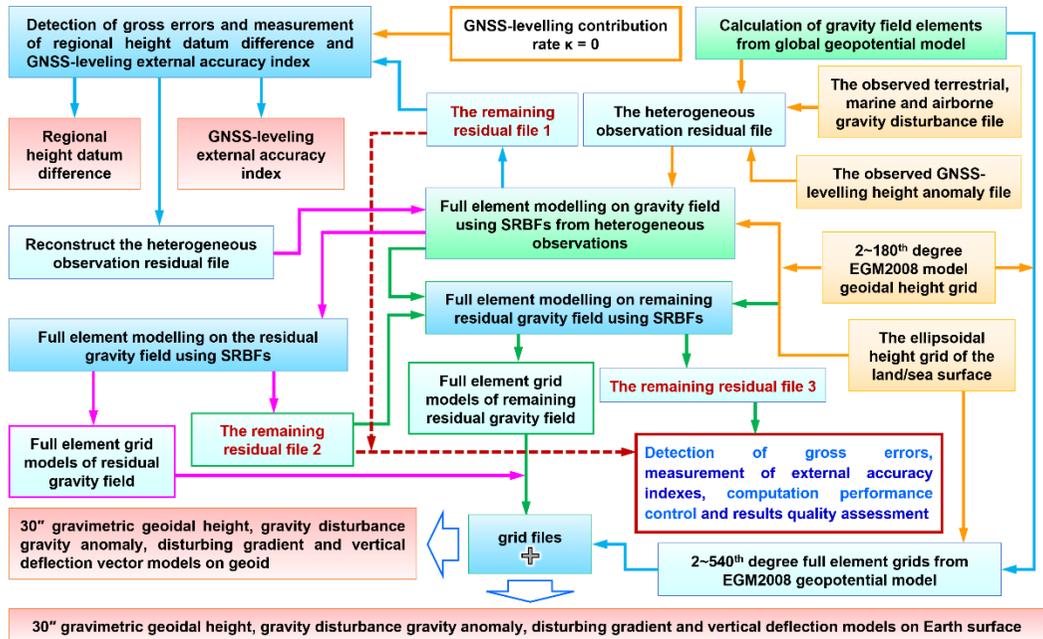


Simple process demo of full element modelling on gravity field using SRBFs in normal height system

Exercise purpose: From the observed terrestrial, marine and airborne gravity disturbances and GNSS-leveling height anomalies in normal height system, make the full element models on gravity field using spherical radial basis functions (SRBFs) in six steps, in which all the terrain effects are not processed, to quickly master the essentials in observation analysis, computation performance control and full element modeling on regional gravity field.



In this section, the observed GNSS-leveling height anomaly in the normal height system is employed to replace the observed GNSS-leveling geoidal height in orthometric height system in the 4.8.2, and the simple process of full element modelling on gravity field using SRBFs is introduced. In the both cases, there is only a slight difference in the processing of the observed GNSS-leveling data, and the other modelling processes are the same. For the convenience, here gives the complete quick process.

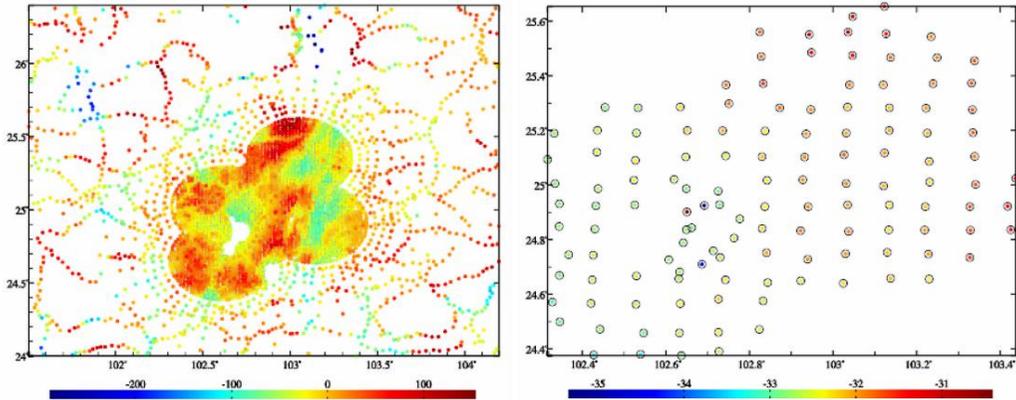
After the terrain effect processing omitted, SRBF approach process of gravity field is very simple because there is no need for additional continuation reduction, gridding and GNSS-leveling fusion process.

