GPS/Levelling Geoid of the Southern Korean Peninsula

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(Manuscript received 2 October, 1997)

Abstract

The GPS/levelling geoid calculated from GPS survey data at 123 bench marks represents an appropriate regional geoid of the southern Korean peninsula. The GPS/levelling geoid fits best to the geoid calculated from the EGM96 geopotential model of degree and order to 360 with RMS difference 0.176 m. The good agreement of the GPS/levelling geoid with the EGM96 geoid suggests that the bench mark network is well established in Korea and the EGM96 geopotential model well represents the gravity field in the southern Korean peninsula.

1. Introduction

New surveying and observation techniques associated with recent developments in aerospace engineering improve the quality and increase the quantities of the various observed data related to the earth. Especially, various studies related to GPS (Global Positioning System) have become popular and have been rewarded with good fruits. GPS provides the accurate absolute coordinates, therefore it is useful for many purposes such as monitoring plate motions and fault displacements related to the statistical earthquake prediction. And GPS can provide the geoid height informations which were not directly measurable in traditional studies. Thus GPS changes the research trend in geodesy which has conventionally used the earth gravity data to calculate the geoid. GPS has been employed for many scientific and engineering purposes such as determining the precise 3-dimensional geodetic coordinates, and now extends to 4-dimensional geodesy which includes the time variation. Due to the improvement in accuracy and its practicality, GPS prevails in many branches, and more applications will come out (Moritz, 1980; Seeber, 1993; Geodetic Society of Japan, 1994; Hofmann-Wellenhof, Lichtenegger, and Collins, 1994).

In order to use GPS efficiently, two problems have to be solved beforehand. One problem is in the coordinate system. GPS adopts the WGS84 (World Geodetic System 84) ellipsoid, but each country uses the reference ellipsoid which best fits the local geoid. In Korea, we use the Bessel1841 ellipsoid as the reference ellipsoid, and its difference from WGS84 ellipsoid is about 510 m in latitude and about -150 m in longitude (Japanese Astronomy Observatory, 1996). The correction can be obtained from the coordinate transformation formula from the local coordinate system to the global one, and it can be calculated from GPS survey results at triangulation marks. In Korea, the National Geographic Survey Institute is presently refining the preexisting triangulation marks. The correction factor based on those survey results is expected to come out in the near future. The other problem is that the height is referenced to the geoid (orthometric height), whereas the GPS height is referenced to the WGS84 ellipsoid (ellipsoidal height). To convert the ellipsoidal height to the orthometric height, one should know the local geoid height, which is traditionally calculated from the earth gravity data. On the other hand, GPS surveys at locations where the precise orthometric heights are known such as bench marks provide the geoid and called the GPS/levelling geoid. The GPS/levelling geoid is utilized to verify the geoid calculated from the gravity data.

This study calculates the GPS/levelling geoid in the southern Korean peninsula from GPS survey results at well controlled bench marks and compares it with the one calculated from the EGM96 global gravity model.

2. GPS Survey and the EGM96 Geopotential Model

To increase the accuracy in calculating the GPS/levelling geoid, GPS surveys at bench marks require a long duration observation. There are 71 preexisting data for this purpose, which are mainly from Korea Astronomy Observatory and Choi et al. (1997). More data are obtained by GPS surveys carried out during February and November 1997 at the 52 first order bench marks established by National Geographic Survey Institute. They are mainly distributed in Kyungsangnam and northern Kangwon provinces. Surveys were carried out by employing Model 4000SSI systems of Trimble Co. owned by Korea Astronomy Observatory. The accuracy of the system is 0.5 cm $\pm$ 1 ppm. Some bench marks were chosen as the local base stations. At each local base station, more than 8 hour continuous observation was carried out to tie with the absolute GPS base station at Korea Astronomy Observatory. At each bench mark, more than 30 minute differential survey relative to a specific local base station was carried out. The baseline distance in differential survey does not exceed 40 km. The collected data were processed using GPSurvey 2.2 of Trimble Co. (Trimble Navigation Limited, 1996).

Recently, improvement of gravimeter quality and technical development in gravity measurement such as satellite tracking and altimetry satellite improved the quality of gravity data and increased the data amount. Furthermore, less than 3 % area of the world would remain to be covered by surface gravity survey by the end of 1995. The global geopotential model derived from the spherical harmonic analysis of the whole gravity data is simple, relatively accurate and efficient in use (Moritz, 1980; Rapp, 1989).

