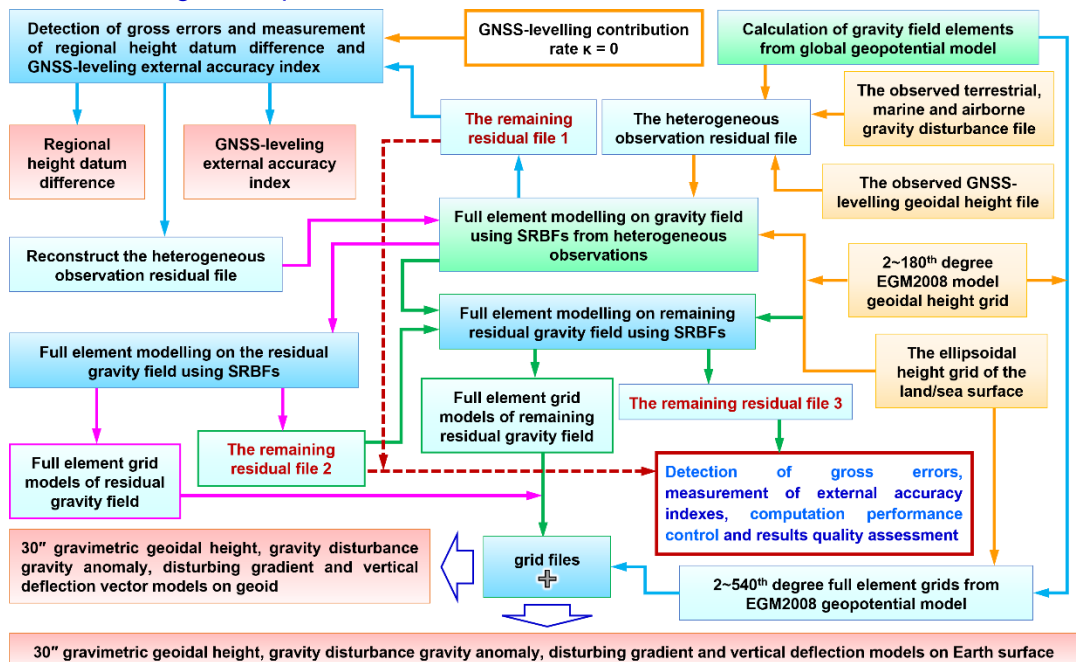


Simple process demo of full element modelling on gravity field using SRBFs in orthometric height system

Exercise purpose: From the observed terrestrial, marine and airborne gravity disturbances and GNSS-leveling geoidal heights in orthometric 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 quality control and full element modeling on regional gravity field.

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.



