REDUCTION OF GRAVIMETRIC DATA USING AN INTEGRATED COMPUTER PROGRAMME

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Abstract

Gravimetric method of geophysical prospecting requires a methodical combination of both field techniques and data processing. For example drift correction in data processing cannot be successfully carried out without an a priori well-structured observational sequence during field observation that takes cognisance of both the instrumental and diurnal drift effects. The rigour of gravimetric data collection, and the non-availability of comprehensive data reduction software that takes care of local peculiarities, have always constituted hindrance to the application of the gravity method of geophysical studies. However, in recent time, the importance of the gravity method in mineral prospecting and geodynamic studies, has spurred researchers into the use of it. This programme is designed bearing in mind the need to include all the requirements for an all-embracing, up-to-date and exhaustive data reduction scheme. Therefore, the programme begins with systematic conversion of the gravimeter scale readings into an appropriate gravity unit, followed by a comprehensive drift correction routine, which employs the cascade model. The programme has a built-in mechanism, which automatically ties the survey to the international reference standard and computes the theoretical absolute gravity value at every station projected to the reference ellipsoid at the given latitude. In addition, the programme also calculates the observed absolute gravity value at every station, from which the various gravity anomalies are determined. A portion of the programme makes use of altimeter data, if available, to compute the elevation of the gravity station about the mean sea level, and return the result to an output data file. The programme is structured in modular form in order to enhance its flexibility, and with appropriate comment facilities in order to aid its comprehensibility.

Keywords: Gravimetric, data, reduction, computer, programme, sequence, modular, cascade, model

Introduction

With the advent of computers in research, scientific data processing has been made easy. Difficulties in data processing vary from one geophysical method to another depending on the complexity of the corrections to be carried out and the precaution to be taken during data collection. In employing the gravity method, complicated but systematic sequence of observations and a series of corrections are involved. Osazuwa (1991, 1992) outlined the methods of observation in a gravimetric network. Similar sequences of observation are discussed in Telford et al (1976), Dobrin (1976), Dobrin and Savit(1988). Other effects in gravimetric measurement are the drift of the gravimeter arising from the creep of the zero-length spring and the drift arising from the external tidal effect. Since the observer has no direct control on the trends that the various drifts can follow, an observational technique can be adopted in order to determine the amount of drifts involved. Therefore Osazuwa (1988) formulated and designed a cascade model

for the elimination and hence removal of drift from gravimetric data.
The major hindrance in employing gravity method for geophysical prospecting and geodetic studies is the lack of comprehensive gravity data reduction algorithms (or computer programmes). This work has succeeded in achieving this task through the design of an integrated computer programme, which combines all the corrections required for the refinement of raw gravimetric data, without which reliable gravity interpretation cannot be obtained.

Programme Structure

Variables

The important variables are described below. For simplicity, the variable names, as used in the programme, are retained in the description.

SNO: Station number which can be specified with 8 alpha-numeric characters.

MAP1, MAP2: The two variables are combined to constitute the station name or map description of a station. Each consists of 8 characters. Thus, a station name can have 16 characters.

XLAT: The latitude of the station.

YLON: The longitude of the station.

T: The time of observation in GMT.

ABG1, ABG2: These are the initial and terminal absolute gravity values for the base station(s) selected for drift correction. If one and the same station is used for the drift control, them ABG1 and ABG2 will each be zero.

ABSGF: The absolute gravity value of the reference station against which the absolute gravity values of other stations within the same loop are determined. Any station in the loop (not necessarily a base station) whose absolute gravity value is known, may be used as a reference station.

NOB: An index number which represents the number of observations in a loop.

IYR, MTH, IDY: Year, Month and Day of observations respectively.

DRC: Estimated drift correction.

DRG: Drift corrected observed gravity value.

TDC: Estimated tidal correction.

GTC: Tidal corrected observed gravity value.

H: Station elevation.

RG: Normal gravity.
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FANOM: Free air anomaly.

BANOM: Bouguer anomaly.