• The observed gravity disturbance and GNSS-leveling data

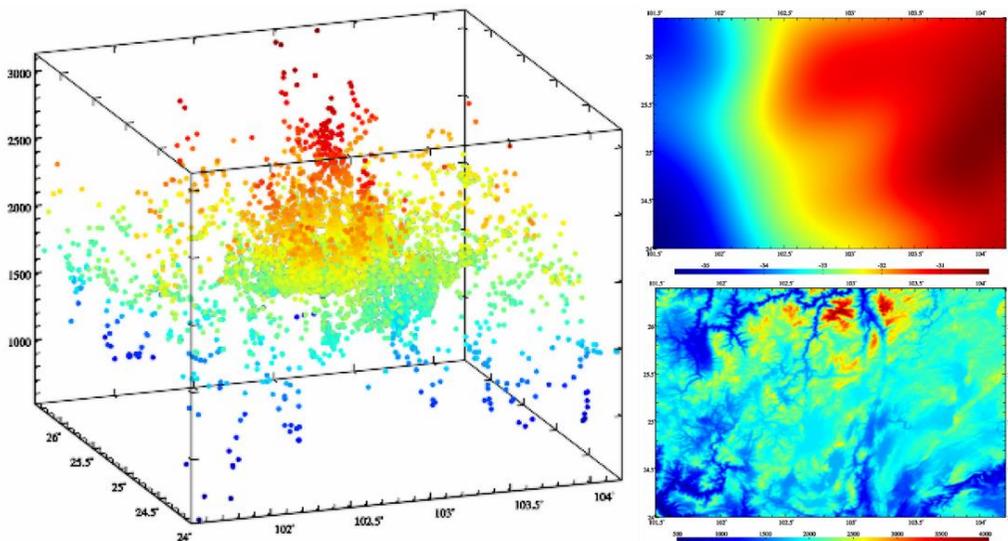
The observed terrestrial, marine and airborne gravity disturbance file obsdistgrav.txt. The file record format: ID, longitude (degree decimal), latitude, ellipsoidal height (m), observed gravity disturbance (mGal), ...

The observed GNSS-leveling height anomaly file obsGNSSlksi.txt in normal height system. The file record format: ID, longitude (degree decimal), latitude, ellipsoidal height (m), observed height anomaly (m), ...

In the example, the observed gravity disturbances and GNSS-leveling anomalies are simulated from the EGM2008 model (the 2~1800th degree) in advance.



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



The distribution of gravity points, 2~180th degree model geoidal height and ellipsoidal height of the terrain surface

● **The ellipsoidal height grid of calculation surface:**

The model geoidal height grid file mdlgeoidh30s.dat calculated from the 2~180th degree geopotential model, which is employed for modeling on gravity field on geoid.

The ellipsoidal height grid file surfhgt30s.dat of the land/sea surface equal to the sum of the digital elevation model grid DEM30s.dat and model geoidal height grid mdlgeoidh30s.dat, which is employed for modeling on ground gravity field.

Here, it is required that the grid range of the calculation surface is larger than the range of the target area to absorb edge effects.

(1) Remove reference model value from all the observations and then construct the heterogeneous observation residual file.

Call the function [Calculation of gravity field elements from global geopotential model], let the minimum degree 2 and maximum degree 540, and input the file EGM2008.gfc, observed gravity disturbance file obsdistgrav.txt and observed GNSS-leveilling height anomaly file obsGNSSIksi.txt, calculate and remove the 2~540th degree model value of these observations to generate the heterogeneous observation file obsresiduals0.txt according to the agreed format.

(1) Remove reference model value from all the observations and then construct the heterogeneous observation residual file.

The screenshot shows the software interface with the following components:

- Algorithmic Formulas:**
 - Click the [Open global geopotential coefficient model file] control button, or the [Open geopotential model] tool button...
 - Open global geopotential coefficient model file C:/PAGrav4.5_win64en/data/EGM2008.gfc.
 - The window below only shows the geopotential coefficients data with no more than 2000 rows in it.
 - Open space calculation points file C:/PAGrav4.5_win64en/examples/Gravmdlexercise/SRBFappwithGNSSIksi/obsGNSSIksi.txt.
 - Look at the file information in the window below and set the discrete point file format.
 - Save the results as C:/PAGrav4.5_win64en/examples/Gravmdlexercise/SRBFappwithGNSSIksi/obsGNSSIksi_GM540.txt.
 - Behind the record of the calculation point file, appends one or more columns of model values of anomalous field elements, and keeps 4 significant figures.
 - The parameter settings have been entered into the system!
 - Click the [Start Computation] control button, or the [Start Computation] tool button...
 - The calculation process need wait, during which you can open the output file to look at the calculation progress.
 - Computation start time: 2023-03-21 15:28:18
 - Complete the calculation of the model value of (residual) gravity field element!
 - Computation end time: 2023-03-21 15:29:04
- Open global geopotential coefficient model file:**
 - Select calculation file format: Discrete calculation points file
- Open space calculation points file:**
 - Set input point file format: Minimum degree: 2, Maximum degree: 540
 - Number of rows of file header: 1
 - Column ordinal number of ellipsoidal height in the record: 5
 - Select elements to be calculated:
 - 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)
- Table of Heterogeneous Observation Residuals:**

