ASSOCIATION INTERNATIONALE DE GÉODÉSIE

BUREAU GRAVIMETRIQUE INTERNATIONAL

BULLETIN D'INFORMATION

N° 55

Décembre 1984

18, avenue Edouard-Belin
31055 TOULOUSE CEDEX
FRANCE

Informations for Contributors

Contributors should follow as closely as possible the rules below :

Manuscripts should be typed (double-spaced) in Prestige-Elite characters (IBM-type), on one side of plain paper 21 cm x 29.7 cm, with a 2 cm margin on the left and right hand sides as well as on the bottom, and with a 3 cm margin at the top (as indicated by the frame drawn on this page).

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

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

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

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

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

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

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

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

Footnotes for the tables should appear below the final double rule and should be indicated by a, b, c, etc. Each table should be referred to in the text.

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

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

B U R E A U   G R A V I M E T R I Q U E
I N T E R N A T I O N A L

Toulouse

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

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TABLE OF CONTENTS

Bull. d'Inf. n° 55

Pages

PART I : *INTERNAL MATTERS*

PART II : *CONTRIBUTING PAPERS*

*Jean **Tournez**, member of the BGI staff in Toulouse since May 1st 1980, is retiring the 4th of January 1985.*

J. Tournez made all his career with the Institut Géographique National and remained under its management even when he was transfered to our office.

He was a surveyor for IGN and participated to many compaigns in the 50's, in Africa, before settling with his family in Dakar, where they lived for six years.

His work at BGI, at the time the office was getting reorganized and trying to find a new way and new goals, has been essential. J. Tournez was responsible for the gravity map catalogues and undertook their digitization. He put all the reference station description documents on microfiches with cross-references in computer form. He coded all gravity observations of the BGI data base according to a country code. He was finally in charge of key cartographic tasks for the IBCM project.

To this very nice fellow whose company everyone enjoyed, and to his wife, we wish a long and pleasant retirement.

PART I

INTERNAL MATTERS

SUMMARY OF BGI ACTIVITIES IN 1984

The Bureau Gravimétrique International, located in Toulouse (7 persons) and Orléans (2 persons) has essentially been continuing his task of data collection and dissemination to users and, besides, has been engaged in data evaluation and other scientific activities.

Data Collection

48 new sources of gravity measurements were collected and added to the BGI data base, for a total of 140773 observations. Land area covereds are : Morocco, Mali, Tanezrouft, Algeria (part), Brazil (part), South-West Africa (part), Greenland (part), Cameroun, Congo Rep., Ivory Coast, Upper Volta, Gabon, Norway, South Africa, Zimbabwe (part), Zambia, Ethiopia (part), Swaziland, Mozambique (part), Tanzania (part), Botswana (part), Malawi (part). Sea gravity data were received from U.K., Japan, USSR.

Data Evaluation and Scientific Activities

(1) At the request of the Soviet Geophysical Committee, BGI issued a series of 10° x 10° maps covering all the North Atlantic Ocean and displaying the cruise tracks together with the gravity measured values along the tracks (sampled or interpolated) ; this material is being used for completing the Atlantic geological-geophysical Atlas (scale 1:10 000 000).

(2) BGI is engaged in the IOC-IBCM project for which he has produced a preliminary set (10 maps at scale 1:1 000 000) of Bouguer anomaly maps of the Mediterranean. The work should be completed sometimes in the second half of 1985. Details are given in the next pages.

(3) Softwares have been developped in the following areas :
- . Stokes, inverse Stokes (revision of previous softwares),
- . Vening-Meinesz (new),
- . Manipulation of high degree and order spherical harmonic expansions (new algorithms : analysis and synthesis, not based on FFT),
- . General collocation (not limited to geodetic quantities) combined with analytical representations.

Technical Notes, of which the production was interrupted during 18 months due to typing volume problems will be issued on each subject.

IBCM AND OVERLAY SHEETS - BOUGUER GRAVITY MAP

PROGRESS STATUS

(M. Sarrailh - G. Balmino)

BGI is involved in a new compilation of gravity data and Bouguer anomaly maps in the context of the International Bathymetric Chart of the Mediterranean and Overlay Sheets activities, under the auspices of the International Oceanographic Commission (of UNESCO).

In its preparatory phase, BGI has undertaken the preparation of all the data (point and mean values, maps) it has at its disposal and has made a preliminary automatic contouring of the 10 sheets covering the Mediterranean area at scale 1:1 000 000. Evaluation of this phase is in progress and partial comparisons are being made with some similar products obtained by the team of Professor Makris (from Hamburg University), who is also involved in the IBCM project.

DATA

a) BGI Data Base

About 113 000 gravity data points were extracted from the data base (26 000 of them have topographic corrections, and 8 400 pts are without bathymetry). Since the points with topographic corrections provide only a partial coverage of high relief areas (South and North-East of Spain, a part of Italy) and are superimposed to surveys without corrections we considered only the simple Bouguer anomaly for all points, in this project.
In order to make use of points without bathymetry, which cover areas without any other information (East Mediterranean Sea), we have used the SYNBAPS bathymetric data file, compiled by the U.S.N.O. (Navoceano) (point values along a 5' x 5' gridding). After taking into account the Matthews correction (1980 tables), we have computed the Bouguer anomaly for these points (the lack of bathymetric data in the Black Sea did not allow us to use the main part of a cruise of the WHOI in this area). We have screened the points extracted from BGI data base, keeping only the nearest point from the center of a 5' x 5' grid.

b) 6' x 10' mean free air anomalies (Institut fur Erdmessung, Universitat Hannover - Torge W., Weber G., Wenzel H.G.)

These values have been digitized mainly from Prof. Morelli et al.'s maps for the West and Central part of the Mediterranean Sea, from Woodside's map for the Eastern part. We have extracted blocks belonging to the sea area, with the help of the USNO bathymetry ; the result is not very accurate with respect to the coast limits (a mean free air block belonging to the sea area if the nearest point from the block center of the bathymetric grid is defined).

c) Bouguer anomaly maps

For areas or countries not covered by a regular digitized gravity data set, we have digitized the available Bouguer gravity maps (Israël, Egypt, Tunisia, Morocco [sedimentary basins], Greece), with a regular gridding of 3' x 5' or 6' x 10', function of the scale and the isanomal interval. The obtained values are converted to the GRS67 system and connected to the IGSN 71 net, after correction of some biases - introduced during the early processing of these data (Israel, Sinaï). Of course, the original density (by example d = 2.3 g/cm^3 in Egypt) could not be modified.

Nota : In Greece, we have used two maps from the IFG of Hamburg ; the first one for Peloponese ; the second one is more recent, more global but with a high degree of smoothing, therefore yielding connection problems with the first one and discrepancies at sea with Morelli's map.

DATA PROCESSING

The whole data set (digitized and screened data, Bouguer anomalies issued from the mean 6' x 10' free-air data set, the points without bathymetry and points from digitized maps) have been interpolated, at the nodes of a 3' x 5' grid.

We have used the following method : we search the nearest gravity point inside each quadrant around the interpolation grid node, at least up to 0°3 degree. The weight of each point is a function of the distance to the grid node (1/d^3). This regular gridding is used by the contouring software (isanomal interval : 10 mgal).

We have plotted on the gravity maps the measurement points, with different symbols, and produced 10 sheets for the whole Mediterranean Sea.

REMAINING PROBLEMS

Various problems appear from the preliminary maps and from the comparison with published maps :

→ None or too few digitized point values in many countries (Albany, Bulgaria, Greece, Israël, Turkey, U.S.S.R., Yugoslavia, Black Sea...) and, when maps have been published, the wedging is unprecise (Israël, Sinaï) or the smoothing too high (Greece).

→ The superposition of the point values at sea (from cruises which often are not well wedged, using or not the SYNBAPS file to determine the Bouguer anomaly) and of the values issued from the mean free-air anomaly set shows in some cases a significant bias, which is difficult to reduce.

→ The smoothing inherent to the averaging procedure which yielded the 6' x 10' mean free air anomalies is increased by the introduction of the USNO 5' x 5' bathymetric gridding (the 5' x 5' grid itself results from a smoothing by spline functions, which have introduced distortions and does not represent the digitization precision).

→ The cartography with superimposed measurement point plots brings out the erroneous data, most often isolated points : digitization errors or mean Bouguer anomalies (issued from 6' x 10' free air) in terrestrial areas. Their elimination will be done by means of an automated cartographic procedure which requires a graphic terminal, with local computing resources.

→ Digitizing Bouguer gravity maps is obviously a simple and efficient way but it does not allow to homogenize all the results : corrections with different densities, with or without topographic (terrain) corrections, at different distances...

AFRICAN GRAVITY STANDARDIZATION NETWORK

ANNOUNCEMENT

Following the presentation of the African Gravity Standardization Network (AGSN) project at the 11th IGC meeting in Hamburg (Fig. 1), discussions between the Earth Physics Branch (EPB, Ottawa, Canada), representatives of african countries and possible supporting organizations (mainly DMA) yielded positive decisions on further steps to be taken.

In order to carry on a first phase of establishment of a zero order net in Africa, to be composed of probably 9 absolute stations, with excenters and relative gravimeter ties (Fig. 2), several actions must be undertaken including a training program for the experimenters. The planning will be discussed and settled at a meeting in Paris, which is presently scheduled for the fourth week in May 1985 (tentative dates are May 21-23).

Those who intend to come to this meeting should notify immediately the Bureau Gravimétrique International. EPB is trying to find some financial support for those who could absolutely not have their travel expenses covered by their own organizations.

A circular letter will be sent out as soon as the dates and place are finalized, and will include a provisional agenda.

