Geoid modelling in Northwestern Tunisia using the Remove – Compute – Restore (RCR) method

Določitev geoida v severozahodni Tuniziji z metodo remove-compute-restore (RCR)

Ali Chaieb, Nahla Gam, Mourad Salhi

UDK: 528.21:528.716.2(611)
Klasifikacija prispevka po COBISS.SI: 1.01
Prispelo: 12. 1. 2026
Sprejeto: 11. 5. 2026

DOI: 10.15292/geodetski-vestnik.2026.03.391-405
SCIENTIFIC ARTICLE
Received: 12. 1. 2026
Accepted: 11. 5. 2026

IZVLEČEK

Članek opisuje določitev in oceno lokalnega gravimetričnega geoidnega modela za severozahodno Tunizijo. Model je bil določen po metodi remove-compute-restore (RCR), na podlagi terestričnih meritev težnosti, podatkov GPS-višinomerstva ter digitalnega modela višin in globalnega geopotencialnega modela EGM2008. Najprej je bila opravljena analiza ustreznosti posameznih globalnih geopotencialnih modelov (EGM96, EGM2008, EIGEN-6C4). Pri tem se je kot najprimernejši pokazal EGM2008, saj je imel najmanjši standardni odklon Za najustreznejši digitalni model višin se je izkazal model SRTM.V postopku določitve so bile najprej izračunane anomalije prostega zraka, potem še drugi popravki po metodi RCR. Kvazigeoidne višine so bile določene z integracijo Stokesove enačbe. Za določitev končnih vrednosti kvazigeoidnih višin smo povrnili sprva odstranjene vrednosti globalnega modela EGM2008, vrednosti terenskih popravkov ter popravkov gravimetričnega signala. Lokalni model geoida je določen iz modela kvazigedoida prek grida naknadno določenih Bouguierovih anomalij težnosti. Model je bil nato izvrednoten glede na merjene vrednosti geoidnih višin, pridobljene z GPS-višinomerstvom. Izračunani lokalni model geoida zagotavlja natančno in zanesljivo referenčno ploskev za pretvorbo elipsoidnih višin, pridobljenih z GNSS, v ortometrične višine znotraj obravnavanega območja.

ABSTRACT

This study presents the development and evaluation of a local gravimetric geoid model for Northwest Tunisia. The model was constructed using the Remove-Compute-Restore (RCR) method, integrating terrestrial gravity measurements, GPS-survey data, digital elevation models, and the global geopotential model EGM2008. A comprehensive accuracy assessment was first conducted. Among the tested global models (EGM96, EGM2008, EIGEN-6C4), EGM2008 demonstrated superior performance, yielding the smallest standard deviation. The SRTM digital elevation model was identified as the most accurate topographic dataset for the region. The computational workflow involved the calculation of free-air anomalies, residual terrain corrections, and residual gravity anomalies. Stokes' integration was then applied to convert the residual gravity field into residual height anomalies. The final quasi-geoid was restored by combining the EGM2008-derived long-wavelength component, the residual terrain effect, and the gravimetrically determined residual signal. The model was subsequently adjusted using an independent set of GPS-levelled benchmarks to ensure consistency with the national vertical datum.The resulting local geoid model provides a precise and reliable reference surface for converting GNSS-derived ellipsoidal heights into orthometric heights within the study area.

KLJUČNE BESEDE

modeliranje geoida, metoda RCR, EGM2008, GPS-višinomerstvo, gravimetrija

KEY WORDS

Geoid Modelling, Remove-Compute-Restore, EGM2008, GPS-Levelling, Gravimetry

1 Introduction

The precise determination of the Earth's geoid the equipotential surface of the gravity field that best approximates mean sea level is a fundamental objective in geodesy (Gurtner,1978) (Jiang and Duquenne, 1995) (Salissou et al., 2016). It serves as the essential reference surface for defining orthometric heights, which are crucial for a wide range of scientific and practical applications, including surveying, civil engineering, hydrology, and climate studies. In the era of Global Navigation Satellite Systems (GNSS) (Kao et al., 2017) (Arana et al.,2017) (Abdalla and Mogren, 2015), which provide ellipsoidal heights with centimetre-level accuracy, the need for a high-precision geoid model to convert these heights into meaningful physical elevations has become paramount.

In Tunisia, as in many regions, the national vertical datum relies on a network of levelled benchmarks. However, direct levelling is time-consuming, costly, and impractical over large or difficult terrains. A local gravimetric geoid model offers an efficient and accurate alternative, enabling the determination of orthometric heights directly from GNSS observations (Silva, 2021) (Kingdom et al., 2009) (Martin et al., 2010). This is particularly valuable for the Northwest region of Tunisia, characterized by varied topography and ongoing developmental projects that require precise elevation data (Rebai et al, 2018).

While global geopotential models (GGMs) like EGM2008 provide a long-wavelength geoid representation (Vaníček et al., 2012) (Koch et al., 2023) (Marques and Guimarães, 2018) (Tocho, 2006) (Ning, 2015), their accuracy is limited at regional and local scales due to the omission of short-wavelength gravity signals caused by local topographic and density variations (Torres, 2022). Therefore, augmenting a global model with local terrestrial gravity data and high-resolution terrain information is necessary to achieve centimetre-level precision.

The determination of the geoid relies on a complementary set of techniques designed to bridge the gap between the Earth's physical surface and its mathematical model (the ellipsoid). The GPS/Leveling method provides a direct geometric approach by calculating the undulation N as the difference between the ellipsoidal height and the orthometric altitude (N = h - H). In contrast, astro-geodetic and gravimetric methods utilize the physics of the gravity field: the former uses astronomical observations of stars to calculate vertical deflections and integrate geoid slopes, while the latter, based on Stokes' formula, converts gravity anomalies into geoid heights (Ma et al., 2025). To overcome theoretical limitations regarding mass density (the Molodensky problem), the quasi-geoid approach is often preferred in modern geodesy as it avoids complex crustal density assumptions. Finally, the Remove-Compute-Restore (RCR) technique represents the most advanced strategy, harmonizing global satellite models (long wavelengths), local gravimetric surveys (medium wavelengths), and Digital Elevation Models (short wavelengths) to achieve the centimeter-level precision required for modern scientific applications (Kalu et al., 2022), (Wang et al., 2025).

