Expedited Workflow Demonstration for All-element Gravity Field Modeling Using SRBFs

PAGravf4.5; https://www.zcyphygeodesy.com/en/
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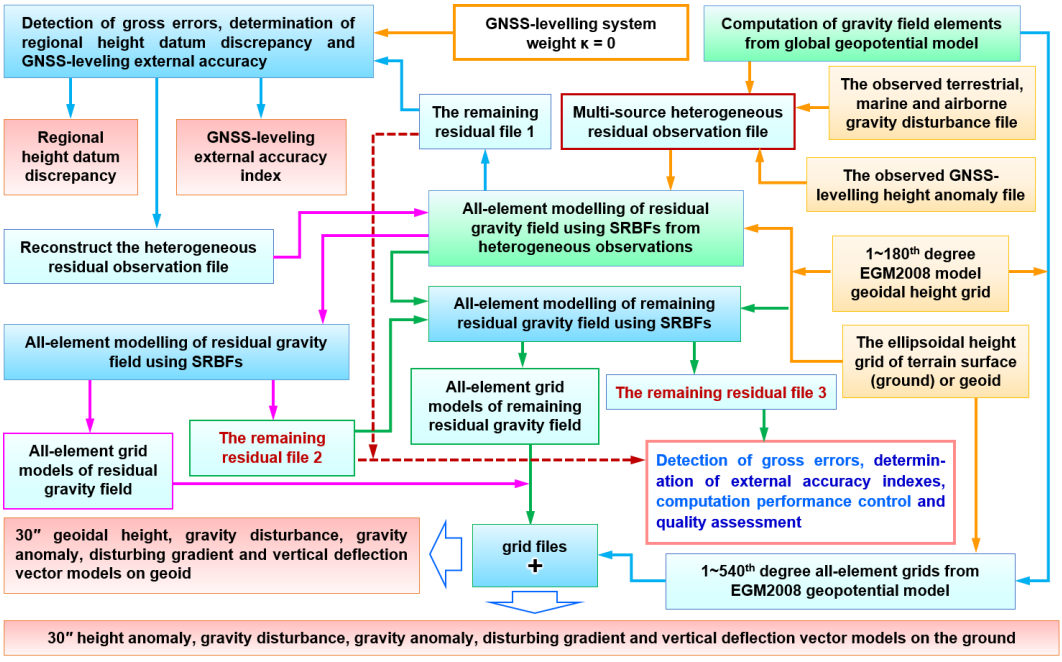
[Purpose] This example demonstrates a streamlined, six-step workflow for all-element gravity field modeling based on the Spherical Radial Basis Function (SRBF) approximation method on both the ground and the geoid. The approach directly utilizes observed gravity disturbances (terrestrial, marine, and airborne) and GNSS-leveling height anomalies (or geoidal heights) without employing complex schemes of terrain effects and traditional pre-processing. This workflow aims to facilitate a rapid understanding of key aspects in spectral-domain local SRBF modeling, including observation data analysis, computational quality control, and gravity field reconstruction techniques.



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Primary Data Sources

(1) Observed Gravity Disturbances (obsdistgrav.txt)

Format: Point ID/Station Name, Longitude (decimal degrees), Latitude (decimal degrees), Ellipsoidal Height (m), Observation Gravity Disturbance (mGal).

(2) GNSS-Leveling Observation Height Anomalies (obsGNSSlksi.txt)

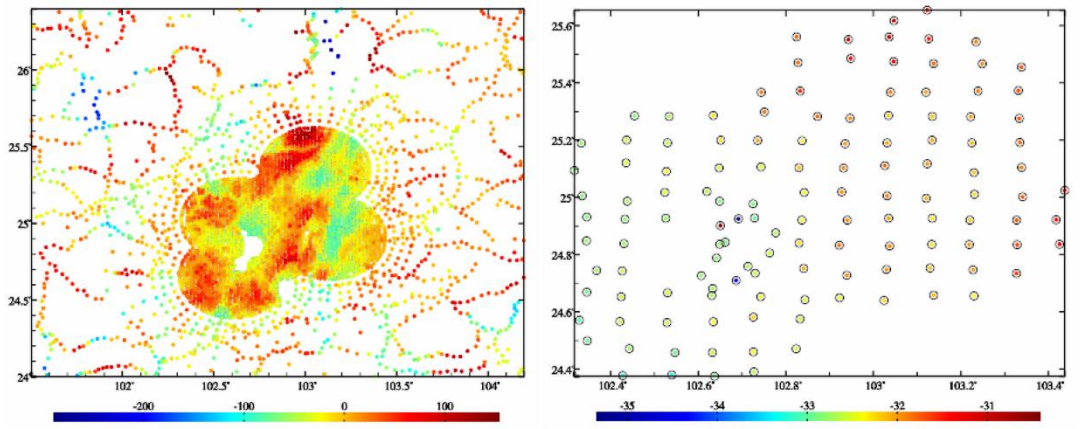
Format: Point ID/Station Name, Longitude (decimal degrees), Latitude (decimal degrees), Ellipsoidal Height (m), Observation Height Anomaly or Geoidal Height (m).

