



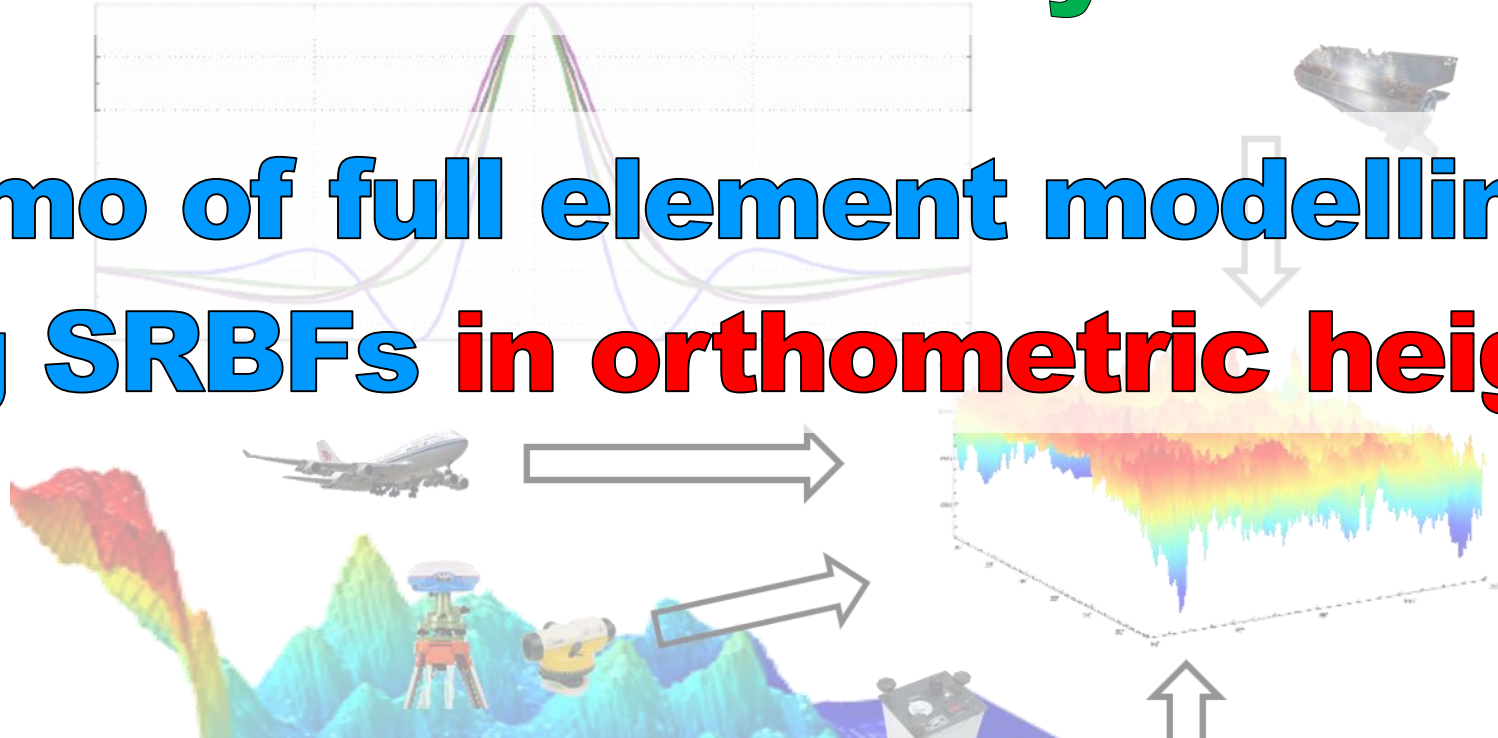
# Process demo of all-element modelling on gravity field using SRBFs



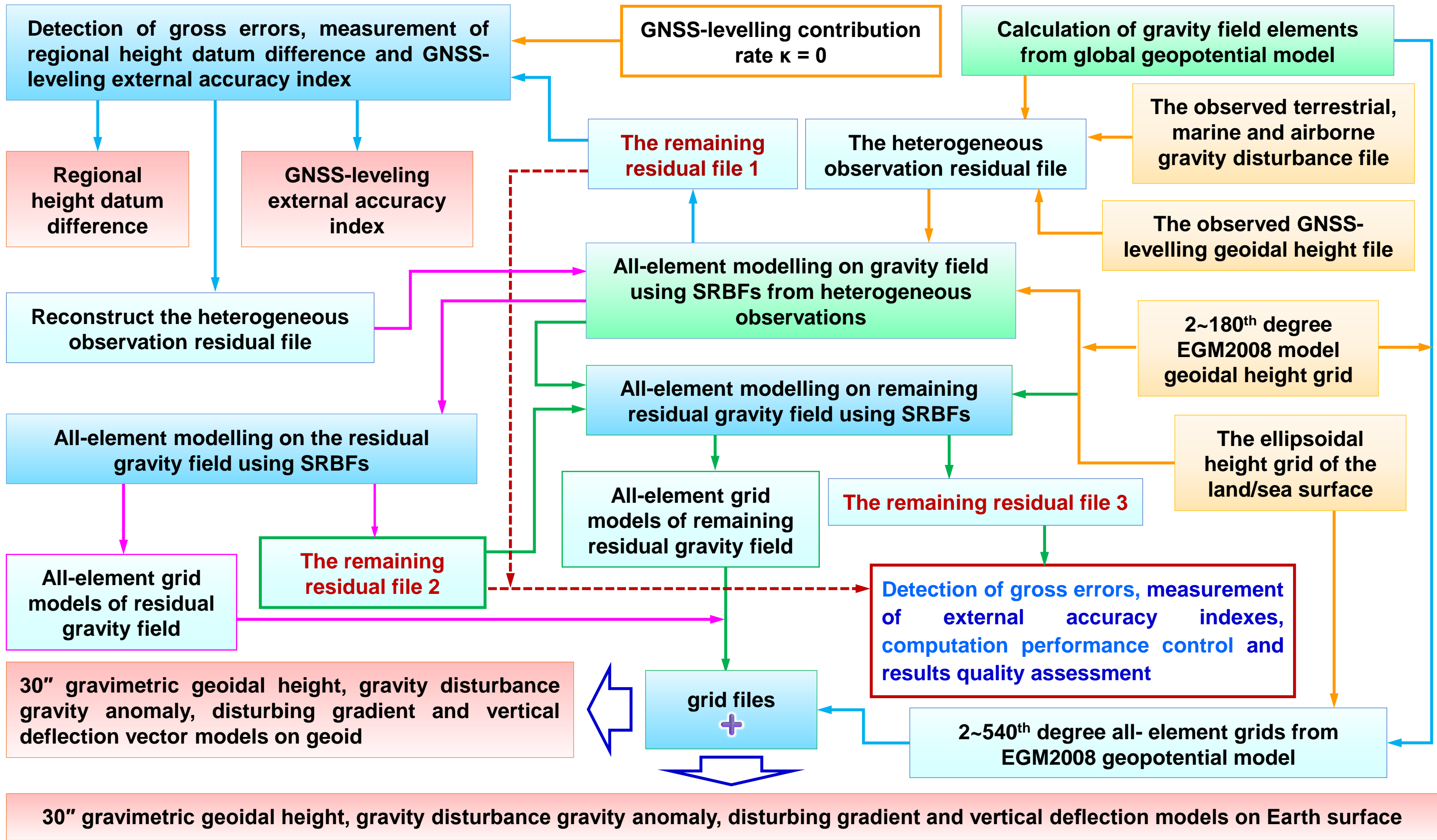
- 🌐 **Various heterogeneous observations can be directly employed to model all-element gravity field without reduction, continuation and gridding.**
- 🌐 **Has the strong ability in detection of gross errors, measurement of external accuracy indexes and control of computational performance.**
- 🌐 **Synchronously realize the all-element analytical modeling on gravity field in whole space on or outside geoid.**
- 🌐 **The analytical relationships between gravity field elements are strict, and the approach performance has nothing to do with observation errors.**

**Only six steps universal in global  
land-sea area. Everyone will !**

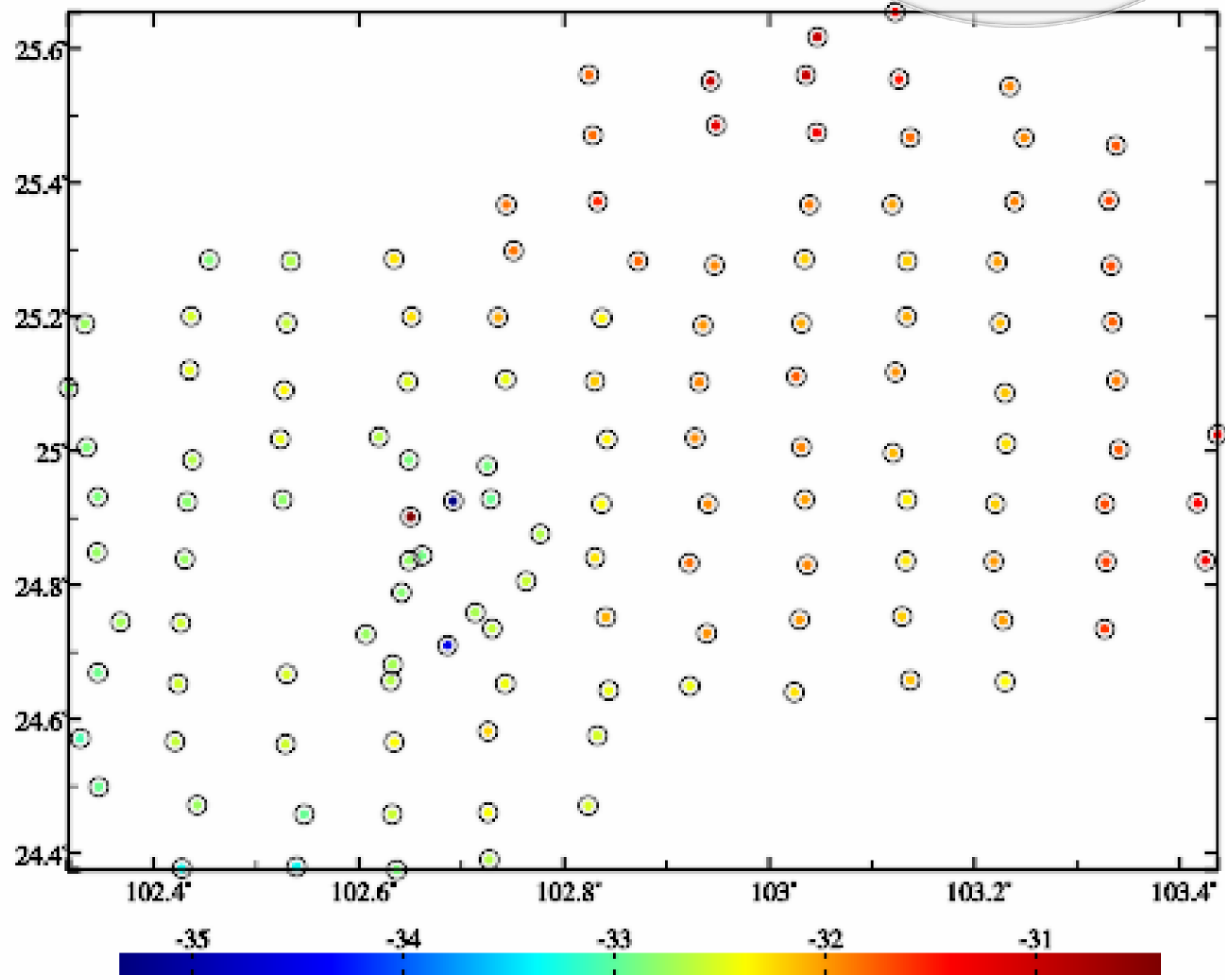
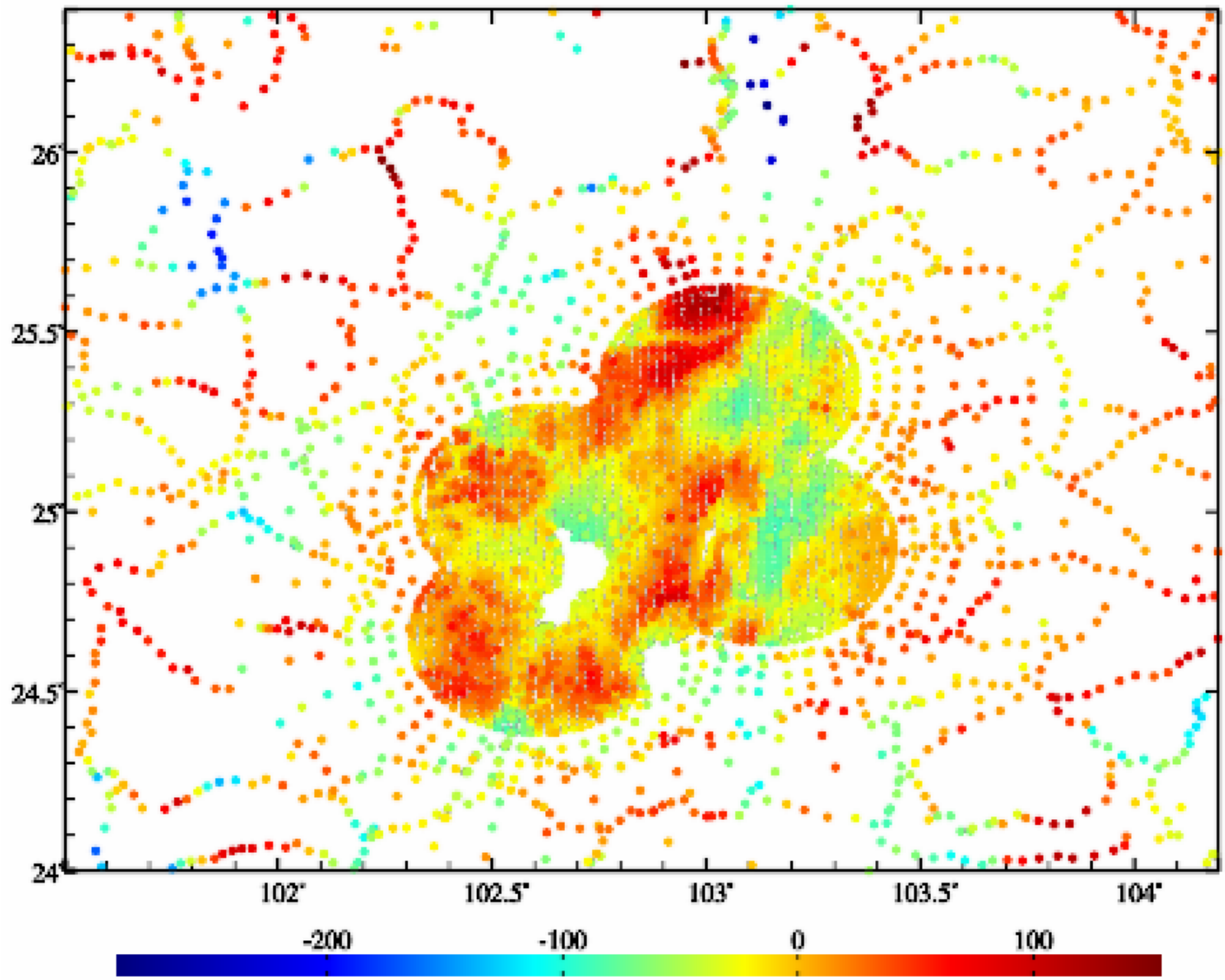
**Process demo of full element modelling on gravity  
field using SRBFs in orthometric height system**



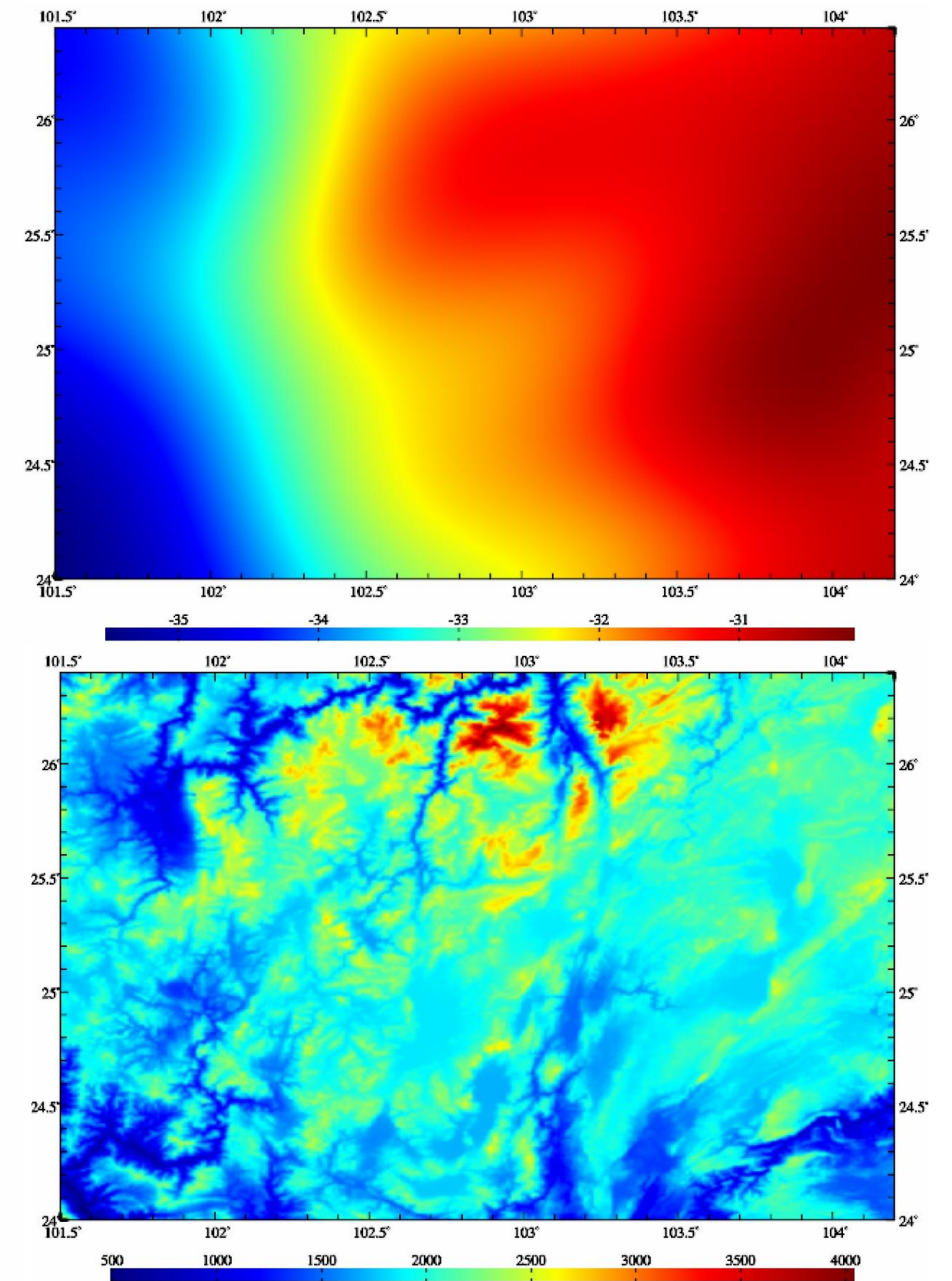
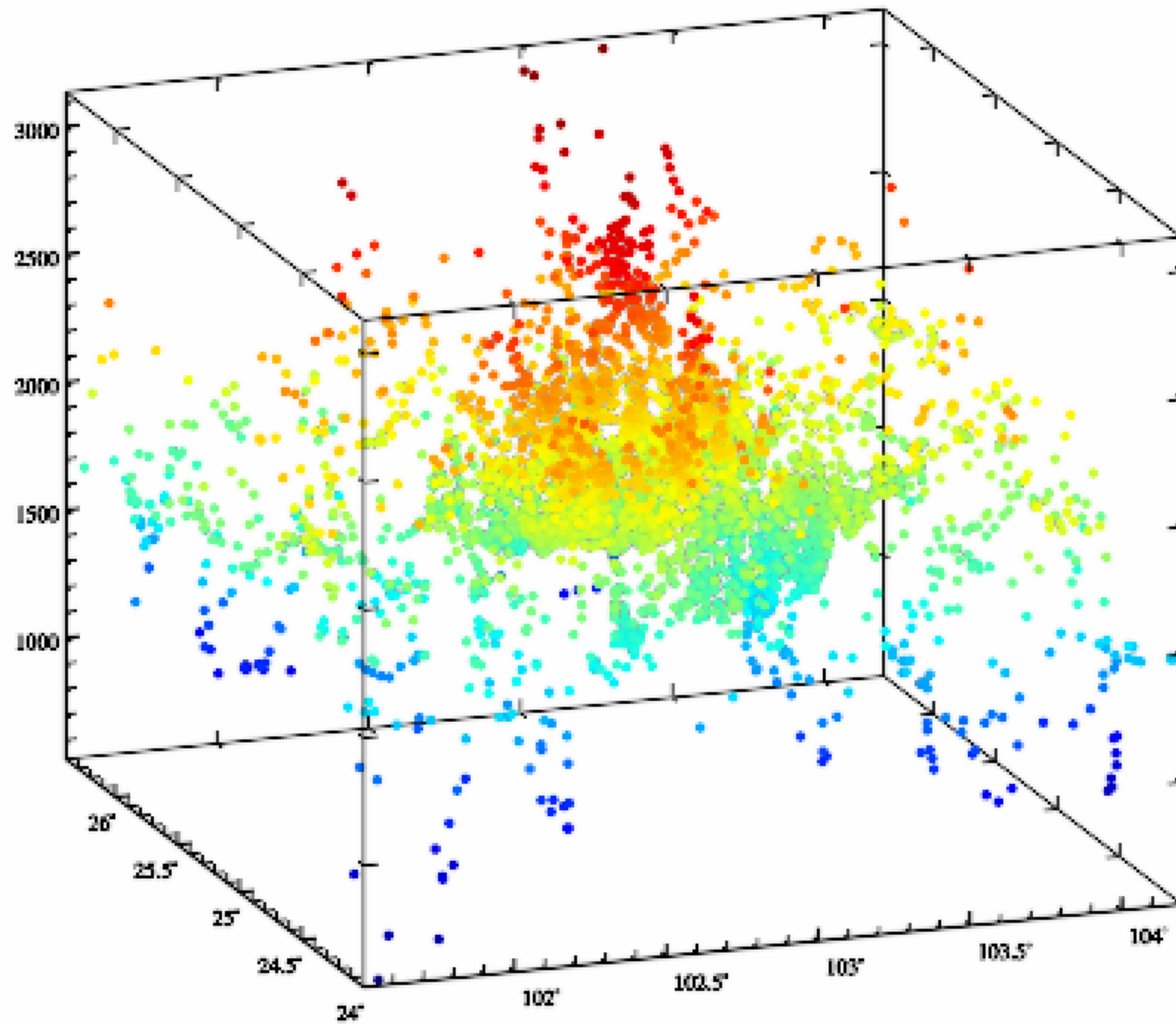
Since the observed geoidal height by GNSS-leveling is essentially the height anomaly on the geoid **in orthometric height system**, the height at GNSS-leveling sites must be **the geoidal height** rather than the **ellipsoidal height** of GNSS-points.



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



The observed gravity disturbances (mGal) and observed GNSS-levelling geoidal heights (m)



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

# (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

Select calculation file format

Discrete calculation points file

Open space calculation points file

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)

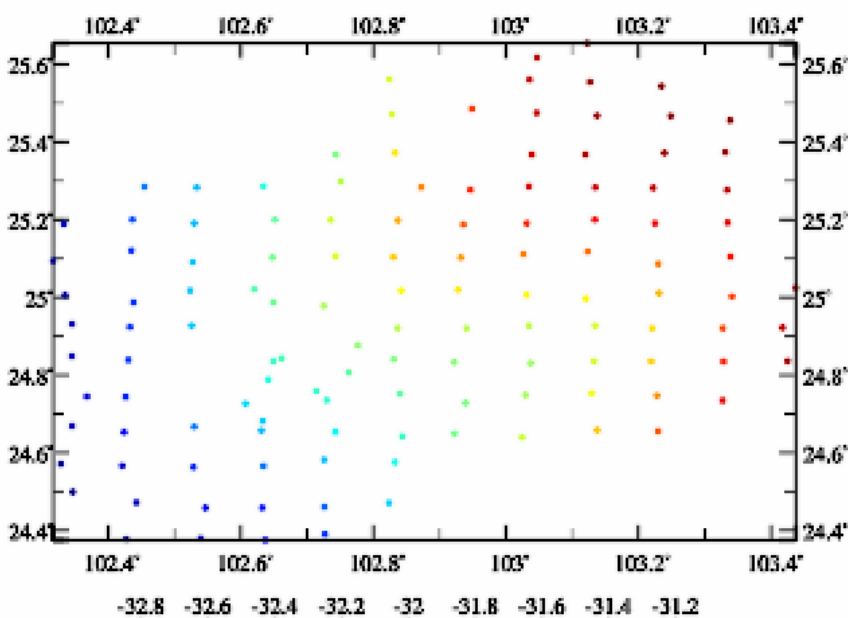
Laplace operator (E)

Minimum degree 2

Maximum degree 540

Extract elements to be plot

Plot



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

Save computation process as

```

** The window below only shows the geopotential coefficients data with no more than 2000 rows in it.
>> Open space calculation points file C:/PAGravf4.5_win64en/examples/Gravfmdlexercise/SRBFapprgeoidexercise/obsGNSSlgeoidh.txt.
** Look at the file information in the window below and set the discrete point file format...
>> Save the results as C:/PAGravf4.5_win64en/examples/Gravfmdlexercise/SRBFapprgeoidexercise/obsGNSSlgeoidh_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 09:46:33
>> Complete the calculation of the model value of (residual) gravity field element!
>> Computation end time: 2023-03-21 09:47:17
    
```

Save the results as Import setting parameters

ID	lon(degree decimal)	lat	ellpH(m)	ksi(m)
1	102.4424	24.4717	1973.56	-32.7581
2	102.5467	24.4580	1659.69	-32.9577
3	102.6324	24.4582	2120.99	-32.5792
4	102.7259	24.4605	2112.20	-32.3917
5	102.4208	24.5663	1991.56	-32.6038
6	102.5286	24.5627	1937.23	-32.5636
7	102.6344	24.5656	2193.72	-32.3822
8	102.7258	24.5819	2304.57	-32.2197
9	102.8326	24.5755	1978.11	-32.5408

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

The observed gravity disturbances

The observed GNSS-levelling geoidal heights

The heterogeneous observation residuals

ID	lon(degree decimal)	lat	ellpH(m)	rent	kind	weight
1	102.3929	24.4944	2228.19	54.9765	0	1
2	102.3959	24.5089	2170.20	50.0971	0	1
3	102.3927	24.5296	2013.33	28.3652	0	1
4	102.3966	24.5453	2122.50	38.3822	0	1
5	102.3965	24.5636	1971.28	20.6411	0	1
6	102.3965	24.5636	1971.28	15.5784	0	1
7	102.3952	24.6036	1965.58	14.5045	0	1
8	102.3931	24.6178	1997.72	14.9731	0	1
9	102.3935	24.6384	1916.15	7.4068	0	1
4221	102.4424	24.4717	-32.6525	-0.1056	1	1
4222	102.5467	24.4580	-32.5340	-0.4237	1	1
4223	102.6324	24.4582	-32.4433	-0.1359	1	1
4224	102.7259	24.4605	-32.3324	-0.0593	1	1
4225	102.4208	24.5663	-32.5734	-0.0304	1	1
4226	102.5286	24.5627	-32.4239	-0.1397	1	1
4227	102.6344	24.5656	-32.3128	-0.0694	1	1
4228	102.7258	24.5819	-32.2069	-0.0128	1	1
4229	102.8326	24.5755	-32.0934	-0.4474	1	1
4230	102.3455	24.6689	-32.6394	-0.2903	1	1
4231	102.4239	24.6529	-32.4801	-0.0740	1	1
4232	102.5297	24.6670	-32.3057	-0.2186	1	1

Residual gravity disturbances (mGal)

Residual GNSS-levelling geoidal height (m)

gravity anomaly (mGal)

When the ellipsoidal height to be set is equal, the program calculates the contribution of the degree n geopotential coefficient model which can be employed to analyze and evaluate the spectral and space properties of the geopotential coefficient model.

**Precise Approach of Earth Gravity Field and Geoid**  
**PAGravf4.5**  
 Chinese Academy of Surveying & Mapping  
 October 2024, Beijing, China

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

### Precise Approach of Earth Gravity Field and Geoid

#### PAGravf4.5

Chinese Academy of Surveying & Mapping  
October 2024, Beijing, China

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 Bjerhammar sphere 10.0km

Action distance of SBRF center 100km

Reuter network level K 3600

Select the adjustable observations height anomaly (m)

Contribution rate  $\kappa$  of adjustable observations 0.00

Open the ellipsoidal height grid file of calculation surface

of file header, whose format: observation type (0~5), source observation mean, standard deviation, minimum, maximum, residual observation mean, standard deviation, minimum, maximum. The record format: ID, longitude, latitude, ellipsoidal height, residual observation, source observation, observation type, weight.

