A STUDY ON THE MOHO UNDULATION OF THE KOREAN PENINSULA FROM SATELLITE GRAVITY DATA

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ABSTRACT:

Gravity characteristics and Moho undulations are investigated in the Korean peninsula by using satellite gravity data. According to the development of satellite geodesy, gravity potential models which have high accuracy and resolution were released. Using the EIGEN-CG01C model based on low orbit satellite data such as CHAMP and GRACE, geoid and gravity anomaly were calculated by spherical harmonic analysis. The study area is located at 123°~132°E, 33°~43°N including Korea. Free-air anomalies, which show the effect of terrain, have the values between -37~72 mgal. After Bouguer correction, the range of simple Bouguer anomalies is -221~246 mgal. Complete Bouguer anomalies after terrain correction increase from continent to marine. This phenomenon is related rise of Moho discontinuity. The cut-frequency for extraction of Moho undulation was determined by power spectrum analysis, and then 3D inversion modeling was implemented. The mean, maximum, minimum, and standard deviation of Moho depth undulation are -26, -36, -8, and 4.9 km, respectively.

KEY WORDS: satellite gravity, EIGEN-CG01C, CHAMP, GRACE, Moho undulation

1. INTRODUCTION

1.1 General Instructions

The Satellite geophysics, which observes Earth's physical or chemical properties like gravity and magnetic fields, was begun from the 1960s. Satellite data are very useful where survey is impossible politically and periodic and long-term observations is needed. As a satellite technology develops, acquisition of earth's information, which have high spatial resolution, become possible.

Global geopotential models, which were calculated from global elevation anomalies by spherical harmonic analysis, were begun GEM-T1(1988) and T2(1989) from NASA GSFC(Goddard Space Flight Center) and OSU91A was released by Ohio State University(Rapp, 1991). EGM96, this model was developed from early 1990s by NASA, GSFC, DMA(Defence Mapping Agency), and OSU, was released(Lemoine et al., 1996). In the 20th century, EIGEN-CG01C model from GRACE and CHAMP missions was released by GFZ-Potsdam(Reigber et al., 2004).

This paper discusses the gravity characteristics and Moho undulations of the Korean peninsula by using EIGEN-CG01C model. The study area is located between the latitude of 33°-43°N and longitude of 123°-132°E. It is very important to understand special quality and apply properly. Therefore this research is compared with previous results that were attained in the Korean peninsula and supply basic information for various Geophysical studies in the future.

1.2 Theory

Global geopotential models, including EIGEN-CG01C, could calculate disturbing potential, geoid, and gravity potential from coefficients C_{nm}, S_{nm} by spherical harmonic analysis(Heiskanen and Moritz, 1967).

The disturbing potential $T(r,\phi,\theta)$ in spherical harmonics is

$$T(r,\phi,\theta)=\frac{GM}{r}\left[\sum_{n=2}^{\infty}\left(\frac{a}{r}\right)^n\sum_{m=0}^{n}\left(C_{nm}\cos m\lambda+S_{nm}\sin m\lambda\right)P_{nm}(\cos\phi)\right]$$

r,ϕ,θ - spherical geocentric coordinates of computation point(radius, latitude, longitude)

GM - gravitational constant times mass of Earth

n,m - degree and order of spherical harmonic

P_{nm} - fully normalized Legendre functions

C_{nm},S_{nm} - Stoke's coefficients (fully normalized)

The geoid is derived from the disturbing potential T by applying Bruns formula

$$N=\frac{T}{\gamma}$$

γ - 'normal' gravity on the surface of the ellipsoid

And the gravity anomaly Δg related to the disturbing potential by

$$\Delta g=\frac{\partial T}{\partial r}-\frac{2}{r}T$$

On the geoid this becomes

$$\Delta g=\delta g-\frac{2}{r}T$$

δg - gravity disturbance

1.3 Data

CHAMP(CHAllenging Minisatellite Payload) is a German small satellite mission for geoscientific and atmospheric research and applications. CHAMP is the first satellite to generate highly precise gravity and magnetic field measurements simultaneously over a 5 years period. This allows detecting the spatial and temporal variations of both fields.

GRACE(Gravity Recovery and Climate Experiment), twin satellites launched in March 2002, is a joint project between the NASA and the DLR. The primary object of the GRACE mission is to provide unprecedented accuracy estimates of the global high-resolution models of the Earth's gravity field for a period of up to five years. The temporal sequence of gravity field estimation yield the mean Earth gravity field, as well as a time history of its variability.

