

Abstract

The maintenance of leveling benchmark is both laborious and costly due to distortions caused by geodynamic activities and local deformations. It is necessary to realize geoid-based vertical datum, which also enables calculation from ellipsoidal heights obtained from GNSS to orthometric heights that have physical meaning. It can be considered as an important step for height system unification as it eliminates the problems stem from the conventional vertical datum. The ongoing height modernization efforts in Turkey focus to improve quality and coverage of the gravity data, eliminate errors in existing terrestrial gravity measurements in order to achieve a precise geoid model. Accuracy of the geopotential model is crucial while realizing a geoid model based vertical datum as well as unifying the regional height systems with the International Heights Reference System. In this point of view, we assessed the accuracies of recently released global geopotential models including XGM2019e_2159, GECO, EIGEN-6C4, EGM2008, SGG-UGM-1, EIGEN-6C3stat, and EIGEN-6C2 using high order GNSS/leveling control benchmarks and terrestrial gravity data in Turkey. The reason for choosing these models in the validations is their relatively higher spatial resolutions and improved accuracies compared to other GGMs in published validation results with globally distributed terrestrial data. The GNSS/leveling data used in validations include high accuracy GNSS coordinates in ITRF datum with co-located Helmert orthometric heights in regional vertical datum. 100 benchmarks are homogeneously distributed in the country with the benchmarks along the coastlines. In addition, the terrestrial gravity anomalies with 1 arc-minute resolution were also used in the tests. In order to have comparable results, residual terrain effect has been restored to the GGM derived parameters. Numerical tests revealed significant differences in accuracies of the tested GGMs. The most accurate GGM has the comparable performance with official regional geoid model solutions in Turkey. The drawn results in the study were interpreted and discussed from practical applications and height system unification points in conclusion.

Characteristics of the GGMs used in this study

Model	Year	Degree	Data
EGM2008	2008	2190	A,G,S(Grace)
EIGEN-6C2	2012	1949	A,G,S(Goce), S(Grace), S(Lageos)
EIGEN-6C3stat	2014	1949	A,G,S(Goce), S(Grace), S(Lageos)
EIGEN-6C4	2014	2190	A,G,S(Goce), S(Grace), S(Lageos)
GECO	2015	2190	EGM2008, S(Goce)
SGG-UGM-1	2018	2159	EGM2008, S(Goce)
XGM2019e-2159	2019	2190	A, G, S(GOCO06s), T

