

Demonstration of Complete Bouguer Gravity Disturbance Computation on a Terrain Equielevation Surface

PAGrav4.5; <https://www.zcyphygeodesy.com/en/>

ZHANG Chuanyin; zpmzsyzy1968@163.com

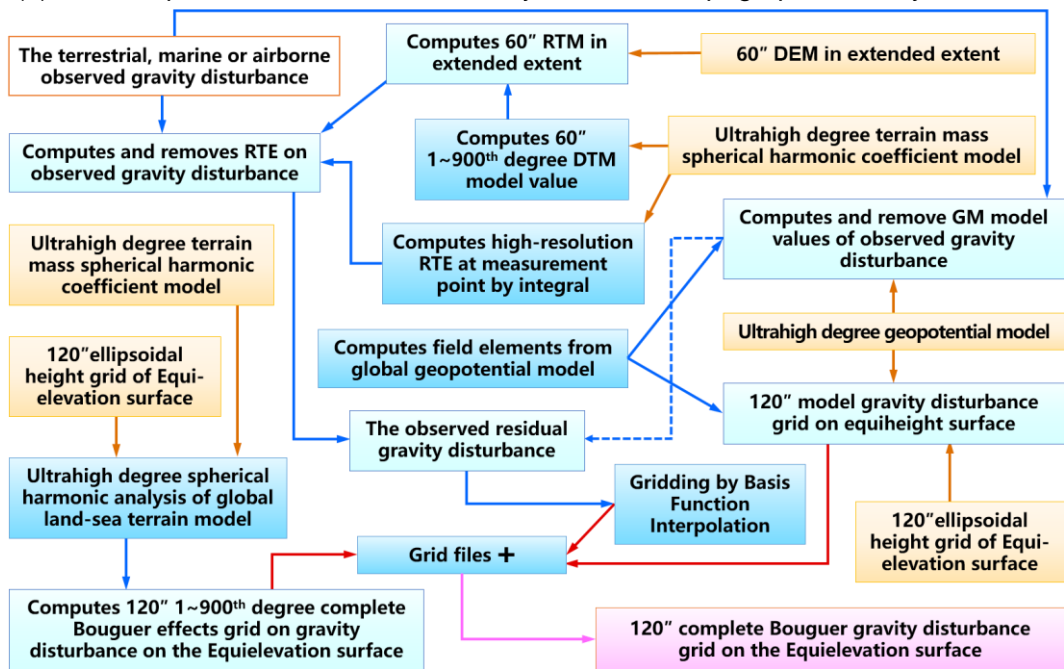
Chinese Academy of Surveying & Mapping

March 2026, Beijing, 100830, China

This module demonstrates the fundamental workflow for computing unified land-sea complete Bouguer effects on gravities. Utilizing a Digital Elevation Model (DEM) and discrete gravity disturbances in near-Earth space derived from the EGM2008 geopotential model, the process employs a Remove-Restore scheme centered on Residual Terrain Effects (RTE). The target output is a grid of complete Bouguer gravity disturbances on a terrain equielevation surface, which simultaneously serves as the observation reduction surface.

[Physical Definition] The Complete Bouguer Effect is defined as the variation in the Earth's gravity field resulting from:

- (1) The removal of topographic masses above the geoid.
- (2) The compensation of seawater density to the land topographic density.



Computation Process of Complete Bouguer Gravity Disturbance on a Terrain Equielevation Surface

3.8.1.1 Input/Output Data and Related Terrain Models

Spatial Domains:

- Terrain Data Domain (Extended Latitude and Longitude Extent): E94.5° – 99.5°, N30.5° – 34.5°.
- Computation Domain (Result/Observation Extent): E95.0° – 99.0°, N31.0° – 34.0°.

- Rationale: The extended extent encompasses the computation domain to suppress integration edge effects.

(1) Observed Gravity Disturbance File (Obsgrav.txt)

Source: Simulated gravity disturbances from degrees 2 to 1800 of the EGM2008 model.

Unified Processing: PAGrav4.5 applies identical algorithms to terrestrial, marine, and airborne data, eliminating the need to distinguish between ground, airborne altitude, or sea-surface observation points.

Record Format: ID, Longitude (°), Latitude (°), Ellipsoidal Height (m), Gravity Disturbance (mGal).

