GOCE USER TOOLBOX AND TUTORIAL

Per Knudsen [1] *and Jerome Benveniste*[2]

[1])*Technical University of Denmark, DTU Space, 2100 Copenhagen, Denmark.*
[2])*European Space Agency – ESRIN, Frascati, Italy.*

Abstract

The GOCE User Toolbox GUT is a compilation of tools for the utilisation and analysis of GOCE Level 2 products. GUT support applications in Geodesy, Oceanography and Solid Earth Physics. The GUT Tutorial provides information and guidance in how to use the toolbox for a variety of applications. GUT consists of a series of advanced computer routines that carry out the required computations. It may be used on Windows PCs, UNIX/Linux Workstations, and Mac. The toolbox is supported by The GUT Algorithm Description and User Guide and The GUT Install Guide. A set of a-priori data and models are made available as well. GUT has been developed in a collaboration within the GUT Core Group.

The GUT Core Group:
- S. Dinardo, D. Serpe, B.M. Lucas, R. Floberghagen, A. Horvath (ESA),
- O. Andersen, M. Herceg (DTU),
- M.-H. Rio, S. Mulet, G. Larnicol (CLS),
- J. Johannessen, L.Bertino (NERSC),
- H. Snaith, P. Challenor (NOC),
- K. Haines, D. Bretherton (NCEO),
- C. Hughes (POL),
- R.J. Bingham (NU),
- G. Balmino,
- S. Niemeijer, I. Price, L. Cornejo (S&T),
- M. Diament, I Panet (IPGP),
- C.C. Tscherning (KU),
- D. Stammer, F. Siegismund (UH),
- T. Gruber (TUM),

Background

The Gravity and Ocean Circulation Experiment - GOCE satellite mission is a new type of Earth observation satellite that will measure the Earth gravity and geoid with unprecedented accuracy. Combining GOCE geoid models with satellite altimetric observations of the sea surface height substantial improvements in the modelling of the ocean circulation and transport are foreseen. No ocean circulation products are planned to be delivered as level-2 products as part of the GOCE project so that a strong need exists, for oceanographers, to further process the GOCE level-2 geoid and merge it with Radar Altimetry. The primary requirement of oceanographers is to have access to a geoid and its error covariance at the highest spatial resolution and accuracy possible, although required resolution depends on application. For effective use of the geoid data, knowledge of the error covariance is mandatory.

Within the ESA supported GUT Specifications project, the user requirements for GUT associated with geodetic, oceanographic and solid earth applications were consolidated. For all applications the absolute minimal requirement of the toolbox includes the computation of geoid heights from the set of spherical harmonic coefficients at a given user-specified harmonic degree and order. For oceanographic applications the key quantity to be computed is the mean dynamic topography which basically is the height of the mean sea surface relative to the geoid. For this application GUT provide the tools for converting the mean sea surface and the geoid into the same geodetic system and for carrying out the needed filtering to compensate for the different resolution capabilities of the two surfaces. Furthermore, a-priori mean dynamic topography models derived from e.g. ocean circulation models, may be used.

To facilitate use in the oceanographic community and the solid earth community the GUT needs to include a number of standard geodetic functionalities as well as functionalities that are more specific to the two fields. The input for GUT will come both from the HPF, mostly in the form of the coefficients of a spherical harmonic expansion and the full variance-covariance matrix for these coefficients, and from auxiliary input for the SSH, MSSH, MDT, and perhaps an a priori MDT. Enough of these auxiliary fields need to be included so that the user can use the toolbox without the need to find these fields. In addition to these inputs some meta data is required concerning the tide system and model used, the atmospheric and ocean corrections made, etc.

Functionalities

In the following a complete list of wanted functionalities will be given. Some of these are vital inclusions in the toolbox while others are perhaps not as vital or perhaps very cumbersome in their need for computing power.