After the gravity model derived from the satellite tracking in 1960s, gravity models accurate enough to be used in geodesy and geophysics have been available since late 1970s. The gravity models of high degree and order have been developed by Prof. Rapp at the Ohio State University, U.S.A. In 1991, the OSU91A model, the last one in OSU model series, came out (Rapp et al., 1991). A new accurate geopotential model is expected to come out as high quality gravity data are accumulated from the observation of altimetry satellites such as Topex/Poseidon, and the GPS survey became practical in late 1980s. Since early 1990s, NASA, GSFC (Goddard Space Flight Center), DMA (Defence Mapping Agency), and outstanding international geodetic groups have cooperated to develop a new model. In October 1996 the EGM96 geopotential model has been announced. Its highest degree and order is 360, and has 50 km resolution. The accuracy of the geoid derived from the EGM96 model is from ± 0.5 m to ± 1.0 m (Lemoine et al., 1996; Pavlis et al., 1996).

3. GPS/Levelling Geoid

The ellipsoidal heights are calculated from GPS data observed at 123 bench marks. The GPS/levelling geoid of the southern Korean peninsula is calculated from the differences between the orthometric height and the calculated ellipsoidal height at each bench mark. The results are presented in Fig. 1, which shows the location of bench marks where GPS survey has been carried. As shown in Fig. 1, the lowest geoid height is 22.0 m at Kanghwa-do, and the highest geoid height is 33.5 m at the southeastern seashore. The geoid height gradually increases from the west to the east with a north-south axis. A small topographic effects can be found in Taebaek mountains, and almost no topographic effects are observable elsewhere. The geoid varies as the surface topography and the subsurface density change. The accurate geoid shows the changes in surface topography well (Choi et al., 1997). For the GPS/levelling geoid which reveals such surface topography changes, very dense survey should be carried out. Presently, this kind of work seems to be almost

