EVALUATION OF THE EARTH GRAVITATIONAL MODEL 2008 IN TURKEY

Ali Kılıçoğlu[1], Ahmet Direnç, Mehmet Simav, Onur Lenk, Bahadır Aktuğ, Hasan Yıldız

Geodesy Department, General Command of Mapping, Turkey

Abstract

A new Earth Gravitational Model (EGM08) to degree 2160 has been released to IAG's EGM Evaluation Group. In this study, we evaluate EGM08 Tide Free Model by using regional gravity, quasi-geoid height and GPS/leveling data. The EGM08-derived quantities are compared with (1)the GPS/leveling quasi-geoid heights, (2)an existing GPS/leveling fitted regional quasi-geoid model (TG03), and (3)the surface gravity anomalies in Turkey. The differences between observed/computed and EGM08-derived quantities are investigated. The mean value and standard deviation of the differences between EGM08 derived and observed quantities are found to be -88.8 cm and 24.2 cm for GPS/leveling height anomalies, 27.1 cm and 75.3 cm for TG03 quasi-geoid heights, and 2.8 mGal and 17.1 mGal for surface gravity anomalies. As Turkish proprietary data were not used in EGM08 computations this work is believed to be an external check for EGM08.

1. Introduction

A new Earth Gravitational Model (EGM2008) to degree 2160 has been released to IAG's EGM Evaluation Group. EGM2008 incorporates 5x5 minutes gravity anomalies and has benefited from the latest GRACE solutions. Improved altimetry-derived gravity anomalies and its implied Dynamic Ocean Topography model were also used in computations (Pavlis et al., 2008).

The evaluation and quality assessment of the EGM08 is important for being used in various geodetic and other scientific applications at global and regional scales. The evaluation of the EGM08 is based on the comparisons with other external data. For this aim external data sets, that mainly include GPS/leveling observations, airborne and surface gravity data, sea surface topography, sea surface heights from altimetry band tide gauge, and deflections of the vertical, are to be used in appropriate evaluation procedures.

The objective of this study is to control, validate and perform quality assessment of EGM08 derived data. As Turkish proprietary gravity and GPS/leveling data were not used in the EGM08 computations this work provides an external evaluation for EGM08 derived surface gravity and height anomalies on the physical surface of the earth.

In this study, we compared EGM2008 Tide Free Model with regional gravity, quasi-geoid height and GPS/leveling data. The EGM08-derived quantities are compared with (1)the GPS/leveling quasi-geoid heights, (2)existing GPS/leveling fitted regional quasi-geoid model, and (3)the surface free-air gravity anomalies in Turkey within boundaries 26°E-45°E and 36°N-42°N.

Computations were achieved by using HARMONIC_SYNTHESIS program that is provided with the EGM08 coefficients (Holmes and Pavlis, 2006).

---

[1] Ph.D., Geodesy Department, General Command of Mapping, TR-06100, Dikimevi, Ankara, Turkey, ali.kilicoglu@hgk.mil.tr. The manuscript solely reflects the personal views of the authors and does not necessarily represent the views, positions, strategies or opinions of Turkish Armed Forces.

2. Comparison with GPS/Leveling quasi-geoid heights

Turkish Vertical Control Network (TUDKA99) was re-adjusted due to two Marmara earthquakes occurred in 1999, with of 243 lines of 25680 points with a total length of 29316 km. Vertical datum for TUDKA99 was defined with arithmetic mean of instantaneous sea level measurements recorded at Antalya tide gauge between 1936 and 1971. The geopotential value for the datum point was determined, by making use of gravity value in Potsdam Datum. In the adjustment, geopotential numbers were used as observations; then, geopotential numbers, Helmert orthometric heights and Molodensky normal heights of all network stations were estimated. Gravity values in Potsdam Datum were used for the calculation of geopotential number differences between network stations. The adjustment resulted in point heights of precisions varying from 0.3 cm to 9.0 cm depending on the distance from the datum point. Helmert orthometric height system was selected to be used in Turkey for all geodetic and practical applications, although normal heights of network points were computed as well (Ayhan and Demir, 1992).

Turkish National Fundamental GPS Network (TUTGA) was established in 2001 and a number of the stations have been re-surveyed due to the earthquakes happened in 1999-2003. The total number of network stations is about 600. For each station 3-D coordinates and their associated velocities were computed in ITRF96. Positional accuracy of the stations is about 1-3 cm while the relative accuracy is better than about 0.01 ppm. Besides, the GPS network has been connected to the Turkish Horizontal and Vertical Control Networks through specified points and time-dependent coordinates of all stations were being computed in the context of the maintenance of the network with periodic GPS observations (Ayhan et al., 2002). Total of 197 GPS network stations have been connected to Turkish vertical network by precise leveling (Ayhan et al., 2002; Kılıçoğlu, 2002; Kılıçoğlu and Fırat, 2003).

