ASSOCIATION INTERNATIONALE DE GEODESIE

# BUREAU GRAVIMETRIQUE INTERNATIONAL


BULLETIN D'INFORMATION

N° 63

Décembre 1988



18, Avenue Edouard-Belin

31055 TOULOUSE CEDEX

FRANCE

# INFORMATIONS FOR CONTRIBUTORS

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

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

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

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

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

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

*Mathematics. For papers with complicated notation, a list of symbols and their definitions should be provided as an appendix. All characters that are available on standard typewriters should be typed in equations as well as test. Symbols that must be handwritten should be identified by notes in the margin. Ample space (1.9 cm above and below) should be allowed around equations so that type can be marked for the printer. Where an accent or underscore has been used to designate a special type face (e.g., boldface for vectors, script for transforms, sans serif for tensors), the type should be specified by a note in a margin. Bars cannot be set over superscripts or extended over more than one character. Therefore angle brackets are preferable to accents over characters. Care should be taken to distinguish between the letter 0 and zero, the letter l and the number one, kappa and k, mu and the letter u, nu and v, eta and n, also subscripts and superscripts should be clearly noted and easily distinguished. Unusual symbols should be avoided.*

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

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

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

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

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

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

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# BUREAU GRAVIMETRIQUE INTERNATIONAL

Toulouse

*BULLETIN D' INFORMATION*

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## Table of Contents

Bull. d'Inf. n° 63

# ANNOUNCEMENT

*The 13th Meeting of the International Gravity Commission will be held in Toulouse from September 10 to 14, 1990.*

*The first day will be devoted to the meeting of the Directing Board of BGI and the attendance restricted to the members of the board.*

*Details will be given in the subsequent circulars.*

PART I

# INTERNAL MATTERS

# GENERAL INFORMATIONS

# 1. HOW TO OBTAIN THE BULLETIN

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

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

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

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

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

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

*You may :*

- *either request a given bulletin, by its number (61 have been issued as Jan. 1, 1988, but numbers 2, 16, 18, 19 are out of print).*
- *or subscribe for regularly receiving the two bulletins per year plus the special issues.*

*Requests should be sent to :*

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

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

*- 65 French Francs without map,*

*- 75 French Francs with map.*

## 2. HOW TO REQUEST DATA

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

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

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

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

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

*Treated as above.*

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

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

**2.4. Gravity Maps**

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

*Whenever available in stock, copies will be sent without charges. If not, two procedures can be used :*

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

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

**2.5. Gravity Measurements**

*They can be requested :*

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

**CGDF RECORD DESCRIPTION**

**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*<br>*1 = Land*<br>*2 = Subsurface*<br>*3 = Ocean surface*<br>*4 = Ocean submerged*<br>*5 = Ocean Bottom*<br>*6 = Lake surface (above sea level)*<br>*7 = Lake bottom (above sea level)*<br>*8 = Lake bottom (below sea level)*<br>*9 = Lake surface (above sea level with lake bottom below sea level)*<br>*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)*<br>*This field will contain depth of ocean positive downward)*<br>*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)*<br>*Simple Bouguer anomaly with mean density of 2.67 - $N_o$ terrain correction* |
| *44- 45* | *Estimation standard deviation Bouguer anomaly (mgal)* |
| *46* | *System of numbering for the reference station*<br>*1 = IGNS 71*<br>*2 = BGI*<br>*3 = country*<br>*4 = DMA* |
| *47- 53* | *Reference station* |
| *54- 56* | *Country code* |
| *57* | *1 : measurement at sea with no depth given*<br>*0 : otherwise* |
| *Col. 58* | *Information about terrain correction*<br>*0 = no information*<br>*1 = terrain correction exists in the archive file* |
| *59* | *Information about density*<br>*0 = no information or 2.67*<br>*1 = density ≠ 2.67 given in the archive file* |
| *60* | *Information about isostatic anomaly*<br>*0 = no information*<br>*1 = information exists but is not stored in the archive file*<br>*2 = information exists and is included in the archive file.* |

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

**ARCHIVE FILES**

**RECORD DESCRIPTION**

**160 CHARACTERS**

| | |
|---|---|
| *Col. 1- 7* | *B.G.I. source number* |
| *8- 12* | *Block number*<br>*Col. 8-10 = 10 square degree*<br>*Col. 11-12 = 1 square degree* |
| *13- 19* | *Latitude (Unit : 1/10 000 degree)* |
| *20- 27* | *Longitude (unit : 1/10 000 degree) (- 180 to + 180 degree)* |

28 *Accuracy of position*

*The site of the gravity measurement is defined in a circle of radius R*

0 = no information on the accuracy
1 = R <= 20 M (approximately 0'01)
2 = 20 < R <= 100
3 = 100 < R <= 200 (approximately 0'1)
4 = 200 < R <= 500
5 = 500 < R <= 1000
6 = 1000 < R <= 2000 (approximately 1')
7 = 2000 < R <= 5000
8 = 5000 < R
9 ...

29 *System of position*

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

30- 31 *Type of observation*

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

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

32 *Elevation type*

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

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

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

40 *Accuracy of elevation (E)*

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

41-42 Determination of the elevation
  = no information
0 = geometrical levelling (bench mark)
1 = barometrical levelling
3 = data obtained from topographical map
4 = data directly appreciated from the mean sea level
5 = data measured by the depression of the horizon (marine)
Type of depth (if Col. 32 contains 3, 4 or 5)
1 = depth obtained with a cable (meters)
2 = manometer depth
4 = corrected acoustic depth (corrected from Mathew's tables, 1939)
5 = acoustic depth without correction obtained with sound speed 1500 M/sec. (or 820 Brasses/sec)
6 = acoustic depth obtained with sound speed 800 Brasses/sec (or 1463 M/sec)
9 = depth interpolated on a magnetic record
10 = depth interpolated on a chart

43-44 Mathews' zone
When the depth is not corrected depth, this information is necessary.
For example : zone 50 for the Eastern Mediterranean Sea

45-51 Supplemental elevation
Depth of instrument, lake or ice, positive downward from surface

52-59 Observed gravity (0.01 mgal)

60 Information about gravity
1 = gravity with only instrumental correction
2 = corrected gravity (instrumental and Eotvos correction
3 = corrected gravity (instrumental, Eötvös and cross-coupling correction)
4 = corrected gravity and compensated by cross-over profiles

61 Accuracy of gravity (e)
When all systematic corrections have been applied
0 = E < = 0.05
1 = .05 < E < = 0.1
2 = 0.1 < E < = 0.5
3 = 0.5 < E < = 1.
4 = 1. < E < = 3.
5 = 3. < E < = 5.
6 = 5. < E < = 10.
7 = 10. < E < = 15.
8 = 15. < E < = 20.
9 = 20. < E

62 System of numbering for the reference station
This parameter indicates the adopted system for the numbering of the reference station
1 = for numbering adopted by IGSN 71
2 = BGI
3 = Country
4 = DMA

63-69 Reference station
This station is the base station to which the concerned station is referred

70-76 Calibration information (station of base)
This zone will reveal the scale of the gravity network in which the station concerned was observed, and allow us to make the necessary corrections to get an homogeneous system

77-81 Free air anomaly (0.1 mgal)

82-86 Bouguer anomaly (0.1 mgal)
Simple bouguer anomaly with a mean density of 2.67 - No terrain correction

87-88 *Estimation standard deviation free air anomaly (mgal)*

89-90 *Estimation standard deviation bouguer anomaly (mgal)*

91-92 *Information about terrain correction*
*Horizontal plate without bullard's term*
*0 = no topographic correction*
*1 = CT computed for a radius of 5 km (zone H)*
*2 = CT 30 km (zone L)*
*3 = CT 100 km (zone N)*
*4 = CT 167 km (zone 02)*
*11 = CT computed from 1 km to 167 km*
*12 = CT 2.5 167*
*13 = CT 5.2 167*

93-96 *Density used for terrain correction*

97-100 *Terrain correction (0.1 mgal)*
*Computed according to the previously mentioned radius (col. 91-92) & density (col. 93-96)*

101-103 *Apparatus used for the measurements of G*
*0.. pendulum apparatus constructed before 1932*
*1.. recent pendulum apparatus (1930-1960)*
*2.. latest pendulum apparatus (after 1960)*
*3.. gravimeters for ground measurements in which the variations of G are equilibrated of detected using the following methods :*
*30 = torsion balance (Thyssen...)*
*31 = elastic rod*
*32 = bifilar system*
*4.. Metal spring gravimeters for ground measurements*
*42 = Askania (GS-4-9-11-12), Graf*
*43 = Gulf, Hoyt (helical spring)*
*44 = North American*
*45 = Western*
*47 = Lacoste-Romberg*
*48 = Lacoste-Romberg, Model D (microgravimeter)*
*5.. Quartz spring gravimeter for ground measurements*
*51 = Norgaard*
*52 = GAE-3*
*53 = Worden ordinary*
*54 = Worden (additional thermostat)*
*55 = Worden worldwide*
*56 = Cak*
*57 = Canadian gravity meter, sharpe*
*58 = GAG-2*
*6.. Gravimeters for under water measurements (at the bottom of the sea or of a lake*
*60 = Gulf*
*62 = Western*
*63 = North American*
*64 = Lacoste-Romberg*
*7.. Gravimeters for measurements on the sea surface or at small depth (submarines..)*
*70 = Graf-Askania*
*72 = Lacoste-Romberg*
*73 = Lacoste-Romberg (on a platform)*
*74 = Gal and Gal-F (used in submarines) Gal-M*
*75 = AMG (USSR)*
*76 = TSSG (Tokyo Surface Ship Gravity meter)*
*77 = GSI sea gravity meter*

104 *Conditions of apparatus used*
*1 = 1 gravimeter only (no precision)*
*2 = 2 gravimeters (no precision)*
*3 = 1 gravimeter only (without cross-coupling correction)*
*4 = 2 gravimeters (influenced by the cross-coupling effect) with the same orientation*

| | |
|---|---|
| | *5 = 2 gravimeters (influenced by the cross-coupling effect) in opposition*<br>*6 = 1 gravimeter (compensated for the cross-coupling effect)*<br>*7 = 1 gravimeter non subject to cross-coupling effect*<br>*8 = 3 gravimeters* |
| *105* | *Information about isostatic anomaly*<br>*0 = no information*<br>*1 = information exists but is not stored in the data bank*<br>*2 = information exists and is included in the data bank* |
| *106-107* | *Type of the isostatic anomaly*<br>*0.. Pratt-Hayford hypothese*<br>*01 = 50 km including indirect effect (Lejay's tables)*<br>*02 = 56.9 km*<br>*03 = 56.9 km including indirect effect*<br>*04 = 80 km including indirect effect*<br>*05 = 96 km*<br>*06 = 113.7 km*<br>*07 = 113.7 km including indirect effect*<br>*1.. Airy hypotheses (equality of masses or pressures)*<br>*10 = T = 20 km (Heiskanen's tables, 1931)*<br>*11 = T = 20 km including indirect effect (Heiskanen's tables 1938 or Lejay's)*<br>*12 = T = 30 km (Heiskanen's tables, 1931)*<br>*13 = T = 30 km including indirect effect*<br>*14 = T = 40 km*<br>*15 = T = 40 km including indirect effect*<br>*16 = T = 60 km*<br>*17 = T = 60 km including indirect effect*<br>*6......*<br>*65 = Vening Meinesz hypothesis "modified Bouguer anomaly" (Vening Meinesz, 1948)* |
| *108-112* | *Isostatic anomaly a (0.1 mgal)* |
| *113-114* | *Type of the isostatic anomaly B* |
| *115-119* | *Isostatic anomaly B* |
| *120-122* | *Velocity of the ship (0.1 knot)* |
| *123-127* | *Eötvös correction (0.1 mgal)* |
| *128-131* | *Year of observation* |
| *132-133* | *Month* |
| *134-135* | *Day* |
| *136-137* | *Hour* |
| *138-139* | *Minute* |
| *140-145* | *Numbering of the station (original)* |
| *146-148* | *Country code (B.G.I.)* |
| *149* | *Flag (internal use)* |
| *150-154* | *Original source number (ex. DMA code)* |
| *155-160* | *Sequence number* |

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

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

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

*where $\phi$ is the geographic latitude.*

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

**Formulas used in computing free-air and Bouguer anomalies**

| Elev Type | Situation | Formulas |
|---|---|---|
| 1 | Land Observation | FA = g + 0.3086*H - gO<br>BO = FA - 0.1119*H |
| 2 | Subsurface | FA = g + 0.2238*D2 + 0,3086*(H-D2)<br>BO = FA - 0.1119*H |
| 3 | Ocean surface | FA = g - gO<br>BO = FA + 0.06886*H<br>(H = depth of ocean positive downward from surface) |
| 4 | Ocean submerged | FA = g - gO<br>BO = FA + 0.06886*H<br>(D2 = depth of instrument positive downward)<br>(H = depth of ocean positive downward) |
| 5 | Ocean bottom | FA = g + 0.3086*H - gO<br>BO = FA + 0.06886*D1<br>(D1 = depth of ocean positive downward) |
| 6 | Lake surface (above sea level) | FA = g + 0.3086*H - gO<br>BO = FA - 0.04191*D1 - 0.1119*(H-D1)<br>(D1 = depth of lake positive downward) |
| 7 | Lake bottom (above sea level) | FA = g + 0.08382*D1 + 0.3086*(H-D1) - gO<br>BO = FA - 0.04191*D1 - 0.1119*(H-D1) |
| 8 | Lake bottom (below sea level) | FA = g + 0.08382*D1 + 0.3086*(H-D1) - gO<br>BO = FA - 0.04191*D1 - 0.06999*(H-D1) |
| 9 | Lake surface (above sea level with bottom below sea level) | FA = g + 0.3086*H - gO<br>BO = FA - 0.04191*H - 0.06999*(H-D1) |
| A | Lake surface (below sea level) | FA = g + 0.3086*H - gO<br>BO = FA - 0.1119*H + 0.06999*D1 |
| B | Lake bottom (surface below sea level) | FA = g + 0.3086*H - 0.2248*D1 - gO<br>BO = FA - 0.1119*H + 0.06999*D1<br>(D1 = depth of lake positive downward) |
| C | Ice cap (bottom below sea level) | FA = g + 0.3086*H - gO<br>BO = FA - 0.03843*H - 0.07347*(H-D1)<br>(D1 = depth of ice positive downward) |
| D | Ice cap (bottom above sea level) | FA = g + 0.3086*H - gO<br>BO = FA - 0.03843*D1 - 0.1119*(H-D1)<br>(D1 = depth of ice) |

**2.6. Satellite Altimetry Data**

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

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

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

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

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

*All requests for data must be sent to :*

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

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

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

# 3. USUAL SERVICES B.G.I. CAN PROVIDE

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

*The costs of the services listed below are a revision of the charging policy established in 1981 (and revised in 1988) in view of the categories of users : (1) contributors of measurements and scientists, (2) other individuals and private companies.*

*The prices given below are in french francs. They are effective January 1, 1988 and will be revised periodically.*

## 3.1. Charging Policy for Data Contributors and Scientists

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

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

### *3.1.1. Digital Data Retrieval*

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

*. minimum charge : 100 F.*

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

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

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

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

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

### *3.1.3. Data Screening*

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

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

*. 100 F minimum charge.*

### *3.1.4. Gridding*

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

*. 10 F/ΔΔ' per degree square*

*. minimum charge : 150 F*

*. maximum area : 40° x 40°*

### *3.1.5. Contour Maps of Bouguer or Free-Air Anomalies*

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

*. 250 F minimum charge*

*. maximum area : 40° x 40°*

*3.1.6. Computation of Mean Gravity Anomalies*

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

*. minimum charge : 150 F*

*. maximum area : 40° x 40°*

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

*3.2.1. Digital Data Retrieval*

*. 1 F per measurement*

*. minimum charge : 150 F*

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

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

*3.2.3. Data Screening*

*. 1 F per screened point*

*. 250 F minimum charge*

*3.2.4. Gridding*

*Same as 2.1.4.*

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

*Same as 2.1.5.*

*3.2.6. Computation of Mean Gravity Anomalies*

*Same as 2.1.6.*

*3.3. Gravity Maps*

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

*3.3.1. Catalogue of all Gravity Maps*

*printout : 200 F*

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

*3.3.2. Maps*

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

*. Special maps :*

*Mean Altitude Maps*

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

*Maps of Gravity Anomalies*

*NORTHERN FRANCE, Isostatic anomalies (1:1 000 000) 1954* — 55 FF

*SOUTHERN FRANCE, Isostatic anomalies Airy 50 (1:1 000 000) 1954* — 55 FF

*EUROPE-NORTH AFRICA, Mean Free air anomalies (1:1 000 000) 1973* — 90 FF

*World Maps of Anomalies (with text)*

*PARIS-AMSTERDAM, Bouguer anomalies (1: 1 000 000) 1959-60* — 65 FF

*BERLIN-VIENNA, Bouguer anomalies (1: 1 000 000) 1962-63* — 55 FF

*BUDAPEST-OSLO, Bouguer anomalies (1: 1 000 000) 1964-65* — 65 FF

*LAGHOUAT-RABAT, Bouguer anomalies (1: 1 000 000) 1970* — 65 FF

*EUROPE-AFRICA, Bouguer Anomalies (1:10 000 000) 1975* — 180 FF with text; 120 FF without text

*EUROPE-AFRICA, Bouguer anomalies Airy 30 (1:10 000 000) 1962* — 65 FF

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

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

*Miscellaneous*

*CATALOGUE OF ALL GRAVITY MAPS (listing)* 1985 — 200 FF

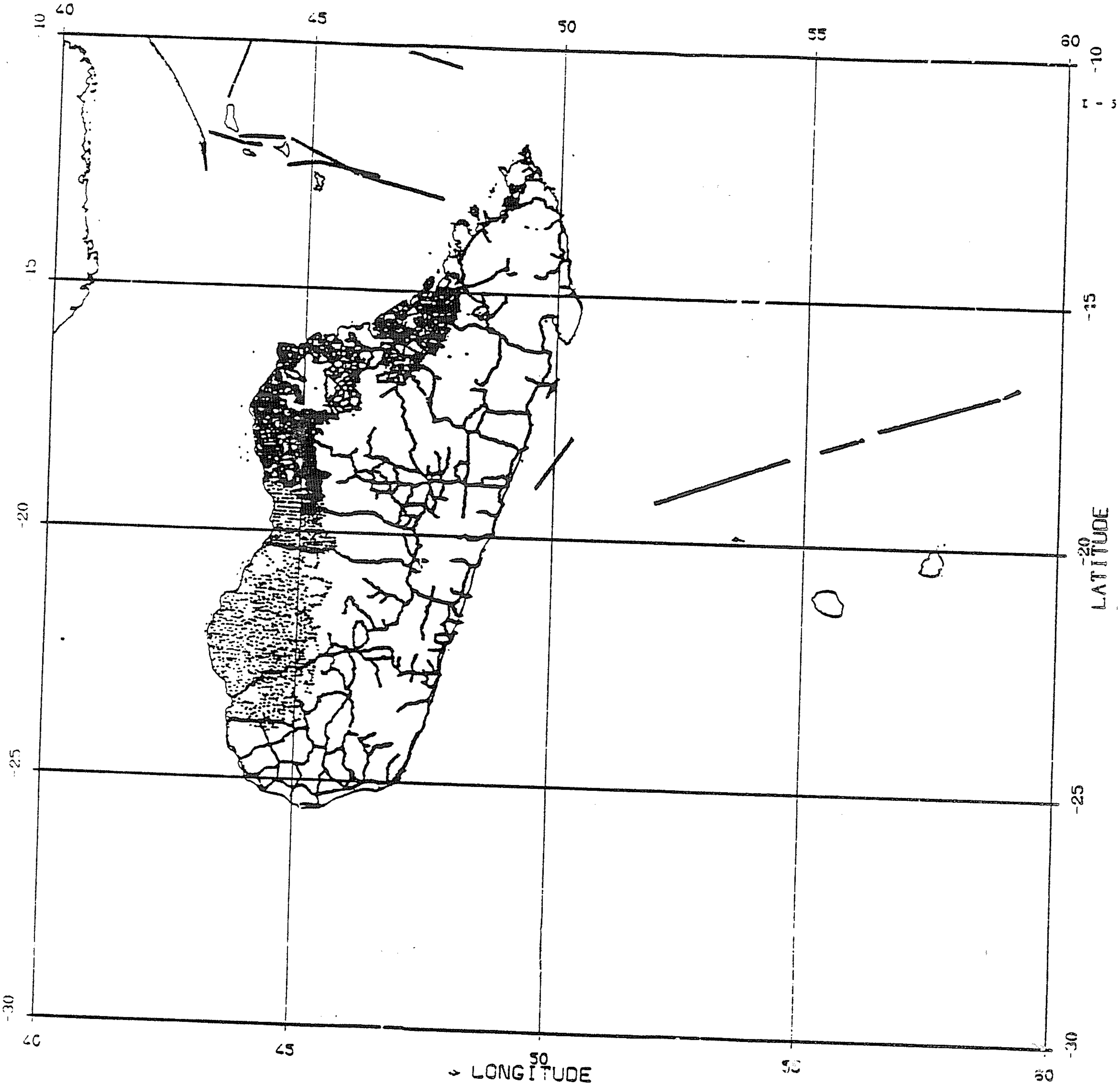
*THE UNIFICATION OF THE GRAVITY NETS OF AFRICA (Vol. 1 and 2)* 1979 — 150 FF