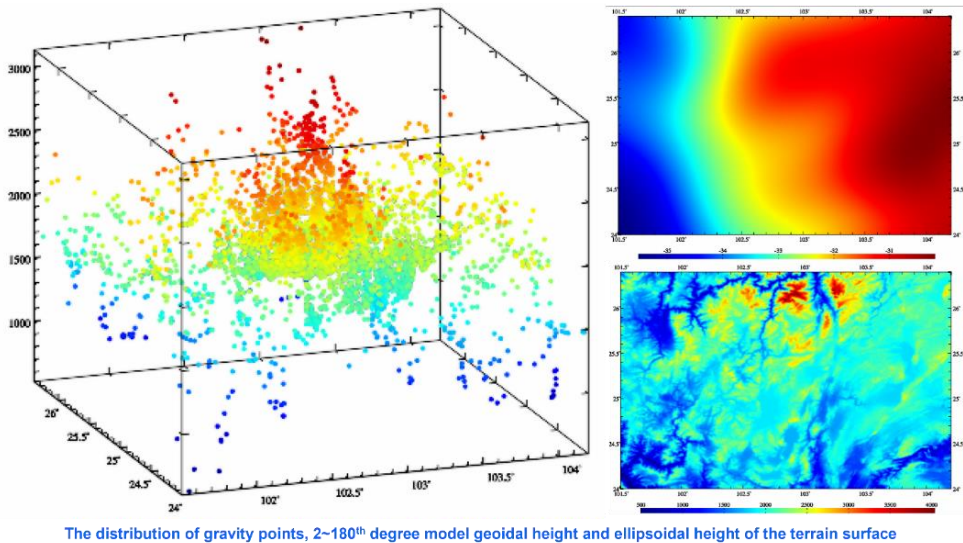
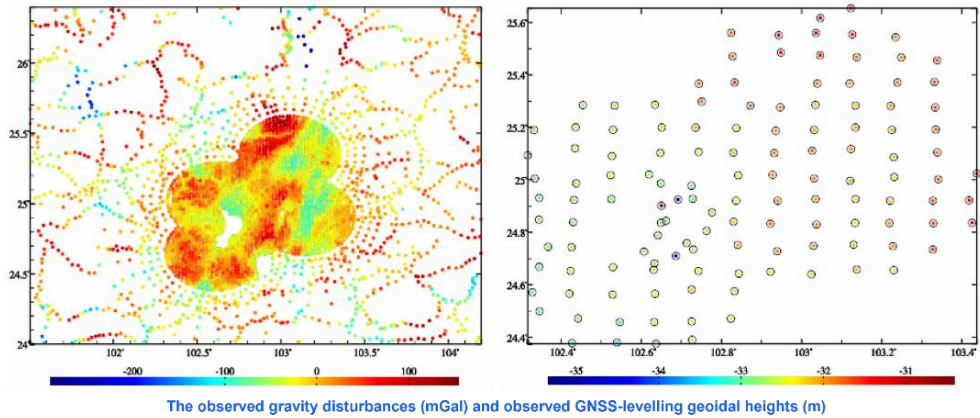
Simple process demo of full element modelling on gravity field using SRBFs in orthometric height system

• 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 geoidal height file `obsGNSSlgeoid.txt` in orthometric height system. The file record format: ID, longitude (degree decimal), latitude, observed geoidal height (m), ...

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



It should be noted that since the observed geoidal height by GNSS-leveling is essentially the height anomaly on the geoid in orthometric height system, the geoidal height at GNSS-leveling sites must be the geoidal height, which can be employed by the observed GNSS-leveling geoidal height or the model geoidal height from the EGM2008 model (the 2~180th degree).

- **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 the 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 geoidal height file obsGNSSlgeoid.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

Calculation of gravity field elements from global geopotential model | Calculation of model value for residual terrain (complete Bouguer) effects | Global geopotential coefficient model Calculator | Calculation and analysis of spectral character of Earth's gravity field

Open global geopotential coefficient model file | Save computation process as | Algorithmic Formulas

Select calculation file format: Discrete calculation points file

Open space calculation points file: C:\PA\Grav4_5_win64en\examples\Gravmdl\exercise\SRBF\apprgeoid\exercise\obsGNSSlgeoidh.txt

Open space calculation points file: C:\PA\Grav4_5_win64en\examples\Gravmdl\exercise\SRBF\apprgeoid\exercise\obsGNSSlgeoidh_GM540.txt

Set input point file format: 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)

Minimum degree: 2 | Maximum degree: 540

Save the results as: obsresiduals0.txt | Import setting parameters

| ID | lon (degree decimal) | lat | ellip(m) | rsnt | kind | weight |
|----|----------------------|---------|----------|----------|----------|--------|
| 1 | 102.4424 | 24.4717 | 1973.56 | -32.7521 | -32.6525 | 1 |
| 2 | 102.5467 | 24.4580 | 1659.69 | -32.9577 | -32.5340 | 1 |
| 3 | 102.6324 | 24.4552 | 2360.99 | -32.5792 | -32.4433 | 1 |
| 4 | 102.7259 | 24.4605 | 2112.80 | -32.3917 | -32.3324 | 1 |
| 5 | 102.4208 | 24.5663 | 1991.50 | -32.6038 | -32.5734 | 1 |
| 6 | 102.5286 | 24.5627 | 1937.23 | -32.5636 | -32.4239 | 1 |
| 7 | 102.4344 | 24.5656 | 2193.72 | -32.3822 | -32.3129 | 1 |
| 8 | 102.7258 | 24.5819 | 2304.57 | -32.2197 | -32.2069 | 1 |
| 9 | 102.8326 | 24.5755 | 1978.11 | -32.5408 | -32.0934 | 1 |

The model geoidal height (m) at the GNSS-leveilling points

The ellipsoidal height here at GNSS-leveilling point is the observed or model geoidal height, not the observed ellipsoidal height.

