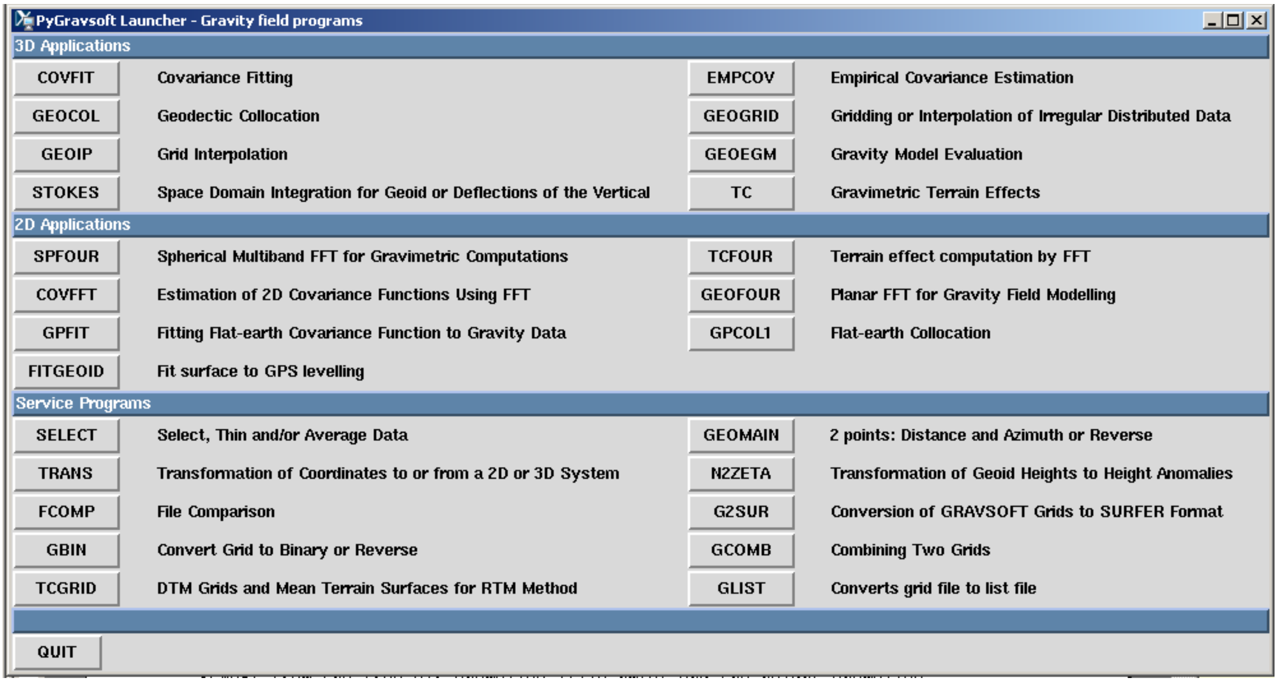
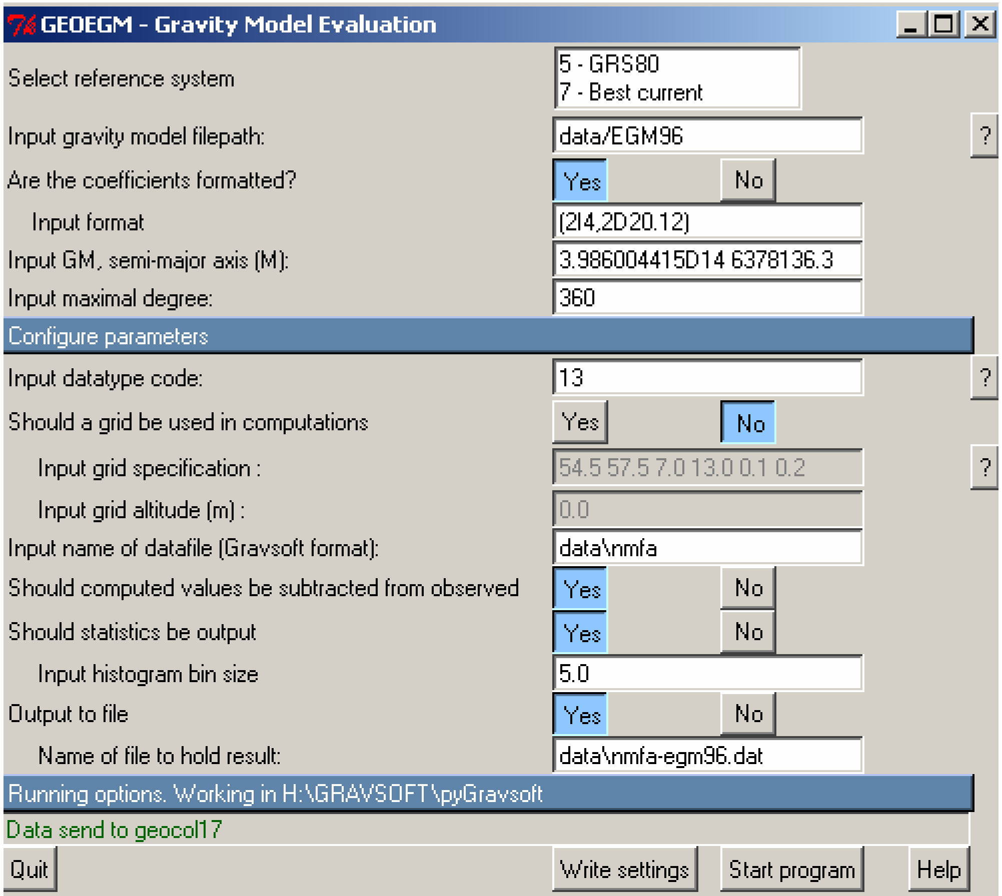
Gravsoft Pyton modules:
2008-09-11.
Prepared by C.C.Tscherning, University of Copenhagen.

We here show step-by-step how the GRAVSOFT programs are used to predict reduced height-anomalies from free-air gravity and height-anomalies derived from GPS-levelling in New Mexico. First an overview of the software:



The Python modules are all stored in a directory pyGravsoft with suffix .py. The source codes are stored in a sub-directory src and the compiled executables in a directory bin. Data to be used in examples are in dataa, and documentation in doc.
When executing a Python-module, two files will be created denoted <program-name>.inp and <program-name>.log. The last file includes the same output as will be send to the screen.

