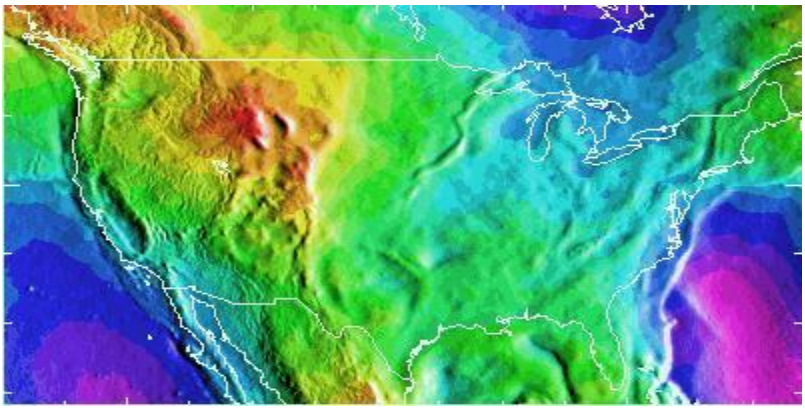
G96SSS



The G96SSS model is a gravimetric geoid model for the conterminous United States, suitable for scientific investigations. Geoid heights are referred to the GRS80 ellipsoid, and the computations were performed in the ITRF94(1996.0) reference frame.

The G96SSS model is not suitable for direct conversion between NAD 83 GPS ellipsoid heights and NAVD 88 orthometric heights.

In the conterminous United States, geoid heights range from a low of -52.8 meters in the Atlantic (magenta) to a high of -7.7 meters (red) in the Rocky Mountains.

It is necessary to subtract 12.0 cm from the G96SSS values to obtain the geoid undulation between the best-fit global geopotential surface and the GRS80 ellipsoid
(when both are expressed in a tide-free system).

Frequently Asked Questions About The Geoid

Dennis G. Milbert, Ph.D. and Dru A. Smith, Ph.D.

"A Work In Progress … " — 7-october-98

Do you have "README" files for your geoid and deflection models? Any on-line papers where I can get more information?

Yes, indeed! We have “README” files for **GEOID96**, **DEFLEC96**, **MEXICO97**, **DMEX97**, and **CARIB97**, **DCAR97**, and **G96SSS**. We also have a collection of **on-line papers** that is expanding.

I downloaded a “GEO” file, but neither GEOID.EXE nor GEOGRD.EXE can open the file.

This is a symptom that the “GEO” file (a binary file in PC format) has been corrupted somehow. Check the file size of the “GEO” files. The file sizes *have* to be:

```
         US (lower 48)      1168096 bytes
          Alaska             1110616 bytes
          Caribbean          1034176 bytes
          Mexico              896896 bytes
          Hawaii              154336 bytes
          Puerto Rico/V.I.     88816 bytes
```

If your file sizes don’t match exactly, please try another download. Oh, by the way, just to be complete:

```
         GEOID.EXE           143872 bytes
          DOSXMSF.EXE         393942 bytes
          DEFLEC.EXE          145408 bytes
          GEOGRD.EXE           68776 bytes
          DEFGRD.EXE           73240 bytes
```

Your PC can lock up if these sizes don’t match.

I was downloading a “GEO” file from your web page with [*name of web browser deleted*] and I got a screen of garbled text instead of a window prompting for where to put the file. What gives?
Some versions of web browsers identify “GEO” files as ASCII text and try to display it directly. To circumvent this, hold down the SHIFT key when you click on a link with your mouse button. This forces a download. This behavior of web browsers is probably related to some cases of corrupted downloads of the GEO files from the web pages. We find the [SHIFT][CLICK] technique gives clean downloads.

Will a “GEO” file work in a UNIX system, or is it for PC’s only?
The “GEO” files are binary files for PC’s. If you need to work on a different kind of system, be sure to get program GEOGRD.EXE. Bring the “GEO” file to a PC system. Run GEOGRD, and convert the input binary file into an output ASCII file. Transfer the ASCII form of the geoid model to your target system. Recompile GEOID and GEOGRD on the new system. Then run GEOGRD, and convert the ASCII back into a binary “GEO” file. By the way, don’t forget to transfer the AREA.PAR file, too.