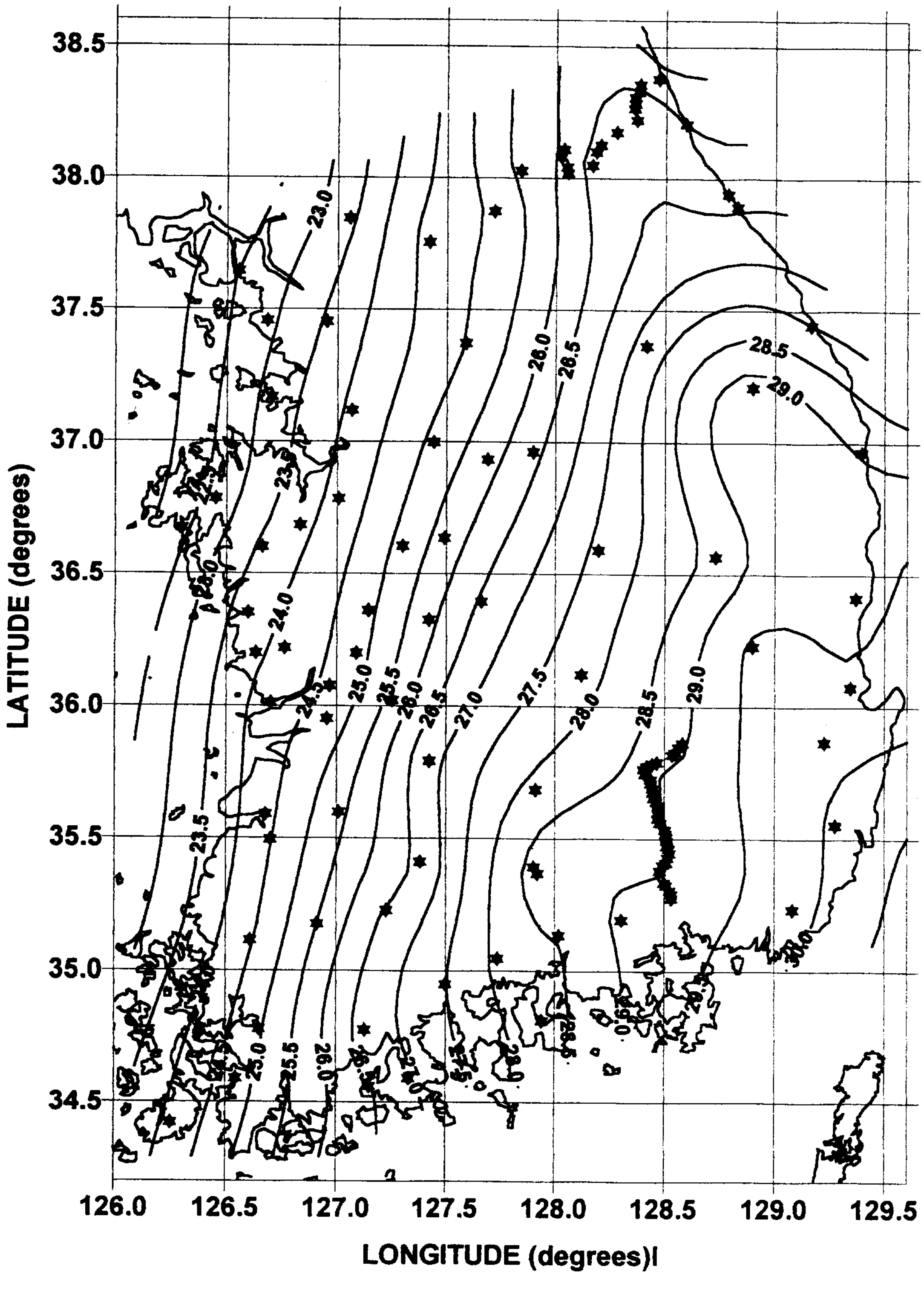

Fig. 1. The GPS/levelling geoid of the southern Korean peninsula calculated from GPS survey data from 123 bench marks. The star mark represents the bench mark location. Counter interval is in 0.5 m.

impossible due the to limited distribution of bench marks. The average sampling density for this study is about a sample per 30 km x 30 km, and the geoid is a regional geoid.

In order to compare this GPS/levelling geoid with the gravity derived geoid, the EGM96 model is employed. Geoids calculated from the EGM96 model with the varying highest degree and order from 100 to 360 are compared with the GPS/levelling geoid and the RMS (Root Mean Square) difference is calculated as a function of the highest degree and order. The results are presented in Fig. 2. In Fig. 2 the RMS difference decreases to 0.176 m as the highest degree and order increase up to 360, the maximum degree and order available in the EGM96 model. The geoid calculated from the EGM96 model of the highest degree and order to 360 is presented in Fig. 3.

Considering that the geoid of the southern Korean peninsula varies from the west to the east by 11.5 m, the 0.176 m RMS difference means those two geoids are in good agreement. The similarity between Fig. 1 and Fig. 3 can be also found easily. From these, ±1.0 m accuracy of GPS/levelling geoid can be deduced as the same in the geoid derived from the EGM96 model.

GPS/levelling geoid developed in this study represents the regional geoid of the southern Korean peninsula. The agreement between GPS/levelling geoid with the EGM96 geoid implies that the bench mark network in the southern Korean peninsula is well established, and that the EGM96 geopotential model represents the gravity field in the southern Korean peninsula well. Furthermore, to obtain more accurate GPS/levelling geoid, the denser GPS/levelling survey is desired.

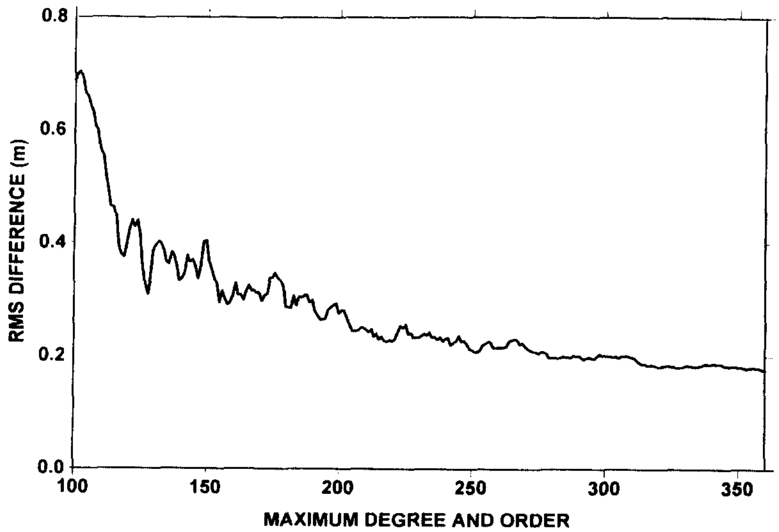

Fig. 2. The variations of the RMS difference between GPS/levelling geoid and EGM96 geoid with the varying highest degree and order from 100 to 360. The minimum RMS difference is 0.176 m which is found at the highest degree and order 360.