G. Balmino

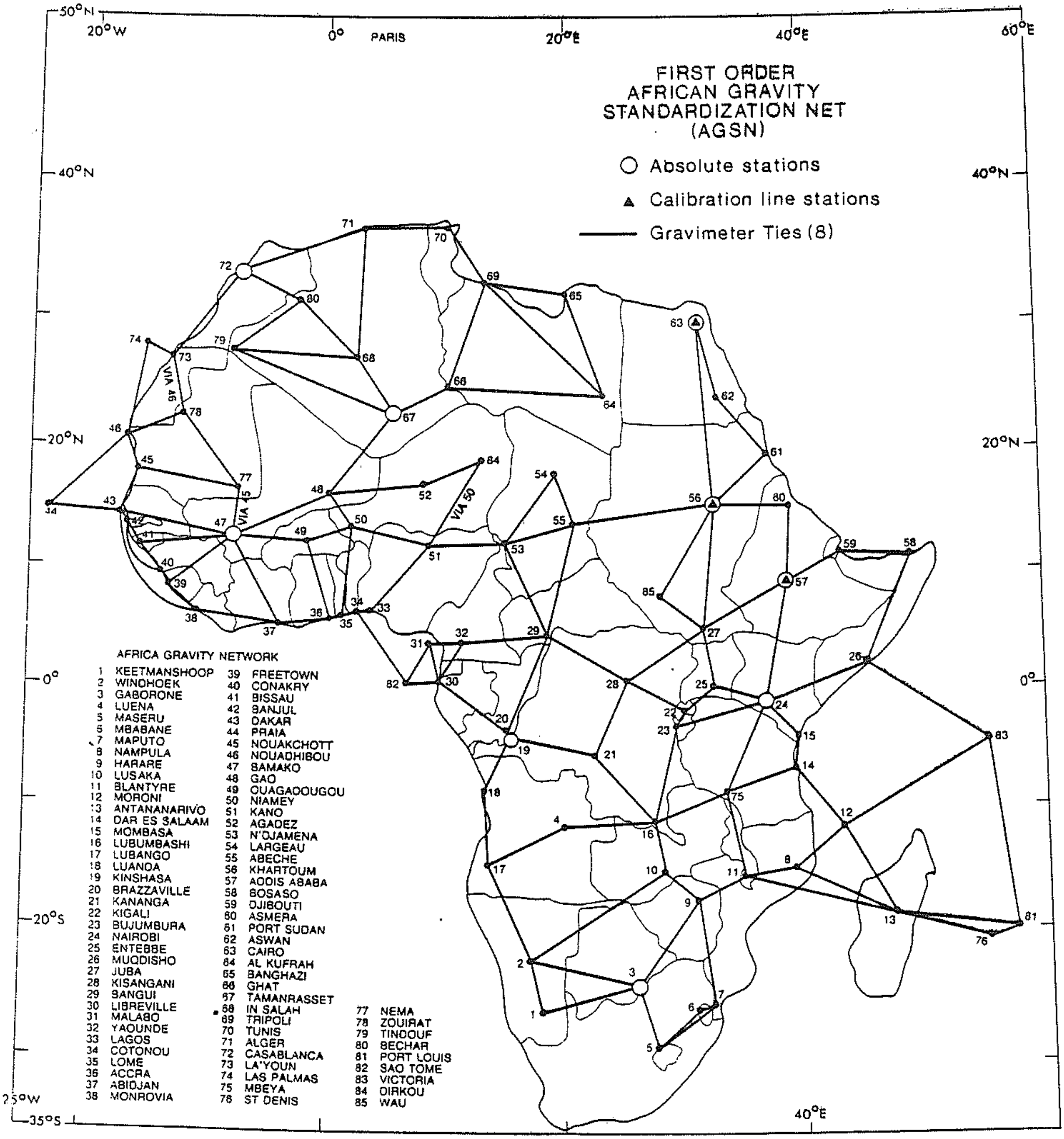
FIRST ORDER
AFRICAN GRAVITY
STANDARDIZATION NET
(AGSN)
Absolute stations
Calibration line stations
Gravimeter Ties (8)
50°N
20°W
0°
PARIS
20°E
40°E
60°E
40°N
20°N
0°
20°S
35°S
AFRICA GRAVITY NETWORK
1 KEETMANSHOOP
2 WINDHOEK
3 GABORONE
4 LUENA
5 MASERU
6 MBABANE
7 MAPUTO
8 NAMPULA
9 HARARE
10 LUSAKA
11 BLANTYRE
12 MORONI
13 ANTANANARIVO
14 DAR ES SALAAM
15 MOMBASA
16 LUBUMBASHI
17 LUBANGO
18 LUANDA
19 KINSHASA
20 BRAZZAVILLE
21 KANANGA
22 KIGALI
23 BUJUMBURA
24 NAIROBI
25 ENTEBBE
26 MUQDISHO
27 JUBA
28 KISANGANI
29 BANGUI
30 LIBREVILLE
31 MALABO
32 YAOUNDE
33 LAGOS
34 COTONOU
35 LOME
36 ACCRA
37 ABIDJAN
38 MONROVIA
39 FREETOWN
40 CONAKRY
41 BISSAU
42 BANJUL
43 DAKAR
44 PRAIA
45 NOUAKCHOTT
46 NOUADHIBOU
47 BAMAKO
48 GAO
49 OUAGADOUGOU
50 NIAMEY
51 KANO
52 AGADEZ
53 N'DJAMENA
54 LARGEAU
55 ABECHE
56 KHARTOUM
57 ADDIS ABABA
58 BOSASO
59 DJIBOUTI
60 ASMERA
61 PORT SUDAN
62 ASWAN
63 CAIRO
64 AL KUFRAH
65 BANGHAZI
66 GHAT
67 TAMANRASSET
68 IN SALAH
69 TRIPOLI
70 TUNIS
71 ALGER
72 CASABLANCA
73 LA'YOUN
74 LAS PALMAS
75 MBEYA
76 ST DENIS
77 NEMA
78 ZOUIRAT
79 TINDOUF
80 BECHAR
81 PORT LOUIS
82 SAO TOME
83 VICTORIA
84 DIRKOU
85 WAU

Fig 1

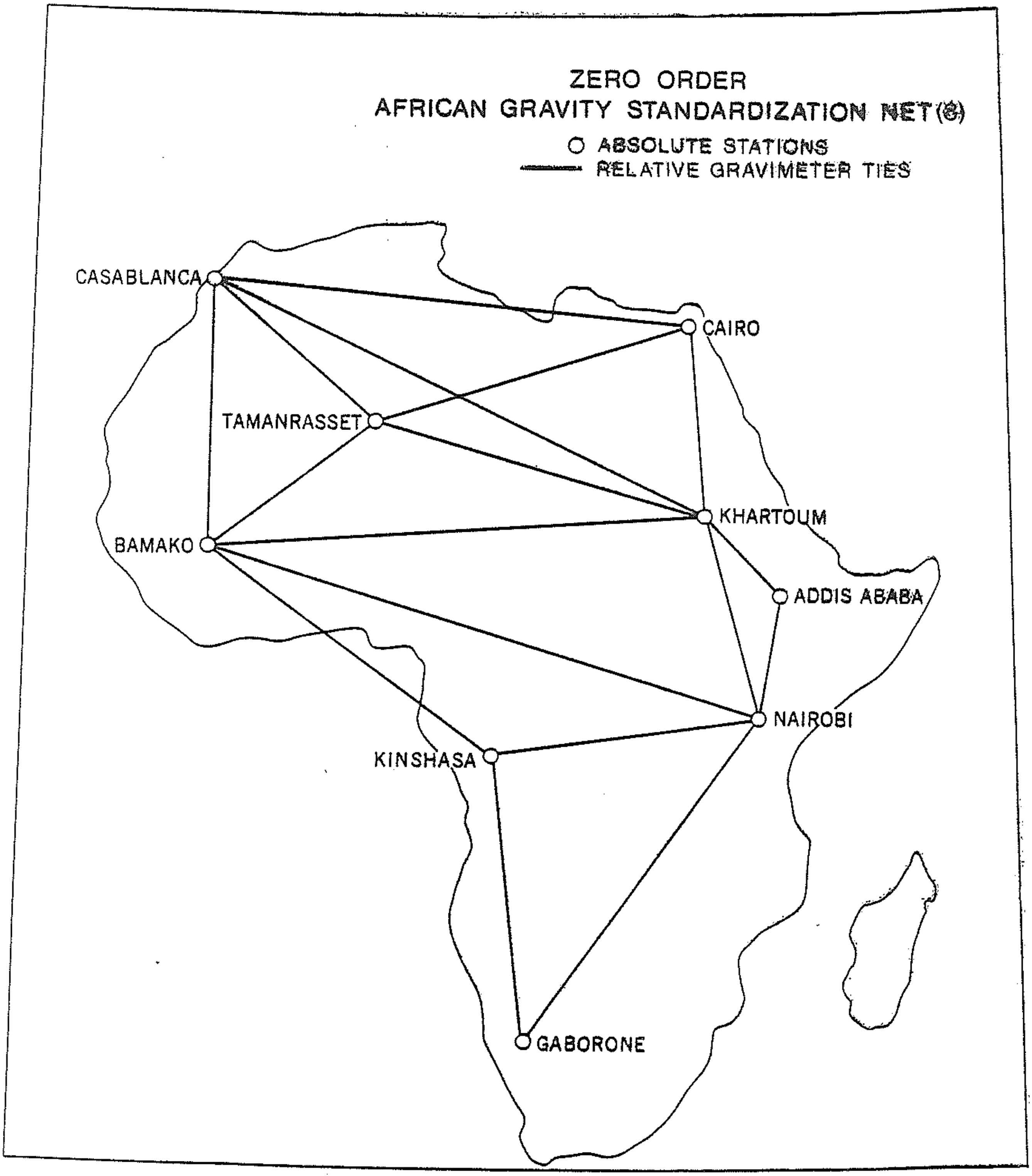
ZERO ORDER
AFRICAN GRAVITY STANDARDIZATION NET(8)
O ABSOLUTE STATIONS
RELATIVE GRAVIMETER TIES
CASABLANCA
CAIRO
TAMANRASSET
KHARTOUM
BAMAKO
ADDIS ABABA
NAIROBI
KINSHASA
GABORONE

Fig 2

ANNOUNCEMENT

The 12th Meeting of the International Gravimetric commission (I.G.C.) will take place in Toulouse (France) from September 23 to September 26, 1986.

Administrative meetings of the Bureau Gravimétrique International (B.G.I.) Directing Board and of the Working Groups will be held the day before (Sept. 22).

A preliminary program is given in the following pages :

Comments and informations should be sent to :

- either the convenor : **J. Tanner**
  Earth Physics Branch
  Department of Energy, Mines & Resources
  3, Observatory Crescent
  OTTAWA, Ont. K1A 0Y3
  CANADA

  Tel. (613) 995-53-07

- either the local organizer
  G. Balmino
  Bureau Gravimétrique International
  18, Avenue Edouard Belin
  31055 TOULOUSE CEDEX
  FRANCE

  Tel. (61) 27-44-27 - **Telex** : CNEST B 531081 F

A first circular will be sent out in May 1985.

Submission of papers will normally start after the second circular in September 1985. The last call for papers will be made in March 1986. The deadline for submitting papers is April 30, 1986.

A separate announcement will appear in the next issue of the Bulletin Géodésique.

12TH I.G.C. MEETING SEPT. 22-26, 1986

Place : **Bureau Gravimétrique International (B.G.I.)**
and
Formation Internationale Aéronautique et Spatiale (F.I.A.S.)

Avenue Edouard Belin, Toulouse, (France)

PROVISIONAL AGENDA

1. **General Time-Table**

Monday Sept. 22

D.B. and W.G. meetings

Tuesday Sept. 23

Morning : Administrative session
Afternoon : Scientific sessions............. 1,2

Wednesday Sept. 24

Scientific sessions (cont.) a.m. 3,4
p.m. 5,6

Thursday Sept. 25

Scientific sessions (cont.) a.m. 7,8
p.m. 9,10*
(10* : special lecture)

Friday Sept. 26

Scientific sessions (cont.) a.m. 11,12
Closing session p.m.

2. Detailed Program

Monday Sept. 22

Directing Board and W.G. meetings (at B.G.I.)

a.m. 9.00 D.B. Briefing
10.00 W.G. 1
11.00 W.G. 2

p.m. 2.00 W.G. 3
(Registration for IGC participants : 2.30 p.m. - 6.00 p.m., at FIAS)
3.00 W.G. 4
5.00 D.B. meeting

- Adjourn 6.00 p.m. -

Tuesday Sept. 23 (at F.I.A.S.)

