Peertechz

Journal of Civil Engineering and Environmental Sciences

ISSN: 2455-488X DOI: https://dx.doi.org/10.17352/jcees

Research Article

Fractal Analysis of the Global Seismicity and Bouguer Gravity Field - Possible Environmental Consequences

Rosen Iliev[1] and Boyko Ranguelov[2,3]*

[1]Independent Researcher, 1000 Sofia, Bulgaria

[2]Bulgarian Academy of Sciences and Arts, Bulgaria

[3]Space Research and Technology Institute, Bulgarian Academy of Sciences, Bulgaria

Received: 19 March, 2025
Accepted: 17 April, 2025
Published: 18 April, 2025

***Corresponding author:** Boyko Ranguelov, Bulgarian Academy of Sciences and Arts, Space Research and Technology Institute, Bulgarian Academy of Sciences, Bulgaria, E-mail: branguelov@gmail.com

Keywords: Bouguer gravity; Fractal analysis; Geodynamics; Strong earthquakes; Environment

Abstract

In this study, an analysis of the connection between the spatial distribution of strong earthquakes (M ≥ 6.0) around the world and the Bouguer gravity anomaly gradients is made. The aim of this study is to use relatively less familiar method of the fractal analysis to reveal the relationship between the global gravity field and the regional seismicity related mainly to the subduction zones (the most powerful seismic energy emitters). For this purpose, the Bouguer gravity anomaly (BGA) field is represented as a synthetic fractal surface. The results obtained show that during the last century, more than 90% of the strong earthquakes occurred in places with maximum gradients in the Bouguer gravity values (Fractal Dimension, FD ≥ 2.6). The discussion shows differences between subduction seismic generators and other geodynamic elements emitting seismic energy like transform faults, intraplate seismic regions (for example, Tibet Plateau, Nasca Plate, Mid-Atlantic ridge, etc.). As the magnitude increases, so does the correlation between them. For earthquakes with M 7.0 - 7.9 and M 8.0 - 8.9, the relationship is 95%, and by M ≥ 9.0, even 100%. This supports the conclusion the self-similarity of the geophysical parameters and their direct connection with the Earth's geodynamics. It is well known that the areas with high geodynamics (strong earthquakes, tsunamis, landslides, etc.) cause significant environmental changes affecting populations, infrastructure, and biodiversity.

Introduction

The Bouguer gravity anomaly is one of the important reference parameters in Earth's geophysics. It gives a good idea of the density of the substance in the Earth's interior and, from there, of the features of the internal structure of the planet. The Bouguer gravity anomalies represent mass anomalies within the Earth's interior due to either variations in crustal thickness or variations in Earth's crust or mantle density (Figure 1). Bouguer anomalies (Δgb) can be described using the following formula:

$$\Delta g_b = \Delta g_\varphi - 0{,}0419\delta H = g - \sigma_0 + 0{,}3086H - 0{,}0419\delta H \qquad (1)$$

where Δg_φ is free air anomaly, δ is density and H is layer thickness.

Recently, in the analysis of geophysical fields—especially the Bouguer anomaly, the mathematical method of fractal analysis has begun to be used. So far, it has been successfully applied in many regional studies about local gravity field peculiarities [1-8]. The results obtained within these studies unequivocally demonstrate the self-similar (fractal) structure of the gravity field, and in particular of the Bouguer one.

On the other hand, seismic activity (Figure 2) is a main indicator of the intensity of the most recent Earth's geodynamics and the character of the deep planetary processes.

In this study, an analysis of the interrelationships between the Bouguer anomaly values variation and the spatial distribution of strong earthquakes (M ≥ 6.0) around the world has been performed. The obtained results show new interrelationships and could be a good basis for new hypotheses and interpretations in the future.

