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Full Length Research Paper

Comparison of global and local gravimetric geoid models in Turkey

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Because ellipsoidal heights gained either through GPS, which is widely used in our age, or through other means do not display the natural situation, they are far from meeting the practical precision needs concerning height. Orthometric heights received from the geoid up are more compatible with physical events and are accepted more natural and thus, with this very feature, they can be used successfully in solving many problems in practice related with height. Obtaining orthometric heights through traditional spirit leveling depends on weather conditions, is costly and requires too much labor and time. This is also the case for Turkey due to its topography being mountainous. In order to be able to convert h ellipsoidal heights which can be easily determined in GPS applications to H orthometric heights, N geoid heights are needed. Determining the best geoid model to be used in this transformation is important. In this article, OSU91A, EGM96, EIGENCG03C, GGM02S, GGM02C, EGM08 global geoid models and the Turkish Geoid – 2009 (TG-09), which is Turkish local gravimetric geoid, are compared with Turkish local GPS/Leveling geoid. In these comparisons, geoid heights at 30 points of Turkish National Fundamental GPS Network were used. In results of comparison, root mean square (RMS) of height differences between TG-09 model and GPS/Leveling geoid was 15 cm. It was observed that the global geoid that best fits GPS/Leveling geoid was EGM08. Root mean square (RMS) of height differences between EGM08 global model and GPS/Leveling geoid calculated was 87 cm.

Key words: Geoid, GPS/levelling, global geopotential model, Turkey.

INTRODUCTION

Geoid surface is the closed surface going under the land which coincides with stable sea surface that is free of effects like temperature, pressure, density, salinity differences, currents and tides, and it is defined by its potential value. Owing to the fact geoid coincides with seas which make up a large part of the earth, it is a unique surface that is compatible with natural events, visible and accessible. Because of these features, the importance that geodesists pay to geoid is further increasing.

Geoid, which represents the shape and the size of the earth, is needed in describing origin surfaces for point heights, determining mean earth ellipsoid, determining the horizontal and vertical datum of reference systems, examining changes in the earth and sea surfaces. Especially recently, the widespread use of GPS technology has further increased the need for geoid in terms of heights and has made it a must for some applications (Karaali and Berber, 2005).

Converting heights obtained through the GPS technique to orthometric heights is only possible by using a sensitive geoid model in the laboring region. Due to the fact that obtaining orthometric heights through traditional spirit leveling is a difficult process, GPS/Leveling was thought as an alternative way for transition to orthometric heights.

Also the GPS method is the most practical and the fastest technique in determining three-dimensional position today. That GPS can be used in any weather condition and that there is no intervisibility between the

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Table 1. Turkish local geoids.

Model	Datum	Reference surface	Data	Method	Number of points	Reference
GPS/Levelling Geoid	ITRF 96	GRS-80 ellipsoid	Elipsoidal heights regarding Turkish National Fundamental GPS Network-1999 and orthometric heights regarding Turkish National Vertical Control Network-1999	GPS/Levelling method	197	Ayhan et al., 2002
Turkish Geoid-2009 (TG-09)	ITRF 96	GRS-80 ellipsoid	EGM08 geoid model, land gravity anomalies, gravity anomalies from ERS1, ERS2 and TOPEX/POSEIDON altimetry data, topographic heights, GPS/Levelling geoid heights	Remove-Compute-Restore technique, least squares collocation method and Fast Fourier Transform	197	Kılıçoğlu et al., 2009

points have increased the reasons why this system is used in geodetic measurements.

In this article, in order to determine the most appropriate geoids; firstly, Turkish Geoid-2009 (TG-09) that was determined through gravimetric method – one of Turkish local geoid models – was compared with Turkish local GPS/Leveling geoid. Then, OSU91A, EGM96, EIGENCG03C, GGM02S, GGM02C and EGM08 of Global Geoid Models were compared with Turkish local GPS/Leveling geoid.

For comparisons, 30 points of Turkish National Fundamental GPS Network were selected. The geoid heights of the selected points in different Turkish Local Geoid Models and different Global Geoid Models were calculated. Calculated geoid heights are compared to Turkish Local GPS/Levelling geoid heights.

Summary of basic data for Turkish local geoid models

In Turkey, many geoid models have been determined so far and various methods were used in determining these geoid models. Basic information such as datum, re-ference surface, data, methods and the number of points used regarding the local geoids used in this study are summarized in Table 1.

Summary of basic data for global geoid models

In this part of the study, in order to determine the Global Geoid Model that best fits in with Turkish local GPS/Leveling, EIGENCG03C, GGM02S, GGM02C (Tapley et al., 2005) and EGM08 geopotential models that were calculated with satellite data from CHAMP and GRACE with the mission of determining gravity field along with OSU91A (Rapp et al., 1991) and EGM96 (Lemoine et al., 1998) geopotential models were used.

The data file of OSU91A and EGM96 geopotential models were downloaded from the website of IGeS (International Geoid Service) and the file of EGM08 was downloaded from National Geospatial-Intelligence Agency website.

The data files of the other geopotential models that were used were downloaded from GFZ POTSDAM website. Table 2 shows some information about these models.

Application area and selecting the points

In the paper, 30 points of Turkish National Fundamental GPS Network were used. Those 30 points, distributed homogenously as possible, are shown in accordance with latitude and longitude in Figure 1. Horizontal axis is longitude and vertical axis is latitude.

Data used in the application

Geographical coordinates (φ, λ, h) regarding the 30 specified points, orthometric heights (H) and dζ correction values used in converting gravimetric height anomalies to geoid heights (N) are shown in Table 3. Also, grid files of global geoid models were used in the study. The grid data were evaluated in harmexp.exe program in GRAVSOFT software package (Tscherning et al., 1994).