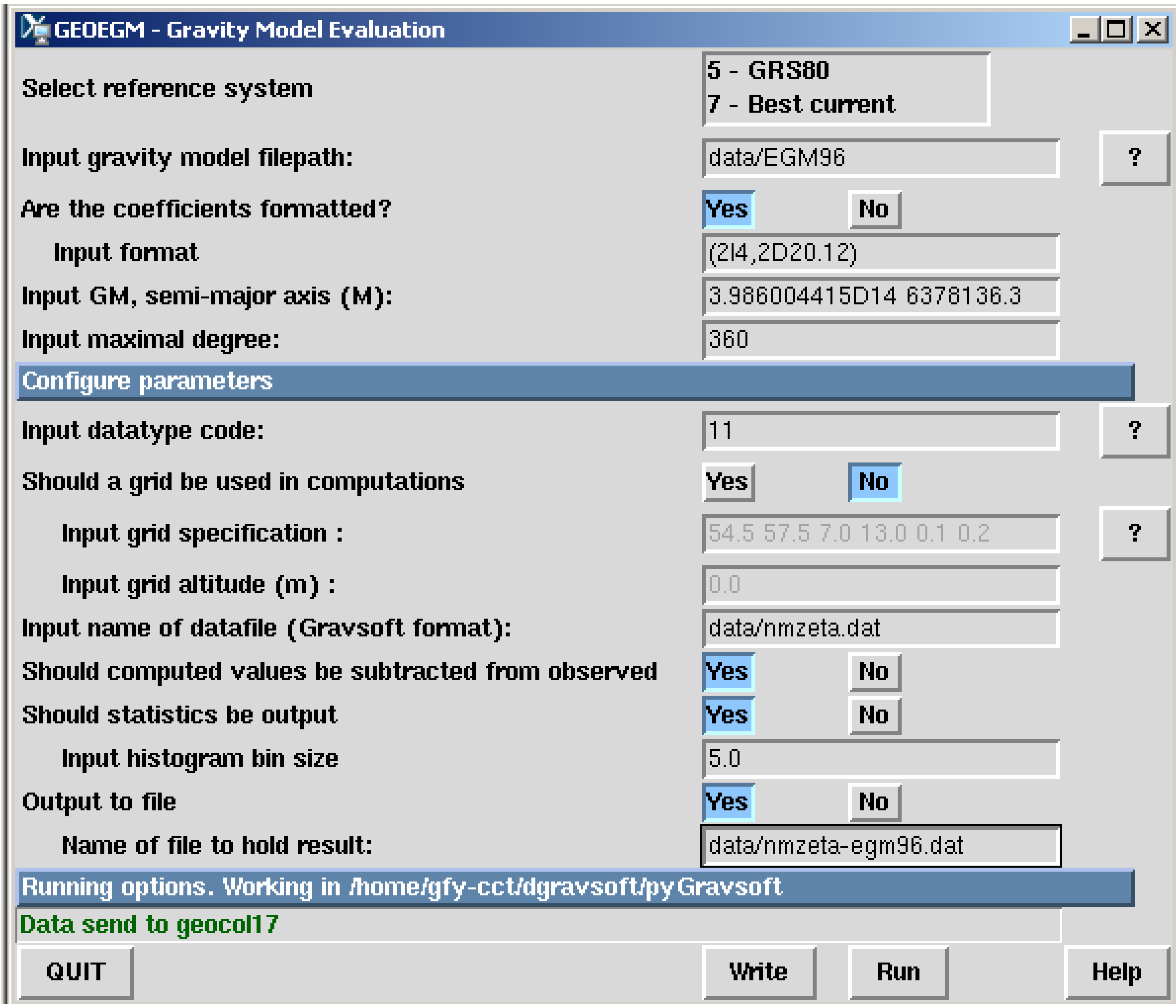
The first steps are to subtract the contribution from a global model (here EGM96) from the free-air anomalies (file data/nmfa) and the height anomalies (data/nmzeta.dat). This is followed by steps where residual terrain effects are subtracted



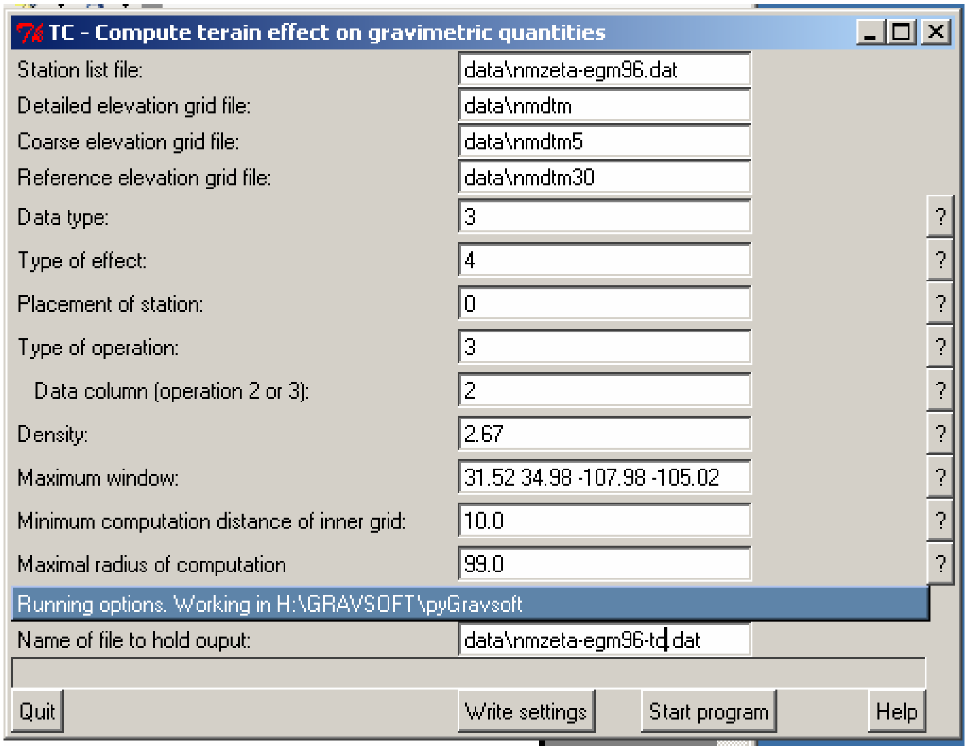
Besides output to the screen, two files are produced: geoegm.inp, which contain input instructions to geocol17 and geoegm.log, which is the output. Here is shown the last lines of the output, with the statistics of the deifferences between dat and model values.

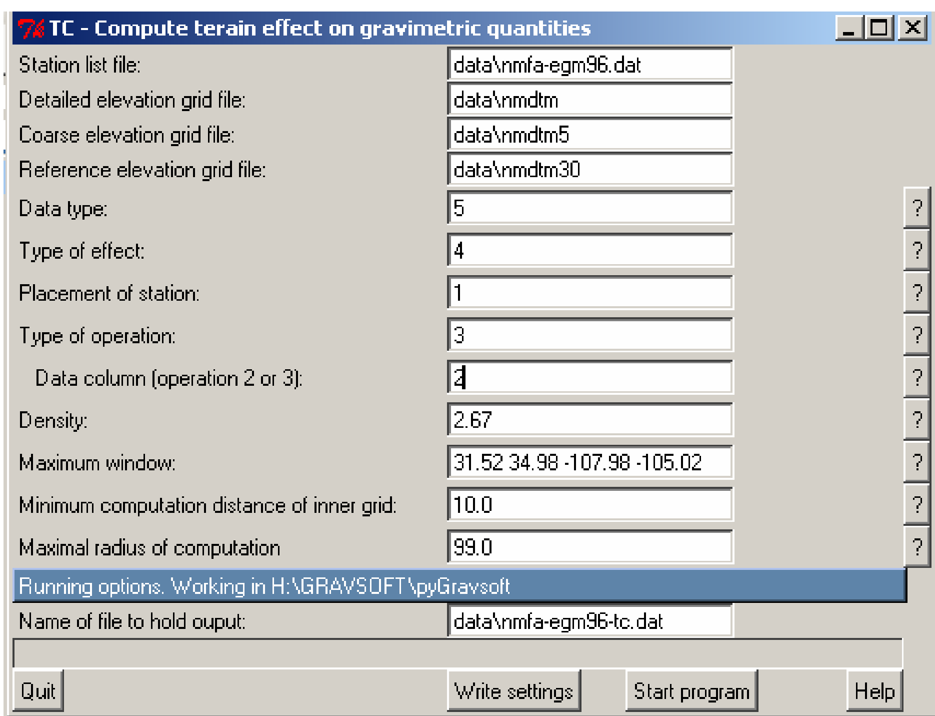
```
COMPARISON OF PREDICTIONS AND OBSERVATIONS
DATA TYPE = 13
 NUMBER:     2920
               OBSERVATIONS      PREDICTIONS     DIFFERENCE
 MEAND             9.181986        12.113826       -2.931840
 ST.DEVI.         30.405342        23.100307       21.283326
 MAX             162.500000        77.947798      126.430468
 MIN             -58.700000       -28.049954      -74.792068
0DISTRIBUTION OF DIFFERENCES, UNITS:   5.000000
  17 21 40 66107169225261317309324279221149110 73 59 29 25 24 19       76
 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1  0  1  2  3  4  5  6  7  8  9 10 OUTSIDE

  GEOCOL TERMINATED AT:
 Mon Aug 18 15:14:06 2008

##### Program completed #####
```

The same operation is then performed on height anomalies.

