	980.526,23	980.511,399	980.511,179	0,07	4225
Stations S.H.O.M. réoccupables (non matérialisées)					
Calais	981.143,94	981.129,74	981.129,651	0,23	1622 B
Bordeaux I	980.585,44	980.570,56	980.570,569	0,12	1439 C
Bordeaux II	980.585,79	980.571,05	980.569,998	0,12	1439 D
Arcachon	980.588,81	980.573,94	980.573,930	0,17	1511
Dieppe	981.065,07	981.050,77	981.050,708	0,17	1619 B
St Malo	980.956,78	980.942,35	980.942,370	0,19	999 B

TABLEAU 9

Résultats calculs premier ordre.

Stations	Nom	Valeur de g
F1	ABLIS	980.870,637
F2	ALLAIN (Colombey)	980.854,958
F3	ARCONNAY (Alençon)	980.871,417
F4	ARGENTON	980.717,224
F5	BAILLEUL (Arras)	981.055,030
F6	BANASSAC (La Canourgue)	980.412,951
F7	BEAUNE	980.726,009
F8	BEAUNE LES MINES (Limoges)	980.603,719
F9	BONO (Auray)	980.857,917
F10	BOUCAU (Bayonne)	980.464,702
F11	BREVIANDES (Troyes)	980.868,130
F12	CAPELLE EN T.	981.011,068
F13	CHALLUY (Nevers)	980.736,146
F14	CHAMBERY	980.513,744
F15	CHAMPAGNOLE	980.635,016
F16	CHATEAU LAVALLIERE	980.819,046
F17	CLERMONT FERRAND	980.556,962
F17	CLOUZEAUX (La Roche s/Yon)	980.736,326
F18	FAGNIERES (Châlons sur Marne)	980.934,257
F19	FONCOUVERTE (Saintes)	980.665,392
F20	LALOUBERE (Tarbes)	980.334,478
F21	LANGRES	980.773,894
F22	LANVALLEY (Dinan)	980.905,846
F23	LUSIGNAN	980.700,436
F24	MERCUES (Cahors)	980.534,014
F25	MONTREUIL SUR MER	981.094,514
F26	NANTES	980.798,628
F27	NEUVILLE S/S (Lyon)	980.641,190
F28	OFFEMONT (Belfort)	980.767,096
F29	PONTAUBAULT	980.940,979
F30	PONT L'EVEQUE	980.995,181
F31	PONT ST ESPRIT	980.520,521
F32	ST MARTIN (Arles)	980.501,437
F33	ST BAUZEILLE (Marmande)	980.544,433
F34	STE MARIE DES CHAMPS (Yvetot)	980.989,582
F35	SENLIS	980.959,666
F36	SISTERON	980.366,527
F37	SOYAUX (Angoulême)	980.635,616
F38	THEILLAY (Vierzon)	980.782,412
F39	TOURNUS	980.703,985
F40	TREGUEUX (St Brieuc)	980.919,130
F41	VALBONNE (Sophia)	980.472,260
F42	VIAS (Agde)	980.465,208
F43	CLERMONT FERRAND	980.556,962
F44	DIJON	980.745,193

Figure 1 - Localisation des stations absolues

TABLEAU 9 (suite)

Stations	Nom	Valeur de g
F45	LEZENNES (Lille)	981.114,532
F46	LUMIGNY (Marseille)	980.455,617
F47	ORLEANS (Ø2)	980.817,446
F48	REIMS (Université)	980.949,202
F49	RENNES	980.894,945
F50	TALENCE (Bordeaux)	980.565,935
F51	TOULOUSE	980.427,961
F52	VENDEUVRES (Nancy)	980.845,172

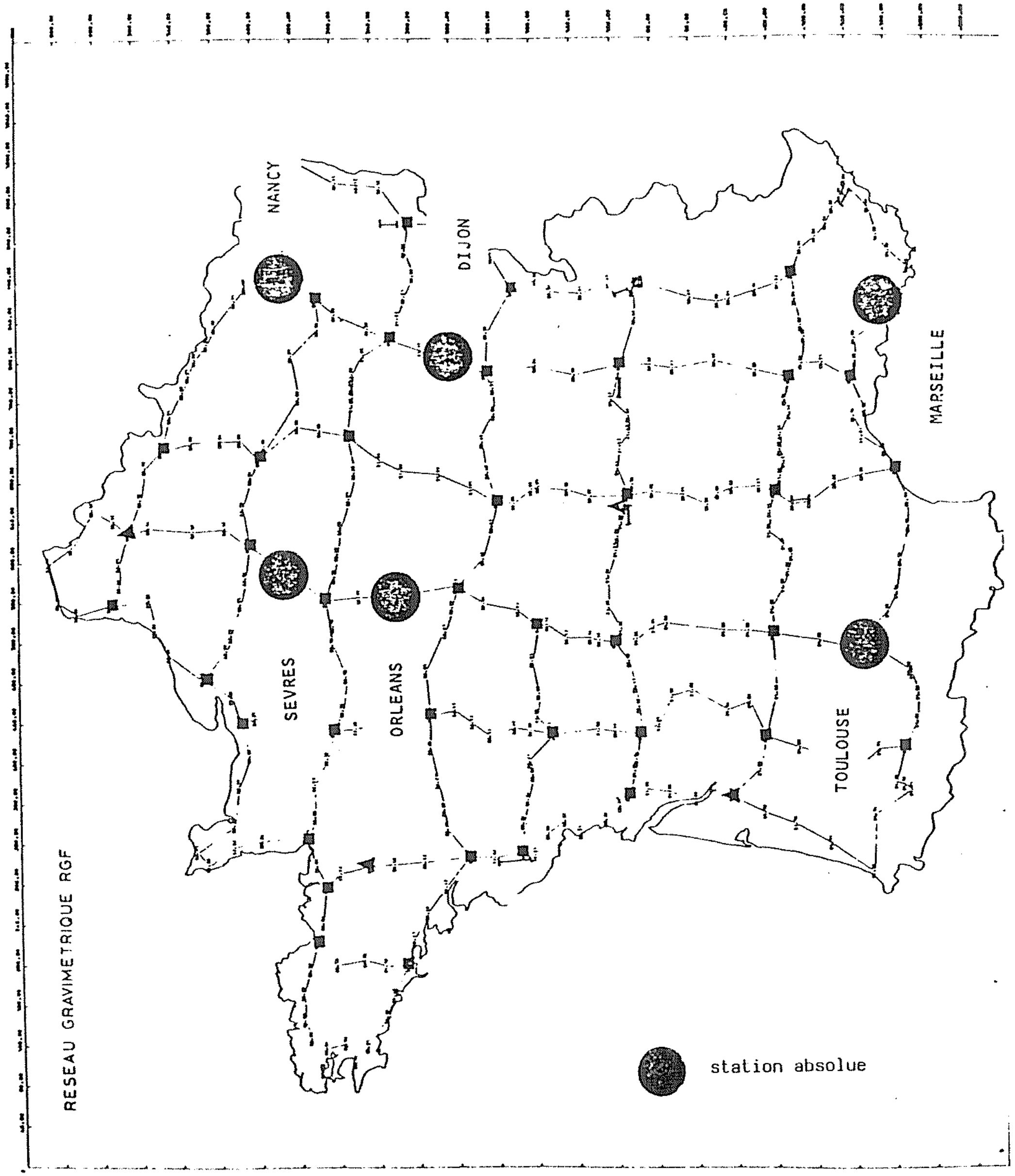
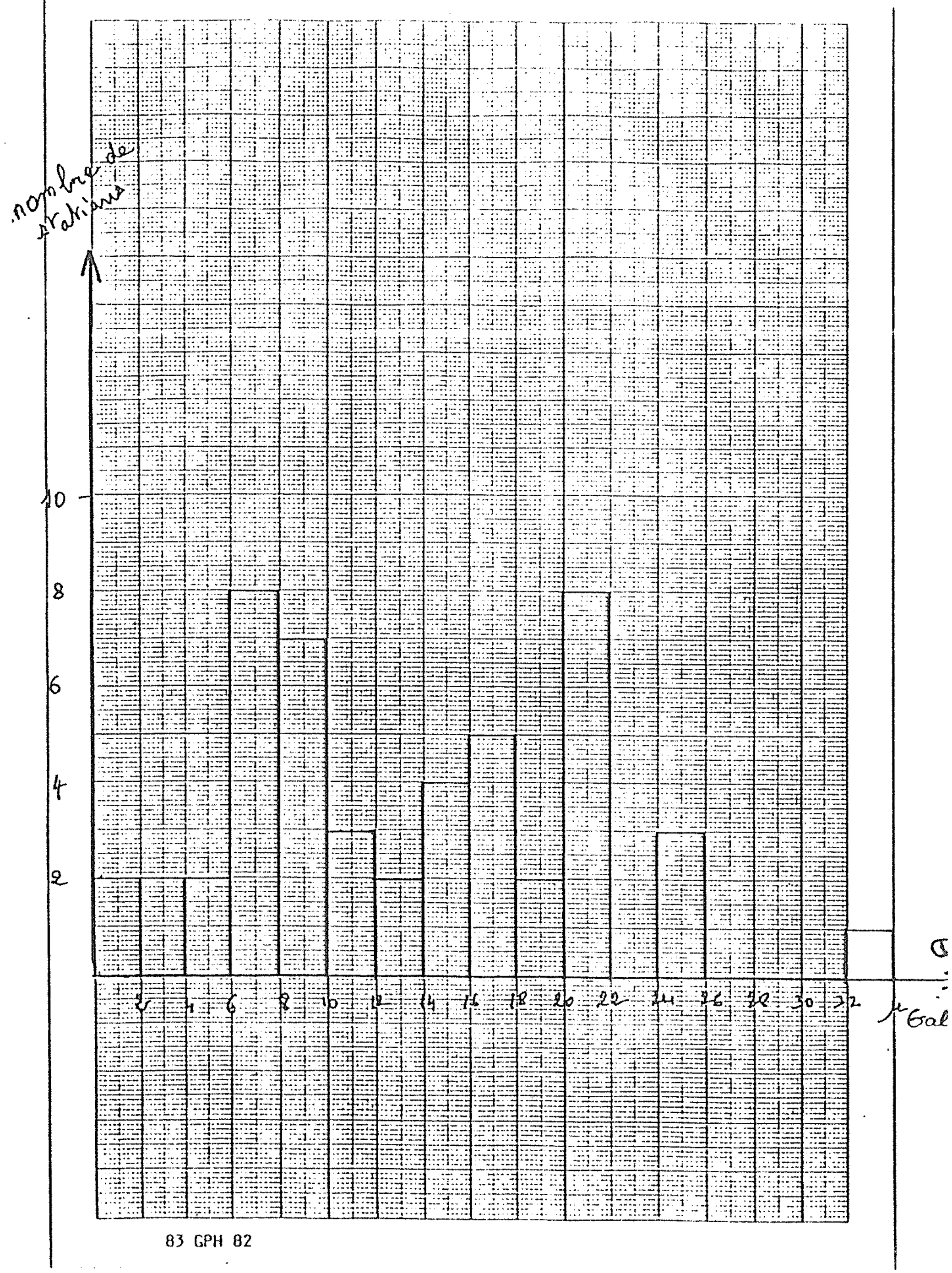


Figure 2 - Précision du réseau de 1er ordre



GRAVITY EMPIRICAL COVARIANCE VALUES FOR THE CONTINENTAL UNITED STATES

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Abstract.

Gravity signal zero-lag covariances (variances) and correlation distances have been determined for the continental United States. Using the techniques of least-squares collocation, 544,000 terrain-corrected Bouguer anomalies from the U.S. National Geodetic Survey Gravity Data Base were fitted with local first-degree polynomial surfaces over 30' x 30' areas. The number of gravity observations used to derive a surface varied from a very few (in areas of little gravity variation) to 188. Correlation distance was found to be correlated with the amount of topographic variability. Large zero-lag covariances are associated with the mid-continental gravity high and the land-water interface on the Pacific Coast.

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Hamburg, 11 - 13 Aug. 1983.

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The Austrian Gravity Base Net

Abstract

Beginning with absolute gravity measurements in 1980 a new base net of Austria was started. The new base net consists of 4 stations 0. order (absolute stations), 20 stations 1. order and about 200 stations 2. order. The first order stations are generally measured with two LCR-D gravity meters in the system ABCABC. The first order measurements were finished in June 1983. In connection a network adjustment will be computed. The second order will be finished 1985.

Introduction

In the period 1960-1970 a gravity base net was made by E.Senftl, BEV (1)(2). This net was connected to the European Calibration Line (ECL), system Marzahn 1963 (3). The measurements were done with the gravity meter Worden Master 500. In cause of the growing traffic and the following road-making many of these stations got lost or got unusable. The number of gravity measurements and the required accuracy grew up in the next years and so it got necessary to make a new base net.
In 1980 at 4 stations absolute gravity measurements were done with the absolute gravity meter of the Instituto di Metrologia of Turin. The accuracy of the results is specified about 12 μgals. The absolute stations are saved with excentres.
In table 1 you can see the selected points.On the base of these stations the establishment of the new base net was initiated.

Selection of stations

Austria should be covered uniform with base points. For reason of the topographic and of the possibility of point arrival 224 stations were projected (table 2).

Number	name	regional character	geology	remarks	excentres
0-01	Graz	eastern-alp -rim	elder paleozoic		8
0-02	Altenburg	outer alpic	bohemian mass	very stable	4
0-03	Kremsmünster	foreland of alps	molasse		4
0-04	Penk im Mölltal	inner alpic	schist	maximum of recent movement	6

table 1 absolute stations in Austria

orders	number of stations	area/point km^2	mean distance km
0.	4	21000	145
0.+1.	24	3500	59
0.+1.+2.	224	375	19

table 2 distribution of the base net stations

The stations were selected on basis of the project under the following criterions:

- local geologic stability
- rigid underground (stone or concrete)
- durability of station (in consideration of mass variation in surroundings)
- usable acess road and public approach
- microseismic influence (because of technical trouble)
- application of available survay points of precise levelling or the expenditure of new levelling

At the moment all stations of the 1.order are fixed. They are mostly under jutting roofs or in open halls.
In the second order 95 points are fixed.

Measurements

In June 1983 the first measurement of the 1.order was finished. The first order is connected to the 4 Austrian absolute stations and to the absolute stations Munich and Chur and to the 1.order point Bad Reichenhall of the German gravity base net (DSGN) too. In principle all connections were measured with two LCR - D gravity meters (LCR-D9 of the Inst.f.Met.and Geophysics, university of Vienna and LCR-D51 of the Bundesamt für Eich- und Vermessungs=wesen in Vienna). During each measuring cycle each station were measured twice at least. To define the instrument drift the points were reached in the succession A-B-C-A-B-C. Therefore it was the optimum to measure 3 or 4 stations aday in triangle or quadrangle. The limits of course were set by the large distances, which amounts a medium range of 77km between two stations. If it was necessary or possible second order points were measured as drift points.

In the 2.order till now 89 points are connected with the 1.order. The measurements were obtained with the LCR-D51 gravity meter. A part of the stations are measured with two meters. The net of the 2.order will be finished 1985.

The scale factors of the used meters were determined between the absolute stations Altenburg and Kremsmünster. To consider the scale factors two new calibration lines were installed and connected with the first order base net.

a) The Vienna calibration line (Wiener Eich-Linie = WEL) was made previously 1976 (4) and now splitted with three intermediate points. The whole line has a gravity difference of 41 mgals. It is used to find out the non linear scale function (5).

b) The Hochkar Calibration Line (HCL) was installed 1982. It has a distance of 20km with an altitude difference of 970m. The gravity difference amounts 198mgals. The HCL is used to control the temporal behaviour of the scale factors.

The Austrian part of the European Calibration Line (ECL) between Kufstein and Brenner is not used any more to determine the calibration function of gravity meters.

Evaluation

A whole network adjustment of observation equations is projected. In moment a specially computer program is not available. To find out greater errors only a tentative net computation was made with fixed 0.order.

The maximum station error is 25 μgals, but there are differences of untill 100 μgals observed between the two gravity meters. There is also a difference of 140 μgals between the absolute difference value Kremsmünster and Munich and the observed difference. The cause of these problems must still be find out.

Comparison with the old base points

Some of the old bases coulb be taken over into the new net, to some other old bases connection measurements were made. It is known that the ECL values in system Marzahn 1963 have a difference of about 15 mgals to the absolute system. These differences could be found in the region of the ECL. To the east the differences grow. The reason is probably the relative inexact measurements with the Worden gravimeter.

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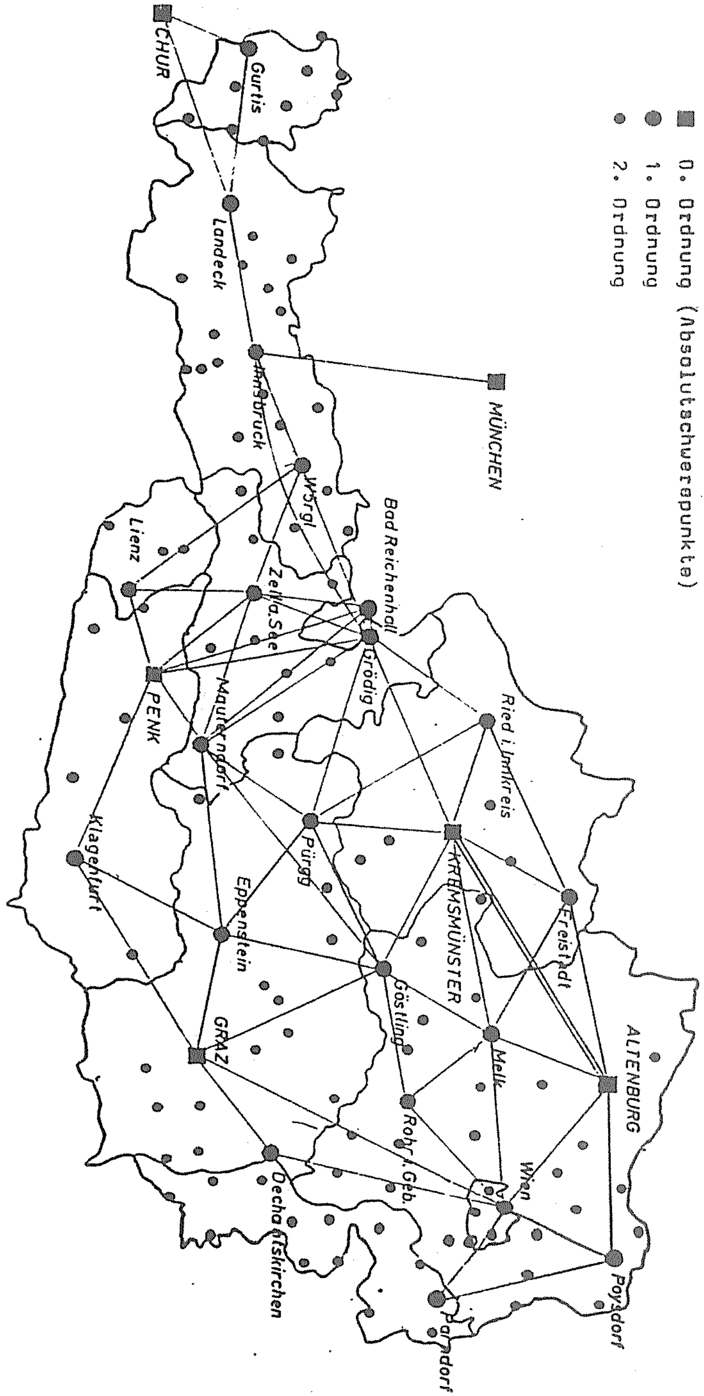
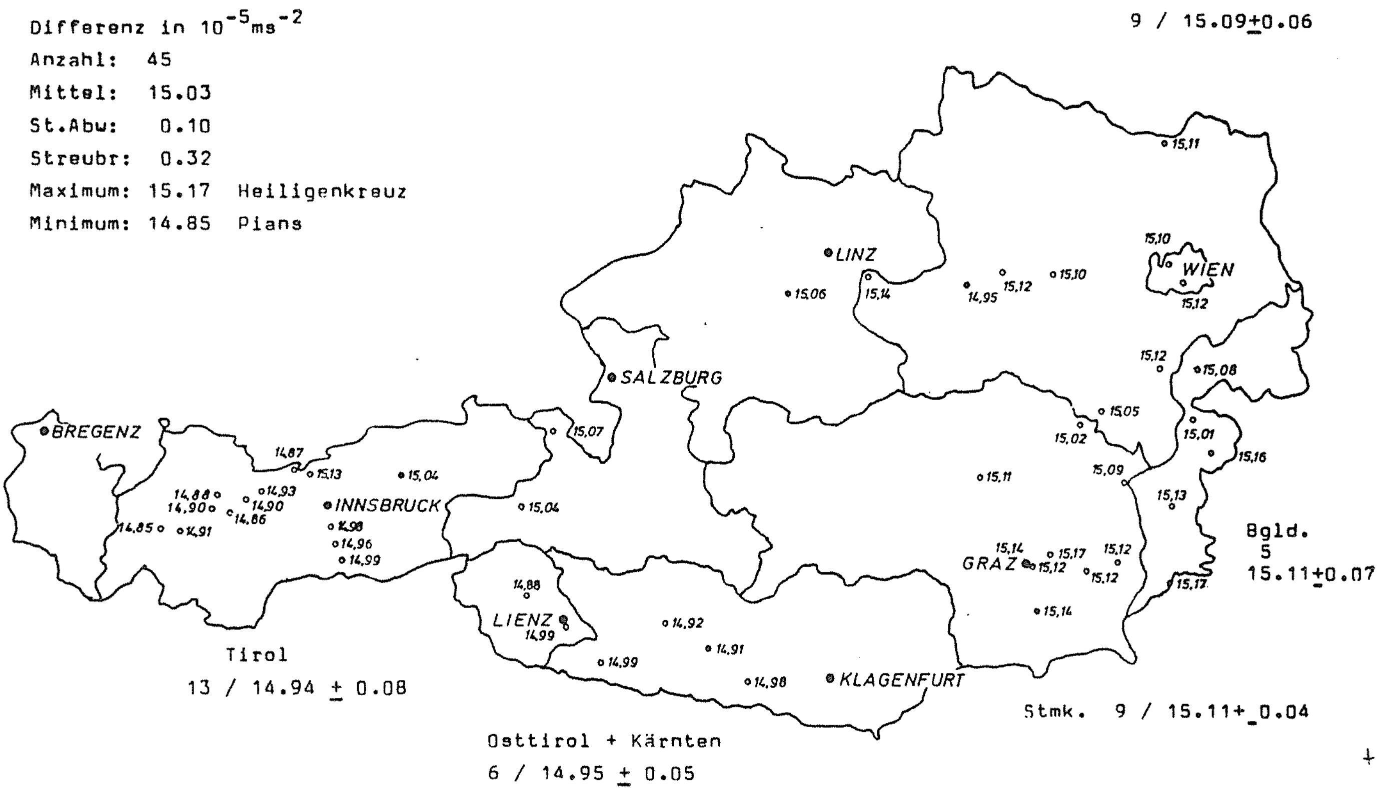
Österreichisches Schweregrundnetz
Punktübersicht (Stand: 1983 06 27)

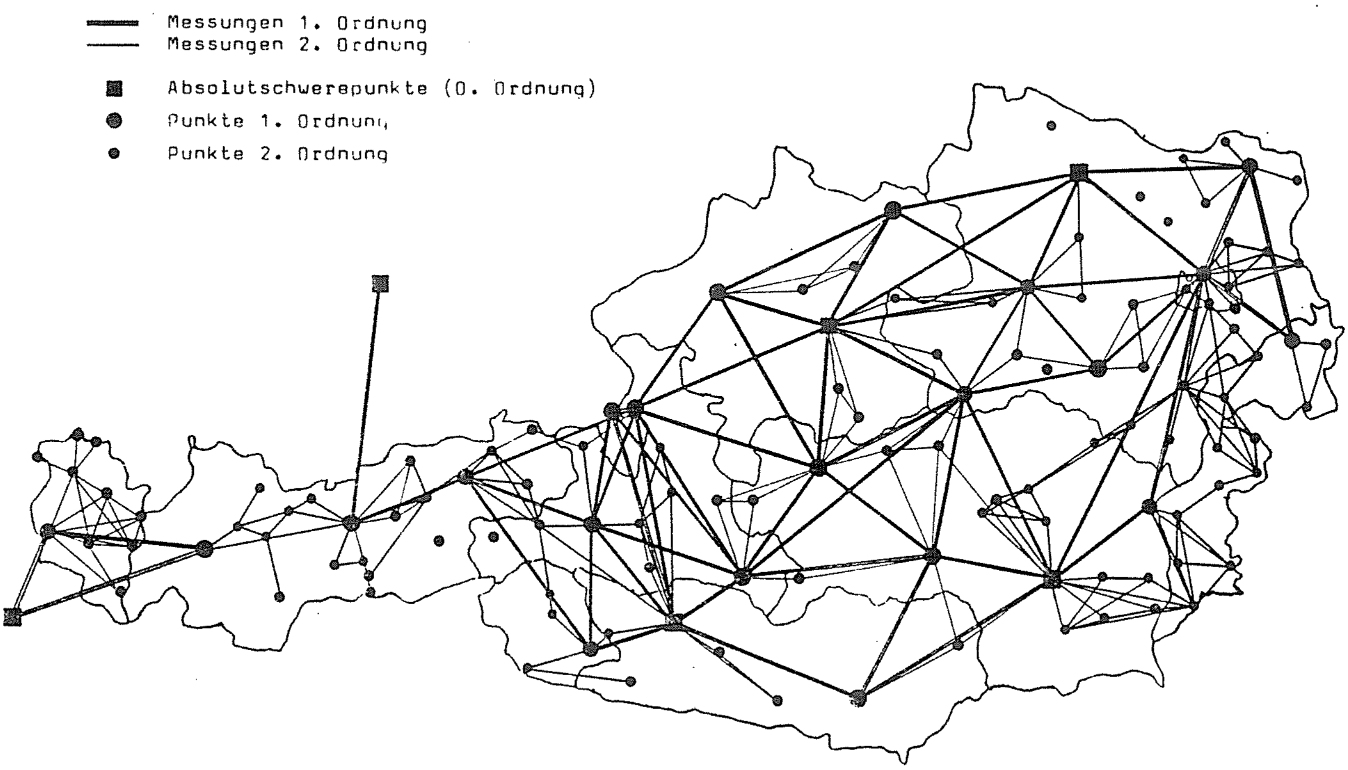
■ 0. Ordnung (Absolutschwerepunkte)
● 1. Ordnung
• 2. Ordnung



Vergleich ÖSGN $g_{alt} - g_{neu}$



Österreichisches Schweregrundnetz (Stand: 1983 06 27)



A New Precise Gravity Network - Activities of the Landsurveying Authorities in Hannover

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Abstract

The land surveying authorities of the Federal Republic of Germany have established a first order gravity network. The paper describes the north western part of this network and the adjustment. A free net adjustment gave a r.m.s.e. for the gravity differences of $2 \ldots 5 \cdot 10^{-8}$ ms^{-2}. An adapted adjustment in which seven points of the new gravity base net 1976 were held fixed gave similar results.