Normal Height System: The "Ellipsoidal Height" attribute corresponds to the GNSS-

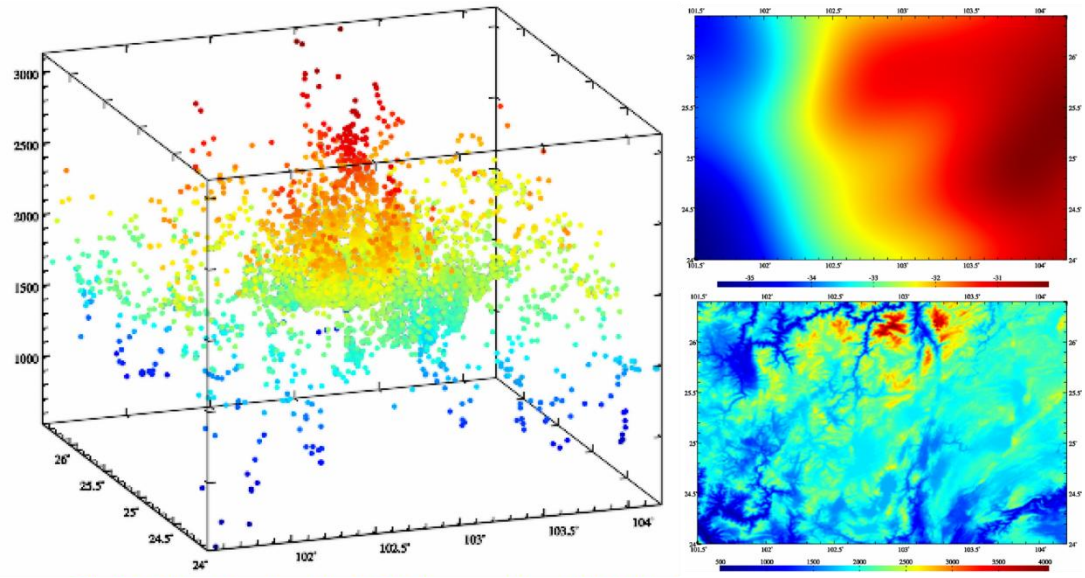
derived ellipsoidal height at the GNSS-leveling site.

Orthometric Height System: The observation geoidal height represents the ellipsoidal height of the geoid. In the file record, this value populates the "Ellipsoidal Height" field.

Note: The SRBF-based all-element modeling workflow is identical for both height systems; only the appropriate ellipsoidal heights for the GNSS-leveling sites are required. This example employs observation height anomalies under the Normal Height System. Both datasets are simulated by adding noise to EGM2008 model values (degrees 1 – 1800).



The observed gravity disturbances (mGal) and observed GNSS-levelling height anomalies (m)



The distribution of gravity points, 1~180th degree model geoidal height and ellipsoidal height of the terrain surface

(3) Computation Surface Ellipsoidal Height Grids

For Geoidal Modeling: The computation surface is defined by the model geoidal height grid. In this example: mdlgeoidh30s.dat.

For Ground Modeling: The computation surface is defined by the ground ellipsoidal height grid. In this example: surfhgt30s.dat (= Land-Sea DEM DEM30s.dat + Model Geoidal Height mdlgeoidh30s.dat).

Model Derivation: Model geoidal heights and ground height anomalies are derived from

a 180-degree gravity field model (steps omitted).

Requirement: The extent of the computation surface grid must exceed the target extent to mitigate edge effects.

Step 1: Remove Reference Model Values and Construct Multi-source Heterogeneous Residual Observations

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

Settings: Maximum degree = 540.

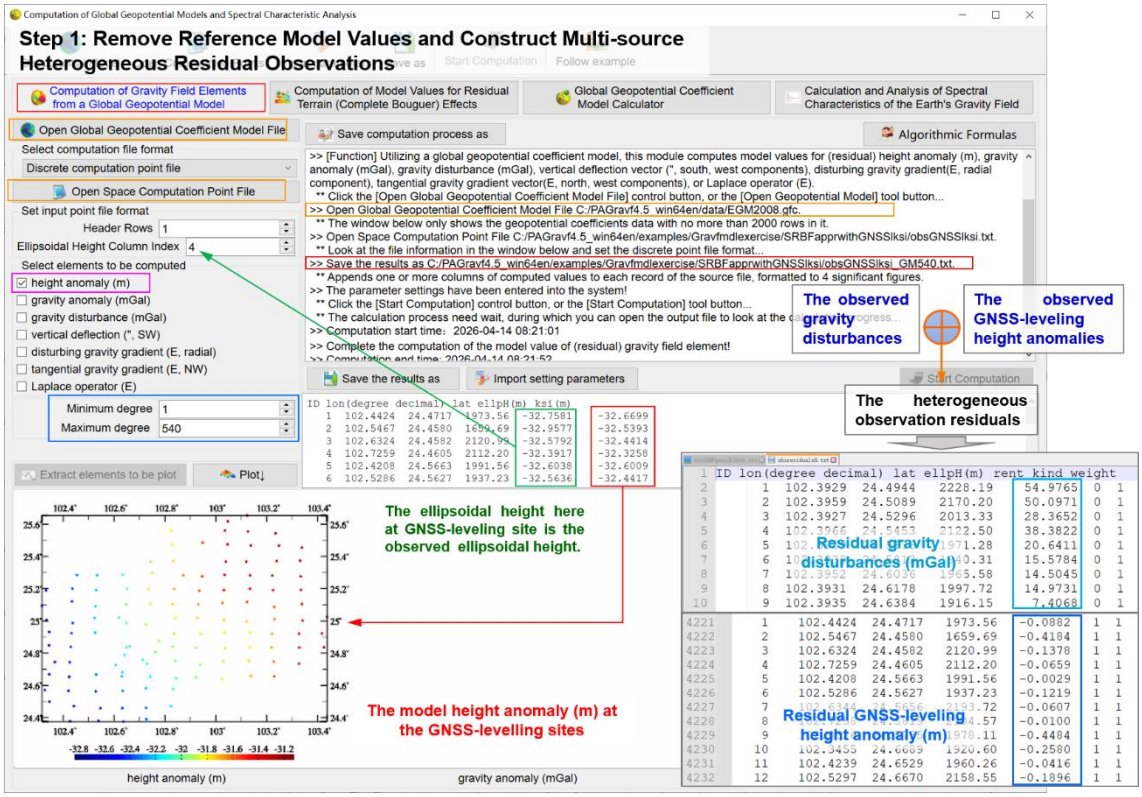
Procedure:

