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A Study on Comparison of Observed and Derived Gravity Data

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ABSTRACT

In studies in earth sciences such as geodesy and geophysics, it is important to determine the gravity field as precisely as possible. In the determination of this field, it is quite common to use data sets obtained from satellites as well as terrestrial measurements. Especially, thanks to Low Earth Orbits (LEO), research conducted to determine the gravity field of the earth has gained speed in recent years. CHAMP (CHAllenging Minisatellite Payload-2000), GRACE (Gravity Recovery And Climate Experiment-2002) and GOCE (Gravity field and steady-state Ocean Circulation Explorer-2009) satellites are at the top of these satellites, respectively. The data collected from these satellites has contributed and continues to contribute to the production of many Global Geopotential Models (GGMs). This study aimed to demonstrate the performance of the eight Global Geopotential Models published by ICGEM (International Centre for Global Earth Models). In this context, the results were evaluated by making a numerical comparison between the gravity values obtained from the GGMs and the observed gravity data.

1. INTRODUCTION

The definition of height can be defined, in the most general sense, as the distance between a point on the ground and the starting surface. Heights may have definitions that are physical and geometric. In general, in engineering applications, it is more fitting to use heights related to gravity, i.e. physical heights. Determining the performance of GGMs produced by many scientists using different data sets is still one of the issues that are being studied. In addition, many scientists conduct regional and global tests in different geographies of the world in order to reveal the performances of GGMs and share the results with the scientific world. Various methods and approaches have been suggested by scientists while conducting these tests. For example, one of the most common methods used to determine the best GGM for a region's gravity field is to compare GGMs using independent data sets. These independent datasets are GNSS/leveling, gravity, etc. (Doğanalp 2016).

As gravity force, the sum of centrifugal and gravity forces on an object is described. Determining the gravitational field of the earth is the same as determining its potential. Since this potential is harmonic from earth-forming masses, spherical harmonic series are typically used to determine the field of gravity (Kaula 1966; Heiskanen and Moritz 1984; Rummel et al. 2002; Seeber 2003; Hofmann-Wellenhof and Moritz 2005; Doğanalp 2016). In this study, gravity values will be calculated with Global Geopotential Models (GGMs) and information about their sensitivity will be given by comparing with observed gravity values.

2. METHOD

GGMs are generally split into three basic classes. These are models, satellite-only models, combined models and tailored models. In the first models, the coefficients of these GGMs are derived from orbit deviation analyses of artificial earth satellites. The second model is generated by combining satellite altimeter data in marine areas, terrestrial gravity observations, gravity data derived from satellite data, and airborne gravimetry. The last models are produced as a result of improving harmonic coefficients of GGMs using special mathematical techniques within the first and second models (Vaniček and Featherstone 1998; Featherstone 2002; Doğanalp 2016). GGMs are described in various wavelengths as spherical harmonic coefficients representing the gravity field of the earth. From satellite orbit deviation analyses, satellite altimeter data, gravity gradiometer data, and gravimeter data,

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these coefficients are obtained. The gravity value is obtained by Eq (1). This equation is calculated from spherical harmonics.

$$g=\sqrt{\left[W_{ar}+\Phi_r\right]^2+\left[\frac{1}{r\cos\phi}\left(W_{a\lambda}+\Phi_\lambda\right)\right]^2+\left[\frac{1}{r}\left(W_{a\phi}+\Phi_\phi\right)\right]^2}$$

$$W_{ar}=-\frac{GM}{r^2}\sum_{n=0}^{n_{\max}}\left(\frac{R}{r}\right)^n(n+1)\sum_{m=0}^{n}P_{nm}(\sin\phi)(C_{nm}\cos m\lambda+S_{nm}\sin m\lambda)$$

$$W_{a\lambda}=\frac{GM}{r}\sum_{n=0}^{n_{\max}}\left(\frac{R}{r}\right)^n\sum_{m=0}^{n}m\,P_{nm}(\sin\phi)(S_{nm}\cos m\lambda-C_{nm}\sin m\lambda)$$

$$W_{a\phi}=\frac{GM}{r}\sum_{n=0}^{n_{\max}}\left(\frac{R}{r}\right)^n\sum_{m=0}^{n}\frac{\partial P_{nm}(\sin\phi)}{\partial\phi}(C_{nm}\cos m\lambda+S_{nm}\sin m\lambda)$$

$$\Phi_r=\omega^2 r\left(\cos\phi\right)^2$$

$$\Phi_\lambda=0 \qquad (1)$$

$$\Phi_\phi=-\omega^2 r^2\cos\phi\,\sin\phi$$

where r, ϕ, λ are the spherical geocentric coordinates of the computation point: radial distance, co-latitude and longitude, respectively, GM is the gravitational constant (G) times mass (M) of the earth, R is the mean earth's equatorial radius, C_{nm}, S_{nm} are fully normalized geopotential coefficients with degree n and order m, P_{nm} fully normalized associated Legendre functions, and n_{max} is the maximum degree of the GGM (Barthelmes 2013; Turgut 2016).

