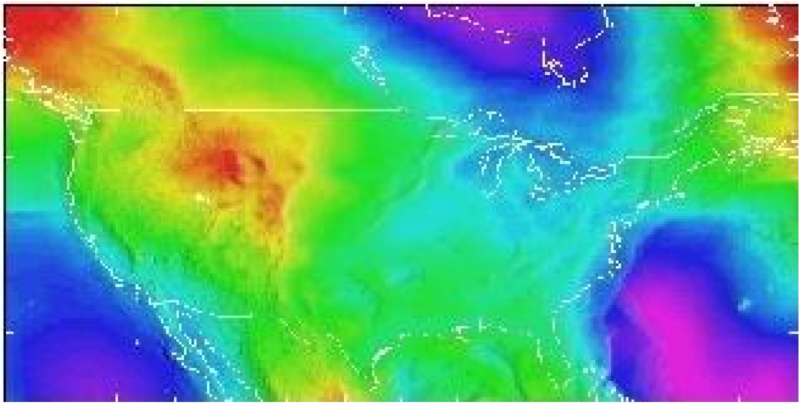
USGG2003



USGG2003 is a gravimetric geoid that served as the basis for GEOID03 within the conterminous United States only.

USGG2003 is very similar to G99SSS differing only in the use of GSFC00.1 instead of KMS98 for the offshore gravity field. The result of changing the altimeter-implied FAGA data was to significantly improve the gravimetric geoid primarily along the East Coast and especially in Florida (a reduction from 40 to 30 cm in misfit).

This 25% improvement was determined by comparison with GPSBM2003 point data. USGG2003 uses the same data format and spacing as G99SSS and can easily swapped in software applications.

Technical Information Page for USGG2003 and GEOID03

Last updated December 30, 2003
(changes since last update are shown in RED)

USGG2003

The **USGG2003** geoid model is a purely gravimetric, geocentric geoid model covering the Conterminous United States. Input data for USGG2003 consisted of:

- 2.6 million terrestrial, ship, and altimetric gravity measurements
- 30 arc second Digital Elevation Data
- A 1 arcsecond DEM for the Northwest USA **(NGSDEM99)**
- The **EGM96** global geopotential model

Using EGM96 as an underlying long wavelength model, USGG2003 was computed using a 1-D FFT remove/compute/restore application of the spherical Stokes integral, where Faye anomalies approximated Helmert anomalies. In computing USGG2003, the geopotential value of the geoid was chosen as W_0= 62636856.88 m^2 / s^2. The USGG2003 geoid undulations refer to a geocentric GRS-80 ellipsoid. USGG2003 was computed on a 1 x 1 arc minute grid, covering the Conterminous United States in the region 24-58 N latitude and 230-300 E longitude.

USGG2003 was generated in much the same manner as G99SSS (click **here** for more details on the generating of G99SSS). The biggest difference between G99SSS and USGG2003 is that the altimeter-derived gravity data were used from GSFC00.1 instead of KMS98. This resulted in a significant improvement in the comparison of USGG2003 to the **GPSBM2003** data. The overall standard deviation dropped from 40 cm to 30 cm in the state of Florida. Other changes occurred all along the East coast and parts of the West coast. As the intent is to have a better forward model of the gravity field, the use of the GSFC00.1 data was adopted.