Citation: Iliev R, Ranguelov B. Fractal Analysis of the Global Seismicity and Bouguer Gravity Field - Possible Environmental Consequences. J Civil Eng Environ Sci. 2025;11(1):026-029. Available from: https://dx.doi.org/10.17352/2455-488X.000092

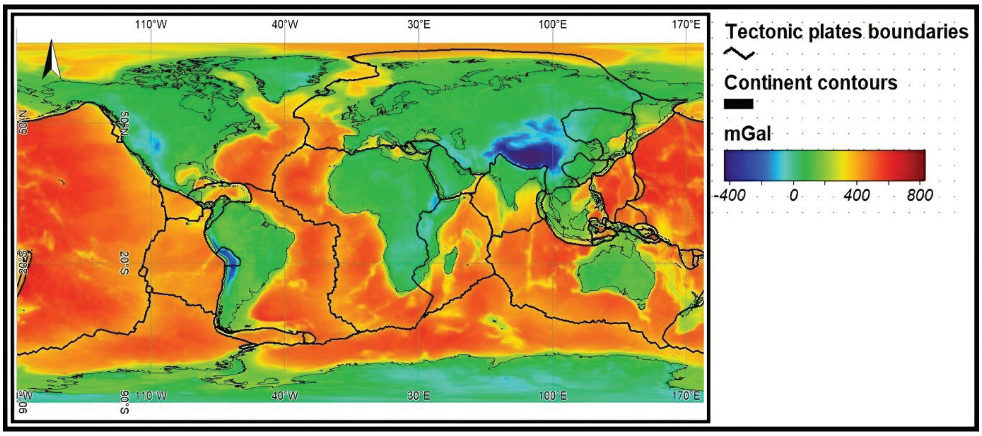

Figure 1: Spatial distribution of the Earth's Bouguer gravity field [in mGal] [12,16].

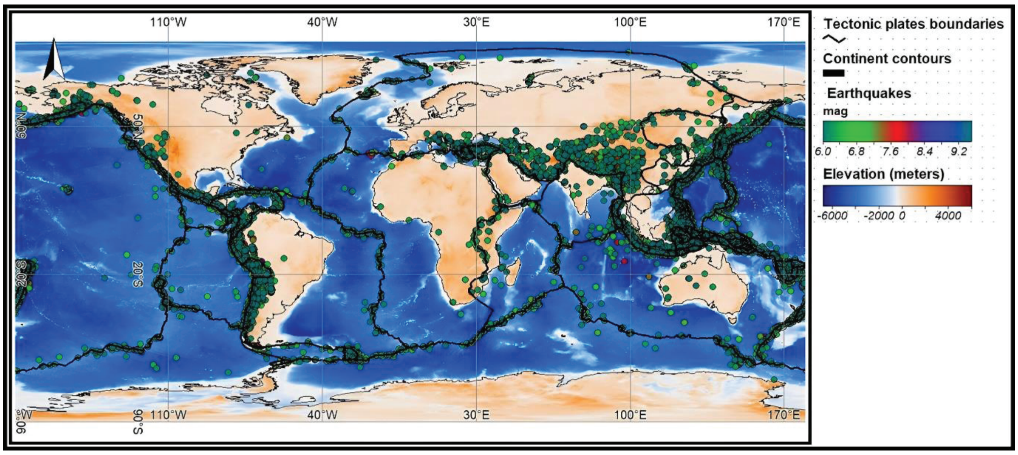

Figure 2: Spatial distribution of strong earthquakes (M ≥ 6.0) worldwide [13,16].

Methods and data

Variogram method for Fractal Dimension (FD) estimation

Within this study, the fractal analysis is performed through the construction of a synthetic fractal surface. The fractal calculator (FocalID), based on the variogram method [9], generates an image through a window around each raster cell. In this way, the fractal calculator initially estimates a variogram, where

$$y(h) = Var(Zi - Zj) \quad (2)$$

Where, i, j are spaced by the distance vector h. It is then derived by regressing the logarithm of the distance vector with the logarithm of the variance [10] is calculated the slope of regression. Finally, the fractal dimension (D) is estimated through the following formula:

$$D = 3 - (B/2) \quad (3)$$

Where D is the fractal dimension and B is the slope of the regression.

