Gravsoft Python modules with New Mexico examples:
2008-09-11, revision 2, 2009-01-30.
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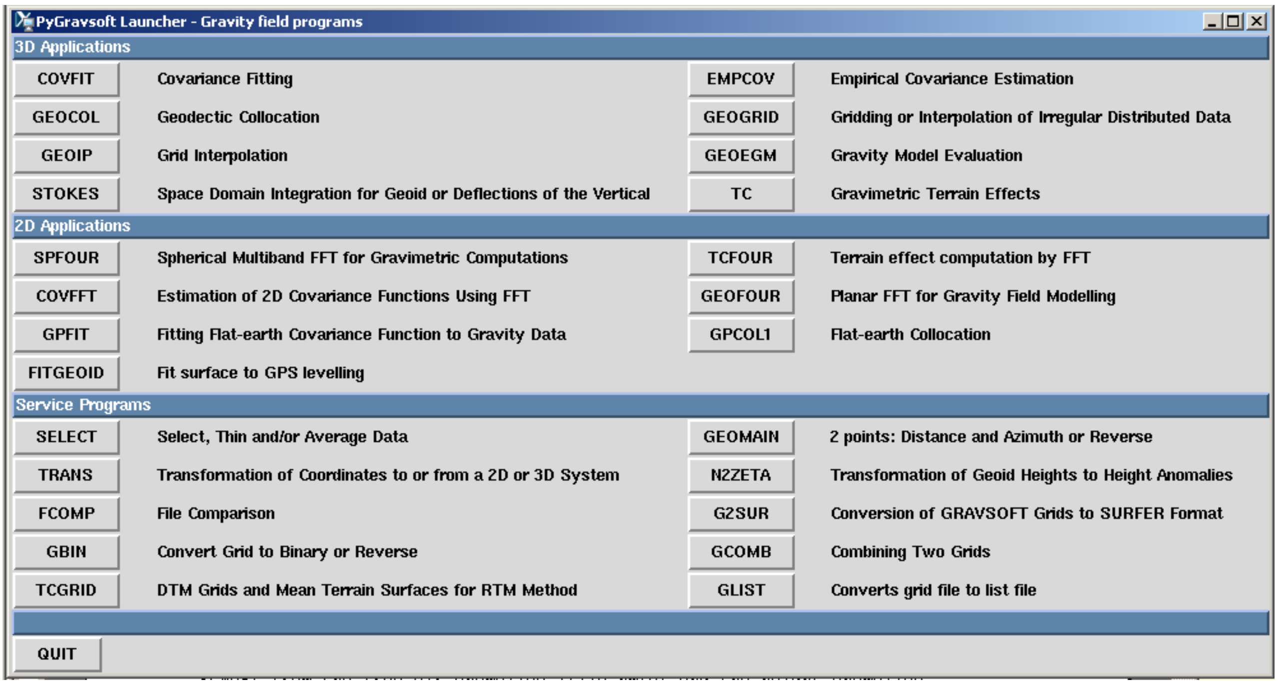
We here show step-by-step how the GRAVSOFT programs are used to predict reduced height-anomalies from free-air gravity and height-anomalies derived from GPS-levelling in New Mexico. As a reference field we use EGM96, but Appendix 2 shows how to use EGM2008. Furthermore the conversion from geoid heights (GPS-levelling) to height anomalies is illustrated in Appendix 1.

First an overview of the software:

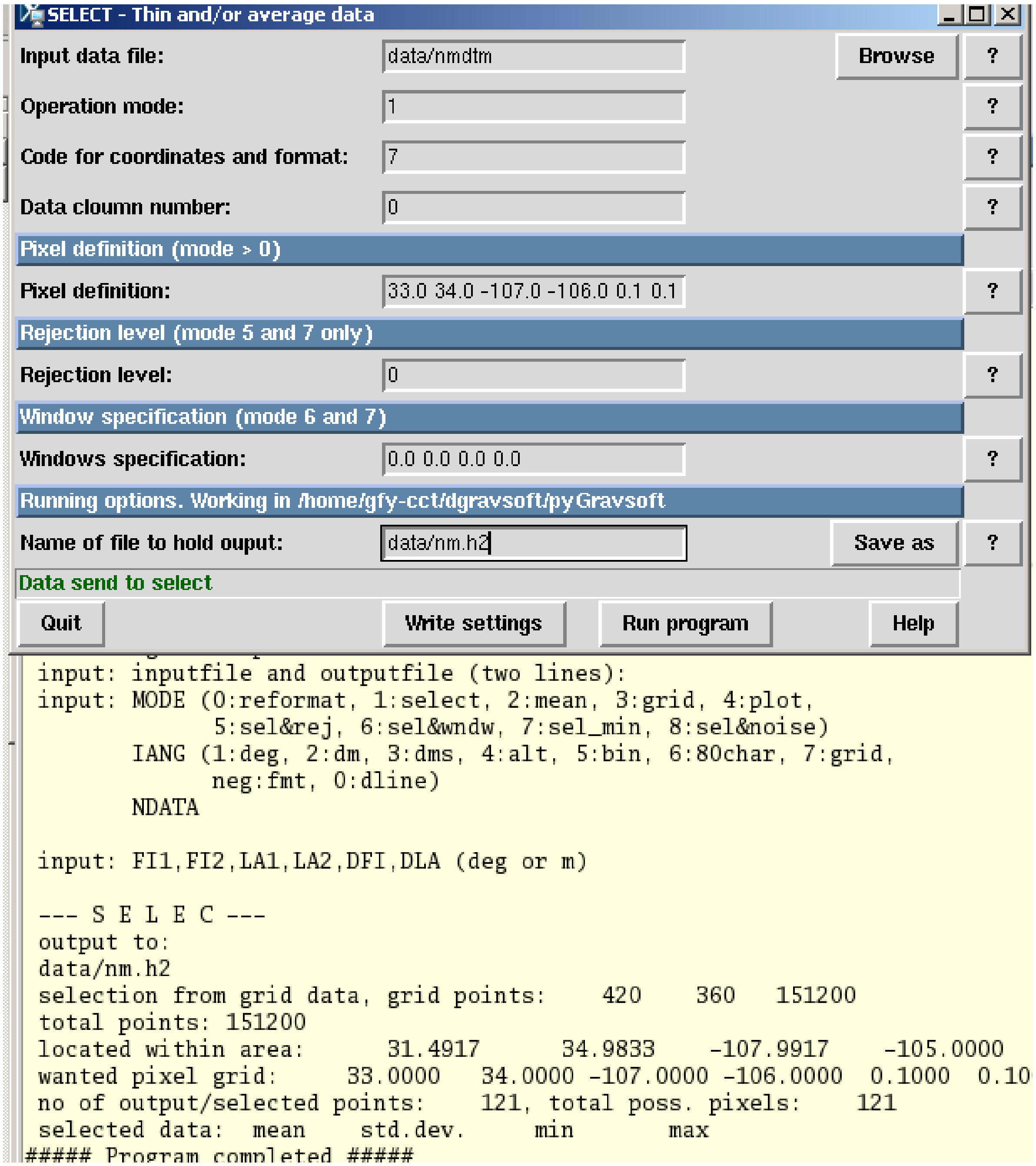


The Python modules are all stored in a directory pyGravsoft with suffix .py. The source codes are stored in a sub-directory src and the compiled executables in a directory bin. Data to be used in examples are in data, and documentation in doc. **Note here, that the GRAVSOFT modules have many more functions than those illustrated here. The source codes of the FORTRAN programs must be inspected if other possibilities are to be used.**

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 step is to select the area (a grid) in which the quasi-geoid is to be computed and decide the grid spacing. The quasi-geoid is to be evaluated at the surface of the Earth, so the grid must be extracted from a digital height model. Here we will use the file data/nmdtm. We will use a grid bounded by minimum latitude 33 deg., maximal latitude 34 deg., minimum longitude -107 deg and maximum longitude 106 deg.

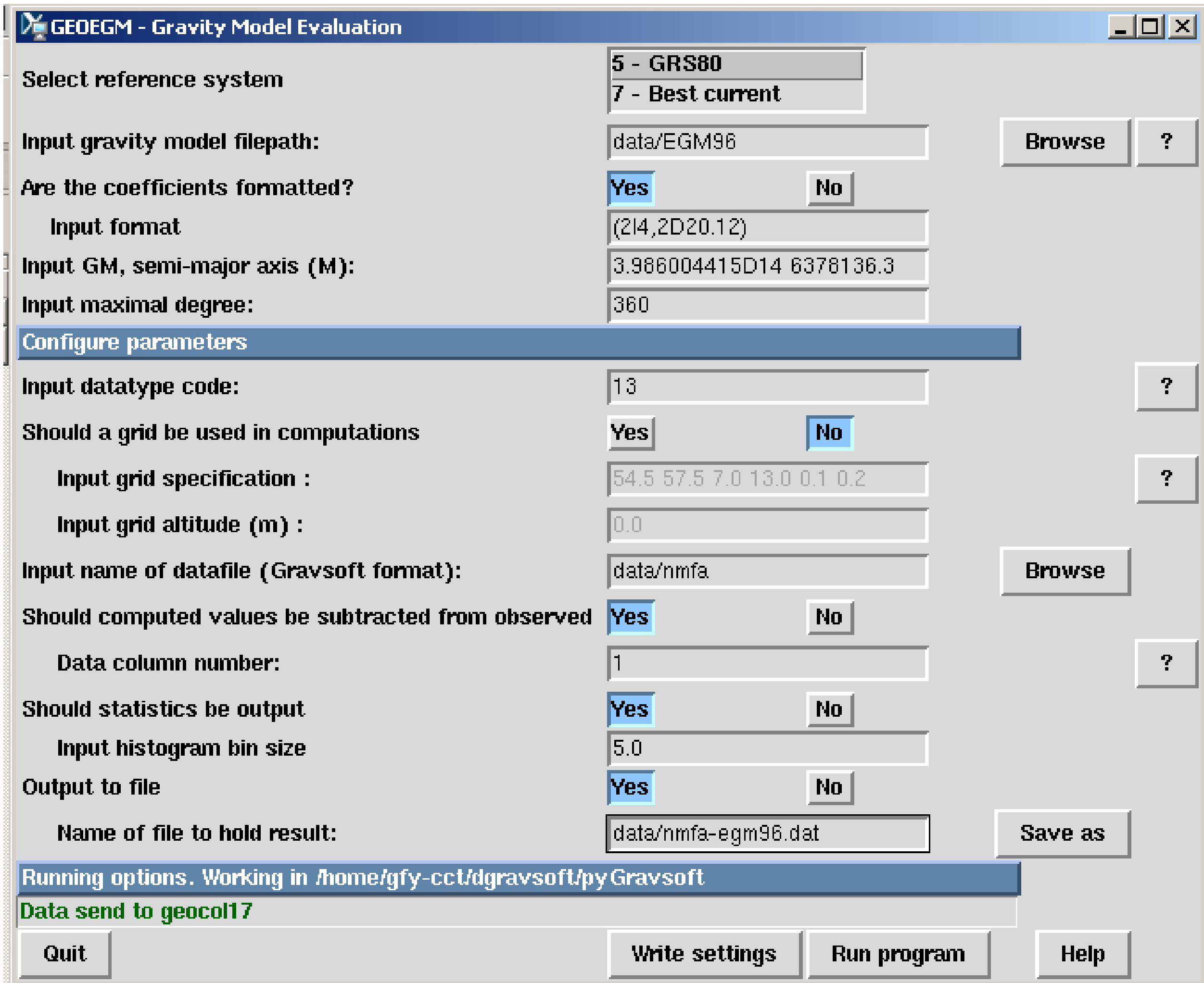
We will use the program "select" to extract the grid-points. Below is shown the filled in input-form for select and the output, which comes to the screen and also is stored in the file select.log.



The first lines of the out-put file nm.h2 are:

```
42600   34.00000 -107.00000   1700.000
42612   34.00000 -106.90000   1440.000
42624   34.00000 -106.80000   1520.000
42636   34.00000 -106.70000   1700.000
42648   34.00000 -106.60000   1650.000
42660   34.00000 -106.50000   1610.000
```

The following 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

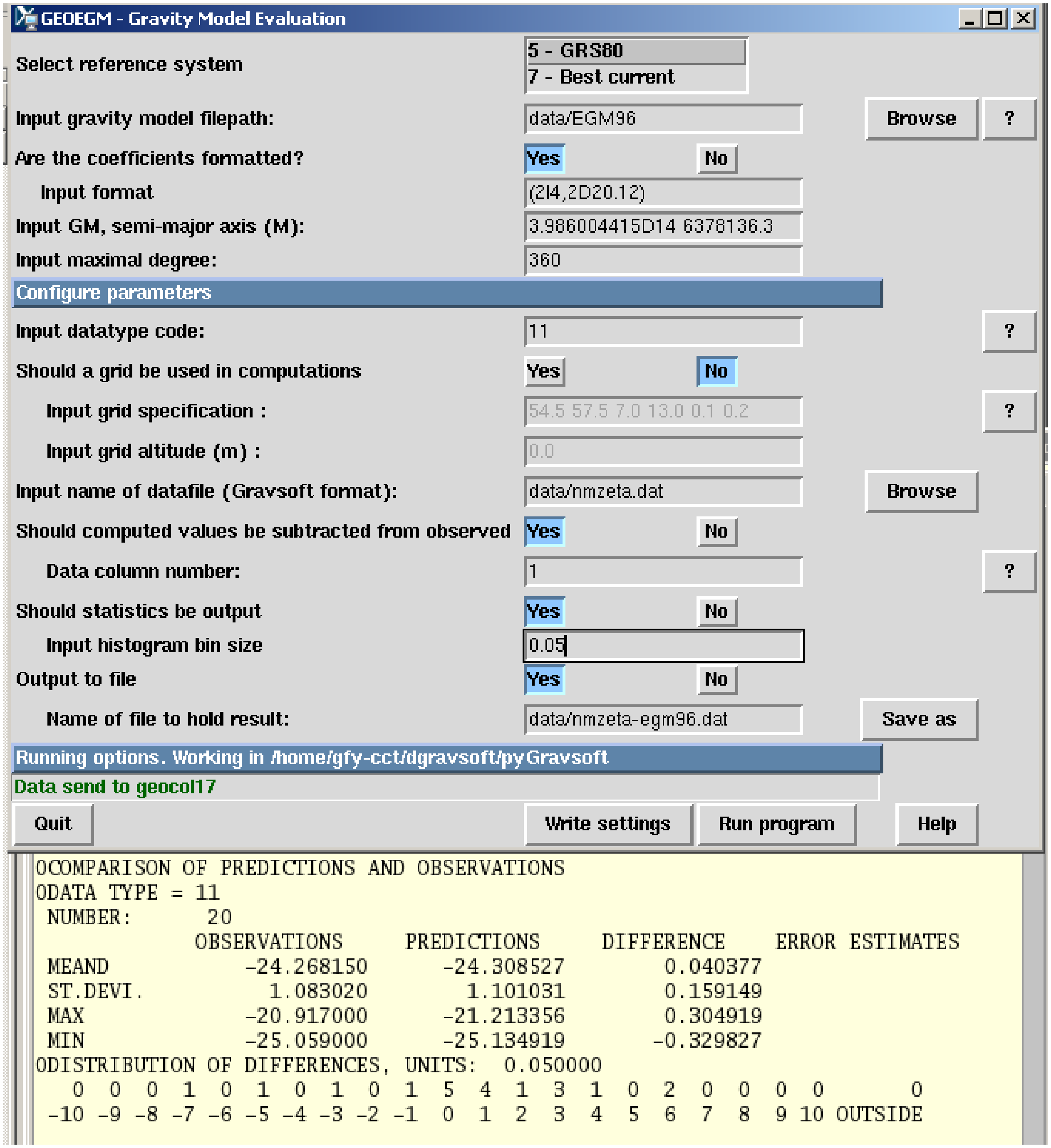


Besides output to the screen, two files are produced:
geoegm.inp, which contain input instructions to geocol17 and geoegm.log, which is the output. Here is shown the last lines of the output, with the statistics of the differences between data and model values.

```
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
```

