# MATLAB script for 3D visualizing geodata on a rotating globe

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**Abstract**

We present a Matlab package for visualizing global data on a 3D sphere, whose rotation can be animated. Planetary elevation data sets such as geoid height or Earth topography can easily be represented through a slightly exaggerated, coloured 3D relief, and then saved either as images or animations. All necessary parameters for the 3D visualization and animation are described and their usage demonstrated on examples. Among other things, users are shown how to easily create their own colour scales. In principle, any geoscientific scalar data given on a global grid of longitudes and latitudes can be visualized with this package. The package requires only the basic module of Matlab, running on an ordinary PC or notebook, and it is available for free download at http://www.asu.cas.cz/~bezdek/vyzkum/rotating_3d_globe/.

*Keywords:* 3D visualization, geoid height, elevation model, planetary topography, Matlab

## 1. Introduction

In geosciences, it is common to plot global data in some projection or on an approximating sphere. For example, many geosciences make use of gravity field models of the Earth. In the last decade, intensive international efforts have been undertaken to improve our knowledge of the Earth gravity field; recent global gravity field models, based on data from space missions CHAMP, GRACE and GOCE, are indeed superior to those from pre-2000 period by a few orders of magnitude (e.g. Pail et al., 2010). Fig. 1 displays a usual way of representing a gravity field model, by highlighting irregularities in the shape of the Earth (the geoid) as revealed by a specific geopotential model. Such a 3D representation of the geopotential is both informative and illustrative, sometimes the geoid is slowly rotating to show its variations all around the globe (e.g. new GOCE geoid, ESA, 2011). For producing 3D animations based on such global views, we present a minimalistic but self-contained Matlab package. This can help to produce attractive presentatations for various scientific or public outreach purposes.

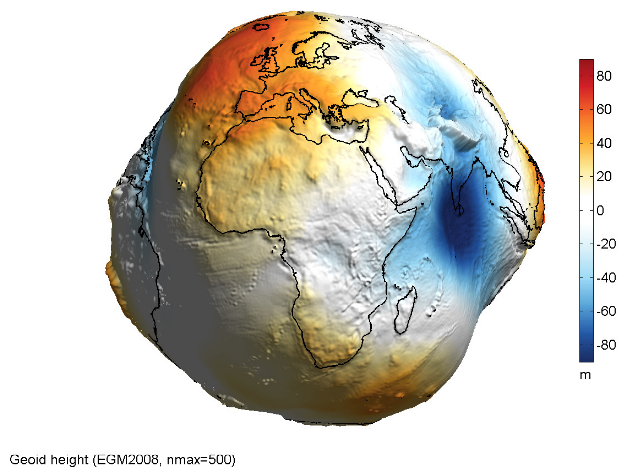


Figure 1: Geoid height, computed from the gravity field model EGM2008 (Pavlis et al., 2012).

## 2. Program description

After installing the package according to the instructions on the website, one may copy and paste the following code to the Matlab command line and run it to produce Fig. 1:

```
%% Geoid height in 3D as PNG image
model='egm2008'; nmax=500;    %selection of geopotential model
[lond,latd,gh]=...
        compute_geopot_grids(model,nmax,'functional','gh');
rotating_3d_globe(lond,latd,gh,'coastlines',1,...
   'exaggeration_factor',1.3e4,'radius',6378e3,'units','m',...
   'graph_label',...
   sprintf('Geoid height (%s, nmax=%d)',upper(model),nmax),...
   'clbr_limits',[-90 90],'clbr_tick',-100:20:100,...
   'cptcmap_pm','BlueWhiteOrangeRed',...
   'window_height',650);
```

First, the selected gravity field model is loaded and the grid of geoid height is computed by the function `compute_geopot_grids`. Then the 3D graph of geoid height is created from its grid using the main function of the package `rotating_3d_globe`, optional arguments specify the appearance of the image. The implementation of functions in the package follows Matlab's object-oriented programming style of

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Property-Value pairs.

