Jour. Korean Earth Science Society, v. 24, no. 3, p. 205–215, April 2003

On the Improvement of Precision in Gravity Surveying and Correction, and a Dense Bouguer Anomaly in and Around the Korean Peninsula

Kwang-sun Choi[1,*] · Chul-soo Yang[2] · Young-hong Shin[3] · Soo-suk Ok[4]

[1]Dept. of Earth Science Education, Pusan National University, Pusan 609-735, Korea
[2]Cadastral Technology Education & Research Institute, Korea Cadastral Survey Corporation,
Yongin-city, Kyunggi-do 449-050, Korea
[3]Dept. of Earth Science Education, Pusan National Univ., Pusan 609-735, Korea
[4]Kyungsung University, Pusan 608-736, Korea

한반도 일원의 중력측정 및 보정의 정밀화와 고밀도 부우게이상

최광선[1,*] · 신영홍[2] · 양철수[3] · 옥수석[4]

[1]부산대학교 사범대학 지구과학교육과, 609-735, 부산광역시 금정구
[2]부산대학교 사범대학 지구과학교육과, 609-735, 부산광역시 금정구
[3]대한지적공사 교육연구원, 449-050, 경기도 용인시 운학동
[4]경성대학교, 608-736, 부산광역시 남구 대연3동

Abstract: A precise and dense Bouguer anomaly is one of the most important data to improve the knowledge of our environment in the aspect of geophysics and physical geodesy. Besides the precise absolute gravity station net, we should consider two parts; one is to improve the precision in gravity measurement and correction of it, and the other is the density of measurement both in number and distribution. For the precise positioning, we have tested how we could use the GPS properly in gravity measurement, and deduced that the GPS measurement for 5 minutes would be effective when we used DGPS with two geodetic GPS receivers and the baseline was shorter than 40km. In this case we should use a precise geoid model such as PNU95. By applying this method, we are able to reduce the cost, time, and number of surveyors, furthermore we also get the benefit of improving in quality. Two kind of computer programs were developed to correct crossover errors and to calculate terrain effects more precisely. The repeated measurements on the same stations in gravity surveying are helpful not only to correct the drifts of spring but also to approach the results statistically by applying network adjustment. So we can find out the blunders of various causes easily and also able to estimate the quality of the measurements. The recent developments in computer technology, digital elevation data, and precise positioning also stimulate us to improve the Bouguer anomaly by more precise terrain correction. The gravity data of various sources, such as land gravity data (by Choi, NGI, etc.), marine gravity data (by NORI), Bouguer anomaly map of North Korea, Japanese gravity data, altimetry satellite data, and EGM96 geopotential model, were collected and processed to get a precise and dense Bouguer anomaly in and around the Korean Peninsula.

Keywords: Bouguer anomaly, network adjustment, GPS measurement, terrain correction, PNU95 geoid model

요 약: 정밀하고 밀도 높은 부우게이상자료는 지구물리학과 물리측지학적인 측면에서 중요한 기초자료가 된다. 이를 위해서 정밀한 절대중력기준점망의 설치외에도 두 가지 측면을 고려해야 하는데, 하나는 중력측정과 보정의 정밀도를 향상시키는 것이며, 다른 하나는 측점의 밀도를 높이는 일이다. 중력측정에서 GPS를 어떻게 적절히 이용할 것인가에 대해서 알아보았는데, 40km 이내의 기선거리에서 두 대의 측지용 GPS수신기를 이용하면, 5분간의 GPS 측정으로도 충분하다고 여

---

*Corresponding author: ksunchoi@pusan.ac.kr
Tel: 82-51-510-1626
Fax: 82-51-513-7495

겨진다. 이 경우 PNU95 지오이드모델과 같은 정밀한 지오이드모델을 사용하여야 한다. 이 방법을 적용함으로써, 비용 및 시간과 인력을 줄일 수 있을 뿐만 아니라 질적인 측면에서도 향상을 가져온다. 또 교점오차를 보정하고 지형효과를 정밀하게 계산하기 위해 컴퓨터 프로그램을 개발했다. 중력탐사에서 같은 지점에서 중복 측정하는 것은 스프링의 변이를 보정하는 것뿐만 아니라 망조정을 적용함으로써 결과들에 대해 통계적으로 접근하는 것을 가능하게 한다. 그럼으로써 다양한 원인에 기인한 큰 오차를 쉽게 찾아내고 보정하여 자료의 질을 향상시킬 수 있으며, 또한 측정의 질을 평가할 수 있다. 최근의 컴퓨터 기술과 디지털 고도자료의 발달도 좀더 정밀한 지형보정을 사용하여 부우게이상의 질을 향상하도록 우리를 고무하고 있다. 본 연구에서는 육상중력, 선상중력, 북한의 부우게이상도, 일본의 중력자료, 고도위성자료, EGM96 지오포텐셜 자료 등, 다양한 중력자료를 입수하였다. 따라서, 이들 자료를 계산하고 편집하여 한반도 일원의 정밀 부우게이상도를 작성할 수 있었는데, 이것은 지구물리학과 물리측지학의 응용에 유용한 자료가 될 것이다.

