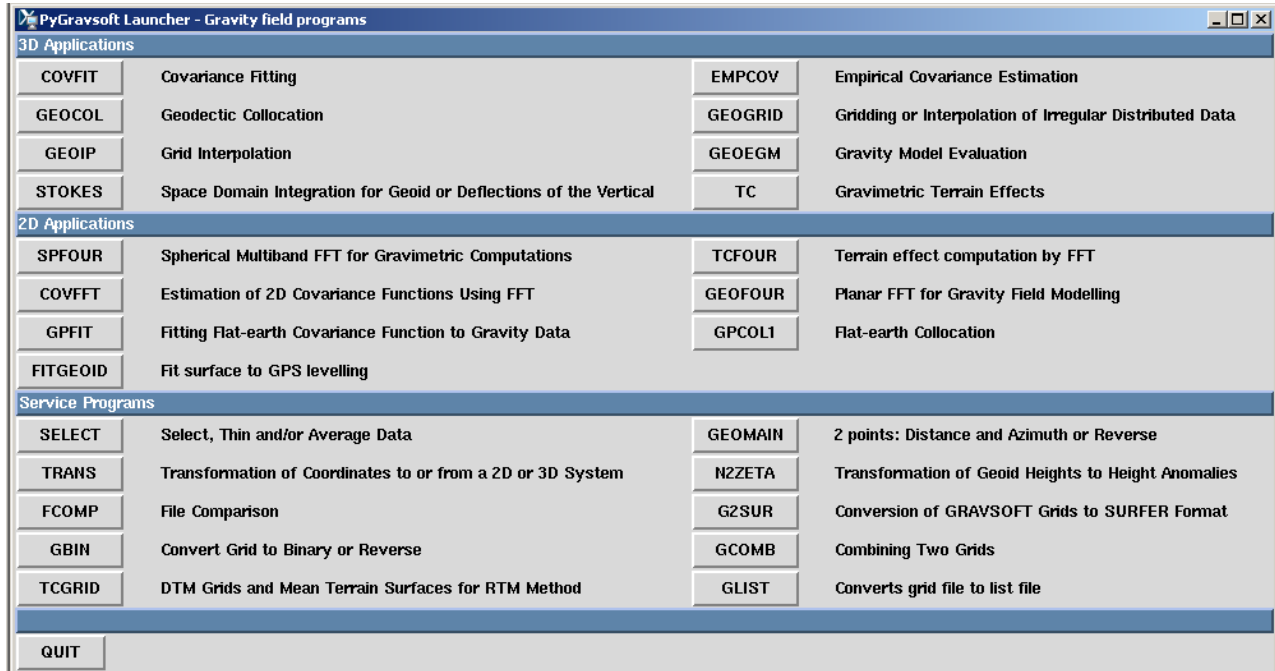


**Gravsoft Python modules with New Mexico examples:
2008-09-11, revision 2, 2009-01-30.
Prepared by C.C.Tscherning, University of Copenhagen.**

We here show step-by-step how the GRAVSOFTE 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 GRAVSOFTE 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/nm dtm. 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.

SELECT - Thin and/or average data

Input data file: ?

Operation mode: ?

Code for coordinates and format: ?

Data cloumn number: ?

Pixel definition (mode > 0)

Pixel definition: ?

Rejection level (mode 5 and 7 only)

Rejection level: ?

Window specification (mode 6 and 7)

Windows specification: ?

Running options. Working in /home/gfy-cct/dgravsoft/pyGravsoft

Name of file to hold ouput: ?

Data send to select

```

input: inputfile and outputfile (two lines):
input: MODE (0:reformat, 1:select, 2:mean, 3:grid, 4:plot,
        5:sel&rej, 6:sel&wndw, 7:sel_min, 8:sel&noise)
      IANG (1:deg, 2:dm, 3:dms, 4:alt, 5:bin, 6:80char, 7:grid,
        neg:fmt, 0:dline)
      NDATA

input: FI1,FI2,LA1,LA2,DFI,DLA (deg or m)

--- S E L E C ---
output to:
data/nm.h2
selection from grid data, grid points:   420   360  151200
total points: 151200
located within area:      31.4917      34.9833   -107.9917   -105.0000
wanted pixel grid:      33.0000   34.0000 -107.0000 -106.0000  0.1000  0.10
no of output/selected points:   121, total poss. pixels:   121
selected data:  mean   std.dev.   min     max
##### Program completed #####