(2) Spherical Harmonic Coefficient Models

Terrain Mass Model: ETOPOcs1800.dat (1800-degree global land-sea terrain mass spherical harmonic coefficient model).

- Generation: Derived via the [Ultrahigh-Degree Spherical Harmonic Analysis of the Global Land-Sea Terrain Model] function from the global 2'x2' ETOPO2v2g model.

Geopotential Model: EGM2008.gfc (2190-degree EGM2008 model).

Path: C:\PAGrav4.5_win64en\data.

(3) Ground Digital Elevation Models (DEMs)

Coverage: Must exceed the computation extent to mitigate edge effects.

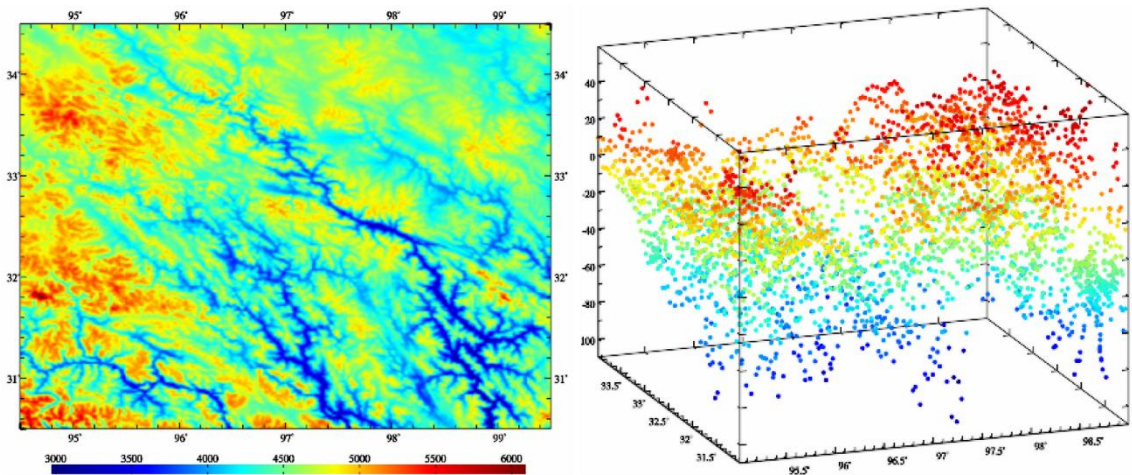
Dual-Resolution Requirement:

- High-Resolution DEM (60"x60", extdtm60s.dat): Used for data reduction (computing/removing RTE at observation points).
- Target-Resolution DEM (120"x120", extdtm120s.dat): Used for result restoration (restoring RTE to the output grid).

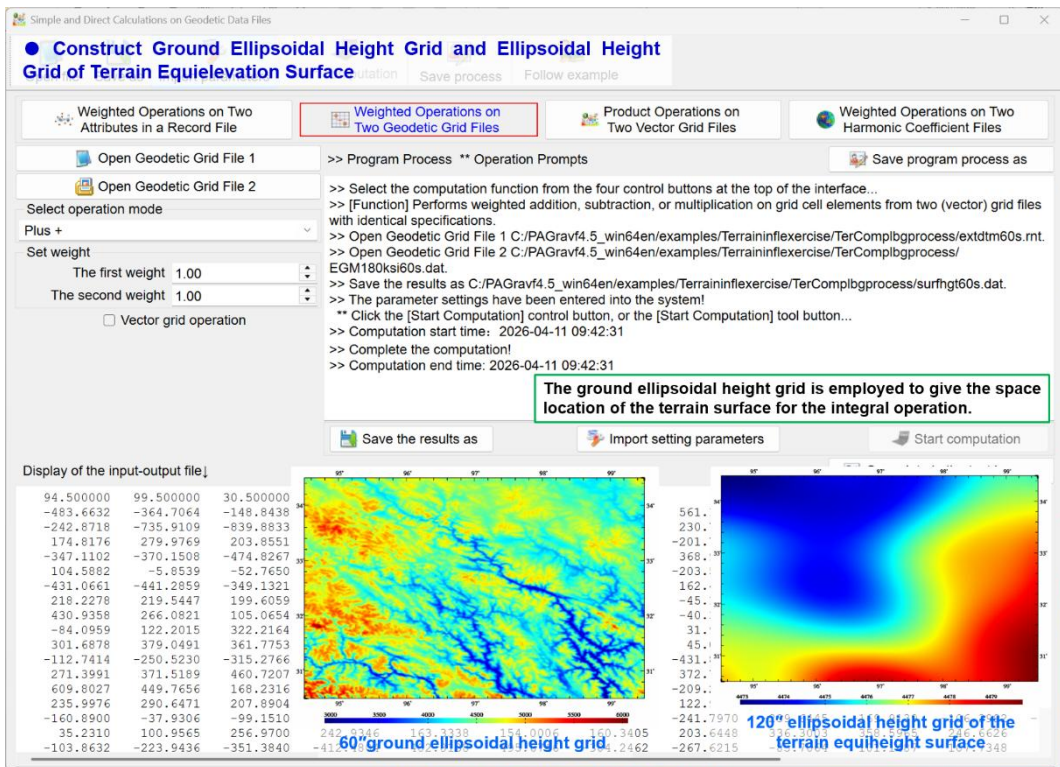
(4) Ground Ellipsoidal Height Grid (surfhgt60s.dat)