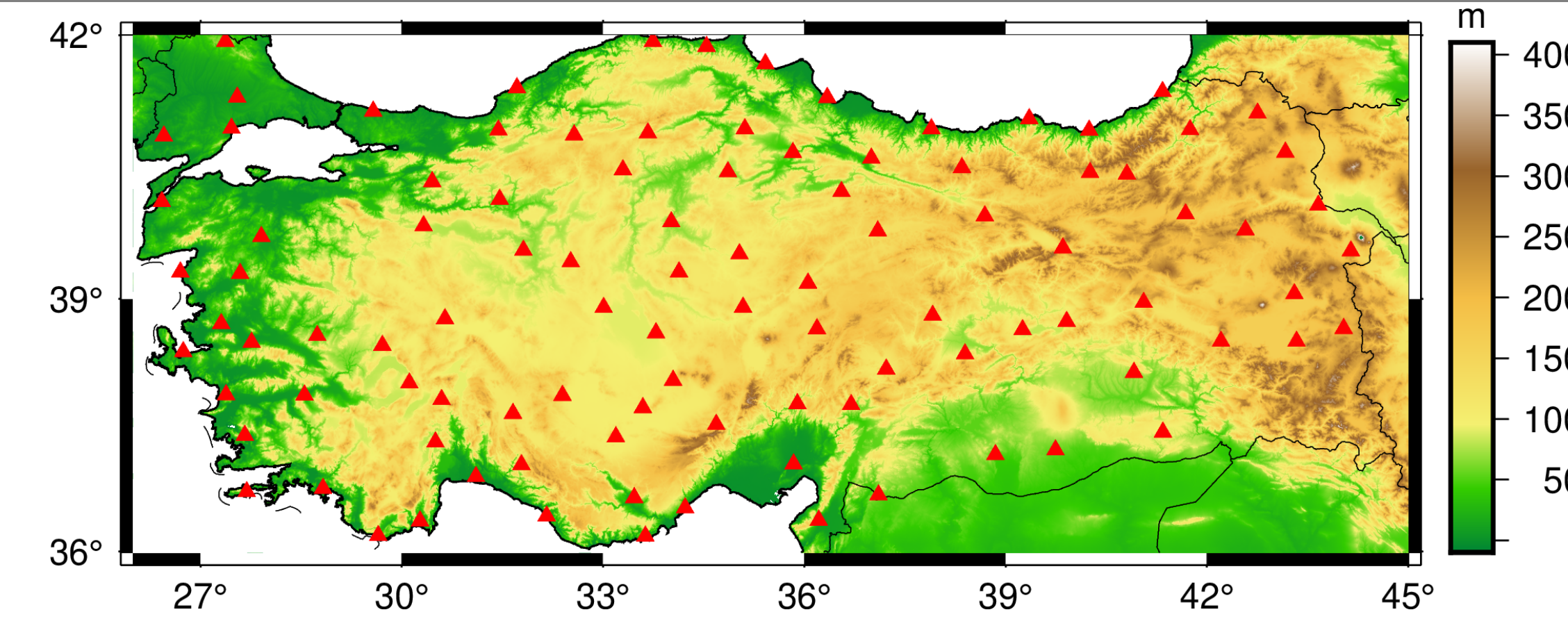
* A is for altimetry, S is for satellite, G for ground data and T is for topography.

All calculations were completed with seven high-degree GGM using their maximum degree and order (d/o) including zero-degree term. Zero-tide system was adopted with respect to GRS80 reference ellipsoid.