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 geoidal height (m).

It should be noted that the ellipsoidal height of GNSS-leveilling must be the geoidal height and not the ellipsoidal height at GNSS-leveilling site.

(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 $\kappa = 0$, and input the heterogeneous residual file obsresiduals0.txt and model geoidal height grid file mdlgeoidh30s.dat to estimate the residual gravity field grid rntSRBFgeoidh30s0.xxx on geoid, and get the remaining residual file rntSRBFgeoidh30s0.chs.

Where, $xx=ksi$ stands for residual geoidal height (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 Bjerrum sphere: 10.0km
 Action distance of SBRF 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

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.

>> 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 10:14:40
 >> Complete the computation!
 >> Computation end time: 2023-03-21 10:19:52
 >> 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, 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
 residual observations: mean 0.7368 standard deviation 16.9838 minimum -105.2639 maximum 114.8811
 >> Type 1 of source observations: mean -0.3510 standard deviation 0.2774 minimum -0.9952 maximum 0.3436
 residual observations: mean -0.0410 standard deviation 0.0287 minimum -0.1943 maximum 0.0132

Solution of normal equation LU triangular decomposition Save the results as Import setting parameters Start Computation

| ID | lon | lat | ellipsoid height | rga | ksi | gra | grr | dft |
|----|-----------|------|------------------|-------------|----------|-----------|----------|---------|
| 1 | 101.50417 | 24.1 | 0 | 0.3186 | 42.1772 | -296.0915 | 165.2611 | 0.7368 |
| 2 | 101.51250 | 24.1 | 1 | -0.3510 | 0.2774 | -0.9952 | 0.3436 | -0.0410 |
| 3 | 101.52083 | 24.1 | 2 | 1.023.39290 | 24.49440 | 2228.190 | 16.4199 | 0.0287 |
| 4 | 101.52917 | 24.1 | 3 | 102.39590 | 24.50890 | 2170.200 | -4.7688 | -0.1943 |
| 5 | 101.53750 | 24.1 | 4 | 102.39270 | 24.52960 | 2013.330 | -10.1876 | 0.0132 |
| 6 | 101.54583 | 24.1 | 5 | 102.39660 | 24.54530 | 2122.500 | 1.0011 | |
| 7 | 101.55417 | 24.1 | 6 | 102.39690 | 24.56360 | 1971.280 | -0.0346 | |
| 8 | 101.56250 | 24.1 | 7 | 102.39390 | 24.58130 | 1940.310 | -12.0941 | |
| 9 | 101.57083 | 24.1 | 8 | 102.39520 | 24.60360 | 1965.580 | 12.1550 | |
| 10 | 101.57917 | 24.1 | 9 | 102.39310 | 24.61780 | 1997.720 | 20.5312 | |
| 11 | 101.58750 | 24.1 | 10 | 102.39350 | 24.63840 | 1916.150 | 3.5946 | |
| 12 | 101.59583 | 24.1 | 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 (")

Separate the remaining residual records of the observed GNSS-leveling and observed gravity disturbance from the remaining residual file `rntSRBFgeoidh30s0.chs`, detect and remove the observation gross error points beyond 3 times standard deviation range of the remaining residuals for the GNSS-leveilling 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 geoid and get the new remaining residual file `rntSRBFdatum30s.chs`.