ID	lon (degree decimal)	lat	ellipH (m)	resid	kind	weight
1	102.4424	24.4792	1973.56	-32.7581	-32.6526	0
2	102.5467	24.4580	1659.69	-32.9377	-32.5340	0
3	102.6324	24.4582	2120.99	-32.5792	-32.4433	0
4	102.7259	24.4605	2112.20	-32.3917	-32.3324	0
5	102.8208	24.5663	1991.56	-32.6038	-32.5778	0
6	102.5286	24.5627	1937.23	-32.5836	-32.4939	0
7	102.6344	24.5656	2193.72	-32.3822	-32.3128	0
8	102.7258	24.5919	2304.57	-32.2197	-32.2069	0
9	102.8326	24.5755	1978.11	-32.5408	-32.0934	0
4221	1	102.4424	24.4717	1973.56	-0.0882	1
4222	2	102.5467	24.4580	1659.69	-0.4184	1
4223	3	102.6324	24.4582	2120.99	-0.1378	1
4224	4	102.7259	24.4605	2112.20	-0.0659	1
4225	5	102.8208	24.5663	1991.56	-0.0029	1
4226	6	102.5286	24.5627	1937.23	-0.1219	1
4227	7	102.6344	24.5656	2193.72	-0.0607	1
4228	8	102.7258	24.5919	2304.57	-0.0100	1
4229	9	102.8326	24.5755	1978.11	-0.4484	1
4230	10	102.4424	24.4717	1973.56	-0.2580	1
4231	11	102.4239	24.6529	1960.26	-0.0416	1
4232	12	102.5297	24.6670	2158.55	-0.1896	1

The agreed format of the heterogeneous observation file record: ID (point no/name), longitude (degree decimal), latitude, ellipsoidal height (m), observation, ..., observation type (0 ~ 5), weight, ... The order of the first five attributes is fixed by convention.

The observation types and units: 0 - residual gravity disturbance (mGal), 1 - residual height anomaly (m).

(2) Detect the gross errors of the observations and then reconstruct the heterogeneous observation residual file.

Call the program [Full element modelling on gravity field using SRBFs from heterogeneous observations], select the height anomaly as the adjustable observation, let the contribution rate $\kappa = 0$, and input the heterogeneous residual file obsresiduals0.txt and terrain surface ellipsoidal height grid file surfhgt30s.dat to estimate the residual gravity field grid SRBFsurfhgt30s0.xxx on geoid, and get the remaining residual file SRBFsurfhgt30s0.chs.

Where, xx=ksi stands for residual height anomaly (m), xxx=rga stands for residual gravity disturbance (mGal), xxx=gra stands for residual gravity anomaly (mGal), xxx=grr stands for residual disturbing gravity gradient (radial, E) and xx=dft stands for residual

vertical deflection (SW, ").

(2) Detect the gross errors of the observations and then reconstruct the heterogeneous observation residual file.

Open the discrete heterogeneous residual observations file

number of rows of file header 1
 column ordinal number of ellipsoidal height in the record 6
 column ordinal number of weight 7

Select SRBF radial multipole kernel
 Order m 5
 Minimum degree 360
 Maximum degree 1800
 Burial depth of Bjerrhammar sphere 10.0km
 Action distance of SRBF center 100km

Reuter network level K 3600

Select the adjustable observations height anomaly (m)
 Contribution rate κ of adjustable observations 0.00

Open the ellipsoidal height grid file of calculation surface

Solution of normal equation LU triangular decomposition

```

>> The parameter settings have been entered into the system!
** Click the [Start Computation] control button, or the [Start Computation] tool button...
>> Computation start time: 2023-03-21 15:48:34
>> Complete the computation!
>> Computation end time: 2023-03-21 15:53:45
>> The program outputs the full elements grid files into the current directory. These grid files include the residual gravity disturbance * rga (mGal), residual height anomaly * ksi (m), residual gravity anomaly * gra (mGal), residual disturbing gravity gradient * grr (E, radial) and residual vertical deflection vector * dft (" SW), where * is the output file name
>> The program also outputs SRBF center file * center.txt into the current directory. The file header format: Reuter grid level, SRBF center number, cell grid number in meridian circle direction, maximum cell grid number in prime vertical circle direction, latitude interval ("). The record format: point no, longitude (degree decimal), geocentric latitude, cell grid area deviation percentage, longitude interval of cell grid in prime vertical circle direction (").
**
>> Type 0 of source observations: mean 0.3186 standard deviation 42.1772 minimum -296.0915 maximum 165.2611
**
  esidual observations: mean 0.7856 standard deviation 17.5917 minimum -105.2839 maximum 114.8811
**
>> Type 1 of source observations: mean -0.3452 standard deviation 0.2739 minimum -0.9755 maximum -0.0702
**
  esidual observations: mean -0.0405 standard deviation 0.0271 minimum -0.1876 maximum 0.0099
  