This article details the comprehensive process of developing a local gravimetric geoid model for Northwest Tunisia. The methodology is based on the established Remove-Compute-Restore technique. The study begins with an evaluation of available global models and digital elevation models to select the optimal foundational datasets. Subsequently, it outlines the sequential steps of data preparation, terrain effect modelling, residual gravity field computation, Stokes' integration, and final model adjustment using GPS-levelled control points.

The primary objective is to produce a validated, reliable geoid solution in the Northwest of Tunisia that bridges the gap between the global reference frame and Tunisia's national height system, thereby supporting the country's geodetic infrastructure and its broader scientific and socioeconomic development.

2 Study area

This study focuses on an area of interest located in northwestern Tunisia, covering a total area of approximately 5,800 km². Spatially, this area is defined by a rectangular box located between longitudes [8.92° E; 9.75° E] and latitudes [36.45° N; 37.15° N]. Administratively, this area encompasses the governorate of La Manouba and extends into a significant portion of the governorate of Béja, while also intersecting the territorial boundaries of Binzart and Jendouba. (Figure 1)

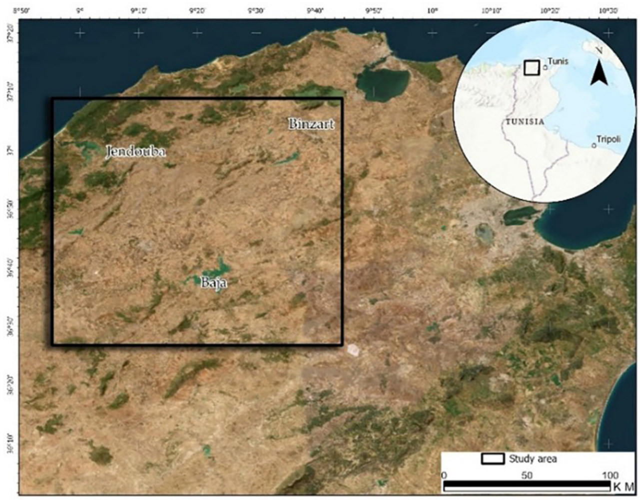

Figure 1: study area: North western part of Tunisia

The choice of this area is based on its topographic and geomorphological complexity, a critical factor for modeling a high-precision local geoid. The area exhibits an abrupt transition between low-lying alluvial plains (the lower Medjerda basin) and the rugged foothills of the Tell Atlas Mountains. This heterogeneity of the terrain induces significant variations in the gravitational field and deviations from the vertical, making the calculation of geoidal heights particularly complex. The diversity of terrains, ranging from near-horizontal surfaces to steeply sloping reliefs, thus provides an ideal setting for testing the robustness of gravimetric calculation models and the integration of leveling data.

This region serves as a representative geodetic testbed for Tunisia due to its diverse geomorphology, allowing for a concentrated validation of the RCR method before national-scale implementation

3 Methodology

To overcome these orographic challenges, this study employs the Remove-Compute-Restore (RCR) technique, a reference method in physical geodesy. Initially, long-wavelength components from a global potential model and high-frequency topographic effects (RTM) are removed from the gravimetric observations to obtain a more homogeneous residual signal. After digital processing of these residuals, the previously extracted contributions are restored to obtain the final geoid height. This approach allows for accurate modelling of the local geoid by seamlessly integrating the influence of the rugged terrain of northwestern Tunisia, thus ensuring a consistent transition between field measurements and the global model (Figure 2).

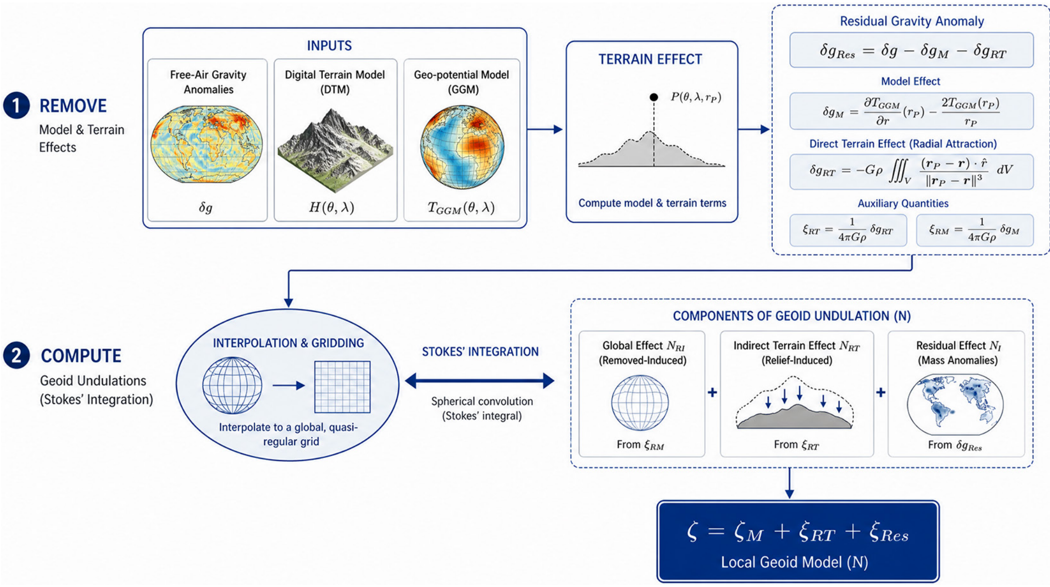

Figure 2: RCR method Flow chart

3.1 Data Preparation

3.1.1 Global Geopotential Models (GGMs)

A global gravity field model, or Global Geopotential Model (GGM), is a mathematical function that describes the Earth's gravity field (Koch et al., 2023). Over the past 30 years, various research teams have computed numerous GGMs. Today, global geopotential models are routinely used as a standard step in gravimetric geoid calculation procedures. During the last two decades, a series of global geopotential models based on spherical harmonic expansions have been developed with increasingly higher resolution. The most recent models can provide information about the long-wavelength component of the Earth's gravity field, with a resolution (minimum half-wavelength) of approximately 18 kilometers. To establish the best method for determining the local geoid, which is essential for deriving GPS-based heights, it is first necessary to select the geopotential model best suited to the Northwest Tunisia region. We used the global geographic potential model EGM08, which represents the long wavelength of the Earth's gravitational field. Our decision to proceed with EGM2008 as the primary reference for the RCR workflow was based on its established reliability in North African geodetic studies and its role as the high-frequency base for many of these newer models. Since our methodology incorporates a high density of local terrestrial gravity observations, the marginal improvements provided by global satellite data in newer models (which primarily refine the long-wavelength components) are largely superseded by our local residual computation.

