ASSOCIATION INTERNATIONALE DE GEODESIE

BUREAU GRAVIMETRIQUE INTERNATIONAL

BULLETIN D'INFORMATION

N° 64

Juin 1989

18, Avenue Edouard Belin
31055 TOULOUSE CEDEX
FRANCE

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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

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ANNOUNCEMENT

(Reminder)

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.

The program will be organized during the Edinburgh meeting (august 1989) and details will be given in the first circular.

Mr. Gilles Balma who had joined the BGI staff in September 1987 and had been since then in charge of the GEBCO digitization, has replaced Mr. Daniel Lamy who left our office on March 1st, 1989.

Mr. Gilles Balma is a member of the Institut Géographique National since September 1st, 1986.

He began to work at the CRIS (Center of Rectifications of Space Images) for the SPOT satellite within the Centre National d'Etudes Spatiales in Toulouse.

From now on, he will therefore be responsible of the data distribution and part of the data collection program.

Part I

INTERNAL MATTER

GENERAL INFORMATIONS

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

1. HOW TO OBTAIN THE BULLETIN

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

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

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

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

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

About three hundred individuals and institutions presently receive the Bulletin.

You may :

- *either request a given bulletin, by its number (64 have been issued as July 1, 1989, but numbers 2, 16, 18, 19 are out of print).*
- *or subscribe for regularly receiving the two bulletins per year plus the special issues.*

Requests should be sent to :

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

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

- 65 French Francs without map,

- 75 French Francs with map.

2. HOW TO REQUEST DATA

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

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

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

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

2.2. G-Value at Base Stations

Treated as above.

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

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

2.4. Gravity Maps

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

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

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

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

2.5. Gravity Measurements

They can be requested :

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

CGDF RECORD DESCRIPTION

60 CHARACTERS

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

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

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

ARCHIVE FILES

RECORD DESCRIPTION

160 CHARACTERS

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

30-31 *Type of observation*
A minus sign distinguishes the pendulum observations from the gravimeter ones.
0 = current observation of detail or other observations of a 3 rd or 4th order network
1 = observation of a 2nd order national network
2 = observation of a 1st order national network
3 = observation being part of a nation calibration line
4 = individual observation at sea
5 = mean observation at sea obtained from a continuous recording
6 = coastal ordinary observation (Harbour, Bay, Sea-side...)
7 = harbour base station

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

33-39 *Elevation of the station (0.1 M)*
This field will contain depth of ocean (positive downward) if col. 32 contains 3, 4 or 5

40 *Accuracy of elevation (E)*
0 = unknown
1 = E < = 0.1 M
2 = 1 < E < = 1
3 = 1 < E < = 2
4 = 2 < E < = 5
5 = 5 < E < = 10
6 = 10 < E < = 20
7 = 20 < E < = 50
8 = 50 < E < = 100
9 = E superior to 100 M

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

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

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

52- 59 *Observed gravity (0.01 mgal)*

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

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

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

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

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

77- 81 *Free air anomaly (0.1 mgal)*

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

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

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

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

93- 96 *Density used for terrain correction*

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

101-103 *Apparatus used for the measurements of G*
0.. pendulum apparatus constructed before 1932
1.. recent pendulum apparatus (1930-1960)
2.. latest pendulum apparatus (after 1960)
3.. gravimeters for ground measurements in which the variations of G are equilibrated of detected using the following methods :
30 = torsion balance (Thyssen...)
31 = elastic rod
32 = bifilar system
4.. Metal spring gravimeters for ground measurements
42 = Askania (GS-4-9-11-12), Graf
43 = Gulf, Hoyt (helical spring)

44 = North American
45 = Western
47 = Lacoste-Romberg
48 = Lacoste-Romberg, Model D (microgravimeter)
5.. Quartz spring gravimeter for ground measurements
51 = Norgaard
52 = GAE-3
53 = Worden ordinary
54 = Worden (additional thermostat)
55 = Worden worldwide
56 = Cak
57 = Canadian gravity meter, sharpe
58 = GAG-2
6.. Gravimeters for under water measurements (at the bottom of the sea or of a lake
60 = Gulf
62 = Western
63 = North American
64 = Lacoste-Romberg
7.. Gravimeters for measurements on the sea surface or at small depth (submarines..)
70 = Graf-Askania
72 = Lacoste-Romberg
73 = Lacoste-Romberg (on a platform)
74 = Gal and Gal-F (used in submarines) Gal-M
75 = AMG (USSR)
76 = TSSG (Tokyo Surface Ship Gravity meter)
77 = GSI sea gravity meter

104 *Conditions of apparatus used*
1 = 1 gravimeter only (no precision)
2 = 2 gravimeters (no precision)
3 = 1 gravimeter only (without cross-coupling correction)
4 = 2 gravimeters (influenced by the cross-coupling effect) with the same orientation
5 = 2 gravimeters (influenced by the cross-coupling effect) in opposition
6 = 1 gravimeter (compensated for the cross-coupling effect)
7 = 1 gravimeter non subject to cross-coupling effect
8 = 3 gravimeters

105 *Information about isostatic anomaly*
0 = no information
1 = information exists but is not stored in the data bank
2 = information exists and is included in the data bank

106-107 *Type of the isostatic anomaly*
0.. Pratt-Hayford hypothese
01 = 50 km including indirect effect (Lejay's tables)
02 = 56.9 km
03 = 56.9 km including indirect effect
04 = 80 km including indirect effect
05 = 96 km
06 = 113.7 km
07 = 113.7 km including indirect effect
1.. Airy hypotheses (equality of masses or pressures)
10 = T = 20 km (Heiskanen's tables, 1931)
11 = T = 20 km including indirect effect (Heiskanen's tables 1938 or Lejay's)
12 = T = 30 km (Heiskanen's tables, 1931)
13 = T = 30 km including indirect effect
14 = T = 40 km
15 = T = 40 km including indirect effect
16 = T = 60 km

17 = T = 60 km including indirect effect
6......
65 = Vening Meinesz hypothesis "modified Bouguer anomaly" (Vening Meinesz, 1948)

108-112	*Isostatic anomaly a (0.1 mgal)*
113-114	*Type of the isostatic anomaly B*
115-119	*Isostatic anomaly B*
120-122	*Velocity of the ship (0.1 knot)*
123-127	*Eötvös correction (0.1 mgal)*
128-131	*Year of observation*
132-133	*Month*
134-135	*Day*
136-137	*Hour*
138-139	*Minute*
140-145	*Numbering of the station (original)*
146-148	*Country code (B.G.I.)*
149	*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 ϕ is the geographic latitude.

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

Formulas used in computing free-air and Bouguer anomalies

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

See also contribution of H. G. WENZEL

2.6. Satellite Altimetry Data

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

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

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

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

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

All requests for data must be sent to :

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

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

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

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

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

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

The prices given below are in french francs. They are effective January 1, 1989 and will be revised periodically.

3.1. Charging Policy for Data Contributors and Scientists

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

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

3.1.1. Digital Data Retrieval

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

. *minimum charge : 100 F.*

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

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

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

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

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

3.1.3. Data Screening

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

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

. *100 F minimum charge.*

3.1.4. Gridding

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

. *10 F/ΔΔ' per degree square*

. *minimum charge : 150 F*

. *maximum area : 40°x 40°*

3.1.5. Contour Maps of Bouguer or Free-Air Anomalies

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

. *250 F minimum charge*

. *maximum area : 40°x 40°*

3.1.6. Computation of Mean Gravity Anomalies

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

. *minimum charge : 150 F*

. *maximum area : 40°x 40°*

3.2. Charging Policy for Other Individuals or Private Companies

3.2.1. Digital Data Retrieval

. 1 F per measurement

. minimum charge : 150 F

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

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

3.2.3. Data Screening

. 1 F per screened point

. 250 F minimum charge

3.2.4. Gridding

Same as 2.1.4.

3.2.5. Contour Maps of Bouguer or Free-Air Anomalies

Same as 2.1.5.

3.2.6. Computation of Mean Gravity Anomalies

Same as 2.1.6.

3.3. Gravity Maps

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

3.3.1. Catalogue of all Gravity Maps

printout : 200 F

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

3.3.2. Maps

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

. Special maps :

Mean Altitude Maps

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

Maps of Gravity Anomalies

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

World Maps of Anomalies (with text)

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

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

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

Miscellaneous

CATALOGUE OF ALL GRAVITY MAPS
(listing) 1985 200 FF

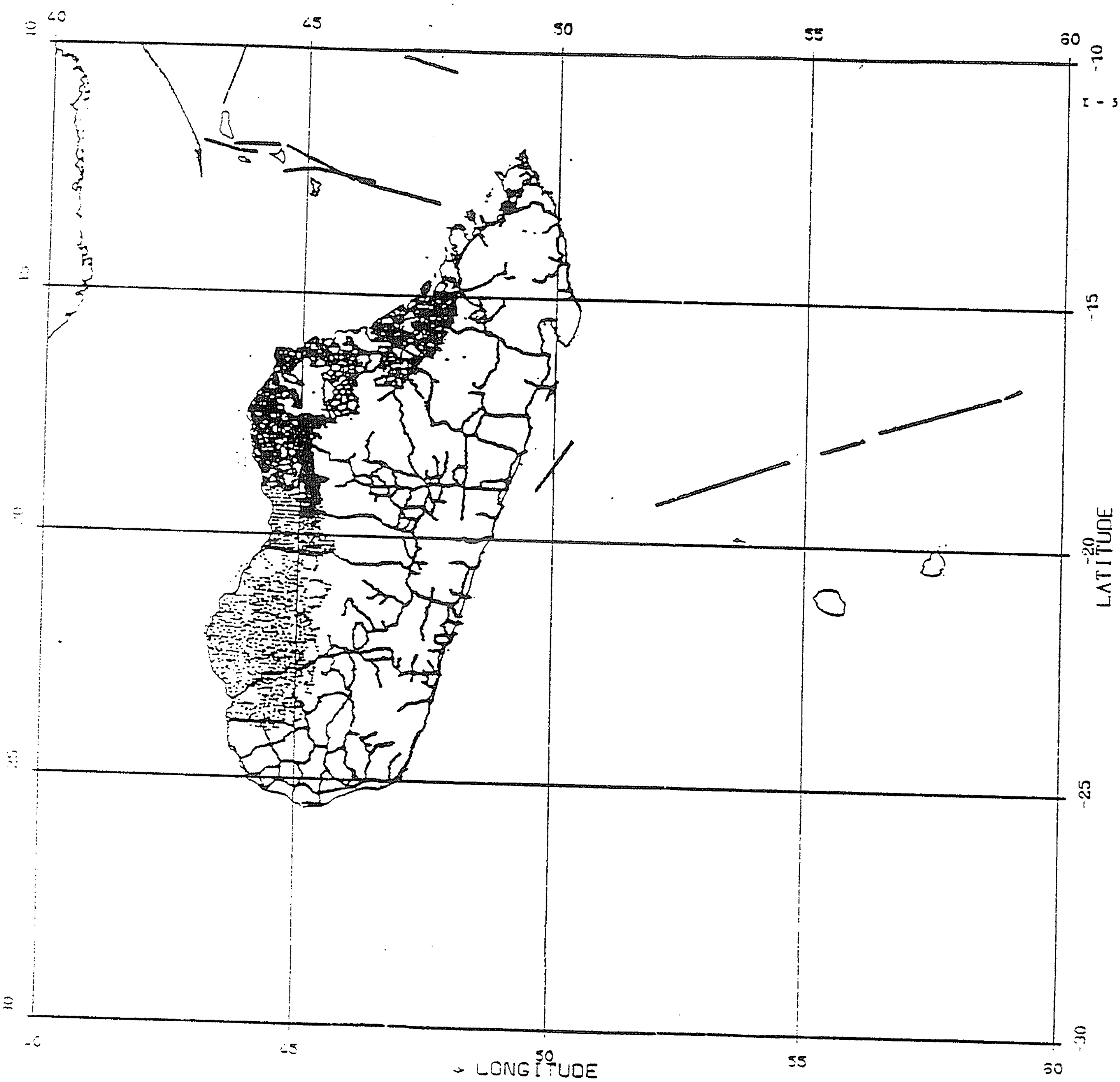
THE UNIFICATION OF THE GRAVITY NETS
OF AFRICA (Vol. 1 and 2) 1979 150 FF

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

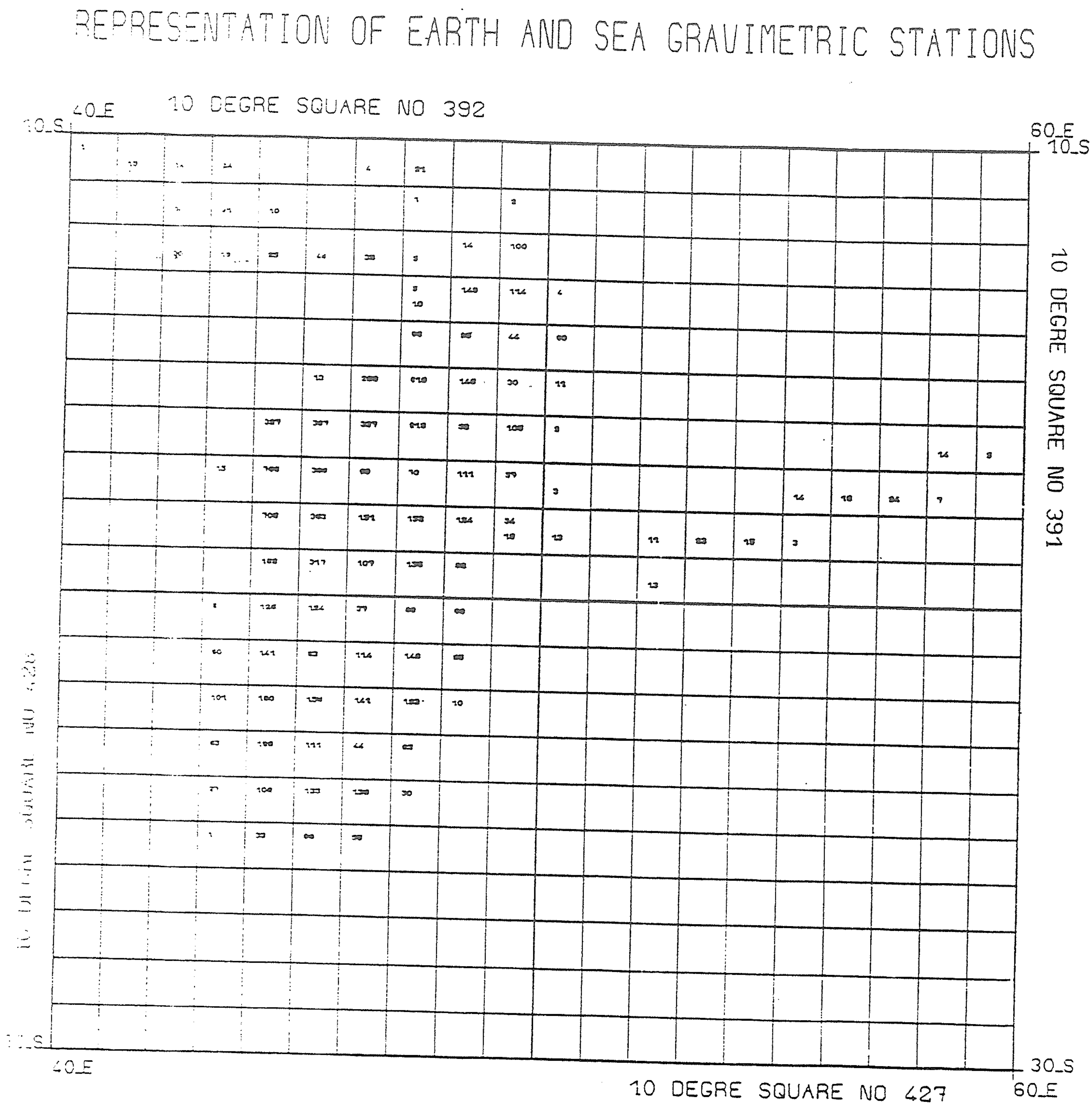
. Colour copy : price according to specifications of request.

