

Some new insights on the correlation of isoseismal maps with terrestrial and satellite gravity data

Dilalos S. & Alexopoulos J.D.

Summary

Based on the results of a previous terrestrial gravity survey that was carried out in Athens basin (Greece) some indications of correlation between terrestrial gravity data and isoseismal maps of Athens earthquake (7/9/1999) had been revealed. In this paper we will present a research for the same area based on a new approach, which investigates the possible correlation of the same isoseismal maps with only satellite gravity data from GOCE and GRACE but also with a combined gravity model of updated terrestrial, marine and satellite data. The combined gravity model of Greece was constructed based on the least-squares collocation.

The previous correlation of isoseismal maps with the older terrestrial gravity data was quite obvious and clear, since the areas with the lower gravity values were simultaneously the ones with the greatest damage distribution. On the other hand, from the satellite gravity data and the combined gravity model we could not identify a clear and obvious correlation, as it was expected, due to the smaller resolution spacing of the satellite data.

Introduction

Based on the results of a previous terrestrial gravity survey that was carried out in Athens basin (Greece) and published by the same authors (Dilalos, 2018; Dilalos & Alexopoulos, 2017), some indications of correlation between terrestrial gravity data and isoseismal maps of Athens earthquake (7/9/1999) had been revealed. More specifically, after the evaluation of the damage distribution caused by the severe earthquake during 7/9/1999 in Athens, some isoseismal maps (Figs. 1-2) had been presented by other authors (Kouskouna *et al.*, 2020; Lekkas, 2001; Tzitziras *et al.*, 2000). After a few years, a gravity survey was organized and carried out with the scope of investigating the geological and tectonic structure of Athens basin for possible concealed fault zones that could give severe earthquakes. Athens is the metropolis of Greece and therefore an area fully urbanized, raising several difficulties for geophysical surveys. As stated in Dilalos & Alexopoulos (2017), “the areas with the most damage, mapped out by the isoseismal contours, seem to be clearly adumbrated by the areas that have the lowest values in the Residual anomaly map”.

In this paper we will present a research for the same area based on a new approach, which investigates the possible correlation of the same isoseismal maps with a) satellite gravity data from GOCE and GRACE satellites (Frommknecht *et al.*, 2011; Van der Meijde *et al.*, 2015) and b) with a combined gravity model of terrestrial, marine and satellite data. The presenting results are part of the generalized project that covers the whole Greek area, known as “Investigation of correlation of the geophysical gravity anomalies from satellite and terrestrial data with isoseismal contours of severe earthquakes of Greece”.

Methodology

The older correlation of isoseismal and gravity anomalies that had been indicated by Dilalos (2018) and Dilalos & Alexopoulos (2017) was based on more than 800 terrestrial gravity measurements, acquired from the authors during 2013-2015, based on a gridded plan of measurements. The initial grid spacing was 1000 meters. The raw data were processed following the standard reduction along with an additional Building correction (Dilalos *et al.*, 2018), applied due to the urban character of the area and the building effect on the data. The correlation was based on the residual anomaly maps that were produced with the application of FFT filters.

In this study, we tried to take a step forward by using the freely available satellite data, downloaded from ICGEM (Ince *et al.*, 2019). We took advantage of their calculation grid procedure and extracted the gravity anomaly distribution for entire coverage of Greece, with a spacing 0.05° . The selected satellite models include the GOCE and GRACE data only (Akyilmaz *et al.*, 2016; Yi *et al.*, 2013). On the other hand, we also used the terrestrial gravity data from the updated Free-Air map provided by the Hellenic Military Geographic Service (retrieved from <http://web.gys.gr/GeoSearch/geoid/hmgs-geoid-index.html>). These data also cover the whole area of Greece, based on more than 26.800 points, illustrated in a FAA map of Greece with spacing 0.008° .

The Terrain Corrections of the whole area were calculated with the contribution of *Gravity and Terrain Correction extension of Oasis Montaj*, for a distance up to 167 kilometres. For that reason we used the European Digital Elevation Model (*EU-DEM*), v.1.1 (retrieved from <https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1?tab=download>) merged with Gebco bathymetry data (retrieved from https://www.gebco.net/data_and_products/gridded_bathymetry_data/). The calculated Terrain Corrections have been added to the FAA map of the terrestrial data by the Hellenic Military Geographic Service and correspondingly to the satellite data in order to produce the corresponding Complete Bouguer Anomaly maps. Afterwards, the residual map was calculated by applying the FFT filters (Fig. 1).