>> The parameter settings have been entered into the system!  
 \*\* Click the [Start Computation] control button, or the [Start Computation] tool button...  
 >> Computation start time: 2024-09-28 18:03:50  
 >> Complete the computation!  
 >> Computation end time: 2024-09-28 18:10:25  
 >> The program outputs the all-element grid files into the current directory. These grid files include the residual gravity disturbance  $\eta_{gr}$  (mGal), residual height anomaly  $\eta_{ksi}$  (m), residual gravity anomaly  $\eta_{gra}$  (mGal), residual disturbing gravity gradient  $\eta_{grr}$  (E, radial) and residual vertical deflection vector  $\eta_{dft}$  (", SW), where \* is the output file name, and whose grid specification are the same as the input ellipsoidal height grid of calculation surface.  
 >> 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: ID, 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 -105.2839 maximum 114.8811  
 >> Type 1 of source observations: mean -0.3510 standard deviation 0.2774 minimum -0.9982 maximum 0.3435  
 \*\* Residual observations: mean -0.0410 standard deviation 0.0287 minimum -0.1943 maximum 0.0132

Solution of normal equation LU

ID	lon	lat	ellipshgt	gra	residuals	residuals	residuals	residuals	residuals
1	101.50417	24.0	0	0.3186	42.1772	-296.0915	165.2611	0.7368	16.9838
2	101.51250	24.0	1	-0.3510	0.2774	-0.9982	0.3435	-0.0410	0.0287
3	101.52083	24.0	1	102.39290	24.49440	2228.190	16.4199	54.9765	0
4	101.52917	24.0	2	102.39590	24.50890	2170.200	-4.7688	50.0971	0
5	101.53750	24.0	3	102.39270	24.52960	2013.330	-18.3876	28.6650	0
6	101.54583	24.0	4	102.39660	24.54530	2122.500	1.0011	38.0211	0
7			5	102.39690	24.56360	1971.280	-0.0346	20.6411	0
8			6	102.39380	24.58130	1940.310	-12.0941	19.0000	0
9			7	102.39520	24.60360	1965.580	12.1550	14.5045	0
10			8	102.39310	24.61780	1997.720	20.5312	14.5045	0
11			9	102.39350	24.63840	1916.150	3.5948	7.4068	0

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

### Algorithm of gravity field approach using SRBFs

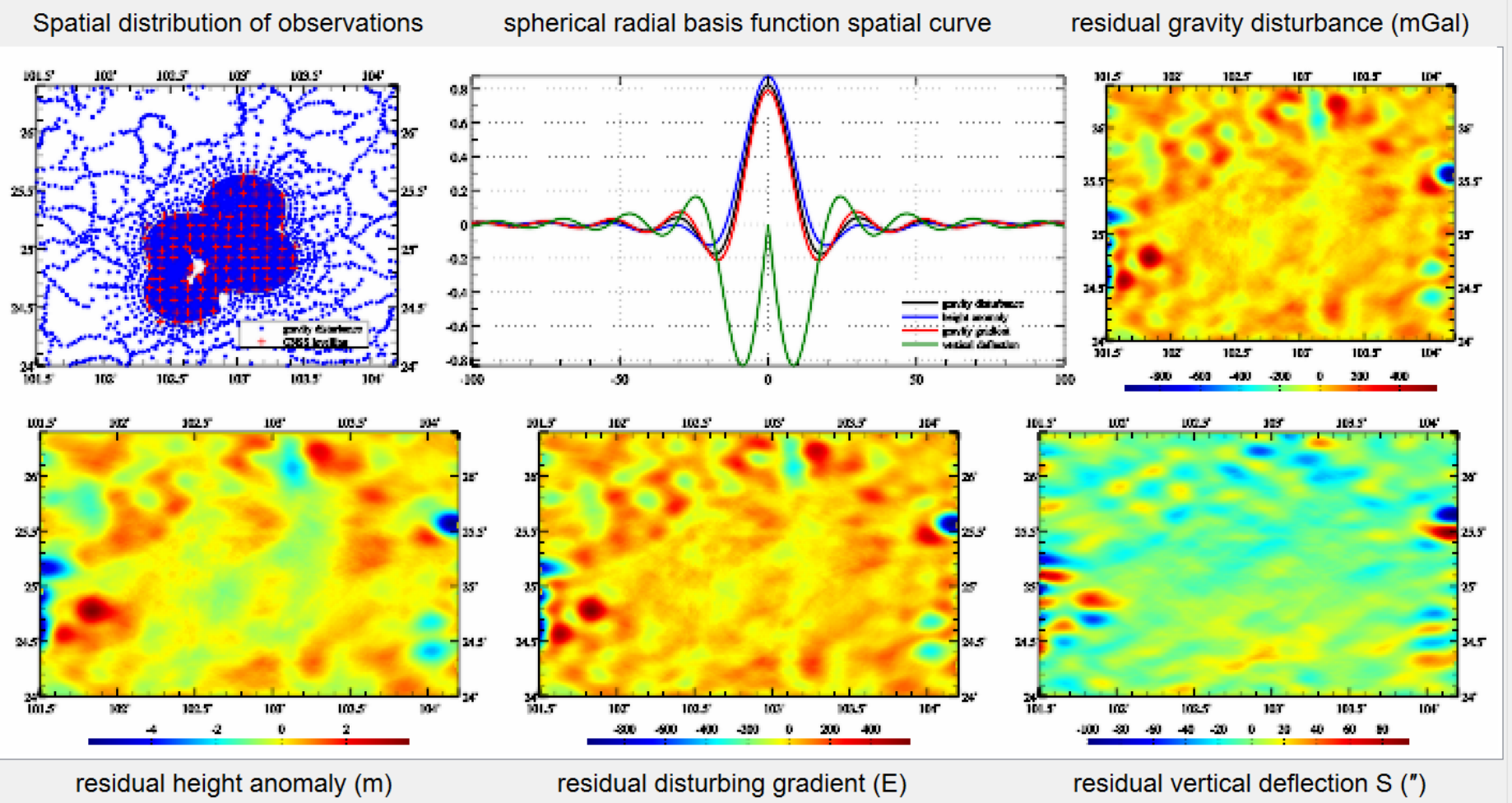
After the first estimation is completed, it is recommended to employ the output residual observation file \*.chs as the input observation file again to refine target field elements. Generally, the stable solution can be achieved by 1 to 3 times cumulative SRBF approach, and the target field elements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

The validity principle of once SRBF approach: (1) The residual target field element grid are 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 modelling tool on local gravity field. Various observations with heterogeneity, different altitudes, cross-distribution and land-sea coexisting can be directly employed to estimate the all-element models of gravity field without reduction, continuation and gridding.

The program has strong capacity on the detection of observation gross errors, measurement of external accuracy indexes and control of computation performance.



# Separate the remaining residuals of the observed GNSS-leveling and observed gravity disturbances from rntSRBFgeoidh30s0.chs.

Gross error detection and basis function gridding of discrete field elements

Open file Save as Import parameters Start Computation Save process Follow example

Gross error detection on observations based on low-pass reference surface

Estimation of observation weight with specified reference attribute

Gridding of heterogeneous data by basis function weighted interpolation

The discrete point file to be detect

Number of rows of file header: 1

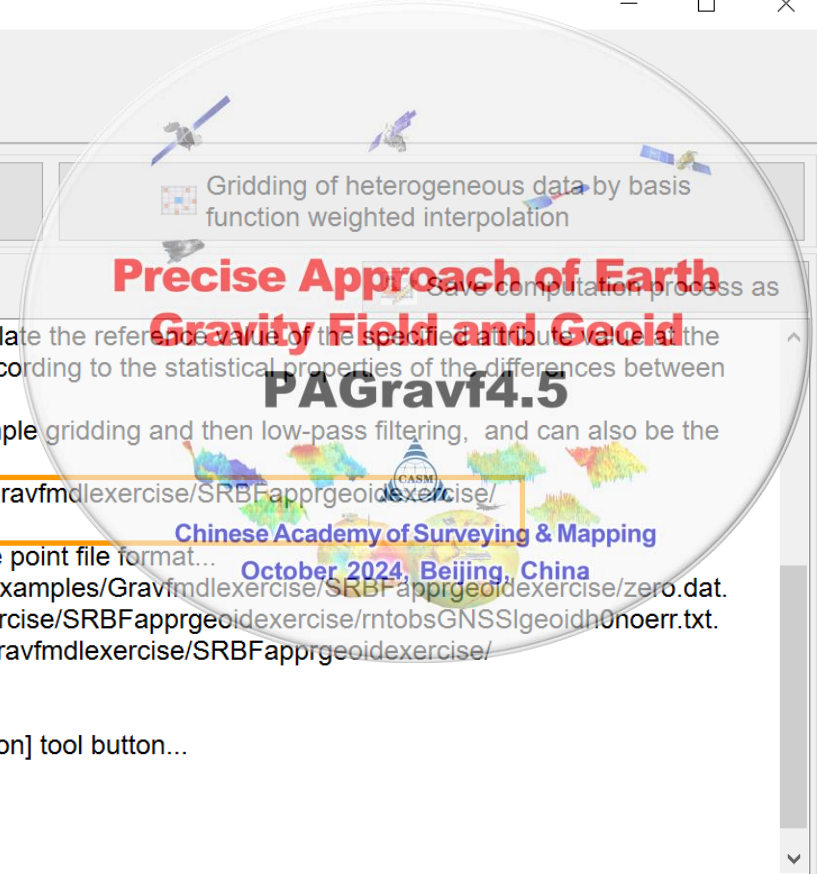
Column ordinal number of the attribute to be detect: 5

Beyond multiples of the standard deviation n: 3.0

Open low-pass reference surface grid file

Save the results as

>> [Function] Select the low-pass grid as the reference surface, interpolate the reference value of the specified attribute value at the discrete point, and then detect and separate the gross error records according to the statistical properties of the differences between the specified attribute value and reference value.  
 \*\* The reference surface can be constructed from discrete data by simple gridding and then low-pass filtering, and can also be the specified attribute grid constructed by weighted basis function gridding.  
 >> Open the discrete geodetic file C:/PAGravf4.5\_win64en/examples/Gravfmdlexercise/SRBFapprgeoidexercise/rntobsGNSSlgeoidh0.txt.  
 \*\* Look at the file information in the window below and set the discrete point file format...  
 >> Open low-pass reference surface grid file C:/PAGravf4.5\_win64en/examples/Gravfmdlexercise/SRBFapprgeoidexercise/zero.dat.  
 >> Save the results as C:/PAGravf4.5\_win64en/examples/Gravfmdlexercise/SRBFapprgeoidexercise/rntobsGNSSlgeoidh0noerr.txt.  
 >> Save no gross error results as C:/PAGravf4.5\_win64en/examples/Gravfmdlexercise/SRBFapprgeoidexercise/rntobsGNSSlgeoidh0error.txt.



Gross error detection and basis function gridding of discrete field elements

Open file Save as Import parameters Start Computation Save process Follow example

Gross error detection on observations based on low-pass reference surface

Estimation of observation weight with specified reference attribute

Gridding of heterogeneous data by basis function weighted interpolation

The discrete point file to be detect

Number of rows of file header: 1

Column ordinal number of the attribute to be detect: 5

Beyond multiples of the standard deviation n: 5.0

Open low-pass reference surface grid file

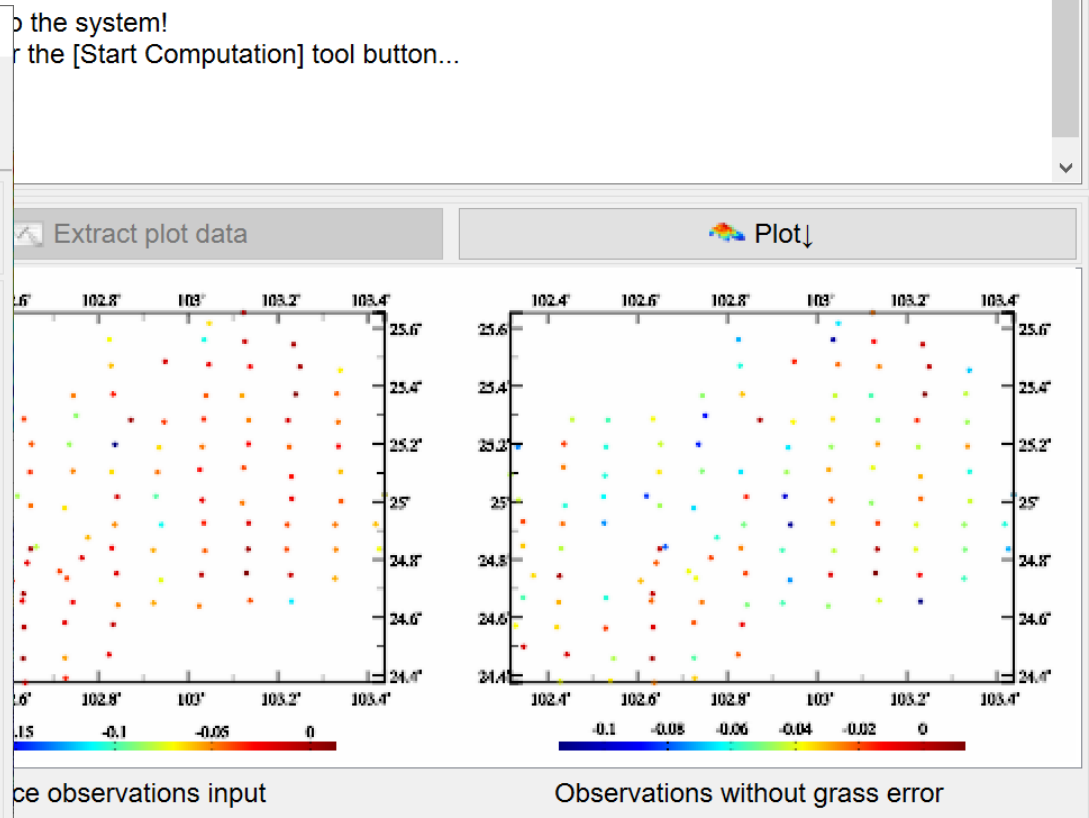
Save the results as

Save gross error as

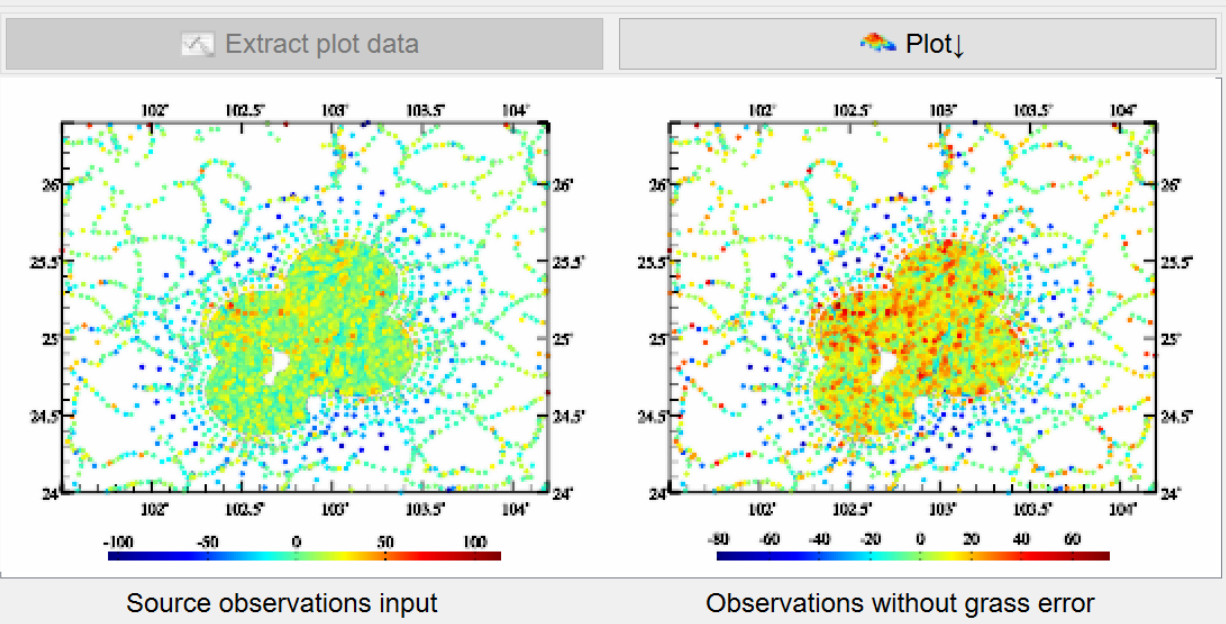
Import setting parameters

Start Computation

>> [Function] Select the low-pass grid as the reference surface, interpolate the reference value of the specified attribute value at the discrete point, and then detect and separate the gross error records according to the statistical properties of the differences between the specified attribute value and reference value.  
 \*\* The reference surface can be constructed from discrete data by simple gridding and then low-pass filtering, and can also be the specified attribute grid constructed by weighted basis function gridding.  
 >> Open the discrete geodetic file C:/PAGravf4.5\_win64en/examples/Gravfmdlexercise/SRBFapprgeoidexercise/rntobsdistgrav0.txt.  
 \*\* Look at the file information in the window below and set the discrete point file format...  
 >> Open low-pass reference surface grid file C:/PAGravf4.5\_win64en/examples/Gravfmdlexercise/SRBFapprgeoidexercise/zero.dat.  
 >> Save the results as C:/PAGravf4.5\_win64en/examples/Gravfmdlexercise/SRBFapprgeoidexercise/rntobsdistgrav0noerr.txt.  
 >> Save no gross error results as C:/PAGravf4.5\_win64en/examples/Gravfmdlexercise/SRBFapprgeoidexercise/rntobsdistgrav0error.txt.  
 >> 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 14:48:43  
 >> Complete computation!  
 >> Computation end time: 2023-03-21 14:48:43



0.6881	16.6838	-80.6303	74.3694	97.1661	97.1661
2158	101.98720	26.38060	1860.000	-105.2839	-105.2839
16069	103.17160	26.38130	1721.800	114.8811	114.8811
16573	102.74440	26.38830	2340.000	101.4916	101.4916
19786	104.19500	24.64660	1799.700		



Reconstruct the heterogeneous observation residual file obsresiduals01.txt.



### (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 Bjerhammar 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

of file header, whose format: observation type (0~5), source observation mean, standard deviation, minimum, maximum, residual observation mean, standard deviation, minimum, maximum. The record format: ID, longitude, latitude, ellipsoidal height, weight.

>> The parameter settings have been entered into the system!  
 \*\* Click the [Start Computation] control button, or the [Start Computation] tool button.

>> Computation start time: 2024-09-28 18:24:31

>> Complete the computation!

>> Computation end time: 2024-09-28 18:29:19

>> The program outputs the all-element 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, and whose grid specification are the same as the input ellipsoidal height grid of calculation surface.

>> 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: ID, 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 -0.5621 standard deviation 13.7996 minimum -80.4161 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

**0.2768m** ← The external accuracy index (SD) of the 2~540<sup>th</sup> degree model geoid

**0.0243m** ← The external accuracy index (SD) of GNSS-leveling

Solution of normal equation LU triangular decomposition

ID	lon	lat	ellipshgt	gravity disturbance(mGal)	height anomaly(m)	gravity anomaly(mGal)	gravity gradient(E)	vertical deflection	
1	101.50417	24.00417	-35.528	-28.0425	-0.4155	-27.9147	-15.9774	9.2237	4.0106
2	101.51250	24.00417	-35.519	-36.6655	-0.4692	-36.5212	-31.9193	10.0940	3.9482
3	101.52083	24.00417	-35.510	-43.9560	-0.5174	-43.7859	-44.4147	10.7654	3.7893
4	101.52917	24.00417	-35.501	-52.5841	-0.5707	-52.4088	-50.2544	11.5110	3.8425
5	101.53750	24.00417	-35.491	-62.9602	-0.6299	-62.7851	-60.6303	12.2592	3.8130
6	101.54583	24.00417	-35.481	-63.3818	-0.6500	-63.1818	-75.1652	12.0262	3.3010

**-0.3482 - (-0.0070) = -0.3412m**  
 ← The measured height datum difference

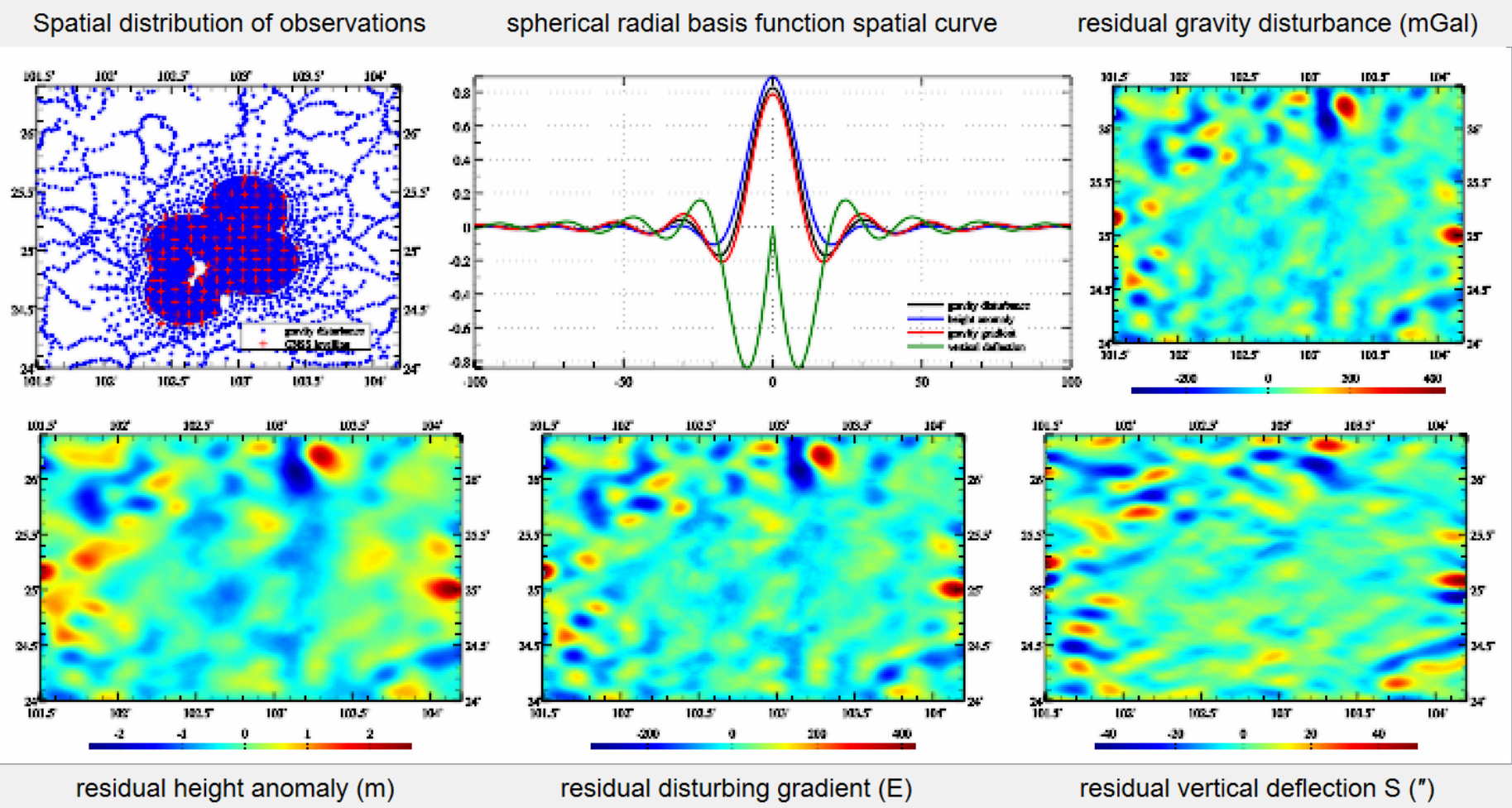
Only using the observed gravity disturbances.

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 elements. Generally, the stable solution can be achieved by 1 to 3 times cumulative SRBF approach, and the target field elements are equal to the sum of these SRBF approach solutions.
- The validity principle of once SRBF approach: (1) The residual target field element grid are 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 modelling tool on local gravity field. Various observations with heterogeneity, different altitudes, cross-distribution and land-sea coexisting can be directly employed to estimate the all-element models of gravity field without reduction, continuation and gridding.
- The program has strong capacity on the detection of observation gross errors, measurement of external accuracy indexes and control of computation performance.



# (4) All-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 SBRF center 100km

Reuter network level K 3600

Select the adjustable observations height anomaly (m)

Contribution rate  $\kappa$  of adjustable observations 1.00

Open the ellipsoidal height grid file of calculation surface

of file header, whose format: observation type (0~5), source observation mean, standard deviation, minimum, maximum, residual observation mean, standard deviation, minimum, maximum. The record format: ID, longitude, latitude, ellipsoidal height, residual observation, source observation, observation type, weight.

>> The parameter settings have been entered into the system!  
 \*\* Click the [Start Computation] control button, or the [Start Computation] tool button...

>> Computation start time: 2024-09-28 18:36:27

>> Complete the computation!

>> Computation end time: 2024-09-28 18:41:35

>> The program outputs the all-element grid files into the current directory. These grid files include the residual gravity disturbance  $\eta_{rga}$  (mGal), residual height anomaly  $\eta_{ksi}$  (m), residual gravity anomaly  $\eta_{gra}$  (mGal), residual disturbing gravity gradient  $\eta_{grr}$  (E, radial) and residual vertical deflection vector  $\eta_{dft}$  (", SW), where \* is the output file name, and whose grid specification are the same as the input ellipsoidal height grid of calculation surface.

>> 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: ID, 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 0.0196 standard deviation 12.9866 minimum -80.4161 maximum 64.8276  
 >> Type 1 of source observations: mean -0.0071 standard deviation 0.2768 minimum -0.6571 maximum 0.6846  
 \*\* Residual observations: mean -0.0002 standard deviation 0.0276 minimum -0.1059 maximum 0.0768

Solution of normal equation LU triangular decomposition

Save the results as Import setting parameters Start Computation

ID	lon	lat	ellipshgt	gravity disturbance(mGal)	height anomaly(m)	gravity anomaly(mGal)	gravity gradient(E)	vertical deflection
1	101.50417	24.00417	-35.528	-40.8686	-0.3641	-40.8686	3.2540	
2	101.51250	24.00417	-35.519	-47.9108	-0.4135	-47.9108	3.2540	
3	101.52083	24.00417	-35.510	-55.2656	-0.4640	-55.2656	3.2540	
4	101.52917	24.00417	-35.501	-64.0905	-0.5229	-64.0905	3.1833	
5	101.53750	24.00417	-35.491	-73.4852	-0.5848	-73.4852	3.1022	
6	101.54583	24.00417	-35.481	-72.3357	-0.5786	-72.1577	2.3703	

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



## Algorithm of gravity field approach using SRBFs

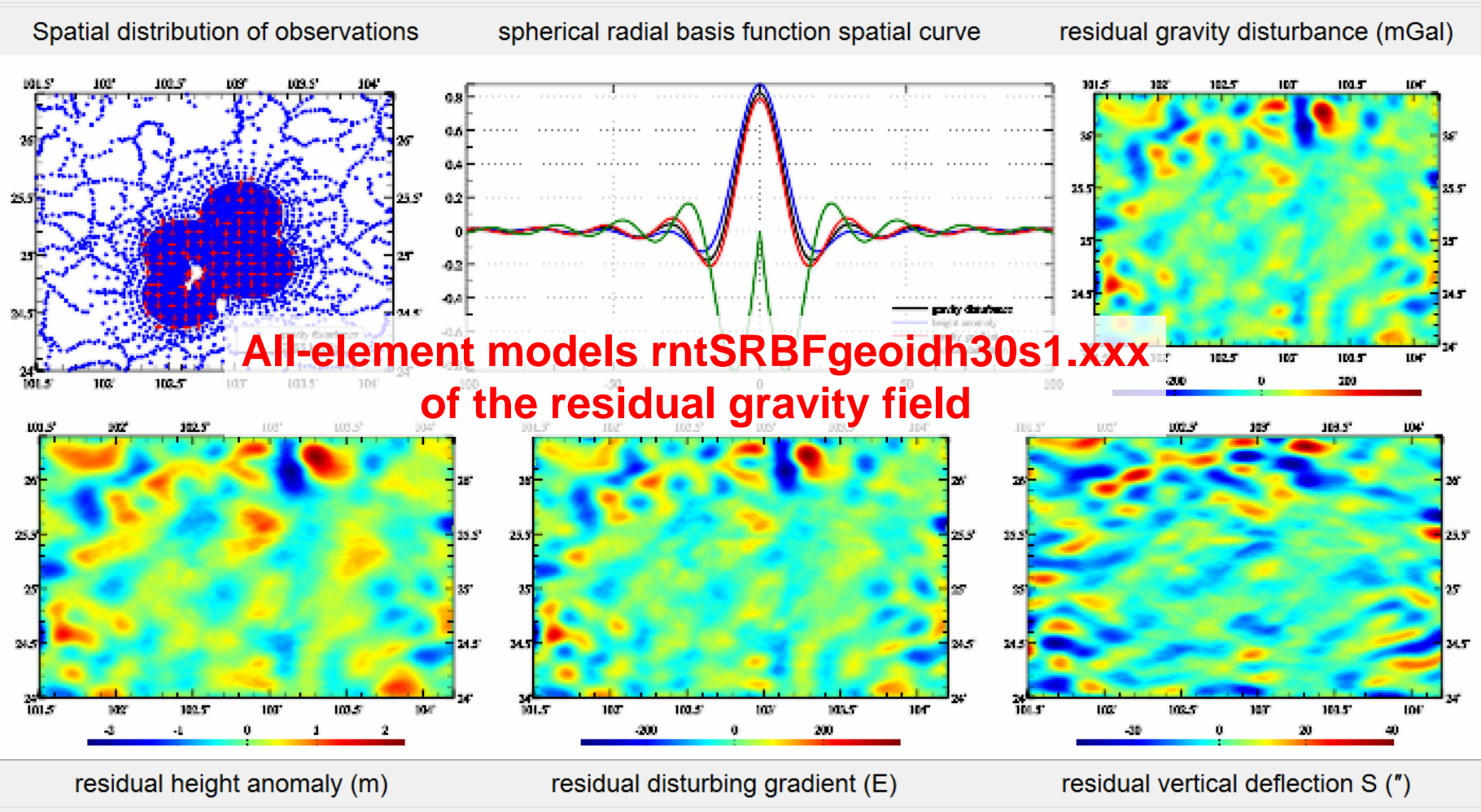
After the first estimation is completed, it is recommended to employ the output residual observation file \*.chs as the input observation file again to refine target field elements. Generally, the stable solution can be achieved by 1 to 3 times cumulative SRBF approach, and the target field elements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

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

The program has strong capacity on the detection of observation gross errors, measurement of external accuracy indexes and control of computation performance.



All-element models rntSRBFgeoidh30s1.xxx of the residual gravity field

# (5) All-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 Poisson wavelet kernel

Order m 5

Minimum degree 540

Maximum degree 5400

Burial depth of Bjerhammar sphere 6.0km

Action distance of SBRF center 60km

Reuter network level K 5400

Select the adjustable observations height anomaly (m)

Contribution rate  $\kappa$  of adjustable observations 1.00

Open the ellipsoidal height grid file of calculation surface

of file header, whose format: observation type (0~5), source observation mean, standard deviation, minimum, maximum, residual observation mean, standard deviation, minimum, maximum. The record format: ID, longitude, latitude, ellipsoidal height, residual observation, source observation, observation type, weight.

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

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

>> Computation start time: 2024-09-28 19:56:11

>> Complete the computation!

>> Computation end time: 2024-09-28 20:03:11

>> The program outputs the all-element 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, and whose grid specification are the same as the input ellipsoidal height grid of calculation surface.