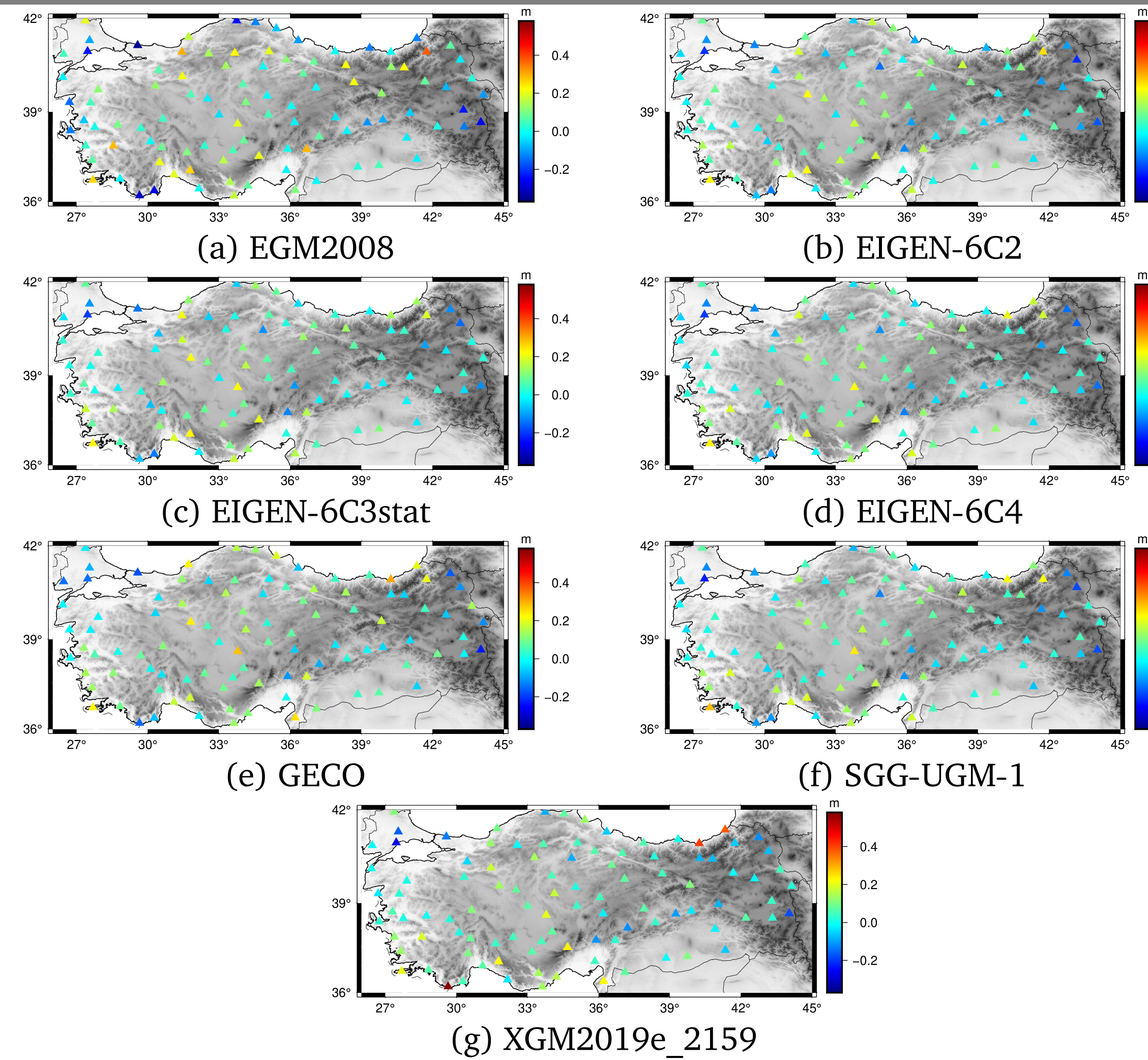
$$N(\lambda, \phi) = \frac{T(r_{ell}, \phi, \lambda) - 2\phi G\rho H^2(\lambda, \phi)}{\gamma(r_{ell}, \phi)} \quad (1)$$

$$\Delta g(r, \lambda, \phi) = \frac{GM}{r^2} \sum_{l=0}^{l_{max}} \left(\frac{R}{r}\right)^l \sum_{m=0}^l P_{lm}(\sin \phi (C_T^{lm} \cos m\lambda + S_T^{lm} \sin m\lambda)) \quad (2)$$