주요어: 부우게이상, 망조정, GPS측정, 지형보정, PNU95 지오이드모델

Introduction

Not only the improvement of gravity meter, but also the development of positioning technology such as GPS and computer technology have made the error reduced in gravity surveying and correction of it. And we are also able to get the gravity data densely with less expense and labor. To make the gravity data precise and dense would be useful for the development in the field of geophysics and physical geodesy. So the paper will focus on the development of the efficient surveying method and correction tools, and on the collecting the various kinds of gravity data in and around the Korean Peninsula.

To advance the surveying method in gravity measurements, we adopted the GPS method, the newly developed global positioning technology, because this method is one of the most precise and easy tools in positioning. The precise positioning in gravity surveying is so important, because the gravity and its anomalies are sensitive to height, latitude and longitude.

To advance the precision in gravity processing, we considered how we should deal the crossover errors and terrain effects. For this purpose, we developed two computer programs; one is to adjust the crossover errors based on the least squares method, and the other is to calculate the terrain effects based on digital terrain data and several formulas derived by some scientists.

And we also collected and compiled gravity data of several kinds of sources to make a dense Bouguer anomaly data. The gravity data collected up to 1995 were

1) land gravity data of 5,249 points in South Korea,

2) marine gravity data around the Korean Peninsula by NOAA(National Oceanic and Atmospheric Administration of U.S.),

3) 5' × 5' mean free-air anomaly data by Fukuda of Tokyo Univ., Japan,

4) altimetry satellite data, and 5) OSU91A(Ohio State University Global Geopotential Model 1991A).

The 3), 4), 5) data above are free-air anomaly data.

The newly added gravity data after 1995 were

1) newly surveyed land gravity data in South Korea up to 6,086 points besides the repeatedly surveyed points,

2) marine gravity data surveyed by NORI (National Oceanographic Research Institute of South Korea) during 1996-2000,

3) Bouguer anomaly map of North Korea,

4) altimetry satellite data, and

5) EGM96 (Earth Gravity Model 1996) global geopotential model.

On the improvement in gravity surveying and corrections

The GPS in gravity surveying

To calculate the gravity anomaly, we should know the normal gravity at the surveying points, which is the function of latitude. And the measurement position (latitude, longitude and height) and time are also important in terrain correction and tidal correction. So, it is a very important problem to improve the precision not only in the gravity measurement itself but also in the positioning.

To obtain the precision of 0.01mGal in gravity surveying, we should know the resolution of latitude within about 10m (about 0.3 arc second) and height within 3cm. It is not realistic to meet this precision in regular gravity surveying, except some surveys of special purpose. So the precision within 0.1mGal in gravity anomaly data have been considered to be a good results.

The modern technology of GPS (global positioning system) make the precision of 0.1ppm of baseline (1cm precision within 100km baseline) possible when the DGPS method with two or more geodetic GPS receiver is used. The conventional surveying methods can not meet this precision but their precision be only 1ppm of baseline, and the more these are limited by the weather, sight and distance. But the GPS surveying is less influenced by the factors mentioned above and the precision is also better about 10 times than the conventional methods. So the GPS is well used to build a precise national geodetic network, GIS, LIS, and etc. (Leick, 1990; Wellenhof *et al.*, 1994).

The precision of GPS is depend on observing time, in other words, we should receive the GPS signal for a long time to get a better precision. Then a question is occurred, "how long should we observe the GPS signal in gravity surveying considering time expenses and precision needed?" And another problem is occurred in height determination. The height obtained directly by GPS is the ellipsoidal height referring WGS84 ellipsoid, but we should use the orthometric height, height above mean sea level. So we should derive the orthometric height from the ellipsoidal height by the simple relation,

$$H_{orthomeric} = H_{ellipsoid} - H_{geoid} \pm \Delta H_{reference}$$

$H_{orthomeric}$: Orthometric Height

$H_{ellipsoid}$: Ellipsoidal Height

H_{geoid}: Geoidal Height

$\Delta H_{reference}$: Errors on the reference station or N_0

In this case, we should know the geoidal height above the reference ellipsoid. Fortunately, we already have a precise geoid model, the PNU95 (Pusan National University Geoid Model 1995 by Choi *et al.*, 1997).