>> 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: ID, 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 0.0196 standard deviation 12.9866 minimum -80.4161 maximum 64.8276

\*\* Residual 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

\*\* Residual observations: mean 0.0008 standard deviation 0.0147 minimum -0.0511 maximum 0.0345

**Input the file rntSRBFgeoidh30s1.chs output from the previous step.**

Solution of normal equation LU triangular decomposition

Save the results as Import setting parameters Start Computation

ID	lon	lat	ellipshgt	gravity disturbance(mGal)	height anomaly(m)	gravity anomaly(mGal)	gravity gradient(E)	vertical deflection	
1	101.50417	24.00417	-35.528	-12.7117	-0.0168	-12.7065	-97.1597	-0.6515	-0.5321
2	101.51250	24.00417	-35.519	-6.6258	-0.0077	-6.6234	-54.9695	-1.2702	-1.0260
3	101.52083	24.00417	-35.510	2.3531	0.0053	2.3505	9.9592	-2.0661	-1.4528
4	101.52917	24.00417	-35.501	11.0246	0.0174	11.0193	11.2222	-2.8001	-1.5321
5	101.53750	24.00417	-35.491	16.8356	0.0255	16.8217	117.3662	-3.7229	-1.4204
6	101.54583	24.00417	-35.481	17.2077	0.0259	17.1991	15.2461	-2.1861	-1.4204

**0.0147m  $\approx$  1.5cm** The accuracy index (SD) of geoid modeling.

## Algorithm of gravity field approach using SRBFs

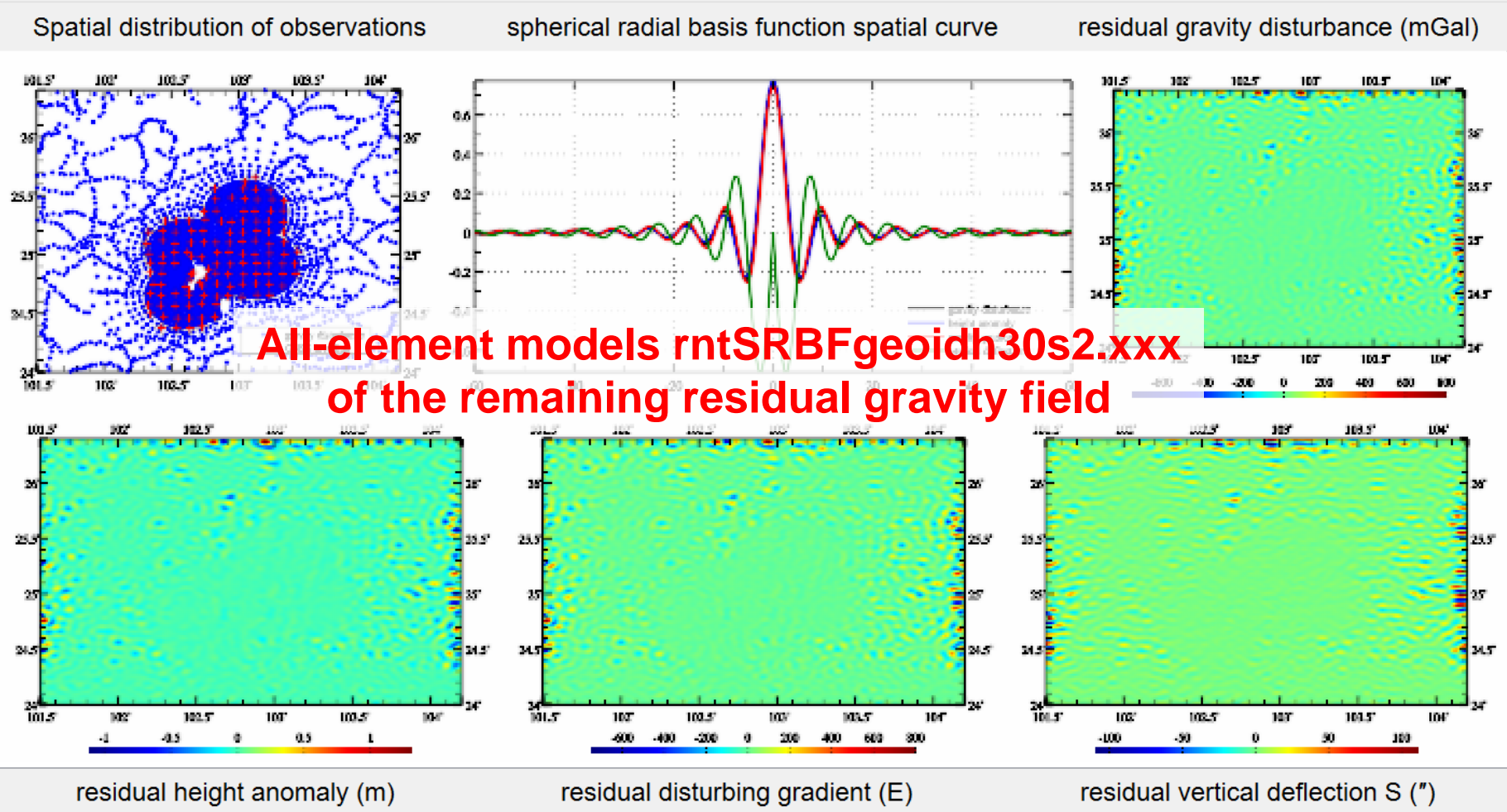
After the first estimation is completed, it is recommended to employ the output residual observation file \*.chs as the input observation file again to refine target field elements. Generally, the stable solution can be achieved by 1 to 3 times cumulative SRBF approach, and the target field elements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

The validity principle of once SRBF approach: (1) The residual target field element grid are 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 modelling tool on local gravity field. Various observations with heterogeneity, different altitudes, cross-distribution and land-sea coexisting can be directly employed to estimate the all-element models of gravity field without reduction, continuation and gridding.

The program has strong capacity on the detection of observation gross errors, measurement of external accuracy indexes and control of computation performance.



**All-element models rntSRBFgeoidh30s2.xxx of the remaining residual gravity field**

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

Gridding of discrete geodetic data by simple interpolation | Interpolation of vector grid from two attributes in geodetic records | Gridding of high-resolution record attributes by direct averaging | Constructing of general geodetic grid file | **Extracting of data according to latitude and longitude range**

Open a source data file | Process batch files with same specifications | Save computation process as

The source file format: geodetic grid file

```
>> [Function] According to the given latitude and longitude range, extract data from the geodetic discrete points file, grid file, or vectors grid file. The program can extract data from batch files.
>> Open the source data file C:/PAGravf4.5_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/rntSRBFgeoidh30s1.rga.
** Look at the input file information in the text box below, set the file format parameters.....
>> Save the results as C:/PAGravf4.5_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/geoidh30s1.rga.
>> Setting parameters have been imported in the program!
** Click the control button [Start computation], or the tool button [Start computation]....
>> Computation start time: 2023-04-01 11:40:05
>> Computation end time: 2023-04-01 11:40:08
>> Complete the computation!
```

Maximum latitude: 25.700° | Minimum longitude: 102.200° | Maximum longitude: 103.700° | Minimum latitude: 24.300°

Save the results as | Import setting parameters | Start computation

102.200000	103.700000	24.300000	25.700000	8.333333333E-03	8.333333333E-03
-38.0078	-42.1226	-39.3375	-37.6521	-33.6938	-29.3611
-12.0662	-15.4777	-24.9972	-31.4477	-36.3290	-33.9446

Calculation of global geopotential model and its spectral character analysis

Geopotential model | Open calculation points | Import parameters | Save as | Start Computation | Follow example

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: Ellipsoidal height grid file

Open ellipsoidal height grid file of calculation surface

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)

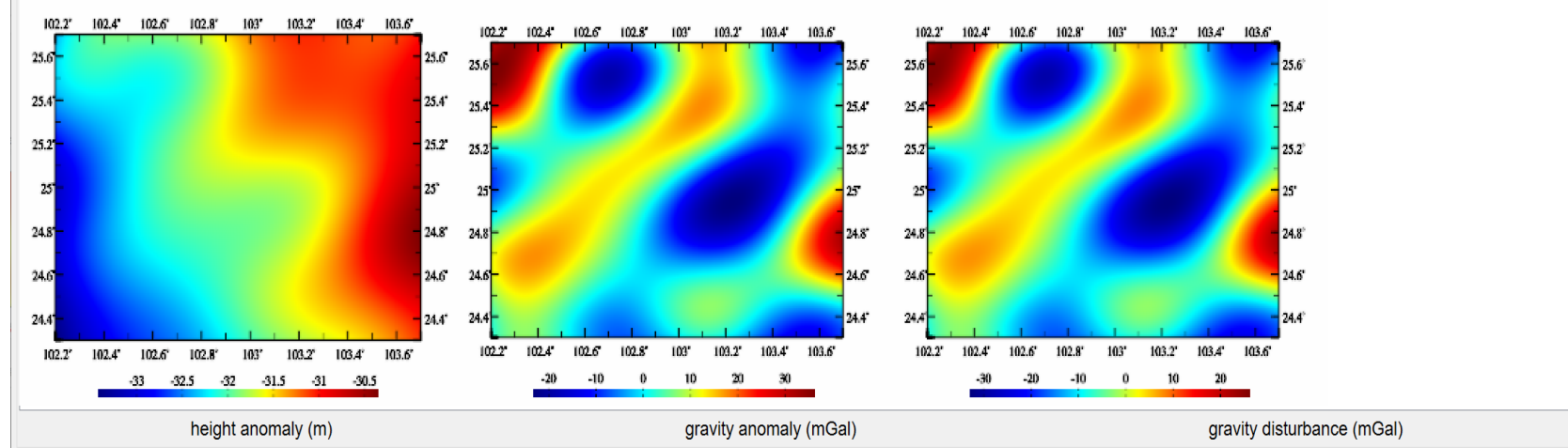
Minimum degree: 2 | Maximum degree: 540

Extract elements to be plot | Plot

```
>> Open global geopotential coefficient model file C:/PAGravf4.5_win64en/data/EGM2008.gfc.
** The window below only shows the geopotential coefficients data with no more than 2000 rows in it.
>> Open ellipsoidal height grid file of calculation surface C:/PAGravf4.5_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/mdgeoidh30srst.dat.
>> Save the results as C:/PAGravf4.5_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/GMgeoidh30s540.ttt.
** The record format: ID (point no/name), longitude, latitude, ellipsoidal height, several columns of the model values of anomalous field elements.
** The program also outputs (residual) height anomaly (*.ksi), gravity anomaly (*.gra), gravity disturbance (*.rga), vertical deflection vector (*.dft), disturbing gravity gradient (*.grr), tangential gravity gradient vector (*.hgd) or Laplace operator (*.lps) model value grid file into the current directory.
Where * is the output file name entered in the interface, and the program outputs the corresponding (residual) model value grid file according to the selected gravity field element type.
>> The parameter settings have been imported 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: 2023-04-01 11:42:23
```

**All-element models geoidh30srst.xxx** | **Residuals geoidh30s1** | **Remaining residuals geoidh30s2** | **Reference models GMgeoidh30s540**

1	102.20417	24.30417	-33.473	-33.4311	2.0759	-8.1920	-1.1911	-7.3808	4.3302
2	102.21250	24.30417	-33.445	-33.4011	2.6900	-7.5686	-1.2046	-7.2536	4.6353
3	102.22083	24.30417	-33.417	-33.3716	3.2706	-6.9790	-1.2167	-7.1219	4.9167
4	102.22917	24.30417	-33.390	-33.3427	3.8166	-6.4241	-1.2274	-6.9861	5.1736
5	102.23750	24.30417	-33.363	-33.3143	4.3272	-5.9048	-1.2367	-6.8465	5.4055
6	102.24583	24.30417	-33.336	-33.2865	4.8015	-5.4220	-1.2446	-6.7034	5.6119
7	102.25417	24.30417	-33.309	-33.2594	5.2389	-4.9763	-1.2512	-6.5572	5.7923
8	102.26250	24.30417	-33.282	-33.2328	5.6388	-4.5682	-1.2564	-6.4083	5.9464
9	102.27083	24.30417	-33.256	-33.2068	6.0007	-4.1983	-1.2603	-6.2570	6.0740
10	102.27917	24.30417	-33.230	-33.1815	6.3243	-3.8669	-1.2629	-6.1038	6.1747



When the minimum and maximum degree n to be set is equal, the program calculates the contribution of the degree n geopotential coefficients to the anomalous gravity field element, which can be employed to analyze and evaluate the spectral and space properties of the geopotential coefficient model.

Open file | Save as | Import parameters | Start computation | Save process | Follow example

Weighted operation on two specified attributes in record file | **Weighted operation on two geodetic grid files** | Weighted operation on two vector grid files | Weighted operation on two harmonic coefficient files

Open geodetic grid file 1 | Open geodetic grid file 2

Select operation mode: Plus +

Set weight: The first weight 1.00 | The second weight 1.00

Vector grid operation

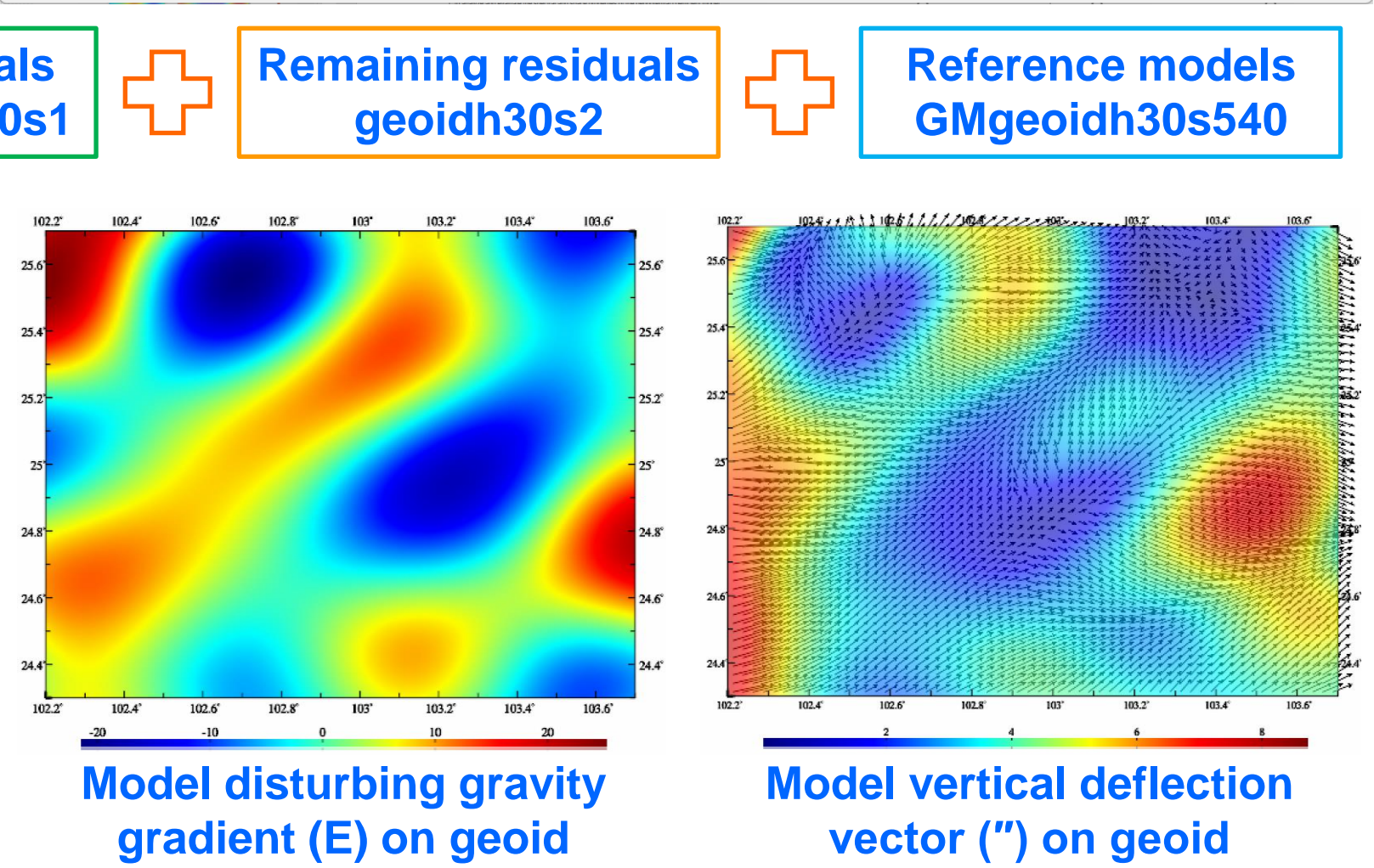
Save the results as | Import setting parameters | Start computation

```
>> [Function] Perform weighted plus, minus, or multiply operation on grid elements in two (vector) grid files with the same specifications.
>> Open geodetic grid file 1 C:/PAGravf4.5_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/geoidh30s1.ksi.
>> Open geodetic grid file 2 C:/PAGravf4.5_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/geoidh30s2.ksi.
>> Save the results as C:/PAGravf4.5_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/ttt.dat.
>> The parameter settings have been entered into the system!
** Click the [Start Computation] control button, or the [Start Computation] tool button....
>> Computation start time: 2023-04-01 11:42:23
>> Complete the computation!
>> Computation end time: 2023-04-01 11:42:23
>> Open geodetic grid file 1 C:/PAGravf4.5_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/ttt.dat.
>> Open geodetic grid file 2 C:/PAGravf4.5_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/GMgeoidh30s540.ksi.
>> Save the results as C:/PAGravf4.5_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/geoidh30srst.ksi.
>> The parameter settings have been entered into the system!
** Click the [Start Computation] control button, or the [Start Computation] tool button....
>> Computation start time: 2023-04-01 11:42:58
>> Complete the computation!
>> Computation end time: 2023-04-01 11:42:58
```

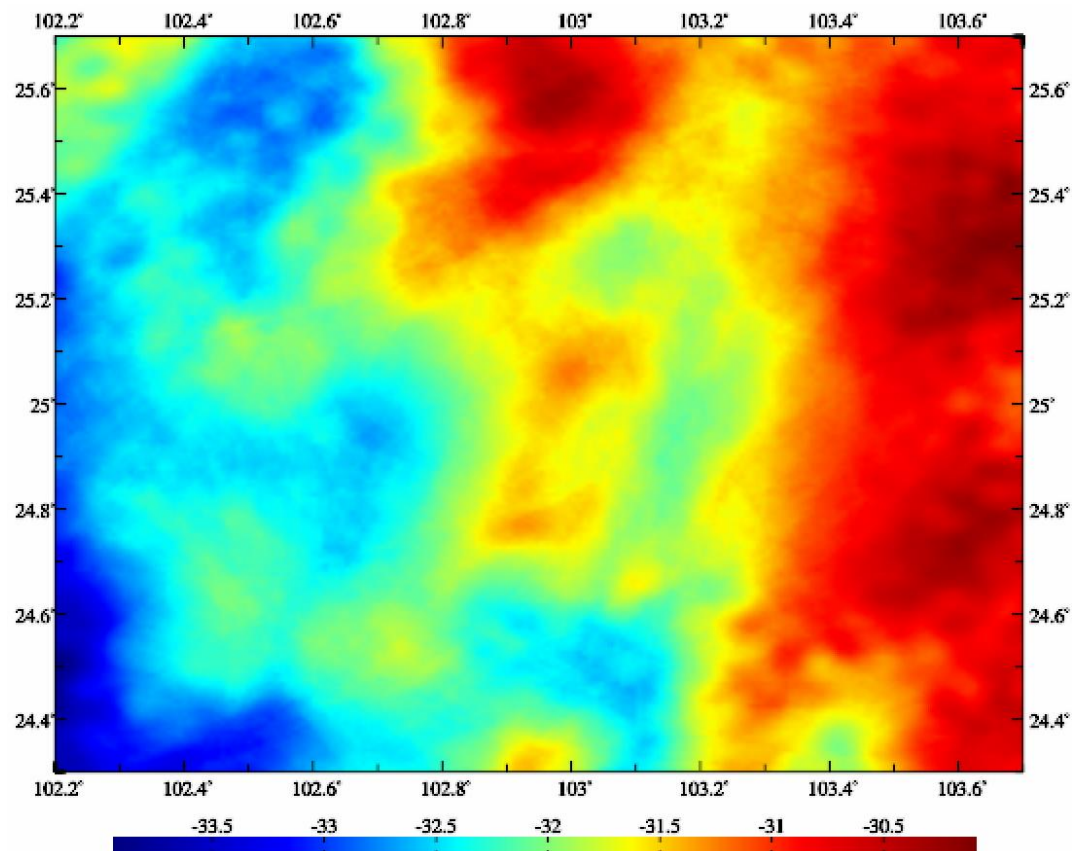
Save the results as | Import setting parameters | Start computation

Display of the input-output file:

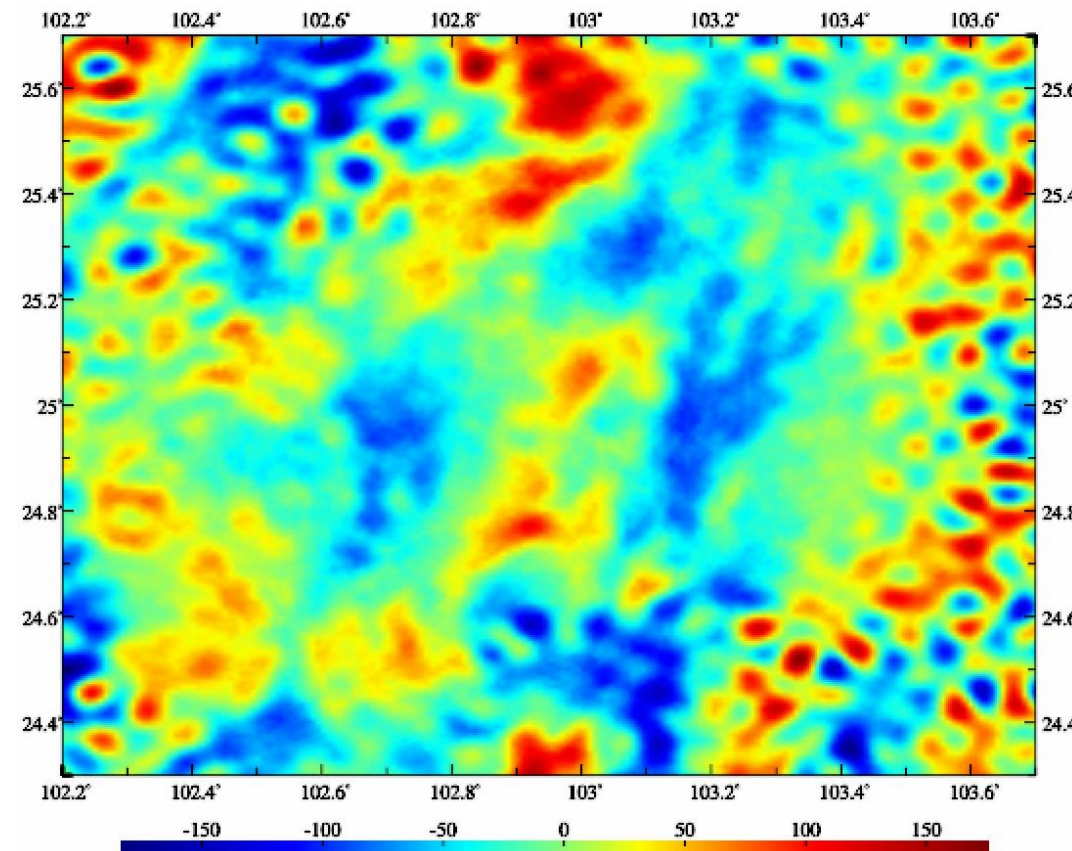
102.200000	103.700000	24.300000	25.700000	8.333333333E-03	8.333333333E-03
-33.8572	-33.8961	-33.8570	-33.8439	-33.8044	-33.7535
-33.4193	-33.4537	-33.5636	-33.6330	-33.6730	-33.6258
-33.4220	-33.4190	-33.4155	-33.4695	-33.4733	-33.4755
-32.8481	-32.7738	-32.7690	-32.6707	-32.5086	-32.4707
-32.2146	-32.1955	-32.1755	-32.1590	-32.2294	-32.2429
-31.8772	-31.8236	-31.7913	-31.6840	-31.5800	-31.4463
-31.0498	-31.1279	-31.2068	-31.2749	-31.3081	-31.4348
-33.0713	-33.0868	-33.1058	-33.0298	-33.0585	-32.9076
-31.5739	-31.4817	-31.3740	-31.2917	-31.2019	-31.1574
-31.7603	-31.8834	-31.9396	-32.0052	-32.0125	-32.0342
-31.9849	-31.8533	-31.7847	-31.6367	-31.4751	-31.3717
-30.2568	-30.1617	-30.1519	-30.1666	-30.1718	-30.1843
-33.8563	-33.8748	-33.8576	-33.8248	-33.7955	-33.7772
-33.3275	-33.3809	-33.4623	-33.5570	-33.6590	-33.6218
-33.4482	-33.4024	-33.4237	-33.4196	-33.4811	-33.4403
-32.8417	-32.8315	-32.7314	-32.6070	-32.6180	-32.5836
-32.2523	-32.2399	-32.2297	-32.2919	-32.2882	-32.3153
-31.8892	-31.8941	-31.8002	-31.7070	-31.6136	-31.4632
-31.0057	-31.1300	-31.1940	-31.2203	-31.3777	-31.4416
-32.9958	-33.0262	-33.0206	-33.0004	-32.9841	-32.9024
-32.8134	-32.7078	-32.5839	-32.4764	-32.3104	-32.1883



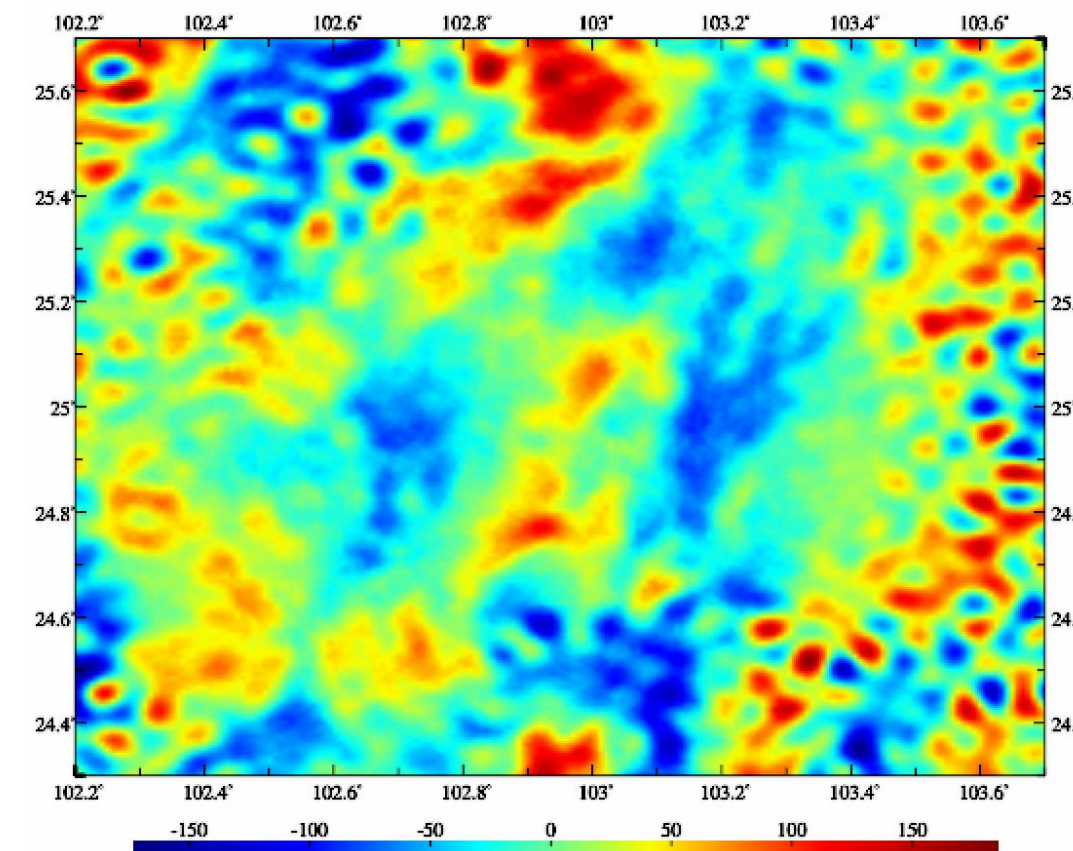
# 30"×30" all-element models of gravity field on geoid



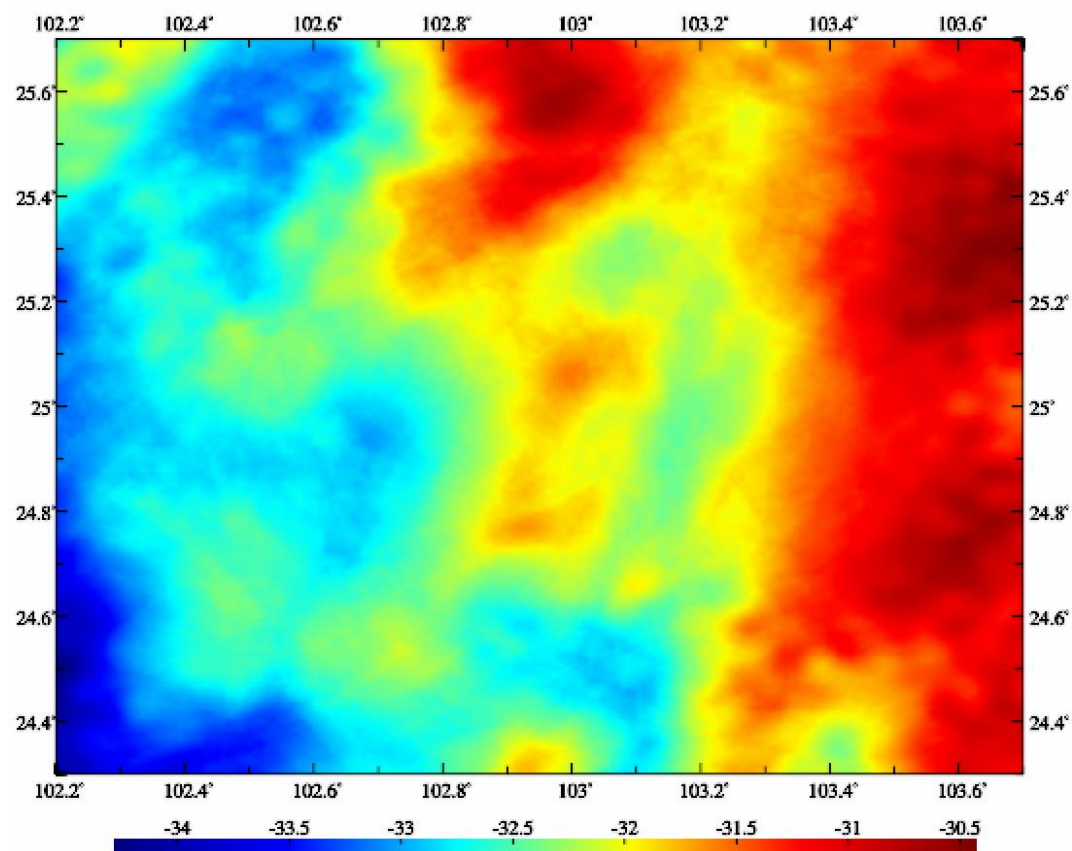
Geoid (m, Global datum)