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

*. Colour copy : price according to specifications of request.*

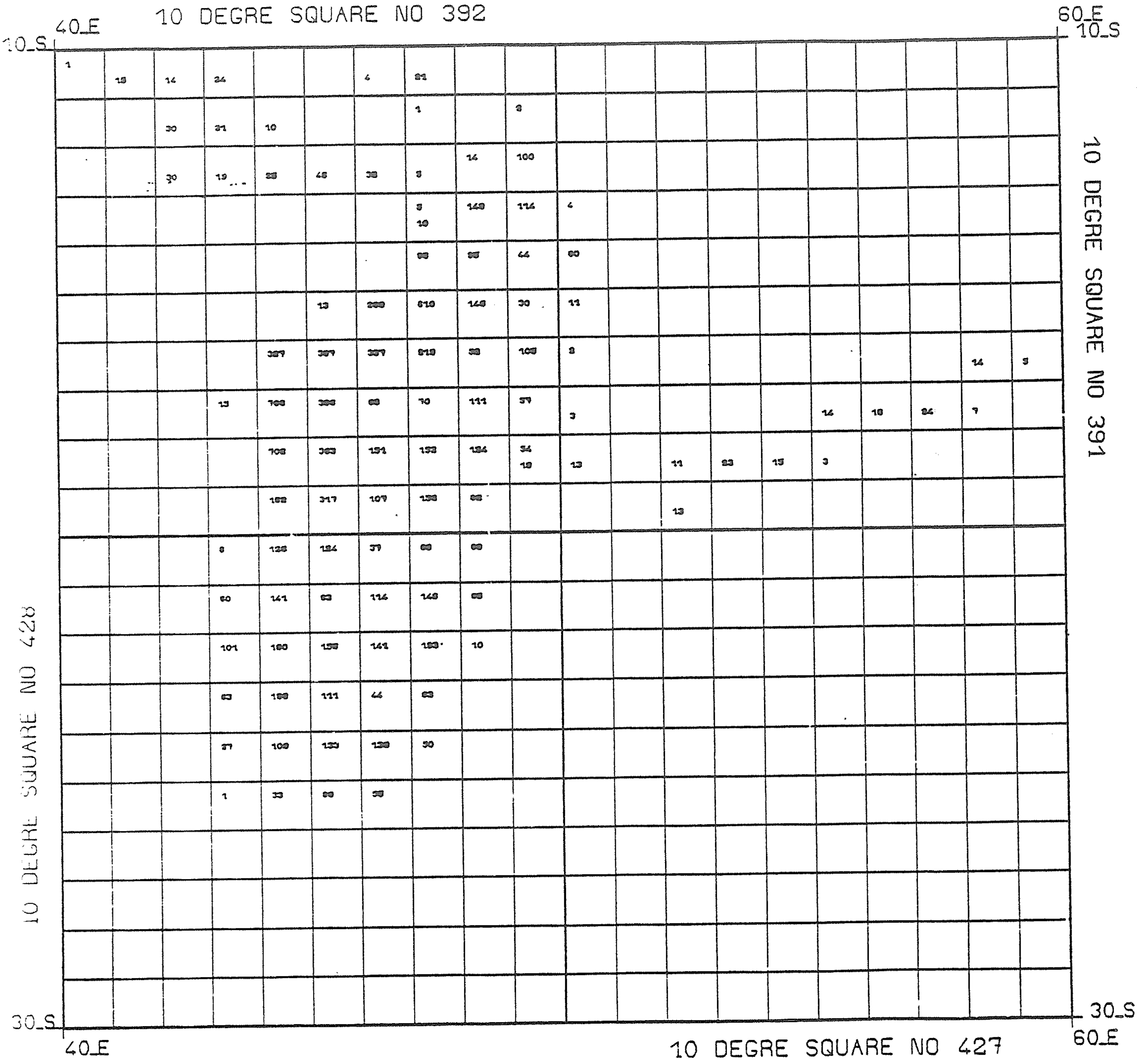
*Mailing charges will be added for air-mail parcels when "Air-Mail" is requested)*

Map 1. Example of data coverage plot



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

REPRESENTATION OF EARTH AND SEA GRAVIMETRIC STATIONS



## 4. PROVIDING DATA TO B.G.I.

### 4.1. Essential Quantities and Information for Gravity Data Submission

*1. Position of the site :*

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

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

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

### 4.2. Optional Information

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

*. Instrumental accuracy :*

- *identify gravimeter (s) used in the survey. Give manufacturer, model, and serial number, calibration factor (s) used, and method of determining the calibration factor (s).*
- *give estimate of the accuracy of measured (observed) gravity. Explain how accuracy value was determined.*

*. Positioning accuracy :*

- *identify method used to determine the position of each gravity measurement site.*
- *estimate accuracy of gravity station positions. Explain how estimate was obtained.*
- *identify the method used to determine the elevation of each gravity measurement site.*
- *estimate accuracy of elevation. Explain how estimate was obtained. Provide supplementary information, for elevation with respect to the Earth's surface or for water depth, when appropriate.*

*. Miscellaneous information :*

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

*. Terrain correction*

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

---

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

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

*. Isostatic gravity*

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

*. Description of geological setting of each site*

### 4.3. Formats

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

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

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

# INFORMATION ON THE BGI DATA BASE

## I - SYSTEM CHANGE

In mid 1988, an important change of the exploitation system was done on the host computer, a CDC CYBER 990 : the NOS/BE system was replaced by NOS/VE, a virtual memory system. This involved main modifications in the data base management software, due to the change of the world length (from 60 bits to 64), change in character code (from 6 bits-Display code to 8 bits-ASCII code), changes in procedure language. Other problems had also to be solved during files migration.

At the end of 1988, a new migration was operated from this CYBER 990 to a new CYBER 992, with a change of the system level (mostly affecting the attach procedures for files).

At the same time, graphic libraries were replaced by new ones, with major impacts on graphic routines used for visualization and cartography.

## II - DATA UPDATING

Updating operations were delayed to the beginning of 1989. New data received at BGI have been reformatted and validated, prior to merging.

## III - NEW DATA BASE STRUCTURE

An analysis has been undertaken about a new structure for the data base, which will allow updating in real time with new validated sources : so far, we have been updating only every other year due to a very complex procedure.

In this new structure, data would be distributed between different files corresponding to specified (equiangular) geographical area ; we would keep the same extraction keys (by geographical area, by source or by country). The main condition to implement such a data base is to reach an agreement with the Space Center Computer Assistance team, due to the great number of files opened under a user identifier.

## IV - DATA VALIDATION

Following the Directing Board recommendations, BGI has implemented a validation software, consisting of :

1) a prediction software (using collocation theory - a tool developed at Hannover University, Dept. of Geodesy) ;

2) a graphic interactive package developed at BGI.

After testing the complete system, BGI will begin the systematic validation of all terrestrial data, starting with South America.

PART II

MEETING OF DIRECTING BOARD

OF THE

BUREAU GRAVIMETRIQUE INTERNATIONAL

June 23-24, 1988

PARIS, FRANCE

# MINUTES
# MEETING OF THE DIRECTING BOARD
# OF THE
# BUREAU GRAVIMETRIQUE INTERNATIONAL

**Paris, France**
**23-24 June, 1988**

Present : J.G. Tanner, Chairman
G. Balmino, Director of BGI
G. Boedecker
Y. Boulanger
J. Faller
K. McConnell
C. Morelli
I. Nakagawa
C. Poitevin
H.G. Wenzell
M. Louis (Deputy Director, Institut Geographique National, Paris)

June 23, 1988

1. Opening remarks

The chairman briefly reviewed the current activities of the IGC and stressed the need for establishing good lines of communication with the newly formed Geoid Commission in order to ensure mutually complementary activities and avoid duplication of effort. With respect to the on-going activities of the Bureau he emphasized the need to review and update the role and mandate of the BGI Working Groups.

2. Report of the Director

Balmino presented a report of activities of the Bureau over the past year.

(a) Data Base Software Development
New Cyber 990 has now been installed at CNES. Changeover from NOS/BE to NOS/VE operating system will require some software to be rewritten. This work expected to be completed by October 1, 1988.

The Bureau is looking at the possibility of adopting the University of Leeds software system for gravity data management. This would help to ensure better protection against loss of operational continuity than the present in-house developed software which is not well documented.

(b) Data Collection
The data base now contains some 3.8 million point gravity values. New data has been received from South Africa, Nigeria, Central African Republic, Sudan, Angola, Canada, and Greenland plus world-wide data from Lamont. 20,000 station from Brazil have been received through Wenzell and 7500 stations for Argentina have been obtained through their Instituto Geografico Militar. In addition, some new data has come from Malaysia and Japan has contributed marine data. With respect to Europe, new data has been received from Italy, England, Northern Ireland, Greece, France, Sweden and Spain.

A new world-wide catalogue in three volumes has been prepared which shows station distribution by degree square with mean Free air anomaly and its standard deviation.

A 5'x5' data set for the Gravity Map of the World is in compilation.

(c) African Gravity Project
With respect to the African Gravity Project of the University of Leeds, Balmino reported that a 5'x5' grid will be produced and made publicly available in 2 years. Point values will not be released for 10 years but BGI will have access to them shortly for use in validating future acquisitions of data from Africa.

(d) South American Gravity Project
BGI will also be involved with the University of Leeds in their South American gravity compilation project on the same basis as the African project.

(e) Data Validation
A sophisticated new system (VERSET) for data validation using statistical techniques and interactive graphics has been developed by Denis Toustou. All previously validated data will be revalidated using this system.

Wenzell noted that various techniques now exist for data validation and proposed a workshop on the subject. Balmino agreed to try to set one up in conjunction with the Edinburgh IAG meeting next year.

(f) Requests
The bureau has received 94 requests for data and services over the past year. 44 requests were received in the first five month of 1988.

(g) GEBCO Project
One person has been assigned by Institute Geographique National to work on the GEBCO hydrographic project. In addition to the Northern Europe sheet (5-01) published in 1987, BGI has produced the North Atlantic sheet (5-04) and is presently compiling the Central Atlantic sheet (5-08).

(h) Bibliography
Compilation of a gravity bibliography continues. A file is now available on floppy disk.

(i) Participation in ICL/CC5 Activities
The first draft of the compilation of data base questionnaires has been received by BGI for validation and addition of missing sources. Balmino will continue to represent the International Gravity Commission on CC5.

(j) Relationship with Other Agencies
There was a long discussion of the future relationship of BGI and the new Geoid Commission formed at the Vancouver IUGG. This commission has proposed the formation of an international centre for geoid information similar in concept to the BGI. The Directing Board felt strongly that every effort should be made to avoid duplication of effort between the two agencies in the areas of data collection and geoid computation. Tanner agreed to meet with the president of the Geoid Commission, Dr. Richard Rapp, to discuss the relative roles and activities of BGI and their proposed data centre.

(k) Miscellaneous
Sarrailh has drafted a report on the International Bathymetric Chart of the Mediterranean and forwarded it to Makris for review.

BGI has been involved in the training of students from developing countries. Activities include training in data validation procedures and compilation of geoids.

3. BGI Working Groups

(a) Review of Working Group Mandates

The chairman briefly summarized the history of the Working Groups noting that WG 1, WG 2, WG 3, and WG 4 were set up to carry out specific functions related to the activities of the BGI. WG 5 and WG 6 deal with other activities of the Commission.

The existing terms of reference of each Working Group were reviewed. After some discussion it was agreed that McConnell and Boedecker should draft revised terms of reference for WGs 1 and 2 respectively. WGs 3 and 4 no longer exist. The terms of reference for WG 5 were deemed to require no change. To remove any confusion over the names of Working Groups it was agreed that the name of WG 5 should be Monitoring of Non-tidal Gravity Variations and the name of WG 6 should be Comparison of Absolute Gravimeters. A new Working Group (WG 7) called Computation of Mean Gravity Anomalies was formed under the chairmanship of H.G. Wenzell.

(b) Reports of Working Groups

WG1 - McConnell reported on progress of compilation of the Bouguer Gravity Map of the World and presented a prototype colour map showing Bouguer anomalies over the world's oceans computed from satellite derived Free air anomalies and mean water depths from the DBDB5 data set. The completion of the map is awaiting compilation of a 5'x5' Bouguer data set for the world at BGI.

WG2 - Boedecker stressed the importance of supporting the African Gravity Net project particularly with respect to the establishment of absolute stations. He noted the absence of absolute measurements in the recent DMA/IGN work in West Africa.

IAGBN progress includes the establishment of stations at Greenbelt, Fort Davis and Minneapolis in the US; Yellowknife in Canada with observations at Penticton and Shefferville planned for the fall of this year; and one station in Greenland. Boedecker estimated that 20 stations would be established world-wide by the end of 1989. There was considerable discussion of the current accuracy specifications (20 microgals) for IAGBN. It was agreed that in the long term an accuracy of 2 microgals should be sought. A proposed format for the description of IAGBN stations was presented along with standards for data reduction. It was noted that there had been little response to the IGB request for submission of absolute measurements for the compilation of an absolute g data base. Members agreed to prod agencies within their respective spheres of influence to send in their measurements. The question of whether or not the data pertaining to individual drops should be stored for later reprocessing when improved tidal models become available. The consensus was that drop data should be stored for IAGBN sites but that averaged data was sufficient for other absolute sites.

WG5 - Poitevin showed a map of locations of superconducting gravimeters planned or installed. The first interconnection of superconducting sites in Hannover and Brussels has already been carried out. Progress reports in the form of two circular letters have been distributed to interested parties.

WG6 - Boulanger reported that arrangements for the third International Comparison of Absolute Gravimeters had been completed. It will take place at Sèvres, France in December of 1989. Ten countries have agreed to participate. As a result of a meeting of WG 6 held earlier in the week some changes to the plans for the intercomparison were agreed upon. These are detailed in the minutes of the WG 6 meeting.

June 24, 1988

(c) Adoption of revised terms of reference for Working Groups Terms of reference for WGs 1, 2 and 7, drafted the previous day were discussed. The final versions are appended to these minutes.

4. Plans for IGC activities at 1989 Edinburgh Meeting of IAG

It was agreed that Balmino should arrange an IGC meeting on August 5 and a Directing Board meeting on August 8 in the evening continuing one additional evening if necessary. Topics suggested for the IGC meeting included a discussion of the new terms of reference for the Working Groups ; a status report and discussion of IAGBN ; progress on intercomparison of absolute gravimeters ; reports from sub-commissions on the status of IGSN71.

5. Plans for 13th IGC Meeting in Toulouse

It was agreed that the meeting would be held the second week of September, 1990. The meeting will take the form of scientific symposia. The first announcement will appear in the December, 1988 Bulletin d'Information.

6. Administrative Matters

Tanner will ask the president (or his delegate) of the Geoid Commission to sit on the BGI Directing Board. FAGS has nominated J. Kovalesky to the Directing Board.

During the meeting at Edinburgh Tanner will ask the IGC to appoint a replacement for Krynski of Poland who has now retired.

Working Group chairmen were asked to review WG memberships and send proposed revisions to Tanner and Balmino for approval at the next Directing Board meeting.

With respect to Morelli request for updating membership of the IGC, all replies have not yet been received. The updated membership will be published in the June, 1989 Bulletin d'Information.

## TERMS OF REFERENCE
## BGI WORKING GROUP 1 - DATA PROCESSING
as revised June 24,1988

In collaboration with BGI and under the guidance of the IGC

1. to provide technical and scientific advice to the BGI with respect to data acquisition, reduction, validation, storage, retrieval and presentation strategy and methodology ;
2. to coordinate the provision of technical assistance to the BGI by agencies who can provide software, computational or other forms of data handling support ;
3. to carry out scientific or technical projects in direct support of BGI activities.

## TERMS OF REFERENCE
## BGI WORKING GROUP 2 - WORLD GRAVITY STANDARDS
## as revised June 24, 1988

In collaboration with BGI and under the guidance of the IGC

1. to provide advice and guidance as requested by the BGI and/or national agencies in activities related to the maintenance of IGSN71 ;
2. to provide advice and guidance to the international scientific community with respect to updates and improvements to regional gravity networks in order to ensure homogeneity of reference gravity values required to satisfy geodetic, geophysical and metrological needs ;
3. to coordinate the establishment of the IAGBN with a design accuracy better than 10 microgals for the purpose of contributing to global geodynamics investigations ;
4. to encourage and provide advice for activities related to IAGBN such as precise positioning of IAGBN stations and the measurement of gravity differences between stations.

## TERMS OF REFERENCE
## IGC WORKING GROUP 7 - COMPUTATION OF MEAN GRAVITY ANOMALIES
## June 24,1988

In collaboration with the BGI and under the guidance of the IGC

1. to compute a set of world-wide mean Free air gravity anomalies and standard deviations with a block size of 5'x5' (or of a size as agreed in consultation with the Geoid Commission), using BGI data holdings ;
2. to evaluate currently available software for the prediction of mean gravity anomalies from point data with respect to accuracy and computation time ;
3. to assist BGI in the collection and compilation of 5'x5' mean gravity anomalies from terrestrial gravity sources other than point observations, e.g. maps or existant sets of mean values at a similar block size.

# WORKING GROUP 2

## Activity Report

### Membership

The former members (before August 1987) of WG2 were : Uotila (Chairman, McConnell, Szabo, Torge.
Asked about prolongation, Torge denied because of his diverse duties within IAG, Szabo and McConnell didn't respond. Currently the members of WG2 are : Hanada, Marson, Peter, Boedecker (Chairman).
A few more would be welcome and will be invited if necessary.

### WG2 Policy

Working Group 2 was formed on the occasion of the IAG General Assembly 1975 in order to meet the "remaining requirements for scientific input to the IGB data management...", thus defining the role of a pure advisory board. As such WG 2 would be obliged to give advice to all problems connected to world gravity standards as e.g. the maintenance of IGSN71, adjustment problems etc., but to sustain from active participation.

This role changed quite a bit since that time because WG2 is now considered a working group of the IGC and can play a more active role for IAGBN besides supervision of e.g. IGSN71. The network aspect and therefore the adjustment problems of relative observations are vanishing in favour of absolute observations of a set of stations. Because of increasing accuracy the global gravity changes problems gained ground.

### Interrelation Between BGI, WG2 and Sub-Commissions

As to the maintenance of IGSN71, the BGI, in accordance with WG2, has now asked the sub-commissions to contribute to updating station descriptions for IGSN71.

Concerning IAGBN the President IGC, J. Tanner has initiated a discussion also with the sub-commissions on the roles of WG2 and SCs. This question has to be clarified at this meeting.

### AGSN

Most other continents have improved their reference given by IGSN71 through continent-wide gravity networks. In all other continents absolute observations have been carried out. Not so in Africa. Therefore it deserves special attention also of WG2. For many years the AGSN project has been defined and developed but no observation has been carried out so far. It is also of no value for AGSN and hence for the world gravity network that in 1987 an extended lavish gravity observation campaign was executed by Non-Africans in some West-African countries, pretending that this project was in accordance with IAG programmes.

### IAGBN Status, Prospects

Some activities as to the IAGBN have been initiated by the former SGG 3.87. Thus to date the status is as follows : the project has been endorsed by the IGC and IAG and is given a high priority by the IGC.

In Canada, the IAGBN station at Yellowknife has been established and observed this year. The stations at Penticton and Shefferville are to follow later this year.

In the US, the proposed IAGBN stations at Greenbelt, Ft. Davis and Minneapolis are all included in the NGS absolute gravity program as primary or primary supplemental stations. The stations near Fairbanks, on Midway and at the Antarctic station McMurdo however, have not yet been considered.

In Greenland, a couple of stations were established and observed in cooperation with the Danish Geodetic Institute and the group of Pr. Torge, Hannover. One of those will be selected as IAGSN station.

In South America a couple of absolute stations will be observed this fall ; one of those is in Venezuela close to the proposed site in Boa Vista, Brazil, and will probably be taken as the IAGBN station.

As to Europe, Sodankyla in Finland has been observed as also Wettzell in Germany. Madrid in Spain has not been active yet.

In Russia, Moscow and Novosibirsk have been observed, but the Siberian stations will be a problem.

For the station in Saudi Arabia no contact could be established to date.

India agrees to have a station in Hydarabad but wants to do observation with their own instrument and refuses to let other groups to there.

China agreed to have a station in Nanjing but strongly wishes to have a second station in Beijing instead of the proposed Mudanjiang.

Australia and New Zealand remained inactive so far.

In Africa, nothing has been achieved so far, c.f. also "AGSN" above.

Further support was announced e.g. by Japan that is willing to do observations at the Antarctic station at Syowa. Finland is willing to observe at about two IAGBN stations per year. In principle, all of the absolute meter groups are willing to contribute, but activities are limited because of limited funds.

In order to introduce standards for the IAGBN, in continuation of the site selection criteria published earlier, a draft for "Absolute observations standards" including "Data processing standards" and for "Station documentation" has been submitted to some experts for discussion and will be published soon. This should be complemented by standards for instrumental details documentation, etc.

Summarizing, there are wide support and many activities, but these activities need to be coordinated and increased further.

In general, the following problems with IAGBN can be identified and countermeasures have to be taken :

1. Structure of coordination : The relations of IGC, WG2, Sub-commissions and other groups have to be clarified immediately.

2. Enhance support : Though general support is rather good it needs to be increased, e.g. in order to get more institutions to do dedicated IAGBN observation campaigns. In order to achieve this, problem 1 has to be solved (clear overhead structure). Further a clear image of the project has to be enhanced by :
   - status reports in the BGI Bulletin d'Information.
   - publication of existing station descriptions on an IAGBN form, a form will be distributed very soon.

3. Coordination of activities : Because IAGBN observations are by voluntary contribution, coordination and synchronization will remain a problem and need much attention, but will be largely improved if problem 1 is solved. Generally it is felt that in the present phase of station establishment and first observations a synchronization will not be possible, but should be aimed at in future campaigns, when the project has been consolidated.