Choi *et al.* (1998) have tested GPS precision according to the first order level Bench Mark line 8, newly constructed and surveyed by NGI (National Geography Institute). They used two geodetic GPS receivers, Trimble 4000SSi, and set one receiver as a reference station on BM8-10. The observing time on each BM was over one hour and the baselines ranged from 1.7km to 37.1km.

As the results of 5 minutes observations, the standard deviations of latitude and longitude were distributed within about 1cm, and the height difference within 10cm referring to the BM leveling height published by NGI. Comparing these results with 60 minutes observations, the height difference were distributed within 2cm. Obviously the standard deviations of 5 minutes observations were greater than those of the 60 minutes observations, nevertheless these deviations are much precise results than what we need in gravity surveying.

So, we are able to deduce that the GPS measurement for 5 minutes would be effective when we used DGPS with two geodetic GPS receivers and the baseline was shorter than 40km. In this case we should use a precise geoid model to determine the orthometric height. By applying this method, we are able to reduce the cost, time, and number of surveyors, furthermore we also get the benefit of improving in quality. But, we should also pay more attention whether the signal could be received from at least 4 healthy satellites simultaneously, and keeping the signal not being violated by buildings, trees, and etc.

The Network adjustment in gravity surveying

Several kinds of corrections such as tidal correction, meter drift correction, and Eötvös correction in dynamic conditions should be applied to get a observed gravity data from the raw data directly obtained by the gravity meter. But the gravity values on the same station (or crossover point) would not be coincide with each other even after applying these corrections. It usually comes from the random errors, so we should correct it based on the probability theory. And the data after the crossover correction could be considered as more precise data in statistical view.

We adopted the least squares methods to adjust the crossover errors. This method make the residuals between the adjusted and observed values be as small as possible, and done by the procedures below (Wolf and Ghilani, 1997; Chapra and Canale, 1988; Press *et al.*, 1992).

The next equation of matrix form can be made based on the gravity observations.

$$AX = L + V$$

A is the coefficients of the unknowns, X is the unknowns to be determined, L is the differences between the observations, and V is the residuals. Then the solution of X can be expressed as

$$X = (A^T A)^{-1} A^T L$$

And if we apply weights, these equations can be expressed as

$$WAX = W\ L + W\ V$$
$$X = (A^T WA)^{-1} A^T WL$$

To know the error size after adjustment, the reference standard deviation can be used like next equation.

$$S_0 = \sqrt{\frac{V^T V}{r}} = \sqrt{\frac{\Sigma v^2}{r}} = \sqrt{\frac{\Sigma v^2}{m-n}}$$

v is the residuals after adjustment, m is the number of equations, n is the number of unknowns, and r = m-n is redundant measurements or degree of freedom. And its weighting form is

$$S_0 = \sqrt{\frac{V^T WV}{r}} = \sqrt{\frac{\Sigma wv^2}{r}} = \sqrt{\frac{\Sigma wv^2}{m-n}}$$

Then, the predicted standard deviations on each points can be calculated with next equation.

$$S_i = S_0 \sqrt{q_{x_i x_i}}$$

$q_{x_i x_i}$ is the diagonal elements of the inverse matrix of the normal equation, $(A^T A)^{-1}$ or $(A^T WA)^{-1}$. The normal equation matrix $A^T A$ or $A^T WA$ is always symmetric, so that this equation can be solved easily and quickly by applying Cholesky decomposition like below.

$$N = A^T A = LU = LL^T = U^T U$$

L is a lower triangular matrix and U is a upper triangular matrix.

The least square adjustment method is based on the mathematical probability theory, and has good benefits listed below. 1) It is most rigorous of adjustments based on the theory of mathematical probability, so the results done by different persons will coincide with each other, if the weights were applied with same method. 2) It permits all observations, regardless of their number and type, to be entered into the adjustment and used simultaneously in the computations. Namely, the data acquired by gravity meters of different type could be dealt simultaneously in one computation. 3) It enables rigorous postadjustment analyses to be made, so we can estimate the errors and find out the blunders to eliminate. 4) It can be used to perform presurvey planning.

Compiling the terrain data and terrain correction

The precision of gravity meters today were advanced to reach the resolution of 1μGal or even 0.1μGal. But the precision of gravity anomalies depend on the positioning (latitude, longitude, height), terrain and density information around the surveying points, besides the gravity measurements itself. The terrain effects usually corrected through two procedures such as Bouguer correction and terrain correction. But the terrain correction have been sometimes omitted, because the correction was not handy and the values were relatively small not in steep area. But nowadays the developments of digital terrain data, computer technology and positioning technology such as GPS make the precise terrain correction possible with great easy and preciseness.