1. Introduction

In the Federal Republic of Germany, a new precise gravity network has been established in 1976 on behalf of the German Geodetic Commission by the German Geodetic Research Institute because the older one - the German Gravity Net 1962 - was no longer suitable to serve as a gravity base net. The latter was characterisied by a large systematic error, by a precision, which is too low for modern requirements, and by the circumstance that more than 30 % of the gravity stations were lost.
A special cause to call for increased requirements for a gravity base net in Germany was the intention of the land surveying authorities to establish precise gravity networks in three densification steps:

1st. order network	with	30 km	average station separation
2nd. order network	with	10 km	average station separation
3rd. order network	with	1 point/5km²	

But the last step of densification will only be executed along the main levelling lines for geodetic purpose in the next future.
This paper deals with the part of the first order gravity net, which has been established by the land surveying office of Lower Saxony, one of the ten states of the Federal Republic of Germany, situated south of Hamburg.

2. Description of Network and Observations

This net is a part of the whole German first order gravity net. Some of the requirements for this are as follows:

- Benchmarks of the established trigonometric or geodetic levelling networks are to be used. (The advantage of this agreement is, that the coordinates of these points are already known and that the gravity net will participate in the periodical control of the stations, which is carried out by the local cadastral authorities.)
- The precision has to be not less than that of the base network. (Because of the increased interest in detecting secular gravity changes, the network should have highest precision. In this case it would be very suitable for this purpose because of the well known long lived existance of official geodetic networks.)

- Homogenity is desired in the accuracy of observations as well as of the results, the gravity values. (In the two densification steps easy stochastic models are preferred for the fixpoints in the further adjustment steps.)

The Lower Saxony part of this network is shown in Figure 1. There are 68 stations. At two of them absolute gravity measurements were carried out by the Metrological Institute of Turin with an accuracy of ± 8 ugal. The method of sequential optimisation for the optimal design with the target function of 'minimizing the average point error and the space of time' is used (WENZEL 1977). For every station there are four connections to the neighboured points.
The observations were carried out with four LCR gravity meters (D - 23, G - 79, D - 14, G - 432) in two observation periods. In every period, two gravity meters are used and every connection is measured twice independently with both instruments in the following well known manner: A - B, B - A .

Tidal corrections have been computed from the Cartwright-Taylor-Edden tidal potential development (505 waves including Honkasalo term) - in agreement with the IAG resolution of the IUGG General Assembly at Canberra 1979. For the main tides real observed values were used. Also, the atmospheric correction and - if necessary - height corrections were incorporated.

3.1 Free Net Adjustment

We use the following functional model:

$$v_{i,i+1} = g_{i+1} - g_i - y \cdot l_{i,i+1} - D \cdot t_{i,i+1} - l_{i,i+1} \ / \ p_i, p_{i+1}$$

It can be seen that the g -model (DREWES 1978) is used. Because these are not the original observations, an algebraic correlation, has to be considered, which leads to a Q_{ll} matrix in which more than the main diagonal may be filled. Also there is one linear term for drift and one term for scale per observation period and gravity meter.

In the first step a separate adjustment for every instrument was carried out in order to get information about the a priori weights. In the next step we use the iterative method of Helmert to define the group weights with the following results:

Instrument	final weight	m_g (free net adjustment)
D - 23	p = 3.0	± 8.4 ugal
G - 79	p = 1.0	± 14.6 ugal
D - 14	p = 2.8	± 8.7 ugal
G - 432	p = 1.9	± 10.5 ugal

In a free net adjustment with all instruments, the root mean square error (r.m.s.e.) for one measured gravity difference should be larger than the corresponding values of the separate adjustment of the different instruments, because of the different scale behaviour. In our case however, there are no significant differences. This leads to the conclusion - as one result of the free net adjustment - that there are no large unlinearities in the scale function of the instruments used.
A statistical analysis of the residuals shows that there is no correlation with time. A good impression of the behaviour of the residuals is given by the computer graphic (Figure 2). The horizontal lines indicate the end of a day. Obviously, there is no trend an no signal. Thus, only one linear drift coefficient for the whole observation champagn and for each instrument can be introduced. Similar experiences - especially not so very successful attempts with prediction can be found in the literature (DREWES 1978).
A very satisfying result is the very high internal precision of this network, which is best characterized by the r.m.s.e. of gravity differences: They vary from ± 2.2 ugal for a directly measured connection of neighboured stations to ± 3 ugal for a not directly measured connection. The extreme values are ± 5 ugal for the largest connection in the north-south direction (280 km) and ± 3.8 ugal in the east-west direction (300 km).

The average r.m.s.e. of the point values is ± 2 ugal. But this value is not very helpful as in indicator.
Also it has to be stated, that this high precision is not an external accuracy because of remaining scale errors. Moreover there are certainly parts of a

quantity of a few ugal which are varying with time e.g. caused by different ground water levels. This occur especially in the flat region in the north western part of Germany over a long span of time.

3.2 Adapted Adjustment

An adapted adjustment was carried out, in which seven points of the German gravity base net are used as fixed points along with their related covariance matrix (BOEDECKER et al.1979). The results shows that these two observation groups are very compatible. The r.m.s.e. rises to $\pm$ 3 ugal for neighboured station differences, and to $\pm$ 8 ugal for the worst case. The residuals for these seven stations are in the range from -7 ugal to + 4 ugal. The average r.m.s.e. of the adjusted gravity values is $\pm$ 8 ugal.

As indicated before, ground water variations or uncontrollable instrumental effects may exceed this small number but there is hope that this first order net will be a good basis for subsequent networks and will fulfill the requirements for detection of secular variations of gravity.

4. References

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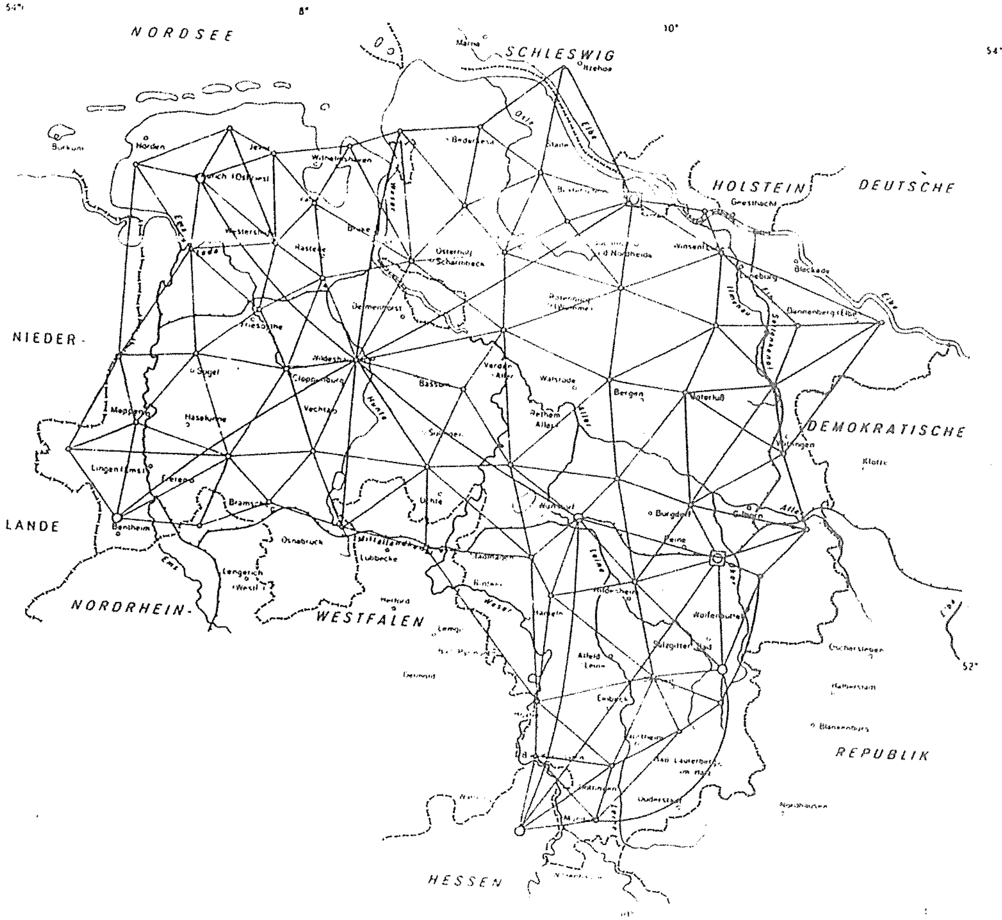

Figure 1. The Lower Saxony Part of the First Order Gravity Net of Germany

FEHLERGLEICHUNGEN UND RESIDUEN V

INSTR	STATION	DATUM	STUNDE	DELTA G	GEWICHT	V
1	36241	780502	8.18			
1	34222	780502	8.98	19.551	3.0	-0.011
1	34222	780502	9.26			
1	36241	780502	10.14	-19.550	3.0	0.013
1	36241	780502	10.29			
1	34252	780502	11.53	12.249	3.0	0.003
1	34252	780502	11.79			
1	36241	780502	12.69	-12.244	3.0	-0.005
1	36241	780502	12.89			
1	37231	780502	14.06	-73.029	3.0	0.007
1	37231	780502	14.44			
1	36241	780502	15.66	73.029	3.0	-0.004
1	34252	780503	7.84			
1	35282	780503	8.86	-5.143	3.0	-0.003
1	35282	780503	9.14			
1	34252	780503	10.13	5.146	3.0	0.006
1	34252	780503	10.41			
1	34222	780503	11.49	7.292	3.0	-0.002
1	34222	780503	11.76			
1	34252	780503	12.84	-7.292	3.0	0.005
1	34252	780503	13.11			
1	31251	780503	14.19	12.191	3.0	0.023
1	31251	780503	14.69			
1	34252	780503	15.74	-12.203	3.0	-0.007
1	38261	780508	8.91			
1	36241	780508	10.11	26.784	3.0	0.002
1	36241	780508	10.28			
1	38261	780508	11.38	-26.782	3.0	-0.001
1	38261	780508	11.66			
1	35282	780508	12.88	33.880	3.0	0.009
1	35282	780508	13.16			
1	38261	780508	14.28	-33.900	3.0	0.014
1	38261	780508	14.59			
1	34252	780508	15.61	39.038	3.0	-0.002
1	34252	780508	15.91			
1	38261	780508	16.96	-39.035	3.0	0.001
1	38231	780509	8.44			
1	36241	780509	9.49	29.522	3.0	-0.010
1	36241	780509	9.68			
1	38231	780509	10.76	-29.521	3.0	0.012
1	38231	780509	11.06			
1	38261	780509	12.03	2.724	3.0	0.001
1	38261	780509	12.33			
1	38231	780509	13.29	-2.734	3.0	0.009
1	38231	780509	13.66			
1	37231	780509	14.84	-43.509	3.0	-0.002
1	37231	780509	15.16			
1	38231	780509	16.29	43.520	3.0	-0.006
1	35282	780510	8.73			
1	37281	780510	9.54	-14.568	3.0	0.008
1	37281	780510	9.74			
1	35282	780510	10.41	14.543	3.0	-0.001
1	35282	780510	10.73			
1	33312	780510	11.96	13.098	3.0	0.007
1	33312	780510	12.23			
1	35282	780510	13.33	-13.098	3.0	-0.004
1	35282	780510	13.63			
1	31271	780510	14.89	18.812	3.0	0.009
1	31271	780510	15.18			
1	35282	780510	16.41	-18.819	3.0	0.001
1	34222	780511	8.78			
1	31251	780511	10.26	4.920	3.0	0.005
1	31251	780511	10.56			
1	34222	780511	11.93	-4.930	3.0	0.009

GRAFIK DER RESIDUEN (1 ZEICHEN ENTSPRICHT 0.002 MGAL)

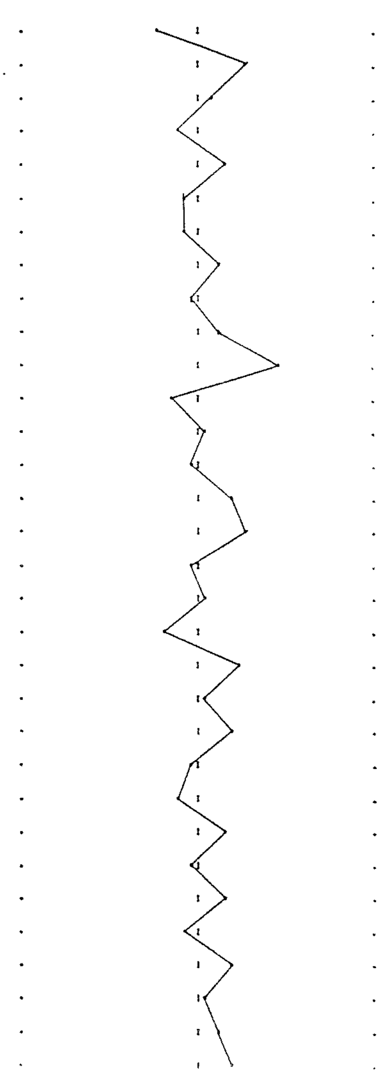

Figure 2.The behaviour of the Residuals of one Instrument During 9 Days in a Free Net Adjustment with all the 4 Instruments

Instrumental Investigations and Improvements of the Calibration Function of a LCR Gravimeter Model D

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For the purpose of high precision gravity measurements some instrumental improvements of a LCR-D gravimeter are made.

To avoid the influence of outer air temperature chances the D-meter is additionally protected by a thermostated aluminium case.

For instrumental checks and levelling of the meter electronic tiltmeter are installed besides more sensitiv spirit levels.

During the observation time the electronic readout of the meter is connected with a strip-recorder to study the behaviour of the gravimeter and the seismic noise at the station.

Besides these instrumental investigations the calibration function is checked. For the LCR gravimeter D-21 several periodic errors have been detected. The ampitudes are not negligible but fall in a range up to 3 µGal ($10^{-8}ms^{-2}$). With these periodic influences it is possible to reduce irregular differences observed during several measuring campaigns. The determined function is effective over the whole range of the measuring screw and can be used also in different reset positions.

Inertial Gravimetry

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Introduction

For about one decade inertial positioning instruments (Inertial Navigation Systems, INS) are at the disposal of surveyors and gained high reliability for operational fieldwork as also decimeter accuracy for coordinate determination. The measurement principle is based on the (double) integration of accelerations along three gyro controlled mutually perpendicular axes. The principle of equivalence of inertial and gravitational accelerations admits also the use of the accelerometers for the determination of the three components of the gravity vector, particularly when the instrument is at rest at the surface of the earth.

The paper deals with the basic equations of inertial positioning, different models for gravity (vector) anomaly recovery, hardware considerations and shows some numerical examples. The title of this paper should be read as "gravimetry with the aid of inertial surveying instruments".

1. Principles of Inertial Positioning and Operation

An inertial Measuring Unit (IMU) contains three accelerometers along three mutually perpendicular axes, which can be transported parallelly in inertial space under control of two (two-degrees-of-freedom) or three gyroscopes. Measuring a mixed signal of kinematic accelerations in inertial space plus gravitational accelerations, we are aiming at the transformation to a local cartesian coordinate system fixed on earth.

Starting (SCHWARZ 1979) from

$$r_i = R \cdot r_\ell , \tag{1}$$

- r_i position vector in inertial space
- r_ℓ position vector in local reference system with identical origin to r_i at some initial time
- R rotation matrix R^i_ℓ from local to inertial reference

the first and second derivatives with time read

$$\dot r_i = \dot R\, r_\ell + R\, \dot r_\ell , \tag{2}$$

$$\ddot r_i = \ddot R\, r_\ell + 2\dot R\, \dot r_\ell + R\ddot r_\ell \tag{3}$$

Taking into account, that

$$\dot R = R \cdot \Omega \tag{4}$$

$$\ddot R = R(\Omega\Omega + \dot\Omega) \tag{5}$$

Ω rotational velocity of local frame with respect to inertial space, i.e. earth`s rotation

we have from (3), (4), (5)

$$\ddot r_i = R(\ddot r_\ell + 2\Omega\dot r_\ell + (\Omega\Omega + \dot\Omega) r_\ell) \tag{6}$$

On the other hand, the inertial accelerations $\ddot r_\ell$ can be represented, by the specific force acting on the accelerometers of an IMU. Basically there are three different mechanizations of an IMU:

1. Space stable
$$\ddot r_i = f_i + R \cdot g'_\ell \tag{7a}$$
2. Local level
$$\ddot r_i = Rf_\ell + Rg'_\ell = R(f_\ell + g'_\ell) \tag{7b}$$
3. Strap down
$$\ddot r_i = R^i_v f_v + R^i_v R^v_\ell g'_\ell = R^i_v(f_v + R^v_\ell g'_\ell) \tag{7c}$$

- f specific force acting on unit mass
- g'_ℓ gravitational vector referred to reference
- v subscript and superscript denoting the vehicle reference.

The Litton and the Ferranti INS, which are most frequently used for geodetic fieldwork, both are utilizing the local level (LL) technique, therefore we shall restrict ourselves to this type of mechanization. Because the numerical examples refer to the Ferranti FILS Mk II, any details refer to that type.

Combining (6) and (7b) we have

$$R(f_\ell + g_\ell') = R(\ddot{r}_\ell + 2\Omega\dot{r}_\ell + (\Omega\Omega + \dot{\Omega})r_\ell)$$

or

$$\ddot{r}_\ell = f_\ell - 2\Omega\dot{r}_\ell + (g_\ell' - \Omega\Omega r_\ell) \quad . \qquad (8)$$

For inertial navigation with an LL-IMU, we have to integrate $\ddot{r}_\ell$ from the signals f_ℓ . Please notice:

1. We assumed $\dot{\Omega} = 0$, i.e. constant Earth's rotation
2. The second term on the righthand side represents the Cariolis acceleration, the last term accounts for the centrifugal acceleration.
3. At this stage, we assume errorfree f_ℓ
4. On the righthand side we have r_ℓ, $\dot{r}_\ell$ which are to be computed from $\ddot{r}_\ell$ by integration. Therefore we are dealing with an iterative process.

The hardware in the Litton LN-15 platform basically consists of two two-degrees-of-freedom air-bearing gyroscopes and two A-200 D accelerometers for the horizontal channels and one A-1000 accelerometer for the vertical channel (HANNAH 1982). The horizontal channel in future may also be upgraded by an A-1000 accelerometer.

The Ferranti FILS MK II houses three floated rate integrating gyros type 125 and three force-feedback viscous-damped accelerometers type FA2-F (FERRANTI 1979). The output of these accelerometers are velocities, the acceleration can be recovered from the timelike derivative. Little is known about the accuracy of the accelerometers except that it is of the order of a few mGal.

2. Principles of Inertial Gravimetry

Equation (8) transforms the equation of motion onto a nonrotating flat earth. If we put for the term in brackets, representing the acting gravity,

$$(g_\ell' - \Omega\Omega r_\ell) = g_\ell = \gamma_\ell + \delta g_\ell \; , \qquad (9)$$

g_ℓ locally acting gravity

γ_ℓ some gravity reference

δg_ℓ gravity disturbance

then we obtain

$$\ddot{r}_\ell = f_\ell - 2\Omega\dot{r}_\ell + \gamma_\ell + \delta g_\ell \; . \qquad (10)$$

In the course of a terrestrial surveying run, an IMU is brought to a complete standstill every about 3 to 5 minutes for error control (Zero Velocity Update, ZUPT). In this case (10) reads as

$$\delta g_\ell = f_\ell - \gamma_\ell \qquad (11)$$

Eq. (11) can be used to determine pointwise gravity disturbances. By interpolation, these disturbances can be used in (10) to obtain, after integration, coordinates free from gravity induced errors.

At the initial alignment before a survey run, the platform adjusts itself to the local plumbline or, provided deflections of the vertical are given, to the normal on some reference ellipsoid. During the subsequent run, the platform is permanently tilted in order to match the curvature of the reference ellipsoid. At the ZUPTs, the deviation of the platform vertical from the local physical plumbline equals the Helmert-type deflections of the vertical. The tilt of the platform with respect to the local level surface lets the horizontal accelerometers sense a part of the gravity component normal to the ellipsoid. If the signals during the ZUPTs are used for the correction of the horizontal coordinates, however, we end up with ellipsoidal coordinates.

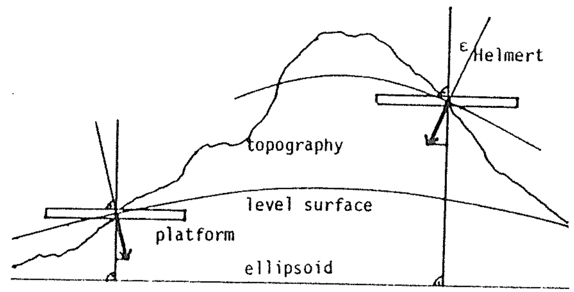

Figure 1

So far, we have assumed error-free instrument behaviour. In practice, the IMU exhibits gyrodrifts, accelerometer bias and drift etc. These effects on the velocity output are mixed with the effects of gravity disturbances and for the ZUPTs we get instead of (11):

$$f_\ell - \gamma_\ell = \delta g_\ell(r) + \delta\varepsilon(t) + n \qquad (12)$$

$\delta\varepsilon(\varepsilon)$ instrumental errors (function of time)

n noise

3. Modelling the IMU Output

So far our developments are based on accelerations. As mentioned above, however, the IMU readout gives us the integrals, i.e. velocities and coordinate differences. Accordingly, our error models can be based on velocity errors or coordinate errors. From the viewpoint of operational strategy, we may e.g. employ the Kalman filter approach, the error velocity approach or the post mission adjustment. All three of them are in the position to provide e.g. coordinates and gravity disturbances.

