Evaluation of Gravity Data by EIGEN-2 (CHAMP-only) Model in China

Yang Lu and Hongling Shi

Institute of Geodesy & Geophysics, Chinese Academy of Sciences, 54 Xudong Road, Wuhan, 430077, P.R. China, *luyang@asch.whigg.ac.cn*

Summary. This paper discussed consistency of long wavelength components of gravity field between the EGM96 and CHAMP gravity models and compared the long wavelength components of surface gravity data with ones from the models of CHAMP within the same spatial resolution, based on the 2-D Gaussian low-pass filter in China and its vicinity. The results show that the models of EGM96 and CHAMP are consistent up to about degree 35, while above this degrees the EIGEN-2 may have inferior estimates. The evaluation of the terrestrial gravity data for China and its vicinities by comparisons with the models of CHAMP has confirmed the existence of larger errors and systemic discrepancy.

Key words: Satellite gravity field mission, Gravity anomaly, Gaussian filter.

1 Introduction

Up to the present, we have three main ways to observe gravity field. One is directly observing on the earth surface, including terrestrial gravity measurement, airborne gravity measurement and shipboard gravity measurement. Another is radar satellite altimetry. Third way is satellite gravity field missions such as CHAMP, GRACE and GOCE mission. In the three measurements, only the terrestrial measurement can provided the full wavelength information of gravity field for points. However the gravity data recovery from satellite altimetry, the presently best space resolution is 2', included about 98.8% information of gravity field according to the study by Tscherning-Rapp spectrum characteristic model for the gravity field (see Tscherning 1974). The gravity satellite mission can provide the medium and long wavelength information of gravity field. The space resolution of gravity field from the CHAMP satellite come to a head about 220 km, only include about 38% information of gravity field. It means that the gravity data from multifarious source has the different resolution, and including multiform wavelength band of gravity field. Therefore calibration and evaluation of gravity data should be transacted under the same dimensional scale. In this paper, we use the 2-D Gaussian low-pass filter to distill the common components of gravity data sets, namely long wavelength components, for comparing and evaluating the gravity data from multifarious source, including the satellite gravity data, satellite altimetry data and terrestrial gravity data in China and its vicinity.

2 Filtering Method

As well known, a grid gravity field with a certain space resolution is as a digitalization image, which is similarly to the two dimensions discrete image function. That so, we can dispose the gravity field data according to the method of the image processing. The 2-D Gaussian low-pass filter will be used to withdraw the long wavelength component of the gravity field. Usually, the Gaussian distribution model definition is writ (see Zhang 1998)

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \tag{1}$$

Here σ is standard deviation.

The 2-D Gaussian filtering made one two-dimension function (original image) *f(x, y)* convolute with the Gaussian function *g(x, y)*, then get the purpose of restraining the noise and smooth. The convolution result is *h(x, y)*. In the frequency domain, according to the convolution theorem we have

$$H(u,v) = G(u,v)F(u,v) \tag{2}$$

Where *G(u, v), H(u, v)* and *F(u, v)* is Fourier transform functions of *g(x, y), h(x, y)* and *f (x, y)*, respectively. As the linear system theory, the *G(u, v)* is a transition function. According to the Fourier transform we can know the Gaussian function after Fourier transformed will be still the Gaussian function with the same form, then using Fourier inversion we have

$$h(x,y) = F^{-1}[G(u,v)F(u,v)] \tag{3}$$

3 Short descriptions of used data

The test area is over the China mainland, China Sea and its vicinities, and western Pacific within the pale of the area ($0° \le \varphi \le 55°N$, $70° \le \lambda \le 140°E$), with three types data areas i.e. mainland area, marine shipboard measurement area and overlapping marine area with altimetry derived gravity datasets (see Fig. 1). All data should been transformed to the reference ellipsoid with a=6378136.46, 1/f=298.25765 as well as EIGEN-2 model used (see Reigber 2003), and arranged in 30'×30' grid.

3.1 Satellite gravity data EIGEN-2 and EIGEN-1S model

EIGEN-2, the CHAMP-only Earth Gravity Field Model, derived from altogether six months of CHAMP data, made by GFZ according to the CHAMP GPS satellite to satellite and

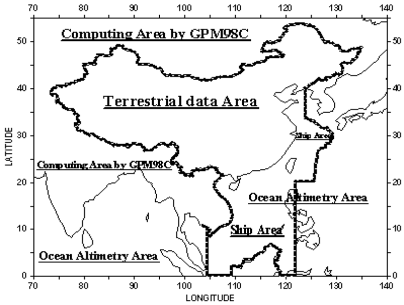

Fig. 1. Distribution of datasets in test area.

accelerometer data. The EIGEN-2 has been developed to degree 140. The accuracy of EIGEN-2 is well below 10 cm and 0.5 mGal in terms of geoid heights and gravity anomalies, respectively, at λ/2=550 km (http://op.gfz-potsdam.de/ champ/results/ index_RESULTS.html, see Reigber 2003).