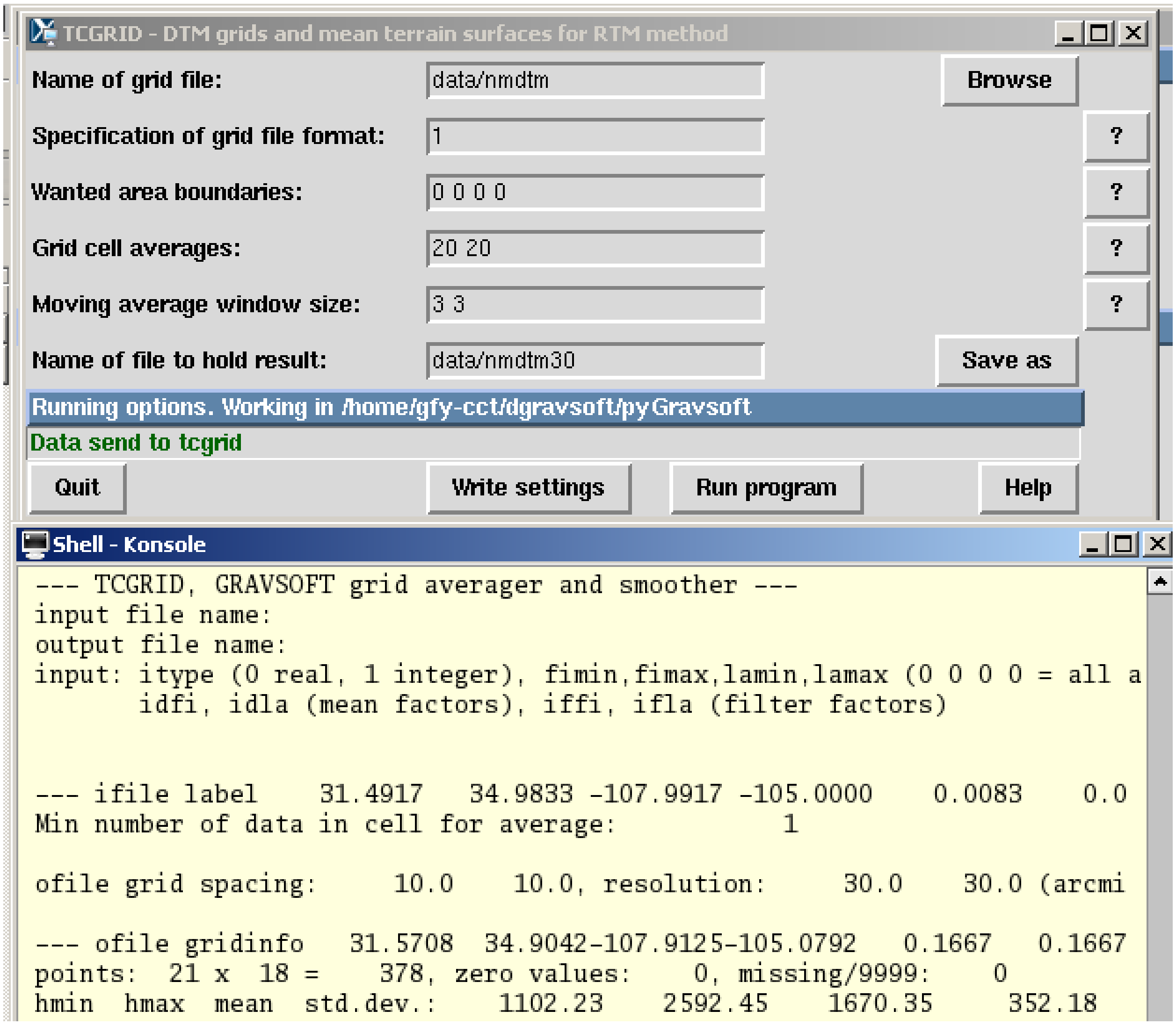
The important numbers to notice are that the mean value has decreased from 8.18 (mgal) to -2.92 and the standard deviation from 30.41 to 21.28. The primitive histogram (with the center-class containing 324 values) shows that the residual data have a distribution resembling a normal distribution.

The same operation is then performed on height anomalies.

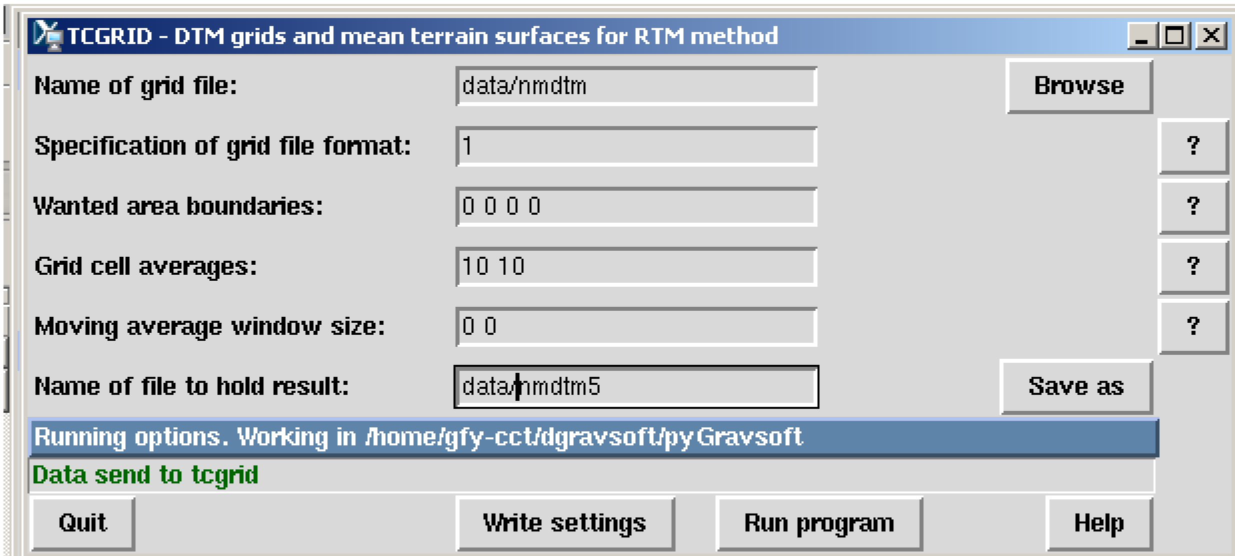


Note again the decrease in mean value and standard deviation.
In order to remove the residual terrain effects, a reference grid and a mean grid must be created. The module tcgrid must be used here. The reference grid must have a resolution corresponding to the gravity model (EGM96) which has been

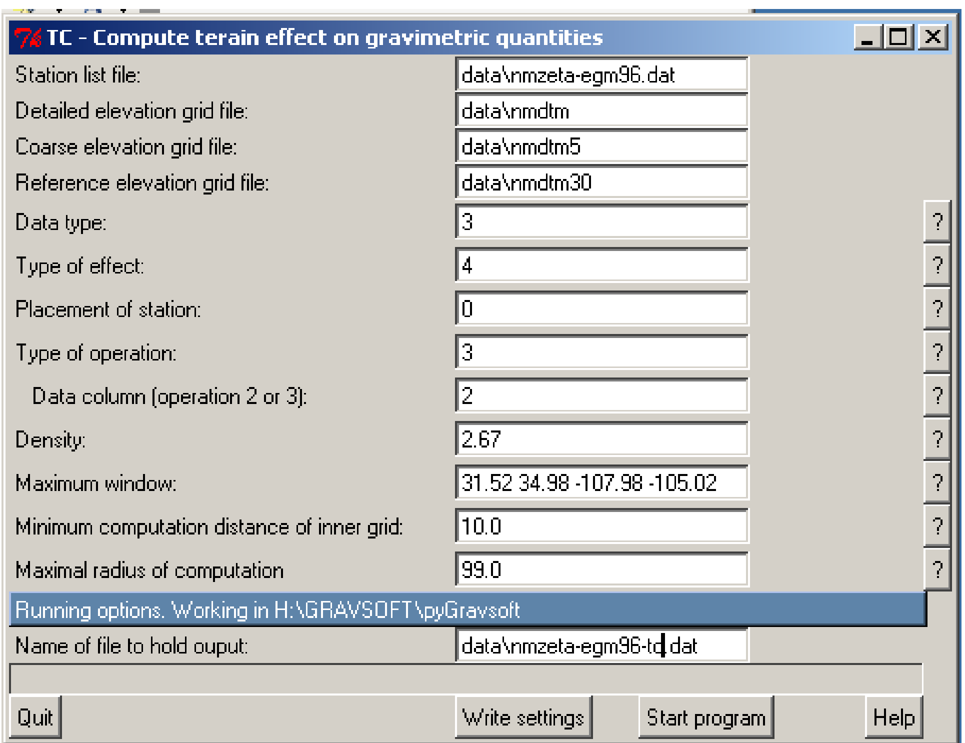
subtracted, i.e. 0.5 degrees. The detailed grid is contained in the file data/nmdtm.

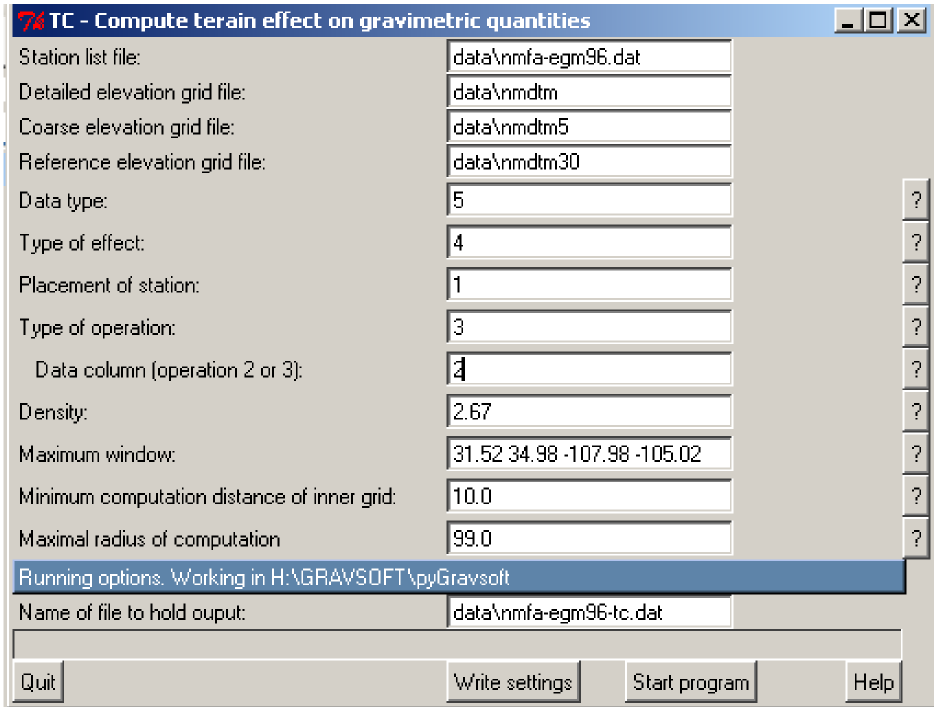


We need a second grid to be used when the calculations of the attractions are at distance from the computational point. In this case the effects may be calculated using 10 times larger grid-cells.



We can now use TC for the calculation (subtraction) of the RTM contribution



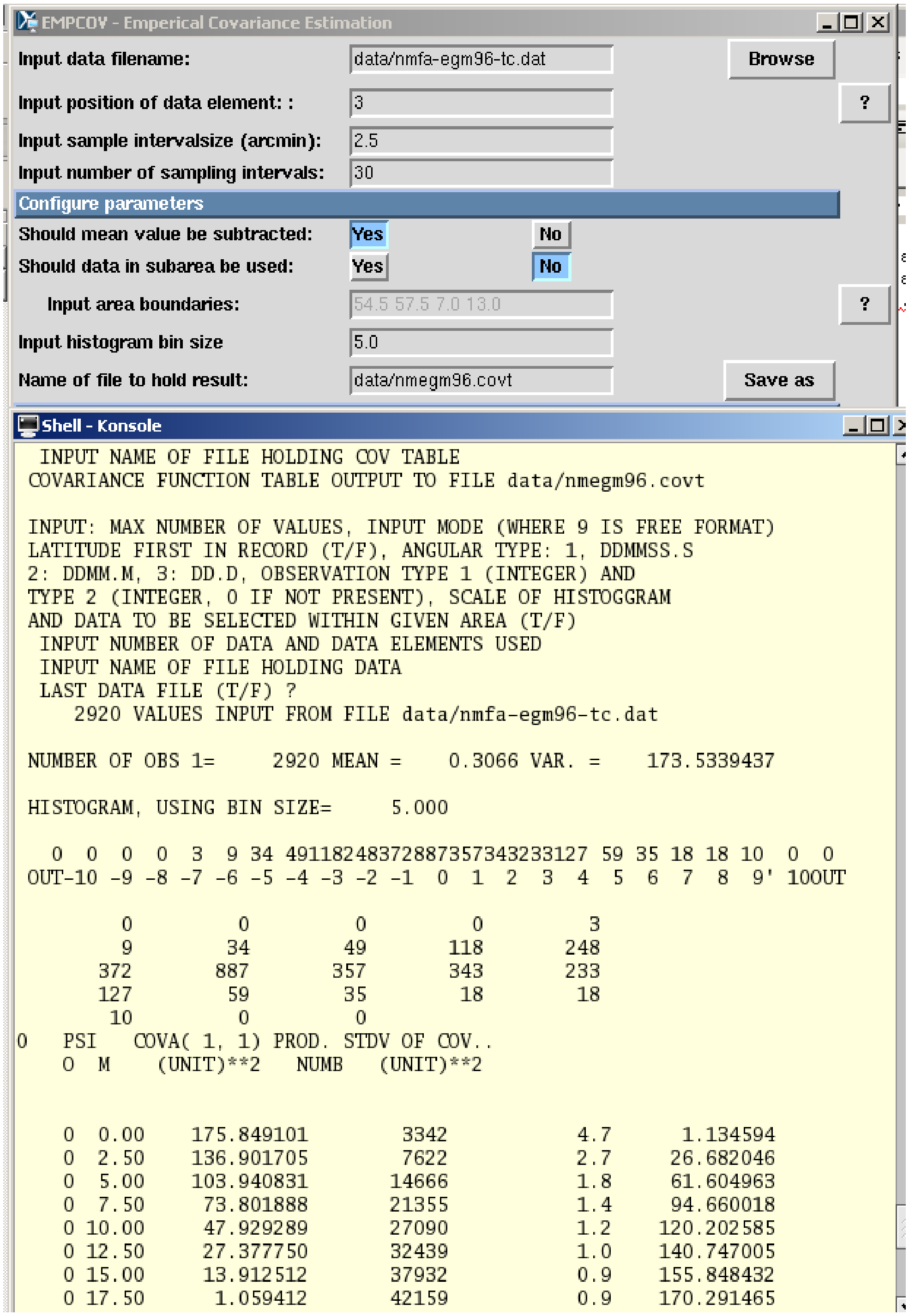


The resulting comparison of the observed and the reduced gravity anomalies shows again a large smoothing effect. The mean value is now 0.31 (mgal) and the standard deviation 13.17 (mgal):

```
 --- average no of prisms/exact formulas pr station:   1677    80
 --- difference given - dtm inferred station heights:
     mean stddev min max:      -1.     29.  -357.   198.
 --- statistics of computed effects, no of points:    2920
       mean     stddev        min        max
       0.00       0.00       0.00       0.00
      -3.24      14.05     -50.53     126.81
 --- statistics of original values in statfile:
       9.18      30.41     -58.70     162.50
      -2.93      21.28     -74.79     126.43
 --- difference output on file:
       9.18      30.41     -58.70     162.50
       0.31      13.17     -41.03      45.90
```

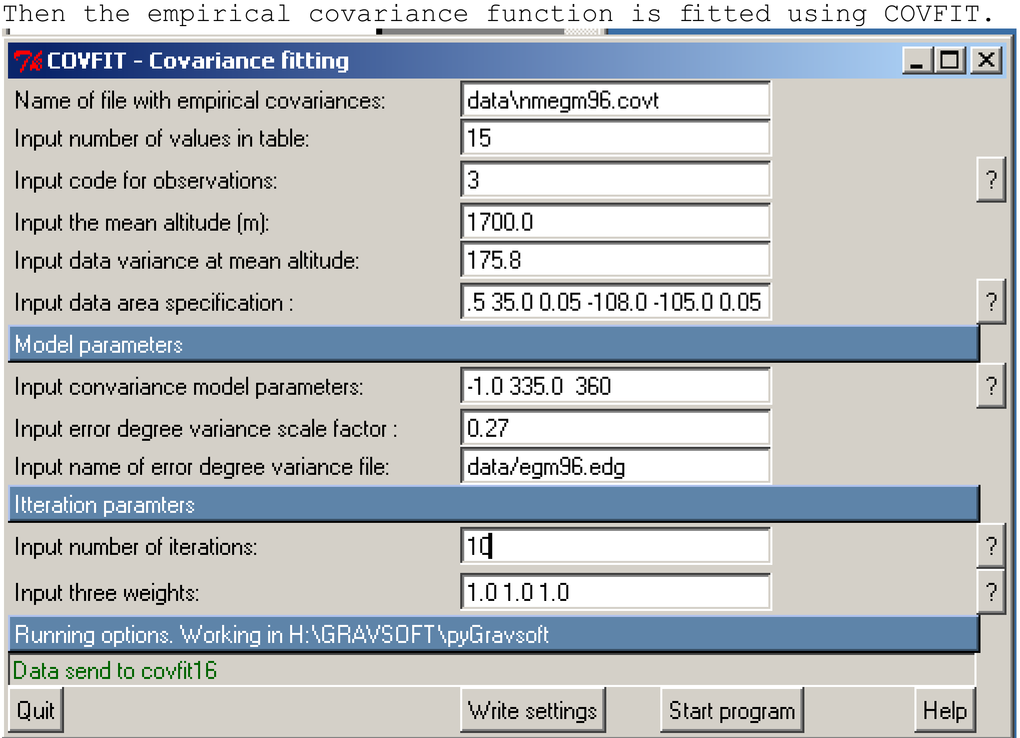
Note also the excellent agreement between the DTM and the heights in the gravity file. Below we will need the average of the topographic heights, which is 1700 m. This value is found in the first part of the tc.log file.

Next step is the computation of the empirical covariance function. The sampling interval size should be less than the minimum distance between the data points. Here we use 2.5', which in fact is a little too large, as can be seen from the number of products used to determine the value for the interval from 0' to 1.25'.