GEOID03

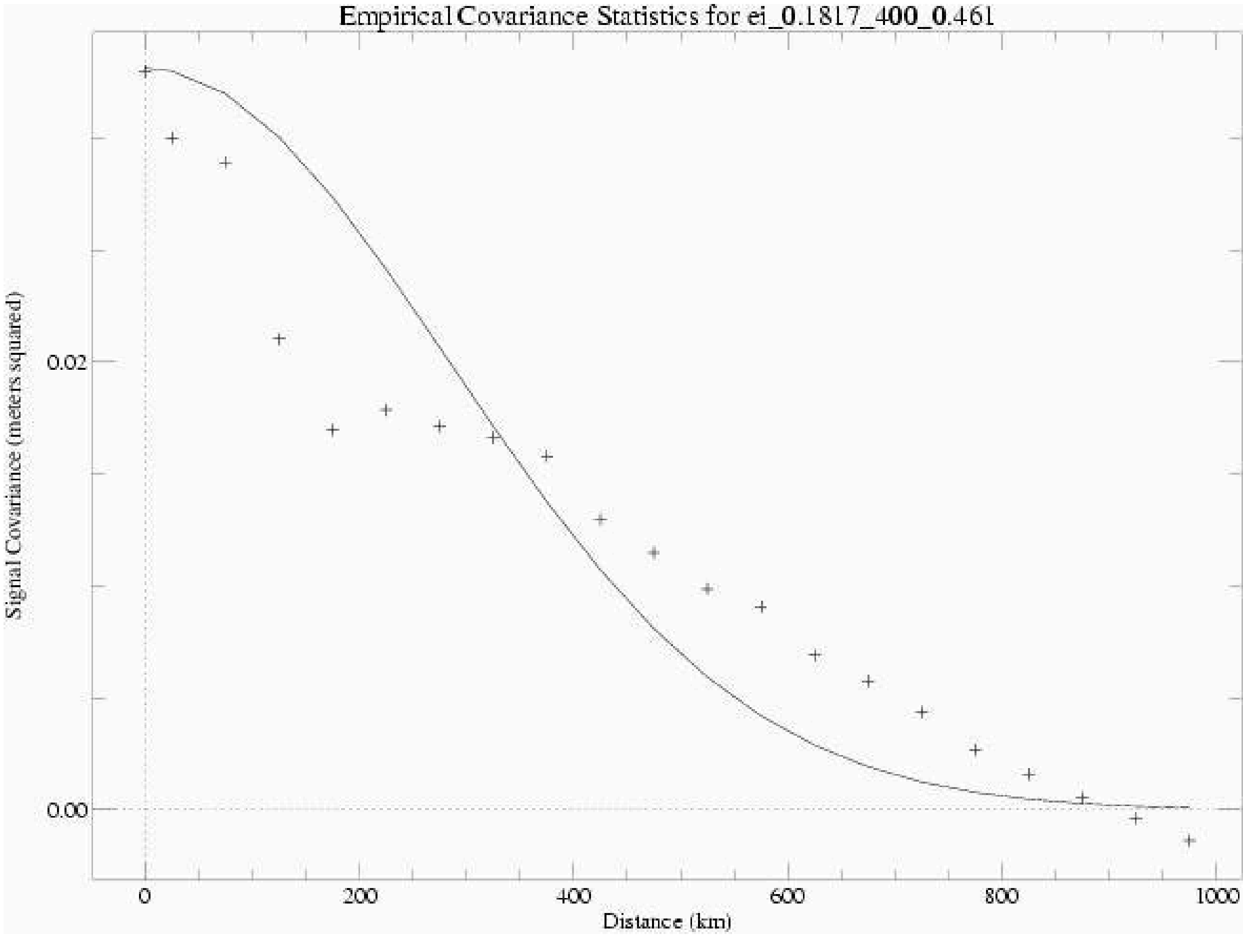
The **GEOID03** geoid model is (in the Conterminous United States) a hybrid geoid model, combining the gravimetric geoid USGG2003 with datum transformations and NAD 83 GPS ellipsoid heights on NAVD 88 leveled bench marks (GPSBM2003).

In addition to the gravimetric geoid model USGG2003, the GEOID03 model consisted of the following input:

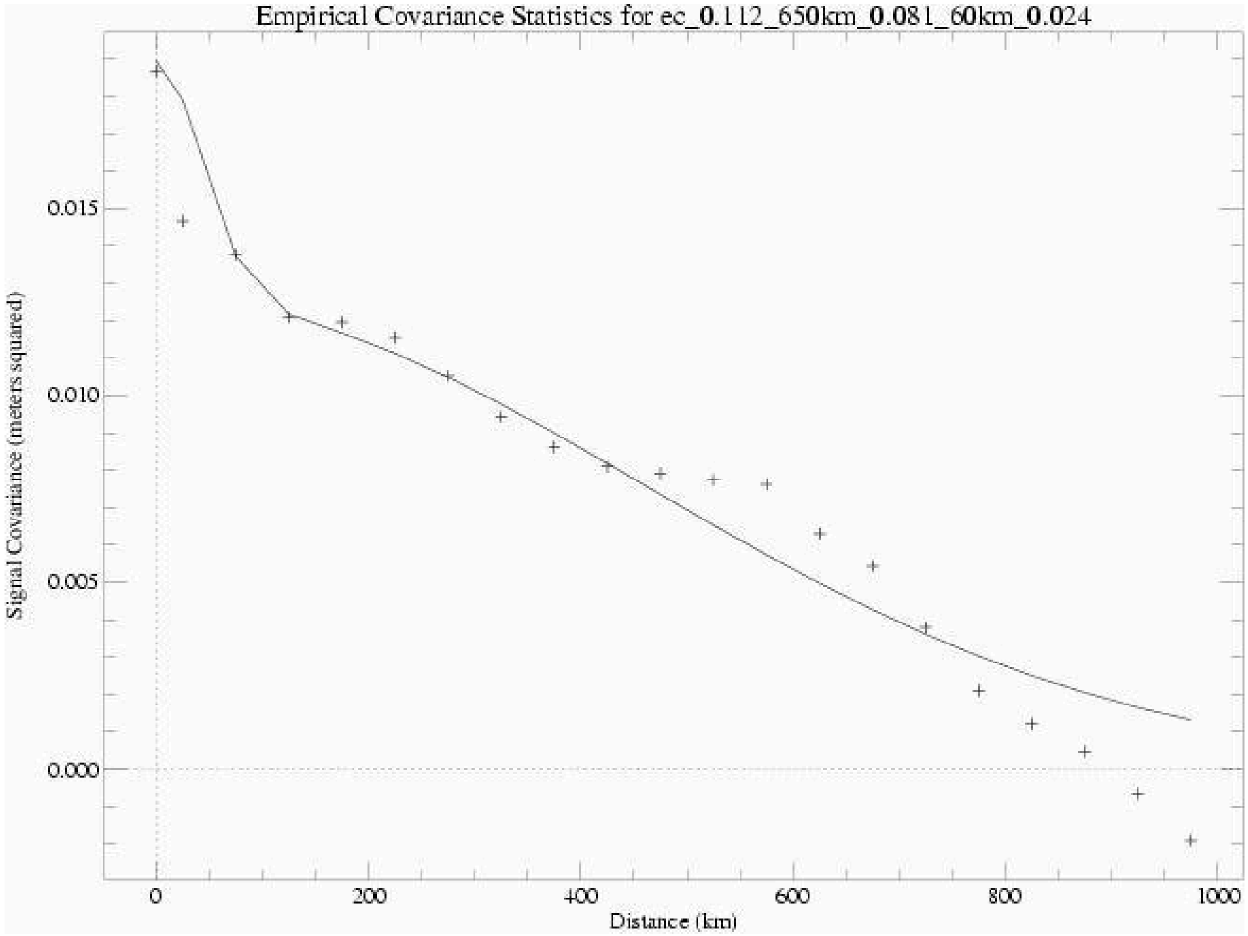
- 14185 NAD 83 GPS heights on NAVD 88 leveled bench marks

The USGG2003 geoid undulations were compared nationally with GPSBM2003. After removing a 55 cm bias and a trend (0.15 ppm, 332 degrees azimuth), an 13.8 cm RMS difference remained. For a discussion of how this signal may have originated, see the **technical details** of GEOID99. The focus here is on how the signal was treated differently for GEOID03 than for GEOID99 using a multi-matrix Least Squares Collocation method.

Instead of fitting a single Gaussian function to the signal implied by the empirical data, two such functions were created and added. The first function had a correlation length of 650 km and a signal amplitude of $(11.2\ cm)^2$. The second had a correlation length of 60 km and an amplitude of $(8.1\ cm)^2$. In the below images, the first shows the fit selected for GEOID99 while the second shows that for GEOID03.



Empirical Covariance Statistics for ei_0.1817_400_0.461
Signal Covariance (meters squared)
0.02
0.00
0
200
400
600
800
1000
Distance (km)