Registration continues : 9.00 a.m. to 12.00 p.m. and 2.00 p.m. to 5.00 p.m.

a.m. Administrative Session

9.30 Opening : Allocution of President of French National Committee of Geodesy and Geophysics
9.45 IGC President report
10.00 BGI report
10.15 WG 1 report
10.25 WG 2 report
10.35 Coffee Break
10.50 WG 3
11.00 WG 4
11.10 Sub-Commission 1 report : North Pacific Region
11.20 Sub-Commission 2 report : South West Pacific Region
11.30 Sub-Commission 3 report : North America
11.40 Sub-Commission 4 report : Central and South America
11.50 Sub-Commission 5 report : Africa
12.00 Sub-Commission 6 report : Western Europe
12.10 Sub-Commission 7 report : Eastern Europe and USSR
12.20 Sub-Commission 8 report : India and Arab Countries

- End of Administrative Session 12.30 -

p.m. 2.15 to 3.45 Session 1. Dynamic Gravimetry
Satellite Results, Airborne and Sea Measurements
SST and Satellite Gradiometry Projects

3.45 to 4.00 Coffee Break

4.00 to 5.30 Session 2. Absolute Comparisons
Sèvres (BIPM) Calibration Activities in June 1985

Wednesday Sept. 24 (at FIAS)

Registration will continue for late arrivals : 9.00 a.m. to 12.00 p.m. and 2.00 p.m. to 5.00 p.m.

a.m. 9.00 to 10.30 Session 3. African Network
The project
Scientific Aspects

10.30 to 10.45 Coffee Break

10.45 to 12.15 Session 4. Regional and National Networks

p.m. 2.15 to 3.45 Session 5. Geophysical Interpretations

3.45 to 4.00 Coffee Break

4.00 to 5.30 Session 6. Geoid Determination & European Geoid

Thursday Sept. 25 (at FIAS)

Registration will continue as on the other days

a.m. 9.00 to 10.30 Session 7. High Precision Gravity Techniques (SSG. 3.85)

10.30 to 10.45 Coffee Break

10.45 to 12.15 Session 8. Secular Changes of Gravity (SSG. 3.86)

p.m. 2.15 to 3.45 Session 9. International Absolute Gravity Base Network (SSG. 3.87)

3.45 to 4.00 Coffee Break

4.00 to 5.00 Session 10. Special Lecture

5.00 to 5.45 Presentation of Resolutions

Evening : Banquet

Friday Sept. 26 (at FIAS)

a.m. 9.00 to 10.30 Session 11. Local Gravity Field Determination (SSG. 3.90)

10.30 to 10.45 Coffee Break

10.45 to 12.15 Session 12. Geodynamics Applications

p.m. 2.15 to 3.45 Closing Session

Proposals and Resolutions
Various Items
Program of the Next Quadriennal

- Closure : 4.00 p.m. -

PART II

CONTRIBUTING PAPERS

RECENT DEFINITION OF ABSOLUTE GRAVITY AT SINGAPORE-2 SITE

Yu.D. Boulanger, G.P. Arnautov**, E.N. Kalish**, Yu.F. Stus**, S.N. Scheglov**

* Institute of Physics of the Earth, Academy of Sciences of the USSR
** Institute of Automatics and Electrometry, Siberian Branch of the Academy of Sciences of the USSR

Abstract

The new results of repeated measurements of absolute gravity given in the paper were obtained by the Soviet gravimeter GABL in July, 1984. Their comparison with the earlier obtained results allowed us to conclude that from 1979 to 1984 the gravity in Singapore remained the same within the accuracy interval of ± 10 to ± 20 μgal.

Lately, developments in the geodynamics resulted in the increasing interest of wider range of specialists to the problem of the Earth's gravity field instability in time. The gravity variation problem concerns many fields of natural sciences, in particular, geosciences, metrology, geodesy, astronomy, etc.

Establishment of principal new measuring techniques, that is, of absolute ballistic gravimeters with accuracy about several units in 10^{-9} provided for a real possibility at least to evaluate the order of probable changes in various regions of the Earth if not to study in detail the character of this phenomenon.

Considering this, the Institute of Physics of the Earth, Academy of Sciences of the USSR (IPE) and Institue of Automatics and Electrometry, Siberian Branch of the Academy of Sciences of the USSR (IAE) carried out a number of repeated measurements of absolute gravity acceleration in the Equator zone, in particular in Singapore, where such variations might be great.

The first gravity measurements in Singapore were made in December, 1976/1/. They turned to be not so good because the vibration-proof equipment of the gravimeter went out of order. That might allow an unconsidered systematic error over 0.2 μgal in the measured gravity acceleration.

The next two measurements were taken at the same site in April and June, 1979, within the framework of the Soviet-Australian expedition on its way from Moscow and Sydney and on its way back from Peru to Moscow /2/.

In December, 1979, unexpectedly, it became clear that, first, the site in Singapore, where the absolute gravity was previously measured, would be closed for the gravimetric work from April, 1982. Second, the site chosen, by us as a perfect one for a prolonged observations could not be used by us : it was an isolated pavilion (with good concrete basement) surrounded by a marsh with constant water level, but from 1980, drianage of the marsh would be initiated. So, we faced the problem where to transfer the site. Due to many things, it was only in February, 1982 that we managed to make measurements connected with the site transfer. Measurements were taken at the "old" site, that is, Singapore-1 and "new" one, that is, Singapore-2 /3/.

In July, 1984, there was an opportunity to repeat measurements in Singapore. The results of these measurements are given in the paper.

Absolute gravity acceleration was measured at Singapore-2 site (1984), as previously, by absolute gravimeter GABL worked out in IAE /4,5/. During the installation of the instrument it was found out that the floor of the laboratory in Singapore-2 which in 1982 was covered by a concrete layer, in 1983, was covered by a ceramic tiles. Therefore, the place where the instrument was installed was uplifted at 63 mm. The place of the instrument installation is marked in figure 1.

In 1984, the measurements were performed according to the previous program. When the gravimeter was installed, all its measuring tracks were heated and the necessary vacuum was achieved. Then, the observations of the free-fall of a test body were made. Each measurement was an average for 100 to 120 drops which followed in 15 to 20 seconds. Each measurement took 30 minutes. The adjustment of the instrument was checked out after each measurement. Then the instrument was set on again and the measurements continued. Two series of such measurements were performed : on July 20, 1984 and on July 23, 1984. The first series comprises 12 and the second 14 measurements.

The measured g values were corrected for :

Δg_p - residual air resistivity in a vacuum,
Δg_c - light velocity,
Δg_δ - tidal gravity variations,
Δg_A - attraction of atmospheric masses.

Corrections for

Δg_φ - deviation of the measurement line from the vertical,
Δg_λ - frequency deviation of a working laser,
Δg_t - error of time intervals,

were methodically reduced to zero and were not introduced. In accordance with the Resolution of the International Association of Geodesy, the Honkasalo correction (Δg_H) was not introduced either.

The expedition did not have high accuracy gravimeters to define vertical gravity gradient. Therefore, like in 1982, the measured gravity acceleration was not reduced to the floor level. The final g value is given at the effective instrument altitude which is 1.274 m.

Correction for the tidal changes of gravity was calculated by linear interprobation for the average moment of time of every measurement from tables previously calculated from formulas published in /6/. The tidal factor δ was assumed equal to 1.16.

Correction for the attraction of atmospheric masses was calculated from formula :

$$\Delta g_A = + 0.406 (P - P_o) \qquad (1)$$

suggested by N. Pariisky /7/, where P is the measured and P_o is the normal atmospheric pressure expressed in millibars.

Evaluation of the accuracy of accomplished measurements was made by formula :

$$M = \pm \sqrt{M_o^2 + \Sigma m_\Delta^2} \qquad (2)$$

where M is the total error of determination of the absolute value of gravity acceleration at the effective height of the instrument, m_Δ is the errors arising due to inaccurate determination of corrections Δg_i, whereas M_o is incidental error determined by convergence of measurements.

The following values for m_Δ errors were assumed from the data obtained as the result of specially conducted experiments :

$m_p = \pm 5$ µgal	$m_\varphi = \pm 2$ µgal	$m_\lambda = \pm 4$ µgal
$m_t = \pm 3$ µgal	$m_c = \pm 0$ µgal	$m_\delta = \pm 2$ µgal
	$m_A = \pm 0.5$ µgal	

The results of measurements at point Singapore-2 (1984) are given in Appendix 1.

It is interesting to compare the obtained results with measurements made earlier /2/, /3/. For this purpose, the measurements made in 1979 and 1982 should be reduced first to one system and then to point Singapore-2 (1984).

Let us analyse the necessary reductions.

1. Honkasalo correction. Since by the IAG Resolution the introduction of Honkasalo correction is not recommended, into all measurements of 1979 and 1982 should be introduced reduction + 35 µgal, which is equal to Honkasalo correction with the sign reversed.

2. Correction for the changes of hydrological conditions at point Singapore-1. This corrections should be introduced into the measurements of 1979. Calculations have shown that its value can reach about 50 ± 15 µgal. Since the masses have diminished, this correction should be introduced with minus when reducing measurements of 1979 to those of 1982.

3. Correction for the attraction of atmospheric masses. In accordance with the recommendation, adopted by the International Gravimetric Commission in 1983 in Hamburg, correction for the attraction of atmospheric masses should be introduced into all absolute determinations. In order to take this effect into acccount we received from the Meteorological Service of Singapore the value of atmospheric pressure which was during the measurements in 1979 and 1982. These data are given in Appendix 2.

4. Reduction to point Singapore-2 (1982). The measurements, made in 1982 at points Singapore-1 and Singapore-2, allow to determine Δg between these points /3/. The results are as follow :

Singapore-1 (1982)	g = 978 069 911 ±	9.4 μgal
Singapore-2 (1982)	g = 978 064 084 ±	8.0 μgal
	Δg = -6827 ±	12.3 μgal

This reduction should be introduced into all measurements made at point Singapore-1.

5. Correction for the change of height of point Singapore-2 (1982). As previously mentioned, the floor on which the gravitymeter was installed in 1982 at point Singapore-2 was subsequently covered by a layer of concrete and ceramic tiles thus raising the height of point Singapore-2 (1984) by 63 mm. Since in future point Singapore-2 (1984) shall be used, all previously made measurements should be reduced to that point. The value of reduction for the change of height H was calculated from the usual formula (correction for height with account of attraction of the intermediate layer) :

$$\Delta g_{\Delta H} = (0.3086 - 0.0418\sigma)\ \Delta H \qquad (3)$$

Assuming in our case $\sigma = 1.8$ (concrete of average density) we shall find that :

$$\Delta g_{\Delta H} = -\ 14.7\ \mu gal$$

Since the precise density of the concrete and tiles is unknown, this reduction should have the error of about ± 2 μgal.

Appendix 3 presents a summary of all absolute determinations made by GABL gravitymeter and of their reductions to point Singapore-2 (1984). Final results are given in Table 1.

Table 1. Results of absolute determinations in Singapore

Year	g (μgal)	M (μgal)	$P = 1000:M^2$
1979.4	978 064 091	± 22.0	2
1982.2	103	8.2	15
1984.6	095	8.3	15
Weight Average	978 064 098	± 2.8	

From the data in Table 1 we obtain :

δg (1982-1972) = + 12 ± 23.5 μgal

δg (1984-1982) = - 8 ± 11.7 μgal
δg (1984-1979) = + 4 ± 23.5 μgal

The given data allow to determine the gravity field stability with time in Singapore with sufficient reliability. All differences were essentially less than the errors with which they were measured. This provides grounds to consider the gravity field in Singapore unchangeable within accuracy of measurements in the time interval 1974.4-1984.6.

In this case, the most probable value of absolute gravity acceleration for point Singapore-2 (1984) at the height over the floor level h = 1.274 m for the epoch 1983.2 should be assumed as average weight from all three determinations, which is

$$g = 978\ 064\ 098 \pm 2.3\ \mu gal$$

In conlusion, the authors consider it their pleasant duty to express deep gratitude to Pr. A. Radjaratnam and his colleagues Dr. Ratnam and Eng. Chou Pow Hust, who were extremely helpful in organising the work of the Expedition. Without their assistance, especially that of Pr. A. Radjaratnam, the described measurements could hardly have been accomplished.