```

ID	lon	lat	ellipsoidht	wt	ksi	gra	grr	dft	rga
1	101.50417	24.101	52150	1	0	0.3186	42.1772	-296.0915	165.2611
2	101.52150	24.101	52083	1	-0.3510	0.2774	-0.9952	0.3435	residuals: -0.0410 0.9287 -0.1943 0.0132
3	101.52083	24.101	52083	3	1	102.39290	24.49440	2228.190	16.4195
4	101.52917	24.101	52917	4	2	102.39590	24.50690	2170.200	-4.7688
5	101.53750	24.101	53750	5	3	102.39270	24.52960	2013.330	-10.3876
6	101.54583	24.101	54583	6	4	102.39660	24.54530	2122.500	1.0011
7	101.55417	24.101	55417	7	5	102.39690	24.56360	1971.280	-0.0346
8	101.56250	24.101	56250	8	6	102.39300	24.58130	1940.310	-12.0941
9				9	7	102.39520	24.60360	1965.580	12.1550
10				10	8	102.39310	24.61780	1997.720	20.5312
11				11	9	102.39350	24.63840	1916.150	3.5948
12				12	10	102.39710	24.65350	2010.670	10.7239

Select the remaining residuals (column 5) as the statistical reference

residual height anomaly (m) residual disturbing gradient (E) residual vertical deflection S (")

Algorithm of gravity field approach using SRBFs

- After the first estimation is completed, it is recommended to employ the output residual observation file *.chs as the input observation file again to refine target field element. Generally, the stable solution can be achieved by 1 to 3 times cumulative SRBF approach, and the target field element is equal to the sum of these SRBF approach solutions.
- The validity principle of once SRBF approach: (1) The residual target field element grid is continuous and differentiable, and whose standard deviation is as small as possible. (2) The statistical mean of residuals tends to zero with the increase of cumulative approach times, and there is no obvious reverse sign.

Extract data to be plot Plot →

- The program is a high performance and adaptable modeling tool on gravity field. Various observations with heterogeneity, different altitudes, cross-distribution, and land-sea coexisting can be directly employed to estimate the full element models of gravity field without reduction, continuation, and gridding.
- The program has strong ability on the observation gross error detection, measurement of external accuracy indexes, computation performance control and result quality assessment.

Separate the remaining residual records of the observed GNSS-leveling and observed gravity disturbance from the remaining residual file SRBFsurfhgt30s0.chs, detect and remove the observation gross error points beyond 3 times standard deviation range of the remaining residuals for the GNSS-leveling sites and beyond 5 times standard deviation range for the disturbance gravity points, and then reconstruct the new heterogeneous observation residual file obsresiduals01.txt.

(3) Measure the regional height datum difference and GNSS-leveling external accuracy index.

Replace the input file obsresiduals0.txt with the new heterogeneous observation residual file obsresiduals01.txt and repeat the step (2) to re-estimate the residual gravity field grid rntSRBFdatum30s.xxx on terrain surface and get the new remaining residual file rntSRBFdatum30s.chs.

Since the contribution rate of GNSS-leveling $\kappa = 0$ is set in advance, it is essentially here directly to measure the external accuracy index of the observed GNSS levelling only using the observed gravity disturbances.

Before and after gross error removed, the statistical results on the observation residuals are as follows.

(3) Measure the regional height datum difference and GNSS-leveling external accuracy index.

Open the discrete heterogeneous residual observations file

number of rows of file header: 1
 column ordinal number of ellipsoidal height in the record: 6
 column ordinal number of weight: 7

Select SRBF: radial multipole kernel
 Order m: 3
 Minimum degree: 240
 Maximum degree: 1800
 Burial depth of Bjerrhammar sphere: 10.0km
 Action distance of SBRF center: 100km

Reuter network level K: 3600

Select the adjustable observations: height anomaly (m)
 Contribution rate k of adjustable observations: 0.00

Open the ellipsoidal height grid file of calculation surface

>> The parameter settings have been entered into the system!
 >> Click the [Start Computation] control button, or the [Start Computation] control button.
 >> Computation start time: 2023-03-21 16:00:13
 >> Complete the computation!
 >> Computation end time: 2023-03-21 16:05:28
 >> The program outputs the full elements grid files into the current directory. Please click to open the residual residual gravity disturbance * rga (mGal), residual height anomaly * ksi (m), residual gravity anomaly * gra (mGal), * dtf (* SV), where * is the output file name

0.2735m The external accuracy index (SD) of the 2~540th degree model height anomaly
 0.0233m The external accuracy index (SD) of GNSS-leveling

>> The program also outputs SRBF center file * center.txt into the current directory. The file header format: Reult: grid level, SRBF center number, cell grid number in meridian circle direction, maximum cell grid number in prime vertical circle direction, latitude interval (*). The record format: point no, longitude (degree decimal), geocentric latitude, cell grid area deviation percentage, longitude interval of cell grid in prime vertical circle direction (*).
 >> Type 0 of source observations: mean 0.2695 standard deviation 42.0737 minimum -296.0915 maximum 165.2611
 residual observations: mean -0.5677 standard deviation 13.8957 minimum -80.4161 maximum 64.8276
 >> Type 1 of source observations: mean -0.3404 standard deviation 0.2735 minimum -0.9755 maximum 0.3702
 residual observations: mean -0.0069 standard deviation 0.0233 minimum -0.1295 maximum 0.0528