Kalman filtering (e.g. WONG 1982) can provide real time results and probably represents the best means for modelling the physical properties of an IMU as e.g. the interaction of errors at two different axes. Major drawbacks are the extended requirements as to computer capacity and the intransparency of the data flow within the filter algorithm. The error velocity (e.g. HERREWEGEN 1981) approach provides a fast transparent algorithm at the expense of neglection of physical correlation between the axes. It is a major advantage of this approach, that it is an equally wide step to the coordinates (integral) as to the accelerations /gravity (differential). It starts directly from the real INS signal. The post mission adjustment (e.g. HANNAH 1982) optimally takes into account restrictions from the underlying geometric network and is best suited for the combination of several runs in a net-like structure. It is, however, less suited for modelling the instrumental behaviour. Therefore, a stepwise procedure may be advisable, preprocessing the data either by means of a Kalman filter or the error velocity method.

In (12) we have indicated, that the gravity disturbance is purely a function of position, whereas the instrumental errors are assumed to be a function of time only. Of course, we have to be cautious, that the two effects can be separated: If e.g. we use some functional of position for the gravity effect and the same functional of time for instrumental drift, our system will become singular, as soon as position becomes a linear function of time, c.f. (13). If it is not possible to select different functionals for gravity and instrumental effects, we have to break the linear dependence of position and time by traversing e.g. back and forth.

From the general simplified linear model for the error velocities

$$y + n = F(r)x_r + G(t)x_t \qquad (13)$$

$$r = \int \bar{y} dt$$

- y velocity output from IMU
- $\bar{y}$ filtered velocity
- n noise
- F gravity functional
- r position
- x_r gravity parameters
- G instrument functional
- t time
- x_t instrumental parameters

it again becomes evident, that we are dealing with an iterative process, which converges the faster, the better gravity and instrumental effects can be separated.

In the sequel, we shall restrict ourselves to the error velocity approach. The only information about the error velocity during a run comes from the ZUPTs and we assume, that the error velocity is made up by instrumental and gravity effects, where the systematic instrumental effects are disturbed by random noise. Thus, if we can find a continuous functional in time for the instrumental effects, the remaining signals at the ZUPTs are composed of gravity signal plus noise.

During one ZUPT, the Ferranti FILS MK II outputs about 32 values of instantaneous velocities with a sampling rate of 0.6 sec in the North, East and Height channels respectively (HERREWEGEN 1981).

The velocity readings at one ZUPT may be approximated by a quadratic function of the type

$$\bar{y} = a + bt + ct^2 \ . \qquad (14)$$

- t time
- a,b,c coefficients
- $\bar{y}$ filtered velocity

With t = 0 we obtain one filtered velocity value of the ZUPT

$$\bar{y}_{j,k} = a_{j,k} \qquad (14)$$

- j ZUPT number
- k N, E, H; North, East, Height

Likewise we get the acceleration

$$\frac{d\bar{y}}{dt} = b + 2ct \qquad (16)$$

for t = 0

$$\left(\frac{d\bar{y}}{dt}\right)_{j,k} = b_{j,k} \qquad (17)$$

and the drift of the accelerometer reading

$$\left(\frac{d^2\bar{y}}{dt^2}\right)_{j,k} = 2c_{j,k} \qquad (18)$$

Figure 2 depicts for one example the individual readings y during one ZUPT and the filtered function $\bar{y}$.

Table 1 lists the first 3 ZUPTs of one sample run the $\bar{y}_{j,k}$, $\left(\frac{d\bar{y}}{dt}\right)_{j,k}$, $\left(\frac{d^2\bar{y}}{dt^2}\right)_{j,k}$ and the respective variances.

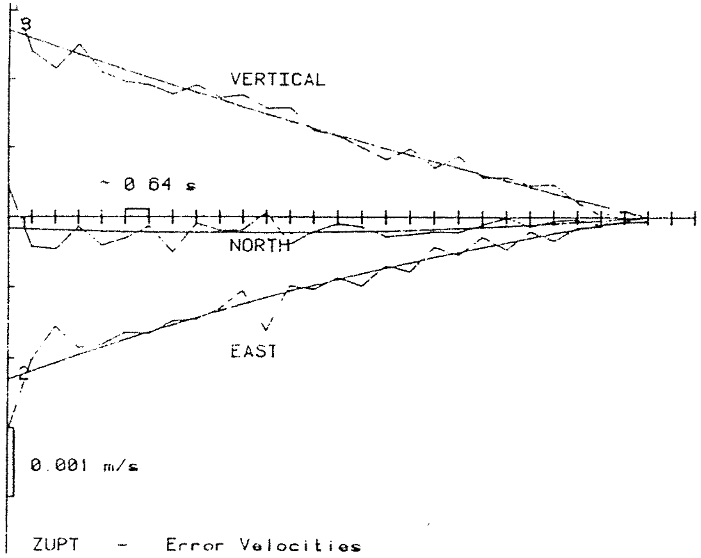

Figure 2

		$\bar{y}$	1σ	$\frac{d\bar{y}}{dt}$	1σ	$\frac{d^2\bar{y}}{dt^2}$	1σ
	NORTH	6 E-3	6 E-5	- 7 E-5	1 E-5	- 7 E-7	8 E-7
1	EAST	10 E-3	6 E-5	- 6 E-5	1 E-5	- 6 E-7	8 E-7
	VERT.	- 8 E-3	6 E-5	17 E-5	1 E-5	-48 E-7	8 E-7
	NORTH	16 E-3	5 E-5	- 8 E-5	1 E-5	- 4 E-7	7 E-7
2	EAST	21 E-3	5 E-5	- 9 E-5	1 E-5	- 2 E-7	8 E-7
	VERT.	-20 E-3	6 E-5	20 E-5	1 E-5	-46 E-7	8 E-7
	NORTH	58 E-3	5 E-5	-10 E-5	1 E-5	0 E-7	7 E-7
3	EAST	45 E-3	5 E-5	-13 E-5	1 E-5	15 E-7	7 E-7
	VERT.	-39 E-3	6 E-5	11 E-5	2 E-5	-31 E-7	9.E-7

(all SI-units)

Table 1

Figure 2 and table 1 are samples of a run just meant to give some idea about the orders of magnitude we are dealing with when handling raw inertial data before applying any correction. In particular they shed some light on the capability for gravity vector determination. This is not only limited by the accelerometers themselves, but e.g. also by vibrations of the vehicle during the 20 sec-ZUPT. At an EW run with 36 ZUPTs along a road with heavy traffic, the average standard deviation of the N accelerometer signal was 3.2 mGal, whereas the E and H accelerometers had 1.9 and 1.5 mGal resp., thus reflecting the the wind gusts of passing-by vehicles, and the N-S vibrations of the vehicle.

In the conventional procedure, the mean velocity of each ZUPT is used for the construction of an error velocity curve, the integral of which gives the coordinate correction.

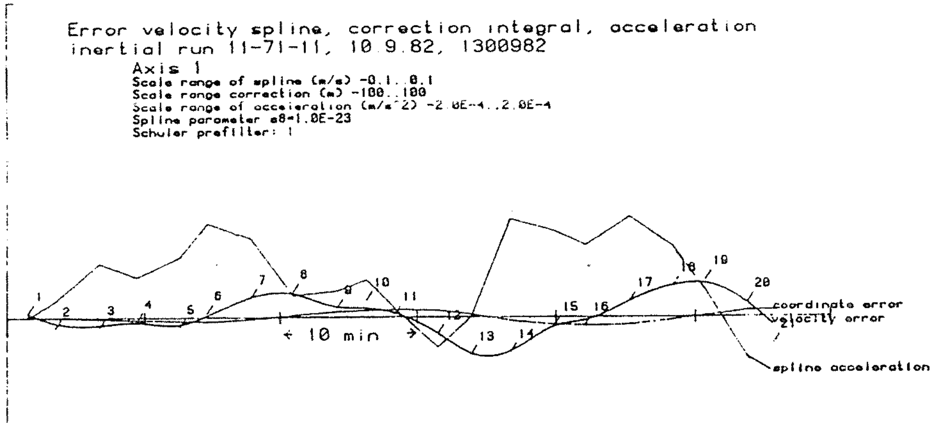

Fig.3

As mentioned above, the error velocity curve exhibits the combined effects of gravity induced and instrumental errors, as e.g. accelerometer bias and drift, gyro bias and drift etc. Integration of the unreduced error velocity function leads to coordinate corrections of typically several hundred meters. A good deal of this amount can be attributed to Schuler oscillation (of the horizontal channels), bias and drift. In a first filtering step, we have therefore removed all (presumed) instrumental effects, thus getting a considerably reduced error velocity, depicted in fig. 3, where the remaining coordinate error is only of the order of some meters. The numbers along the error velocity spline curve denote ZUPT-numbers.

In order to interpolate the discrete error velocities inbetween the ZUPTs we have employed smoothing splines with the ZUPT mean velocities as knot input. The differentials of the splines at the knots (ZUPTs) give us accelerations. This can be used for a comparison of accelerations directly derived from (16) and gives us some idea about the representation error and the instrumental noise.

If the reasoning above is correct, the spline derived accelerations should only contain random instrumental noise plus position dependant gravity signals. Because the inertial run depicted in fig. 4 is a back and forth run, we should find more or less the same signals on identical stations in both directions.

For the transformations of acceleration signals to deflections of the vertical we have

$$\xi_j = \frac{1}{g} \cdot \left(\frac{d\bar{\bar{y}}}{dt}\right)_{j,N} + \xi_o$$

$$\eta_j = \frac{1}{g} \cdot \left(\frac{\delta\bar{\bar{y}}}{dt}\right)_{j,E} + \eta_o \qquad (19)$$

ξ_j, η_j North, East deflections of the vertical at station j

ξ_o, η_o North, East deflections of the vertical at the initial alignment station

$\bar{\bar{y}}$ error velocity after spline filter

For the (vertical) gravity anomaly,some normal reference field is taken into account by the FILS system. Therefore we have

$$\left(\frac{\delta\bar{\bar{y}}}{dt}\right)_{j,H} = g_j - g_o - F(H_j - H_o) - a(\sin^2\varphi_j - \sin^2\varphi_o) \qquad (20)$$

g gravity

F vertical gradient

a coefficient

φ latitude

From (20), g_j can be computed and thus any type of gravity anomaly desired. Fig. 4 shows the trace of the same run as in fig.3, now with the accelerations converted to relative (NORTH) deflections. We recognize, that the deflections of the forward and backward leg all agree within 0.5 arcsec. Further runs on the same traverse showed also good agreement. A final statement as to the quality of deflection determination by FILS has to be postponed, however, until any yet undetected systematic effect can be excluded after checking the deflections of the vertical by independant methods.

Conclusion

The control of the platform orientation of a Ferranti FILS Mk2 in space during short runs (20 km back and forth) is better than 0.5 arcsec. Before interpreting this figure as an accuracy measure for vertical deflections, independant deflection determinations have to be carried out. The numerical example concentrated on the horizontal channel. The vertical channel should provide an accuracy of a few mGal.

The application of the error velocity method in combination with a two-step filter and smoothing splines proved to be a very usefull tool for modelling IMU output when aiming at vector gravity disturbances.

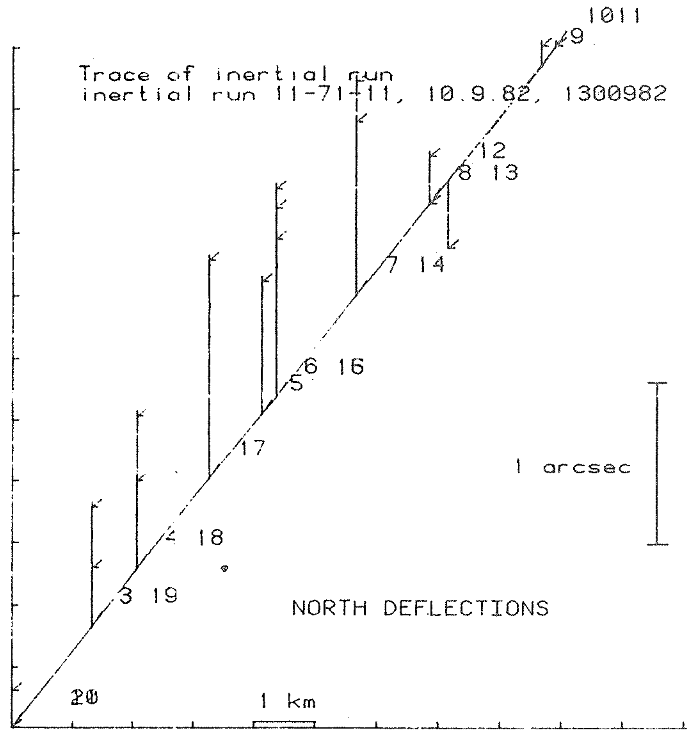

Figure 4

Acknowledgements

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PARTIAL ANALYSIS OF GRAVITY MEASUREMENTS ON THE FENNOSCANDIAN GRAVITY LINES

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Abstract

In close cooperation with Finnish, Swedish and Norwegian institutes the IPG, TH Darmstadt, participated in gravity measurements on the fennoscandian land uplift lines. Results of these measurements are presented, also including observations on the Gävle and Joensuu calibration lines. The accuracy of gravity differences measured by four gravimeters was found to be 3 to 4 μgal. Possible error sources, like ocean tidal loading and differences between different instruments are discussed. The computation of additional observations on the European Absolute Calibration line between Göteborg and Hammerfest indicates accuracies for the scale factor of some parts in 10^5. Norwegian gravimeter data were kindly given by the Land Survey of Norway.

1. Introduction

Since 1971, five years after the installation of the first fennoscandian gravity monitoring line by Prof. Kiviniemi (e.g. Kiviniemi 1974) the IPG participated in the repeated measurements. Here we want to summarize our experiences and publish the results of five campaigns; 1971/72, 1979, 1981 and 1982 when IPG participated in finnish, swedish and norwegian campaigns. The results, in combination with others already published, should serve as a basis for computing the geometric land uplift from gravity and repeated levelling data and also for geophysical hypothesis about the origin of land uplift. These topics are delt with in a paper to be presented at the IUGG General Assembly by (Groten et al., 1983). It can now, 16 years after the first gravimeter observations on the land uplift lines, be assumed that, in spite of the relatively poor accuracy of a single measurement, combined gravity measurements of several instruments sampled over a considerable time span are indicating a significant gravity change.

2. Measurements of the fennoscandian part of the European Absolute Calibration line

In October 1982 the four gravimeters G45, G378 of NGO and D38, G258 of IPG were calibrated on the European Absolute Calibration line. Starting in Göteborg a symmetric measurement was made up to Hammerfest and back in twelve days. With the use of intermediate stations (see tab. 2.2 and fig. 2.1) the maximum gravity difference was 167 mgal and so the D-meter could be used without resetting. At first every instrument was adjusted separately in a Serbetci-type model (see Becker 1981 for computational details). The linear and quadratic scale factors and the drift rates of the instruments are given in tab 2.1. In fig. 2.1 the

	m.s.e.	Drift rate [μgal/day]	Scale factor linear	Scale factor quadratic
G 45	±18.3	- 2.0±10.3	$1+(25.11\pm12.8)\cdot10^{-5}$	$1-(0,15\pm0,09)\cdot10^{-5}$
G 378	±11.8	+19.3± 4.3	$1-(\ 2.09\pm\ 2.8)\cdot10^{-5}$	
G 258	±21.1	+ 4.4± 8.8	$1-(\ 2.28\pm\ 6.9)\cdot10^{-5}$	
D 38	±13.0	+ 0.7± 5.0	$1+(16.62\pm\ 7.3)\cdot10^{-5}$	

Tab. 2.1

cummulative differences of every instrument are plotted against the absolute values. We used the absolute values of (Cannizzo et al., 1978) except for Sodankylä, where, according to (Mäkinen, Haller, 1982) a new determination of the vertical gradient increased Cannizzo's value by 37 μgal. The peak of all curves at the Vaasa station can be explained either by a nonlinearity in the scale factor common to all four instruments or by a wrong absolute value. We tend to accept the second case which is indicated also in the computations of (Mäkinen, Haller 1982) and (Torge, Kanngießer, 1979) where Vaasa shows the largest residual of the absolute stations in the adjustment. Therefore in the combined adjustment only four absolute values were fixed and the one in Vaasa was adjusted. The results of the single adjustments with complete variance-covariance matrix were introduced and it was solved for the calibration factors and station gravity values, see tab. 2.2 and tab. 2.1.

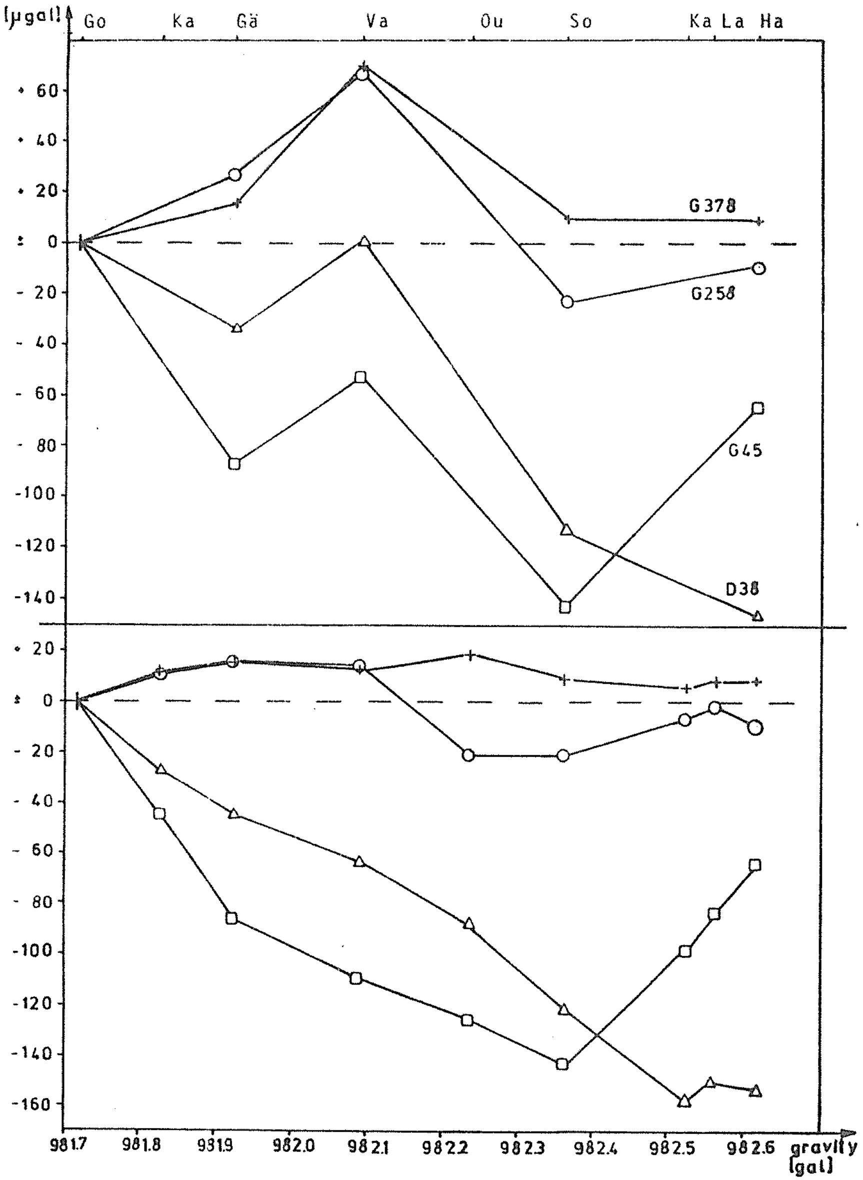

Fig. 2.1 top: cumulative gravity differences of single instruments versus Cannizzo's absolute values

bottom: cumulative gravity differences versus adjusted gravity values

The value in Vaasa was found to be about 57 µgal larger than the original value. This corresponds well with the 60 µgal reported by Mäkinen and Haller. The scale factor (see appendix for a summary of all instrumental corrections used) determined earlier on this line (G378) or on parts of IGSN are confirmed for the G-meters. D38 had a significant improvement in the scale factor of 1.6 parts in 10^4.

	Gravity value [mgal]	m.s.e. [mgal]
Hammerfest (Abs.)	982 617.588	
Lakselev	982 557.573	±5
Karigasniemi	982 524.836	±9
Sodankylä (Abs.)	982 362.243	
Oulu	982 236.183	±2
Vaasa	982 090.845	±5
Gävle (Abs.)	981 923.528	
Karlstad	981 828.210	±7
Göteborg (Abs.)	981 718.774	
Hönefoss (Norway)	981 901.042	±8

tab. 2.2 Adjusted gravity values of the European Absolute Calibration line and intermediate stations.

The plots of G45 and G258 in fig. 2.2 show some systematic nonlinearities which could be caused by long periodic circular errors of 1206 or 603 c.u. The deviation of G45 can be explained either with the quadratic calibration function given in tab. 2.1 or as one half of the 1206 c.u. periodic error, but because of the limited range of the calibration line a final decision can not be made. A tentatively fit of the 1206 c.u. period resulted in an amplitude of 71.4±10.9 µgal and $-18^{0}\pm9^{0}$ phase lag.

The tentative fit for the 603 c.u. period of the G258 gave an amplitude of 21.7±7.3 µgal and a phase lag of $175.46^{0}\pm18.34^{0}$. More measurements on an extended line are necessary to confirm these values. In general the gravimeter measurements on the calibration line are not accurate enough or not numerous enough to determine the nonlinearities of the overall scale factor corresponding to an improvement of the factory determined interval factors for the 100 mgal intervalls.

3. The calibration lines in Gävle and Joensuu

The calibration line of Gävle consists of 8 points with gravity differences of approximately 0.2 mgal and 7 further points with 0.6 mgal subdivision, all together 5.8 milligal, situated in a staircase. As the gravity differences on the land uplift lines are rather small, maximally 1.5 mgal on the line of 63°, only the 1 c.u. and 3.94 c.u. periodical errors of the G-meter and the 1.625 and 3.25 c.u. periodical errors of the D-meter take effect on the measurements. In order to determine these periods in the gravity range of the uplift lines 164 observations with G45, G378, G258 and D 38 took place in October 1982. In addition the LMV of Sweden supplied another 731 observations made with G54, G120 and G290 earlier on these lines. In tab. 3.1 the gravity values found in a combined adjustment are given.

STATION 1 mgal	4 mgal	G(µgal) $m_0 = \pm 9.5$	Δg (µgal) 1 mgal	4 mgal
8806	8807	191.3±1.3		
4007		442.0±1.5	250.7	
3007		620.9±1.5	178.9	
2007		813.1±1.5	192.2	
2907	2907	1000.0	186.9	808.7
3907		1197.7±1.5	197.7	
1907		1395.8±1.5	198.1	
2807		1586.9±1.5	191.1	
	1807	2100.5±1.7		1100.5
	1707	2738.5±2.2		638.0
	1607	3336.2±2.0		597.7
	1507	3957.6±2.2		621.4
	1407	4536.6±2.0		579.0
	1307	5050.3±2.2		513.7
	1106	6007.1±2.0		956.8

Tab. 3.1: Gravity values and differences on the Gävle calibration lines (point 2907 fixed with 1 mgal)

The m.s.e of unit wheight is 9.5 µgal, which is more than twice as large as the corresponding values of single instrument adjustments and therefore indicates systematic differences between the instruments. However, the attempt to solve also for periodical errors for single instruments failed. Only for G54 a significant amplitude of 3.60 µgal and a phase lag of 38.47° for the 1. c.u. period was found (see appendix for definition of these values and other instrumental corrections). From our calculations the following conclusions can be drawn. On one hand there are some instruments where the observations are not accurate enough to determine periodical errors at the one to 6 µgal level. This can partly be caused by aftereffects of the hard environmental conditions during the measurements on the European Absolute Calibration line. On the other hand even instruments which have an internal precision of 1 to 2 µgal during the Gävle observations do not have modellable periodic errors. The differences between different gravimeters are more complicated in nature and superposed by random deviations. A further problem are the reference values of the calibration line. Their formal accuracy of 1 to 2 µgals is not sufficient to determine periodic errors with amplitudes < 4 µgal. There is a need for quasi "errorless" calibration lines determined by instruments not affected by cyclic errors, like instruments equipped with electrostatic or electromagnetic feedback systems in order to become independent of the assumption of averaging out of single instruments periodical errors.