We have access to three global models which test them before choosing the EGM08 (Figure 3):

- **EGM96:** Earth Gravitational Model 1996
- **EGM08:** Earth Gravitational Model 2008
- **EIGEN-6C4:** European Improved Gravity Model of the Earth by New Techniques

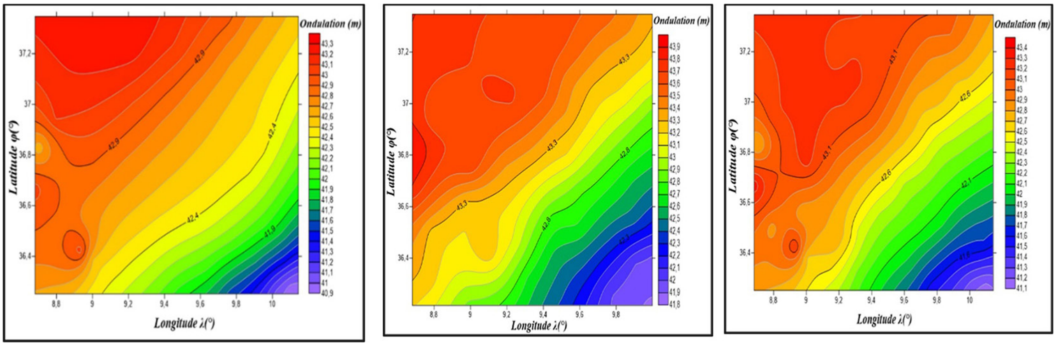

Figure 3: Geoid Undulation in the Northwest Region of Tunisia According to EGM96, EIGEN-6C4, EGM2008 respectively

3.1.2 Digital Terrain Models (DTMs)

Several global DEMs have been developed and published over the past two decades. Nevertheless, the spatial resolution and accuracy of these models vary considerably. The calculation of topographic effects requires the availability of a high-resolution digital terrain model (Table 1).

Recent comparative studies conducted specifically in Tunisia (e.g., in the Grombalia and Kasserine regions) have shown that SRTM consistently outperforms ASTER GDEM and GTOPO30.(Chaieb et al., 2016).

Table 1: The ASTER, GTOPO and SRTM Digital Elevation Model spécifications

Feature	SRTM (1-arc-sec)	ASTER GDEM	GTOPO30
Technology	C-band Radar	Optical/Stereo	Multi-source Map data
Resolution	~30 m	~30 m	~900 m
Topography	Best for rugged/mountainous	Prone to artifacts in hills	Too coarse for hills
Accuracy (Tunisia)	Higher (RMSE ~8.9m)	Lower (RMSE ~10.1m)	Very low (Outdated)

3.1.3 GPS/Levelled Points

A rigorous validation workflow has been implemented using 25 high-precision GPS-levelled benchmarks. To ensure an independent assessment of model performance, this dataset was randomly split into two subsets: a control set (12 points) and an independent validation set (13 points). The control set serves as the foundation for three geodetic tasks: selecting the optimal global geopotential model, evaluating the digital elevation model, and applying the final geoid adjustment. The independent validation set is reserved exclusively for the final accuracy assessment of the computed geoid, thereby avoiding circularity and providing an unbiased estimate of the model's real-world performance.

The 25 points are defined by their latitude (φ), longitude (λ), ellipsoidal height (h), orthometric altitude (H), and geoid undulation (N) (Figure 4).

3.1.4 Gravity Data

The gravity data used, consisting of 74 points distributed across the study area belonging to the Tunisian gravity network, with an accuracy not exceeding 25 microgals. . The density of gravity measurements is approximately:

- **1 point/18 km²** for first-order measurements
- **1 point/9 km²** for second-order measurements

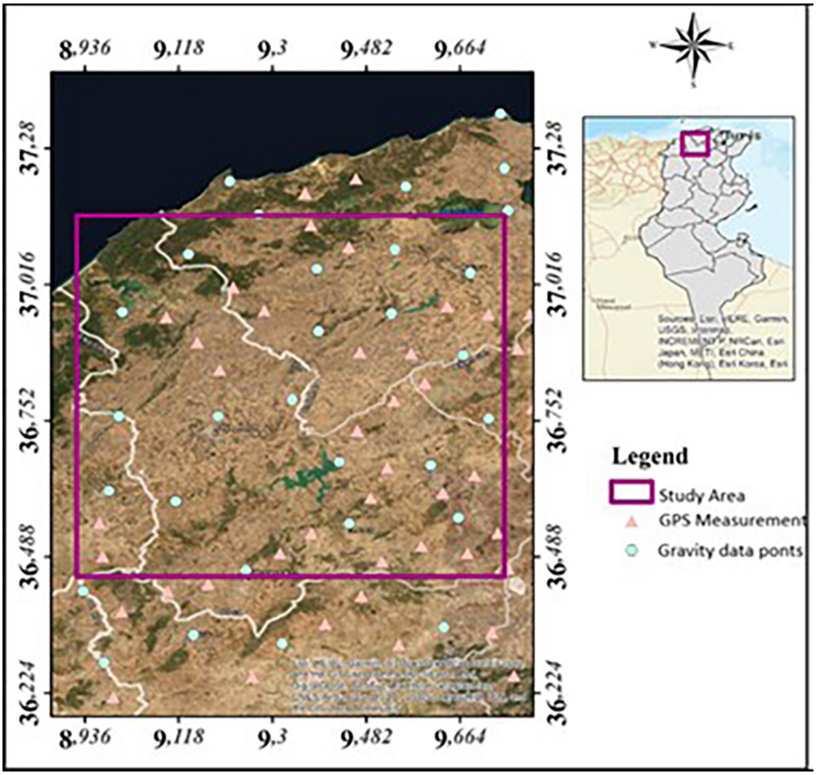

Figure 4: GPS and Gravity data distribution

Evaluation of the Global Geoid Model

This evaluation was conducted using GPS-leveled control points. The global geoid model undulations were extracted by interpolating the model grids at the control point coordinates (Salissou et al., 2016). The statistical discrepancies (ΔN) between the GPS-leveled geoid heights (N_GPS/Niv) and the model-derived geoid heights (N_GGM) were calculated using the formula (1):