As output we get the distance (PSI), the covariance, the number of products (NUMB), an error-measure and the value of the variogram. Note the correlation distance (the distance where the covariance is 50 % of the variance) which is approximately 6 minutes or ca. 12 km.

Then the empirical covariance function is fitted using COVFIT.



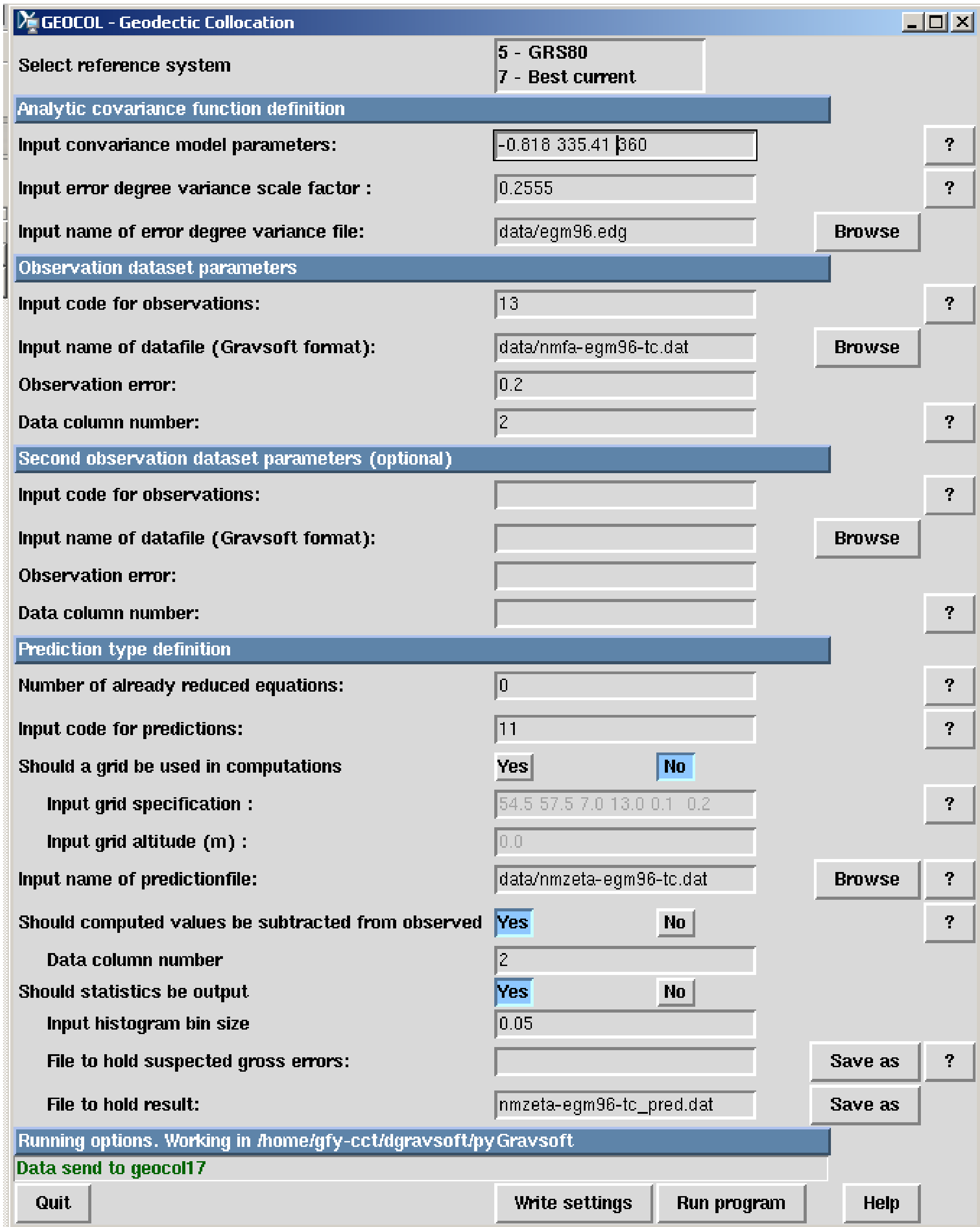
Below we show the final part of covfit.log with the results of the fitting. The values VARDG=335.41, AA=0.2555 and RE-RB = -819.7 are used as parameters for GEOCOL. The column with the heading OBS are the values estimated by EMPCOV.

```
 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
```

The important quantities here – to be used in GEOCOL – are the scale factor AA, the depth to the Bjerhammar-sphere RE-RB and the variance of the gravity anomalies at zero height, VARG. Note that RE-RB later is to be used in units of km.

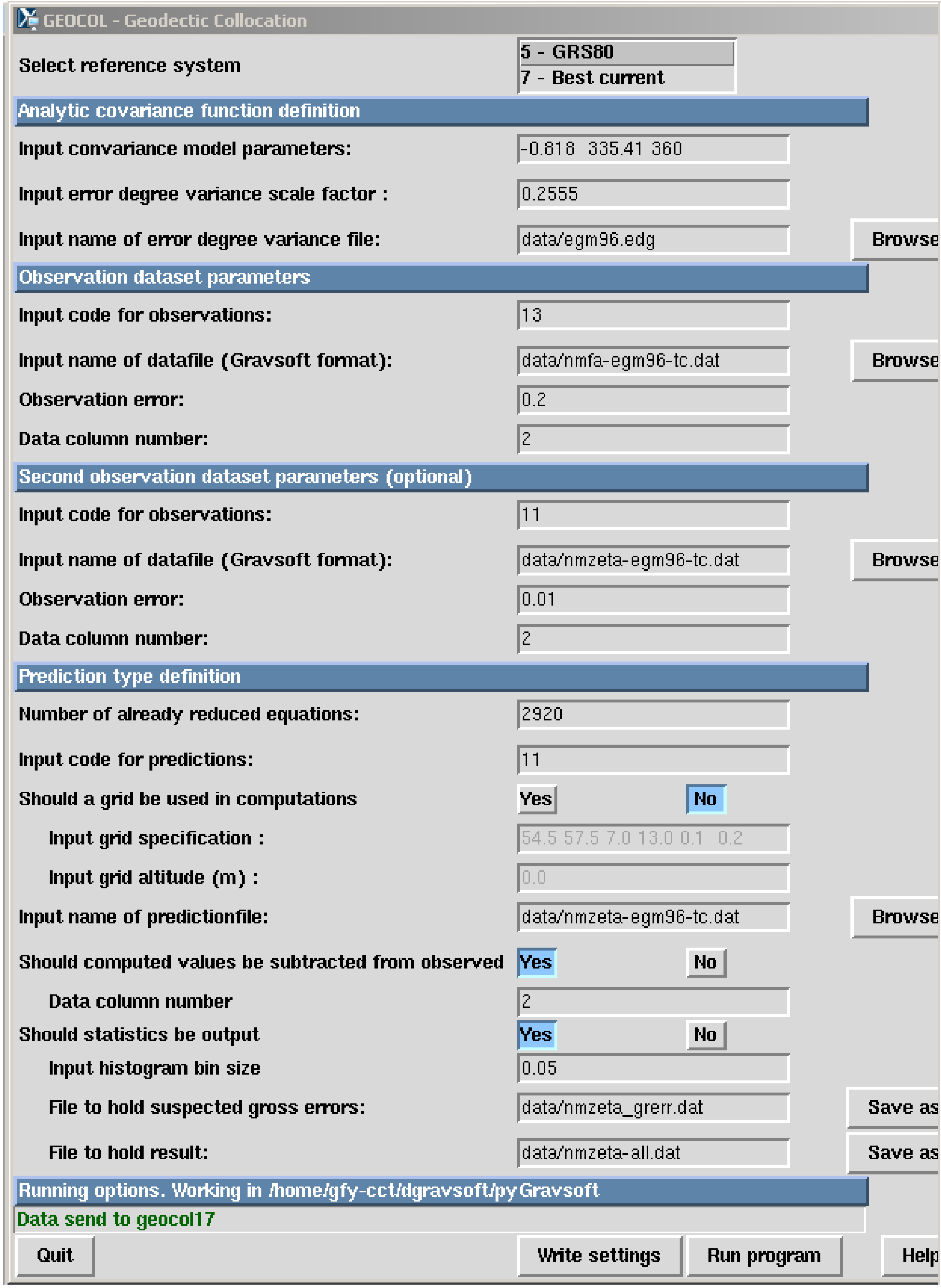
In the following step we predict the reduced height-anomalies from the reduced gravity anomalies. This is then followed by a step where both the reduced gravity data and the reduced height anomalies are used to predict height anomalies at terrain level. Note, that in the final step we use that 2920 columns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



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
0DATA TYPE = 11
 NUMBER:       20
             OBSERVATIONS      PREDICTIONS     DIFFERENCE    ERROR ESTIMATES
 MEAND            -0.897275        -0.000249       -0.897026         0.057190
 ST.DEVI.          0.159149         0.145570        0.051812         0.014751
 MAX              -0.632800         0.210112       -0.789374         0.090755
 MIN              -1.267500        -0.320436       -0.987110         0.045836
0DISTRIBUTION 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

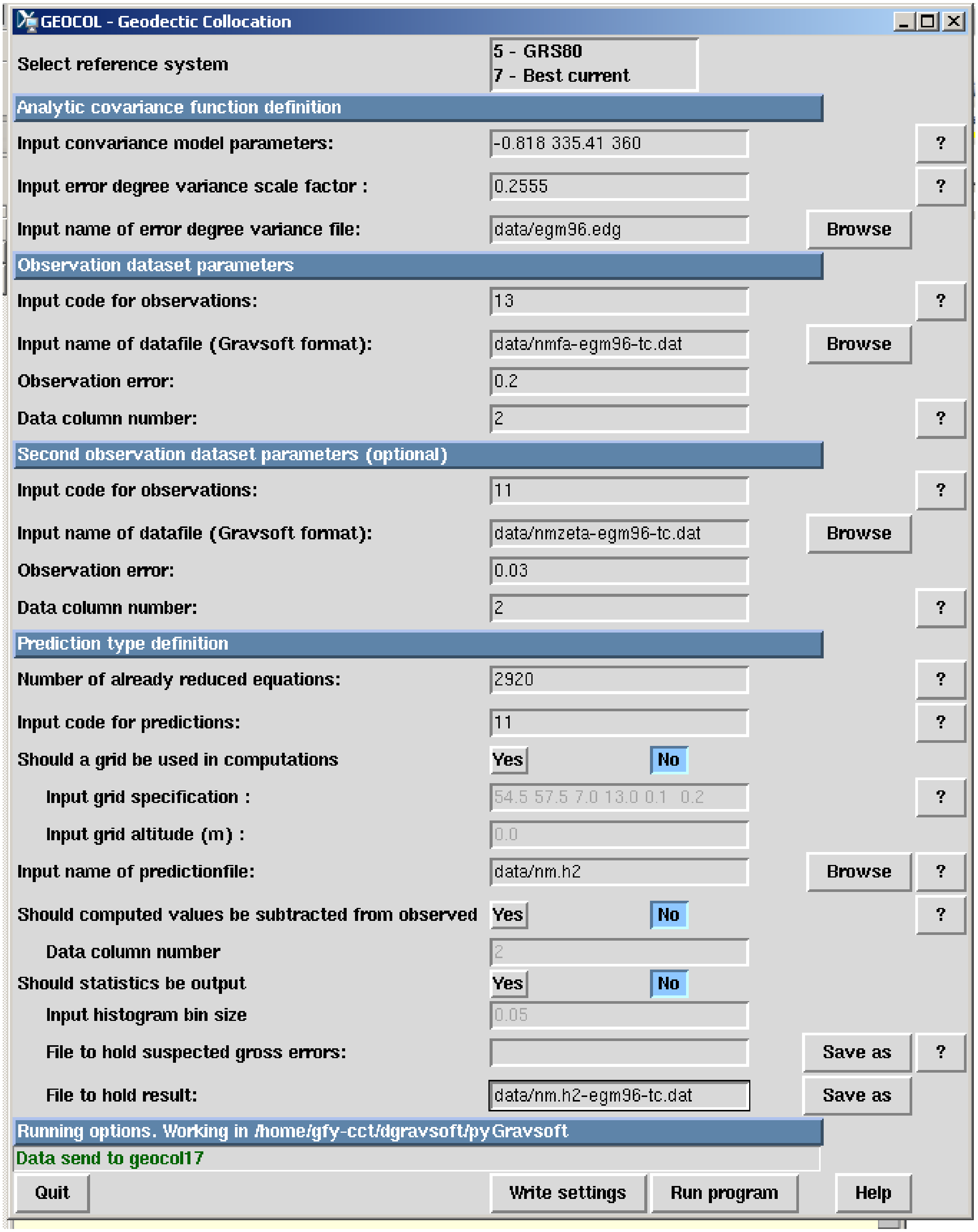
```
ELEMENTS OF (AT*C**-1*A)**-1.
   0.0085
  CORRELATION MATRIX:
    1.0000
 PARAMETER    TYPE     ESTIMATE       ERROR ESTIMATE (FOR TILT: ZERO POINT
           1       11111   -0.783996623    0.092367316
```

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

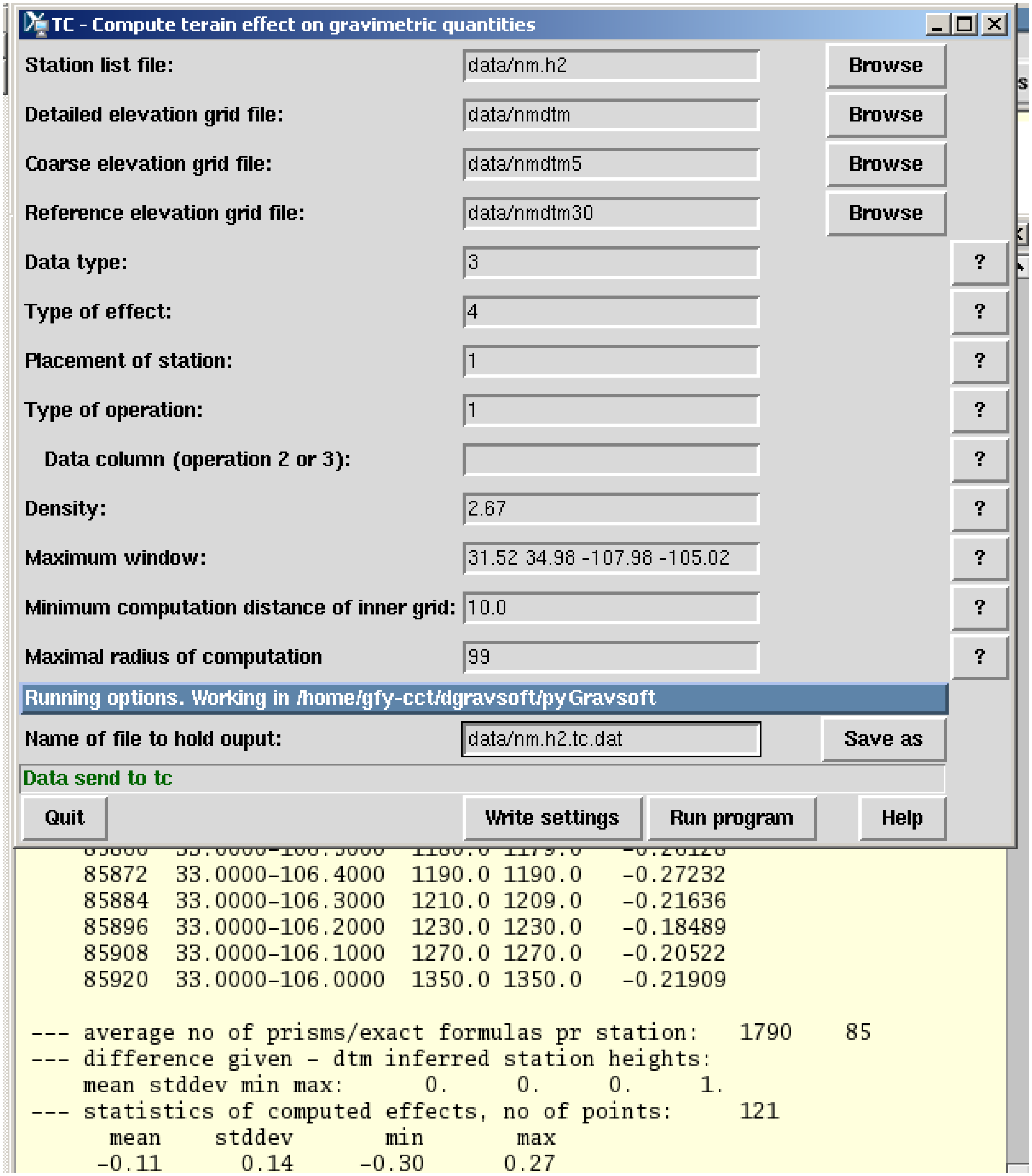
```
COMPARISON OF PREDICTIONS AND OBSERVATIONS
DATA TYPE = 11
 NUMBER:      20
             OBSERVATIONS     PREDICTIONS     DIFFERENCE    ERROR ESTIMATES
 MEAND            -0.897275       -0.897275        0.000000        0.080819
 ST.DEVI.          0.159149        0.151404        0.032276        0.000334
 MAX              -0.632800       -0.657844        0.054209        0.081490
 MIN              -1.267500       -1.229374       -0.054223        0.080234
0DISTRIBUTION OF DIFFERENCES, UNITS:  0.050000
   0  0  0  0  0  0  0  0  0  5 11  4  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


 HISTOGRAM RATIO ABS(ERROR)/ERROR ESTIMATE IN 0.5 INTERVALS .
      15       5       0       0       0       0       0       0
  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
```

No suspected gross-errors were detected. All differences are smaller than 4 times the error-estimate.