3. RESULTS

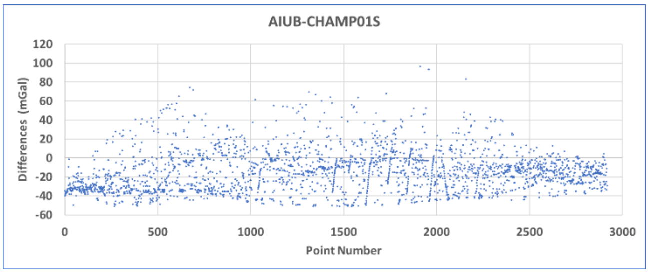
In this study, 2918 data points of gravity used as of March 21, 2016, in the Milford, Utah FORGE project were used. This data set compared the performance of the GGMs produced in recent years with some of the models produced in previous years. For detailed information about the data set, please see the reference given in the references section. The data set consists of latitude and longitude (decimal degrees), ellipsoidal height (m), gravity observed (mGal), terrain correction of the inner zone (mGal), terrain correction of the outer zone (mGal), values of the free air anomaly (mGal) and values of the complete Bouguer gravity anomaly (mGal).

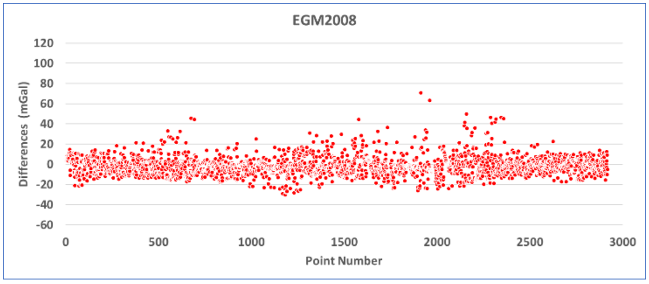
Table 1. Characteristics of GGMs

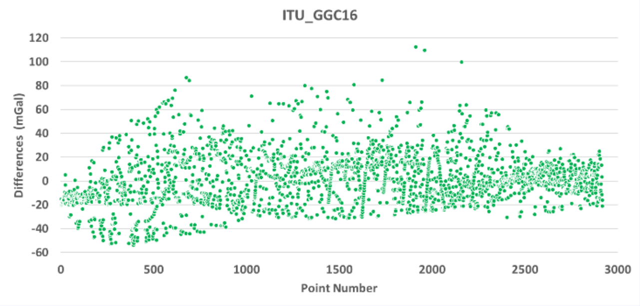
Model Name	Year	n_{max}	Data	References
AIUB-CHAMP01S	2007	70	S(Champ)	Prange et al. 2009
EGM2008	2008	2190	A,G, S(Grace)	Pavlis et al. 2008
ITU_GGC16	2016	280	S(Goce) S(Grace)	Akyilmaz et al. 2016
GOCO06s	2019	300	S	Kvas et al. 2019
EIGEN-GRGS.RL04.MEAN-FIELD	2019	300	S	Lemoine et al. 2019
ITSG-Grace2018s	2019	200	S(Grace)	Mayer-Gürr et al. 2018
GO_CONS_GCF_2_TIM_R6e	2019	300	G(Polar) S(Goce)	Zingerle et al. 2019
XGM2019e_2159	2019	2190	A,G,T S(GOCO06s)	Zingerle et al. 2019

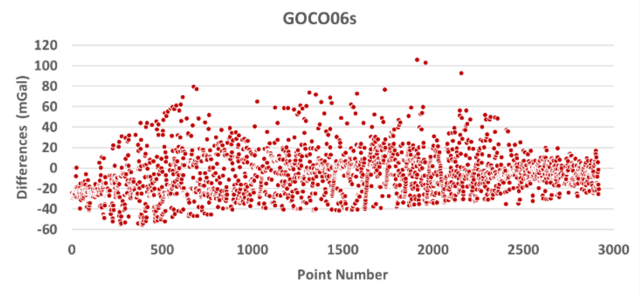
S: satellite tracking data, G: gravity (ground) data,
A: satellite altimetry data, T: topography