Resolution: 60"x60".

Function: Provides the geodetic coordinates of residual terrain masses (integration moving cells), critical for high-precision RTE computation.



Ground digital elevation model (m) and gravity observation point distribution



(5) Terrain Equelevation Surface Grid (equihgt120s.dat)

Resolution: 120"×120".

Definition: Serves as both the reduction surface and the computation surface, treated physically as an equipotential surface.

Ellipsoidal Height h_e (Terrain Equelevation Surface) = N (EGM2008, 2 – 360) + h_e (mean_DEM).

Theoretical Basis: Gridding is a non-analytical operation that can degrade the analytical nature of the gravity field. Performing such operations on an equipotential surface minimizes these adverse effects.

Special Case: If the normal/orthometric height of this surface is zero ($h_e = N$), it corresponds to the traditional geoid.

(6) Final Product:

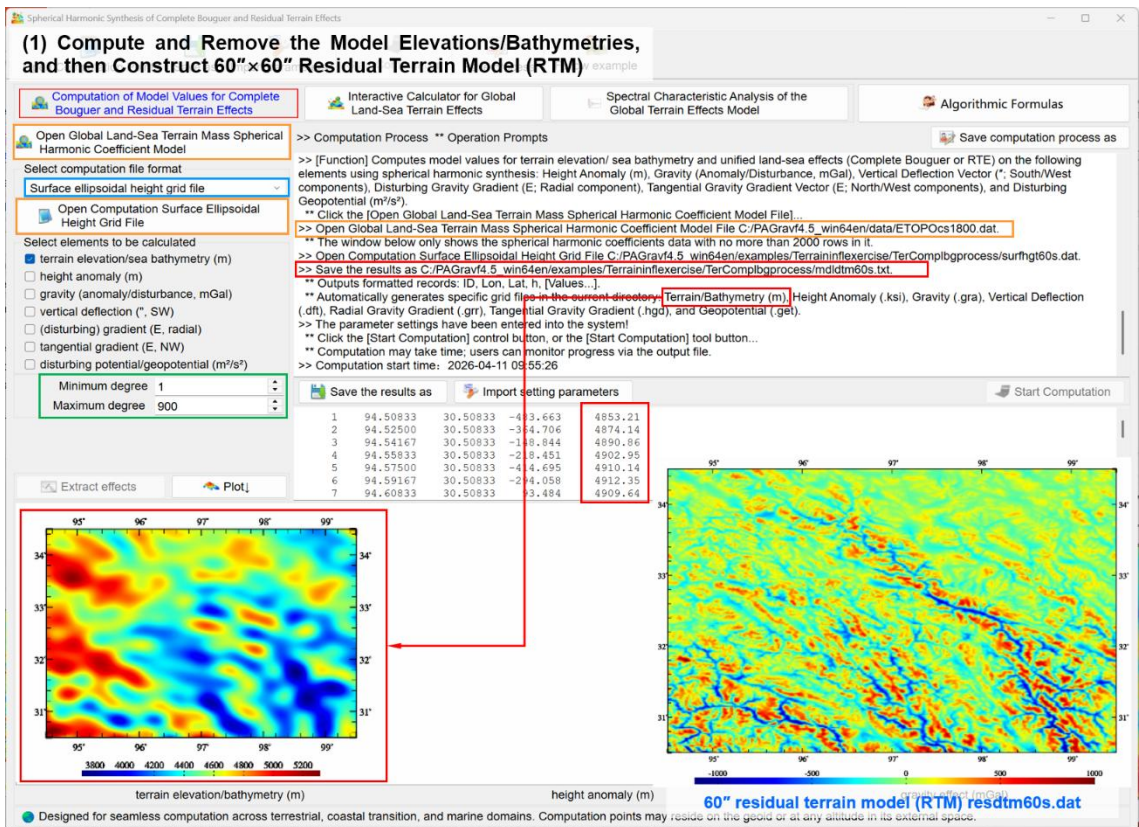
A 120"×120" grid of Complete Bouguer Gravity Disturbances on the terrain equelevation surface.