Since the contribution rate of GNSS-leveilling $\kappa = 0$ 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 SRBF 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 10:27:20
 >> Complete the computation!
 >> Computation end time: 2023-03-21 10:32:36
 >> The program outputs the full elements grid files into the current directory. These grid files include the residual residual gravity disturbances * rgs (mGal), residual height anomaly * ksi (m), residual gravity anomaly * gra (mGal), and residual vertical deflection * 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 0.2695 standard deviation 42.0737 minimum -296.0915 maximum 165.2611
 residual observations: mean -0.3482 standard deviation 13.2986 minimum -61.1040 maximum 64.8276
 >> Type 1 of source observations: mean -0.3482 standard deviation 0.2768 minimum -0.9982 maximum 0.3435
 residual observations: mean -0.0070 standard deviation 0.0243 minimum -0.1327 maximum 0.0561

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 gradient (E) | vertical deflection (S,W) |
|----|-----------|----------|----------------------|----------------------------|--------------------|----------------------|---------------------------|
| 1 | 101.50417 | 24.00417 | -35.528 | -28.0425 | -0.4155 | -27.9147 | 9.2237 4.0106 |
| 2 | 101.51250 | 24.00417 | -35.519 | -36.6455 | -0.4692 | -36.5212 | -31.9193 3.9492 |
| 3 | 101.52083 | 24.00417 | -35.510 | -43.9560 | -0.5174 | -43.7969 | -44.4147 10.7054 3.7823 |
| 4 | 101.52917 | 24.00417 | -35.501 | -52.5841 | -0.5707 | -52.3512 | -52.3512 17.5212 3.6273 |
| 5 | 101.53750 | 24.00417 | -35.491 | -62.9602 | -0.6294 | -62.7257 | -62.7257 24.2457 3.4823 |
| 6 | 101.54583 | 24.00417 | -35.481 | -63.3818 | -0.6825 | -63.1472 | -63.1472 30.9707 3.3373 |
| 7 | 101.55417 | 24.00417 | -35.471 | -67.1305 | -0.7256 | -67.5687 | -67.5687 37.7057 3.1923 |
| 8 | 101.56250 | 24.00417 | -35.461 | -73.7600 | -0.7625 | -73.5892 | -73.5892 44.4407 3.0473 |
| 9 | 101.57083 | 24.00417 | -35.450 | -79.1701 | -0.7625 | -78.9356 | -78.9356 51.1757 2.9023 |

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.

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

0.2768m The external accuracy index (SD) of the 2~540th degree model geoid
0.0243 m The external accuracy index (SD) of GNSS-levelling (E, radial) and residual vertical deflection (S, W) vector
-0.3482 (-0.0070) = -0.3412m
 The measured height datum difference

| | | 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 | -0.4584 | 13.6071 | -61.1040 | 64.8276 |
| GNSS levelling geoidal height (m) | Original residuals | 125 | -0.3510 | 0.2774 | -0.9982 | 0.3435 |
| | Residuals without error | 124 | -0.3482 ^① | 0.2768 | -0.9982 | 0.3435 |
| | Remaining residuals | 124 | -0.0070 ^② | 0.0243 ^③ | -0.1328 | 0.0561 |

The statistical mean ① minus ② of the GNSS-levelling remaining residuals in the table, that is, $-0.3482^{①} - (-0.0070^{②}) = -0.3412$ m, is the difference between the regional height datum and global height datum (gravimetric geoid). Here provides the SRBF measurement method for regional height datum difference.

In the table, 0.0243^③m is the external accuracy index of the observed GNSS-levelling expressed as standard deviation, that is, 2.43 cm. Here provides the SRBF

measurement method for the external accuracy index of GNSS-levelling. The result indicates that the external accuracy of the observed GNSS-levelling is not bad than 2.43 cm (standard deviation).

In general, it is necessary to make 1 to 2 cumulative SRBF approach with *.chs as the input file to obtain the minimum of the standard deviation of the 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 -0.3411m from the 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 the model geoidal height grid file mdlgeoidh30s.dat to estimate the 30" residual gravity field grid rntSRBFgeoidh30s1.xxx on geoid, and get the remaining residual file rntSRBFgeoidh30s1.chs.