4. Station accessability versus quality : There is a continued discussion whether one should maintain very stringent site selection and preparation criteria so that some of the stations may be at rather remote places and preparation expenses may be considerable or whether one should ease access and accept nearly arbitrary stations at international airports. From the author's viewpoint, this cannot be answered definitely. However, the more support and funds are focussed at this project, the more it will be possible to achieve higher quality.

**Positioning of IAGBN stations**

Precise position monitoring of IAGBN stations in a global frame is an integral part of monitoring gravity changes in view of geodynamics. For this reason IAGBN station sites were co-located to VLBI - or SLR-stations wherever possible. In other cases continent-wide GPS-networks may be a proper solution.

Another chance may be the Geodynamics Laser Ranging System (GLRS). This system advanced by NASA includes a spaceborne laser ranging system to be flown in the late 1990's. Obviously it is primarily intended for positioning of reflector target clusters in tectonically active regions, where it will yield cm accuracy.

The announcement of opportunity (AO) however, also mentions global cm-networking. Nevertheless it is open, whether it will be suited for a rather sparse global network like IAGBN. This has to be found out.

**Cooperation with Other Groups**

In order to bundle energy from different groups it seems fruitful to cooperate, besides WG6, which is clear anyway, e.g. with WG5, SEDI etc. It has to be decided whether these contacts are established on the level of IGC, on WG level or whatsoever.

**Standards**

It appears necessary to standardize a few things for IAGBN work :

1. Stations
   1.1. Site selection and preparation
   1.2. Station documentation
2. Absolute Observations
   2.1. Data processing standards
   2.2. Documentation
3. Subsidiary Observations
   3.1. Ties to other networks
   3.2. Precise positioning
   3.3. Levelling
   3.4. Hydrological monitoring

From these, 1.1. "Site selection and preparation" has been published in an IAGBN status report (Boedecker/Fritzer, 1986) and is widely accepted. A draft for 1.2. "Station documentation" and 2.1. "Data processing standards" was distributed to a few experts and will be published after revision. Further standards for 2.2. "Absolute observations documentation" and other instrumental standards may prove necessary and should be published by WG6.

G. BOEDECKER
Chairman, WG2

## WORKING GROUP 3

### Activity Report "Gravimetric maps" (1986-1988)

The Working Group 3 DB IGB "Gravimetric maps" was set up to coordinate activities in compilation of the Gravimetric Map of the World in scale 1/15.000.000 in ten sheets. This work is completed and the map published. A few copies were sent to IGB. Those specialists who wish to obtain the map (free of charge) should apply to the World Data Center B2 (Molodezhnaya 3, Moscow 117296, USSR).

At a later stage, in 1984, it became necessary to assist in compilation of different gravimetric maps for geological-geophysical atlases of the Atlantic and Pacific Oceans. They are now being prepared for publication in the USSR on the basis of international cooperation in the frame of the International Oceanographic Commission of UNESCO.

The attached Table shows a list of maps now in preparation and the degree of their readiness for publication. The work on the maps for the Atlantic Ocean is completed and they are with the Publishers. The issue of the Atlas is expected in the first quarter of 1989.

The basic maps on the Pacific Ocean, i.e., 1, 2, 3, 7a, 7b, 7c, 8a and 8b, are compiled, edited and now with the Publishers. The remaining maps shall be ready in the first half of 1989. Tentatively the Atlas shall be published in 1991 for the General IUGG Assembly in Vienna.

This time and effort consuming scientific and organisational work, in particular collection, systematisation and filtration of data for the two Atlases, could not have been accomplished without the serious and persistent help on the part of Pr. G. Balmino, Director of IGB, Ing. M. Sarrailh, his collaborator, and the staff of IGB. I extend our heartfelt gratituted to them in the name of all members of WG3.

Yu.D. BOULANGER
Convener, WG3

Table

List of gravimetric maps and materials included into the International Geological-Geophysical Atlases of the Atlantic and Pacific Oceans

| N | Name of map, material | Scale | Number of sheets | Editors | State of readiness |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| | | | Atlantic Ocean | | |
| 1. | Gravity anomalies in free air | 1:10,000,000 | 4 | Yu.D.Boulanger (curator) N.B.Sazhina | Compilation completed. Expected to be published in the Atlas in the first quarter of 1989. |
| 2. | Relief of the ocean's surface | 1:10,000,000 | 4 | R.Rapp | |
| 3. | Gravity field from data of satellite altimetry | 1:30,000,000 | 1 | V.Heksby | |
| 4. | Averaged 1° x 1° gravity anomalies in free air | 1:30,000,000 | 1 | V.A.Taranov, P.A.Stroev, A.G.Gainanov | |
| 5. | Averaged 1° x 1° Gleni gravity anomalies (modified Bouguer anomalies, R > 220 km) | 1:30,000,000 | 1 | A.G.Gainanov, P.A.Stroev, T.P.Zakharova | |
| 6. | Averaged 1° x 1° gravity isostatic anomalies (Erie scheme; T=33 km, $\Delta\sigma$ =0.4 g/cm$^3$) | 1:30,000,000 | 1 | M.E.Artemiev, A.G.Gainanov, P.A.Stroev | |
| 7. | Long-wave component of isostatic anomalies | 1:30,000,000 | 1 | M.E.Artemiev | |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 8. | Bay of Biscay: | | | | |
| | a. relief of ocean's surface | 1:2,500,000 | 1 | R.Rapp | |
| | b. gravity anomalies in free air | 1:2,500,000 | 1 | Sibouet | |
| 9. | Caribbean Sea: | | | | |
| | a. relief of ocean's surface | 1:6,000,000 | 1 | R.Rapp | |
| | b. gravity anomalies in free air | 1:6,000,000 | 1 | K.Bowin | |
| | | <u>Pacific Ocean</u> | | | |
| 1. | Gravity anomalies in free air | 1:10,000,000 | 7 | Yu.D.Boulanger, (curator) N.B.Sazhina | Authors original |
| 2. | Relief of ocean's surface | 1:10,000,000 | 7 | R.Rapp | Publishers original |
| 3. | Gravity field from data of satellite determinations | 1:30,000,000 | 1 | V.Heksby | Authors original |
| 4. | Averaged 1°x1° gravity anomaly in free air | 1:30,000,000 | 1 | V.A.Taranov, P.A.Stroev, A.G.Gainanov | 1989, first quarter |
| 5. | Averaged 1°x1° gravity Glenny anomalies (modified Bouguer anomalies, $R \geq 220$ km) | 1:30,000,000 | 1 | A.G.Gainanov, P.A.Stroev, T.P.Zakharov | 1989, first quarter |
| 6. | Averaged 1°x1° gravity isostatic anomalies (Erie scheme; $T=33$ km, $\Delta\sigma = 0.4\ g/cm^3$) | 1:30,000,000 | 1 | A.G.Gainanov, P.A.Stroev, T.P.Zakharov | 1989, first quarter |

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| 7. | Japan Sea:<br>a. gravity anomalies; free air reduction | 1:5,000,000 | 1 | P.A.Stroev | Publishers original |
| | b. gravity anomalies; Bouguer reduction | 1:5,000,000 | 1 | " | " |
| | c. gravity anomalies; isostatic | 1:5,000,000 | 1 | " | " |
| 8. | East China Sea:<br>a. gravity anomalies; free air reduction | 1:5,000,000 | 1 | " | " |
| | b. gravity anomalies; Bouguer reduction | 1:5 000,000 | 1 | " | " |
| 9. | Geotraverse Primorie-Japan Sea-Japan-Pacific Ocean | 1:5,000,000 | 1 | A.G.Rodnikov, P.A.Stroev | 1989, first quarter |
| 10. | Geotraverse: China-East China Sea-Okinawa-Philippine Sea | 1:5,000,000 | 1 | A.G.Rodnikov, P.A.Stroev | 1989, second half |

# WORKING GROUP 6

## Activity Report

## "Comparison of Absolute Gravimeters"

At the General Assembly of the International Association of Geodesy (Vancouver, August 1987) it was considered necessary to organise the 3rd International Comparison of Absolute Ballistic Gravimeters. With this purpose in view, the International Gravimetric Commission has entrusted Pr. Yu.D. Boulanger to form a Working Group 6 "Comparison of Absolute Gravimeters" and to take the necessary steps to carry out this comparison and not later than 1989 at the next IGC meeting to discuss the obtained results. During the interim period the following was achieved.

1. In December 1987, Pr. Yu.D. Boulanger travelled to Paris to meet Pr. P. Giacomo, Director of the Bureau International des Poids et Mesures, and Dr. M. Louis, General Secretary of IAG, and discuss the possible place and dates of comparison. As a result of this talk, the BIPM agreed to have the comparison in Sèvres at the main laboratory building in November-December 1989. It was also decided that, in view of the many difficulties in the organisation of comparison in 1985, a meeting of the leaders of the teams should be held at least a year before the Third Comparison. At this meeting the future participants would work out a detailed program of measurements and the rules of arrival, sejourn at BIPM, hotel accomodations, customs releases.
   After consultations with Pr. P. Giacomo, Dr. M. Louis, Dr. J. Tanner, and Pr. G. Balmino, this meeting is to be held on 21-22 June 1988 before the meeting of the Directing Board IGB. The IAG Central Bureau in Paris has kindly undertaken to organise this meeting.

2. In order to set up WG6, Pr. Yu.D. Boulanger has applied to the National Committees of countries, which have absolute gravimeters, asking them :
   - to inform him of their possible participation in the Third Comparison in 1989 ;
   - to name the responsible executive who will supervise the measurements ;
   - to inform of the possible participation in setting up a micro-gravimetric network and measurements of vertical gradients.

All countries gave positive answers. The list of WG 6 members is appended as also the information on participation of countries in the comparison.

Yu.D. BOULANGER
Convener, WG6

Appendix 1

**List of Members of WG6**

**"Comparison of Absolute Gravimeters"**

| | |
|---|---|
| 1. Prof. Yu.D. Boulanger | Institute of Physics of the Earth<br>B. Gruzinskaya 10, Moscow 123242<br>USSR, Telex : 411478 SGC SU |
| 2. Dr. G. Cerutti | IMGC, Strada Delle Cacce 73<br>Torino, Italy, Teleph. : (011) 348784 |
| 3. Dr. A.D. Geodacre | Geophysics Division, GSC,<br>1, Observatory Crescent, Ottawa, Ontario<br>Canada K1A OY3, Telex : 0533117 EMAR OTT |
| 4. Dr. Guo You-guang | National Institute of Metrology<br>Beijing, The People's Republic of China |
| 5. Prof. Haruo Ishi | Geographical Survey Institute<br>Ministry of Construction, Kitazate 1<br>Tsukuba-shi, Ibaraki-ken, 305 Japan<br>Teleph. : 0298-64-1118 |
| 6. Prof. A. Kiviniemi | Geodetic Institute, Ilmalankatu 1A<br>00240 Helsinki, Finland<br>Teleph. : 358-0-410433 |
| 7. Dr. G. Peter | Geodetic Research and Development<br>Laboratory N/CG114, National Geodetic<br>Survey, NOAA, Rockville, Maryland 20852<br>USA |
| 8. Dr. D. Ruess | Bundesamt für Eich-und Vermessungswesen<br>Abteilung für Grundlagenvermessungen<br>Schiffamtsgasse 1-3, A-1025 Wien<br>Australia |
| 9. Prof. A. Sakuma | BIPM, Pavillon de Breteuil, Sèvres<br>France, Telex : 201067 BIMP F |
| 10. Prof. W. Torge | Institut für Erdmessung Universität<br>Hannover, FRG, Telex : 923868 UNIHN I |

## Appendix 2

**Participation of countries in**

**the comparison of absolute gravimeters**

| Country | Agreement to participate | Leader of team | Number of specialists | Agreement to Δ g measurements | Number of relative gravimeters | Period of Observations of absolute gravimeters | Participation in Meeting on 21-22 June |
|---|---|---|---|---|---|---|---|
| Japan | yes | Pr. Haruo Ishi | 3 | yes | 1 | 7 | ? |
| China | yes | Dr. Guo Youguang | 7 | yes | 3 | 7 | - |
| Austria | yes | Pr. D. Ruess | 2 | yes | 2 | 4 | yes |
| Italy | yes | Dr. G. Cerutti | 3 | yes | 1-2 | 5-6 | yes |
| BRD | yes | Pr. W. Torge | 3 | yes | 8 | 5 | yes |
| Finland | yes | Pr. A. Kiviniemi | 2 | yes | 1 | 6 | yes |
| Canada | yes | Dr. A. Geodacre | 2 | no | - | 4 | yes |
| BIPM | yes | Pr. A. Sakuma | 1 | ? | ? | ? | yes |
| USA | yes | Pr. G. Peter | 3 | yes | 2 | 3 | yes |
| USSR | yes | Pr. Yu.D. Boulanger | 6 | no | - | 6 or 10 | yes |
| | 10 | | 32 | | 20 | 3-7 | 8 |

# MEETING OF WG 6, 21-22 June 1988

Problems for discussion at the meeting.

1. By demand from BIPM :
   1.1. the final number of teams and their membership shall be finally determined,
   1.2. observation sites and, accordingly, dates of arrivals and time of observations shall be fixed,
   1.3. Leaders of teams shall advise BIPM and Bureau Central of IAG not later than a month prior to comparison campaign,
   1.3.1. names and passport data of all participants of work,
   1.3.2. date, flight number and time of arrival of cargo at Paris
   1.3.3. number of cargo items, content of each item with cost of every piece ; weight of every item, total weight of cargo,
   1.4. the teams shall striclty keep to the announced dates of arrivals and shall take into consideration that meeting at the airport and seeing off of teams can be offered till 7.00 p.m. only ; arrival or departure on week-end days are extremely undesirable,
   1.5. the teams working on the night shifts shall. inform BIPM Directory 24 h prior to the shift and strictly follow the set rules, for example, it is forbidden to leave the building during free time,
   1.6. smoking is not allowed in the Laboratory building.
2. Hotel reservations shall be made by the Bureau Central of IAG not later than two months prior to commencement of work.
3. Distribution of instruments and time of observations.
   3.1. The beginning of work with absolute instruments of the first group is November 21, 1989.
   3.2. Beginning of relative measurements for micronetwork and determination of $W_{22}$ is on November 28, 1989. By that time all points with absolute gravimeters shall be free for relative instruments. Relative measurements shall be terminated on December 3, 1989.
   3.3. Beginning of work with absolute instruments of the second group on December 5, 1989.
   3.4. The following distribution of instruments is suggested :

| | |
|---|---|
| A. BIPM 21-26 XI<br>FRG 5-10 XII | A5 USA 21-26 XI<br>Finland 5-10 XII |
| A3 Italy 21-26 XI<br>USSR 10-15 XII | A6 USSR 5-10 XII<br>USSR 5-10 XII |
| A4 Austria 21-26 XI<br>China 5-10 XII | A7 Canada 21-22 XI<br>Japan 5-10 XII |

4. The teams working with relative gravimeters shall have device for installation of gravimeters in such a way as to set the centre of weight of the sample mass at each point at the height of 0.20 m (?) and 0.80 m (?) over the pillar with accuracy ± 5 mm (?). Measurements of $\Delta$ h in $W_{22}$ determinations shall have ± 1 mm accuracy.

5. In preliminary interpretation during observations it is suggested to introduce corrections :
   - for atmospheric masses attraction.
   - for the pole coordinates.
   - for earth tides.

6. In order to standardize introduction of corrections for Earth tides, the leader of team should approach Pr. P. Melchior with request to calculate corrections with accuracy ± 5 μgal in the time interval from 21.XI to 13.XII 1989 with one minute or 0.01 h (?) interval. There is a possibility to send Dr. S. Molodensky to Brussels for a few days to calculate and multiply the Tables.

7. During the period of relative measurements, a Workshop of SSG 3.89, WG 5 and WG 6 should meet to discuss details of interpretation of observations of absolute and relative gravimeters, the problems connected with the preparation of results of comparison for publication, and the problems of establishing the new global network of gravimetric points of the highest accuracy.

## Appendix 1

### List of Members of WG6

### "Comparison of Absolute Gravimeters"

| | |
|---|---|
| 1. Prof. Yu.D. Boulanger | Institute of Physics of the Earth<br>B. Gruzinskaya 10, Moscow 123242<br>USSR, Telex : 411478 SGC SU |
| 2. Dr. G. Cerutti | IMGC, Strada Delle Cacce 73<br>Torino, Italy, Teleph. : (011) 348784 |
| 3. Dr. A.D. Geodacre | Geophysics Division, GSC,<br>1, Observatory Crescent, Ottawa, Ontario<br>Canada K1A OY3, Telex : 0533117 EMAR OTT |
| 4. Dr. Guo You-guang | National Institute of Metrology<br>Beijing, The People's Republic of China |
| 5. Prof. Haruo Ishi | Geographical Survey Institute<br>Ministry of Construction, Kitazate 1<br>Tsukuba-shi, Ibaraki-ken, 305 Japan<br>Teleph. : 0298-64-1118 |
| 6. Prof. A. Kiviniemi | Geodetic Institute, Ilmalankatu 1A<br>00240 Helsinki, Finland<br>Teleph. : 358-0-410433 |
| 7. Dr. G. Peter | Geodetic Research and Development<br>Laboratory N/CG114, National Geodetic<br>Survey, NOAA, Rockville, Maryland 20852<br>USA |
| 8. Dr. D. Ruess | Bundesamt für Eich-und Vermessungswesen<br>Abteilung für Grundlagenvermessungen<br>Schiffamtsgasse 1-3, A-1025 Wien<br>Australia |
| 9. Prof. A. Sakuma | BIPM, Pavillon de Breteuil, Sèvres<br>France, Telex : 201067 BIMP F |
| 10. Prof. W. Torge | Institut für Erdmessung Universität<br>Hannover, FRG, Telex : 923868 UNIHN I |

Appendix 2

**Participation of countries in**

**the comparison of absolute gravimeters**

| Country | Agreement to participate | Leader of team | Number of specialists | Agreement to Δ g measurements | Number of relative gravimeters | Period of Observations of absolute gravimeters | Participation in Meeting on 21-22 June |
|---|---|---|---|---|---|---|---|
| Japan | yes | Pr. Haruo Ishi | 3 | yes | 1 | 7 | ? |
| China | yes | Dr. Guo Youguang | 7 | yes | 3 | 7 | - |
| Austria | yes | Pr. D. Ruess | 2 | yes | 2 | 4 | yes |
| Italy | yes | Dr. G. Cerutti | 3 | yes | 1-2 | 5-6 | yes |
| BRD | yes | Pr. W. Torge | 3 | yes | 8 | 5 | yes |
| Finland | yes | Pr. A. Kiviniemi | 2 | yes | 1 | 6 | yes |
| Canada | yes | Dr. A. Geodacre | 2 | no | - | 4 | yes |
| BIPM | yes | Pr. A. Sakuma | 1 | ? | ? | ? | yes |
| USA | yes | Pr. G. Peter | 3 | yes | 2 | 3 | yes |
| USSR | yes | Pr. Yu.D. Boulanger | 6 | no | - | 6 or 10 | yes |
| | 10 | | 32 | | 20 | 3-7 | 8 |

# WORKING GROUP 6

## "Comparison of Absolute Gravimeters"

## Circular Letter

*To all participants of the Third International Comparison of Absolute Gravimeters*

The joint meeting of Working Group 6 "Comparison of Absolute Gravimeters" and Working Group 2 "The International Absolute Gravimetric Basis Network" was held in Paris (21-22 June, 1988). The participants of this meeting discussed questions of the Third International Comparison of Absolute Gravimeters and the establishment of the International Absolute Gravimetric Basis Network. The participants of all countries, which expressed their wish to work in the comparison, were present at the meeting except the Chinese People's Republic.

After discussions :

1. The meeting thanked the Bureau International de Poids et Mesures for presenting an opportunity to convene the Third International Comparison of Absolute Gravimeters in Sèvres from 15 of November to 4 of December, 1989.
2. As there is not enough room in IBPM to install ten absolute gravimeters at a time, the meeting recognized that two groups of five instruments should convene comparison measurements during the following intervals of time :<br>the first group - 15-22 November, 1989<br>the second group - 28-4 December, 1989.
3. Taking into account remarks of the participants concerning weak steadiness of points A4, A5, A6 and A7 in the Comparator Hall, the meeting requested IBPM to have more steady points in other rooms.<br>After the meeting Pr. Yu.D. Boulanger went to Sèvres and as Pr. A. Sakuma suggested point A4 was replaced by point A8 in the room point A is installed ; points A5 and A6 were replaced by points A9 and A10 respectively in the room where point A3 is installed. All new points were set up on big and steady pillars.
4. The meeting applied to Pr. W. Torge to be responsible during the Third ICAG for the conduction of all relative measurements, which are necessary for the establishment of the micro-gravimetric network and determination of vertical gradients.
5. The meeting applied with the request to the countries, which expressed wish to participate in the establishment of micro-gravimetric network and measurements of $W_{zz}$, to conduct relative measurements from 23 to 28 of November, 1989.
6. The meeting suggested the following distribution of the pillars among the countries :

| Pillar | The First Group | The Second Group |
|---|---|---|
| A | IBPM | USA |
| $A_3$ | FRG | Italy |
| $A_8$ | Finland | Japan |
| $A_9$ | Austria | USSR |
| $A_{10}$ | China | Canada |

7. Taking into consideration organizing problems of conducting this comparison all participants were informed that in accordance with IBPM orders the leaders of the groups should send to IBPM and to the IAG Central Bureau the following no later than a month :

7.1. Lists of members of each group with names, surnames, birth dates, numbers of passports ;

7.2. Information of their arrival to Paris (date, time, flight which brings loads) ;

7.3. Lists of luggage, contents of each piece of luggage with costs of each thing of the piece, weight of each piece and general weight.

