User's Manual, build 18: ECEF & EMG in WGS84

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Installation

ECEF & EGM in WGS84 is distributed as (1) Python source code, which requires a Python interpreter to run, and as a (2) Windows executable (*.exe), which can be run by launching the executable. Required supporting files are also distributed. Download the distribution at ftp://www.hydrometronics.com, userID is ecefdocuments and password is 4rfv$RFV. Use an FTP app like FileZilla. The zip files should be extracted into a suitable directory.

(1) Source-Code Installation

• Four files are currently required for the installation of **ECEF & EGM in WGS84**:

> (1) the Python source code (15KB), a text file
>
> (2) the full EGM2008 geoid model (about 140MB), a binary file
>
> (3) the reduced geoid (about 2.4MB), a text file,
>
> (4) the world coastline (about 2.4MB), a text file.

• The EGM2008 geoid file is included with the distribution, but it can be downloaded here:

> https://earth-info.nga.mil/php/download.php?file=egm-08interpolation

• <Und_min2.5x2.5_egm2008_isw=82_WGS84_TideFree_SE> is the name of the file, which downloads immediately (no further clicking) as a zip file when you click on the NGA link. Unzip and rename the mentioned file as <undx25org>. Place it in the same directory as the Python source code so that the application can find it. The granularity of this 140MB-model is 2.5 minutes in latitude and longitude. This is a little endian binary. There is also a 1-minute EGM2008 model available, but at a considerable increase in size and computational overhead. It's a trade off between convenience and precision (if not accuracy). The EMG2020 model (long overdue) will be in the same format as EGM2008. EGM2020 will be included in a later version of this application.

• **ECEF & EGM in WGS84** is Python software that will run on a Python 3 interpreter on most computers. The application was developed on Python version 3.10. Python comes preloaded on Linux and Mac operating systems. Make sure it's a recent version of Python 3 and not Python 2.

• Python must be installed on Windows computers, but it's easy. Open a command prompt. Navigate to the folder in which the code and the EGM model are placed. Type python in the command prompt. Python will be loaded without

further intervention.

• After installation you'll be placed in the REPL (Read-Eval-Print Loop). You can experiment. For example 1+2 <enter> yields 3. Type Ctrl-D to exit the REPL.

• The **ECEF & EGM in WGS84** application imports several modules (AKA packages) in their own namespaces. Most come with your Python installation, but they still need to be imported in the code. Two packages, however, are not routinely installed with Python. These are numpy, the Matlab-like numerical module, and matplotlib, the plotting library. Instructions for installing numpy and matplotlib follow.

• In the command prompt (not the REPL), type: <pip3 install numpy>. Numpy will be installed. Type: <pip3 install matplotlib> and matplotlib will be installed.

• Finally, at the command prompt, enter <python **ECEF_EGM18.py**> and the application should launch. Enjoy!

(2) Executable Installation

After downloading the executable, double click on the **ECEF_EGM18.exe** file and the application should launch. Enjoy!

Overview of ECEF, EGM and gradient (AKA deflection of the vertical)

• Earth-Centered Earth-Fixed (ECEF) is the geocentric Cartesian coordinate system used by GPS. A useful Wikipedia article on ECEF is here:

http://en.wikipedia.org/wiki/ECEF

• ECEF supports visualization in 3D without cartographic distortion. See the section on Plotting below.

• The Earth Gravitational Model (EGM) of 2008 provides the separation between the geoid and the WGS84 ellipsoid, which allows one to transform between ellipsoidal height and elevation.

• In 3D ECEF visualization EGM is important as a reference to the geoid (level surface) and the vertical.

• A useful article on geoid models is here:

https://en.wikipedia.org/wiki/Earth_Gravitational_Model

• The deflection of the vertical is the difference between the normal to the ellipsoid and "up" as defined by gravity. A useful article on the deflection of the vertical is here:

• Deflection of the vertical (DoV) is emulated in **ECEF & EGM in WGS84** by computing the gradient of the geoidal undulation from the four points surrounding the target and changing the sign. Gradient and DoV agree within 0.1 seconds 67% of the time and within 0.3 seconds 90% of the time (personal investigation), but extreme outliers can occur in mountainous areas. A local (country-specific) geoidal model (rather than a global model) would be more accurate. Back in the day DoV would have been valuable knowledge for land surveyors (because DoV introduces a bias into observations taken with a gravity-leveled theodolite), not so much in the GPS era.

• A brief user's guide for the software follows.

Overview of the Software

• You should first read this manual.

• You may choose one of two geographical formats in the lower left, (1) decimal degrees and (2) the (so-called) HP format (+/-DDD.MMSSsssss). The mariner's format (+/-DDD.MMmmmm) may be introduced in a later version.

• The default geoidal model is EGM2008. The release of EGM2020 is overdue. It will be included in this software when available.

• Latitude, Longitude and Ellipsoidal height are converted to ECEF X, Y, Z with the "**=>**" button.

• ECEF X, Y and Z are converted to Latitude, Longitude and Ellipsoidal Height with the "**<=**" button. The point converted in this direction must be within 20% of the radius of the earth from the geocenter due to the algorithm used, which is wonderful near the surface, but not so wonderful out in space or near the geocenter.

• If geoidal metrics are desired, the EGM model must be loaded using the appropriate button. Loading takes 10-15 seconds depending on your computer.

• Then, if the "Undulation" button is pressed, the geoidal height, orthometric height (elevation), grad N and grad E fields are computed.