Moscow, August 1984

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Addendum 1

Results of measurements at point Singapore-2(1984)

No	T_o	k	g_o	m_o	A	Corrections			g
						Δg_p	Δg_γ	Δg_A	
1	2	3	4	5	6	7	8	9	10
			mcgal	mcgal	mcbar	mcgal	mcgal	mcgal	mcgal
	20 July								
1	12^h25^m - 12^h55^m	117	978 064 046	± 14	1008	+ 42	+ 45	− 2	978 064 107
2	13 10 - 13 40	116	084	16	8	42	+ 28	2	128
3	14 00 - 14 30	117	095	16	8	42	+ 9	2	120
4	14 45 - 15 15	113	080	14	8	40	− 4	2	090
5	15 40 - 16 10	115	109	12	8	40	− 13	2	110
6	18 15 - 18 45	118	082	14	8	38	+ 13	2	107
7	19 00 - 19 30	115	065	15	7	38	+ 31	3	107
8	19 45 - 20 15	117	040	18	7	38	+ 49	3	100
9	20 30 - 21 00	117	029	18	7	37	+ 66	3	105
10	21 15 - 21 45	117	995	18	7	37	+ 79	3	084
11	22 00 - 22 30	117	008	18	7	37	+ 85	3	103
12	22 45 - 23 15	118	988	19	7	37	+ 85	3	083

1	2	3	4	5	6	7	8	9	10
	23 July								
13	11^h10^m - 11^h30^m	58	978 064 030	± 17	1008	+ 41	+ 53	- 2	978 064 098
14	11 45 - 12 00	60	019	24	9	41	+ 66	- 2	100
15	12 05 - 12 35	118	988	15	9	40	+ 75	- 2	077
16	13 00 - 13 30	120	964	19	11	38	+ 86	- 1	063
17	13 45 - 14 15	120	956	20	11	38	+ 86	- 1	055
18	14 25 - 14 55	115	993	15	11	38	+ 79	- 1	085
19	15 10 - 15 40	115	009	14	11	38	+ 64	- 1	086
20	15 55 - 16 25	115	036	19	11	38	+ 44	- 1	093
21	16 45 - 17 15	111	073	15	9	36	+ 18	- 2	101
22	17 35 - 18 05	119	100	16	8	36	- 7	- 2	103
23	18 20 - 18 50	118	120	22	8	35	- 25	- 2	104
24	19 05 - 19 35	120	132	19	8	34	- 36	- 2	104
25	19 50 - 20 20	116	116	17	8	34	- 37	- 2	087
26	20 40 - 21 10	120	101	19	8	33	- 28	- 2	082

$\sum k = 2922$ $\quad \bar{m}_o = \pm 17{,}0$

$n = 26$

Constant corrections : $g_c = -24$ mcgal

$g_h = 0$ mcgal

$\bar{g} = 978\ 064\ 095$ mcgal

$m = \pm 16{,}1$ mcgal

$M_o = \pm 3{,}2$ mcgal

$M = \pm 8{,}3$ mcgal

Addendum 2

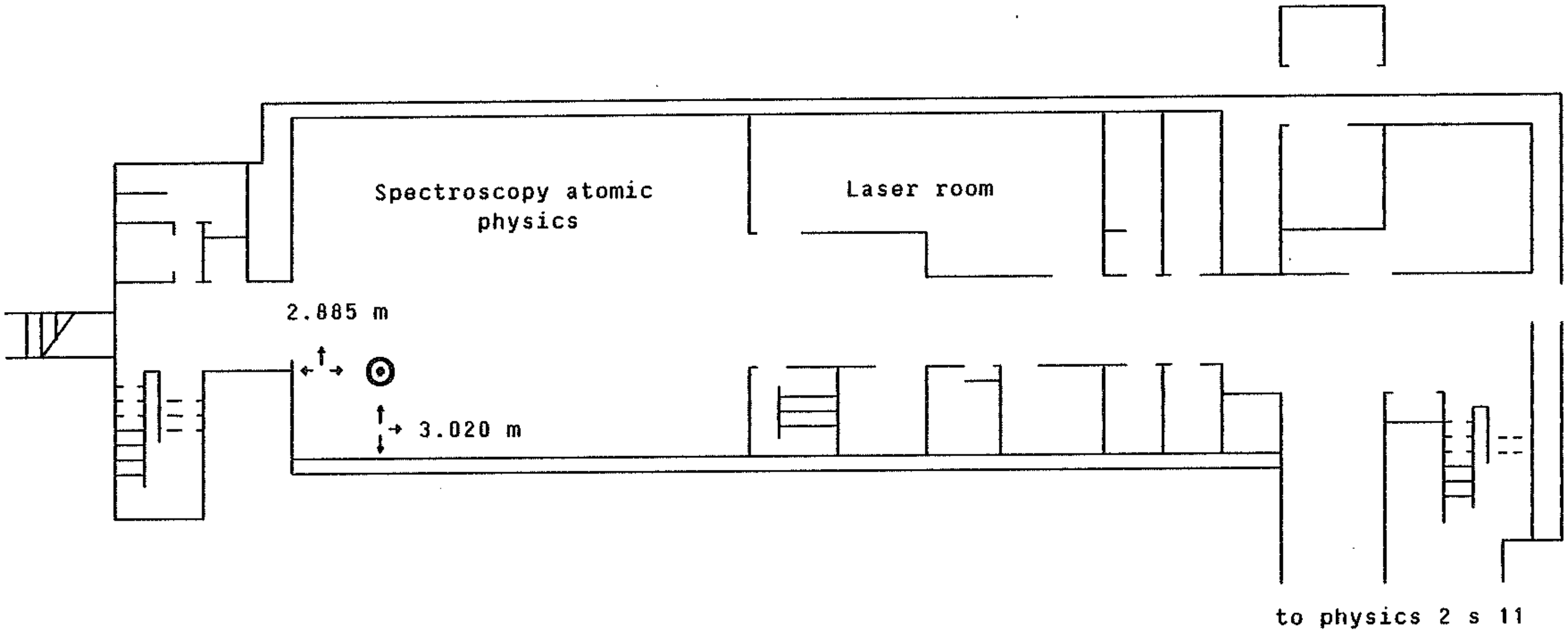
Atmospheric pressure at Singarore

Point	Date	Time	Pressure	Δg_A
Singapore 1	1979 April 12	$14^h\ 00^m$	1009,9	
		15 00	1010,6	
	April 14	17 00	1010,7	
		18 00	1010,3	
	Average		1010,3	- 1,2 mcgal
	1979 June 1	20 00	1009,7	
		21 00	1009,3	
	Average		1009,5	-1,5 mcgal
Singapore 1	1982 February 18	20 00	1011,2	
		21 00	1011,1	
	Average		1011,2	- 0,8 mcgal
Singapore 2	1982 February 24	15 00	1009,4	
	February 27	15 00	1010,7	
	Average		1010,0	- 1,3 mcgal

Addendum 3

Point	Date	g	Correcitons for: Honkasalo	Correcitons for: hydlogical effect	Correcitons for: height change	Correcitons for: atm. attrac.	Δg Singapore 2 – Singapore 1	g
		mcgal	mcgal	mcgal	mcgal	mcgal	mcgal	mcgal
Singapore 1	1979,IV	978069959 ±14,1						
	1979,VI	939 ±14,7						
	Average:	978069949 ±10,2	+ 35	– 50±15	– 15±2	–1	– 5827 ±12,3	978064091 ±22,0
Singapore 1	1982,II	978069911 ± 9,4	+ 35	–	– 15±2	–1	– 5827 ±12,3	978064102 ±15,6
Singapore 2	1982,II	978064084 ± 8,0	+ 35	–	– 15±2	–1	–	978064102 ± 8,2
Singapore 2	1984,VII	978064095 ± 8,3	–	–	–	–	–	978064095 ± 8,3

POINT SINGAPORE-2



◎ observation point

Official address : Physics Department, National University of Singapore
Faculty of Science,
Kent Ridge Singapore 0511

Coordinates : $\varphi = 1°17'.5$; $\lambda = + 103°47'$; H = 15,9 m

AN IMPROVED ELECTRONIC FEEDBACK FOR LACOSTE-ROMBERG GRAVITY METERS

by M. Schnüll, R.H. Röder and H.-G. Wenzel

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Abstract

The electronic feedback circuit developed by HARRISON and SATO 1983 for LaCoste-Romberg model G gravity meters has been improved in order to compensate a much larger asymmetry of the capacitor's plates at the gravimeters reading line. Additionally, a new output filter circuit has been constructed, which generates ± 0.5 µgal reading precision under normal conditions at less than 1 minute delay time. The electronic feedback can be operated from the gravimeters's 12 V battery and because of it's small size of 72 mm x 50 mm x 18 mm, it can be installed directly in the gravimeter's box. The improved electronic feedback system has been installed in LaCoste-Romberg model G No. 79 and has been used to determine the 1 mgal and the 7.88 mgal periodic calibration function of the gravimeter, to observe the gravity gradient and some small gravity differences without using the gravimeter's screw.

1. Introduction

For the past ten years, LaCoste-Romberg (LCR) model G and D field gravity meters have been equipped by the manufacturer with a capacitive position indicator (CPI) to improve the reading precision. For field observations, the filtered CPI output can be observed with a digital voltmeter and gives a reading precision of about ± 1 µgal (e.g. WENZEL 1978). For gravimetric earth tide observations, the filtered CPI output can be recorded with an electronic strip chart recorder and gives a reading precision of some 0.1 µgal (e.g. WENZEL 1976). The major disadvantage of observing the CPI output is the dependence of the sensitivity from the tilt of the instrument by about 1 % per arc sec and the complicate frequency transfer function of the instrument due to hysteresis effects of the spring (e.g. WENZEL 1976, SATO 1978).

HARRISON and SATO 1983 have shown, that an electronic feedback system can be applied to LCR model G and D meters, which holds the beam in a fixed zero position, by simply attaching the feedback circuit to already available connections on the CPI board. The electronic feedback system is a priori non-linear, because the electrostatic force is proportional to the square of the voltage applied to the capacitor's plates. By applying two bias voltages, the feedback system can be linearized, even if the zero position of the beam is not exactly centered between the capacitor's fixed plates (HARRISON and SATO 1983). The major advantage of the feedback system is the independence of the feedback's sensitivity from tilt, the much easier frequency transfer function of the feedback instrument due to the elimination of hysteresis effects of the spring, and the practical independence of the frequency transfer function from tilt. This opens new dimensions for observing small gravity differences without using the gravimeters screw, and better accuracy of earth tide recording because the calibration of the electronic feedback is stable. The major disadvantage of the development made by HARRISON and SATO 1983 to linearize the electronic feedback, is that it can be applied only for small deviations of the beam's zero position from the center between the capacitors fixed plates. In practice, deviations up to 50 % have been observed (e.g. BECKER 1984) and thus not all LCR model G or D meters can be equipped with an electronic feedback system applying the HARRISON and SATO 1983 method.

2. Design of the Feedback

HARRISON and SATO 1983 have given a circuit diagram of an electronic feedback system, which can be applied to LaCoste and Romberg (LCR) gravity meters with a capacitive readout in order to hold the gravimeters beam at a fixed position, when the gravity is changing. This feedback system eliminates hysteresis effects of the spring, and the calibration of the feedback output voltage is independent from tilt. The relation between feedback output voltage and applied electrostatic force can be linearized even if the fixed position of the beam is not exactly halfway between the capacitors fixed plates. The schematic circuit diagram of the feedback's plate drive section is given in Fig. 2.1.