$$\Delta N = \sum_{i=1}^{64} N^{i}_{GPS/Niv} - N^{i}_{EGM} \qquad (1)$$

The results for the evaluated models (EGM96, EGM2008, and EIGEN-6C4) are presented in (Table 2). The comparison indicates that EGM2008 performs best, as it exhibits the smallest standard deviation. EIGEN-6C4 relies more on satellite data (GOCE) with longer wavelengths; EGM2008 includes more terrestrial data, which benefits Tunisia's regional gravity field.

Table 2: Discrepancies Obtained Relative to the GPS/Leveled Points

	Leveled GPS/EGM 96	Leveled GPS/EGM 2008	Leveled GPS/EIGEN-6C4
Min (m)	-1.43	-1.33	-1.31
Max (m)	0.21	0.23	0.21
Mean (m)	-0.61	-0.57	-0.59
Standard Deviation (m)	0.26186801	0.22857794	0.311493862

The implementation of such a geoid model with a significant discrepancy in height suggests the need to apply a correction to the global geoid model.

Adaptation of the GGM (Local Geoid Model)

The principle of adapting a global geoid model to an altimetric geoid model is based on comparing the undulations of the global model with the undulations from GPS-leveled points (Koch et al., 2023).

Evaluation of DTMs

For the evaluation of DTMs, we interpolated the GPS-leveled points and then compared them to the observed orthometric heights (Enriquez et al, 2021). The table 2 below shows the results of interpolating the GPS/Leveled points relative to the DTMs (SRTM, GTOPO, and ASTER).

Clearly, it can be seen that the difference produced by SRTM is the smallest, the standard deviation value of ASTER is close to second, and the difference of GTOPO30 is the largest. Therefore, we can conclude that SRTM is the most accurate Digital Terrain Model (DEM) representing the terrain topography of our study area in Northwest Tunisia (Table 3).

The superior performance of SRTM over ASTER GDEM and GTOPO30 in this region stems from fundamental differences in sensor technology and production methods. SRTM uses active C-band radar interferometry, which directly measures surface elevation with high coherence and minimal atmospheric interference, resulting in consistent error characteristics even over vegetated or moderately rugged terrain. In contrast, ASTER GDEM relies on passive optical stereophotogrammetry, which is prone to artifacts from cloud cover, shadows, and varying illumination angles particularly problematic in the hilly topography of the Tell Atlas foothills. GTOPO30, being a coarse (~ 900 m) compilation of diverse legacy maps, simply lacks the spatial resolution to capture the short-wavelength topographic signals that significantly affect local gravity fields. Consequently, SRTM's combination of fine resolution (~ 30 m), radar-based surface penetration, and global consistency makes it the most appropriate DEM for residual terrain modeling in this geodynamically complex region.

In conclusion, based on all the results from the evaluations of the GGMs and DTMs, we can finally state that EGM2008 is the most accurate GGM in terms of geoid undulations. Regarding the overall DTM evaluation, the obtained results show that SRTM produces the smallest difference.

Table 3: Results of the Interpolation of GPS/Leveled Points

	ΔZ_SRTM	ΔZ_GTOPO	ΔZ_ASTER
Min (m)	-8	-69	-6
Max (m)	14	59	19
Mean (m)	2	-11	4
Standard Deviation (m)	4.04	24.36	4.48

Free-air Anomaly

The calculation of the free-air anomaly (Figure 5) is performed in an Excel file containing the necessary information (ID, Latitude (φ), Longitude (λ), measured g value, ellipsoidal height (h_e), and altitude (H)). This anomaly can be computed using the Somigliana formula and the free-air correction formula (Table 4).

Table 4: Statistics of Free Air Gravity Anomaly

	Min	Max	Mean
FAA	0.13509534	36.09581426	21.47598

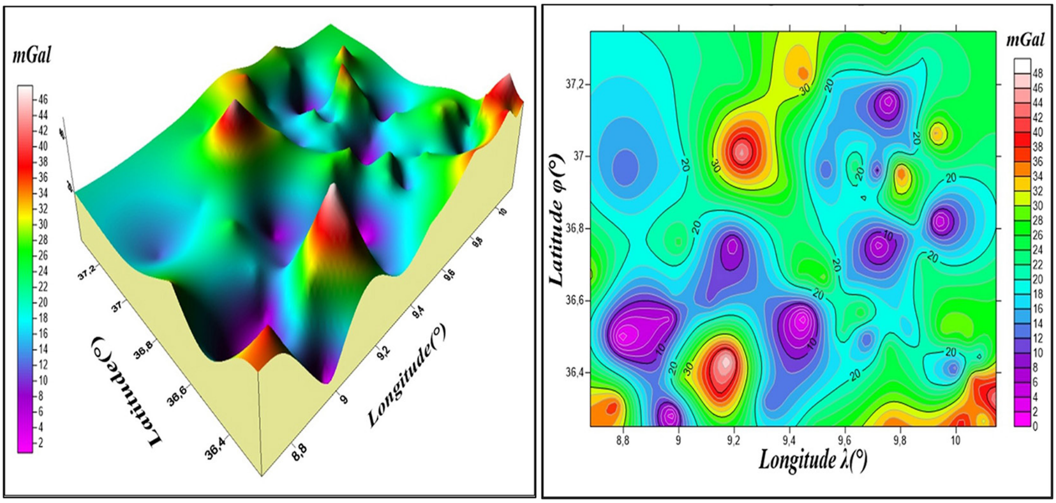

Figure 5: Free-Air Gravity Anomaly Map

4 Results and discussion

4.1. Geoid Calculation Steps

4.1.1 Remove-Compute-Restore (RCR)

We recall that the RCR step involves removing the long-wavelength and short-wavelength gravity anomalies in order to obtain a residual anomaly (Koch et al., 2023). Therefore, we need to prepare a filtered Digital Terrain Model (DTM) and a reduced-resolution DTM. These will allow us to determine the gravitational effect due to the terrain (topographic effect) and subsequently obtain the residual gravity anomaly (Figure 6).

