GUT TUTORIAL

10 March 2016

Document change record

Version	Date	Prepared by	Change description
1.0	31 March 2008	MH Rio	Initial version
1.1	30 September 2008	MH Rio	Beta version
2	24 March 2009	MH Rio	Final version
3	9 April 2009	MH Rio	Final version after ESA review
4	14 March 2011	MH Rio	Initial version of GUT v2.0 tutorial
5	22 March 2011	MH Rio	Final version of GUT v2.0 after ESA review
6	16 May 2011	MH Rio	GUT v2.1
6.1	23 June 2011	MH Rio	GUT v2.1
7.0	19 December	S. Mulet	GUT v2.2 (add information about simple Bouguer)
7.1	19 December	C. Braitenberg	GUT v2.2 (more detail about simple Bouguer)
7.2	22 January	S.Mulet	Take into account

			ESA reviews
8.0	05 May 2015	S. Mulet	Initial version of GUT 3.0
8.1	09 Sept 2015	S. Mulet	Correction of the simple function of the diffusive filter Update scale_gf
8.2	30 September 2015	C. Braitenberg	Update of Bouguer and Airy sections
8.3	07 October 2015	S. Mulet	Update after GUT Final meeting
8.4	11 December 2015	S. Mulet	Take into account ESA reviews
8.5	11 December 2015	S. Mulet	Correction of use cases n°11 and 12
8.6	17 February 2016	P. Knudsen	Revisions according to review of 16/12/2015
8.7	23 February 2016	A. Ambrózio	Revisions according to review of 16/12/2015
8.8	10 March 2016	A. Ambrózio	Minor Corrections

GOCE User Toolbox (GUT)

GUT Implementation and Supporting Scientific Studies

Table of content

Table of illustrations

References

RD 1 ESA document: GOCE standards GO-TN-HPF-GS-0111

RD 2 GO-MA-HPF-GS-0110: GOCE Level 2 Product Data Handbook, Issue 3.3, 08.05.2007

RD 3 GUT User guide v1.2: ESA-GUT-AD-001

RD 4 C.W. Hughes and R.J. Bingham, 2006 : An oceanographer's guide to GOCE and the geoid. Ocean Sci. Discuss., 3, 1543-1568.

RD 5 Le Provost, C., J.P. Le Grand, E. Dombrowsky, P.Y. Le Traon, M. Losch, F. Ponchaut, J. Schröter, B. Sloyan, et N. Sneeuw, 1999: Impact of GOCE for ocean circulation studies. *Report n°* 13175/98/NL/GD, *edited by* ESA study contract 13175/98/NL/GD.

RD 6 Le Traon, P.-Y., F. Hernandez, M.-H. Rio, et F. Davidson, 2002: How operational oceanography can benefit from dynamic topography estimates as derived from altimetry and improved geoid, in *GOCE conference*, ed., Berne.

RD 7 Sanso, F. and C.C.Tscherning: Notes on Convergence Problems in collocation Theory. Bolletino di Geodesia e Scienze Affini, Vol. XXXIX, No. 2, pp. 221-252, 1980.

RD 8 Tapley, B.D., Chambers, D.P., Bettadpur, S. and Ries, J.C., 2003. Large scale ocean circulation from the GRACE GGM01 Geoid. Geophysical Research Letters, 30(22): 2163-2166.

RD 9 Claessens S.J. and C. Hirt (2013) Ellipsoidal topographic potential: New solutions for spectral forward gravity modeling of topography with respect to a reference ellipsoid, Journal of Geophysical Research - Solid Earth, Vol. 118(11), 5991-6002, doi: 10.1002/2013JB010457.

RD 10 Grombein, T.; Luo, X.; Seitz, K.; Heck, B. (2014): A wavelet-based assessment of topographic-isostatic reductions for GOCE gravity gradients. Surveys in Geophysics 35(4):959–982.

RD 11 Hirt, C. and Rexer, M. (2015) Earth2014: 1' shape, topography, bedrock and ice-sheet models - Available as gridded data and degree 10,800 spherical harmonics; International Journal of Applied Earth Observation and Geoinformation, Vol. 39, 103-112,doi: 10.1016/j.jag.2015.03.001.

RD 12 Jekeli, C. (1981) Alternative Methods to Smooth the Earth's Gravity Field, Volume 327, Department of Geodetic Science and Surveying: Report, Ohio State University Columbus

Acronyms

ADT	Absolute Dynamic Topography
BRAT	Broadview Radar Altimetry Toolbox
GOCE	Gravity Field and Steady-State Ocean Circulation Explorer
GUI	Graphical User Interface
GUT	GOCE User Toolbox
MDT	Mean Dynamic Topography
MSS	Mean Sea Surface
NetCDF	Network Common Data Format
RR	Remove-Restore
SLA	Sea Level Anomaly
SMDT	Satellite-only Mean Dynamic Topography

1. Introduction

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 objective of the GUT tutorial, together with the GUT Algorithm Description and User Guide (RD3) is to assist you in getting acquainted with the GOCE User Toolbox, whose objective is to help you take major benefit from the GOCE data for your own application.