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)



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.

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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.

Part II

CONTRIBUTING PAPERS

On the Definition and Numerical Computation of Free Air Gravity Anomalies

by H.-G. Wenzel

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Abstract

The computation procedure for classical free air gravity anomalies includes several approximations and can result in errors up to $10^{-5} \cdot m \cdot s^{-2}$. It should be replaced by the MOLODENSKII type free air gravity anomalies, which are consistent with most concepts in modern physical geodesy and can be computed which high accuracy. A FORTRAN 77 subroutine is presented, which gives normal gravity refering to a number of Geodetic Reference Systems for stations up to 10 km height with a numerical accuracy better than $0.6 \cdot 10^{-8} m \cdot s^{-2}$.

1. Definition of Free Air Gravity Anomalies

The classical concept of free air gravity anomalies (e.g. HEISKANEN and MORITZ 1967, TORGE 1980) is "reduction of the surface gravity value g_P to the geoid value g_O using the vertical gravity gradient $\partial g/\partial H$, valid in free air, and the orthometric height H" (TORGE 1980, p. 161) and gives

$$\Delta g_F = g_P - \frac{\partial g}{\partial H} \cdot H - \gamma_R \qquad (1)$$

with γ_R = normal gravity at the reference ellipsoid (see Fig. 1). This is in fact only a linear approximation of the problem (TAYLOR series expansion of gravity to first degree). The vertical gravity gradient is in any case unknown (even it is observed at the surface of the earth with e.g. a gravimeter and a tripod in different elevations, it is much disturbed by local topographic masses and thus not valid for the path $P \rightarrow 0$), and has to be replaced by the computable normal vertical gravity gradient $\partial\gamma/\partial h$:

$$\Delta g_F \approx g_P - \frac{\partial_\gamma}{\partial_h} \cdot H - \gamma_R . \qquad (2)$$

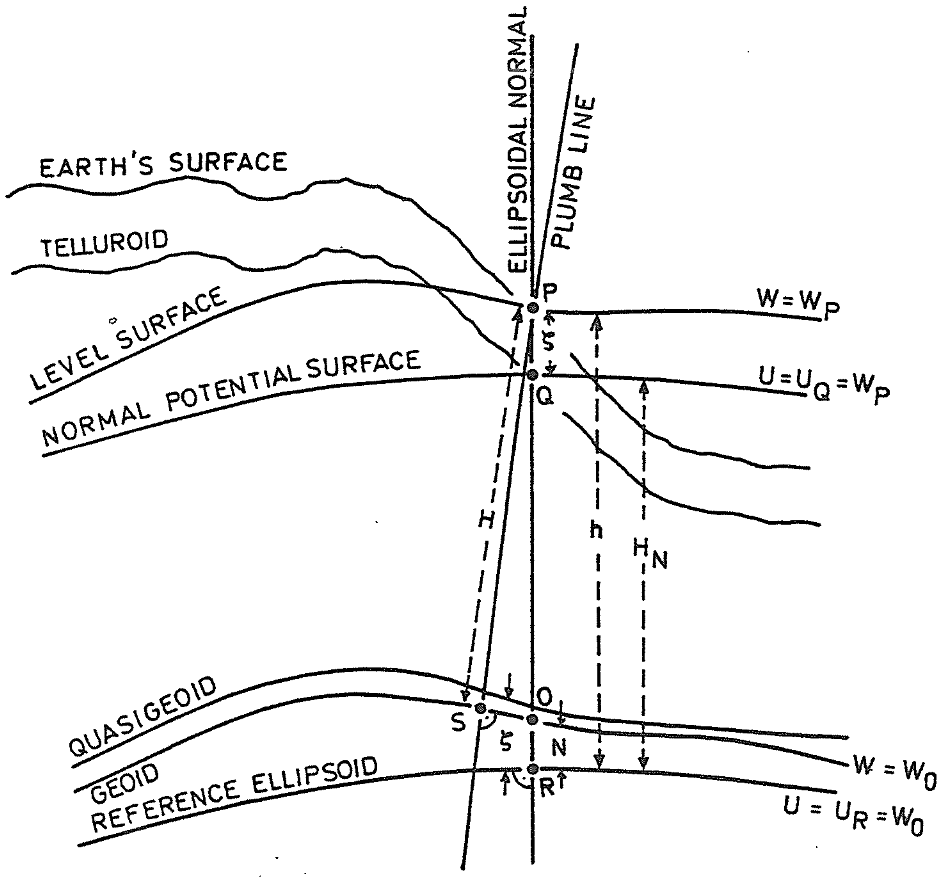

Fig. 1: Reference surfaces for free air gravity reduction

The normal vertical gravity gradient $\partial\gamma/\partial h$ is slightly dependent from latitude; a rough approximation is $\partial\gamma/\partial h \approx -0.3086\cdot 10^{-5} m\cdot s^{-2}$ per m. This approximation is frequently used in free air gravity anomaly computation (e.g. BGI 1988), but can produce errors up to $2.7\cdot 10^{-5} m\cdot s^{-2}$ for elevations of 10 km (HECK 1989).

The classical concept of free air gravity reduction has several weak points, e.g.

- the topographic masses above the geoid are condensed on ore shifted under the geoid,
- a linear approximation of the gravity field is used,
- the vertical gravity gradient is approximated by the normal vertical gravity gradient.

But fortunately, the classical concept of free air reduction can be replaced by an accurate modern concept without drastic changes of the computed free air gravity anomalies.

The basic concept of MOLODENSKII 1960 gives for the gravity anomaly vector $\underline{\Delta g}$

$$\underline{\Delta g} = \underline{grad}\ (W_P) - \underline{grad}\ (U_Q) \tag{3}$$

with W_P = gravity potential at the surface point P, U_Q = normal (ellipsoidal) potential at the Telluroid point Q (see Fig. 1) and for the scalar gravity anomaly Δg

$$\Delta g = g_P - \gamma_Q \tag{4}$$

with g_P = gravity at the surface point P, γ_Q = normal (ellipsoidal) gravity at the Telluroid point Q.

For the computation of normal gravity γ_Q at point Q with ellipsoidal height h = normal height H_N of point P, there exist currently several methods, as e.g. expansion of the normal potenial in ellipsoidal harmonics (e.g. HEISKANEN and MORITZ 1967), expansion of the normal potential in spherical harmonics (e.g. HEISKANEN and MORITZ 1967, TSCHERNING 1976) or TAYLOR series expansion of the normal gravity at the ellipsoid point R (e.g. HEISKANEN and MORITZ 1967, WENZEL 1985). We have chosen the TAYLOR series expansion because it enables a direct comparison of the scalar gravity anomaly Δg with the classical free air gravity anomaly Δg_F, is more suitable for the routine computation for a huge number of stations stored in a gravity data base because coordinate transformations are avoided, and allows analytical integration (computation of mean normal gravity, needed for the computation of the normal potential).

The TAYLOR series expansion of the normal gravity at the reference ellipsoid yields in

$$\gamma(h) = \gamma_R + \frac{1}{1!}\left(\frac{\partial\gamma}{\partial h}\right)_R \cdot h + \frac{1}{2!}\left(\frac{\partial^2\gamma}{\partial h^2}\right)_R \cdot h^2 + \frac{1}{3!}\left(\frac{\partial^3\gamma}{\partial h^3}\right)_R \cdot h^3 + \ldots \tag{5}$$

It will be shown below, that an expansion to 3. degree is sufficient for a numerical accuracy of $10^{-9} m\cdot s^{-2}$. The mean gravity $\bar{\gamma}_{RQ}$ for the path $R \rightarrow Q$, defined by

$$\bar{\gamma}_{RQ} = \frac{1}{H_N} \cdot \int_R^Q \gamma_{(h)} \cdot dh \tag{6}$$

can easily derived by integration of (5), yielding

$$\bar{\gamma}_{RQ} = \gamma_R + \frac{1}{2} \cdot \left(\frac{\partial\gamma}{\partial h}\right)_R \cdot H_N + \frac{1}{6} \cdot \left(\frac{\partial^2\gamma}{\partial h^2}\right)_R \cdot H_N^2 + \frac{1}{24} \cdot \left(\frac{\partial^3\gamma}{\partial h^3}\right)_R \cdot H_N^3 + \ldots \tag{7}$$

Inserting (5) into (4) gives for the MOLODENSKII scalar gravity anomaly

$$\Delta g = g_P - \gamma_R - \left(\frac{\partial\gamma}{\partial h}\right)_R \cdot H_N - \frac{1}{2} \cdot \left(\frac{\partial^2\gamma}{\partial h^2}\right)_R \cdot H_N^2 - \frac{1}{6} \cdot \left(\frac{\partial^3\gamma}{\partial h^3}\right)_R \cdot H_N^3 \ldots \tag{8}$$

which is in fact very close to the classical free air gravity anomaly (2), but uses no approximation at all and is based on a clearly defined and widely applied concept in physical geodesy (solution of geodetic boundary value problem as described by MOLODENSKII 1960). Thus, we propose to replace the classical free air gravity anomaly computation (2) in all gravity data bases - especially in the BGI data base - by the accurate formulation (8), but to preserve the expression free air gravity anomaly, as has already been proposed by HEISKANEN and MORITZ 1967. The procedure for subsequent computation of BOUGUER gravity anomalies, which are of great importance for geophysical purposes, is not affected by a change in the free air reduction procedure.

It should finally be mentioned, that besides the problem of accurate definition of free air gravity anomalies and accurate normal gravity computation, there exist a number of systematic error sources affecting the gravity anomalies, e.g. vertical, horizontal and gravity datum offsets, problems of the definition and realization of height systems. For a detailed analysis see HECK 1989.

2. Computation of Normal Gravity

For the computation of MOLODENSKII type free air gravity anomalies according to (4) or (8), normal gravity has to be computed at and above the reference ellipsoid ($H_N \leqslant 10$ km) with a numerical accuracy better than $10^{-8} m \cdot s^{-2}$. Unfortunately, for the currently used reference ellipsoids (IAG 1971, IAG 1984), there exist only definitions for the normal gravity at the reference ellipsoids. Thus, for the proposed TAYLOR expansion (5) of the normal gravity with respect to height, the necessary degree of expansion as well as formulas for the derivatives of the normal gravity have to be defined.

For an estimation of the magnitude of higher derivatives of the normal gravity and their contribution to the computed normal gravity for normal heights $H_N \leqslant 10$ km, one can use the rough approximation

$$\frac{\partial^n \gamma}{\partial h^n} \approx - \frac{\partial^{n+1} U}{\partial r^n} \tag{9}$$

with U = normal potential and its spherical approximation

$$U_{(r,\psi)} = \frac{GM}{r} + \frac{1}{2}\, \omega^2 r^2 \cos^2\psi \tag{10}$$

with r = geocentric radius ($\sim 6.37 \cdot 10^6$ m), ψ = geocentric latitude, GM = geocentric gravitational constant ($\sim 3.986 \cdot 10^{14} m^3 \cdot s^{-2}$), ω = angular velocity of the Earth's rotation ($\sim 7.292 \cdot 10^{-5} s^{-1}$) and

$$\frac{\partial \gamma}{\partial h} \approx - \frac{\partial^2 U}{\partial r^2} \approx - \frac{2GM}{r^2} - \omega^2 \cos^2\psi \tag{11}$$

$$\frac{\partial \gamma}{\partial h} \approx (-0.30842 - 0.00053 \cdot \cos^2\psi) \cdot 10^{-5} s^{-2}$$

$$\frac{\partial^2 \gamma}{\partial h^2} \approx - \frac{\partial^3 U}{\partial r^3} \approx + \frac{6GM}{r^4} \approx + 1.45 \cdot 10^{-12}\ m^{-1} \cdot s^{-2}, \qquad (12)$$

$$\frac{\partial^3 \gamma}{\partial h^3} \approx - \frac{\partial^4 U}{\partial r^4} \approx - \frac{24GM}{r^5} \approx - 9.12 \cdot 10^{-19}\ m^{-2} \cdot s^{-2}, \qquad (13)$$

$$\frac{\partial^4 \gamma}{\partial h^4} \approx - \frac{\partial^5 U}{\partial r^5} \approx + \frac{120GM}{r^6} \approx + 7.16 \cdot 10^{-25}\ m^{-3} \cdot s^{-2} \quad . \qquad (14)$$

The contribution to normal gravity for a station with normal height H_N = 10 km is about $+ 7.2 \cdot 10^{-6}\ m \cdot s^{-2}$, $-15 \cdot 10^{-8}\ m \cdot s^{-2}$ and $+0.03 \cdot 10^{-8} m \cdot s^{-2}$ for second, third and fourth derivative. Thus, the TAYLOR series has to be expanded up to and inclusive third derivative for $10^{-9}\ m \cdot s^{-2}$ numerical accuracy and whole earth validity.

The normal gravity at the reference ellipsoid can be computed using SOMIGLIANA's formula

$$\gamma_R = \gamma_e\ (1 + p \cdot \sin^2\phi) \cdot (1 - e^2 \cdot \sin^2\phi)^{-1/2} \qquad (15)$$

with γ_e = equatorial normal gravity, p = SOMIGLIANA constant, e^2 = square of first numerical eccentricity, ϕ = ellipsoidal latitude. The needed parameters γ_e, p and e^2 can be derived in a straight forward manner with high numerical accuracy from the given primary parameters of the reference ellipsoid a = semi major axis, GM = geocentric gravitational constant, J_2 = second degree zonal hamonic coefficient and ω = angular velocity (e.g. HEISKANEN and MORITZ 1967, IAG 1971, IAG 1984, WENZEL 1985). SOMIGLIANA's formula has the advantage over conventional series developments of unlimited numerical accuracy and of higher computational speed.