Geodetic functionalities

In a variety of geophysical studies information associated with the Earth's gravity are used in form of geoid heights, gravity anomalies or deflections of the vertical. Those quantities may be represented in the

nodes along a profile, in a grid or in discretely located points. Associated with such quantities error covariance information may be needed. Hence, the following functionalities are required:

- Computation of global, gridded geoid heights or gravity anomalies at a given, user-specified, degree and order of the spherical harmonic expansion.
- Computation of geoid heights at a given spatial resolution and a given point or list of points.
- Option to replace geoid heights by deflections from the vertical.
- Computation of geoid heights covariance for any pair of points on the sphere or the computation of a full covariance matrix for a given maximum degree and order of the spherical harmonic expansion.
- Computation of geoid cumulative height errors and error covariances at a given spatial resolution on a global regular grid or for a list of points.
- Covariance error matrix within chosen degree/order range for commission and omission error.
- Option to include the omission errors for the GOCE gravity field.
- Regional geoid solutions starting from the global products.

Oceanographic functionalities

The primary oceanography variable of interest to be provided by the tool box is the dynamic topography resulting from the difference between altimetric measurements and the geoid model. Altimetric MSSH fields or time-varying SSH fields would be auxiliary input data set fields from which a consistently filtered mean dynamic topography (and associated mean geostrophic circulation) need to be computed by the toolbox. This leads to the following functionalities:

- Interpolation of external MSSH on any regular grid or at given points.
- Spatial filtering of MSSH consistent with a specific harmonic geoid height field expansion.
- Change of reference system for the geoid and/or MSSH.
- Computation of a 'GOCE' MDT at a given spatial resolution.
- Computation of altimetric time-varying absolute dynamic topography.
- Provision of a priori MSSH, MDT and Geoid data on a grid
- Provision of tools to produce a global description of a combination of these a priori gridded fields in spherical harmonics
- Computation of altimetric absolute geostrophic velocities.
- Covariance error matrix within chosen degree/order range for commission and omission error for mean dynamic surface topographies.

- Option to include the omission errors for the MDT and the associated geostrophic surface currents.

Solid earth functionalities

The commonly used quantity in solid earth studies is gravity anomalies and associated error information. Hence, the main required functionalities are covered by general functionalities described above. However, on land the quantities may be needed on the surface of the earth. Hence, a few additional functionalties are required:

- Computation of geoid heights, gravity anomalies or deflections of the vertical at a given, user-specified, degree and order of the spherical harmonic expansion at the surface of the terrain.
- Computation of geoid cumulative errors and error covariances associated with the above at a given spatial resolution on a global regular grid or for a list of points.
- Covariance error matrix within chosen degree/order range for commission and with the option of including the omission errors for the GOCE gravity field.

Additional functionalities

In addition to the functionalities given above the toolbox will need to be able to handle:

- Auxiliary fields given by the user, this includes SSH, MDT, etc. but the ability for the user to introduce another set of spherical harmonic coefficients and the variance-covariance matrix should also exist.
- Compute differences between GOCE geoid and external geoids / 'GOCE' MDT and external MDT / between absolute altimetric geostrophic velocities and in situ geostrophic velocities.
- Determine the parameters in a priori degree variance model for the modeling of the gravity field a priori spectrum.
- Derive a degree variance model for the MDT and determine statistical properties of the MDT and its associated geostrophic surface currents.
- Derive an optimal filter for the low pass filtering of the altimetric MSSH and/or the MDT.
- Previewing. A need exists for the user to be able to do a quick preview when using the toolbox to find some quantity.

The GOCE User Toolbox

The GOCE User Toolbox GUT is a compilation of tools for the utilisation and analysis of GOCE Level 2 products. GUT support applications in Geodesy, Oceanography and Solid Earth Physics. The GUT Tutorial provides information and guidance in how to use the toolbox for a variety of applications. GUT consists of a series of advanced computer routines that carry out the required computations. It may be used on Windows PCs, UNIX/Linux Workstations, and Mac.