3.8.1.2 Workflow: Function Calls and Data Flow

(1) Compute and Remove the Model Elevations/Bathymetries, and then Construct 60"×60" Residual Terrain Model (RTM)

Action: Compute and remove model terrain elevations/sea bathymetries.

Function: [Computation of Model Values for Complete Bouguer and Residual Terrain Effects].



Parameters: Degrees 1 – 900; Type: Terrain Elevation/ Sea Bathymetry.

- Inputs: ETOPOcs1800.dat, surfhgt60s.dat.
- Output: Model terrain grid mldtm60s.dtm.
- Operation: $RTM = DTM (extdtm60s.dat) - DTM (mldtm60s.dtm)$

Result: Extended extent 60"×60" RTM grid resdtm60s.dat.

- Inputs: ETOPOcs1800.dat, surfhgt120s.dat.
- Output: Model terrain grid mldtm120s.dtm.
- Operation: $RTM = DTM (extdtm120s.dat) - DTM (mldtm120s.dtm)$

Result: Extended extent 120"×120" RTM grid resdtm120s.dat.

Statistics: See Table 3.8 (Mean, STD, Min, Max of RTM).

Table 3.8: Statistics for Residual Terrain Model

	Mean	STD	Minimum	Maximum
60" RTM (m)	0.0053	175.5869	-959.5450	59.0160
120" RTM (m)	0.0053	175.5869	-959.5450	886.2500

(2) Compute and Remove the Ultrahigh-degree Model Gravity Disturbances at the Observation Points

Action: Compute and subtract model gravity disturbances at observation points.

Function: [Computation of Gravity Field Elements from a Global Geopotential Model].

Parameters: Degrees 1 – 720; Type: Gravity Disturbance.

Inputs: EGM2008.gfc, Obsgrav.txt.

Output: Model disturbances Obsgravmdl.txt (Col 6).

- Operation: δg (residual) = δg (obs, Col 5) – δg (model, Col 6).
- Result: Residual gravity disturbance file Obsgravmdlresd.txt (Col 7).

Statistics: See Table 3.9 (Significant reduction in STD after removing degrees 1 – 720).

Table 3.9: Statistics for gravity disturbances after removing the model values.

Observed points	Mean	STD	Minimum	Maximum
Observed gravity disturbance (mGal)	-15.6106	25.5080	-110.7251	59.0160
Residual of gravity disturbance (mGal)	-0.4881	17.4588	-74.6129	71.5003

(3) Compute and Remove the Residual Terrain Effects (RTE) on Gravity Disturbances at Observation Points

Action: Compute and subtract short-wavelength RTEs on gravity disturbances.

Function: [Rigorous Numerical Integration of Land-Sea Residual Terrain Effects].

Inputs: Obsgravmdlresd.txt, extdtm60s.dat (High-res), mldtm60s.dtm (Low-pass), surfhgt60s.dat.

Parameter: Integration Radius = 90 km.

Output: RTE file Obsgravresdtm.txt (Col 8).

Operation: δg (final_res) = δg (residual, Col 7) – RTE (Col 8).

Result: Final residual gravity disturbance file Obsgravresidual.txt (Col 9).

Approximation: Continuation corrections for residual radial gradients are neglected (valid for elevation differences < 1000 m). Thus, δg (final_res) at the observation point \approx its value on the equipotential surface.

