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REPORT ON HIGH PRECISION GRAVIMETRY

by R Brein, C Gerstenecker,
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Introduction

Professor E Groten, chairman of Special Study Group 3.37, has asked a panel consisting of Dr R Brein, West Germany, Prof C Gerstenecker, West Germany, Dr A Kiviniemi, Finland, and Dr L Pettersson, Sweden, to prepare a report on microgravimetry for the Study Group. The present report is the result of discussions, by correspondence, between the members of the panel on the problems encountered in high-precision gravimeter measurements. The report deals almost exclusively with the following items of Prof Groten's preliminary programme for SSG 3.37:

- Instrumental problems inherent in submicrogal accuracy

- Physical (tidal, atmospherical etc) corrections

- Applications for practical and scientific purposes

The instrumental problems described, refer primarily to the LaCoste & Romberg G-model gravimeter, as this is the instrument commonly used in these connections. However, similar problems can be encountered with other types of gravimeters. The main aim of the report is to draw attention to the problems and to serve as a basis for discussions. In addition, reference is made to some experiences obtained by the members of the panel.

The following abbreviations will be used for the institutes involved:

<u>IfAG</u>: Institut für Angewandte Geodäsie, Frankfurt am Main (Brein)

<u>THD</u>: Technische Hochschule, Darmstadt (Gerstenecker)

<u>GL</u>: Geodeettinen Laitos, Helsinki (Kiviniemi)

<u>LMV</u>: Statens lantmäteriverk, Gävle (Pettersson)

1 Instrumental problems

a Transportation problems

Quite obviously the gravimeters must be protected against mechanical shocks, but even small vibrations can produce an adverse influence on them. Gravimeters can be specially sensitive to vibrations at certain frequencies and special care should, therefore, be taken to identify these frequencies and to protect the instrument from them.

An even temperature is essential, see section b below. The temperature during the transportation and also when making breaks for meals, sleep etc, should be approximately the same as during the observations. If the sites are outdoor ones, a good ventilation during transportation must be provided for in order to maintain an air temperature as near as possible to that prevailing at the sites.

LMV has constructed a wooden stand of ribs with space for transporting four gravimeters. This construction allows air to circulate around the instruments, thus avoiding the warming up by the gravimeter heating system, which takes place within the carrying box, even if the lid is open.

Air transport is not suitable, because in aircraft dangerous vibrations are frequent and rapid changes in air pressure and temperature can occur. Besides, in any case the gravimeters have to be transported by car from the airports to the sites. If possible, car transport should, therefore, be used. A car is the most flexible mean of transportation and meets most easily the above mentioned demands (the gravimeters should preferably be placed between the axles of the car). Another advantage is the possibility to use the car generator to charge the gravimeter accumulators to a fixed voltage during transport, so that the observations can start at the same voltage at every station. This should be advantageous for obtaining equal illumination in the reading microscope, even drift, consistent function of the electronic reading systems etc.

In this connection it can be mentioned that the gravimeters should be subjected to shaking before the day's first observation by driving a reasonable distance of say 10-30 km.

b Influence of the air temperature

Changing air temperature affects the gravimeters in different ways.

GL has investigated a number of gravimeters in a thermostatically controlled room at temperatures between $8^{\circ}C$ and $30^{\circ}C$. Before every observation the gravimeters were kept at constant temperature for several hours to allow them to adopt the desired temperature.

For five gravimeters was obtained:

- a drift change between:

  $- 6.5 \pm 1.2$ and $+ 3.6 \pm 1.6$ µgal/day and $10^{\circ}C$ change
- a reading change (after correction for drift) between:

  $- 16.0 \pm 3.7$ and $+ 5.8 \pm 4.0$ µgal/$10^{\circ}C$

GL has also investigated the influence of the air temperature on the scale factor by measuring inside and outside a tower at temperatures $14^{\circ}C$ and $- 10^{\circ}C$ resp and has obtained for four gravimeters values between:

$$(-1.2 \pm 0.1) \cdot 10^{-3} \text{ and } (0.2 \pm 0.2) \cdot 10^{-3} \text{ µgal/day and } 10^{\circ}C \text{ change}$$

The results of the investigations above are applicable, when the gravimeters are allowed to fully adopt the new temperature. However, GL has also found that for the first hours after a temperature change the drift will become irregular and that the variations in the drift depend on the rate of change of the temperature. This makes it impossible to make a correct temperature correction in field conditions.