EIGEN-1S, the satellite-only Earth Gravity Field Model, to degree 119 including 88 days of CHAMP data was made by GFZ. The solution has got full power only up to about degree/order 35 (http://op.gfz-potsdam.de/champ/results/ index_RESULTS.html). The accuracy of EIGEN-1S is ±2.5 mGal in terms of the gravity anomaly, at λ/2=550 km (see Reigber 2001, 2002).

3.2 Terrestrial data sets and marine satellite altimetry data sets

Terrestrial gravity data include ground gravity data in China mainland, shipboard gravity data on China Sea and its vicinity with 30'×30' grid, and altimetry derived gravity data sets in West Pacific, include KMS02 (see Andersen 1998, 2001), Sandwell's V.9.2 (see Sandwell 1997), and GMGA97 (see Hwang 1998).

4 Comparison and evaluation of gravity data

Before evaluating terrestrial gravity data we compare the satellite gravity models EIGEN-1S, -2 and EGM96 in order to examine or look the differences of CHAMP models at in a comprehensive way. One possibility to evaluate the models is the computation of anomaly difference grids with a varying maximum degree of the expansion. The Table 1 and Table 2 show gravity anomaly differences between EGM96 with EIGEN-2 and EGM-1S in the test area for a varying maximum degree of the expansion, respectively. The statistics shows that the RMS difference between the EIGEN-2 and EGM96 model miss 1.0 mGal (Table 1), while EIGEN-1S exceeds 1.0 mGal (Table 2) at degree 40. The agreement of the two models is quite good up to degree 35(less 0.8 mGal), and thus three models should be useful for the detection of long wavelength errors in the terrestrial gravity data. However, we would rather EIGEN-2 model than others.

L_{max}	Num.	Mean	RMS	Min.	Max.
5	5516	-0.000	0.004	-0.010	0.010
10		0.002	0.026	-0.070	0.050
15		-0.012	0.106	-0.210	0.190
20		0.000	0.191	-0.620	0.530
25		-0.016	0.293	-0.850	0.680
30		0.005	0.397	-1.150	1.110
35		0.011	0.703	-2.20	1.760
40		0.031	0.956	-2.780	2.850
45		-0.060	1.982	-7.100	6.700

Table 1. Gravity anomaly differences between EIGEN-2 and EGM96 in the test area for a varying maximum degree of the expansion. Units are mGal.

L_{max}	Num.	Mean	RMS	Min.	Max.
5	5516	0.001	0.004	-0.010	0.010
10		0.005	0.042	-0.100	0.100
15		-0.010	0.096	-0.200	0.200
20		-0.002	0.253	-0.600	0.600
25		-0.025	0.382	-0.800	1.100
30		-0.003	0.543	-1.600	1.700
35		-0.012	0.806	-2.800	2.600
40		-0.025	1.118	-3.700	3.200
45		-0.137	2.761	-10.900	9.000

Table 2. Gravity anomaly differences between EIGEN-1 and EGM96 in the test area for a varying maximum degree of the expansion. Units are mGal.

Data type	Num	Mean	RMS	Min	Max
EIGEN-2—GMGA97	4357	-0.03	2.12	-15.9	12.1
EIGEN-2—V.9.2	4357	-0.08	2.68	-12.5	32.6
EIGEN-2—Kms02	4357	-0.08	2.87	-17.5	33.6
Average		-0.06	2.56	-15.3	26.1

Table 3. Evaluations of the altimeter derived gravity anomalies, with a spatial wavelength about 1100 km, by EIGEN-2 model in the western Pacific area. Units are mGal.

For evaluating the terrestrial data we compute the gravity anomalies from EIGEN-2 up to degree 140 on 30' grid in the test area (Fig. 2.a). The original gravity is plot on Fig. 2 b, c, d, and e. Using 2-D Gaussian low-pass filter we distill the common components from the gravity datasets. In this way, we have the long wavelength component of datasets with a space domain wavelength roughly 10° (see Fig. 3). From Fig. 2 we can see obviously different from EIGEN-2 and terrestrial datasets. However, after filtering the long wavelength components of gravity from EIGEN-2 are primitively similar to ones of the terrestrial and altimetry data (comparable Fig. 3.a with Fig. 3.b, c, d, e). In other words, we have accomplished successfully the common components of gravity field from multifarious source by low-pass filtering.