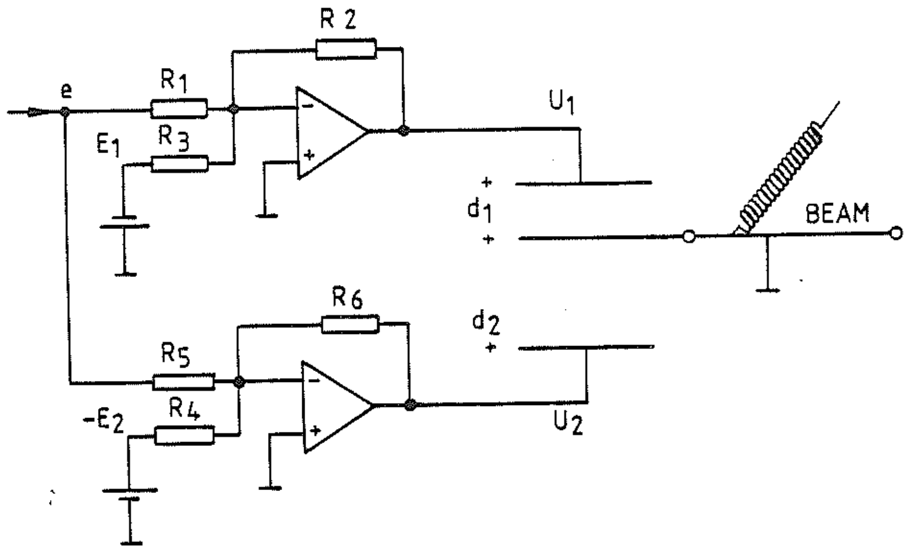

Fig. 2.1: Schematic diagram of the electronic feedback's plate drive circuit

The force applied to the plate attached to the gravimeter's beam is given by

$$F = \frac{C_0 \cdot d^2}{d_1 + d_2} \left| \frac{U_1^2}{d_1^2} - \frac{U_2^2}{d_2^2} \right| \qquad (2.1)$$

with d_1, d_2 = distances of the beam plate to the fixed plates,
U_1, U_2 = voltages applied to the fixed plates

and $d = (d_1 + d_2)/2$. (2.2)

Substituting $d_1 = d(1-\delta/d)$, (2.3)

$d_2 = d(1+\delta/d)$, (2.4)

with δ = distance of the beam to the center
gives

$$F = \frac{C_0}{d_1 + d_2} \left| \frac{U_1^2}{(1-\delta/d)^2} - \frac{U_2^2}{(1+\delta/d)^2} \right| . \quad (2.5)$$

Using the plate drive circuit schematically given in Fig. 2.1, the plate voltages U_1 and U_2 are given by

$$-U_1 = e \cdot \frac{R_2}{R_1} + E_1 \cdot \frac{R_2}{R_3} , \quad (2.6)$$

$$-U_2 = e \cdot \frac{R_6}{R_5} - E_2 \cdot \frac{R_6}{R_4} , \quad (2.7)$$

HARRISON and SATO 1983 assumed that

$$E_1 \cdot \frac{R_2}{R_3} = E_2 \cdot \frac{R_6}{R_4} = E \quad (2.8)$$

which in practice can only be fulfilled by an adjustment of the resistors R_2, R_3, R_4 and R_6 for the individual bias voltages E_1 and E_2. Substituting $R_2/R_1 = 1+k$, $R_6/R_5 = 1-k$ gives the feedback force

$$F = \frac{C_0}{2d} \left| \frac{[(1+k)e+E]^2}{(1-\delta/d)^2} - \frac{[(1-k)e-E]^2}{(1+\delta/d)^2} \right| \quad (2.9)$$

A series development of $(1-\delta/d)^{-2}$ and $(1+\delta/d)^{-2}$, which is valid only for $|\delta/d| \ll 1$, gives

$$F = \frac{C_0}{2d} \left| (1 + \frac{2\delta k}{d}) eE + \left\{ \frac{\delta}{d}(1+k^2)+k \right\} e^2 + \frac{\delta}{d} E^2 \right| \quad (2.10)$$

und thus the feedback can be linearized for small δ/d by adjusting

$$\frac{\delta}{d}(1 + k) + k = 0. \quad (2.11)$$

Because of $|k| \leq 1$, $|\delta/d| \leq 0.5$ is a limit for applying the method developped by HARRISON and SATO 1983. In practice, this condition is not fulfilled for all LCR model D and G meters (e.g. BECKER 1984) and thus not all instruments can be equipped with the HARRISON and SATO 1983 feedback system.

Without changing the feedback circuit in principle, we will show in the following how to adjust the electronic feedback system in order to be applied even for instruments with large asymmetry of the beam.

Substituting

$$V_1 = \frac{R_2}{R_1}, \quad 0 \leq V_1 \leq \infty \tag{2.12}$$

$$V_2 = \frac{R_6}{R_5}, \quad 0 \leq V_2 \leq \infty \tag{2.13}$$

$$k_1 = \frac{R_1}{R_3}, \quad 0 \leq k_1 \leq \infty \tag{2.14}$$

$$k_2 = \frac{R_5}{R_4}, \quad 0 \leq k_2 \leq \infty \tag{2.15}$$

yields

$$-U_1 = (e + E_1 k_1) V_1 \tag{2.16}$$

$$-U_2 = (e - E_2 k_2) V_2 \tag{2.17}$$

and the feedback force

$$F = \frac{C_0}{2d} \left| \frac{(e + E_1 k_1)^2 V_1^2}{(1-\delta/d)^2} - \frac{(e - E_2 k_2)^2 V_2^2}{(1+\delta/d)^2} \right| \tag{2.18}$$

The gain factors V_1 and V_2 can be adjusted with R_2 and R_6 resp., so that the conditions

$$V_1 = 1 - \delta/d \tag{2.19}$$

$$V_2 = 1 + \delta/d \tag{2.20}$$

are fulfilled, and the gain factors k_1 and k_2 can be adjusted with R_3 and R_4 resp., so that the condition

$$E_1 k_1 = E_2 k_2 = Ek \tag{2.21}$$

holds; under these conditions the force function becomes

$$F = \frac{C_0}{2d} \cdot 4eEk, \tag{2.22}$$

and the feedback force is perfectly linear with the feedback voltage e.

Output Low Pass Filter

The feedback voltage shows a noise of about ± 10 ... 30 µgal with periods of about 6 seconds due to microseismic. In order to increase the reading precision, a low pass filter can be used. The low pass filter applied by HARRISON and SATO 1983 with a cutoff frequency of 0.167 s^{-1} and 20dB/decade damping is not appropriate to give a reading accuracy better than ± 3 µgal. We have used a double section low pass filter with 0.0482 s^{-1} cutoff frequency and 40dB/decade damping per section (see Fig. 2.2). The frequency transfer function of the improved low pass filter, as observed using a signal generator and a recorder, is given in Fig. 2.3. The step response of the low pass filter, shown in Fig. 2.4, can also be used to determine the frequency transfer function (e.g. WENZEL 1976); both methods agree well in the range of $10^{-3} \dots 10^{-1}$ s^{-1}. At 6 sec period with maximum noise amplitude of the feedback voltage, the damping of the improved filter is about 30dB better than the filter used by HARRISON and SATO 1983. Additionally, the delay time of the improved filter is much smaller.

The step response of the complete measuring system (gravimeter, feedback, filter, recorder) given in Fig. 2.4, can be used to determine the frequency transfer function of the complete measuring system, which is necessary for phase lag correction for earth tide observations (e.g. WENZEL 1976). The frequency transfer function for the main tidal bands is given in Table 2.2.

Table 2.2: Frequency transfer function of LCR G-79 feedback system for tidal waves

Wave	Frequency [h^{-1}]	Period [h]	Amplitude Gain	Phase Lag [°]
S1	0.042	24	1.00000	0.062
S2	0.083	12	1.00000	0.122
S3	0.125	8	1.00000	0.184

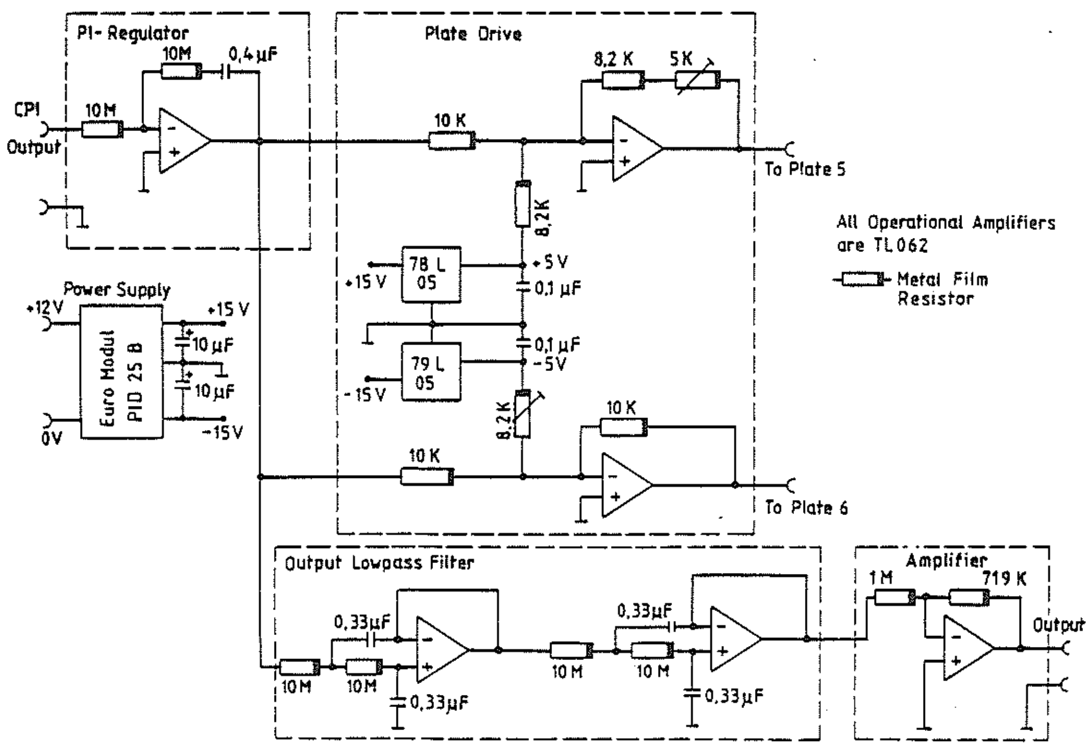

Fig. 2.2: Circuit diagram of the improved electronic feedback system

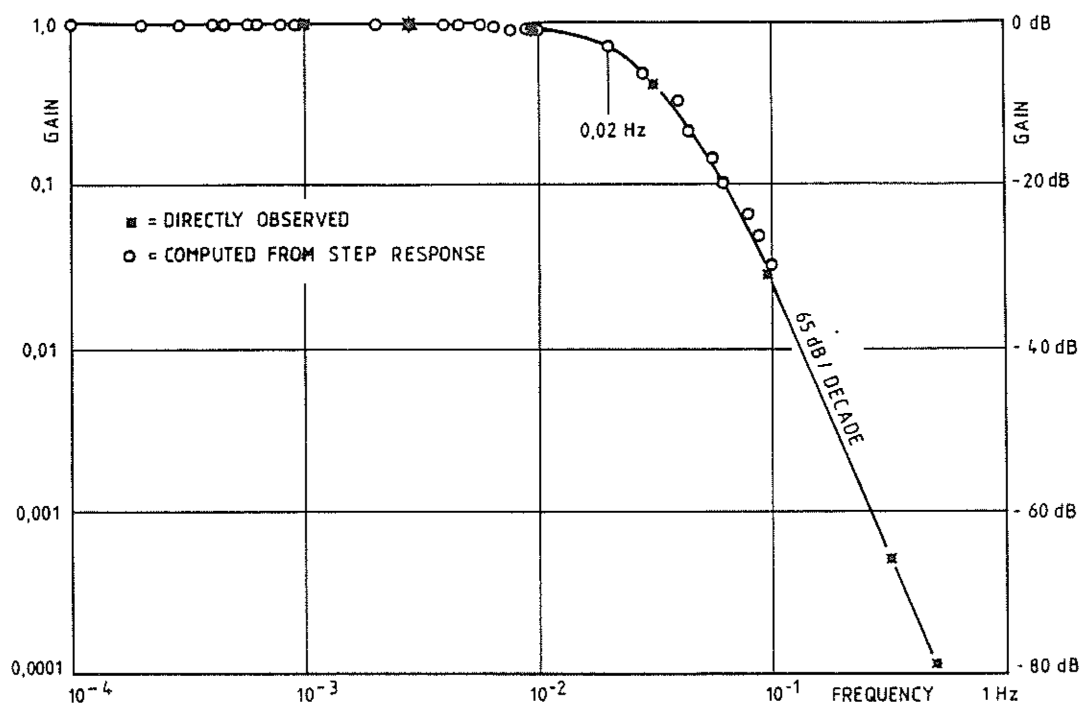

Fig. 2.3: Amplitude gain of the improved low pass filter

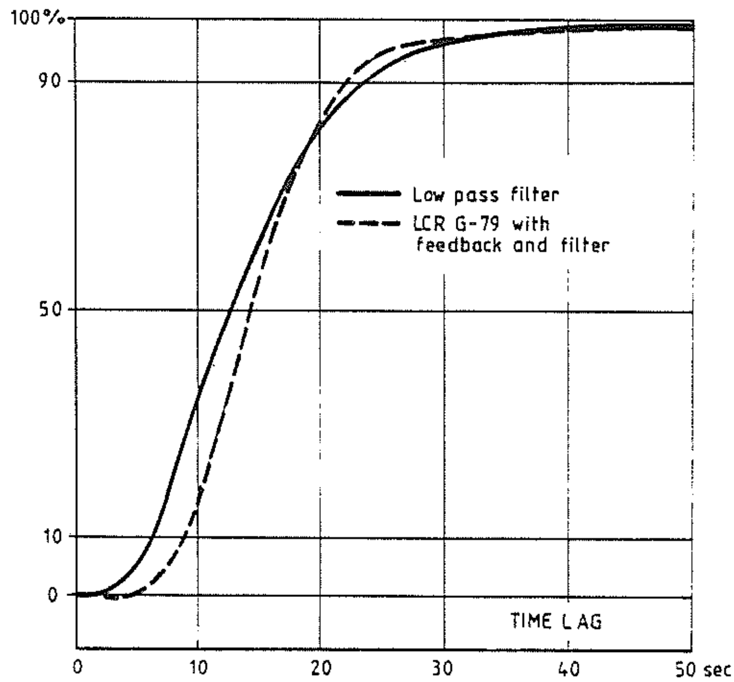

Fig. 2.4: Step response of the improved low pass filter and of the complete measuring system (LCR G-79 gravimeter, feedback including low pass filter, and recorder)