For the first derivative of normal gravity at the reference ellipsoid with respect to height we can use BRUNS formula (e.g. HEISKANEN and MORITZ 1967, p. 78)

$$\left(\frac{\partial \gamma}{\partial h}\right)_R = - \frac{\gamma}{a(1-e^2)} \cdot (1 - e^2 \sin^2\phi)^{1/2} (2 - e^2 - e^2 \sin^2\phi) - 2\omega^2. \qquad (16)$$

For the second and third derivative of normal gravity with respect to height, we dont need a very high accuracy and thus we can use an expansion of the normal potential in spherical harmonics to degree 2

$$U_{(r,\psi)} \approx \frac{GM}{r} - \frac{GM}{r} \cdot \left(\frac{a}{r}\right)^2 J_2 \cdot \left(\frac{3}{2} \sin^2\psi - \frac{1}{2}\right) + \frac{1}{2}\ \omega^2 r^2 \cos^2\psi \qquad (17)$$

and

$$\frac{\partial^n \gamma}{\partial h^n} \approx - \frac{\partial^{n+1} U}{\partial r^{n+1}} \tag{18}$$

yielding in

$$\frac{\partial^2 \gamma}{\partial h^2} \approx \frac{6GM}{r^4} - \frac{60GM}{r^4} \cdot \left(\frac{a}{r}\right)^2 J_2 \left(\frac{3}{2} \sin^2\psi - \frac{1}{2}\right), \tag{19}$$

$$\frac{\partial^3 \gamma}{\partial h^3} \approx - \frac{24GM}{r^5} + \frac{360GM}{r^5} \cdot \left(\frac{a}{r}\right)^2 J_2 \left(\frac{3}{2} \sin^2\psi - \frac{1}{2}\right) . \tag{20}$$

Using the approximation $\psi \approx \phi$ and

$$r \approx a \sqrt{1 - e^2 \sin^2\phi} \tag{21}$$

gives

$$\left(\frac{\partial^2 \gamma}{\partial h^2}\right)_R \approx \frac{6GM}{a^4 (1-e^2 \sin^2\phi)^2} - \frac{30GM \cdot J_2 \cdot (3\sin^2\phi - 1)}{a^4 (1-e^2 \sin^2\phi)^3} \tag{22}$$

and with sufficient accuracy

$$\left(\frac{\partial^3 \gamma}{\partial h^3}\right)_R \approx - \frac{24GM}{a^5} \tag{23}$$

There have been established the FORTRAN 77 subroutines GEOREF and GEOGAM, where the first one has to be called one times to derive all necessary parameters from the given primary parameters of the reference ellipsoid (International Ellipsoid 1930, Geodetic Reference Systems 1967 and 1980, and IAG Reference Ellipsoids 1975 and 1983 beeing currently implemented). The subroutine GEOGAM computes normal gravity and its first, second and third derivatives with respect to height at the ellipsoid, normal gravity at the telluroid point, mean normal gravity for the path between ellipsoid and telluroid, and normal potential at the telluroid point. Both subroutines have been tested on CDC Cyber 990 and IBM-AT computers; the listings are given in the appendix. For a numerical test of subroutine GEOGAM, normal gravity values at different latitudes and elevations up to 10 km referring to the Geodetic Reference System 1967 have been used (Table 1). One reference set of normal gravity values has been computed and supplied by TSCHERNING 1988, using an approximation formula for moderate heights to values derived from a spherical harmonic expansion of the normal potential (abbreviated with GAMC in Table 1); another reference set of normal gravity values has been computed by the author using an expansion of the normal potential in ellipsoidal harmonics (abbreviated with GAME in Table 1). The normal gravity values computed with subroutine GEOGAM (abbreviated with GAMT in Table 1) show a maximum discrepancy of $0.6 \cdot 10^{-8} m \cdot s^{-2}$ to the reference values GAME, demonstrating clearly the high numerical accuracy of normal gravity values GAME and GAMT. For the reference set GAMC, the maximum discrepancy is $4.5 \cdot 10^{-8} m \cdot s^{-2}$ for heights up to 2 km and $19.6 \cdot 10^{-8} m \cdot s^{-2}$ for heights up to 10 km, indicating the neglection of a term proportional to the third power of heights in the reference set GAMC.

TABLE 1: NORMAL GRAVITY VALUES REFERRING TO GEODETIC REFERENCE SYSTEM 1967

LAT IS ELLIPSOIDAL LATITUDE IN DEGREE.
HEIGHT IS ELLIPSOIDAL HEIGHT IN METER.
GAMC IS NORMAL GRAVITY IN MICROGAL COMPUTED FROM EXPANSION OF THE NORMAL POTENTIAL IN SPHERICAL HARMONICS, SUPPLIED BY C.C. TSCHERNING 1988.
GAME IS NORMAL GRAVITY IN MICROGAL COMPUTED FROM EXPANSION OF THE NORMAL POTENTIAL IN ELLIPSOIDAL HARMONICS.
GAMT IS NORMAL GRAVITY IN MICROGAL COMPUTED FROM TAYLOR SERIES DEVELOPMENT USING SUBROUTINE GEOGAM.
DGAMC IS GAMC - GAMT.
DGAME IS GAME - GAMT.

LAT	HEIGHT	GAMC	GAME	GAMT	DGAMC	DGAME
0.0000	0.	978031850.0	978031845.6	978031845.6	4.4	0.0
0.0000	2000.	977414583.0	977414579.1	977414579.1	3.9	0.0
0.0000	4000.	976797898.0	976797893.1	976797893.1	4.9	0.0
0.0000	6000.	976181794.0	976181786.9	976181786.8	7.2	0.1
0.0000	8000.	975566271.0	975566259.6	975566259.5	11.5	0.1
0.0000	10000.	974951330.0	974951310.7	974951310.5	19.5	0.1
10.0000	0.	978187552.0	978187549.7	978187549.7	2.3	0.0
10.0000	2000.	977570312.0	977570309.7	977570309.7	2.3	0.0
10.0000	4000.	976953653.0	976953650.1	976953650.1	2.9	0.0
10.0000	6000.	976337575.0	976337570.2	976337570.1	4.9	0.1
10.0000	8000.	975722079.0	975722069.3	975722069.2	9.8	0.1
10.0000	10000.	975107164.0	975107146.6	975107146.5	17.5	0.1
20.0000	0.	978636111.0	978636113.2	978636113.2	-2.2	0.0
20.0000	2000.	978018948.0	978018949.4	978018949.4	-1.4	0.0
20.0000	4000.	977402365.0	977402365.9	977402365.8	-0.8	0.0
20.0000	6000.	976786363.0	976786361.9	976786361.9	1.1	0.0
20.0000	8000.	976170943.0	976170936.8	976170936.7	6.3	0.1
20.0000	10000.	975556103.0	975556089.8	975556089.7	13.3	0.1
30.0000	0.	979324016.0	979324019.3	979324019.3	-3.3	0.0
30.0000	2000.	978706969.0	978706972.4	978706972.4	-3.4	0.0
30.0000	4000.	978090503.0	978090505.6	978090505.6	-2.6	0.0
30.0000	6000.	977474608.0	977474618.1	977474618.1	-10.1	0.0
30.0000	8000.	976859313.0	976859309.2	976859309.2	3.8	0.1
30.0000	10000.	976244589.0	976244578.2	976244578.2	10.8	0.1
40.0000	0.	980168964.0	980168965.9	980168965.9	-1.9	0.0
40.0000	2000.	979552061.0	979552062.6	979552062.6	-1.6	0.0
40.0000	4000.	978935738.0	978935739.1	978935739.1	-1.1	0.0
40.0000	6000.	978319996.0	978319994.7	978319994.7	1.3	0.0
40.0000	8000.	977704834.0	977704828.6	977704828.5	5.5	0.1
40.0000	10000.	977090253.0	977090240.1	977090240.0	13.0	0.1
50.0000	0.	981069482.0	981069479.7	981069479.7	2.3	0.0
50.0000	2000.	980452732.0	980452729.4	980452729.4	2.6	0.0
50.0000	4000.	979836562.0	979836558.7	979836558.6	3.4	0.0
50.0000	6000.	979220972.0	979220966.7	979220966.6	5.4	0.1
50.0000	8000.	978605963.0	978605952.8	978605952.7	10.3	0.1
50.0000	10000.	977991533.0	977991516.2	977991516.0	17.0	0.2
60.0000	0.	981916953.0	981916948.8	981916948.8	4.2	0.0
60.0000	2000.	981300347.0	981300342.5	981300342.5	4.5	0.0
60.0000	4000.	980684320.0	980684315.5	980684315.5	4.5	0.1
60.0000	6000.	980068874.0	980068867.0	980068866.9	7.1	0.1
60.0000	8000.	979454008.0	979453996.3	979453996.1	11.9	0.2
60.0000	10000.	978839722.0	978839702.7	978839702.4	19.6	0.3
70.0000	0.	982608722.0	982608719.6	982608719.6	2.4	0.0
70.0000	2000.	981992233.0	981992230.9	981992230.9	2.1	0.0
70.0000	4000.	981376324.0	981376321.3	981376321.2	2.8	0.1
70.0000	6000.	980760995.0	980760989.9	980760989.7	5.3	0.2
70.0000	8000.	980146246.0	980146236.1	980146235.8	10.2	0.3
70.0000	10000.	979532076.0	979532059.1	979532058.7	17.3	0.5

TABLE 1: NORMAL GRAVITY VALUES REFERRING TO GEODETIC REFERENCE SYSTEM 1967 (CONTINUED)

LAT IS ELLIPSOIDAL LATITUDE IN DEGREE.
HEIGHT IS ELLIPSOIDAL HEIGHT IN METER.
GAMC IS NORMAL GRAVITY IN MICROGAL COMPUTED FROM EXPANSION OF THE NORMAL POTENTIAL IN SPHERICAL HARMONICS, SUPPLIED BY C.C. TSCHERNING 1988.
GAME IS NORMAL GRAVITY IN MICROGAL COMPUTED FROM EXPANSION OF THE NORMAL POTENTIAL IN ELLIPSOIDAL HARMONICS.
GAMT IS NORMAL GRAVITY IN MICROGAL COMPUTED FROM TAYLOR SERIES DEVELOPMENT USING SUBROUTINE GEOGAM.
DGAMC IS GAMC - GAMT.
DGAME IS GAME - GAMT.

LAT	HEIGHT	GAMC	GAME	GAMT	DGAMC	DGAME
80.0000	0.	983060680.0	983060681.6	983060681.6	-1.6	0.0
80.0000	2000.	982444268.0	982444269.8	982444269.7	-1.7	0.0
80.0000	4000.	981828436.0	981828436.8	981828436.7	-0.7	0.1
80.0000	6000.	981213183.0	981213181.9	981213181.7	1.3	0.2
80.0000	8000.	980598510.0	980598504.5	980598504.1	5.9	0.4
80.0000	10000.	979984417.0	979984403.7	979984403.2	13.8	0.6
90.0000	0.	983217724.0	983217727.9	983217727.9	-3.9	0.0
90.0000	2000.	982601339.0	982601342.8	982601342.7	-3.7	0.0
90.0000	4000.	981985533.0	981985536.4	981985536.3	-3.3	0.1
90.0000	6000.	981370308.0	981370308.1	981370307.9	0.1	0.2
90.0000	8000.	980755661.0	980755657.2	980755656.8	4.2	0.4
90.0000	10000.	980141594.0	980141583.0	980141582.4	11.6	0.6

RMS DGAMC : 7.9 MICROGAL. RMS DGAME : 0.2 MICROGAL.
MAX.DGAMC : 19.6 MICROGAL. MAX.DGAME : 0.6 MICROGAL.