```

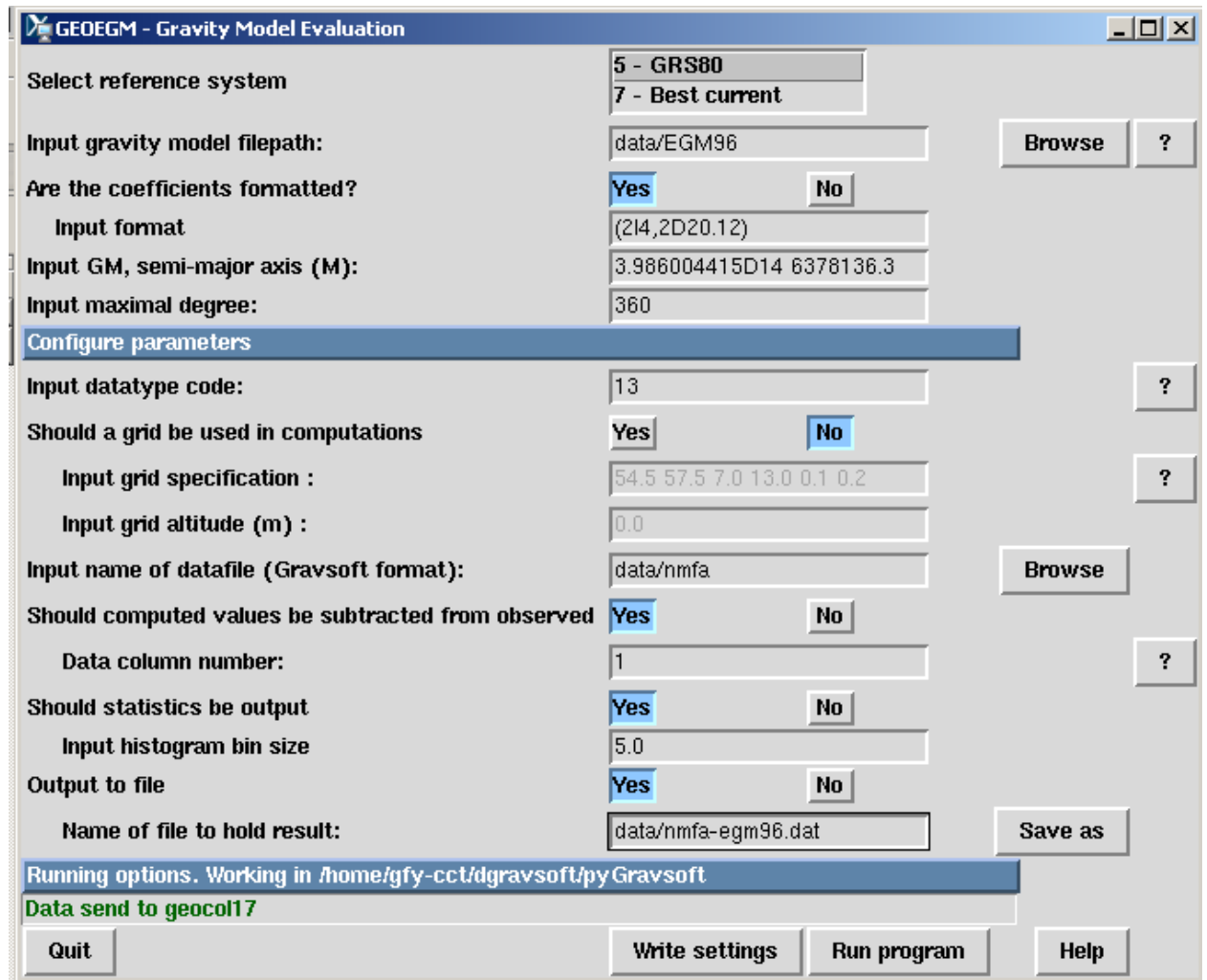
The first lines of the out-put file nm.h2 are:

```

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

ODISTRIBUTION 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.

Running options. Working in /home/gfy-cct/dgravsoft/py Gravsoft

Data send to geocol17

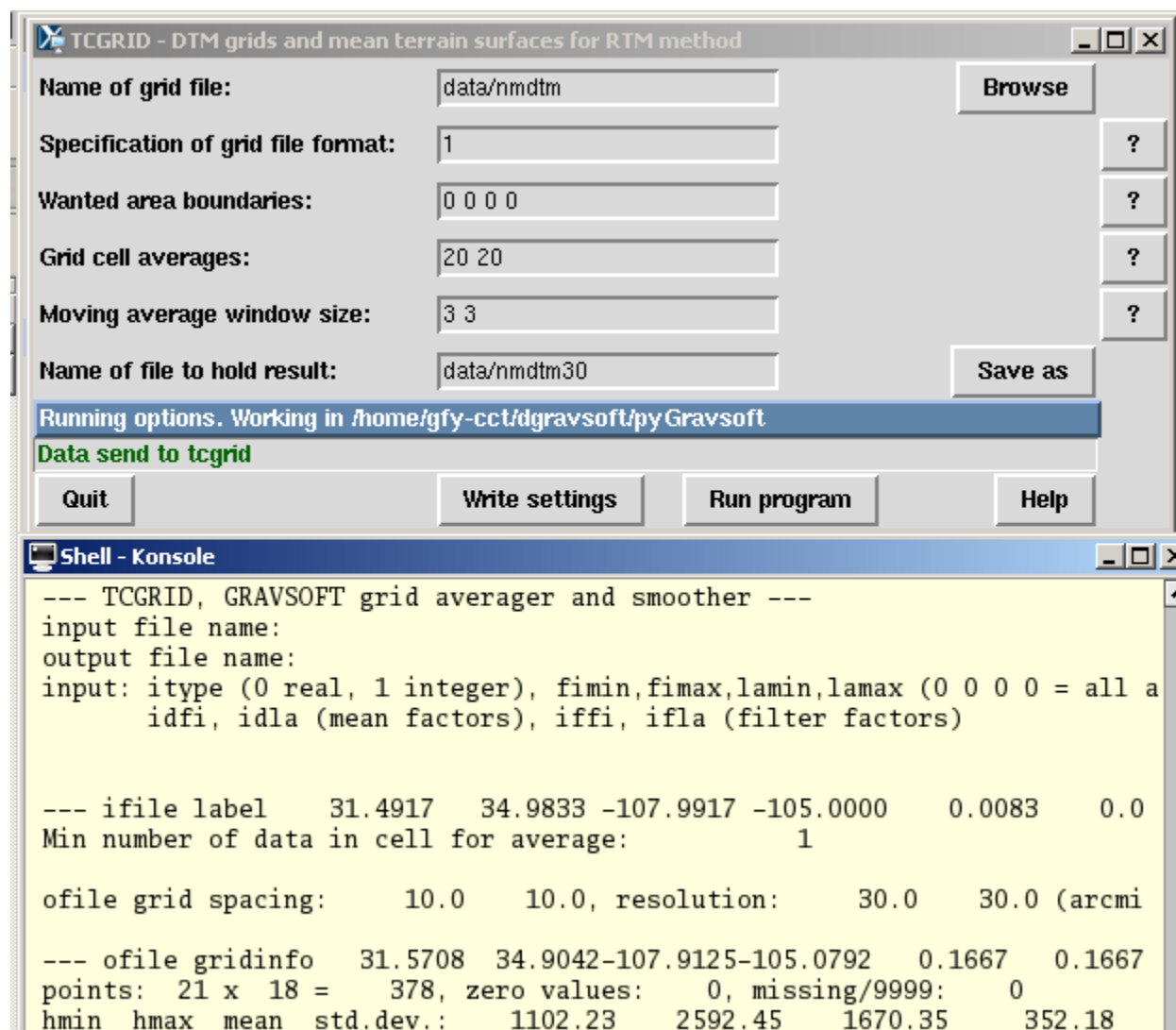
```

COMPARISON OF PREDICTIONS AND OBSERVATIONS
ODATA TYPE = 11
NUMBER:      20
OBSERVATIONS  PREDICTIONS  DIFFERENCE  ERROR ESTIMATES
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
ODISTRIBUTION OF DIFFERENCES, UNITS: 0.050000
 0 0 0 1 0 1 0 1 0 1 5 4 1 3 1 0 2 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