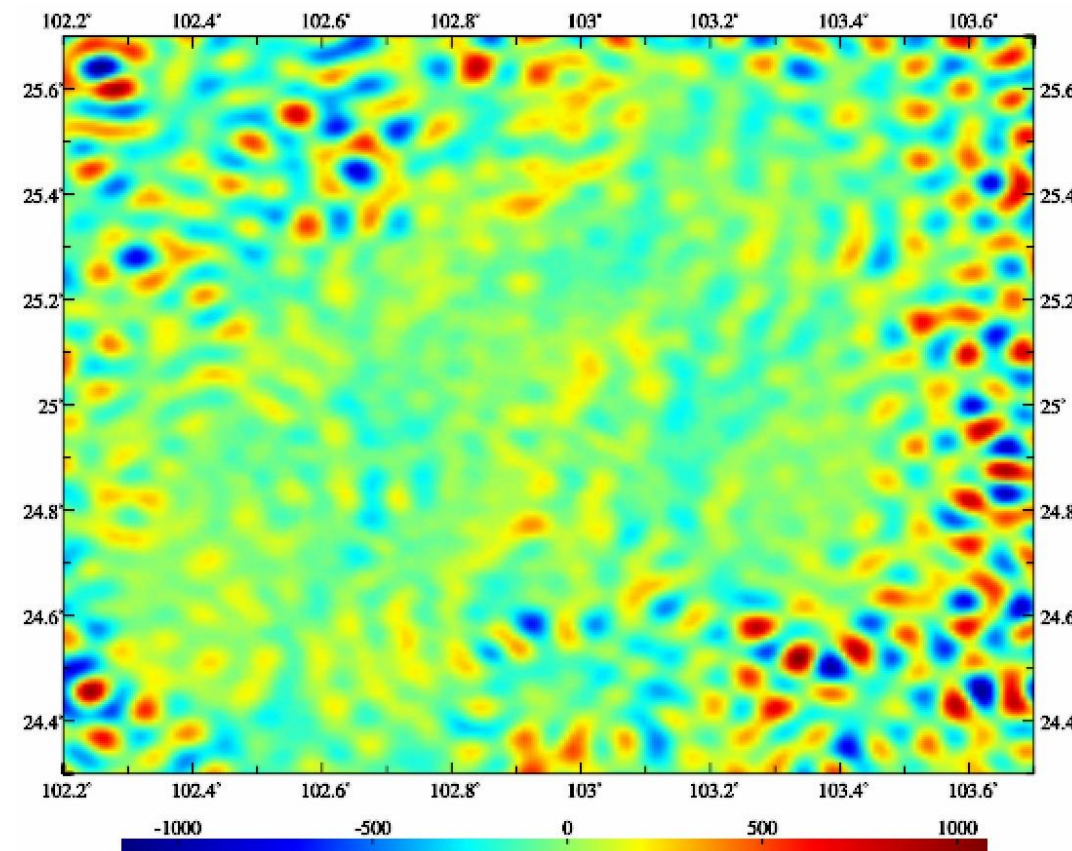
gravity disturbance (mGal)



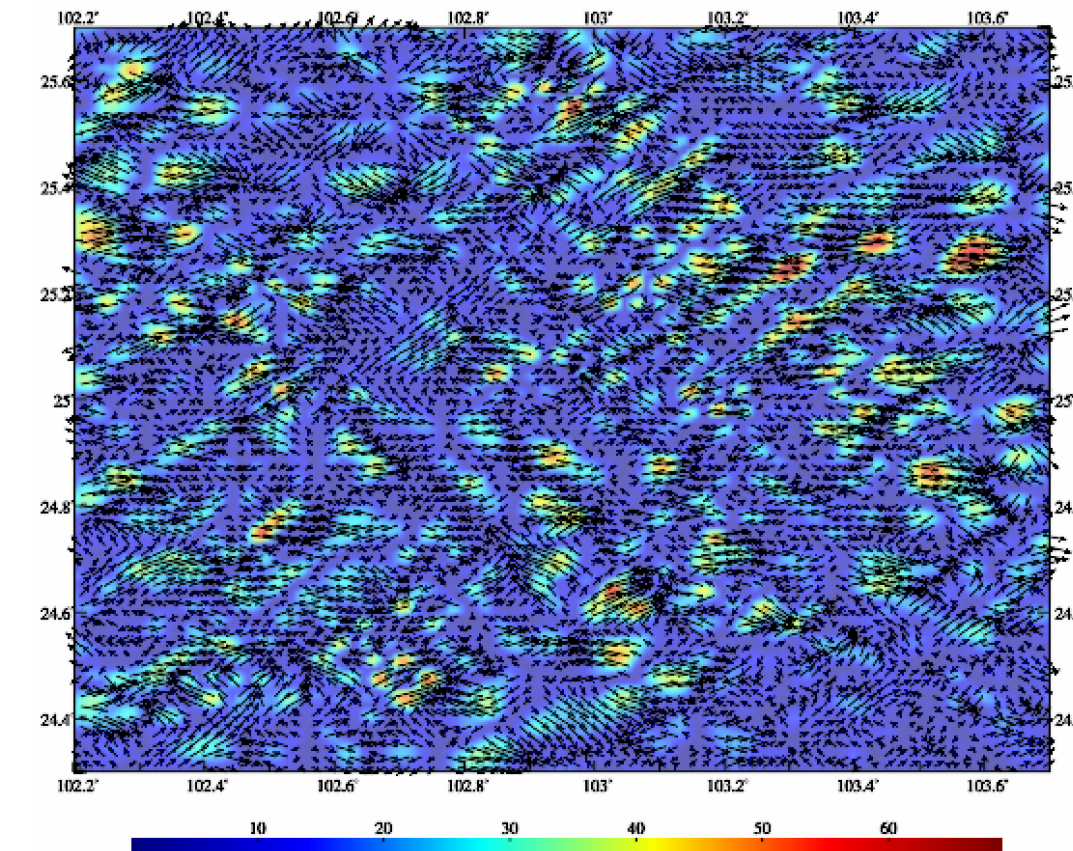
gravity anomaly (mGal)



Geoid (m, Regional datum)



disturbing gravity gradient (E)



vertical deflection vector (")

Observation file Save as Import parameters Start Computation Save process Follow example

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 SBRF center 100km

Reuter network level K 3600

Select the adjustable observations height anomaly (m)

Contribution rate  $\kappa$  of adjustable observations 1.00

Open the ellipsoidal height grid file of calculation surface

In step (3) to step (6) above, the input data file and all the parameters 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.

```
>> Complete the computation!
>> Computation end time: 2024-09-28 20:24:03
>> The program outputs the all-element 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, and whose grid specification are the same as the input ellipsoidal height grid of calculation surface.
>> 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: ID, 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 0.0196 standard deviation 12.9866 minimum -80.4161 maximum 64.8276
>> Type 1 of source observations: mean -0.0071 standard deviation 0.2768 minimum -0.6571 maximum 0.6846
** Residual observations: mean -0.0002 standard deviation 0.0276 minimum -0.1059 maximum 0.0768
```

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

ID	lon	lat	ellipshgt	gravity disturbance(mGal)	height anomaly(m)	gravity anomaly(mGal)	gravity gradient(E)	vertical deflection
1	101.50417	24.00417	2427.222	-35.5841	-0.3173	-35.4866	-50.2992	6.9434
2	101.51250	24.00417	2480.981	-41.6169	-0.3594	-41.5065	-60.1830	7.5622
3	101.52083	24.00417	2435.157	-48.2338	-0.4049	-48.1094	-71.2065	8.2217
4	101.52917	24.00417	2229.999	-56.3053	-0.4602	-56.1639	-85.3176	9.0076
5	101.53750	24.00417	2032.509	-65.3908	-0.5207	-65.2308	-101.7457	9.7120
6	101.54583	24.00417	1906.019	-64.7895	-0.5187	-64.6301	-95.3891	9.2967

### Algorithm of gravity field approach using SRBFs

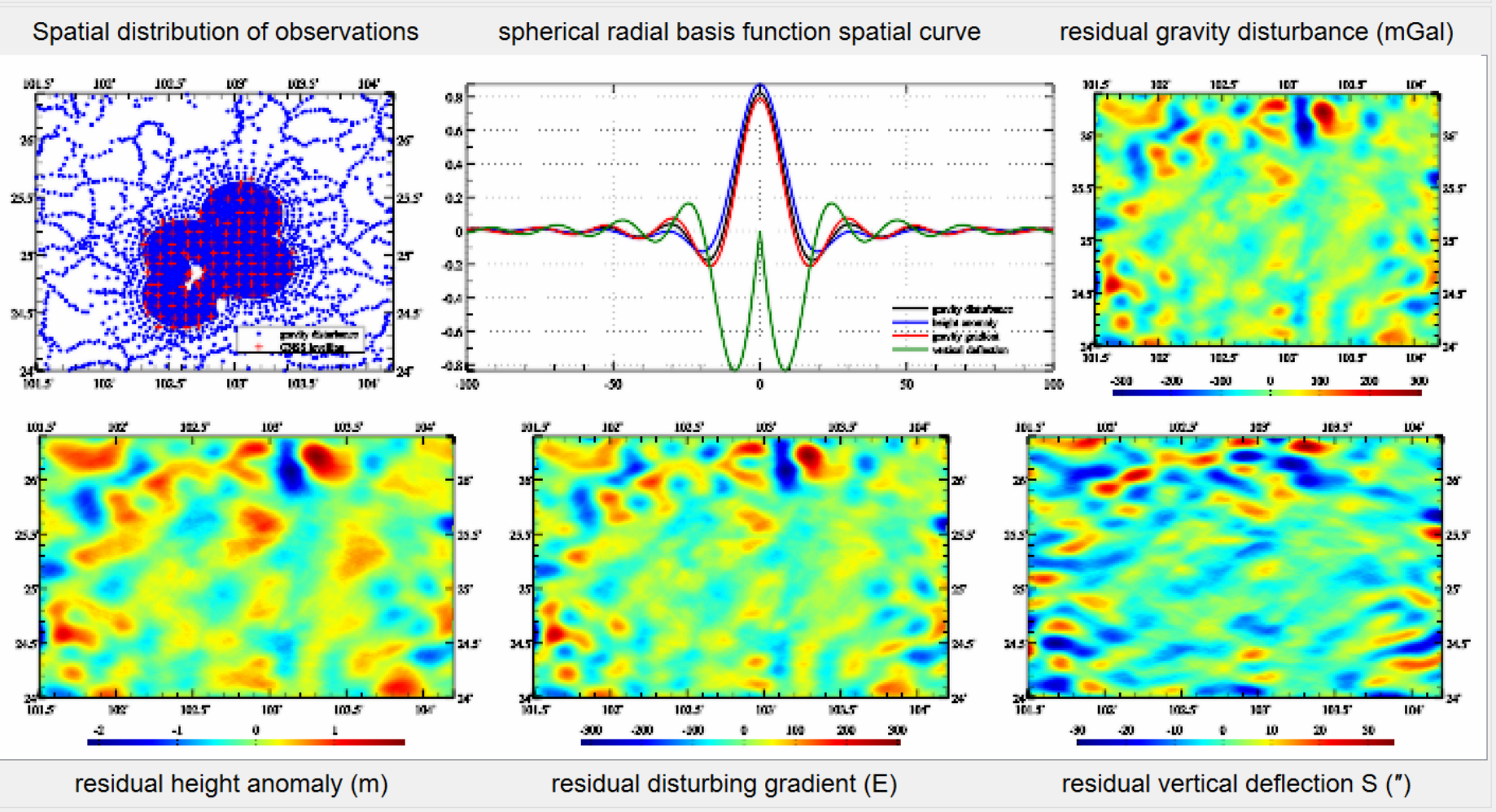
After the first estimation is completed, it is recommended to employ the output residual observation file \*.chs as the input observation file again to refine target field elements. Generally, the stable solution can be achieved by 1 to 3 times cumulative SRBF approach, and the target field elements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

The validity principle of once SRBF approach: (1) The residual target field element grid are 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.

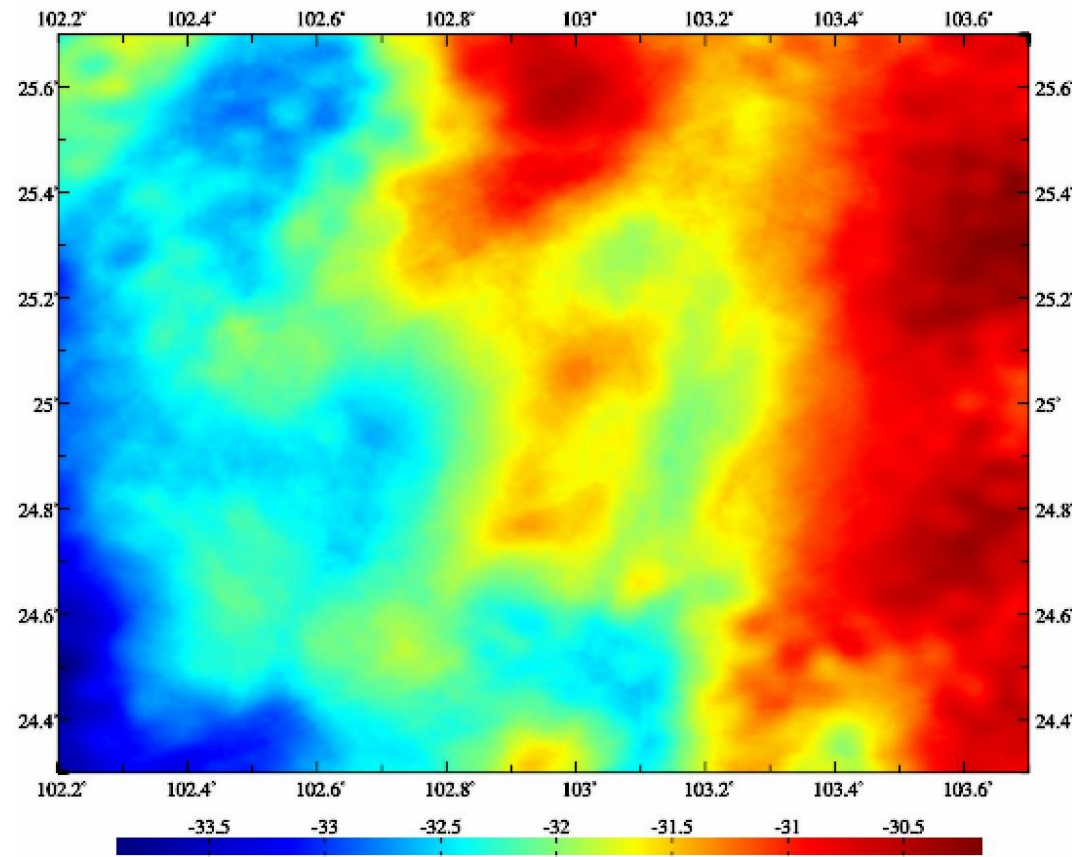
Extract data to be plot Plot →

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

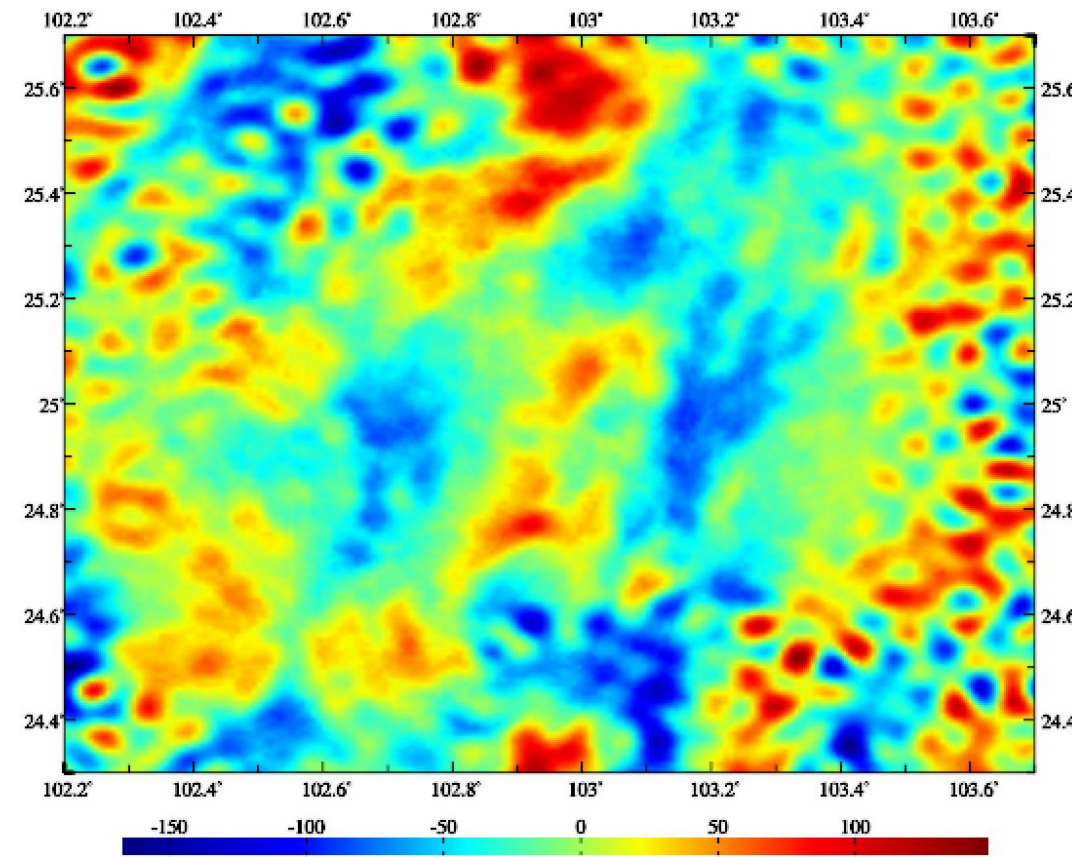
The program has strong capacity on the detection of observation gross errors, measurement of external accuracy indexes and control of computation performance.



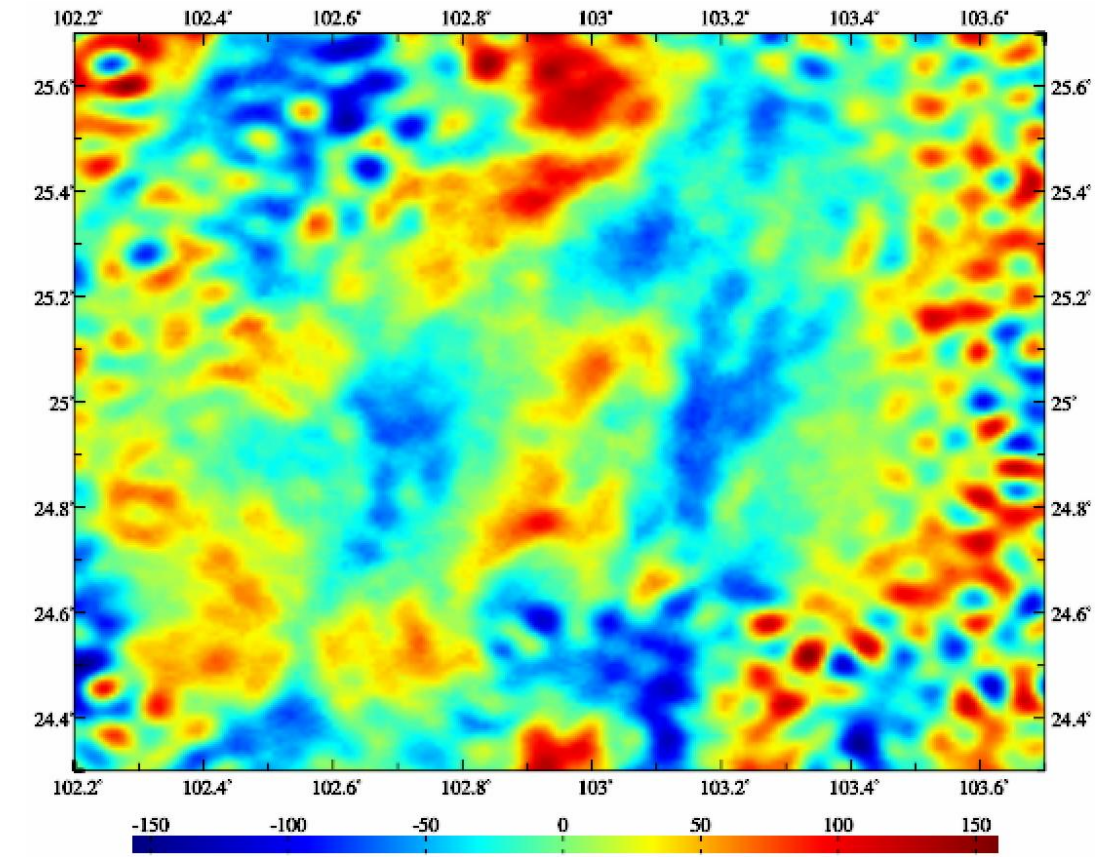
# 30"×30" full element models of gravity field on terrain surface



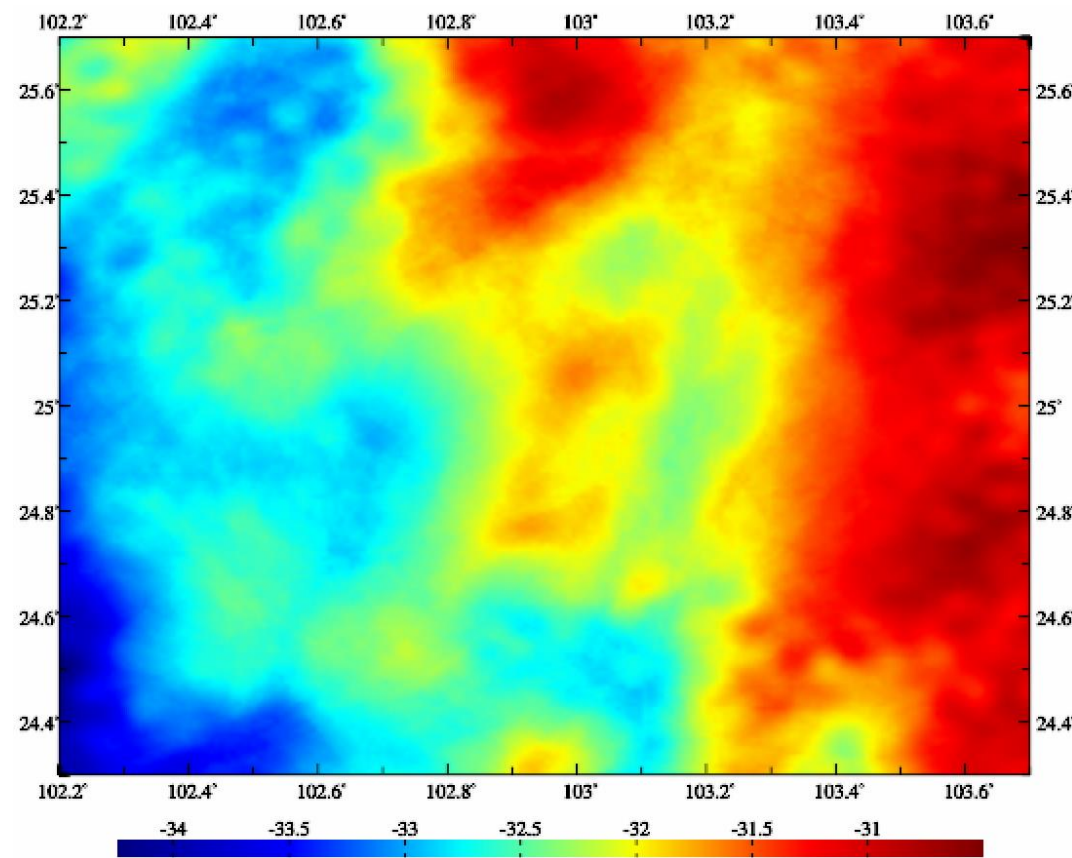
Height anomaly (m, Global datum)



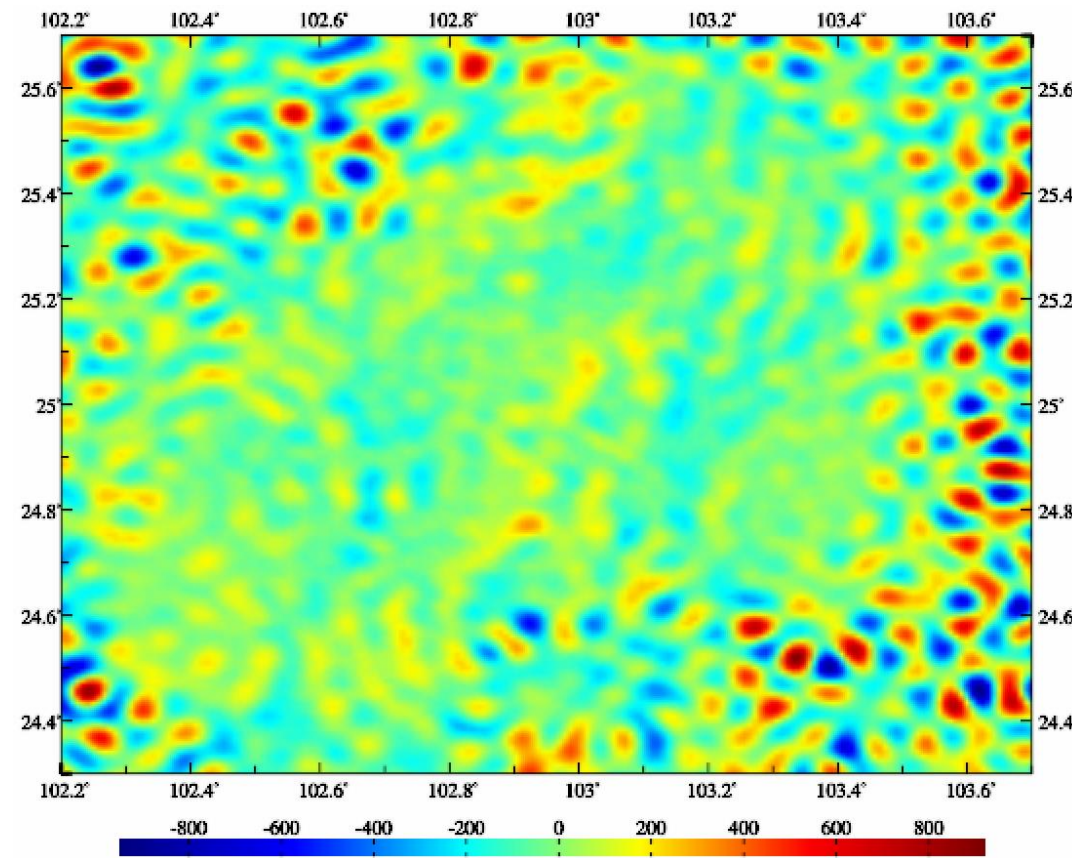
gravity disturbance (mGal)



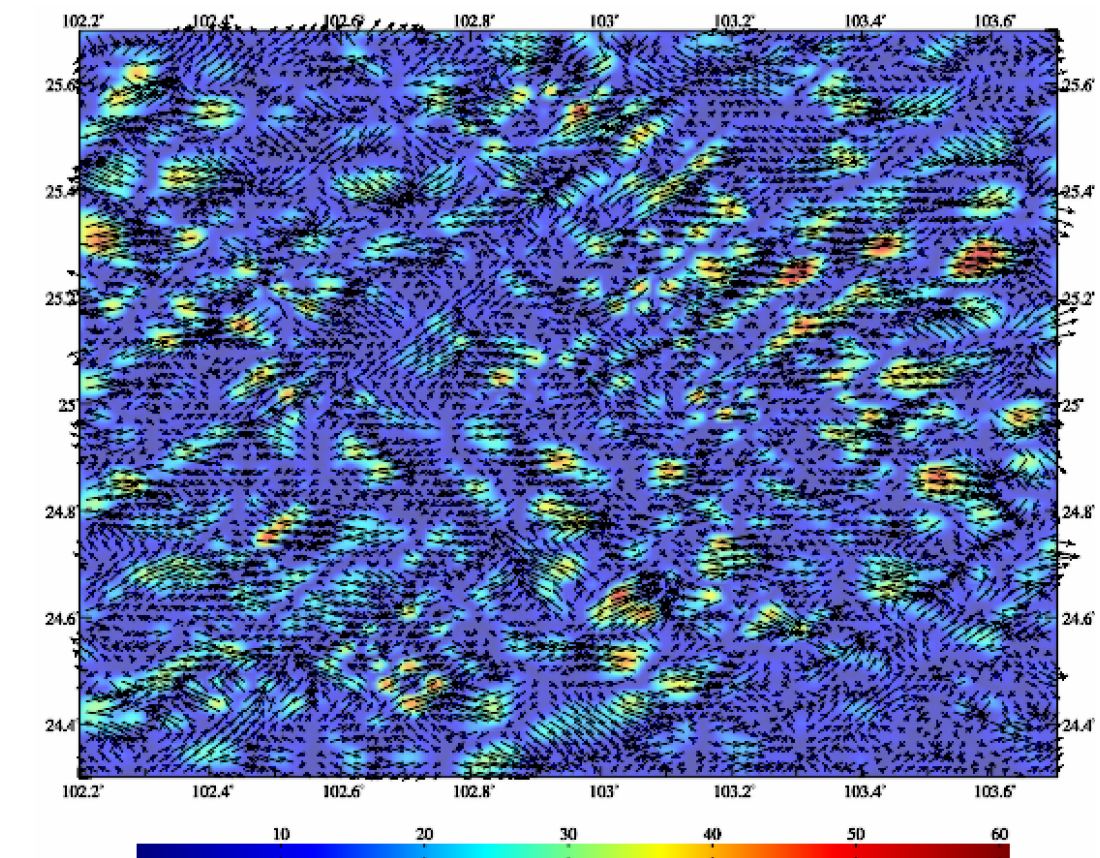
gravity anomaly (mGal)



Height anomaly (m, Regional datum)



disturbing gravity gradient (E)

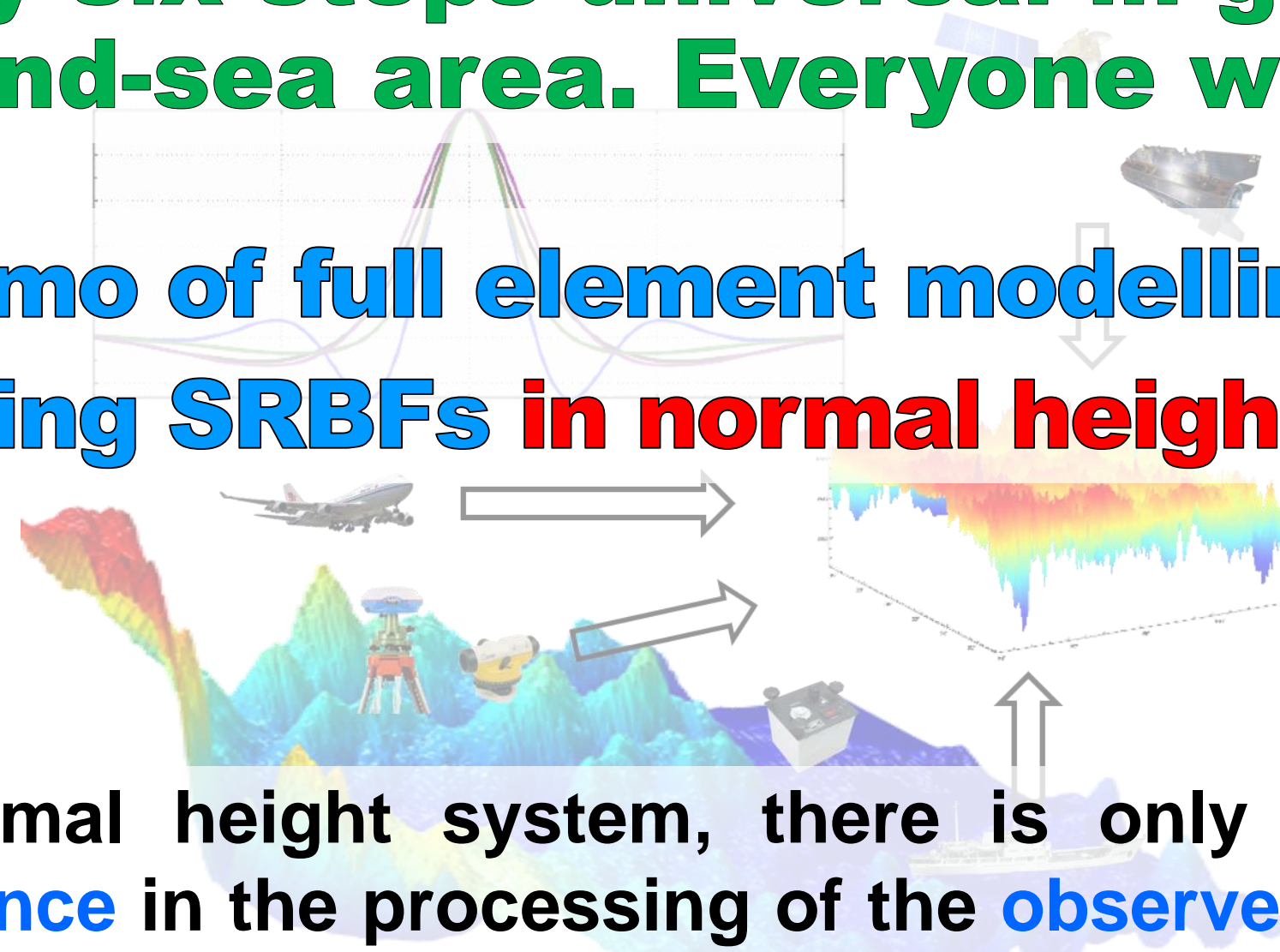


vertical deflection vector (")