IfAG has found that temperature changes of 10°C have a maximum effect of ± 2 µgal.

THD has found that fast changes and one-sided influence (by wind, sun) are especially dangerous. Changes up to 40 µgal were obtained for a temperature change of about 20°C. Also the drift showed irregularities, which lasted for several days.

The gravimeter response to changes in temperature is not very consistent and irregularities appear, above all for the first hours after a change. The temperature must,therefore, be kept within close limits. Improved insulation, especially in the level region can help. A more elaborate approach would be to enclose the whole gravimeter in a thermostatically controlled box. This would ensure constant temperature during both the transportation and the observations, but it would require some form of remote control system.

In order to avoid the systematic temperature effect caused by the diurnal variation of the air temperature, the measurements should be started from the different sites symmetrically.

c Levelling error

It is doubtful whether the standard levelling system used in the gravimeters meets the requirements of high precision measurements. THD has e g found that the levelling error amounts to as much as ± 7.5 µgal. The inner surface of the glass vials may not be smooth, which can cause non uniform movements of the bubble. The length of the bubble, which depends on the temperature, influences the position of the bubble. This is one of the reasons for maintaining an even temperature. It can also be difficult to read the bubble ends accurately because of uneven illumination and parallax errors. Marks on the protecting glass could be a useful aid in eliminating the parallax errors. The best solution would be to replace the whole system, with, for example, electronic levels and levelling screws of matching accuracy. It should, in this connection, be pointed out that adjustment of the levels should be carried out in the same temperature interval as that within which the measurements are to be carried out.

d Clamping error

When unclamping the gravimeter an elastic after-effect can appear which can take the form of a short time drift. This will here be called "clamping error".

IfAG has found that the clamping error is dependent on the way in which the clamping and unclamping is carried out and recommends that it should be done carefully and always in the same way.

THD has determined the clamping error as an exponential function $Y = ax^b$. Deviations from this curve up to 10 μgal could be found, mainly within the first five minutes after the unclamping. By waiting about three minutes before taking readings the error drops to about ± 4 μgal.

GL has found that there is no reason to lengthen the observation time with some waiting time to reduce the effect of clamping, because the transport and temperature variations cause errors, which are essentially greater than the clamping error (see section e below). In addition the difference between transport temperature and the observation temperature causes the greater error the longer the waiting time is at the station.

LMV has found that different instruments seem to respond differently to the clamping. The accuracy obtained by some gravimeters was found to be hardly better when measuring gravity differences between stations a few tens of meters apart than when measuring stations hundreds of kilometers apart. This fact can probably be attributed to the clamping error. LMV now starts the readings four minutes after unclamping to minimize the error.

Summarizing: Gravimeters react differently to clamping. This must be investigated and the time, which must be allowed to elapse before beginning observations, must be determined accordingly. It should be noted that there are contradictory conditions: waiting too long to allow the clamping error to reach a minimum can increase other error sources, e g temperature changes, while reading too quickly can increase the risk of large clamping errors. In all circumstances, the observations should be carried out uniformly at all stations and the clamping and unclamping should be done gently and always in the same way.

e The reading system

The optical readings can be systematically affected by variations of the illumination both in the reading microscope and in the surroundings. The former can be avoided by keeping the accumulator voltage constant, the latter may be more difficult to avoid in field measurements. If it is necessary to observe in very different light conditions, the influence of this factor should be investigated to make it possible to compensate for its effect on the observations.

GL points out that the error caused by the variation in the outer illumination can be eliminated by symmetrical observations (at every station equal number of observations in dark and light circumstances). When setting the crosshair, GL has used either the left or the right side. Symmetrical setting is not possible with the variable illumination. If the beam were sharper and a little narrower than the distance between the reading lines, also symmetrical setting of it would be possible and so the effect of the variation in outer illumination would decrease.