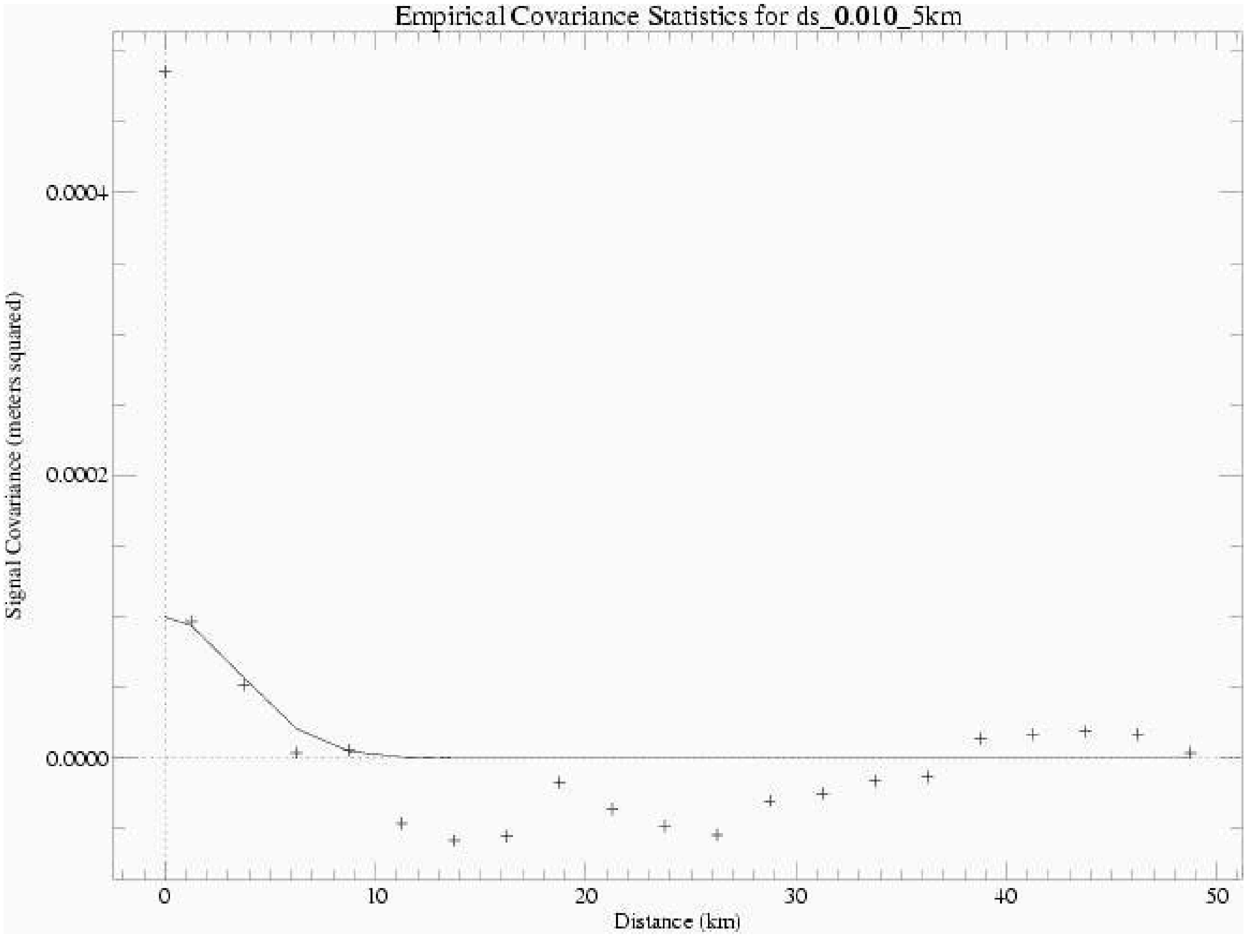


Clearly, then the second fit is better. This improved fit reflects the modeling of data at varying quality and spatial distribution. The results show a significantly improved fit between GEOID03 and the GPSBM2003 data. The grid generated by the multi-matrix Least Squares Collocation method, along with the bias, trend and ITRF00/NAD 83 transformation were used to compute a conversion surface which when removed from USGG2003 yields GEOID03. GEOID03 undulations have a 2.4 cm RMS difference when compared to the GPSBM2003 data, which represents 50% improvement over the GEOID99 model.

Furthermore, the actual geoid error is under 1.0 cm. The total misfit between the data is a combination of the uncorrelated signal deriving from the GPS observations (random error) and a correlated signal that could derive from either GPS or leveling data as well as USGG2003. The uncorrelated signal is about 2.1 cm. Note how there is a spike on the y-axis where the data auto-correlate. This spike represents the uncorrelated signal, because random error at one point does not impact the signal at another. In the below figure, the correlated signal can be projected into the y-axis at about 1.0 cm of signal. Hence, the actual geoid error is 1.0 cm for one sigma or 2.0 cm for 2 sigma (95% confidence level). This relationship is expressed through the variances (the squares of the numbers discussed here).

