Toolbox for NGGM / MAGIC

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Abstract
The NGGM/MAGIC missions are envisaged to advance the applications of satellite based gravity field information for tracking changes in the mass distribution and transport in ground water storages, ice sheets and oceans. The GOCE User Toolbox GUT was originally developed for the utilisation and analysis of GOCE products to support applications in Geodesy, Oceanography and Solid Earth Physics. GUT consists of a series of advanced computer routines that carry out the required computations without requiring expert knowledge of geodesy. Hence, with its advanced computer routines for handling the gravity field information rigorously, GUT may support the MAGIC mission in reaching its goals.

Focusing on NGGM/MAGIC mission goals on unprecedented recovery of ocean bottom pressures, a more flexible processing of the gravity field information may become essential. Furthermore, an integration of ocean bottom pressure changes with changes in the geostrophic surface currents may advance the analyses further. GUT facilitates such a flexible processing and, in addition, contains tools for the computation of the dynamic ocean topography and the associated geostrophic surface currents.

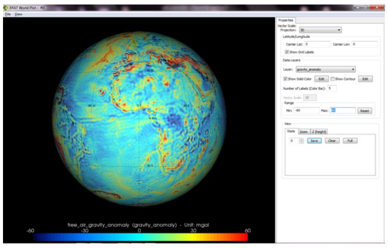


Figure 2: A computation of free-air gravity anomalies may be computed to any degree and order, also applying filtering. In addition, Bouguer anomalies and second order derivatives may be computed.

1. Introduction
Launched in March 2009, the Gravity field and steady-state Ocean Circulation Explorer (GOCE) satellite mission was an innovative Earth observation satellite that measured Earth's global gravity field with unprecedented spatial resolution. The main level-2 product of the mission was Earth Gravity Models (EGM) represented as spherical harmonic coefficients. Additional level 2 products released included the full error variance-covariance matrices for each EGM. GUT was developed to facilitate the use of these products by users working in fields including oceanography, geodesy and solid earth physics, without requiring expert knowledge of geodesy.

2. The GOCE User Toolbox – GUT
The GOCE User Toolbox (GUT) can compute and process a range of higher level products at global and regional scales. GUT can also process any global gravity model in the ICGEM format.

GUT may be used on Windows PCs, UNIX/Linux workstations and Mac and comes as fully open source software package under GNU GPL licence.
GUT generates all output files in netCDF format in compliance with the CFConventions, and gridded results may be visualised using the BratDisplay tool from ESA's Broadview Radar Altimetry Toolbox (BRAT).
From version 3.0 the original GUT command line tool, has been enhanced with a graphical user interface.

The GUT package includes:
- The source package for building on UNIX/Linux/Mac
- Binary packages for Linux and Windows, include BratDisplay
- The GUT Algorithm Description and User Guide
- The GUT Tutorial
- The GUT Install Guide
- A set of a-priori data and models
- The Balmino error computation tool.

3. MAGIC objectives
The main objective of MAGIC is to extend the mass transport time series of previous gravity missions such as GRACE and GRACE-FO with significantly enhanced accuracy, spatial and temporal resolutions and to demonstrate the operational capabilities of MAGIC with the goal of answering global user community needs to the greatest possible extent.
The main thematic fields investigated by MAGIC are:
- Hydrology,
- Cryosphere,
- Oceanography,
- Solid earth,
- Climate change, and
- Neutral atmosphere.

Investigation of ocean circulation models is included, hereby, linking directly to the main objectives of GOCE.
In most applications, though, the analyses will be based on processing of EGMs which require expert knowledge in the field of geodesy.
Hence, with its advanced computer routines for handling the gravity field information rigorously, GUT may support the MAGIC mission in reaching its goals.