The Joensuu calibration line has accurately the gravity differences occuring on the line of 63°. It was planned to eliminate systematic differences between instruments on the basis of simultaneous measurements on this line. The 5 points are situated in a distance of only about 30 m and the gravimeters can be carried by hand from one station to the other. However, due to the heavy drift of most of the instruments (e.g. G 258 had about 1 mgal/month) readings changed rapidly and the direct relation of deviations at a certain counter position in Joensuu and the corresponding ones on the land uplift lines was lost. For the four instruments used in 1979 and 1982 we could not reduce the discrepances on the land uplift lines by use of the Joensuu results. The gravity values for Joensuu of the combined adjustment of 157 observations with 4 gravimeters in 1979 and 1982 are given in tab. 3.2.

Station	G (μgal) m_0=±5.2	Δg (μgal)
1001	1637.1±1.5	-392.0
65362	1245.1±1.5	-245.1
1002	1000.0	-349.2
1003	650.8±1.5	-486.8
1004	164.0±1.5	

Tab. 3.2 Gravity values of the Joensuu calibration line

4. Evaluation of the measurements on the land uplift lines.

Here we will present the results of the campaigns in 1971, 1972, 1979, 1981 and 1982. All computations were done using the model mentioned in section 1. For combined adjustments the instruments where weighted according to 1/(m.s.e.)^2. This was done mainly because of the big discrepancies 1971 where G258 suffered from some disturbances. In the other years weighting changed the adjusted gravity values by less than 1 μgal. In 1979 and 1981 the drift during driving was significantly different from the one during the nightly rests, therefore the drift curve was computed not considering these quiescent drifts. In 1982 there was no significant difference and hence we did not eliminate the nocturnal drifts. One drift polynomial was used for the whole duration of the campaign, the order varying from one to three. The results given here for the 1971 measurements are slightly different from the ones published earlier in (Gerstenecker, 1973).

Instrument	G258	G142	combined
m_0	±21.7	±13.9	
Deg. of freedom	41	43	
Station			
Kramfors D			(372.9±7.6)
Kramfors A	-505.5±11.4	-486.5±6.9	-491.6±6.6
Vaasa	489.8±10.0	503.8±6.4	499.7±6.1
Äänekoski	-352.7± 9.5	-348.2±6.1	-349.5±5.8
Joensuu			

Tab. 4.1 Results 1971, line of 63°
(Gravity difference Kramfors D → Kramfors A 864.5±3.8 μgal according to a priv. comm. with Prof. Petterson)

Instrument	G258	G195	combined
m_0	±26.6	±13.6	
Deg. of freedom	80	80	
Vågstranda	537.1±13.0	564.2±6.6	558.3±5.6
Meldal	-3.8±13.1	4.5±6.8	1.4±5.8
Kopperå	-81.6±13.1	-77.9±6.6	-80.2±5.6
Stugun	48.9±13.2	50.8±6.7	49.3±5.7
Kramfors D	383.3±13.2	371.2±6.7	372.0±5.7
Vaasa			

Tab. 4.2 Results 1972, line of 63°

Instrument	G258	D38	combined
m_o	±11.1	±17.3	
Deg. of freedom	58	57	
Kopperå	-56.9±6.2	-66.2±9.7	-59.6±2.4
Föllinge	-36.6±5.5	-29.6±8.6	-34.6±2.1
Stugun	919.9±5.5	913.3±8.6	918.0±2.1
(Kramfors D)			(53.5±4.3)
Kramfors A	-492.1±5.5	-495.2±8.6	-493.0±2.1
			(371.5±4.3)
Vaasa	51.9±5.3	54.3±8.3	52.6±2.0
Kuortane	-98.3±5.2	-95.9±8.2	-97.6±2.0
Alajärvi	537.6±5.2	539.0±8.2	538.0±2.0
Äänekoski	-352.4±5.8	356.3±9.0	-353.5±2.2
Joensuu			

Tab. 4.3 Results 1979, line of 63°, values for the main station Kramfors D in brackets

Instrument	G258	D38	combined
m_o	±11.9	±19.1	
Deg. of freedom	37	36	
Korgen	15.0±8.0	9.4±13.0	13.4±2.0
Lumbukta	-9.1±7.3	-11.3±11.8	-9.7±1.8
Sensele	-74.3±6.8	-71.2±11.0	-73.4±1.7
Lyksele	-36.8±6.8	-33.5±12.1	-36.0±1.8
Sävar	127.1±7.0	120.8±12.2	125.6±1.8
Kalajoki	-30.5±6.8	-34.4±11.0	-31.6±1.7
Haapavesi	-62.4±6.8	-65.0±11.0	-63.1±1.7
Ristijärvi	-90.8±7.7	-88.7±12.3	-90.2±1.9
Kuhmo			

Tab. 4.4 Results 1981, line of 65°

Station	G258	G38	G45	G378	combined
	±9.7	±13.7	±11.6	±9.9	
	73	74	74	74	
Vågstranda	543.0±5.8	563.4±8.0	534.1±6.8	545.2±5.8	545.0±3.6
Meldal	8.5±6.4	0.1±8.8	7.7±7.5	16.4±6.4	9.4±4.0
Kopperå	-59.2±6.2	-50.2±8.8	-65.3±7.5	-57.0±6.4	-58.4±4.0
Föllinge	-45.2±6.4	-30.8±8.8	-45.4±7.5	-44.8±6.4	-42.8±4.0
Stugun	42.7±6.4	54.0±8.8	57.1±7.5	57.8±6.4	52.3±4.0
Kramfors D	378.8±5.6	386.1±7.7	362.6±6.6	374.4±5.6	375.1±3.5
Vaasa	48.2±5.6	46.0±8.4	64.0±8.4	51.8±6.1	52.6±3.8
Kuortane	-88.0±6.0	-93.9±8.4	-85.6±7.1	-92.8±6.1	-89.9±3.8
Alajärvi	548.4±6.4	532.2±8.8	552.0±7.5	532.7±6.4	-541.9±4.0
Äänekoski	-354.7±6.0	-346.4±8.4	-366.5±7.1	-355.2±6.1	-356.1±3.8
Joensuu					

Tab. 4.5 Results 1982, one drift through the campaign, line of 63°

Station	G255		D38		all instruments
	west→east	east→west	west→east	east→west	combined equal weight
Vågstranda	545.5± 6.8	537.9±17.9	576.3±11.7	545.4± 7.9	546.0±5.0
Meldal	0.0±27.5	19.8± 5.0	-10.5±10.7	-6.1± 6.9	5.5±4.0
Kopperå	-61.1± 0.7	-57.1± 1.8	-38.1± 5.6	-58.8±20.6	-58.1±3.4
Föllinge	-38.7± 1.6	-43.6± 3.9	-25.3±13.0	-38.7± 1.8	-41.5±5.0
Stugun	40.3± 6.6	52.0± 9.8	49.5± 6.9	52.6± 1.4	51.9±1.9
Kramfors D	367.1±15.5	383.9± 6.8	391.0±15.4	386.0± 7.2	374.8±4.5
Vaasa	49.9± 3.5	45.7± 4.1	45.0± 3.1	45.5± 8.8	51.9±3.3
Kuortane	-85.5± 3.4	-91.4± 4.1	-99.2± 3.0	-84.1± 8.8	-89.2±2.0
Alajärvi	548.3± 4.0	549.6± 1.0	533.4± 3.7	536.3± 2.2	541.0±3.9
Äänekoski	-347.0± 7.9	-363.5± 5.2	-340.4± 4.6	-354.5±14.4	-356.2±3.5
Joensuu					

Tab. 4.6.a Results 1982, line of 63°, daily drifts for every instrument

Station	G45 west→east	G45 east→west	378 west→east	378 east→west	all instruments combined weighted $p=1/(m_0)^2$
Vågstranda					
Meldal	539.4±6.3	528.7± 9.6	541.1± 9.7	553.7± 2.4	550.2±4.2
Kopperå	16.1±11.6	1.7±19.4	17.7±11.6	5.4±12.0	9.0±7.0
Föllinge	-64.4±20.3	-69.7± 3.7	-51.3± 6.9	-64.3± 1.7	-60.1±1.3
Stugun	-63.9± 6.6	-29.6± 2.9	-60.9± 5.8	-31.4± 8.8	-42.3±2.2
Kramfors D	57.2± 9.9	56.7± 2.2	53.6± 0.7	53.1±13.6	53.4±1.2
Vaasa	362.1±20.4	358.0± 4.2	383.5± 1.6	366.4± 1.7	374.6±2.4
Kuortane	52.3±12.8	73.5±25.1	52.4± 5.7	50.6± 5.4	47.9±3.8
Alajärvi	-86.3±12.6	-82.8±24.8	-90.8± 5.6	-93.4± 5.3	-92.2±3.7
Äänekoski	549.0± 0.2	550.6± 2.5	518.5±21.1	542.6±21.7	548.9±0.4
Joensuu	-373.4±14.4	-359.1± 6.9	-354.2±12.2	-357.5± 7.2	-353.2±5.5

Tab. 4.6b Results 1982, line of 63°, daily drifts for every instrument

Because of restrictions like ferryboat timetables and hotel reservations there is only a limited choice of observation schemes. In 1979 and 1981 the lines were measured 4 and 3 times respectively forth and back, from one end to the other, taking about three days without drift control for one way. In 1982 we measured 3 ties between adjacent stations a day, once on the way eastbound and a second time on our way back to Norway. This means that we had the same number (8) observations on every station as in 1979, but distributed over 4 days instead of 8. The daily drift controls were thought to allow a better monitoring of the instruments behaviour and a better drift elmination. In tab. 4.6 the results of daily adjustments for the gravity differences of every instrument are given with two results for the common adjustment of all instruments. Comparing to tab. 4.5 it can be concluded that the computation of daily drifts did not change the results more than 1 μgal in almost all cases when using equal weights for every day. Using weights equal to $1/(m_0)^2$ for every day there are deviations of 1 to 7 μgal. However, in the special case of gravimeter measurements and their unknown systematic errors the m.s.e. is not necessarily a measure for the accuracy of the instrument, therefore it is not clear which result should be recommended as the final one. Possibly the comparison with other measurements performed simultaneously by Prof. Kiviniemi on this line will be helpful. A typical example for the discrepancy between instrumental precision and accuracy can be seen in the difference Äänekoski - Alajärvi. Besides G378 3 instruments show very good agreement in the measurements forth and back, with small standard errors < 4 μgal. Nevertheless the mean values of G and D-meters are different by 16 μgal. The purpose of this rather detailed presentation is to give every reader and possible user of the data an insight in how the results are gathered and how careful one should be in their interpretation.

5. Environmental perturbation in the gravity differences

The well designed land uplift lines and the careful planning of repeated measurements eliminates several environmental error sources of precise gravimetry. The bedrock chosen for most of the stations makes it unnecessary to consider groundwatertable changes and moisture content of the upper soil. Repeated measurements are always made in autumn in order to get rid of seasonal gravity variations and to ensure similar and stable temperature conditions. Regional atmospheric pressure variations are reduced to a standard atmosphere using the factor of 0.35 μgal/mbar. The main factors still inherent in the gravity measurements are the water level variations of the coastal stations and ocean tidal loading effects.

Anderson (1980) quotes a maximum response of about 1 μgal per mean cm of water level variation for the Gulf of Bothnia. However, computing the attractional effect of a Bouguer plate for the stations in Vaasa and Kramfors we obtained 0.0003 μgal/cm and 0.026 μgal/cm respectively. This means that long and short term variations of the sea surface up to 50 cm are allowed without disturbing gravity more than 1 μgal.

Intensive studies about the ocean tidal loading effect are under progress for fennoscandia. For the Blue Road Geotraverse (Jentsch, 1981) gives the following residual values due to loading:

	Norway	Mid Sweden	Mid Finnland
[μgal]	7...9	3...5	1...3

Tab. 5.1

As we did not use any emprical α and δ factors in our computations we made an estimation of a possible bias in a gravity difference. Fig. 5.1 is taken from (Jentsch, 1982), considering the driving time between these two stations the maximum effect in the gravity difference is < 3 μgal and < 1.5 μgal in west-east and east-west measurements respectively. As the two stations are the ones closest to the atlantic ocean the effect should be smaller in the subsequent differences. In our measurements there is no indication of a tidal loading effect, as for example would be a greater standard deviation of gravity differences in Norway or Sweden than in Finland. Summarizing it can be stated that presently instrumental perturbations are covering the effects of tidal loading so that not clear cut conclusion about this effect can be drawn from relative measurements. However, when the final empirical amplitudes and phase lags are available for all land uplift stations they should be used in order to avoid any possible bias in the results.

6. Drift behaviour of the instruments

Looking at the drift behaviour of the G-meters brought from Germany to Fennoscandia they are exhibiting a typical common feature (see fig. 6.1). G258 and G195 both have an abnormal large negative drift ob about 1 mgal/month which becomes smaller with time and after about 25 days turns to a more normal slightly positive drifting. This effect is probably caused by a mechanical internal adjustment in the measuring system of the gravity meter associated with the change of the counter reading corresponding to an increase in gravity of about 1000 mgal. The major part of the readjustment seems to happen during the rest times at night, whereas during the daily transportation effects due to temperature and vibrations are superposed. The readjustment of the measuring system is closely related to the

DRIFT LAND UPLIFT LINE OF 63 DEGREES

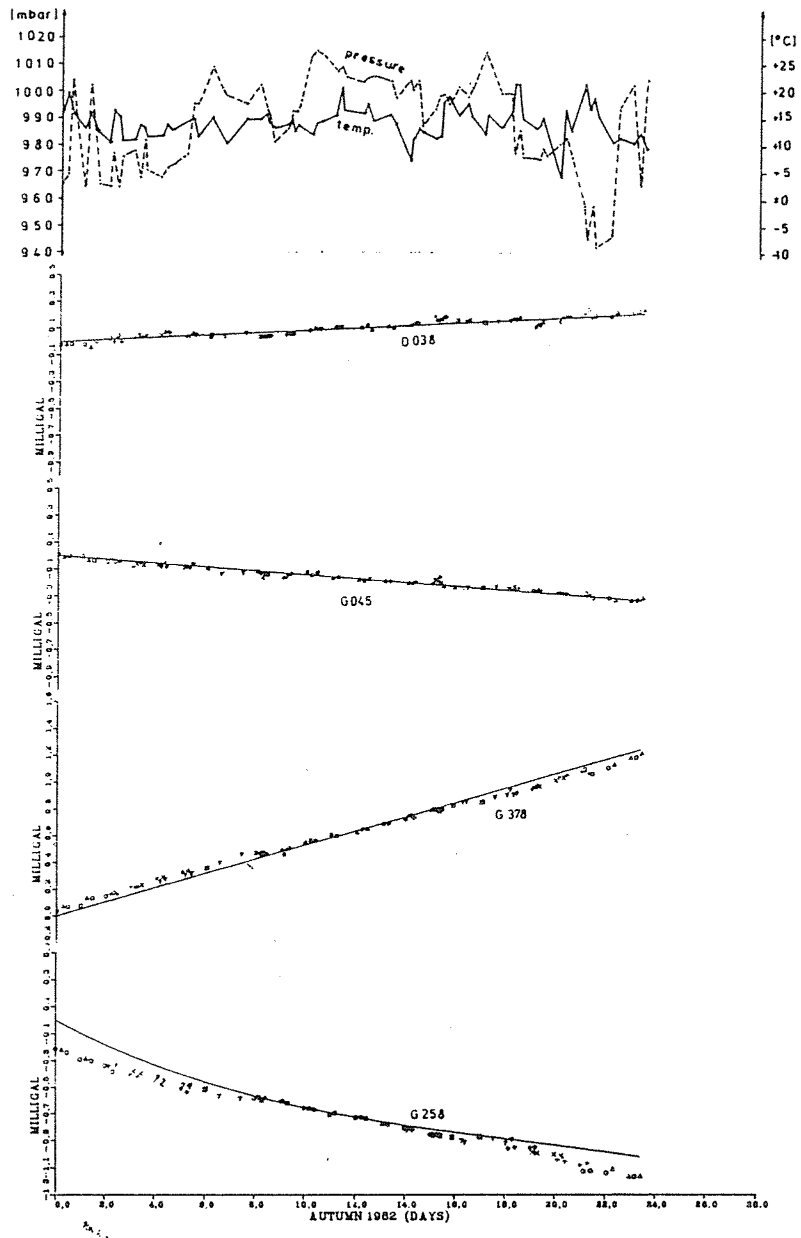

Fig. 6.2

variation of the mechanical sensitivity in the g-meters with gravity. As mentioned already in (Gerstenecker, 1973) the sensitivity of the LCR gravimeters decreases with increasing gravity. In order to obtain the desired sensitivity of 1 turn/ten divisions in the optical scale on the land uplift lines we had to adjust the meters in Germany with 0.8 turns/ten divisions. On the circumpacific gravity connection (Nakagawa et al. 1983) covering 5.6 gal it was shown that the sensitivity, corresponding to a certain value of the gravimeter's astatization angle, can be modeled by a second order polynomial of the intensity of gravity. A higher gravity value changes the geometry of the measuring system and causes the astatization angle to become larger.

The D-meter had, in spite of the change in sensitivity, only in 1979 for a short time a negative drift. It seems that the readjustment here is happening faster because of the different range adjust by resetting. In general the D-meter has a low overall drift rate but large irregularities, e.g. the quiescent drifts over night were of changing sign with maximum values of 0.1 mgal/night.

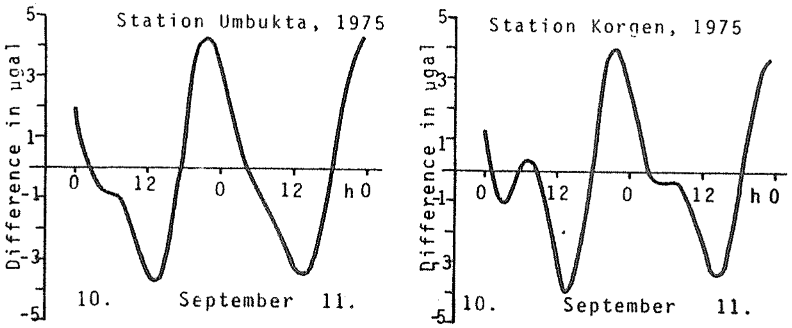

Fig. 5.1 Differences of the tidel corrections over two days provided by measurements to over-all corrections of δ = 1.14 and 0^{0} phase used

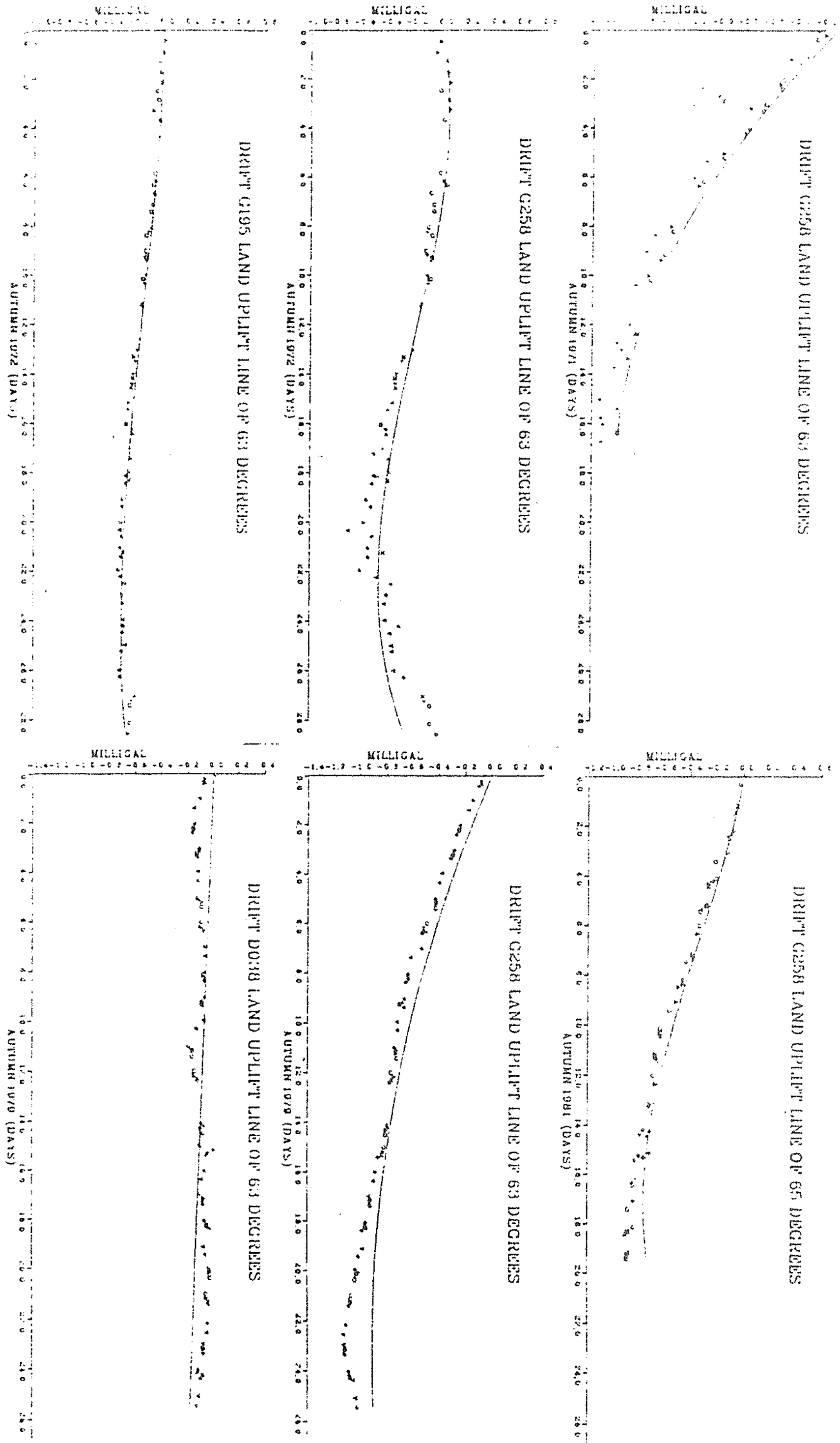

Fig. 6.1 Comparison of G-meter Drift

7. Conclusion

In tab. 7.1 all measurements on the land uplift line of 63° are summarized. Some sources and single results are included in the appendix. The average mean square error of a gravity difference observed with 1 to 9 gravity meters is ± 3.4 µgal. This accuracy is achieved in spite of much larger differences for single measurements by averaging out short term disturbances in the drift using several repetitions and several instruments simultaneously. Besides these short term drift-irregularities which are probably caused by temperature variations and vibrations during driving, systematic errors of the instruments also have to be averaged out. Systematic environmental effects, mainly the ocean tidal loading are in general of smaller size but nevertheless have to be considered because they can cause a bias common to all simultaneous measurements in one campaign.

The aim of repeated gravity measurements is the detection of possible gravity changes associated with the fennoscandian uplift. Model calculations indicate an expected change of about -0.2 µgal/mm of uplift. Fig. 7.1, which is taken from (Groten, et al., 1983), shows the changes of gravity at the main stations of the line of 63°. They are computed from tab. 7.1, referring the differences to the Vaasa station (because Vaasa is included in almost all campaigns) and eliminating a trend common to all measurements in each campaign. The final slope of the lines of regression was found by assuming a zero gravity variation in Vågstranda, which was indicated by mareograph records.

One can see clearly the decrease in gravity and also the decreasing slope of the lines of regression due to the larger distance from the center of uplift. Both in Äänekoski and in Kopperå there may be local disturbances because the scatter of measurements is higher than on the other main stations. Looking at fig. 7.1 it should be clear that there is a significant change in gravity at most of the stations, even if the figures might be uncertain. Tab. 7.2 finally gives a comparison of model calculations and the observed values.