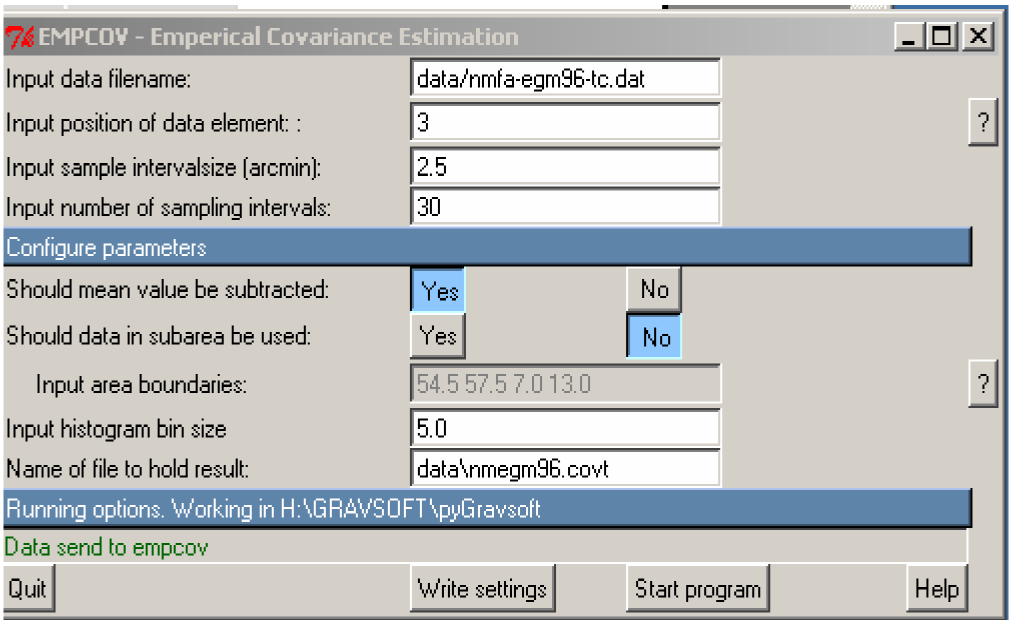


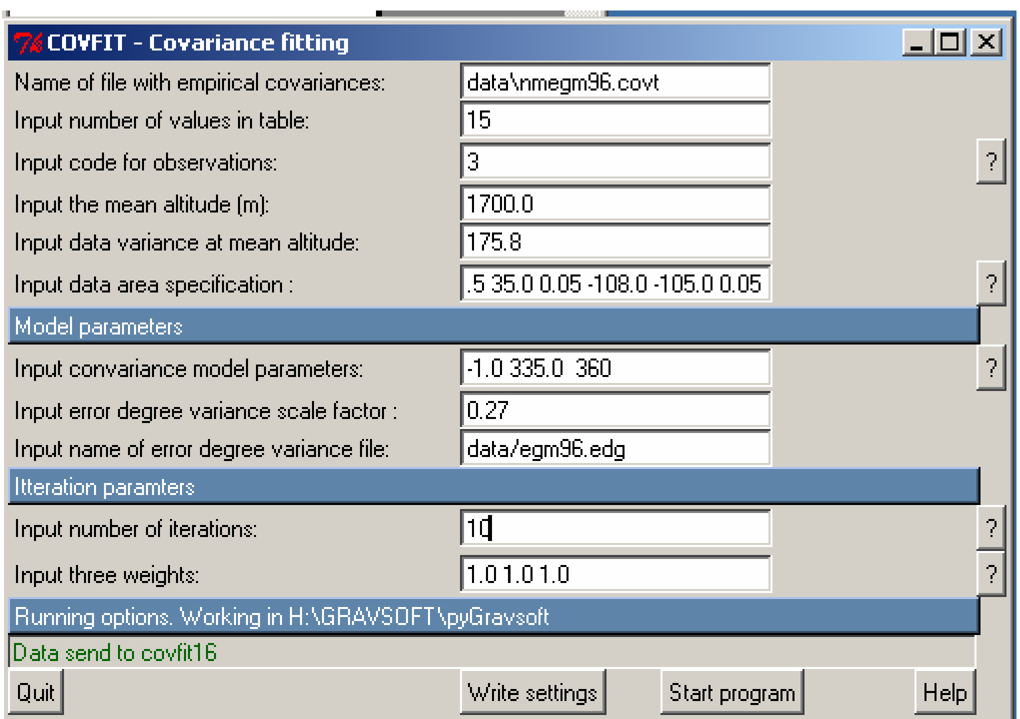

```
0COMPARISON OF PREDICTIONS AND OBSERVATIONS
0DATA TYPE = 11
 NUMBER:       20
0          OBSERVATIONS     PREDICTIONS     DIFFERENCE
 MEAND          -24.268150       -24.308527        0.040377
 ST.DEVI.         1.083020         1.101031        0.159149
 MAX            -20.917000       -21.213356        0.304919
 MIN            -25.059000       -25.134919       -0.329827
0DISTRIBUTION OF DIFFERENCES, UNITS:   5.000000
   0   0   0   0   0   0   0   0   0   0 20   0   0   0   0   0   0   0   0   0   0       0
 -10  -9  -8  -7  -6  -5  -4  -3  -2  -1   0   1   2   3   4   5   6   7   8   9  10 OUTSIDE


  GEOCOL TERMINATED AT:
 Mon Aug 18 15:24:31 2008

##### Program completed #####
```


TC - Compute terain effect on gravimetric quantities
Station list file:
data\nmzeta-egm96.dat
Detailed elevation grid file:
data\nmdtm
Coarse elevation grid file:
data\nmdtm5
Reference elevation grid file:
data\nmdtm30
Data type:
3
Type of effect:
4
Placement of station:
0
Type of operation:
3
Data column (operation 2 or 3):
2
Density:
2.67
Maximum window:
31.52 34.98 -107.98 -105.02
Minimum computation distance of inner grid:
10.0
Maximal radius of computation
99.0
Running options. Working in H:\GRAVSOFT\pyGravsoft
Name of file to hold ouput:
data\nmzeta-egm96-tc.dat
Quit
Write settings
Start program
Help


TC - Compute terain effect on gravimetric quantities
Station list file:
data\nmfa-egm96.dat
Detailed elevation grid file:
data\nmdtm
Coarse elevation grid file:
data\nmdtm5
Reference elevation grid file:
data\nmdtm30
Data type:
5
Type of effect:
4
Placement of station:
1
Type of operation:
3
Data column (operation 2 or 3):
2
Density:
2.67
Maximum window:
31.52 34.98 -107.98 -105.02
Minimum computation distance of inner grid:
10.0
Maximal radius of computation
99.0
Running options. Working in H:\GRAVSOFT\pyGravsoft
Name of file to hold ouput:
data\nmfa-egm96-tc.dat
Quit
Write settings
Start program
Help

Then the empirical covariance function is estimated and fitted using COVFIT.