The general mathematical process for the RCR step is given by the following equation (2):

$$\Delta g_{Res} = \Delta g_{FA} - \Delta g_{M} - \Delta g_{RT} \qquad (2)$$

Note that

- Δg_{Res}: Residual Gravity Anomalies
- Δg_{FA}: Free-Air Gravity Anomalies

- Δg_{GM}: Gravity Anomalies from the Global Geopotential Model
- Δg_{RT}: Residual Terrain Correction (Terrain Effect)

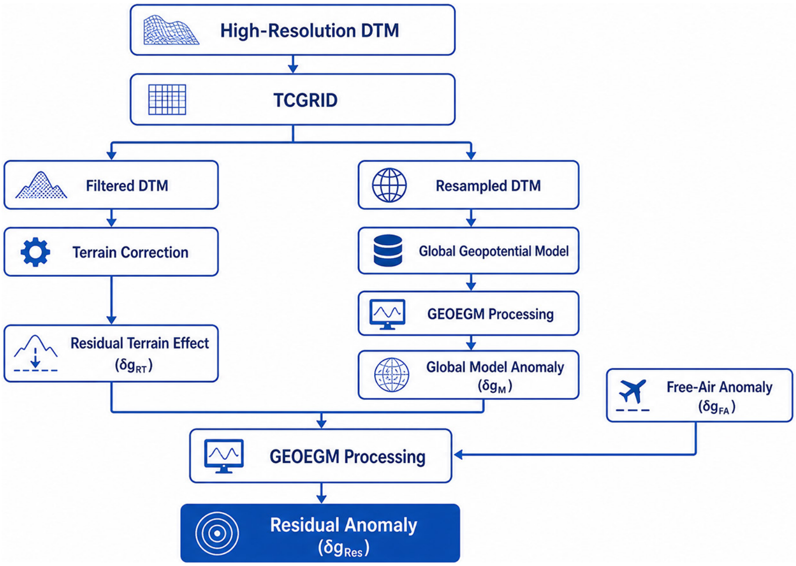

Figure 6: Flowchart of the "Remove" Step

a/ The Reduced-Resolution and Filtered DTM

In terrain correction calculations, both the reduced-resolution DTM and the filtered DTM will be used. The area of the fine-resolution DTM must be slightly larger than the area of the reduced-resolution and filtered DTMs in order to compute them.

Reduced-Resolution DTM

A coarser digital terrain model can be generated by applying defined degradation factors to the original high-resolution grid, where these factors directly scale the spatial resolution in the latitudinal and longitudinal directions. The process requires specifying the source and destination files, the geographic domain of interest, and the numerical scaling parameters that control the degree of resolution reduction and any optional smoothing, with typical values provided for straightforward down sampling (Salissou et al., 2016).

Filtered DTM

The filtered DTM is generated by introducing two filtering factors, p and q, which correspond to the longitude and latitude dimensions of the filter window, respectively. These dimensions relate to the half-wavelength of the field model at the fine DTM grid spacing.

In our case, the complete filtering factor will be:

f = 9300 / 30 = 310.

Therefore, with degradation factors n = 15 and m = 15, the filtering factors should be set to:

p = 20 and q = 20 (since 15 × 20 = 300).

b/ Calculation of Residual Terrain Correction

The calculation of the Residual Terrain Correction (RTC), this process is essential for high-precision geoid modeling as it accounts for the gravitational effects of topography that are not captured by the Global Geopotential Model (GGM) (Figure 7). The most critical parameters in this operation are the "integration radii." These represent the half-sides of the coverage area for each Digital Terrain Model (DTM). The software uses these radii to define the spatial limits within which the terrain's mass is integrated to compute its gravitational effect on a specific point (Table 5).

Table 5: Statistics of Terrain Correction Anomalies (in mGal)

	Min	Max	Mean
Δg_{AAL}	3.9393	32.3695	22.1796
Δg_{RT}	-14.3828	1.7287	-9.742

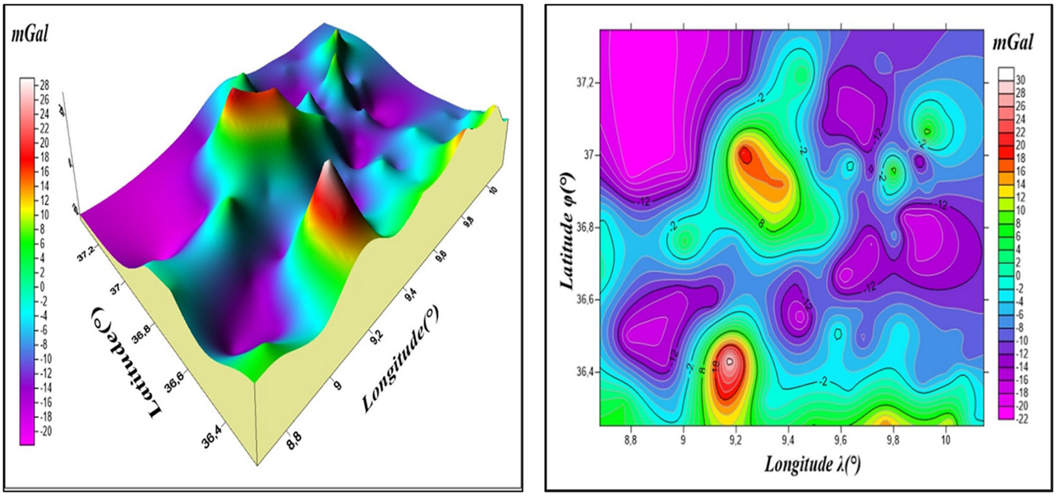

Figure 7: Map of Residual Terrain Correction Anomalies Δg_{RT}

c/ Calculation of Model Gravity Anomalies and Residual Anomalies

In this study, the model gravity anomalies Δg_{GGM} are calculated based on the global geopotential model EGM2008 (Figure 8). To compute these anomalies from the spherical harmonic coefficient file, the GEOEGM program is utilized. This program is highly efficient as it simultaneously calculates both the global model gravity anomalies and the final residual anomalies (Table 6).