Year	1966	1967	1967	1971	1972	1972	1973	1975	1977	1978	1979	1982
observer	AK,SE	AK	LP	AK,CG	AK	CG,LP	AK	RB	AM	AK	AK,EG,LP	AM,MB
publ.	AK,1978	AK,1978	AM,1978	Tab. A.1	AK,1978	Tab.A.2	AK,1978	AK,1978	AM,1978	AK,1982	Tab.A.3	
no. of grav.	4	3	3	5	2	1	2	1	9/3	1	5/4	4
Station	µgal	µgal	µgal	µgal	µgal	µgal	µgal	µgal	µgal	µgal	µgal	µgal
Joensuu												
	+356.7±4.7	+351.6±1.9		+352.7±2.7				+353.8±1.9	*) +359.7±3.0		+353.8±2.4	+356.1±3.8
Äänekoski												
											-539.0±1.0	-541.8±4.1
Alajervi												
	-492.1±2.4	-488.4±4.1		-484.8±12.1	-488.4±1.0		-481.6±4.9	-486.7±2.2	*) -495.3±4.1 (-490.9±0.3)	-487.5±3.4	+94.6±3.0	+89.9±3.8
Kuortane												
											-54.3±1.7	-52.6±3.8
Vaasa												
		-374.5±3.1	-374.5±4.6	-372.1±0.7		-370.2±1.8			*) -372.4±0.3		-371.6±1.6	-375.1±3.6
Kramfors												
			-55.0±5.9			-51.0±1.8			-53.5±1.9		-49.0±4.5	-52.4±4.1
Stugun												
			+73.9±3.8			+86.2±6.0			+93.6±2.3		+40.0±5.5	+44.7±4.1
Follinge												
											+57.8±1.3	+56.4±4.0
Kopperå												
			+2.6±3.5			-2.6±1.2			-10.9±3.4			-9.4±4.1
Meldal												
			-552.6±6.5			-552.0±1.7			-560.2±1.3			-549.3±3.7
Vågstranda												

Abbreviations:

RB = Dr. Rudolf Brein, Institut für Angewandte Geodäsie
SE = Mr. Sven Ernberg, Defense Mapping Agency Topographic Center
CG = Prof. Carl Gerstenecker, Technische Hochschule Darmstadt
BH = Mr. B.G. Harsson, Geographical Survey of Norway
LH = Mr. Lars-Ake Haller, Geographical Survey Office of Sweden
AK = Prof. Aimo Kiviniemi, Finnish Geodetic Institute
EK = Dr. Erik Lingele, Swiss Federal Institute of Technology
MJ = Mr. Jaakko Mäkinen, Finnish Geodetic Institute
AM = Mr. Age Midtsundstad, Geographical Survey of Norway
LP = Dr. Lennart Pettersson, Geographical Survey of Sweden
EG = Prof. Erwin Groten, Technische Hochschule Darmstadt
MB = Dipl.-Ing. Matthias Becker, Technische Hochschule Darmstadt
*) see Tab. A.4

Tab. 7.1 Summary of gravity measurements on the line of 63°

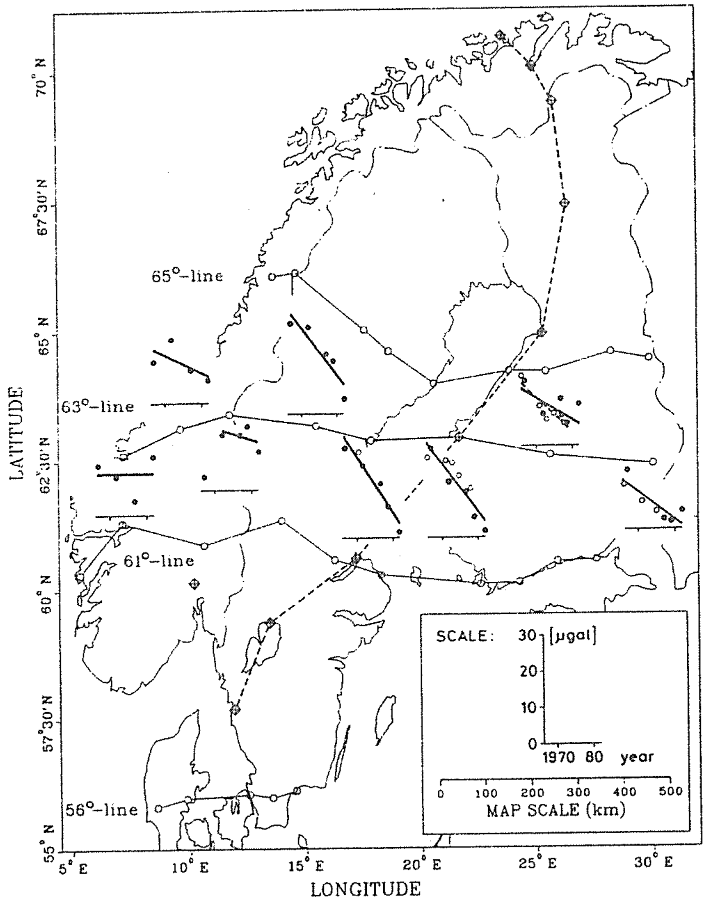

Fig. 7.1 Regression lines of observed gravity variations at the land uplift line od 63°

Station	obs.	r*	model	difference
Joensuu	-0.67	0.85	-0.70	+0.03
Äänekoski	-0.55	0.65	-1.24	-0.69
Vaasa	-1.25	0.94	-1.56	-0.31
Kramfors	-1.54	0.97	-1.54	±0.00
Stugun	-1.28	0.93	-1.30	-0.02
Kopperå	-0.30	0.49	-0.82	-0.52
Meldal	-0.46	0.63	-0.56	-0.10
Vågstranda	+0.04	0.05	-0.26	-0.30

r* = Regression-coefficient of observed values

Tab. 7.2 Comparison of observed and modeled gravity changes [μgal/year]

Acknowledgement

The authors gratefully acknowledge the good cooperation and assistance given by the following institutes:

Finnish Geodetic Institute, FGI, Helsinki, Finland
Lantmäteriet, LMV, Gävle, Sweden
Norges Geografiske Oppmaling, NGO, Hønefoss, Norway.

Prof. C. Gerstenecker of the Institute of Physical Geodesy, IPG, made available the measurements of 1971 and 1972.

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Appendix

A.1. Instrumental corrections

A.1.1 Scale factor

Instr.	Scale factor
G54	1.000
G120	1.00025
G290	1.000
G45	1.00084
G142	1.00009
G195	1.0000
G258	1.00037
G378	1.00058
D38	1.00122

A.1.2 Periodic errors

Instr.	Period P c.u.	Amplitude A [μgal]	Phase x_o [°]
G45	1.0	3.0	317.0
G142	1.0	3.8	272.0
D38	1.625 3.25	3.13 2.79	145.8 52.9

periodic errors are given as $A \cdot \sin\left(\frac{360^o}{P} \cdot \text{reading} + x_o\right)$

A.2 Partial results

observer	AK	CG	weighted mean
publ.	AK,1978		mean
number of grav.	n=3	n=2	
Station	μgal	μgal	μgal
Joensuu			
Äänekoski	+355.1 3.3	+349.5 5.8	+352.9 2.7
Vaasa	-474.9 1.3	-499.7 6.1	-484.8 12.1
Kramfors	-371.5 4.0	-372.9 7.6	-372.1 0.7

Tab. A.1 Measurements in 1971 on the line of 63°

observer	LP	CG	weighted
publ.	AM,1978		mean
no. of grav.	n=2(?)	n=2	
Station	μgal	μgal	μgal
Vaasa			
	-368.3±2.7	-372.0±5.7	-370.2±1.8
Kramfors			
	-52.8±2.3	-49.3±5.7	-51.0±1.8
Stugun			
	+92.1±2.5	+80.2±5.6	+86.2±6.0
Kopperå			
	-3.7±2.3	-1.4±5.8	-2.6±1.2
Meldal			
	-565.7±2.5	-558.3±5.6	-562.0±3.7
Vågstranda			

Tab. A.2 Measurements in 1972 on the line of 63°

observer	AK	EG	LP	weighted
publ.	AK,1982		LP, priv.comm.	mean
no. of grav.	n=1	n=2	n=2	
Station	μgal	μgal	μgal	
Joensuu				
	+347.8±6.4	+353.5±2.2	+357.0±8.0	+353.8±2.4
Äänekoski				
		-538.0±2.0	-540.0±8.0	+539.0±0.4
Alajervi				
		+97.6±2.0	+91.5±10.5	+96.4±2.3
Kuortane				
		-52.6±2.0	-56.0±1.0	+53.0±1.5
Vaasa				
	-375.9±5.0	-371.5±4.3	-369.5±3.9	-371.6±1.6
Kramfors				
		-53.5±4.3	-44.5±3.8	-49.0±4.5
Stugun				
		+34.6±2.1	+45.5±0.5	+40.0±5.5
Follinge				
		+59.6±2.4	+56.0±6.0	+57.8±1.8
Kopperå				

Tab. A.3 Measurements in 1979 on the line of 63°

observer	AK	LP,LH	AM	weighted
publ.	AK,1978	AK,1978	AM,1978	mean
no. of grav.	n=2	n=4	n=3	
Station	μgal	μgal	μgal	μgal
Joensuu				
	+357.4±2.0	+356.3±2.6	+365.7±6.4	+359.7±3.0
Äänekoski				
	-489.3±0.2	-492.2±1.9	-503.4±6.5 -489.9±5.5*	-495.3±4.1 -490.9±0.8
Vaasa				
	-372.8±3.5	-372.0	-372.8±4.6	-372.4±0.3
Kramfors				

* using only 2 gravimeters

Tab. A.4

Investigation of Non-Linear Calibration Terms for LaCoste-Romberg Model D Gravity Meters

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Hamburg 11. - 13. August 1983

Abstract

Non-linear calibration terms for three LaCoste-Romberg model D gravity meters have been investigated using the recently established 300 mgal calibration line "Cuxhaven - Hannover - Harz", which is an enlargement of the "Hannover - Harz" calibration line. Significant quadratic and cubic calibration terms have been detected, which produce deviations up to ± 30 µgal from a linear calibration function. The accuracy of observed gravity differences, estimated by adjustments of gravity networks, improved by approximately 30% when regarding the non-linear calibration terms.

1. Introduction

Since several years, LaCoste-Romberg (LCR) gravity meters model D are available, possessing a limited measuring range of approximately 200 mgal (1 mgal = 1000 µgal = 10^{-5} m·s^{-2}), which can be shifted over the earth's gravity range by turning a reset screw. The model D meter is a modification of the model G meter by reducing the transmission ratio of the lever system by a factor of 1:17. This modification results in reduction of periodic errors compared to model G meters, produced by the masuring screw and the gears (HARRISON and LaCOSTE 1978). Although the manufacturer determines only a uniform calibration factor for model D gravity meters, there is no reason to suppose an elimination of non-linearities in the lever system, as a result of this modification.

To investigate non-linear effects at LCR model D gravimeters, the following methods can be applied:

1. The "Cloudcroft-Junior" method used by the manufacturer for the relative calibration of Model G meters (KRIEG 1981) is transferable to model D meters calibration (LAMBERT et al. 1981). By this purely laboratory method, a constant gravity change is induced to the gravity meter, when a small auxiliary mass is added to the beam's weight and removed. Because the gravimeter's beam acts as a lever, different gravity ranges can be simulated by moving a second, displacable mass which changes the center of the mass of the beam. This enables to observe a constant gravity difference at different measuring screw positions and to determine relative scale factors which have to be converted to absolute values by measuring a known gravity difference. The disadvantage of this method is, that it can only be applied by the manufacturer.

2. A constant gravity difference of about 30 mgal is observed at different positions of the measuring range by small changes of the reset screw position. If the gravity difference is known with high accuracy, this is an absolute calibration method. Otherwise it gives only relative scale fators. This method allows not the separation of possible effects produced by changing the reset screw position from non-linear effects in one reset screw position. Advantageous is, that the observations can be carried out inside a multy-storey building under good environmental conditions.

3. Observations on a high accuracy calibration line covering the measuring range of model D meters are used at the third method. For that purpose, the calibration line "Cuxhaven - Hannover - Harz" (see section 2) can be used. Advantageous hereby is that possible effects caused by resets can not influence the results, when the observations are made in one reset screw position. A disadvantage of the method shows itself in the larger effort of collecting a reasonable number of data and in the existence of only a very limited number of calibration lines, suitable for the intended purpose.

Non-linear effects at LCR model D gravity meters have been found by a number of investigators. STEINHAUSER (1978) got non-linearities up to 72 µgal at LCR D-9, when comparing measurements of the same gravity difference carried out at different reset screw positions. At LCR D-6 and LCR D-13, LAMBERT et al. (1979) found a dependence of the scale factor from the dial reading of some parts in 10^4 applying the same method; but application of the determined scale factor functions in a network resulted in deterioration in agreement between the two instruments. A dependence of the scale factor function from the reset screw position is not ruled out. The same effect is supposed by TORGE and KANNGIESER (1980) after analyzing observations with LCR D-14 on the European absolute calibration line, introducing a constant scale factor for different reset screw positions. Quadratic calibration functions for LCR D-14 and LCR D-23 have been determined by KANNGIESER et al. (1983), giving up to 30 μgal deviations from the manufacturer calibration. GÖTZE and MEURER (1983) found non-linear effects up to 60 μgal at LCR D-8 and LCR D-9 using observations of a single gravity difference at different reset screw positions.

In the presented report a description of our investigations concerning non-linear calibration terms for the instruments LCR D-8, D-14, and D-23 on the calibration line "Cuxhaven - Hannover - Harz" as well as a description of this calibration line is given.

2. The calibration line "Cuxhaven - Hannover - Harz"

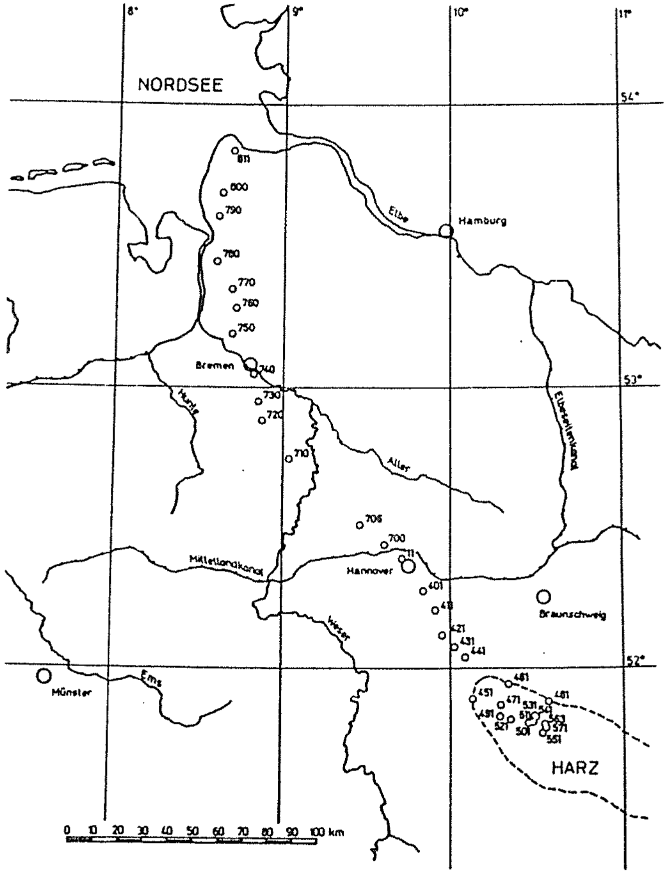

Fig. 1: Calibration line Cuxhaven-Hannover-Harz

The aim of the gravity meter calibration system Hannover (KANNGIESER et al. 1983) is to establish a number of stable gravity stations with high accuracy. The calibration line "Cuxhaven - Hannover - Harz" (Fig. 1) is an enlargement of the former "Hannover - Harz" line and is part of this system. The gravity meter calibration system Hannover allows the determination of all periodic, linear and non-linear calibration terms for LCR model D and G meters. The calibration line "Cuxhaven - Hannover - Harz" utilizes the gravity variation with latitude and height, extending from station Cuxhaven no. 811 (ϕ = 53°50'19", H=9 m) to station Oberharz no. 571 (ϕ = 51°47'10", H = 824.844 m). The stations are monumented with concrete pillars (45 cm x 45 cm), allowing simultaneous observations with four LCR gravity meters. The maximum gravity difference is about 300 mgal and neighboured stations have an average gravity difference of 10 mgal.

Between 1977 and 1983, more then 3000 gravity differences have been observed on the calibration line, employing altogether 10 LCR model G and 3 LCR model D gravity meters. The calibration line has been connected by 7 LCR model G and 1 LCR model D gravimeter to 10 absolute stations, observed by the Istituto di Metrologia << G. Colonnetti <<, Torino (CANIZZO et al. 1978, Fig. 2) and by 2 model G gravimeters to the absolute station Paris A.

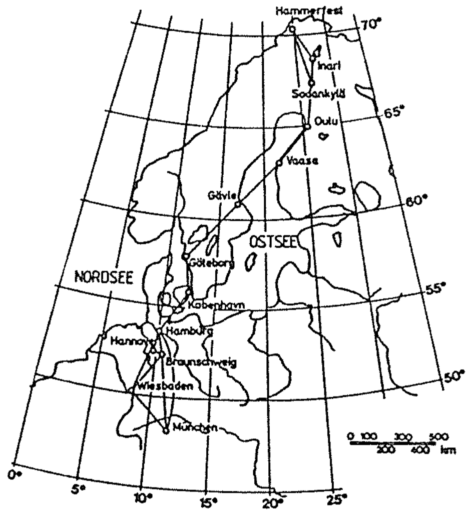

Fig. 2: Gravity measurements on the northern part of the European gravimetric absolute calibration line used for the gravity meter calibration system Hannover

The data preprocessing comprises the transformation of the gravity meter readings to gravity units, using the manufacturer's conversion tables for the model G instruments and the manufacturers constant calibration factors for the model D instruments, the tidal reduction and the correction of air pressure influence. For the calculations of earth tides, the CARTWRIGHT/TAYLER/EDDEN tidal potential development with 505 waves (CARTWRIGHT and TAYLER 1971, CARTWRIGHT and EDDEN 1973) has been used, including the time independent terms M_o, S_o. The program has been developed by WENZEL (1976).

Common adjustments have been performed introducing the preprocessed gravity differences and the absolute gravity values. The standard deviation of the absolute values of CANNIZZO et al. (1978) is estimated to ± 10 µgal and of SAKUMA (1976) to ± 2 µgal. The quality of the calibration line is documented by the standard deviation of the adjusted gravity differences, which is about ± 2 µgal for the Hannover-Harz division of the line and ± 5 µgal for the Cuxhaven-Hannover division due to the low number of observations carried out in this part up to now. The precision of the division Cuxhaven-Hannover will be improved by subsequent measurements.

A gravity calibration line should guarantee stable gravity values for a long time. This requires a stable monumentation of the stations, the non-appearance or the control of height variations, and the absence or control of gravity variations due to environmental conditions. The monumentation and height control of the calibration line Cuxhaven-Hannover-Harz is excellent, because the stations are integrated within the height control network of the Niedersächsisches Landesverwaltungsamt - Abt. Landesvermessung - and thus being regulary controlled and surveyed. Possible gravity variations due to ground water table changes will be controlled for five stations in the division Cuxhaven-Hannover, because they are situated in direct neighbourhood of ground water gauges.

3. Non-linear Calibration Terms for LCR Model D gravity meters

Between 1977 and 1983 in total about 1100 gravity differences have been observed in different reset screw positions with LCR model D-8, D-14 and D-23 on the Hannover-Harz division of the calibration line, suitable for the determination of non-linear calibration terms. By selecting the observations carried out in a specific reset screw position for a single instrument, free network adjustments can be carried out, which contain only readings at approximately the same dial position for the observed sites. The comparison of the gravity values determined in this manner, with values determined in a common adjustment using all instruments (KANNGIESER et al. 1983), gives a number of differences, named in the following "empirical calibration function", for the reset screw position in question. Carrying out free adjustments for all used reset screw positions of an instrument, a number of empirical calibration functions for each instrument can be collected. An example for LCR model D-23 is given in Fig. 3; deviations from the manufacturer's calibration up to 50 µgal are apparent, but can reach up to 160 µgal for other instruments. The standard deviations of the sample points of the empirical calibration functions are estimated to ± 5...10 µgal; the empirical calibration functions, sampled in different epochs and at different reset screw positions, agree within the noise level. An influence due to changing the reset screw position cannot be recognized, but naturally we cannot exclude reset screw effects beyond the noise level of 5...10 µgal. The investigations of LCR D-8 and LCR D-14 gave similar results.

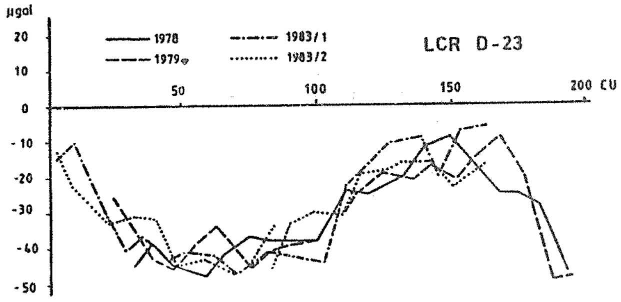

Fig. 3: Empirical calibration functions for LCR D-23 obtained in different epochs and at different reset screw positions

For the processing of gravity observations with a computer, it is convenient to have a continous calibration function, defined by a set of parameters. Moreover, a parametrized function is necessary in order to adjust a calibration function from calibration measurements. Because no physical assumptions for the structure of the D meter's calibration function are available, we have chosen the following polynomial model:

$$F(z_i) = z_i' + \Delta F(z_i') \quad , \qquad (1)$$

$$z_i' = F_o \cdot z_i \qquad (2)$$

$$\text{and } \Delta F(z_i') = \sum_{k=1}^{m} z_i'^{k} \cdot E_k \qquad (3)$$

with z_i = gravimeter's reading at station i,
$F(z_i)$ = calibrated reading
z_i' = gravimeter's reading multiplied by the manufacturer's calibration factor
$\Delta F(z_i')$ = corrections to be applied to z_i'
m = maximum degree of the calibration polynomial
E_k = polynomial calibration coefficient of degree k
F_o = manufacturer's calibration factor.

In Fig. 4 are shown the corrections $\Delta F(z_i')$ computed from the adjusted polynomial calibration model of degree 1, 2 and 3 for the instrument D-23 in comparison with the corresponding empirical calibration functions. The 1. degree and 2. degree functions have been shifted vertically. Obviously, the calibration function cannot be sufficiently approximated by a polynomial of degree 1 or 2 to the empirical calibration functions because of large discrepancies. The approximation by a third degree polynomial is sufficient, the deviations to the empirical calibration functions are in the order of the 5...10 µgal noise level. The adjustment of calibration polynomials, valid for the whole measuring range of the instruments, is only possible if the introduced observations are regulary sampled within the whole measuring range of the instrument. Otherwise, the adjusted calibration function is only valid for the part of the measuring range covered with observations and large errors are produced in the other parts. This problem increases with the degree of the calibration polynomial, thus higher degree polynomials have not been determined.

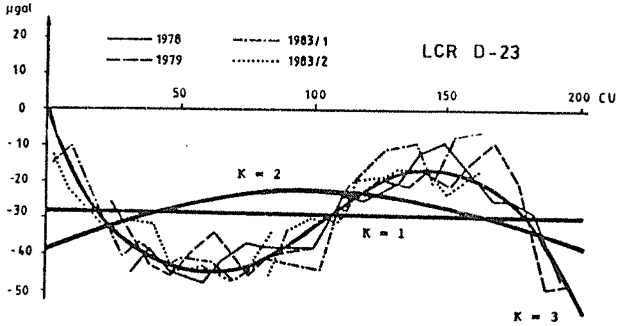

Fig. 4: Adjusted polynomial calibration functions of different degrees k in comparison with empirical calibration functions

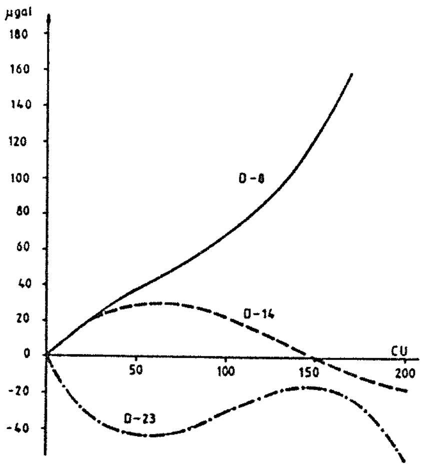

Fig. 5: Calibration functions of 3rd degree for LCR D-8, D-14 and D-23

In Fig. 5 are given corrections $\Delta F(z_i')$ computed from a third degree polynomial calibration model for the instruments LCR D-8, D-14 and D-23. Remarkable deviations from the manufacturers calibration up to 160 μgal are displayed for the LCR D-8, which are mainly produced by an error of the manufacturer's calibration factor of about one part in 10^3. The calibration for that instrument could be much improved by consideration of a more accurate calibration factor, i.e. a first degree calibration polynomial. But the restriction to a first degree calibration polynomial can not approximate the calibration function sufficiently, as shown in Fig. 6 by the differences between third and first degree polynomial calibration for the three investigated instruments.