The toolbox is supported by The GUT Algorithm Description and User Guide and The GUT Install Guide. A set of a-priori data and models are made available as well.

Hence, the GUT package includes

 * The source package for building on UNIX/Linux/Mac
 * Binary packages for Linux and Windows that include BratDisplay (v2.0.0b)
 * The GUT Algorithm Description and User Guide
 * The GUT Tutorial
 * The GUT Install Guide (applicable to ALL packages).

The a-priori data package gut-apriori.zip is available as well.

GUT use GOCE data associated with the following GOCE-L2 products:
EGM_GCF_2: Spherical harmonic series in ICGEM format
EGM_GEO_2: Grid with geoid heights in Grid format
EGM_GAN_2: Grid with gravity anomalies in Grid format
EGM_GVE_2: Grid with east-west vertical deflections in Grid format
EGM_GVN_2: Grid with north-south vertical deflections in Grid format
EGM_GVC_2: Variance-covariance matrix file of the spherical harmonics coefficients
These products will be stored in XML format, except for the Variance-Covariance Matrix (Internal HPF VCM format)

In addition GUT uses auxiliary data such as MSS and errors, MDT, DEM in NetCDF format (COARDS/CF standard).

GUT is a command line processor. Its output may be exported and visualised using the ESA Basic Radar Altimetry Toolbox BRAT (http://earth.esa.int/brat).
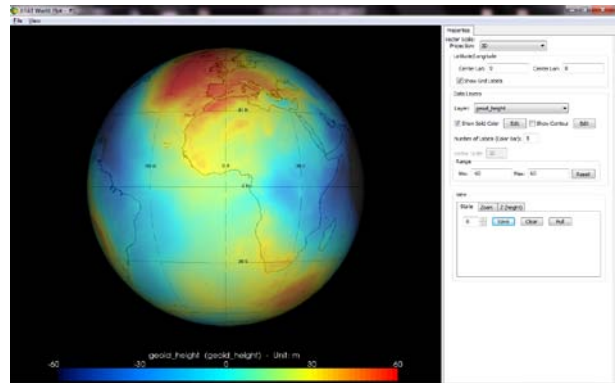
GUT is a command line processor. An example is the following command that will make GUT compute the geoid in a specified region to a specified maximum harmonic degree and order. That is:
C:\gut geoidheight_gf -InFile egm_dir_r1.HDR -R 0.0:360.0,-80.0:80.0 -I 0.125:0.125 -DO 200

Using the BratDisplay the geoid is visualized.
C:\BratDisplay geoid_heights.nc

GUT has help / man functionality

Workflows combine series of funcionalities for e.g. computing a MDT:
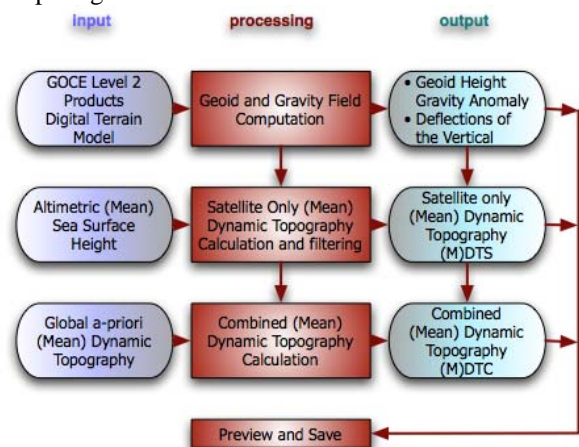
Use the GUT workflow for computing a MDT:
spatialmdt_gf
        -InShpFile EGM.HDR   -InSshFile MSS.nc
        -R 280.0:320.0,25.0:45.0 -I 0.125:0.125
        -DO 240
   -Ftg 1.0
The workflow ensure consistency in
 • Grids
 • Reference frame
 • Tidal system

Furthermore GUT perform filtering considering a land mask using a user specified filter wrt type and width.