R: Instrument reading.

GMET: Gravimeter code number; it is made up of four alpha-numeric characters.

MGAL: Milligal (*mGal*) value of the instrument reading, R.

TC: A number which specifies whether or not there should be tidal correction. If TC is zero, no tidal correction is required. But if TC is either negative or positive integer then tidal correction will be required. Note: for tidal correction, TC can be assigned any positive or negative non-zero integer.

SNF: Reference station number whose absolute gravity value ABGF is known.

ABSG: Absolute gravity value at a station.
AGTC: Observed value, whether corrected for tidal effect or not, which is used for the drift computation in SUBROUTINE DRCVAL.

Note: GTC = MGAL + TDC, and GTC is returned as AGTC before the call to DRCVAL is made. AGTC = MGAL if TDC = 0 that is if tidal correction is not effected; in other words, only AGTC is carried over to SUBROUTINE DRCVAL.

CONS: Instrument constant for a single-constant gravity meter like Worden, Sharp, LaCoste and Romberg model D *etc.*

ID: Index number which determines which records are to be read from the tidal table. For this purpose, all observations are arranged sequentially on daily basis. Each day is assigned an integer. For example if there are twenty days of observations, ID will be assigned values from 01 to 20.

STC: Standard time correction. This correction is necessary in order to adjust local times to the standard universal time (UT) or GMT, the value of STC is the difference between the local time and the universal time. STC can either be positive or negative depending on whether the local time is ahead or behind the universal time. This correction may also be applied in regions of the world where the local time is varied during the summer season.

ACOMP: Determines whether altimeter computation is required in order to evaluate station elevation, H. ACOMP = 0 implies that no altimeter computation is required.

ACALF: Altimeter calibration factor; maximum of three altimeters are supported in this programme.

SNAR: Altimeter reference station number.

NALT: Number of altimeters used; the maximum value for this variable is 3, since three altimeters are supported in the programme.

HFM: Conversion factor from feet to metres.

REFH: Reference height for the computation of heights (elevations) at other stations from altimeter data.

Subroutines

START

For other gravimeters with single constant values, the conversion is done outside this subroutine in the calling subprogram. The relevant conversion formula is given by

$$\Delta g_R = \Delta g_{R_0} + (R - R_0)C \qquad (1)$$

where

Δg_R is the upper interval gravity value for the range of conversion,

Δg_{Ro} is the lower interval gravity value for the range of conversion,

R is the instrument scale reading to be converted to *mGal*,

R_0 is the nominal lower scale value for the interval,

C Scale conversion-factor for the interval.

ELEVATE

This subroutine computes the height, H, from altimeter readings on which humidity correction has been carried out.

GVALUE

This subroutine makes use of the scale conversion factors of the LaCoste and Romberg (LCR) gravity meter (LaCoste and Romberg instrument manual for the relevant model and year of manufacture) to convert field readings to gravity values in *mGal*. Only the range of the instrument for a particular country or region is built into the program. As many instruments as possible can be included in the subprogram; all it requires is first to establish the range of the LCR gravimeter over the country or region. This can be done by observing the gravimeter along a suitably established standard gravimeter calibration line for the country or region. In this subprogram the ranges of LCR G446, G464, G468 and G512 determined for Nigeria are, incorporated. A value MGAL for each of the observations computed using equation (1) is returned to the calling subprogram.

TIDALC

This subroutine computes the tidal correction using the tidal correction tables published by the European Association of Exploration Geophysicist (EAEG). The tidal tables are published on annual basis. In fact, the tables for a particular year are published in December of the preceding year. For an epoch of observations, record, each of length 75 bytes, are extracted appropriately from the EAEG tables into a super table whose number of records is equal to twice the number of observation days. The records are arranged serially and sequentially according to the days of observation. An identification index, ID, identifies which records are to be read from the super table stored in the input file called TIDTAB.