Fig. 4 shows the residuals of long wavelength gravity between EIGEN-2 and ground and shipboard in the test area, respectively. We can see that the plus biggish

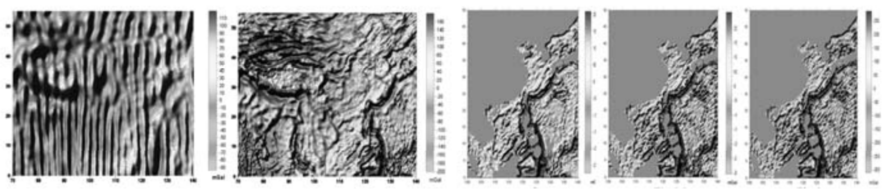

Fig. 2.a. Fig. 2.b. Fig. 2.c. Fig. 2.d. Fig. 2.e.

Fig. 2. The gravity anomalies data sets from multifarious source in the test area. Fig. 2.a is anomaly computed from EIGEN-2 up to degree 140. Fig. 2.b is the ground- shipboard dataset. Fig. 2.c, d, e are the data of KMS02, GMGA97 and V.9.2, respectively.

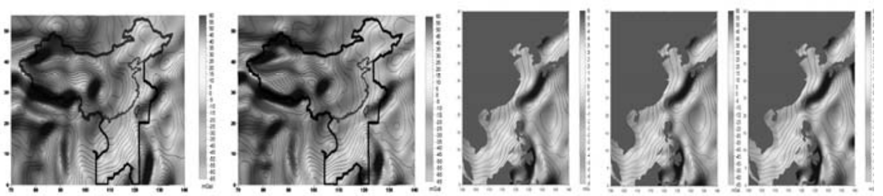

Fig. 3.a. Fig. 3.b. Fig. 3.c. Fig. 3.d. Fig. 3.e.

Fig. 3. Long wavelength gravity anomalies after low-pass filtering by 2D Gaussian filter Fig. 3. a, b, c, d, e are long wavelength components of the EIGEN-2, the ground-shipboard, and KMS02, GMGA97 and V9.2, respectively.

residuals present to the northwestern China and its vicinities, and Qinghai-Tibet Plateau ($75^\circ\leq\lambda\leq107^\circ E$, $26^\circ\leq\varphi\leq35^\circ N$). The negative biggish residual was located on the Chaidamu basin of China ($81^\circ\leq\lambda\leq87^\circ E$, $35^\circ\leq\varphi\leq38^\circ N$). The statistics shows that the RMS difference between the EIGEN-2 and the ground data has a stupendous value about ±8.7 mGal. The mean value of the differences is largish about 7.0 mGal, which should be predicated an existence of the biggish systemic discrepancy for ground data. On marine of test area with the shipboard data, the biggish long wavelength residuals present to the Southern China Sea and its vicinities. The statistics shows that the RMS difference between the EIGEN-2 and shipboard data is about ±4.19 mGal. The mean value of the differences is 2.68 mGal, which should be implied systemic discrepancy for the shipboard data. On the West Pacific, the residual differences between EIGEN-2 and altimetry data are plot in Fig. 4.b, c, d. The complicated area is mainly centralized nearby offshore with Philippines, Indonesia and Malaysia, nearby Ryukyu, and South China Sea. In these region there are more islands and reef, which influence the altimetry accuracy. The statistics shows that the RMS of the long wavelength differences between EIGEN-2 and altimetry data exceeds ±2.0 mGal (average is ±2.56 mgal). The mean difference is less than -0.08 mGal (average -0.06 mgal, see Table 3), which means system error from altimetry data is acceptable in the West Pacific.

5 Conclusions

The comparisons of gravity models showed that the global gravity field models EIGEN-2, EIGEN-1S and EGM96 are consistent up to about degree 35, while above this degrees the EIGEN-2 may have inferior estimates due to the limitation of CHAMP resolution. That imply three models should be useful for detection of long wavelength errors in the terrestrial data. The evaluation of the gravity data for China and its vicinities by comparisons of long wavelength with the model EIGEN-2 has confirmed the existence of larger errors and systemic discrepancy. The majority of biggish differences converged in the Northwestern and the Qinghai-Tibet plateau of China. It was found apparent inconsistencies between