Is the format of the new “GEO” files the same as under GEOID93?
Yes! We maintained the same format. The grid spacing has changed, as well as the number of rows and columns, but this is encoded in the header part of the GEO files. As long as an application reads and processes the header information, it can access the remaining data.

Does this mean I could use the new "GEO" files with an old version of program GEOID.EXE (versions 1.0 or 2.0)?

Yes, it is *that* compatible. (We don't recommend this due to enhancements regarding number of files supported, updates to the Blue-Book records, etc. …)

I heard a rumor that there is a new version of program GEOID.EXE. Do I need to get it?

Probably not. Version 3.1 of program GEOID.EXE was created May 7, 1997 (with a minor update to the interactive prompts on July 17) to support new Blue Book format codes for the geoid models of Mexico (**MEXICO97**) and the Caribbean (**CARIB97**). If you do not use those models, or if you do not require that Blue Book *86 records be created by GEOID.EXE, then you can use version 3.0. We have placed the latest version (3.1) of GEOID.EXE on our Web and FTP sites.

I see you have two different models for the U.S., GEOID96 and G96SSS. Which should I use?

In general, most users should work with GEOID96. It is constructed to relate GPS ellipsoid heights in NAD 83 and orthometric heights in the NAVD 88 datum. These are the datums used in many maps and charts, and it is likely that your application requires that consistency.

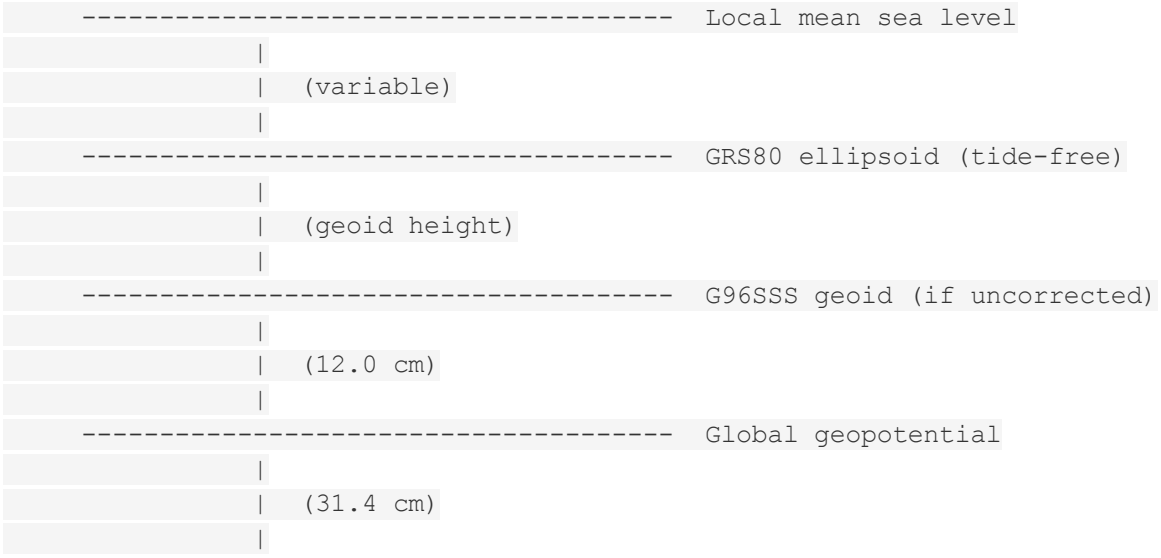
When would anybody want to use G96SSS?

G96SSS is appropriate for specialized studies that require a geocentric (ITRF94) reference system. One example would be to relate satellite altimetry data or GPS receivers mounted on buoys to ocean circulation models. If you use G96SSS with GPS heights in an ITRF94 reference frame, you will detect an offset of 32 to 45 cm in the NAVD 88 datum.

What is the G96SSS model relationship to sea level?

It is necessary to subtract 12.0 cm from the G96SSS values to obtain the geoid undulation between the best-fit global geopotential surface and the GRS80 ellipsoid (when both are expressed in a tide-free system).