- Compute and remove reference gravity field values from obsdistgrav.txt and obsGNSSlksi.txt.
- Merge results into a Multi-source heterogeneous discrete residual observation file: obsresiduals0.txt.

File Convention (obsresiduals0.txt):

- Columns: ID, Lon, Lat, Ellipsoidal Height (m), Residual Value, Element Type (0 – 5), Obs Weight, Sys Weight, ...
- Fixed Attributes: The first five columns are fixed in position and order.
- Element Types: 0 = Residual Gravity Disturbance (mGal); 1 = Residual Height Anomaly (m).

Critical Action: Set the System Weights for all GNSS-leveling sites in obsresiduals0.txt to zero.



Step 2: Gross Error Detection via SRBF and Data Reconstruction

Function: [All-element Gravity Field Modeling Using Multi-source Heterogeneous Data with SRBFs].

Inputs: obsresiduals0.txt and surfhgt30s.dat.

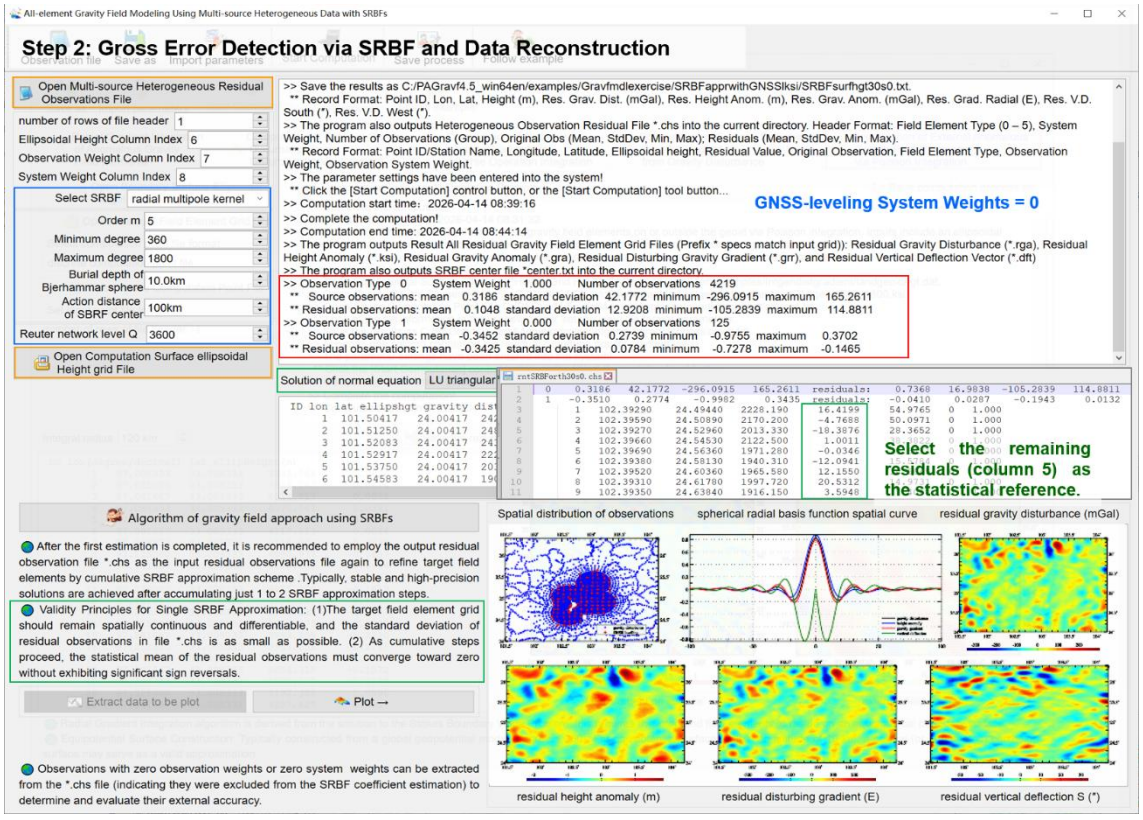
Outputs:

- ○ Residual ground all-element grids: SRBFsurfhgt30s0.xxx (.ksi, .rga, .gra, .grr, .dft).
- ○ Remaining residual observation file: SRBFsurfhgt30s0.chs.