EIGEN-CG01C model, which used in this research, is generated by CHAMP(860 days), GRACE(200 days), and various surface data(gravimetry and altimetry). Model's gravitational potential of the Earth in terms of 130317 spherical harmonic coefficients complete to degree and order 360 and resulting representation of the global geoid and the global free-air gravity anomalies down to spatial features of 100 km full wavelength.

2. DATA PROCESSING AND RESULTS

2.1 Gravity Reductions

The following sum shows the various components to free-air gravity with the name of the corrections shown in parentheses

free-air gravity = attraction of the reference ellipsoid
+ effect of 'normal' mass above sea level (Bouguer and terrain)
+ effect of masses that support topographic loads (isostatic)

In this research, Bouguer and terrain effect in the study area were adjusted by SRTM30_Plus topography data(Figure 1; Becker and Sandwell, 2004) in WGS84 reference ellipsoid system. Specially, terrain correction was performed algorithm of Ma and Watts(1994).

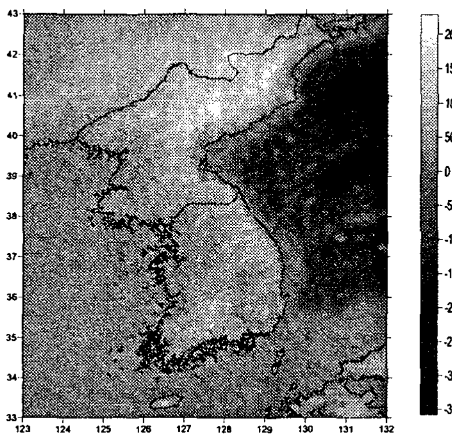

Figure 1. Topographic map.

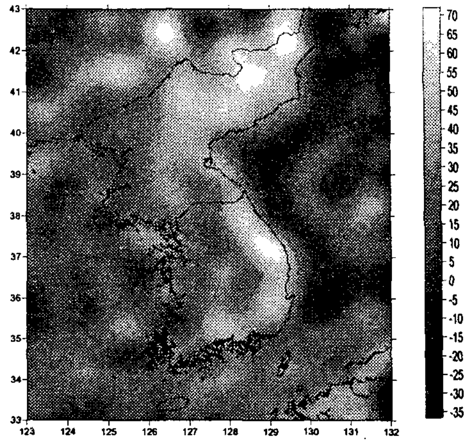

Figure 2. free-air gravity anomaly map.

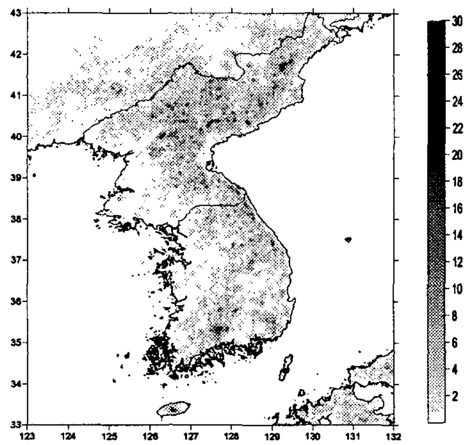

Figure 3. Terrain effects.

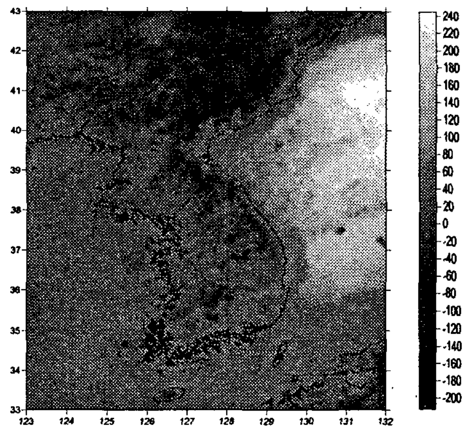

Figure 4. Complete Bouguer anomaly map.

After all corrections, each results were recorded to Table 1. In the table, 'total', 'continent', and 'marine' means total area, continent region, and marine region, respectively. And 'min', 'max', 'mean', and 'std' means minimum, maximum, mean, and standard deviation, respectively.