The fractal value of each pixel reflects the complexity of variation [11] of the study parameter. The fractal signal value is much higher when parameter values have a more complex variation in regard to their neighboring pixel cells.

Finally, using GIS techniques, a fractal model of the Bouguer gravity field (such as 2D maps) was constructed and statistics were extracted.

Data and software

The gravity data used in this study are derived from the Global Gravity Model- WGM2012 [12]. The elevation data about the world is based on the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM V2) [13]. The DEM data are available in GeoTIFF format and has a resolution of 1 arc-second (30 x 30 m) grid.

Seismic analysis is based on the USGS Seismic Hazard Program [14] free earthquake catalogue (nearly 12,700 events with magnitude ≥ 6.0 on the Richter scale) for the statistical period from 1900 to 2025.

The data have been processed and explored using Geographic Information System (GIS) – SAGA-GIS [15] and LandSerf free software.

Citation: Iliev R, Ranguelov B. Fractal Analysis of the Global Seismicity and Bouguer Gravity Field - Possible Environmental Consequences. J Civil Eng Environ Sci. 2025;11(1):026-029. Available from: https://dx.doi.org/10.17352/2455-488X.000092

Results and discussion

The results from the analysis of relationships of Bouguer gravity field and worldwide strong earthquakes are presented in textual form in Table 1 and in visual form by Figure 3. An explanation and interpretation of the results is given further.

It is evident from Table 1 that strong earthquakes (M ≥ 6.0) occur in places with maximum variation of the Bouguer gravity field (FD ≥ 2.6). In case of destructive earthquakes (M ≥ 7.0), the correlation is even stronger (95% - 100%). Figure 3 shows that the exceptions to the rule are related to specific geographic areas with specific behavior of seismicity. These are the Tibetan Plateau, the southern edge of the Australian plate, the western edges of the Nazca tectonic plate (East Pacific Ridge), and some sections of the Mid-Atlantic Ridge. These seismic events tend to be very shallow (focal depth ≤ 20 km). With the exception of the Tibetan Plateau (intercontinental collision), the remaining regions are associated with divergent tectonic boundaries. Within the Tibetan Plateau, we have negative Bouguer gravity values (due to the high elevation), while at the rest we have positive gravity values (Figure 1). This clearly demonstrates that the high seismicity and strong earthquakes are strongly related to the high stress accumulation in subduction zones and transform faults. These areas are characterized by the highest geodynamics. Strong earthquakes in these areas often alter Earth's surface elevation, produce tsunamis, activate surface and submarine landslides, etc. All these secondary events kill people, cause infrastructure damage and lead to ecological disasters (e.g., the Fukushima accident) and strongly change the coastal and underwater biodiversity (especially within areas affected by huge tsunamis (for example, the 2004 Indian Ocean (Sumatra) tsunami, when a lot of species were eliminated for certain time and Japan tsunami (2011) with the same effects)).

From the engineering point of view, the antiseismic measures performed in the highly active seismic zones are always recommended. The Global practices indicate significant variations in seismic codes and regulations across countries. During the last decade, only Europe has tried to unify the regulations (so-called EUCODE8), and this is considered a positive step towards the unification of the antiseismic mitigation measures.

The applied method does not pretend to be about fundamental novelty in the field of comparison of gravity field (BGA) and strong seismicity. Its aim is just to show a new approach, giving reasonable results and the possibility to use new tools in the field of revealing the relationships between different geodynamic parameters.