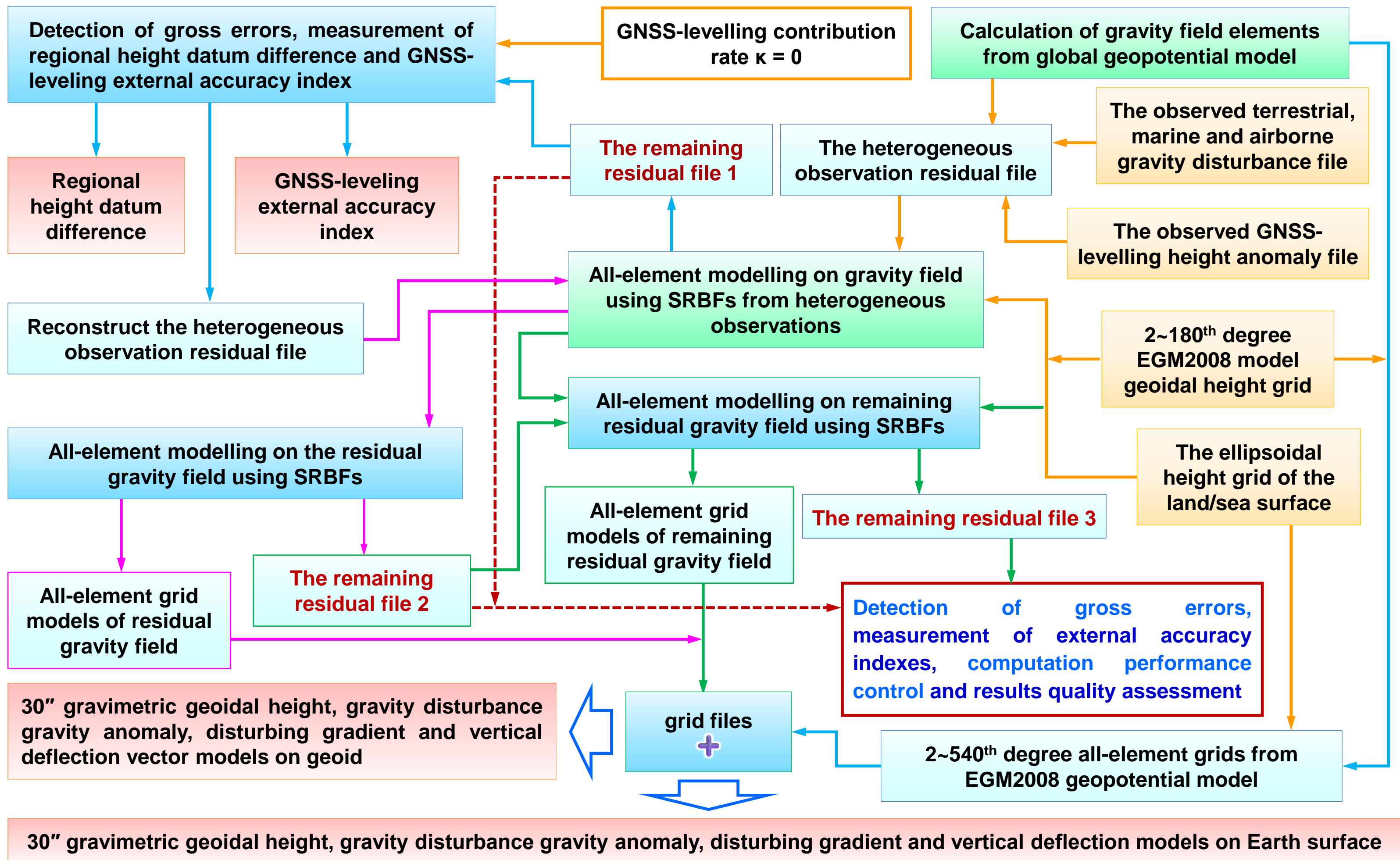
**Only six steps universal in global  
land-sea area. Everyone will !**

**Process demo of full element modelling on gravity  
field using SRBFs in normal height system**

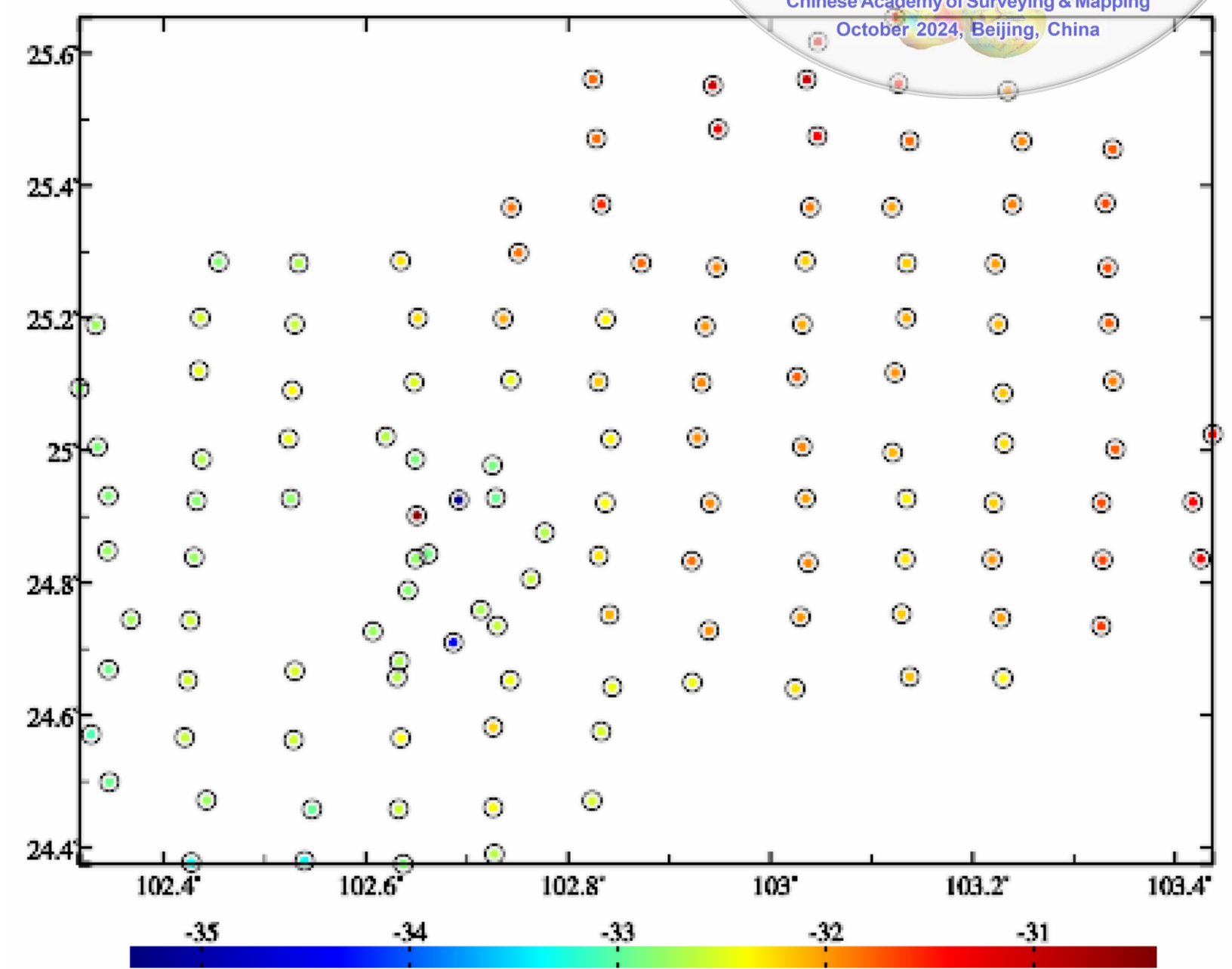
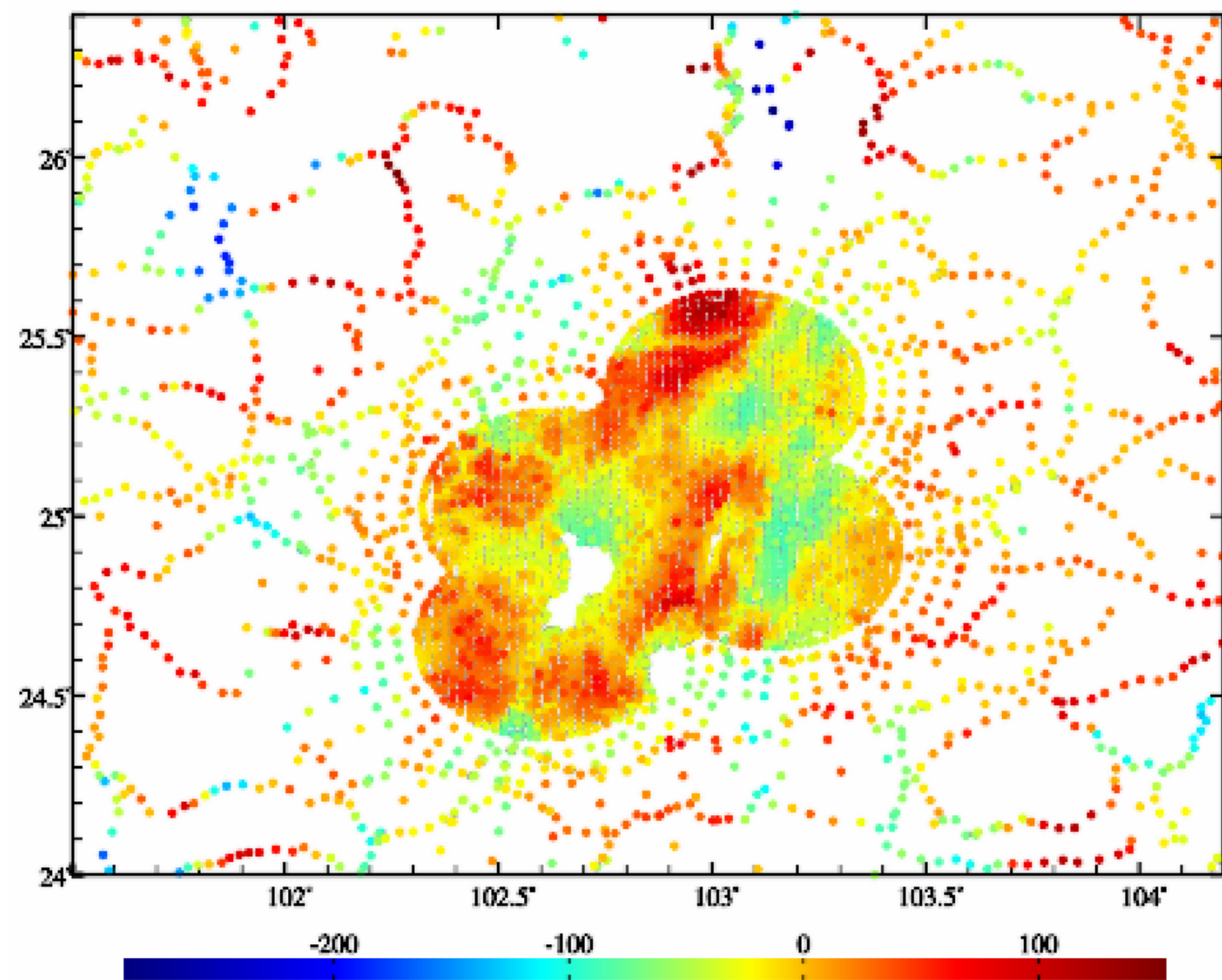
In normal height system, there is only a slight difference in the processing of the observed GNSS-leveilling data, and the other modelling processes are same with that in orthometric height system.



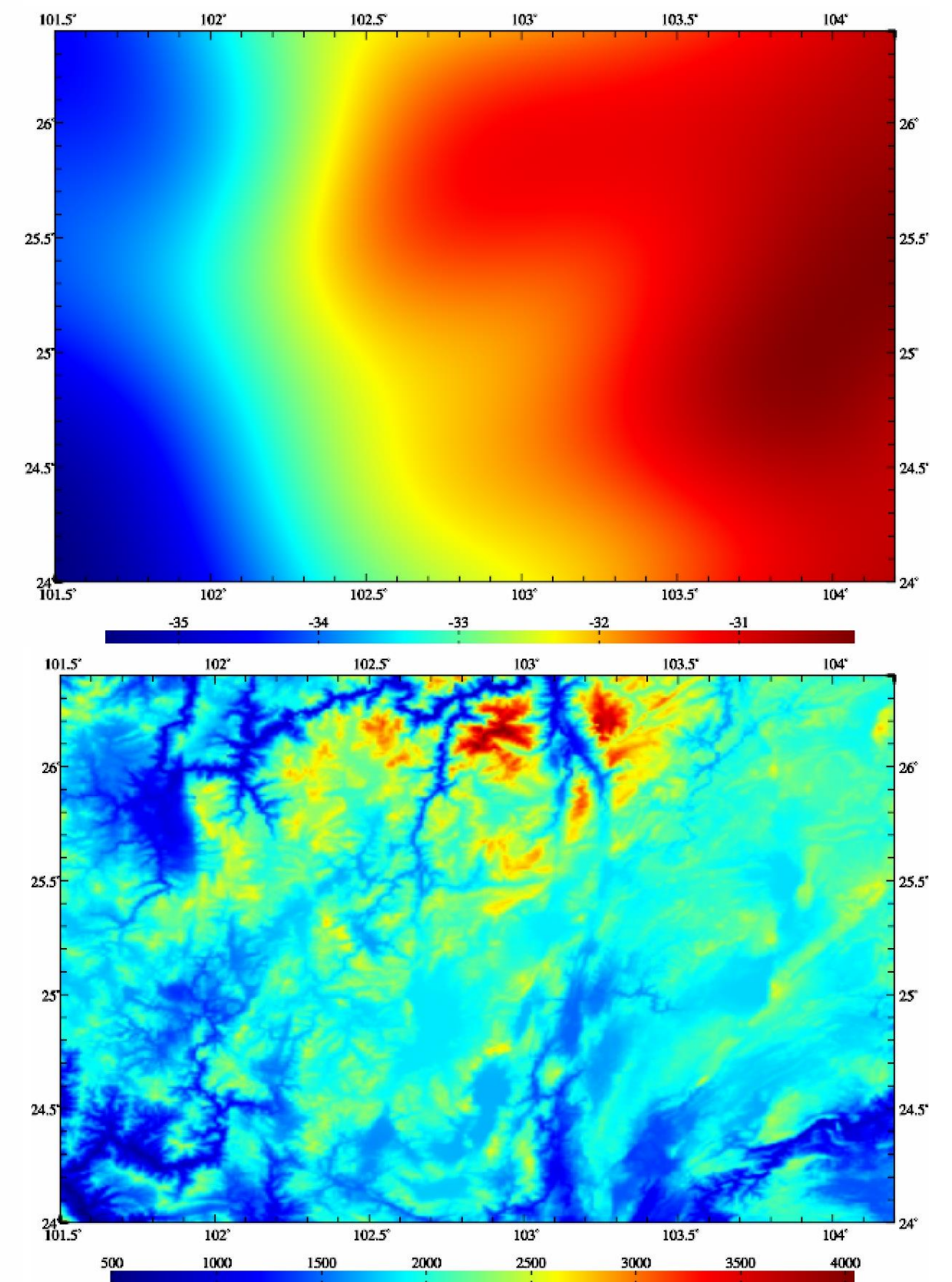
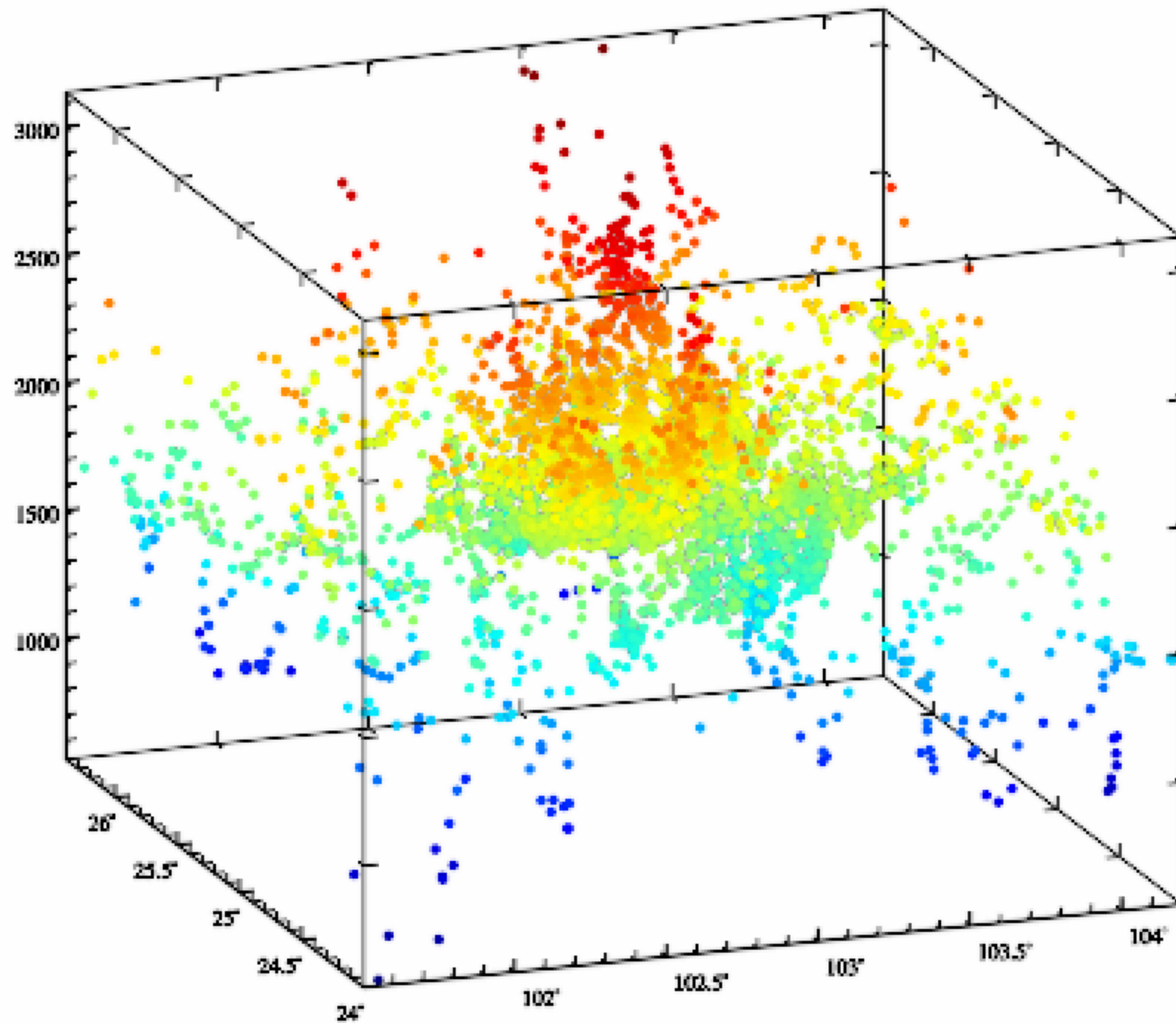




**Simple process demo of all-element modelling on gravity field using SRBFs in normal height system**



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



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

# (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

Open global geopotential coefficient model file

Select calculation file format  
Discrete calculation points file

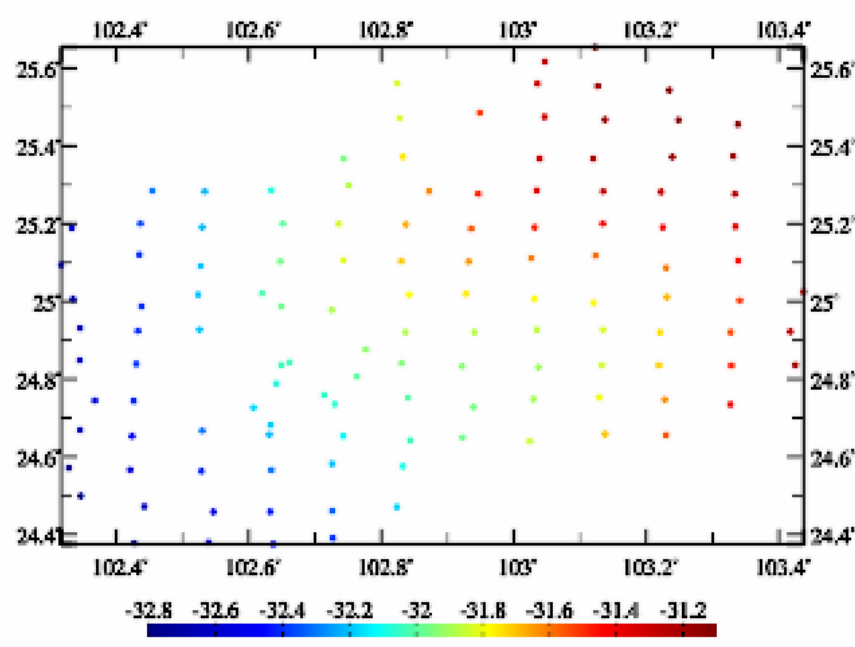
Open space calculation points file

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

Extract elements to be plot Plot



The model height anomaly (m) at the GNSS-levelling points

When the minimum and maximum degree to be set is equal, the program calculates the contribution of the degree n geopotential... can be employed to analyze and evaluate the spectral and space properties of the geopotential coefficient model.

Calculation of model value for residual terrain (complete Bouguer) effects

Save computation process as

```

** Click the [Open global geopotential coefficient model file] control button, or the [Open geopotential model] tool button...
>> Open global geopotential coefficient model file C:/PAGravf4.5_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:/PAGravf4.5_win64en/examples/Gravfmdlexercise/SRBFapprwithGNSSiksi/obsGNSSiksi.txt.
** Look at the file information in the window below and set the discrete point file format...
>> Save the results as C:/PAGravf4.5_win64en/examples/Gravfmdlexercise/SRBFapprwithGNSSiksi/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
    
```

Save the results as Import setting parameters

ID	lon(degree decimal)	lat	ellpH(m)	ksi(m)	
1	102.4424	24.4717	1973.56	-32.7581	-32.6525
2	102.5467	24.4580	1659.69	-32.9577	-32.5340
3	102.6324	24.4582	2120.99	-32.5792	-32.4433
4	102.7259	24.4605	2112.20	-32.3917	-32.3324
5	102.4208	24.5663	1991.56	-32.6038	-32.5734
6	102.5286	24.5627	1937.23	-32.5636	-32.4239
7	102.6344	24.5656	2193.72	-32.3822	-32.3128
8	102.7258	24.5819	2304.57	-32.2197	-32.2069
9	102.8326	24.5755	1978.11	-32.5408	-32.0934

The ellipsoidal height here at GNSS-levelling point is the observed ellipsoidal height.

Global geopotential coefficient model Calculator

Algorithmic Formulas

Calculation and analysis of spectral character of Earth's gravity field

Precise Approach of Earth Gravity Field and Geoid  
**PAGravf4.5**  
Chinese Academy of Surveying & Mapping  
October 2024, Beijing, China

The observed gravity disturbances

The observed GNSS-levelling height anomalies

The heterogeneous observation residuals

ID	lon(degree decimal)	lat	ellpH(m)	rent	kind	weight
1	102.3929	24.4944	2228.19	54.9765	0	1
2	102.3959	24.5089	2170.20	50.0971	0	1
3	102.3927	24.5296	2013.33	28.3652	0	1
4	102.3966	24.5453	2122.50	38.3822	0	1
5	102.3938	24.5813	1971.28	20.6411	0	1
6	102.3938	24.5813	1971.28	15.5784	0	1
7	102.3952	24.6036	1965.58	14.5045	0	1
8	102.3931	24.6178	1997.72	14.9731	0	1
9	102.3935	24.6384	1916.15	7.4068	0	1
4221	102.4424	24.4717	1973.56	-0.0882	1	1
4222	102.5467	24.4580	1659.69	-0.4184	1	1
4223	102.6324	24.4582	2120.99	-0.1378	1	1
4224	102.7259	24.4605	2112.20	-0.0659	1	1
4225	102.4208	24.5663	1991.56	-0.0029	1	1
4226	102.5286	24.5627	1937.23	-0.1219	1	1
4227	102.6344	24.5656	2193.72	-0.0607	1	1
4228	102.7258	24.5819	2304.57	-0.0100	1	1
4229	102.8326	24.5755	1978.11	-0.4484	1	1
4230	102.3455	24.6689	1920.60	-0.2580	1	1
4231	102.4239	24.6529	1960.26	-0.0416	1	1
4232	102.5297	24.6670	2158.55	-0.1896	1	1

Residual gravity disturbances (mGal)

Residual GNSS-levelling height anomaly (m)

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

### Precise Approach of Earth Gravity Field and Geoid

#### PAGravf4.5

Chinese Academy of Surveying & Mapping  
October 2024, Beijing, China

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 Bjerhammar sphere 10.0km

Action distance of SBRF center 100km

Reuter network level K 3600

Select the adjustable observations height anomaly (m)

Contribution rate  $\kappa$  of adjustable observations 0.00

Open the ellipsoidal height grid file of calculation surface

of file header, whose format: observation type (0~5), source observation mean, standard deviation, minimum, maximum, residual observation mean, standard deviation, minimum, maximum. The record format: ID, longitude, latitude, ellipsoidal height, residual observation, source observation, observation type, weight.

>> The parameter settings have been entered into the system!  
 \*\* Click the [Start Computation] control button, or the [Start Computation] tool button...  
 >> Computation start time: 2024-09-28 21:09:13  
 >> Complete the computation!  
 >> Computation end time: 2024-09-28 21:14:56  
 >> The program outputs the all-element grid files into the current directory. These grid files include the residual gravity disturbance  $\eta_{rg}$  (mGal), residual height anomaly  $\eta_{ksi}$  (m), residual gravity anomaly  $\eta_{gra}$  (mGal), residual disturbing gravity gradient  $\eta_{grr}$  (E, radial) and residual vertical deflection vector  $\eta_{dft}$  (", SW), where \* is the output file name, and whose grid specification are the same as the input ellipsoidal height grid of calculation surface.  
 >> 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: ID, 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 0.7856 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 0.3702  
 \*\* Residual observations: mean -0.0405 standard deviation 0.0271 minimum -0.1876 maximum 0.0099

Solution of normal equation LU tria

ID	lon	lat	ellipshgt	gravit	residuals
1	101.50417	24.0041			
2	101.51250	24.0041			
3	101.52083	24.0041			
4	101.52917	24.0041			
5	101.53750	24.0041			
6	101.54583	24.0041			

1	0	0.3186	42.1772	-296.0915	165.2611	residuals:	0.7368	16.9838	-105.2839	114.8811
2	1	-0.3510	0.2774	-0.9982	0.3435	residuals:	-0.0410	0.0287	-0.1943	0.0132
3	1	102.39290	24.49440	2228.190	16.4199		54.9765	0	1.000	
4	2	102.39590	24.50890	2170.200	-4.7688		50.0971	0	1.000	
5	3	102.39270	24.52960	2013.330	-18.3876		28.3652	0	1.000	
6	4	102.39660	24.54530	2122.500	1.0011		38.3822	0	1.000	
7	5	102.39690	24.56360	1971.280	-0.0346		15.5784	0	1.000	
8	6	102.39380	24.58130	1940.310	-12.0941		14.9731	0	1.000	
9	7	102.39520	24.60360	1965.580	12.1550		17.1065	0	1.000	
10	8	102.39310	24.61780	1997.720	20.5312		15.1065	0	1.000	
11	9	102.39350	24.63840	1916.150	3.5948		15.1065	0	1.000	

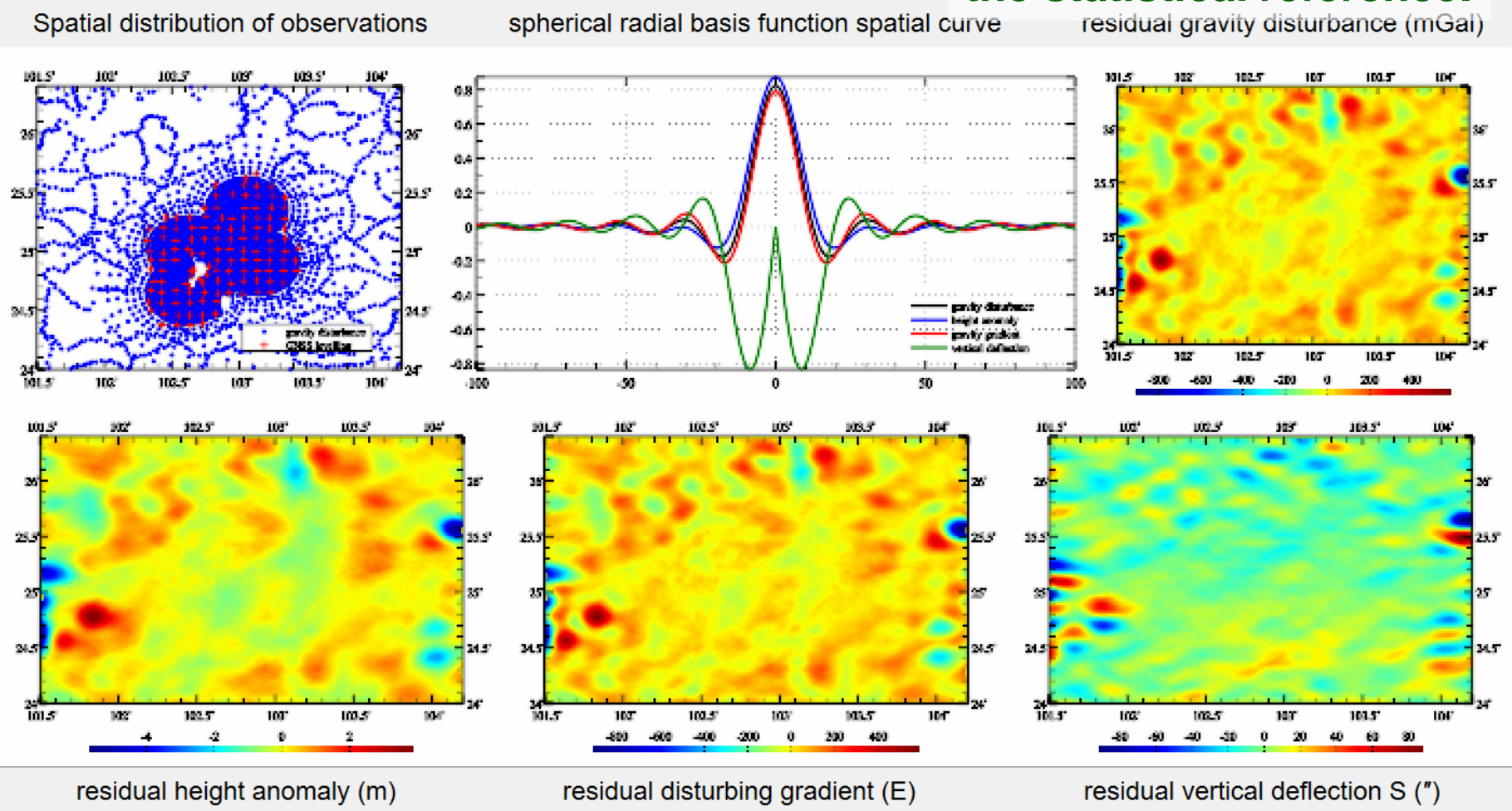
Select the remaining residuals (column 5) as the statistical reference.