Solution of normal equation LU triangular decomposition

Save the results as Import setting parameters Start Computation

ID	lon	lat	ellipsoid	height	gravity disturbance (mGal)	height anomaly (m)	gravity anomaly (mGal)	gravity gradient (E)	vertical deflection (S)
1	101.50417	24.00417	2427.222	-25.2756	-0.3847	-25.1574	-13.6591	8.3938	3.6177
2	101.51250	24.00417	2480.981	-33.0116	-0.4329	-32.8786	-27.9459	9.1477	3.5535
3	101.52083	24.00417	2435.157	-39.4282	-0.4769	-39.2817	-38.4331	8.8069	3.4221
4	101.52917	24.00417	2229.999	-47.4915	-0.5290	-47.4915	-47.4915	-47.4915	-47.4915
5	101.53750	24.00417	2032.509	-57.3974	-0.5878	-57.3974	-57.3974	-57.3974	-57.3974
6	101.54583	24.00417	1906.019	-58.2186	-0.6407	-58.2186	-58.2186	-58.2186	-58.2186
7	101.55417	24.00417	1925.362	-61.7261	-0.6407	-61.7261	-61.7261	-61.7261	-61.7261
8	101.56250	24.00417	1563.539	-69.2694	-0.6921	-69.2694	-69.2694	-69.2694	-69.2694

-0.3404 - (-0.0069) = -0.3335m
 The measured height datum difference

Only using the observed gravity disturbances.

Algorithm of gravity field approach using SRBFs

After the first estimation is completed, it is recommended to employ the output residual observation file *.chs as the input observation file again to refine target field element. Generally, the stable solution can be achieved by 1 to 3 times cumulative SRBF approach, and the target field element is equal to the sum of these SRBF approach solutions.

The validity principle of once SRBF approach: (1) The residual target field element grid is continuous and differentiable, and whose standard deviation is as small as possible. (2) The statistical mean of residuals tends to zero with the increase of cumulative approach times, and there is no obvious reverse sign.

Extract data to be plot Plot

The program is a high performance and adaptable modeling tool on gravity field. Various observations with heterogeneity, different altitudes, cross-distribution, and land-sea coexisting can be directly employed to estimate the full element models of gravity field without reduction, continuation, and gridding.

The program has strong ability on the observation gross error detection, measurement of external accuracy indexes, computation performance control and result quality assessment.

Spatial distribution of observations spherical radial basis function spatial curve residual gravity disturbance (mGal)

residual height anomaly (m) residual disturbing gradient (E) residual vertical deflection S (")

		number of points	mean	standard deviation	minimum	maximum
Gravity disturbance (mGal)	Original residuals	4219	0.3186	42.1772	-296.0915	165.2611
	Residuals without error	4215	0.2695	42.0737	-296.0915	165.2611
	Remaining residuals	4215	-0.5677	13.8957	-80.4161	64.8276
GNSS levelling 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

The statistical mean ① minus ② of the GNSS-levelling remaining residuals in the table, that is, $-0.3404^{①} - (-0.0069^{②}) = -0.3335\text{m}$, is the difference between the regional height datum and the global height datum (gravimetric geoid). Here provides the SRBF measurement method for regional height datum difference.

In the table, $0.0233^{③}\text{m}$ is the external accuracy index of the observed GNSS-levelling expressed as standard deviation, that is, 2.33cm. Here provides the SRBF measurement method for the external accuracy index of GNSS-levelling. The result indicates that the external accuracy of GNSS-levelling is not bad than 2.33 cm (SD).

In general, it is necessary to make 1 to 2 cumulative SRBF approach with *.chs as the input file to obtain the minimum of standard deviation of GNSS-levelling remaining residuals as the external accuracy index, and this process is omitted in this example.

After removing the regional height datum difference of -0.3345m from GNSS-levelling residuals, the new heterogeneous observation residual file obsresiduals1.txt is reconstructed again.

(4) Full element modelling on the residual gravity field using SRBFs

Call the program [Full element modelling on gravity field using SRBFs from heterogeneous observations], let the contribution rate $\kappa = 1$, and input the heterogeneous residual file obsresiduals1.txt and terrain surface ellipsoidal height grid file surfhgt30s.dat to estimate the 30" residual gravity field grid SRBFsurfhgt30s1.xxx on terrain surface, and get the remaining residual file SRBFsurfhgt30s1.chs.