Afterwards, we proceeded to the production of the combined gravity model with a least-squares collocation procedure, using the prementioned complete anomaly data, satellite and terrestrial

originated. Several global combined gravity models have been presented so far in the literature (e.g. Fecher *et al.*, 2017; Tapley *et al.*; 2005). In our case we have not produced a global gravity model but instead we focused on the area of Greece. A similar procedure of FFT filtering was also applied in order to isolate the residual anomaly map of this combined gravity model.

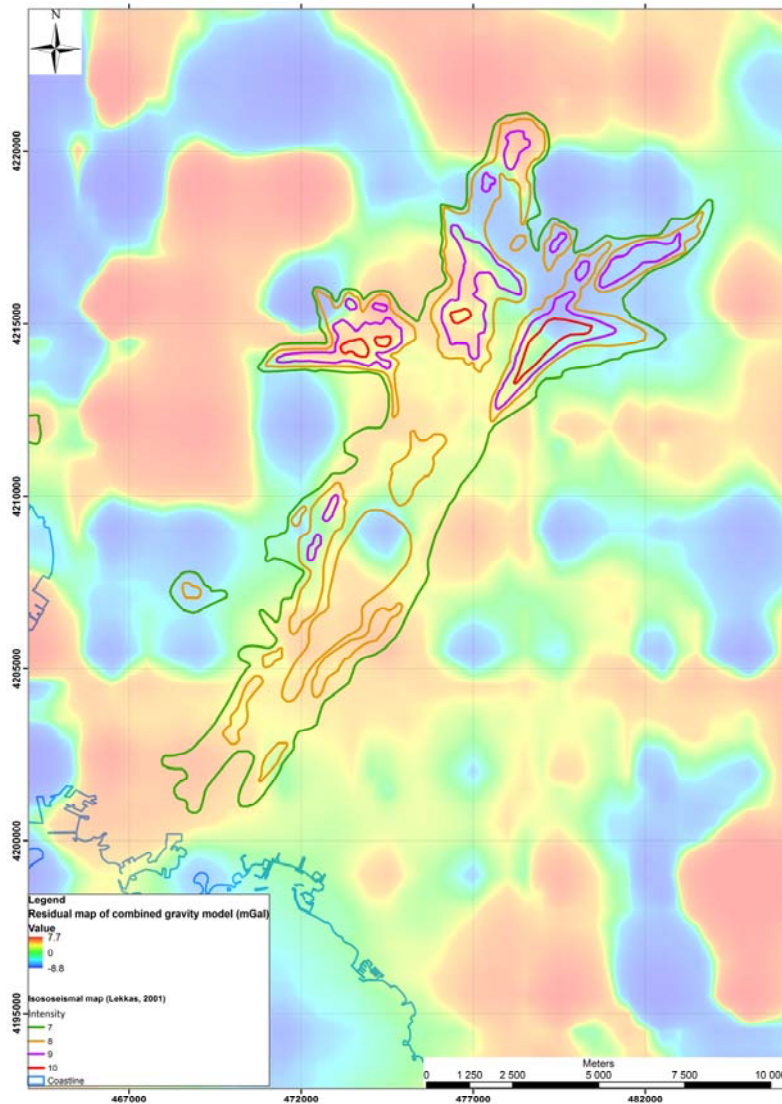


Figure 1 Residual gravity map of the combined gravity model along with the isoseismal map of Lekkas (2001).

Discussion and Conclusions

The previous correlation of isoseismal maps by Tzitziras *et al* (2000) and Lekkas (2001) with the terrestrial gravity data of Dilalos (2018) and Dilalos & Alexopoulos (2017) was quite obvious and clear, since the areas with the lower gravity values were simultaneously the ones with the greatest damage distribution. On the other, hand, based on the residual maps derived from the satellite gravity data and the combined gravity model, a clear and obvious correlation was not observed. The similarity between the isoseismal contours and the residual combined gravity data is not great, as it was expected though, due to the smaller resolution spacing of the satellite data (about 80 kilometres). Even though we do not have clear correlations, there are some indications. For example, the northern area, which suffered more from the damage, is also identified with low gravity values on the satellite gravity map and the combined gravity anomaly maps. We cannot say the same for the smaller zones identified from the isoseismal maps.