NIMA (the National Imagery and Mapping Agency of U.S.) have been updating global terrain data, and have released the DTED (Digital Terrain Elevation Data) series. These are the 1" × 1" to 30" × 30" mean elevation data referring the WGS84 ellipsoid. We compiled 3" × 3" mean elevation data based on the DTED level 1 (3" × 3" mean elevation data) of NIMA (NIMA, 1994) as a land area data and bathymetry data of NORI (National Oceanographic Research Institute of South Korea) as a marine area data.

And we can also use the rigorous formulas instead of simple formulas in calculating the terrain effect, for the computing speed has been developed much rapidly. Choi and Lee (2001) coded a FORTRAN program for terrain correction based on the formulas of Nagy (1966), Bott (1959), Jung (1961), Kane (1962), Ma and Watts (1994). The mean of the terrain correction values was 1.298mGal and the maximum value, 12.324mGal (at longitude 128.8675°E, latitude 35.3675°N, height 944m) according to the test results on 42,385 points in South Korea when the integrating radius was 50km × 50km. Therefore, we should correct the terrain effects if we want to get more precise Bouguer anomaly.

Gravity data collected up to 1996

We had collected gravity data in and around the Korean Peninsula up to 1996, and they are listed below.

Land gravity data

The land gravity data have been surveyed mainly by Choi and NGI. And their numbers were up to 5,367 points until 1996. But their positions were acquired by mapping, so the accuracy were relatively poor. And, the height were determined by leveling or referring BM (Bench Mark) height constructed and surveyed by NGI, so the most gravity data were distributed in low areas not in mountainous areas.

Marine gravity data around the Korean Peninsula

Marine gravity surveying around the Korean Peninsula were begun in 1960s by U.S., Russia, England, and Japan. And anyone can get these data from NOAA. Most of the data were surveyed by several institutes of Japan and distributed around the Japan.

Gravity data of Tokyo Univ. of Japan

Fukuda (1990) collected land gravity data, marine gravity data, and altimetry satellites data in and around the Japan and compiled 5' × 5' mean free-air anomaly data to study the geoid. The resolution of the data is low but it is still useful if we need to know the gravity data in and around the Japan not far from Korea.

Altimetry Satellite data

The sea surface height measured by altimetry satellites can be used to determine the gravity anomaly. But the altimeter data were useful in ocean area between 72°S and 72°N because of the orbit and albedo. And the precision of the altimeter becomes poor in the high tide areas and near earth areas. But these are most useful when marine gravity data are absent (Sandwell and McAdoo, 1990).

OSU91A Geopotential Model

Professor Rapp of Ohio State University have been analysing the gravity data of various sources to make the global geopotential model since 1970s,

Table 1. Numbers of gravity surveying points and reference standard deviations (mGal) after network adjustment according to their surveying areas during 1995. 10.~2002. 3. Please refer the text for area name ⓐ~ⓛ.

area	ⓐ	ⓑ	ⓒ	ⓓ	ⓔ	ⓕ	ⓖ	ⓗ	ⓘ	ⓙ	ⓚ	ⓛ
surveying points	384	472	102	599	282	1029	635	814	180	288	226	1145
crossover points	30	94	22	123	385	280	151	186	26	91	36	254
reference standard deviation	0.023	0.013	0.014	0.020	0.021	0.019	0.020	0.022	0.019	0.022	0.018	0.054

and the results were the series of OSU models such as OSU91A (Rapp, Wang and Palvis, 1991). With these models, we can synthesize the geoid and free-air anomaly of any regions, but their trends only represent regional variation of long wave length because the original analysing data were the 30'× 30' mean free-air anomaly. But, these models have been most useful when we needed the gravity data of North Korea and China.

Gravity data newly obtained since 1996

Newly surveyed or collected gravity data are listed below

Gravity surveying in South Korea

Gravity surveyings have been done in the rarely surveyed area, and the areas are ⓐ western part of Jiri Mt. (1995. 10.~1996. 5), ⓑ middle area of Gangwon province (1996. 8. 9~8. 25), ⓒ northern part of Gangwon province (1997. 10. 21~10. 25), ⓓ eastern part of Mt. Jiri (1998. 1. 22~7. 27), ⓔ gravity stations in meteorological observatories and on BMs near the stations (1998. 8. 18~2000. 12. 17), ⓕ Younghae, Gyungbuk province (1999. 1. 20~2001. 5. 12), ⓖ Jinan, Junbuk province (1999. 7. 22~2000. 2. 29), ⓗ Hapcheun, Gyungnam province (1999. 1. 13~2000. 3. 26), ⓘ Pusan (1999. 8. 9~8. 15), ⓙ Ulsan (2000. 8. 19~8. 30), ⓚ Masan, Gyungnam province (2001. 7. 5 ~2001. 7. 10), ⓛ north-eastern Gyunggi province and north-western Gangwon province (2001. 8. 6~2002. 3. 1).