Gross Error Detection Protocol:

- ○ Extract remaining residual gravity disturbances (rntobsdistgrav0.txt) and GNSS-leveling height anomalies (rntobsGNSSlksi0.txt) from SRBFsurfhgt30s0.chs.
- ○ Use the remaining residual value (Column 5) as the statistical metric for outlier detection:
  - • Gravity disturbances: Reject observations exceeding 5σ (5 times the standard deviation).
  - • GNSS-Leveling sites: Reject observations exceeding 3σ.

Regenerate the cleaned heterogeneous residual observation file: obsresiduals01.txt.



Step 3: Determination of Height Datum Discrepancy and GNSS-Leveling External Accuracy

Input: Cleaned file obsresiduals01.txt.

Procedure: Repeat Step 2 to re-estimate residual grids (rntSRBFdatum30s.xxx) and output the remaining residual observation file rntSRBFdatum30s.chs.

Methodological Note: Since GNSS-leveling sites' system weights were previously set to zero, this step effectively uses only the discrete residual gravity disturbances to evaluate the

external accuracy of the GNSS-leveling height anomalies.

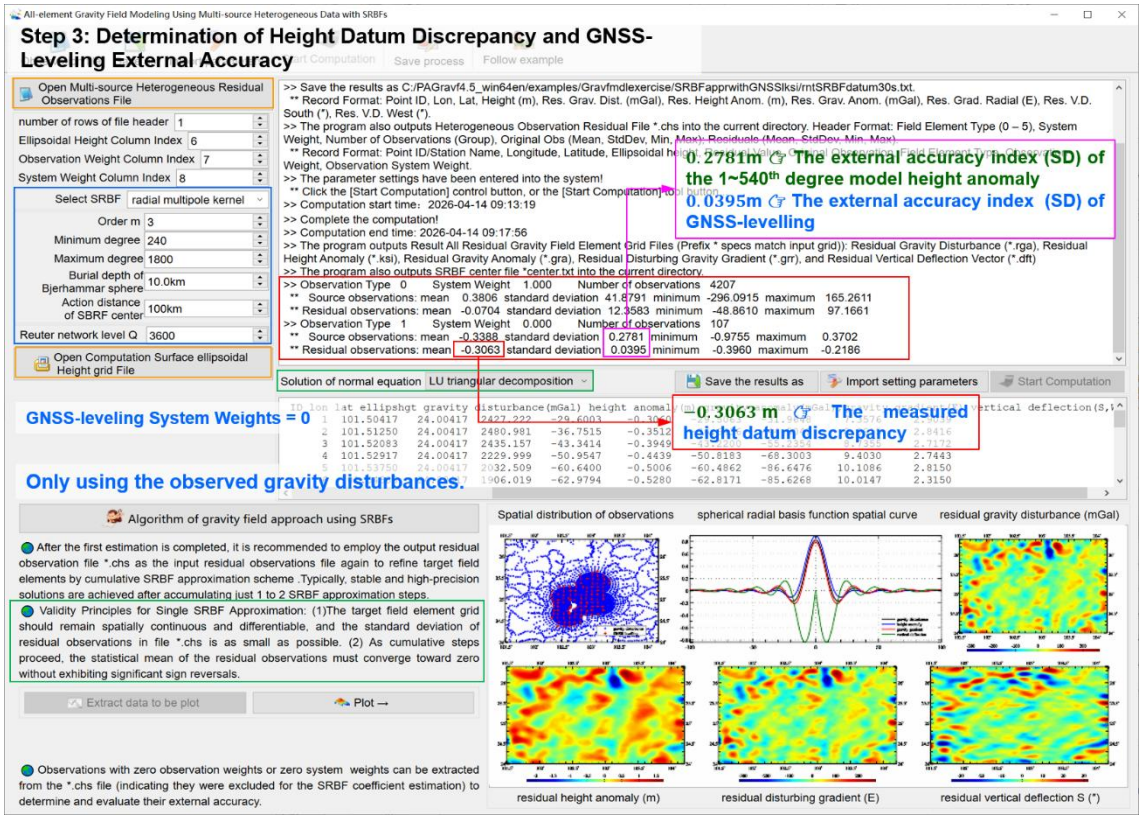


Table 4.35: Statistics of Residual Observations before and after Gross Error Detection/Elimination (SRBF Approximation)

Data Type	Stage	Count	Mean	Std. Dev.	Min	Max
Gravity Disturbance (mGal)	Original Residuals	4219	0.3186	42.1772	-296.0915	165.2611
	Post-Rejection Residuals	4215	0.2695	42.0737	-296.0915	165.2611
	Remaining Residuals	4215	-0.5677	13.8957	-80.4161	64.8276
GNSS-Leveling Height Anomaly (m)	Original residuals	125	-0.3452	0.2739	-0.9755	0.3702
	Residuals without error	123	-0.3404(1)	0.2735	-0.9755	0.3702
	Remaining residuals	123	-0.0069(2)	0.0233(3)	-0.1295	0.0528

Regional Height Datum Discrepancy: The statistical mean of the GNSS-leveling residual height anomalies (-0.3404 m marked as (1)) represents the determined discrepancy between the regional height datum and the global height datum (gravimetric geoid). This illustrates the SRBF method for datum unification.