Table 6: Statistics of Residual Gravity Anomalies

	Min	Max	Mean
Δg_{AAL}	0.1351	36.0958	19.72384
Δg_{RT}	-17.9948	5.6673	-9.84473
Δg_{M}	6.6602	40.5009	23.15454
Δg_{Res}	-21.1604	24.8568	6.414031

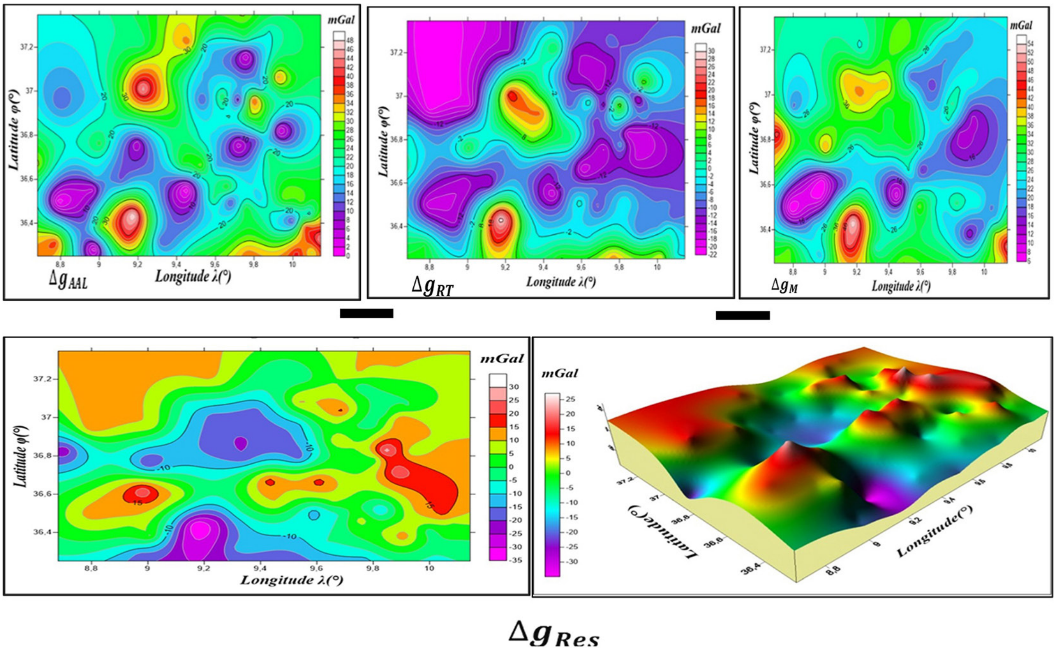

Figure 8: Residual Gravity Anomalies

4.1.2 Calculation

Before being integrated using Stokes' formula, the point-based residual anomalies must be transformed into a regular grid through interpolation. Stokes' integral is then applied to the residual gravity anomalies Δg_{Res} to generate ζ_{Res}, the residual height anomaly (residual quasi-geoid height).

a/ Interpolation

This step produces the residual anomalies at the gravity stations, which are then interpolated over the entire study area. This interpolation enables the conversion to residual undulations via Stokes' formula. The program performs interpolation on point-based residual gravity anomalies.

b/ Integration

The STOKES module calculates the residual height anomalies (Figure 9), (Table 7) from the grid of residual gravity anomalies using a discretized convolution with subsampling near the zero point.

Table 7: Statistics of Residual Height Anomalies

	Min	Max	Mean
ARes Alt (m)	-0,256	0,155	-0.427

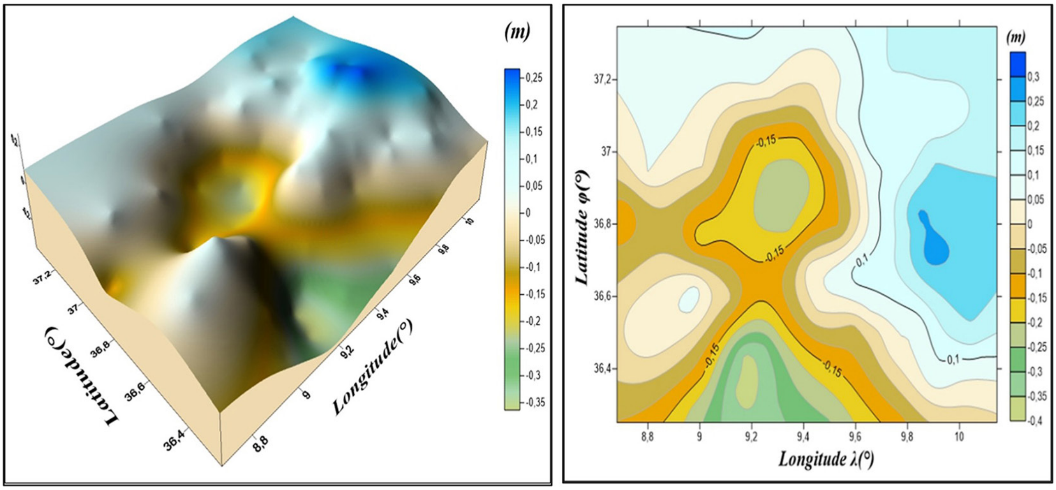

Figure 9: Map of Residual Height Anomalies

4.1.3 Restoration

This final step represents the "Restore" phase of the Remove-Compute-Restore (RCR) technique. After performing the integration to find the local details, you must add back the global and terrain components to obtain the complete physical surface.

To obtain the total height anomaly (ζ), which defines the Quasi-geoid, the components previously removed are added back to the residual result.

The Restoration Equation (3):

$$\zeta = \zeta_M + \zeta_{RT} + \zeta_{Res} \tag{3}$$

a/ Height Anomaly Due to Residual Terrain Effect

To calculate the height anomaly contribution from topography, the TC (Terrain Correction) program is utilized. This step ensures that the short-wavelength topographic signals are properly converted from gravity effects into height effects, allowing them to be correctly "restored" in the final geoid computation (Table 8).