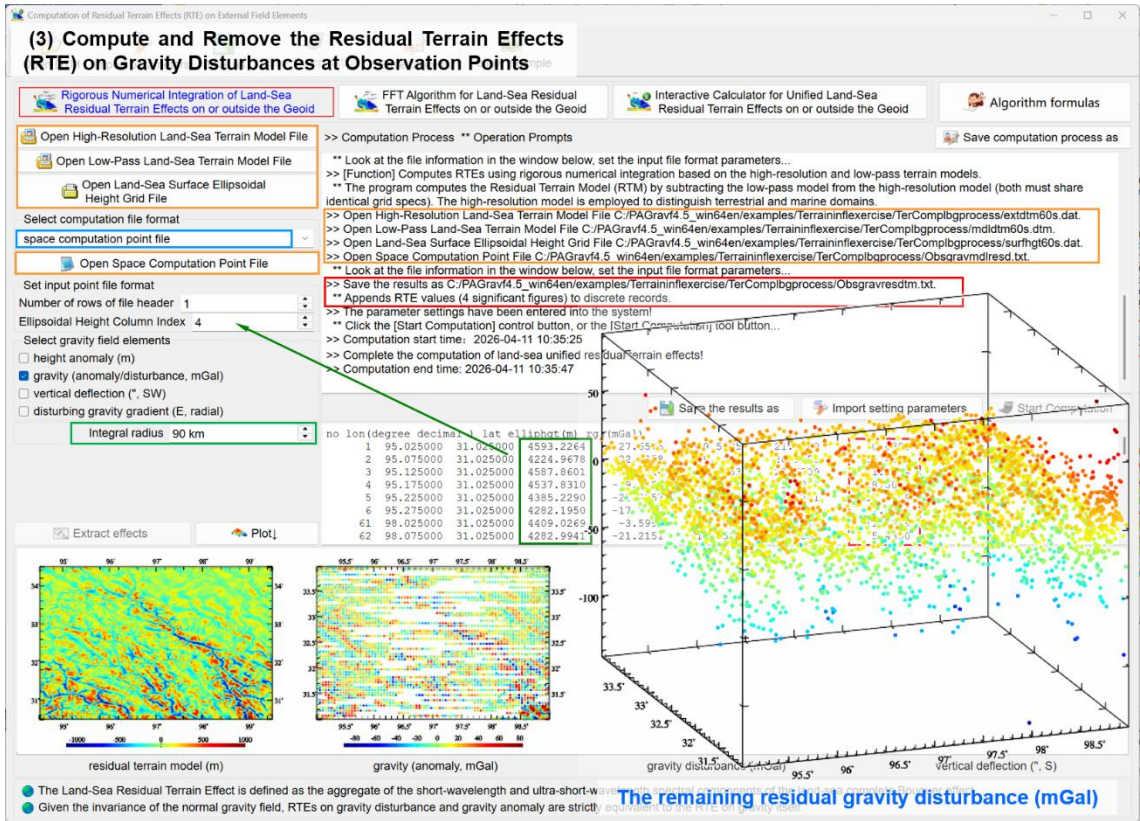


Table 3.10: Statistics for residual gravity disturbances after the residual terrain effects.

Observed points	Mean	STD	Minimum	Maximum
RTE on gravity disturbance (mGal)	4.8843	7.2038	-73.7901	118.6158
Remaining residual gravity disturbance (mGal)	-5.3034	19.7638	-144.5444	92.4782

Note: Tables 3.8 – 3.10 facilitate algorithm optimization based on the terrain effect quantitative criteria. This step is omitted here due to the simulated nature of the data lacking real ultra-short-wavelength content.

Status: Reduction from observation points to the terrain equipotential surface is complete.

(4) Gridding on Remaining Residual Gravity Disturbances to 120"×120" on Terrain Equipotential Surface.

Action: Interpolate heterogeneous residual data onto the target grid.

Function: [Gridding of Heterogeneous Data by Basis Function Weighted Interpolation].

Strategy: Equal weights (or weights estimated via RTE reference attributes).

Input: Column 9 of Obsgravresidual.txt.

Output: 120"×120" final residual grid distgravresidual.dat.

Specification: Matches the target computation domain and resolution.

(5) Compute the Ultrahigh-degree Model Gravity Disturbances on Terrain Equelevation Surface

Function Call: [Computation of Gravity Field Elements from a Global Geopotential Model].