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.

mean_dynamic_topography (mdt) - Unit: m
-0.4   -0.1   0.2   0.5   0.8
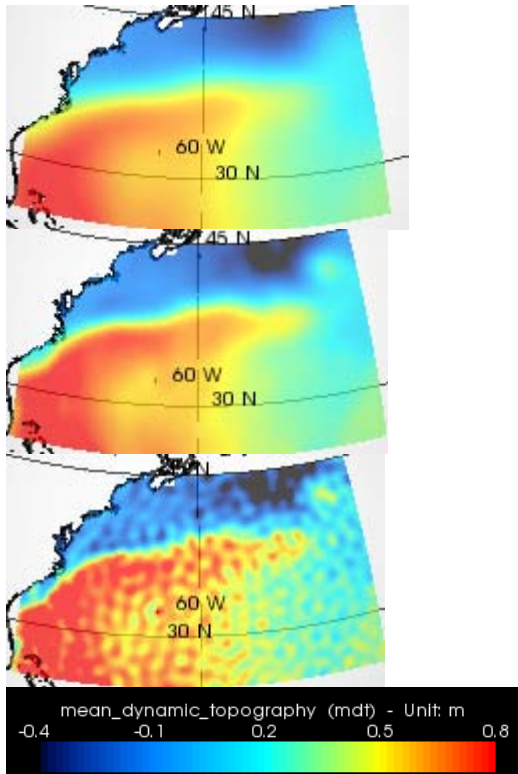
Also geostrophic current components may be computed. Below are shown the east-west cunts associated with the MDTs above.

eastward_velocity (eastward_velocity) - Unit: m s-1
-0.1   0.025   0.15   0.275   0.4
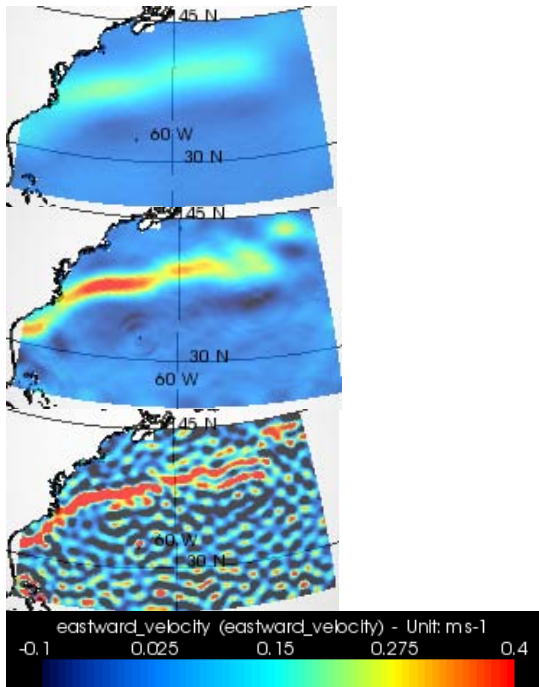
GUT has implemented several filters:
-F[filter_type] filter_scale
-Fg: Gaussian with given Half-Width at Half-Maximum (HWHM = 1.1774 sigma)
-Ftg :   Truncated Gaussian (- at a radius of 3 sigma)
-Fsc :   Spherical Cap
-Fhan : Hanning
-Fham : Hamming
-Fbox : Pill Box
Both isotropic and simple anisotropic.
Also Spectral filtering through spherical harmonic expansion.

Applications of the Variance-covariance Matrix require additional software not included in GUT. The software has been developed by Georges Balmino and made available to the community. Those applications require heavy computational resources. In the current version of GUT documentation and tutorial they are not supported.

Future Work
The GUT will be further developed through a collaborative effort where the scientific communities participate aiming on an implementation of remaining functionalities facilitating a wider span of research in the fields of Geodesy, Oceanography and Solid earth studies.