The quasi-geoid heights ($\zeta_{GPS/lev}$) of the 197 collocated stations were computed by subtracting the Molodensky Normal Heights ($H^*_{TUDKA99}$) from ellipsoidal heights ($h_{TUTGA99A}$) as follows.

$$\zeta_{GPS/lev} = h_{TUTGA99A} - H^*_{TUDKA99} \tag{1}$$

The statistics of the differences are given in Table-1, and a histogram graph of the differences is given in Figure-1. The collocated stations and quasi-geoid differences ($\zeta_{GPS/lev} - \zeta_{EGM08}$) between EGM08 and GPS/leveling are shown in Figure-2.

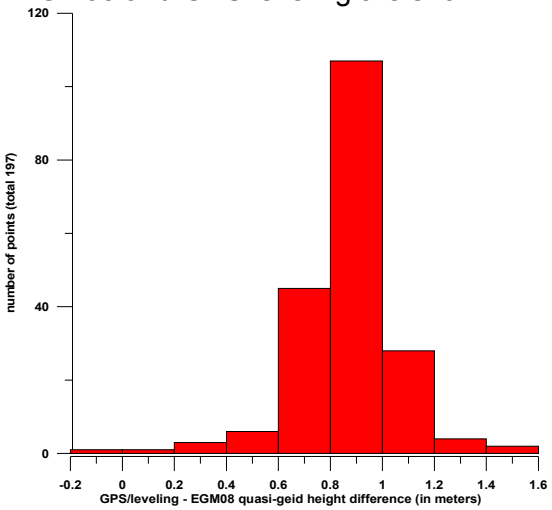

Figure-1: Histogram of the EGM08 - GPS/leveling quasi-geoid height differences

Table-1: Quasi-geoid height differences EGM08 - GPS/leveling.

Number of values	197
Minimum	-0.184 m
Maximum	1.505 m
Mean	0.860 m
Standard deviation	0.189 m

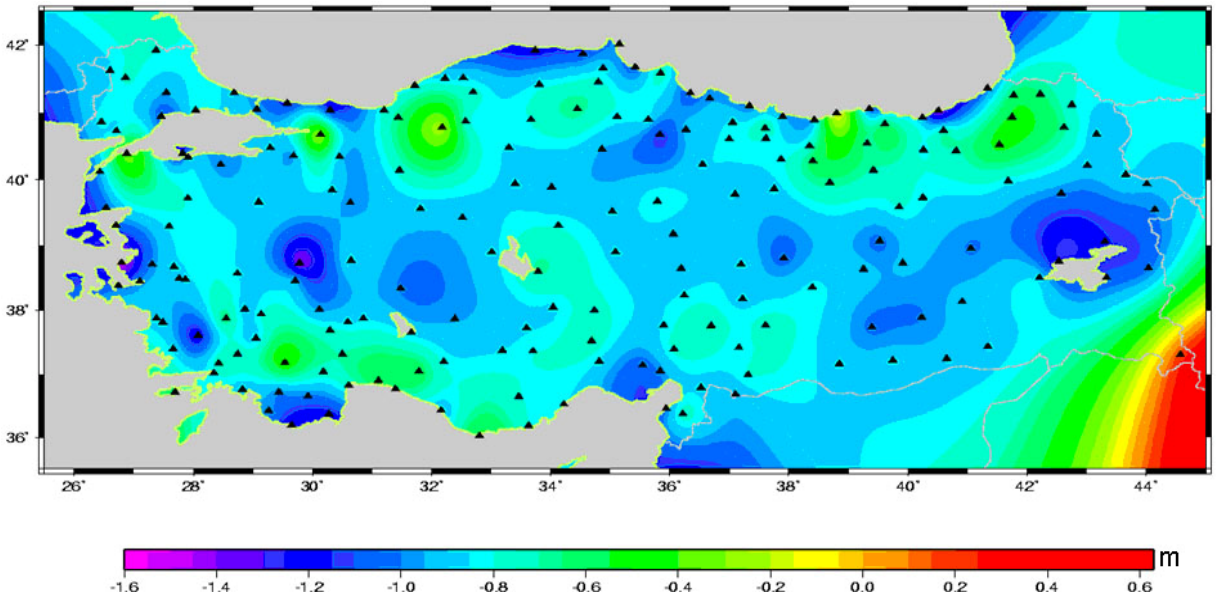

Figure-2: The difference between EGM08 and GPS/leveling quasi-geoid heights in Turkey. Black triangles (197) shows the collocated GPS/leveling stations.