The geoid heights of the selected points in different Turkish local geoid models

Height anomalies for TG-09 geoid was calculated with data mentioned in Table 1 by General Command of Map-ping in Turkey. The study obtained the height anomalies for the 30 points, and geoid heights (N) of the specified points in TG-09 model were calculated by having applied the dζ=ζ-N correction to height

Table 2. Global geoid models.

Model	Max. resolution (degree)	Data	Institution
OSU91A	360	Satellite tracking + altimeter + gravimeter	OHIO
EGM96	360	Satellite tracking + altimeter + gravimeter	NASAGSFC+NIMA+OHIO
EIGENCG03C	360	CHAMP+GRACE+ altimeter + gravimeter	GFZ
GGM02S	160	GRACE	UTCSR
GGM02C	200	GRACE+ altimeter + gravimeter	UTCSR
EGM08	2159	GRACE	NGA

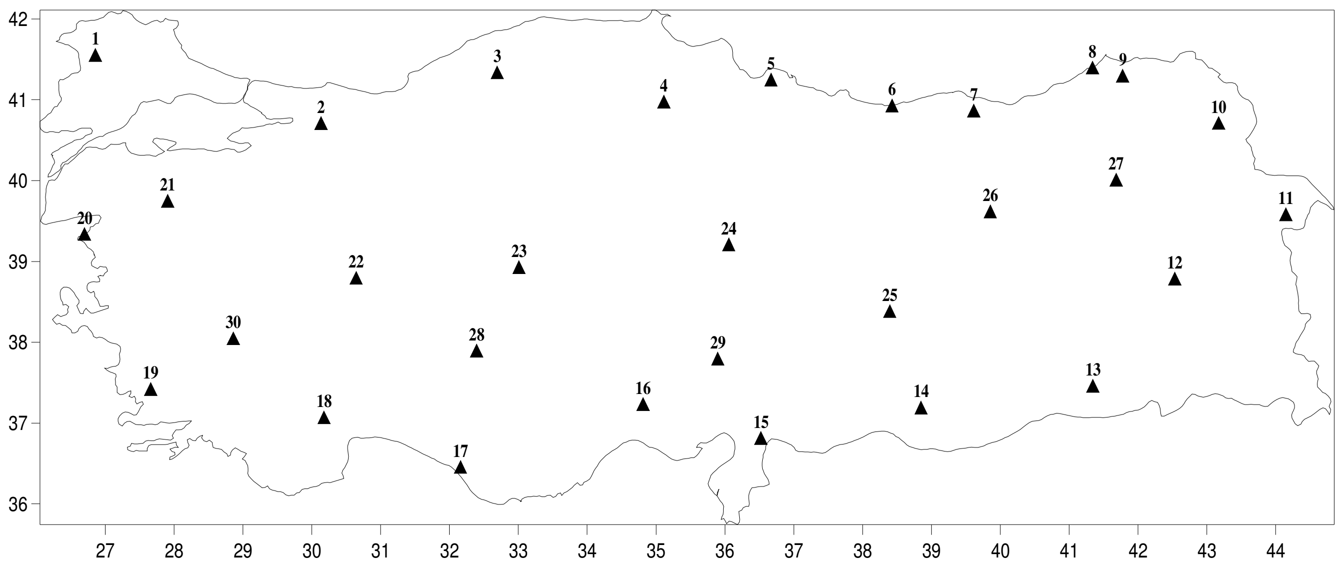

Figure 1. Positions of points.

Table 3. Data used in the application.

Point No	Latitude (degree)φ	Longitude (degree) λ	Orthometric height H (m)	Ellipsoidal height h (m)	dζ Correction
1	41.52647	26.85857	143.8827	182.9942	-0.0014
2	40.68223	30.13313	510.6212	548.1760	0.0031
3	41.31073	32.69392	909.6400	945.5467	-0.0017
4	40.94944	35.11299	854.1896	888.1105	0.0303
5	41.22045	36.66915	15.1787	43.1707	-0.0001
6	40.90173	38.42659	216.1831	243.6590	-0.0026
7	40.83748	39.61471	832.0689	860.4165	0.0238
8	41.37056	41.33871	7.3858	30.1790	-0.0002
9	41.26802	41.77701	288.3085	313.6850	0.0228
10	40.68534	43.16953	1846.2478	1871.1180	0.3083
11	39.55561	44.14494	1555.0286	1577.8730	0.2413
12	38.75943	42.53173	1691.4762	1716.7800	0.2377
13	37.4342	41.34487	976.6762	998.8345	0.0764
14	37.16559	38.84852	507.6026	532.3930	0.0235
15	36.78796	36.52351	404.1737	432.2256	0.0135
16	37.2067	34.81055	785.5074	815.6803	0.0765
17	36.43085	32.15983	60.0010	87.4360	-0.0012

Table 3. Contd.

18	37.04295	30.17824	1085.8402	1116.2550	0.0814
19	37.39535	27.66037	100.2777	134.8520	-0.0045
20	39.31131	26.70002	59.1133	98.2089	-0.0021
21	39.72167	27.90643	409.0186	447.5946	-0.0014
22	38.76888	30.64437	1182.1537	1219.9000	0.0936
23	38.90111	33.00963	1087.2560	1123.2500	0.0708
24	39.18273	36.05526	1271.3797	1305.3060	0.1617
25	38.3585	38.39381	1110.0351	1140.0810	0.0834
26	39.59078	39.85349	1501.7747	1532.4540	0.2323
27	39.98204	41.68113	1735.3093	1762.9800	0.3382
28	37.86887	32.39391	1375.8953	1411.9050	0.1182
29	37.77106	35.89635	707.8182	739.6496	0.0625
30	38.02062	28.86042	673.3114	708.6318	0.0292

Table 4. GPS/levelling and TG-09 geoid heights.