Distribution of 100 GNSS/leveling benchmarks on SRTM topography



Differences between $N_{GNSS/leveling}$ and N_{GGM}

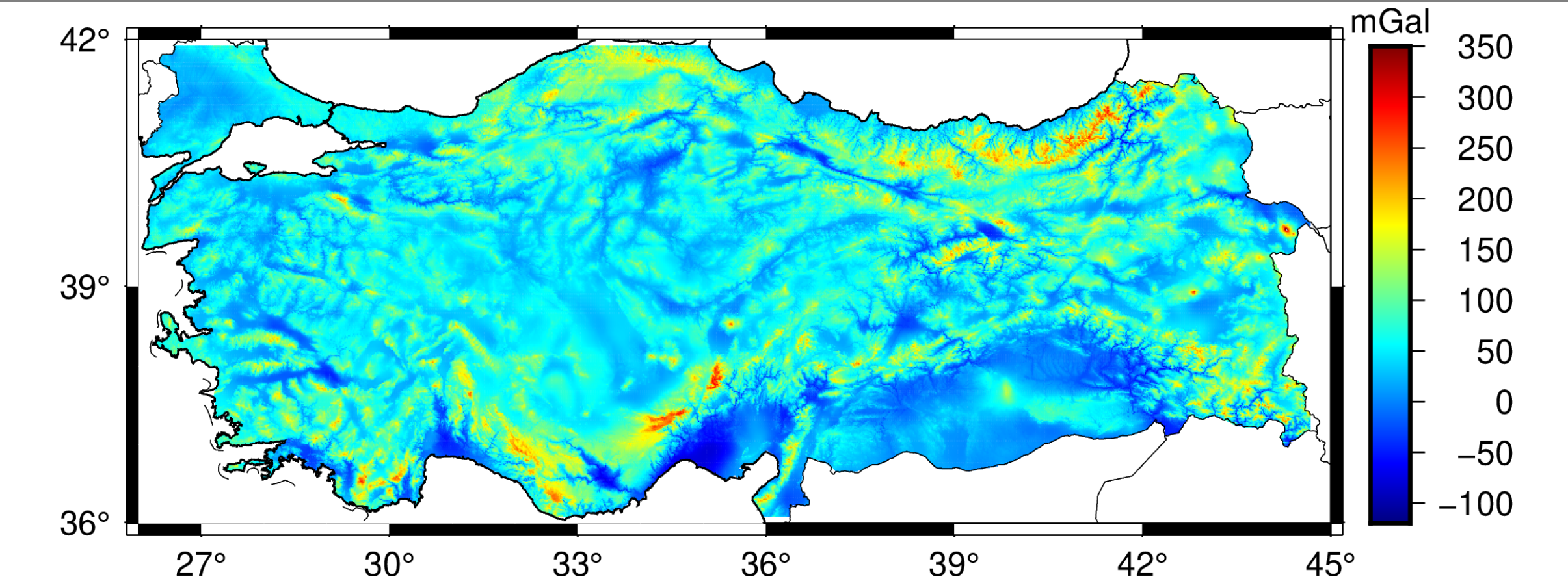


Statistics of the Residual Geoid Heights [m]