7.4. The participants should strictly follow dates of luggage arrival, which were informed earlier. They also should remember that luggage is registrated till 7 p.m. It is not desirable to arrive on Saturday or Sunday.

7.5. If it is necessary to conduct measurements at night, the participants should inform the administration board of IBPM a day before. They also should striclty keep the rules of work at night, in particular, it is categorically prohibited to go out of the building.

7.6. It is categorically prohibited to smoke inside.

8. Applications for hotel reservations should be sent to the Bureau Central of IAG no later than three months before the arrival.

9. Pr. A. Sakuma informed the participants that during the measurements it would be possible to compare working frequencies of laser gravimeters with the frequency of the standard laser in Sèvres.

10. The meeting applied to Pr. A. Sakuma to determine on five points absolute gravity value and vertical gradients before the beginning of ICAG activities.

11. In order to reduce the influence of non-linearity of $W_{zz}$ above the pillars the meeting recommended exactly over the mark of installation of absolute gravimeter to conduct measurements by relative instruments in three points so that to make their sensible masses to be above the pillars at heights of 0.10 m, 0.80 m, and 1.20 m. When determining the vertical gradient within heights of 0.80-1.20 m it is necessary to determine $\Delta h$ with the accuracy $\pm$ 1 mm, and the height of sensible mass of the gravimeter with the accuracy $\pm$ 5 mm. For all this the meeting also recommended in addition for the traditional reductions the gravity value, which was measured on the effective height = 0.80 m. It enables to compare the measurements of absolute gravimeters more exactly.

12. The participants of the meeting thought it advisable :

12.1. to convene the workshop of Working Groups 1 and 6 in Edinburgh during the next IAG Assembly to work out the final program of the Third International Comparison of absolute gravimeters.

12.2. Exactly after these activities to held a joint meeting of SSG 3.110 "Local Gravity Variations", Working Group 2 "International Absolute Gravity Basic Net", and Working Group 6 "Comparison of Absolute Gravimeters" for discussion of preliminary results of the Third ICAG (Paris, 5-6 December 1989), of the order of processing of data, and the publication of the obtained materials.

Appendix 1 contains the corrected list of Working Group 6 and Appendix 2 - information about participation of countries in the Third ICAG.

Pr. Yu.D. Boulanger
Convener ICAG

## Appendix 1

List of Members of WG6

"Comparison of Absolute Gravimeters"

| | |
|---|---|
| 1. Prof. Yu.D. Boulanger | Institute of Physics of the Earth<br>B. Gruzinskaya 10, Moscow 123242<br>USSR, Telex : 411478 SGC SU |
| 2. Dr. G. Cerutti | IMGC, Strada Delle Cacce 73<br>Torino, Italy, Teleph. : (011) 348784 |
| 3. Dr. N. Cortier | Geophysics Division, GSC,<br>1, Observatory Crescent, Ottawa, Ontario<br>Canada K1A OY3, Telex : 0533117 EMAR OTT |
| 4. Prof. J. Faller | SGD Quantum Physics Division 525<br>National Bureau of Standards<br>Boulder, CO. 80309, USA |
| 5. Dr. Guo You-guang | National Institute of Metrology<br>Beijing, The People's Republic of China |
| 6. Prof. Haruo Ishi | Geographical Survey Institute<br>Ministry of Construction, Kitazate 1<br>Tsukuba-shi, Ibaraki-ken, 305 Japan<br>Teleph. : 0298-64-1118 |
| 7. Prof. A. Kiviniemi | Geodetic Institute, Ilmalankatu 1A<br>00240 Helsinki, Finland<br>Teleph. : 358-0-410433 |
| 8. Dr. G. Peter | Geodetic Research and Development<br>Laboratory N/CG114, National Geodetic<br>Survey, NOAA, Rockville, Maryland 20852<br>USA |
| 9. Dr. D. Ruess | Bundesamt für Eich-und Vermessungswesen<br>Abteilung für Grundlagenvermessungen<br>Schiffamtsgasse 1-3, A-1025 Wien<br>Australia |
| 10. Prof. A. Sakuma | BIPM, Pavillon de Breteuil, Sèvres<br>France, Telex : 201067 BIMP F |
| 11. Prof. W. Torge | Institut für Erdmessung Universität<br>Hannover, FRG, Telex : 923868 UNIHN I |

## Appendix 2

**Participation of countries in**

**the comparison of absolute gravimeters**

| Country | Agreement to participate | Leader of team | Number of specialists | Agreement to g measurements | Number of relative gravimeters | Period of Observations of absolute gravimeters |
|---|---|---|---|---|---|---|
| Austria | yes | Pr. D. Ruess | 2 | yes | 2 | 4 |
| BIPM | yes | Pr. A. Sakuma | 1 | yes | 2 | 4 |
| BRD | yes | Pr. W. Torge | 3 | yes | 8 | 5 |
| Canada | yes | Dr. N. Cortier | 2 | no | - | 4 |
| China | yes | Dr. Guo Youguang | 7 | yes | 3 | 7 |
| Finland | yes | Pr. A. Kiviniemi | 2 | yes | 1 | 6 |
| Italy | yes | Dr. G. Cerutti | 3 | yes | 1-2 | 5-6 |
| Japan | yes | Pr. Haruo Ishi | 3 | yes | 1 | 7 |
| USA | yes | Pr. J. Faller | 3 | yes | 2 | 3 |
| USSR | yes | Pr. Yu.D. Boulanger | 6 | no | - | 6 |
| | 10 | | 32 | | 20 | |

## INFORMATION

## IAG GENERAL MEETING 1989 - EDINBURGH, 7-12 August 1989

## List of Symposia

0 Global and Regional Geodynamics (CSTG/CRGM

1 GPS Applications and Techniques
GPS Modelling and Optimization
New Satellite Radio Tracking Systems

2 High Precision Gravimetry and Gradiometry
Non-Newtonian Gravity

3 Geodetic Reference Framework
Earth Rotation Parameter Determination

4 Geodesy and Oceanography
High Accuracy Geoid Determination
Definition of Vertical Datum

# PART III

# CONTRIBUTING PAPERS

## International Absolute Gravity Basestation Network (IAGBN) Absolute Gravity Observations Data Processing Standards & Station Documentation

International Gravity Commission - Working Group II
"World Gravity Standards"; Gerd Boedecker, Chairman

IGC-Working Group II "World Gravity Standards" promotes, among other projects, the creation of a homogeneous set of absolute gravity values for IAGBN stations. Thus it is necessary to agree on a set of standards as to station implementation and observations.

At present it is not possible and/or advisable to fix a definite set of standards. Rather, a set of working standards should be defined some of which may persist. Recommendations for site selection criteria - on the basis of various existing procedures - have been published within the framework of the former IAG-Special Study Group 3.87 by Boedecker/Fritzer 1986 and are widely accepted. This publication includes absolute observations data processing standards and a station description form recommended for use. Standards on instrumental or observations documentation procedures as also on precise positioning may follow. It is left open, whether there should be a recommendation for the absolute observation procedure, particularly calibration. Recommendations for subsidiary observations are to follow.

### Station documentation

For station documentation use of the attached form is recommended. "Station location" indicates the name of the city or habitat where the station is located. The second block gives the coordinates as geographic latitude, longitude and elevation (above sea level in meters) to enable tidal reduction computation and to ease identification on a map. The approximate g-value should be given to $10^{-6}$ $ms^{-2}$ in order to ease presetting of instruments. Precise gravity and positioning results from different epochs will be stored in a data base. The third block should assist in getting to the proper place within a habitat. The next block indicates how a station is marked and whether it is identical with a station belonging to another station set or network. The last block should facilitate

to locate the station to centimeter and to judge whether the station marker remained unchanged.
Reasoning: From experience with IGSN71 and practically all networks it is known that a uniform appearance of station descriptions eases utilization. The list of items to be contained in such a form has to be short in order to ensure complete use, comprehensive and should allow different personal styles.

Absolute observations data processing standards

As far as possible the basis for the following recommendations were taken from IAG/IUGG resolutions.

- Light travel time correction is based on c = 299 792 458 [$ms^{-1}$] (IAG 1983 resolution no. 1)

- Earth tides reduction: It is recommended to apply the Cartwright-Tayler-Edden development supplemented by the ICET to yield a total of 505 tidal constituents. Observed tidal parameters (amplitude factors and phase lags) should be used, if available. At stations where observed tidal parameters are not available, an amplitude factor of 1.164 and zero phase lag should be used. The direct constant part of the tidal gravity effect should also be removed from the observed gravity data using:

  $$\delta g\ (\text{MOSO}) = -\ 4.83 + 15.73 \cdot \sin^2\psi - 1.59 \cdot \sin^4\psi \quad [10^{-8} m \cdot s^{-2}]$$
  $\psi$ geocentric latitude

  but the indirect part due to permanent yielding of the earth should not be (IAG 1983 resolution no. 9 and no. 16; details see Rapp 1983).

- Earth rotation changes: The geometric position of the earth's body relative to its spin axis causes a gravity change up to the order of $5 \cdot 10^{-8}$ [$ms^{-2}$] and therefore has to be referenced to mean position. It is recommended to use (e.g. Wahr 1985)

$$\delta g = 1.164 \cdot 10^{8} \cdot \omega^{2} \cdot a \cdot 2 \cdot \sin\phi \cdot \cos\phi \ (x \cdot \cos\lambda - y \cdot \sin\lambda)$$
$$[10^{-8} ms^{-2}]$$

where

x, y pole coordinates in IERS system in radian

$\omega$ = 7 292 115$\cdot 10^{-11}$ [rad$\cdot s^{-1}$] angular velocity

a = 6 378 136 [m] semimajor axis

$\phi$, $\lambda$ geographic coordinates of the observation station (longitude positive east of Greenwich)

If real time evaluation is desired, an appropriate prediction may be used (e.g. Sheng 1982). At present, a reduction for angular velocity variations is not recommended.

Reasoning: A polar motion model so far has not been standardized by IUGG/IAG. Because the effect of up to 5 $10^{-8}$ [$ms^{-2}$] exceeds the threshold of 1 $10^{-8}$ [$ms^{-2}$], it should be corrected for, as suggested by Torge/Röder/Schnüll/Wenzel/Faller 1987. Angular velocity variation effects hardly exceed 1 $10^{-8}$ [$ms^{-2}$] for annual and sub-annual periods. Secular variations, however, should not be removed but considered part of the looked-for geodynamic effects, open for a posteriori analysis.

o Air pressure: The lumped effects of direct gravitation of air mass changes and indirect effect via deformation of the solid earth have been determined empirically. It is recommended to reduce these effects through (IAG 1983 resolution no. 9)

$$\delta g = 0.30 \cdot 10^{-10} \cdot \delta p \ [ms^{-2}]$$

where

$\delta p$ = $(p_a - p_n)$ [Pa]

$p_a$ actual observed air pressure

$p_n$ normal pressure,

unless it is determined by special investigations, in which case the values used must be published together with the results.

As a working standard for the normal pressure it is recommended to use DIN 5450:

$$p_n = 1.01325 \cdot 10^5 \, (1 - 0.0065 \cdot H/288.15)^{5.2559} \quad [Pa]$$

where

H station elevation in [m]

Reasoning: The above reduction formula does not cover instrumental effects; these should be cared for by the respective groups. The given empirical parameter may also include effects of sea level and ground water deformations, therefore it may be replaced once a superior value has been found. This and of course also the Standard Atmosphere is very much a matter of convention. Resolution no. 9 (1983) announces that a Standard Atmosphere should be published by the BGI. As long as this is not published, the above standards are proposed also in accordance with Torge/Röder/Schnüll/Wenzel/Faller 1987.

o Absolute gravity height reference: The reference height of the absolute gravity observations differs from the marker height. It is recommended to use three different station elevation definitions:

A: Primary reference point defined at an elevation of 0.800 m above the marker.

B: Observation reference point defined as a result of the observation evaluation (usually ranging from 0.8 ...1.1 m)

C: Marker at ground (highest point of knob)

These three points should be within a radius of 0.01 m around the plumb line through the station marker; if this is not feasible, the appropriate reduction has to be given.

The respective gravity values are related through:

$$g_A = g_B - (\partial g/\partial H)_{AB} \cdot (H_B - H_A)$$
$$g_C = g_A - (\partial g/\partial H)_{AC} \cdot (H_A - H_C)$$

where

$g_B$ observed absolute gravity (after reductions for tides etc., c.f. above),

$(\partial g/\partial H)_{AB}$ observed gravity gradient; derived (normally) from relative meter observations at A and B or nearby stations including the height interval AB.

$(\partial g/\partial H)_{AC}$ approximate observed gravity gradient between primary reference point and marker.

The reference height A at 0.800 m above marker at ground represents the primary reference height. For high precision gravity links, this reference height should be used.
The reference height C of the marker is inaccessible for the proof mass of an absolute or a relative gravity meter, therefore it is less suited for high precision observations but is important for different types of gravity surveys.

Reasoning: None of the instruments is observing at the marker elevation, neither the absolute nor the relative meters, thus any comparison of different instruments or at different epochs via the marker gravity values is corrupted by

- irregular vertical gradient; this is particularly true close to the ground, therefore a precise value for the marker itself never will be known. Even a difference by relative meters between A and C will depend on the height of the sensitive mass within a gravity meter and therefore on the type of the meter.
- observation noise of "gradient" observation.

Thus one has to use a reference height which is closer to the observation itself and where the relative meter sensor can really be put to the proper location. A reference height of 0.800 m is suggested because

- the observation reference height of the existing gravity meters is ranging between 0.8 to 1.2 m and will be decreasing in future
- it is a round value
- it is easily possible to construct a stable tripod for a relative meter of that height.

For the gravity gradient the best available approximation should be used. Because at typical station sites the gradient can deviate by 20 % or even more from the normal gradient, even a rather poor relative gravity meter difference will be superior to the normal gradient. For the height difference AB nevertheless the error should be kept within $3 \cdot 10^{-8} [ms^{-2}]$ and normally below $1 \cdot 10^{-8} [ms^{-2}]$.

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# International Absolute Gravity Basestation Network (IAGBN)

| Station Location: | | Country: | |
|---|---|---|---|
| $\varphi =$ | $\lambda =$ | H= | g= |

Overview / Access / Outside View / Topo Map

Remarks / Station Identity / Contact

Detailed Sketch (North? Station Marker?) / Photograph

Date / Author

G.P.Arnautov, E.N.Kalish, Yu.F.Stus,
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# Determination of the absolute gravity value in Singapore in 1987

The study of the nonstability of the Earth's gravity field in time is an important problem of modern gravimetry. There are different evaluations of the possible non-tidal gravity variations, from a few microgal to hundreds of microgal per year. Theoretically, the maximal changes, connected with the irregularities in the Earth's rotation, displacement of the center of the Earth's mass, and so on, are expected in the equatorial zone.

Considering the actuality of this kind of research, the International Association of Geodesy has adopted the program of high accuracy absolute gravity determinations in different regions of the world with the purpose of studying non-tidal changes of the gravity field. In the frame of this program, the USSR Academy of Sciences has undertaken gravimetric research with absolute laser ballistic gravimeter (GABL) in Singapore located almost on the equator ( $\varphi$ = 1°30').

As part of the program, repeated determinations of absolute gravity value were carried out in Singapore by the Institute of Physics of the Earth, USSR Academy of Sciences, in cooperation with the Institute of Automatics and Electrometry, Siberian Department of the USSR Academy of Sciences. The first measurements were made in December 1976 /1/. They were not successful because the vibroprotective device of the gravimeter failed to operate. Repeated measurement at the same point in Singapore were made in April and June 1979, before and after the termination of point work of the Soviet-Australian expedition on the territory of Australia /2/. In 1980 it became known that the building, in which the measurements were made, will be destroyed in view of reconstruction of this part of Singapore. Consequently, the gravimetric point will be lost and it was necessary to locate it at a new site in the new building of the Faculty of Physics of the Singapore University. This work was done in February 1982 /3/, when measurements were made at two points: at the old "Singapore 1" to determine the possible gravity changes during the interim years, and at the new "Singapore II" to establish zero for future measurements. The next measurement of absolute gravity value at Singapore II site was made in July 1984 /4/.

In April 1987 it was possible to organise another set of measurements by GABL instrument at Singapore II, the results of which are given below. We have also compared all gravity measurements made in Singapore earlier.

In 1987 the measurements were carried out by the new modification of the GABL absolute instrument of smaller size and weight. This gravimeter took part in the international comparison of absolute gravimeters in Sèvres in 1985.

The principle of operation of the gravimeter remained based on the observations of free fall of angle reflector in vacuum. The procedure of absolute gravity determination follows the scheme according to which the time intervals of freely falling body are measured against the given intervals of passage. The time intervals of the angle reflector fall were measured by rubidium frequency standard, whereas the intervals of passage were given by the laser interferometer with the working laser stabilised by Lamb's gap. The control laser stabilised by iodine absorption cell checked the frequency emitted by the working laser. The obtained gravity value $g_0$ is related to the point located at a distance up along the vertical from the pillar on which the GABL instrument is mounted. This distance is called the effective height of the gravimeter ( $h_{eff}$); in 1987 it was 0.990 m, and for earlier measurements it was 1.274 m.

Corrections were introduced into the obtained $g_0$ values (see Appendix 1): for remainant air resistance in the vacuum chamber ( $\Delta g_p$), for finiteness of light velocity ( $\Delta g_c$), for tidal changes of gravity ( $\Delta g_\delta$ ), for the Pole movements ( $\Delta g_\omega$ ), for atmospheric mass attraction ( $\Delta g_{pa}$). Corrections were reduced to zero by the methods applied and were not introduced for deviation of the measurement line from the vertical ( $\Delta g_\varphi$ ), for deviation of frequency of the operating laser ( $\Delta g_\lambda$ ), and for time intervals ( $\Delta g_t$). In accordance with IAG Recommendations, the Honkasalo correction ( $\Delta g_H$) was not introduced. Since the Expedition did not have high accuracy relative gravimeters, the vertical gravity gradient was not measured at point Singapore II, the measured $g_0$ value was not reduced to pillar level (correction $\Delta g_h$), and the final gravity value is given for the effective height of the gravimeter equal to 0.990 m.

In accordance with IAG Resolution N 9 (1983) the correction for atmospheric mass attraction ( $\Delta g_{pa}$) is calculated by formula:

$$\Delta g_{pa} = 0.30 \cdot 10^{-11} \cdot \delta P \quad (m/c^2),$$

where $\delta p = P_a - P_n$ (pascal).

$P_a$ is the measured atmospheric pressure,

$P_n$ is the normal atmospheric pressure calculated by formula:

$$P_n = 1.01325 \cdot 10^5 \left(1 - 0.0065 \frac{H}{288.15}\right)^{5,2559} \text{ (pascal)}$$

where H is the height of gravimetric point in meters above sea level.

Correction for movement of the Pole was calculated by formula:

$$\Delta g_\omega = -(AX + BY),$$

where $A = 0.1906 \cdot \sin 2\varphi \cdot \cos \lambda$ ,

$B = 0.1906 \cdot \sin 2\varphi \cdot \sin \lambda$

$\lambda > 0$ west of Greenwich.

X and Y are coordinates of the Pole selected from the Tables of the Time Service. It should be noted that for Singapore point the correction $\Delta g_\omega$ was equal to zero.

The evaluation of the accuracy of the obtained measurements was made by formula:

$$M = \pm \sqrt{M_o^2 + m_\Delta^2} ,$$

where $M_o$ is an accidental measurements error calculated by correlation of series.

$m_\Delta$ are errors appearing from inaccurate determinations of $\Delta g_i$ corrections.

From the data of special studies for errors $m_\Delta$ the following values were obtained

$m_p = \pm 2$ mcgal, $m_c = \pm 0$ mcgal, $m_\delta = \pm 2$ mcgal,
$m_{pa} = \pm 0.5$ mcgal, $m_t = \pm 1$ mcgal, $m_\lambda = \pm 4$ mcgal,
$m_\varphi = \pm 2$ mcgal.

The results of measurements of absolute gravity values obtained at Singapore II point in 1987 are given in Appendix 1.

It is interesting to compare the obtained result with measurements carried out earlier. In paper /4/ this comparison is made in measurements made in 1979-84 period. In order to compare g measurement results in 1987 and those in paper /4/, corrections for the change of effective height of absolute gravimeter should be introduced into measurements of 1987. In previous years gravity value at Singapore II was related to effective height $h_{eff}$ = 1.274 m. In 1987, the measurements were made by the new modification of GABL instrument, whose effective height was 0.990 m, and gravity value is related actually to this height (Appendix 1). Therefore, the reduction for gravity change with height should be introduced into the g value obtained in 1987. The exact value of the vertical gravity gradient at point Singapore II was not determined. For such types of gravimetric points as Singapore II the vertical gravity is normally about 260 mcgal/m. If we assume this value, we shall obtain the reduction for the effective height change:

$$\Delta g_{\delta h} = 260\ (1.274 - 0.990) = 74 \text{ mcgal}$$

This reduction with "minus" is introduced into the measurements of 1987.

Appendix 2 shows all absolute gravity determinations made by GABL gravimeter in Singapore and reductions for their adjustment to Singapore II point. All g values are related to effective height equal to 1.274 m.

The final result by years is given in Table 1.