Point No	GPS/Levelling (m)	TG-09 (m)
1	39.112	39.047
2	37.555	37.526
3	35.907	35.892
4	33.921	33.861
5	27.992	27.933
6	27.476	27.424
7	28.348	28.264
8	22.793	22.907
9	25.377	25.343
10	24.870	24.453
11	22.845	22.806
12	25.304	25.222
13	22.158	21.982
14	24.790	24.702
15	28.052	27.950
16	30.173	30.061
17	27.435	27.338
18	30.414	30.284
19	34.574	34.513
20	39.096	39.013
21	38.576	38.516
22	37.746	37.625
23	35.994	35.814
24	33.926	33.773
25	30.046	29.875
26	30.680	30.332
27	27.671	27.303
28	36.010	35.865
29	31.831	31.724
30	35.320	35.251

anomalies.

The GPS/Leveling geoid heights of these 30 points were calculated with the general equality of $h=H+N_{GPS/Lev}$.

In Table 4 shows geoid heights of these Turkish local geoid models.

Table 5. Geoid heights of OSU91A, EGM96, EIGENCG03C, GGM02S, GGM02C and EGM08.

Point No	OSU91A (m)	EGM96 (m)	EIGENCG03C (m)	GGM02S (m)	GGM02C (m)	EGM08 (m)
1	40.441	40.321	40.501	38.931	40.421	39.898
2	36.317	37.227	37.617	37.677	38.117	37.859
3	33.322	34.262	35.792	36.072	36.102	36.669
4	31.710	31.430	34.300	33.750	34.340	34.746
5	27.180	26.280	29.120	28.990	29.160	28.960
6	25.443	25.283	27.813	28.273	27.713	28.371
7	25.176	26.666	28.526	28.566	27.736	28.988
8	19.590	21.340	21.790	22.410	22.810	23.811
9	21.627	23.327	23.877	24.307	24.627	25.993
10	24.992	26.392	26.502	27.482	27.432	25.759
11	22.569	22.609	22.439	23.959	22.689	23.835
12	27.292	27.342	27.262	26.352	27.512	26.548
13	22.854	22.634	22.774	22.174	22.744	23.060
14	25.617	26.357	25.777	25.377	25.297	25.680
15	28.347	29.467	27.777	27.557	27.597	28.930
16	33.154	32.844	32.254	31.204	31.934	31.036
17	26.751	28.371	29.041	27.761	27.531	28.348
18	27.839	30.409	30.519	30.139	30.069	31.170
19	33.345	35.575	35.715	34.735	35.395	35.439
20	39.892	40.812	40.472	39.522	40.312	40.143
21	39.261	39.861	39.811	39.381	39.691	39.379
22	38.086	40.006	39.136	38.066	39.616	38.601
23	36.229	37.009	36.599	36.259	36.379	36.870
24	34.388	35.678	35.558	35.058	35.008	34.836
25	31.087	31.327	31.087	30.937	30.977	30.879
26	28.498	31.168	32.598	32.198	32.728	31.476
27	26.722	28.112	29.422	29.612	29.492	28.503
28	35.942	36.542	36.622	37.722	37.072	36.968
29	34.628	34.418	32.718	33.818	33.328	32.678
30	33.851	36.441	36.671	37.821	36.571	36.230

The geoid heights of the selected points in different global geoid models

To obtain the geoid heights in the different global geoid models of the 30 selected points on Turkey surface; firstly, by using the known latitude, longitude and heights of points, the height anomaly values of points were enterpoled according to each model with the program harmp.exe (Tscherning et al., 1994) of GRAVSOFT software package. Then, having applied the $d\zeta=\zeta$-N correction to the determined height anomalies, geoid heights (N) were calculated. N geoid heights determi-nations according to the different specified models are shown in Table 5.

Table 5 shows geoid heights for each different global geoid model. To obtain the geoid heights, firstly height anomalies enterpolated. Later, $d\zeta$ corrections (Table 3) were applied to heights anomalies.

Comparison of the geoid models with GPS/leveling

The differences between GPS/Leveling model and the other geoid models that were calculated at the 30 selected points are shown in Table 6 in centimeters. Figures 2, 3, 4, 5, 6, 7 and 8 were created from these differences. All the Figures were prepared using Surfer software.

ANALYSIS OF THE RESULTS

From the statistical data regarding height differences, which was previously listed in Table 6; minimum, maximum, mean, standard deviation and root mean square values are shown in Table 7.

Also, to see datum differences of different geoid models, the averages of the height differences from the models listed in Table 6 were calculated and trend surfaces were applied. The trend surface values (average values) were subtracted from height differences and minimum, maximum, mean, standard deviation, root mean square values regarding the remaining differences were

Table 6. Differences between GPS/levelling geoid and other geoid models.