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APPENDIX A: SUBROUTINE GEOREF
=============================

```
      SUBROUTINE GEOREF(IUN6,IUN7,CREFSN,IPRINT)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                       C
C     ROUTINE GEOREF, VERSION 881215 FORTRAN 77.                        C
C                                                                       C
C     === VERSION FOR IBM-AT ===                                        C
C                                                                       C
C     THE ROUTINE GEOREF DEFINES THE PRIMARY CONSTANTS AND COMPUTES     C
C     THE DERIVED CONSTANTS OF THE INTERNATIONAL ELLIPSOID 1930,        C
C                              THE GEODETIC REFERENCE SYSTEM 1967,      C
C                              THE REFERENCE SYSTEM IAG 1975,           C
C                              THE GEODETIC REFERENCE SYSTEM 1980   OR  C
C                              THE REFERENCE SYSTEM IAG 1983.           C
C                                                                       C
C     THE PRIMARY PARAMETERS DA, DGM, DJ2 AND DOM FOR THE INTERNATIO-   C
C     NAL ELLIPSOID 1930 HAVE BEEN COMPUTED FROM THE DEFINED PARAME-    C
C     TERS DA, DF, DGE AND DOM WITH PROGRAM INT30 BY H.-G. WENZEL AT    C
C     870724.                                                           C
C                                                                       C
C     REFERENCE... I.A.G. 1967..GEODETIC REFERENCE 1967.                C
C                  PUBLICATION SPECIALE DU BUREAU GEODESIQUE,           C
C                  PARIS 1967.                                          C
C     REFERENCE... MORITZ,H. 1975... REPORT OF SSG NO.5.39 OF I.A.G.    C
C                  PAPER PRESENTED TO 16 TH IUGG GENERAL ASSEMBLY,      C
C                  GRENOBLE 1975.                                       C
C     REFERENCE... MORITZ,H. 1980..GEODETIC REFERENCE SYSTEM 1980.      C
C                  BULLETIN GEODESIQUE, VOL.54 NO.3, P.385-405 ,        C
C                  (THE GEODESIST'S HANDBOOK 1980), PARIS 1980.         C
C     REFERENCE... RAPP,R.H. 1983.. REPORT OF SSG NO. 5.39 OF I.A.G.,   C
C                  FUNDAMENTAL GEODETIC CONSTANTS. PAPER PRESENTED TO   C
C                  18 TH IUGG GENERAL ASSEMBLY, HAMBURG 1983.           C
C                                                                       C
C     INPUT PARAMETER DESCRIPTION...                                    C
C     ==============================                                    C
C                                                                       C
C     VARIABLES WITH D AS FIRST CHARACTER ARE DOUBLE PRECISION.         C
C                                                                       C
C     IUN6...      FORMATTED LINE PRINTER UNIT.                         C
C     IUN7...      FORMATTED CONSOLE UNIT (DATA TERMINAL SCREEN).       C
C     CREFSN...    DEFINES THE GEODETIC REFERENCE SYSTEM WHICH WILL BE  C
C                  USED (CHARACTER*10).                                 C
C                  CREFSN='INT 1930  '... THE INTERNATIONAL ELLIPSOID   C
C                                         1930 WILL BE USED.            C
C                  CREFSN='GRS 1967  '... THE GEODETIC REFERENCE        C
C                                         SYSTEM 1967 WILL BE USED.     C
C                  CREFSN='IAG 1975  '... THE REFERENCE SYSTEM IAG      C
C                                         1975 WILL BE USED.            C
C                  CREFSN='GRS 1980  '... THE GEODETIC REFERENCE        C
C                                         SYSTEM 1980 WILL BE USED.     C
C                  CREFSN='IAG 1983  '... THE REFERENCE SYSTEM IAG      C
C                                         1983 WILL BE USED.            C
C                  IF THE INPUT VALUE OF CREFSN DOES NOT AGREE WITH     C
C                  ONE OF THE ABOVE DEFINED STRINGS, THE GEODETIC       C
C                  REFERENCE SYSTEM 1980 WILL BE USED. I.E. IF          C
C                  CREFSN='UNKNOWN ' WILL BE TRANSFERRED TO ROUTINE     C
C                  GEOREF, THE GEODETIC REFERENCE SYSTEM 1980 WILL BE   C
C                  USED.                                                C
C     IPRINT...    LINE PRINTER OUTPUT PARAMETER.                       C
C                  IPRINT=0...NOTHING WILL BE WRITTEN ON UNIT IUN6.     C
C                  IPRINT=1...THE NAME OF THE USED REFERENCE SYSTEM     C
C                             WILL BE WRITTEN ON UNIT IUN6.             C
C                  IPRINT=2...THE PRIMARY AND DERIVED CONSTANTS WILL    C
C                             BE WRITTEN ON UNIT IUN6.                  C
```

```
C                                                                        C
C     OUTPUT PARAMETER DESCRIPTION...                                    C
C     ===============================                                    C
C                                                                        C
C     THERE ARE NO OUTPUT PARAMETERS. THE COMPUTED CONSTANTS WILL BE     C
C     TRANSFERRED TO CALLING ROUTINE BY COMMON/REFELL/ AND COMMON        C
C     /REFSYS/.                                                          C
C                                                                        C
C     COMMON BLOCK DESCRIPTION...                                        C
C     ===========================                                        C
C                                                                        C
C     COMMON/REFELL/...  PARAMETERS OF THE REFERENCE ELLIPSOID.          C
C                   THE PARAMETERS OF COMMON/REFELL/ WILL BE DEFINED BY C
C                   CALLING ROUTINE GEOREF.                              C
C                                                                        C
C     DGM...        GEOCENTRIC GRAVITATIONAL CONSTANT IN                 C
C                   METER**3/SEC**2.                                     C
C     DA...         MAJOR SEMI AXIS IN METER.                            C
C     DJ2...        SECOND DEGREE ZONAL HARMONIC COEFFICIENT (WITHOUT    C
C                   DIMENSION).                                          C
C     DF...         FLATTENING.                                          C
C     DOM...        ROTATION SPEED IN RADIANS/SEC.                       C
C     DRMEAN...     MEAN EARTH'S RADIUS IN METER.                        C
C     DGMEAN...     MEAN EARTH'S GRAVITY IN METER/SEC**2.                C
C     DGE...        EQUATORIAL NORMAL GRAVITY IN METER/SEC**2.           C
C     DRK...        CONSTANT FOR SOMIGLIANA NORMAL GRAVITY FORMULA.      C
C     DE2...        SQUARE OF FIRST ECCENTRICITY.                        C
C     DES2...       SQUARE OF SECOND ECCENTRICITY.                       C
C     DUO...        NORMAL POTENTIAL OF THE LEVEL ELLIPSOID IN           C
C                   METER**2/SEC**2.                                     C
C     DCN...        FULLY NORMALIZED ZONAL HARMONIC COEFFICIENTS OF      C
C                   THE ELLIPSOIDAL NORMAL GRAVITY POTENTIAL UP TO       C
C                   DEGREE 10. THE COEFFICIENT C(L,0) IS STORED IN       C
C                   DCN(L+1). THE COEFFICIENT C(0,0) IS SET TO 1 AND     C
C                   STORED IN DCN(1).                                    C
C                                                                        C
C     COMMON/REFSYS/...NAME OF THE USED REFERENCE ELLIPSOID.             C
C     CREFSY...NAME OF THE USED REFERENCE ELLIPSOID (CHARACTER*10).      C
C                                                                        C
C     USED ROUTINES... NONE.                                             C
C     ===============                                                    C
C                                                                        C
C                                                                        C
C     NUMERICAL ACCURACY...                                              C
C     =====================                                              C
C                                                                        C
C     THE RELATIVE ERROR OF ALL VARIABLES IS LESS 10**-10 ON IBM-AT      C
C     AND LESS 10**-20 ON CDC CYBER 990.                                 C
C                                                                        C
C                                                                        C
C     EXECUTION TIME...                                                  C
C     =================                                                  C
C                                                                        C
C     0.003 SEC CPU TIME WITH IPRINT=0 AND 1, 0.006 SEC CPU TIME WITH    C
C     IPRINT=2 ON CDC CYBER 76 OF RRZN HANNOVER. SAME EXECUTION TIME     C
C     ON CDC CYBER 990 OF RRZN HANNOVER.                                 C
C                                                                        C
C     ROUTINE TESTS...                                                   C
C     ================                                                   C
C                                                                        C
C     SUCCESSFULLY COMPLETED 830615 BY F.BOECKMANN                       C
C                                                                        C
C     ROUTINE CREATION...      830408 BY H.-G.WENZEL,                    C
C                              GEODAETISCHES INSTITUT,                   C
C                              UNIVERSITAET KARLSRUHE,                   C
C                              ENGLERSTR. 7,                             C
```

```
C                               D-7500 KARLSRUHE 1,                           C
C                               FEDERAL REPUBLIC OF GERMANY.                  C
C     PROGRAM MODIFICATION...881215 BY H.-G.WENZEL.                           C
C*****************************************************************************C
      IMPLICIT DOUBLE PRECISION (D)
      CHARACTER CRS(5)*8,CREFSN*10,CREFSY*10
      COMMON/REFELL/ DGM,DA,DJ2,DF,DOM,DRMEAN,DGMEAN,DGE,DRK,DE2,DES2,
     1 DUO,DCN(11)
      COMMON/REFSYS/ CREFSY
      DATA CRS/'INT 1930  ','GRS 1967  ','IAG 1975  ','GRS 1980  ',
     1'IAG 1983  '/
      KRS=0
      DO 10 I=1,5
      IF(CREFSN.EQ.CRS(I)) KRS=I
   10 CONTINUE
      IF(KRS.EQ.0) GOTO 5000
      GOTO (100,200,300,400,500) KRS
  100 CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     DEFINE THE PRIMARY PARAMETERS FOR INTERNATIONAL ELLIPSOID 1930.         C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DA=6378388.D0
      DGM=398632.904400795D9
      DJ2=1092.03876103097D-6
      DOM=7.292115D-5
      CREFSY=CRS(1)
      GOTO 1000
  200 CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     DEFINE THE PRIMARY CONSTANTS FOR GRS 1967 REFERENCE ELLIPSOID.          C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DA=6378160.D0
      DGM=398603.D9
      DJ2=1082.7D-6
      DOM=7.2921151467D-5
      CREFSY=CRS(2)
      GOTO 1000
  300 CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     DEFINE THE PRIMARY CONSTANTS FOR IAG 1975 REFERENCE ELLIPSOID.          C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DA=6378140.D0
      DGM=398600.5D9
      DJ2=1082.63D-6
      DOM=7.292115D-5
      CREFSY=CRS(3)
      GOTO 1000
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     DEFINE THE PRIMARY CONSTANTS FOR GRS 1980 REFERENCE ELLIPSOID.          C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
  400 CONTINUE
      DA=6378137.D0
      DGM=398600.5D9
      DJ2=1082.63D-6
      DOM=7.292115D-5
      CREFSY=CRS(4)
      GOTO 1000
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     DEFINE THE PRIMARY CONSTANTS FOR IAG 1983 REFERENCE ELLIPSOID.          C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
  500 CONTINUE
      DA=6378136.D0
      DGM=398600.44D9
      DJ2=1082.629D-6
      DOM=7.292115D-5
      CREFSY=CRS(5)
```

```
 1000 CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     COMPUTE DERIVED CONSTANTS.                                          C
C     ITERATIVE COMPUTATION OF THE SQUARE OF FIRST ECCENTRICITY.          C
C     COMPUTATION OF INITIAL VALUE DE20 FOR THE SQUARE OF FIRST           C
C     ECCENTRICITY ACCORDING TO...                                        C
C                 CHEN,Y.1981...FORMULAE FOR COMPUTING ELLIPSOIDAL        C
C                           PARAMETERS. BULLETIN GEODESIQUE, VOL.55,      C
C                           NO.2, PP.170 - 178, PARIS 1981.               C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DQ=DOM*DOM*DA*DA*DA/DGM
      DE20=3.D0*DJ2+DQ-3.D0*DQ*(9.D0*DJ2+3.D0*DQ)/14.D0+(408.D0*DJ2*DQ
     1+149.D0*DQ*DQ-117.D0*DJ2*DJ2)*DQ/392.D0
 1010 CONTINUE
      DES2=DE20/(1.D0-DE20)
      DES=DSQRT(DES2)
      DT=DATAN(DES)
      DM=DQ*DSQRT(1.D0-DE20)
      DQ0=((1.D0+3.D0/DES2)*DT-3.D0/DES)/2.D0
      DE2=3.D0*DJ2+2.D0*DM*DES*DE20/(15.D0*DQ0)
      DERR2=(DE2-DE20)*(DE2-DE20)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     NUMERICAL ACCURACY RESTRICTED TO 1.D-25 ON CDC CYBER 990:           C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C CDC IF(DERR2.LT.1.D-50) GOTO 1020
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     NUMERICAL ACCURACY RESTRICTED TO 1.D-13 ON IBM-AT :                 C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(DERR2.LT.1.D-27) GOTO 1020
      DE20=DE2
      GOTO 1010
 1020 CONTINUE
      DF=1.D0-DSQRT(1.D0-DE2)
      DES2=DE2/(1.D0-DE2)
      DES=DSQRT(DES2)
      DT=DATAN(DES)
      DE=DSQRT(DE2)
      DU0=DGM*DT/(DA*DE)+DOM*DOM*DA*DA/3.D0
      DM=DQ*(1.D0-DF)
      DQ0=((1.D0+3.D0/DES2)*DT-3.D0/DES)/2.D0
      DQS=3.D0*(1.D0+1.D0/DES2)*(1.D0-DT/DES)-1.D0
      DGE=DGM*1.D0/(DA*DA*(1.D0-DF))*(1.D0-DM-DM*DES/6.D0*DQS/DQ0)
      DGP=DGM*1.D0/(DA*DA)*(1.D0+DM/3.D0*DES*DQS/DQ0)
      DRK=(1.D0-DF)*DGP/DGE-1.D0
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     MEAN RADIUS AND MEAN NORMAL GRAVITY.                                C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DC=DA/(1.D0-DF)
      DRMEAN=DC*(1.D0-2.D0/3.D0*DES2+26.D0/45.D0*DES2*DES2-100.D0/
     1 189.D0*DES2*DES2*DES2+7034.D0/14175.D0*DES2*DES2*DES2*DES2)
      DGMEAN=DGE*(1.D0+DE2/6.D0+DRK/3.D0+59.D0/360.D0*DE2**2+5.D0/
     1 18.D0*DE2*DRK+2371.D0/15120.D0*DE2**3+259.D0/1080.D0*DE2**2*DRK+
     2 270229.D0/1814400.D0*DE2**4+9623.D0/45360.D0*DE2**3*DRK)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     COMPUTE FULLY NORMALIZED SPHERICAL HARMONIC COEFFICIENTS.           C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DCN(1)=1.
      DO 1030 L=1,10
      LP1=L+1
 1030 DCN(LP1)=0.
      DEL2=1.D0
      DL2=0.D0
      DO 1040 L2=1,5
      L=2*L2
      DL2=DL2+1.D0
      K=L+1
```

```
      DEL2=-DEL2*DE2
      DCN(K)=DEL2*3.D0/(DSQRT(4.D0*DL2+1.D0)*(2.D0*DL2+1.D0)*
     1 (2.D0*DL2+3.D0))
      DCN(K)=DCN(K)*(1.D0-DL2+5.D0*DL2*(1.D0/3.D0-2.D0/45.D0*DM*DES
     1 /DQ0))
 1040 CONTINUE
      IF(IPRINT.EQ.1) WRITE(IUN6,7000) CREFSY
      IF(IPRINT.EQ.1) WRITE(IUN7,7000) CREFSY
      IF(IPRINT.NE.2) RETURN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     OUTPUT ON LINE PRINTER.                                           C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DF1=1./DF
      DJ21=DJ2*1.D6
      DGM1=DGM*1.D-9
      DOM1=DOM*1.D5
      WRITE(IUN6,7001) CREFSY,DA,DJ21,DGM1,DOM1
      WRITE(IUN7,7001) CREFSY,DA,DJ21,DGM1,DOM1
      WRITE(IUN6,7002) CREFSY,DE2,DES2,DF1,DGE,DGP,DRK,DRMEAN,DGMEAN,
     1 DUO
      WRITE(IUN7,7002) CREFSY,DE2,DES2,DF1,DGE,DGP,DRK,DRMEAN,DGMEAN,
     1 DUO
      WRITE(IUN6,7003) CREFSY
      WRITE(IUN7,7003) CREFSY
      DO 1050 L2=1,5
      L=2*L2
      LP1=L+1
      WRITE(IUN6,7004) L,DCN(LP1)
 1050 WRITE(IUN7,7004) L,DCN(LP1)
      WRITE(IUN6,7006)
      WRITE(IUN7,7006)
      RETURN
 5000 CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     PARAMETER CREFSN NOT ALLOWED. GEODETIC REFERENCE SYSTEM GRS 1980 C
C     WILL BE USED AND THE EXECUTION WILL BE CONTINUED.                 C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      KRS=4
      CREFSY=CRS(4)
      WRITE(IUN6,7005) CREFSY
      WRITE(IUN7,7005) CREFSY
      GOTO 400
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     FORMAT STATEMENTS.                                                C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
 7000 FORMAT(/' ROUTINE GEOREF, VERSION 881215, FTN 77.'//
     1 ' GEODETIC REFERENCE SYSTEM USED IS',2X,A8//)
 7001 FORMAT('1ROUTINE GEOREF, VERSION 881215, FTN 77.'//
     1 ' PRIMARY CONSTANTS OF GEODETIC REFERENCE SYSTEM',2X,A8//
     2 ' MAJOR SEMI AXIS',15X,F15.1,' METER'/
     3 ' J2',28X,F15.3,' *10**-6'/
     4 ' GEOCENTRIC GRAVITATION', 8X,F15.2,' *10**9 METER**3/SEC**2'/
     5 ' ROTATION SPEED',16X,F15.10,' *10**-5 RADIAN/SEC'/)
 7002 FORMAT(//' DERIVED CONSTANTS OF GEODETIC REFERENCE SYSTEM',2X,
     1 A8//' SQUARE OF FIRST ECCENTRICITY', 1X,F16.14/
     2 ' SQUARE OF SECOND ECCENTRICITY', F16.14/
     3 ' FLATTENING',18X,'1/',F15.10/
     4 ' EQUATORIAL NORMAL GRAVITY', 5X,F15.8,' METER/SEC**2'/
     5 ' POLAR NORMAL GRAVITY',10X,F15.8,' METER/SEC**2'/
     6 ' CONSTANT OF SOMIGLIANA FORMULA',F15.12/
     7 ' MEAN EARTH RADIUS',13X,F15.1,' METER'/
     8 ' MEAN EARTH NORMAL GRAVITY', 5X, F15.8,' METER/SEC**2'/
     9 ' NORMAL POTENTIAL',14X,F15.3,' METER**2/SEC**2'/)
 7003 FORMAT(//' FULLY NORMALIZED ZONAL SPHERICAL HARMONIC',
     1 ' COEFFICIENTS'/
     2 ' OF THE ELLIPSOIDAL NORMAL GRAVITY POTENTIAL FOR THE'/
```

```
    3 ' GEODETIC REFERENCE SYSTEM',2X,A8//
    4 '    DEGREE                         C(L,0)'//)
7004 FORMAT(I10,E25.15)
7005 FORMAT(//' *****ERROR IN ROUTINE GEOREF, VERSION 881215 FTN 77.'/
    1 ' *****THE PARAMETER CREFSN=',A10,' USED IN THE CALL OF ROUTINE',
    2 ' GEOREF IS NOT ALLOWED.'/
    4 ' *****THE GEODETIC REFERENCE SYSTEM 1980 WILL BE USED AND THE',
    5 ' EXECUTION WILL BE CONTINUED.'//)
7006 FORMAT(// ' *****EXECUTION OF ROUTINE GEOREF FINISHED.')
      END
```