GNSS-Leveling External Accuracy Index: The standard deviation of the remaining residuals (e.g., 0.0233 m marked as (3), corresponding to 2.33 cm) serves as the external accuracy index. This indicates that the external accuracy of the GNSS-leveling data is no worse than this standard deviation value.

Standard Practice: Typically, one iterates the SRBF approximation 1 – 2 more times using the *.chs file to minimize the standard deviation of remaining residuals, establishing the final accuracy index.

Critical Action:

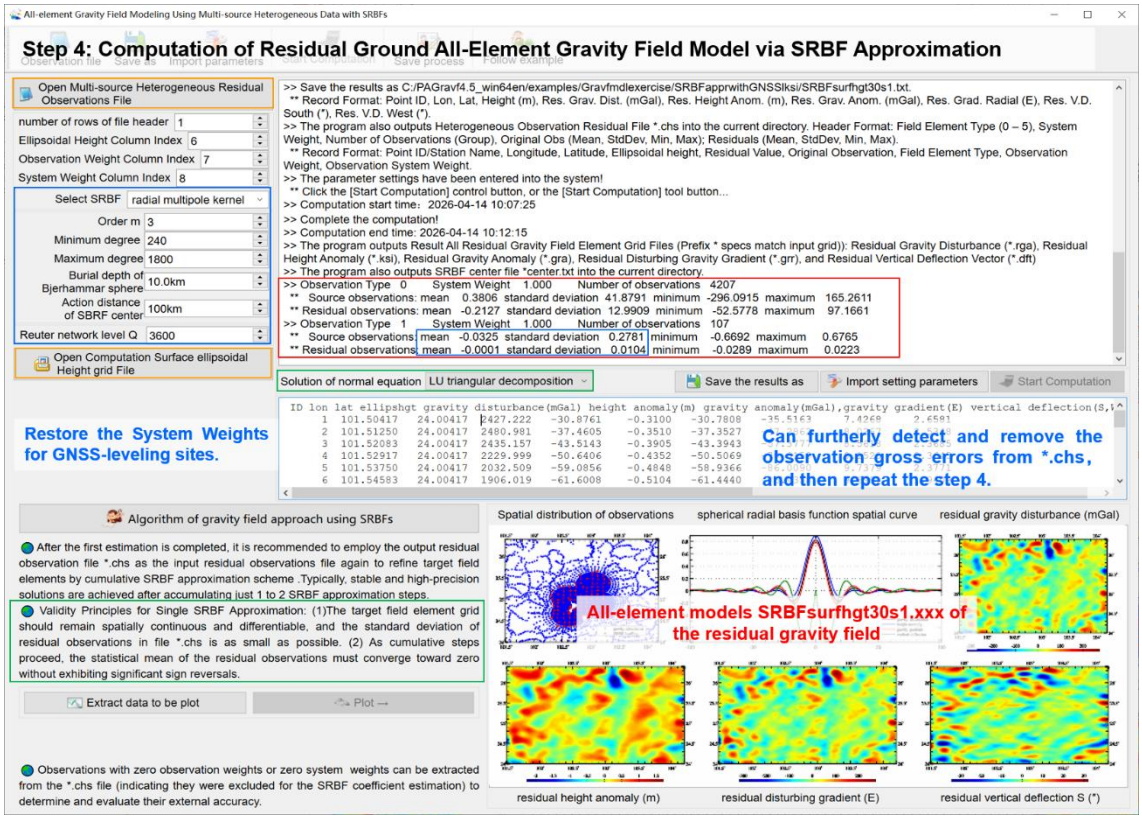
- ○ Remove the determined regional height datum discrepancy (e.g., -0.3404 m) from the observation GNSS-leveling residual height anomalies.
- ○ Restore the System Weights for GNSS-leveling sites.
- ○ Regenerate the final heterogeneous residual observation file: obsresiduals1.txt.

Step 4: Computation of Residual Ground All-Element Gravity Field Models via SRBF Approximation

Function: [All-element Gravity Field Modeling Using Multi-source Heterogeneous Data with SRBFs].

Inputs:

- ○ Multi-source heterogeneous residual observation file: obsresiduals1.txt.
- ○ Ground ellipsoidal height grid: surfhgt30s.dat.



Procedure:

- ○ Estimate the residual ground all-element gravity field grids: SRBFsurfhgt30s1.xxx.

○ Output the remaining residual observation file: SRBFsurfhgt30s1.chs.

Quality Control (QC):

○ The .chs file can be utilized for further gross error detection using the 5σ criterion for gravity disturbances and the 3σ criterion for GNSS-leveling sites.

○ Upon outlier rejection, the workflow should restart from Step 3. This iterative refinement is omitted in the current example.

Step 5: Cumulative SRBF Approximation using Remaining Residuals

Function: [All-element Gravity Field Modeling Using Multi-source Heterogeneous Data with SRBFs].

Inputs:

○ Remaining residual observation file: SRBFsurfhgt30s1.chs.

○ Ground ellipsoidal height grid: surfhgt30s.dat.

Procedure:

○ Estimate the higher-order remaining residual ground all-element gravity field grids: SRBFsurfhgt30s2.xxx.

○ Output the updated remaining residual observation file: SRBFsurfhgt30s2.chs.