Temperature Effects

The output of the electronic feedback system depends slightly on the temperature; the main influence is caused by the bias voltage regulators ($1...5 \cdot 10^{-5}/^{\circ}C$ change of the bias voltage). The temperature dependency of the whole electronic feedback system, as observed in a thermostatically controlled oven, is shown in Fig. 2.5. The calibration factor of the feedback changes linearly by $-2 \cdot 10^{-5}/^{\circ}C$, whereas the zero point changes quadratically with zero at 30°C and ±3µgal/°C at 20° resp. 40°C. Because the feedback has finally been installed inside the gravimeters box, the temperature will not change by more than ±0.3°C at 20°C change of the outer temperature and thus the calibration should remain stable within $\pm 1 \cdot 10^{-5}$.

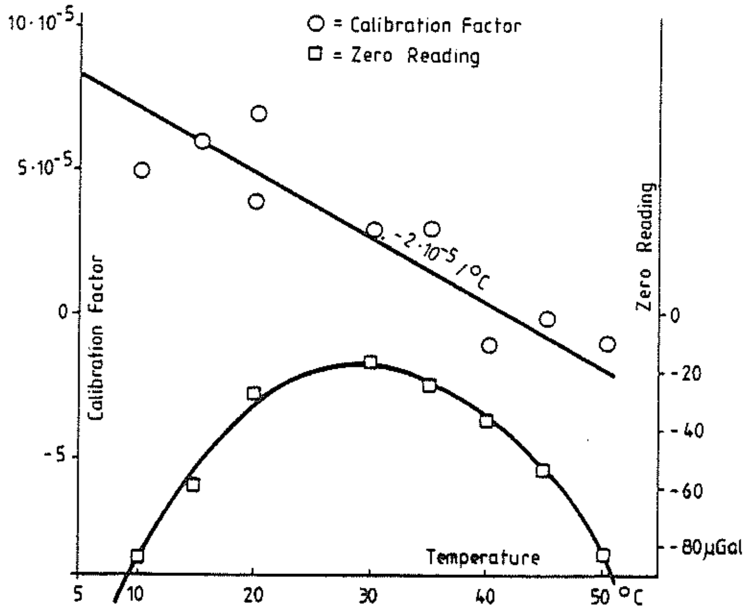

Fig. 2.5: Temperature dependency of the electronic feedback system installed in LCR G-79.

3. Adjustment and Calibration

A major problem is the accurate adjustment and calibration of the electronic feedback system. The feedback output has to be linearized by changing the gain of one of the plate drive amplifiers (see Fig. 2.1). This can be done with an accuracy of some µgal by observing the feedback output voltage at different positions of the gravimeter's screw. The major limitation is caused by the (unknown or unsufficient known) screw errors of the gravimeter.

A calibration of the adjusted feedback can also be performed by observing some gravity differences at different feedback output voltages on a suitable calibration line (e.g. KANNGIESSER et al. 1983).

Comparing the results of this two methods we found a linear discrepancy of about $6 \cdot 10^{-3}$. The reason for that is unknown. All external physical effects, e.g. magnetic and air pressure effects can be excluded to be responsible. We suspect this discrepancy is caused by the different working points of the electrostatic force and the spring force at the beam. Therefore, the base line calibration has to be used.

We have determined the linear and quadratic scale factor of the LCR G-79 feedback system to 1.0328 resp. $625 \cdot 10^{-6}$ by observing a number of gravity differences of 1...8 mgal at different positive and negative output voltages. The accuracy of this calibration allows the determination of gravity differences < 8 mgal with an accuracy of $\pm 5 \cdot 10^{-4}$.

4. Determination of Periodic Calibration Errors

By observing the feedback output voltage in a station at different positions of the gravimeter's screw, the differences between feedback output voltage and screw position are created by the non-linearity of the feedback and the calibration function of the screw. Provided the non-linearity of the feedback has carefully been adjusted, the observations can be used to determine periodic calibration errors of the gravimeter, caused by ecentricities of the screw and the gears. Due to the limited feedback range of ± 4 mgal, only periodic errors with periods less than 8 mgal can be determined. Compared to the conventional method for the determination of periodic errors by observing a number of gravity differences at a suitable calibration line (e.g. KANNGIESER et al. 1983), the feedback method is more accurate because no transportation errors occur and the enivironmental conditions remain stable and needs only approximately 1 hour for a set of observations at 30 different screw positions in a double loop. In Fig. 4.1 is compared the determination of the 1 mgal periodic error of LCR G-79 by the feedback method with the calibration line method; both methods agree within ± 2 µgal, which is approximately the accuracy of setting the dial at a defined position.

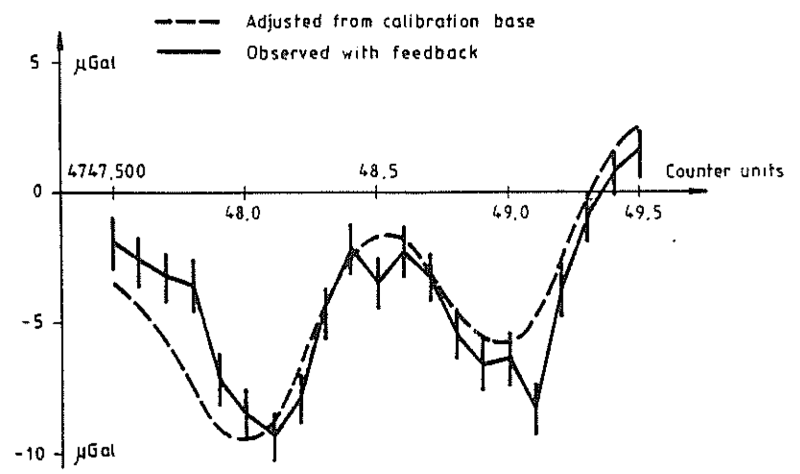

Fig. 4.1: Comparison of the 1 mgal periodic error of LCR model G No. 79 determined with feedback and calibration line method.

5. Observation of the Vertical Gravity Gradient

For combining absolute and relative gravity measurements, the knowledge of the vertical gravity gradient in the absolute station is necessary, because absolute gravity is normally observed in a point approximately one meter above the ground, whereas the gravity value of the station is defined at the ground. Provided the gravity gradient is constant over this distance, it can be computed from gravity observations at two different positions in height. The error of the gradient should be less than the sum of the known systematic errors of the absolute gravimeter (e.g. FALLER et al. 1982). By observing the gravity gradient with LCR D or G meters, it's accuracy is limited by the unsufficient knowledge of short periodic calibration errors (e.g. GROTEN and BECKER 1983). A gradient observed with a single LCR gravimeter in usual manner can have a several µgal error, even if a number of repetitions have been carried out and the internal precision is better than ±1 µgal (e.g. Table 5.1). Additionally, the observation of the gravity gradient is very time consuming and can exceed the time required for the absolute observation.

By applying an electronic feedback system to LCR gravimeters, small gravity differences can be observed without changing the dial and thus any calibration error of the meter is eliminated. The limitation of the feedback method is the adjustment and the calibration of the feedback system, which is in the order of $\pm 5 \cdot 10^{-4}$ and thus restricts the accuracy of determind gravity gradients to some 0.1 µgal/m. In Table 5.1 are compared observations of the gravity gradient in the station station Hannover 2 by two LCR model G and three LCR model D gravimeters using the conventional observation method with observations using the feedback system installed in LCR G-79. Applying the feedback system, the observation time for a single gravity difference is about two times less compared to the conventional method. Additionally the accuracy of the observed gravity gradients using 10 feedback observations is ±1...2 µgal compared to ±3...4 µgal by using 50 observations carried out in conventional manner.

Table 5.1: Comparison of the gravity gradient in the station Hannover determined by conventional gravity observations and by feedback observations

Conventional observations					Feedback observations with LCR G-79		
Instr.		Epoch	Gradient [µgal/m]	n	Date	Gradient [µgal/m]	n
LCR	D-8	1984	265.9±0.5	50	1984/06/16	265.4±0.6	10
LCR	D-14	1984	266.3±0.5	50	1984/06/16	268.2±0.4	10
LCR	D-23	1984	269.2±0.6	50	1984/06/17	268.1±0.6	10
LCR	G-79	1983	274.3±0.9	52	1984/06/17	268.6±0.5	10
LCR	G-79	1984	268.8±0.5	50	1984/06/18	266.9±0.4	10
LCR	G-298	1983	272.3±0.9	46			
		Mean:	269.5±1.4	298	Mean:	267.4±0.6	50

n = number of observed gravity differences.

6. Field Observations

As final test of the feedback system, we have observed two gravity differences of 6 mgal resp. 8 mgal located at the Hannover - Harz calibration line. The precision of a single observation was ± 6 µgal; the mean of the observations agreed with the given gravity differences within 3...4 µgal which is in the order of the calibration uncertainty of feedback system.

For observations of gravity differences greater than 8 mgal during a field campaign of several weeks duration, the feedback system in combination with the mechanical system was applied instead of the CPI output, because of it's better low pass output filter.

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6' x 10' BOUGUER ANOMALIES AND ELEVATIONS OF EUROPE INCLUDING MARINE AREAS

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Abstract

A set of 47,473 mean elevations for 6' x 10' blocks has been computed covering main parts of Europe and surrounding marine areas. These data are based on a collection of mean values, gridded resp. ungridded point data and bathymetric maps. In connection with already published mean free air anomalies of Europe, the mean elevations have been used for the computation of 41,678 6' x 10' Bouguer anomalies. The precision of the mean Bouguer anomalies is estimated to $\pm$ 7 mgal; the precision of mean elevations is estimated to $\pm$ (5 m + 0.03 $\cdot \bar{H}$).

1. Introduction

The compilation of high resolution free air anomalies for Europe (see e.g. TORGE et al. 1983a) was a preliminary condition for the determination of geoid heights and vertical deflections as published e.g. by TORGE et al. 1983b. As these anomalies have been computed partly from Bouguer anomalies by restituting the Bouguer plate reduction, comprehensive sets of 6' x 10' mean elevations resp. mean Bouguer anomalies were established. Since they can be generally utilized for geodetic or geophysic purposes as e.g. smoothing and interpolation of earth gravitational field parameters or geophysical analysis, both data sets are presented here in order to satisfy requirements of scientific investigators outside the Institut für Erdmessung.

2. 6' x 10' Mean Elevations

Concerning the area of Europe and surrounding marine regions, no homogeneous set of high resolution mean elevations was available. Therefore the compilation based on data sources of different type, applying specific estimation procedures for the determination of 6' x 10' block means.