The bias (+86 cm) between two sets is due to definition of local vertical datum (mean sea level at Antalya). GPS observations in Turkey were achieved within the last two decades, whereas precise leveling measurements were achieved during the period of 1936-1994. Since Anatolian plate lies in a very active tectonic region, that is within the boundary zones of Eurasian, African and Arabian tectonic plates, tectonic framework of Mediterranean, in which Anatolia is located, is dominated by collision of Arabian and African Plates with Eurasia. Thus, tectonic regime of Anatolia involves various kinds of tectonic phenomena such as continental collision, strike-slip and thrust faulting, subduction, contraction and extension (Aktug and Kilicoglu, 2006; Aktug et al., 2008). Interseismic vertical rates of GPS stations have been computed by repeated GPS observations within the establishment of TFGN99-A (Ayhan et al, 2002; Aktug et al., 2008). Vertical velocity field of Turkey is given in Figure-3.

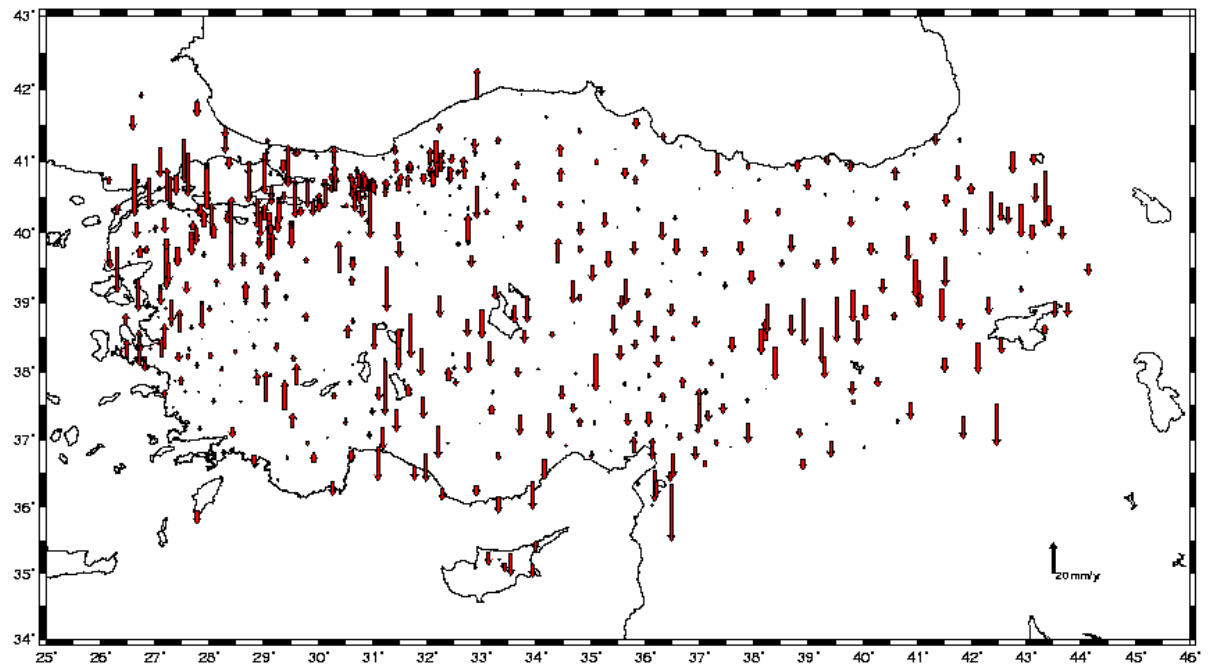

Figure-3 : Vertical velocity field of Turkey as deduced from repeated GPS measurements in the last two decades.

Figure-2 includes interseismic and coseismic (and relatively small effects of postseismic deformation) vertical deformation as well as other network deformations caused by observations and adjustment, whereas Figure-3 shows only interseismic deformation. The differences were also investigated in terms of active fault traces and seismicity. Figure-4 shows that large differences are observed within compresion zones. However, differences in northwestern part of Anatolia (Marmara) which underwent large earthquakes are lower than expected. In this respect, neither active fault traces nor seismicity provide a direct correlation, to which all the differences between EGM08 and GPS/leveling quasi-geoid heights could be attributed. Turkish leveling network has been very much affected by tectonic phenomena and other network distortions. Thus, GPS/leveling quasi-geoid heights may consist of large vertical deformations. Considering the vertical deformation in Turkey in the light of the two figures, the discrepancy between GPS/leveling and EGM08 seems reasonable.