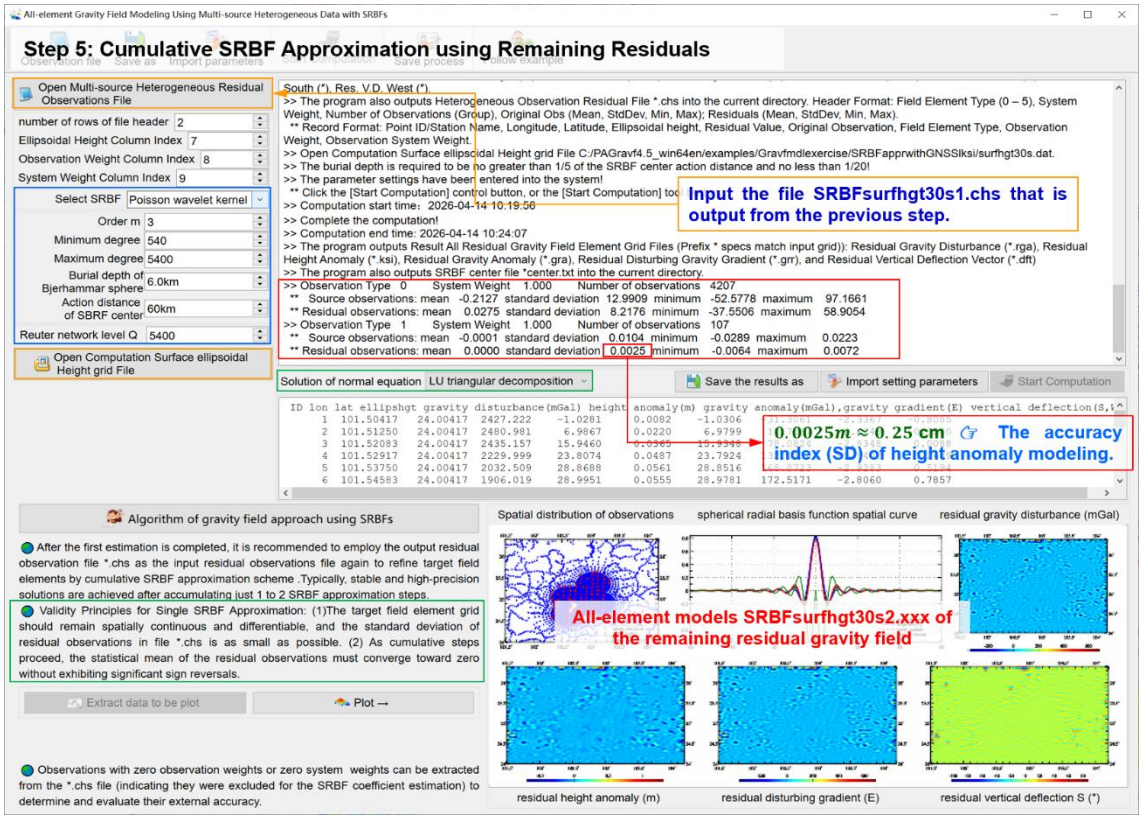


Table 4.36: Statistical Comparison of Residuals Before and after Cumulative SRBF Approximations

Data Type	Stage	Mean	Std. Dev.	Min	Max
Residual gravity disturbance	Initial Residuals	0.2695	42.0737	-296.0915	165.2611
	After 1st SRBF	0.0620	12.9866	-80.4161	64.8276

(mGal)	After 2nd SRBF	0.1309	8.5135	-50.6030	57.3920
Residual GNSS-levelling height anomaly (m)	Initial Residuals	-0.0071	0.2768	-0.6571	0.6846
	After 1st SRBF	-0.0014	0.0291	-0.1886	0.0595
	After 2nd SRBF	-0.0013	0.0154(4)	-0.0708	0.0315

Accuracy Metric: The value 0.0154 m (4) = 1.54 cm cited in the analysis serves as the accuracy index for gravity disturbance-derived ground height anomaly modeling.

Quality Control (QC) Measures:

○ Gross error detection (5σ for gravity disturbances, 3σ for GNSS-leveling sites) can be repeated using SRBFsurfhgt30s2.chs, necessitating a restart from Step 3 if outliers are found (omitted here).

○ If result quality is insufficient, further cumulative approximations may be performed. This is also omitted for brevity.

Step 6: Restoration of Reference Field Values to Generate Final Ground All-Element Models

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

Settings: Maximum degree = 540.

Input: Ground ellipsoidal height grid (edge-effect corrected): surfhgt30srst.dat.

Procedure: Compute the 540-degree reference gravity field element grids: GMsurfhgt30s540.ksi (Height Anomaly), GMsurfhgt30s540.rga (Gravity Disturbance), GMsurfhgt30s540.gra (Gravity Anomaly), GMsurfhgts540.grr (Disturbing Gravity Gradient), and GMsurfhgt30s540.dft (Vertical Deflection).

Final Model Synthesis: Sum the following three components (after trimming edges from SRBF grids):

○ 1st SRBF Residuals: surfhgt30s1.xxx (derived from SRBFsurfhgt30s0.xxx).

○ 2nd SRBF Remaining Residuals: surfhgt30s2.xxx (derived from SRBFsurfhgt30s1.xxx).

○ 540-degree Reference Field: GMsurfhgt30s540.xxx.