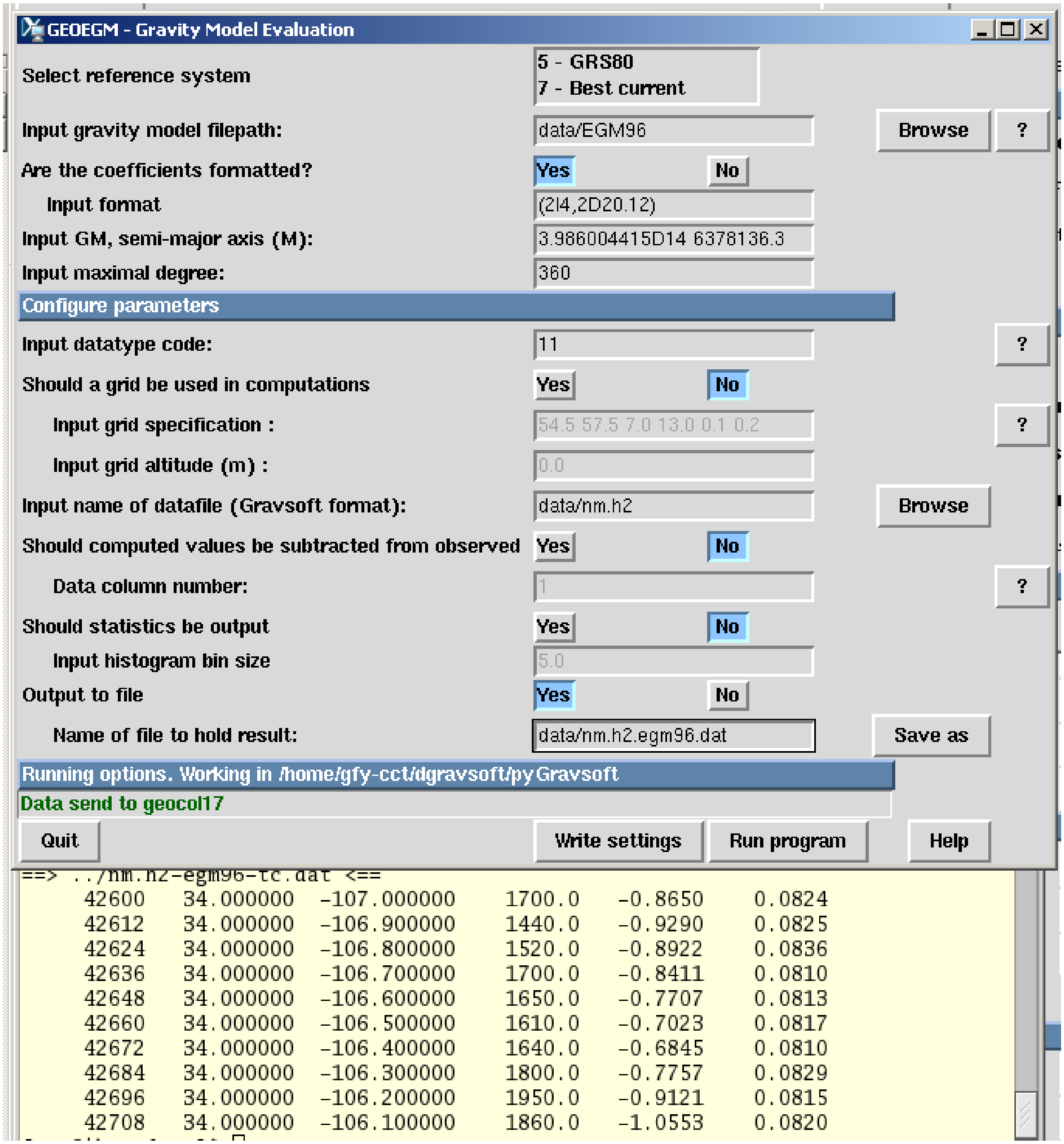
We now predict height anomalies at the surface of the Earth:


GEOCOL - Geodectic Collocation
Select reference system
5 - GRS80
7 - Best current
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
Browse
Observation dataset parameters
Input code for observations:
13
Input name of datafile (Gravsoft format):
data/nmfa-egm96-tc.dat
Browse
Observation error:
0.2
Data column number:
2
Second observation dataset parameters (optional)
Input code for observations:
11
Input name of datafile (Gravsoft format):
data/nmzeta-egm96-tc.dat
Browse
Observation error:
0.03
Data column number:
2
Prediction type definition
Number of already reduced equations:
2920
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/nm.h2
Browse
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
File to hold suspected gross errors:
Save as
File to hold result:
data/nm.h2-egm96-tc.dat
Save as
Running options. Working in /home/gfy-cct/dgravsoft/pyGravsoft
Data send to geocol17
Quit
Write settings
Run program
Help
?

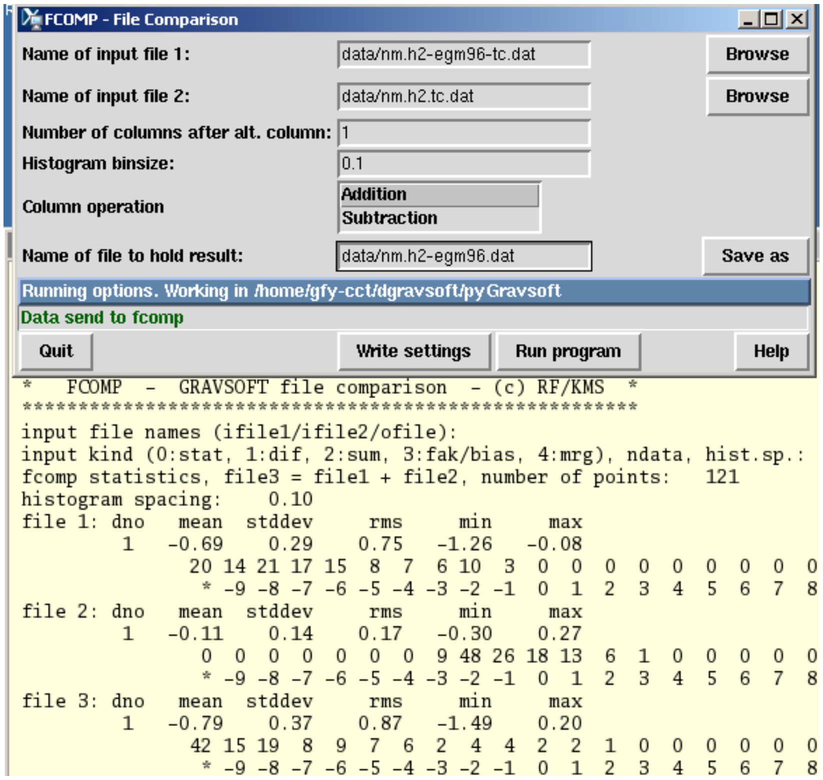
Remaining step is that TC is used to compute the effect of the residual topography.

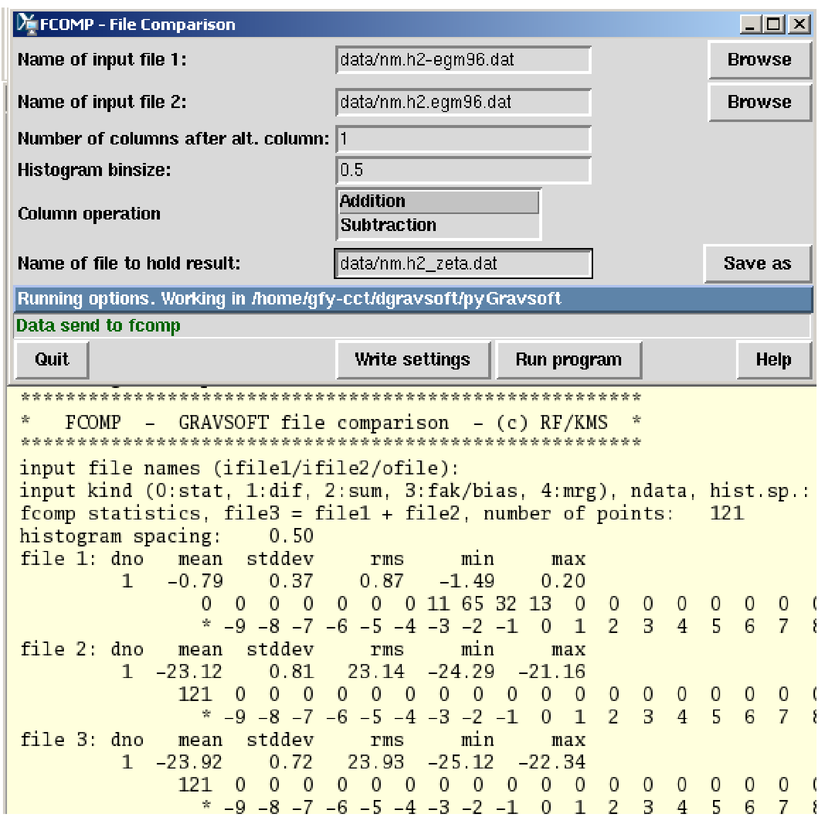


Furthermore, the contribution from EGM96 must be computed:



The 3 files: nm.h2.egm96.dat, nm.h2-egm96-tc.dat and nm.he.tc.dat must now be added using fcomp.

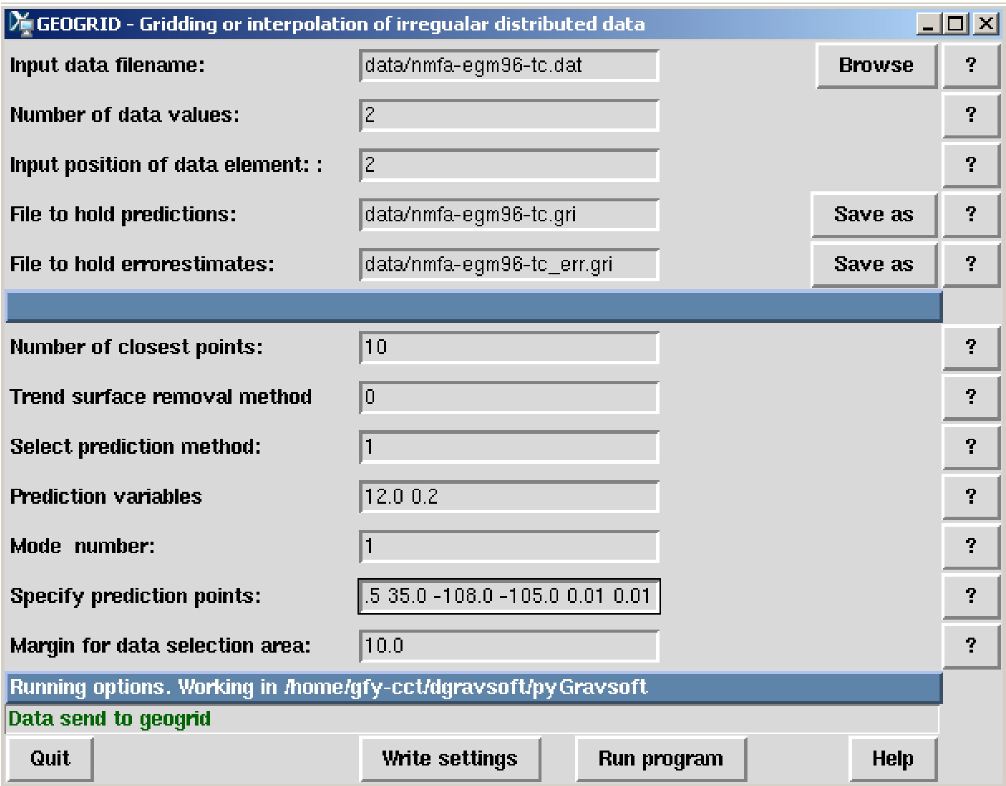




So the final result is the height anomalies stored in the file data/nm.h2_zeta.dat. The error-estimates are in the file data/nm.h2-egm96-tc.dat.

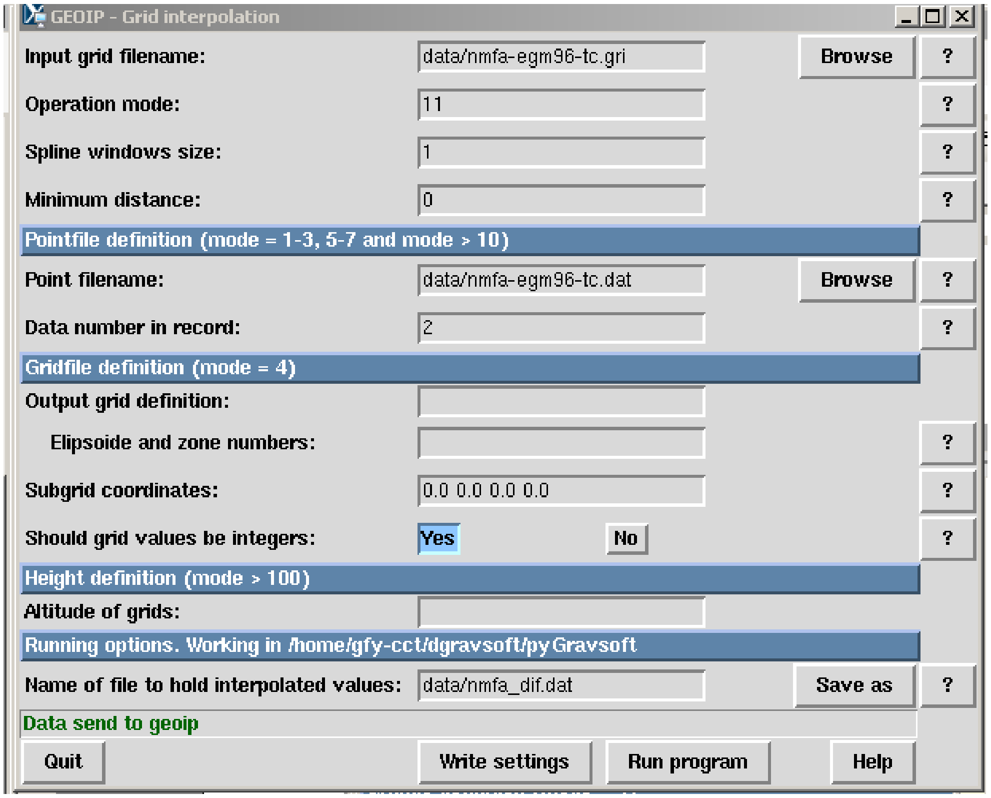
We now prepare for 2D solutions using Stokes or Collocation.

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

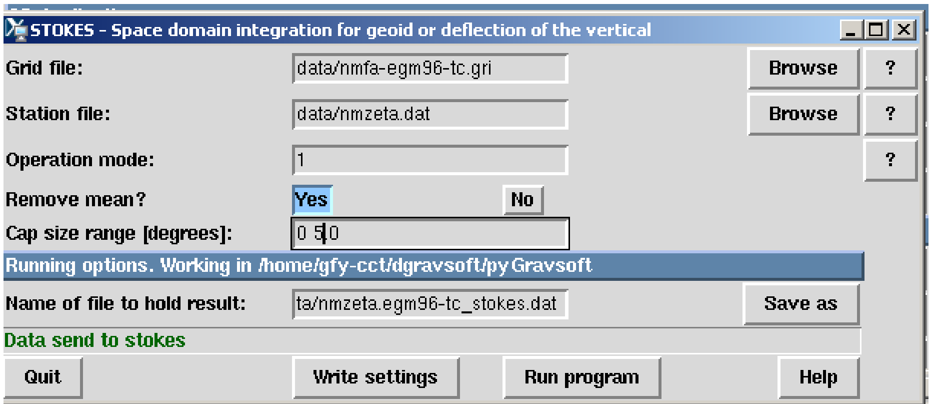



```
*    GEOGRID - GRAVSOFT data gridding - vers. SEP 92 - (c) RF/KMS   *
***********************************************************************
 INPUT NAMES OF IFILE, OFILE, EFILE
 INPUT NDATA, DATA NO, MAX USED FOR PRED, ITREND, METH 1 OR 2
 INPUT CORR. LENGTH (KM) AND VAR. NOISE
 INPUT MODE (1-8) AND SEL. RADIUS (KM)
 Input grid specification
        351          301
rkm =   10.0, data selection area:   31.4100  35.0900-108.1076-104.8924

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  12.00   0.20
selection: 10 closest points per quadrant
- large organization, rdat increased -

data organization limits:   31.6836  34.8134-107.8166-105.1850
subrectangles (n,e,total):    26    18   468
size (km):       13.4      13.6, average pts per rect (rdat):    6.239
max points in subrects:   16, percentage with no points:   1.3

predicted:  105651 points
prediction  min max mean std.dev.:    -41.67     57.73     0.49     12.33
```

We now check the quality of the grid by using it to calculate the original values used to create the grid. The result shows that the grid represents the original data very well.