APPENDIX B: SUBROUTINE GEOGAM
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```
      SUBROUTINE GEOGAM(IUN6,IUN7,DLAT,DHNORM,DGAM0,DGAMH,DGAMQ,DGAMD1,
     1 DGAMD2,DGAMD3,DGPC,DGPU)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                      C
C     ROUTINE GEOGAM, VERSION 881213 FORTRAN 77.                       C
C                                                                      C
C     === VERSION FOR IBM-AT ===                                       C
C                                                                      C
C     THE ROUTINE GEOGAM COMPUTES THE NORMAL GRAVITY, THE MEAN NORMAL  C
C     GRAVITY AND THE NORMAL POTENTIAL FOR A POINT WITH GIVEN          C
C     ELLIPSOIDAL LATITUDE AND NORMAL HEIGHT. ALL QUANTITIES ARE       C
C     COMPUTED FROM A THIRD ORDER TAYLOR EXPANSION OF THE NORMAL       C
C     GRAVITY VERSUS HEIGHT.                                           C
C                                                                      C
C     REFERENCE: HEISKANEN, W.A. AND H. MORITZ 1967: PHSYICAL GEODESY. C
C                FREEMAN AND COMPANY, SAN FRANCISCO 1967.              C
C                                                                      C
C                WENZEL, H.-G. 1985: HOCHAUFLOESENDE KUGELFUNKTIONS-   C
C                MODELLE FUER DAS GRAVITATIONSPOTENTIAL DER ERDE.      C
C                WISSENSCHAFTLICHE ARBEITEN DER FACHRICHTUNG VER-      C
C                MESSUNGSWESEN DER UNIVERSITAET HANNOVER NO. 137,      C
C                HANNOVER 1985.                                        C
C                                                                      C
C     INPUT PARAMETER DESCRIPTION...                                   C
C     ==============================                                   C
C                                                                      C
C     ALL VARIABLES WITH D AS FIRST CHARACTER ARE DOUBLE PRECISION.    C
C                                                                      D
C     IUN6...      FORMATTED LINE PRINTER UNIT.                        C
C     IUN7...      FORMATTED CONSOLE UNIT (DATA TERMINAL SCREEN).      C
C     DLAT...      ELLIPSOIDAL LATITUDE IN DEGREE REFERRING TO THE     C
C                  CHOSEN GEODETIC REFERENCE SYSTEM.                   C
C     DHNORM...    NORMAL HEIGHT IN METER.                             C
C                                                                      C
C     OUTPUT PARAMETER DESCRIPTION...                                  C
C     ===============================                                  C
C                                                                      C
C     DGAM0...     NORMAL GRAVITY AT THE ELLIPSOID IN METER/SEC**2.    C
C     DGAMH...     NORMAL GRAVITY OF THE STATION IN METER/SEC**2.      C
C     DGAMQ...     MEAN (INTEGRATED) NORMAL GRAVITY FOR THE PATH       C
C                  BETWEEN ELLIPSOID AND TELLUROID IN METER/SEC**2.    C
C     DGAMD1...    1. DERIVATION OF NORMAL GRAVITY AT THE ELLIPSOID    C
C                  WITH RESPECT TO HEIGHT IN METER/SEC**2 PER METER.   C
C     DGAMD2...    2. DERIVATION OF NORMAL GRAVITY AT THE ELLIPSOID    C
C                  WITH RESPECT TO HEIGHT IN METER/SEC**2 PER METER**2.C
C     DGAMD3...    3. DERIVATION OF NORMAL GRAVITY AT THE ELLIPSOID    C
C                  WITH RESPECT TO HEIGHT IN METER/SEC**2 PER METER**3.C
C     DGPC...      NORMAL POTENTIAL OF THE STATION IN METER*SEC.       C
C     DGPU...      NORMAL POTENTIAL OF THE STATION IN GEOPOTENTIAL     C
C                  UNITS (KGAL*METER). DGPU IS ZERO FOR A STATION      C
C                  WITH ZERO ELEVATION.                                C
C                                                                      C
C     COMMON BLOCK DESCRIPTION...                                      C
C     ===========================                                      C
C                                                                      C
C     COMMON /REFELL/... PARAMETERS OF THE REFERENCE ELLIPSOID.        C
C                  THE PARAMETERS OF THIS COMMON HAVE TO BE DEFINED    C
C                  BEFORE THE EXECUTION OF ROUTINE GEOGAM BY THE CALL  C
C                  OF ROUTINE GEOREF.                                  C
C                                                                      C
C     DGM...       GEOCENTRIC GRAVITATIONAL CONSTANT IN                C
C                  METER**3/SEC**2.                                    C
```

```
C     DA...         MAJOR SEMI AXIS IN METER.                                 C
C     DJ2...        SECOND DEGREE ZONAL HARMONIC COEFFICIENT (WITHOUT         C
C                   DIMENSION).                                               C
C     DF...         FLATTENING.                                               C
C     DOM...        ROTATION SPEED IN RADIAN/SEC.                             C
C     DRMEAN...     MEAN EARTH'S RADIUS IN METER.                             C
C     DGMEAN...     MEAN EARTH'S GRAVITY IN METER/SEC**2.                     C
C     DGE...        EQUATORIAL NORMAL GRAVITY IN METER/SEC**2.                C
C     DRK...        CONSTANT FOR SOMIGLIANA NORMAL GRAVITY FORMULA.           C
C     DE2...        SQUARE OF FIRST ECCENTRICITY.                             C
C     DES2...       SQUARE OF SECOND ECCENTRICITY.                            C
C     DU0...        NORMAL POTENTIAL OF THE LEVEL ELLIPSOID IN                C
C                   METER**2/SEC**2.                                          C
C     DCN(11)...    FULLY NORMALIZED ZONAL HARMONIC COEFFICIENTS OF           C
C                   THE ELLIPSOIDAL NORMAL POTENTIAL UP TO DEGREE 10.         C
C                   THE COEFFICIENT C(L,0) IS STORED IN DCN(L+1), THE         C
C                   COEFFICIENT C(0,0) IS SET TO 1 AND STORED IN DCN(1).C
C                                                                             C
C     COMMON/REFSYS/...NAME OF THE USED REFERENCE ELLIPSOID.                  C
C     CREFSY...     NAME OF THE REFERENCE ELLIPSOID (CHARACTER*10).           C
C                                                                             C
C     USED ROUTINES...NONE.                                                   C
C     ================                                                        C
C                                                                             C
C     NUMERICAL ACCURACY...                                                   C
C     =====================                                                   C
C                                                                             C
C     BETTER 1*10**-9 METER/SEC**2 FOR THE NORMAL GRAVITY UP TO               C
C     10 000 METER ELEVATION.                                                 C
C                                                                             C
C     EXECUTION TIME...                                                       C
C     =================                                                       C
C                                                                             C
C     ABOUT 0.0016 SEC CPU TIME PER CALL OF ROUTINE GEOGAM ON CDC             C
C     CYBER 990 OF RRZN HANNOVER.                                             C
C                                                                             C
C     ROUTINE CREATION...    841004 BY H.-G.WENZEL,                           C
C                            GEODAETISCHES INSTITUT,                          C
C                            UNIVERSITAET KARLSRUHE,                          C
C                            ENGLERSTR. 7,                                    C
C                            D-7500 KARLSRUHE 1,                              C
C                            FEDERAL REPUBLIC OF GERMANY,                     C
C     ROUTINE MODIFICATION...881213 BY H.-G.WENZEL.                           C
C*****************************************************************************C
      IMPLICIT DOUBLE PRECISION (D)
      CHARACTER CREFSY*10
      COMMON /REFELL/ DGM,DA,DJ2,DF,DOM,DRMEAN,DGMEAN,DGE,DRK,DE2,DES2,
     1 DU0,DCN(11)
      COMMON /REFSYS/ CREFSY
      SAVE DRAD
      DATA DRAD/0.0174532925199432D0/
      DSLAT=DSIN(DLAT*DRAD)
      DSLAT2=DSLAT*DSLAT
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     NORMAL GRAVITY AT THE ELLIPSOID ACCORDING TO SOMIGLIANA :                C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DGAM0=DGE*(1.D0+DRK*DSLAT2)/DSQRT(1.D0-DE2*DSLAT2)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     FIRST DERIVATIVE OF NORMAL GRAVITY AT THE ELLIPSOID FROM BRUN'S         C
C     FORMULA :                                                               C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DGAMD1=-DGAM0/(DA*(1.D0-DE2))*DSQRT(1.D0-DE2*DSLAT2)*
     1 (2.D0-DE2*DSLAT2-DE2)-2.D0*DOM*DOM
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     SECOND DERIVATIVE OF NORMAL GRAVITY AT THE ELLIPSOID FROM               C
C     SPHERICAL HARMONIC EXPANSION OF THE NORMAL POTENTIAL TO                 C
```