Conclusion

Based on the results obtained in the course of this research, the interrelationships between natural risk processes (natural hazard – strong earthquakes) and the fractal nature of Earth's geodynamics were confirmed. This study confirms globally that the strongest earthquakes are closely related to the BGA with higher fractal dimensions due to the fragmentation of the gravity field dictated by internal inhomogeneity of the density of Earth's substrate. In this way, the fractal approach is becoming an increasingly important tool of the methodological scientific toolkit in the study of natural disasters and environmental changes. Fractal analysis facilitates the tracing of interrelationships in the spatial distribution of natural hazard processes.

Table 1: Relationship between strong earthquakes (M ≥ 6.0) with Bouguer gravity fractal surface presented by FD.

Bouguer gravity		Earthquakes (total number/share)				
FD	Gradient	All values (M ≥ 6.0)	M 6.0 - 6.9	M 7.0 - 7.9	M 8.0 - 8.9	M ≥ 9.0
2.0 - 2.4	low	416 (3.27%)	401 (3.55%)	14 (1.08%)	1 (1.18%)	-
2.4 - 2.6	medium	791 (6.23%)	731 (6.46%)	54 (4.19%)	3 (3.53%)	-
2.6 - 3.0	high	11 483 (90.5%)	10 179 (89.99%)	1221 (94.7%)	81 (95.29%)	5 (100%)

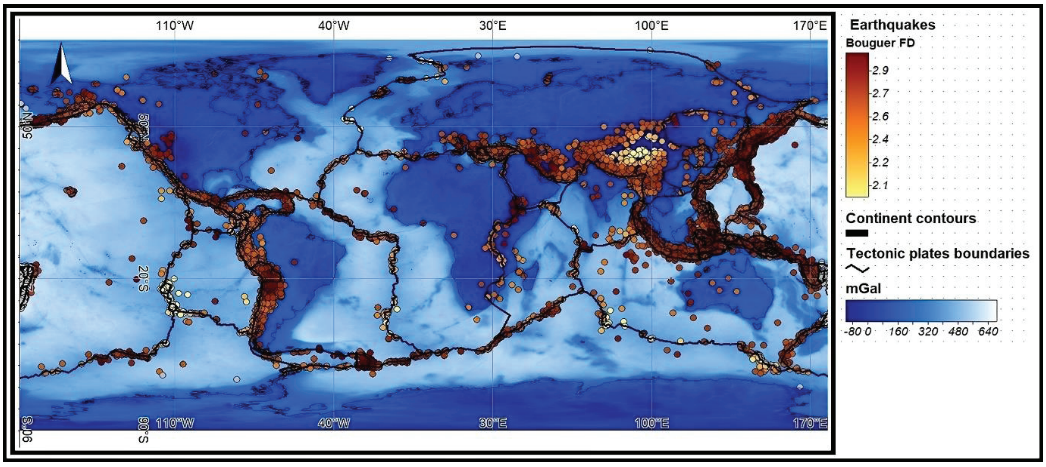

Figure 3: Relationship between fractal model of global Bouguer gravity field and strong earthquakes worldwide [16].

Citation: Iliev R, Ranguelov B. Fractal Analysis of the Global Seismicity and Bouguer Gravity Field - Possible Environmental Consequences. J Civil Eng Environ Sci. 2025;11(1):026-029. Available from: https://dx.doi.org/10.17352/2455-488X.000092

References

1. Thorarinsson F, Magnusson SG. Bouguer density determination by fractal analysis. Geophysics. 1990;55(7):932–5. Available from: https://einmitt.is/Gravity/Bouguer-Fractal.pdf

2. Keating P. The fractal dimension of gravity data sets and its implication for gridding. Geophys Prospect. 1993;41(8):983–93. Available from: https://doi.org/10.1111/j.1365-2478.1993.tb00894.x

3. Lawal KM, Akaolisa CZ. Bouguer correction density determined from fractal analysis using data from part of the Nigerian basement complex. Niger J Phys. 2006;18(2):251–4. Available from: http://dx.doi.org/10.4314/njphy.v18i2.38111