THD has investigated the errors, which influence the readings at a station and has found the following m s e:

levelling error	± 7.5 μgal
clamping error	± 4 "
reading error	± 3 "
total error	± 9 μgal

This shows clearly the importance of diminishing the levelling error.

GL has investigated the reading accuracy in laboratory conditions. Measurements have been carried out on a 1 mgal calibration line, the Honkasalo base line, (consisting of six stations in a stair case) with several gravimeters and with many observation series, every series consisting of 36 observations (six sites and six times). The standard deviation of one observation, computed by adjustment, was ± 4.2 gal. This standard deviation consists of errors caused by clamping, levelling, transport between four steps, setting of the cross-hair and reading of the dial. Every individual error must then be smaller than the total ± 4.2 μgal. (In field conditions with transport of several kilometers, the accuracy was found to be about ± 13 μgal).

The nature of the optical reading system is such that it may be difficult to position the crosshair in a consistent way, even with equal illumination conditions. The electronic output system which LCR has introduced seems, therefore, to be an improvement. One drawback may be that this system seems to be more sensitive to microseism, which can make it necessary to introduce a filter in the circuit.

LMV uses both systems simultanously. The difference between optical and electronic readings should be constant. It has, however, been found that this difference changes, usually rather slowly, in both directions between extreme limits of about 10 μgal in an observation period of some weeks. But sometimes there are also sharper jumps. Whether these changes are due to the optical or the electronic system has not been clarified.

IfAG uses a device, where the gravity differences are compensated by means of an electromagnetic force, which can be determined from readings of a digital volt meter. This system eliminates the reading error to well below ± 1 μgal.

ELectronic reading systems have also the great advantage that they can fairly easily be connected to a recorder, which can be very useful especially for gradient measurements.

f Influence of air pressure on the gravimeters

Changing air pressure can affect the gravimeter readings. For the LCR gravimeters this effect is generally very small. However, different instruments react differently, for which reason an investigation in a low pressure chamber is necessary to determine the corrections which may be needed. To what extent the rate of change influences the results should also be investigated at the same time.

IfAG has found that a pressure change of 65 mbar had no appreciable effect on the reading.

THD has obtained similar results as IfAG but for fast pressure changes - more than 30 torr/minute - changes in readings amounting to 0.04 μgal/torr and minute were obtained.

GL has investigated five gravimeters and has obtained extreme values:

$$\text{from } -2.7 \pm 2.1 \text{ to } +2.1 \pm 0.6 \ \mu\text{gal}/100 \text{ mbar}$$

LMV has, for two gravimeters found:

$$-2.7 \text{ and } -2.4 \ \mu\text{gal}/100 \text{ mbar}$$

Clearly it is more important to take this effect into account, if the stations are at very different altitudes.

g Effect of the earth's magnetic field on the gravimeters

The gravimeters can become magnetized by an outer magnetic field or by vibrations during transport. Therefore the gravimeter response to the earth's magnetic field must be investigated.

IfAG found that, for the gravimeter with the electronic system mentioned in section e, a horisontal component of 0.15 Oersted gives an effect of $12 \cdot \cos \alpha$ μgal. (α = azimuth of the gravimeter beam). The influence of the vertical component was slightly less. These effects obtained by IfAG are quite large and may partly be due to the magnetic influence on the electronic reading system.

GL has investigated two gravimeters in magnetic fields amounting to -5 to +5 times the earth's field without finding any influence, but on another occasion an influence was revealed.

It is probable that gravimeters can have a sensitivity to magnetic fields which may vary from time to time. This must be investigated.

If they are sensitive, it is advisable to measure the earth's field to enable a sufficiently accurate correction. In all circumstances it is a good practice always to orientate the instruments in the same azimuth to minimize the influence of the horisontal component and also to avoid exposing them to magnetic fields, e g fields accompanying high voltage power lines.

h Calibration

The gravimeters should be calibrated to give gravity differences in the IGSN 71 system. This should be done in the same gravity range as the range of the study in question. As many calibration stations as possible should be used, but care should be taken to avoid stations where there is any risk for changed gravity value because of factors such as reconstructions or changed ground water level.