(4) Full element modelling on the residual gravity field using SRBFs

The parameter settings have been entered into the system!
 ** Click the [Start Computation] control button, or the [Start Computation] tool button...
 ** Computation start time: 2023-03-21 16:14:51
 ** Computation end time: 2023-03-21 16:20:03
 ** Complete the computation!
 ** The program outputs the full elements grid files into the current directory. These grid files include the residual residual gravity disturbance * rga (mGal), residual height anomaly * asi (m), residual gravity anomaly * gra (mGal), residual disturbing gravity gradient * grr (E, radial) and residual vertical deflection vector * dh (*, SW), where * is the output file name
 ** The program also outputs SRBF center file * center.txt into the current directory. The file header format: Reuter grid level, SRBF center number, cell grid number in meridian circle direction, maximum cell grid number in prime vertical circle direction, latitude interval (*), the record format: point no, longitude (degree decimal), geocentric latitude, cell grid area deviation percentage, longitude interval of cell grid in prime vertical circle direction (*).
 ** Type 0 of source observations: mean 0.2695 standard deviation 42.0737 minimum -296.0915 maximum 165.2611
 ** esidual observations: mean 0.0620 standard deviation 12.9896 minimum -80.4161 maximum 64.8276
 ** Type 1 of source observations: mean -0.0107 standard deviation 0.2739 minimum -0.6410 maximum 0.7047
 ** esidual observations: mean -0.0014 standard deviation 0.0291 minimum -0.1886 maximum 0.0595

ID	lon	lat	ellipsoid height (m)	gravity disturbance (mGal)	height anomaly (m)	gravity anomaly (mGal)	gravity gradient (E)	vertical deflection (S,")	
1	101.50417	24.00417	2427.222	-33.8830	-0.3067	-33.7888	-45.5553	7.3477	3.0805
2	101.51250	24.00417	2480.981	-41.3359	-0.3579	-41.2260	-58.7998	8.0721	3.0387
3	101.52083	24.00417	2435.157	-47.3401	-0.3908	-47.2176	-68.4950	8.5660	3.0527
4	101.52917	24.00417	2229.999	-38.4958	-0.4544	-38.3962	-48.5171	-64.8434	-65.2877
5	101.53750	24.00417	2032.509	-65.0026	-0.5171	-64.8434	-0.5213	-65.2877	-67.8768
6	101.54583	24.00417	1906.019	-65.4479	-0.5408	-64.8434	-0.5598	-76.3512	-76.3512
7	101.55417	24.00417	1925.362	-68.0460	-0.5408	-67.8768	-0.5598	-76.3512	-76.3512
8	101.56250	24.00417	1560.839	-76.5357	-0.5598	-76.3512	-0.5598	-76.3512	-76.3512

Algorithm of gravity field approach using SRBFs

After the first estimation is completed, it is recommended to employ the output residual observation file *.chs as the input observation file again to refine target field element. Generally, the stable solution can be achieved by 1 to 3 times cumulative SRBF approach, and the target field element is equal to the sum of these SRBF approach solutions.

The validity principle of once SRBF approach: (1) The residual target field element grid is continuous and differentiable, and whose standard deviation is as small as possible. (2) The statistical mean of residuals tends to zero with the increase of cumulative approach times, and there is no obvious reverse sign.

The program is a high performance and adaptable modeling tool on gravity field. Various observations with heterogeneity different altitudes, cross-distribution, and land-sea coexisting can be directly employed to estimate the full element models of gravity field without reduction, continuation, and gridding.

The program has strong ability on the observation gross error detection, measurement of external accuracy indexes, computation performance control and result quality assessment.

Spatial distribution of observations

spherical radial basis function spatial curve

residual gravity disturbance (mGal)

Full element models SRBFsurfhgt30s1.xxx of the residual gravity field

residual height anomaly (m)

residual disturbing gradient (E)

residual vertical deflection S (")

Can furtherly detect and remove the observation gross errors from *.chs, and then repeat the step (4).

[The quality control scheme] You can furtherly detect and remove the observation gross error points beyond 3 times standard deviation range of the remaining residuals for the GNSS-levelling sites and beyond 5 times standard deviation range for the disturbance gravity points from the remaining residual file SRBFsurfhgt30s1.chs, and then repeat the step (4). This process is omitted in this example.

(5) Full element modelling on the remaining residual gravity field using SRBFs

Call the program [Full element modelling on gravity field using SRBFs from heterogeneous observations], let the contribution rate $\kappa = 1$, and input the remaining

residual file SRBFsurfhtg30s1.chs and terrain surface ellipsoidal height grid file surfhtg30s.dat to estimate the 30" remaining residual field grid SRBFsurfhtg30s2.xxx on the terrain surface, and get the remaining residual file SRBFsurfhtg30s2.chs.

(5) Full element modelling on the remaining residual gravity field using SRBFs

Open the discrete heterogeneous residual observations file

number of rows of file header: 2
 column ordinal number of ellipsoidal height in the record: 7
 column ordinal number of weight: 8

Select SRBF Position wavelet kernel
 Order m: 3
 Minimum degree: 540
 Maximum degree: 1800
 Burial depth of Bjerrhmar sphere: 6.0km
 Action distance of SRBF center: 60km

Reuter network level K: 5400

Select the adjustable observations: height anomaly (m)
 Contribution rate x of adjustable observations: 1.00