Total Signal = Uncorrelated + Correlated

$(2.4\text{ cm})^2 = (2.1\text{ cm})^2 + (1.0\text{ cm})^2$



Acknowledgements for GEOID03

The National Geospatial-Intelligence Agency

The National Geospatial-Intelligence Agency **(NGA)**, has been of immense help in this endeavor. NGA has provided a major portion of the NGS land gravity data set. NGA has also been instrumental in the creation of the various 30″ and 3″ elevation grids in existence. And, NGA was a partner in the joint project to compute the new global geopotential model, EGM96. Although the work of NGA generally precludes public recognition, their cooperation is gratefully acknowledged.

GSFC/NIMA Geopotential Model, EGM96

The Goddard Space Flight Center **(GSFC)** and the The National Geospatial-Intelligence Agency **(NGA)**, were engaged in a joint project to compute an improved global spherical harmonic model of the Earth's geopotential. This model incorporated the latest satellite tracking data, as well as altimeter data from TOPEX/Poseidon, ERS-1, and the Geosat Geodetic Mission. **EGM96** also incorporated new surface and marine gravity data covering the globe, including the former Soviet Union.

EGM96 is a global geopotential model expressed as spherical harmonic coefficients complete to degree and order 360. Therefore, the shortest wavelength this model can exhibit is one degree, and its resolution is one-half degree (about 50 km). Although this model does not reproduce geoid structure at very fine resolution, it is global. We thank the many members of the project team for making this model available.

The United States Geological Survey

The United States Geological Survey **(USGS)**, has for years been producing high resolution digital elevation models for the United States. Using the highest resolution (10 and 30 meter) DEMs from USGS, the National Geodetic Survey created a new 1 arcsecond DEM for the Northwest United States, **NGSDEM99**. This new DEM significantly improved our knowledge of the gravimetric geoid in the Northwest. We thank USGS for making their raw DEM data available to us.

Natural Resources Canada

The **Geodetic Survey Division** of **Natural Resouces Canada** has long been a partner with NGS in scientific research and studies. They have provided control data for the generation of GEOID03 along the northern tier states, as well gravity and terrain data for regions of Canada that impact the generation of USGG2003. We thank them for this direct support in the form of data as well as the in depth discussions relating to geodesy.

THE GEOID03 README FILE

```
Original: 2003 December 30 (drr)
Update  : g2003rme.txt - 1.6 - 2006/05/05 (ccyy/mm/dd)

NOTE:
The GEOID03 file number 7 has been updated.  A Vertical Time Dependent
Positioning (VTDP) model has been developed to account for subsidence in
the southern Louisiana region.  As a result, many of the orthometric
heights at the bench marks have been altered.  The update to the GEOID03
model reflects the VTDP modified heights.  The region affected is limited
and the changes to GEOID03 immediately taper off outside the southern
Louisiana region.  For more details, follow the links on the main
NGS GEOID03 web page for discussions about VTDP.
```

The GEOID03 GEOID MODELS

You have received these models on CD-ROM, or downloaded them from the National Geodetic Survey (NGS) web site or the NGS FTP site.

Files you may have received include:

```
 INTG.EXE (PC) or   The geoid interpolation program (source code is
 INTG     (Sun)     INTG.FOR)

 XNTG.EXE (PC) or   Program for extracting, translating (ascii/binary)
 XNTG     (Sun)     and yielding statistics of geoid files (source code
                    is XNTG.FOR)
```

The following file names are valid for binary data
(if, however, you downloaded the ASCII versions of these files,
 the suffix will be ".asc" rather than ".bin"):

```
 g2003u01.bin       GEOID03 grid #1 for CONUS  (40-58N, 230-249E)
 g2003u02.bin       GEOID03 grid #2 for CONUS  (40-58N, 247-266E)
 g2003u03.bin       GEOID03 grid #3 for CONUS  (40-58N, 264-283E)
 g2003u04.bin       GEOID03 grid #4 for CONUS  (40-58N, 281-300E)
 g2003u05.bin       GEOID03 grid #5 for CONUS  (24-42N, 230-249E)
 g2003u06.bin       GEOID03 grid #6 for CONUS  (24-42N, 247-266E)
 g2003u07.bin       GEOID03 grid #7 for CONUS  (24-42N, 264-283E)
 g2003u08.bin       GEOID03 grid #8 for CONUS  (24-42N, 281-300E)
 g2003a01.bin       GEOID03 grid #1 for Alaska (60-72N, 172-204E)
 g2003a02.bin       GEOID03 grid #2 for Alaska (60-72N, 202-234E)
 g2003a03.bin       GEOID03 grid #3 for Alaska (49-61N, 172-204E)
 g2003a04.bin       GEOID03 grid #4 for Alaska (49-61N, 202-234E)
 g2003h01.bin       GEOID03 grid #1 for Hawaii (18-24N, 199-206E)
 g2003p01.bin       GEOID03 grid #1 for PR/VI  (15-21N, 291-296E)
```