In the case of ⓐ and ⓑ, the heights were obtained by conventional surveying with Total Station, and the latitudes and longitudes were determined by mapping, but in the other cases, the positions were acquired by GPS observation and PNU95 geoid model. The latitudes and longitudes obtained by mapping were transformed from Bessel1841 to WGS84, the reference ellipsoid of GPS, using the formula of DMA (1987).

The repeated gravity measurements have been done at least three points on each day to correct the meter drift and to adjust the crossover errors. The used gravity meters were L&R G899 and Scintrex CG-3M, and the reference gravity station was Pusan National University Gravity Station(longitude 129.08100°E, latitude 35.23356°N, height 52.732m, gravity value 979,759.931mGals). The number of gravity surveying points and their reference standard deviations of each areas are listed in Table 1. The total number of surveying points was 6,241 since 1996.

And the total number of land gravity data of South Korea is 11,335 points, not including the repeated measurements (Fig. 1). As shown in the figure, the data of mountainous areas such as Mt. Jiri, Gangwon province have been increased, but the density of data distribution in the middle of South Korea is still relatively low.

Marine gravity data by NORI

There are three research ships equipped with marine gravity meters in Korea (Table 2). The data surveyed by NORI are very important, because they are densely distributed around the Korean Peninsula.

The data surveyed during 1996-2000 were processed by the authors, and their Bouguer anomaly are shown in Fig. 2. But the data of the northern part of the East Sea in the figure were processed by other institute.

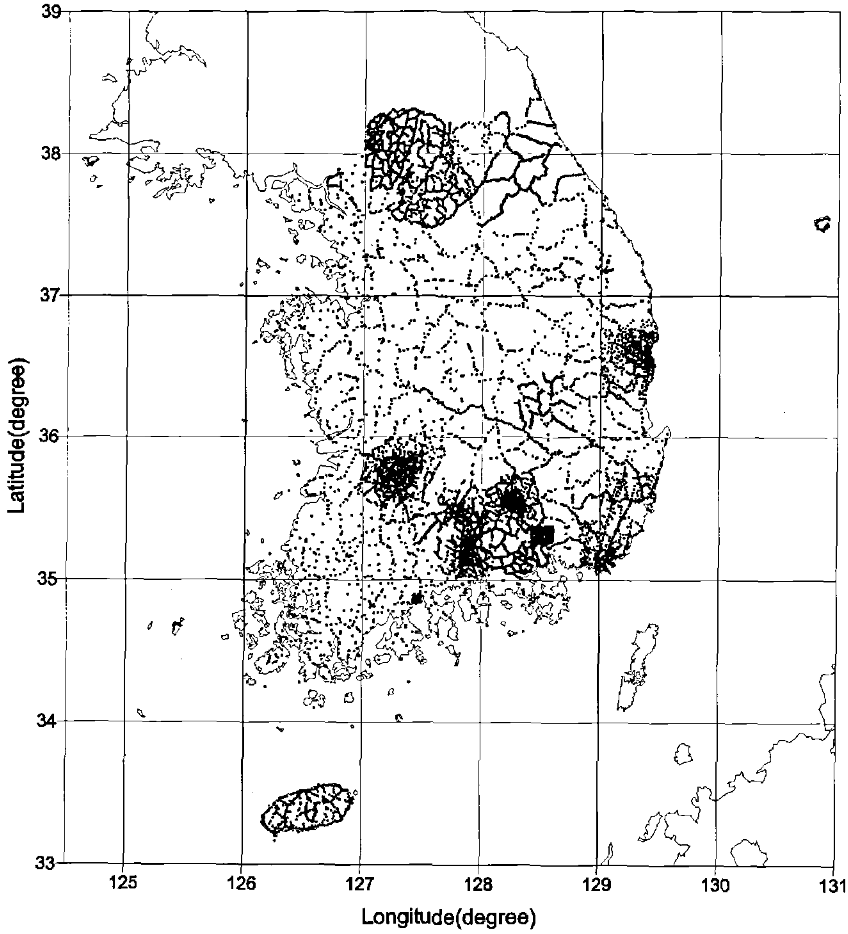

Fig. 1. Land gravity data distribution of South Korea up to 2002 (11,335 points).