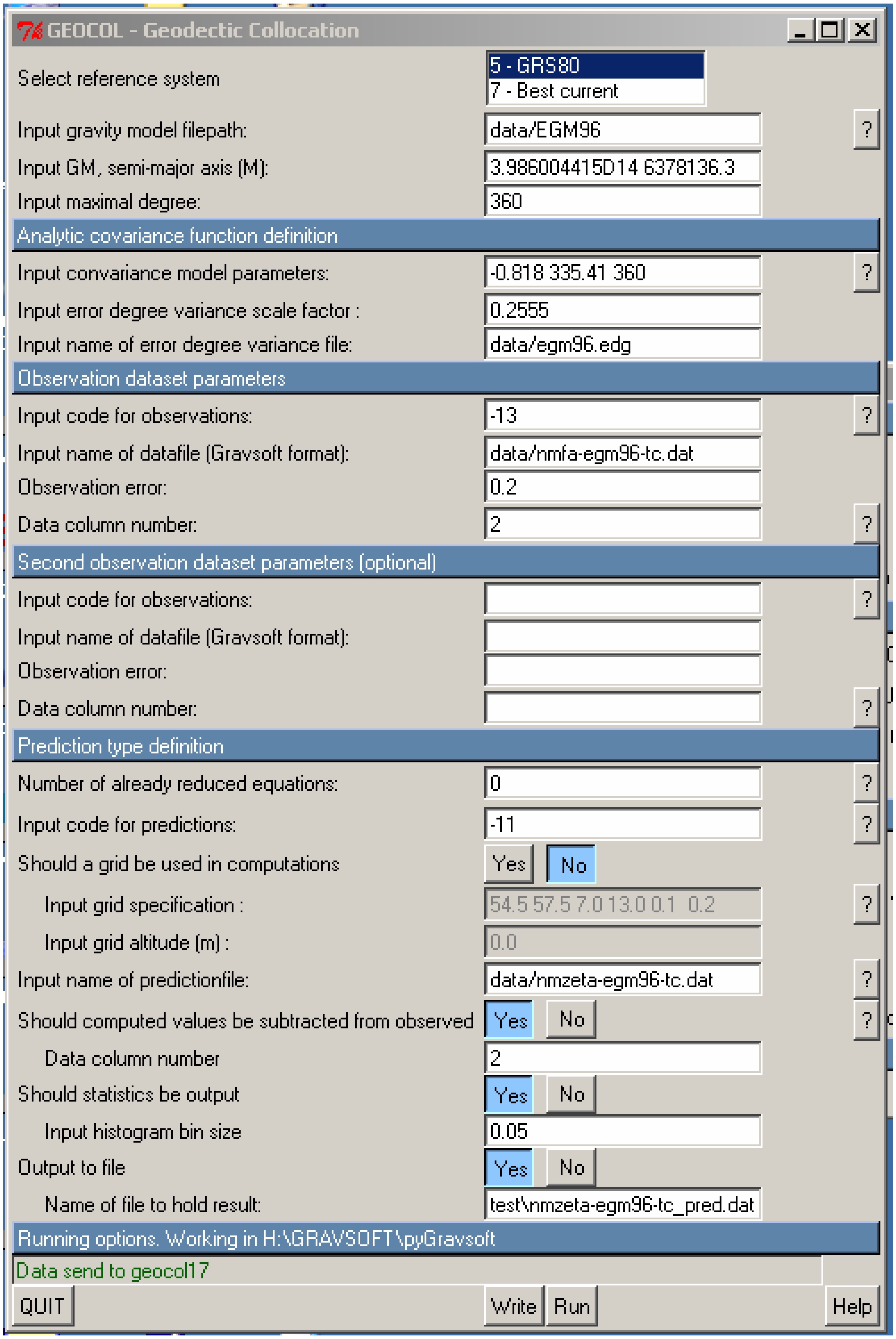




Final part of covfit.log with the results of the fitting.
The values VARDG=335.41, AA=0.2555 and RE-RB = -819.7 are used as parameters for GEOCOL. The column with the heading OBS are the values estimated by EMPCOV.

```
 RESULT OF ITERATION NO.  5:
 --------------------------
                                AA             A           RB-RE
 NEW VALUE:                   0.255454       682639.      -819.274
 LAST ADJ.:                   0.000109         -345.         1.570

     KP KQ    PSI      HP      HQ       OBS     MODEL       ERR   DIF/ERR

   1  3  3   0.000   1700.0   1700.0  175.8490  174.1635    3.4091  0.4944
   2  3  3   0.042   1700.0   1700.0  136.9017  147.2436    6.5481 -1.5794
   3  3  3   0.083   1700.0   1700.0  103.9408  105.6302    6.7251 -0.2512
   4  3  3   0.125   1700.0   1700.0   73.8018   70.2822    7.0395  0.5000
   5  3  3   0.167   1700.0   1700.0   47.9292   43.5676    7.3255  0.5954
   6  3  3   0.208   1700.0   1700.0   27.3777   24.3020    7.6195  0.4037
   7  3  3   0.250   1700.0   1700.0   13.9125   10.0831    7.9262  0.4831
   8  3  3   0.292   1700.0   1700.0    1.0594    0.2856    8.2305  0.0940
   9  3  3   0.333   1700.0   1700.0   -4.8086   -5.8998    8.5167  0.1281
  10  3  3   0.375   1700.0   1700.0  -10.9165   -9.5143    8.8516 -0.1584
  11  3  3   0.417   1700.0   1700.0  -13.9891  -11.0021    9.0615 -0.3296
  12  3  3   0.458   1700.0   1700.0  -17.2667  -10.9209    9.3502 -0.6787
  13  3  3   0.500   1700.0   1700.0  -18.5129   -9.7227    9.7607 -0.9006
  14  3  3   0.542   1700.0   1700.0  -19.3898   -7.7919    9.9716 -1.1631
  15  3  3   0.583   1700.0   1700.0  -18.5653   -5.5235   10.2708 -1.2698
 RMS VALUE OF DIFFERENCES/ERRORS:      0.739308
 (RELATIVE CHANGE:                     0.000002).

  TAU(J) USED IN THE CX MATRIX      0.10E+01      0.10E+01      0.10E+01
RESULTS IN VARIANCE OF GRAVITY ANOMALIES:
  1'TH ROW OF INVERSE MATRIX      0.5870E-01   -0.1459E-01   -0.3330E-01
  2'TH ROW OF INVERSE MATRIX     -0.1459E-01    0.1312E-01    0.4660E-01
  3'TH ROW OF INVERSE MATRIX     -0.3330E-01    0.4660E-01    0.1796E+00
  STD.DEV.       0.618907E-01  0.781821E+05  0.347233E+03
  STD.DEV.*RMS   0.457563E-01  0.578007E+05  0.256712E+03
 RESULTS IN VARIANCE OF GRAVITY ANOMALIES:   335.41 MGAL**2.

 N       RATIO      AA      A          RE-RB    VARG IT
 360  0.7393D+00  0.2555  0.6826D+06  -819.27   335.41    5
```

In the following step we predict the reduced height-anomalies from the reduced gravity anomalies. This is then followed by a step where both the reduced gravity data and the reduced height anomalies are used to predict heigt anomalies at terrain level. Note, tat in the final step we use that 2920 columns of the normal-equations already have been reduced.