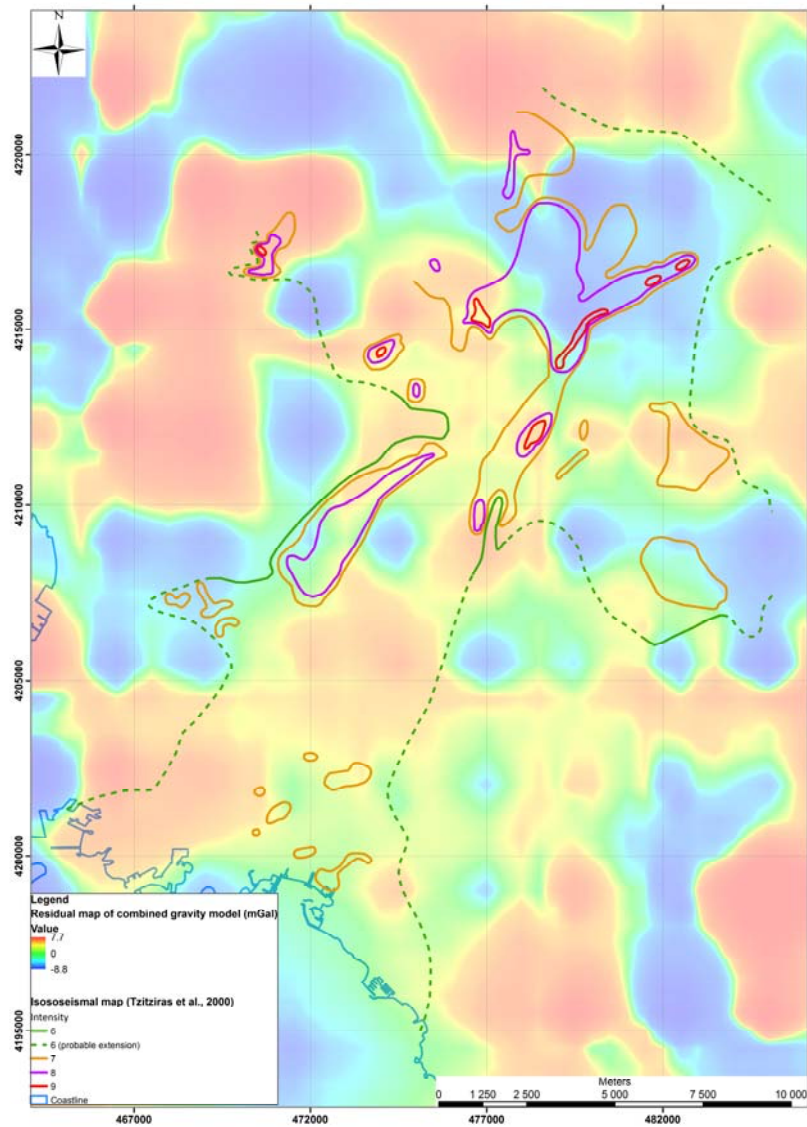


Figure 2 Residual gravity map of the combined gravity model along with the isoseismal map of Tzitziras et al. (2001).

The acquisition spacing of the terrestrial gravity data presented in Dilalos (2018) and Dilalos & Alexopoulos (2017) was 500-1000 meters, when the accuracy spacing of the satellite data is 60-80 kilometres. Of course, this accuracy has been improved due to their combination with the newly provided terrestrial data by Hellenic Military Geographic Service. Unfortunately, it seems that it is not good enough to reach the great accuracy of the older data. Therefore, it seems quite difficult and somehow uncertain to compare isoseismal maps with that type of gravity data (satellite or combined gravity data) for the adumbration of areas prone to greater damage after a severe earthquake.

Even though the satellite data provide information for greater areas, their accuracy seems not capable enough for providing accurate correlations with existing isoseismal maps, produced from the damage distribution of older severe earthquakes in Athens. Unfortunately, even the combined gravity model could not reveal the valuable accurate correlation between the damaged areas and the ones with the lower gravity values. On the other hand, we could say that slight indications of correlation exist, yet they are not clear and obvious enough.