Table 2. List of ocean research ships of Korea and their gravity meter models

Name	Institute	year	gravity meter type
Onnuri	KORDI	1994	LaCoste and Romberg Model S
Haeyang2000	NORI	1996	LaCoste and Romberg Model S
Tamhae2	KIGAM	1997	LaCoste and Romberg Model S

KORDI: Korea Ocean Research & Development Institute
NORI: National Oceanographic Research Institute
KIGAM: Korea Institute of Geoscience and Mineral Resources

Gravity data of North Korea

The gravity data of North Korea were not released, so the global geopotential models and terrain data have been used. These lack of gravity data in North Korea area have been a obstacle to study in geophysics and physical geodesy of South Korea. But, a book written by North Korean scientists says that gravity surveyings have been done on 2,308 points in North Korea until 1996 (by Paek *et al.*, 1996). And it contains a Bouguer anomaly map of 1 : 8,000,000 and two residual and regional Bouguer anomaly maps of 1 : 6,000,000. The residual and regional Bouguer maps were scanned and synthesized to get a Bouguer anomaly map of North Korea.

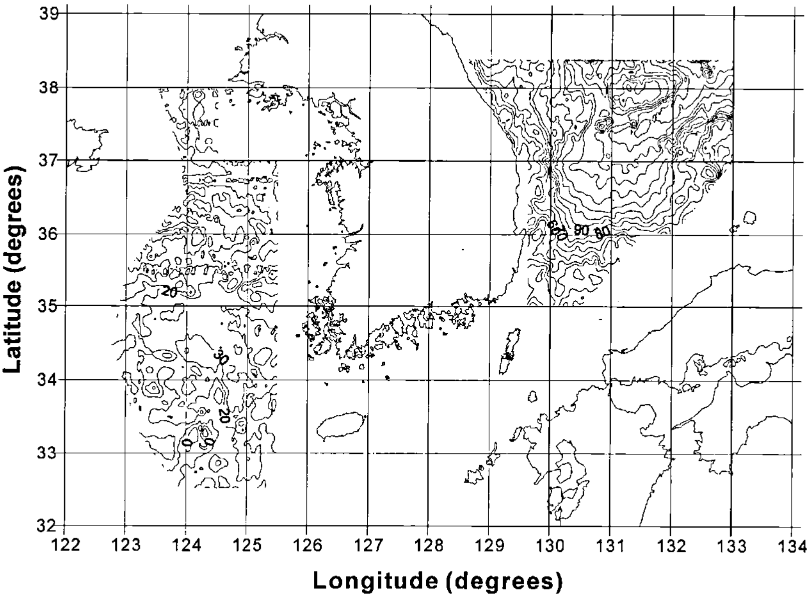

Fig. 2. Bouguer anomaly map surveyed by Haeyang 2000 of NORI (National Oceanographic Research Institute, Korea) during 1996-2000.

Altimetry satellites data

Sandwell and Smith (1997) have been calculating the geoid and free-air anomaly with the altimetry satellites data, and their new version was Version 9.1 (http://topex.ucsd. edu/mar_grav.html), the data of 1 arc minute interval. And the data used were

- Geosat/ERM (Average of 62 Geosat Exact Repeat Mission profiles)
- Geosat/GM (Recently declassified Geosat Geodetic mission data for all ocean areas)
- ERS (ERS OPR GDR's from the first 42 repeat cycles of the 35-day repeat orbit)
- ERS-1/GM (ERS-1 OPR GDR's from the entire geodetic mission)
- TOPEX (TOPEX GDR's from the first 120 repeat cycles of the mission).

The high density coverage obtained by ERS 1 during its geodetic mapping phase (April, 1994 to March, 1995) prompted the U.S. Navy to declassify all of the Geosat altimeter data on June 22, 1995, so that an equatorial ground track spacing of 8 km could be completed (Sandwell and Smith,1997).

EGM96 Geopotential Model

The vast amount of global gravity data of various sources can be expressed with a global geopotential model. It consists of the coefficients of spherical harmonic analysis and it is easy to deal. These geopotential model had been developed as the series of OSU model by Rapp of Ohio State University, and their final model was OSU91A (Ohio State Univ. geopotential model 1991A).

But it had been limited to collect the worldwide gravity data by nongovernment researchers and some problems had also revealed in short wavelengths of the models. So the NASA GSFC, DMA and OSU had joined together to develop new geopotential model since early 1990s, and the final model was EGM96.

The maximum degree and order of the EGM96 are 360. And this model is similar to OSU91A model, but is different in the amount of data. The data newly added are listed below(Lemoine *et al.*, 1998).