Here we want to comment on using the optional argument called 'exaggeration_factor', which is important for the overall impression of the produced 3D relief images. In Fig. 2, in the middle panel we depicted only the equatorial variations of geoid height; they display the whole range ±100 m of geoid height, which is by five orders of magnitude smaller compared to Earth radius. To highlight the tiny differences of real gravity field with respect to that of a reference ellipsoid (more about it in Section 3.3), we define an exaggeration factor $E$ by which the Earth radius $R$ is divided to make the geoid height variations $h$ stand out from the zero level, which is a spherical surface of diameter $R/E$. This is shown in the bottom panel of Fig. 2, where an exaggeration factor of $1.3\times10^4$ was applied.

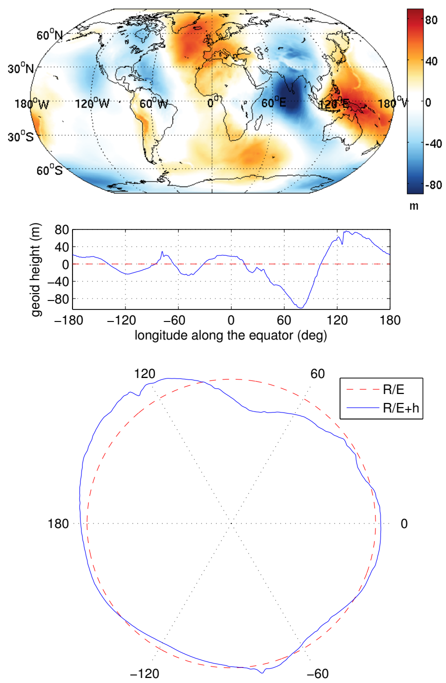


Figure 2: Geoid height on a 2D map (upper panel), vertical variations of geoid height along the equator (middle panel), and equatorial cross-section of the exaggerated geoid height as shown in Fig. 1 (bottom panel).

Making animations is done by including optional arguments, which define the time for the full rotation and frame rate, by replacing the last line in the preceding code snippet with this one:

```
'video_format','wmv',...
'anim_gif',1,...
'clbr_anim',1,'clbr_reduce',0.4,...
'anim_angle',360,'time_for_360deg',42,'fps',1,...
'window_height',500);
```

one obtains an animated version of Fig. 1 with the frame rate of 1 fps, which takes 42 s to make a full rotation angle of 360°. The animation will be saved to the current Matlab folder as an animated GIF image and also as a compressed WMV file. Both possibilities have their pros and cons. While animated GIFs are convenient because of their easy use (e.g. on websites), they have a restricted colour palette of 8 bits and may become huge in size, if images of large dimensions are animated or if smooth motion is required (higher fps). Compressed video formats are more appropriate, when larger images are animated in a smoothly looking motion.

Use of the package is explained in a step-by-step manual, accessible from the website and also included in the package.

## 3. Examples of application

In this section we demonstrate by way of examples that any scalar valued data given on longitude-latitude grid can be easily and illustratively represented using the presented package. A natural supplement to this paper is the package website, where all the codes and data sets used in generating the presented images are available, so that the reader may quickly try them and subsequently modify according to his/her needs.