Open the ellipsoidal height grid file of calculation surface

>> The parameter settings have been entered into the system!
 >> Click the [Start Computation] control button, or the [Start Computation] control button, or the [Start Computation] control button.
 >> Computation start time: 2023-03-21 16:56:45
 >> Complete the computation!
 >> Computation end time: 2023-03-21 17:01:14
 >> The program outputs the full elements grid files into the current directory. These grid files include the residual residual gravity disturbance * rga (mGal), residual height anomaly * ksi (m), residual gravity anomaly * gra (mGal), residual disturbing gravity gradient * grr (E, radiat) and residual vertical deflection vector * dft (* SV), where * is the output file name
 >> The program also outputs SRBF center file * center.txt into the current directory. The file header format: Reuter grid level, SRBF center number, cell grid number in meridian circle direction, maximum cell grid number in prime vertical circle direction, latitude interval (*), The record format: point no, longitude (degree decimal), geocentric latitude, cell grid area deviation percentage, longitude interval of cell grid in prime vertical circle direction (*).
 >> Type 0 of source observations: mean: 0.0620 standard deviation: 12.9866 minimum: -80.4161 maximum: 64.8276
 ** residual observations: mean: 0.1225 standard deviation: 9.4454 minimum: -42.1769 maximum: 57.3920
 >> Type 1 of source observations: mean: -0.0014 standard deviation: 0.0291 minimum: -0.1886 maximum: 0.0595
 ** residual observations: mean: -0.0013 standard deviation: 0.0154 minimum: -0.0708 maximum: 0.0315

Solution of normal equation LU triangular decomposition

Save the results as Import setting parameters Start Computation

ID	lon	lat	ellipsoid height (m)	gravity disturbance (mGal)	height anomaly (m)	gravity anomaly (mGal)	gravity gradient (E)	vertical deflection (S)
1	101.50417	24.00417	2427.222	-17.6250	-0.0737	-17.6024	-44.0716	1.1775
2	101.51250	24.00417	2480.981	-17.1942	-0.0720	-17.1721	-43.0375	1.2277
3	101.52083	24.00417	2435.157	-16.3729	-0.0689	-16.3510	-40.9296	1.2935
4	101.52917	24.00417	2229.999	-15.3566	-0.0552	-15.3347	-38.8217	1.3593
5	101.53750	24.00417	2032.509	-13.7680	-0.0593	-13.7461	-36.7138	1.4251
6	101.54583	24.00417	1906.019	-11.8549	-0.0522	-11.8330	-34.6059	1.4909
7	101.55417	24.00417	1925.362	-9.2722	-0.0425	-9.2503	-32.4980	1.5567
8	101.56250	24.00417	1563.539	-6.9749	-0.0340	-6.9530	-30.3901	1.6225

0.0154m ≈ 1.5 cm The accuracy index (SD) of height anomaly modeling.

Algorithm of gravity field approach using SRBFs

After the first estimation is completed, it is recommended to employ the output residual observation file *.chs as the input observation file again to refine target field element. Generally, the stable solution can be achieved by 1 to 3 times cumulative SRBF approach, and the target field element is equal to the sum of these SRBF approach solutions.

The validity principle of once SRBF approach: (1) The residual target field element grid is continuous and differentiable, and whose standard deviation is as small as possible. (2) The statistical mean of residuals tends to zero with the increase of cumulative approach times, and there is no obvious reverse sign.

Extract data to be plot Plot

The program is a high performance and adaptable modeling tool on gravity field. Various observations with heterogeneity, different altitudes, cross-distribution, and land-sea coexisting can be directly employed to estimate the full element models of gravity field without reduction, continuation, and gridding.

The program has strong ability on the observation gross error detection, measurement of external accuracy indexes, computation performance control and result quality assessment.

Spatial distribution of observations spherical radial basis function spatial curve residual gravity disturbance (mGal)

Full element models SRBFsurfhtg30s2.xxx of the remaining residual gravity field

residual height anomaly (m) residual disturbing gradient (E) residual vertical deflection S (")

In the table below, $0.0154^{\text{④}}$ m = 1.5cm can be considered as the accuracy index of ground height anomaly (quasigeoid) modeling.

		mean	standard deviation	minimum	maximum
Residual gravity disturbance (mGal)	Residuals	0.2695	42.0737	-296.0915	165.2611
	First SRBF	0.0620	12.9866	-80.4161	64.8276
	Second SRBF	0.1309	8.5135	-50.6030	57.3920
Residual GNSS-levelling height anomaly (m)	Residuals	-0.0071	0.2768	-0.6571	0.6846
	First SRBF	-0.0014	0.0291	-0.1886	0.0595
	Second SRBF	-0.0013	0.0154 ^④	-0.0708	0.0315

[The quality control scheme] You can furtherly detect and remove again the observation gross error points beyond 3 times standard deviation range of the remaining residuals for the GNSS-levelling sites and beyond 5 times standard deviation range for the disturbance gravity points on the remaining residual file SRBFsurfhtg30s2.chs, and then repeat from step (4). This process is omitted in this example.

You can also do further cumulative SRBF approach to improve the results. This

example omits this process.

(6) Restore the reference gravity field and generate the 30" full element models of the gravity field on the terrain surface.