Calibrations as described above can only give a main scale factor. There are, however, a number of short period terms in the calibration function and to determine these the IGSN 71 stations are not usable.

GL has investigated errors of different periods (revolutions of the measuring screw) on different gravimeters. The results can be summarized as follows:

Period	Amplitude μgal	Number of gravimeters
1	2.0 ± 0.9 ——— 5.5 ± 1.3	4
3.94	1.9 ± 1.3	1
7.88	0.8 ± 0.25 ——— 15.3 ± 2.5	4
35.47	2.7 ± 0.3 ——— 11.8 ± 3.7	4
70.84	1.7 ± 0.3 ——— 19.8 ± 3.7	4
603	3.8 ± 2.4	1
1206	2.5 ± 4.8	1

In fact, as e g THD has shown, μgal accuracy is only obtainable when measuring small gravity differences, differences of a few mgal. It is then essential to determine the short period terms, especially the 1 period term of the calibration function. To enable this to be done, a number of internationally acknowledged short base lines should be established in different gravity ranges. Most important would be 1 mgal base lines with divisions in 5-10 steps. Part of the base lines should be further subdivided to suit investigations of the D-model.[x)] In addition, a special calibration line should be established in connection with every precise measurement. The gravity difference in this line should be about two or three times the gravity difference to be measured and the distance between the observation points only some meters. Therefore, the accuracy of this line should be very high. When the measurements of this calibration line is connected with the actual measurements, the scale of the measurements is then referred to the calibration line and, therefore, the scale can be reconstructed at any later time.

The calibration observations must be repeated at suitable intervals to determine possible time variations in the calibration function.

[x)] It should be taken into account that the 4 period term can have a significant influence on the determination of the 1 period term.

i Drift

At rest in laboratory conditions, the drift of the LCR gravimeter is small and generally very linear. In field work, the drift function will become more complicated because of shaking during transport, temperature changes, clamping effects etc. A linear term will now also be present. The rate of change may, however, be different between travelling and rest. To take care of irregularities, terms of higher order can be introduced. The best way to treat the drift mathematically can depend on the procedure according to which the observations are repeated at the stations and on the behaviour of the gravimeter.

IfAG, when computing the measurements on one of the Fennoscandian lines (chapter 3), determines one linear drift for each day, when repeated observations have been carried out. Otherwise an average linear drift is used.

THD has investigated how the standard deviation of unit weight depends on the degree of the drift polynomial. It was found that the largest improvement was obtained when going from linear to quadratic drift and that development above the fifth degree was meaningless.

GL, when computing the measurements on the Fennoscandian lines, uses a drift function of the form:

$$(at + bt^2) + cx + dh$$

where

- the terms within the bracket express the daily drift from an epoch $t = t_o$,
- cx, where x = the actual travel time, expresses a travel drift caused by the shaking of the gravimeter
- the drift dh indicates the jumps, which can be explained by some evident physical reasons.

Computation of 21 observation series showed:

- only the terms of first order were significant in 11 cases:
- terms of first and second order were significant in 10 cases
- travel drifts were significant in 6 cases

Attempts were also made to use terms of higher order than second, but no significant values were then found.

LMV divides the total observation period in a number of intervals. The division is based on a drift curve, which is constructed graphically. Within each interval a linear drift is determined.

To minimize the influence of the drift, it is important that the temperature is as equal as possible both at the stations and during transportation, as has been pointed out above. Systematic differences between the temperature at the stations, e g by always measuring one station in the morning and the next station always at noon, must be avoided.

The transportation time between the stations should be as equal as possible in both directions.

In this connection, the question of the most favourable observation scheme arises. E g when measuring a line of stations, should the whole line be measured in the forward and reverse direction a number of times, should one section at a time be observed the required number of times or should some combined method be used?

It should also be noted that, if several gravimeters are used and transported in the same car, a correlation between the results obtained with the instruments may exist. It would, therefore, be advantageous, if they could be transported in different cars.