Data are arranged into TIDTAB with the following dimension INS (I, J, K): I is the total number of days that actual observations were made (that is number of observation days); J is always 25, that is 24 hours data points in a day plus one hour data point overlap into the next day (it should be noted that data are arranged in the EAEG tables at hourly intervals); K is always 2 representing the two segments of the table. For K = 1, data are taken from the north (N) segment of the tidal table, while for K = 2 data are read from the south (S) segment of the tidal table which has now been condensed into a super tidal table. If for example I is 10 observation days, the number of records in the super table with be 20, that is 10 for N and 10 for S. This reduces the task of encoding the entire EAEG tidal table into the computer, thus saving time, space and, of course, money.

Before data are read, the super tidal table TIDTAB is first of all rewound. This is necessary in order to read the appropriate data from the table correctly. The computation of the tidal correction is made using the equations given by Goguel (1954).

$$C = P + N \cos\varphi (\cos\varphi + \sin\varphi) + S \cos\varphi (\cos\varphi - \sin\varphi) \quad (2)$$

The first term P (the correction required at the pole) is always negative and varies slowly and it is single-valued for each day. Since only the difference in correction value is required, as is often the case in gravimetric observations, the term P can be ignored (see Tidal Gravity Corrections, 1988 P. 1 or any year as the case may be). Equation (2) becomes

$$C = aN + bS \quad (3)$$

where

$$a = \cos\varphi (\cos\varphi + \sin\varphi) \quad (4)$$

$$b = \cos\varphi (\cos\varphi - \sin\varphi) \quad (5)$$

and φ is the latitude of the station.

The terms N and S are the corrections at latitude 45° N and 45° S respectively when P is ignored. At any other latitude φ, N and S must first be multiplied by the respective coefficients a and b then added to yield the desired correction. For further detail on how to use the tidal table, the reader is referred to the tidal gravity correction of the appropriate year. The tidal corrections were computed for the meridian 15°E and 75°W of Greenwich and for the times corresponding to these meridian. They can also be used for the opposite meridian, that is, 165°W and 105°E of Greenwich respectively, by interchanging the values of N and S. For greater accuracy, 4 min for each degree east of the central meridian of the time zone was added or subtracted for each degree *east* or *west* respectively of the central meridian of the time zone (see tidal gravity corrections, 1988, page 1 or any year as the case may be). For example the Nigerian central meridian is based on longitude 15°E and therefore the Nigerian local time is 1 hour ahead of the GMT.

DRCVAL

This subroutine calculates the drift correction and the absolute gravity values at the stations. The method of drift correction employed is based on the cascade model designed by Osazuwa (1988). A test of the various observational sequences is carried out in order to effect the appropriate drift correction within a loop on daily bases. If the daily observations are properly controlled as recommended by Osazuwa (1988), all repeated observations at the same base station must have the same drift corrected value.

DRIFT

This subroutine carries out the actual computation of the drift correction. The subroutine is called by subroutine DRCVAL after the later has tested the observational sequence used. The theory of the drift correction is given below. Let μ be the drift rate within a particular loop then,

$$\mu = \frac{g_A - g_B - \left(\bar{g}_A - \bar{g}_B\right)}{\left(t_B - t_A\right)} \qquad (6)$$

where g_A and g_B are the absolute gravity values at base stations A and B respectively, which terminate the corresponding loop;

$\bar{g}_A$ and $\bar{g}_B$ are the observed gravity at stations A and B at times t_A and t_B respectively. If measurements within a loop is closed on one and the same base, then

$$g_B - g_A = 0 \qquad (7)$$

This is the case when a single base loop is adopted for the observations. At any intermediate station within the loop, the required drift correction, for measurement taken there at time t_S with respect to time t_A is given by

$$\delta_s = \mu\,(t_S - t_A) \qquad (8)$$

ABSVALUE

This subroutine computes the absolute values of, height, H, or gravity, ABSG, and returns the result to the appropriate section of the programme.

GRANOM

This subroutine computes the free air anomaly and the Bouguer anomaly.

