QUALIFICATION AND REFINEMENT OF THE IRANIAN GRAVITY DATABASE

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ABSTRACT

Since 1986 several gravimetric geoid models were published in the Iran region. Based on primary investigation on these gravimetric geoid models, it is found that their relative and absolute accuracies versus GPS/levelling are more or less the same or in some cases worse than the current available global geopotential models (Kiamehr 1997, 2001, 2003a , 2003b, 2004 and Kiamehr and Sjöberg 2004). Regardless the effect of choosing proper computational method in determination of any geoid models, the quantity and quality of the gravity anomaly database plays a major rule in the final result of them. The main aim of this research is the creation of a more complete and also refined new gravity database for Iran. For this purpose different dataset from different sources are gathered and combined in a single database. Then we start to refine it from possible outliers by using Least Squares Collocation (LSC) approach. A special method used for the interpolation scheme of free-air gravity anomalies in order to take into account the effect of topography. The final grid file was creates based on the Kriging method with 80" * 90" resolution. The overall accuracy for the current database is estimated to near 10 mGal.

Key Words: Least Squares Collocation, Gravity Anomaly, Outlier, RTM, Geoid.

1- Introduction

The computation of gravimetric geoid models for the Iranian region suffers mainly from the few gravity observations available . On the other hand, the quality of the data is questionable because they have been gathered from different organisations for different purpose and with differencing accuracies during the long time. In order to obtain reasonable results, we should start this research by collecting and qualifying current gravity data from different sources. Thus, all available gravity data has been collected for both land and marine regions and an editing of blunder-removal processing scheme has been followed to generate an optimal gravity dataset for use in geoid determination. The basic analysis and validation of the gravity databank was based on a gross-error detection visualization and collocation scheme.

The geoid models are strongly dependent on gravity data entering into the solutions. Perfection of any theoretical method is diminished or even meaningless with insufficient data quality and coverage . In a few cases they are accurate to 1 cm (in relative sense for short baselines below 10 km) geoid can be obtained with gravity data spaced around 2-3 km (see, e.g., Forsberg 2001).

Gravity anomalies are mainly used for the determination of the geoid , interpolation and geophysical extrapolation of gravity, geological mapping, exploration for natural resource, and investigation of the Earth's crust. Free-air gravity anomaly (Δg_F) referred to the ground level, is defined as the difference between the actual gravity measured on the ground g_p and the normal gravity γ_Q:

$$\Delta g_{F(mGal)} = g_p - \gamma_Q = g_p - \gamma_0 + 0.3086\ H_{(metres)}, \qquad (1)$$

Where Q is realted to the normal height H (continued upwards from the reference ellipsoid) of the survey point. The gravity γ_0 is latitude-dependent normal gravity and can be calculated by a series expansion, e.g. after Moritz (1992). The Bouguer anomaly is given by

$$\Delta g_B = \Delta g_F - 2\pi G \rho H = \Delta g_F - 0.11187H = g_p - \gamma_0 + 0.1967H, \qquad (2)$$

Where G is the Newton's gravity constant G = 6.672585 *

$m^3Kg^{-1}s^{-2}$ and ρ = 2.67 g cm^3. It is clear that gravity anomalies are depending on height and topography.

The free - air anomaly is known to be more sensitive to the topography , so, if there are rough topographic masses in the computation area, the free-air anomalies will be rough and that is why the interpolation cannot always be successful. In order to achieve a better result for such an area, the interpolation could be done by means of the less topography dependent Bouguer anomaly.

The geoid determination methods can be classified in different ways with respect to using gravity data. We can distinguish two techniques, one used reduced gravity data (e.g. RCR which also use topography and EGM reduced data) and other used unreduced data (e.g. combined approach of Sjöberg (2003)). The most common technique for reducing topographic effect is the Residual Terrain Model (RTM) (Forsberg, 1984). The gravity data is usually presented as surface blocks thus an error occurs due to loss of short wavelenght gravity information (so called discretisation error) when estimating the mean anomalies Δg from point gravity data. The main difference of these two mentioned methods stems from the fact that the discretisation errors are larger in the full-field (unreduced) case. Figure 1 shows the effect of RTM based on SRTM DEM in Iran.