Parameters:

- Degree Range: Minimum = 1, Maximum = 720.
- Output Type: Gravity Disturbance.

Inputs:

- Geopotential Model: EGM2008.gfc.
- Computation Surface Grid: equihgt120s1.dat (The terrain equelevation surface, derived from equihgt120s.dat with edge trimming).

Output File: 120"×120" grid of model gravity disturbances: distgravmdl.rga.

Consistency Constraint: The geopotential model and degree range must strictly match those used in Step (2) to ensure spectral consistency of the reference field model component.

(5) Compute the Ultrahigh-degree Model Gravity Disturbances on Terrain Elevation Surface

Computation of Gravity Field Elements from a Global Geopotential Model | Computation of Model Values for Residual Terrain (Complete Bouguer) Effects | Global Geopotential Coefficient Model Calculator | Calculation and Analysis of Spectral Characteristics of the Earth's Gravity Field

Open Global Geopotential Coefficient Model File | Save computation process as | Algorithmic Formulas

Select computation file format: Surface Ellipsoidal height grid file

Open Computation Surface Ellipsoidal Height Grid File

Select elements to be computed:

- height anomaly (m)
- gravity anomaly (mGal)
- gravity disturbance (mGal)
- vertical deflection (", SW)
- disturbing gravity gradient (E, radial)
- tangential gravity gradient (E, NW)
- Laplace operator (E)

Minimum degree: 1 | Maximum degree: 720

Save the results as | Import setting parameters | Start Computation

```
>> [Function] Utilizing a global geopotential coefficient model, this module computes model values for (residual) height anomaly (m), gravity anomaly (mGal), gravity disturbance (mGal), vertical deflection vector (", south, west components), disturbing gravity gradient(E, radial component), tangential gravity gradient vector(E, north, west components), or Laplace operator (E)
** Click the [Open Global Geopotential Coefficient Model File] control button, or the [Open Geopotential Model] tool button...
>> Open Global Geopotential Coefficient Model File C:/PA/Grav4_5_win64en/data/EGM2008.gfc.
** The window below only shows the geopotential coefficients data with no more than 2000 rows in it.
>> Open Computation Surface Ellipsoidal Height Grid File C:/PA/Grav4_5_win64en/examples/terraininflexercise/tercompbgprocess/euheight120s1.dat
>> Save the results as C:/PA/Grav4_5_win64en/examples/terraininflexercise/tercompbgprocess/distgravmdl.txt
** The record format: ID (point no/name), longitude, latitude, ellipsoidal height, several columns of the model values of anomalous field elements.
** The program automatically generates corresponding (residual) model value grid files in the current directory with the following extensions based on the selected element: height anomaly (*.ksi), gravity anomaly (*.gra), gravity disturbance (*.rga), vertical deflection vector (*.dvt), disturbing gravity gradient (*.grg), tangential gravity gradient vector (*.hgd), or Laplace operator (*.lps) into the current directory. Where * is the user-defined output filename prefix
>> The parameter settings have been entered into the system!
```

1	95.01667	31.01667	4476.835	-49.50559
2	95.05000	31.01667	4476.835	-48.34774
3	95.08333	31.01667	4476.837	-47.06997
4	95.11667	31.01667	4476.835	-45.78666
5	95.15000	31.01667	4476.83	-44.50335
6	95.18333	31.01667	4476.83	-43.22004
7	95.21667	31.01667	4476.83	-41.93673

(6) Compute and Restore Model Complete Bouguer Effects on Terrain Elevation Surface

Objective: Compute the grid of model complete Bouguer effects on gravity disturbances for the terrain elevation surface (120"×120").

Function Call: [Computation of Model Values for Complete Bouguer or Residual Terrain Effects].

Parameters:

- Degree Range: Minimum = 1, Maximum = 900.
- Output Type: Gravity Disturbance (effect component).

Inputs:

- Terrain Mass Model: ETOPOCs1800.dat.
- Surface Elevation Grid: surfhgt120s1.dat (120"×120" ground ellipsoidal height grid corresponding to the terrain elevation surface).

Output File: 120"×120" grid of model complete Bouguer effects: distgravmdlcmpbg.gra.

Consistency Constraint: The terrain mass model and maximum degree must strictly match those used in Step (1) to ensure consistency of the topographic spectrum.