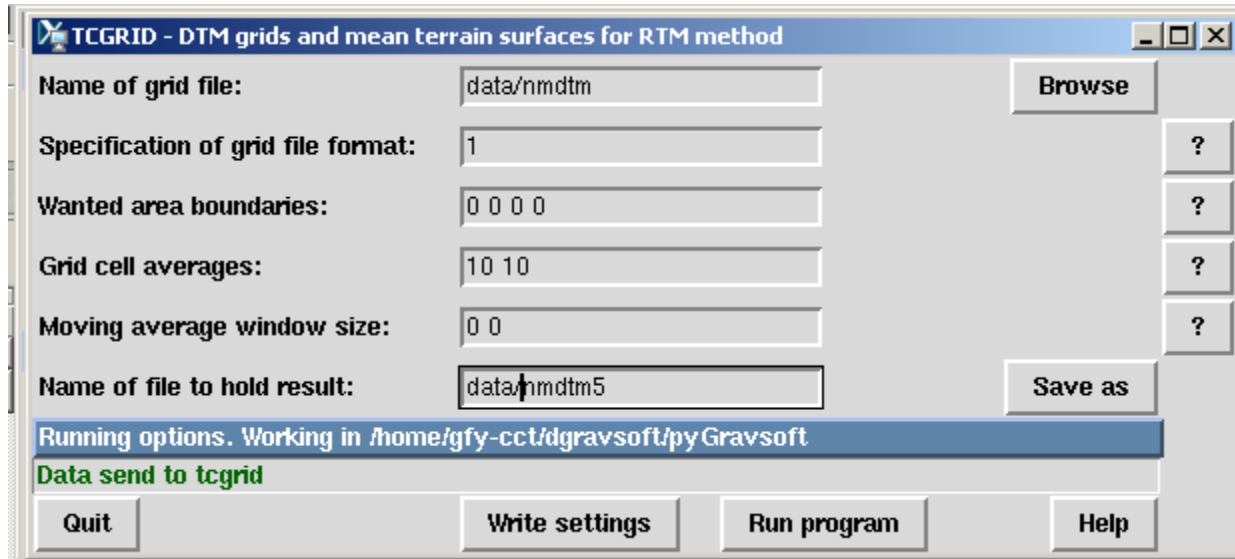
```

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

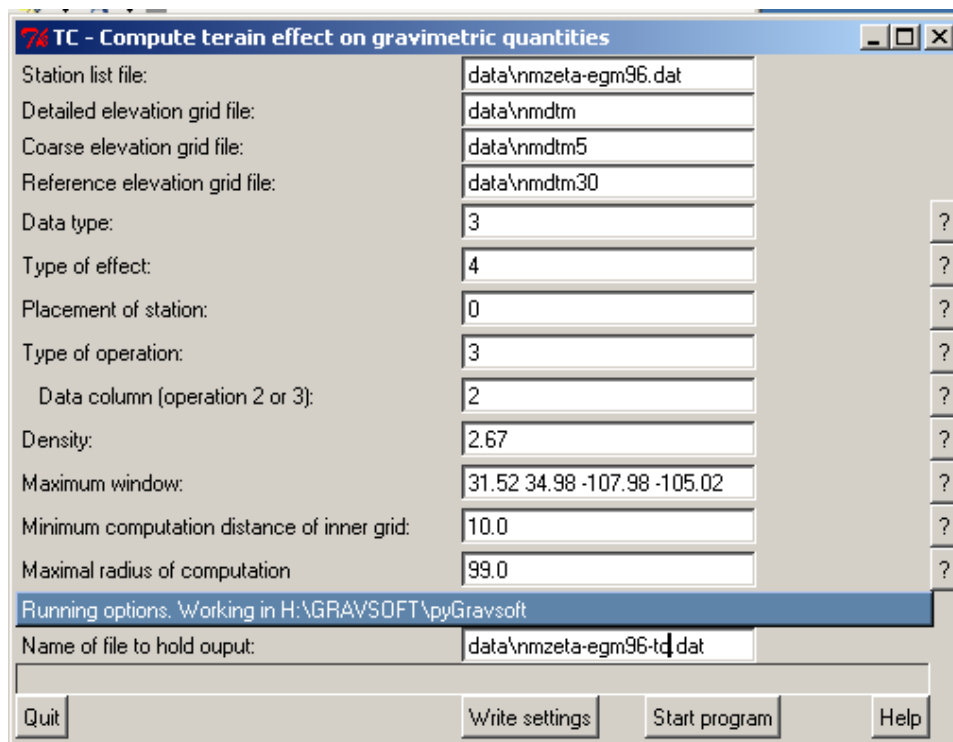
subtracted, i.e. 0.5 degrees. The detailed grid is contained in the file data/nmdtm.

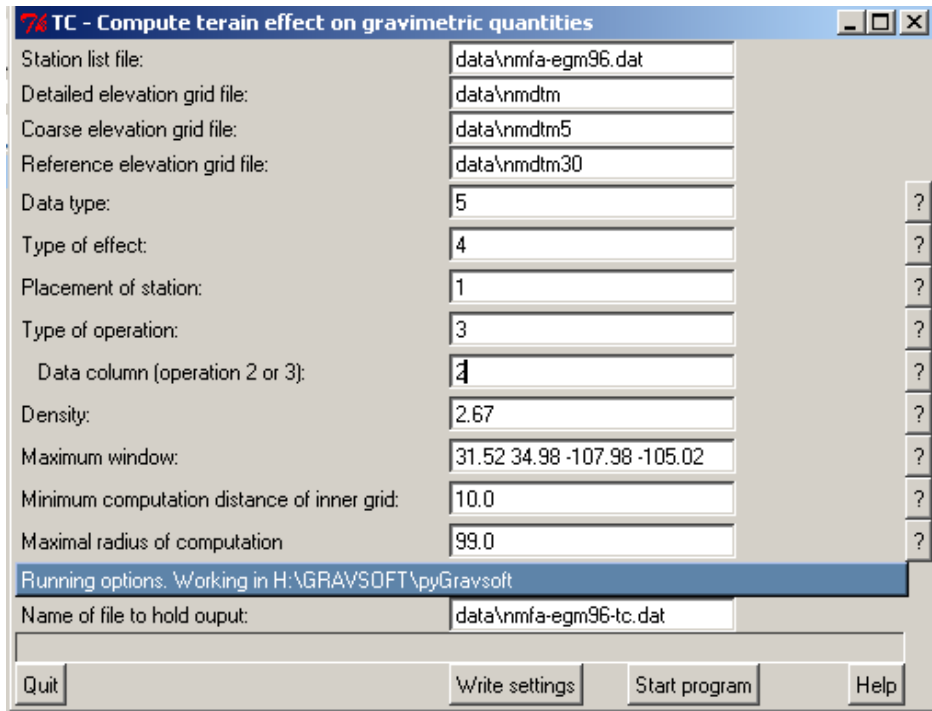


We need a second grid to be used when the calculations of the attractions are at distance from the computational point. In this case the effects may be calculated using 10 times larger grid-cells.



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'.

The screenshot shows the EMPCOV - Empirical Covariance Estimation software interface. The input parameters are as follows:

- Input data filename: data/nmfa-egm96-tc.dat
- Input position of data element: 3
- Input sample interval size (arcmin): 2.5
- Input number of sampling intervals: 30
- Configure parameters:
 - Should mean value be subtracted: Yes
 - Should data in subarea be used: Yes
 - Input area boundaries: 54.5 57.5 7.0 13.0
 - Input histogram bin size: 5.0
 - Name of file to hold result: data/nmegm96.covt

The Shell - Konsole window displays the following output:

```

INPUT NAME OF FILE HOLDING COV TABLE
COVARIANCE FUNCTION TABLE OUTPUT TO FILE data/nmegm96.covt

INPUT: MAX NUMBER OF VALUES, INPUT MODE (WHERE 9 IS FREE FORMAT)
LATITUDE FIRST IN RECORD (T/F), ANGULAR TYPE: 1, DDMSS.S
2: DDMM.M, 3: DD.D, OBSERVATION TYPE 1 (INTEGER) AND
TYPE 2 (INTEGER, 0 IF NOT PRESENT), SCALE OF HISTOGRAM
AND DATA TO BE SELECTED WITHIN GIVEN AREA (T/F)
INPUT NUMBER OF DATA AND DATA ELEMENTS USED
INPUT NAME OF FILE HOLDING DATA
LAST DATA FILE (T/F) ?
2920 VALUES INPUT FROM FILE data/nmfa-egm96-tc.dat

NUMBER OF OBS 1=    2920 MEAN =    0.3066 VAR. =    173.5339437

HISTOGRAM, USING BIN SIZE=    5.000

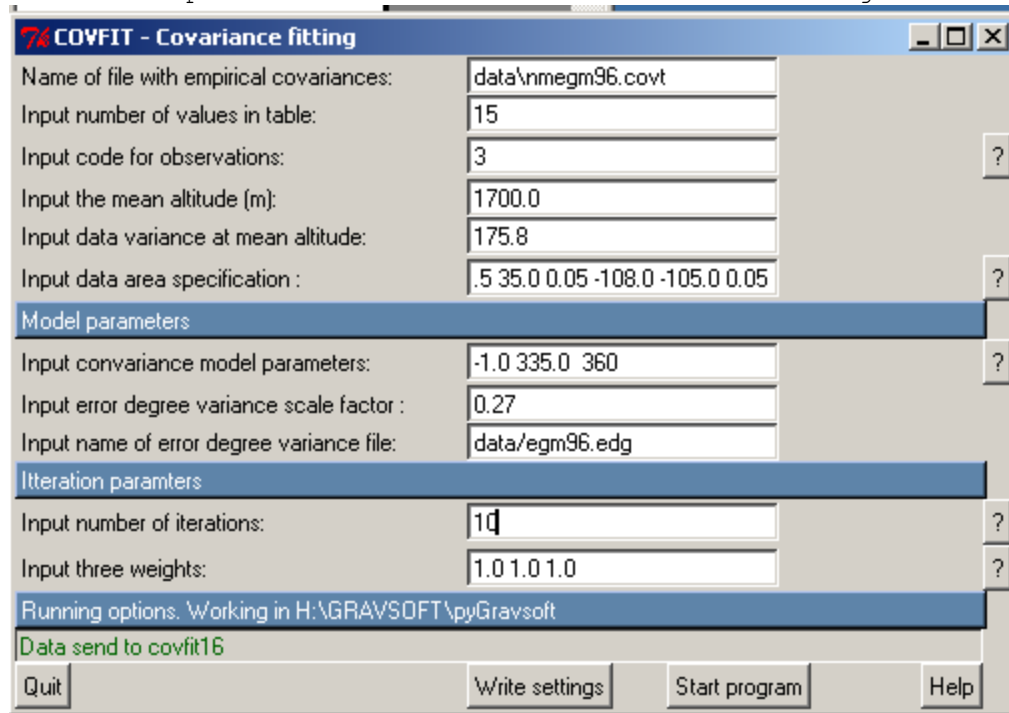
  0  0  0  0  3  9 34 49118248372887357343233127 59 35 18 18 10 0 0
OUT-10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9' 100OUT

      0      0      0      0      3
      9     34     49     118     248
     372    887    357     343    233
     127     59     35     18     18
      10      0      0
0 PSI COVA( 1, 1) PROD. STDV OF COV..
  0 M (UNIT)**2 NUMB (UNIT)**2