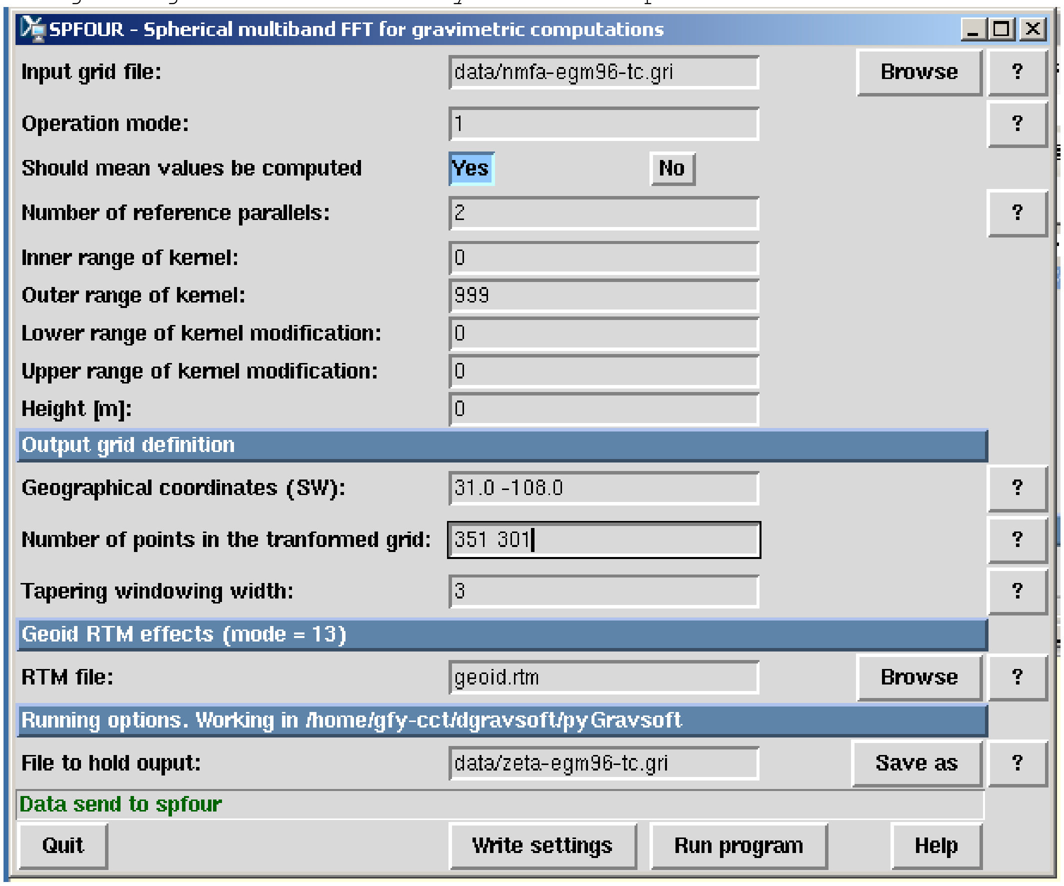



```
*********************************************************************
 *   GEOIP - GRAVSOFT GRID INTERPOLATION - vers. MAY04  (c) RF/KMS   *
 *********************************************************************
 input name of gridfile to be interpolated:
 input name of outputfile:
 input: mode  (1:pointfile deg, 2:ptfile dms, 3:ptfile utm, 4:grid,
               5:lat/lon deg, 6:lat/lon dms, 7:N/E,
               11/13:dif, 12/14:sum, 15:grid dif, 16:grid sum ..)
        nsp   (interpolation type - 0:linear, 1:spline)
        rmin  (minimum dist to grid edge, km)
        lsel  (true if subarea to be selected)
 input name of file with pointdata:
 input position of data in pointfile line:
 ---  G E O I P  ---
 grid file name: data/nmfa-egm96-tc.gri
 output file name: data/nmfa_dif.dat
 mode = 1, nsp =  8, minimum edge dist   0.0 km
 point file name: data/nmfa-egm96-tc.dat
 - windowed spline 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  35.0000-108.0000-105.0000    0.0100    0.0100  351 301
 selected subgrid:   31.6300  34.8600-107.8700-105.1400
 points: 324 x 274 =    88776, zero values:       6, unknown (9999):       0
 min  max  mean  std.dev.:    -41.67      57.73      0.78      13.17
 points predicted:   2920,  skipped points:      0
 minimum distance to grid edges for predictions:    17.1 km
 statistics:                    mean    std.dev.   min       max     unknown
 original data (pointfile) :    0.307    13.173  -41.031    45.899       0
 grid interpolation results:    0.306    13.167  -41.005    45.892       0
 predicted values output   :    0.000     0.057   -0.749     0.567       0
```



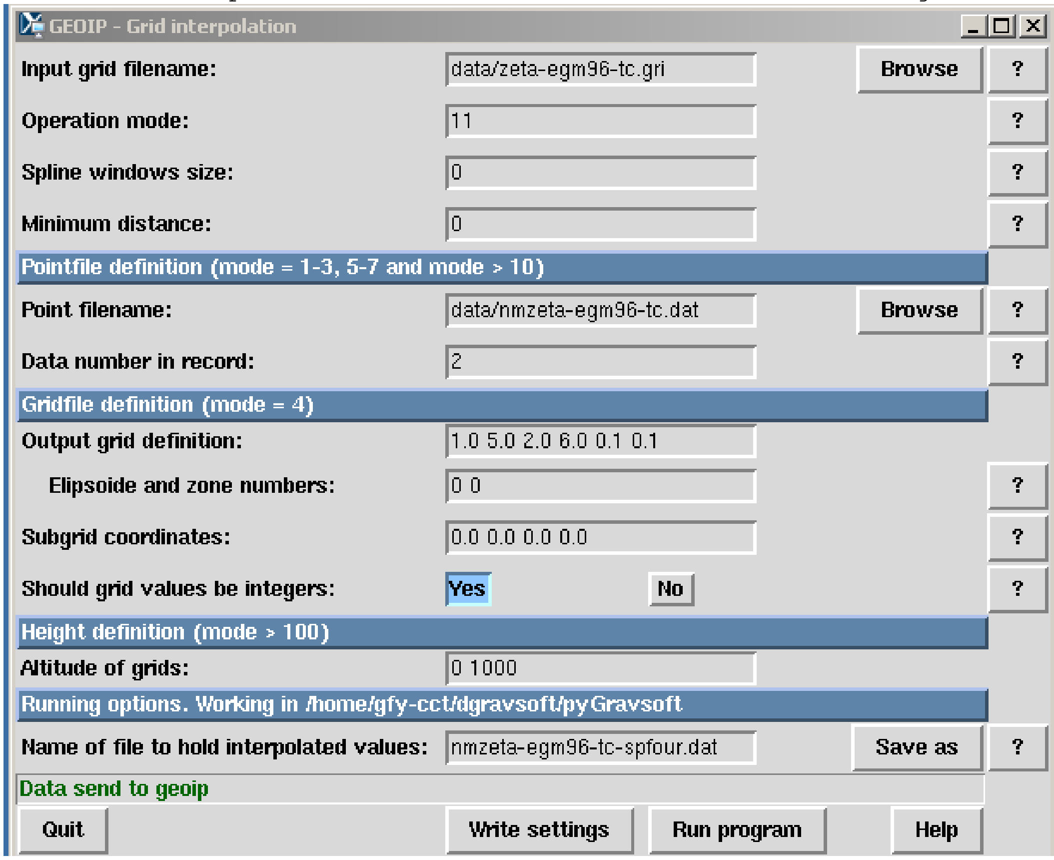

```
input file names (gfile/sfile/ofile):
input: mode (1:stoke, 2:vm), lmean, psi1, psi2
--- stokes ---
integral formula evaluation from gridded data
grid file: data/nmfa-egm96-tc.gri
point file: data/nmzeta.dat
output file: data/nmzeta.egm96-tc_stokes.dat
mode:  1, range   0.0000 to   5.0000 degrees

--- data grid   31.5000  35.0000-108.0000-105.0000   0.0100   0.0100
points: 351 x 301 = 105651, zero values:     8, missing/9999:     0
min  max  mean  std.dev.:     -41.67      57.73       0.49      12.33
corner values:     -0.85      1.61      0.17      0.27

mean of gravity data removed prior to integration

                geoid undulations (meter)
  stat     lat        lon        h      inner    total

  9025  32.33370-106.79410 1191.10   -0.004    0.000
  8929  32.36370-106.75110 1311.66    0.017    0.084
  8734  31.80160-106.30740 1215.28   -0.026   -0.055
  8138  32.27730-106.90320 1317.95   -0.031   -0.152
  8134  32.40040-106.34250 1228.21   -0.013    0.047
  7830  32.40030-106.33340 1231.38   -0.011    0.048
  6894  34.41830-106.84020 1446.10   -0.012    0.072
  6646  31.76990-106.41220 1130.41   -0.033   -0.049
  6645  31.77080-106.41410 1132.30   -0.033   -0.046
  5670  32.29100-106.92220 1354.64   -0.020   -0.133
  5315  33.68200-105.85240 1662.00    0.018    0.100
  4121  32.27740-106.76810 1183.10   -0.004    0.023
  3950  32.32030-106.80820 1188.33   -0.018   -0.039
  3122  31.89180-106.59610 1147.41    0.015    0.152
  2999  32.85990-105.99860 1278.33   -0.045   -0.382
  2173  32.86170-107.28970 1276.86   -0.025   -0.211
  2145  32.40090-106.36180 1219.70   -0.016    0.049
  1347  32.84640-105.98220 1279.02   -0.044   -0.369
  1301  33.23850-107.26550 1467.66   -0.022   -0.137
   395  32.29890-106.80610 1186.99   -0.022   -0.051
```

Using the gridded data we may also use spfour.




```
**************************************************************
 *   SPFOUR  -  GRAVSOFT spherical FFT - (c) RF/KMS feb 2002   *
 **************************************************************
 Gridfile: data/nmfa-egm96-tc.gri
 mode =    1, distance range =      0.000 to    999.000 degrees
 SW corner:     31.0000  -108.0000, points:   351   301
 GEOID HEIGHTS FROM GRAVITY
 Input grid:
 Gridlab:   31.5000   35.0000 -108.0000 -105.0000    0.0100    0.0100   351 301
 Selected: sw corner     31.0100 -108.0000, points     351    301
 Statistics of data selected from input grid:
 pts mean std.dev. min max:    90902      0.60     11.98    -38.33     57.73
 Zero padding done on grid, no of rows/cols S/N/E/W:  49    0    0    0
 power space domain      111.75, mean       0.36
 mean value subtracted from input data prior to fft
 power after window      111.49, wsum =    0.9816
 - make innerzone corrections -
 - fourier transform of data -
 - fourier transformation of data completed -
 Central latitudes and interpolation bands in the internal grid of 351 rows:
   34.51000       50      351
   31.50000     -999     -999
 Latitude  33.0000, r.m.s. signal and difference  0.1682E+08  0.1697E+06
 Output grid written:
    31.50000   34.51000 -108.00000 -105.00000  0.010000  0.010000
 Minimal and maximal values:      -0.429      0.780
 R.m.s. and max abs value of innerzone correction:     0.007     0.034
```

We want to compare the values to the observed values using GEOIP:

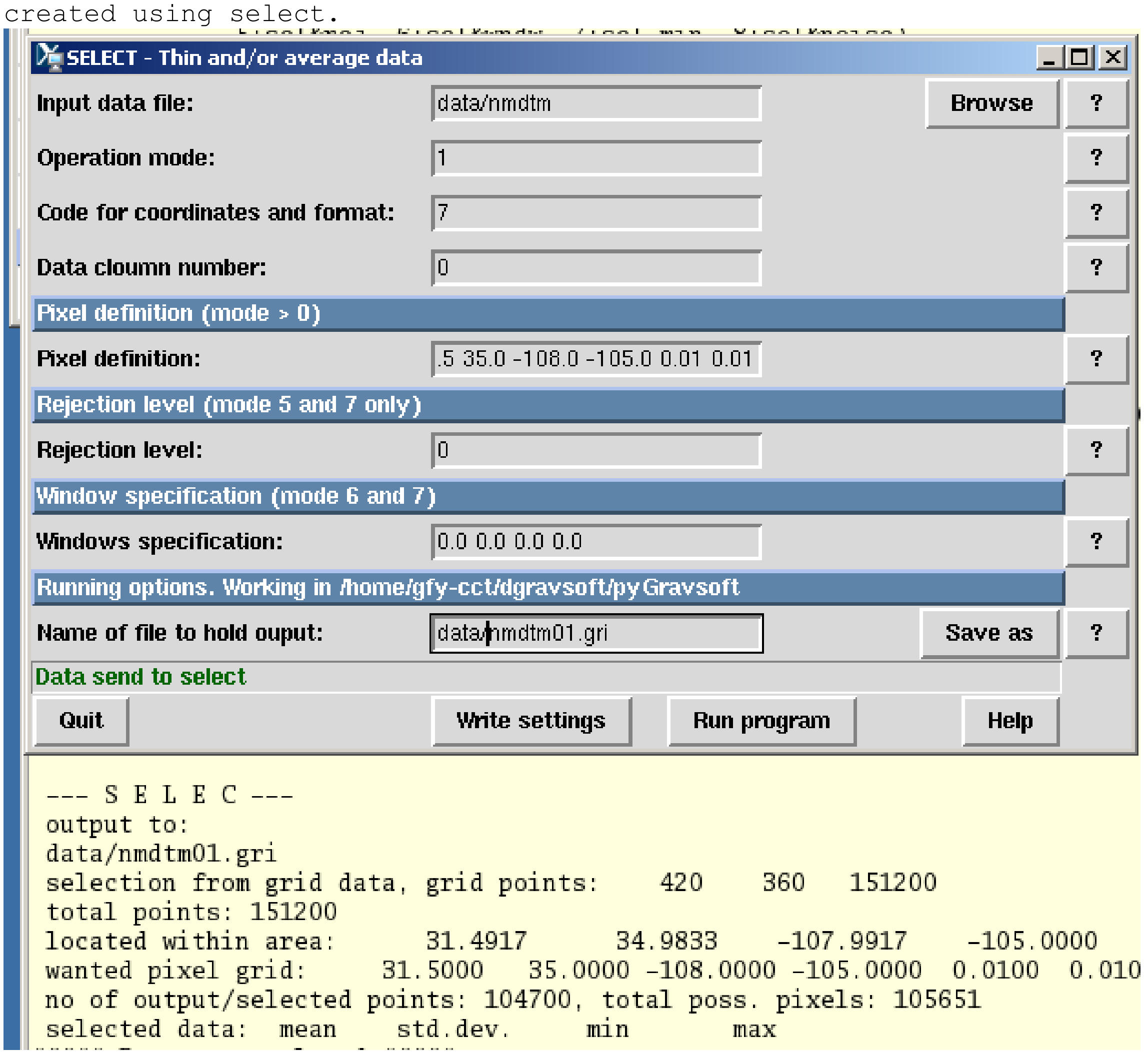


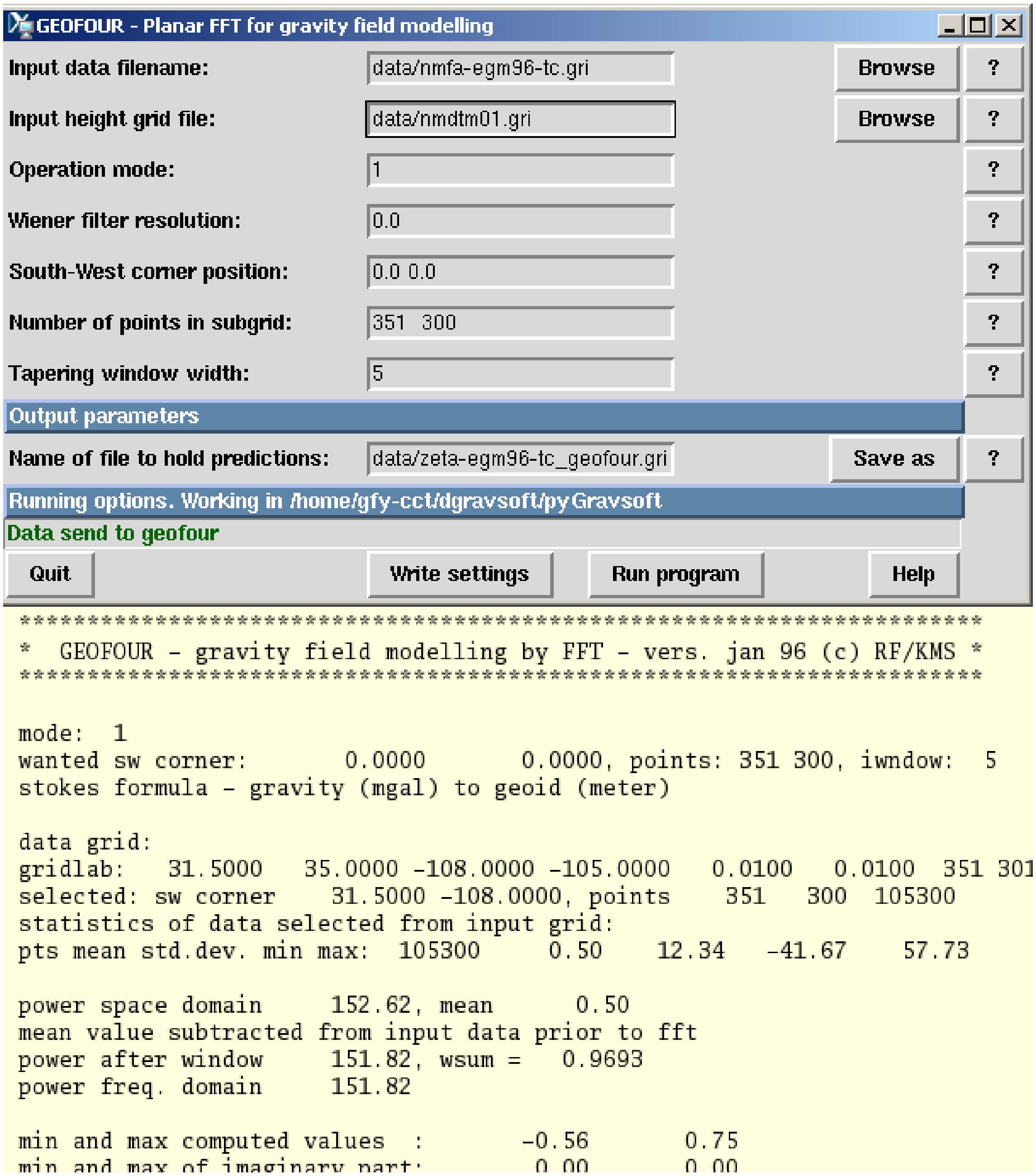

```
*********************************************************************
 *   GEOIP - GRAVSOFT GRID INTERPOLATION - vers. MAY04  (c) RF/KMS   *
 *********************************************************************
 input name of gridfile to be interpolated:
 input name of outputfile:
 input: mode  (1:pointfile deg, 2:ptfile dms, 3:ptfile utm, 4:grid,
               5:lat/lon deg, 6:lat/lon dms, 7:N/E,
               11/13:dif, 12/14:sum, 15:grid dif, 16:grid sum ..)
        nsp   (interpolation type - 0:linear, 1:spline)
        rmin  (minimum dist to grid edge, km)
        lsel  (true if subarea to be selected)
 input name of file with pointdata:
 input position of data in pointfile line:

 ---  G E O I P  ---
 grid file name: data/zeta-egm96-tc.gri
 output file name: nmzeta-egm96-tc-spfour.dat
 mode = 1, nsp =  0, minimum edge dist   0.0 km
 point file name: data/nmzeta-egm96-tc.dat
 - bilinear interpolation -
 - subtraction of interpolated values from pointfile -
 number of prediction points:      20
 within area    31.7699   34.4183 -107.2897 -105.8524
 grid file information:
 gridlab:    31.5000  34.5100-108.0000-105.0000    0.0100    0.0100  302 301
 selected subgrid:   31.7600  34.4200-107.2900-105.8500
 points: 267 x 145 =   38715, zero values:     128, unknown (9999):       0
 min  max  mean  std.dev.:      -0.43       0.78       0.06       0.22
 points predicted:      20,  skipped points:      0
 minimum distance to grid edges for predictions:   10.2 km
 statistics:                      mean    std.dev.   min       max    unknown
 original data (pointfile) :   -0.897    0.159   -1.268   -0.633       0
 grid interpolation results:   -0.053    0.145   -0.357    0.151       0
 predicted values output   :   -0.844    0.047   -0.921   -0.784       0
```

A similar comparison with the result from GEOCOL stored in data/nm.h2-egm96-tc.dat shows that the results agree within 27 mm:

```
points predicted:    121,  skipped points:      0
minimum distance to grid edges for predictions:   56.7 km
statistics:                        mean    std.dev.   min       max     unknown
original data (pointfile) :    -0.689     0.286    -1.257    -0.076       0
grid interpolation results:     0.146     0.281    -0.409     0.769       0
predicted values output   :    -0.836     0.027    -0.985    -0.773       0
```

Another possibility is to use geofour. However to use this program we must have a height file so that the result can be computed at the terrain. This grid is created using select.



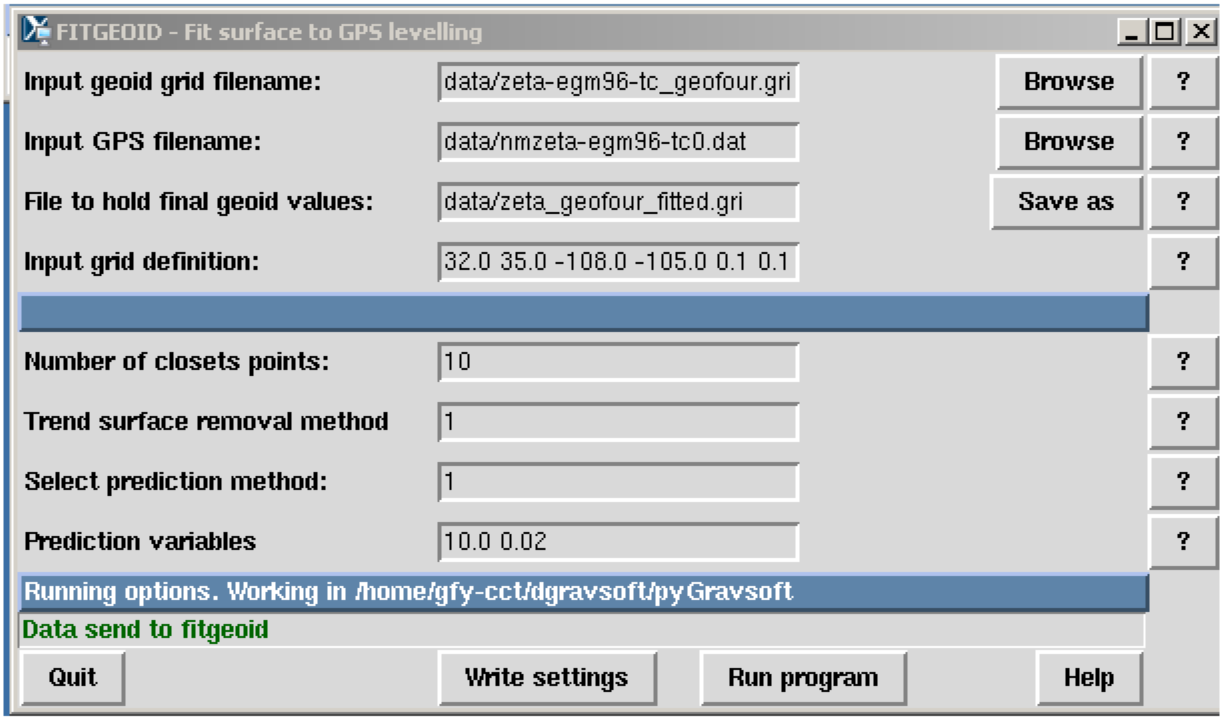


A comparison with the GEOCOL result using GEOIP gives

```
points predicted:     121,  skipped points:       0
minimum distance to grid edges for predictions:   91.8 km
statistics:                       mean   std.dev.   min      max     unknown
original data (pointfile) :    -0.689    0.286   -1.257   -0.076       0
grid interpolation results:     0.134    0.281   -0.431    0.744       0
predicted values output   :    -0.823    0.010   -0.847   -0.802       0
```

As can be seen from the statistics, there is a large bias of -0.823 m. We may remove this and fit the surface to the GPS_levelling data using the module FITGEOID. The program requires that the data are in column 1, so we must create a new file:

```
awk '{print $1, $2, $3, $4, $6 }' nmzeta-egm96-tc.dat > ! nmzeta-egm96-tc0.dat
```

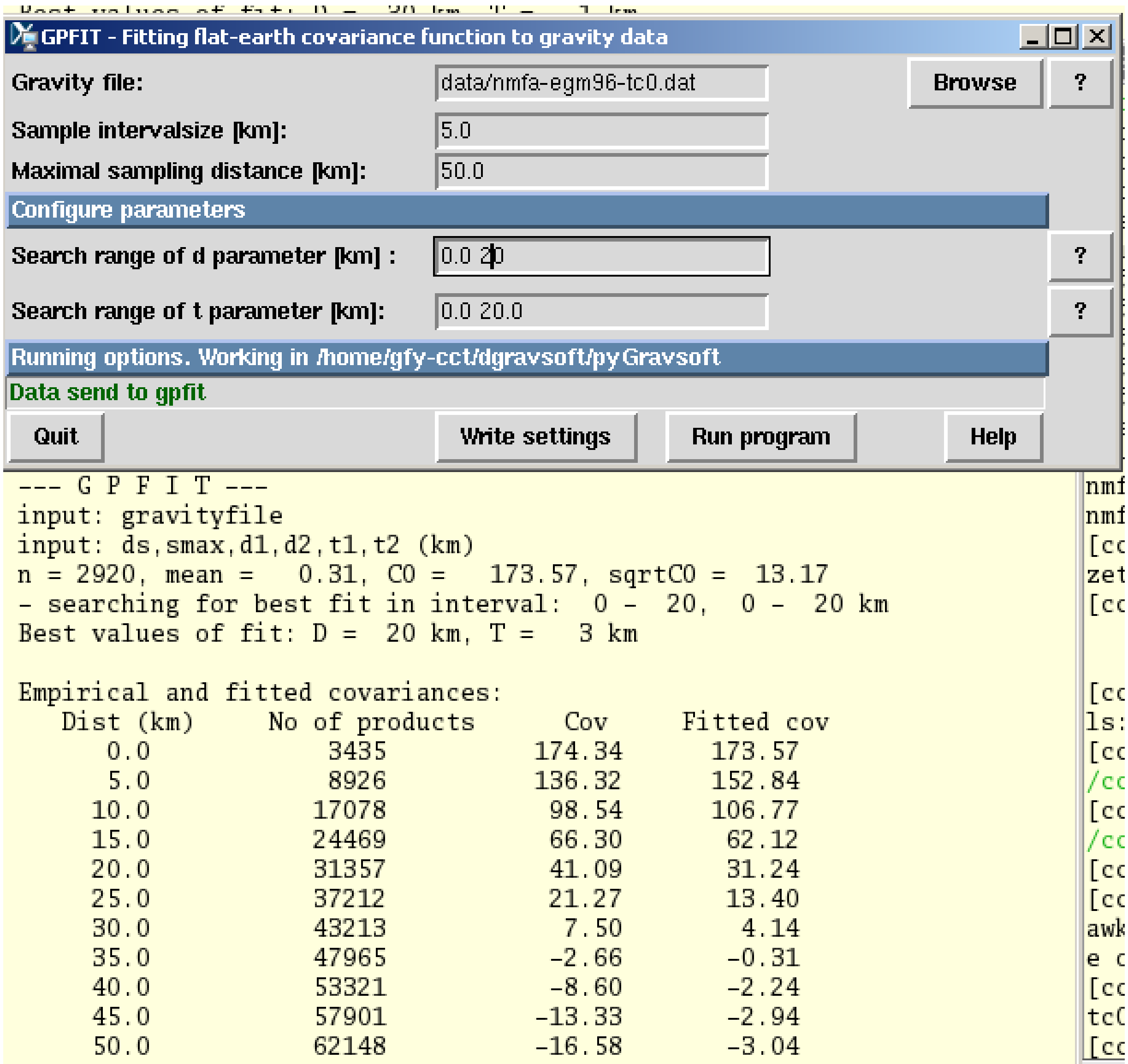


The last output in fitgeoid.log shows how well the values agree after the surface has been changed:

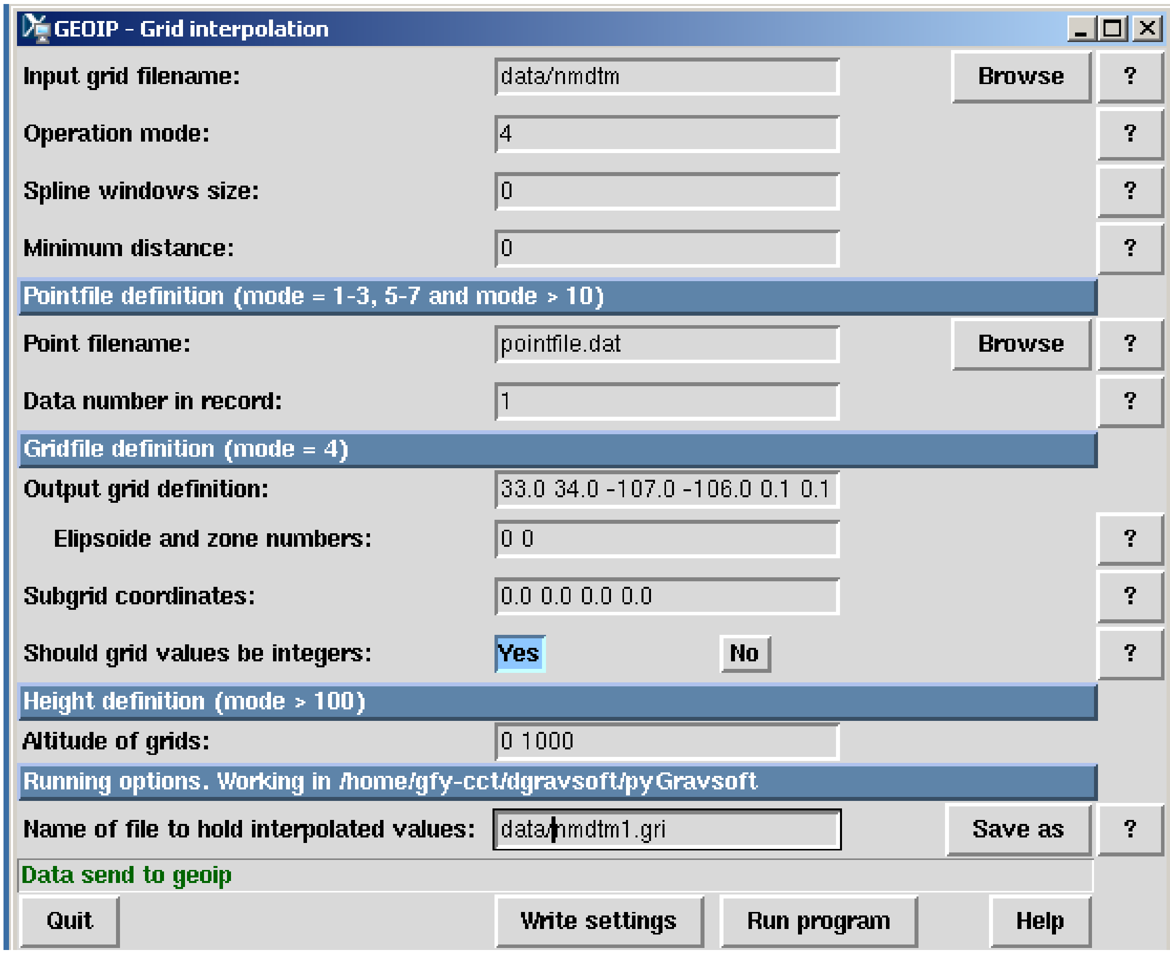
```
points predicted:      20,  skipped points:       0
minimum distance to grid edges for predictions:    30.0 km
statistics:                        mean    std.dev.    min       max     unknown
original data             :    -0.897     0.159    -1.268    -0.633       0
grid interpolation results:    -0.918     0.159    -1.237    -0.669       4
predicted values output   :     0.002     0.022    -0.033     0.035       4
```