Output Products: The final ground all-element gravity field model grids (30″×30″ resolution) are generated, comprising:

○ Ground Height Anomaly: surfhgt30srst.ksi

○ Ground Gravity Disturbance: surfhgt30srst.rga

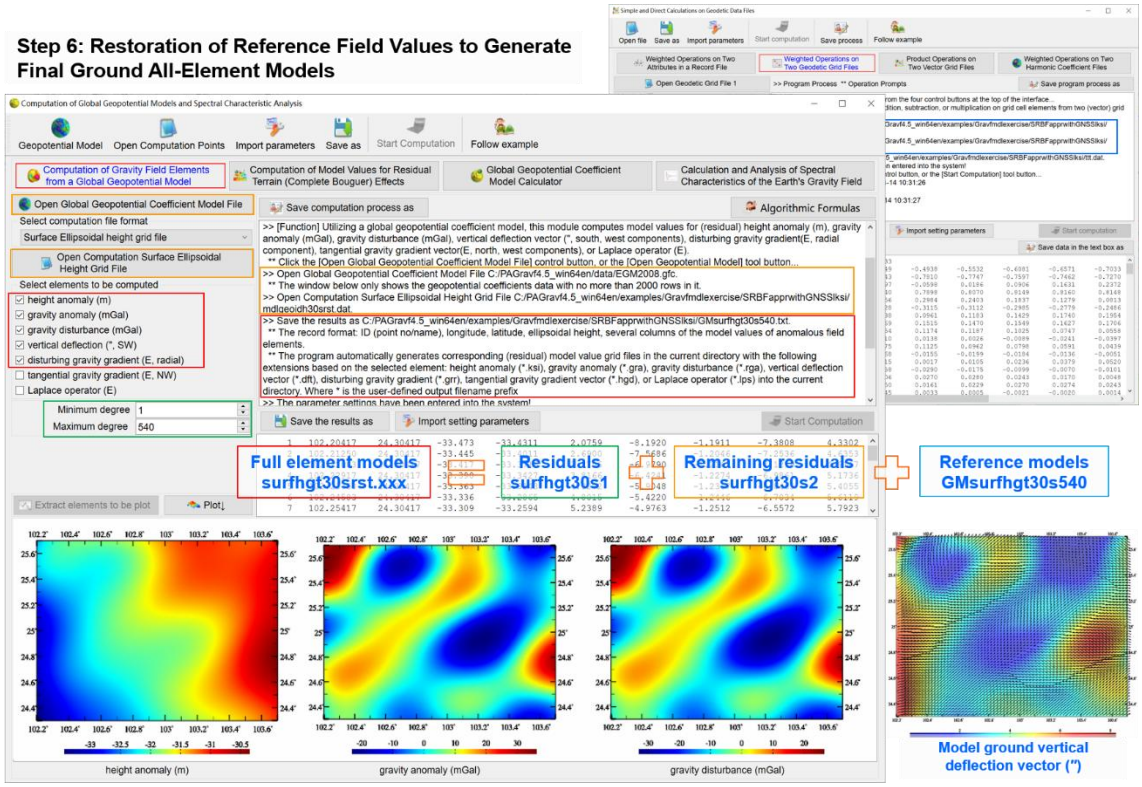
○ Ground Gravity Anomaly: surfhgt30srst.gra

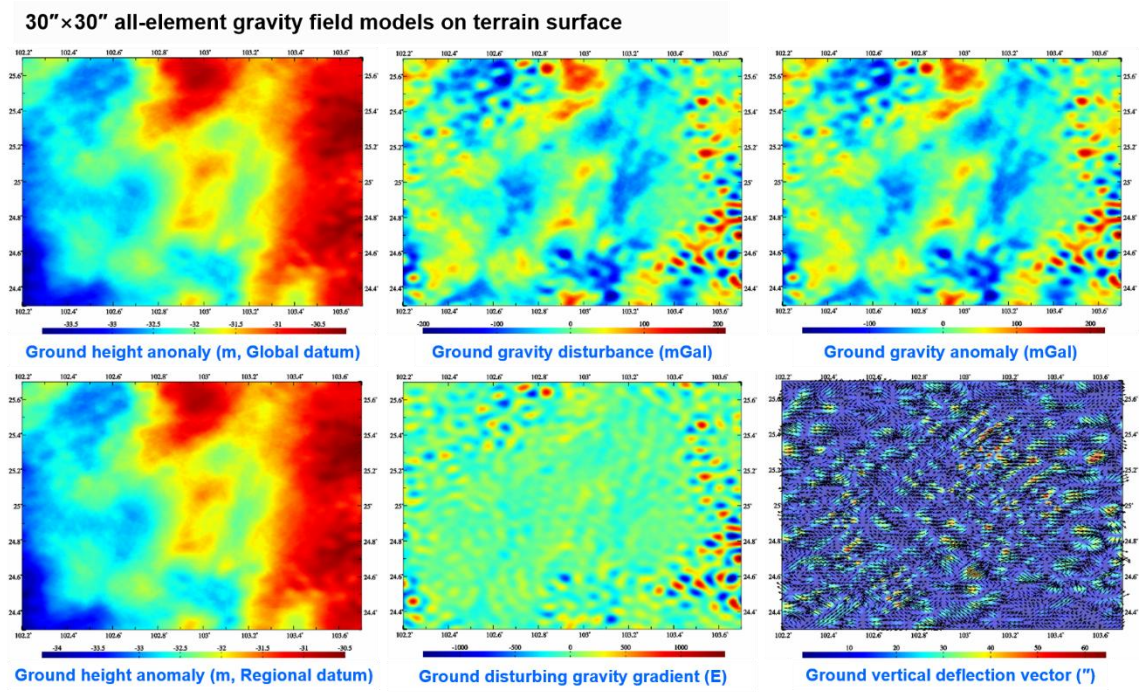
○ Ground Disturbing Gravity Gradient: surfhgt30srst.grr