Table 1

Results of absolute determinations of gravity at Singapore II point

| Year | g | M(g) |
|---|---|---|
| | mcgal | mcgal |
| 1979 | 978 064 090 | ± 22.0 |
| 1982 | 102 | 8.2 |
| 1984 | 096 | 8.3 |
| 1987 | 097 | 5.9 |
| average: | 978 064 096 | ± 4.9<br>± 2.5 |

Therefore, the absolute gravity value for Singapore II ( $h_{eff}$ = 1.274 m) can be assumed equal to:

$$g = 978\ 064\ 096 \pm 2.5 \text{ mcgal}$$

At the bottom of Table 1 we have:

$$\delta g(1982-1979) = +12 \pm 23.5 \text{ mcgal}$$

$$\delta g(1984-1982) = -6 \pm 11.7 \text{ mcgal}$$

$$\delta g(1987-1984) = +1 \pm 10.2 \text{ mcgal}$$

All $\delta g$ differences were less than the errors with which they were determined. This result gives grounds to consider the gravity field in Singapore stable (within measurement accuracy) during 1979-1987 period.

We should note that at Singapore II point it is necessary to make high accuracy measurement of vertical gravity gradient to obtain more reliable data for comparison of measurements carried out in different years .

In conclusion the authors wish to express their deep grati-

tude to Prof. A.Radjaratnam, Dean of the Physics Faculty of the Singapore University, and his colleagues Dr. Ratnam and Dr. Chua Poh Huat, who rendered great assistance in the arrangement of measurements and extended to us warm hospitality.

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15 june 1988

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Appendix 1

## Results of absolute gravity measurements

## at Singapore II point in 1987

| | Time of meas. by Greenwich | Measured value | Mean square error | Number of falls | Corrections | | | | | | Air pressure value | Corrected value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | for resistence of air | for finiteness of light velocity | for gradient | for tide | for movement of the Pole | for atmospheric attraction | | |
| | $T_o$ | $g_o$ | $m_o$ | K | $\Delta g_p$ | $\Delta g_c$ | $\Delta g_h$ | $\Delta g_\delta$ | $\Delta g_\omega$ | $\Delta g_{pa}$ | $P_a$ | g |
| | | mcgal | mcgal | | mcgal | mcgal | mcgal | mcgal | mcgal | mcgal | mbar | mcgal |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| | 18.IV.1987 | | | | | | | | | | | |
| 1 | $12^h46^m-13^h01^m$ | 978 064 214 | ± 5 | 75 | + 10 | - 21 | - | - 33 | 0 | - 1 | 1010 | 978 064 169 |
| 2 | 13 07 -13 22 | 223 | 6 | 75 | + 10 | - 21 | - | - 38 | 0 | - 1 | 1010 | 174 |
| 3 | 13 34 -13 49 | 226 | 6 | 75 | + 9 | - 21 | - | - 44 | 0 | - 1 | 1011 | 169 |
| 4 | 14 02 -14 17 | 232 | 6 | 75 | + 9 | - 21 | - | - 46 | 0 | - 1 | 1011 | 173 |
| 5 | 14 42 -14 57 | 217 | 6 | 74 | + 8 | - 21 | - | - 42 | 0 | - 1 | 1011 | 161 |
| 6 | 15 03 -15 18 | 213 | 6 | 74 | + 8 | -21 | - | - 37 | 0 | - 1 | 1011 | 162 |
| 7 | 15 26 -15 41 | 225 | 7 | 74 | + 8 | - 21 | - | - 30 | 0 | - 1 | 1011 | 181 |
| 8 | 15 53 -16 08 | 203 | 7 | 75 | + 8 | - 21 | - | - 19 | 0 | - 1 | 1011 | 170 |
| 9 | 16 17 -16 32 | 191 | 5 | 74 | + 8 | - 21 | - | - 7 | 0 | - 1 | 1011 | 170 |
| 10 | 16 42 -16 57 | 185 | 5 | 74 | + 8 | - 21 | - | + 7 | 0 | - 1 | 1011 | 178 |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 17 12-17 27 | 160 | 7 | 75 | + 8 | - 21 | - | + 23 | 0 | - 1 | 1010 | 169 |
| 12 | 17 42-17 57 | 978 064 142 | ± 7 | 75 | + 7 | - 21 | - | + 40 | 0 | - 1 | 1010 | 978 064 167 |
| 13 | 18 12-18 27 | 145 | 9 | 75 | + 7 | - 21 | - | + 55 | 0 | - 2 | 1009 | 184 |
| 14 | 18 42-18 57 | 125 | 9 | 75 | + 7 | - 21 | - | + 68 | 0 | - 2 | 1009 | 177 |
| 15 | 19 12-19 27 | 107 | 6 | 74 | + 6 | - 21 | - | + 78 | 0 | - 2 | 1009 | 168 |
| 16 | 19 42-19 57 | 103 | 6 | 75 | + 6 | - 21 | - | + 84 | 0 | - 2 | 1009 | 170 |
| 17 | 20 12-20 27 | 102 | 7 | 75 | + 6 | - 21 | - | + 87 | 0 | - 2 | 1009 | 172 |
| 18 | 20 42-20 57 | 093 | 8 | 74 | + 6 | - 21 | - | + 85 | 0 | - 2 | 1009 | 161 |
| 19 | 21 13-21 28 | 103 | 7 | 75 | + 6 | - 21 | - | + 79 | 0 | - 2 | 1009 | 165 |
| 20 | 21 42-21 57 | 131 | 7 | 75 | + 6 | - 21 | - | + 69 | 0 | - 2 | 1009 | 183 |

Average : g = 978 064 171

m = ± 6,8

$M_o$ = ± 1,5

M = ± 5,6

The g value is obtained at effective height equal to 0,990 m.

Comparison of results of absolute gravity measurements in Singapore in 1979-1987

| Point | Date of measurement (month, year) | g and M(g) | Corrections: Honkasalo | Corrections: For hydrological effect | Corrections: For change of height of point | Corrections: For atmospheric attraction | Corrections: For change of effective height | Δ g Singapore II-Singapore I | g and M(g) at point Singapore II |
|---|---|---|---|---|---|---|---|---|---|
| | | mcgal | mcgal | mcgal | mcgal | mcgal | mcgal | mcgal | mcgal |
| Singapore I | IV.1979 | 978069959 ±14,1 | | | | | | | |
| Singapore I | VI.1979 | 939 14,7 | | | | | | | |
| Average: | | 978069949 ±10,2 | + 35 | -50 ±15 | -16 ±2 | - 1 | - | - 5827 ±12,3 | 978 064 090 ±22,0 |
| Singapore I | II.1982 | 978069911 ± 9,4 | + 35 | - | -16 ± 2 | - 1 | - | - 5827 ±12,3 | 978 064 102 ±15,6 |
| Singapore II | II.1982 | 978064084 ± 8,0 | + 35 | - | - 16 ±2 | - 1 | - | - | 978 064 102 ± 8,2 |
| Singapore II | VII.1984 | 978064095 ± 8,3 | - | - | - | + 1 | - | - | 978 064 096 ± 8,3 |
| Singapore II | IV.1987 | 978064171 ± 5,6 | - | - | - | - | -74±2 | - | 978 064 097 ± 5,9 |

# GRAVITY ON A TALL TOWER

by

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Abstract

In the summer of 1987 gravity data were collected both on and around a television transmitting tower using the LaCoste-Romberg model G gravimeter #152. The surface data were upward continued and compared with the tower data in searching for departures from Newton's inverse-square law. The surface data are good to about 20 μGal while the tower data are good to better than 30 μGal.

## Data Acquisition

The object of our study was the WTVD television tower in Garner, North Carolina, which rises 610 m above the surface to the top of the antenna. There were 77 surface data points collected within a 5 km radius of the tower, six data points collected on the tower at various elevations, along with one at the tower base. The coordinates of the surface data points are WGS 72 geodetic positions determined by the Defense Mapping Agency / Geodetic Survey Squadron. The horizontal positioning was done with the aid of the Inertial Positioning System (IPS) to an accuracy of 1 m, and the vertical positions are NGVD 29 elevations obtained using differential leveling to an accuracy of 2 cm. The exceptions are stations: TG27, TG28, TG35, TG57, TG65, and TG67 whose elevations are only accurate to 60 cm. The elevations of the tower data points were determined using a conventional Electronic Distance Meter (EDM) to an accuracy of 1 cm relative to the tower base. The EDM used was a GTS 10D Topcon which is good to 5 mm ± 5 ppm.

## Data Reduction

The data were reduced using a least-squares network adjustment. All observations were corrected for tides (no Honkasalo correction) and gravimeter drift. Table 1 is a list of all 77 surface data points, and Table 2 lists the tower data. The coordinates in Table 1 are in degrees and decimal minutes, and the elevations are in meters above mean sea level. The free air anomalies were computed using the GRS67 normal gravity formula, and Bruns' Equation for the vertical gradient of the normal field. Two IGSN 71 stations, 11658 B and 11658 K, were transferred to the tower site obtaining a base value of 979740.565 ± .018 mGal. This base was used for both the surface and the tower stations. The errors in Table 1 reflect the internal errors derived from the adjustment. There are additional errors that must be included in the error budget (e.g. position error, screw error, water table) yielding final error estimates of about 20 μGal for all the surface data with the exception of the six previously mentioned points. Due to the elevation uncertainty in those points, they are only accurate to 200 μGal. The scale factor for G-152 was also determined on a Colorado/Wyoming calibration line to be 1.000703 ± .000091. For more details concerning the data reduction see Romaides et al. (1988).

## Conclusion

All the data that were collected, both surface and tower data, are of high quality, thus providing us with the means to evaluate the possible existence of a non-Newtonian force (Eckhardt et al., 1988). More details concerning the mechanics of collecting gravity on a tower will be presented later, but due to numerous requests, we make the data available here.

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TABLE 1. Surface Gravity Data Points

| Station | Latitude | Longitude | Elevation | Anomaly | Gravity | Error |
|---|---|---|---|---|---|---|
| TG01 | 35 40.151 | -78 31.952 | 96.71 | -19.453 | 979740.638 | .006 |
| TG02 | 35 40.127 | -78 31.922 | 97.57 | -19.282 | 979740.513 | .005 |
| TG03 | 35 40.104 | -78 31.909 | 96.48 | -19.239 | 979740.854 | .010 |
| TG04 | 35 40.075 | -78 31.926 | 95.29 | -19.376 | 979741.049 | .010 |
| TG05 | 35 40.060 | -78 31.939 | 94.19 | -19.479 | 979741.261 | .010 |
| TG06 | 35 40.047 | -78 31.975 | 92.64 | -19.756 | 979741.444 | .009 |
| TG07 | 35 40.055 | -78 32.014 | 85.65 | -20.684 | 979742.684 | .010 |
| TG08 | 35 40.076 | -78 32.040 | 81.90 | -21.063 | 979743.492 | .010 |
| TG09 | 35 40.134 | -78 32.021 | 85.18 | -20.775 | 979742.851 | .010 |
| TG10 | 35 40.155 | -78 31.991 | 91.84 | -20.071 | 979741.530 | .010 |
| TG11 | 35 40.361 | -78 32.067 | 94.40 | -19.660 | 979741.445 | .010 |
| TG12 | 35 40.302 | -78 31.834 | 97.14 | -19.551 | 979740.627 | .010 |
| TG13 | 35 40.214 | -78 31.755 | 103.02 | -19.119 | 979739.115 | .006 |
| TG14 | 35 40.114 | -78 31.742 | 95.11 | -19.863 | 979740.673 | .011 |
| TG17 | 35 39.884 | -78 31.972 | 80.98 | -21.113 | 979743.455 | .010 |
| TG18 | 35 39.900 | -78 32.080 | 78.02 | -21.177 | 979744.328 | .010 |
| TG19 | 35 39.991 | -78 32.211 | 76.79 | -21.052 | 979744.965 | .009 |
| TG20 | 35 40.210 | -78 32.211 | 86.07 | -20.493 | 979742.967 | .010 |
| TG21 | 35 40.567 | -78 32.149 | 102.10 | -18.579 | 979740.422 | .005 |
| TG22 | 35 40.477 | -78 31.621 | 110.12 | -18.665 | 979737.754 | .004 |
| TG23 | 35 40.130 | -78 31.365 | 104.81 | -19.125 | 979738.443 | .010 |
| TG24 | 35 39.903 | -78 31.549 | 94.56 | -19.858 | 979740.544 | .010 |
| TG26 | 35 39.622 | -78 32.103 | 68.15 | -22.338 | 979745.813 | .010 |
| TG27 | 35 40.105 | -78 32.555 | 76.90 | -20.326 | 979745.820 | .010 |
| TG28 | 35 40.184 | -78 32.657 | 76.70 | -20.308 | 979746.016 | .010 |
| TG29 | 35 40.279 | -78 31.555 | 108.37 | -18.880 | 979737.796 | .010 |
| TG30 | 35 40.472 | -78 32.401 | 88.18 | -19.653 | 979743.529 | .010 |
| TG31 | 35 41.020 | -78 31.919 | 104.59 | -19.529 | 979739.369 | .010 |
| TG32 | 35 40.788 | -78 31.391 | 111.35 | -19.087 | 979737.399 | .007 |
| TG33 | 35 40.446 | -78 31.231 | 112.11 | -19.370 | 979736.387 | .006 |
| TG34 | 35 40.067 | -78 31.155 | 105.15 | -19.294 | 979738.073 | .007 |
| TG35 | 35 39.710 | -78 31.355 | 92.30 | -20.419 | 979740.405 | .011 |
| TG36 | 35 39.217 | -78 32.155 | 103.50 | -17.720 | 979738.949 | .010 |
| TG37 | 35 39.400 | -78 32.581 | 107.40 | -17.011 | 979738.713 | .010 |
| TG38 | 35 39.741 | -78 32.801 | 108.92 | -17.256 | 979738.482 | .008 |
| TG39 | 35 40.356 | -78 32.981 | 76.75 | -19.941 | 979746.603 | .008 |
| TG40 | 35 40.751 | -78 32.558 | 80.00 | -20.641 | 979745.464 | .008 |
| TG41 | 35 41.459 | -78 31.637 | 111.49 | -19.448 | 979737.953 | .009 |
| TG42 | 35 40.850 | -78 30.899 | 109.03 | -19.783 | 979737.507 | .010 |
| TG43 | 35 40.131 | -78 30.608 | 108.66 | -19.667 | 979736.708 | .010 |
| TG44 | 35 39.549 | -78 30.690 | 104.52 | -19.116 | 979737.709 | .010 |
| TG45 | 35 38.851 | -78 31.860 | 103.90 | -17.700 | 979738.324 | .010 |
| TG46 | 35 38.775 | -78 32.358 | 103.64 | -16.607 | 979739.385 | .007 |
| TG47 | 35 39.516 | -78 33.473 | 97.58 | -16.273 | 979742.641 | .010 |
| TG48 | 35 40.178 | -78 33.306 | 84.55 | -18.823 | 979745.060 | .010 |
| TG49 | 35 40.950 | -78 33.040 | 97.06 | -17.879 | 979743.245 | .010 |
| TG50 | 35 41.453 | -78 32.349 | 95.69 | -19.591 | 979742.671 | .008 |
| TG51 | 35 42.180 | -78 32.060 | 122.26 | -16.971 | 979738.133 | .008 |
| TG52 | 35 41.936 | -78 30.736 | 92.03 | -22.397 | 979741.690 | .010 |
| TG53 | 35 40.675 | -78 30.237 | 105.47 | -20.690 | 979737.450 | .010 |
| TG54 | 35 39.487 | -78 30.208 | 105.26 | -18.926 | 979737.582 | .008 |
| TG55 | 35 38.406 | -78 30.686 | 89.14 | -18.838 | 979741.103 | .008 |
| TG56 | 35 38.308 | -78 31.942 | 83.53 | -18.933 | 979742.599 | .008 |
| TG57 | 35 38.276 | -78 33.004 | 74.50 | -18.630 | 979745.640 | .010 |
| TG58 | 35 39.746 | -78 34.122 | 105.32 | -14.035 | 979742.822 | .011 |
| TG59 | 35 40.764 | -78 34.099 | 101.99 | -15.308 | 979744.024 | .010 |

| | | | | | | |
|---|---|---|---|---|---|---|
| TG60 | 35 41.748 | -78 33.008 | 110.76 | -16.788 | 979741.245 | .010 |
| TG61 | 35 42.872 | -78 31.352 | 84.68 | -22.225 | 979745.467 | .010 |
| TG62 | 35 42.149 | -78 29.844 | 77.36 | -25.367 | 979743.551 | .010 |
| TG63 | 35 40.150 | -78 29.290 | 97.50 | -21.769 | 979738.081 | .010 |
| TG64 | 35 38.725 | -78 29.759 | 107.31 | -16.293 | 979738.495 | .006 |
| TG65 | 35 37.645 | -78 30.791 | 97.90 | -15.018 | 979741.131 | .010 |
| TG66 | 35 37.642 | -78 32.981 | 60.88 | -18.238 | 979749.316 | .010 |
| TG67 | 35 38.760 | -78 34.152 | 96.30 | -13.262 | 979744.971 | .010 |
| TG68 | 35 40.180 | -78 34.545 | 111.64 | -12.859 | 979742.667 | .009 |
| TG69 | 35 41.720 | -78 34.073 | 98.78 | -15.951 | 979745.742 | .011 |
| TG70 | 35 42.689 | -78 32.578 | 113.12 | -16.803 | 979741.848 | .010 |
| TG71 | 35 40.119 | -78 31.958 | 96.64 | -19.262 | 979740.805 | .008 |
| TG72 | 35 40.108 | -78 31.949 | 97.47 | -19.181 | 979740.627 | .006 |
| TG73 | 35 40.088 | -78 31.952 | 96.59 | -19.345 | 979740.694 | .007 |
| TG74 | 35 40.076 | -78 31.968 | 93.76 | -19.757 | 979741.138 | .010 |
| TG75 | 35 40.075 | -78 31.988 | 89.71 | -20.291 | 979741.853 | .010 |
| TG76 | 35 40.083 | -78 32.004 | 87.70 | -20.567 | 979742.209 | .010 |
| TG77 | 35 40.097 | -78 32.011 | 87.66 | -20.623 | 979742.191 | .010 |
| TG78 | 35 40.115 | -78 32.008 | 87.47 | -20.572 | 979742.320 | .010 |
| TG79 | 35 40.126 | -78 31.995 | 90.97 | -20.192 | 979741.635 | .010 |
| TG80 | 35 40.127 | -78 31.972 | 94.85 | -19.513 | 979741.119 | .010 |

TABLE 2. Tower Gravity Data

| Elevation (AGL) | Gravity (mGal) | Anomaly (mGal) | Formal Error (mGal) | Total Error (mGal) |
|---|---|---|---|---|
| 0.69 | 979740.244 | -19.506 | .008 | .017 |
| 93.92 | 979711.181 | -19.796 | .014 | .022 |
| 192.17 | 979681.040 | -19.622 | .016 | .024 |
| 283.58 | 979653.021 | -19.436 | .017 | .026 |
| 379.54 | 979623.638 | -19.207 | .013 | .024 |
| 473.24 | 979594.990 | -18.946 | .014 | .026 |
| 562.27 | 979567.797 | -18.671 | .014 | .027 |

Number Of Loops................... 5
Number Of Stations................ 6
Number Of Observations............ 30

Mean Loop Closure RMS............... 10 μGal
Maximum Loop Closure RMS............ 16
Mean Station Standard Error......... 15
RMS Observation Error............... 23

Tower Latitude.............. 35 40.101
Tower Longitude............. -78 31.980
Tower Elevation............. 96.96 m AMSL

# THE FUNDAMENTAL GRAVITY NETWORK OF SWEDEN

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Abstract

The Swedish fundamental gravity net consists of 25 stations, including stations on the Fennoscandian land uplift gravity lines and absolute stations. It has been measured with high precision using LaCoste & Romberg gravimeters. Corrections are applied for earth tides, polar motion, land uplift, vertical gradient and air pressure. The adjustment gives gravity values with standard errors ranging from 4 to 11 μgals. To each gravity value there is also attached an estimated annual decrease due to the land uplift.

With the results of the fundamental network a new Swedish gravity system, RG 82, is introduced. It is defined by the following items: 1) The level and scale are determined from the corrected and weighted Italian absolute measurements in northern Europe. 2) The epoch is 1982. 3) The permanent tidal deformation of the Earth is retained whereas the permanent tidal attraction of the Moon and Sun is eliminated. In a final section comparisons between RG 82 and IGSN 71 are made.

## 1. Background

The first Swedish gravity measurement was made in 1741 at the Uppsala Observatory by Anders Celsius. He determined the gravity difference between London and Uppsala using a pendulum-clock constructed for him by Graham in London (Celsius, 1744). This pendulum-clock is still in operation in Uppsala. Nearly a century later, in 1833, Jöns Svanberg determined the gravity value of the Stockholm Observatory (Svanberg, 1834).

Taking advantage of the introduction of the Sterneck pendulum instrument, Per G. Rosén in 1889 - 1896 observed the gravity differences between five stations along a north-south line running through the whole of Sweden. He connected this line to Potsdam (Rosén, 1898).

A complete first order gravity network was built up by Bror Wideland in 1941 - 1948 using the then newly invented Nørgaard gravimeter (Wideland, 1946 & 1951). The number of stations was 33. The net was connected to Potsdam by the Baltic Geodetic Commission.

In 1960 - 1966 Lennart Pettersson measured a new first order network with a Worden gravimeter (Pettersson, 1967). It consists of 198 stations. The connection to Potsdam was made via the European Calibration System 1962 (ECS 62); later on the net was provisionally connected to the International Gravity Standardization Net 1971 (IGSN 71).