```
C     DEGREE 2 :                                                        C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DGAMD2=6.D0*DGM/(DA**4*(1.D0-DE2*DSLAT2)**2)
     1-60.D0*DGM*DJ2*(1.5D0*DSLAT2-0.5D0)/(DA**4*(1.D0-DE2*DSLAT2)**3)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     THIRD DERIVATIVE OF NORMAL GRAVITY AT THE ELLIPSOID FROM          C
C     SPHERICAL APPROXIMATION :                                         C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DGAMD3=-24.D0*DGM/DA**5
      DGAMH=DGAM0+DGAMD1*DHNORM+0.5D0*DGAMD2*DHNORM**2
     1+1.D0/6.D0*DGAMD3*DHNORM**3
      DGAMQ=DGAM0+0.5D0*DGAMD1*DHNORM+1.D0/6.D0*DGAMD2*DHNORM**2
     1+1.D0/24.D0*DGAMD3*DHNORM**3
      DGPC=DGAMQ*DHNORM
      DGPU=0.1D0*DGPC
      DGPC=DGPC+DU0
      IF(DHNORM.GT.10001.) WRITE(IUN6,7001)
      IF(DHNORM.GT.10001.) WRITE(IUN7,7001)
      RETURN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C     FORMAT STATEMENTS.                                                C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
 7001 FORMAT(/' *****WARNING FROM ROUTINE GEOGAM, VERSION 881213.'/
     1' *****ELEVATION EXCEEDS 10001 METER.'/
     2' *****NUMERICAL ACCURACY MAY BE INSUFFICIENT.'/)
      END
```

THE METHODOLOGY FOR PERFORMING GRAVIMETRIC MEASUREMENTS ON A TELEVISION TRANSMITTING TOWER

by

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Abstract

We instituted a nation-wide search seeking a tall vertical structure that was stable enough to allow accurate gravimetric measurements. After careful reconnaissance, we decided upon the WTVD tower in Clayton, NC. Ensuing dynamic and gravimetric tests assured us of the feasibility of collecting accurate gravity data on such a structure. Gravity measurements were made on the tower using the LaCoste-Romberg model G gravimeter #152. The data were reduced and possess an accuracy of approximately 30 μGal.

Introduction

An experiment was performed in the summer of 1987 in Clayton, North Carolina, to test for possible departures from Newton's inverse-square law of gravity. The test involved making very accurate gravimetric measurements on a tall tower. The tower data would then be compared with surface data, analytically upward continued using Laplace's equation. The tower we chose was a television transmitting tower that had to be both tall and stable. Prior to performing the experiment the range of this possible departure from Newton's law was unknown, thus the tallest possible structure was needed. Also, the total magnitude of the non-Newtonian effect (if it exists) was not well known. Our best estimates put the effect at 100 to 150 μGal. To see this effect we required gravity data accurate to 30 μGal. Making gravimetric measurements on a television tower poses several problems, both scientific and logistical. All these problems had to be overcome if the experiment was to be a success. The mechanics of tower gravity data collection are described here, as well as the difficulties and obstacles that were overcome.

Tower Selection

Before any data could be collected, we had to locate a tower that was tall and stable enough for accurate gravimetric measurements to be made. We obtained a list from the Defense Mapping Agency of vertical obstructions taller than 550 m. The list contained 40 towers in the continental United States that met the requirement.

We began our reconnaissance in Alliance, Nebraska, where there was a 599 m television tower. This tower was a three legged tower in which all three legs were anchored to a base (Figure 1). The surrounding area was very flat and the gravity field was relatively benign and well mapped. The Alliance area, however, was very windy and this tower was old and not very stable. High winds would set up vibrations within the tower that could even be felt by the observers. As a matter of fact, the station manager informed us that ten towers of this type were constructed and this was the only one left standing (and this was after we had come down off the tower!) Therefore, this tower was quickly rejected on the basis of being too unstable to allow accurate gravity measurements.

The next tower we tested was a 610 m television tower in Clayton, North Carolina, built by Kline Iron and Steel of Columbia, South Carolina. The construction of this tower was different. Unlike the Alliance tower, this was a single point tower, meaning the three legs of the tower all tapered to a point at the base of the tower (Figure 2). The point at the tower base then rested on a large "ball-bearing" which combined with an extensive network of guy wires, allowed for much greater stability. The area in the vicinity of the tower was relatively flat both topographically and gravimetrically. The area was not very windy thus making this tower an extremely stable structure. Based on these criteria, this tower was seriously considered as a possible site for our experiment.

Finally our reconnaissance brought us to Houston, Texas, where there was another 610 m television tower. This was also a single point tower built by the same manufacturer, Kline Iron and Steel. The topography surrounding the tower was quite flat but there were many salt domes and oil wells in the vicinity. This meant a constantly changing gravity field with substantial high frequency content. Also, although this tower was very stable, there was a large candelabra structure on the top which could conceivably catch the wind and cause minor instabilities. Despite these problems this tower was reasonably stable, and was also considered as a possible site for our experiment.

After careful consideration, the Clayton tower was deemed the best possible site because of its stability, accessibility, and benign local gravity field. Another asset was the excellent co-operation that was extended to us by the transmitter supervisor and the station management. The chosen tower was the WTVD-TV tower which is the Capital Cities ABC affiliate, channel 11 in Durham, North Carolina. The tower is 610 m high with the highest accessible platform at about 562 m. It is constructed of mild steel, is triangular in cross section, measuring 3 m on each side, and weighs approximately 293000 kg. At each of the three vertices of the triangle, there are nine sets of guy wires, fairly evenly distributed from top to bottom, giving a total of 27 guy wires. These wires pull down with an enormous force that serves to stabilize the tower. Table 1 lists the tension in each of the sets of guy wires. The guy wires also contain two types of motion dampers. A SANDAMPER, located near each anchor point, traverses part of the guy wire maintaining the tension and damping out low frequency (<1 Hz) vibrations. The other type of damper is fixed on the guy near its connection point to the tower, and damps out high frequency vibrations (>1 Hz). This tower is plumbed annually, and during the last year was found to be no more than an average of 3 cm off from vertical. Even though this tower was amazingly stable, it yet had to be determined if indeed it was stable enough to allow accurate gravimetric readings.

Motion Tests

The first set of dynamic tests on the tower were done with seismometers in the summer of 1986 in both calm and windy (20-30 km/h) conditions. Both vertical and horizontal motions were measured at the bottom of the tower as well as half-way up and at the top. The results of the motion tests revealed there is a 2.5 s resonant period with an amplitude of at most 5 mm. Also, the analysis indicated there is more motion half-way up the tower than there is at the top. The most probable cause for this is at about 290 m above ground there is a backup antenna which protrudes from the tower, about 3 m, causing the additional motions at higher wind speeds. During the seismometer tests we performed another crude motion test. On one of the calm days we took a cup and filled it with water above the rim so that only the surface tension of the water was keeping it in the cup. At no time, during the course of the test did we notice any ripples in the water, due to tower vibrations, nor did the water overflow the cup.

We also tried to measure the amplitude of any possible tower swaying using a 1" Wild T2 theodolite. We set up a target at the 562 m level with four spacings on it. The target was made by taping five parallel strips of pink reflecting surveyor's tape on a white background at different spacings. The spacings between the five strips of tape were: 5 mm, 1 cm, 2 cm, and 3 cm. From a distance of about 650 m we lined the theodolite so that the reticle exactly filled the 5 mm gap. At this distance, 3 mm subtends 1". After two days of careful observations in 16-20 km/h winds, we could discern no motions greater than 5 mm amplitude with periods of less than 15 s. Motions with periods greater than this would have surely been detected by the gravimeter during our measurements.

Instrumentation

The gravimeter we used in our experiment is a LaCoste-Romberg model G gravimeter, #152. This model G gravimeter was chosen because it was an instrument that was on hand, and it was one whose history was well known. We have had a lot of good experience with this gravimeter, and have never been disappointed by its performance. LaCoste-Romberg model G meters have been used successfully in the field for years, and have been found to be extremely reliable surveying instruments. Prior to performing the tower experiment, our gravimeter was sent to LaCoste-Romberg to be refurbished. The gravimeter is tested for magnetic fields by L & R, and degaussed if necessary. The meter is then assembled using the magnetic shielding material Conetic Foil Type AA. The shielding is .1 mm thick and is used just inside the gravimeter box and inside the thermostated heater box around the actual sensor. Finally the meter is rotated about six cardinal points in the presence of a magnetic field to check for any magnetic sensitivity. The sensor is also sealed and a constant temperature and pressure is maintained thus eliminating any buoyant forces caused by changes in atmospheric pressure. When our meter was brought to the factory for refitting all the seals were changed. If the seal does fail, however, there is a device known as a windbag which compensates for changes in atmospheric pressure. This device is actually a small can which is placed on the lever arm in such a way that it compensates for any changes in buoyancy of the proof mass. During tests, the windbag is positioned and the gravimeter is sealed. A pressure increase equivalent to 1 in. Hg is applied and a gravity reading is taken. Then the pressure increment is released and a second reading is then taken. A pressure change of 1 in. Hg is equivalent to an altitude increase of about 300 m. The tolerance for this test is 100 μGal, but for our gravimeter it was able to compensate to within 40 μGal.