4. Nur AA, Syafri I, Muslim D, Hirnawan F, Raditya PP, Sulastri M, et al. Fractal characteristics of geomorphology units as Bouguer anomaly manifestations in Bumiayu, Central Java, Indonesia. IOP Conf Ser Earth Environ Sci. 2016;29:012019. Available from: https://iopscience.iop.org/article/10.1088/1755-1315/29/1/012019

5. Herrera C, Aldana M, Sánchez-Rojas J, Schmitz M. Depth to sources and Bouguer density determination of the Merida Andes, Venezuela, by means of a fractal analysis of gravity data. In: SEG Technical Program Expanded Abstracts 2017. Society of Exploration Geophysicists; 2017. Available from: https://doi.org/10.1190/segam2017-17781037.1

6. Tzankov Tz, Iliev R, Ranguelov B. Fractal structure of the positive free-air gravity anomalies within the Balkan Peninsula. To Phys J. 2018;1(3):225–33. Available from: https://www.researchgate.net/publication/330010962_Fractal_structure_of_the_positive_free-air_gravity_anomalies_within_the_Balkan_Peninsula

7. Hassouna RMK. The fractal behaviour of gravity field elements: case study in Egypt. J Spat Sci. 2021;68(2):175–90. Available from: http://dx.doi.org/10.1080/14498596.2021.1950582

8. Liang X, Chen S, Chu F, Xu R, Sun H, Xiao W, et al. Resolution analysis of the gravity survey network in the middle and south sections of Tan-Lu fault and recent changes in the gravity field. Geod Geodyn. 2024. Available from: https://doi.org/10.1016/j.geog.2024.08.001

9. Mark DM, Aronson PB. Scale-dependent fractal dimensions of topographic surfaces: an empirical investigation with applications in geomorphology and computer mapping. Math Geol. 1984;16(7):671–83. Available from: https://link.springer.com/article/10.1007/BF01033029

10. Zhou G, Lam N. A comparison of fractal dimension estimator based on multiple surface generation algorithms. Comput Geosci. 2005;31:1260–9. Available from: https://doi.org/10.1016/j.cageo.2005.03.016

11. Pentland AP. Fractal-based description of natural scenes. IEEE Trans Pattern Anal Mach Intell. 1984;PAMI-6:661–74. Available from: https://doi.org/10.1109/tpami.1984.4767591

12. Bonvalot S, Balmino G, Briais A, Kuhn M, Peyrefitte A, Vales N, et al. World Gravity Map. Paris: Commission for the Geological Map of the World; 2012. Available from: http://dx.doi.org/10.14682/2012GRAVISOST

13. Reuter HI, Neison A, Strobl P, Mehl W, Jarvis A. A first assessment of ASTER GDEM tiles for absolute accuracy, relative accuracy and terrain parameters. In: Geoscience and Remote Sensing Symposium, IEEE International, IGARSS 2009. 2009;5:240–3. Available from: http://dx.doi.org/10.1109/IGARSS.2009.5417688

14. USGS Seismic Hazard Program. Available from: https://earthquake.usgs.gov

15. Conrad O, Bechtel B, Bock M, Dietrich H, Fischer E, Gerlitz L, et al. System for Automated Geoscientific Analyses (SAGA) v. 2.1.4. Geosci Model Dev. 2015;8:1991–2007. Available from: https://gmd.copernicus.org/articles/8/1991/2015/gmd-8-1991-2015.html

16. Bird P. An updated digital model of plate boundaries. Geochem Geophys Geosyst. 2003;4(3):1027. Available from: https://doi.org/10.1029/2001GC000252s

Citation: Iliev R, Ranguelov B. Fractal Analysis of the Global Seismicity and Bouguer Gravity Field - Possible Environmental Consequences. J Civil Eng Environ Sci. 2025;11(1):026-029. Available from: https://dx.doi.org/10.17352/2455-488X.000092