The primary way of data compilation was the adaption of already existing mean or gridded point elevations, convenient small compartments supposed. A short description of existing appropriate sources is given in Tab. 1 (sources 1..7). Due to the fact that the original gridding of sources 2 and 3 was compatible to the desired block size, 6' x 10' mean values could be computed from these data using the simple arithmetic means procedure, whereas the least squares prediction algorithm has been applied for the processing of sources 4..7.

About 62,000 point elevations were available especially for marine areas inside the borders $47° < \varphi < 65°$, $-11° < \lambda < 16°$. Mean elevations have been estimated from these data by averaging point data located inside 6' x 10' block borders (source 8); around 10 observations per block were available. In order to generate a mostly complete data set, mean elevations for remaining gaps in marine areas have been estimated by digitizing bathymetric maps (source 9).

Due to some source overlappings, a final merging was necessary to produce an univocal data set. The total number of compiled 6' x 10' elevations has been reduced by this procedure from 52,718 to 47,473. Their precision is estimated to ± (5 m + 0.03 · H). This is only a rough estimation because detailed error analysis are generally not available for the collected elevation data. The location of compiled block means can be taken from Fig. 1. A mostly complete coverage is shown for western Europe except Spain and adjacent parts of the Mediterranean Sea.

3. 6' x 10' Mean Bouguer Anomalies

High resolution mean free air anomalies are available for Europe from TORGE et al. 1983a, WEBER 1984). Concerning main parts of the land areas, these anomalies are terrain corrected. Applying the Bouguer plate reduction

$$\delta\bar{g}_P = 2\,\pi\,G\,\rho\,\bar{H}\,,$$

with G = gravitational constant

$\bar{H}$ = mean elevation

$$\rho = \begin{cases} 2.67\ \mathrm{g/cm^3}\,, & \bar{H} > 0 \\ 1.64\ \mathrm{g/cm^3}\,, & \bar{H} < 0, \end{cases}$$

the mean free air anomalies $\Delta\bar{g}_F$ have been used for the determination of mean Bouguer anomalies

$$\Delta\bar{g}_B = \Delta\bar{g}_F - \delta\bar{g}_P\,.$$

Mean values for 41,678 6' x 10' blocks were estimated by this procedure for those compartments where both mean free air anomalies and mean elevations could be supplied. Their precision is estimated to ± 7 mgal, considering the accuracy of the elevation data and error estimations for the free air anomalies. The data distribution is given in Fig. 2, showing again a mostly complete coverage for western Europe except Sweden and Spain. A contour line map of mean Bouguer anomalies for the southeast North Sea and adjacent land areas is shown in Fig. 3. This computer plot offers a visual impression of the resolution of the compiled data set.

4. Data Availability

In order to satisfy the request on 6' x 10' mean elevations and mean Bouguer anomalies for Europe, the described data have been made available for the scientific community. These unclassified block means, released for public use by the originators, were surrendered to the Bureau Gravimetrique International. The Bouguer anomalies are refered to the International Gravity Standardization Net 1971 and to the Geodetic Reference System 1967.

Table 1: Description of compiled elevation sources

source number	reference	type of referenced data source	area	number of estimated 6' x 10' mean elevations	estimation procedure
1	SCHLEUSENER 1959	6' x 10' mean elevations	Central Europe	9 215	---
2	GEODETIC INSTITUTE DELFT UNIVERSITY	3' x 5' mean elevations	Netherlands	137	arithm. means
3	INSTITUT FÜR ERDMESSUNG UNIVERSITÄT HANNOVER 1979	2' x 2' point elevations	Sweden	912	arithm. means
4	CENTRE NATIONAL D'ETUDES SPATIALES 1981	2.16' x 2.70' mean elevations	France	4 959	least squares prediction
5	DEFENSE MAPPING AGENCY 1979	5' x 5' mean elevations	Great Britain Ireland North Sea	7 414	least squares prediction
6	BALLARIN 1959	5' x 7.5' mean elevations	Italy Mediterranean Sea	9 495	least squares prediction
7	GEOGRAPHICAL SURVEY OF NORWAY and RIKETS ALLMÄNNA KARTVERK	5' x 10' mean elevations	Norway Sweden	10 568	least squares prediction
8	INSTITUT FÜR ERDMESSUNG UNIVERSITÄT HANNOVER 1981	point elevations	North Sea North Atlantic Norwegian Sea	6 115	arithm. means
9	INSTITUT FÜR ERDMESSUNG UNIVERSITÄT HANNOVER 1980	bathymetric maps	North Sea Englisch Channel Baltic Sea	3 903	digitization

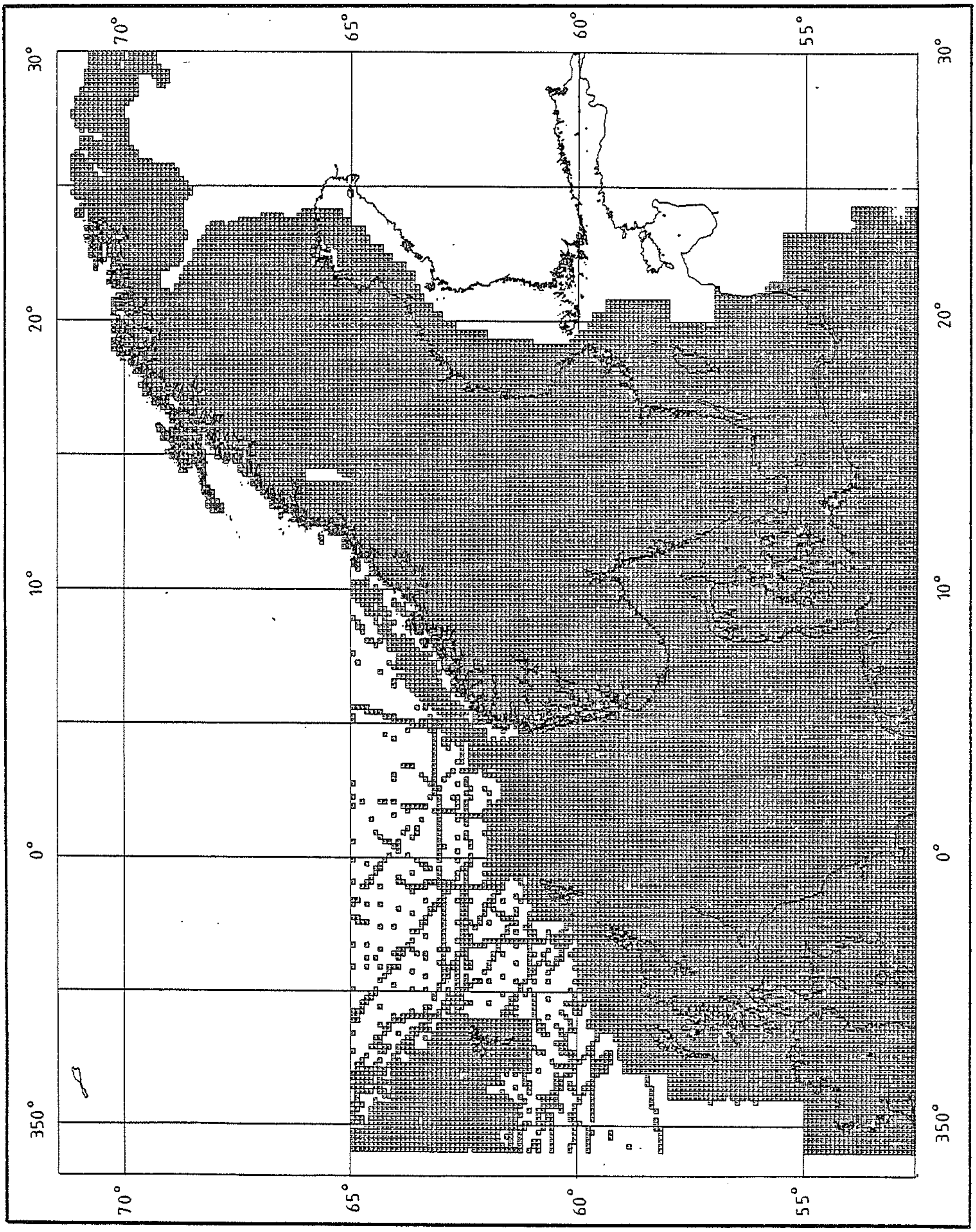

Figure 1: Distribution of 6' x 10' mean elevations

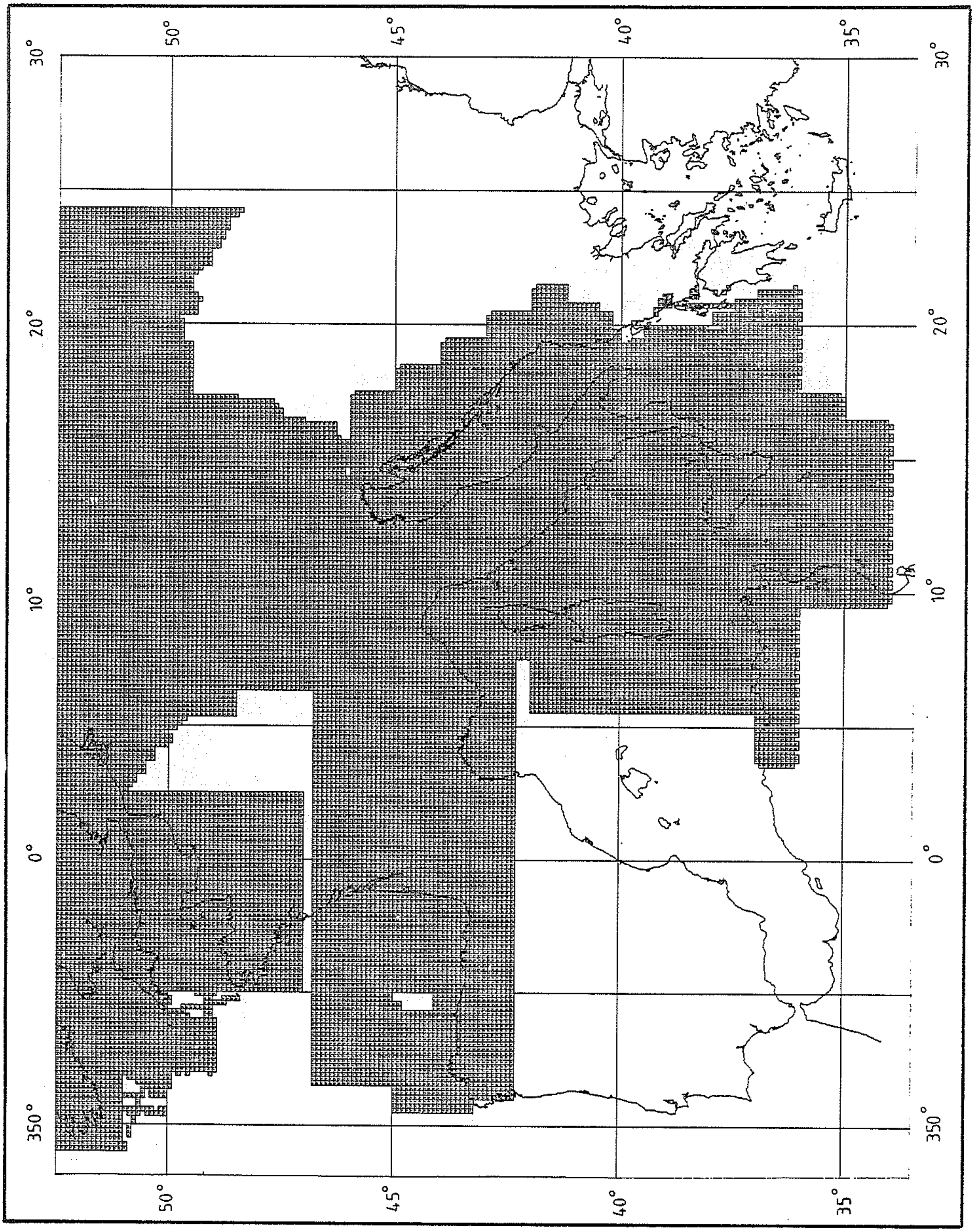

Figure 1: Distribution of 6' x 10' mean elevations (continued)