The effect of this error can be reduced by using special interpolation technique. We first make a topographic correction that results into reduced gravity anomalies, which are assumed to be smoother than the original ones. In the next step the observations are interpolated to a denser grid and the topographic corrections are finally reserved , i.e. the masses are put back again. Notice , however, that this requires that a good Digital Terrain Model (DTM) is available with at least the same resolution as the new interpolated grid. Thus, by using the above interpolation procedure on the smooth topographically reduced gravity anomalies, the combined estimator can be expected to yield more or less similar accuracy as when the remove - compute - restore estimator is used. Agern (2004) numerically showed that the using of this interpolation step reduce the discretisation errors significantly in combined approach of Sjöberg (ibid) and improve result of geoid determination versus GPS/levelling.

In this sub-section we summarizes the generation of a consistent and accurate gravity database for Iran. The structure of the procedure followed can be simarized as:a) collection and unification of all available gravity data, b) blunder removal and editing , c) database and gridding of data.

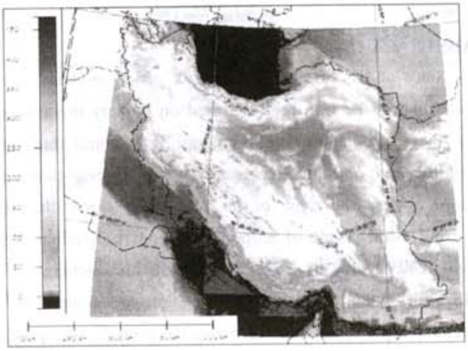

Fig 1. RTM effect based on SRTM DEM. (Unit: mGal)

2. Gravity data

For the generation of the gravity database a total number of 26125 point and mean gravity data were collected from different data sources. Various databases including absolute gravity measurements, relative marine and land observations were collected for the area of Iran bounded between 23° < φ < 42° and 41° < λ < 67°. The distribution of the gravity data, free from outliers, is presented in Figure 2 (a and b).

The original datasets used are : a) 9566 data from Bulletin d Information (BGI) gravity database b) 8949 gravity data from the NCC c) 7610 marine free - air gravity anomalies. All observation are referred to IGSN71, the gravity anomalies were computed using the International Gravity Formula of 1980 for the normal gravity.

Unfortunately, the available observations have been observed during a long time span, using different equipment , methods and reference frames. As a consequence they are prone to be affected by various types of systematic errors, which are mainly of long - wavelenght nature. It should also be mentioned that the data type in question is usually 10^{-11}

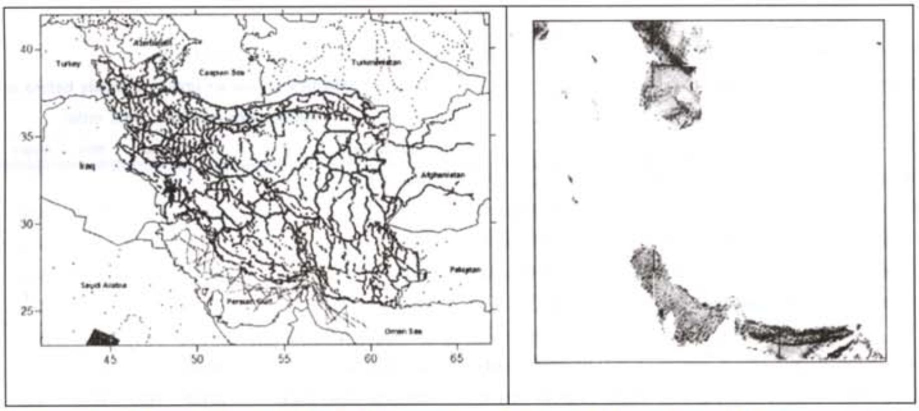

Fig. 2a . Terrestrial gravity anomalies data (BGI, NCC and shipborne) Fig 2b. Satellite altimetry marine data (From Sandwell at al., 1997)

Fig 2. Gravity data distribution in Iran

heterogeneous : Very dense high quality observations might have been collected in some geophysically interesting areas (Oil area in south - west), while the data are sparse and of diverse quality in other places. It can also be mentioned that the lack of accurate heights is often source of a crucial error.

The horizontal position of BGI data mostly extracted from 1/250,000 and 1/50,000 maps that have accuracies between (25-100) m. Heights of gravity stations located along the levelling, networks has absolute accuracy near 0.7m, but other points usually have barometric heights with accuracy between (5-10) m.

The NCC data was observed with modern gravimeters and are located along the levelling network. The horizontal position of these new points is derived from GPS.