Table 8: Statistics of Height Anomalies Due to Residual Terrain Effect

	Min	Max	Mean
ζ_{Res}	-0.226	0.27	0.0153
ζ_{RT}	-0.3546	0.538	-0.04753

b/ Height Anomalies

We calculated the global model height anomaly ζ_M and combined it with the residual height anomaly ζ_{Res} and the height anomaly due to residual terrain effect ζ_{RT} to compute the quasi-geoid ζ (Table 9) (Figure 10).

Table 9: Statistics of Height Anomalies

id	Min	Max	Mean
ζ_{Res}	-0.226	0.27	0.0153
ζ_{RT}	-0.3546	0.538	-0.04753
ζ_{M}	41.4927	42.7099	42.1354
ζ	41.4718	42.8671	42.14094

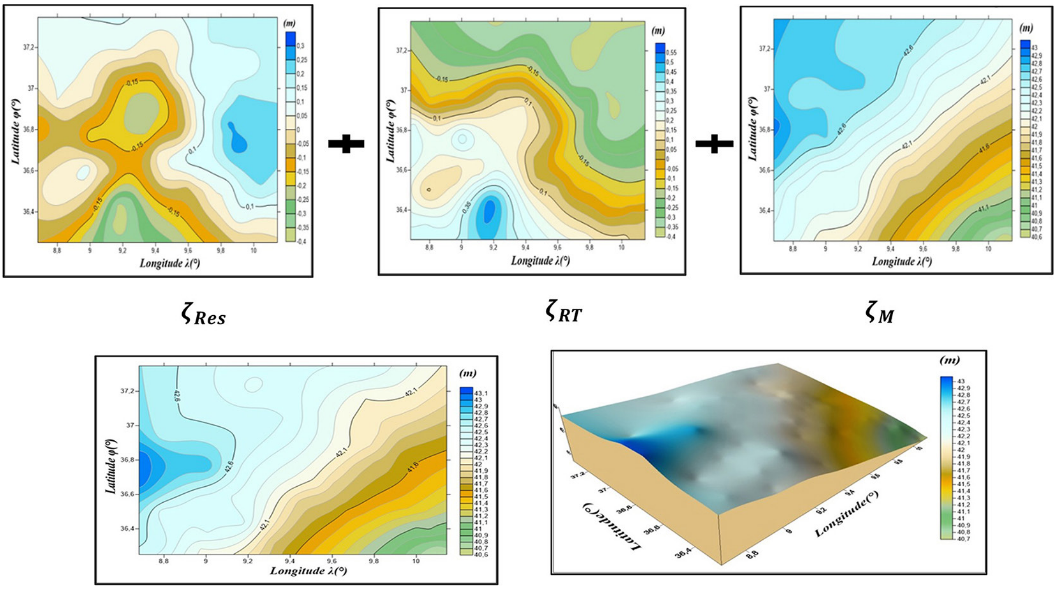

Figure 10: Altitude anomaly map (ζ)

The Gravimetric Geoid

Calculating the gravimetric geoid from the quasi-geoid requires computing the grid of the correction term ($N - \zeta$). To obtain this grid, it is necessary to prepare a grid from the Digital Terrain

Model (DTM) and derive the grid of the Bouguer anomaly from the calculated results of the simple Bouguer anomaly correction Δg_{BS} equation (4).

$$\Delta g_{BS} = \Delta g_{AAL} - 0.1119 * H \quad (4)$$

Adjustment

It is often useful to adjust the gravimetric geoid model using GPS-leveled points. Adjusting the gravimetric geoid to these benchmark (reference) points will allow users to determine orthometric heights from GNSS observations and the adjusted geoid that are compatible with the national height system.

In the final adjustment phase, the gravimetric geoid model is fine-tuned using independent GPS-leveled benchmarks to align the theoretical gravity data with the national height system. This calibration ensures that the final model provides accurate orthometric heights from GNSS observations, specifically optimized for the unique topography of North-West Tunisia (Figure 11).

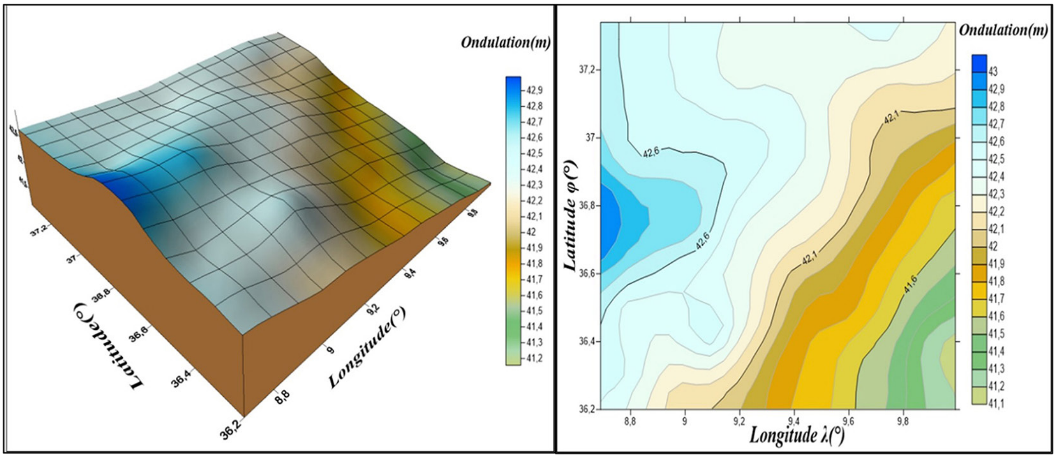

Figure 11: Local Geoid Model of the Northwest Region of Tunisia

5 Conclusion

This study successfully developed and validated a high-precision local geoid model for Northwest Tunisia through a rigorous gravimetric approach.

While the spatial extent of this study is regional, the demonstrated RCR workflow combining EGM2008, SRTM, and sparse terrestrial gravity data provides an effective methodological template for geoid modeling in other parts of Tunisia. However, extending this approach to a unified national geoid will require significantly denser gravity coverage, especially in mountainous regions, as well as integration with a nationwide GPS/leveling network.