(1) Data of DMA (Defence Mapping Agency), and newly surveyed land and marine gravity data in Europe, Russia, China, S. America, Africa, and

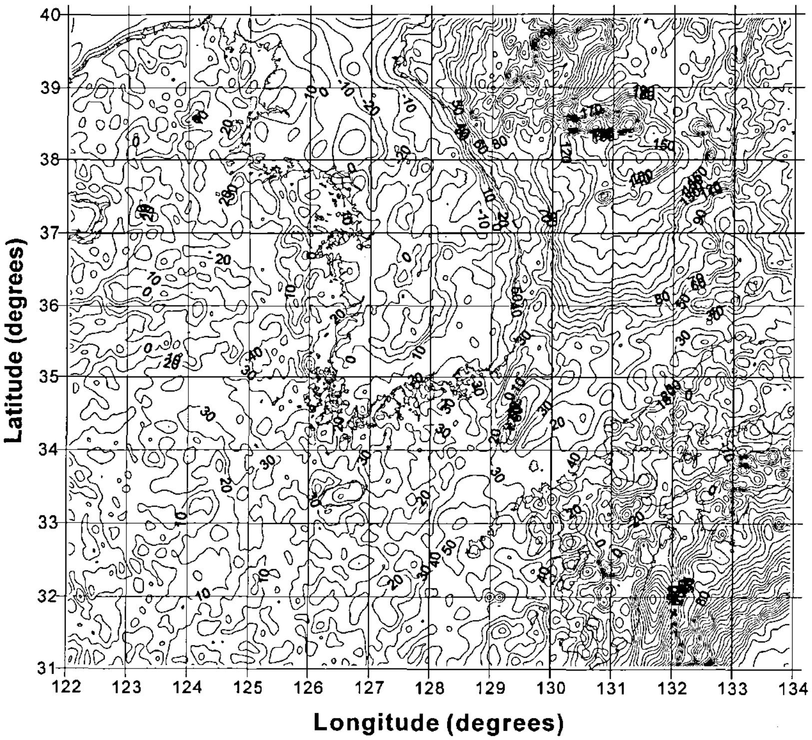

Fig. 3. A Precise and dense Bouguer anomaly map in and around the Korean Peninsula by compiling various gravity data such as land gravity, shipboard gravity, altimery satellite gravity data, and EGM96 global geopotential model.

Greenland.

(2) Geosat GM (Geodetic mission) altimeter data by DMA

(3) Satellite tracking data, GPS data of various sources, and newly surveyed altimeter data of Satellites ERS-1 and Topex.

(4) The predicted gravity data in the area of no gravity data (under 3% of the whole Earth) using newly developed topographic model.

The fact that the gravity data of China and Russia have been included in the model would be helpful to study the gravity field in and around the Korean Peninsula

A precise and dense Bouguer anomaly

A precise and dense Bouguer anomaly map in and around the Korean Peninsula could be made by compiling the data mentioned above. The land gravity data of Choi *et al.* and marine gravity data of NORI were used for the region of South Korea, the Bouguer anomaly map of North Korea for the Northern part of the Korean Peninsula, altimetry satellites data for the ocean area of no marine gravity data by NORI, gravity data of Fukuda for the Japan area, and EGM96 for the other area. The Bouguer and terrain corrections (including the ocean area) were also calculated to get Bouguer anomaly from free-air anomaly data. And, the results were shown in Fig. 3.

The figure shows good harmony at the edges of each data sets but the northern edge of the marine gravity data of NORI in the East Sea. These data were surveyed in 1997 by NORI and processed by other institute, so it will not be profitable for us to discuss the causes, but we are now processing the original data to find out and correct the problem.

The mean value and standard deviation of Bouguer anomaly were 8.37 and 18.08 mgal respectively, and the range were from −34.18 to 142.67 mgal in the land area of South Korea. And in the whole study area, the mean was 40.18mgal, the standard deviation 55.77mgal, minimum −107.41 mgal, and the maximum 322.62mgal. The maximum and minimum values were distributed in the south-eastern part of the study area, and the negative relation with topography was observed obviously in the figure.

The Bouguer anomaly map by this study is the results by collecting the various gravity data up to date, so it will be of great useful in the further researches in geophysics and geodesy.

Summary

1. To use the GPS for the positioning in gravity surveying gives many benefits of reducing the cost, time, and number of surveyors, furthermore we also get the benefit of improving in quality. The GPS measurement for 5 minutes would be effective when we use DGPS with two geodetic GPS receivers and the baseline shorter than 40km. In this case we should use a precise geoid model such as PNU95 to get the orthometric height. Then we are able to get the precisions of latitude and longitude within 3cm, and the height within 10cm.