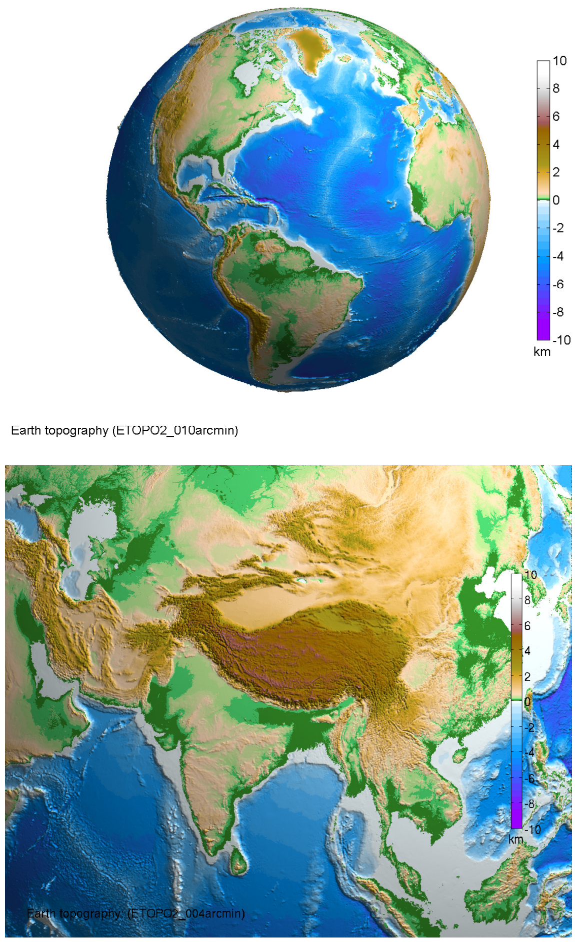


Figure 3: Earth topography from model ETOPO2 (http://rda.ucar.edu/datasets/ds759.3/). In the upper panel, the global view is displayed using 10×10 downsampled grid, in the lower panel the Himalayas are zoomed in on 4×4 grid.

### 3.1. *Topography of Earth*

An obvious choice for visualizing scalar valued data is Earth topography (Fig. 3). We used the ETOPO2 model, which combines land elevations and bathymetry (ocean depths) on 2×2 arcmin grid. Taking into account the resolution of our images, and also to speed up image rendering, we found that 10×10 downsampled grid is sufficient for global Earth views, and that 4×4 grid shows up details in the zoomed views and still enters within the 4-GB RAM memory of an ordinary computer. When representing Earth elevations, it is of utmost importance to use a proper colour scale, e.g. to faithfully discriminate between lowlands and shallow shelf seas. There are many colour scales constructed specifically for this purpose, in Fig. 3 we used the 'GMT_globe' palette. For the exaggeration factor $E$ we chose the value of 13, higher values cause unnaturally looking relief, low values make the 3D image too flat.

### 3.2. *Topography of the Moon and Mars*

In Fig. 4 we show the topography of the Moon and Mars based on data from satellite laser altimeters. It is interesting to note the similarity of the greyscale image of the Moon elevations to a photography of the Moon; although, strictly speaking, the two images show different physical quantities – elevations measured by an altimeter vs. bright and dark spots – there is an apparent correspondence, which is due to the non-existence of the Moon atmosphere and to the correlation of the lunar surface colour with its altitude. As regards the topography of Mars, its slightly exaggerated 3D representation exhibits nicely the tallest mountain on any planet in the solar system, the 22-km high volcano Olympus Mons, accompanied by other large volcanoes, and the nearby 4000-km long canyon system Valles Marineris. For false colour, we made use of the 'GMT_wysiwygcont' palette.

### 3.3. *Visualization of geopotential functionals*

As stated in Introduction, our motivation for developing the package was to visualize new global gravity field models. Such models are currently provided in the form of harmonic coefficients for a series expansion of the geopotential, from which one can calculate other quantities, called geopotential functionals, as for example gravity acceleration. In the package we included the harmonic coefficients of a widely used model EGM2008, also a function is provided enabling the reader to work with many other models from the ICGEM website (http://icgem.gfz-potsdam.de/ICGEM/).

In the upper panel of Fig. 5 we have the geoid height, also called the geoid undulation, which shows the radial departures of the geoid from a reference ellipsoid. The geoid closely approximates mean sea level and to a large extent (70 %) describes real Earth's shape; the geoid is a surface of constant gravity potential. A reference ellipsoid, or normal ellipsoid, is a mathematical approximation to Earth's shape, and its associated normal potential is defined in such a way to comprise 99.9995 % of the total gravity potential (Jekeli, 2007).