GEOCOL - Geodectic Collocation
Select reference system
5 - GRS80
7 - Best current
Input gravity model filepath:
data/EGM96
Input GM, semi-major axis (M):
3.986004415D14 6378136.3
Input maximal degree:
360
Analytic covariance function definition
Input convariance model parameters:
-0.818 335.41 360
Input error degree variance scale factor :
0.2555
Input name of error degree variance file:
data/egm96.edg
Observation dataset parameters
Input code for observations:
-13
Input name of datafile (Gravsoft format):
data/nmfa-egm96-tc.dat
Observation error:
0.2
Data column number:
2
Second observation dataset parameters (optional)
Input code for observations:
Input name of datafile (Gravsoft format):
Observation error:
Data column number:
Prediction type definition
Number of already reduced equations:
0
Input code for predictions:
-11
Should a grid be used in computations
Yes
No
Input grid specification :
54.5 57.5 7.0 13.0 0.1 0.2
Input grid altitude (m) :
0.0
Input name of predictionfile:
data/nmzeta-egm96-tc.dat
Should computed values be subtracted from observed
Yes
No
Data column number
2
Should statistics be output
Yes
No
Input histogram bin size
0.05
Output to file
Yes
No
Name of file to hold result:
test\nmzeta-egm96-tc_pred.dat
Running options. Working in H:\GRAVSOFT\pyGravsoft
Data send to geocol17
QUIT
Write
Run
Help

The comparison between predicted and observed height anomalies are found in the file geocol.log, of which here is shown the last part:

```
 COMPARISON OF PREDICTIONS AND OBSERVATIONS
 DATA TYPE = 11
 NUMBER:      20
          OBSERVATIONS     PREDICTIONS     DIFFERENCE
 MEAND            -0.897275       -0.000249       -0.897026        0.057190
 ST.DEVI.          0.159149        0.145572        0.051812        0.014752
 MAX              -0.632800        0.210118       -0.789369        0.090756
 MIN              -1.267500       -0.320443       -0.987109        0.045835
 DISTRIBUTION OF DIFFERENCES, UNITS:  0.050000
   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0       20
 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1  0  1  2  3  4  5  6  7  8  9 10 OUTSIDE
```

The result shows that we are able to predict the reduced height anomalies with an error standard deviation of 0.05 m. Due to the bias, the histogram values can not be used. Now we add the height anomalies to the data and predict the data as well. The bias value will be estimated.

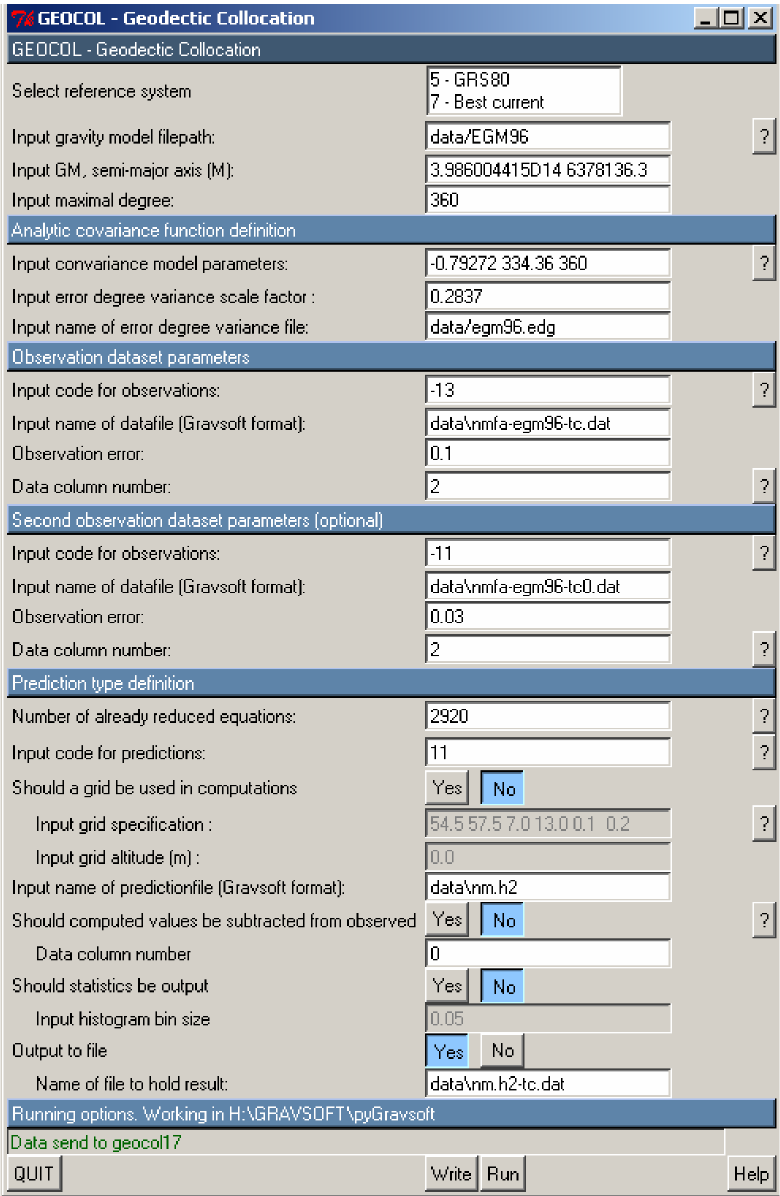
Here we see the height system bias N_0

```
ELEMENTS OF (AT*C**-1*A)**-1.
   0.0085
  CORRELATION MATRIX:
    1.0000
 PARAMETER    TYPE     ESTIMATE       ERROR ESTIMATE (FOR TILT: ZERO POINT
           1       11111   -0.783996623    0.092367316
```