Schematic of vertical reference surfaces (not to scale):



The schematic above shows the G96SSS geoid below the ellipsoid. This is the case in the conterminous United States, and corresponds to the negative values for our geoid heights. Our current estimate of the NAVD 88 vertical datum offset is 31.4 cm below the current best estimate of the Earth's best-fit global geopotential. (A piece of good news: the NAVD88 offset seems to be a constant offset; the same throughout the conterminous United States.) None of these surfaces are the same as local mean sea level (LMSL). The LMSL surface varies from place to place due to oceanographic and meteorologic effects, such as wind setup, prevailing currents, mean temperature, and salinity variations. One can think of of LMSL as an approximation to the global geopotential (or vice versa), but departures can range up to a meter or two.

So the NAVD 88 vertical datum is not at mean sea level?

No. The NAVD 88 datum was obtained by fixing a single datum point, Father Point/Rimouski, in Quebec, Canada. A number of factors went into selecting the number to be fixed. The foremost requirement was to select a value that would minimize the need to recompile topographic maps. At the time, there were not enough GPS heights on benchmarks to establish the true offset.

Even today, getting a precise number for the NAVD 88 offset is tricky. It is sensitive to data processing procedures used to obtain gravity anomalies (derived from satellite altimetry data) in the oceans. The uncertainty in the 31.4 cm value may be at the +/- 10 cm level. Getting a more exact figure depends upon the computational treatment of ocean circulation and the tides.

Is this uncertainty in the offset of NAVD 88 a problem?

For most applications, no. GEOID96 establishes the relationship between NAVD 88 and a non-geocentric GRS80 ellipsoid to about +/- 2.5 cm (one sigma). For accurate results, one should tie into one or more nearby NAVD 88 benchmarks. By using them as vertical constraints in conjunction with GEOID96 or the G96SSS models, the accuracy of the NAVD 88 heights you get from GPS will be limited primarily by how accurately you can measure the vertical with the GPS.