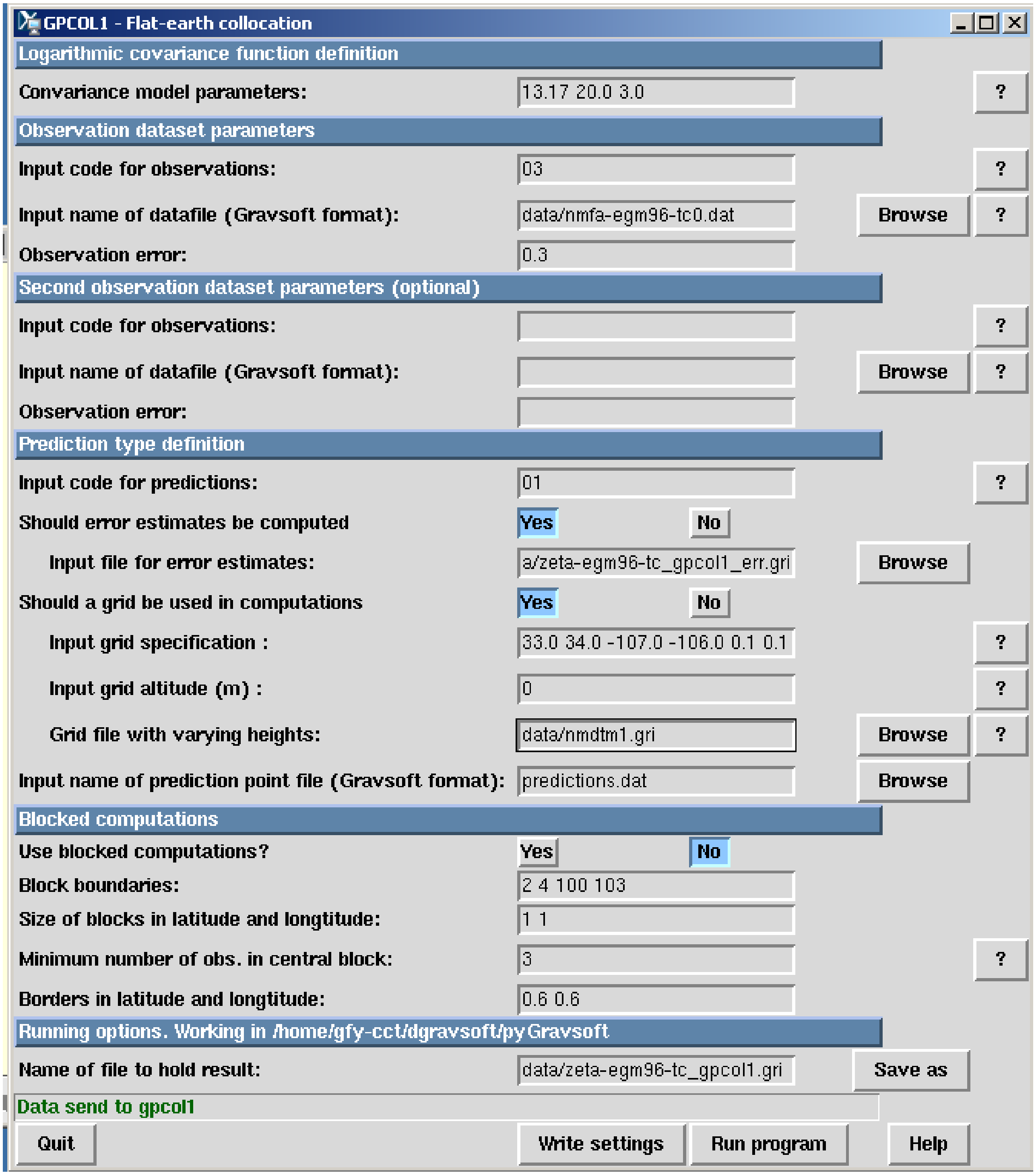
We may directly from the point data estimate geoid heights using planar collocation with gpcol1. First we have to find a planar covariance-function using GPFIT. However it requires the data to be in column 1 after the altitude, so we skip column 5:

```
awk '{print $1,$2,$3,$4,$6}' nmfa-egm96-tc.dat > ! nmfa-egm96-tc0.dat
```



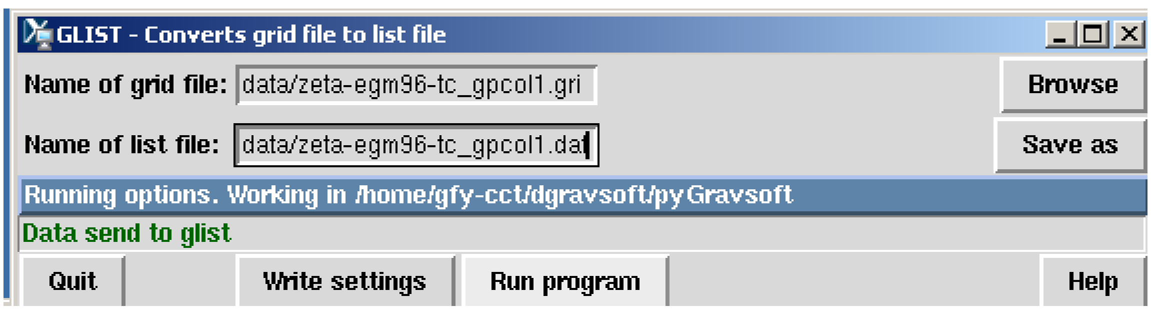
We must first create a file on grid-form with the heights:



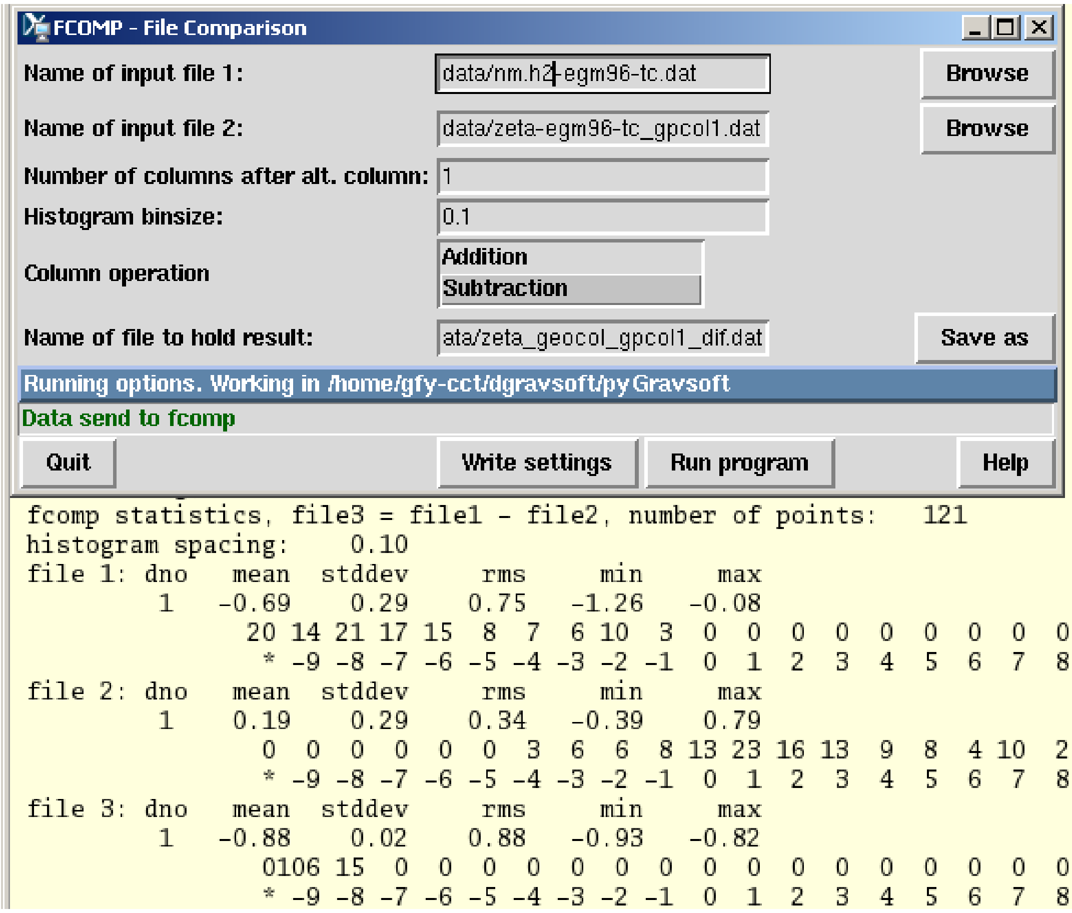

GPCOL1 - Flat-earth collocation
Logarithmic covariance function definition
Convariance model parameters:
13.17 20.0 3.0
?
Observation dataset parameters
Input code for observations:
03
Input name of datafile (Gravsoft format):
data/nmfa-egm96-tc0.dat
Browse
Observation error:
0.3
Second observation dataset parameters (optional)
Input code for observations:
Input name of datafile (Gravsoft format):
Browse
Observation error:
Prediction type definition
Input code for predictions:
01
Should error estimates be computed
Yes
No
Input file for error estimates:
a/zeta-egm96-tc_gpcol1_err.gri
Browse
Should a grid be used in computations
Yes
No
Input grid specification :
33.0 34.0 -107.0 -106.0 0.1 0.1
Input grid altitude (m) :
0
Grid file with varying heights:
data/nmdtm1.gri
Browse
Input name of prediction point file (Gravsoft format):
predictions.dat
Browse
Blocked computations
Use blocked computations?
Yes
No
Block boundaries:
2 4 100 103
Size of blocks in latitude and longtitude:
1 1
Minimum number of obs. in central block:
3
Borders in latitude and longtitude:
0.6 0.6
Running options. Working in /home/gfy-cct/dgravsoft/pyGravsoft
Name of file to hold result:
data/zeta-egm96-tc_gpcol1.gri
Save as
Data send to gpcol1
Quit
Write settings
Run program
Help

```
--- G P C O L ---
 input no of inputfiles (0 = list covariances)
 input sqrtC0 (mgal), D, T (km):     (0 0 0 = stop)
 Covariance model: sqrtC0,D,T =     13.17    20.00     3.00
 Covariances for gravity, geoid and along-track dfv for selected model:
   dist(km)  Cgg (mgal**2)  Cgn (mgal*m)   Cnn (m**2)  Cee (arcsec**2)
       0.       173.449        2.143         0.053         3.687
      10.       106.700        1.692         0.049         1.630
      20.        31.214        0.985         0.041        -0.360
      30.         4.133        0.535         0.033        -0.738
      40.        -2.241        0.301         0.028        -0.609
      50.        -3.039        0.180         0.023        -0.436
      60.        -2.618        0.114         0.020        -0.306
      70.        -2.055        0.076         0.017        -0.217
      80.        -1.580        0.053         0.016        -0.158
      90.        -1.218        0.038         0.014        -0.117
     100.        -0.948        0.029         0.013        -0.089
     110.        -0.747        0.022         0.012        -0.069
     120.        -0.597        0.017         0.011        -0.054
 Model correlation length in km:           12

 Data input from file: data/nmfa-egm96-tc0.dat
 Min and max of input data:    -41.031    45.899
 Total number of observations input:         2920
 - Collocation equations solved -
 - Predicted:   121 points, min max =     -0.38866     0.79348
 - min/max of prediction point heights =    1180.0   2070.0
 Collocation results output on:
 data/zeta-egm96-tc_gpcol1.gri
```

We can also compare this grid with the grid from GEOCOL but we first convert to list form:



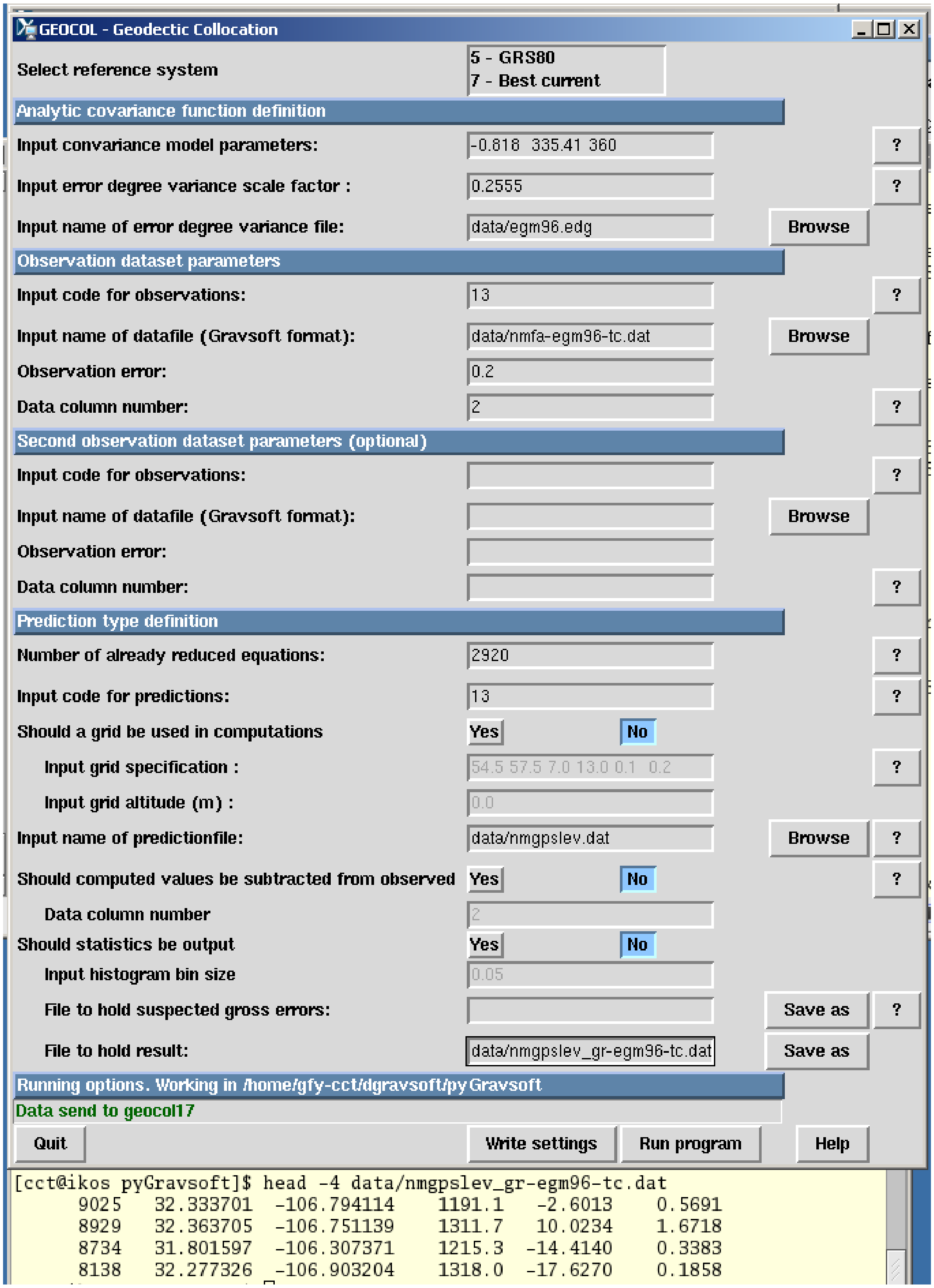
Now we can use fcomp to subtract the two results:



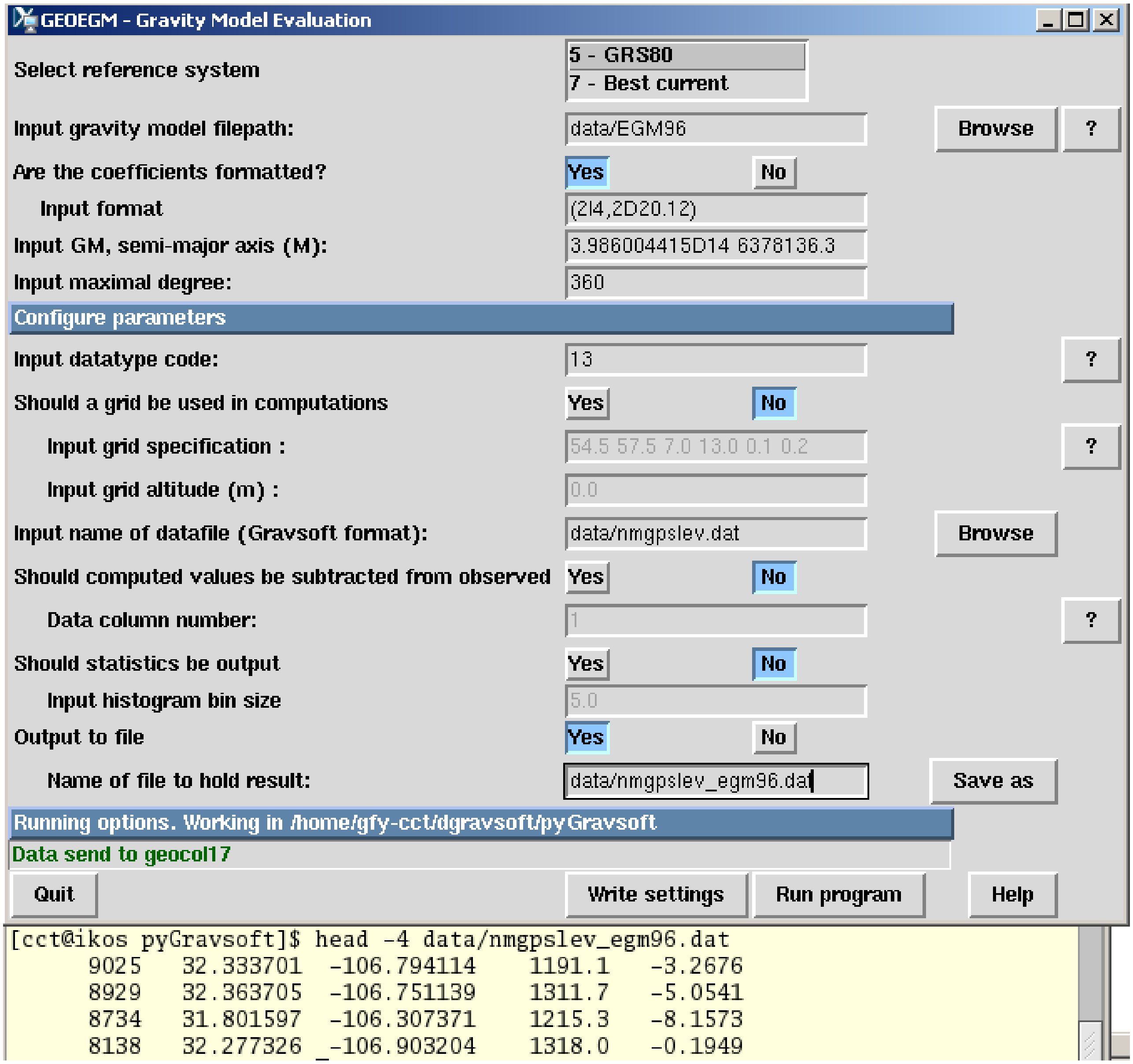
Here we see an agreement at the 2 cm level for the 2 results.