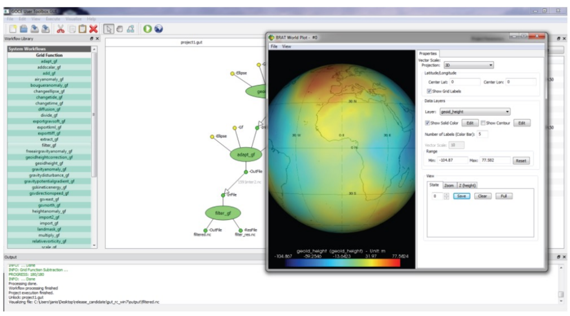


Figure 1: A user defined processing chain consisting of multiple workflows created using the GUT3 GUI, visualising the output using the BratDisplay tool from ESA's BRAT. (Credits S&T)

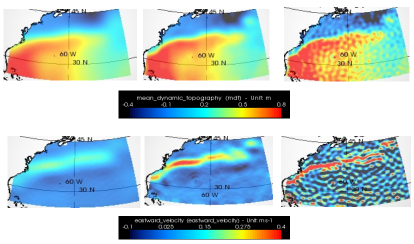


Figure 4: An example is shown below where MDTs have been computed using different filters having half-width lengths of 2.0, 1.0, and 0.5 degrees. Also geostrophic current components may be computed. Below are shown the east-west currents associated with the MDTs

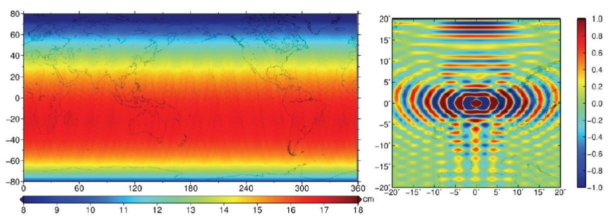
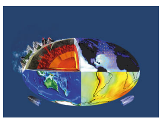


Figure 5: The formal geoid error for one of the GOCE gravity model (TIM5) expanded to degree and order 280 – the maximum degree and order to which the model is defined (left) and the correlation between the TIM5 geoid error at one location (0E, 60N) and the error at surrounding points (right). (Credits UB)

4. Examples
- Computation of geoid heights from the EGMs at any specific grid to any max degree and order. Conversion between reference ellipsoids and tidal systems are facilitated as well (Figure 1),
- Computation of free-air gravity anomalies may be computed to any degree and order, also applying filtering. In addition, Bouguer anomalies and second order derivatives may be computed (Figure 2 + 3)
- Computation of dynamic ocean topography by combining a mean sea surface with a geoid model ensuring consistency in reference ellipsoids, tidal systems, grid specs. Both simple and more advanced filters are available (Figure 4),
- Computation of statistics of models and differences for assessing and comparing models,

The GUT package also includes additional tools for fully exploiting the error variance-covariance matrix of gravity models. They allow both the magnitude and correlation structure of the formal errors for the geoid, or other derived quantities, to be rigorously determined (Figure 5).



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GUT specifications and tutorials have been developed with contributions from:
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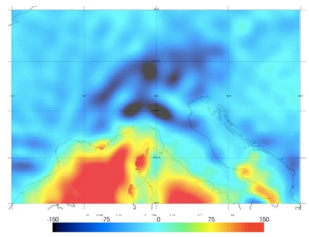

Figure 3: Map of simple Bouguer gravity anomalies (mgal) obtained over the Alps using the simple bouguer workflow.

Among its functionality, GUT allows a user to:
- Read the GOCE level 2 products and ancillary datasets, including a priori surfaces, calibrated gravity gradients and geoid height errors
- Read global and local gravity models in ICGEM format
- Compute geoid heights at a chosen maximum degree and order over a grid or transect
- Compute gravity and height anomalies, and vertical deflections on the surface of the terrain for a range of maximum degree and order expansions over a grid or transect
- Compute the spherical harmonic synthesis and calculate the 6 potential gradients
- Compute the ocean's mean dynamic topography and associated geostrophic velocities, kinetic energy and the vertical component of relative vorticity
- Smooth gridded fields with a wide range of spatial and spectral filters, including diffusive filtering
- Transform data between different reference ellipsoid and tide-systems
- Compute gravity disturbances, Bouguer and free-air anomalies at different heights
- Produce final output products in netCDF format
- Develop high-level processing routines and workflows.