  0 0.00 175.849101 3342 4.7 1.134594
  0 2.50 136.901705 7622 2.7 26.682046
  0 5.00 103.940831 14666 1.8 61.604963
  0 7.50 73.801888 21355 1.4 94.660018
  0 10.00 47.929289 27090 1.2 120.202585
  0 12.50 27.377750 32439 1.0 140.747005
  0 15.00 13.912512 37932 0.9 155.848432
  0 17.50 1.059412 42159 0.9 170.291465
  
```

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:
-----
NEW VALUE:           AA           A           RB-RE
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 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.

GEOCOL - Geodetic Collocation

Select reference system:

Analytic covariance function definition

Input convariance model parameters:

Input error degree variance scale factor:

Input name of error degree variance file:

Observation dataset parameters

Input code for observations:

Input name of datafile (Gravsoft format):

Observation error:

Data column number:

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:

Input code for predictions:

Should a grid be used in computations: Yes No

Input grid specification:

Input grid altitude (m):

Input name of predictionfile:

Should computed values be subtracted from observed: Yes No

Data column number:

Should statistics be output: Yes No

Input histogram bin size:

File to hold suspected gross errors:

File to hold result:

Running options. Working in /home/gfy-cct/dgravsoft/pyGravsoft

Data send to geocol17

GEOCOL - Geodectic Collocation

Select reference system: 5 - GRS80
7 - Best current

Analytic covariance function definition

Input covariance 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.

TC - Compute terrain effect on gravimetric quantities

Station list file: data/nm.h2 **Browse**

Detailed elevation grid file: data/nmdtm **Browse**

Coarse elevation grid file: data/nmdtm5 **Browse**

Reference elevation grid file: data/nmdtm30 **Browse**

Data type: 3 ?

Type of effect: 4 ?

Placement of station: 1 ?

Type of operation: 1 ?

Data column (operation 2 or 3): ?

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 ?

Running options. Working in /home/gfy-cct/dgravsoft/pyGravsoft

Name of file to hold output: data/nm.h2.tc.dat **Save as**

Data send to tc

Quit **Write settings** **Run program** **Help**

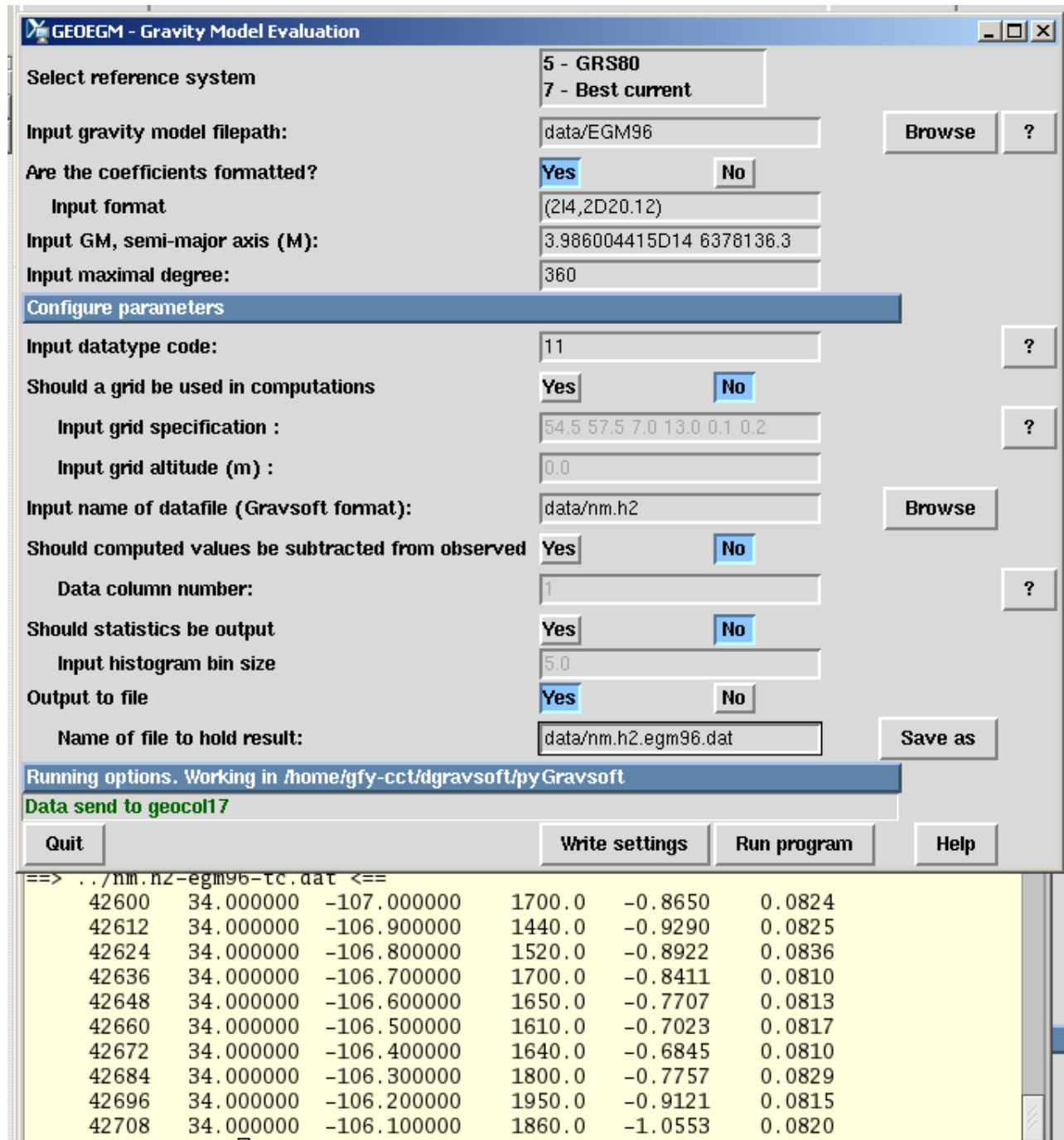
```

85880 33.0000-106.5000 1180.0 1179.0 -0.20128
85872 33.0000-106.4000 1190.0 1190.0 -0.27232
85884 33.0000-106.3000 1210.0 1209.0 -0.21636
85896 33.0000-106.2000 1230.0 1230.0 -0.18489
85908 33.0000-106.1000 1270.0 1270.0 -0.20522
85920 33.0000-106.0000 1350.0 1350.0 -0.21909

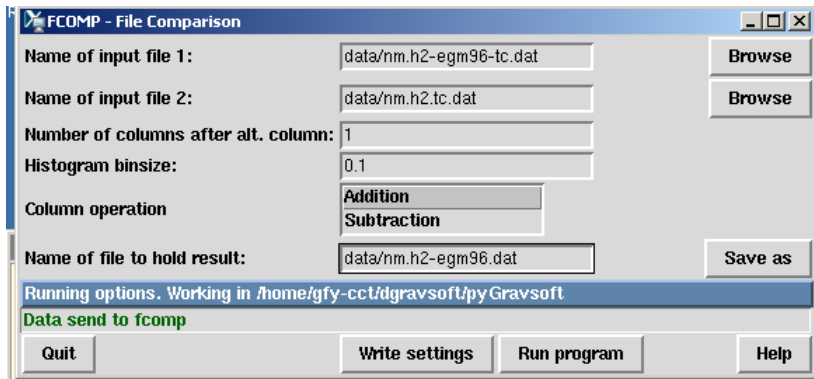
--- average no of prisms/exact formulas pr station: 1790 85
--- difference given - dtm inferred station heights:
mean stdev min max: 0. 0. 0. 1.
--- statistics of computed effects, no of points: 121
mean stdev min max
-0.11 0.14 -0.30 0.27

```

Furthermore, the contribution from EGM96 must be computed:



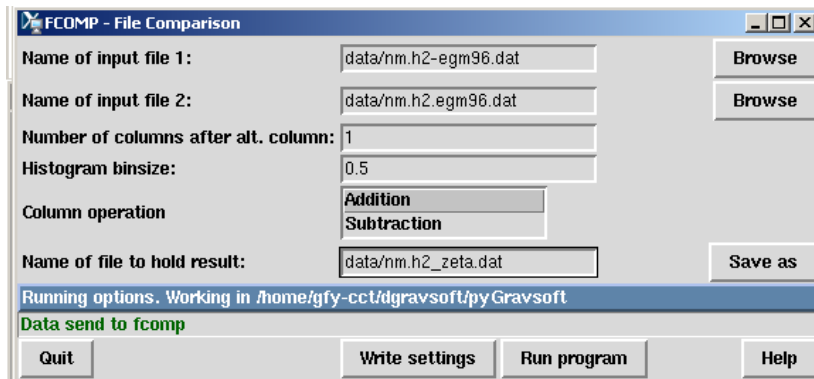
The 3 files: nm.h2.egm96.dat, nm.h2-egm96-tc.dat and nm.he.tc.dat must now be added using fcomp.