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

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 360
Maximum degree 1800
Burial depth of Bjerhammar 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 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] tool button...
>> Computation start time: 2023-03-21 10:42:16
>> 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 *.ksi (m), residual gravity anomaly *.gra (mGal), residual disturbing gravity gradient *.gr (E, radial) and residual vertical deflection vector *.dt (* 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 0.0198 standard deviation 12.9865 minimum -80.4161 maximum 64.8276
** Type 1 of source observations: mean -0.0071 standard deviation 0.2768 minimum -0.6571 maximum 0.6846
** esidual observations: mean -0.0002 standard deviation 0.0276 minimum -0.1059 maximum 0.0768
```

| ID | lon | lat | ellipshgt | gravity disturbance (mGal) | height | anomaly (m) | gravity gradient (E) | vertical deflection (S, W) |
|----|-----------|----------|-----------|----------------------------|---------|-------------|----------------------|----------------------------|
| 1 | 101.50417 | 24.00417 | -35.528 | 40.8686 | -0.3641 | -40.7566 | -57.8306 | 7.9481 3.4054 |
| 2 | 101.51250 | 24.00417 | -35.519 | -47.9108 | -0.4135 | -47.7836 | -69.2552 | 8.7393 3.2540 |
| 3 | 101.52083 | 24.00417 | -35.510 | -55.2656 | -0.4640 | -55.1220 | -81.5702 | 9.3575 3.1155 |
| 4 | 101.52917 | 24.00417 | -35.501 | -64.0905 | -0.5229 | -63.9294 | -93.8848 | 9.9357 2.9770 |
| 5 | 101.53750 | 24.00417 | -35.491 | -73.4852 | -0.5848 | -73.3055 | -106.1994 | 10.5139 2.8385 |
| 6 | 101.54583 | 24.00417 | -35.481 | -72.3357 | -0.5786 | -72.1577 | -118.5140 | 11.0921 2.7000 |
| 7 | 101.55417 | 24.00417 | -35.471 | -76.9013 | -0.6113 | -76.7132 | -130.8286 | 11.6703 2.5615 |
| 8 | 101.56250 | 24.00417 | -35.461 | -84.2142 | -0.6615 | -84.0100 | -143.1432 | 12.2485 2.4230 |
| 9 | 101.57083 | 24.00417 | -35.450 | -88.9580 | -0.6936 | -88.7444 | -155.4578 | 12.8267 2.2845 |

Solution of normal equation LU triangular decomposition

Save the results as Import setting parameters Start Computation

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 rntSRBFgeoidh30s1.xxx of the residual gravity field

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

[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 rntSRBFgeoidh30s1.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 `rntSRBFgeoidh30s1.chs` and model geoidal height grid file `mdlgeoidh30s.dat` to estimate the 30" remaining residual gravity field grid `rntSRBFgeoidh30s1.xxx` on geoid, and get the remaining residual file `rntSRBFgeoidh30s1.chs`.