Table 1. Distributions of topography(meter) and gravity anomalies(mgal) in study area

		min	max	mean	std
Topography	Total	-3580	2286	-247	1017
	Continent	0	2286	415	392
	Marine	-3580	0	-765	1054
Free-air	Total	-37	72	19	18
	Continent	-31	72	29	17
	Marine	-37	67	11	15
Simple Bouguer	Total	-221	246	26	70
	Continent	-221	62	-21	40
	Marine	-35	246	63	65
Terrain effects	Total	0	38	1	2
	Continent	0	38	2	3
	Marine	0	6	0	0
Complete Bouguer	Total	-213	246	27	69
	Continent	-213	62	-19	39
	Marine	-35	246	63	65

2.2 Power Spectrum Analysis

Power spectrum method is used to calculate the boundary of mean depth caused by density contrast. Filtering process in frequency domain is implemented to separate gravity anomaly into regional and residual gravity anomaly.

Figure 5 shows the power of complete Bouguer anomaly. The wavenumber 0.15 is decided for filtering. The mean depth, which was calculated from low frequency region, is about -26 km.

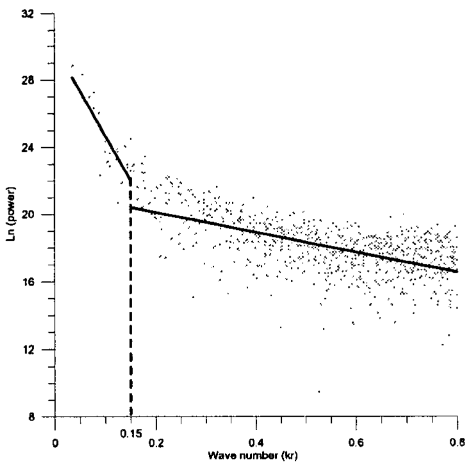

Figure 5. 2D power spectrum of the complete Bouguer anomaly for the whole area.

2.3 3D Inversion Modelling

In 2.2 section, mean depth -26 km is estimated as the depth of Moho discontinuity because the depth of Moho discontinuity is usually around -30 km in continent, and -15 km in marine. Low frequency gravity anomalies which separated using cut-off frequency are estimated as the Moho discontinuity and undulation of this can be achieved using inversion method. 3DINVER program was used (Ortiz and Agarwal, 2005) which calculate the gravity inversion using the relation between FFT of gravity anomalies and undulation of mass(Parker, 1973; Oldenburg, 1974). Inversion is performed by 3DINVER program with -26 km initial value of the Moho depth.

Figure 6 and 7 show regional and residual gravity anomalies. After inversion modelling, calculated Moho undulations are shown to figure 8.

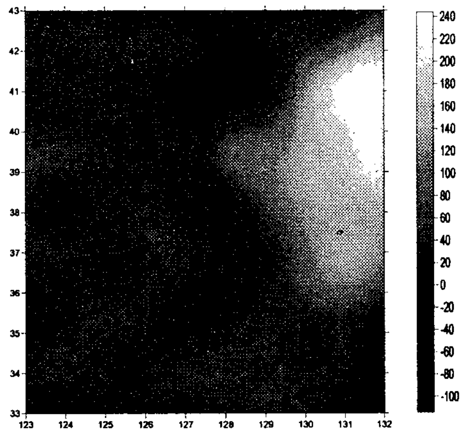

Figure 6. Regional gravity anomaly map.

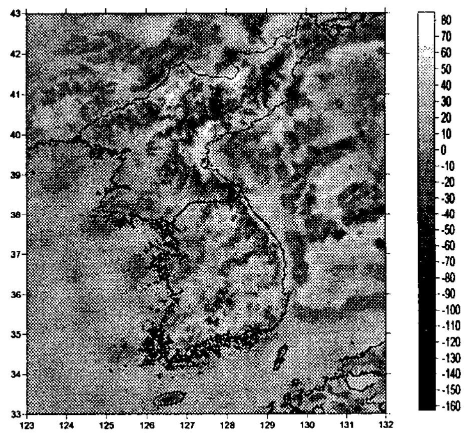

Figure 7. Residual gravity anomaly map.

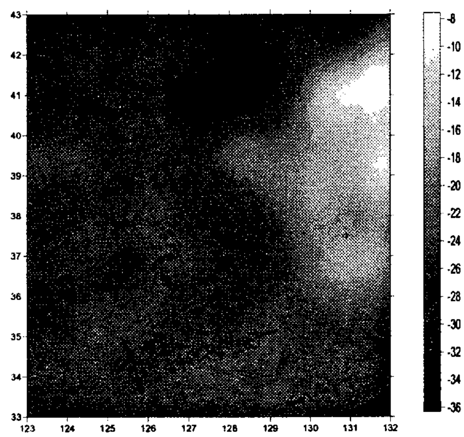

Figure 8. Moho undulation derived from inversion.