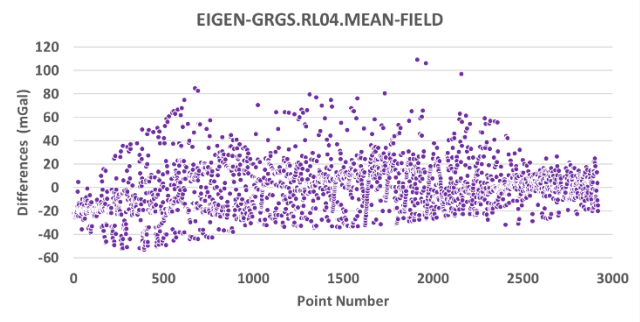
The gravity values of the 2918 points used in the study were obtained separately for the GGMs given in Table 1 with the help of the calculation service on the International Centre for Global Earth Models (ICGEM) website (http://icgem.gfz-potsdam.de/ICGEM). The gravity differences obtained from the GGMs are shown in Figure 1. For a better understanding of the difference values, the difference values were transferred to histogram graphics and reinforced with statistical information (Figure 2). The statistical information obtained as a result of the evaluation of the GGMs is presented in Table 2.











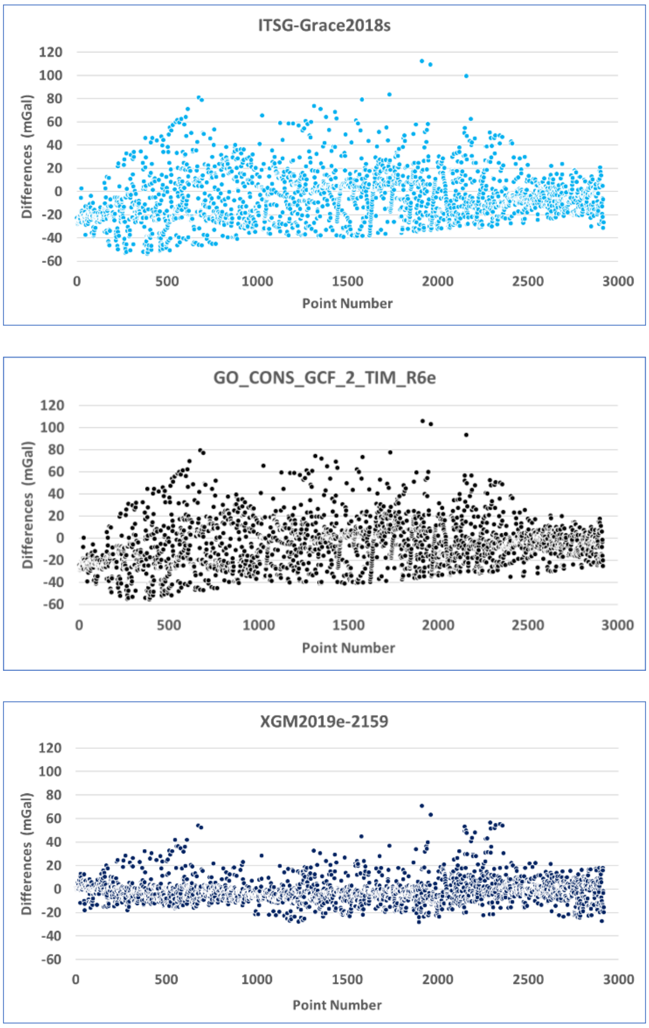
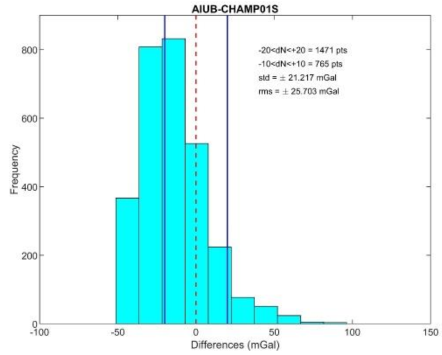
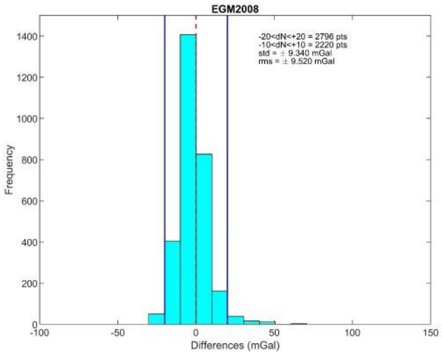
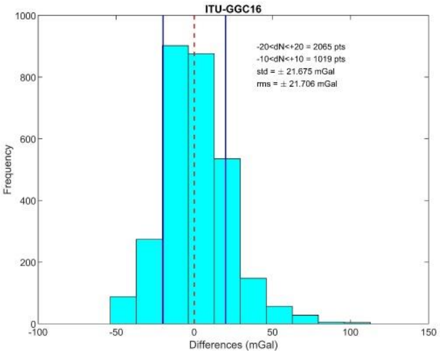
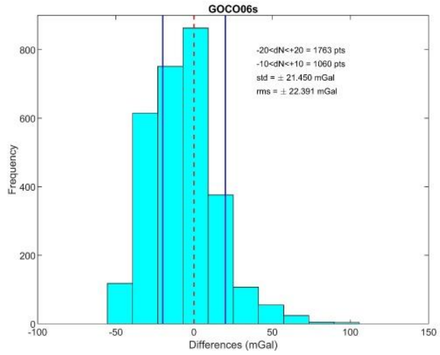