The screenshot shows the software interface for 'Full element modelling on gravity field using SRBFs from heterogeneous observations'. The main window displays the following content:

- Parameter Settings (Left Panel):**
 - 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: 5
 - Minimum degree: 540
 - Maximum degree: 5400
 - Burial depth of Bjerrummar sphere: 60km
 - Action distance of SRBF center: 60km
 - Reuter network level K: 5400
 - Select the adjustable observations: height anomaly (m)
 - Contribution rate κ of adjustable observations: 1.00
 - Open the ellipsoidal height grid file of calculation surface
- Main Text Area (Center):**
 - Execution logs showing parameter settings and computation results.
 - Key results:
 - Type 0 of source observations: mean 0.0196, standard deviation 12.9866, minimum -80.4161, maximum 64.8276
 - esidual observations: mean 0.0200, standard deviation 8.4565, minimum -54.9649, maximum 58.6241
 - Type 1 of source observations: mean 0.0002, standard deviation 0.0276, minimum -0.1059, maximum 0.0768
 - esidual observations: mean 0.0008, standard deviation 0.0147, minimum -0.0511, maximum 0.0345
 - Resolution of normal equation: LU triangular decomposition
- Bottom Section (Right):**
 - Algorithm of gravity field approach using SRBFs
 - Instructions on refining the target field element and the validity principle of the SRBF approach.
 - Four plots:
 - 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 (°)

| | | mean | standard deviation | minimum | maximum |
|--|-------------|---------|---------------------|-----------|----------|
| Residual gravity disturbance (mGal) | Residuals | 0.3523 | 42.1561 | -296.0915 | 165.2611 |
| | First SRBF | 0.0196 | 12.9866 | -80.4161 | 64.8276 |
| | Second SRBF | 0.0200 | 8.4565 | -54.9649 | 58.6241 |
| Residual GNSS-levelling geoidal height (m) | Residuals | -0.0071 | 0.2768 | -0.6571 | 0.6846 |
| | First SRBF | -0.0002 | 0.0276 | -0.1059 | 0.0768 |
| | Second SRBF | 0.0008 | 0.0147 ^④ | -0.0511 | 0.0345 |

In the table, 0.0147^④m = 1.5cm can be considered as the accuracy index of geoid modeling.

[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 disturbing gravity points from the remaining residual file SRBFgeoidheight30s2.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 geoid.

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 model geoidal height grid file mdlgeoidh30srst.dat (from mdlgeoidh30s.dat with grid edge removed), to calculate the full element grid GMgeoidh30s540.xxx of the reference gravity field on geoid.

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

The screenshot displays a software window with several sections:

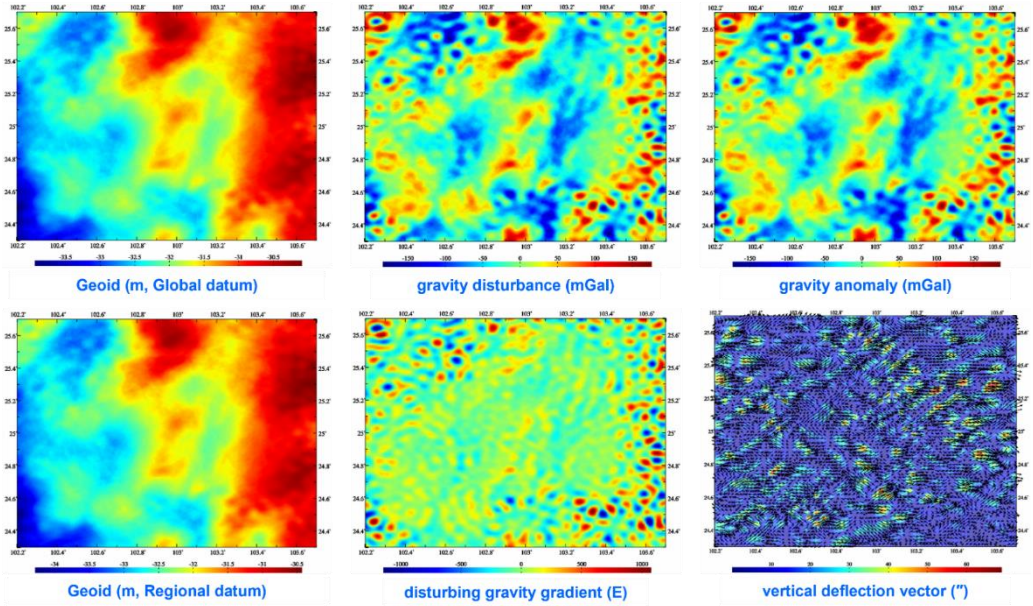