Point No	GPS/Lev-TG09 (cm)	GPS/ Lev-OSU91A (cm)	GPS/Lev-EGM96(cm)	GPS/ Lev - EIGENCG03C(cm)	GPS/Lev-GGM02S(cm)	GPS/Lev-GGM02C (cm)	GPS/Lev - EGM08 (cm)
1	7	-133	-121	-139	18	-131	-79
2	3	124	33	-6	-12	-56	-30
3	2	259	165	12	-17	-20	-76
4	6	221	249	-38	17	-42	-82
5	6	81	171	-113	-100	-117	-97
6	5	203	219	-34	-80	-24	-89
7	8	317	168	-18	-22	61	-64
8	-11	320	145	100	38	-2	-102
9	3	375	205	150	107	75	-62
10	42	-12	-152	-163	-261	-256	-89
11	4	28	24	41	-111	16	-99
12	8	-199	-204	-196	-105	-221	-124
13	18	-70	-48	-62	-2	-59	-90
14	9	-83	-157	-99	-59	-51	-89
15	10	-29	-141	28	50	46	-88
16	11	-298	-267	-208	-103	-176	-86
17	10	68	-94	-161	-33	-10	-91
18	13	258	1	-10	28	35	-76
19	6	123	-100	-114	-16	-82	-86
20	8	-80	-172	-138	-43	-122	-105
21	6	-69	-129	-124	-81	-112	-80
22	12	-34	-226	-139	-32	-187	-86
23	18	-24	-102	-61	-27	-39	-88
24	15	-46	-175	-163	-113	-108	-91
25	17	-104	-128	-104	-89	-93	-83
26	35	218	-49	-192	-152	-205	-80
27	37	95	-44	-175	-194	-182	-83
28	14	7	-53	-61	-171	-106	-96
29	11	-280	-259	-89	-199	-150	-85
30	7	147	-112	-135	-250	-125	-91

computed and showed in Table 8.

Results

According to the results of the comparison at 30 points; there is a difference of minimum -11 cm and of maximum 42 cm between GPS/Levelling and TG-09 geoid models. RMS value was calculated as 15 cm and when the distribution of differences in the country was examined, the differences are larger in places that were close to seas and to country boundaries.

This was thought to stem from lack of data used in computations. When the differences between Global Geoid Models and GPS/Levelling along with Figures of the differences were examined, it was observed that EGM08 global geoid was the geoid which best fits with GPS/Levelling. There is a difference of minimum -124 cm and of maximum -30 cm between GPS/Levelling and EGM08 geoid models. RMS value of the difference was calculated as 87 cm. The RMS value regarding the differences between EGM08 and GPS/Levelling was observed as the smallest when compared to RMS values regarding the differences between other global models and GPS/ Levelling. The result indicates that the best fitting global geoid model for Turkey is EGM08 model and the model is very compatible with GPS/Levelling. That EGM08 model is the highest resolution of Global Geoid Models which is thought to be the basis this result. When Global Geoid Models were examined from the past to the present, it observed that there is a significant increase in accuracy and resolution of the models.

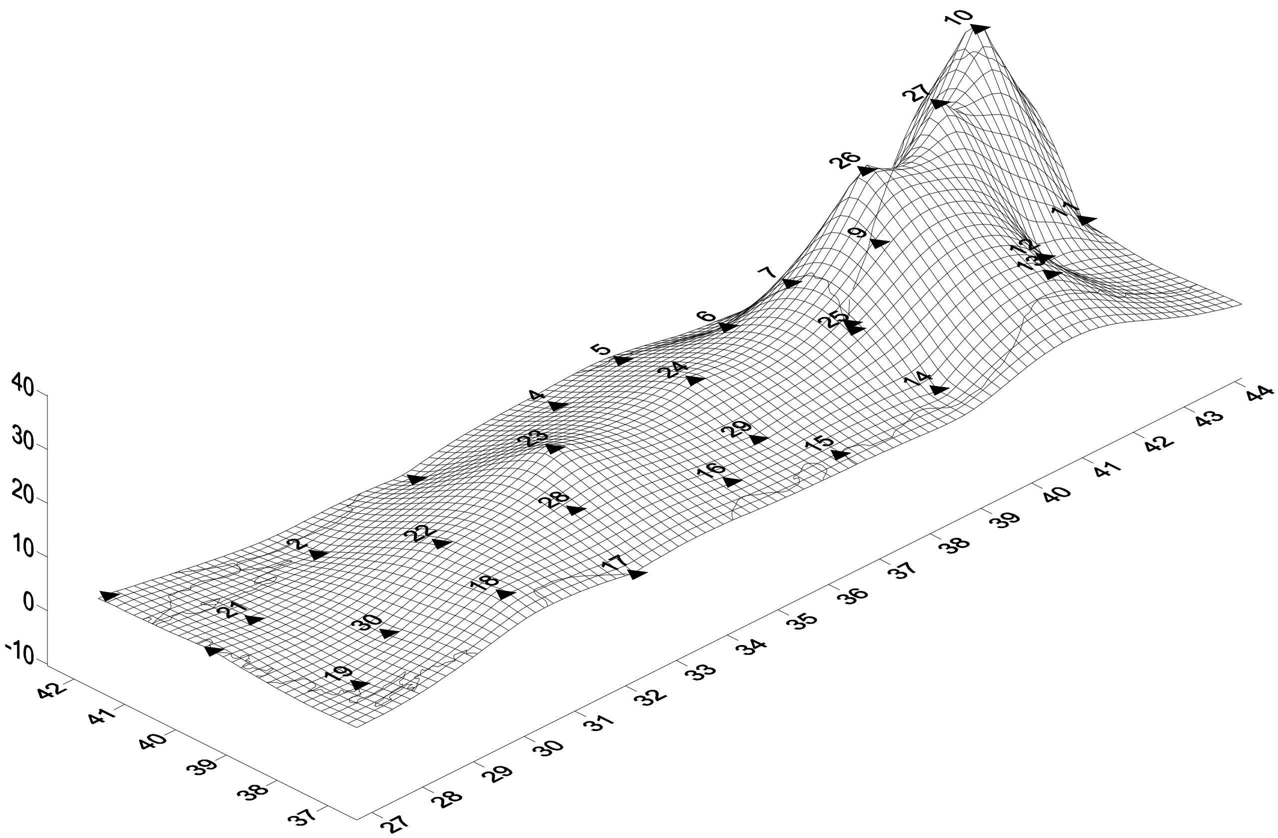

Figure 2. Perspective view of GPS/Levelling-TG09 geoid height differences (Units in cm).