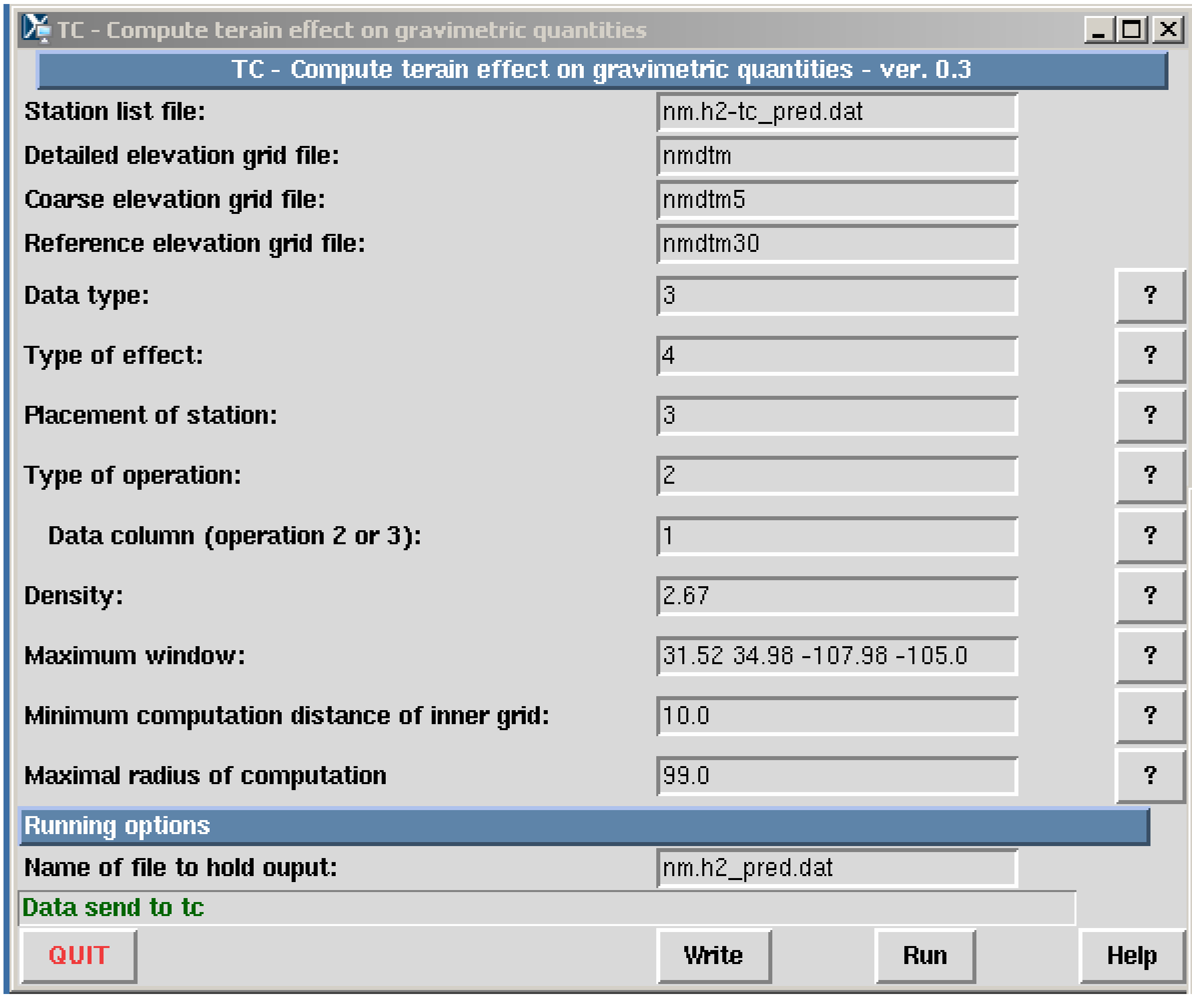
And the comparison of observed and values predicted in the observed points:

```
COMPARISON OF PREDICTIONS AND OBSERVATIONS
DATA TYPE = 11
 NUMBER:      20
                       OBSERVATIONS     PREDICTIONS     DIFFERENCE
 MEAND           -0.897275       -0.897275        0.000000        0.184852
 ST.DEVI.         0.159149        0.156162        0.015303        0.000101
 MAX             -0.632800       -0.635039        0.038347        0.185066
 MIN             -1.267500       -1.246579       -0.028575        0.184632
DISTRIBUTION OF DIFFERENCES, UNITS:  0.010000
   0  0  0  0  0  0  0  1  3  1 10  2  2  0  1  0  0  0  0  0  0       0
 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1  0  1  2  3  4  5  6  7  8  9 10 OUTSIDE
```

We now predict height anomalies at the surface of the Earth:

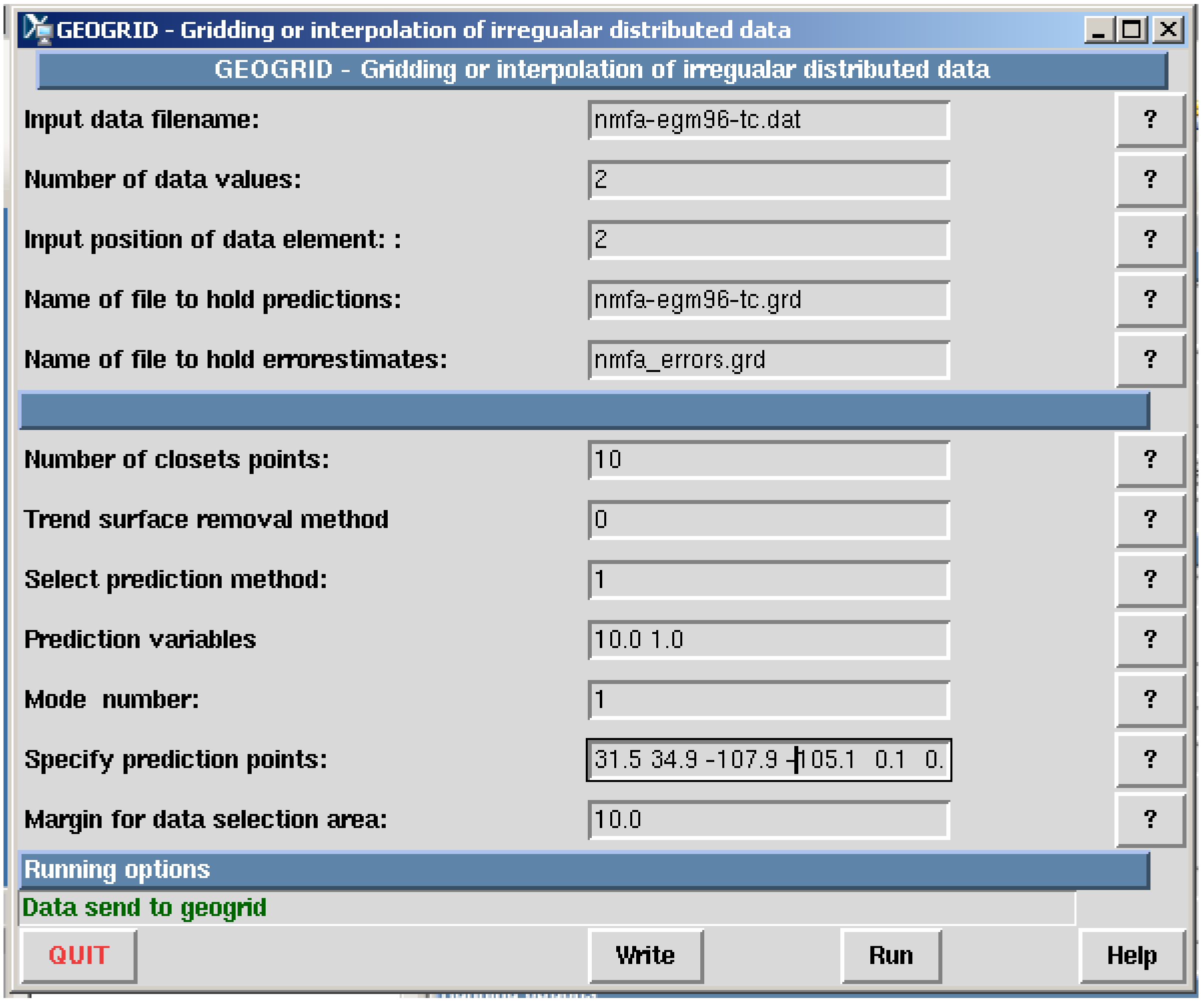


Remaining step is that TC is used to add back the effect of the residual topography.