```

* FCOMP - GRAVSOFT file comparison - (c) RF/KMS *
*****
input file names (ifile1/ifile2/ofile):
input kind (0:stat, 1:dif, 2:sum, 3:fak/bias, 4:mrg), ndata, hist.sp.:
fcomp statistics, file3 = file1 + file2, number of points: 121
histogram spacing: 0.10
file 1: dno mean stddev rms min max
1 -0.69 0.29 0.75 -1.26 -0.08
20 14 21 17 15 8 7 6 10 3 0 0 0 0 0 0 0 0 0
* -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8
file 2: dno mean stddev rms min max
1 -0.11 0.14 0.17 -0.30 0.27
0 0 0 0 0 0 0 9 48 26 18 13 6 1 0 0 0 0 0
* -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8
file 3: dno mean stddev rms min max
1 -0.79 0.37 0.87 -1.49 0.20
42 15 19 8 9 7 6 2 4 4 2 2 1 0 0 0 0 0 0
* -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8

```



```

* FCOMP - GRAVSOFT file comparison - (c) RF/KMS *
*****
input file names (ifile1/ifile2/ofile):
input kind (0:stat, 1:dif, 2:sum, 3:fak/bias, 4:mrg), ndata, hist.sp.:
fcomp statistics, file3 = file1 + file2, number of points: 121
histogram spacing: 0.50
file 1: dno mean stddev rms min max
1 -0.79 0.37 0.87 -1.49 0.20
0 0 0 0 0 0 0 11 65 32 13 0 0 0 0 0 0 0 0
* -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8
file 2: dno mean stddev rms min max
1 -23.12 0.81 23.14 -24.29 -21.16
121 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
* -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8
file 3: dno mean stddev rms min max
1 -23.92 0.72 23.93 -25.12 -22.34
121 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
* -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8

```

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 geoiip.

The screenshot shows the GEOGRID software interface. The title bar reads "GEOGRID - Gridding or interpolation of irregular distributed data". The interface includes several input fields and buttons:

- Input data filename:** data/nmfa-egm96-tc.dat (with a "Browse" button)
- Number of data values:** 2
- Input position of data element :** 2
- File to hold predictions:** data/nmfa-egm96-tc.gri (with a "Save as" button)
- File to hold errorestimates:** data/nmfa-egm96-tc_err.gri (with a "Save as" button)
- Number of closest points:** 10
- Trend surface removal method:** 0
- Select prediction method:** 1
- Prediction variables:** 12.0 0.2
- Mode number:** 1
- Specify prediction points:** .5 35.0 -108.0 -105.0 0.01 0.01
- Margin for data selection area:** 10.0

Below the input fields, there is a status bar indicating the working directory: "Running options. Working in /home/gfy-cct/dgravsoft/pyGravsoft". A "Data send to geogrid" button is also present.

The bottom section of the window shows the terminal output of the program:

```
* 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

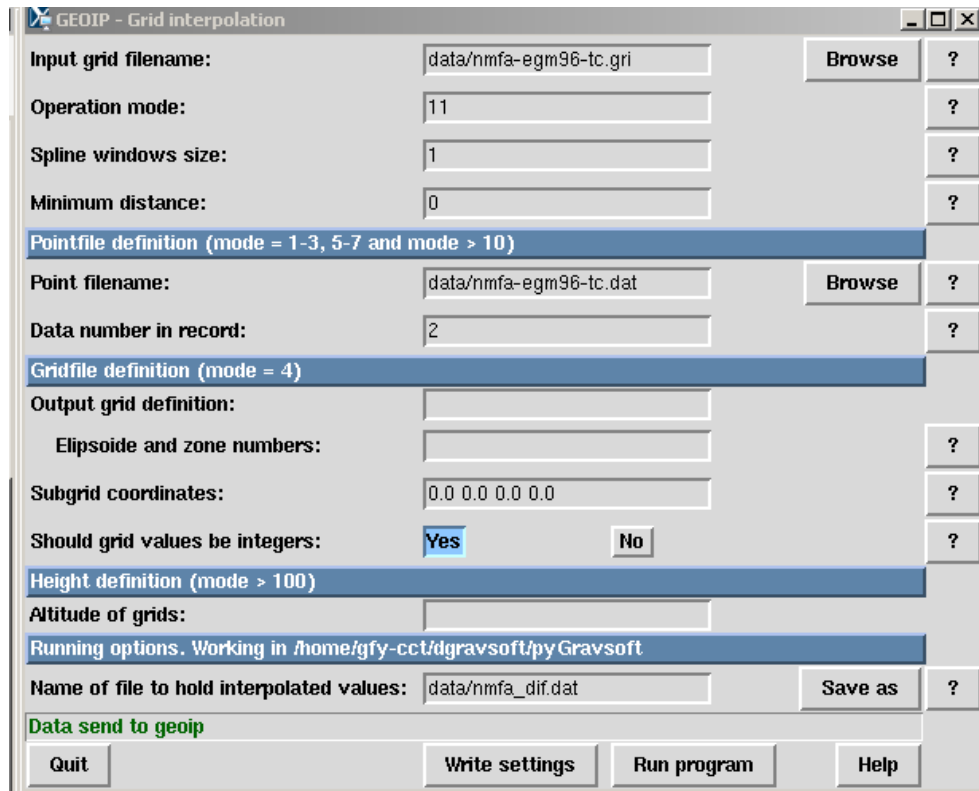
data values per point:  2, used no.:  2
total points in file:  2920, selected:  2920
min max mean stddev:  -41.031  45.899  0.307  13.173

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

```

STOKES - Space domain integration for geoid or deflection of the vertical

Grid file:

Station file:

Operation mode:

Remove mean? Yes No

Cap size range [degrees]:

Running options. Working in /home/gfy-cct/dgravsoft/pyGravsoft

Name of file to hold result:

Data send to stokes

```
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:
original data (pointfile) :  mean  std.dev.  min    max    unknown
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.

SELECT - Thin and/or average data

Input data file: ?

Operation mode: ?

Code for coordinates and format: ?

Data column number: ?

Pixel definition (mode > 0)

Pixel definition: ?

Rejection level (mode 5 and 7 only)

Rejection level: ?

Window specification (mode 6 and 7)

Windows specification: ?

Running options. Working in /home/gfy-cct/dgravsoft/pyGravsoft

Name of file to hold output: ?

Data send to select

```

--- S E L E C ---
output to:
data/nmdtm01.gri
selection from grid data, grid points:  420  360  151200
total points: 151200
located within area:    31.4917    34.9833   -107.9917   -105.0000
wanted pixel grid:    31.5000    35.0000  -108.0000  -105.0000  0.0100  0.010
no of output/selected points: 104700, total poss. pixels: 105651
selected data:  mean  std.dev.  min    max
  
```

GEOFOUR - Planar FFT for gravity field modelling

Input data filename: ?