PRINTAL

This subroutine prints the results in three output files, containing absolute gravity values, Bouguer anomaly values and Free Air anomaly values respectively.

Functions

In order to facilitate computation, the following functions are built into the programme. Each of them perform a specific task as explained.

FAC

The function computes the free air correction. It has on its arguments the latitude, XLAT and elevation, H at each station. It does double precision arithmetic.

BBC

The function computes the Bouguer and Bullard term corrections. Details of the Bullard term correction is given by Officer (1974). The function has as its arguments the station elevation, *H*, the radius of the earth, *R* (in metre) and the Bullard factor, PHI (= 1.4994444).

GRAVNORM

The function computes the theoretical (or normal) gravity *utilising* the 1967 Geodetic Reference system (GRS' 67) by Morelli *et al.* (1974) The only parameter in its argument is the latitude, XLAT, of the station.

TCONV

This function converts time (in hour, minute and second) or geographical coordinates (in degree, minute and second) to decimal hour or decimal degree respectively.

Input Files

The input files contain different sets of data (coded numerical values) arranged in sequential order, which the programme requires, at various stages, to carry out the necessary computations. In this programme, the input data are in three sets.

First set of input data substitutes for the following respective set of variable parameters together with *their specified* dimensions, if any, as defined in the programme:

TC, CONS, ACOMP, NALT, HFM, (ACALF(J),J=1,NALT).

Second set of input data, as defined in the programme, is:

NOB, IYR, MTH, IDY, GMET, STC, ABG1, ABG2, ABSG, REFH, SNF, SNAR, ID.

Third set of input data, with their specified dimensions as defined in the programme, is: SNO(I), MAP1(I), MAP2(I), XLAT(I), YLON(I), (AH(I,J),J=1,NALT), T(I), R(I); where I=1,NOB.

Output Files

The output files contain different sets of data (coded numerical values) arranged in sequential order, which the programme requires, at various stages, to transmit the results of the computations carried out. In this programme, there are five sets of output files into which the results are transmitted. Texts can also be written into an output file in order to explain what the data represent.

First output file contains data represented by the following respective variable parameters: IDY, MTH, IYR, GMET, ABG1, ABG2

Second output file contains data represented by the following respective variable parameters:
SNO(I), MAP1(I), MAP2(I), XLAT(I), YLON(I), T(I), MGAL(I), DRC(I), DRCG(I); where I=1,NOB.

Third output file contains data represented by the following respective variable parameters:
SNO(II), MAP1(II), MAP2(II), XLAT(II), YLON(II), T(II), MGAL(II), TDC(II), GTC(II), DRC(II), DRCG(II); where II=1,NOB.

Fourth output file contains data represented by the following respective variable parameters:
SNO(J), MAP1(J), MAP2(J), XLAT(J), YLON(J), H(J), R(J), RG(J), ABSG(J); where J=1,NOB.

Fifth output file contains data represented by the following respective variable parameters:
SNO(K), MAP1(K), MAP2(K), XLAT(K), YLON(K), H(K), FANOM(K), BANOM(K); where K=1,NOB

Conclusion

This programme has been used extensively since the past three decades to reduce land gravity data, and in the process, it has undergone several modifications. The drift correction subroutine is based on the cascade model designed by Osazuwa (1988). This model has also been modified to take care of all possible combinations of observational techniques. In its present form the drift computation has been rewritten to remove the repetition of the value of the first station in the loop during the transmission of the result into the output file. After the application of the drift correction, the repeat observations at any station in a given loop retain the same value; this is a test of the reliability of this gravity reduction programme. The current setback of the programme is that the tidal correction subroutine can no longer be used in reducing gravity data collected after 1994 when the production of the tidal correction tables by the European Association of Geophysicists and Engineers (EAGE) was discontinued. The tables are now replaced by another software, which predicts tidal correction over a long period of time. This programme has been modified to include the software mentioned above, so that all computations will be done within the programme and not partly outside. This computer programme, in its present form, is available from the author.

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