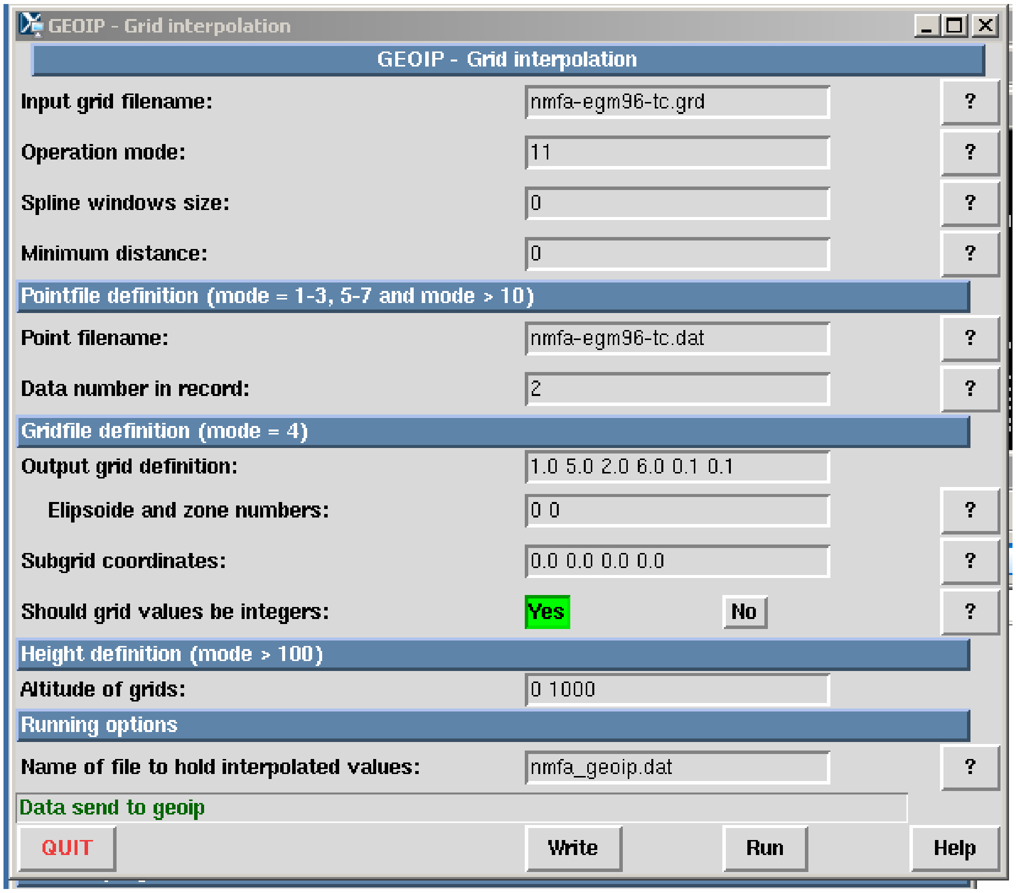


We now prepare for 2D solutions using Stokes or Collocation.

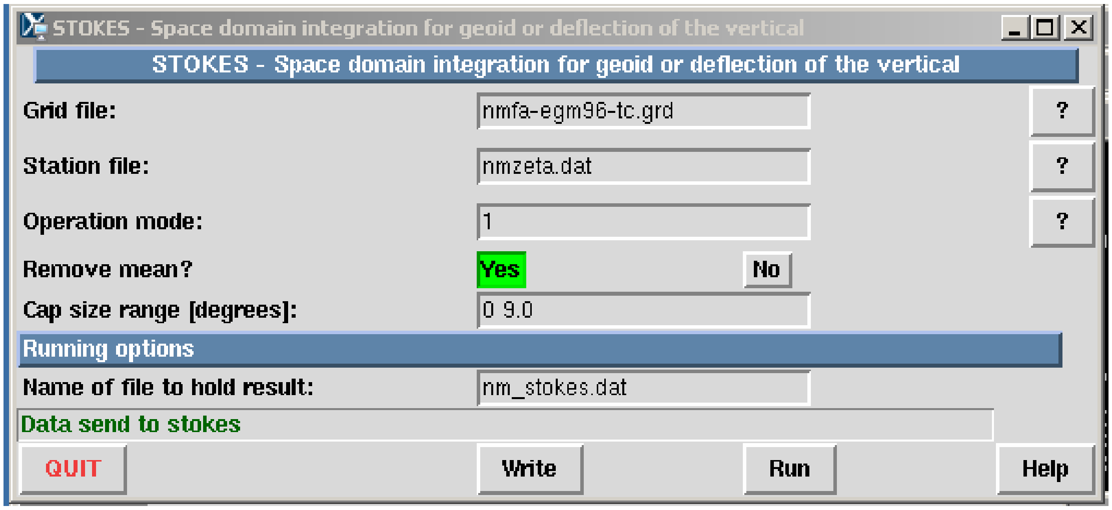
First a gridding is needed using geogrid. The result is compared with the original data using geoip.



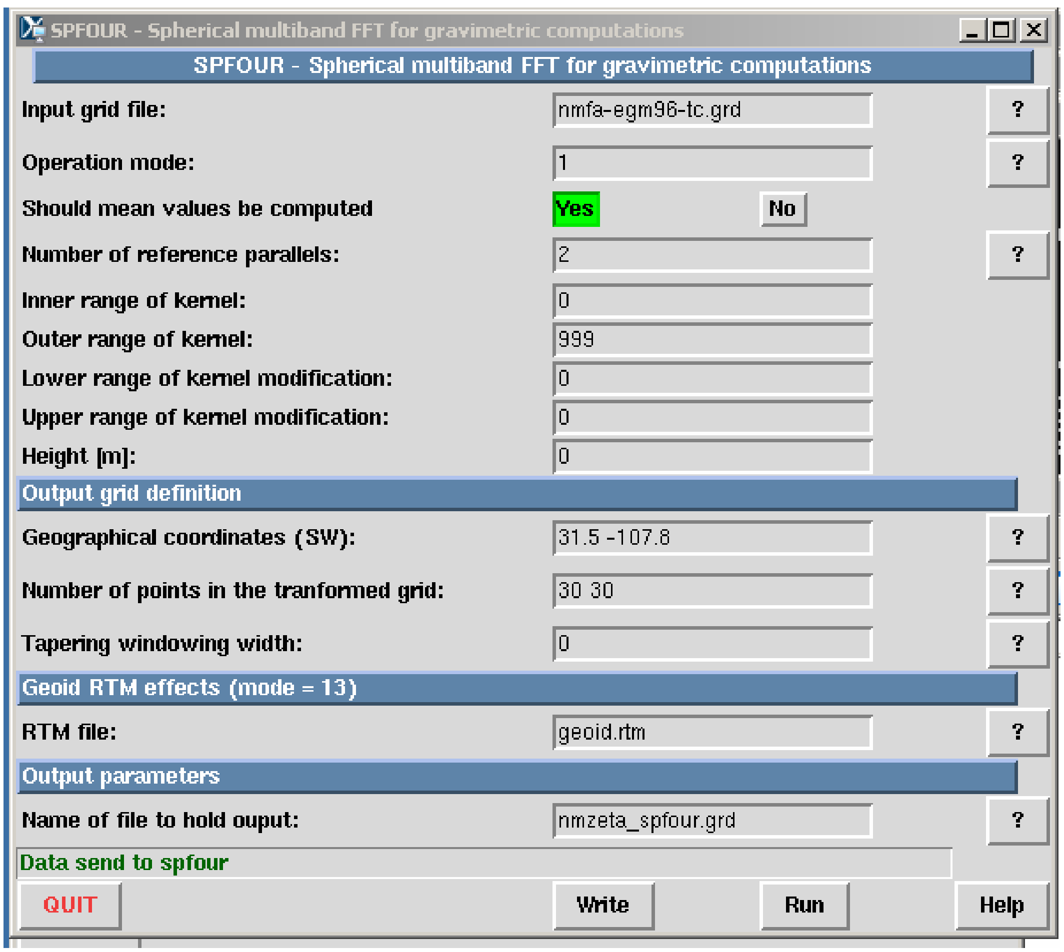

```
 *******************************************************************
  *    GEOGRID - GRAVSOFT data gridding - vers. JAN 06 - (c) RF/DNSC  *
  *******************************************************************
  internal lambert map projection center:    33.200 -106.500
  rkm =   10.0, data selection area:   31.4100  34.9900-108.0075-104.9925

  data values per point:  2, used no.:  2
  total points in file:   2920, selected:   2920
  min max mean stddev:    -41.031    45.899     0.307    13.173

  collocation prediction - sqrc0,xhalf(km),rmsn =   13.17  10.00   1.00
  selection: 10 closest points per quadrant

  data organization limits in lambert proj: -168534.  179793. -124480.  124377.
  subrectangles (n,e,total):    37   26   962
  size (km):      9.41     9.57, average pts per rect (rdat):    3.035
  max points in subrects:   11, percentage with no points:   7.5

  predicted:    1015 points
  prediction pts mean std.dev. min max:      0.55     12.35    -37.59     47.66
  prediction error values min max:                                 0.94     13.14
```