In this connection, the importance of formulating objective rules for rejecting dubious observations must be emphasized, as such observations can have a comparably great influence on the final results.

2 Physical corrections

a Tidal correction

The tidal correction should be calculated using a theoretical formula giving an accuracy better than 1 μgal. The Cartwright-Tayler-Edden development seems to be the best now available. THD has investigated and compared some other formulae with the above mentioned and has found the following m s e:

Bartels's	± 1.39 μgal
Longman's	± 1.77 "
Goguel's	± 5.28 "

THD has also investigated the accuracy in position necessary to obtain 1 μgal accuracy in tidal correction and has found for latitude 45°:

Maximum error in latitude:	7'.2
Maximum error in longitude:	40 s

Errors in longitude and time are corresponding. The value 40 s above, therefore, also indicates that the observation time must be read with an accuracy of about 1 minute.

The amplitude factors and phase delays should be taken into consideration. They can show regional (or local ?) variations. To determine relevant values it would, therefore, be very advantageous, if earth tide recordings could be carried out within the investigation area, simultaneously with the gravimeter observations.

The error caused by the uncertainity in the amplitude factors will diminish, if the observation programme is planned in such a way that the average tidal correction at every station is small.

GL points out that different computer programmes can give results which differ by some microgals from each other. Therefore, it is important that programmes are checked carefully before the computation in order to avoid errors. To help comparisons GL is preparing a detailed description of its own programme.

b Loading effect

For near-ocean stations (out to about 100 km according to THD) the loading effect should be computed. It should also be investigated, whether there is a loading effect caused by different water levels in the lakes or by different depths of snow. The seasonal character of these effects should be especially noted as well as the possibility of delayed loading effects.

c Influence of air pressure on gravity

Variations inpressure changes the gravity at a station because the mass of air above the station will change. Theoretically, the relation should be - 0.43 µgal/mbar. However, the earth's crust is deformed by the pressure, which reduces this factor. Investigations have given results between approximately - 0.1 and - 0.4 µgal/mbar. Thus the value of the factor seems to be dependent on local conditions. Earth tide recordings within the investigation area,as recommended for determination of tidal corrections,can also be analyzed to determine this factor.

Using an appropriate value for the air pressure factor, the observations should be corrected, from the gravity value at the prevailing air pressure,to the gravity value at a standard air pressure at the station (normal air pressure at the altitude of the station).

d Effect of changes of ground water level

The effect of changes of ground water level can be difficult to compensate for. If the aim of the investigation is not to study this phenomenon, the sites should be selected so as to minimize the risk of gravity changes due to this influence.

e Effect of vertical movements

It is evident that stations should be stable, preferably placed on bedrock, thereby minimizing more or less local vertical movements caused by changing ground water etc. But there are also other kinds of movements, e g the Fenno-scandian land uplift and movements caused by tectonic forces. The station heights should, therefore, always be checked by appropriate levelling in order to reveal any vertical movement.

f Gravity gradients

The individual gravimeter heights above the reference mark should be reduced to a common height. For small height differences, the free air reduction is sufficient, but if they exceed, say 50 mm, the actual vertical gradient should be determined to enable a sufficiently accurate reduction. It should be noted that it is the height of the gravity sensing unit that matters and this can, vary if different types of instruments are used.

Also the horizontal gradient can in, certain circumstances, have an unacceptable influence. THD has in order to examplify this computed the influence of a wall of the dimensions 0.27 x 50 x 20 m and density 1.89 g/cm^3 at different distances from its gravity center. The following values were obtained:

Distance	dg_i	$dg_{i+1} - dg_i$
cm	μgal	μgal
10	- 28.3	2.5
20	- 25.8	1.7
30	- 24.1	1.4
40	- 22.7	1.1
50	- 21.6	1.0
60	- 20.6	

To avoid errors, the instruments should be placed in the same position as near the reference mark as possible. If a special type of instrument does not allow this, the horizontal gradient should be determined.

g Topographic corrections etc

In certain investigations the topographic or perhaps the isostatic correction has to be added. Such corrections must, naturally, be calculated with an accuracy compatible with the measurements themselves. This puts special demands on the knowledge of the topographic features and the computation methods, which should be investigated.