### 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 elements. Generally, the stable solution can be achieved by 1 to 3 times cumulative SRBF approach, and the target field elements are equal to the sum of these SRBF approach solutions.
- The validity principle of once SRBF approach: (1) The residual target field element grid are 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 modelling tool on local gravity field. Various observations with heterogeneity, different altitudes, cross-distribution and land-sea coexisting can be directly employed to estimate the all-element models of gravity field without reduction, continuation and gridding.
- The program has strong capacity on the detection of observation gross errors, measurement of external accuracy indexes and control of computation performance.



# Separate the remaining residuals of the observed GNSS-leveling and observed gravity disturbance from rntSRBFgeoidh30s0.chs.

Gross error detection and basis function gridding of discrete field elements

Open file Save as Import parameters Start Computation Save process Follow example

Gross error detection on observations based on low-pass reference surface

Estimation of observation weight with specified reference attribute

Gridding of heterogeneous data by basis function weighted interpolation

The discrete point file to be detect

Number of rows of file header 1

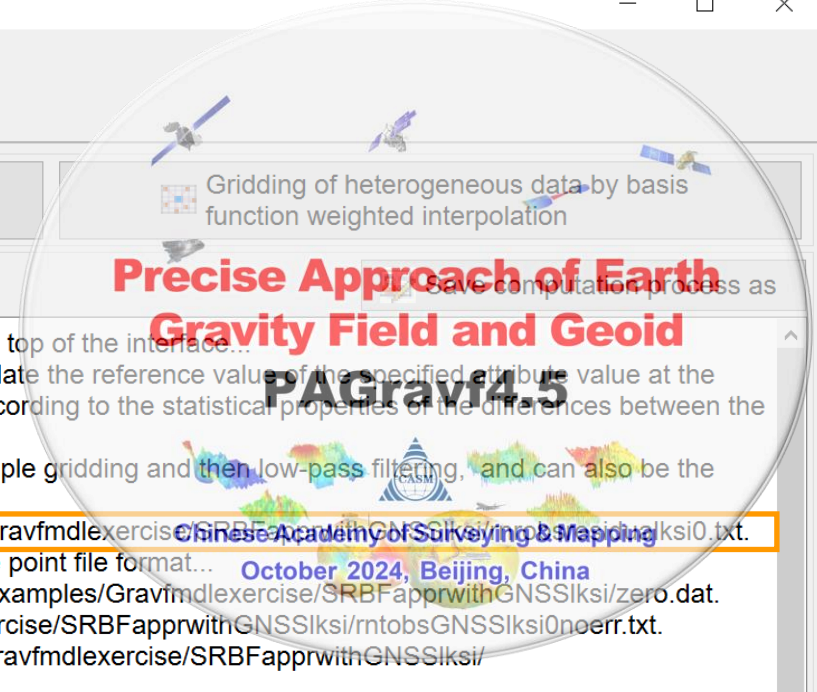
Column ordinal number of the attribute to be detect 5

Beyond multiples of the standard deviation n 3.0

Open low-pass reference surface grid file

Save the results as

>> Select the computation function from the three control buttons at the top of the interface...  
 >> [Function] Select the low-pass grid as the reference surface, interpolate the reference value of the specified attribute value at the discrete point, and then detect and separate the gross error records according to the statistical properties of the differences between the specified attribute value and reference value.  
 \*\* The reference surface can be constructed from discrete data by simple gridding and then low-pass filtering, and can also be the specified attribute grid constructed by weighted basis function gridding.  
 >> Open the discrete geodetic file C:/PAGravf4.5\_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/rntobsdistgrav0.txt.  
 \*\* Look at the file information in the window below and set the discrete point file format...  
 >> Open low-pass reference surface grid file C:/PAGravf4.5\_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/zero.dat.  
 >> Save the results as C:/PAGravf4.5\_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/rntobsdistgrav0noerr.txt.  
 >> Save no gross error results as C:/PAGravf4.5\_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/rntobsdistgrav0error.txt.



Gross error detection and basis function gridding of discrete field elements

Open file Save as Import parameters Start Computation Save process Follow example

Gross error detection on observations based on low-pass reference surface

Estimation of observation weight with specified reference attribute

Gridding of heterogeneous data by basis function weighted interpolation

The discrete point file to be detect

Number of rows of file header 1

Column ordinal number of the attribute to be detect 5

Beyond multiples of the standard deviation n 5.0

Open low-pass reference surface grid file

Save the results as

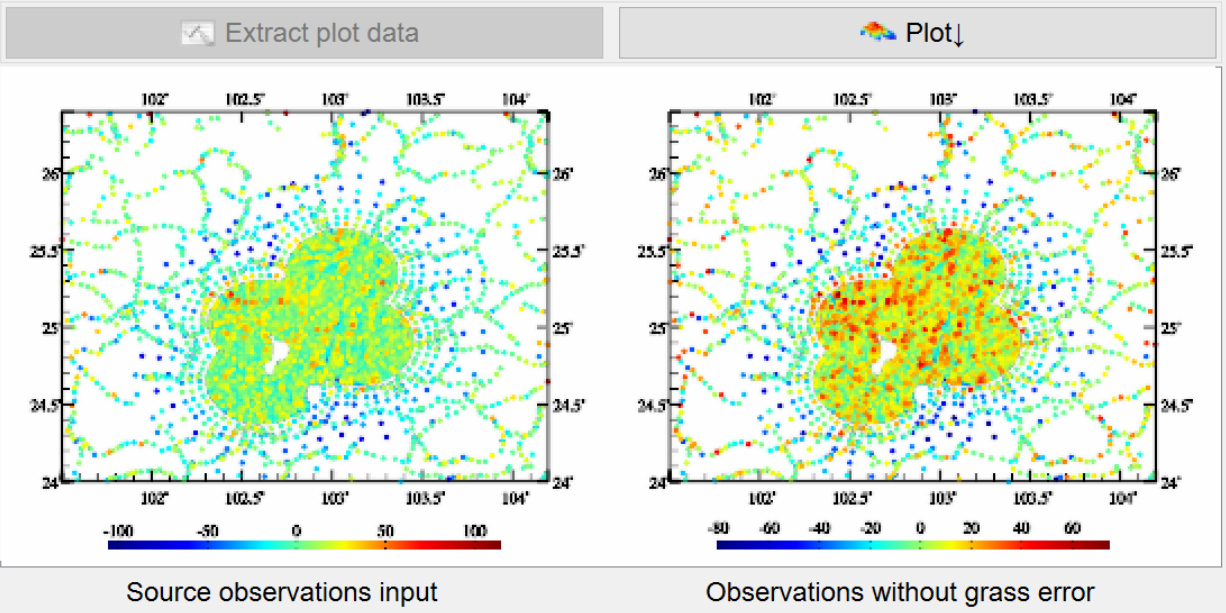
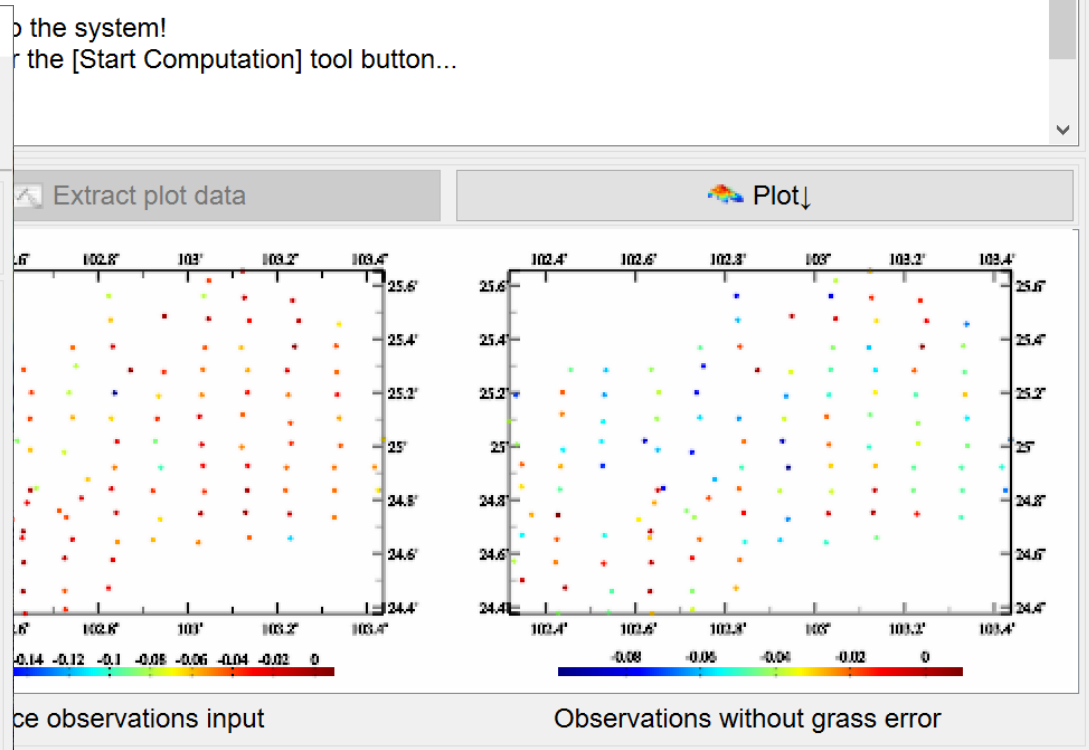
Save gross error as

Import setting parameters

Start Computation

>> [Function] Select the low-pass grid as the reference surface, interpolate the reference value of the specified attribute value at the discrete point, and then detect and separate the gross error records according to the statistical properties of the differences between the specified attribute value and reference value.  
 \*\* The reference surface can be constructed from discrete data by simple gridding and then low-pass filtering, and can also be the specified attribute grid constructed by weighted basis function gridding.  
 >> Open the discrete geodetic file C:/PAGravf4.5\_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/rntobsdistgrav0.txt.  
 \*\* Look at the file information in the window below and set the discrete point file format...  
 >> Open low-pass reference surface grid file C:/PAGravf4.5\_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/zero.dat.  
 >> Save the results as C:/PAGravf4.5\_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/rntobsdistgrav0noerr.txt.  
 >> Save no gross error results as C:/PAGravf4.5\_win64en/examples/Gravfmdlexercise/SRBFApprgeoidexercise/rntobsdistgrav0error.txt.  
 >> 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 14:48:43  
 >> Complete computation!  
 >> Computation end time: 2023-03-21 14:48:43

0.6881	16.6838	-80.6303	74.3694	97.1661	97.1661
2158	101.98720	26.38060	1860.000	-105.2839	-105.2839
16069	103.17160	26.38130	1721.800	114.8811	114.8811
16573	102.74440	26.38830	2340.000	101.4916	101.4916
19786	104.19500	24.64660	1799.700		



Reconstruct the heterogeneous observation residual file obsresiduals01.txt.

### (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 Bjerhammar 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

```

of file header, whose format: observation type (0~5), source observation mean, standard deviation, minimum, maximum, residual observation mean,
standard deviation, minimum, maximum. The record format: ID, longitude, latitude, ellipsoidal height, weight, source observation mean, standard deviation,
type, weight.
>> The parameter settings have been entered into the system!
** Click the [Start Computation] control button, or the [Start Computation] tool button.
>> Computation start time: 2024-09-28 21:17:31
>> Complete the computation!
>> Computation end time: 2024-09-28 21:22:53
>> The program outputs the all-element 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, and whose grid specification are the same as the input ellipsoidal height grid of calculation surface.
>> 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: ID, 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
    
```

**0.2735m** ← The external accuracy index (SD) of the 2~540<sup>th</sup> degree model height anomaly

**0.0233 m** ← The external accuracy index (SD) of GNSS-leveling

Solution of normal equation LU triangular decomposition

ID	lon	lat	ellipshgt	gravity disturbance (mGal)	height anomaly (m)	gravity anomaly (mGal)	gravity gradient (E)	vertical deflection
1	101.50417	24.00417	2427.222	-25.2756	-0.3847	-32.8786	-1.6774	-3.9938
2	101.51250	24.00417	2480.981	-33.0116	-0.4329	-32.8786	-27.9459	-3.5535
3	101.52083	24.00417	2435.157	-39.4282	-0.4529	-32.8786	-33.1339	-3.4221
4	101.52917	24.00417	2229.999	-47.4915	-0.5290	-47.3290	-52.9274	-3.5187
5	101.53750	24.00417	2032.509	-57.3974	-0.5878	-57.2168	-72.2220	11.4284
6	101.54583	24.00417	1906.019	-58.2186	-0.6102	-58.0311	-67.6348	11.2885

**-0.3404 - (-0.0069) = -0.3335m**

← The measured height datum difference

Only using the observed gravity disturbances.

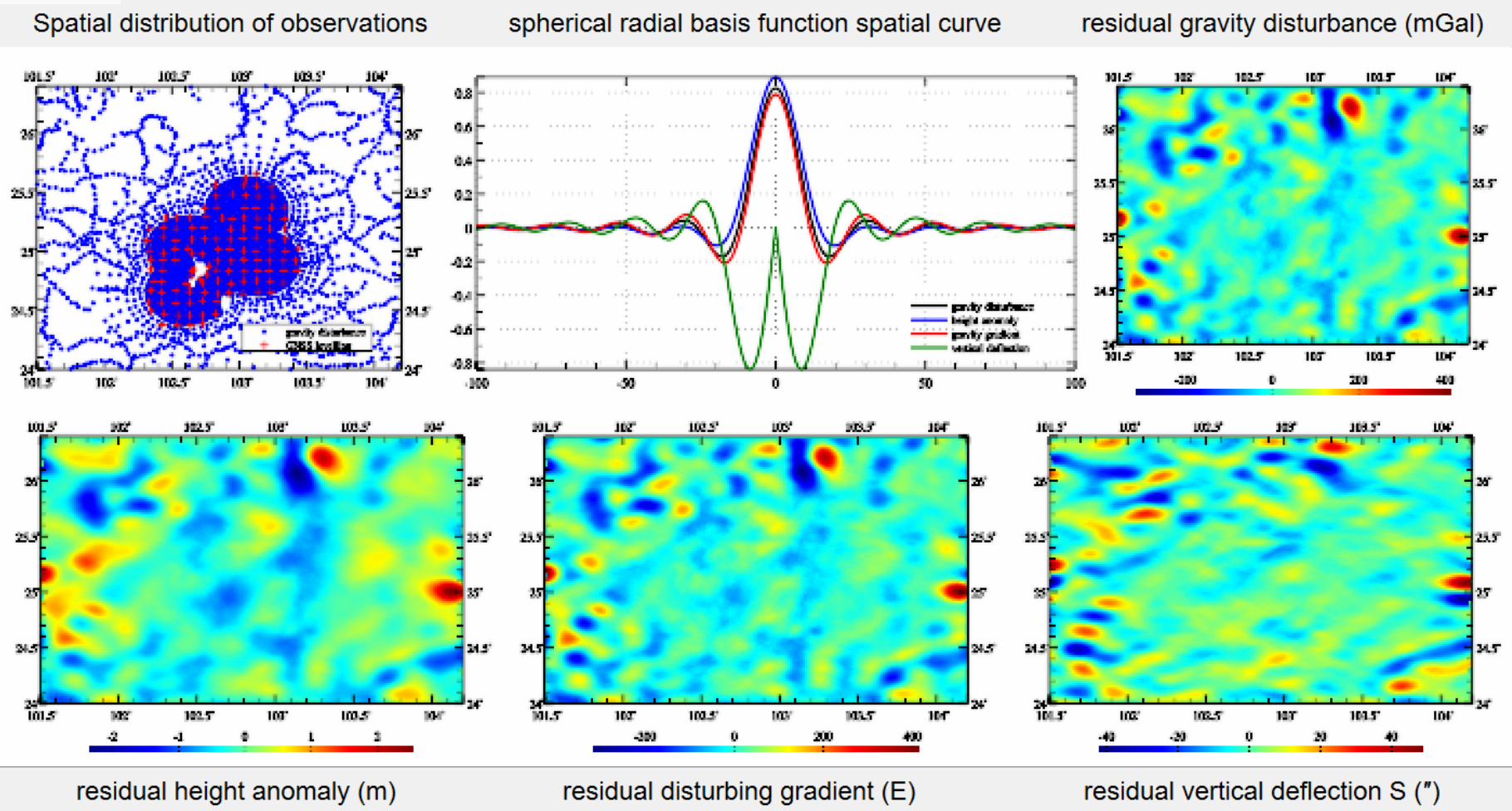
Algorithm of gravity field approach using SRBFs

- 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 elements. Generally, the stable solution can be achieved by 1 to 3 times cumulative SRBF approach, and the target field elements are equal to the sum of these SRBF approach solutions.
- The validity principle of once SRBF approach: (1) The residual target field element grid are 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 modelling tool on local gravity field. Various observations with heterogeneity, different altitudes, cross-distribution and land-sea coexisting can be directly employed to estimate the all-element models of gravity field without reduction, continuation and gridding.
- The program has strong capacity on the detection of observation gross errors, measurement of external accuracy indexes and control of computation performance.



# (4) All-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 SBRF center 100km

Reuter network level K 3600

Select the adjustable observations height anomaly (m)

Contribution rate  $\kappa$  of adjustable observations 1.00

Open the ellipsoidal height grid file of calculation surface

of file header, whose format: observation type (0~5), source observation mean, standard deviation, minimum, maximum, residual observation mean, standard deviation, minimum, maximum. The record format: ID, longitude, latitude, ellipsoidal height, residual observation, source observation, observation type, weight.

>> The parameter settings have been entered into the system!  
 \*\* Click the [Start Computation] control button, or the [Start Computation] tool button...  
 >> Computation start time: 2024-09-28 21:43:45  
 >> Complete the computation!  
 >> Computation end time: 2024-09-28 21:48:27

>> The program outputs the all-element grid files into the current directory. These grid files include the residual gravity disturbance  $\eta$  (mGal), residual height anomaly  $\zeta$  (m), residual gravity anomaly  $\sigma$  (mGal), residual disturbing gravity gradient  $\gamma$  (E, radial) and residual vertical deflection vector  $S$  (", SW), where  $\ast$  is the output file name, and whose grid specification are the same as the input ellipsoidal height grid of calculation surface.

>> The program also outputs SRBF center file  $\ast$ 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: ID, 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 0.0620 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  
 \*\* Residual observations: mean -0.0014 standard deviation 0.0291 minimum -0.1886 maximum 0.0595

Solution of normal equation LU triangular decomposition

Save the results as Import setting parameters Start Computation

ID	lon	lat	ellipshgt	gravity disturbance (mGal)	height anomaly (m)	gravity anomaly (mGal)	gravity gradient (E)	vertical deflection
1	101.50417	24.00417	2427.222	-33.8830	-0.3067	-33.8830	0.0000	0.0000
2	101.51250	24.00417	2480.981	-41.3359	-0.3579	-41.2260	-58.7998	8.0721
3	101.52083	24.00417	2435.157	-47.3401	-0.3988	-47.2102	-66.8100	9.0686
4	101.52917	24.00417	2229.999	-55.4958	-0.4544	-55.3562	-82.8302	9.4262
5	101.53750	24.00417	2032.509	-65.0026	-0.5171	-64.8450	-100.3242	10.1478
6	101.54583	24.00417	1906.019	-65.4479	-0.5213	-65.2877	-96.5237	9.8143

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

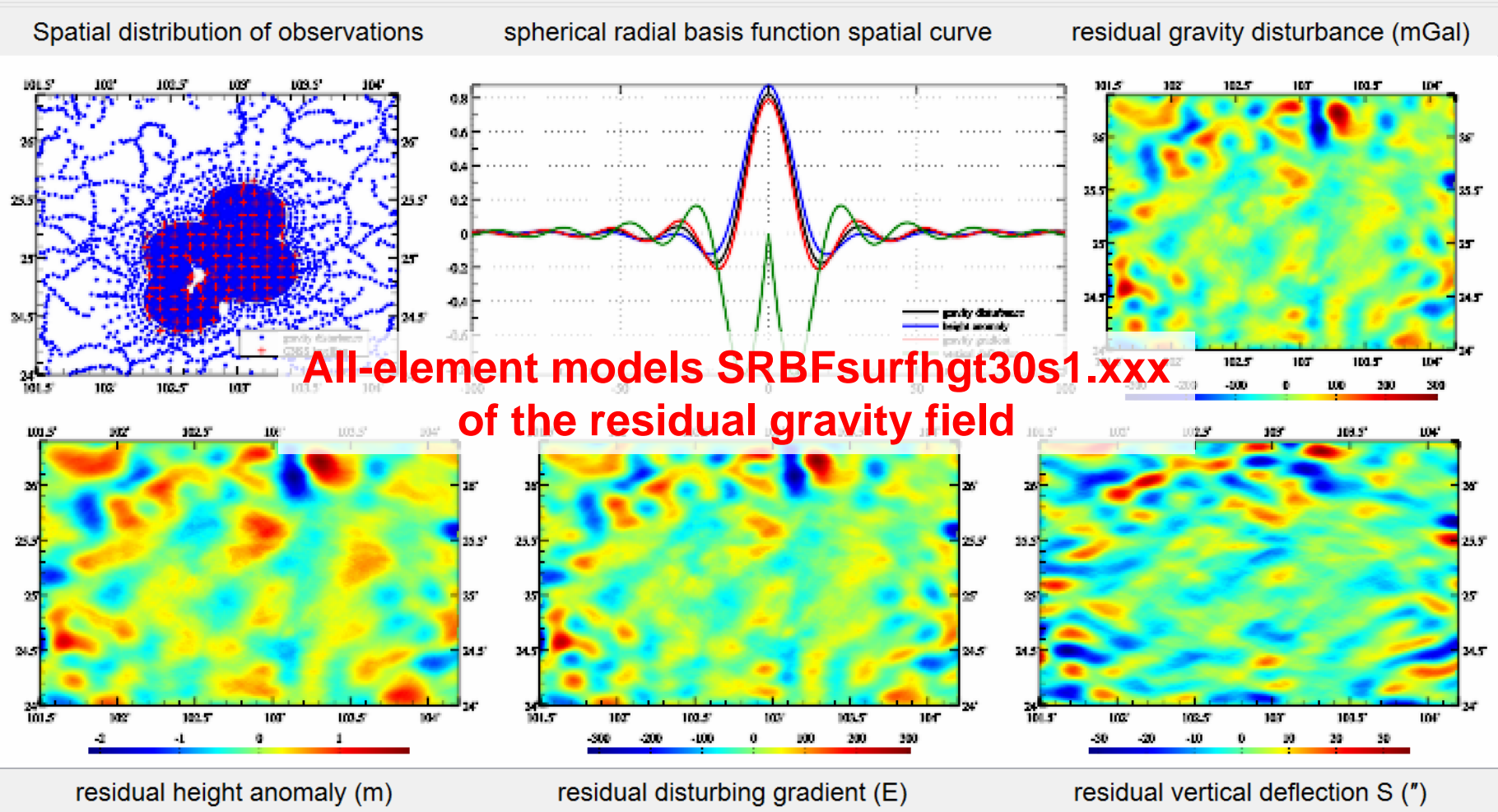
## Algorithm of gravity field approach using SRBFs

- 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 elements. Generally, the stable solution can be achieved by 1 to 3 times cumulative SRBF approach, and the target field elements are equal to the sum of these SRBF approach solutions.
- The validity principle of once SRBF approach: (1) The residual target field element grid are 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.

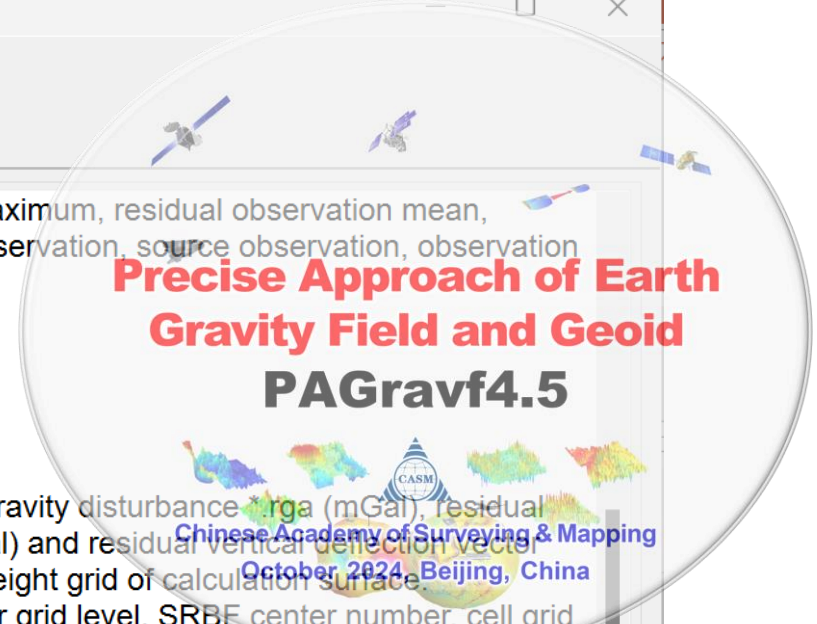
Extract data to be plot Plot →

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

The program has strong capacity on the detection of observation gross errors, measurement of external accuracy indexes and control of computation performance.



All-element models SRBFsurfhtg30s1.xxx of the residual gravity field





# (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 Poisson wavelet kernel

Order m 3

Minimum degree 540

Maximum degree 1800

Burial depth of Bjerhammar sphere 6.0km

Action distance of SBRF center 60km

Reuter network level K 5400

Select the adjustable observations height anomaly (m)

Contribution rate  $\kappa$  of adjustable observations 1.00

Open the ellipsoidal height grid file of calculation surface

of file header, whose format: observation type (0~5), source observation mean, standard deviation, minimum, maximum, residual observation mean, standard deviation, minimum, maximum. The record format: ID, longitude, latitude, ellipsoidal height, residual observation, source observation, observation type, weight.

>> The parameter settings have been entered into the system!  
 \*\* Click the [Start Computation] control button, or the [Start Computation] tool button.

>> Computation start time: 2024-09-28 21:56:01

>> Complete the computation!  
 >> Computation end time: 2024-09-28 22:00:17

>> The program outputs the all-element 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, and whose grid specification are the same as the input ellipsoidal height grid of calculation surface.

>> 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: ID, 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 12.9896 minimum -80.4161 maximum 64.8276  
 \*\* Residual observations: mean 0.1225 standard deviation 9.4454 minimum -42.1759 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

**Input the file SRBFsurfhtg30s1.chs that is output from the previous step.**

Solution of normal equation LU triangular decomposition

Save the results as Import setting parameters Start Computation

ID	lon	lat	ellipshgt	gravity disturbance(mGal)	height anomaly(m)	gravity anomaly(mGal)	gravity gradient(E)	vertical deflection	
1	101.50417	24.00417	2427.222	-17.6250	-0.0737	-17.6024	-44.0716	1.1775	0.1831
2	101.51250	24.00417	2480.981	-17.1942	-0.0720	-17.1721	-43.0375	1.2277	0.1211
3	101.52083	24.00417	2435.157	-16.3729	-0.0689	-16.3518	-40.9296	1.2935	0.0907
4	101.52917	24.00417	2229.999	-15.3566	-0.0652	-15.3366	-38.8217	1.4193	0.1193
5	101.53750	24.00417	2032.509	-13.7680	-0.0593	-13.7498	-34.0240	1.5375	-0.0901
6	101.54583	24.00417	1906.019	-11.8549	-0.0522	-11.8399	-28.8302	1.6583	-0.0583

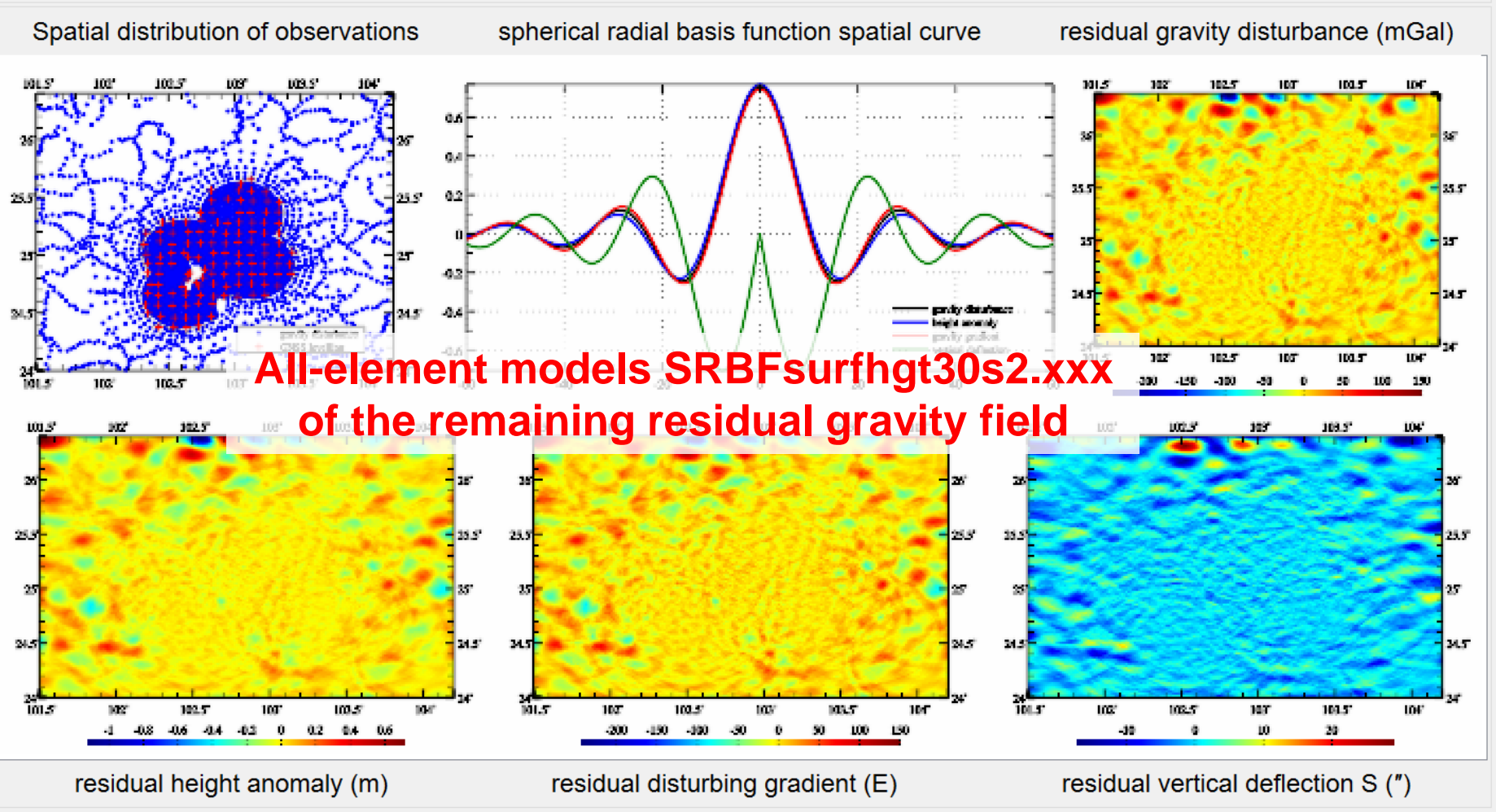
**0.0154m ≈ 1.5 cm The accuracy index (SD) of height anomaly modeling.**

## 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 elements. Generally, the stable solution can be achieved by 1 to 3 times cumulative SRBF approach, and the target field elements are equal to the sum of these SRBF approach solutions.
- The validity principle of once SRBF approach: (1) The residual target field element grid are 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 modelling tool on local gravity field. Various observations with heterogeneity, different altitudes, cross-distribution and land-sea coexisting can be directly employed to estimate the all-element models of gravity field without reduction, continuation and gridding.
- The program has strong capacity on the detection of observation gross errors, measurement of external accuracy indexes and control of computation performance.