• There is no error checking for latitudes crossing the poles (e.g. 95N) or longitudes wrapping the globe (e.g. 400E). They will compute normally. So, beware.

• Slightly bizarre behavior occurs at the pole. Mathematically, X and Y should be

0. But then longitude is lost in the reverse computation.

Plotting

• Two plots are available in **ECEF & EGM in WGS84**:

      (1) a 2D filled contour plot of the geoidal height for the entire world, the complete 2.5-minute model of EGM2008, and

      (2) a 3D plot of the world with the geoidal undulations exaggerated 5,000x for visual effect. The 3D plot is in ECEF X, Y & Z, of course. The plot is interactive; you may rotate it in any or all axes. For computational and interactive efficiency the 3D plot is constructed with a reduced geoid, only 2.4MB, a severe decimation of the full model. Both plots require the loading of the coastline.
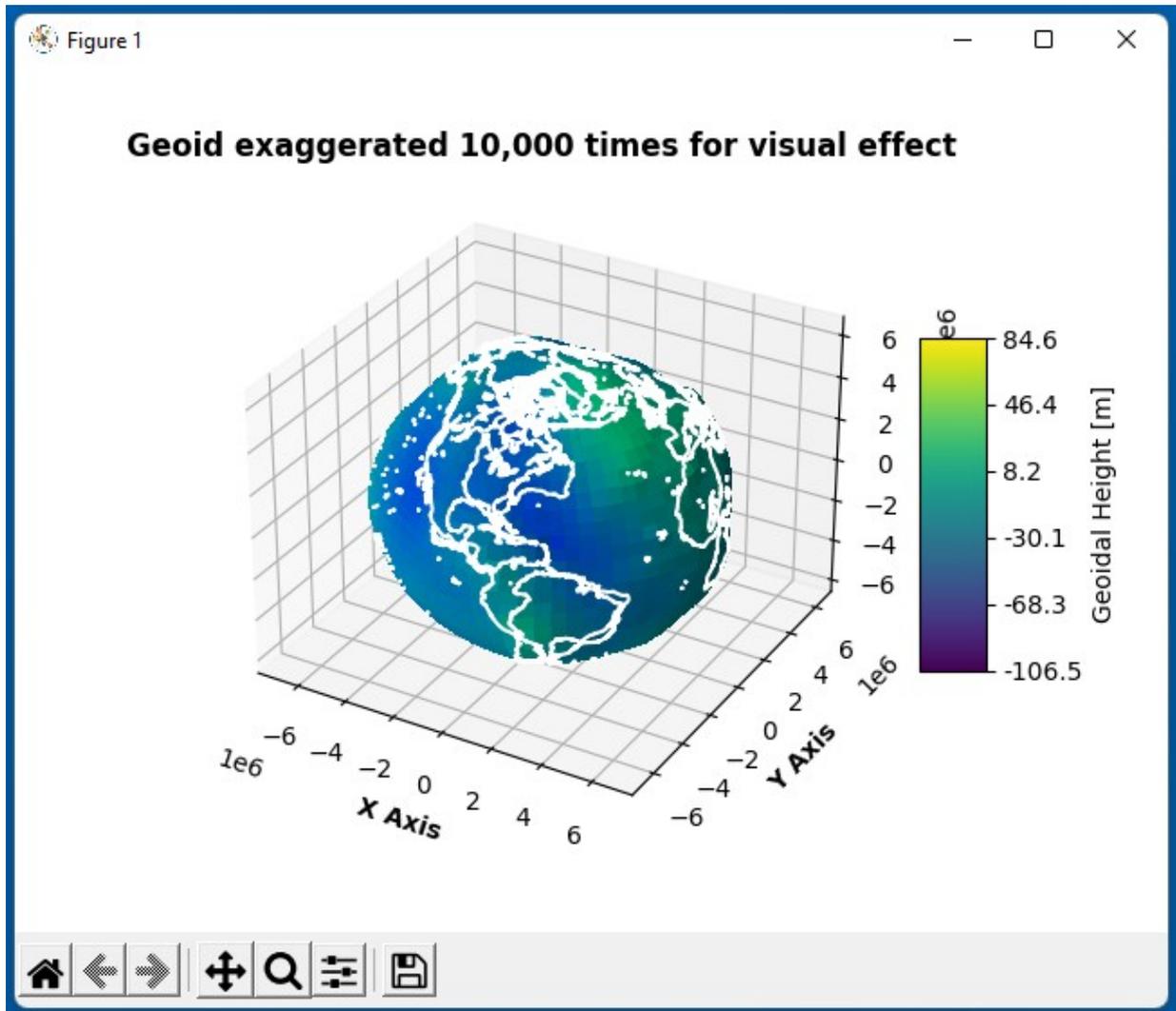
• The 2D EGM contour plot requires loading the full EGM model and the coastline. An example of this plot is on the next page.

• The interactive 3D earth requires loading the decimated geoid and the coastline. An example of this plot is on the following page.

• The plots have buttons in the lower left that enable moving and enlarging the plot or saving it in one of several formats.

The contact for corrections, feedback or help is:

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(Plots follow)

3D Interactive Globe

Geoid exaggerated 10,000 times for visual effect

Geoid Contour Plot (next page)

EGM2008 Geoidal Contour

Geoidal Height (m)

Latitude -90 to +90 degrees

Longitude 0 to 360 degrees