Today Pettersson's first order net does no longer meet the requirements of a basic gravity network. First of all, the accuracy is nowadays too low. Second, the stations are not marked. Third, some thirty percent of the stations are destroyed. Consequently a new net is needed.

As a first step a supreme network of 25 stations - the fundamental gravity network - has been established. It was measured in 1981 - 1982 by Lennart Pettersson and Lars Åke Haller, both using two LaCoste & Romberg gravimeters. In addition, measurements on the Fennoscandian land uplift gravity lines are used. Two absolute stations are included and connections are made to another two absolute stations in Denmark and Finland, all of which belong to the European set of stations measured with the Italian instrument IMGC. Furthermore, the measurements of the fundamental net have been sent for inclusion in the Unified European Gravity Network (UEGN).

## 2. Stations

The net consists of 25 stations, of which 12 also belong to the Fennoscandian land uplift gravity lines. Mårtsbo A and Göteborg A are absolute stations. In addition to these, the absolute stations Sodankylä in northern Finland and København in Denmark are included in the computation of the network. (So is also the Danish station Helsingør, used for the connection to København.) A fifth absolute station, Vaasa in western Finland, has been excluded because of a suspected error (Mäkinen & Haller, 1982).

The distances between the stations have been chosen to make it possible to drive from one station to a neighbour station and back again in one day. Furthermore, the stations have been located such that the gravity differences between them in the east-west direction are small (hundreds of μgals).

All stations (except Pello NA) are situated on bedrock. Thereby the influence of ground water variation on gravity is made negligible. With exception for the absolute ones all stations are outdoors, their sites being marked by bench

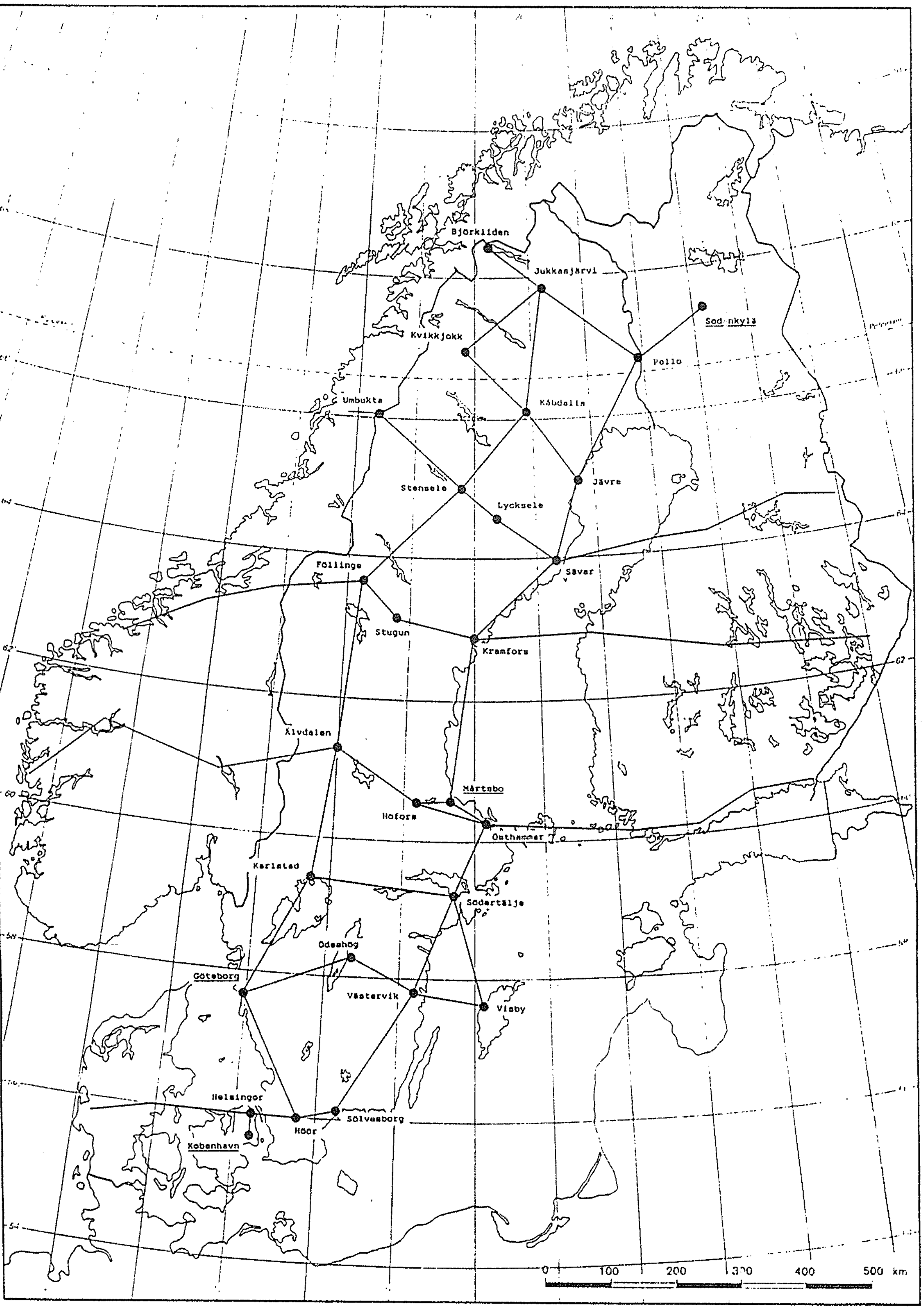



Figure 1. The fundamental gravity net of Sweden. The Fenno-scandian land uplift gravity lines are outlined. Nɐmes of absolute stations are underlined.

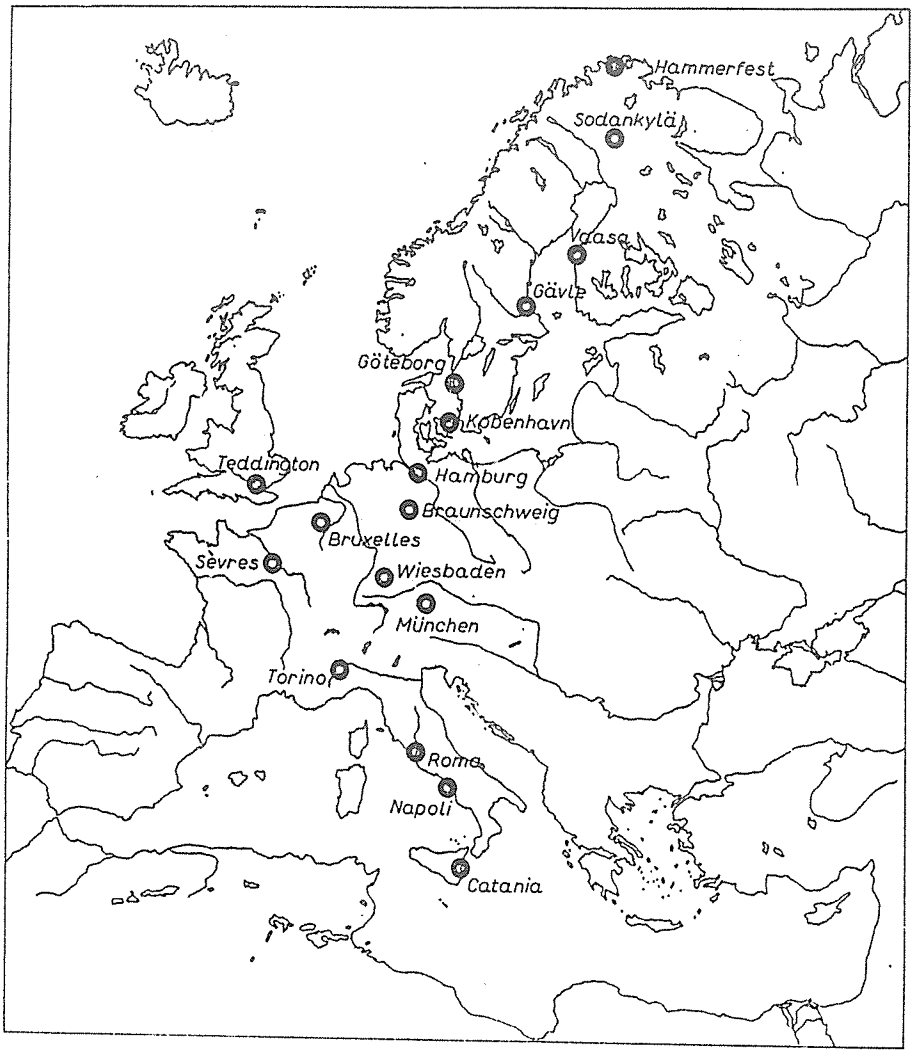



Figure 2. The European set of absolute stations measured by the IMGC instrument. (Note: Gävle = Mårtsbo A.)

marks. To every station there is at least one excenter (also on bedrock wherever possible), serving as a reserve station in case the main one is destroyed.

A map of the net is shown in Figure 1. Figure 2 shows the European set of absolute stations to which those of the net belong.

## 3. Measurements

The measurements have been carried out with two LaCoste & Romberg (LCR) model G gravimeters, no. 54 and no. 290. It would have been desirable to measure the net with a few more gravimeters but for economic reasons the number had to be limited to two. The observers have been Lennart Pettersson for the northern half of the network, and Lars Åke Haller for the southern half. All observations of the main stations were made in 1981 and 1982.

The measurements between neighbouring stations have been performed according to the scheme A - B - B - A, B - A - A - B Each station is directly connected to two, three or four other stations in the net, except for one station in the far north (Björkliden) which has only one connection.

The gravimeters have been transported by car; for one station (Visby on the island of Gotland) also a quite long transportation by ferry boat was necessary. Considerable efforts were made to protect the gravimeters from mechanical shocks and sudden temperature changes. The instrument G-54 has been read using the microscope, G-290 using the galvanometer. The waiting time between unclamping and the first reading was usually four minutes. To avoid possible magnetic effects the gravimeters were oriented in the same way at almost all stations.

For the land uplift lines the results from all participating gravimeters during the years 1977 - 1984 have been used (Mäkinen et al., 1986). The number of gravimeters is here between 8 and 10.

The connections to the absolute stations Sodankylä and København have been determined by 4 gravimeters. For Sodankylä results of the instruments no. G-55 and G-600 (communicated by J. Mäkinen) are used in addition to the Swedish measurements with G-54 and G-290. For København results of the instruments no. G-466 and G-495 (communicated by F. Madsen) are used together with the Swedish measurements. The very short connection to Göteborg A (from Göteborg NB) was measured with 3 gravimeters, the additional one being no. D-56.

The absolute stations themselves were measured in 1976 by two Italian institutes using their own instrument IMGC (Istituto di Metrologia G. Colonetti). Their results are published by Cannizzo et al. (1978). However, the values are not used as they stand but have been corrected for some effects as described later on. The station Mårtsbo A (= Gävle) was made one of the three European main stations (the other two being Sevres in France and Torino in Italy); it was measured at three different occasions.

## 4. Corrections

Before proceeding with actual corrections the LCR readings of each station occupation have been condensed to a single observation by taking the average value. The observations have then been corrected mainly according to the Nordic standard recently adopted for the computation of the Fennoscandian land uplift gravity lines; see Mäkinen et al. (1986). Corrections are applied as follows.

1. Earth tides: The computations were performed with the program of Heikkinen (1978), which gives the same results (within 0.1 µgal) as the method of Cartwright-Tayler-Edden. The elasticity factor $\delta$ = 1.16 and zero phase lag are used. Wahr's theory as recently amended by Dehant & Ducarme (1987) would give $\delta$ = 1.15 as a weighted mean of the factors for the tidal waves at the mid-latitude of Sweden ($62^o$).

The permanent tide can, in principle, be treated in three different ways: 1) according to Honkasalo (1964), agreeing with IGSN 71; 2) according to Heikkinen (1979), agreeing with the IAG resolution of 1979; 3) according to Ekman (1979) and Groten (1980), agreeing with the IAG resolution of 1983. This leads to gravity systems differing by small amounts depending on latitude; see further section 6. The last method - unlike in Mäkinen et al. (1986) - is adopted as the main one here.

2. Polar motion: The correction was made using a sub-routine in Heikkinen (1978). The observation is reduced to the Conventional International Origin (CIO).

3. Postglacial land uplift: This correction has been introduced only for the absolute measurements, being made six years earlier than the net itself; se further Table 1.

4. Vertical gradient: Gravity is reduced to the top of the bench mark, applying the standard gradient of - 0.309 µgal/mm.

5. Attraction and loading of the atmosphere: The observation is reduced to the normal air pressure of the station, applying the factor - 0.30 µgal/mbar.

6. Influence of air pressure on the gravimeter: Only for the gravimeter G-54 there is a significant effect, amounting to 0.05 µgal/mbar. The observation is reduced to 1000 mbar.

Table 1. Corrected absolute gravity values. Unit: μgal.

| | Sodankylä | Mårtsbo A | Göteborg A | København |
|---|---|---|---|---|
| (1) | 982 362 206 | 981 923 528 | 981 718 774 | 981 549 602 |
| (a) | - 47 | - 39 | - 35 | - 32 |
| (b) | - 2 | - 2 | - 3 | - 3 |
| (c) | - 9 | - 10 | - 3 | 0 |
| (d) | + 37 | + 7 | + 15 | + 17 |
| (2) | 982 362 185 | 981 923 484 | 981 718 748 | 981 549 584 |

(1) Absolute gravity value according to Cannizzo et al. (1978); for Mårtsbo A (Gävle) the mean of three values. Corrected for earth tides as in IGSN 71 and for vertical gradient using own gradient determinations.

(a) Elimination of permanent tidal attraction of Moon and Sun to obtain agreement with the IAG resolution of 1983. Cf. section 6.

(b) Correction for polar motion. To be consistent with (c) the reduction should really be made to the mean pole of 1982 instead of the CIO, but in our case this makes practically no difference (less than 1 μgal).

(c) Correction for land uplift. Reduction to 1982 using the approximate factor - 0.2 μgal/mm (cf. Ekman et al., 1987), and the following absolute land uplift values: Sodankylä 7.5, Mårtsbo A 8.0, Göteborg A 2.5, København < 1 mm/year.

(d) Correction for vertical gradient error. Gradients corrected to the following new values: Sodankylä 0.343 (Arnautov et al., 1982), Mårtsbo A 0.295 (not published before), Göteborg A 0.302 (estimated, cf. Torge et al., 1987), København 0.259 μgal/mm (Torge et al., 1987).

(2) Absolute gravity value corrected for the above effects. To be used in the adjustment.

7. Scale of the gravimeter: The correction factor to the manufacturer's scale factor table is determined within the adjustment. The periodic error for 1 reading unit (mgal) is not significant for any of the two gravimeters; the other periodic errors are unknown.

For details on corrections to absolute values we refer to Table 1.

## 5. Adjustment

The least squares adjustment has been performed with a computer program designed at the National Land Survey (Malmberg, 1986). It benefits from the statistical ideas of Förstner (1979) and Persson (1981).

There are three groups of input data: absolute measurements, relative measurements, and precomputed differences. They are weighted according to the following a priori standard errors.

An absolute measurement with the IMGC instrument is known to have a standard error of about 8 μgals (cf. Cannizzo et al. 1978). This value is used a priori for Sodankylä and København. For Mårtsbo A, being measured three times, the a priori standard error is put to 5 μgals. Göteborg A, lacking accurate information on the gravity gradient, is given a standard error of 12 μgals.

The relative measurements are those performed with the two gravimeters LCR G-54 and G-290. These are given equal weight. On the basis of long experience the standard error of one measurement (of a station, not of a difference of succesive stations) is put to 12 μgals (cf. Mäkinen et al., 1986).

The precomputed differences contain the results on the land uplift gravity lines. Each difference is the result from one gravimeter, with the standard error of the difference as given by Mäkinen et al. (1986). Normally this is between 5 and 8 μgals. A small group of differences, being determined with few degrees of freedom, was assigned conventional standard errors instead of those published. Also the results from gravimeters other than G-54 and G-290 on the connections to the absolute stations are included as precomputed differences, with a standard error of 5 μgals for Sodankylä and København (combined results of two gravimeters) and 8 μgals for Göteborg A (one gravimeter).

The adjustment gave a posteriori standard errors close to the a priori ones, showing the input data to be properly weighted. It should be mentioned that in order to check the absolute values also an adjustment with comparatively low weights for these values was made; it indicated nothing suspicious.

Measurements have been rejected on physical grounds only (like mechanical shock etc.). The adjustment indicated no remaining gross errors.

The drift of a gravimeter during transport is modelled as a linear function of time. When the gravimeter has not been transported (nights etc.) a shift of the reading level has been introduced.

## 6. Results

The final results are summarized in Table 2, showing the gravity values and their standard errors for all stations. It may be noted that the adjustment changed the gravity values of the absolute stations by only 1 μgal for Göteborg A and by nothing at all for Sodankylä, Mårtsbo A and København (cf. Table 1). In Table 2 is also given approximate time derivatives of the gravity values, described closer later on. The small Table 3 gives scale correction factors with standard errors for the two gravimeters.

The standard errors of the gravity values range from 4 to 11 μgals, the extremes being 4 μgals for the central absolute station Mårtsbo A and 11 μgals for the northern station Björkliden with only one connection. The accuracy of the Swedish fundamental net is thus about the same as that of the corresponding German net (Sigl et al., 1981), where the standard errors range from 6 to 12 μgals.

The gravity values of Table 2 constitute the Gravity System 1982 of Sweden ("Rikets tyngdkraftssystem 1982", RG 82). This system is defined by the following items:

1. The level and the scale of the system are determined from the corrected and weighted Italian absolute measurements at Sodankylä, Mårtsbo A, Göteborg A and København.

2. The epoch of the system is 1982.

3. The permanent tide is treated according to the IAG resolution of 1983, i.e. the permanent tidal deformation of the Earth is retained whereas the permanent tidal attraction of the Moon and the Sun is eliminated.

According to the earlier IAG resolution of 1979 the permanent tidal deformation should be removed to the extent allowed by the elasticity factor $\delta = 1.16$. The gravity values of Table 2 can be transformed to such a system by adding

$$c_1 = 4.9 - 14.6 \sin^2\varphi \quad \mu\text{gals} \qquad (1)$$

In IGSN 71, on the other hand, not only the permanent tidal

Table 2. Adjusted gravity values of the Swedish fundamental gravity network, including estimated annual decrease due to postglacial land uplift. Gravity system: RG 82. Unit: µgal. Stars (*) denote absolute stations.

| Station | Gravity value | Standard error | Annual decrease |
|---|---|---|---|
| Björkliden NA | 982 362 145 | 11 | 1.0 |
| Björkliden NB | 982 365 553 | 11 | 1.0 |
| Jukkasjärvi NA | 982 361 917 | 9 | 1.5 |
| Jukkasjärvi NB | 982 362 156 | 10 | 1.5 |
| Pello NA | 982 362 461 | 8 | 1.7 |
| Pello NB | 982 365 580 | 8 | 1.7 |
| * Sodankylä | 982 362 185 | 7 | 1.5 |
| Kvikkjokk NA | 982 269 111 | 10 | 1.4 |
| Kvikkjokk NB | 982 268 767 | 10 | 1.4 |
| Kåbdalis NA | 982 270 445 | 8 | 1.8 |
| Kåbdalis NB | 982 268 958 | 9 | 1.8 |
| Jävre NA | 982 269 347 | 8 | 2.1 |
| Jävre NB | 982 268 824 | 8 | 2.1 |
| Umbukta A | 982 191 185 | 7 | 1.1 |
| Umbukta B | 982 191 341 | 10 | 1.1 |
| Stensele A | 982 191 189 | 7 | 1.6 |
| Stensele B | 982 191 251 | 10 | 1.6 |
| Lycksele A | 982 191 124 | 7 | 1.7 |
| Lycksele C | to be measured 1988 | | 1.7 |
| Lycksele B | destroyed | | |
| Sävar A | 982 191 088 | 7 | 2.0 |
| Sävar B | 982 191 060 | 8 | 2.0 |
| Föllinge A | 982 075 771 | 6 | 1.5 |
| Föllinge B | 982 075 738 | 7 | 1.5 |
| Stugun B | 982 075 728 | 6 | 1.6 |
| Stugun A | 982 076 474 | 7 | 1.6 |
| Stugun C | 982 075 670 | 7 | 1.6 |
| Stugun D | 982 075 942 | 7 | 1.6 |
| Kramfors D | 982 075 783 | 6 | 1.9 |
| Kramfors A | 982 076 644 | 6 | 1.9 |
| Kramfors B | 982 077 100 | 7 | 1.9 |
| Kramfors C | 982 075 573 | 7 | 1.9 |

| | | | |
|---|---|---|---|
| Älvdalen A | 981 908 201 | 5 | 1.5 |
| Älvdalen B | 981 908 200 | 7 | 1.5 |
| Hofors A | 981 908 210 | 5 | 1.5 |
| Hofors B | 981 908 224 | 7 | 1.5 |
| * Mårtsbo A | 981 923 484 | 4 | 1.6 |
| Mårtsbo B | 981 923 646 | 5 | 1.6 |
| Östhammar A | 981 908 210 | 5 | 1.4 |
| Östhammar B | 981 908 206 | 5 | 1.4 |
| Karlstad NA | 981 828 158 | 6 | 1.0 |
| Karlstad NB | 981 828 082 | 6 | 1.0 |
| Södertälje NA | 981 828 128 | 6 | 1.1 |
| Södertälje NB | 981 828 024 | 6 | 1.1 |
| Göteborg NB | 981 718 370 | 6 | 0.5 |
| * Göteborg A | 981 718 749 | 7 | 0.5 |
| Ödeshög NA | 981 718 430 | 7 | 0.7 |
| Ödeshög NB | 981 718 473 | 8 | 0.7 |
| Västervik NA | 981 718 574 | 6 | 0.5 |
| Västervik NB | 981 718 453 | 7 | 0.5 |
| Visby NA | 981 719 266 | 7 | 0.5 |
| Visby NB | 981 718 567 | 8 | 0.5 |
| * København | 981 549 584 | 7 | - |
| Helsingør | 981 580 371 | 7 | 0.2 |
| Höör A | 981 580 437 | 7 | 0.2 |
| Höör B | 981 580 438 | 9 | 0.2 |
| Sölvesborg A | 981 580 437 | 7 | 0.2 |
| Sölvesborg B | 981 580 443 | 8 | 0.2 |

Table 3. Scale correction factors for the Swedish gravimeters.

| Gravimeter | Correction factor | Standard error |
|---|---|---|
| LCR G-54 | 1.00075 | 0.00002 |
| LCR G-290 | 1.00083 | 0.00002 |

deformation but also the permanent tidal attraction are retained. To convert the gravity values of Table 2 to such a system one should add

$$c_2 = -30.4 + 91.2 \sin^2\varphi \quad \mu\text{gals} \qquad (2)$$

Both formulae can be found in Ekman (1988); (1) is related to (2) through $c_1 = (1 - \delta)c_2 = -0.16\ c_2$. For the stations in Table 2 we have $5 < -c_1 < 8$ μgals and $32 < c_2 < 48$ μgals.