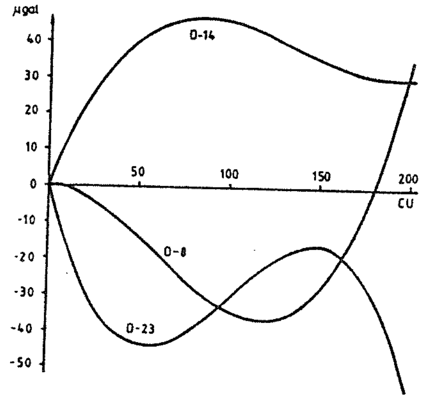

Fig. 6: Differences between adjusted 1st degree and 3rd degree calibration functions for LCR D-8, D-14 and D-23

The quality of polynomial calibration models of degree 1, 2 and 3 may be expressed by the standard deviation of a gravity difference beeing once observed in a network. The standard deviations given in Table 1 are only comparable for a specific instrument in a specific network because they strongly depend on the particular configuration of the observations. Even if the considered networks - containing mainly small differences (~10 mgal) - are not very sensitive for the verification of different calibration models, the advantage of calibration by 3. degree polynomials becomes clear (Table 1).

The transfer of the determined polynomial calibration model to a different gravity range has been investigated by the evaluation of observations carried out at the Cuxhaven-Hannover division of the calibration line. These observations had not been introduced in the adjustment of the calibration parameters. Preliminary gravity values of the stations have been computed by a common adjustment of the three instruments introducing the adjusted 3. degree polynomial calibration parameters; by carrying out adjustments introducing only observations for a specific instrument, the differences between gravity values from the common adjustment and from the adjustment of the specific instrument's observations should be random, if the non-linear effects have been successfully modeled. This can be assumed for the 3. degree calibration parameters, as shown in Fig. 7a; the 1. degree calibration parameters produce a worse agreement between the three instruments. as shown in Fig. 7b. The rms deviations for the specific instruments (table 2) are between ± 3 and ± 7 µgal for the 3. degree calibration polynomials and between ± 9 and ± 14 µgal for the 1. degree polynomials.

a: Instrument b: observation period	Standard deviation [µgal] Manufacturers calibration	Calibration polynomial of degree K adjusted K = 1	K = 2	K = 3
a: LCR D-8 b: 1983	± 36	± 17	± 12	± 11
a: LCR D-14 b: 1977-1983	± 14	± 13	± 11	± 10
a: LCR D-23 b: 1978-1983	± 12	± 12	± 11	± 9

Table 1: Standard deviations obtained for LCR D-8, D-14 and D-23 when adjusting polynomial calibration functions of different degrees.

Instrument	RMS deviation [µgal] calibration polynomial of degree K introduced K = 1	K = 3
LCR D- 8	± 14	± 7
LCR D-14	± 10	± 7
LCR D-23	± 9	± 3

Table 2: RMS deviations for LCR D-8, D-14 and D-23 obtained in a network when applaying calibration polynomials of degree 1 and 3 have been adjusted

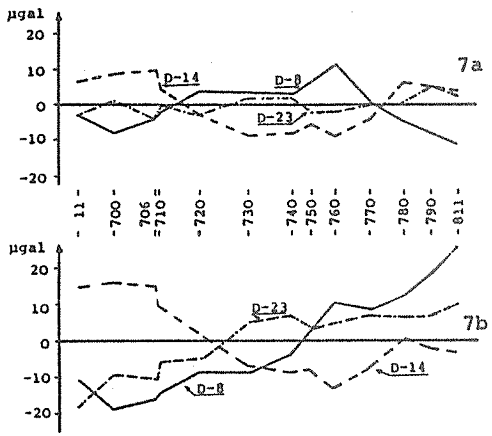

Fig. 7: Transfer of the calibration model to a different gravity range.
7a: Deviations for 3. degree calibration polynomials
7b: Deviations for 1. degree calibration polynomials

The calibration parameters of LCR D-8, determined on the calibration line, can be compared with non-linear effects investigated by GÖTZE and MEURERS (1983) for the same instrument, using obervations of an unknown gravity difference (~27.3 mgal) at different reset screw positions. The corrections for the observed gravity differences can be computed from the adjusted 3. degree calibration polynomial and are compared in Fig. 8 with the results from GÖTZE and MEURERS (1983). The rms discrepancy of ± 7 µgal is compatible with the noise level of the observations as well as the calibration parameters.

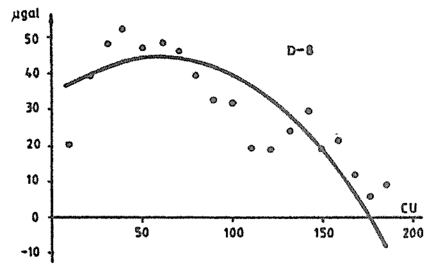

Fig. 8: Non-linear effects of LCR-D-8 for a 27.3 mgal gravity difference.
Dots: Observations of GÖTZE and MEURERS (1983)
Line: Computed from calibration polynomial of degree 3

4. Conclusions

Non-linear effects up to ± 30 μgal have been found for three LCR D meters, and have been modeled sufficiently by a third degree calibration polynomial. The application of the calibration model improved the accuracy of observed gravity differences by about 30% for the investigated gravity networks. But the adjustment of calibration functions from any gravity networks may be dangerous; special calibration measurements carried out on a calibration line should be used for that purpose. No changes of the non-linear effects with time or connected with changing the reset screw position above the noise level of ± 5...10 μgal occured in our investigations. But even by carrying out carefully numerous calibration measurements, the calibration of a LCR model D gravity meter can only be guaranteed within ± 5...10 μgal accuracy. Thus, larger gravity differences observed with a single LCR D meter may have an uncertainity of the same order; which means that the μgal level cannot be guaranteed.

Acknowledgements

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Calculations have been carried out at CDC Cyber 76 of the Regionales Rechenzentrum für Niedersachsen, Hannover.

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Consideration about gravity and elevation changes observed in the Travale geothermal field

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Abstract

Renewal of exploitation in the Travale geothermal field began in 1973. Since then a precise levelling network has been set up and several observations made.

In 1973 a microgravity network was established as well, and reobserved four times.

Finally in 1983 an absolute gravity site has been included into the gravity net.

Results of combined gravity and height measurements have been indicative of physical phenomena developing within the reservoir.

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Introduction.

The complex interaction between exploitation of a geothermal field and the environments has multiple aspects.

One of them, which plays a quite important role, is certainly the subsidence effect.

The simple height variation is, of course, associated with a gravity change. Thus in principle, it is possible to study a subsiding field by means of gravity measurements.

The correlation between gravity and height variation is, however, complicated in first place by the different accuracy level achievable by high precision levelling and microgravity. This actually limits to about 1 cm the sensibility of a microgravity network in terms of height changes.

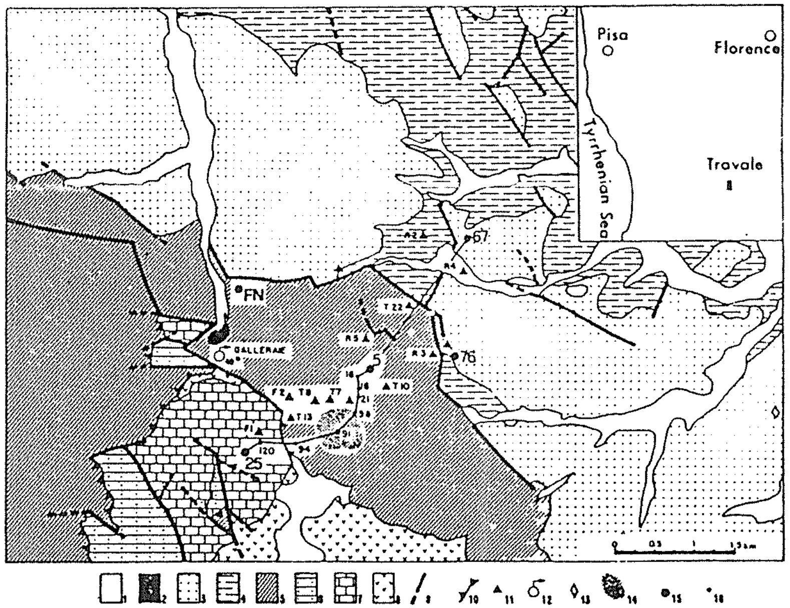
In second place, the subsidence is not the only effect to which a gravimeter is sensitive.

Even bigger effects may be due to water table variations, or fluid movement within the reservoir. In addition, the subsidence could be the effect of a density variation or could result in a compaction of the first layers.

These considerations suggest cautele in the interpretation of gravity changes in terms of height variations.

In case of significative residuals, after applying a free air correction to gravity data, these could be interpreted in terms of physical phenomena of the geothermal field.

In this the case of highest interest, because it could be then possible to achieve important information about the dynamic of the field.



Geological sketch map. (1) Recent alluvia; (2) travertines (Quaternary); (3) marine deposits: mainly conglomerates, sands and clays (Pliocene); (4) lacustrine and lagoonal deposits: predominantly clays, sands and conglomerates; gypsum layers in lagoonal clays; (5) flysch facies formations: mainly shales, marls, limestones, sandstones, ophiolites (Eocene – Upper Jurassic); (6) quartzose – feldspatic – micaceous sandstones ('macigno'); varicoloured shales, marls ('scaglia') (Oligocene – Cretaceous); (7) radiolarites, Posidonia-bearing marls, cherty limestones, ammonite-bearing nodular limestones, blackish limestones and magnesian limestones (Malm – Rhaetian); (8) brecciated magnesian limestones and cavernous limestones (Norian); (9) normal fault; (10) main tectonic sliding; (11) well; (12) thermal spring; (13) mofette; (14) densely drilled area; (15) main gravity stations; (16) auxiliary gravity stations. Drawn partly from detailed survey by Lazzarotto and Mazzanti, 1976.

The aim of the project in the Travale geothermal field, in the most important geothermal area in Italy, was just to study the actual limits of microgravity networks for subsidence observations, and to verify the possibility to achieve information about the dynamic of the reservoire by means of associated observations of gravity and height variations.

Data recording and analysis.

As already discussed ina previous report (Geri et al., 1982), a precise levelling network has been set up in the Travale field since 1973. Results of reobservations performed during 1978 - 1980 indicate a subsidence of the central part of the geothermal field at an average rate of 20 mm/year (Geri et al., 1981).

A precision gravity network was set up in 1979 and reobserved four times.

The survey consists in a first order net which includes three external points located on sites considered to be geologically stable outside the geothermal field. (Fig. 1). One of this (Z 2) has been replaced in 1981 by an absolute site observed with the IMGC transportable absolute gravimeter.

The first order net has been integrated with an auxiliary net of 27 bases which were distributed within and around the main geothermal field (Fig. 2). The aim of the net is to survey points or areas most affected by extraction activities.

Field procedure were standard in order to minimize the effects of drift, external temperature variations, tares in the meters.

The two meter used (D - 18 and G-297) have been trasported on the seat of a car and exposure of the gravity meters to temperature gradients have been avoided.

Each pair of stations was linked by four independent ties according to the scheme A B A B A.

The D meter was reset at the beginning of each survey, at the same counter reading to avoid periodical errors effect.

The recorded data have been adjusted by means of the processing system developed in the Earth Physics Branch, Dep. of Mines and Resources, Canada (Morelli et al., 1972).

Because of the unknown effect of non linearities, mainly on the G meter, the data of the two gravimeter have been treated separately.

Discussion of the results.

a) Accuracy limits.

The r.m.s.e. of observations of unit weight ranges from 3 to 4 μGal for the D-meter and from 4 to 5 μGal for the G meter. From these results it may be said that the improvement obtained by the use of a model D with respect to model G is of the order of magnitude of 2.

However more important differences appear if we look over the residuals hystograms.

In Fig. 3 the hystograms of the observed gravity variations with time are depicted.

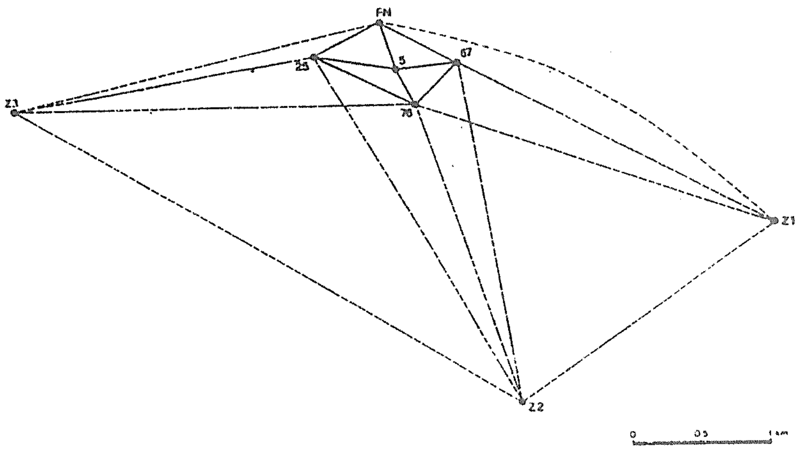


Fig. 1 The main gravity network, comprising five stations within the geothermal area and three external bases located on geologically stable sites

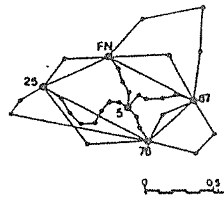


Fig. 2 The auxiliary gravity network, comprising 27 stations distributed over the main network area, for a detailed monitoring of the points most affected by extraction activities.

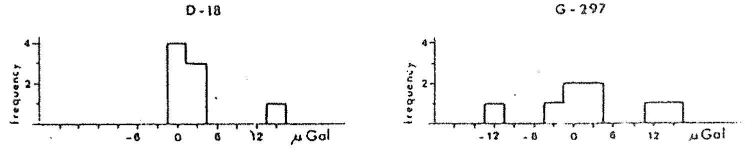


Fig.3a Histogram of the gravity differences observed on the main network between March, 1979 and September, 1980, without free-air correction. The Δg values are grouped in classes of 3 μGal. Average standard errors: 3 - 4 μGal for the D18 data, 4 - 6 μGal for the G-297 data.

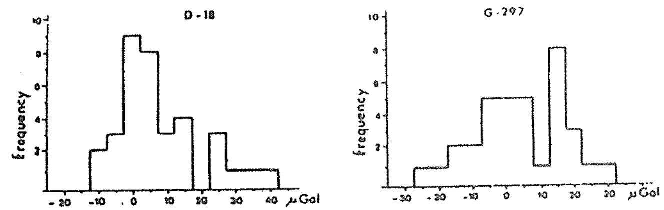


Fig.3b Histogram of the gravity differences observed on the entire network between March, 1979 and September, 1980, without free-air correction. The Δg values are grouped into classes of 5 μGal. Average standard errors: 5 - 8 μGal for the D-18 data, 6 - 12 μGal for the G-297 data.

It appears clearly that while with the D meter it is possible to identify a normal gauss distribution curve and lobs which lie outside the confidence interval, the curves with the G model results are not easily interpretable in this sense.

It is our opinion that the main difference between the quality of the results of the two meters is mainly due to periodical errors in the reading screw and to problem related to it.

As known the D meter reset screw allows to observe gravity always in the same counter range, so that the periodical errors effect can be avoided, even if it is unknown.

b) <u>Observed gravity variations with the time.</u>

The highest gravity variation observed in the Travale field range from 30 to 40 μGal (<u>Fig. 4</u>). These figures are well outside the confidence interval and could be than considered a physical phenomenum.

As already noticed, the geothermal field is subsiding with a rate of 20 mm/year.

The gravity changes may be than related with the subsidence, throught the free air gradient, or be related with density variations or mass movements within the reservoir, or both.

In all these cases the phenomena have an arel. pattern, and the net design allows to follow an areal variation of the potential field.

Thus, in order to give a more intelligible picture, a contouring of the height and gravity variations with

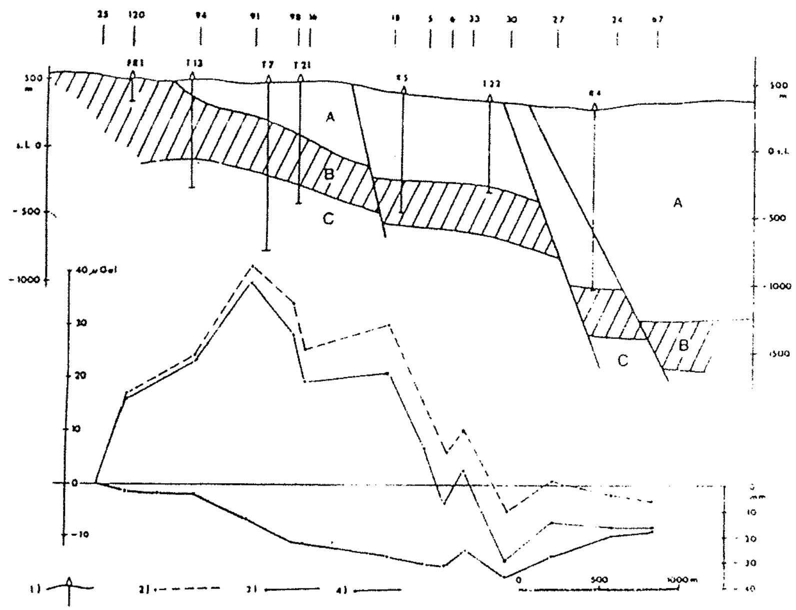


Fig. 4 Schematic cross-section. (A) Impermeable cover complex; (B) main reservoir; (C) metamorphic complex; (1) drilled wells; (2) observed gravity variations (March, 1979 – September 1980); (3) gravity variations corrected for topographic changes; (4) topographic changes (November, 1978 – October, 1980). Stratigraphic data from Cataldi *et al* (1970), Burgassi *et al.* (1975) and Casertano *et al.* (1977).

time has been performed.

As can be seen from the position map, the station density is enough to describe the "time" anomalies quite well in the central-southern part of the map where the more important exploitation activities occour.

By means of contouring program developed by dr. E. Klingele, Eidgenossische Technische Hochschule, Zurich, maps of height variations, gravity changes and residual gravity variations with respect March 1979 have been produced for the Nov. 1979, September 1980 and November 1982 surveys. (Fig. 5 to 13).

The height variarions with the time show a progressive land subsidence with a general trend which agrees with the trend observed over a longer period (1973 - 1980).

The central part of the field shows an heigh variation of 87 mm over three years.

If now we look over the observed gravity variations, some important features may be seen.

In first place, the main characteristics of the subsidence field are maintened by the gravity changes isolines, too.

The gravity field locates the area of highest subsidence rate with the same regional trend as well.

Applying a free air gradient correction however, an important difference appears.

From Fig. 11 to 13 it may be seen that the residual gravity variations isolines for the march 79 and November 1980 surveys have the same pattern as the total field. It might be than argued that the height variation doesn't fully explain the observed gravity change.

Fig. 13, relative to the 1982 survey however shows residuals which are not longer significative. At this time all gravity changes are explained be the associated height variations.

It is evident that the subsidence effect cannot be solved by a simple relationship between height and gravity variations.

It is more likely that exploitation activity results first in a density variation within the reservoir which has the land subsidence as effect. Thus the gravity change may be enhanced by the density variation.

Now, results of 1982 survey which, on the other hand, are quite fully explained by height variations, could be indicative of a slowing down of the process, source of the density variation hypotized in the previous surveys.

Furthermore, the south - west area of the survey indicates another interesting phenomenum.

As shown in Fig. 8 to 10 in this area a large gravity change, which has reached the highest value (42 µGal) in 1980, can be observed.

The gravity change is not associated with levelling variation.

This way interpreted in the past (Geri et al., 1982) as water saturation level variations within the reservoir.

Also this time anomaly has been reduced in amplitude and size in 1981 and 1982.

It is likely that these fluctuations are induced by alternating stages of exploitation and shut - in in the wells of the same area affected by the gravity variations.

Conclusions.

Land subsidence is a problem of primary interest in many areas in Italy.

Subsidence control by means of high accuracy levelling is an high cost tool.

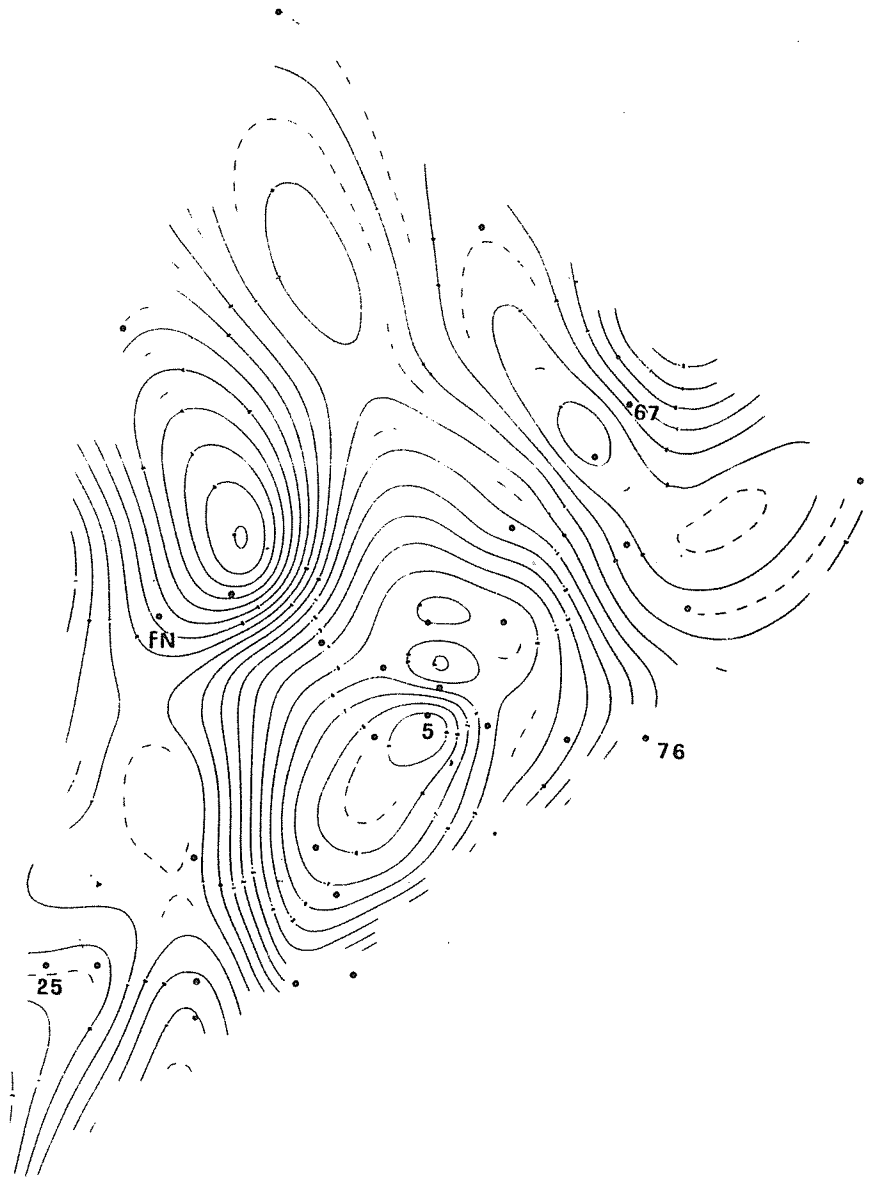
Results obtained in the Travale geothermal field are indicative of the fact that a subsiding area can be studied by means of gravity observations provided that the general subsidence trend and the interaction between internal density variations, or mass movements, and gravity are known.