The disturbing potential, $T=W-U$, is the difference between Earth's gravity potential $W$ and the approximative normal potential $U$. In the so-called spherical approximation, commonly used in geodesy, the geoid height $N$ is linearly related to the disturbing potential $T$ via the Bruns formula:

$$N = \frac{T}{\gamma} ,$$

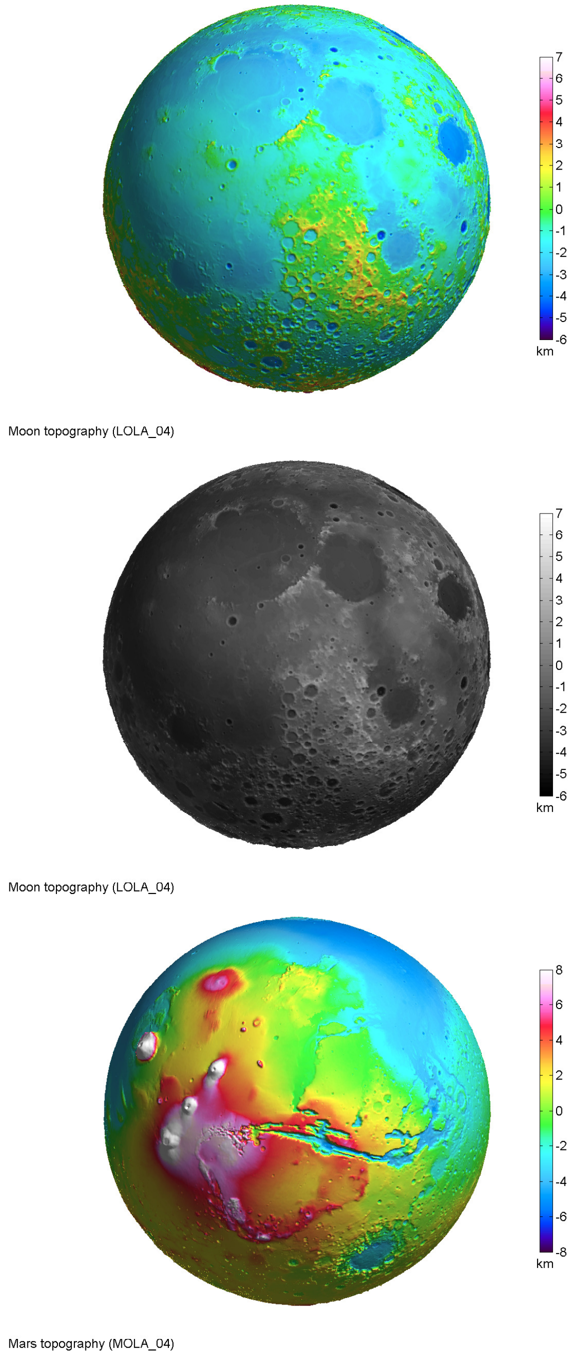


Figure 4: Topography of the Moon from the LOLA data (http://pds-geosciences.wustl.edu/missions/lro/lola.htm), in the upper panel the near side shown in false colour (cf. http://en.wikipedia.org/wiki/Topography_of_the_Moon), and using greyscale (middle panel). In the bottom panel, topography of Mars from the MOLA experiment (http://pds-geosciences.wustl.edu/missions/mgs/mola.html) in false colour (cf. http://en.wikipedia.org/wiki/Geography_of_mars). To generate the images, LOLA and MOLA grids of 15×15 arcmin resolution were used.