README file

```
README file    9-oct-96   dgm/das
updated        7-may-97   das/dgm
  --  Documentation updated for the new version (3.1) of GEOID.EXE
  --  Program GEOID.EXE was updated to version 3.1 to support Blue Book
      codes for Mexico and Caribbean geoid models.  If you are working
      in the conterminous United States, Alaska, Hawaii, Puerto Rico or
      the Virgin Islands, you do not need to change from version 3.0 to
      3.1 of GEOID.EXE.

The G96SSS SCIENTIFIC GEOID MODELS
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You have received these models on CD-ROM, or downloaded them from the National
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Geodetic Survey (NGS) web site, the NGS FTP site, the NGS bulletin board system, or have received the models on individual floppy disks.

Among the files you have received are:

GEOID.EXE	the geoid interpolation program (GEOID.FOR is source code) (version 3.1)
DOSXMSF.EXE	32-bit DOS extender (needed for GEOID.EXE)
AREA.PAR	text file of the filenames of geoid height grids
SSS96NE.GEO	the G96SSS grid for the Northeastern U.S. 36-50N, 89- 66W
SSS96NC.GEO	the G96SSS grid for the Northcentral U.S. 36-50N, 107- 84W
SSS96NW.GEO	the G96SSS grid for the Northwestern U.S. 36-50N, 125-102W
SSS96SE.GEO	the G96SSS grid for the Southeastern U.S. 24-38N, 89- 66W
SSS96SC.GEO	the G96SSS grid for the Southcentral U.S. 24-38N, 107- 84W
SSS96SW.GEO	the G96SSS grid for the Southwestern U.S. 24-38N, 125-102W

(note: the scientific model only exists for the conterminous United States)

GEOGRD.EXE	utility program for sub-area extraction and format conversion (GEOGRD.FOR is the source code)

To Install (after uncompressing the files)

1) Make a subdirectory on your hard disk (example: mkdir c:\g96sss).
2) Copy the various geoid files into that subdirectory.
   copy *.* c:\g96sss /v (for example)
3) Repeat step 2) as required for your other sets of geoid files.
   (If you have also received GEOID96 model files, do not place them in the same subdirectory as your G96SSS files.)
   (If you have installed from floppies, the files are put in the designated subdirectory.)

4) Check your AUTOEXEC.BAT and CONFIG.SYS files to insure compliance with the following notes:

Note 1: DOSXMSF.EXE must either be present in the same directory as GEOID.EXE, or, it must be in a directory in your DOS PATH environment variable. (such as: c:\dos, for example) DOSXMSF.EXE may be freely reproduced and distributed, without royalty.

Note 2: You must have a statement FILES=25 (or a number greater than 25) in your CONFIG.SYS file.

To Execute

Type GEOID , 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.

How Program GEOID Works

The various geoid height grids are stored in the ".GEO" files. Program GEOID will assume that any file in your local directory with a .GEO extension is a geoid height file. You can operate with as few as one .GEO file, or as many as 15. When the program interpolates a given point, it checks an internal list of .GEO boundaries, and uses the earliest list entry whose boundaries contain that point. The order in which the .GEO file names appear on the opening screen indicates the order in which the .GEO files are searched. Note that program GEOID (Version 3.10) is used to interpolate both GEOID96 as well as G96SSS .GEO files. To avoid problems in Blue Book record generation (and to avoid confusion), users are encouraged to keep GEOID96 .GEO files in a separate subdirectory from the G96SSS .GEO files.

When running program GEOID.EXE, the latitude and longitude of each point must be input. The GEOID96 models are heights above the NAD83 ellipsoid, while all other recent geoid models (G96SSS, MEXICO97, and CARIB97) are heights above a GRS-80 ellipsoid, centered at the ITRF94(1996.0) origin. However, latitudes and longitudes in the ITRF94/GRS-80 system are very close to those of the NAD 83 system (with only 1-2 meters of horizontal shift.) So either type of latitude and longitude 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 interchangably with ITRF94/GRS-80 latitudes and longitudes is merely an acceptable horizontal approximation. Each geoid model will always contain geoid heights above the specific ellipsoid, stated above.

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

The AREA.PAR File

AREA.PAR is a plain, ASCII text file. It specifies the order in which .GEO files are to be used. If you have a favorite .GEO file, put it at the top of the AREA.PAR list. There is no problem in having overlapping .GEO files, nor is there any problem in having nested .GEO files. The AREA.PAR file specifies their priority of use.

PLEASE NOTE:

The AREA.PAR file we distribute contains the names of all the G96SSS grid files. You may not have received them all; you may not want them all. This is not a problem. If a .GEO file name is in the AREA.PAR file, but not in the local directory, then a warning message is issued, and program GEOID proceeds with the files that are available. You must have an entry in AREA.PAR for each .GEO file to be searched.

An Example:

You just wish to work with the G96SSS - Northwest file. So, load AREA.PAR into your favorite line editor, and delete the lines referring to the other geoid regions. You may now delete those .GEO files without receiving the warning messages on the opening screen of program GEOID. Save the updated AREA.PAR as plain ASCII text.

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 an input file name. That file doesn't need to exist if you are only going to look at the supported formats in the "Help".

Data Output