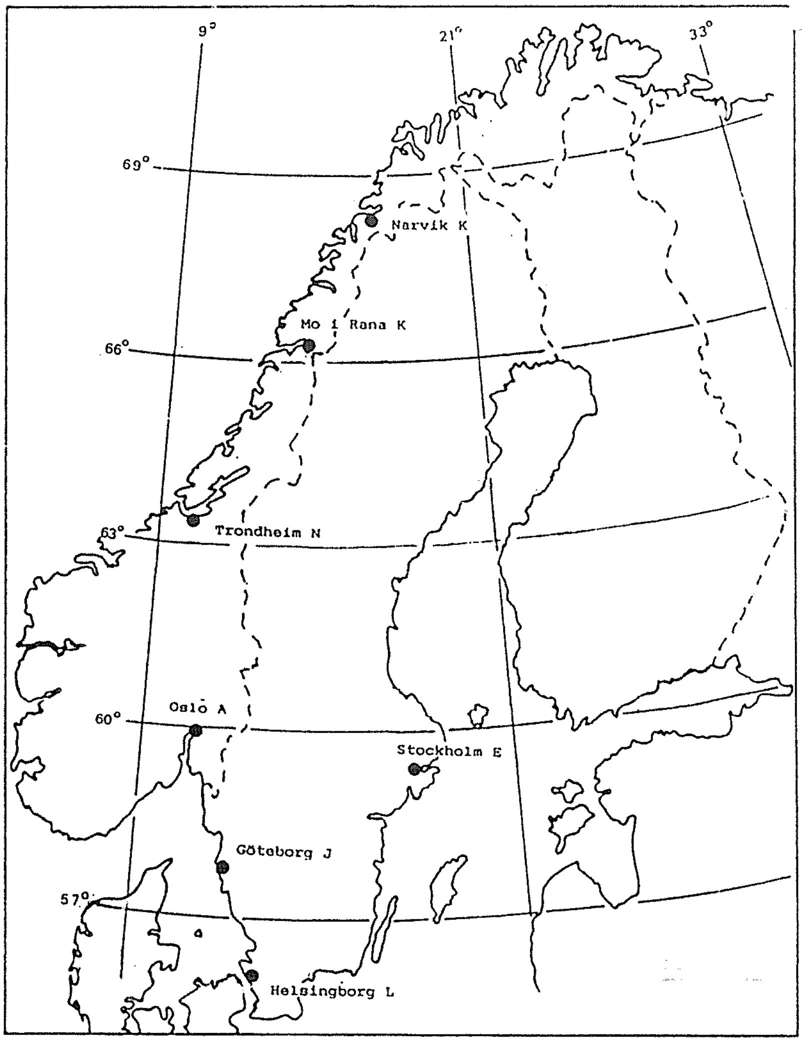
To allow the calculation of gravity values for some other year than 1982, an estimated annual gravity decrease due to land uplift is given in Table 2 for each station. The annual decrease has been estimated using the approximate factor 0.2 μgal per mm absolute land uplift, the absolute land uplift being the apparent land uplift corrected for eustatic rise of sea level and rise of the geoid. The most rapid decrease of gravity amounts to 2.1 μgals/year (at Jävre), corresponding to an absolute land uplift of 10.5 mm/year. Future research on the Fennoscandian land uplift gravity lines will, hopefully, give us a better knowledge of the land uplift factor.

## 7. Comparisons

From the Swedish fundamental network connections have been made to seven IGSN 71 stations in Norway and Sweden. For these stations gravity values are calculated in the system RG 82, allowing a comparison between the systems; see Table 4. The maximum discrepancy is about 100 μgals. A part of this originates from the permanent tidal attraction according to (2). Taking this into account, the maximum discrepancy decreases to 60 μgals, still leaving a discrepancy of 110 μgals in the gravity differences. These figures may be taken as measures of the true errors in IGSN 71. Comparisons with ECS 62 will be performed later.

Table 4. Comparisons between IGSN 71 and RG 82. Unit: mgal. A = IGSN 71 - RG 82. B = IGSN 71 - RG 82 - (2).

| Station | IGSN 71 | RG 82 | A | B |
|---|---|---|---|---|
| Narvik K | 982 436.99 | 982 436.90 | 0.09 | 0.04 |
| Mo i Rana K | 982 308.94 | 982 308.84 | 0.10 | 0.05 |
| Trondheim N | 982 138.43 | 982 138.35 | 0.08 | 0.04 |
| Oslo A | 981 912.61 | 981 912.58 | 0.03 | - 0.01 |
| Stockholm E | 981 827.96 | 981 827.97 | - 0.01 | - 0.05 |
| Göteborg J | 981 727.10 | 981 727.12 | - 0.02 | - 0.06 |
| Helsingborg L | 981 609.70 | 981 609.66 | 0.04 | 0.01 |



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# FIRST YEAR'S RESULTS WITH THE JILAG-4 ABSOLUTE GRAVIMETER

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Abstract

Between May 1987 and June 1988 the National Geodetic Survey (NGS), together with the Defense Mapping Agency, Hydrographic and Topographic Center (DMAHTC) has been testing the field performance of one of the six absolute gravimeters (JILAG-4) developed and built by the Joint Institute for Laboratory Astrophysics (JILA) between 1982 and 1985. Of the 30 sites visited during the test period, 10 were occupied more than once. The scatter about the mean at six of these sites was under ±1 microgal, at the remaining sites it varied between ±2.5 and ±4 microgals. Intercomparison measurements between JILAG-4 and JILAG-1 in the JILA laboratory agreed within ±1 microgal, and preliminary results suggest that the agreement with the Canadian absolute gravimeter (JILAG-2) during an intercomparison in March 1988 in Ottawa (Gatineau) was also within ±1 microgal (J. Liard, personal communication). The high degree of repeatability is the result of three factors; the latest improvements made to the instrument at JILA in 1986, methods of observation and quality control of the data sets, and the meticulous monitoring and correcting for the time varying environmental effects on gravity.

## 1. Introduction

In 1985-1986 six new generation JILA absolute gravimeters were delivered to six institutions in North America and Europe. Following the receipt of their absolute gravimeter, each organization proceeded with a program of testing and further familiarization with their instrument. Then, on the basis of their experience and program requirements, each developed an operational procedure and field program. Technical details of these latest series of JILA instruments have been given in Niebauer et al. (1986) and Niebauer (1987); additional laboratory tests and field results have been given in Goodacre et al. (1987), Moose et al. (1988), Peter et al. (1987, 1988), and Torge et al. (1987, 1988). It appears from these reports that each organization now uses the JILA instrument somewhat differently. This healthy diversity will allow for intercomparison of instrumental settings, observational procedures, and an eventual better understanding and evaluation of this instrument's true capabilities under a wide variety of environmental settings.

Niebauer (1987) estimated that the absolute accuracy of the JILA instruments constructed since 1985 is ±3 microgal. The NGS and DMAHTC tests of JILAG-4 were aimed at ascertaining the best possible repeatability with the instrument. Toward this end the emphasis was placed on the optimization of procedures for site selection, observations, and quality control of the data, and on the corrections for the effects of environmental influences on the observed gravity. The NGS program objective was to use absolute gravity observations in conjunction with other geophysical measurements and VLBI and GPS observations to monitor vertical crustal motions and learn more about crust-mantle geophysical processes. Our aim was to test, therefore, whether a repeatability under ±3 microgal could be achieved, which would translate to a sensitivity of 1 cm in elevation.

## 2. Field Observations and Quality Control

An important consideration during field observations is to minimize the frequency changes of the laser due to environmental influences. The frequency stability of the JILA He-Ne lasers is obtained by locking the cavity length so that the intensities of the two orthogonally polarised light beams produced by the laser remain the same. There are two possible lock points near central tuning, one below the center frequency of the neon emission line (red side), and one above it (blue side). Both of these frequencies change over time due to aging and due to environmental influences. However, Niebauer's (1987) studies show that the temporal changes of the side lock frequencies of the JILAG-4 laser are symmetrical about the center frequency. This means that as long as measurements are taken with both lock positions, the mean of the red and blue sets (representing the center frequency) will not be affected. We try to obtain, therefore, equal number of measurements with each laser lock mode. Also, we are switching the laser locks frequently, and are staying on station for two days to minimize the effects of changing environmental influences.

In 1987, prior to the installation of automatic laser switching circuitry by JILA, we collected 250 drop sets at 4 hour intervals for 2 days. The laser lock modes were switched after every second drop set. With automated laser switching installed, we now collect 250 drops at 2-hour intervals, and switch the laser lock modes after every drop set. The histograms of the 250 drop sets approach Gaussian, and the means of the drop sets are well defined. The 2-days-long observations at a station also minimize the errors left in the data after the application of corrections for the temporally varying environmental effects. In 1987 at several sites 100 drop hourly data sets were collected. The histograms of these drop sets, particularly at seismically active sites, were often skewed and tri-modal, so these shorter drop sets are no longer used.

After the drop sets are examined for obvious instrumental (bottomed superspring mass) or environmental influences (earthquakes, personnel interferences with the instrument) and the affected drop sets are rejected, all drops exceeding 3 standard deviation of the mean in each drop set are eliminated (Figure 1). The addition of environmental and instrumental corrections follows this quality control step. The weighted means of the red and blue drop sets are then computed separately. A simple average of these two means is used to obtain the station's absolute gravity value.

## 3. Corrections

The largest environmental correction is for the Lunar-Solar attraction, which is computed in the field by the gravimeter controller using Longman's (1959) formulation. This correction and the velocity of light correction are the only ones computed in the field. All other corrections are performed after all observed gravity and environmental data are sent to the office from the field. In post- processing, the field-computed Earth tide correction is replaced by a more accurate formulation by Tamura (1982, 1987). Differences of up to 6 microgals have been noted between the two programs. As part of this correction a specific, frequency dependent gravimetric factor is applied (Wahr, 1981; Dehant and Ducarme, 1986).

The variation in the atmospheric mass attraction is referenced to the mean station pressure using the U.S. Standard Atmosphere (Boedecker et al., 1979) and the regional pressure approximation of -0.42 microgal/millibar. The atmospheric loading is corrected for by using the world-wide loading model of VanDam and Wahr (1987). The loading corrections are referenced to the mean station pressure, using the two term regression expression of Rabbel and Zschau (1985). Typical corrections applied to the drop sets to compensate for these atmospheric effects have been less than 5 microgals.

Two unpublished programs have been used to compute corrections for the effects of ocean loading (one from T. Sato and H. Hanada, International Latitude Observatory, Misuzawa, Japan, and another from D. Agnew, Scripps Institution of Oceanography). Both programs are still under testing and evaluations, but preliminary results indicate that they agree with each other at sites within the interior of the continent. The programs give different corrections at our oceanic island sites and at the southeast U.S. coastal sites. At these sites the computed amplitudes of the loading corrections by both programs are too high. With further testing of these programs and better modelling of the shorelines we expect to resolve this problem. In the interim, however, we have applied a preliminary ocean loading correction (using Sato's program), by scaling the computed corrections to match the observed data. The actual change in the final mean gravity values as a result of this correction had been typically only a few tenths of a microgal in the continental interior, and 2-3 microgals at the oceanic island and coastal sites.

The above corrections are applied to the individual drops or to the drop set means. The remaining corrections are applied to the station gravity value. An example of the reduction of the drop set scatter achieved as a result to the application of the corrections cited so far is shown in Figure 2 for the Ottawa, Canada site.

At three sites, where we are able to monitor the water table levels in shallow aquifers (approximately 5-10 meters below the surface), corrections for water table levels have also been applied. Based on sediment analyses at the Herndon, VA site, we estimated a 120 kg/m³ mass change per meter of water table change. Because our repeat measurements at these sites were in the same season (maximum water table change approximately 30 cm), the corrections applied to the final gravity value have been less than 2 microgals. The 1986-1987 seasonal water table change at Herndon, VA could have produced a peak-to-peak change of 13 microgals. This correction will be further tested and refined with additional sediment analyses, and verified when gravity reobservations are made at times when the water table changes are larger.

In post processing we also correct the station gravity value for the effects of the changing position of the rotation axis of the Earth by correcting the gravity values to the mean pole position. The pole positions are determined at 5-day intervals and published monthly by NGS (issued in the IRIS Earth Orientation Bulletin). To compute the correction, the formulation of Heikkinen (1978) has been used. The magnitude of this correction on an inter annual time scale can reach ±9 microgals at our sites.

Instrumental corrections involved laser aging and laser temperature effects, both determined by Niebauer (1987). While the laser frequency drift due to aging is well defined (the correction is +0.016 microgal/day), the exact effect of the temperature difference between that at calibration and at field laser lock is less well known. Niebauer (1987) suggested a correction of 0.4 microgal/C°, measured from the laser calibration temperature of 21.7 C°. Because at some of our sites the ambient temperatures were high, corrections as large as 2 microgals have been applied.

Gravity gradients were determined in 1987 from six gravity difference observations between the observed height and the ground level. Two LaCoste & Romberg D gravimeters, equipped with electronic levels and electrostatic feedback nulling, were used for these measurements. In 1988 we began using three height differences with 12 repeats with a single gravimeter. With both methods the vertical gradient determination errors have been usually less than 0.03 microgal/cm. This adds a ±1.5 microgal error term to the uncertainty estimates for the gravity values reported on the floor mark.

## 4. Field Experience

To provide a solid foundation for the instrument and to avoid the effect of groundwater table changes on gravity, we selected (when possible) buildings located on nonporous bedrock. Isolated buildings away from road traffic were preferred to reduce vibrations introduced by human activity. The instrument was usually set up in a room located at or below ground level, where the temperature fluctuations were expected to be minimal.

It was found that only in a very few sites can all these desirable conditions be satisfied. A good, after the fact, measure of the vibrations was the scatter of the individual drops from the mean in a given drop set. At the seismically quietest sites, the standard deviation of the drop sets was in the 5-10 microgal range; at the noisiest sites it was in the 50-70 microgal range. The most common range was 15-30 microgal. Sites were abandoned when the drop-to-drop scatter exceeded 100 microgals, or the scatter of the means of successive drop sets exceeded 20 microgals. Even at the noisiest accepted sites, however, the mean of the successive drop sets stayed in the 5-10 microgal range. The principal problematic vibration sources were air conditioning equipment and nearby construction and, at our island sites, oceanic microseisms.

The effect of temperature fluctuations on the JILA gravimeter was the most likely cause of the up to 15 microgal differences among the means of successive drop sets at some of our seismically very quiet sites. Temperatures exceeding 27 C° may have affected the laser lock mode frequencies and the initial position of the dropped object. Attempts to readjust the dropping chamber control circuit to correct for the creep of the carriage return position in response to temperature changes has been difficult and time consuming. This adjustment is not considered to be a routine operational procedure, and the preferred alternative is to look for a more suitable site. Temperature fluctuations also affect the super spring. Cooling down at night several times has caused a drift and bottoming of the mass of the super spring, resulting in unacceptable drop-to-drop scatter. The readjustment of the super spring is simple, but operators usually are not present when this problem occurs during the overnight observation periods.

Additional problems included occasional electronic component and connecting cable failures, and the intermittent failure of the portable power supply of the ion pump. The latter has been causing partial vacuum loss in the dropping chamber during transport of the instrument between sites.

The supports and cushioning that have been designed for transporting the JILA instrument by van have been successful in preventing damage due to transport under normal road conditions. A special crate has been designed and built for air transport. Both in the van and in the crate the super spring and the dropping chamber can be transported in a vertical position. The crate requires, however, shipment in a large aircraft. An alternate solution being considered is to ship the super spring and the dropping chamber separately from the rest of the equipment in the passenger compartment of smaller aircraft.

## 5. Results and Discussion

The results of the first year's observations are given in Table 1. In addition to the gravity values at the measurement height, gravity values are also given at the 1 m and the ground levels. Table 1 also contains the uncertainty estimates for each of these gravity values, the gradients measured (or obtained from other sources), and the errors of the gradient determinations (where available).

The uncertainty estimates in Table 1 represent the root sum squares of the error terms applicable to a given site, environmental condition, available correction, and elevation. These terms include the 3 microgal systematic instrument error of Niebauer (1987), the standard error of the mean of the drop sets (characterizing the scatter of the final, corrected mean of the drop sets, which ranged between 2 and 5 microgals), the error term of the laser temperature correction (1-2 microgals), the water table correction error (estimated to be 1 microgal/ m of water table change), and the applicable error of the gradient determination.

Separate errors for the gravitational tide, atmospheric attraction and loading, and ocean loading were not used because 1) it is reasonable to assume that the scatter of the environmental effects corrected drop set means encompasses the errors of these corrections, and 2) the error term derived from the scatter of the means is considerably larger than the sum of the individual errors of these environmental effects corrections, because the corrections themselves were small. However, where the correction process was still incomplete, additional error terms were added to reflect a maximum projected error of 5 microgal for the missing atmospheric attraction correction, 2 microgals for the missing atmospheric loading correction, and 1 microgal for the missing ocean loading correction at some of our continental sites.

Other possible sources of errors that still affect the reported absolute gravity values are related to 1) the validity of the assumption used in the derivation of the effective measurement height (referred to as instrument height) (Zumberge, 1981), 2) the temperature fluctuation related creep of the initial position of the dropped object, and 3) the influence of the floor rebound accelerations. Methodology is being developed to correct the effects of these problems, which, now may be contributing another error term of approximately 2-3 microgals.

As seen in Table 1, the repeat observations agree within 1-4 microgals. At our best sites the agreements are within ±1 microgal. The 2 to 4 microgal repeat differences could be due in part to changed ground water levels. The La Jolla gravity value is suspect because of instrument malfuntions. There are large time gaps between successive drop sets, and there is a step-like offset of about 15 microgals between the first and last two days of observations. The gravity value at the Hamilton AA (Lick Observatory) site is based on only a 1-day occupation (five drop sets), and was obtained at a different location than the previous observations at that site.

## 6. Conclusions

The large number of observations performed with the JILAG-4 instrument during its first year of field operations proves its versatility and field worthiness. The sensitivity of the instrument to temperature fluctuations requires either the selection of better temperature controlled sites or the improvement of the instrument to reduce its sensitivity to temperature fluctuations.

Although the first operational year has largely been dedicated to training and experimentation, the potential of this instrument for monitoring vertical crustal motion has been proven by high station repeatability. Within the NOAA Climate and Global Change Program, the JILAG-4 instrument now is in use to supplement Very Long Baseline Interferometry (VLBI) and Global Positioning System (GPS) observations in establishing a global geodetic reference system for the determination of absolute sea level changes. Absolute gravity values will be available by mid-1989 at about 20 geologically stable sites in the United States. These will support national and international requirements for gravity reference and gravimeter evaluation purposes, and for monitoring the temporal variations of gravity.