3. Blunder detection

For the indentification and removal of blunders a two - step procedure was followed, a) visual inspection and b) least - squares interpolation . Taking into account that data related to the gravity field are spatially correlated, gravity quantities of the same type and not far apart will be very simialr. Especially , after the removal of a highly expanded geopotential model and of the effect thr neighbouring masses, the distribution of the data should be close to normal. According to BGI (1992) an effective check can be done by ID contouring the data. Thus, following this method, a map ot residual, i.e., EGM (Earth Gravity Model) and topographically reduced gravity anomalies , was generated and deep holes and steep spikes were considered to indicate suspicious observations. Since the smoothness of the field is the highest one after the removal of high and low frequency information , large discrepancies can be identified as blunders.

The total number of free-air gravity anomalies were collected and reformatted in a single file using station number as characteristic code for each dataset, so they could be distinguished at a later step. For the visual inspection, the contribution of the EGM96 (Lemoine et al. 1998) was removed from the raw while the topographic effects were taken into account through a simple Bouguer reduction.

Employing the reduced anomaly field, a contour map of the area was generated. Some outliers were identified by considering that spikes and holes in the gravity field do not describe local irregularities since the main topographic signal from a Bouguer plate was removed. After this visual inspection test, 578 gravity anomaly observations were identified as outliers and were subsequently removed from the database.

Least squares collocation (LSC) was also used to remove any existing outliers that were not removed during the preceding visual processes . A gravity anomaly was predicted from a set of values x, in neighbouring points, spaced as evenly as possible in all directions according to the well-known collocation formula (Heiskanen and Moritz 1967)

$$\bar{y} = C_y \bar{C}^{-1} x, \quad (3)$$

Where C_y is the vector of covariances between y and the x_i, values and $\bar{C} = C + D$ is the sum of the covariance matrix of the x_i, quantities (C) and the variance - covariance matrix of the noise (error) associated with the quantities (D). An error estimate was also computed for the difference $|y - \bar{y}|$ as :

$$\sigma^2 (y - \bar{y}) = C_0 - C_y^T C^{-1} C_y, \quad (4)$$

Where C_0 is the variance of the gravity values. A gross - error was then detected when

$$|y_{obs} - \bar{y}| > k \sqrt{\sigma^2 (y - \bar{y}) + \sigma_y^2}, \quad (5)$$

Where k is a constant generally having a value between 3 and 5 depending on the check strictness, and σ_y^2 is the error variance of the observation y_{obs}. From the above equations it is obvious that gross - errors are most easily found if C_0 is small. Thus it is obvious that the removal of the long and short wavelengths of the gravity field is necessary for the outlier detection to lead to realistic results.

The procedure described was followed to eliminate any existing gross - errors that passed the visual inspection test. The data were then reduced to the EGM96 geopotential model and an empirical covariance function was computed and fitted to the Tscherning and Rapp (1974) analytical model from the observations of the first data file. Using the parameters of this model, predictions at the locations of the points of the second file were then estimated. Due to the unavailability of proper measurement error and the ambiguous quality of the data, an error of +5 mGal was assigned in each observations. A rejection criterion with a parameter k=3 was followed so as to remove more suspicious observations and generate a more accurate gravity database. This parameter in conjunction with the overestimated σ of the observations ensured the removal of the largest blunders. A total number of 442 points were rejected as suspicious gross-errors. The points removed represent 3.9% of the total database, while those remaining were 25105 gravity observations. The statistics and contour plot of the gravity anomalies before and after the blunder removal are tabulated in Table 1 and figure 3 respectively.

Table 1 - Statistics of free air gravity anomaly before and after the blunder removal . Unit: mGal

Gravity Data Unit: mGal	No	Min.	Max.	Mean	RMS
EGM96	Model	-151.94	168.47	5.68	45.97
BGI	9566	-163.20	234.60	9.36	50.23
NCC	8949	-292.99	1220.11	94.88	280.06
Marine	7610	-128.46	40.04	-53.85	32.58
All Data(Before outlier)	26125	-343.03	992.27	-83.61	136.65
All Data(After outlier)	25105	-163.2	234.6	-7.08	54.83
Database (Filled Gaps)	27172	-163.2	234.6	-6.34	54.04

The total area of Iran is estimated to be 1,648,195 km^2, so it is simple to show that we have about one gravity point per 65 km^2. The largest gap area mostly located in Zagros and Alborz mountains areas, Lout and Kavir central desert areas, Sistan & Balochestan state (in south-east of country) and marine areas say the Persian Gulf, Oman and Caspian sea. On the other hand in order to compute geoid model for the entire country we must have data out of boarder, In order to fill these gaps we use original 0.5°*0.5° surface free air gravity anomalies used in the modelling of EGM96 model and free air gravity anomalies derived from satellite altimetry (Sandwell at al., 1997).