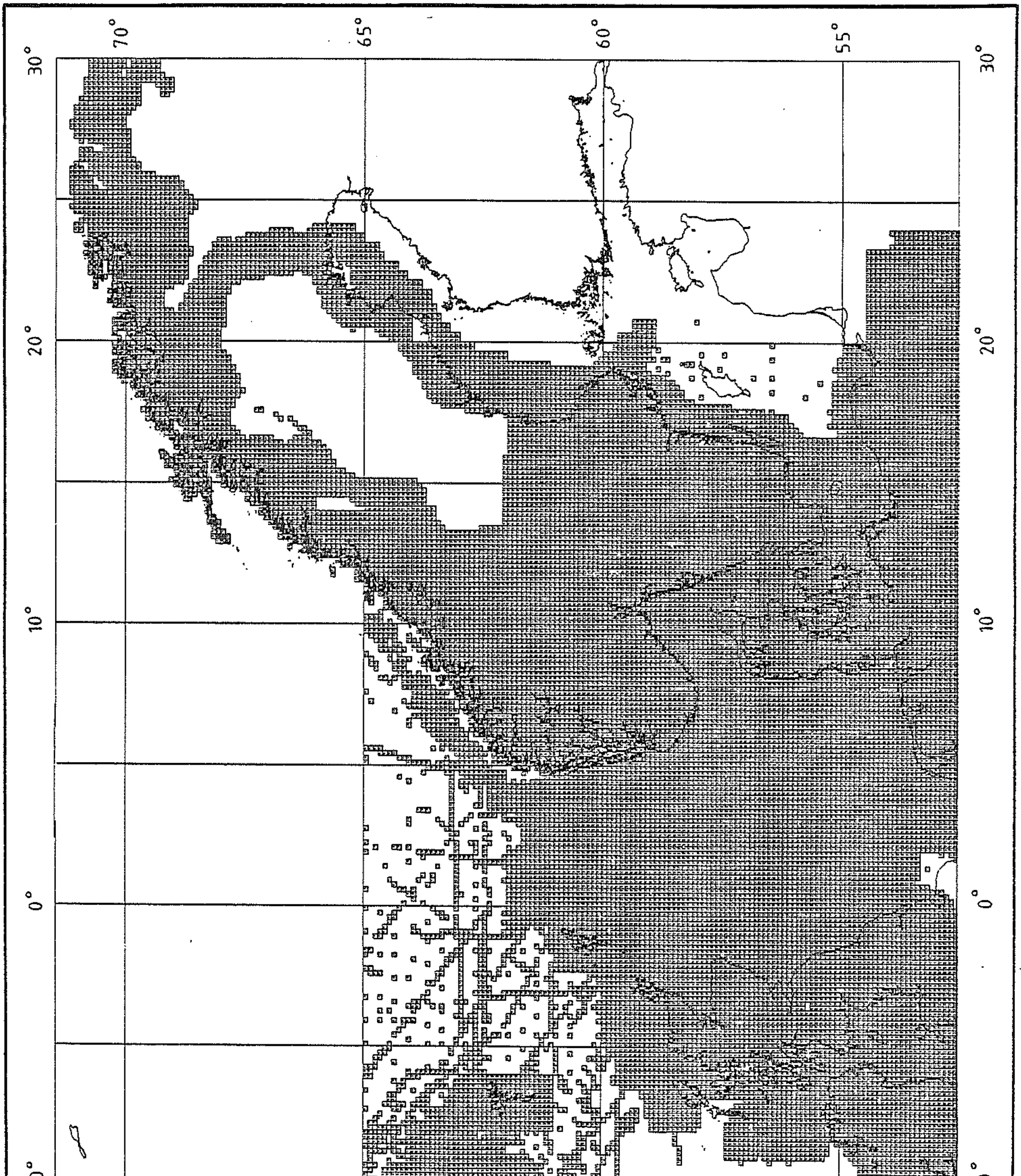

Figure 2: Distribution of 6' x 10' mean Bouguer anomalies

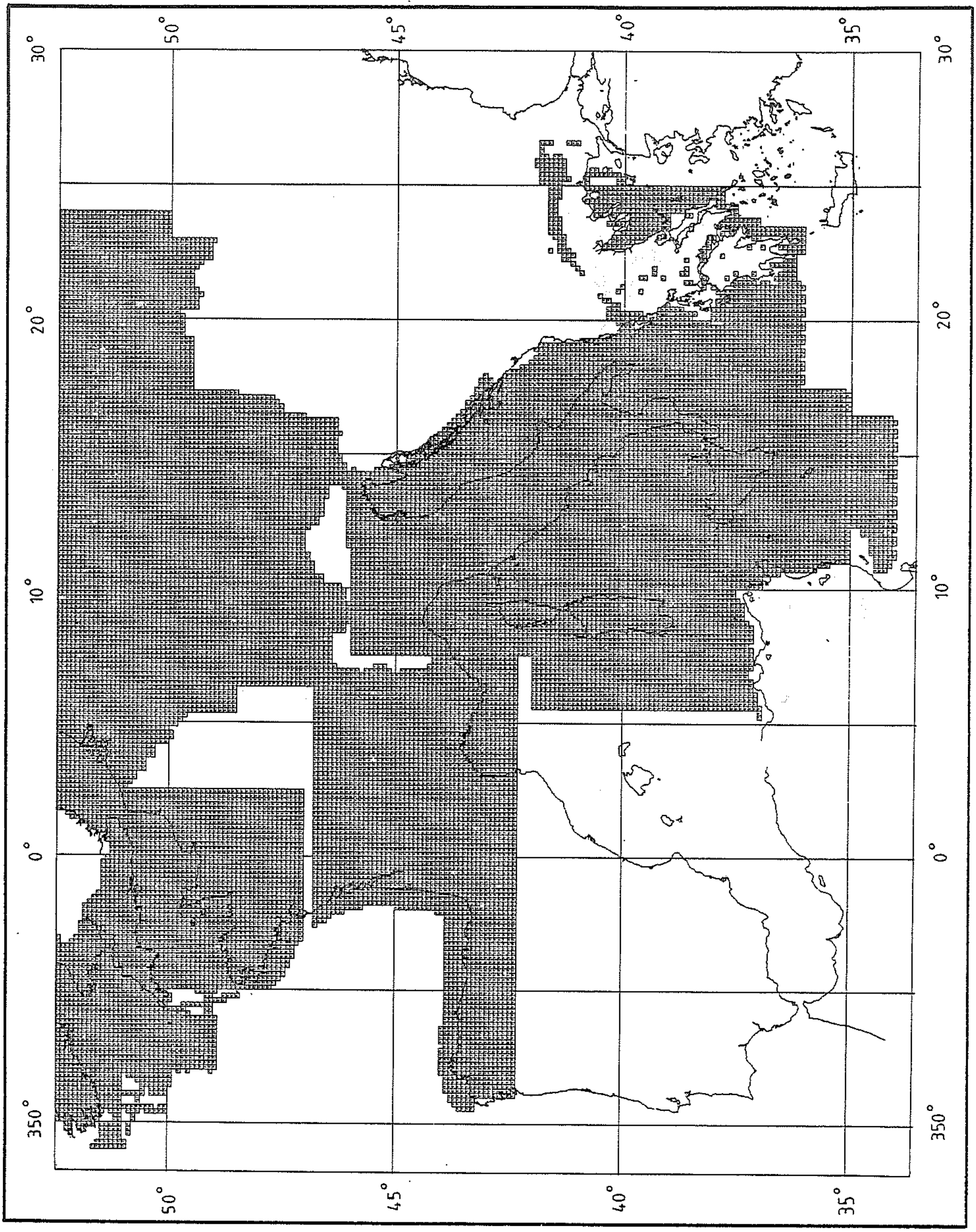

Figure 2: Distribution of 6' x 10' mean Bouguer anomalies (continued)

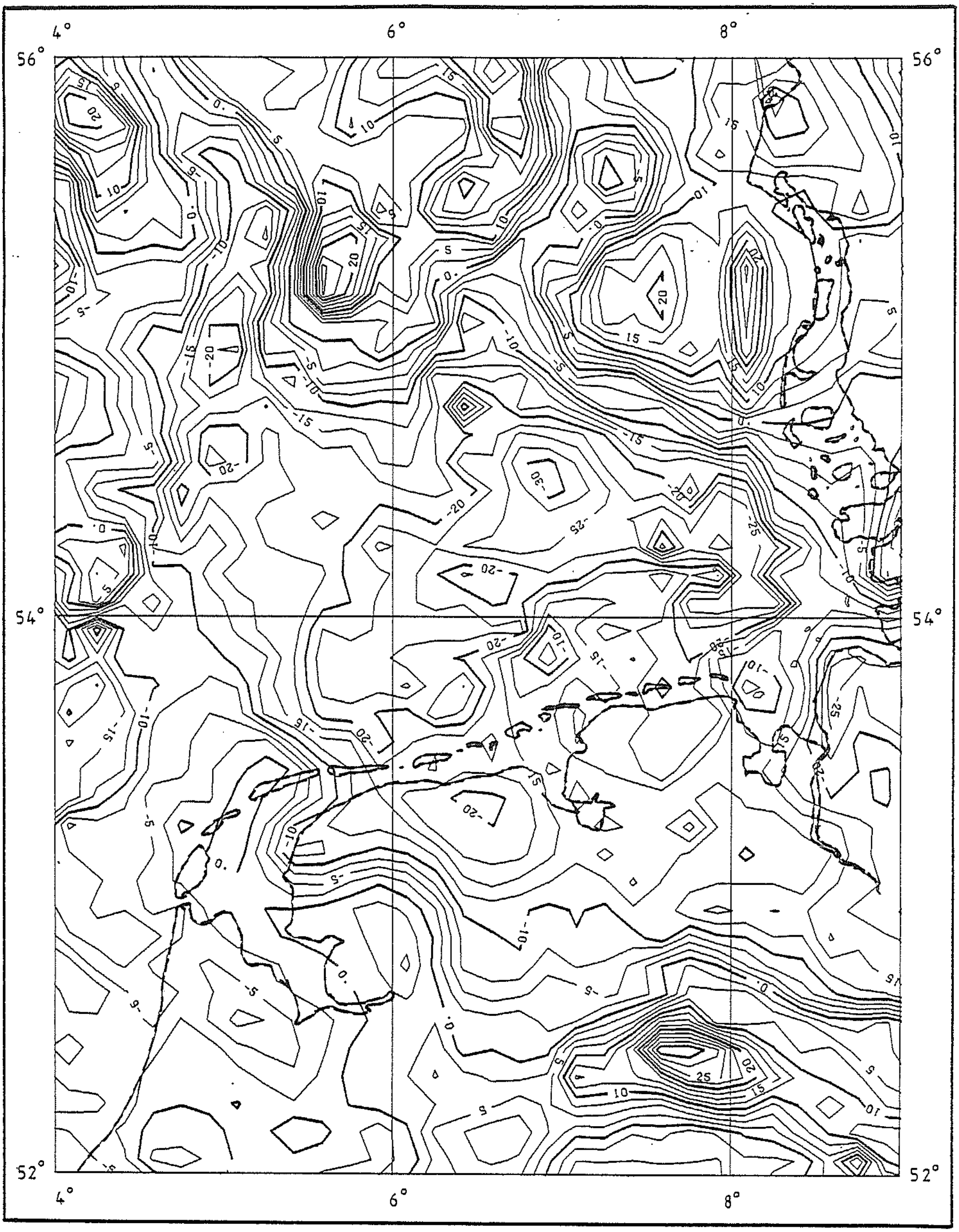

Figure 3: Contour map of 6' x 10' mean Bouguer anomalies, contour interval 2.5 mgal

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