By implementing the Remove-Compute-Restore (RCR) technique and integrating multiple data sources, key findings were established. The evaluation of global geopotential models identified EGM2008 as the most accurate reference, exhibiting the smallest standard deviation (±0.229 m) when compared to GPS-levelled points. Similarly, among digital elevation models, SRTM provided the best topographic representation, with the lowest vertical discrepancies (mean = 2 m, σ = 4.04 m).

The calculated local gravimetric geoid model was adjusted using an independent set of GPS-levelled benchmarks, ensuring compatibility with the national height system. The final model synthesizes:

- Long-wavelength signals from EGM2008
- Short-wavelength contributions from residual terrain effects
- Residual gravity field components derived from terrestrial gravity data

This tailored geoid solution effectively captures the region's complex topography and gravity variations, providing a reliable foundation for the accurate conversion of GNSS-derived ellipsoidal heights into orthometric heights. The model supports a wide range of geodetic, engineering, and geophysical applications in Northwest Tunisia and establishes a reproducible framework for future geoid refinement in other regions.

References

Abdalla, A., & Mogren, S. (2015). Implementation of a rigorous least-squares modification of Stokes' formula to compute a gravimetric geoid model over Saudi Arabia (SAGEO13). Canadian Journal of Earth Sciences, 52(10), 823-832.

Arana, D., Camargo, P. O., & Guimaraes, G. N. (2017). Hybrid geoid model: theory and application in Brazil. Anais Da academia brasileira de ciências, 89(3), 1943-1959.

Chaieb, A., Rebai, N., & Bouaziz, S. (2016). Vertical accuracy assessment of SRTM Ver 4.1 and ASTER GDEM Ver 2 using GPS measurements in Central West of Tunisia. Journal of Geographic Information System, 8(1), 57-64.

Enríquez, D., Leiva, C., Cárdenas, S., & Carrión, J. (2021). Validation of the GPS leveling method: through the gradient analysis of the geoidal wave. Case study of Ecuador. Revista Geográfica Venezolana, 62(2), 316-330.

Gurtner, W. (1978). Das Geoid in der Schweizerland. Institute fur Geodesie une photogrammetrie.

Jiang, Z., & Duquenne, H. (1995). Fast integration for the integrals of Stokes, potential and terrain correction in geoid determination. French National Geographical Inst, Latest Developments in the Computation of Regional Geoids, 23-31.

Kalu, I., Ndehedehe, C. E., Okwuashi, O., & Eyoh, A. E. (2022). Integration of satellite geodetic observations for regional geoid modeling using remove-compute-restore technique. Earth Science Informatics, 15(1), 233-251.

Kao, S. P., Ning, F. S., Chen, C. N., & Chen, C. L. (2017). Using particle swarm optimization to establish a local geometric geoid model. Boletim de Ciências Geodésicas, 23(2), 327-337.

Kingdon, R., Vaníček, P., & Santos, M. (2009). Modeling topographical density for geoid determination. Canadian Journal of Earth Sciences, 46(8), 571-585.

Koch, J. A., Marti, U., Herrera Pinzón, I. D., Willi, D., Soja, B., & Rothacher, M. (2023). Geoid Computation for the Future Circular Collider at CERN. In International Union of Geodesy and Geophysics General Assembly (pp. 235-243). Cham: Springer Nature Switzerland.

Ma, J., Wei, Z., Zhai, Z., Li, D., Feng, C., Liu, X., & Guan, B. (2024). Modification methods of the Stokes' kernel for determining the (quasi-) geoid with the Remove-Compute-Restore technique. Journal of Geodesy, 98(11), 99.

Marques, É. T., Dal Poz, W. R., & do Nascimento Guimarães, G. (2018). Geoid modelling using integration and FFT associated with different gravimetric reduction methods. Brazilian Journal of Geophysics, 36(1), 81-96.

Martin, A., Anquela, A. B., Padín, J., & Berné, J. L. (2010). Ability of the EGM2008 high degree geopotential model to calculate a local geoid model in Valencia, Eastern Spain. Studia Geophysica et Geodaetica, 54(3), 347-366.

Ning, F. S. (2015). Using surface fitting and buffer analysis to estimate regional geoidal undulation. Boletim de ciências geodésicas, 21(3), 624-636.

Rebaï, N., Zenned, O., Trabelsi, H., & Achour, H. (2018). Computing local geoid model using DTM and GPS geodetic points. Case study: Mejez El Bab-Tunisia. International Journal of Geosciences, 9(3), 161-178.

Salissou, I. Y., El Hassan, E. B., & Driss, E. A. (2016). Evaluation of Digital Terrain Models and Handling of the Topography by Two Approaches for Geoid Computation in Niger. Evaluation.

Silva, F. R. D. (2021). Contribuição para a determinação da separação geoide e quase-geoide no território brasileiro.

Tocho, C. (2006). A gravimetric geoid modelling for Argentina (Doctoral dissertation, Universidad Nacional de La Plata).

Torres, S. A. (2022). Estudo da separação entre o geoide e o quase geoide no estado do Rio Grande do Sul, Brasil.

Vaníček, P., Kingdon, R., & Santos, M. (2012). Geoid versus quasigeoid: a case of physics versus geometry. Contributions to Geophysics and Geodesy, 42(1), 101-118.

Wang, J., Xu, H., Wang, J., Lin, L., & Liu, N. (2025). Seamount topography study based on the remove–restore method. Marine Geophysical Research, 46(3), 17

Chaieb A., Gamm N., Salhi M., (2026). Geoid modelling in Northwestern Tunisia using the Remove – Compute – Restore (RCR) method. Geodetski vestnik, 70 (3), 391-405.
DOI: 10.15292/geodetski-vestnik.2026.03.391-405

Ali Chaieb, Ph. D.
University of Tunis El Manar,
National Engineering School of Tunis,
Geotechnical Engineering and Georisk Laboratory,
B.P 37 le Belveldère 1002, Tunis, Tunisia
e-mail: chaieb.aly@gmail.com

Nahla Gamm, Ing.
University of Tunis El Manar,
National Engineering School of Tunis,
Geotechnical Engineering and Georisk Laboratory,
B.P 37 le Belveldère 1002, Tunis, Tunisia
e-mail: nahla.gam@gmail.com

Mourad Salhi, Ing.
National Center for Mapping and Remote Sensing,
El Aouina Tunis, Tunisia
e-mail: Mourad.salhi99@gmail.com