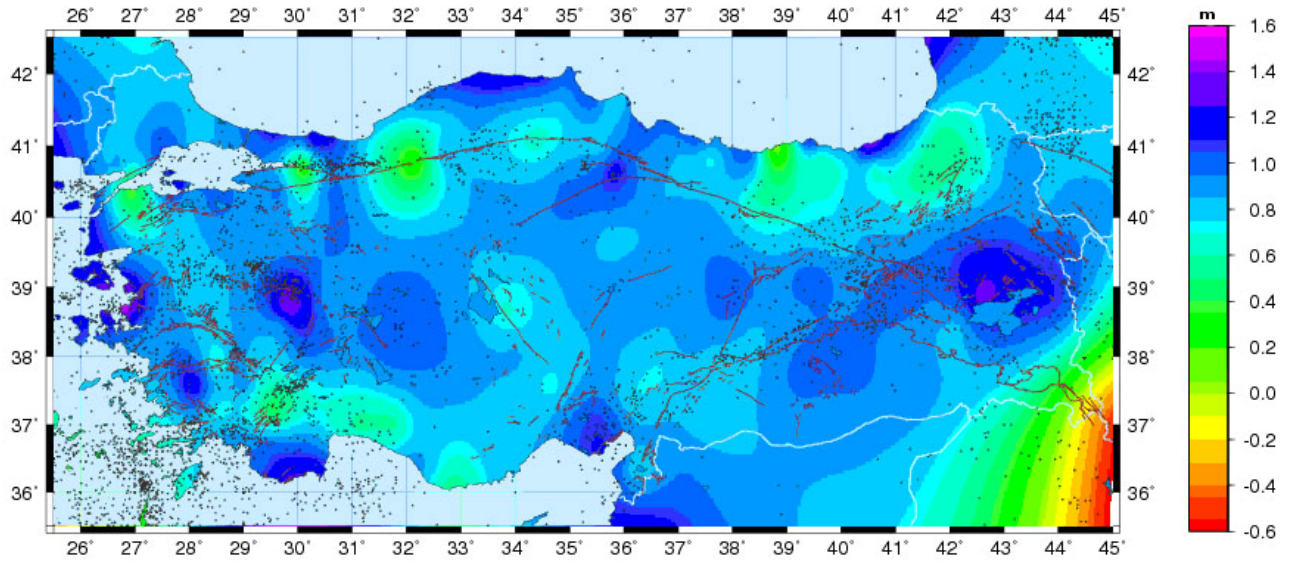

Figure 4. Differences between EGM08 and GPS/Leveling quasi-geoid heights. Earthquakes with magnitudes larger than Mw obtained from KOERI (Kandilli Observatory and Earthquake Research Institue, http://www.koeri.boun.edu.tr). Active fault traces were adapted from (Saroglu et al., 1992).

3. Comparison with a regional gravimetric quasi-geoid height model.

As a precise geoid model referring to a global geocentric datum is essential for determination of the orthometric heights by GPS/leveling, the new Turkish Geoid (TG03) was computed in 2003 as new and more data were available (Kilicoglu, 2005). Heterogeneous data (gravity, topography and geoid heights) were used by Least Squares Collocation (LSC) in a remove-restore procedure (Tscherning et al.,1994). EGM96 (Lemoine et al., 1996) was used as the reference model of the Earth's geopotential model. The data used consist of surface gravity anomalies (on ~ 65000 stations), gravity anomalies derived from ERS1, ERS2 and TOPEX/POSEIDON altimetry data (on ~ 20000 stations), gravity anomalies derived from ship observations (on ~ 10000 stations), GPS/leveling geoid heights (on 197 stations) and topographic heights. Surface gravity values are in Potsdam Datum, and the free air anomalies were computed in GRS80. No surface gravity data were used outside the Turkish border where topographic heights were obtained from GTOPO30 global topography. The residual terrain model (RTM) effect of the topography was computed using a detailed (20"x15") Digital Terrain Model (DTM), coarse (3'x3') DTM and reference (10'x10') DTM. The DTM used consists of high-resolution topographic heights within the borders, and dense bathymetry near the shoreline. Evenly distributed GPS/leveling geoid heights were introduced so as to compute the final geoid in agreement with GPS ellipsoidal heights. As described above, ellipsoidal heights of the GPS/leveling points refer to well-established Turkish National GPS Network (aligned to ITRF96), while orthometric heights refer to Turkish National Vertical Datum.