2. To adjust the crossover errors, we adopted the least square method based on the mathematical probability theory, and coded a FORTRAN program adjusting and analysing the crossover errors. This is powerful to analyse the results statistically, so to find out the blunders of various causes easily and also to enhance the quality of the measurements. And the data of various sources could be dealt simultaneously with weights according to their quality.

3. The mean of terrain correction values was 1.298mGal and the maximum value was 12.324 mGal according to the test results on 42,385 points in South Korea when the integrating radius was 50km × 50km. Therefore, we should correct the terrain effects with precise terrain data and formulas if we want to get more precise Bouguer anomaly.

4. The mean value and standard deviation of the Bouguer anomaly were 40.18mgal and 55.77mgal, respectively. And the Bouguer anomalies were distributed from −107.41mgal to 322.62mgal, and the negative relation with topography was observed obviously.

5. The Bouguer anomaly map by this study is the results by compiling the various gravity data up to date, so it will be of great useful in the further researches in geophysics and geodesy.

Acknowledgments

We acknowledge financial support for the Korea Research Foundation in 1996.

References

Bott, M.H.P., 1959, The use of electronic digital computers for the evaluation of gravimetric terrain corrections. Geophysical Prospecting, 8(1), 45-54

Chapra, S.C. and R.P. Canale, 1988, Numerical methods for engineers. McGraw-Hill, 963 p.

Choi, K.S., 1986, A study on the gravity in the southern part of the Korean Peninsula (in Korean). Doctoral thesis of Seoul national university, 110p.

Choi, K.S., J.H. Kim and C.S. Yang, 1997, PNU95 Geoid. Korean Journal of Geophysical Research, 25(1), 1-13.

Choi, K.S., P.H. Park and Y.H. Shin, 1998, On the GPS in gravity surveying (in Korean). Journal of the Korean Earth Science Society, 19(2), 120-126

Choi, K.S. and Y.C. Lee, 2001, On the terrain correction with digital terrain data (in Korean). Journal of the Geological Society of Korea, 37(1), 133-142

DMA, 1987, Supplement to department of defence World Geodetic System 1984, Technical Report. DMA TR #8350.2-A, DMA.

Fuhuda, Y., 1990, Precise determination of local gravity field using both the satellite data and the surface gravity data. Bulletin of the Ocean Research Institute, University of Tokyo, no. 28, p. 1-133.

Kane, M.F., 1962, A comprehensive system of terrain corrections using a digital computer. Geophysics, 27(4), 455-462.

Leick, A., 1990, GPS satellite surveying. John-Wiley & Sons.

Lemoine, F.G., S.C. Kenyon, J.K. Factor, R.G. Trimmer, N.K. Pavlis, D.S. Chinn, C.M. Cox, S.M. Klosko, S.B. Luthcke, M.H. Torrence, Y.M. Wang, R.G. Williamson, E.C. Pavlis, R.H. Rapp and T.R. Olson, 1998, The development of the joint NASA GSFC and the National Imagery and Mapping Agency (NIMA) Geopotential Model EGM96. Goddard Space Flight Center, NASA/TP-1998-206861.

Ma, X.Q. and D.R. Watts, 1994, Terrain correction program in regional gravity surveys. Computers & Geoscience, 20(6), 961-972.

Nagy, D., 1966, The gravitational attraction of a right rectangular prism. Geophysics, 31(2), 62-371.

Paek, R. and H. Kang and G. Jon, 1996, Geology of Korea. the Foreign Language Books Publishing House. 631 p.

Press, W. H., S. A. Teukolsky, W. T. Vetterling and B. P. Flannery, 1992, Numerical recipes in FORTRAN. Cambridge University Press, 963 p.

Rapp, R.H., Y.M. Wang and N.K. Palvis, 1991, The Ohio State 1991 geopotential and sea surface topography harmonic coefficient models. Report no. 410, Dept of Geodetic Sci. and Surveying, The Ohio Univ, Columbus, Ohio, p. 1-94.

Sandwell, D.T. and D.C. McAdoo, 1990, High accuracy, high resolution gravity profile from 2 years of the Geosat Exact Repeat Mission. Journal of Geophysical Research, 95, 3049-3050.

Sandwell, D.T. and W.H.F. Smith, 1997, Marine gravity anomaly from Geosat and ERS-1 satellite altimetry. Journal of Geophysical Research, 102, 10039-10054.

Wellenhof, B. H., H. Lichtenegger and J. Collins 1994, GPS-Theory and practice. Springer-Verlag Wien New York.

Wolf, P.R. and C.D. Ghilani, 1997, Adjustment computations-Statistics and least squares in surveying and GIS. John Wiley & Sons, 564 p.

Manuscript received January 22, 2003
Revised manuscript received March 18, 2003
Manuscript accepted March 22, 2003