## Acknowledgments

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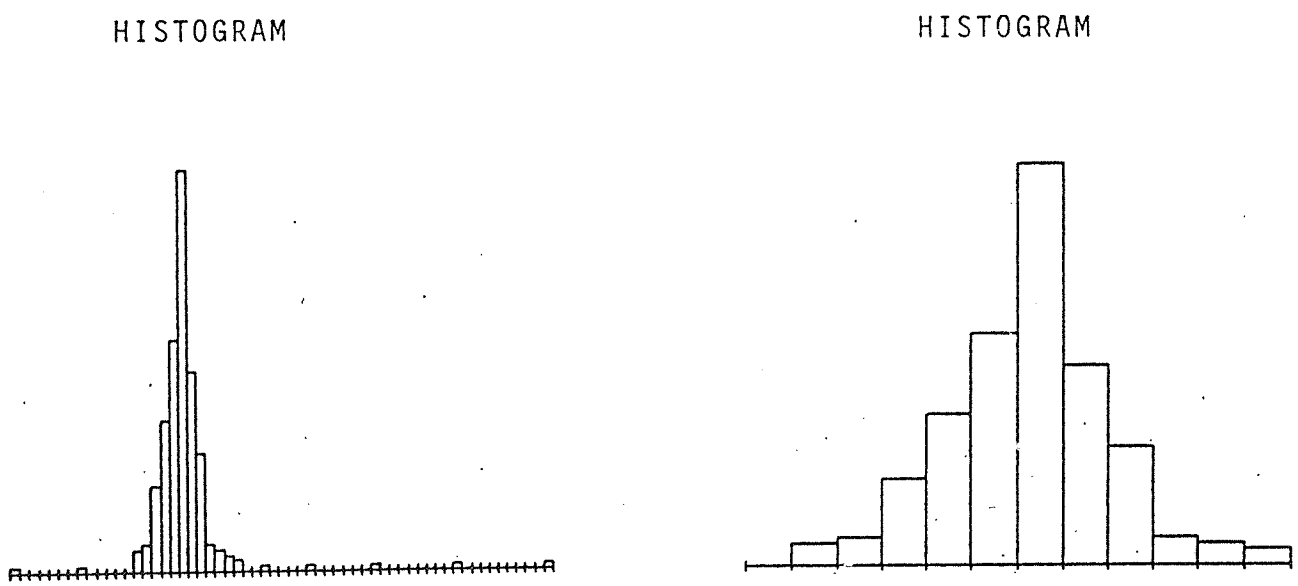
GREAT FALLS PARK AA

Bars are arranged in 5 microgal intervals




Ending date/time of run:
870527084036
Weighted mean gravity value:
980.113568 gals
Sigma (single drop):
18.59 microgals
Sigma (mean): 1.18 microgals

Number of drops: 250

Ending date/time of run:
870527084036
Weighted mean gravity value:
980.113566 gals
Sigma (single drop):
8.90 microgals
Sigma (mean): 0.56 microgal

Number of drops: 241

FIGURE 1. Example of the application of the 3 sigma acceptance quality control procedure.

WEIGHTED MEAN ERRORS ( OTWA AB 03/11/88 - 03/14/88 )

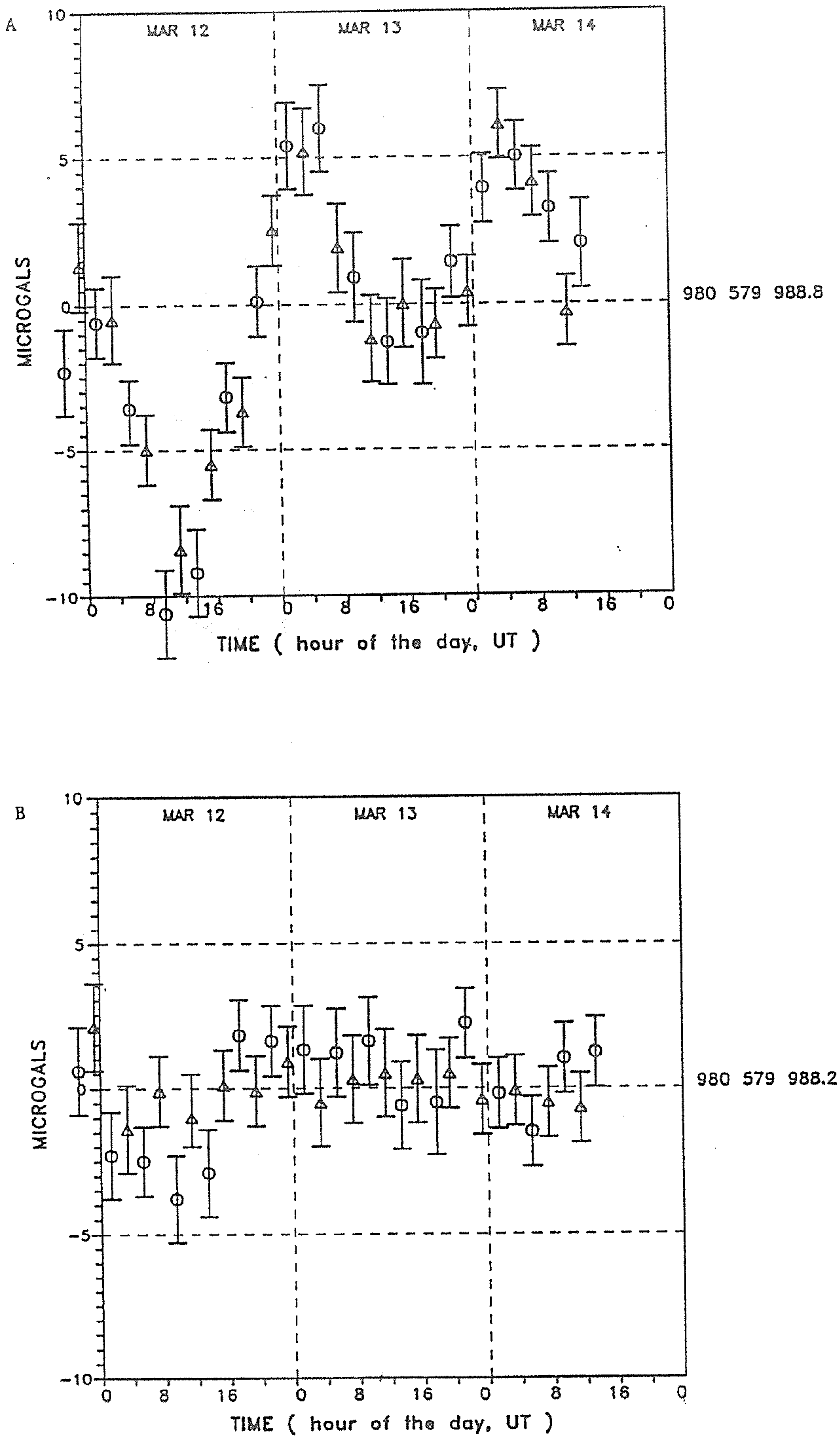



FIGURE 2. Distribution of drop set means before (A) and after (B) the application of all environmental corrections at Ottawa AB, Canada.

TABLE 1. Absolute gravity values obtained between May 1987 and June 1988 with JILAG-4. Values denoted by * denote incomplete data processing; the final values at these sites may change by ± 2 microgals. The mark behind some of the gradients indicate adopted values (not measured by NGS).

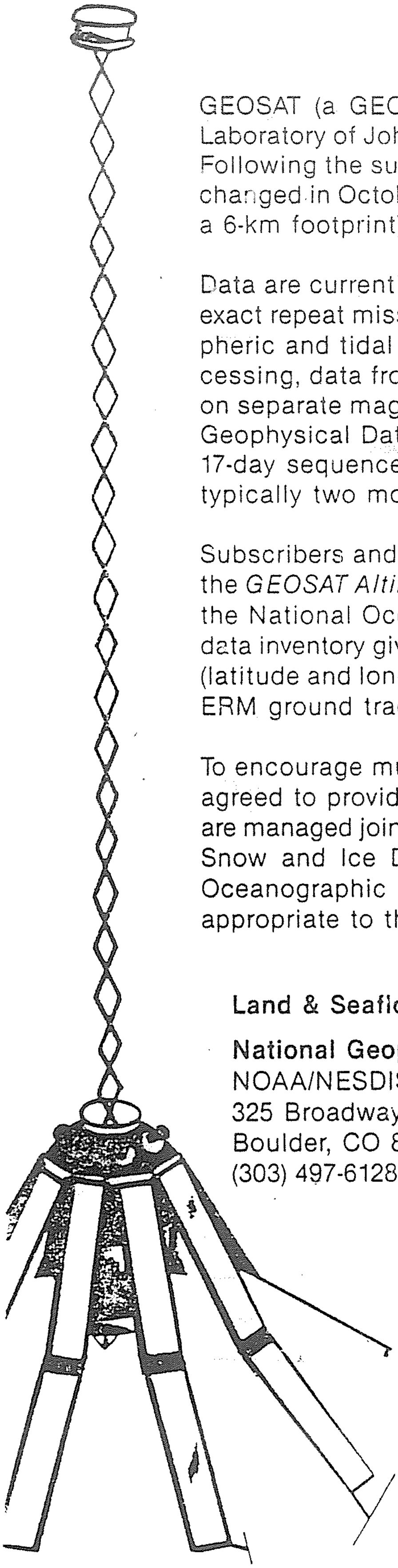
| STATION | GRAVITY READING INSTR HEIGHT | UNCERTAINTY INSTR HEIGHT | GRAVITY READING AT ONE METER | UNCERTAINTY ONE METER | GRAVITY READING AT GROUND LEVEL | UNCERTAINTY GROUND LEVEL | GRAVITY GRADIENT |
|---|---|---|---|---|---|---|---|
| | ugals | ugals(+/-) | ugals | ugals(+/-) | ugals | ugals(+/-) | ugals/cm |
| Atlanta AA | | | | | | | |
| 07/20/87 | 979 515 457.4 | 5.3 | 979 515 402.0 | 5.3 | 979 515 705.1 | 5.8 | 3.031(+-)0.03 |
| Atlanta AB | | | | | | | |
| 07/23/87 | 979 524 218.2 | 5.0 | 979 524 164.3 | 5.1 | 979 524 463.6 | 6.0 | 2.992(+-)0.04 |
| Bergen Park AA | | | | | | | |
| 10/06/87 | 979 468 886.9 | 3.5 | 979 468 835.1 | 3.5 | 979 469 129.8 | 4.3 | 2.947(+-)0.03 |
| Bermuda AA | | | | | | | |
| 06/21/87 | 979 806 807.8 | 4.7 | 979 806 752.4 | 4.7 | 979 807 069.0 | 4.9 | 3.169(+-)0.02 |
| Boulder AA | | | | | | | |
| 04/22/87 | 979 608 364.0 | 6.2 | 979 608 323.5 | 6.3 | 979 608 558.5 | 7.4 | 2.350(+-)0.05^ |
| 05/05/87 | 979 608 366.7 | 6.2 | 979 608 326.0 | 6.3 | 979 608 560.6 | 7.4 | 2.350(+-)0.05^ |
| 09/30/87 | 979 608 369.9 * | 4.2 | 979 608 328.4 * | 4.3 | 979 608 563.4 * | 5.9 | 2.350(+-)0.05^ |
| Boulder AE | | | | | | | |
| 04/24/87 | 979 616 983.7 | 3.5 | 979 616 928.4 | 3.6 | 979 617 140.2 | 4.8 | 3.109(+-)0.04^ |
| 04/29/87 | 979 616 978.2 | 4.0 | 979 616 924.8 | 4.1 | 979 617 135.7 | 5.5 | 3.109(+-)0.04^ |
| 10/02/87 | 979 616 980.9 * | 4.0 | 979 616 926.0 * | 4.1 | 979 617 137.8 * | 5.2 | 3.109(+-)0.04^ |
| Blacksburg AA | | | | | | | |
| 07/14/87 | 979 715 488.1 | 6.6 | 979 715 433.5 | 6.6 | 979 715 729.0 | 7.3 | 2.955(+-)0.04 |
| 05/12/88 | 979 715 483.2 * | 4.0 | 979 715 432.2 * | 4.1 | 979 715 727.7 * | 5.2 | 2.955(+-)0.04 |
| Boston AA | | | | | | | |
| 03/28/88 | 980 378 449.9 * | 4.4 | 979 378 397.6 * | 4.4 | 979 378 708.1 * | 5.0 | 3.105(+-)0.03 |
| Byrd AA | | | | | | | |
| 05/29/87 | 979 779 023.8 | 3.8 | 979 778 969.6 | 3.8 | 979 779 286.4 | 4.2 | 3.168(+-)0.02 |
| 04/21/88 | 979 779 016.9 * | 4.6 | 979 778 964.6 * | 4.6 | 979 779 281.4 * | 4.9 | 3.168(+-)0.02 |
| Charlotte AA | | | | | | | |
| 05/17/88 | 979 728 437.3 * | 7.5 | 979 728 392.1 * | 7.5 | 979 728 647.8 * | 7.9 | 2.557(+-)0.03 |
| Denver H | | | | | | | |
| 04/25/87 | 979 598 084.2 | 3.9 | 979 598 033.6 | 4.0 | 979 598 326.2 | 5.7 | 2.927(+-)0.05^ |
| 05/01/87 | 979 598 076.2 | 4.6 | 979 598 025.9 | 4.7 | 979 598 318.6 | 6.2 | 2.927(+-)0.05^ |
| Golden AA | | | | | | | |
| 04/25/87 | 979 570 947.1 | 4.7 | 979 570 908.9 | 4.8 | 979 571 132.6 | 5.3 | 2.237(+-)0.03 |
| 05/03/87 | 979 570 947.3 | 4.4 | 979 570 909.1 | 4.5 | 979 571 132.8 | 5.1 | 2.237(+-)0.03 |
| Greenbank AA | | | | | | | |
| 04/27/88 | 979 795 452.2 * | 7.3 | 979 795 409.3 * | 7.4 | 979 795 654.3 * | 8.0 | 2.450(+-)0.04 |
| Greenbank AB | | | | | | | |
| 04/29/88 | 979 791 947.9 * | 5.5 | 979 791 904.7 * | 5.7 | 979 792 154.6 * | 10.0 | 2.4(+-)0.10 ^ |

TABLE 1. Continued.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Great Falls AA | | | | | | | |
| 05/26/87 | 980 113 569.0 | 5.1 | 980 113 517.7 | 5.1 | 980 113 812.1 | 5.7 | 2.945(+-)0.03 |
| 06/04/87 | 980 113 569.2 | 4.9 | 980 113 516.6 | 4.9 | 980 113 811.0 | 5.5 | 2.945(+-)0.03 |
| 04/11/88 | 980 113 566.0 * | 5.1 | 980 113 515.9 * | 5.1 | 980 113 810.4 * | 5.7 | 2.945(+-)0.03 |
| Great Falls AB | | | | | | | |
| 07/01/87 | 980 113 532.9 | 4.3 | 980 113 477.9 | 4.2 | 980 113 774.1 | 4.9 | 2.962(+-)0.03 |
| Hamilton (Lick Observatory) AA | | | | | | | |
| 12/15/87 | 979 635 060.3 | 4.0 | 979 634 980.8 | 4.0 | 979 635 430.4 | 4.4 | 4.496(+-)0.025^ |
| Herndon AA | | | | | | | |
| 05/23/87 | 980 094 536.6 | 5.7 | 980 094 481.1 | 5.8 | 980 094 796.2 | 6.6 | 3.151(+-)0.04 |
| 06/11/87 | 980 094 537.6 | 4.1 | 980 094 481.3 | 4.2 | 980 094 796.3 | 5.3 | 3.151(+-)0.04 |
| 06/29/87 | 980 094 536.6 | 3.9 | 980 094 480.2 | 3.9 | 980 094 795.2 | 5.1 | 3.151(+-)0.04 |
| 04/06/88 | 980 094 538.2 * | 4.1 | 980 094 483.1 * | 4.2 | 980 094 798.2 * | 5.3 | 3.151(+-)0.04 |
| Kauai AA | | | | | | | |
| 11/05/87 | 979 787 889.0 | 5.0 | 978 787 822.4 | 5.0 | 978 788 195.2 | 5.2 | 3.728(+-)0.02 |
| Kennedy Space Center AB | | | | | | | |
| 08/01/87 | 979 226 509.7 | 10.1 | 979 226 450.6 | 10.1 | 979 226 767.3 | 10.9 | 3.128(+-)0.05^ |
| LaJolla AA | | | | | | | |
| 12/01/87 | 979 514 891.9 | 9.6 | 979 514 837.3 | 9.7 | 979 515 145.3 | 12.7 | 3.08(+-)0.10^ |
| Maui AA | | | | | | | |
| 10/28/87 | 978 216 030.1 | 6.3 | 978 215 954.7 | 6.3 | 978 216 381.2 | 6.5 | 4.264(+-)0.02 |
| Menlo Park C-14 | | | | | | | |
| 12/12/87 | 979 945 667.7 | 9.5 | 979 945 628.7 | 9.5 | 979 945 849.3 | 10.1 | 2.206(+-)0.04^ |
| Menlo Park 3AA | | | | | | | |
| 12/17/87 | 979 944 382.5 | 6.5 | 979 944 327.8 | 6.5 | 979 944 637.1 | 7.3 | 3.093(+-)0.04^ |
| Oahu AA | | | | | | | |
| 10/22/87 | 978 871 332.8 | 5.0 | 978 871 275.3 | 5.1 | 978 871 602.5 | 5.6 | 3.272(+-)0.03 |
| Orono AA | | | | | | | |
| 03/21/88 | 980 591 849.0 * | 5.6 | 980 591 810.7 * | 5.7 | 980 592 037.9 * | 7.0 | 2.272(+-)0.05 |
| Ottawa AA | | | | | | | |
| 03/09/88 | 980 579 971.0 | 3.5 | 980 579 907.6 | 3.5 | 980 580 283.6 | 3.7 | 3.760(+-)0.013^ |
| 03/14/88 | 980 579 972.4 | 3.8 | 980 579 908.8 | 3.8 | 980 580 284.8 | 4.0 | 3.760(+-)0.013^ |
| Ottawa AB | | | | | | | |
| 03/11/88 | 980 579 980.4 | 3.3 | 980 579 917.4 | 3.3 | 980 580 293.4 | 3.9 | 3.760(+-)0.0265^ |
| Patrick AA | | | | | | | |
| 08/07/87 | 979 194 337.3 | 16.6 | 979 194 284.3 | 16.6 | 979 194 584.1 | 17.1 | 3.003(+-)0.05^ |
| Washington AA | | | | | | | |
| 06/01/87 | 980 102 987.8 | 4.6 | 980 102 931.1 | 4.6 | 980 103 260.8 | 4.9 | 3.297(+-)0.02 |
| 07/06/87 | 980 102 989.8 | 4.0 | 980 102 930.9 | 4.1 | 980 103 260.6 | 4.4 | 3.297(+-)0.02 |
| 04/18/88 | 980 102 988.5 * | 4.4 | 980 102 931.8 * | 4.4 | 980 103 261.5 * | 4.7 | 3.297(+-)0.02 |

# GEOSAT: Satellite Altimetry Data

SE-0901
2/88



GEOSAT (a GEOdetic SATellite) was designed and built by the Applied Physics Laboratory of Johns Hopkins University and launched by the U.S. Navy in March 1985. Following the successful conclusion of its military mission, the satellite's orbit was changed in October 1986 to permit acquisition of additional radar altimetry data (with a 6-km footprint) for the research community.

Data are currently being collected and organized based on a 244 revolution, 17-day, exact repeat mission (ERM) cycle. The detailed sensor data, as well as orbital, atmospheric and tidal data, are processed by the National Geodetic Survey. During processing, data from ocean areas and from land/ice areas are segregated and stored on separate magnetic tapes. The data are contained in a standard format known as Geophysical Data Records (GDR). Each GDR archive tape (6250 bpi) contains two 17-day sequences; the delay time from satellite observation to data availability is typically two months.

Subscribers and customers submitting individual data orders will receive a copy of the *GEOSAT Altimeter Geophysical Data Record (GDR) User Handbook* produced by the National Ocean Survey; in addition, each tape will be accompanied by a brief data inventory giving the beginning and ending date and time, the geographic position (latitude and longitude) of each data file (day) on the tape, and a plot of the GEOSAT ERM ground track for the data.

To encourage multidisciplinary use of these data, three national data centers have agreed to provide services (including subscriptions) to researchers. Land/ice data are managed jointly by the National Geophysical Data Center (NGDC) and the National Snow and Ice Data Center (NSIDC). Ocean data are managed by the National Oceanographic Data Center (NODC). Potential users should contact the Center appropriate to their primary area of interest:

**Land & Seafloor Applications:**

**National Geophysical Data Center**
NOAA/NESDIS (E/GC1)
325 Broadway, Dept. 445
Boulder, CO 80303
(303) 497-6128

**Snow & Ice Applications:**

**National Snow & Ice Data Center**
CIRES, Campus Box 449
University of Colorado
Boulder, CO 80309
(303) 492-1834

**Oceanographic Applications:**

**National Oceanographic Data Center**
NOAA/NESDIS (E/OC21)
User Service Branch
Washington, DC 20235
(202) 673-5549

## GEOSAT Land/Ice Data Order Form

*Annual Subscription:*

☐ I would like to receive GEOSAT GDR data on annual subscription: Twelve 34-day data tapes (6250 bpi)

Cost: $1,176 *($98 per tape, $15 less than if tapes are ordered individually.)*

*Individual Order:*

☐ I would like to receive GEOSAT GDR data covering the time period from:

Day ______________ Month ______________ Year ______________ to

Day ______________ Month ______________ Year ______________

Please let me know the number of tapes that span this period.
Cost: $113 per tape (6250 bpi)
$98 per tape (1600 bpi)
*(One 6250 tape equals approximately four 1600 bpi tapes.)*

*Data Exchange Option:*

☐ I would like to obtain GEOSAT GDR data on a data exchange basis.

*Format Options:*

All GEOSAT GDR tapes are in 'binary' format; available options are:

☐ 6250 bpi, non-labeled, multifile (one file per day), Hewlett-Packard binary data structure.

☐ 6250 bpi, standard label, multifile (one file per day), ANSI standard (VAX) data structure (ASCII). Please call for more information.

☐ 1600 bpi, standard label, multifile (one file per day), ANSI standard (VAX) data structure (ASCII). Available on individual orders only—not on subscription. Please call for more information.

*How to Order:*

Please contact appropriate Data Center for ordering and payment procedures.

*Agreement:*

I understand that the contacted Data Center should be notified of any redistribution of these data. I further understand that GEOSAT data subscriptions may be cancelled by the purchaser and refunds made. Subscription cancellations, however, require two weeks written advance notice.

Signature ______________________________ Date ______________

Name ______________________________

Title/Department ______________________________

Organization ______________________________

Street Address ______________________________

City ______________ State ______________ Zip ______________

Country ______________________________

Telephone No. (with area code) ______________________________