**All-element models SRBFsurfhtg30s2.xxx of the remaining residual gravity field**

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

Gridding of discrete geodetic data by simple interpolation | Interpolation of vector grid from two attributes in geodetic records | Gridding of high-resolution record attributes by direct averaging | Constructing of general geodetic grid file | **Extracting of data according to latitude and longitude range**

Open a source data file | Process batch files with same specifications | Save computation process as

The source file format: geodetic grid file

Maximum latitude: 25.700° | Minimum longitude: 102.200° | Maximum longitude: 103.700° | Minimum latitude: 24.300°

Save the results as | Import setting parameters | Start computation

```

>> [Function] According to the given latitude and longitude range, extract data from the geodetic discrete points file, grid file, or vectors grid file. The program can extract data from batch files.
>> Open the source data file C:/PAGrav4.5_win64en/examples/Gravfmdlexercise/SRBFApprwithGNSSikis/SRBFsurfhtg30s1.rga.
** Look at the input file information in the text box below, set the file format parameters.....
>> Save the results as C:/PAGrav4.5_win64en/examples/Gravfmdlexercise/SRBFApprwithGNSSikis/surfhtg30s1.ksi.
>> Setting parameters have been imported in the program!
** Click the control button [Start computation], or the tool button [Start computation]....
>> Computation start time: 2023-04-01 10:56:03
>> Computation end time: 2023-04-01 10:56:06
>> Complete the computation!
    
```

102.200000	103.700000	24.300000	25.700000	0.00833333	0.00833333
-32.3767	-37.3331	-35.5653	-34.6078	-31.2030	-27.5479
-10.5088	-12.9787	-22.3161	-28.8119	-32.3888	-31.1601

Geopotential model | Open calculation points | Import parameters | Save as | Start Computation | Follow example

**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: Ellipsoidal height grid file

Open ellipsoidal height grid file of calculation surface

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

Extract elements to be plot | Plot

```

>> Open ellipsoidal height grid file of calculation surface C:/PAGrav4.5_win64en/examples/Gravfmdlexercise/SRBFApprwithGNSSikis/surfhtg30s1rsg.dat.
>> Save the results as C:/PAGrav4.5_win64en/examples/Gravfmdlexercise/SRBFApprwithGNSSikis/GMsurfhtg30s540.txt.
** The record format: ID (point no/name), longitude, latitude, ellipsoidal height, several columns of the model values of anomalous field elements.
** The program also outputs (residual) height anomaly (*.ksi), gravity anomaly (*.gra), gravity disturbance (*.rga), vertical deflection vector (*.dft), disturbing gravity gradient (*.grr), tangential gravity gradient vector (*.hgd) or Laplace operator (*.lps) model value grid file into the current directory.
Where * is the output file name entered in the interface, and the program outputs the corresponding (residual) model value grid file according to the selected gravity field element type.
>> 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 10:10:23
>> Complete the calculation of the model value of (residual) gravity field element!
>> Computation end time: 2023-03-21 10:10:41
    
```

1	102.20417	24.30417	1702.027	-33.4342	1.3482	-8.9123	-1.2109	-7.1176	3.9728
2	102.21250	24.30417	1880.999	-33.4056	1.8359	-8.4148	-1.2243	-6.9794	4.2096
3	102.22083	24.30417	1895.916	-33.3772	2.3592	-7.8828	-1.2349	-6.8610	4.4575
4	102.22917	24.30417	1797.388	-33.3490	2.9054	-7.3284	-1.2435	-6.7530	4.7110
5	102.23750	24.30417	1688.137	-33.3212	3.4302	-6.7956	-1.2509	-6.6413	4.9480
6	102.24583	24.30417	1551.997	-33.2937	3.9415	-6.2765	-1.2570	-6.5276	5.1721
7	102.25417	24.30417	1622.247	-33.2675	4.3140	-5.8956	-1.2631	-6.3884	5.3193
8	102.26250	24.30417	1674.884	-33.2418	4.6607	-5.5408	-1.2679	-6.2495	5.4471
9	102.27083	24.30417	1746.522	-33.2168	4.9619	-5.2316	-1.2715	-6.1077	5.5455
10	102.27917	24.30417	1844.270	-33.1926	5.2130	-4.9726	-1.2741	-5.9634	5.6126

Simple and direct calculation on geodetic data files

Open file | Save as | Import parameters | Start computation | Save process | Follow example

Weighted operation on two specified attributes in record file | **Weighted operation on two geodetic grid files** | Weighted operation on two vector grid files | Weighted operation on two harmonic coefficient files

Open geodetic grid file 1 | Open geodetic grid file 2

Select operation mode: Plus +

Set weight: The first weight 1.00 | The second weight 1.00

Vector grid operation

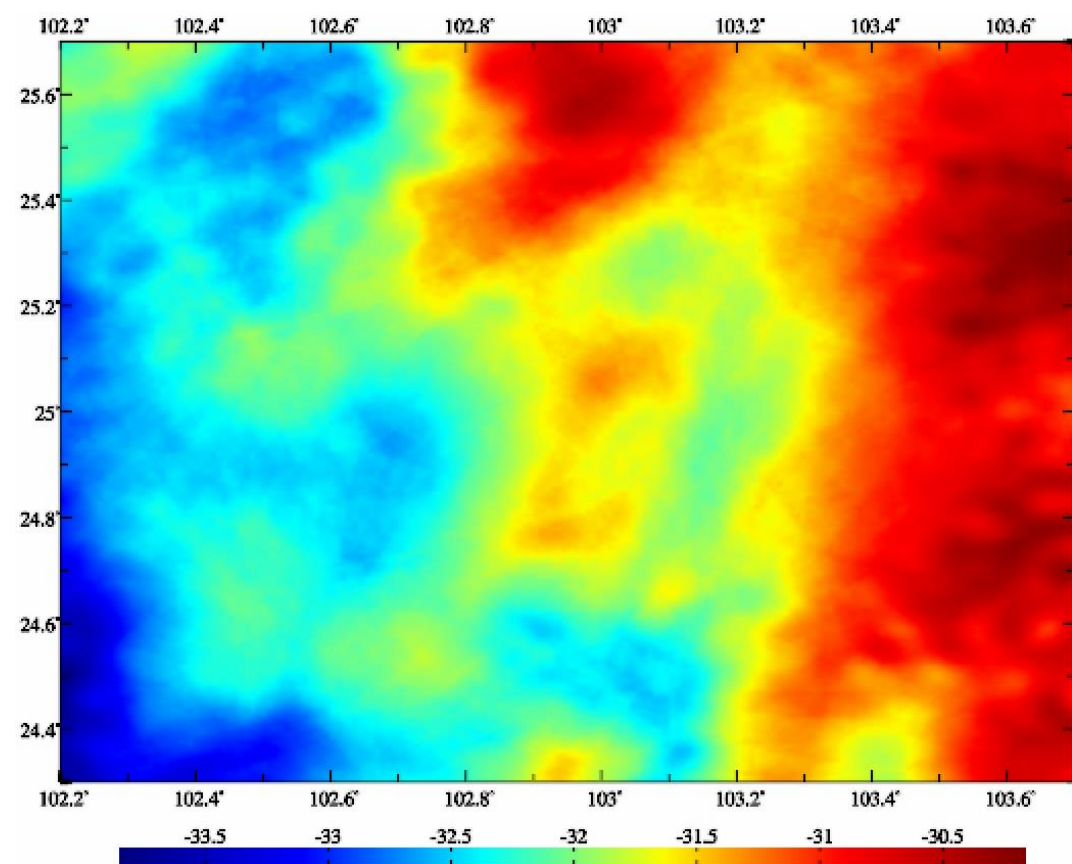
```

>> [Function] Perform weighted plus, minus, or multiply operation on grid elements in two (vector) grid files with the same specifications.
>> Open geodetic grid file 1 C:/PAGrav4.5_win64en/examples/Gravfmdlexercise/SRBFApprwithGNSSikis/surfhtg30s1.ksi.
>> Open geodetic grid file 2 C:/PAGrav4.5_win64en/examples/Gravfmdlexercise/SRBFApprwithGNSSikis/surfhtg30s2.ksi.
>> Save the results as C:/PAGrav4.5_win64en/examples/Gravfmdlexercise/SRBFApprwithGNSSikis/ttt.dat.
>> The parameter settings have been entered into the system!
** Click the [Start Computation] control button, or the [Start Computation] tool button....
>> Computation start time: 2023-04-01 10:48:54
>> Complete the computation!
>> Computation end time: 2023-04-01 10:48:54
>> Open geodetic grid file 1 C:/PAGrav4.5_win64en/examples/Gravfmdlexercise/SRBFApprwithGNSSikis/ttt.dat.
>> Open geodetic grid file 2 C:/PAGrav4.5_win64en/examples/Gravfmdlexercise/SRBFApprwithGNSSikis/GMsurfhtg30s540.ksi.
>> Save the results as C:/PAGrav4.5_win64en/examples/Gravfmdlexercise/SRBFApprwithGNSSikis/surfhtg30s1rsg.ksi.
>> The parameter settings have been entered into the system!
** Click the [Start Computation] control button, or the [Start Computation] tool button....
>> Computation start time: 2023-04-01 10:49:36
>> Complete the computation!
>> Computation end time: 2023-04-01 10:49:36
    
```

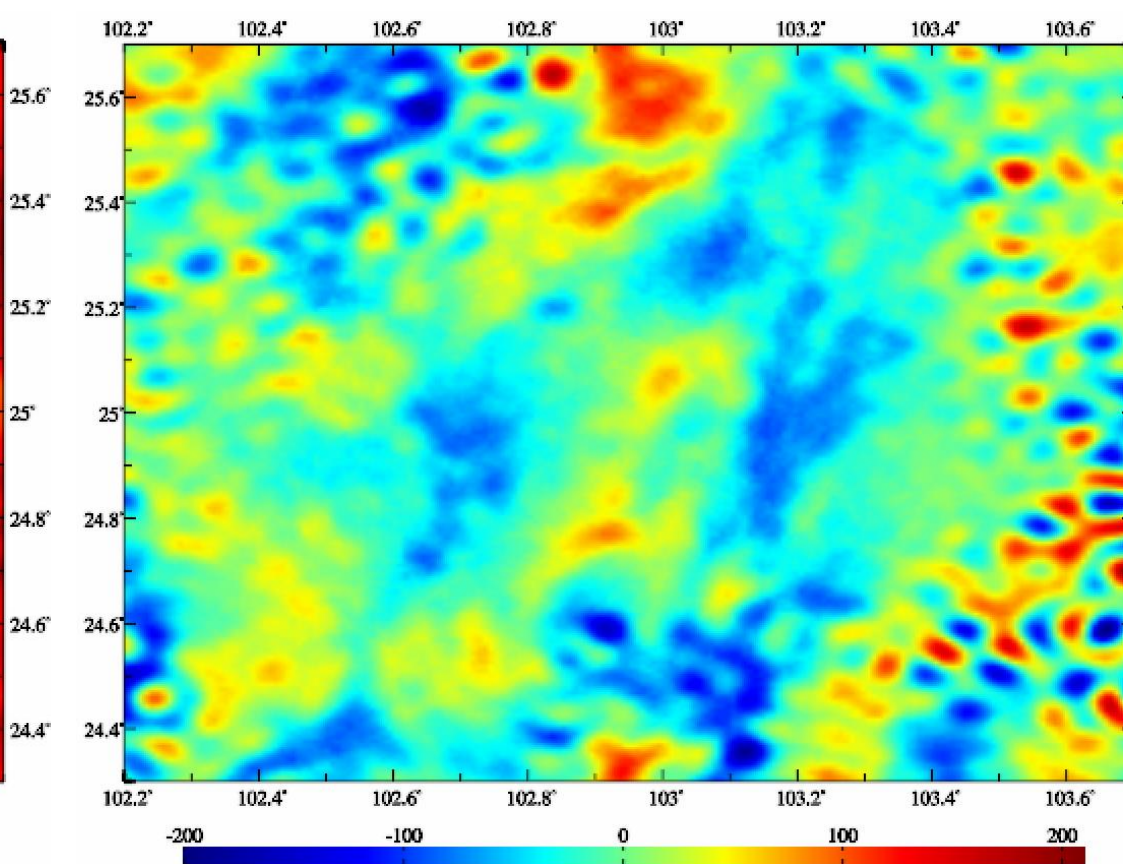
Display of the input-output file:

102.200000	103.700000	24.300000	25.700000	0.00833333	0.00833333	-33.4576	-33.4101	-33.3326	-33.2573	-33.2106	-33.1816	-33.1467	-33.1147	-33.0847	-33.0557	-33.0267	-32.9977	-32.9687	-32.9397	-32.9107	-32.8817	-32.8527	-32.8237	-32.7947	-32.7657	-32.7367	-32.7077	-32.6787	-32.6497	-32.6207	-32.5917	-32.5627	-32.5337	-32.5047	-32.4757	-32.4467	-32.4177	-32.3887	-32.3597	-32.3307	-32.3017	-32.2727	-32.2437	-32.2147	-32.1857	-32.1567	-32.1277	-32.0987	-32.0697	-32.0407	-32.0117	-31.9827	-31.9537	-31.9247	-31.8957	-31.8667	-31.8377	-31.8087	-31.7797	-31.7507	-31.7217	-31.6927	-31.6637	-31.6347	-31.6057	-31.5767	-31.5477	-31.5187	-31.4897	-31.4607	-31.4317	-31.4027	-31.3737	-31.3447	-31.3157	-31.2867	-31.2577	-31.2287	-31.1997	-31.1707	-31.1417	-31.1127	-31.0837	-31.0547	-31.0257	-30.9967	-30.9677	-30.9387	-30.9097	-30.8807	-30.8517	-30.8227	-30.7937	-30.7647	-30.7357	-30.7067	-30.6777	-30.6487	-30.6197	-30.5907	-30.5617	-30.5327	-30.5037	-30.4747	-30.4457	-30.4167	-30.3877	-30.3587	-30.3297	-30.3007	-30.2717	-30.2427	-30.2137	-30.1847	-30.1557	-30.1267	-30.0977	-30.0687	-30.0397	-30.0107	-29.9817	-29.9527	-29.9237	-29.8947	-29.8657	-29.8367	-29.8077	-29.7787	-29.7497	-29.7207	-29.6917	-29.6627	-29.6337	-29.6047	-29.5757	-29.5467	-29.5177	-29.4887	-29.4597	-29.4307	-29.4017	-29.3727	-29.3437	-29.3147	-29.2857	-29.2567	-29.2277	-29.1987	-29.1697	-29.1407	-29.1117	-29.0827	-29.0537	-29.0247	-28.9957	-28.9667	-28.9377	-28.9087	-28.8797	-28.8507	-28.8217	-28.7927	-28.7637	-28.7347	-28.7057	-28.6767	-28.6477	-28.6187	-28.5897	-28.5607	-28.5317	-28.5027	-28.4737	-28.4447	-28.4157	-28.3867	-28.3577	-28.3287	-28.2997	-28.2707	-28.2417	-28.2127	-28.1837	-28.1547	-28.1257	-28.0967	-28.0677	-28.0387	-28.0097	-27.9807	-27.9517	-27.9227	-27.8937	-27.8647	-27.8357	-27.8067	-27.7777	-27.7487	-27.7197	-27.6907	-27.6617	-27.6327	-27.6037	-27.5747	-27.5457	-27.5167	-27.4877	-27.4587	-27.4297	-27.4007	-27.3717	-27.3427	-27.3137	-27.2847	-27.2557	-27.2267	-27.1977	-27.1687	-27.1397	-27.1107	-27.0817	-27.0527	-27.0237	-26.9947	-26.9657	-26.9367	-26.9077	-26.8787	-26.8497	-26.8207	-26.7917	-26.7627	-26.7337	-26.7047	-26.6757	-26.6467	-26.6177	-26.5887	-26.5597	-26.5307	-26.5017	-26.4727	-26.4437	-26.4147	-26.3857	-26.3567	-26.3277	-26.2987	-26.2697	-26.2407	-26.2117	-26.1827	-26.1537	-26.1247	-26.0957	-26.0667	-26.0377	-26.0087	-25.9797	-25.9507	-25.9217	-25.8927	-25.8637	-25.8347	-25.8057	-25.7767	-25.7477	-25.7187	-25.6897	-25.6607	-25.6317	-25.6027	-25.5737	-25.5447	-25.5157	-25.4867	-25.4577	-25.4287	-25.3997	-25.3707	-25.3417	-25.3127	-25.2837	-25.2547	-25.2257	-25.1967	-25.1677	-25.1387	-25.1097	-25.0807	-25.0517	-25.0227	-24.9937	-24.9647	-24.9357	-24.9067	-24.8777	-24.8487	-24.8197	-24.7907	-24.7617	-24.7327	-24.7037	-24.6747	-24.6457	-24.6167	-24.5877	-24.5587	-24.5297	-24.5007	-24.4717	-24.4427	-24.4137	-24.3847	-24.3557	-24.3267	-24.2977	-24.2687	-24.2397	-24.2107	-24.1817	-24.1527	-24.1237	-24.0947	-24.0657	-24.0367	-24.0077	-23.9787	-23.9497	-23.9207	-23.8917	-23.8627	-23.8337	-23.8047	-23.7757	-23.7467	-23.7177	-23.6887	-23.6597	-23.6307	-23.6017	-23.5727	-23.5437	-23.5147	-23.4857	-23.4567	-23.4277	-23.3987	-23.3697	-23.3407	-23.3117	-23.2827	-23.2537	-23.2247	-23.1957	-23.1667	-23.1377	-23.1087	-23.0797	-23.0507	-23.0217	-22.9927	-22.9637	-22.9347	-22.9057	-22.8767	-22.8477	-22.8187	-22.7897	-22.7607	-22.7317	-22.7027	-22.6737	-22.6447	-22.6157	-22.5867	-22.5577	-22.5287	-22.4997	-22.4707	-22.4417	-22.4127	-22.3837	-22.3547	-22.3257	-22.2967	-22.2677	-22.2387	-22.2097	-22.1807	-22.1517	-22.1227	-22.0937	-22.0647	-22.0357	-22.0067	-21.9777	-21.9487	-21.9197	-21.8907	-21.8617	-21.8327	-21.8037	-21.7747	-21.7457	-21.7167	-21.6877	-21.6587	-21.6297	-21.6007	-21.5717	-21.5427	-21.5137	-21.4847	-21.4557	-21.4267	-21.3977	-21.3687	-21.3397	-21.3107	-21.2817	-21.2527	-21.2237	-21.1947	-21.1657	-21.1367	-21.1077	-21.0787	-21.0497	-21.0207	-20.9917	-20.9627	-20.9337	-20.9047	-20.8757	-20.8467	-20.8177	-20.7887	-20.7597	-20.7307	-20.7017	-20.6727	-20.6437	-20.6147	-20.5857	-20.5567	-20.5277	-20.4987	-20.4697	-20.4407	-20.4117	-20.3827	-20.3537	-20.3247	-20.2957	-20.2667	-20.2377	-20.2087	-20.1797	-20.1507	-20.1217	-20.0927	-20.0637	-20.0347	-20.0057	-19.9767	-19.9477	-19.9187	-19.8897	-19.8607	-19.8317	-19.8027	-19.7737	-19.7447	-19.7157	-19.6867	-19.6577	-19.6287	-19.5997	-19.5707	-19.5417	-19.5127	-19.4837	-19.4547	-19.4257	-19.3967	-19.3677	-19.3387	-19.3097	-19.2807	-19.2517	-19.2227	-19.1937	-19.1647	-19.1357	-19.1067	-19.0777	-19.0487	-19.0197	-18.9907	-18.9617	-18.9327	-18.9037	-18.8747	-18.8457	-18.8167	-18.7877	-18.7587	-18.7297	-18.7007	-18.6717	-18.6427	-18.6137	-18.5847	-18.5557	-18.5267	-18.4977	-18.4687	-18.4397	-18.4107	-18.3817	-18.3527	-18.3237	-18.2947	-18.2657	-18.2367	-18.2077	-18.1787	-18.1497	-18.1207	-18.0917	-18.0627	-18.0337	-18.0047	-17.9757	-17.9467	-17.9177	-17.8887	-17.8597	-17.8307	-17.8017	-17.7727	-17.7437	-17.7147	-17.6857	-17.6567	-17.6277	-17.5987	-17.5697	-17.5407	-17.5117	-17.4827	-17.4537	-17.4247	-17.3957	-17.3667	-17.3377	-17.3087	-17.2797	-17.2507	-17.2217	-17.1927	-17.1637	-17.1347	-17.1057	-17.0767	-17.0477	-17.0187	-16.9897	-16.9607	-16.9317	-16.9027	-16.8737	-16.8447	-16.8157	-16.7867	-16.7577	-16.7287	-16.6997	-16.6707	-16.6417	-16.6127	-16.5837	-16.5547	-16.5257	-16.4967	-16.4677	-16.4387	-16.4097	-16.3807	-16.3517	-16.3227	-16.2937	-16.2647	-16.2357	-16.2067	-16.1777	-16.1487	-16.1197	-16.0907	-16.0617	-16.0327	-16.0037	-15.9747	-15.9457	-15.9167	-15.8877	-15.8587	-15.8297	-15.8007	-15.7717	-15.7427	-15.7137	-15.6847	-15.6557	-15.6267	-15.5977	-15.5687	-15.5397	-15.5107	-15.4817	-15.4527	-15.4237	-15.3947	-15.3657	-15.3367	-15.3077	-15.2787	-15.2497	-15.2207	-15.1917	-15.1627	-15.1337	-15.1047	-15.0757	-15.0467	-15.0177	-14.9887	-14.9597	-14.9307	-14.9017	-14.8727	-14.8437	-14.8147	-14.7857	-14.7567	-14.7277	-14.6987	-14.6697	-14.6407	-14.6117	-14.5827	-14.5537	-14.5247	-14.4957	-14.4667	-14.4377	-14.4087	-14.3797	-14.3507	-14.3217	-14.2927	-14.2637	-14.2347	-14.2057	-14.1767	-14.1477	-14.1187	-14.0897	-14.0607	-14.0317	-14.0027
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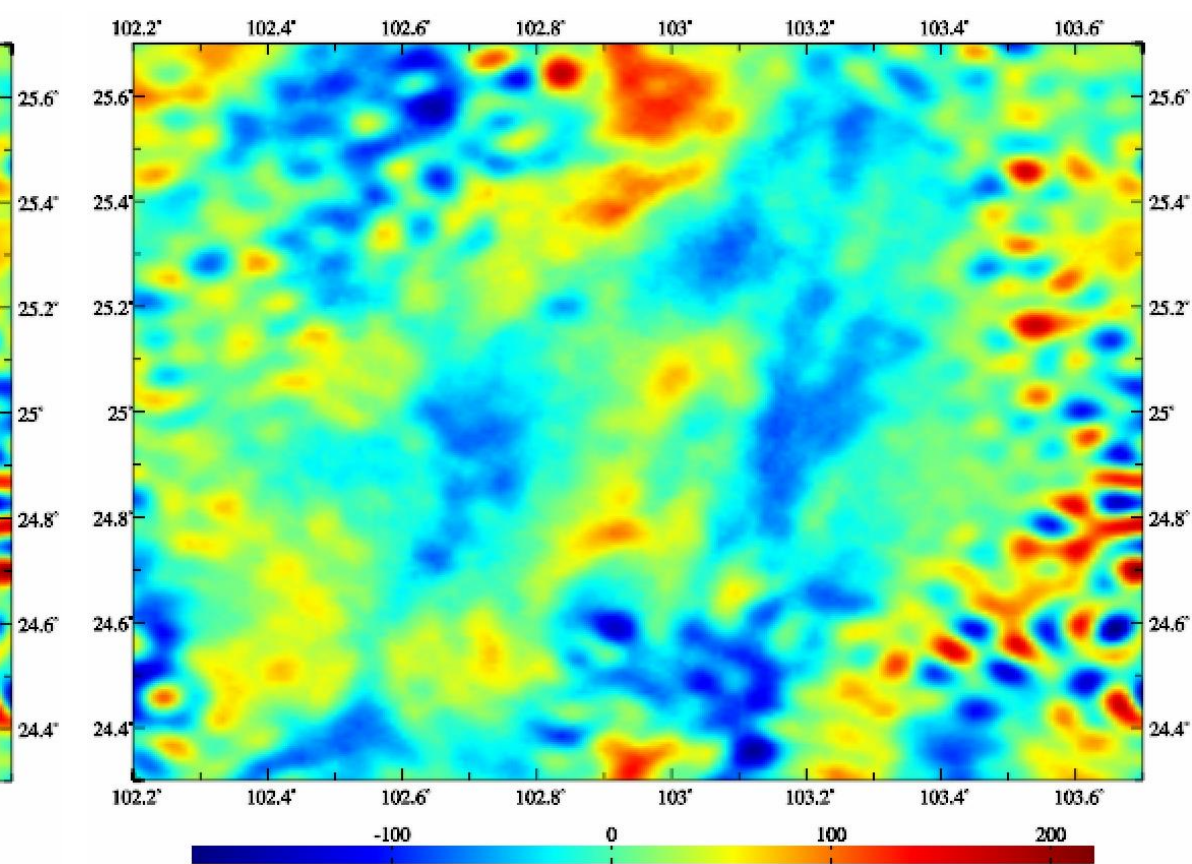
# 30"×30" full element models of gravity field on terrain surface



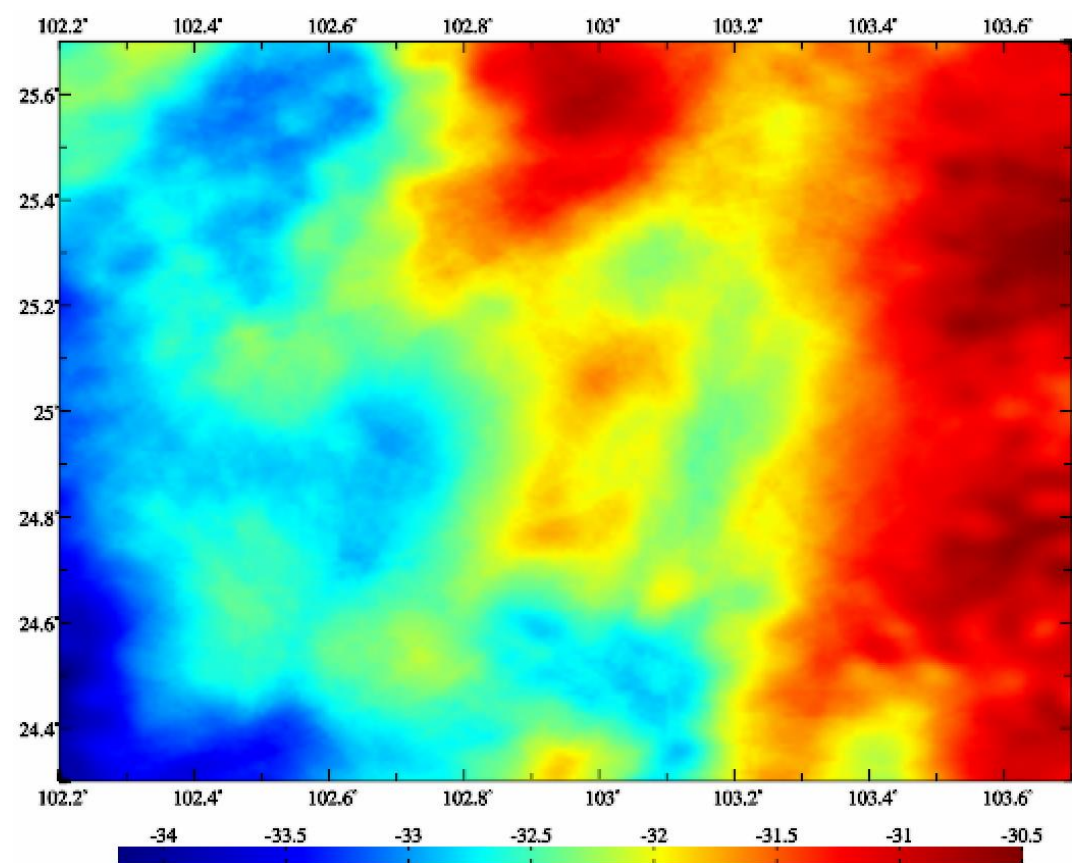
Height anomaly (m, Global datum)