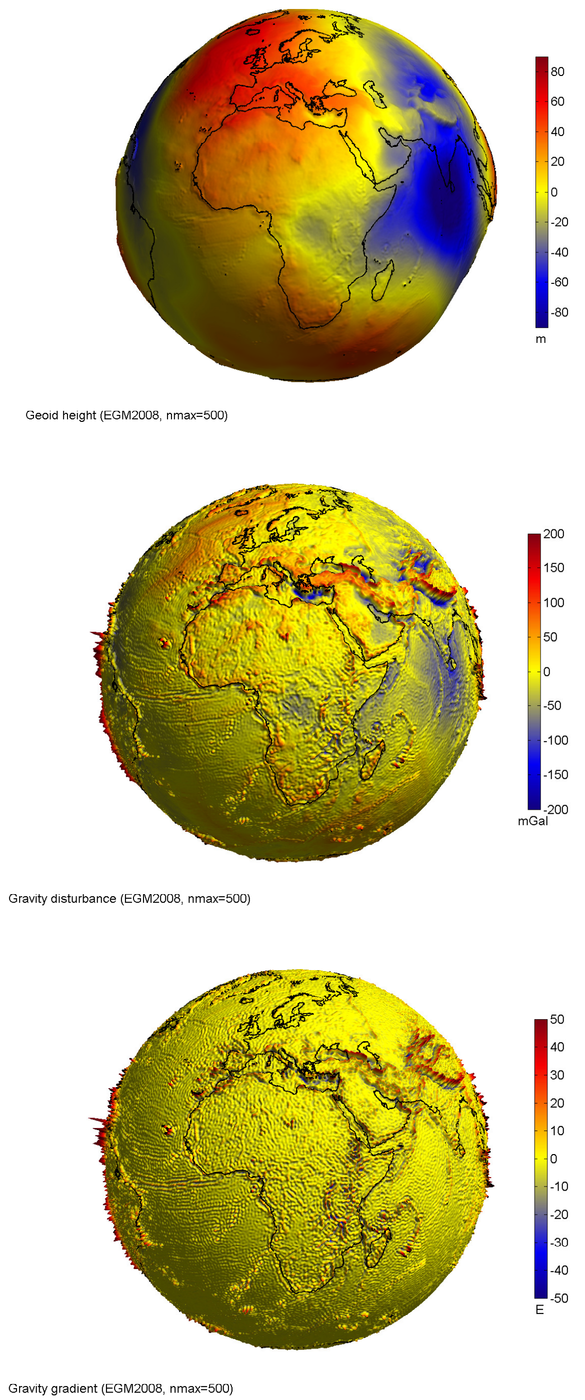


Figure 5: Geoid height (in metres), gravity disturbance (in milligals, 1 mGal=$10^{-5}$ m/s$^2$), and gravity gradients (in eotvos, 1 E=$10^{-9}$ s$^{-2}$) computed from the gravity field model EGM2008.

where $\gamma$ is a normal acceleration.

The middle panel of Fig. 5 shows the gravity disturbance

$$\delta g = -\frac{\partial T}{\partial r} ,$$

which is the difference between Earth's gravity $g$ and normal gravity $\gamma$. As the first radial derivative (up to the sign; $r$ indicates the radial direction), the graph of gravity disturbance has more short-wavelength variations compared to the smoothly changing disturbing potential (or geoid height) in the upper panel.

Finally, in the bottom panel of Fig. 5, there is the second radial derivative of the disturbing potential,

$$T_{rr} = \frac{\partial^2 T}{\partial r^2} ,$$

which is the vertical component of the tensor of gravity gradients (Rummel et al., 2002). It describes the rate of change of gravity $g$ with height. As with the gravity disturbance, further differentiation leads to the amplification of local features in the disturbing potential.

The colour scale used in all panels of Fig. 5 was created from scratch in Matlab, an easy-to-follow example is described in the package manual. The 3D relief maps like those in Fig. 5 are well suited for showing different spectral contents of the three gravity functionals.

## 4. Program availability and system requirements

The presented package is freely available for scientific use at: http://www.asu.cas.cz/~bezdek/vyzkum/rotating_3d_globe/. The package requires only the basic module of Matlab (http://www.mathworks.com/products/matlab/). When using the lower resolution data (from which all figures in this paper were produced, except for the lower panel of Fig. 3), an ordinary PC or notebook suits well with 1 GB of free RAM memory, for high resolution images, a RAM memory of 4 GB is necessary (see e.g. Topography of Earth in high resolution on the package website). We tested the package with Matlab under 32/64-bit Windows and Linux systems.

## Acknowledgements

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