To construct the final gravity grid, different gridding algorithms such as spline interpolation and weighted means were tested. But, for the gridding procedure to be rigorous we chose to grid the data using Kriging. This method is obviously more time consuming compared to the other two, but provides statistically optimal results. The accuracy of gridded gravity anomalies can be determined empirically by comparing the gridded values at known control points. For this purpose 120 points of the Iranian gravity network were used. The precision of the free-air anomaly grid in Iran is estimated near 10 mGal. This information can be used for evaluating the internal accuracy of the geoid models. According to Vermeer (1995) the following empirical expression is useful for evaluating the short wavelength geoid error:

$$\sigma_{N(mm)} = 0.3 * d_{km} * \sigma_{\Delta g\ (mGal)}, \quad (6)$$

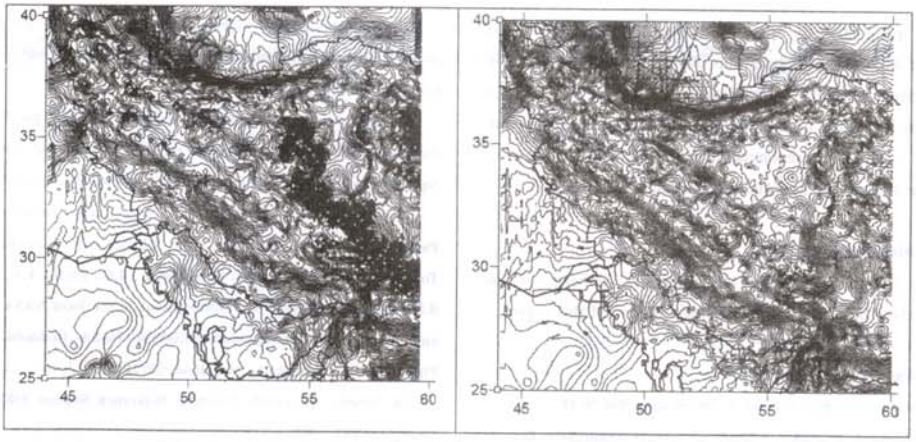

Fig.3a . Before

Fig.3b.After

Fig.3. Contour plot of the gravity anomalies before and after outlier detection procedure. Contour interval 5 mGal.

Where $\sigma_{\Delta g}$ the accuracy of prediction of gravity anomalies and d is average point spacing . For Iran we take d = 65 km and $\sigma_{\Delta g}$ = 10 mGal. Thus the expected relative accuracy (with respect to the closest grid points) of the geoid models can be estimated near σ_N = 20 cm by using these database. However , this is just approximate overall estimation for geoid and we can get better results in the areas with denser gravity data. The predicted 80" * 90" grid of free - air gravity anomalies is presented in figure 8. Within the whole target area free-air anomalies vary from (-182 to +352) mGal. The overall range of anomalies is thus almost 3 mGal.

4. Conclusion and Recommendations

During this research , Iranian new gravity anomaly database is created and all possible outliers are detected and removed from the database. Also we estimate the overall accuracy of this new database. It is clear that reaching to the cm level of accuracy even with good and well distributed gravity data for any geoid is really difficult in the rough and mountainous areas like as Iran. It is absolutely evident that with the current distribution of gravity data (1 data per 65 km) and 10 mGal overall accuracy for data; to obtain dm accuracies for geoid is almost impossible . There are large in mountains areas in Alborz and Zagros that do not have any gravity data at all.

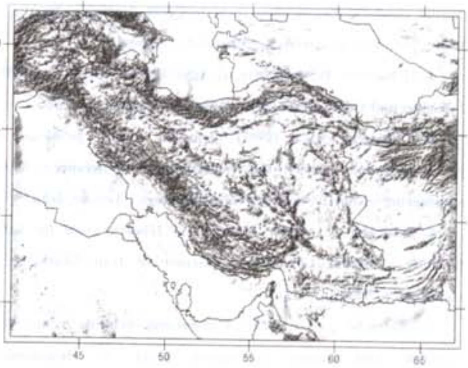

Fig 4. The 80" * 90" grid of free - air gravity anomalies in the target area. The minimum, maximum, mean and standard deviation of data are -182.35 , 352.62 3.37 and 50.78 mGal.

It seems that most of these areas will not accessible also near in future. The distribution of data is not uniform and mostly they are gathered for some special engineering or geophysical purpose projects with different tools and during the long time. However, based on Kiamehr (2005) he got very good results comparing recent local gravimetric geoid models