The geoid heights at 3'x3' grid points within Turkey (25E-46E, 35N-43N) were computed to be further interpolated in practical use in accordance with Turkish National Vertical Datum. The final geoid was tested at GPS/leveling test stations which were not used in the computations, and the external accuracy was found to be within 10 cm as varying with respect to the data distribution and density. Actually, the quasi-geoid heights were computed, then combined with GPS/leveling, and finally transformed to geoid heights by making use of the formula below.

$$N = \varsigma + \frac{\bar{g} - \bar{\gamma}}{\bar{\gamma}} H \cong \varsigma + \frac{\Delta g_{BO}}{\bar{\gamma}} H \qquad (2)$$

Where, $\bar{g}$ is the mean gravity along the plumb line between geoid and the physical earth, $\bar{\gamma}$ is the mean normal gravity along the normal plumb line between ellipsoid and telluroid, Δg_{BO} is Bouguer gravity anomaly and H is orthometric height. (Hoffmann-Wellenhof and Moritz, 2005, p.326).

The quasi-geoid heights from EGM08 and TG03 (unfitted to GPS/leveling) were compared at 3'x3' grid nodes (Figure-5). Figure-6 and Table-2 show the statistics of the differences.

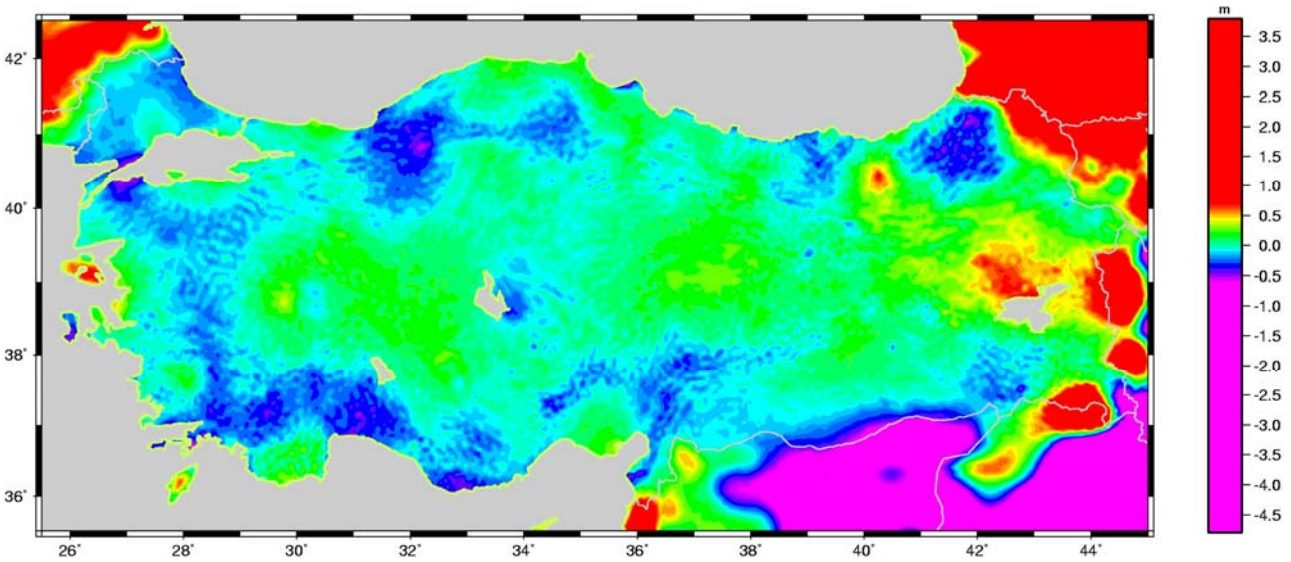

Figure-5: The difference between EGM08 and TG-03 quasi-geoid heights in Turkey. The data within boundaries are taken into account.

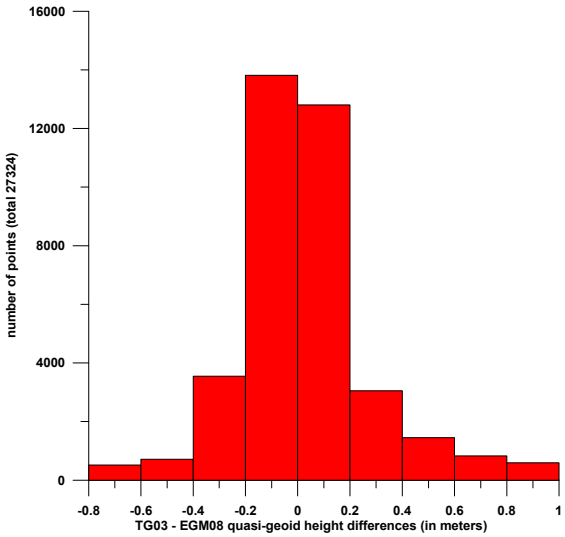

Figure-6: Histogram of the GPS/lev - EGM08 quasi-geoid height differences. Total number of points compared is 37324.