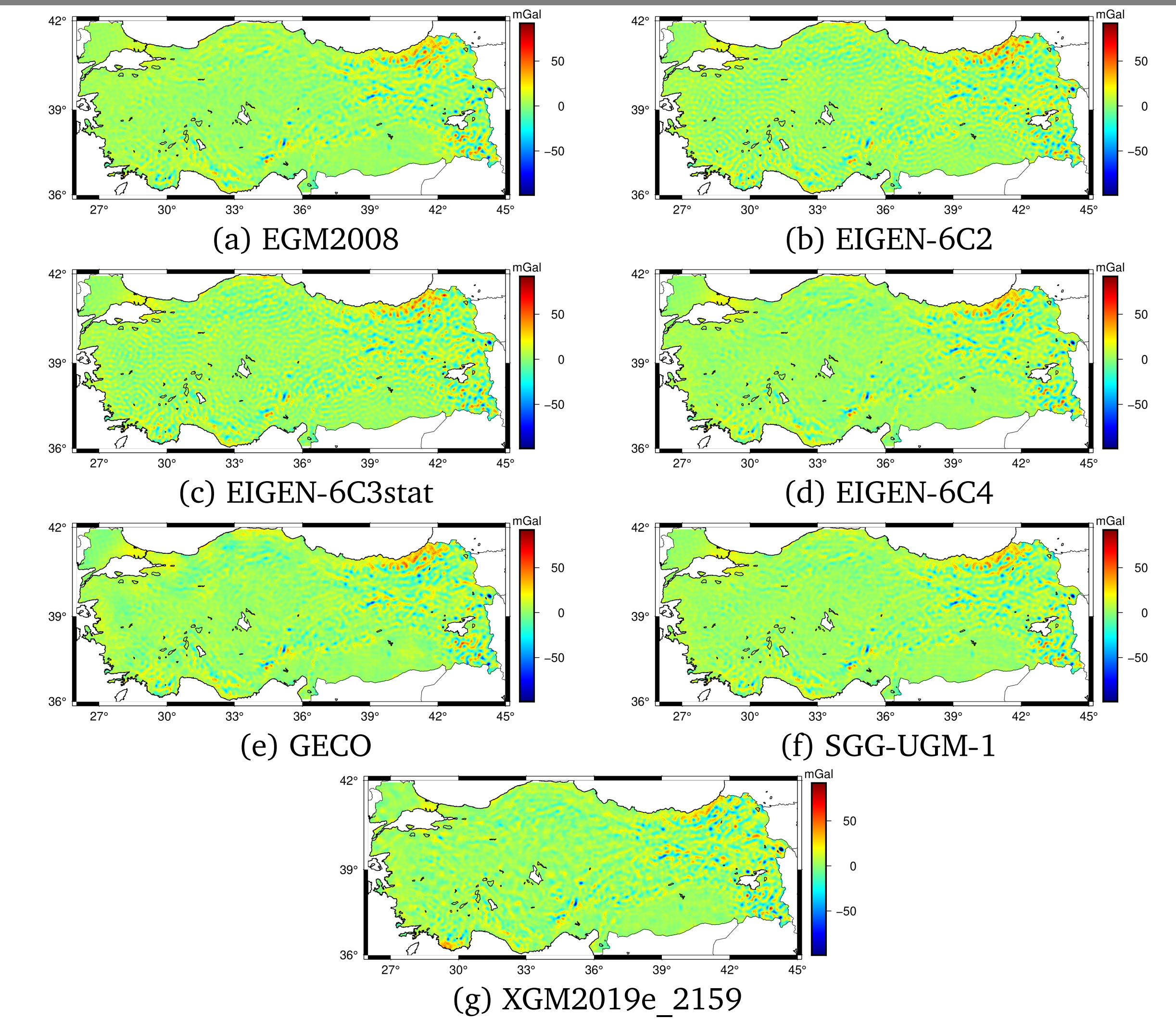
Model	min	max	mean	std	std*
EGM2008	-0.364	0.368	0.028	0.140	0.134
EIGEN-6C2	-0.217	0.244	0.031	0.101	0.095
EIGEN-6C3stat	-0.206	0.226	0.032	0.096	0.090
EIGEN-6C4	-0.210	0.230	0.032	0.093	0.086
GECO	-0.234	0.297	0.039	0.108	0.101
SGG-UGM-1	-0.231	0.283	0.036	0.098	0.092
XGM2019e-2159	-0.278	0.574	0.046	0.117	0.110

*std represents standard deviation:after fit (4-parameter model)

Terrestrial gravity anomalies



Differences between $\Delta g_{Terrestrial}$ and Δg_{GGM}



Statistics of the Residual Gravity Anomalies [mGal]

Model	min	max	mean	std
EGM2008	-170.063	83.743	3.203	9.277
EIGEN-6C2	-163.909	92.099	2.906	10.296
EIGEN-6C3stat	-165.143	90.454	2.889	10.273
EIGEN-6C4	-173.555	79.692	2.875	9.336
GECO	-169.551	78.789	2.913	9.754
SGG-UGM-1	-175.192	81.579	2.953	9.370
XGM2019e-2159	-171.437	84.471	2.729	10.362

Conclusion

- In this study accuracies of high-degree global geopotential models were evaluated by comparing 100 GNSS/leveling control benchmarks and terrestrial gravity data with 1' resolution in Turkey.
- The comparison between $N_{GNSS/leveling} - N_{EIGEN-6C4}$ shows 8.6 cm and $\Delta g_{Terrestrial} - \Delta g_{EIGEN-6C4}$ 9.336 mGal agreement in standard deviation. These are most accurate results among the seven GGMs.
- The EIGEN-6C4 model will be selected as suitable GGM for study of height system modernization and height system unification in Turkey.