To Install:

1) Make a subdirectory on your hard disk.
2) Copy the various geoid files into that subdirectory. You need not

put the geoid files in the same directory as the programs. (If you have also received USGG2003 model files, you may safely place them in the same directory as GEOID03, if you like.)

3) If you are using a PC, check your AUTOEXEC.BAT and CONFIG.SYS files to insure compliance with the following notes:

Note: You must have a statement FILES=25 (or a number greater than 25) in your CONFIG.SYS file.

To Execute

(PC or Sun) Type INTG, and follow the prompts.

To Terminate

You can stop the program at any time by the Control C key combination.

BUT, PLEASE DON'T START YET. PLEASE KEEP READING THIS DOCUMENT.

Check The Byte Counts of all Downloaded Files

Before beginning, it will be useful to ensure that all files you have received are the correct size. (Download problems are often manifested by incorrect byte counts in the files). Check with the list below to make sure your files match these numbers exactly.

PC or Sun Data:

```
     g2003u**.bin    4,933,728 bytes
     g2003a**.bin    5,540,208 bytes
     g2003h01.bin      607,968 bytes
     g2003p01.bin      434,688 bytes
```

ASCII Data:

```
     g2003u**.asc   12,488,896 bytes (uncompressed)
     g2003a**.asc   14,024,273 bytes (uncompressed)
     g2003h01.asc    1,558,212 bytes (uncompressed)
     g2003p01.asc    1,114,182 bytes (uncompressed)
```

PC executables:

INTG.EXE	147,950 bytes
XNTG.EXE	282,624 bytes
DOSXMSF.EXE	393,942 bytes

Sun executables:

INTG	367,344 bytes
XNTG	426,924 bytes

How Program INTG Works

The various geoid height grids are stored in the ".bin" files. Program INTG will prompt you for the name of the directory where you have chosen to store the .bin files, as well as prompting you for which geoid model you wish to use. You can operate with as few as one .bin file, or as many as 14. When the program interpolates a given point, it checks an internal list of .bin boundaries, and uses the earliest list entry whose boundaries contain that point. The order in which the .bin file names appear on the opening screen indicates the order in which the .bin files are searched.

When running program INTG.EXE (PC) or INTG (Sun), the latitude and longitude of each point must be input. The GEOID03 models are heights above the NAD 83 ellipsoid. However, latitudes and longitudes in the ITRF00/GRS-80 and WGS84(G873) systems are very close to those of the NAD 83 system (with only 1-2 meters of horizontal shift.) So any of these types of latitude and longitude (NAD 83, ITRF00, WGS84) may be input, without affecting the interpolated geoid value. This does *not* imply that the geoid heights are heights above a different ellipsoid. Using NAD 83 latitudes and longitudes interchangeably with ITRF00/GRS-80 or WGS84 latitudes and longitudes is merely an acceptable horizontal approximation. GEOID03 geoid heights, will always be above the NAD83 ellipsoid.

Do *NOT* use NAD 27 latitudes and longitudes. The horizontal shifts between NAD 83 and NAD 27 can exceed 100 meters, causing a noticeable difference in the interpolated geoid value. To convert from NAD 27 to NAD 83 latitudes and longitudes you may use program NADCON, available from NGS, or CORPSCON, available from the Army Corp of Engineers:

- either http://crunch.tec.army.mil/#products   select CORPSCON,
- or   http://crunch.tec.army.mil/software/corpscon/corpscon.html

Data Input

You can key data by hand, point by point, or you can create an input file using a text editor. Several file formats are provided, including the NGS "Blue Book" format. These formats are detailed in a "Help" menu option which appears if you specify that you wish to use an input file.

Data Output

Results may be collected into an output file. There is no default output file name. The format of the output file is linked to the format of the input file to maintain consistency. If, however, you input your data by keyboard, and ask for an output file, the format of that output file will be in the format known as "Free Format, Type 1".