Table-2: Quasi-geoid height differences TG03 – EGM08

Number of values	37324
Minimum	-0.75 m
Maximum	0.99 m
Mean	0.02 m
Standard deviation	0.25 m

4. Comparison with surface free-air gravity anomalies

Surface free air gravity anomalies at 64992 stations in Turkey are used for EGM08 evaluation. Surface gravity anomalies are computed in Potsdam datum and referred to GRS80 normal gravity field. Gravity observations were carried out by using LaCoste&Romberg Gravimeters with reference to Turkish National Gravity Network-1956, of which point gravity accuracies vary between 0.07 to 0.19 mGal (Demir et al., 2006).

EGM08 free air gravity anomalies at observation points are computed as follows (Holmes and Pavlis, 2006; Pavlis et al., 2008).

$$\Delta g = -\frac{\partial T}{\partial r} - 2\frac{T}{r} \tag{3}$$

The distribution of the surface gravity data used in comparison is given in Figure-7 and the differences between EGM08 and surface free air gravity anomalies in Turkey are shown in Figure-8. Figure-9 and Table-3 show the statistics of the differences.

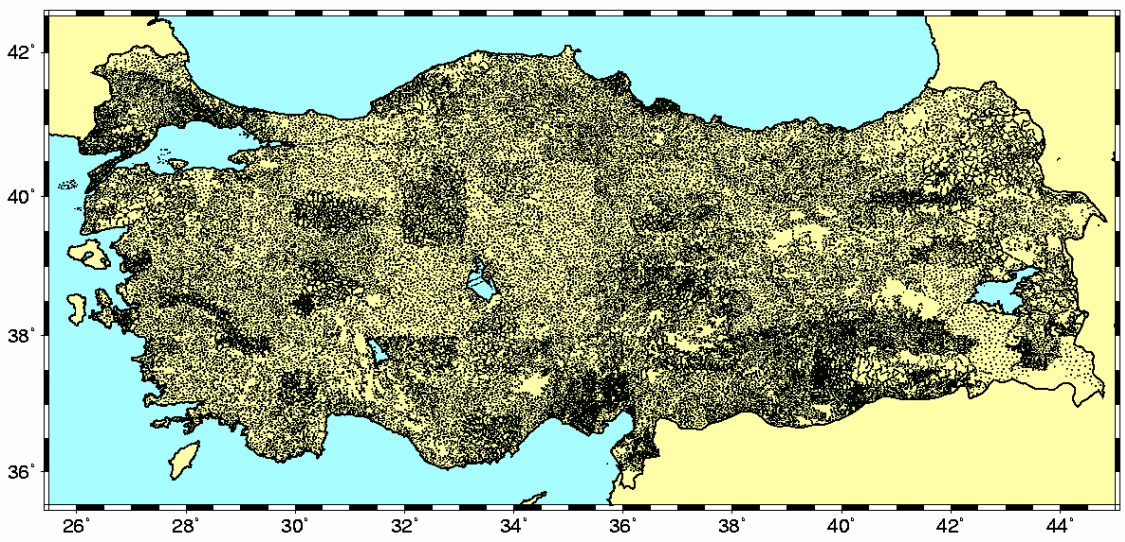

Figure-7: The distribution of the surface gravity data used in comparison in Turkey.