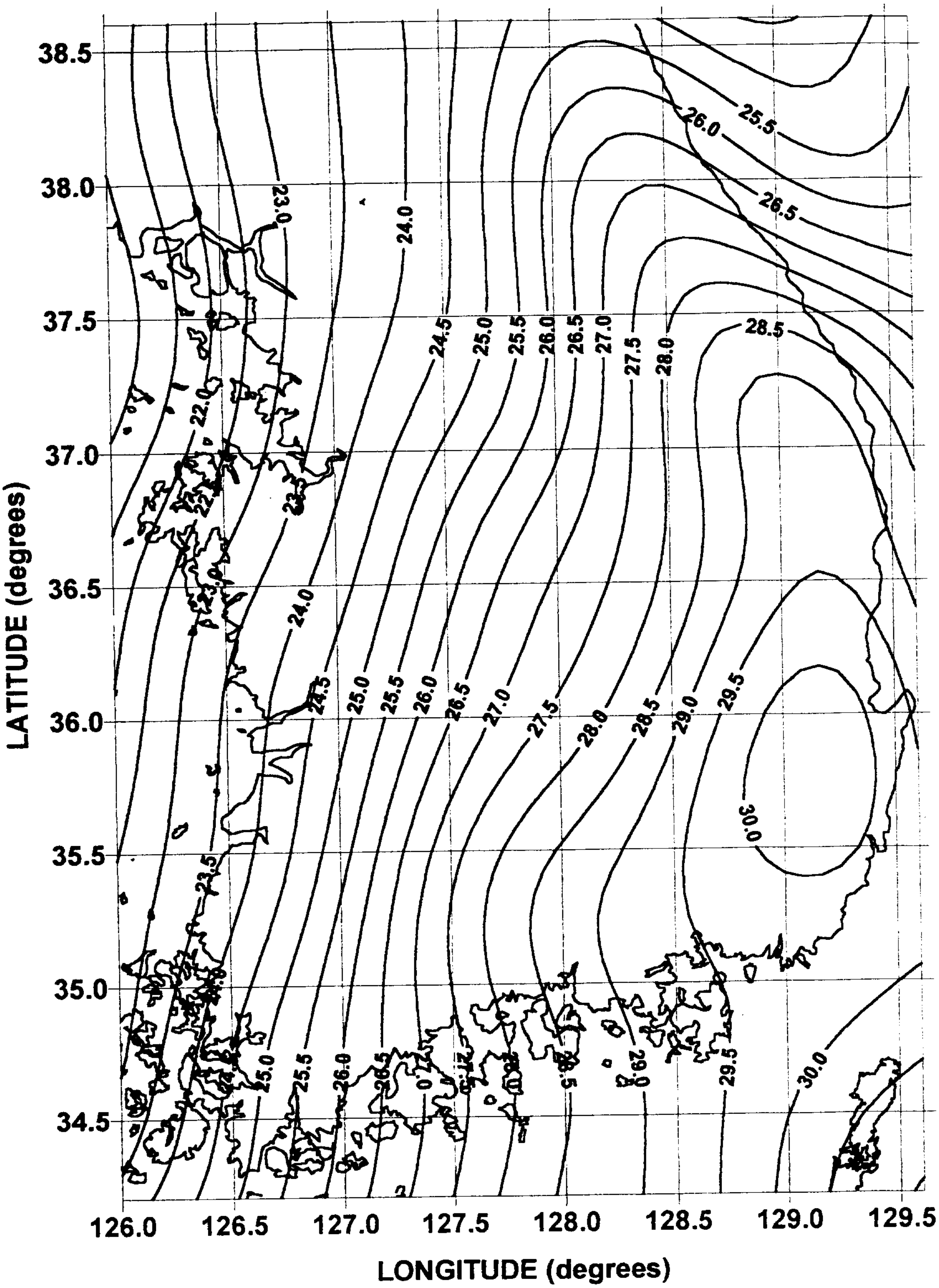

Fig. 3. The EGM96 geoid of the southern Korean peninsula with the highest degree and order to 360. Counter interval is in 0.5 m.

4. Conclusions

The results of this study are summarized as;

1. The GPS/levelling geoid calculated from GPS survey data from well distributed 123 bench marks well represents the regional geoid of the southern Korean peninsula.
2. The GPS/levelling geoid fits best to the geoid calculated from the EGM96 geopotential model of highest degree and order to 360. In this case, the RMS difference is 0.176 m.
3. Agreement between GPS/levelling geoid with the EGM96 geoid implies that the bench mark network in the southern Korean peninsula is well established, and that the EGM96 geopotential model well represents the gravity field in the southern Korean peninsula.
4. To obtain more accurate GPS/levelling geoid, the denser GPS/levelling survey is desired.

Acknowledgement

This study was supported by KOSEF (95-0703-01-01-3)

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