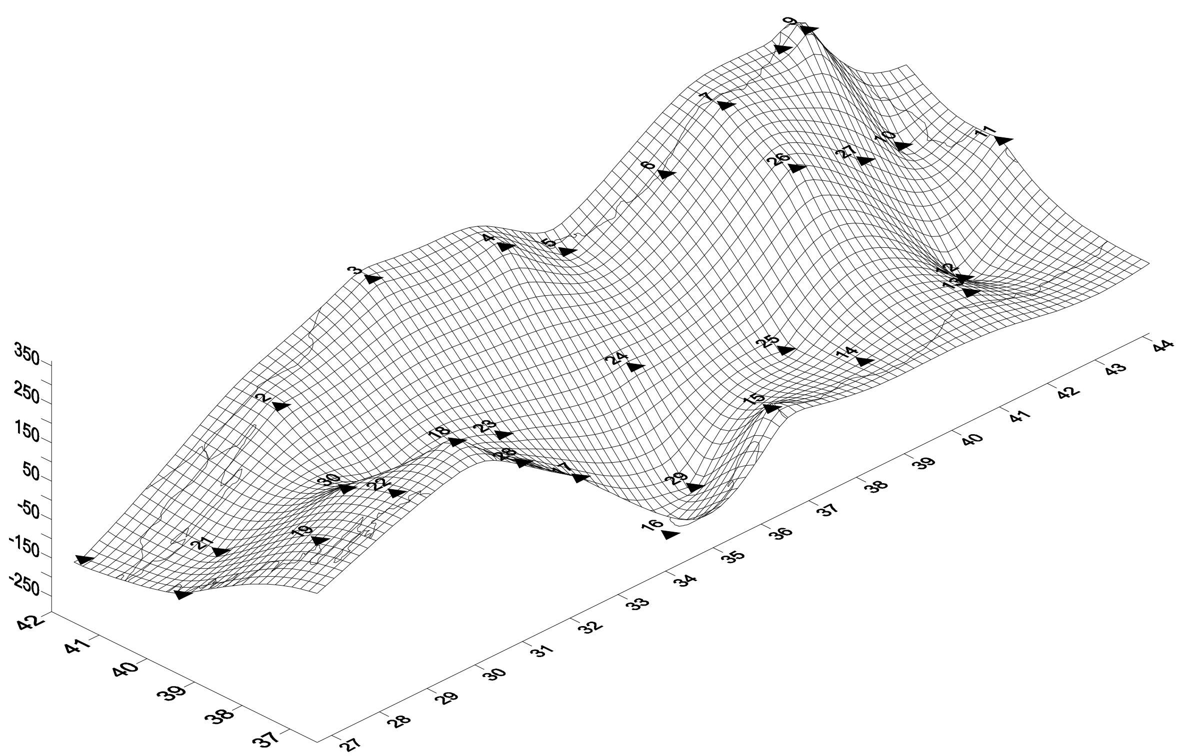

Figure 3. Perspective view of GPS/Levelling-OSU91A geoid height differences (Units in cm).