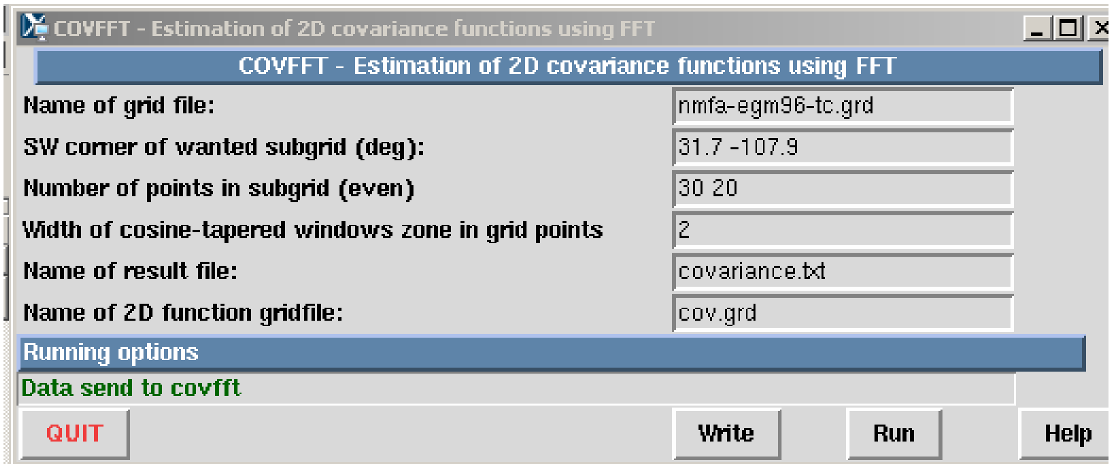

```
---  G E O I P  ---
 grid file name: nmfa-egm96-tc.grd
 output file name: nmfa_geoip.dat
 mode = 1, nsp =  0, minimum edge dist   0.0 km
 point file name: nmfa-egm96-tc.dat
 - bilinear interpolation -
 - subtraction of interpolated values from pointfile -

 number of prediction points:    2920
 within area    31.6836   34.8134 -107.8166 -105.1850

 grid file information:
 gridlab:    31.5000  34.9000-107.9000-105.1000   0.1000   0.1000   35  29
 selected subgrid:   31.6000  34.9000-107.9000-105.1000
 points:  34 x  29 =     986, zero values:       0, unknown (9999):       0
 min  max  mean  std.dev.:    -37.59     47.66      0.57     12.53

 points predicted:   2920,  skipped points:      0
 minimum distance to grid edges for predictions:    7.8 km
 statistics:                     mean   std.dev.   min      max    unknown
 original data (pointfile) :    0.307   13.173  -41.031   45.899      0
 grid interpolation results:    0.291   11.606  -34.880   43.166      0
 predicted values output   :    0.016    3.699  -17.386   21.422      0
```



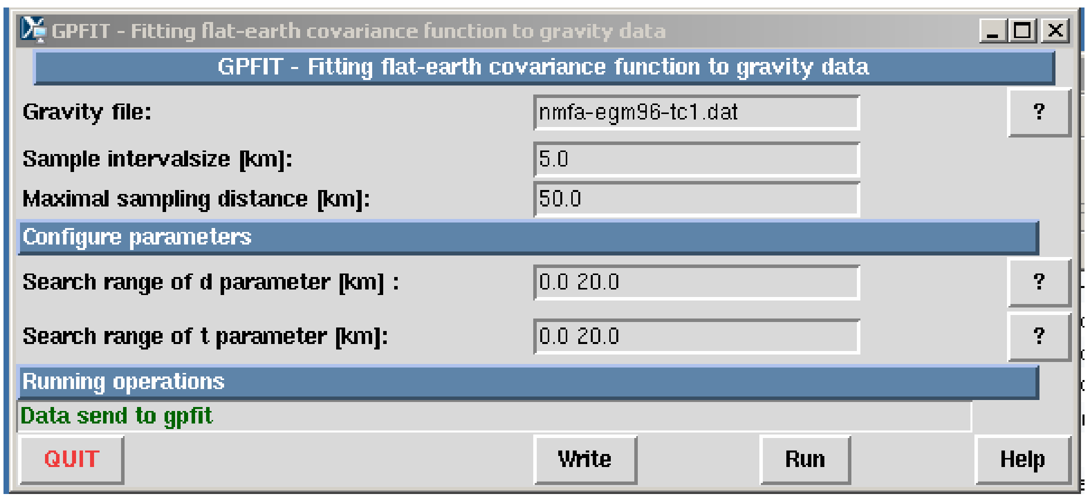
Using the gridded data we use spfour.



Again, using the gridded data, we may compute the covariance function using covfft.



Or, we may directly from the point data estimate geoid heights using planar collocation with gpcol1.




```
--- G P F I T ---
 input: gravityfile
 input: ds,smax,d1,d2,t1,t2 (km)
 n = 2920, mean =   0.31, C0 =   173.57, sqrtC0 =  13.17
 - searching for best fit in interval:  0 -  20,  0 -  20 km
 Best values of fit: D =  20 km, T =   3 km

 Empirical and fitted covariances:
    Dist (km)     No of products      Cov     Fitted cov
       0.0           3435          174.34     173.57
       5.0           8926          136.32     152.84
      10.0          17078           98.54     106.77
      15.0          24469           66.30      62.12
      20.0          31357           41.09      31.24
      25.0          37212           21.27      13.40
      30.0          43213            7.50       4.14
      35.0          47965           -2.66      -0.31
      40.0          53321           -8.60      -2.24
```

45.0	57901	-13.33	-2.94
50.0	62148	-16.58	-3.04