Appendix 1: Conversion from geoid heights to height anomalies.

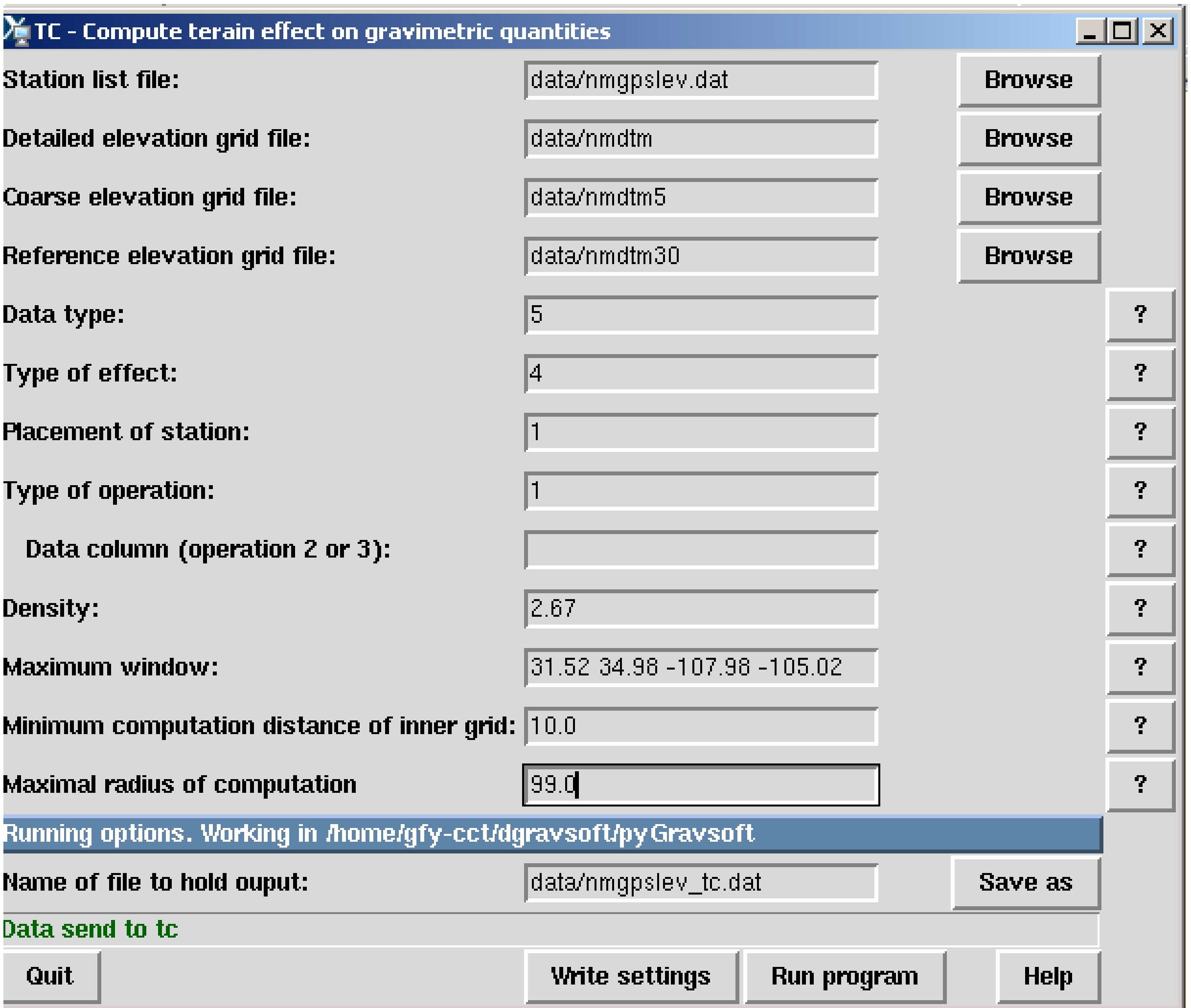
In order to convert the gps-levelling heights to height anomalies we need the free-air anomaly (and subsequently the Bouguer-anomaly) in the points. We first predict using GEOCOL the free-air anomalies minus the contribution from EGM96 and the residual topography. Below the screen-dump is shown the first 4 values.



The contribution from EGM96 is calculated using GEOEGM:

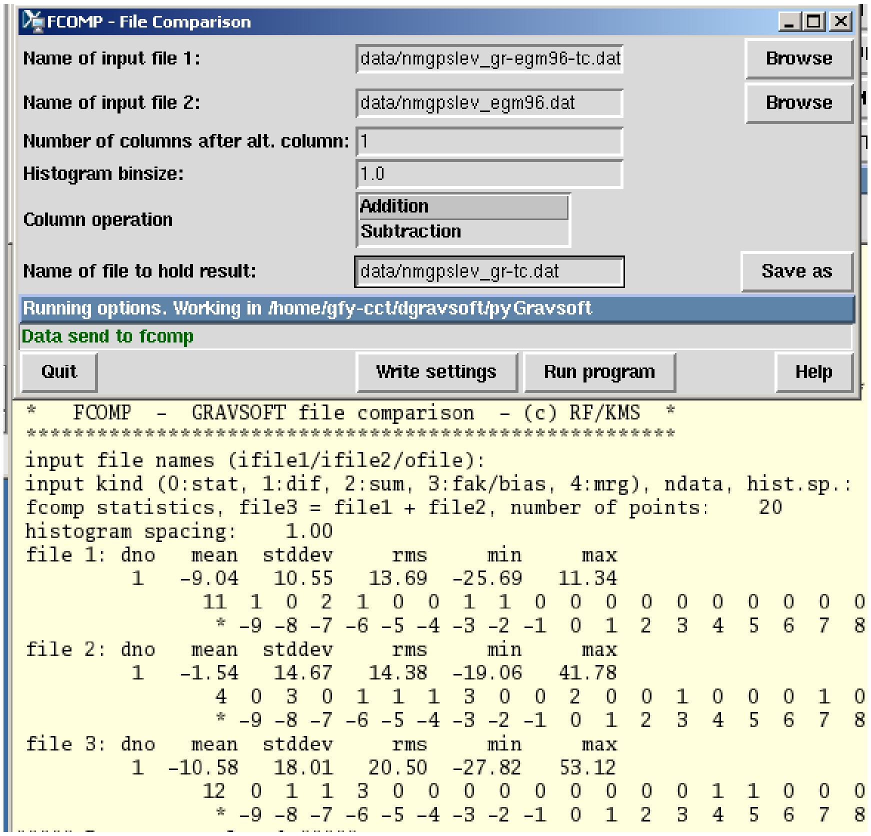


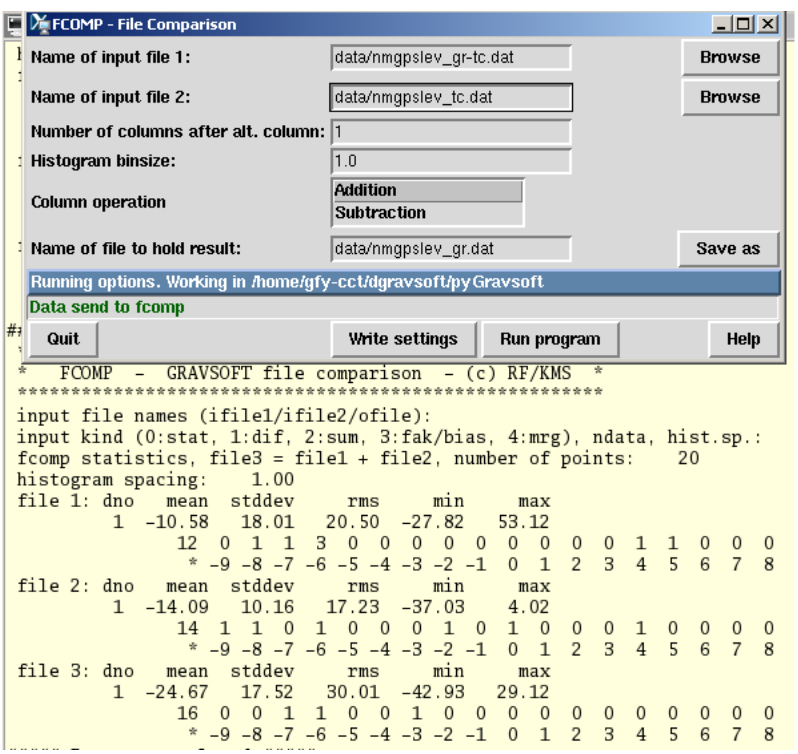
Furthermore the contribution from the residual topography must be calculated using TC:



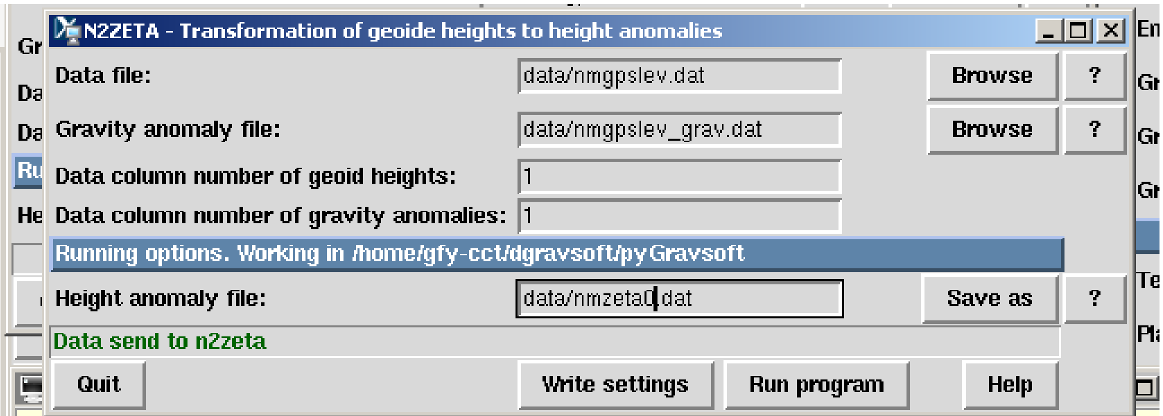

```
head -4 data/nmgpslev_tc.dat
      9025  32.33370 -106.79411  1191.10  -18.8424
      8929  32.36371 -106.75114  1311.66   -8.0022
      8734  31.80160 -106.30737  1215.28   -2.0984
      8138  32.27733 -106.90320  1317.95    0.1128
```

The 3 files must then be added using FCOMP 2 times.





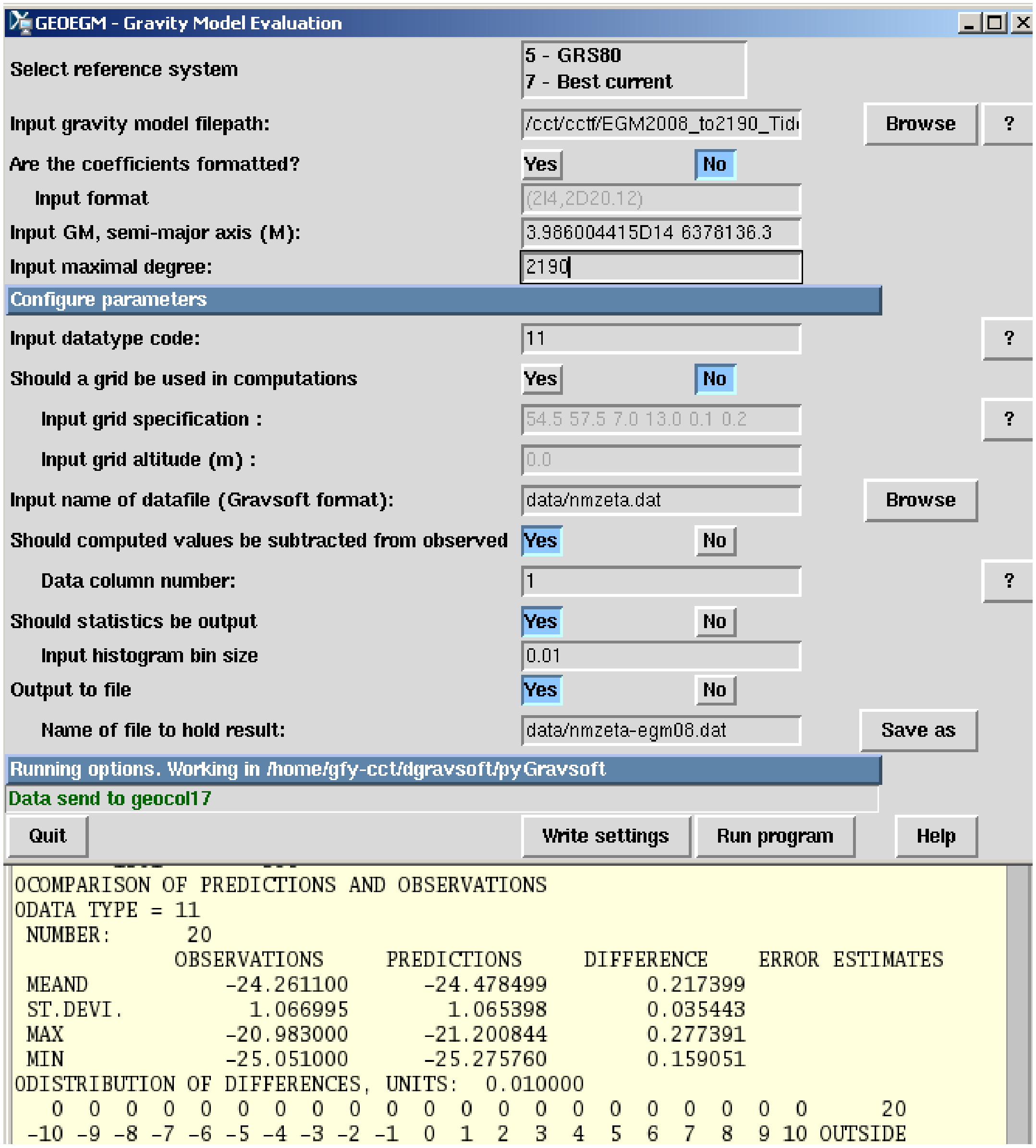
We now have estimates of the free-air anomalies in the GPS-Levelling points, so we are now ready to use the module N2ZETA:




```
 orth2normal, ver. 2002-07-20
 conversion geoid to height anomalies or the reverse ?
 conversion from geoid to height anomalies
 input input and output file names (2 lines)
 files =
data/nmgpslev_grav.dat
data/nmzeta0.dat                                            [redacted]
 input data element number (max 10)
 correction to be applied on file ? (t/f)
 input data file name
data/nmgpslev.dat
 input data element number (max 10)
 free-air anomalies = fa
 Bouger anomalies = ba
no     lat       long        H          fa       ba       corr      N       zeta
 9025  32.3337 -106.7941 1191.10    4.420 -128.864   -0.157  -25.040  -24.883
 8929  32.3637 -106.7511 1311.66   21.150 -125.625   -0.169  -24.840  -24.671
 8734  31.8016 -106.3074 1215.28  -12.980 -148.970   -0.185  -25.120  -24.935
 8138  32.2773 -106.9032 1317.95  -10.320 -157.799   -0.213  -25.150  -24.937
 8134  32.4004 -106.3425 1228.21   -1.560 -138.997   -0.175  -24.740  -24.565
 7830  32.4003 -106.3334 1231.38   -0.870 -138.661   -0.175  -24.720  -24.545
 6894  34.4183 -106.8402 1446.10   -3.360 -165.179   -0.244  -22.810  -22.566
 6646  31.7699 -106.4122 1130.41  -19.630 -146.123   -0.169  -25.240  -25.071
 6645  31.7708 -106.4141 1132.30  -19.480 -146.184   -0.169  -25.220  -25.051
 5670  32.2910 -106.9222 1354.64   -4.320 -155.904   -0.216  -25.120  -24.904
 5315  33.6820 -105.8524 1662.00   14.340 -171.638   -0.292  -21.250  -20.958
 4121  32.2774 -106.7681 1183.10    5.630 -126.759   -0.153  -25.050  -24.897
 3950  32.3203 -106.8082 1188.33   -3.430 -136.404   -0.166  -25.090  -24.924
 3122  31.8918 -106.5961 1147.41   11.590 -116.805   -0.137  -24.980  -24.843
 2999  32.8599 -105.9986 1278.33  -26.570 -169.615   -0.222  -23.350  -23.128
 2173  32.8617 -107.2897 1276.86   -6.440 -149.321   -0.195  -24.600  -24.405
 2145  32.4009 -106.3618 1219.70   -3.320 -139.804   -0.174  -24.770  -24.596
 1347  32.8464 -105.9822 1279.02  -26.450 -169.572   -0.222  -23.240  -23.018
 1301  33.2385 -107.2655 1467.66   -0.860 -165.091   -0.248  -24.120  -23.872
  395  32.2989 -106.8061 1186.99   -5.060 -137.884   -0.167  -25.130  -24.963
 number of data           20
                            mean      std.
corrections               -0.192     0.039
height anomalies (zeta)  -24.287     1.073
geoid heights (N)        -24.479     1.041
```

Appendix 2: Use of EGM2008.

We may also use EGM2008 as a reference field:



Note the excellent 0.035 m agreement.