3 Applications for practical and scientific purposes

High precision gravimetry methods can be applied to many tasks. Some of the most important are:

- to connect absolute gravity stations or other special stations to the World Net, to establish special calibration lines and to make an accurate survey for special geodetic or geophysical purposes

- to determine the vertical gradient, which can be used for geophysical purposes, especially for detailed density studies, and which will also be of increasing importance in physical geodesy for solution of the boundary value problems.

- to determine non-tidal gravity changes by means of observations, repeated within resonable time intervals, e g for studies of changes of ground water level or of gravity changes related to tectonic activities or secular land uplift.

Below will now be given some results of certain high precision gravimetry observations carried out by the members of the panel.

a Determination of the vertical gradient

IfAG has determined vertical gradients. A special stand allowing observations at two levels, about 1.5 m apart, has been constructed. Using the gravimeter with electric compensation mentioned in section 1 e and a recording system, very good results have been obtained. E g from five observations at the higher and four observations at the lower level on each of two consecutive days, the following gravity differences were obtained:

1st day: 445.4 μgal   2nd day: 444.7 μgal

The standard deviation of one observation became for the two days: ± 1.16 resp ± 1.57 μgal.

The difference between the two height levels was 1.458 m on both days. The vertical gradient then becomes:

1st day: 305,5 μgal/m   2nd day: 305.0 μgal/m

b Observations on the Fennoscandian lines for the study of secular change in gravity

This study was initiated by GL. At present, three lines running across Finland, Sweden and Norway have been observed. They are (in order according to the year of the first observation):

Vågstranda - Joensuu (V-J), consisting of 8 stations at about latitude 63°.

Korgen - Kuhmo (K-K), consisting of 9 stations at latitude 64° - 66°.

Bergen - Virolahti (B-V), consisting of 10 stations at latitude 60° - 61°.

The distance between consecutive stations in the lines varies between 70 and 300 km. The stations are situated on bedrock and marked with brass or steel bolts. The gravity values of the stations in respective line are equal within 0.2 - 1 mgal Observations of the whole or of part of the lines have been carried out as follows (NGO = Norges geografiske oppmåling, Oslo):

Line	Years	Institute
V-J	1966, 1967, 1971, 1972, 1973	GL
	1967, 1972	LMV
	1971, 1972	THD
	1972	NGO
	1975	IfAG
K-K	1975	GL, LMV, NGO
B-V	1976	GL, LMV, NGO

Generally, each observation group uses 2 to 4 gravimeters. In all, 16 different gravimeters have been used on these lines. Normally, each group carried out 6 to 8 singel runs between the stations during each observation period. Many of the points of view given in chapters 1 and 2 above have been taken into account, to an increasing extent during the later years as new experiences have been gained. To examplify what can be obtained from observations of this kind some data are given in tables 1-3. It must be emphasized that some of the data are preliminary and the given values should, therefore, be regarded only as illustrations for the present purpose and not used otherwise. To underline this, all the values are given in whole μgals, even though they are given with decimals in the original papers.

Table 1 shows the standard deviation of one observation obtained for different gravimeters in different observation periods. It shows that there are great differences between the instruments: e g no 24 is clearly a poor instrument. A good instrument should give a standard deviation around ± 15 μgal and a very good one about ± 10 μgal.

Table 2 and 3 show examples of the results obtained. From these it can be seen that when observing as outlined above the resulting values of different gravimeters often can agree within a few μgal, but that occasionally differences up to about 30 μgal can be obtained. Sometimes a certain gravimeter can differ systematically from the others without any obvious cause, which may indicate that there are still unknown effects which influence the behaviour of the gravimeters.

Using 3 to 4 gravimeters and making 6 to 8 single measurements a m.s.e of $\pm 2 - \pm 4$ μgal is obtainable. However, some still unidentified systematic errors may bias the results. On the line Vågstranda - Joensuu rather many measurements have been carried out in 1966-1975. There are some indications of unexpected gravity changes, but the results are partly somewhat contradictory and, in spite of the quite high accuracy, the time interval seems to be too short to give significant values of the small changes, which are dealt with here.