- Input Parameters:** Includes fields for 'Minimum degree' (set to 2) and 'Maximum degree' (set to 540).
- File Selection:** Points to 'Full element models geoidh30srst.xxx', 'Residuals geoidh30s1', 'Remaining residuals geoidh30s2', and 'Reference models GMgeoidh30s540'.
- Computation Log:** Shows the progress of the calculation, including 'Start computation' and 'Save the results as'.
- Data Table:** A large table of numerical values representing the calculated gravity field elements.
- Visualizations:** Two heatmaps at the bottom showing 'Model disturbing gravity gradient (E) on geoid' and 'Model vertical deflection vector (n) on geoid'.

Add the residual gravity field grid geoidh30s1.xxx (from SRBFgeoidheight30s1.xxx with grid edge removed) and remaining residual gravity field grid geoidh30s2.xxx (from SRBFgeoidheight30s2.xxx with grid edge removed) to the reference gravity field grid GMgeoidh30s540.xxx, the 30" full element gravity field models geoidh30srst.xxx on the geoid are obtained, which include the 30" gravimetric geoidal height grid (geoidh30srst.ksi, m), gravity disturbance grid (geoidh30srst.rga, mGal), gravity anomaly grid (geoidh30srst.gra, mGal), disturbing gravity gradient grid (geoidh30srst.grr, radial, E) and vertical deflection vector grid (geoidh30srst.dft, SW, ").

Add the regional height datum difference -0.3411m to the 30" gravimetric geoidal

height grid geoidh30srst.ksi in global height datum, the 30" gravimetric geoidal height grid geoidh30srgrn.ksi in regional height datum can be obtained.

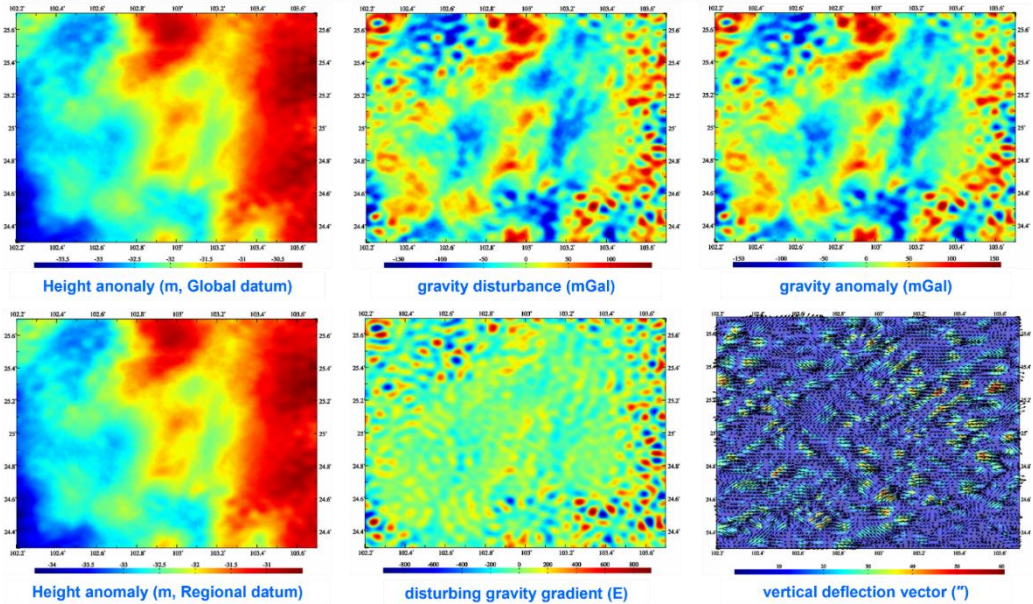
30"×30" full element models of gravity field on geoid



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

- Let the terrain surface as the calculation surface, and directly generate the 30" full element models of the gravity field on the terrain surface.

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



In step (3) to step (6) above, the input data file and all the parameter settings are kept the same, and only the calculation surface is changed to the terrain surface surfhgt30s.dat. Using the same computation process, you can synchronously obtain the

30" full element models surfhgt30srst.xxx of the gravity field on the terrain surface, which include the 30" gravimetric ground height anomaly grid (surfhgt30srst.ksi, m, in global height datum), ground gravity disturbance grid (surfhgt30srst.rga, mGal), ground gravity anomaly grid (surfhgt30srst.gra, mGal), ground disturbing gravity gradient grid (surfhgt30srst.grr, radial, E), ground vertical deflection vector grid (surfhgt30srst.dft, SW, ") and ground height anomaly grid (surfhgt30srgn.ksi, m, in regional height datum).