○ Ground Vertical Deflection Vector: surfhgt30srst.dft

○ Regional Datum Application: Add the determined regional height datum discrepancy (-0.3063 m) to surfhgt30srst.ksi to obtain the ground height anomaly grid referenced to the regional height datum: surfhgt30srgn.ksi.

Completion: The ground all-element gravity field modeling is now complete, yielding ground 30″×30″ all-element grid models.





Generation of the Geoidal Model

By switching the computation surface to the geoid, the 30″×30″ all-element gravity field model on the geoid can be directly generated.

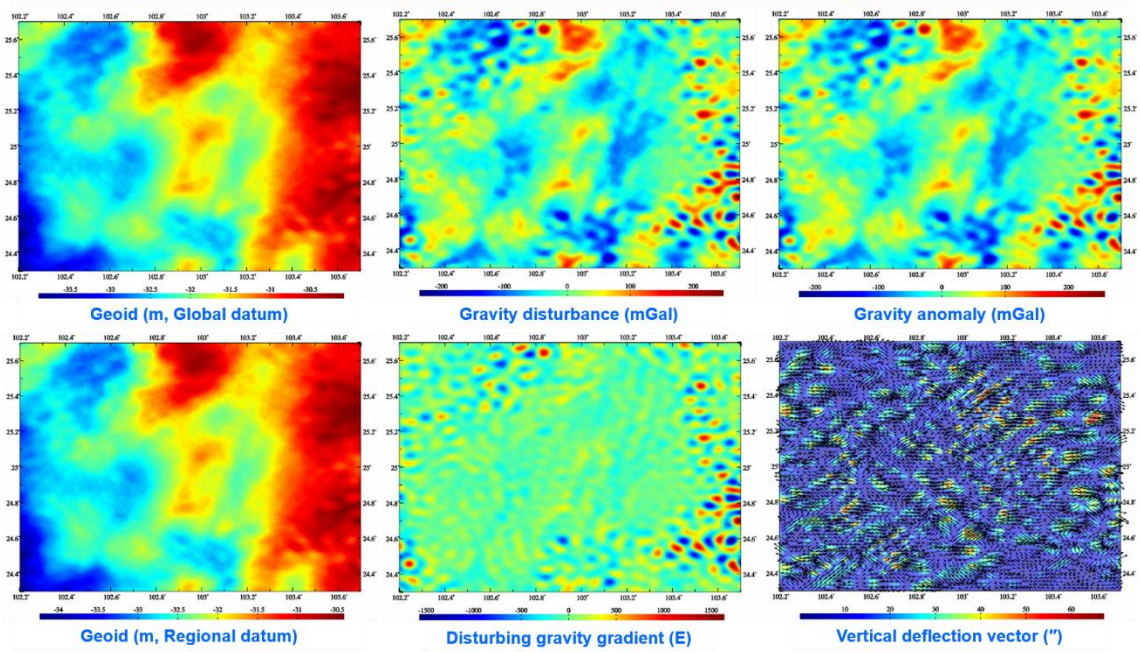
Workflow: In Steps 3 through 6, maintain all input data files and parameter settings

unchanged. Only replace the computation surface with the model geoidal height grid (e.g., mdlgeoidh30s.dat).

Synchronous Outputs: Following the identical workflow above yields the geoidal all-element model geoidh30srst.xxx, including:

- ○ Geoidal Height: geoidh30srst.ksi
- ○ Gravity Disturbance: geoidh30srst.rga
- ○ Gravity Anomaly: geoidh30srst.gra
- ○ Disturbing Gravity Gradient: geoidh30srst.grr
- ○ Vertical Deflection Vector: geoidh30srst.dft
- ○ Gravimetric Geoid (Regional Datum): geoidh30srgn.ksi

In Steps 3 through 6, maintain all input data files and parameter settings unchanged. Switching computation surface to geoid, 30″×30″ all-element gravity field models on the geoid can be directly generated.



Technical Features of the SRBF Gravity Field Approximation Program

● Rigorous Analytical Relationships: Strict analytical mathematical relationships exist between observation elements, target elements, and among the elements themselves. The algorithm's performance remains robust regardless of the error distribution characteristics within the observation data.

● One-Step Analytical Fusion of Heterogeneous Data: Capable of fusing multiple types of heterogeneous gravity observations (varying heights, cross-distributed, land-sea coexistence) in a single analytical step. No preprocessing such as reduction, continuation, or gridding is required.

● Unified Modeling Framework: Enables synchronous analytical modeling of the geoid and all external gravity field elements. Effectively integrates sparse data sources, such as astronomical vertical deflections and GNSS-leveling observations.

● Robust Quality Control: Possesses advanced capabilities for gross error detection in

gravity observations, precise determination of external accuracy indices and height datum discrepancies, and rigorous control over computational performance.