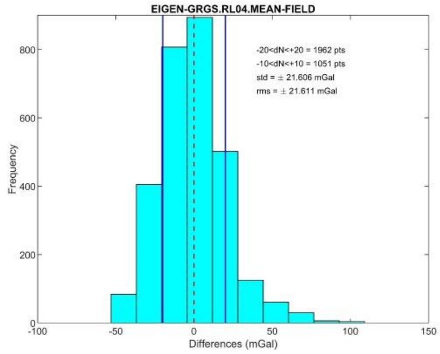
Figure 1. The gravity differences (unit: mGal)

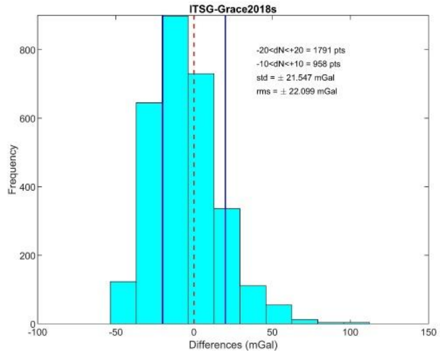


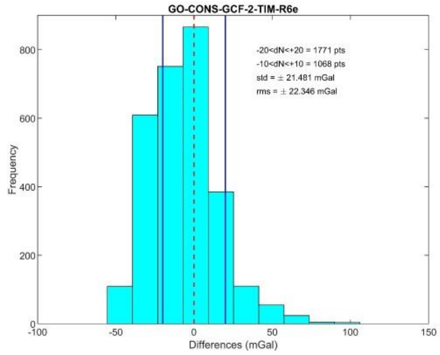












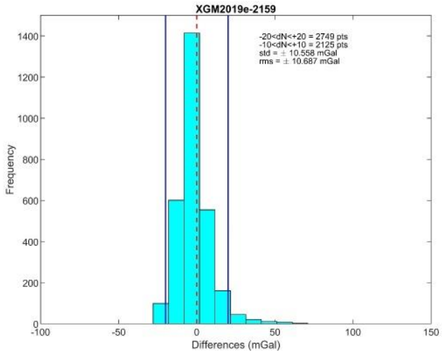


Figure 2. The gravity difference values as a histogram (unit: mGal)

Table 2. Statistics of gravity differences (mGal)

Model Name	min	max	mean	std
AIUB-CHAMP01S	-51.189	96.365	-14.513	21.217
EGM2008	-30.248	70.852	-1.853	9.340
ITU_GGC16	-53.765	112.650	1.231	21.675
GOCO06s	-55.345	105.621	-6.436	21.450
EIGEN-GRGS...	-53.042	109.037	-0.622	21.606
ITSG-Grace2018s	-53.532	112.304	-4.923	21.547
GO_CONS...R6e	-55.461	105.983	-6.167	21.481
XGM2019e_2159	-27.940	71.009	-1.667	10.558

4. CONCLUSION

As a result of the calculations, it was seen that the best GGMs for this test area were EGM2008 and XGM2019e_2159. The standard deviation values were obtained 9.340 mGal from the EGM2008 model and 10.558 mGal from the XGM2019e_2159 model. In other GGMs, very close standard deviation values have been calculated. For this study, it can be said that one of the most important reasons affecting accuracy is the variety of data used (altimetry, gravity, and satellites) and a high degree (n_{max}) model.

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