Gravimetric Tests

The first set of gravimetric tests were done on the tower in December, 1986. At this point our meter had not been refurbished, and we were still uncertain if meaningful gravity data could be collected on this tower. On the first day of the test, there were very strong winds (40-50 km/h) setting up resonant vibrations within the tower, and preventing the acquisition of any data. Despite the winds however we took the gravimeter to the 9.4 m level, and were able to level it.

We returned to the tower at about 0200 h the next day. The sky was overcast with a light drizzle, but the winds were calm. We took a reading at the base of the tower, and then proceeded to the 9.4 m level. There was a light breeze but we were able to level and read the gravimeter with same precision we had achieved on the base (6 μGal). During the readings, the beam of the meter was very stable as were both levels. Next we proceeded to the 188.2 m level. The wind was stronger at this elevation, perhaps 8 km/h, but we were able to level and read the gravimeter to an estimated precision of 20 μGal. Wind speeds increased to about 15 km/h as we ascended to the 283.6 m level. We were still able to level the meter easily but noticed a less stable reading line. Despite the slight beam vibrations, we estimate our reading precision at this elevation to be 40 μGal. At about 400 m we entered the clouds encountering heavy winds and rain, forcing us to return to the 9.4 m level. By this time the winds had picked up and there was moderate rain forcing us to terminate operations that morning.

Later that morning the skies cleared, and there was no apparent wind. After taking a reading at the base, we proceeded directly to the top level (562.2 m). Upon arrival, we were greeted with stiff 30-40 km/h gusts making leveling the instrument difficult but attainable. The beam wandered slowly between the 2.0 and 3.0 readings. The reading line for this gravimeter is 2.3, but due to instabilities at this level the reading was averaged at 2.5. We waited and took several readings but the winds would not subside, and we were forced to return. We estimate our readings at the top were only accurate to about 150 μGal.

The data were then reduced using a least-squares network adjustment. Table 2 shows the results of the reduction. The preliminary results clearly indicated that making accurate gravimetric measurements on a tower is indeed feasible. The WTVD tower is an extremely stable platform, as good repeatability results (10-40 μGal) were obtained despite adverse weather conditions. The internal consistency of the data reduction was also good, on the order of 20 to 50 μGal.

Tower Measurements

Based on all reconnaissance and preliminary work, we decided to make the WTVD tower the site of the experiment. There were three major problems in the effort to make gravimetric readings: First there was elevation determination. We had to know our vertical position on the tower to within 2 cm. A small error in vertical positioning could easily vitiate the results. Secondly, there was the problem of wind and determining its speed. There are no anemometers on the tower so there was no way we could ascertain precise wind speeds at the various levels. The determination therefore, had to be made by other means. Finally there was the problem of how to actually make gravimetric readings. The elevations where we took measurements contain .5 m x 1.2 m platform gratings (Figure 3). There is obviously little room to maneuver which made the data collection quite difficult and potentially dangerous.

We decided to use a conventional Electronic Distance Meter (EDM) to measure the elevations on the tower. The EDM emits a microwave beam that reflects off a prism obtaining a very accurate distance measurement. The instrument was a GTS 10D Topcon EDM which is accurate to 5 mm ± 5 ppm. The problem was, however, that the head of the EDM could not be aimed straight up in the vertical direction. The head of the instrument could be pivoted vertically but there would no way it could be aimed and read. So to obtain a vertical measurement we would have to take the EDM a far enough distance away so we could measure the hypotenuse of a triangle to the various levels of the tower, and then use the angles to determine the vertical distance above ground. We felt, however, that the more distances and angles we had to measure the more possibility there was for error. Also, to obtain an accurate reading we would have to triangulate on a particular level from three different locations, which would be very time consuming. Therefore, we devised a way to set up the EDM so we could emit the beam vertically up the tower. We tied two of the legs of the tripod to the base of the tower and had the third leg driven in the ground (Figure 4). We then leveled the instrument using conventional levels to insure that it was aimed perfectly vertical. To obtain the total distance, we had to measure the distance from the computation point of the EDM to the ground. Using this method we were able to obtain very accurate vertical distance measurements for our gravity points on the tower.

The winds posed the most difficult problem in performing the experiment. Normally during the summer months July, August, the winds in North Carolina are quite calm and the weather is hot and humid. In our case the winds were not calm and the weather was hot but dry. Because of the delays caused by the winds it took almost three months to painstakingly obtain all the necessary readings. The problem with the wind was not that the wind was moving the tower, but that the wind was hitting the gravimeter. While on the tower there was no way to shield the instrument from the wind; for unlike observing on the ground, the instrument is impacted with winds from all different directions, impairing the maintainability of the instrument levels. As previously stated with no anemometer on the tower there was no way to determine wind velocities at an instant. To compound the problem, just because the winds were calm on the surface that didn't mean they were calm at the various altitudes. At first we used various means to determine the wind velocity. If the wind is not too severe one can stand directly underneath each of the three sets of guy wires and see that they are lined up perfectly. When winds are heavy, however, some of the wires are offset. Also, during heavy winds one can actually hear the air resonating in the tower. Both these methods, however, only allowed us to determine severe wind speeds (>45 km/h), not moderate wind speeds which were also unacceptable. After a while, our experience with the tower enabled us to determine the best possible observing conditions. By climbing onto the elevator while it was at the bottom, and feeling the vibrations in the elevator cables, we were able to get a good idea what the wind speeds were like at the higher elevations on the tower. This simple method proved very reliable, and was used throughout the latter part of the experiment in our wind velocity determination.

On the ground under good observing conditions, a LaCoste-Romberg model G gravimeter can be read to an accuracy of about 10 μGal. While on the tower we had to contend with the wind along with the difficult observing conditions thus decreasing our expected level of accuracy. Adding to the difficulties was the fact that at three of the elevations (23.07 m, 45.93 m, and 68.76 m) there were no platform gratings. At these elevations we had to construct a measurement platform for the gravimeter, and clamp it to the tower (Figure 5). During a period of four months from July to September, 1987, and July 1988, we managed to obtain a total of 59 good observations contained in seven adjustment loops. An almost equal number of observations had to be discarded due to poor observing conditions. There was, however, one day and part of another where there was absolutely no wind anywhere on the tower. These are the days where we obtained the majority of our observations, and we used these observations as a baseline for most of the others. We therefore had observations in wind velocities varying from no wind to a light 16 km/h breeze. We did an analysis of the data searching for possible rectification in the meter due high frequency vibrations but found the gravity observations showed no definitive correlation to the wind velocities.

<u>Tower Data Reduction</u>

The data were reduced using a least-squares network adjustment. All of the data and loop statistics are given in Table 3. As can be seen in the table the data are very good (<20 μGal). The drift rates were computed from station reoccupations using linear regression, and were usually low, between 10 and 20 μGal/h. The observations were corrected for tides using Longman's equations with the Love number, δ = 1.2 (Longman, 1959). Once the adjustment was done, gravity anomalies (on the tower) were computed by removing a reference gravity field from the observations. The reference field that we used was the GRS67 normal gravity, and normal gravity at altitude was computed using Bruns' Equation for the normal gradient. By computing gravity anomalies at altitude we overcame the problems in reducing the values to the geoid where one must know the anomalous vertical gradient in the vicinity of the observation point. The same procedure was applied to the surface data points (Romaides and Sands, 1988) which were eventually used for the upward continuation and comparison with the tower data. All observations were tied to the International Gravity Standardization Network of 1971 (I.A.G., 1971).

Error Analysis

There were many sources of possible errors in our tower measurements but the three major concerns were: 1) Radio-frequency interference, 2) Gravimeter scale factor, and 3) Gravimeter screw error. There were other sources of error such as a changing water table, tower expansion, tower sway, but they were all investigated and the observations were corrected accordingly.

The LaCoste-Romberg model G gravimeter contains two layers of magnetic shielding on all sides with the only unshielded part being the galvanometer. In spite of the shielding one of our concerns was the possibility of Radio Frequency Interference (RFI) affecting the gravimeter. The reason for the concern is the WTVD tower is one of three towers in an area of about one km^2. One of the other towers, WPTF, is a 5 MW transmitter with a frequency of 500 Mhz. When we were at the top of the WTVD tower we were very close to WPTF's horizontal beam of transmission. We performed some preliminary calculations that indicated a field strength of 2-4 W/m^2 was possible at the top of the WTVD tower due to WPTF. We also suspected there might be RF leakage from the WTVD transmission line on the order of 1 W/m^2. To test for possible RFI we used a Narda field intensity meter, model 8616, with probe model no. 8662B. This probe is sensitive to frequencies from .3 to 1000 Mhz, and can measure power output down to .2 W/m^2. We made several tests with the field strength meter on and around the tower, and found the RF to be negligible ($<.1$ W/m^2).