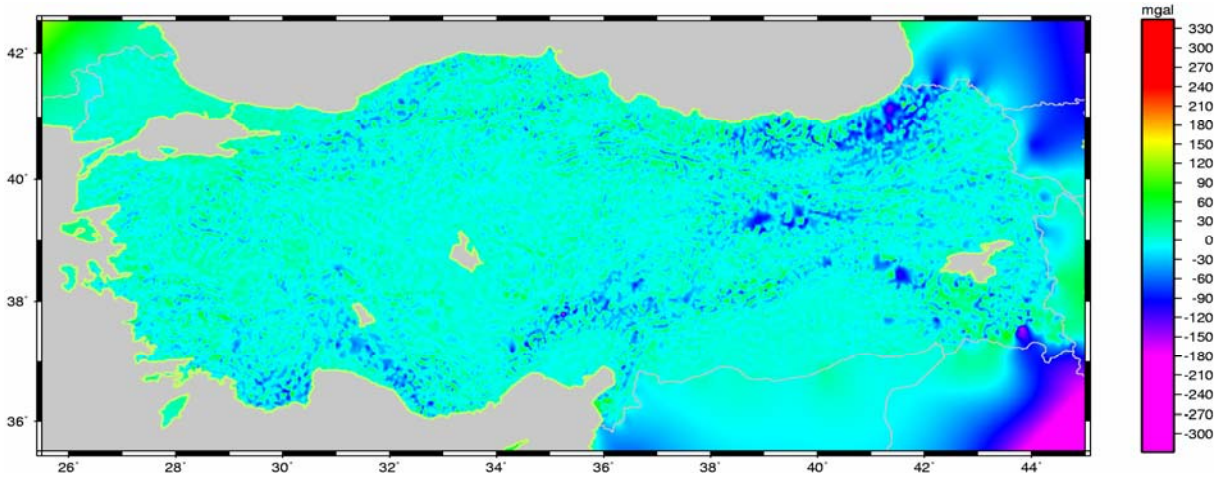

Figure-8: The difference between EGM08 and surface free air gravity anomalies in Turkey. The data within boundaries are taken into account.

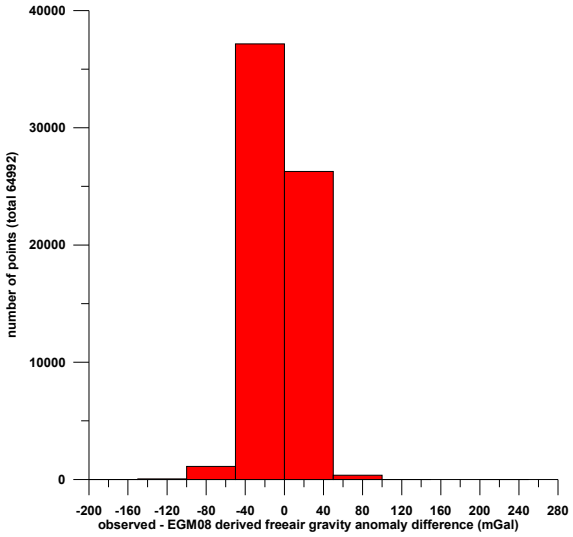

Figure-9: Histogram of the differences between EGM08 and surface free gravity anomalies.

Table-3: Statistics of the differences between EGM08 and surface free gravity anomalies.

Number of values	64992
Minimum	-177.29 mGal
Maximum	238.57 mGal
Mean	-3.28 mGal
Standard deviation	18.36 mGal

5. Conclusions

A new Earth Gravitational Model (EGM2008) to degree 2160 has been released to IAG's EGM Evaluation Group. The objective of this study was to evaluate EGM08 derived quantities with Turkish proprietary surface data.

The evaluation of the EGM08 was based on the comparisons with other external data. In this study, we compared EGM2008 Tide Free Model with regional gravity, quasi-geoid height and GPS/leveling as external data sets. The EGM08 derived quantities were compared with the GPS/leveling quasi-geoid heights, existing GPS/leveling fitted regional quasi-geoid model, and the surface free-air gravity anomalies in Turkey within boundaries 26°E-45°E and 36°N-42°N.

EGM08 derived height anomalies were compared with observed GPS/leveling observed quasi geoid heights at 197 stations spread over the Turkish territory. The statistics of the differences two sets of height anomalies ($\zeta_{GPS/lev} - \zeta_{EGM08}$) are given in Table-1 (mean:+86 cm, st.dev.; 18.9 cm). The bias and the discrepancies between two data sets should be further investigated considering the tectonic phenomena and other network deformations in and around Turkey.

Regional gravimetric quasi-geoid height model for Turkey (TG03) was compared to EGM08. TG03 was computed based on EGM96 with respect to GRS80 ellipsoid. The statistics of the differences (TG03 – EGM08) are given in Table-2 (mean: +2cm, st.dev.: 25 cm). TG03 and EGM08 have no bias factor with respect to each other. The differences show highs and lows in regions with rough topography in Turkey. The large differences might be caused by different resolutions of TG03 and EGM08, and by the lack of data outside Turkish border in TG03 model.

Surface free air gravity anomalies, in Potsdam datum and referred to GRS80 at 64992 stations, in Turkey were used for the evaluation of EGM08. The statistics of the differences (EGM08-observed) of surface gravity anomalies were given in Table-3 (mean: -3.28 mGal, st.dev.: 18.36 mGal). Some highs are seen in the regions with rough topography. This might be caused by the different resolution of DTMs used in EGM08 and reduction of observed gravity.

As Turkish proprietary gravity and GPS/leveling data were not used in the EGM08 computations this work provides an external control for EGM08 derived surface gravity and height anomalies on the physical surface of the earth.

The evaluation of EGM08 over Turkey shows a good agreement in overall. We think that EGM08 will cotribute much to the computation of a new geoid model for Turkey, as well as various geosicence applications.