3. CONCLUSIONS

Free-air anomalies, which show the effect of terrain, has the value between -37~72 mgal. After Bouguer correction, the range of simple Bouguer anomalies is -221~246 mgal.

Figure 3 is terrain effects map. It reflects terrain effect well as big values in the mountain and small values in the plain.

Complete Bouguer anomalies after terrain correction has the range of -213~246 mgal. Anomalies increase from continent, including Yellow sea, to marine area(East sea). And this phenomenon is related to rise of Moho discontinuity.

Power spectrum analysis is implemented and 0.15 is decided as a cut-off frequency to extract effects of Moho discontinuity. Regional and residual gravity anomalies have the ranges -114~244 mgal, and -162~85 mgal, respectively.

Moho undulations after inversion modelling have the range of -36~-7 kms. According to the results, crust depth of China, Yellow sea, and Korea which located in the west side of study area show typical continental crust depth around -30 km and become shallow to the East sea.

This study using gravity anomalies should be investigated combined with other geophysical data for verification.

4. REFERENCES

References from Journals:

Ma X.Q., Watts D.R., 1984. Terrain correction program for regional gravity surveys. Computers and Geosciences, 20(10). pp. 961-972.

Marsh, J.G., Lerch, F.J., Putney, B.H., and 17 others, 1988. A New Gravitational Model for the Earth from Satellite Tracking Data: GEM-T1. J. Geophys. Res., 93, pp. 6169-6215.

Lemoine, F.G., Smith, D.E., Smith, R., Kunz, L., Pavlis, N.K., Klosko, S.M., Chinn, D.S., Torrence, M.H., Williamson, R.G., Cox, C.M., Rachlin, K.E., Wang, Y.M., Pavlis, E.C., Kenyon, S.C., Salman, R., Trimmer, R., Rapp, R.H., Nerem, R.S., 1997. The development of the NASA GSFC and DMA joint geopotential model. Gravity, Geoid and Marine Geodesy, Springer, Berlin, Germany, pp. 461-469.

Marsh, J.G., Lerch, F.J., Putney, G.H., Felsentreger, T.L., Sanchez, B.V., Klosko, S.M., Patel, G.B., Robbins, J.R., Williamson, R.G., Engelis, T.E., Eddy, W.F., Chandler, N.L., Chinn, D.S., Kapoor, S., Rachlin, K.E., Braatz, L.E., and Pavlis, E.C., 1989. The GEM-T2 Gravitational Model. NASA TM-100746.

Oldenburg, D.W., 1974, The inversion and interpretation of gravity anomalies. Geophysics, vol. 39, no. 4, pp. 526-536.

Ortiz, D. and Agarwal B.N.P., 2005. 3DINVER.M: a MATLAB program to invert the gravity anomaly over a 3D horizontal density interface by Parker–Oldenburg's algorithm. Computers & Geosciences, vol 31. no 4. pp. 513-520.

Parker, R.L., 1973, The rapid calculation of potential anomalies. Geophysical Journal of the Royal Astronomical Society, vol. 31, pp. 447-455.

References from Books:

Heiskanen W.A.-H. Moritz., 1967. *Physical Geodesy*. W.H. Freeman and Company, San Francisco and London.

References from Other Literature:

Rapp, R. H., Y. M. Wang, N. K. Pavlis, 1991. The Ohio State 1991 Geopotential and Sea Surface Topography Harmonic Coefficient Models. Report No.410, Department of Geodetic Science and Surveying, The Ohio State University, Columbus, Ohio 43210 – 1247.

References from websites:

Becker, J.J. and Sandwell, D.T., 2004. "SRTM30_PLUS: SRTM30, Coastal & Ridge Multibeam, Estimated Topography". http://topex.ucsd.edu/WWW_html/srtm30_plus.html

Reigber, Ch., Schwintzer, P., Stubenvoll, R., Schmidt, R., Flechtner, F., Meyer, R., König, R., Neumayer, H., Förste, Ch., Barthelmes, F., Zhu, S.Y., Balmino, G., Biancale, R., Lemoine, G.-M, Meixner, H., and Raimondo, J.C., 2004. Joint CHAMP/GRACE Science Meeting "A High Resolution Global Gravity Field Model Combining CHAMP and GRACE Satellite Mission and Surface Gravity Data: EIGEN-CG01C", Potsdam, Germany. http://www.gfz-potsdam.de/grace/index_GRACE.html