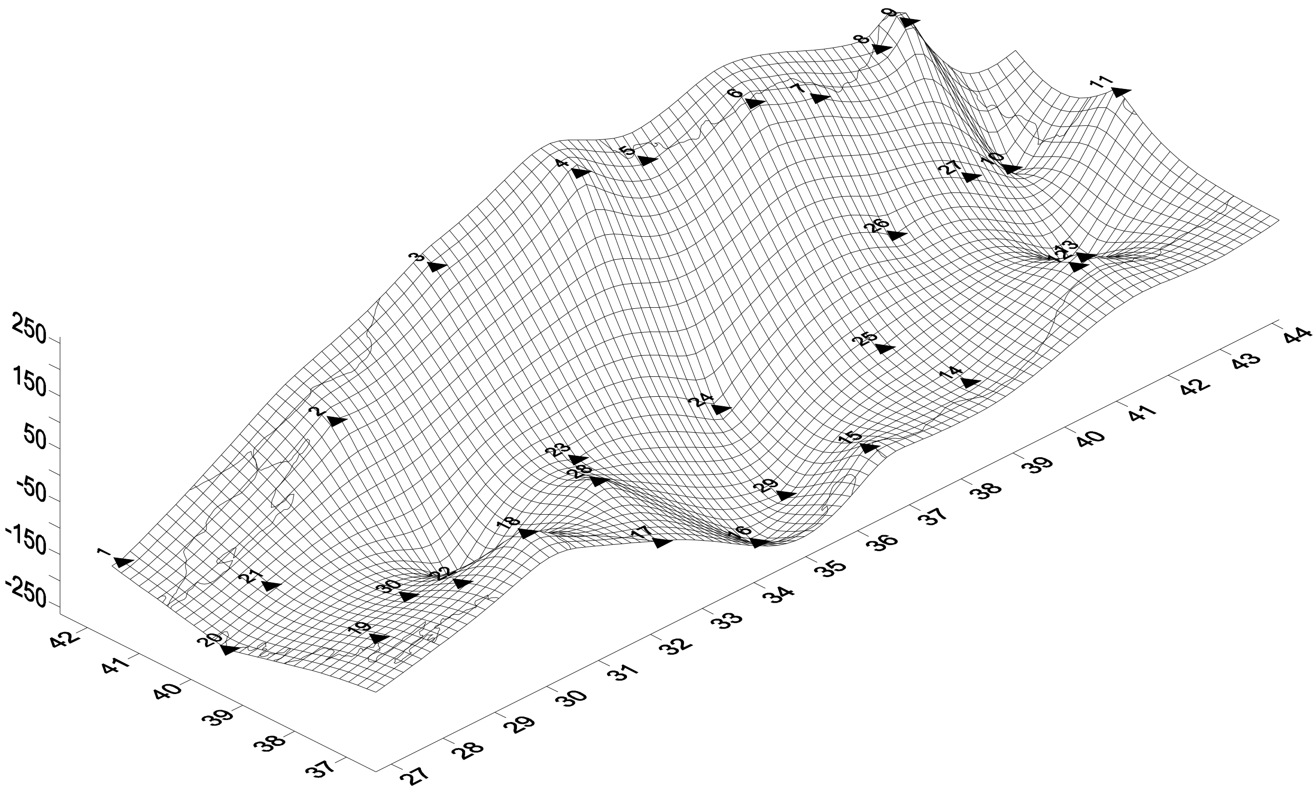

Figure 4. Perspective view of GPS/Levelling-EGM96 geoid height differences (Units in cm).

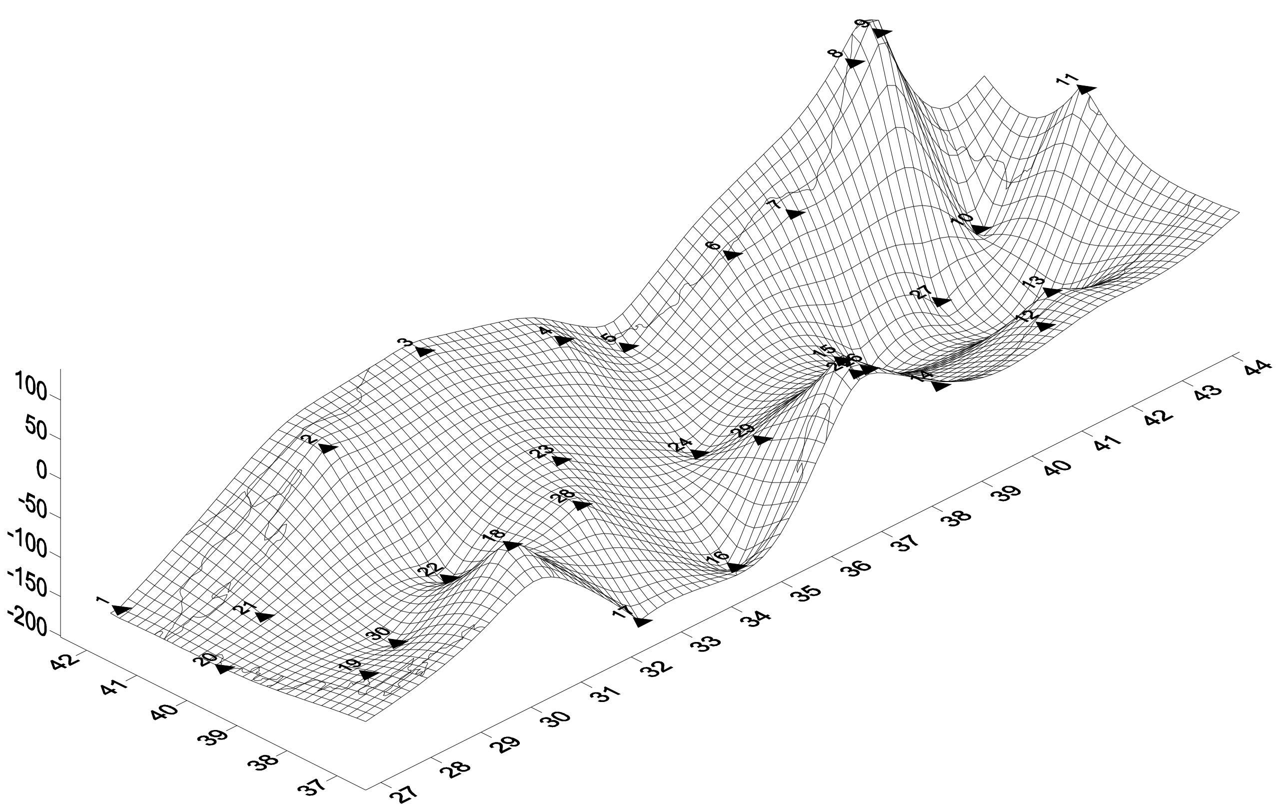

Figure 5. Perspective view of GPS/Levelling- EIGENCG03C geoid height differences (Units in cm).