This would led to the conclusion that gravity observations must be always associated with levelling data.

Even if this should be considered generally true, it is however possible, in our opinion, to use gravity to interpolate data between levelling surveys, reducing in this way the total cost of a land subsidence control program.

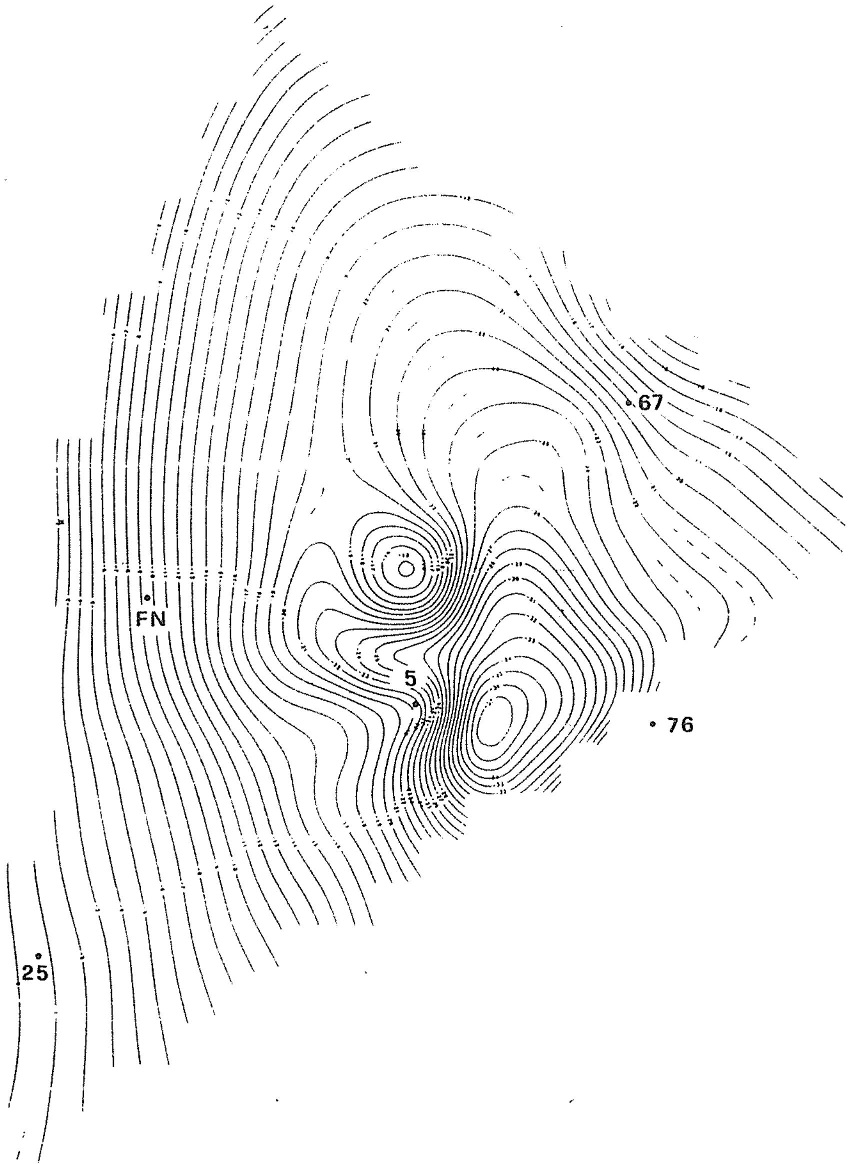
Furthermore, internal density variations, or mass movements, could have an effect on gravity data even bigger than the height variation itself.

These phenomena, if interpreted correctely, could give important information about the dynamic of the reservoir, or, generally, of the field.



C.I. : 1mm

Fig. 5 : Height variations "Nov. 79"



I, 1 mm

Fig. 6 : Height variations "Sep. 80"

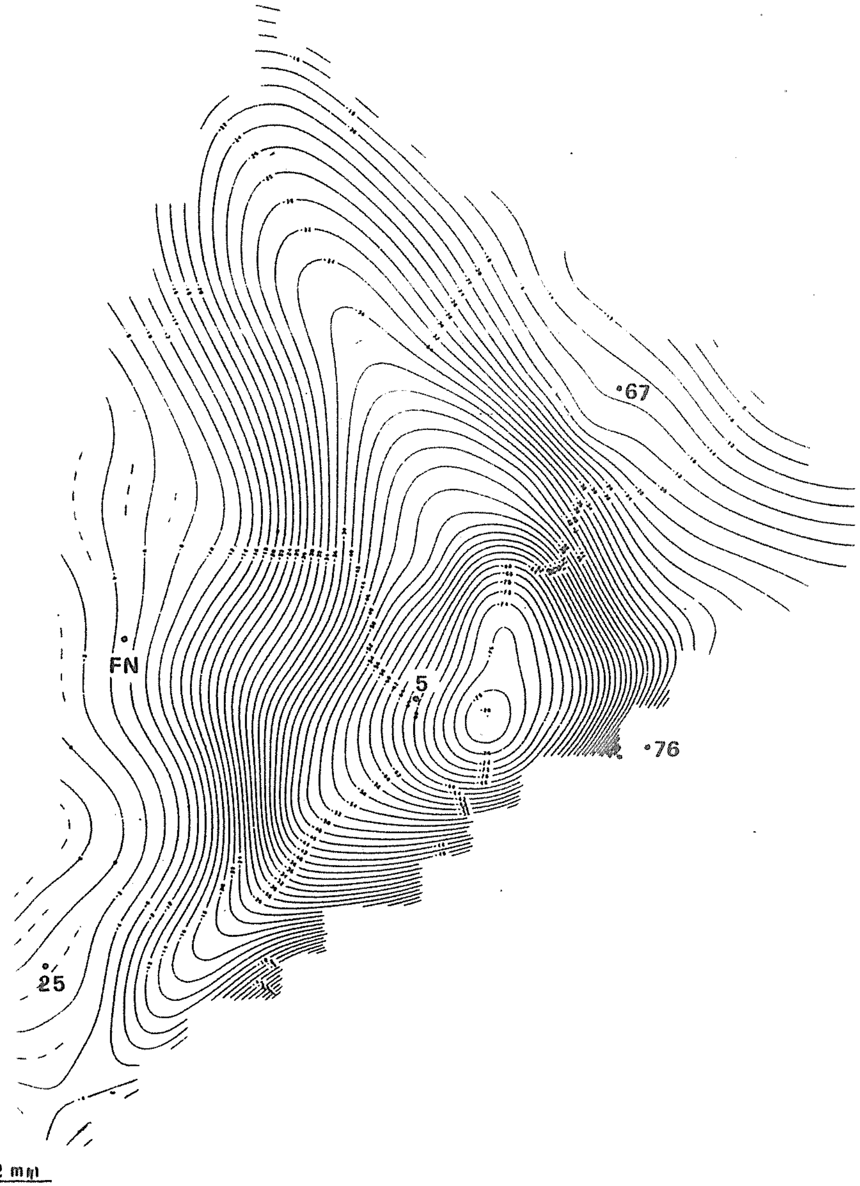
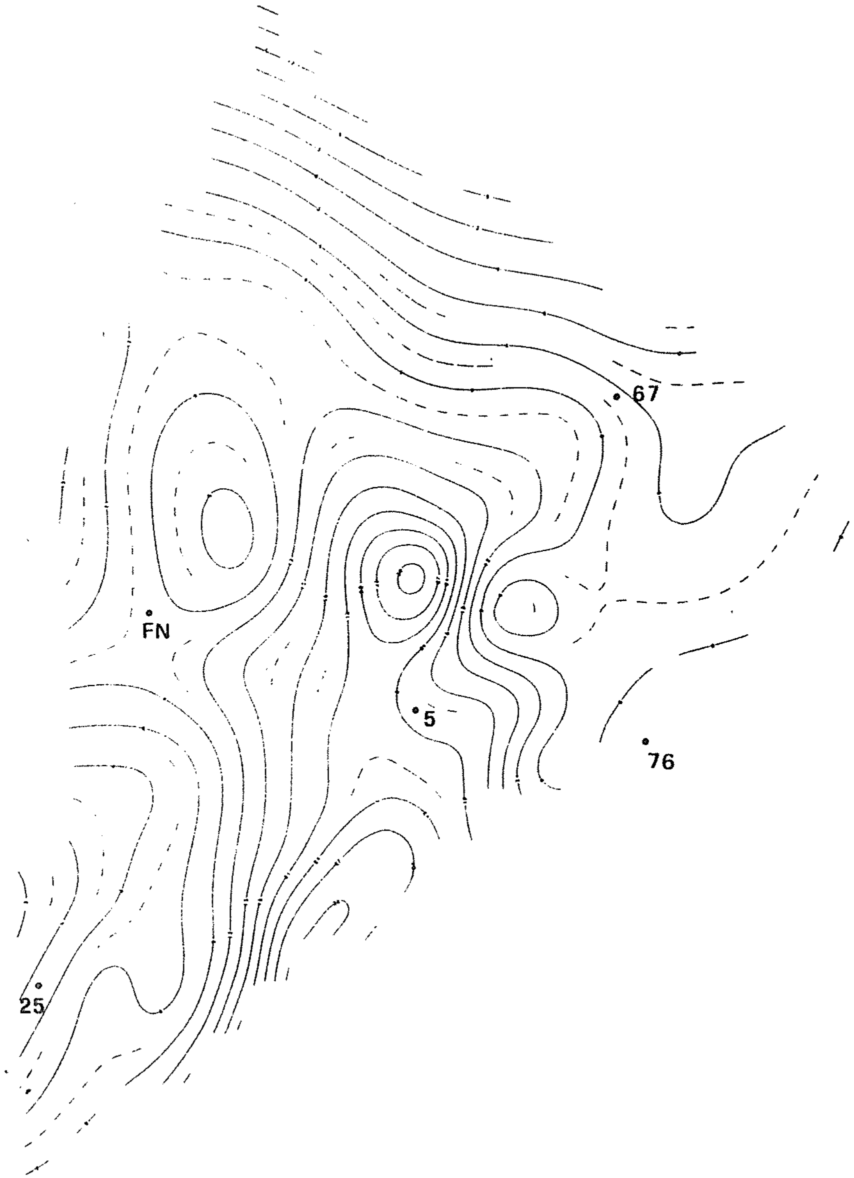
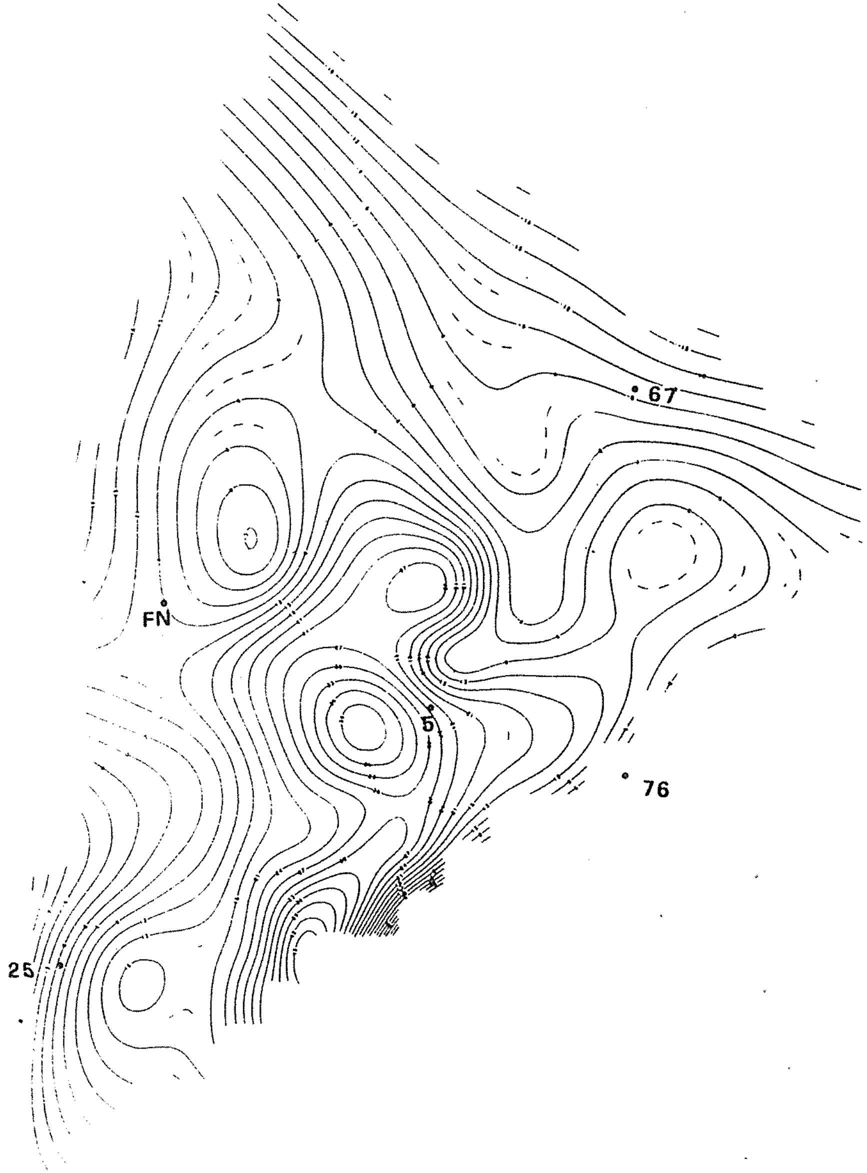


Fig. 7 : Height variations "Nov. 82"



C.I. 3 μGal

Fig. 8 : Gravity variations "Nov. 79"



C.I. 3 μGal

Fig. 9 : Gravity variations "Sep. 80"

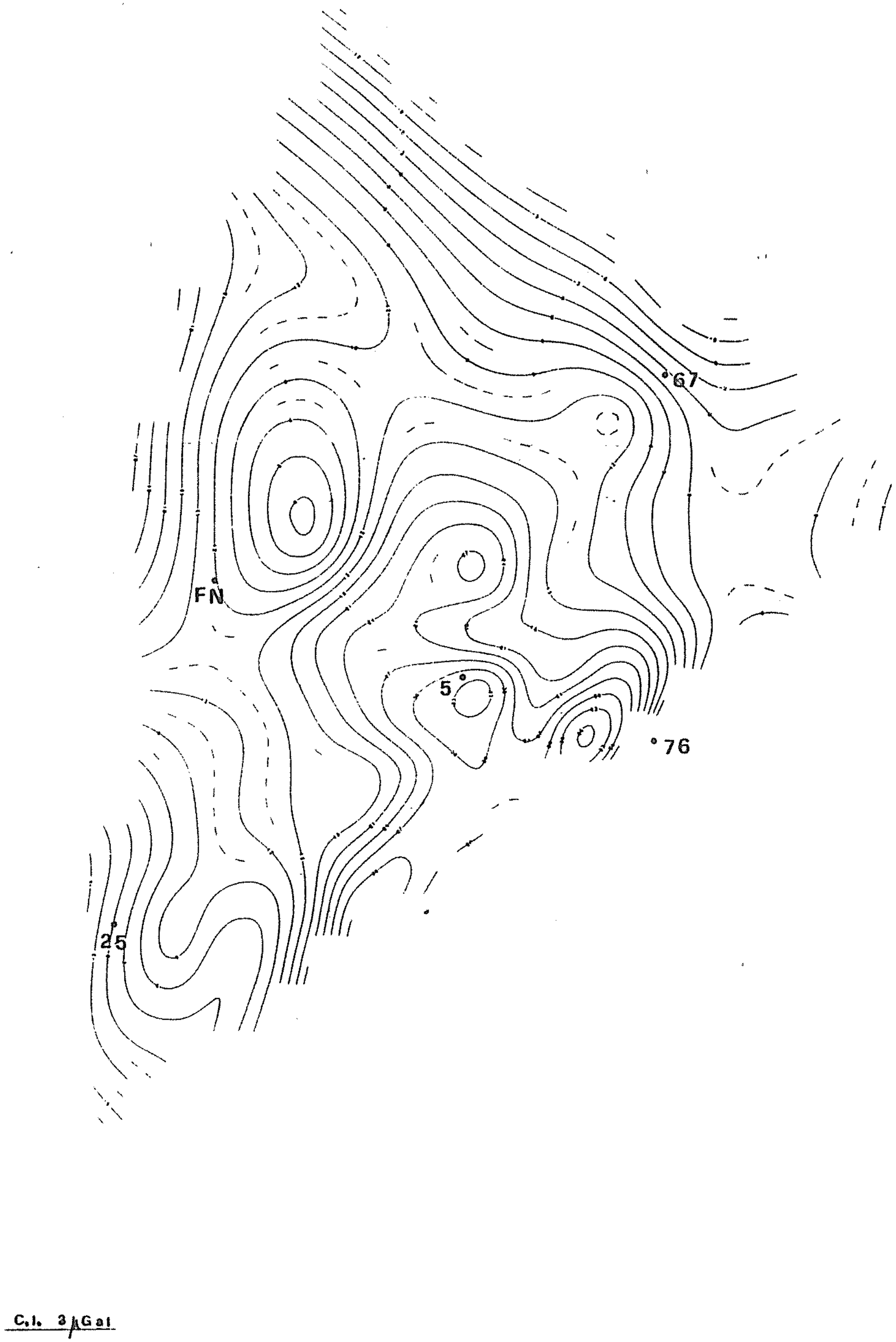


Fig. 10 : Gravity variations "Nov. 82"

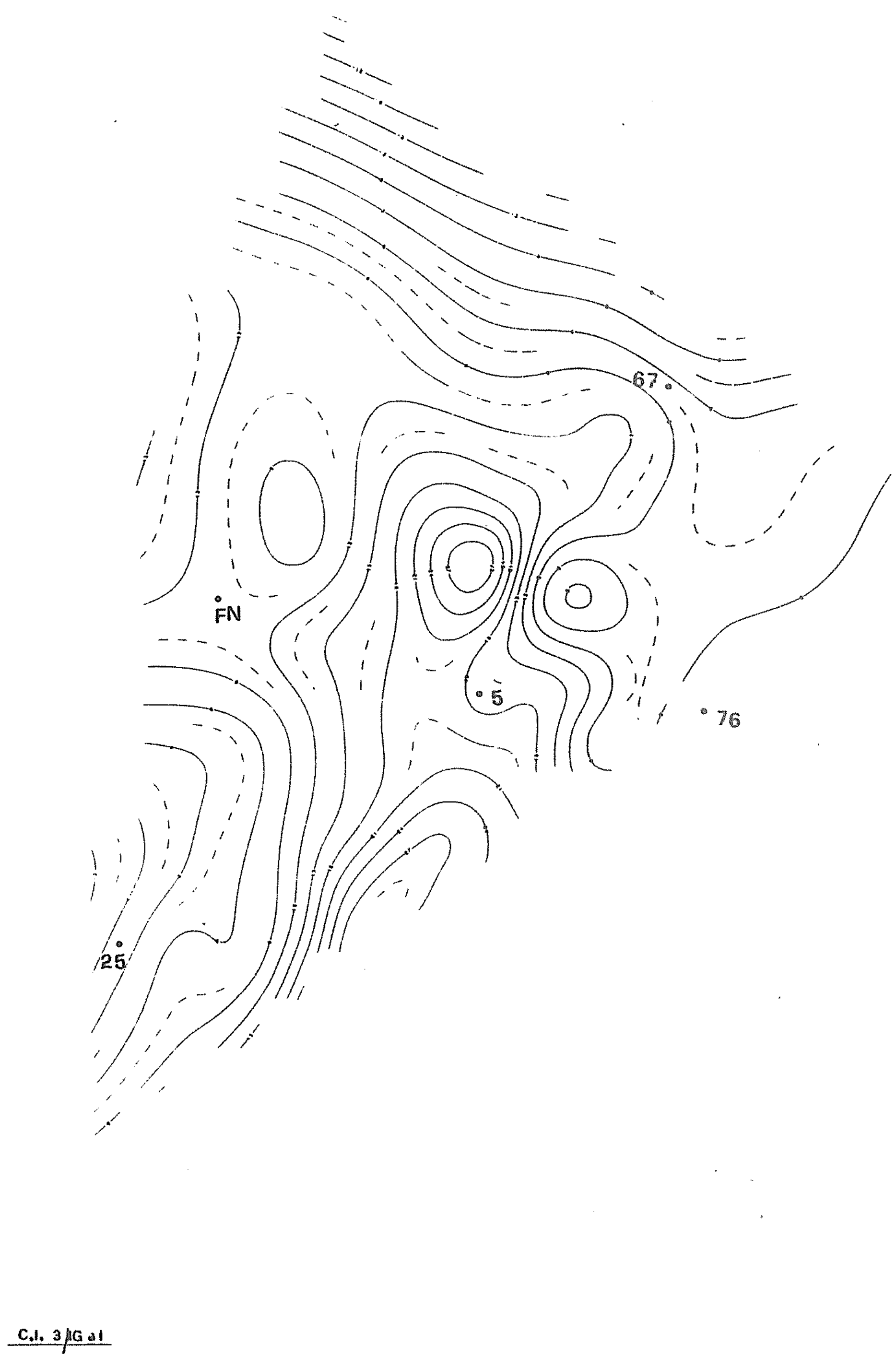
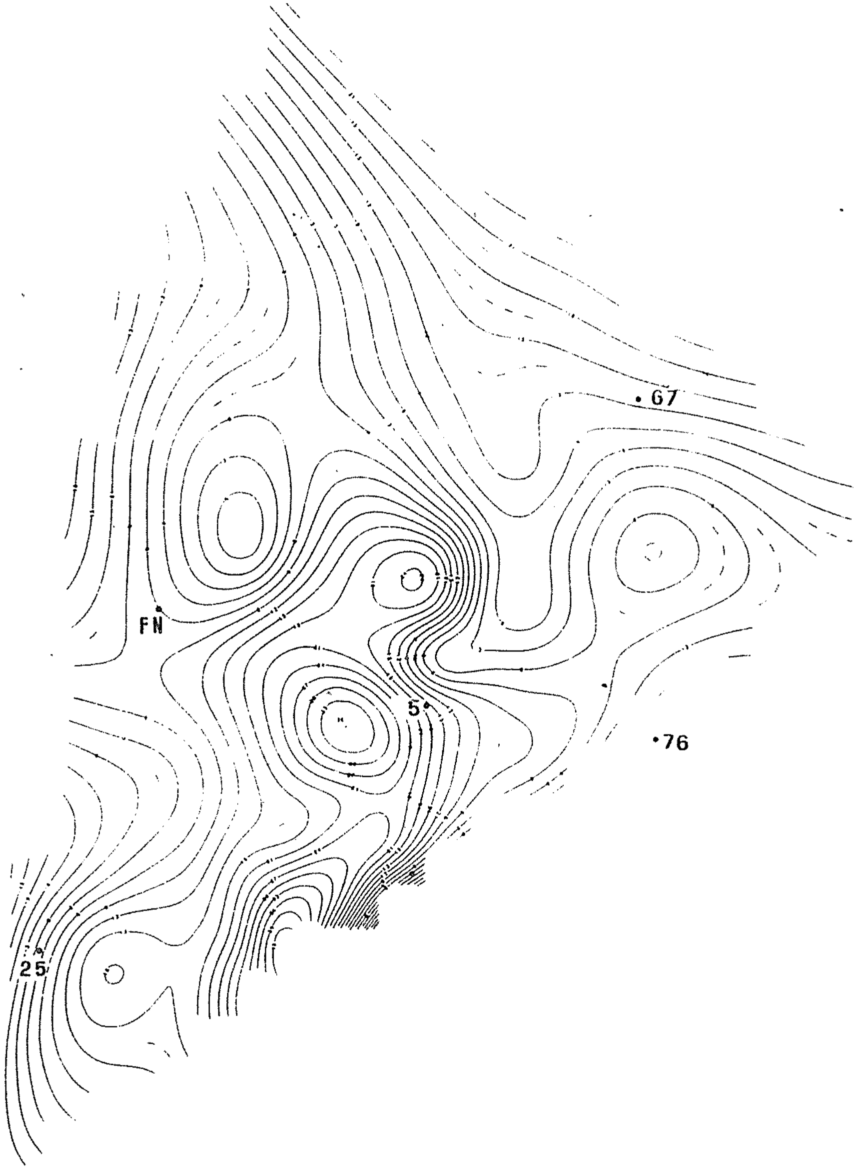
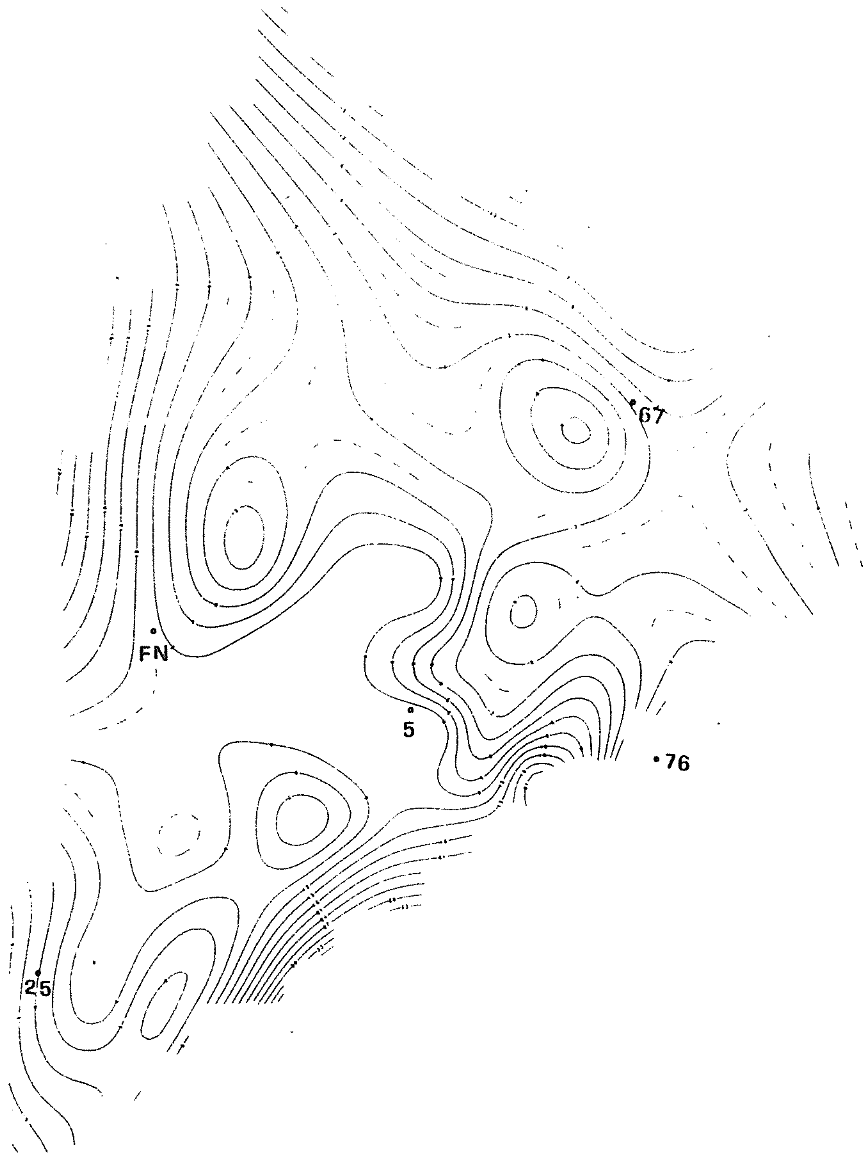