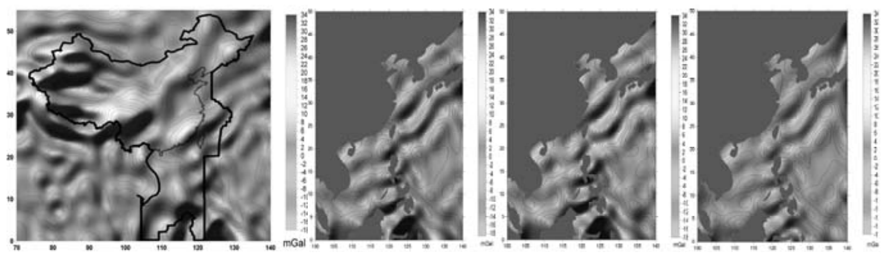

Fig. 4.a. Fig. 4.b. Fig. 4.c. Fig. 4.d.

Fig. 4. Long wavelength anomaly residuals with the spatial wavelength about 550 km. Fig. 4.a, b, c, d are long wavelength residuals between EIGE-2 and ground-shipboard, and KMS02, GMGA97 and V9.2, respectively.

shipboard data and EIGEN-2 on the China Sea and its vicinities, and between altimetry derived datasets and EIGEN-2 model on the Western Pacific. The reasons for the revealed errors may be traced back to lacking or poor quality gravity data and substitute errors, especially in the Western mainland of China, while on the ocean we suspect datum inconsistencies or errors from the shipboard surveying and the satellite altimetry, which one is satellite altimetry errors, the other is recovery errors of gravity anomalies from the altimetry data. Otherwise, it is not allow neglect that possible reference system inconsistencies or inaccurate coordination of gravity stations used. Certainly, it is difficult to avoid these infections. Therefore, we expect by dint of the high accuracy global gravity field models derived from the satellite gravity missions such as CHAMP, GRACE and GOCE to significantly improve the gravity field in terms of a homogeneous and high accuracy and resolution.

Acknowledgement. Thanks are due to C.C. Tscherning and R. Forsberg for providing GRAVSOFT, and to D.T. Sandwell, C. Hwang, O.B. Andersen, and P. Knudsen for providing the altimetry gravity datasets. This work is supported in part by Key Project of Chinese Academy of Sciences (KZCX2- SW- T1, KZCX3- SW-132).

References

Andersen OB, Knudsen P (1998) Globe marine gravity field from the ERS-1 and GEOSAT geodetic mission altimetry. J Geophys Res *103(C4)*: 8129-8137.

Andersen OB, Knudsen P, Trimmer R (2001) THE KMS2001 global mean sea surface and gravity field. Proc. IAG2001 Scientific Assembly, Budapest, Hungary [CD-ROM]

Hwang C, Kao EC, Parsons BE (1998) Global derivation of marine gravity anomalies from SEASAT, GEOSAT, ERS-1 and TOPEX/POSEIDON altimeter data. Geophy J Int *134*: 449–459.

Reigber C, Balmino G, Schwintzer P, Biancale R, Bode A, Lemoine JM, König R, Loyer S, Neumayer H, Marty JC, Barthelmes F, Perosanz F, and Zhu SY (2002) A high quality global gravity field model from CHAMP GPS tracking data and Accelerometry (EIGEN-1S). Geophys Res Lett *29(14)*: 371-374.

Reigber Ch, Schwintzer P, König R, Neumayer KH, Bode A, Barthelmes F, Förste Ch, Balmino G., Biancale R, Lemoine J M, Loyer S, Perosanz F (2001) Earth Gravity Field Solutions from Several Months of CHAMP Satellite Data. EOS Trans. AGU, Fall Meet. Suppl. *82(47)*: G4IC-02.

Reigber Ch, Schwintzer P, Neumayer K H, Barthelmes F, König R, Förste Ch, Balmino G., Biancale R, Lemoine J M, Loyer S, Bruinsma S, Perosanz F, Fayard T (2003) The CHAMP-only Earth Gravity Field Model EIGEN-2. Adv Space Res *31(8)*: 1883-1888.

Sandwell DT, Smith WHF (1997) Marine gravity anomaly from GEOSAT and ERS-1 satellite altimetry. J Geophys Res *102(B5)*: 10,039-10,054.

Tscherning CC and Rapp RH (1974) Closed covariance expressions for gravity anomalies, geoid undulations, and deflections of the vertical implied by anomaly degree variance models. Ohio State University, Columbus, Ohio, OSU Rep. No. 208.

Zhang YJ (1998) Image engineering I: Image processing and image analysis. Qinghua University publishing Company, Beijing.