(6) Compute and Restore Model Complete Bouguer Effects on Terrain Equelevation Surface

Computation of Model Values for Complete Bouguer and Residual Terrain Effects | Interactive Calculator for Global Land-Sea Terrain Effects | Spectral Characteristic Analysis of the Global Terrain Effects Model | Algorithmic Formulas

Open Global Land-Sea Terrain Mass Spherical Harmonic Coefficient Model

Select computation file format: Surface ellipsoidal height grid file

Open Computation Surface Ellipsoidal Height Grid File

Select elements to be calculated:

- terrain elevation/sea bathymetry (m)
- height anomaly (m)
- gravity (anomaly/disturbance, mGal)
- vertical deflection (" SW)
- (disturbing) gradient (E, radial)
- tangential gradient (E, NW)
- disturbing potential/geopotential (m²/s²)

Minimum degree: 1 | Maximum degree: 900

Save the results as: C:/PA/Grav4.5_win64en/examples/TerrainInflexercise/TerCompibprocess/distgravmdlcmpbg.txt

Start Computation

Computation Process ** Operation Prompts

>> [Function] Computes model values for terrain elevation/ sea bathymetry and unified land-sea effects (Complete Bouguer or RTE) on the following elements using spherical harmonic synthesis: Height Anomaly (m), Gravity (Anomaly/Disturbance, mGal), Vertical Deflection Vector (" South/West components), Disturbing Gravity Gradient (E: Radial component), Tangential Gravity Gradient Vector (E: North/West components), and Disturbing Geopotential (m²/s²)

** Click the [Open Global Land-Sea Terrain Mass Spherical Harmonic Coefficient Model File C:/PA/Grav4.5_win64en/data/EETOPOCs1800.dat.

>> Open Global Land-Sea Terrain Mass Spherical Harmonic Coefficient Model File C:/PA/Grav4.5_win64en/data/EETOPOCs1800.dat.

** The window below only shows the spherical harmonic coefficients data with no more than 2000 rows in it.

>> Open Computation Surface Ellipsoidal Height Grid File C:/PA/Grav4.5_win64en/examples/TerrainInflexercise/TerCompibprocess/equihgt120s1.dat.

>> Save the results as C:/PA/Grav4.5_win64en/examples/TerrainInflexercise/TerCompibprocess/distgravmdlcmpbg.txt

** Outputs formatted records: ID, Lon, Lat, N, [Values...]

** Automatically generates specific grid files in the current directory: Terrain/Bathymetry (m), Height Anomaly (m), Gravity (.gra), Vertical Deflection (.dft), Radial Gravity Gradient (.gr), Tangential Gravity Gradient (.hgd), and Geopotential (.get).

>> The parameter settings have been entered into the system!

** Click the [Start Computation] control button, or the [Start Computation] tool button...

** Computation may take time; users can monitor progress via the output file.

** Computation start time: 2026-04-11 10:50:33

1	95.01667	31.01667	4476.835	619.8669
2	95.05000	31.01667	4476.835	
3	95.08333	31.01667	4476.837	
4	95.11667	31.01667	4476.835	
5	95.15000	31.01667	4476.837	
6	95.18333	31.01667	4476.840	593.2676
7	95.21667	31.01667	4476.846	590.7708

Extract effects | Plot

(7) Generate Final 120"×120" Complete Bouguer Gravity Disturbances on Terrain Equelevation surface

Objective: Assemble the final product by superimposing all processed components.

Operation: Perform an algebraic summation of the following four (120"×120") gravity disturbance grids:

- Final Residual Grid: distgravresidual.dat (The residual field after remove processing).
- Ultra-High-Degree Model Grid: distgravmdl.rga [The long-wavelength background field restored from Step (5)].
- Restored Residual Terrain Effect (RTE) Grid: distgravresidtm.dat [The short-wavelength terrain signals removed in Step (3), now restored].
- Model Complete Bouguer Effect Grid: distgravmdlcmpbg.gra [The model complete Bouguer effects computed in Step (6)].

Output File: 120"×120" Complete Bouguer Gravity Disturbance Grid: distgravcmpbg.dat.

Mathematical Formulation: δg^{mcb} (Complete Bouguer gravity disturbance) = δg_m (Model gravity disturbance) + δg_{res} (residual gravity disturbance) + RTE (Restored) + g^{cB} (Model complete Bouguer effects).