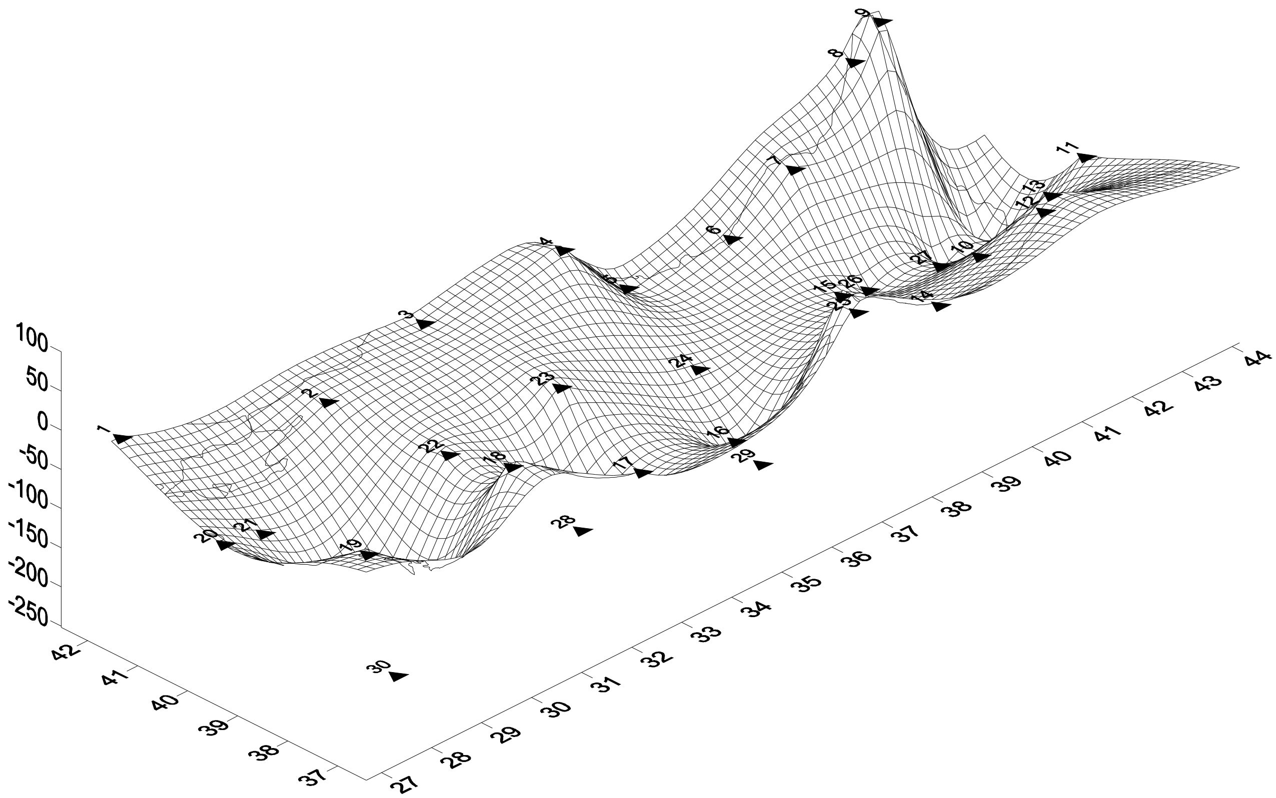

Figure 6. Perspective view of GPS/Levelling-GGM02S geoid height differences (Units in cm).

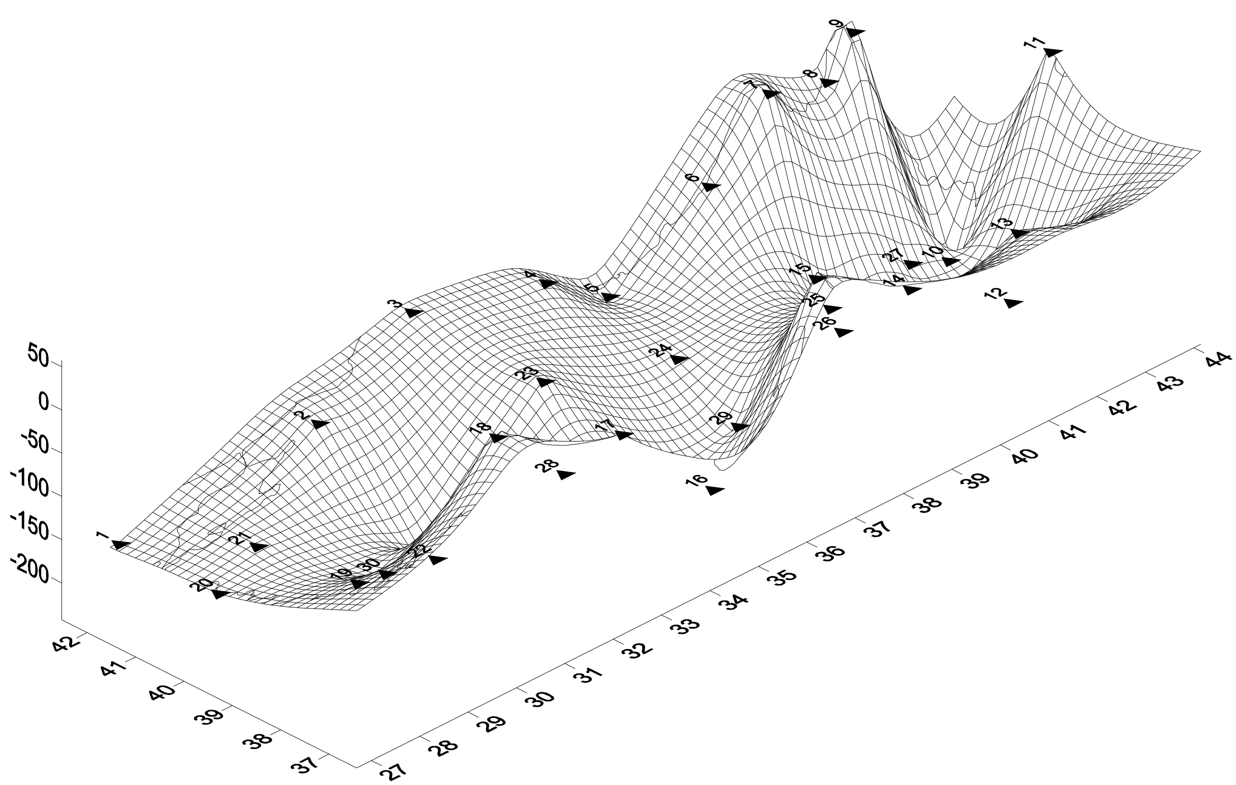

Figure 7. Perspective view of GPS/Levelling-GGM02C geoid height differences (Units in cm).