We then subjected our gravimeter to a field of 1 W/m^2 at a frequency of 27 Mhz which is at least five times the measured intensity. Not surprisingly the galvanometer, which is unshielded, was affected by the RF. The beam however, was unaffected, and did not move from its null position. We then produced a field of 1 W/m^2 at a frequency of 400 Mhz and again the beam was unaffected. The obvious conclusion is that the presence of any kind of RF field disables the galvanometer but has no effect on the beam. During the tower gravity measurements we observed both the beam and the galvanometer and found no evidence of disagreement. We therefore conclude that RFI is not affecting our results in any way.

It is interesting to note that during the first set of gravimetric tests done in the early morning in 1986, the WTVD transmitter was off the air, and the WPTF transmitter was not yet built. Examination of Tables 1 and 3 show the 1986 results in good agreement with those of 1987 which is further evidence against instrument malfunction due to RFI.

Another minor concern was possible sensitivity of the instrument to the vertical magnetic field component as this cannot be tested by rotation. We set up the meter on a flat paved driveway. We then read it several times placing both a steel plate and plywood between the meter and the pavement thus altering the magnetic field slightly. The two sets of readings were in excellent agreement (1 μGal) with no apparent magnetic sensitivity.

Prior to the tower observations our gravimeter G-152 did not have a predetermined scale factor, and given the large gravity difference between the bottom and top of the tower (~172 mGal), an incorrect scale factor can mean erroneous results. After all tower observations were completed we took the gravimeter to the Colorado/Wyoming area to determine its scale factor. This area was chosen for two reasons: First, the area contained very accurate base stations, several of which were absolute sites, where we could make observations. Secondly, the base stations had gravity values which were the same as those we measured from the bottom to the top of the tower. While reducing the data from the gravimeter calibration run, we located some data, at the Geodetic Survey Squadron, which had been collected with G-152 in 1971 along the entire Mid-Continent calibration line. Using that older data we computed a scale factor of 1.000702 ± .000036. We then proceeded to reduce our own data and computed a scale factor of 1.000703 ± .000091 which is in excellent agreement with the old factor. Table 4 lists the base stations that were used in the calibration run.

Since we were striving for 30 μGal data, the screw error was a potential problem. After completing the calibration run, the gravimeter was sent to LaCoste-Romberg to have the screw error analyzed. The analysis was conducted over a range of about 350 counter units which included all the dial readings that were observed on the tower including the base. The analysis indicated that the RMS screw error over that range was no more than 15 μGal with a maximum peak to peak scatter of 60 μGal. Figure 6 shows a plot of the screw error analysis. Upon closer examination we found that for the particular counter readings that were observed on the tower, the screw error is ~10 μGal with a peak to peak scatter of about 35 μGal.

In evaluating the screw error, LaCoste-Romberg must disassemble the gravimeter, and attach the sensor to the mini-calibration line "Cloudcroft Junior". Because of this, we were concerned that the scale factor could have changed slightly. We therefore returned the gravimeter to our calibration sites and redid the same scale runs that we had done previously. The results of that calibration yielded a scale factor of 1.000710 ± .000181 which is in excellent agreement with the previously determined factor. Also during the screw error analysis, all the pressure seals were rechecked and found to be in good condition.

There were several more or less minor error sources which were estimated. The instrument reading error was estimated to be 7 μGal as was the error in the drift correction. The errors in the table of dial factors and the tide correction were both estimated to be 5 μGal, and the errors in relative vertical and horizontal positioning contribute 6 μGal and 4 μGal respectively (Defense Mapping Agency, 1987). All other errors (e.g. mass of tower, water table error) were deemed insignificant.

Conclusion

Despite less than ideal wind conditions and a variety of logistical problems, we were able to successfully acquire very accurate gravimetric data on the WTVD transmitting tower. The data consist of gravity obtained at 11 elevations on the tower, as well as one station on the base. After taking into account all the possible sources of error we find the tower gravity data are accurate to better than 30 μGal. We used only one instrument in the survey, but it was an instrument that had been thoroughly tested, and one whose history and performance had been well studied. The data were subsequently used as a comparison with analytically upward continued surface data in searching for departures in Newton's inverse-square law of gravity (Romaides et al., 1988; Eckhardt et al., 1988).

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Table 1. Tensions Of Tower Guy Wires

Guy Numbers	Guy Elevation (meters AGL)	Tension (Newtons) At Tower	At Anchor
1A, 1B, 1C	54.278	110492.843	107525.004
2A, 2B, 2C	111.345	139568.058	131414.952
3A, 3B, 3C	170.682	174615.426	158464.011
4A, 4B, 4C	232.482	139880.766	123230.264
5A, 5B, 5C	296.441	147769.204	124978.851
6A ,6B, 6C	360.400	202449.592	155137.647
7A, 7B, 7C	426.757	173589.671	139588.964
8A, 8B, 8C	495.286	234558.924	182801.003
9A, 9B, 9C	561.562	189599.632	138638.384

TABLE 2. Original Tower Gravity Data

Elevation (AGL)	Gravity (mGal)	Anomaly (mGal)	Formal Error (mGal)	Total Error (mGal)
9.38	979737.368	-19.698	.026	.050
187.60	979682.423	-19.648	.034	.050
283.58	979653.155	-19.300	.034	.050
562.27	979567.736	-18.731	.034	.075

Number Of Loops.................. 1
Number Of Stations................ 4
Number Of Observations............ 5

Mean Loop Closure RMS............... 32 μGal
Maximum Loop Closure RMS............ 32
Mean Station Standard Error......... 30
RMS Observation Error............... 31

TABLE 3. Tower Gravity Data

Elevation (Meters AGL)	Gravity (mGal)	Anomaly (mGal)	Formal Error (mGal)	Total Error (mGal)
0.69	979740.244	-19.506	.008	.019
7.58	979737.974	-19.649	.012	.021
9.38	979737.402	-19.665	.012	.021
23.07	979733.086	-19.757	.012	.022
45.93	979725.978	-19.811	.012	.022
68.76	979718.913	-19.830	.012	.022
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.................. 7
Number Of Stations................ 12
Number Of Observations............ 59

Mean Loop Closure RMS............... 11 μGal
Maximum Loop Closure RMS............ 20
Mean Station Standard Error......... 14
RMS Observation Error............... 19

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

Table 4. Base Stations Used In Gravimeter Scale Factor Determination

Station Designation	Latitude Deg	Latitude Min	Longitude Deg	Longitude Min	Elevation (Meters AMSL)	Gravity (mGal)	Error (mGal)
Chugwater T	45	45.40	-104	49.36	1615.44	979831.874	.012
Cheyenne O	41	09.00	-104	48.00	1876.35	979686.715	.012
Boulder AE	40	00.75	-105	14.98	1601.50	979616.978	.005
Golden AA	39	45.07	-105	08.18	1752.00	979570.945	.005
Bergen Park	39	25.08	-105	13.28	~1800.00	979468.892	.005

Figure Captions

Figure 1 : Three-legged 599 m television transmitting tower in Alliance, Nebraska. The tower is KDUH-TV in Alliance, Nebraska.

Figure 2 : Single point 610 m television transmitting tower in Clayton, North Carolina. The tower is WTVD-TV channel 11 in Durham, NC.

Figure 3 : A horizontal cross-section of the WTVD tower showing the relative positions of the elevator, ladder, transmission line, guy lines, and platform gratings.

Figure 4 : The EDM set-up used in the elevation determination. EDM is a GTS 10D Topcom Electronic Distance Meter.

Figure 5 : Three views of the temporary platform used in some of the lower elevations. The top photograph shows a close-up of the platform clamped to the tower girder. The middle photograph shows a top view of the platform from a distance of about 2.5 m. The bottom photograph shows one of the authors from a distance of about 2 m standing on the temporary platform

Figure 6 : A plot of the screw error analysis with the abscissa being dial divisions on our gravimeter, and the ordinate being the scatter in mGal over that dial division range.

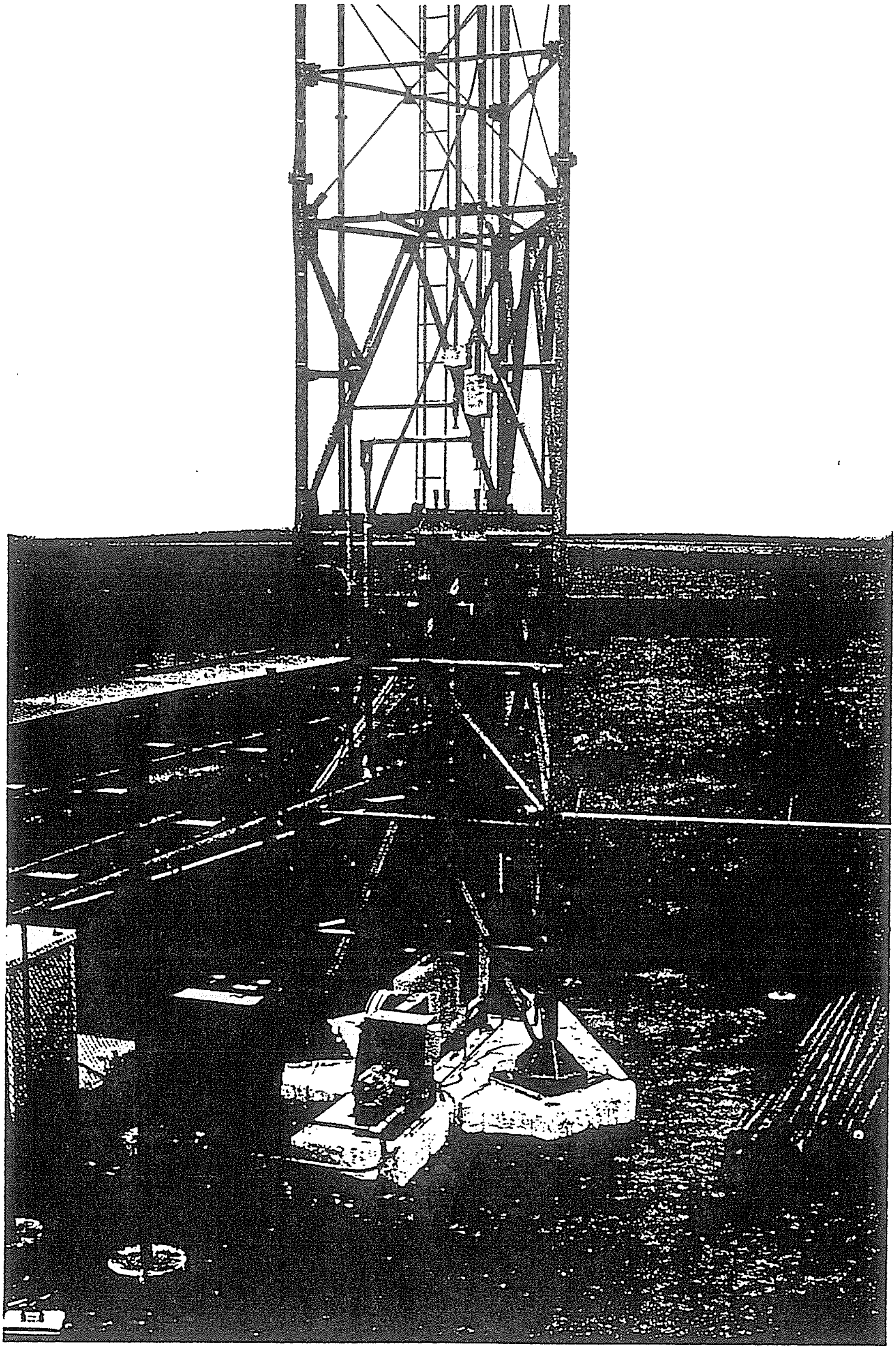


Figure 1.

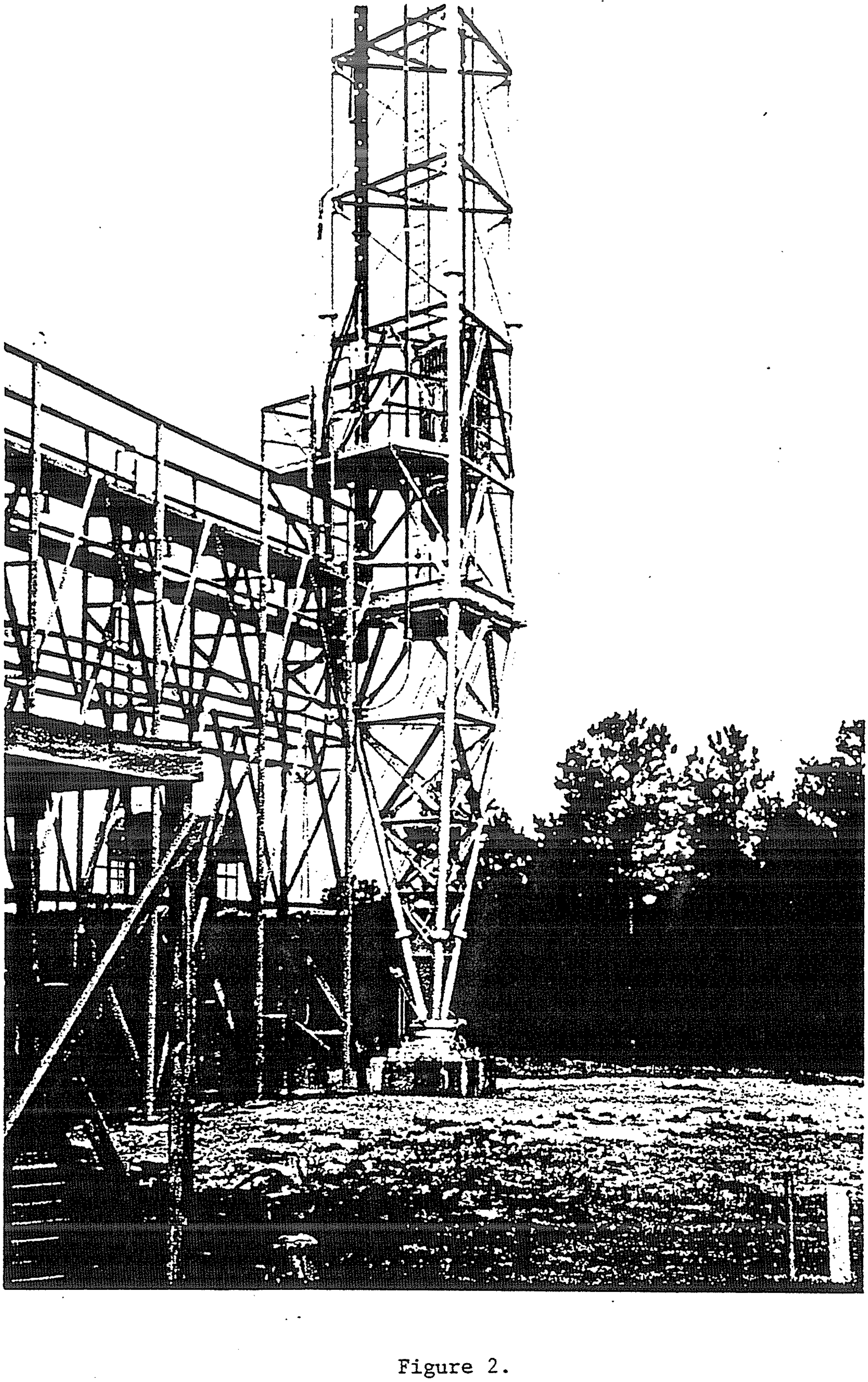
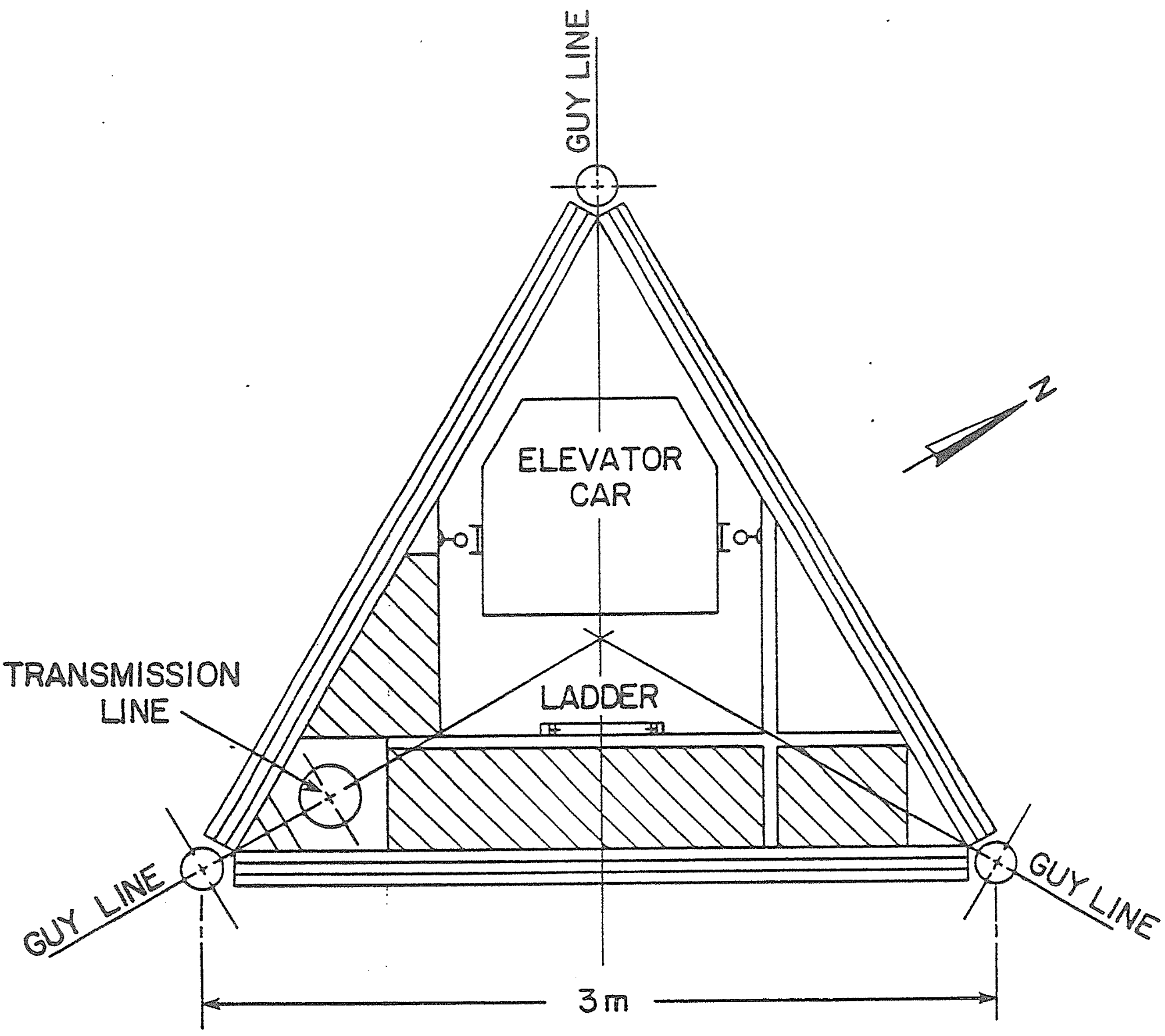


Figure 2.



WTVD TOWER PLATFORM

Figure 3.

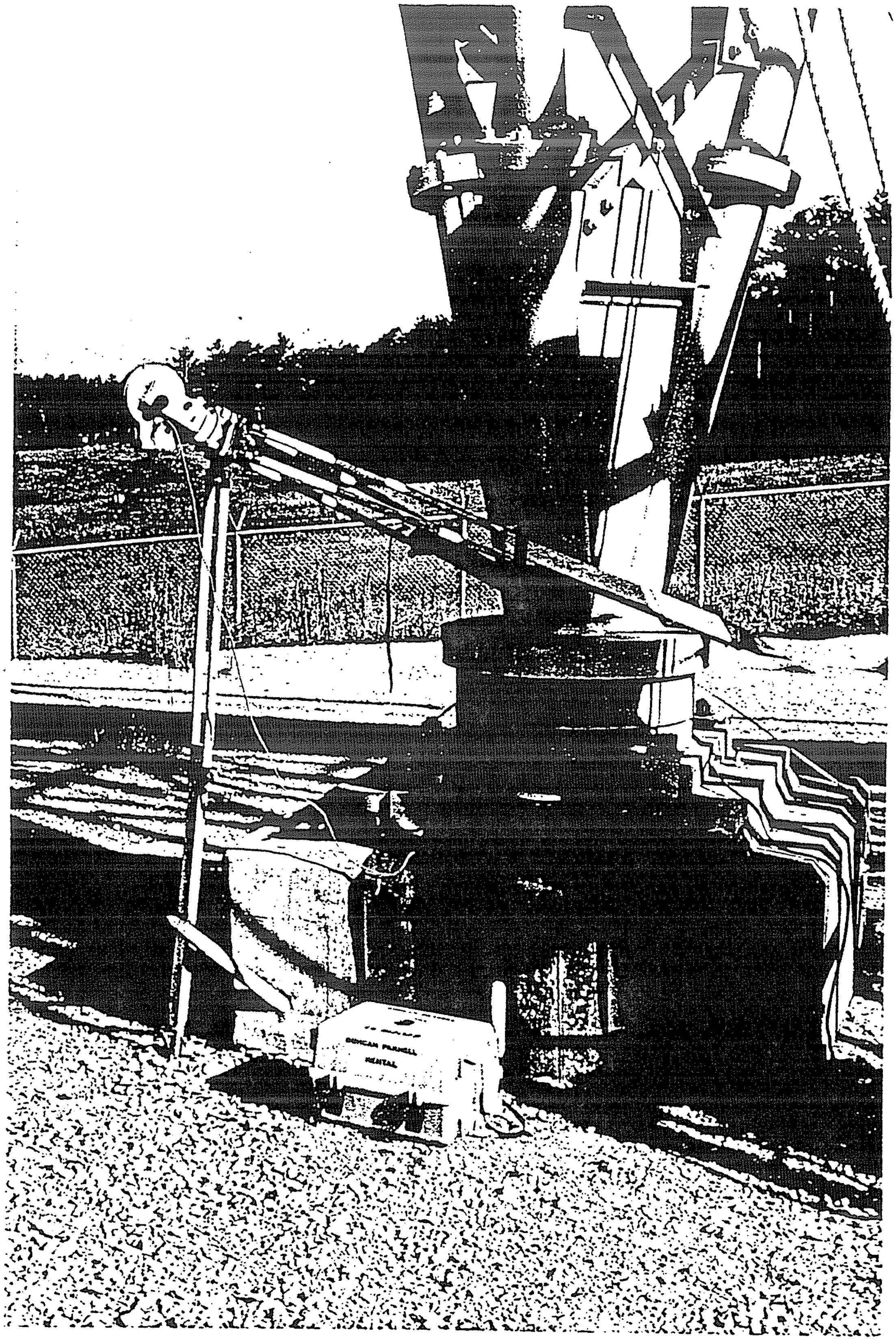


Figure 4.

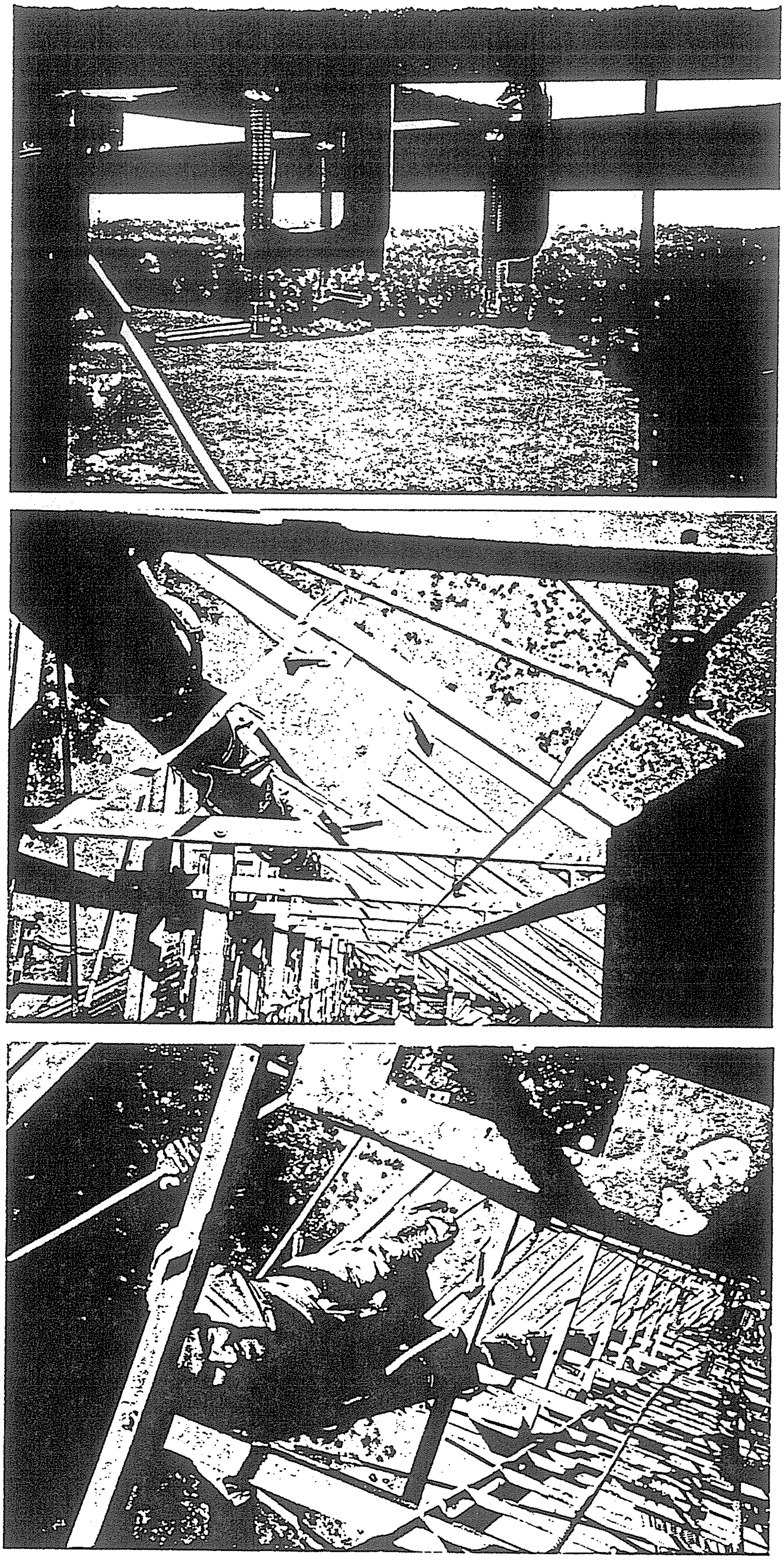
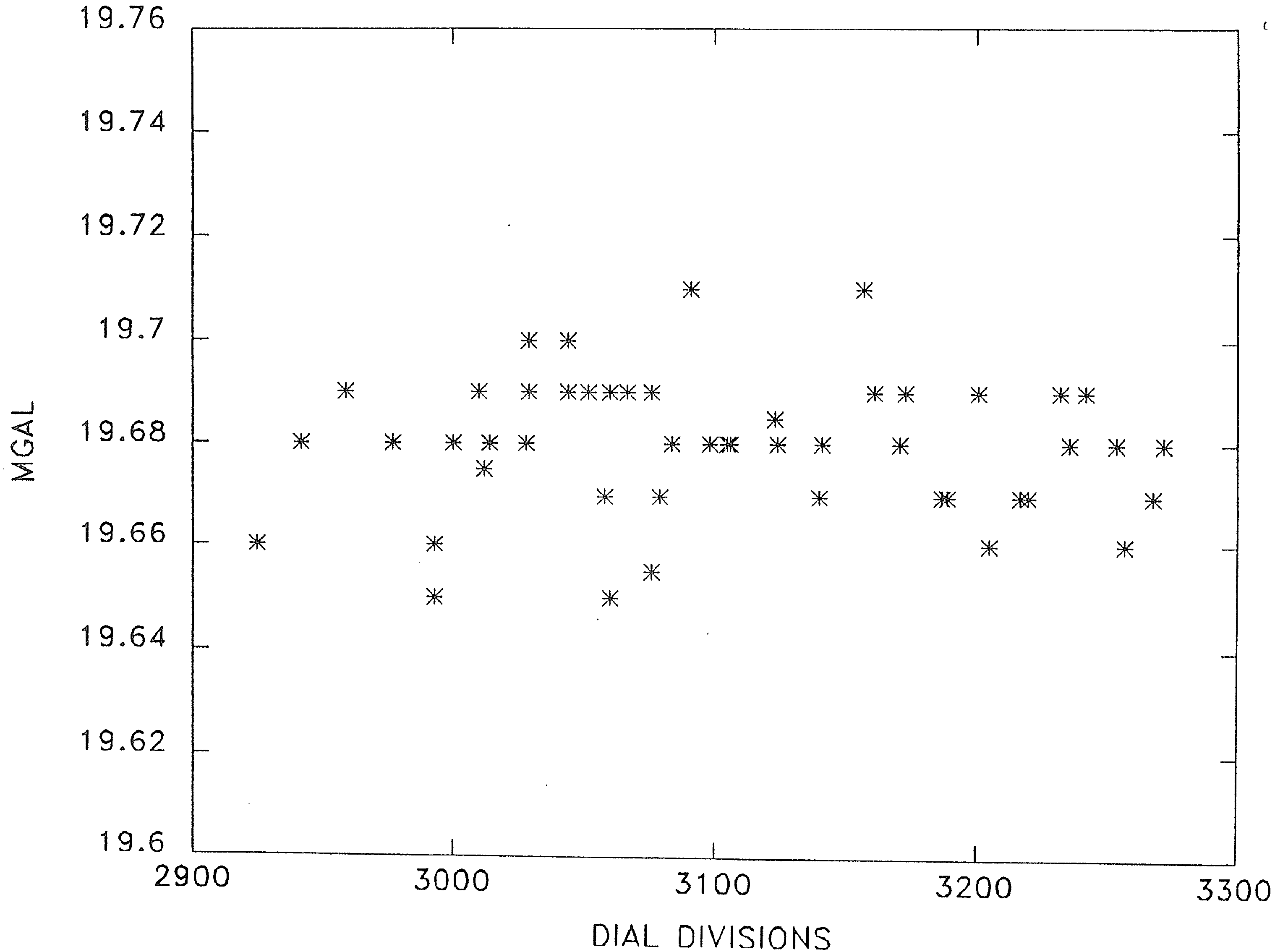


Figure 5.



19.76
19.74
19.72
19.7
19.68
19.66
19.64
19.62
19.6
MGAL
2900
3000
3100
3200
3300
DIAL DIVISIONS

Figure 6.

Announcement of the NOAA,

NATIONAL GEOPHYSICAL DATA CENTER

The National Geophysical Data Center is pleased to announce the availability of the Directory of Data Sources for Lithospheric Investigations, Volume I. This 400-page catalog lists geophysical data sources from more than 70 countries around the world. Also included in the report are summaries of three major lithospheric studies : the Global Transects Project, the Federation of Digital Seismographic Networks, and the World Stress Map Project. The production of this volume was a joint project by the World Data Center-A for Solid Earth Geophysics (Boulder, colorado, USA), the Institute for Physics of the Earth (Moscou, USSR), and the International Lithosphere Program (Utrecht, The Netherlands). The Bureau Gravimétrique International also participated in the compilation of the Gravity Data Sources and Centers.

The catalog is available from the National Geophysical Data Center at a single-copy cost of \$20.00. For those wanting multiple copies, additional copies are available at \$10.00 each. This catalog will certainly be of special interest to our Community.

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