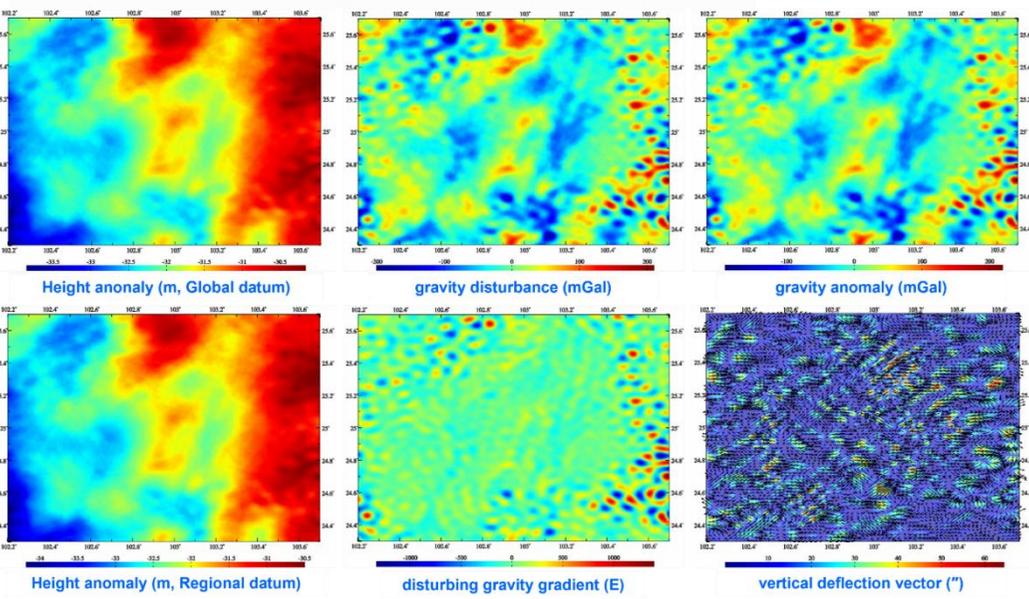
Call the function [Calculation of gravity field elements from global geopotential model], let the minimum degree 2 and maximum degree 540, input the file EGM2008.gfc, and the terrain surface ellipsoidal height grid file surfhgt30rst.dat (from surfhgt30s.dat with grid edge removed), to calculate the full element grid GMSurfhgt30s540.xxx of the reference gravity field on the terrain surface.

The screenshot displays the software's main interface for gravity field calculations. The top section contains input parameters for the calculation, including 'Maximum latitude' (25.700°) and 'Maximum longitude' (102.200°). The central part of the interface features a table with the following entries:

Full element models	surfhgt30rst.xxx
Residuals	surfhgt30s1
Remaining residuals	surfhgt30s2
Reference models	GMSurfhgt30s540

Below the table, there are three heatmaps representing different gravity field components: 'Model ground disturbing gravity gradient (E)', 'Model ground vertical deflection vector (\"), and 'Reference models GMSurfhgt30s540'. The interface also includes various control buttons and a 'Start computation' button.

30"×30" full element models of gravity field on terrain surface



Add the residual gravity field grid surfhgt30s1.xxx (from SRBFsurfhtg30s0.xxx with grid edge removed) and remaining residual gravity field grid surfhgt30s2.xxx (from SRBFsurfhtg30s1.xxx with grid edge removed) to the reference gravity field grid GMsurfhtg30s540.xxx, the 30" full element gravity field models surfhgt30srst.xxx on the terrain surface are obtained, which include the 30" gravimetric ground height anomaly grid (surfhtg30srst.ksi, m), ground gravity disturbance grid (surfhtg30srst.rga, mGal), ground gravity anomaly grid (surfhtg30srst.gra, mGal), ground disturbing gravity gradient grid (surfhtg30srst.grr, radial, E) and ground vertical deflection vector grid (surfhtg30srst.dft, SW, ").

Add the regional height datum difference -0.3411m to the 30" gravimetric height anomaly grid surfhgt30srst.ksi in global height datum, the 30" gravimetric height anomaly grid surfhgt30srgn.ksi in regional height datum can be obtained.

So far, the full element modeling on gravity field on the terrain surface have been completed.

○ **Let the geoid as the calculation surface, and directly generate the 30" full element models of the gravity field on the geoid.**

In step (3) to step (6) above, the input data file and all the parameter settings are kept same, and only the calculation surface is changed to the geoid. Using the same process, you can synchronously obtain the 30" full element models geoidh30srst.xxx of the gravity field on the geoid, which include the 30" gravimetric geoidal height grid (geoidh30srst.ksi, m, in global height datum), gravity disturbance grid (geoidh30srst.rga, mGal), gravity anomaly grid (surfhtg30srst.gra, mGal), disturbing gravity gradient grid (geoidh30srst.grr, radial, E), vertical deflection vector grid (geoidh30srst.dft, SW, ") and geoidal height grid (geoidh30srgn.ksi, m) in regional height datum.

30"×30" full element models of gravity field on geoid