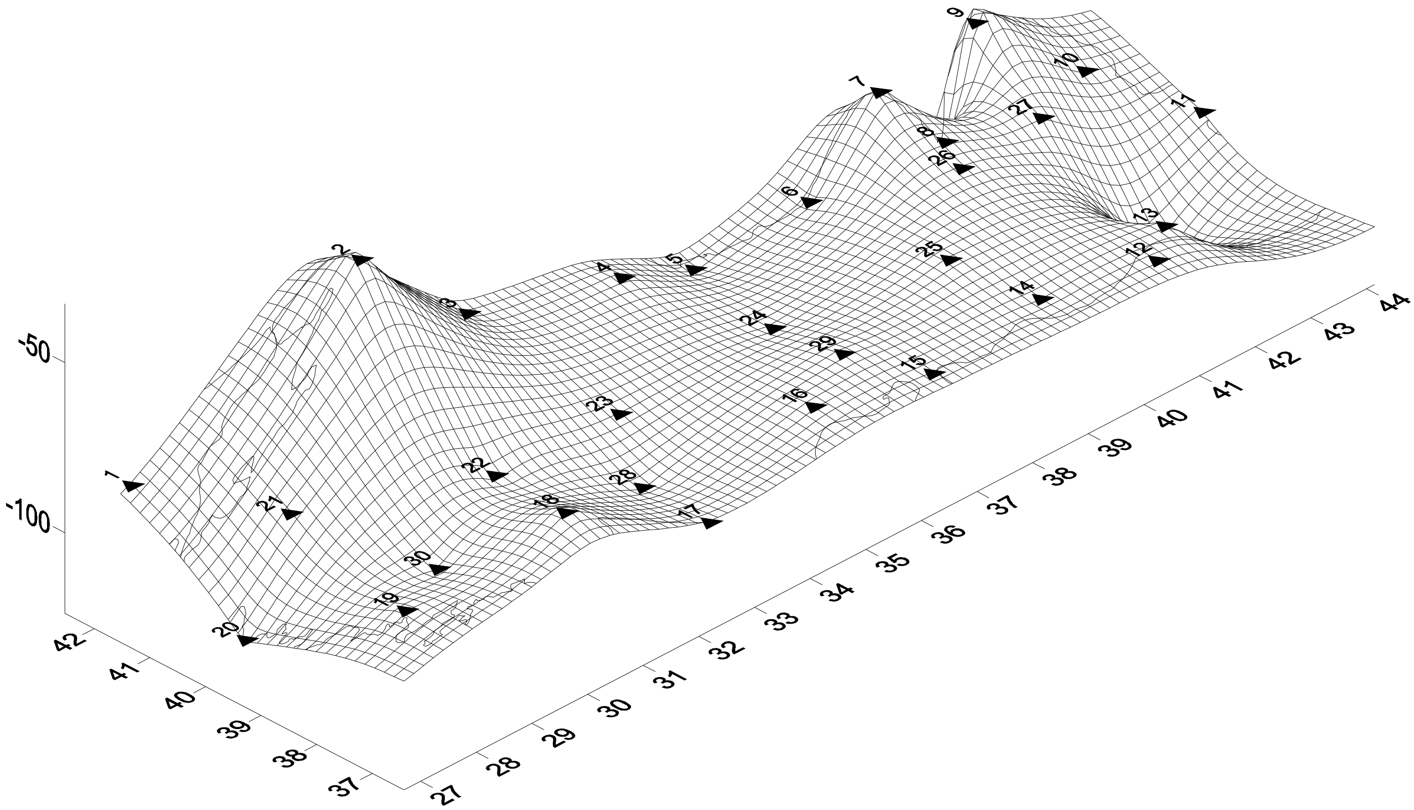

Figure 8. Perspective view of GPS/Levelling- EGM08 geoid height differences (Units in cm).

Table 7. Statistics of the differences between GPS/Levelling and different geoid models.

Differences	Minimum (m)	Maximum (m)	Mean (m)	Standard deviation (m)	RMS (m)
GPS/Lev-TG09	-0.114	0.417	0.113	0.107	0.154
GPS/Lev-OSU91A	-2.981	3.749	0.461	1.749	1.780
GPS/Lev-EGM96	-2.671	2.491	-0.451	1.504	1.546
GPS/Lev-EIGENCG03C	-2.081	1.499	-0.803	0.889	1.187
GPS/Lev-GGM02S	-2.612	1.069	-0.671	0.888	1.101
GPS/Lev-GGM02C	-2.562	0.749	-0.814	0.866	1.178
GPS/Lev-EGM08	-1.244	-0.304	-0.856	0.157	0.869

Table 8. Statistics of the differences from trend surfaces (averages).

Differences	Minimum (m)	Maximum (m)	Mean (m)	Standard deviation (m)	RMS (m)
GPS/Lev-TG09	-0.227	0.304	0.000	0.107	0.105
GPS/Lev-OSU91A	-3.442	3.288	0.000	1.749	1.719
GPS/Lev-EGM96	-2.220	2.942	0.000	1.504	1.479
GPS/Lev-EIGENCG03C	-1.277	2.303	0.000	0.889	0.874
GPS/Lev-GGM02S	-1.941	1.740	0.000	0.888	0.873
GPS/Lev-GGM02C	-1.748	1.563	0.000	0.866	0.852
GPS/Lev-EGM08	-0.389	0.552	0.000	0.157	0.154

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