Input height grid file: ?

Operation mode: ?

Wiener filter resolution: ?

South-West corner position: ?

Number of points in subgrid: ?

Tapering window width: ?

Output parameters

Name of file to hold predictions: ?

Running options. Working in /home/gfy-cct/dgravsoft/pyGravsoft

Data send to geofour

```

*****
* GEOFOUR - gravity field modelling by FFT - vers. jan 96 (c) RF/KMS *
*****

mode: 1
wanted sw corner:      0.0000      0.0000, points: 351 300, iwndow: 5
stokes formula - gravity (mgal) to geoid (meter)

data grid:
gridlab:  31.5000  35.0000 -108.0000 -105.0000  0.0100  0.0100  351 301
selected: sw corner  31.5000 -108.0000, points  351  300 105300
statistics of data selected from input grid:
pts mean std.dev. min max: 105300  0.50  12.34  -41.67  57.73

power space domain  152.62, mean  0.50
mean value subtracted from input data prior to fft
power after window  151.82, wsum =  0.9693
power freq. domain  151.82

min and max computed values :      -0.56      0.75
min and max of imaginary part:      0.00      0.00

```

A comparison with the GEOCOL result using GEOIP gives

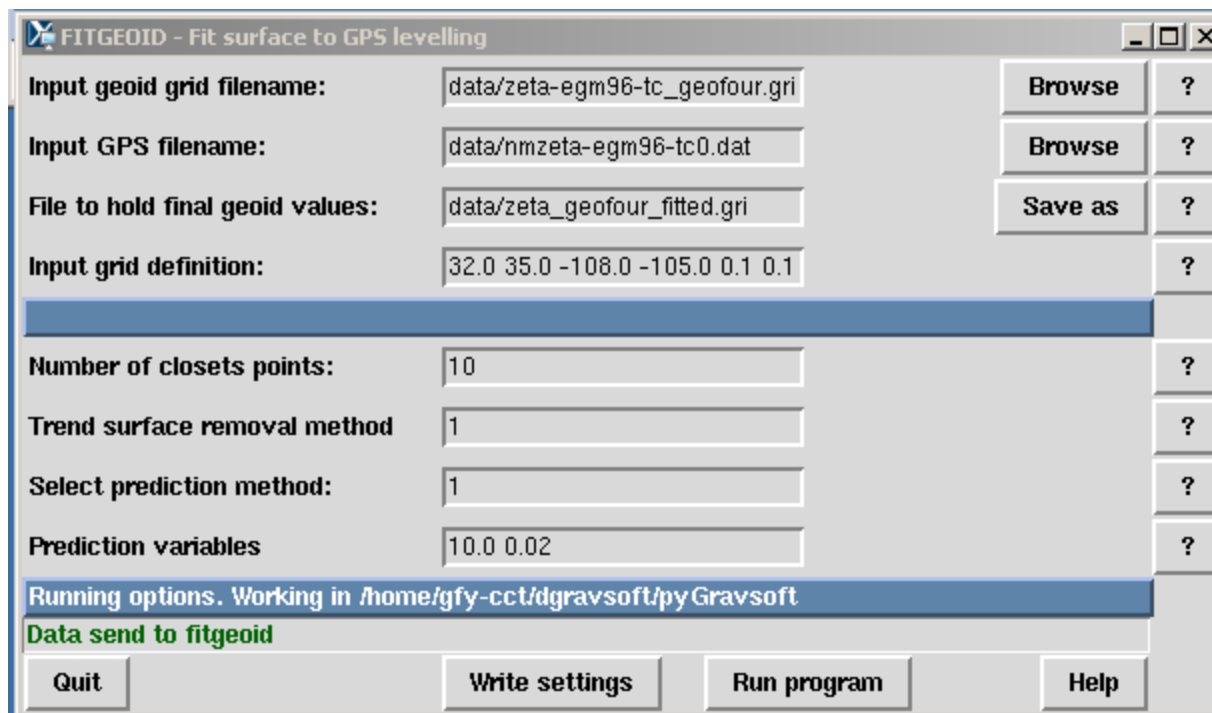
```

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:
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 gpcoll. 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
```

Best values of fit: D = 20 km, T = 3 km

```

--- 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
  
```

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

GEOIP - Grid interpolation

Input grid filename: data/nmdtm **Browse** ?

Operation mode: 4 ?

Spline windows size: 0 ?

Minimum distance: 0 ?

Pointfile definition (mode = 1-3, 5-7 and mode > 10)

Point filename: pointfile.dat **Browse** ?

Data number in record: 1 ?

Gridfile definition (mode = 4)

Output grid definition: 33.0 34.0 -107.0 -106.0 0.1 0.1

Elipsoide and zone numbers: 0 0 ?

Subgrid coordinates: 0.0 0.0 0.0 0.0 ?

Should grid values be integers: Yes No ?

Height definition (mode > 100)

Altitude of grids: 0 1000

Running options. Working in /home/gfy-cct/dgravsoft/pyGravsoft

Name of file to hold interpolated values: data/nmdtm1.gri **Save as** ?

Data send to geoip

Quit **Write settings** **Run program** **Help**

GPCOL1 - Flat-earth collocation

Logarithmic covariance function definition

Covariance 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 longitude: 1 1

Minimum number of obs. in central block: 3 ?

Borders in latitude and longitude: 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:

FCOMP - File Comparison

Name of input file 1:

Name of input file 2:

Number of columns after alt. column:

Histogram binsize:

Column operation:

Name of file to hold result:

Running options. Working in /home/gfy-cct/dgravsoft/pyGravsoft

Data send to fcomp

```

fcomp statistics, file3 = file1 - file2, number of points: 121
histogram spacing: 0.10
file 1: dno  mean  stddev   rms   min   max
         1  -0.69  0.29   0.75  -1.26 -0.08
           20 14 21 17 15  8  7  6 10  3  0  0  0  0  0  0  0  0
           * -9 -8 -7 -6 -5 -4 -3 -2 -1  0  1  2  3  4  5  6  7  8
file 2: dno  mean  stddev   rms   min   max
         1   0.19  0.29   0.34  -0.39  0.79
           0  0  0  0  0  0  3  6  6  8 13 23 16 13  9  8  4 10  2
           * -9 -8 -7 -6 -5 -4 -3 -2 -1  0  1  2  3  4  5  6  7  8
file 3: dno  mean  stddev   rms   min   max
         1  -0.88  0.02   0.88  -0.93 -0.82
           0106 15 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
           * -9 -8 -7 -6 -5 -4 -3 -2 -1  0  1  2  3  4  5  6  7  8

```

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.