The GEOID03 Model

The GEOID03 model is known as a hybrid geoid model, combining gravimetric information with GPS ellipsoid heights on leveled bench marks. The GEOID03 model was developed to support direct conversion between NAD 83 GPS ellipsoidal heights and NAVD 88 orthometric heights.

When comparing the GEOID03 model with GPS ellipsoidal heights in the NAD 83 reference frame and leveling in the NAVD 88 datum, it is seen that GEOID03 has roughly a 2.4 cm absolute accuracy (one sigma) in the regions of GPS on Bench Mark coverage. In those states with sparse (150km+) GPS on Bench Mark coverage, less point accuracy may be evident; but relative accuracy at about a 1 to 2 part-per-million level, or better, should still be obtained. For users with less stringent accuracy requirements, simple height conversions with GEOID03 in the conterminous United States can be sufficient. For users with more stringent accuracy requiements, please see the section entitled "Deriving Orthometric Heights From GPS", later in this document.

Users should be aware that GPS ellipsoid height error, by itself, can be significantly greater than error in geoid height differences.

GPS on Bench Mark Coverage

As of the date of computation of GEOID03, all 48 of the Conterminous United States had re-observations of their HARN's with respect to CORS data. This has resulted in a significant improvement in both spatial coverage and data quality.

GEOID03 in Alaska

�� It must be emphasized that the GEOID03 model in Alaska was NOT computed by incorporating GPS on leveled bench marks. This was due to a shortage of reliable NAD 83 GPS ellipsoidal heights on NAVD 88 bench marks in this region. The GEOID03 geoid model provided in this area is an equilpotential surface refers to NAD 83. However, this surface is not tied to NAVD 88 or any tidal datums. For this reason, users should refer to the section entitled "Deriving Orthometric Heights From GPS", later in this document.

�

�� Due to poorer data coverage, error estimates for GEOID03 in this region is larger.� Long-wavelength errors may be as large as 4-5 parts-per-million in some areas.� Particular care must be used in computing heights in the tectonically active areas in southern Alaska.� Crustal motion may exceed 1 meter even after accounting for the shift of the 1964 Prince William Sound Earthquake.

Deriving Orthometric Heights From GPS

One key problem is deciding which orthometric height datum to use. NGVD 29 is not a sea-level datum, and the heights are not true orthometric heights. The datum of NAVD 88 is selected to maintain reasonable conformance with existing height datums, and its Helmert heights are good approximations of true orthometric heights. And, while differential ellipsoidal heights obtained from GPS are precise, they are often expressed in the NAD 83 datum, which is not exactly geocentric. In addition, GEOID03 rests upon an underlying EGM96 global geopotential model, and EGM96 does possess some error of commission.

This leads to a warning:

Do not expect the difference of a GPS ellipsoidal height at a point and the associated GEOID03 height to exactly match the vertical datum you need. The results will be close when converting NAD 83 GPS ellipsoidal heights into NAVD 88 elevations; but, maybe not accurate enough for your requirement.

However, one can combine the precision of differential carrier phase GPS with the precision of GEOID03 height differences, to approach that of leveling.

Include at least one existing bench mark in your GPS survey (preferably many bench marks). The difference between the published elevation(s) and the height obtained from differencing your adopted GPS ellipsoidal height and the GEOID03 model, could be considered a "local orthometric height datum correction." If you are surveying an extensive area (100+ km), and you occupy a lot of bench marks, then you might detect a trend in the corrections up to a one part-per-million level. This may be error in the GEOID03 model.

We do not currently consider geoid-corrected GPS orthometric heights as a substitute for geodetic leveling in meeting the Federal Geodetic Control Subcommittee(FGCS) standards for vertical control networks. Studies are underway, and many less stringent requirements can be satisfied by geoid modeling. Widespread success has been achieved with the preceeding models, GEOID99, GEOID96, GEOID93 and GEOID90.

The XNTG Utility Program

The XNTG program can perform various functions, none of which are required to use the INTG program. The functions of XNTG are the extraction of sub-grids from the provided geoid grids, the translation between ASCII and binary grids, and the reporting of basic statistics for geoid grids.

Future Plans

New gravimetric and hybrid geoid models will be generated in the next year (USGG2006 and GEOID06) for all U.S. regions including the conterminous United States. These models may adopt newer global gravity field models derived from the GRACE mission as well as improved terrain and gravity field information.