Results are collected into an output file. The default name of these files is GEOID.OUT, but you can use any legal file name you choose. (A word of advice: Don't use misleading extensions such as .EXE, .GEO, .BAT, etc.) The format of the output file is linked to the format of the input file to maintain consistency.

The G96SSS Model

The G96SSS model was computed on September 30, 1996 using over 1.8 million terrestrial and marine gravity values. The method of computation uses a Fast Fourier Transform (FFT) technique to compute the detailed geoid structure, which is then combined with an underlying EGM96 geopotential model. The result is a gravimetric geoid height grid with a 2' X 2' spacing in latitude and longitude, referred to the Geodetic Reference System 1980 (GRS 80) normal ellipsoid in an International Terrestrial Reference System 1994 (ITRF94) frame. The EGM96 model was evaluated to conform to a "tide-free" system, insofar as the Earth's permanent tide effect is concerned.

When comparing the G96SSS model with GPS ellipsoidal heights in the ITRF94 reference frame and leveling in the NAVD 88 datum, one can discern a systematic offset at a 30 to 45 cm level. It is likely that this offset is inherent in the definition of the NAVD 88 datum; where the NAVD 88 zero reference is below the current estimate of global mean sea level. In addition, long-wavelength systematic errors are evident in the comparisons. These errors are a composite of error in the NAVD 88 elevations, error in the GPS ellipsoidal heights, and error in the G96SSS model itself. Since the errors are long-wavelength, they can be modeled locally as a plane; usually at a 1 to 2 part-per-million level.

Alaska, Hawaii, Puerto Rico and the Virgin Islands

The difference between G96SSS and GEOID96 is primarily a difference of reference frames. G96SSS is a gravimetric geoid relative to a geocentric GRS80. GEOID96, in the conterminous United States, is computed through a conversion using knowledge of reference frame differences and GPS ellipsoidal heights on leveled benchmarks. In Alaska, Hawaii, Puerto Rico and the Virgin Islands, only the gravimetric, geocentric, geoid models are available. These models are designated as GEOID96 to facilitate ordering by our users.

The National Imagery and Mapping Agency

The National Imagery and Mapping Agency (NIMA), which incorporates the former Defense Mapping Agency (DMA), has been of immense help in this endeavor. NIMA has provided a major portion of the NGS land gravity data set. NIMA has also been instrumental in the creation of the various 30" and 3" elevation grids in existence. And, NIMA was a partner in the joint project to compute the new global geopotential model, EGM96. Although the work of the NIMA generally precludes public recognition, their cooperation is gratefully acknowledged.

GSFC/NIMA Geopotential Model, EGM96

The Goddard Space Flight Center (GSFC) and the National Imagery and Mapping Agency (NIMA) have been engaged in a joint project to compute an improved global spherical harmonic model of the Earth's geopotential. This model incorporates the latest satellite tracking data, as well as altimeter data from TOPEX/Poseidon, ERS-1, and the Geosat Geodetic Mission. EGM96 also incorporates 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.

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, G96SSS 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 G96SSS height to exactly match the vertical datum you need. However, one can combine the precision of differential carrier phase GPS with the precision of G96SSS height differences, to approach that of leveling.

Include at least one existing benchmark in your GPS survey (preferably many benchmarks). The difference between the published elevation(s) and the height obtained from differencing your adopted GPS ellipsoidal height and the G96SSS 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 benchmarks, then you might detect a trend in the corrections up to a one part-per-million level. This may be error in the G96SSS 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, GEOID93 and GEOID90.

The GEOGRD Utility Program

GEOGRD -- This converts to and from ".GEO" binary files and ASCII text files. It can also be used to extract subgrids in the process of conversion. For example: one can make a .GEO grid for the

state of Colorado by using SSS96NW.GEO, "converting" from
binary, .GEO into binary, .GEO, and specifying the Colorado
state boundaries.

A Technical Note on Program GEOID

Some users prefer to write their own interpolation software. If you do, please be aware that there is a loss of precision in the grid file headers for grid spacings of 2' (or 4'). This is accomodated in program GEOID 3.10 by internally re-computing the grid spacing in subroutine GRIDS. You might need to place similar code in your interpolation software, depending upon how it was written.

--- (Example Fortran 77 code) ---

```
*** patch for inexact headers (due to 2' spacing)

          idx1=idnint(DX1*3600.d0)
          DX(NAREA) = dble(idx1)/3600.d0

          idy1=idnint(DY1*3600.d0)
          DY(NAREA) = dble(idy1)/3600.d0

*****     DX(NAREA) = DX1     **** old code
*****     DY(NAREA) = DY1     **** old code
```

Future Plans

A research effort is underway to improve geoid height estimates in the future, perhaps at the 1-cm accuracy level. One important direction is integrating gravity data with GPS and geodetic leveling measurements, and the study of error in GPS ellipsoid heights and in the NAVD88 vertical datum. It is likely that this research, in conjunction with the completion of the state upgrade GPS surveys, will yield a significant improvement to our geoid model in 1999.

README file 9-oct-96 dgm/das