GEOCOL - Geodetic Collocation

Select reference system: 5 - GRS80
7 - Best current

Analytic covariance function definition

Input covariance 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: ?

Input name of datafile (Gravsoft format): Browse

Observation error: ?

Data column number: ?

Prediction type definition

Number of already reduced equations: 2920 ?

Input code for predictions: 13 ?

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/nmgpslev.dat 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/nmgpslev_gr-egm96-tc.dat Save as

Running options. Working in /home/gfy-cct/dgravsoft/pyGravsoft

Data send to geocol17

Quit Write settings Run program Help

```
[cct@ikos pyGravsoft]$ head -4 data/nmgpslev_gr-egm96-tc.dat
9025 32.333701 -106.794114 1191.1 -2.6013 0.5691
8929 32.363705 -106.751139 1311.7 10.0234 1.6718
8734 31.801597 -106.307371 1215.3 -14.4140 0.3383
8138 32.277326 -106.903204 1318.0 -17.6270 0.1858
```

The contribution from EGM96 is calculated using GEOEGM:

GEOEGM - Gravity Model Evaluation

Select reference system: 5 - GRS80, 7 - Best current

Input gravity model filepath: data/EGM96 [Browse ?]

Are the coefficients formatted? Yes (selected) No

Input format: (214,2D20.12)

Input GM, semi-major axis (M): 3.986004415D14 6378136.3

Input maximal degree: 360

Configure parameters

Input datatype code: 13 [?]

Should a grid be used in computations: Yes (selected) 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 datafile (Gravsoft format): data/nmgpslev.dat [Browse]

Should computed values be subtracted from observed: Yes (selected) No

Data column number: 1 [?]

Should statistics be output: Yes (selected) No

Input histogram bin size: 5.0

Output to file: Yes (selected) No

Name of file to hold result: data/nmgpslev_egm96.dat [Save as]

Running options. Working in /home/gfy-cct/dgravsoft/pyGravsoft

Data send to geocol17

Quit Write settings Run program Help

```
[cct@ikos pyGravsoft]$ head -4 data/nmgpslev_egm96.dat
9025 32.333701 -106.794114 1191.1 -3.2676
8929 32.363705 -106.751139 1311.7 -5.0541
8734 31.801597 -106.307371 1215.3 -8.1573
8138 32.277326 -106.903204 1318.0 -0.1949
```

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

TC - Compute terrain effect on gravimetric quantities

Station list file:

Detailed elevation grid file:

Coarse elevation grid file:

Reference elevation grid file:

Data type:

Type of effect:

Placement of station:

Type of operation:

Data column (operation 2 or 3):

Density:

Maximum window:

Minimum computation distance of inner grid:

Maximal radius of computation

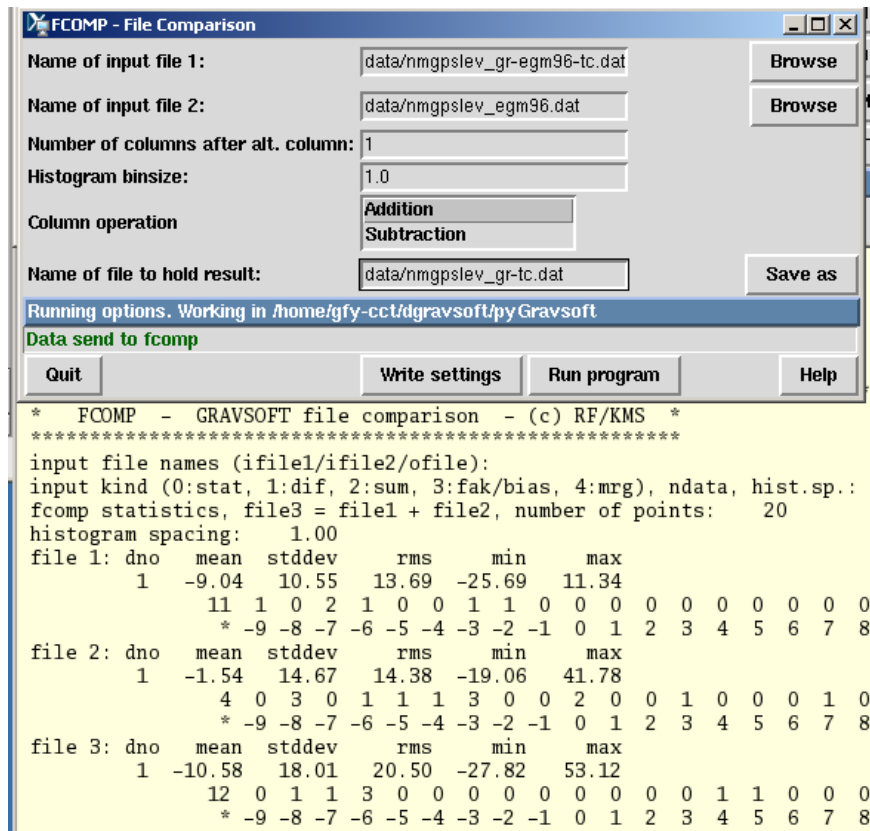
Running options. Working in /home/gfy-cct/dgravsoft/py Gravsoft

Name of file to hold output:

Data send to 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.



NZZETA - Transformation of geoid heights to height anomalies

Data file: ?

Gravity anomaly file: ?

Data column number of geoid heights:

Data column number of gravity anomalies:

Running options. Working in /home/gfy-cct/dgravsoft/pyGravsoft

Height anomaly file: ?

Data send to nzzeta

```

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
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:

Configure parameters

Input datatype code: 11

Should a grid be used in computations: Yes

Input grid specification: 54.5 57.5 7.0 13.0 0.1 0.2

Input grid altitude (m): 0.0

Input name of datafile (Gravsoft format): data/nmzeta.dat

Should computed values be subtracted from observed: Yes

Data column number: 1

Should statistics be output: Yes

Input histogram bin size: 0.01

Output to file: Yes

Name of file to hold result: data/nmzeta-egm08.dat

Running options. Working in /home/gfy-cct/dgravsoft/pyGravsoft

Data send to geocol17

Quit Write settings Run program Help

```

OCOMPARISON OF PREDICTIONS AND OBSERVATIONS
ODATA TYPE = 11
NUMBER: 20
OBSERVATIONS PREDICTIONS DIFFERENCE ERROR ESTIMATES
MEAND -24.261100 -24.478499 0.217399
ST.DEVI. 1.066995 1.065398 0.035443
MAX -20.983000 -21.200844 0.277391
MIN -25.051000 -25.275760 0.159051
ODISTRIBUTION OF DIFFERENCES, UNITS: 0.010000
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
    
```

Note the excellent 0.035 m agreement.