Fig. 11 : Residual gravity variations "Nov. 79"



C.I. 3 μGal

Fig. 12 : Residual gravity variations "Sep. 80"



C.I. 3 μGal

Fig. 13 : Residual gravity variations "Nov. 82"

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TIDE CORRECTIONS OF GRAVITY MEASUREMENTS IN CHINA

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Abstract

According to theoretical earth model and taking the effect of ocean tide into account (using the local map of Schwiderski and that in the coastal waters of China), the gravity tide values in the territory of our country have been estimated. Furthermore, in the light of the comparison of gravity tide variations actually observed in our country with the above-mentioned theoretical values, the accuracy of the gravity model aforesaid may each ±2 μgal. On these grounds, tide corrections for eleven observation values of absolute gravity observations in China are carried out.

I. Introduction

In our country, all of the completed absolute gravity measurement and extensivly launched fundamental gravimetric network as well as precise gravimetry require gravity tide corrections. According to paper[1], in order to make the accuracy of this correction reach the level of microgal, the accuracy determined for the gravity tide factor should be 1% and that of phaselag should be 0°.5. At present, the density of tide observations having been carried out in our country has not met the above-mentioned needs yet. To this end, the model of gravity tide correction set up in terms of theory in this paper is to provide for use. For the sake of testing its effectiveness, the comparison of it with the result actually observed has been also carried out. The result shows that the accuracy of the theoretical values of tide correction may amount to ±2 μgal.

II. Theoretical Gravity Tide Model

For the body tide, the theoretical gravity tide model may be composed of by complete harmonic expansions of Cartwright et al[2]:

$$\delta g_B = \sum_{i=1}^{505} \delta_i H_i \cos(\omega_i t + \chi_i - \Delta\varphi_i) \qquad (1)$$

Hi, χ_i and ω_i are the theoretical amplitude, the initial phase and angular frequency which may be calculated from astronomical parameters, δ_i, $\Delta\varphi_i$ are the tidal factor and phase lag of i constituent, which may be reduced from the internal structure model of the earth. If we assum the earth to be totally elastic, it is obvious that all $\Delta\varphi_i = 0$; in the meantime, for the sake of reducing the amount of work, equation (1) can be also simplified as follows:

$$\delta g_B = \delta_{th} \cdot \sum H_i \cos(\omega_i t + \chi_i) = \delta_{th} \cdot G(t) \qquad (2)$$

Where δ_{th} denotes the theoretical average tidal factor of gravity, G(t) is the theoretical gravity value calculated from astronomical parameters, which can be estimated by method as everyone knows[8]. Attention should be paid that, within the body tide obtained from formula (2) there exists apparemtly a constant term which has no relation with time, and in the meantime the permanent deformation of the earth is also assumed to be elastic, i.e. the permanent Love numbers and the elastic Love numbers are identically equal. In order to avoid this assumption, we adopt the suggestion of the International Committee of Standard Earth Tide. It is necessary to deduct the direct part of tidal gravitation in equation (2) and not the indirect part of permanent deformation. In other words, we use equation[3]:

$$\delta g_{\delta} = \delta_{th} \cdot G(t) - \delta \bar{f}_c \qquad (3)$$

$$\delta \bar{f}_c = -4.83 + 15.73 \sin\psi - 1.59 \sin^4\psi \quad \mu\text{gal} \qquad (4)$$

ψ is the geocentric latitude.

The most perfect theoretical model of gravity tidal factor is the solution given out by Wahr from an elliptical, rotating, elastic and oceanless earth model[4]. His solution shows that, the tidal factor will depend on latitude, as to diurnal wave, it will also relate to the angular frequency due to the dynamic effect of liquid core. But according to the analysis of relevant literatures, when comparing Wahr's theoretical value with the result actually observed, it is found the tidal factor has systematically a little lower level of 1%[5]. In this connection, Melchior and Debecker have given out a statistic theoretical tide formula. During our work, we will use these two formulas in order to have a comparison:

Wahr model:

$$\left.\begin{aligned}
\delta^{th}_{semi} &= 1.160 - 0.005\left[\frac{\sqrt{3}}{2}(7\sin^2\varphi - 1)\right] \\
\delta^{th}_{O_1} &= 1.152 - 0.006\left[\frac{\sqrt{6}}{4}(7\sin^2\varphi - 3)\right] \\
\delta^{th}_{P_1} &= 1.147 - 0.006\left[\frac{\sqrt{6}}{4}(7\sin^2\varphi - 3)\right] \\
\delta^{th}_{K_1} &= 1.132 - 0.006\left[\frac{\sqrt{6}}{4}(7\sin^2\varphi - 3)\right]
\end{aligned}\right\} \qquad (5)$$

Empirical model:

$$\left.\begin{aligned}
\delta^{th'}_{semi} &= 1.1777 - 0.0046\left[\frac{\sqrt{3}}{2}(7\sin^2\varphi - 1)\right] \\
\delta^{th'}_{O_1} &= 1.1625 - 0.0047\left[\frac{\sqrt{6}}{4}(7\sin^2\varphi - 3)\right] \\
\delta^{th'}_{P_1} &= 1.1522 - 0.0059\left[\frac{\sqrt{6}}{4}(7\sin^2\varphi - 3)\right] \\
\delta^{th'}_{K_1} &= 1.1457 - 0.0058\left[\frac{\sqrt{6}}{4}(7\sin^2\varphi - 3)\right]
\end{aligned}\right\} \qquad (6)$$

According to the above formulas, we may calculate the theoretical tidal value of each wave group in different latitudes, and take its weighting average by amplitude:

$$\delta_{th} = \frac{\sum \delta_p H_p}{\sum H_p} \qquad (7)$$

which will be regarded as the mean tidal factor of station. Then, substituting it in equation (2), we may find any instantaneous theoretical gravity tidal value at this station. H_p, δ_p in equation (7) are the theoretical amplitude and tidal factor of tidal group prespectively. Therefrom, the values of δ_{th} of 10 absolute gravity stations in our country are listed in Table 1, which have been found separately from Wahr and empirical formulas.

Besides, the effect of ocean tide needs also taking into account. As everyone knows, this comprises the effect of direct attraction of the sea water and load deformation. If the global cotidal map is precise and known enough, the above-mentioned effect may be found out from the • volution of tidal height[6] with the Green function, or using mixture method[7] of convolution and spherical expansion of tidal height.

The result of gravity tide observations in our country shows that Schwiderski's cotidal map accords quite well with actual observations; but in the offshore area, consideration must be given to local tidal influence in areas along the coast. Therefore, in order to set up theoretical gravity tide model, we have used 8 Schwiderski's diurnal and semi-diurnal cotidal maps, i.e. M_2, S_2, N_2, K_2, O_1, Q_1, P_1, K_1 and 4 of those in coastal areas, i.e. M_2, S_2, O_1 and K_1. The amplitudes and phases of oceanic loading corrected calculated for eight constituents at 10 stations in our country are listed in Table 2. Thus, the oceanic loading corrections of any instantaneous gravity value at each station may be calculated from the following equation:

$$\delta g_l = \sum_{p=1}^{8} A_p(\theta,\lambda) \cos(\omega_p t + \chi_p - \alpha(\theta,\lambda)) \qquad (8)$$

where A_p, α_p are the amplitude and phase of ocean tide corrections, θ, λ are colatidude and longituee of stations and other symbols are as before.

Summing up the effects of body tide and ocean tide, we may find the theoretical gravity tide correction of any station to be:

$$\delta g = \delta_{th} \cdot G(t) - \delta \bar{f}_c + \sum_{p=1}^{8} A_p \cos(\omega_p t + \chi_p - \alpha_p) \qquad (9)$$

III. Error Analysis

In order to inspect the error of model set up according to equation (9), we have compared the gravity tide variation estimated from model (9) with that in actual observations, the instantaneous variations of tidal gravity observed are synthesized by using the tidal factors and phase lags obtained at each station. The computation results of 4 stations: Wuhan, Shanghai, Hainan and Wulumuchi, are shown in figures 1-4, here curve 1 represents the error of model (9) and curve 2 shows error of model (3), without taking the effects of ocean tide into consideration. In both cases, values of th we taken from the Wahr's. The mean square errors obtained from five days of data segment are listed in Table 3. On the other hand, we have used several meters of different type in each of the above-mentioned stations to carry out observations simultaneously. For the sake of comparison, the differences of different kinds of meters in the same time segment are also listed in that table.

Table 1. Body Tide Model

station	δ_{th} (Wahr)	δ_{th} (Emp.)
Wuhan	1.1525	1.1667
Beijing	1.1469	1.1613
Shanghai	1.1520	1.1665
Kuenming	1.1548	1.1695
Guangzhou	1.1562	1.1710
Qingdao	1.1490	1.1634
Changsha	1.1535	1.1679
Zhengzhou	1.1498	1.1642
Xian	1.1501	1.1645
Nanning	1.1563	1.1711

Table 3. Error Estimation
(unit: ugal)

station	Model (9)		Model (3)	
	M.S.E	MAX	M.S.E	MAX
Yulin	±2.27	4.9	±4.74	9.7
Wuhan	±0.47	1.1	±1.28	3.1
Shanghai	±1.06	2.6	±1.86	3.7
Wulumuqi	±0.92	1.8	±0.92	1.8

Table 2. Ocean Tide Model

(unit: Amp. - ugal, Pha. - degree)

station	O_1		K_1		P_1		Q_1		M_2		S_2		N_2		K_2	
	Amp.	Pha.	Amp.	Pha.	Amp.	Pha.	Amp.	Pha.	Amp.	Pha.	Amp.	Pha.	Amp.	Pha.	Amp.	Pha.
Wuhan	0.67	-5	0.60	-33	0.19	-39	0.13	-5	0.78	-31	0.17	-25	0.15	-11	0.08	-6
Beijing	0.54	20	0.55	2	0.16	-5	0.11	20	0.48	17	0.23	15	0.11	22	0.09	18
Shanghai	1.16	-9	1.50	-22	0.43	-32	0.25	-3	2.46	-75	0.38	244	0.35	-53	0.12	-50
Kunming	0.34	23	0.18	-69	0.08	-86	0.07	-16	0.31	-79	0.12	184	0.08	-85	0.04	172
Guangzhou	1.15	-45	1.13	267	0.40	269	0.24	-42	1.06	-45	0.30	-10	0.24	-45	0.07	-64
Qingdao	0.64	-26	0.39	-30	0.15	-35	0.13	-7	1.53	22	0.75	-20	0.43	24	0.29	6
Changsha	0.67	-10	0.58	-48	0.19	-53	0.20	3	0.76	-25	0.18	-28	0.14	-18	0.06	-9
Zhengzhou	0.56	8	0.50	-16	0.15	-24	0.19	17	0.56	-7	0.18	3	0.10	.15	0.08	17
Xian	0.48	17	0.36	-15	0.11	-23	0.17	18	0.39	14	0.12	22	0.07	6	0.04	28
Nanning	0.19	-51	0.15	256	0.14	262	0.13	-10	0.46	-36	0.06	263	0.11	-51	0.01	234

It may be considered that the accuracy of values of theoretical gravity tide set up according to the model of equation (9) is about $\pm 2\ \mu gal$.

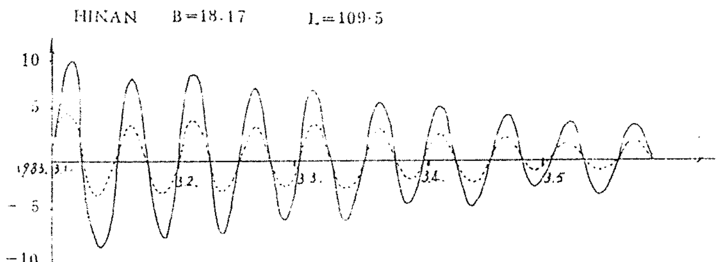

Figure 1.

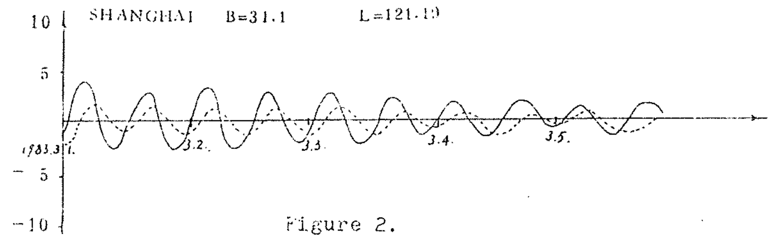

Figure 2.

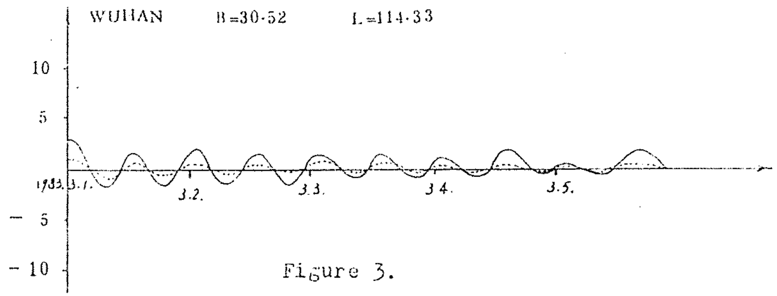

Figure 3.

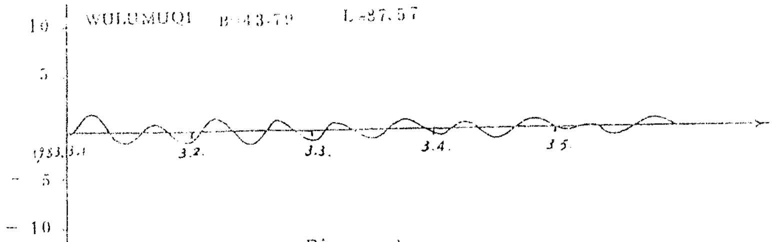

Figure 4.

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TEXTS OF RESOLUTIONS PRESENTED BY IAG SECTION III AND ADOPTED AT THE XVIIIth MEETING OF THE IUGG - HAMBURG (Aug. 27, 1983)

Resolution	Topic	IAG or IUGG
III/1	Release of Land Gravity Data	IAG
III/2	Standard Gravity Corrections System	IAG
III/3	Comparison of Absolute Gravity Instruments	IUGG
III/4	Precise Relative Gravity Measurements	IAG
III/5	Global Precise Gravity Net	IAG

III/1

THE INTERNATIONAL ASSOCIATION OF GEODESY

Recognizing that the study of many geophysical phemena in the 200 - 2 000 km range of wavelength is severely handicaped by large gaps in the available surface gravity coverage, especially over land,

urges all countries to release their land gravity measurements to the scientific community via the International Gravity Bureau ; if national interests prevent the release of detailed data, national agencies are requested to release 1° x 1° mean values of free air gravity anomalies and elevations, which are of fundamental importance for global scientific pursuits.

L'A.I.G.

Reconnaissant que l'étude de nombreux phénomènes géophysiques dans la bande des longueurs d'onde (200 - 2 000 km) est sévèrement handicapée par les insuffisances de la couverture des données gravimétriques, particulièrement sur les terres émergées,

demande à tous les pays de rendre accessibles leurs mesures gravimétriques à la communauté scientifique via le Bureau Gravimétrique International ; si des intérêts nationaux s'opposent à la cession des données détaillées, les agences nationales sont invitées à fournir les valeurs moyennes 1° x 1° des anomalies à l'air libre et des altitudes, qui sont d'importance fondamentale pour la réalisation de programmes globaux scientifiques.

III/2

THE INTERNATIONAL ASSOCIATION OF GEODESY

Recognizing the high level of accuracy of both absolute and relative gravity measurements recently attained ;
considering the necessity to adopt standard corrections to gravity observations in order to allow intercomparisons between measurements at different epochs of time ;

Recommends :

1. that the tidal correction applied to the gravity observations follow the final recommendations of the Standard Earth Tide Committee as presented at the XVIII IUGG General Assembly, Hamburg 1983 ;

2. that the atmospheric pressure corrections refer to a common Standard Atmosphere, the sensitivity coefficient being - 0,3.10^{-8} m sec^{-2}/mbar (- 0,3 microgal/mbar), unless it is determined by special investigations, in which case the value used must be published together with the results.

   The closed formula for the computation of this Standard Atmosphere will be published in a future issue of the Bulletin d'Information du Bureau Gravimétrique International with the corresponding numerical tables and the programming code.

3. that the gravity gradient corrections be published with the adopted local gradient and/or the adopted height difference so that the original values may be recovered.

L'A.I.G.

Reconnaissant le haut niveau de précision actuellement atteint à la fois par les gravimètres absolus et relatifs ;
considérant la nécessité d'adopter des corrections standardisées aux observations gravimétriques - de façon à permettre des comparaisons entre mesures à différentes époques ;

Recommande :

1. que la correction de marée appliquée aux observations gravimétriques suive les recommandations finales du comité de la "Marée Terrestre Standard" (Standard Earth Tide Committee) telles qu'elles ont été présentées à la XVIIIe Assemblée Générale de l'UGGI, Hambourg, 1983 ;

2. que les corrections de pression atmosphérique soient référées à la même Atmosphère Standard, le coefficient de sensibilité étant de - 0,3.10^{-8} m sec^{-2}/mbar, à moins qu'il soit déterminé par des recherches spéciales auquel cas la valeur utilisée devra être publiée en même temps que les résultats.

   La formule finie pour le calcul de cette Atmosphère Standard sera publiée dans une édition future du Bulletin d'Information du BGI, avec les tables numériques correspondantes et le code de programmation.

3. que les corrections de gradient de pesanteur soient publiées avec le gradient local adopté et/ou la différence d'altitude adoptée de telle façon que les valeurs d'origine puissent être retrouvées.

III/3

THE INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

Considering the importance of highly accurate absolute gravity measurements for geophysical and geodetic research and applications,

Recognizing that future comparisons of different absolute gravity apparatus are necessary to study sources of systematic error,

Requests the support of the Bureau International des Poids et Mesures (BIPM) (International Bureau of Weights and Measures) in hosting an international campaign to compare absolute apparatus, and requests all countries having transportable apparatus to take part in the campaign and the subsequent analysis.

L'U.G.G.I.

Considérant l'importance des mesures de pesanteur absolues de haute précision pour la recherche géophysique et géodésique et leurs applications,

Reconnaissant que les comparaisons futures entre les divers appareils de mesure absolue sont nécessaires pour l'étude des sources d'erreurs systématiques,

Demande l'appui du BIPM (Bureau International des Poids et Mesures) pour accueillir une campagne internationale en 1984 pour la comparaison des appareils de mesure absolue, et demande à tous les pays possédant un appareil absolu transportable de participer à cette campagne et aux réductions et analyses qui en découleront.

III/4

THE INTERNATIONAL ASSOCIATION OF GEODESY

Recognizing that techniques of repeated relative gravity measurement have achieved increased accuracy and have been applied :

1. as a fast and efficient tool to detect and investigate gravity changes associated with recent crustal movements,
2. in combination with other techniques such as levelling and VLBI to give a deeper insight into the underlying dynamic processes,
3. as an element in earthquake prediction research, and

Noting the success of recent campaigns in various parts of the world,

Recommends that high priority is given to this research.

L'A.I.G.

Reconnaissant que les techniques de mesures relatives répétées de la pesanteur ont atteint une plus grande précision et ont été utilisées :

1. comme un outil rapide et efficace pour la détection et l'étude des changements de pesanteur attribuées aux mouvements récents de la croûte,
2. en conjonction avec d'autres techniques telles que le nivellement et l'interférométrie à longue base afin de mieux connaître les processus dynamiques internes, et
3. comme outil lors de recherches sur la prédiction des tremblements de terre, et

Notant le succès de récentes campagnes dans différentes parties du monde,

Recommande qu'une haute priorité soit donnée à cette recherche.

III/5

THE INTERNATIONAL ASSOCIATION OF GEODESY

Recognizing that be physical interpretation of time variations of the natural coordinates, height above sea level, astronomic latitude and longitude, requires knowledge of the time variation of the earth's gravity field, and

considering that this latter can be determined by a world-wide net of gravity stations with repeated precise observations of absolute gravity and height above the current mean sea level

recommends that efforts be made to observe and re-observe a large number of such stations favourably distributed around the globe.

L'A.I.G.

Reconnaissant que l'interprétation physique des variations temporelles des coordonnées naturelles, altitude par rapport au niveau de la mer, latitude et longitude astronomiques, exige la connaissance de la variation temporelle du champ de pesanteur terrestre, et

considérant que cette variation peut être déterminée par un réseau mondial de stations gravimétriques établi par des observations précises et répétées de la pesanteur absolue et de l'altitude par rapport à l'actuel niveau moyen des mers

recommande que des efforts soient faits pour observer et réobserver un grand nombre de telles stations favorablement distribuées autour du globe.