Acknowledgments

This research is co-financed by Greece and the European Union (European Social Fund- ESF) through the Operational Programme «Human Resources Development, Education and Lifelong Learning» in the context of the project “Reinforcement of Postdoctoral Researchers - 2nd Cycle” (MIS-5033021), implemented by the State Scholarships Foundation (IKY).



References

- Akyilmaz O., Ustun A., Aydin C., Arslan N., Doganalp S., Guney C., Mercan H., Uygur S.O., Uz M., Yagci O., 2016. ITU_GGC16 The combined global gravity field model including GRACE & GOCE data up to degree and order 280. *GFZ Data Services*.
- Dilalos S., 2018. Application of geophysical technique to the investigation of tectonic structures in urban and suburban environments. A case study in Athens basin. *Ph.D. Thesis*, National and Kapodistrian University of Athens, 321p. Athens, Greece.
- Dilalos S. & Alexopoulos J.D., 2017. Indications of correlation between gravity measurements and isoseismal maps. A case study of Athens basin (Greece). *Journal of Applied Geophysics*, 140, 62-74. <https://doi.org/10.1016/j.jappgeo.2017.03.012>
- Dilalos S., Alexopoulos J.D., Tsatsaris A., 2018. Calculation of Building Correction for urban gravity surveys. A case study of Athens metropolis (Greece). *Journal of applied geophysics*, 159, 540-552. <https://doi.org/10.1016/j.jappgeo.2018.09.036>
- Fecher T., Pail R., Gruber T., Goco Consortium, 2017. GOCO05c: a new combined gravity field model based on full normal equations and regionally varying weighting. *Surveys in geophysics*, 38(3), 571-590. Doi: 10.1007/s10712-016-9406-y
- Frommknecht B., Lamarre D., Meloni M., Bigazzi A., Floberghagen R., 2011. GOCE level 1b data processing. *Journal of Geodesy*, 85(11), 759-775. <https://doi.org/10.1007/s00190-011-0497-4>
- Ince E.S., Barthelmes F., Reißland S., Elger K., Förste C., Flechtner F., Schuh H., 2019. ICGEM–15 years of successful collection and distribution of global gravitational models, associated services, and future plans. *Earth System Science Data*, 11(2), 647-674. <https://doi.org/10.5194/essd-11-647-2019>
- Kouskouna V., Ganas A., Kleanthi M., Kassaras I., Sakellariou N., Sakkas G., Valkaniotis S., Manousou E., Bozionelos G., Tsironi V., Karamitros I., Tavoularis N., Papaioannou Ch., Bossu, R. (2021). Evaluation of macroseismic intensity, strong ground motion pattern and fault model of the 19 July 2019 Mw5. 1 earthquake west of Athens. *Journal of Seismology*, 25(3), 747-769. <https://doi.org/10.1007/s10950-021-09990-3>
- Lekkas E., 2001. The Athens earthquake (7 September 1999): intensity distribution and controlling factors. *Engineering Geology*, 59 (3-4), 297-311. [http://dx.doi.org/10.1016/S0013-7952\(00\)00119-8](http://dx.doi.org/10.1016/S0013-7952(00)00119-8)
- Tapley B., Ries J., Bettadpur S., Chambers D., Cheng M., Condi F., Gunter B., Kang Z., Nagel P., Pastor R., Pekker T., Poole S., Wang, F., 2005. GGM02–An improved Earth gravity field model from GRACE. *Journal of Geodesy*, 79(8), 467-478. Doi: 10.1007/s00190-005-0480-z
- Tzitziras A., Rozos D., Vakondios I., Elias P., Kynigalaki M., Nikolaou N., Konstantopoulou G., 2000. Macroseismic observations from the earthquake of 7/9/99 in Attiki area. *Annales Géologiques des Pays Helléniques*, Vol. 38, pp. 145-152.
- Van der Meijde M., Julià J., Assumpção M., 2013. Gravity derived Moho for South America. *Tectonophysics*, 609, 456-467, <https://doi.org/10.1016/j.tecto.2013.03.023>
- Yi W., Rummel R., Gruber T., 2013. Gravity field contribution analysis of GOCE gravitational gradient components. *Studia Geophysica et Geodaetica*, 57(2), 174-202. <http://web.gys.gr/GeoSearch/geoid/hmgs-geoid-index.html>