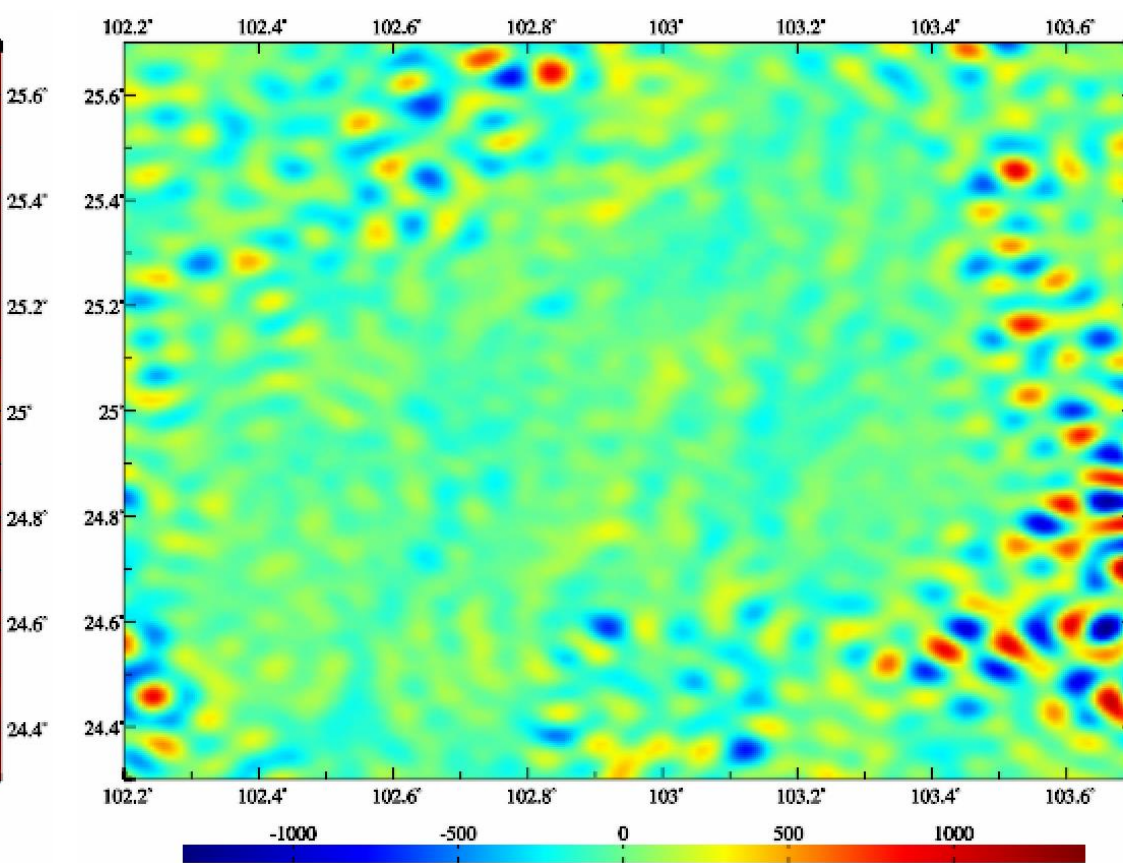
gravity disturbance (mGal)



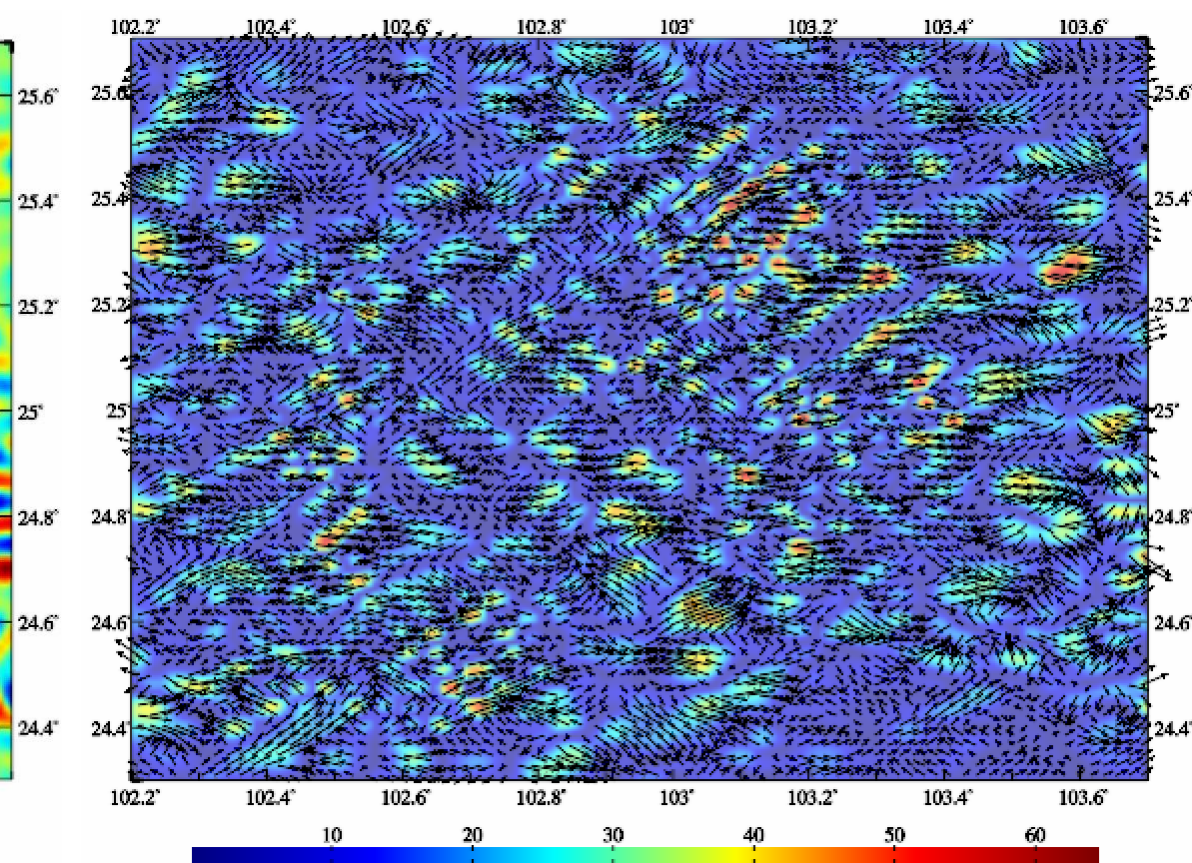
gravity anomaly (mGal)



Height anomaly (m, Regional datum)



disturbing gravity gradient (E)



vertical deflection vector (")

Observation file Save as Import parameters Start Computation Save process Follow example

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 SBRF center 100km

Reuter network level K 3600

Select the adjustable observations height anomaly (m)

Contribution rate  $\kappa$  of adjustable observations 1.00

Open the ellipsoidal height grid file of calculation 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 geoid `mdlgeoidh30s.dat`. Using the same computation process, you can synchronously obtain the 30" full element models `geoidh30srst.xxx` of the gravity field on the geoid.

```
>> Computation start time: 2024-09-28 22:09:35
>> Complete the computation!
>> Computation end time: 2024-09-28 22:15:24
>> The program outputs the all-element 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, and whose grid specification are the same as the input ellipsoidal height grid of calculation surface.
>> 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: ID, 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 0.0620 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
** Residual observations: mean -0.0014 standard deviation 0.0291 minimum -0.1886 maximum 0.0595
```

Solution of normal equation LU triangular decomposition

Save the results as Import setting parameters Start Computation

ID	lon	lat	ellipshgt	gravity disturbance(mGal)	height anomaly(m)	gravity anomaly(mGal)	gravity gradient(E)	vertical deflection
1	101.50417	24.00417	-35.528	-38.9218	-0.3520	-38.8135	-52.4075	8.4087
2	101.51250	24.00417	-35.519	-47.5954	-0.4118	-47.4688	-67.6813	9.3274
3	101.52083	24.00417	-35.510	-54.2226	-0.4570	-54.0820	-78.4029	9.8732
4	101.52917	24.00417	-35.501	-63.1927	-0.5163	-63.0339	-94.5026	10.7196
5	101.53750	24.00417	-35.491	-73.0584	-0.5808	-72.8797	-112.7679	11.4077
6	101.54583	24.00417	-35.481	-73.0444	-0.5814	-72.8656	-107.7382	10.9638

### Algorithm of gravity field approach using SRBFs

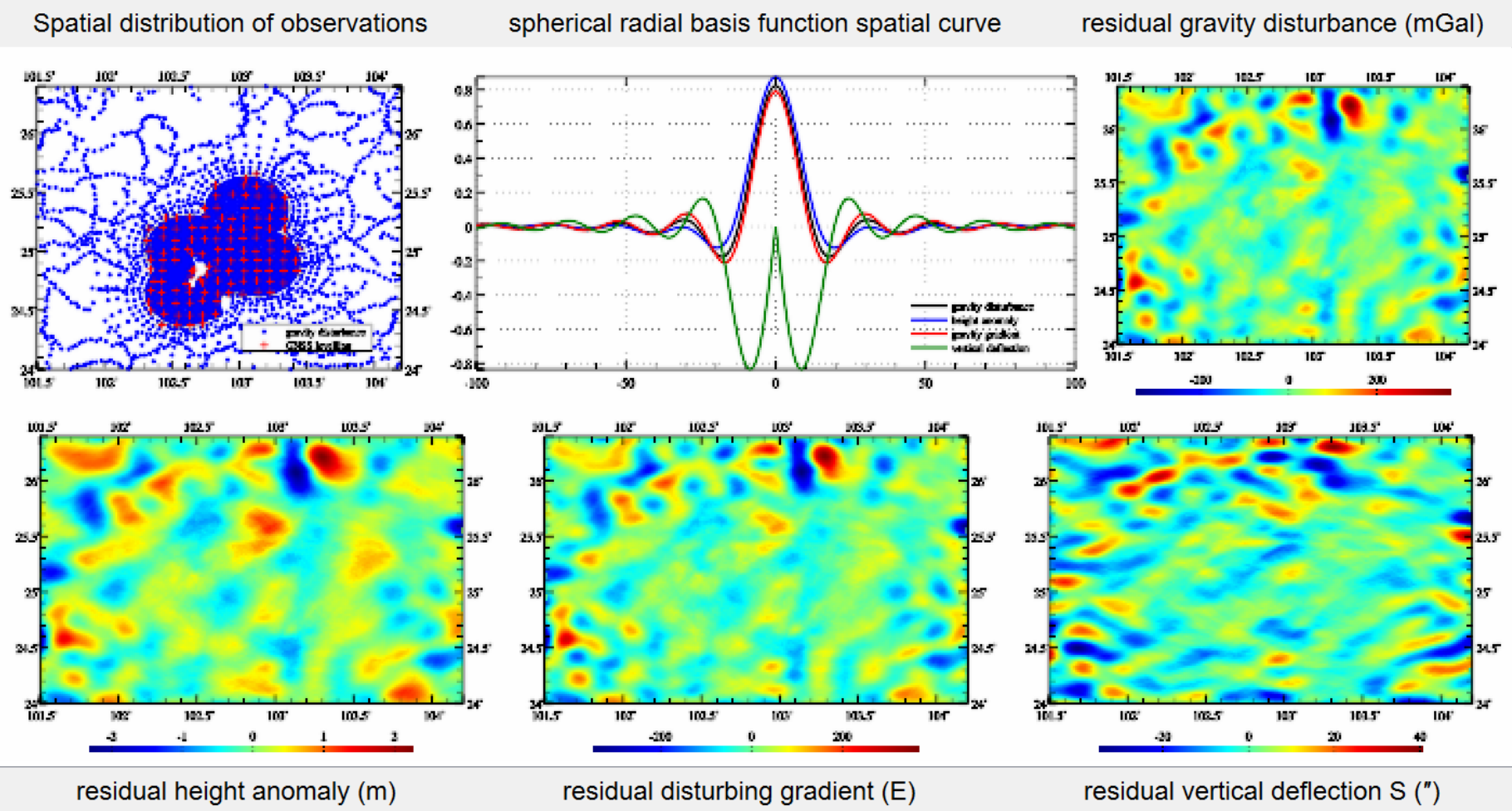
After the first estimation is completed, it is recommended to employ the output residual observation file \*.chs as the input observation file again to refine target field elements. Generally, the stable solution can be achieved by 1 to 3 times cumulative SRBF approach, and the target field elements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

The validity principle of once SRBF approach: (1) The residual target field element grid are 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.

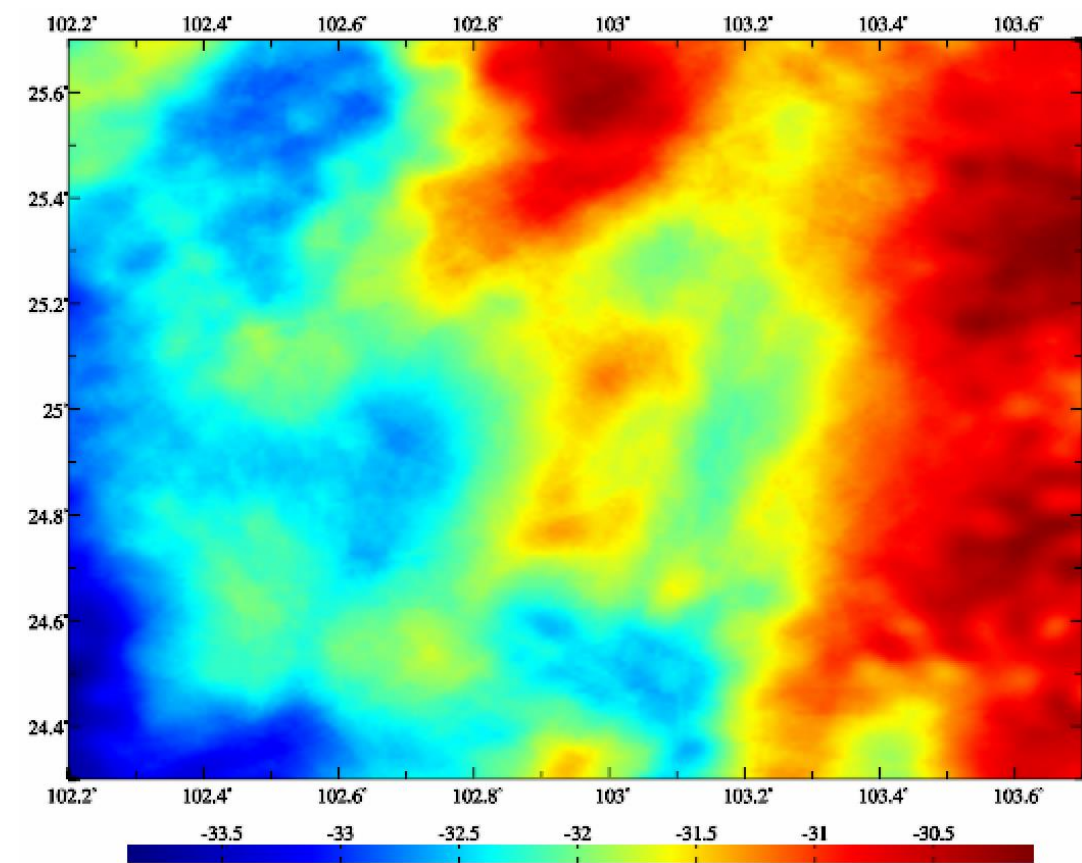
Extract data to be plot Plot →

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

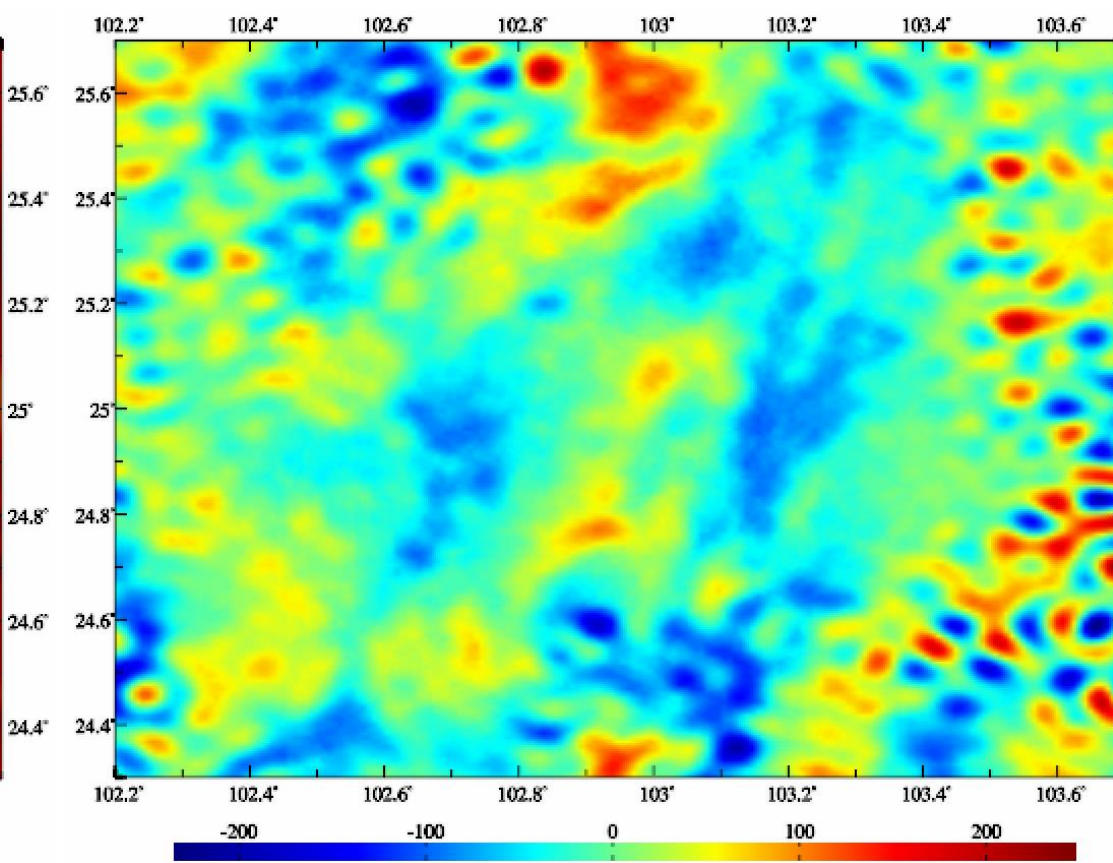
The program has strong capacity on the detection of observation gross errors, measurement of external accuracy indexes and control of computation performance.



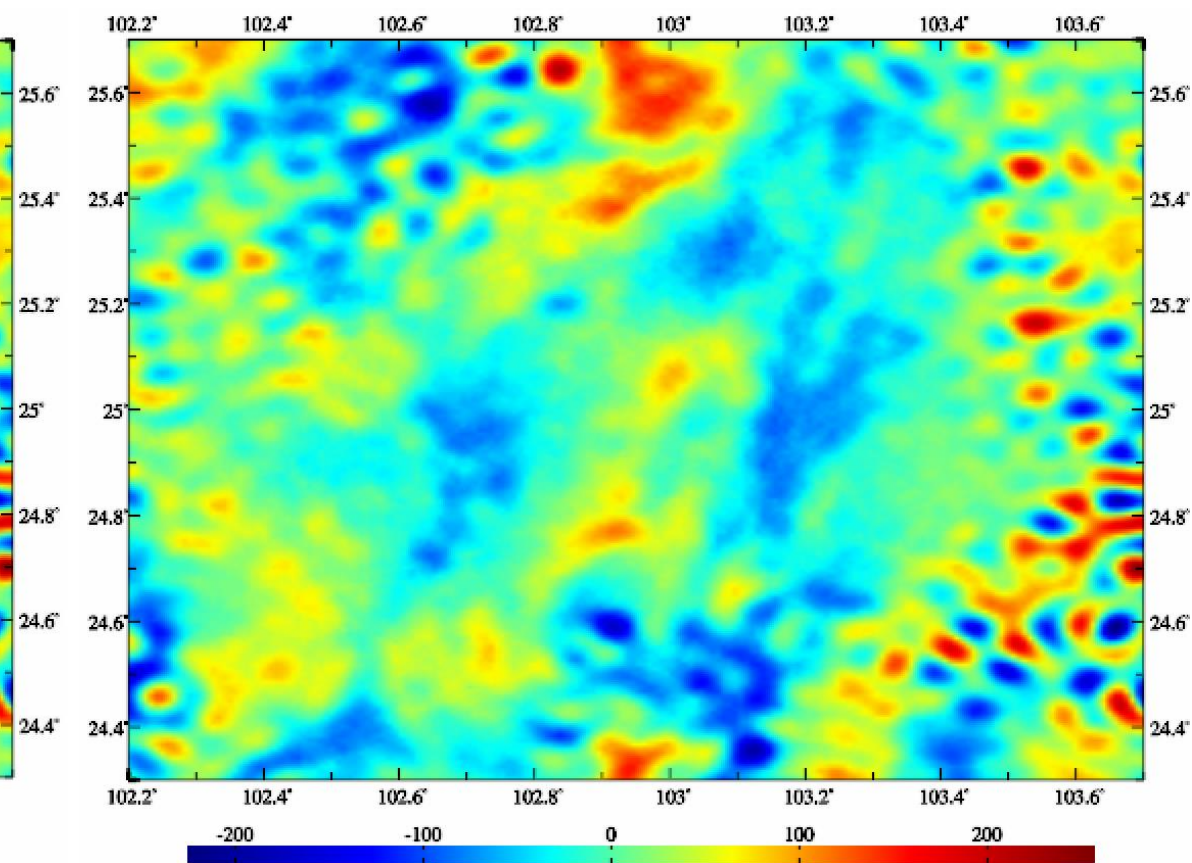
# 30"×30" full element models of gravity field on geoid



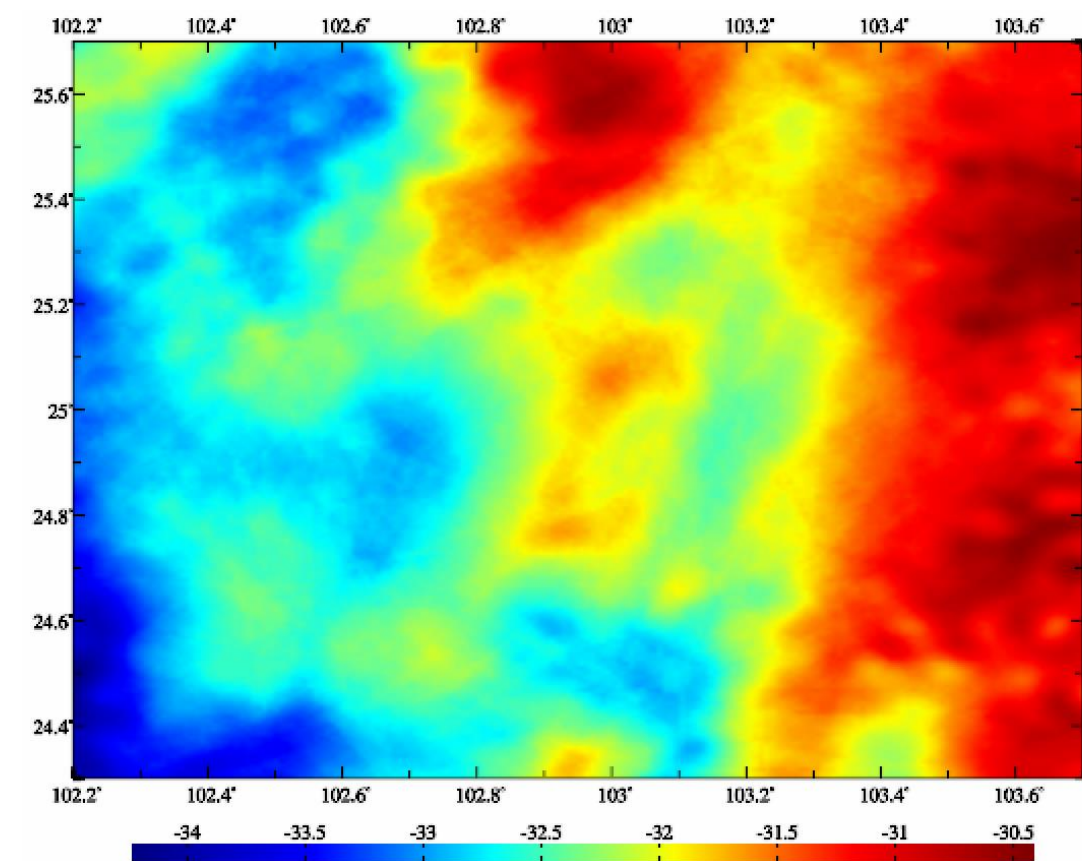
Geoid (m, Global datum)



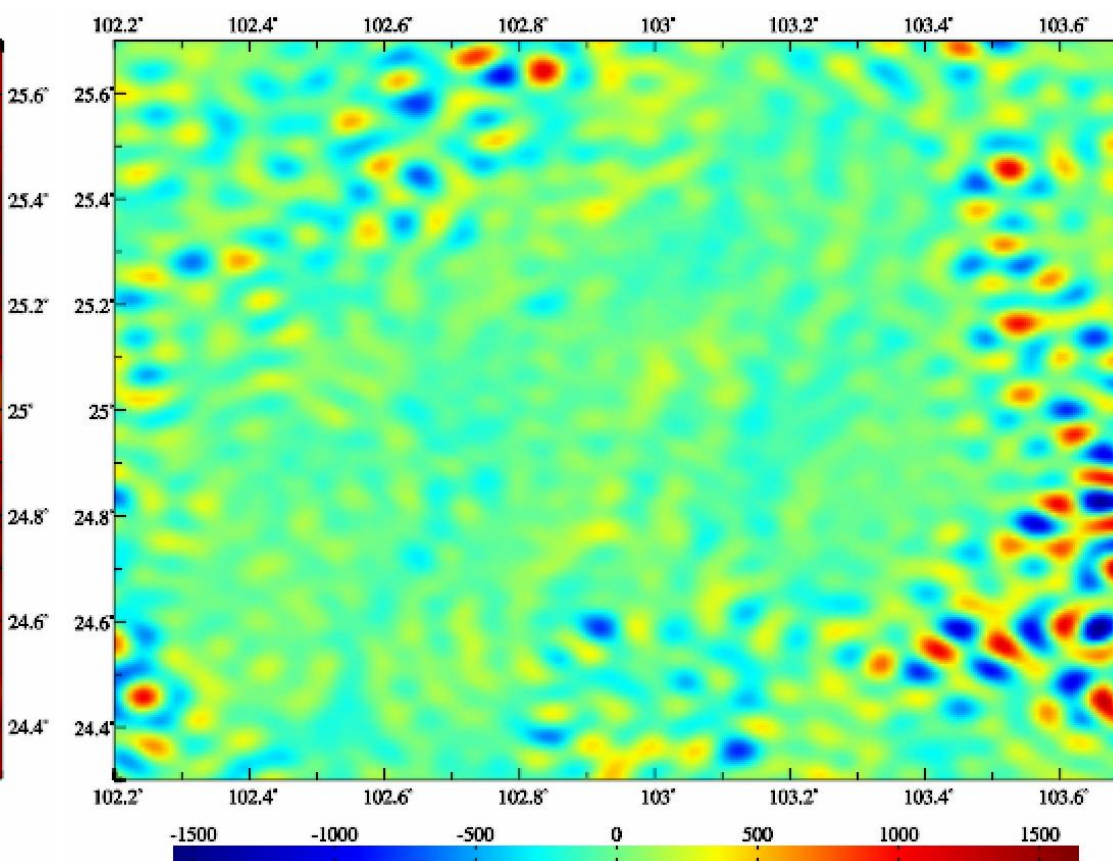
gravity disturbance (mGal)



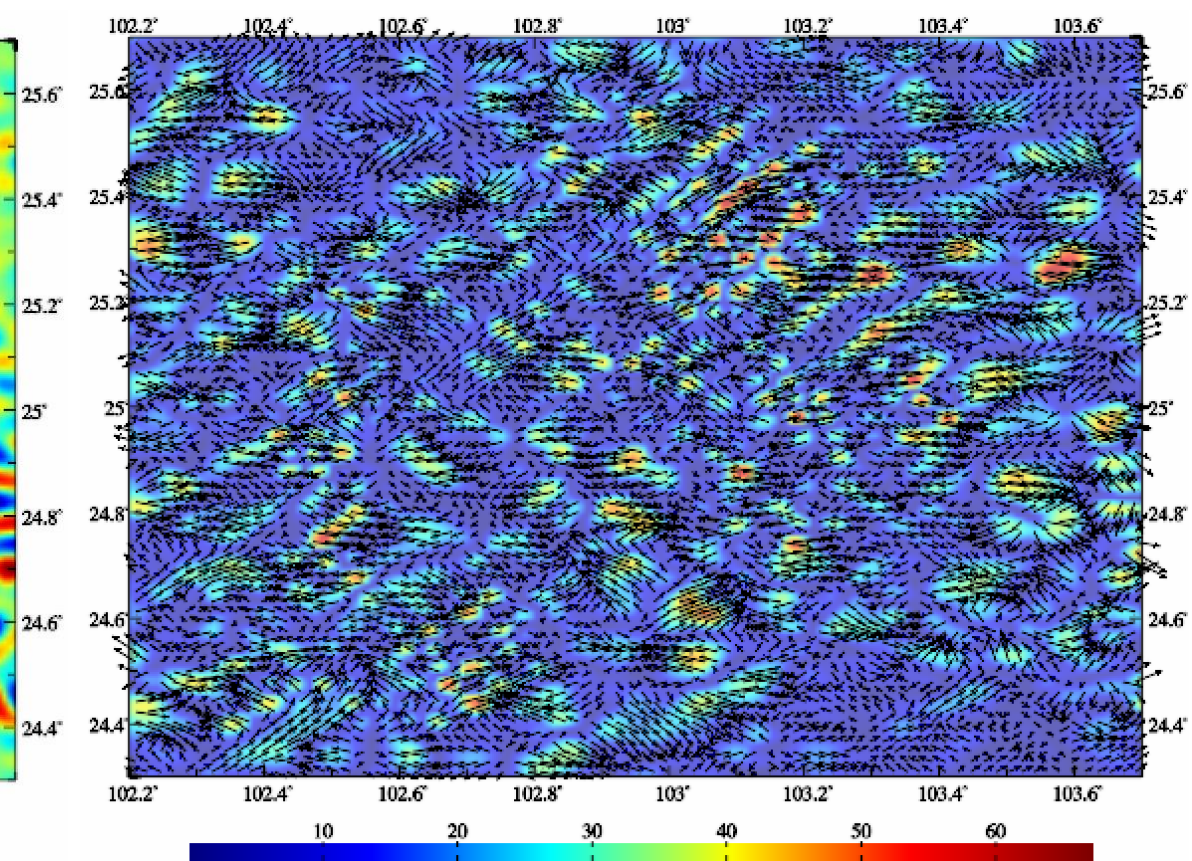
gravity anomaly (mGal)



Geoid (m, Regional datum)



disturbing gravity gradient (E)



vertical deflection vector (")

① The analytical function relationships between gravity field elements are strict, and the SRBF approach performance has nothing to do with the observation errors.

② Various heterogeneous observations in the different altitudes, cross-distribution, and land-sea coexisting cases can be directly employed to model the all-element gravity field models on or outside the geoid without reduction, continuation and gridding.

③ Can integrate very few astronomical vertical deflection or GNSS-levelling data, and effectively absorb the edge effect.

④ Has the strong capacity in the detection of observation gross errors, measurement of external accuracy indexes and control of computational performance.



**More innovation and application potential need to be discovered and excavated in the future computing practice !**