Repeated gravimeter measurements can, naturally, only give relative changes of gravity, but they could be transformed into absolute changes, if also some repeated supplementary absolute gravity determinations could be carried out. This will be done on the Fennoscandian lines, where a first absolute gravity determination was made in 1976 at one station near each of the three lines.

4 Some remarks on the presentation of results

Especially in studies, where measurements are likely to be carried out by different institutes, with different types of instruments or in a long space of time, it is very important that certain information regarding the computation procedure is clearly stated. Otherwise, it may be difficult, or even impossible, to make correct comparisons between the results. It is the physical corrections discussed in chapter 2 that must be accounted for, if possible in tabular form, in connection with the final results. Especially the following three corrections should be specified:

i Correction for earth tides

- formulae

- value of amplitude factor(s) and phase lag(s)

- mean value of the tidal correction at the two stations for each observed gravity difference

ii Correction for influence of air pressure on the gravity

- mean value of the observed air pressure at the two stations for each observed gravity difference

- standard air pressure for each station

- factor for reduction of gravity at observed air pressure to standard air pressure iii Correction for instrumental heights

- mean instrumental height above reference mark at the two stations for each observed gravity difference

- common instrumental height to which the observations are reduced

- value of the gravity gradient used for the reduction

Note. Definition of the instrumental height (e g as height of the top plate or a certain foot screw above the reference mark) should be stated as well as its relation to the height of the gravity sensing unit.

Table 1

Observations on the Fennoscandian lines: standard deviation of one observation for different gravimeters for different years.

	Standard deviation of one observation ± μgal						
LCR no \ year	1966	1967	1971	1972	1973	1975	1976
24		27 25 39					
45				17			
54				16		9	10
55	13	17 14 19	13 9	13 14	18		10
62	15		8 8	8 12	10		
67	15						
69	18	17 8 20					
100			8 4	17			
115		13					
120						10	10
139						22	24
142				19			
195				23			
258				28			
290				24		22	24
380						6	

Table 2

Some results of the measurements on the Fennoscandian line Vågstranda - Joensuu.

LCR no	Year	Gravity difference and m s e in μgal		
		Kopperå - Stugun	Kramfors - Vasa	Vasa - Äänekoski
45	1972	- 535 ± 7		
54	1972	- 533 ± 6		- 508 ± 6
55	1971		- 496 ± 4	- 476 ± 6
	1972			- 488 ± 6
	1972	- 547 ± 6		- 508 ± 6
	1973			- 488 ±14
62	1971		- 484 ± 4	- 472 ± 4
	1972			- 489 ± 4
	1972	- 537 ± 5	- 484 ± 6	
	1973			- 478 ± 5
100	1971		- 495 ± 2	- 476 ± 4
	1972	- 543 ± 7		
142	1971		- 499 ±11	- 508 ± 9
	1972	- 532 ± 7		
195	1972	- 527 ± 7		- 504 ± 9
258	1971		- 504 ±12	- 509 ±10
	1972	- 527 ± 9	- 476 ±11	
290	1972	- 548 ± 8	- 486 ± 9	
380	1975	- 537 ± 2		- 487 ± 2

Table 3

Some results of the measurements in 1975 on the Fennoscandian line Korgen - Kuhmo.

LCR no	Gravity difference and m s e in μgal		
	Umbukta - Stensele	Sävar - Kalajoki	Kalajoki - Haapavesi
45	3	121	- 33
54	- 3 ± 3	129 ± 3	- 38 ± 3
55	- 11 ± 5	129 ± 4	- 38 ± 4
69	- 11 ± 5	128 ± 4	- 46 ± 5
100	- 16	127	- 39
120	0 ± 4	123 ± 4	- 37 ± 4
139	9 ± 8	123 ± 8	- 36 ± 8
290	11 ± 8	136 ± 8	- 36 ± 8
378	- 18	116	- 45