References

Aktug, B., A.Kilicoglu (2006) Recent crustal deformation of Izmir, Western Anatolia and surrounding regions as deduced from repeated GPS measurements and strain field. Jornal of Geodynamics, Vol.41, pp.471-484.

Aktug, B., O.Lenk, A.Kilicoglu, A.Cingoz, S.Ozdemir (2008) : Velocity field of Turkey and surrounding region. Submitted to be presented at Active Tectonig Research Froup Workshop, 13-15 November, Ankara.

Aktug, B., A.Kilicoglu, O.Lenk, M.A. Gürdal (2007): Establishment of regional reference frames for quantifying active deformation areas in Anatolia, Studia Geophysica Geodetica (in review).

Ayhan, M.E., C.Demir (1992) : Turkish National Vertical Control Network (in Turkish). Türkiye Ulusal Düşey Kontrol (Nivelman) Ağı 1992 (TUDKA92). Harita Dergisi (Journal of Mapping), ISSN 1300-5790, No.109, pp.

Ayhan, M.E., C.Demir, O.Lenk, A.Kılıçoğlu, B.Aktuğ, M.Açıkgöz, O.Fırat, Y.S.Şengün, A.Cingöz, M.A.Gürdal, A.İ.Kurt, M.Ocak, A.Türkezer, H.Yıldız, N.Bayazıt, M.Ata, Y.Çağlar and A.Özerkan (2002) : Turkish Fundamental GPS Network – 1999A (TUTGA-99A). Harita Dergisi (Journal of Mapping). ISSN 1300-5790, Special Issue 16, GCM, Ankara.

Demir, C., A.Kılıçoğlu, O.Fırat (2006) : Turkish Fundamental Gravity Network (in Turkish), Türkiye Temel Gravite Ağı-1999 (TTGA-99). Harita Dergisi (Journal of Mapping), ISSN 1300-5790, No. 136. pp. 50-63. General Command of Mapping. Ankara

Hofmann-Wellenhof, B., H.Moritz (2005) : Physical Geodesy. Springer

Holmes.,S.A., N.K.Pavlis (2006) : A Fortran program for very-high-degree harmonic synthesis (version 05/01/2006).

Kılıçoğlu, A. (2002) : Updated Turkish Geoid TG99A (in Turkish). Güncelleştirilmiş Türkiye Jeoidi 1999 (TG99A). Proceedings of the Tectonics and Geodetic Networks Workshop, Scientific Meeting of TNGC, TUJK 2002 Yılı Bilimsel Toplantısı Tektonik ve Jeodezik Ağlar Çalıştayı Bildiri Kitabı. pp. 153-166. Boğaziçi Üniversitesi, KRDAE, İstanbul.

Kılıçoğlu, A., O.Fırat (2003) : Büyük ölçekli harita üretiminde GPS ile Ortometrik yükseklik belirlemeye yönelik jeoid modelleme ve uygulamalar. Proceedings of the GIS and Geodetic Networks Workshop, Scientific Meeting of TNGC, TUJK 2003 Yılı Bilimsel Toplantısı, Coğrafi Bilgi Sistemleri ve Jeodezik Ağlar Çalıştayı Bildiri Kitabı, s: 27-35. Selçuk Ü. Jeodezi ve Fotogrametri Bölümü, Konya

Kılıçoğlu, A., O. Fırat, C. Demir (2005) : Observations and methods used in the computation of new Turkish geoid (TG-03). Proceedings of the Geoid and Vertical Datum Workshop, Scientific Meeting of TNGC, Karadeniz Technical University, Trabzon.

Lemoine, F. G., S. C. Kenyon, J. K. Factor, R. G. Trimmer, N. K. Pavlis, D. S. Chinn, C. M. Cox, S. M. Klosko, S. B. Luthcke, M. H. Torrence, Y. M. Wang, R. G. Williamson, E. C. Pavlis, R. H. Rapp, and T. R. Olson (1998), The Development of the Joint NASA GSFC and the National Imagery and Mapping Agency (NIMA) Geopotential Model EGM96, National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland 20771.

Pavlis, N.K., S.A.Holmes, S.C.Kenyon, J.K.Factor (2008) : An Earth Gravitational Model to Degree 2160 : EGM2008. EGU General Assembly, April 13-18, 2008, Vienna, Austria.

Saroglu, F., Emre, O. & Kuscu, I., 1992. Turkish Active Faults Map, Directoriate of Mineral Research and Exploration, Ankara, Turkey,

Tscherning, C.C., P.Knudsen, R.Forsberg (1994) : Description of the GRAVSOFT Package. Geohysical Institute, University of Copenhangen.