2. The GOCE mission

The GOCE (Gravity Field and Steady-State Ocean Circulation) satellite, launched on March, 17th 2009, is the first Earth Explorer Core Missions identified by ESA in the framework of the Living Planet Programme. Its primary objectives are to determine, at a spatial resolution of 100km the Earth's gravity field and the geoid height with unprecedented accuracy of respectively 1mGal and 1 cm.

The principle of the measurement is based on satellite gradiometry: the gradiometer embarked on GOCE satellite consists of three pairs of three axis accelerometers, each of which will measure the Earth's varying gravity field caused by the passage of the spacecraft over varying masses of mountains, ocean ridges, subduction zones… The basic gradiometric measurement is the difference of acceleration measured between two accelerometers in the direction joining them, which correspond to the second derivatives of the gravitational potential.

The gradiometer will provide information for the short and medium wavelengths of the Earth Gravity field. It will be supplemented, for the retrieval of long wavelengths, by high-accuracy Satellite-to-Satellite (SST) measurements and star tracker information

3. The GOCE applications

The GOCE mission will serve numerous science objectives, covering varying disciplines like Solid Earth, Geodesy and Oceanography.

3.1. Solid Earth

From http://www.esa.int/esaLP/ESA31L1VMOC_LPgoce_0.html

Since the gravity measurements taken by GOCE reflect density variations in the Earth's interior, the resulting data will lead to new insights into processes occurring in the lithosphere and upper mantle - down to a depth of about 200 km. This detailed mapping along with seismic data is expected to shed new light on the processes causing earthquakes and volcanic activity and potentially lead to an improvement in the prediction of such events.

GOCE will also further our knowledge of land uplift due to post-glacial rebound. This process describes how the Earth's crust is rising a few centimetres in Scandinavia and Canada as it has been relieved of the weight of thick ice sheets since the last Ice Age - when the heavy load caused the crust to depress. As a result, there is global redistribution of water in the oceans. Hence, a better understanding of these processes help in assessing the potential dangers of current sea-level change.

3.2. Geodesy

From http://www.esa.int/esaLP/ESAG4L1VMOC_LPgoce_0.html

Geodesy is concerned with the measurement of the Earth's shape and the mapping of its regions. Its products are used extensively in all branches of the Earth sciences. In addition, they are applied to many areas of civil engineering, exploration, mapping and cadastral work and are the basis of all geo-information systems. Whereas positioning on the Earth's surface in two- or three-dimensional co-ordinates is based on purely geometric techniques, height determination requires knowledge of the Earth's gravity field. Only through knowledge of differences in gravity potential is it possible to decide on the direction of the flow of water or the direction of 'up' and 'down'

Since it represents a surface along which no water would flow, the geoid defines our sense of the horizontal and is the classical reference surface for establishing height. However, there is currently no globally unified height-reference system. There are numerous practical implications of having any number of nationally accepted benchmark references, such as how to define the true height of a mountain.

Data from GOCE will lead to a global unification of height systems, so that mountain ranges in American will be able to be measured against those in Europe or Asia. In the construction industry, an accurate geoid will be used for levelling, for example, to ensure that water flows in the direction intended. It will also aid such things as the building of bridges over water and tunnels through mountains - especially those linking different countries currently using different reference benchmarks. This issue was illustrated in the 1990s with the construction of the Øresund Bridge, which now links Denmark and Sweden. Much effort was taken in connecting two national height systems and precise levelling over the 22 km span of the bridge.

GOCE data will also facilitate one global system for tide-gauge records, so that sea levels can be compared all over the world. This will also contribute to observing and understanding sea-level change as a result of melting continental ice-sheets associated with a changing climate and postglacial rebound.

The GOCE geoid will provide a global standard that will greatly simplify all these height-related issues.

3.3. Oceanography

From http://www.esa.int/esaLP/ESA4ZK1VMOC_LPgoce_0.html

A better understanding of Earth's gravity field and its associated geoid will significantly advance our knowledge of how the Earth-system works. In particular, an accurate model of the geoid will advance our understanding of global ocean circulation patterns.

Ocean circulation plays a crucial role in climate regulation by transporting heat from low to high latitudes in surface waters, while currents cooled at high latitudes flow in deeper waters back towards the Equator. The Gulf Stream, which carries warm surface waters northwards from the Gulf of Mexico, is a good example of the important role ocean currents play in moderating the climate. Thanks to this current, the coastal waters of Europe are actually 4°C warmer than waters at equivalent latitudes in the North Pacific. However, knowledge of the role that the oceans play in the Earth system is currently insufficient for the accurate prediction of climate change.

In order to study ocean circulation more effectively it is necessary to have an accurate map of the Earth’s geoid. The geoid represents the shape of a hypothetical ocean surface at rest in response to variations in the Earth's gravity field. External forces such as the wind cause the actual sea surface to deviate from the geoid. Existing ESA ocean altimeter systems such as those on ERS and Envisat measure sea-surface height and typically show +/- 1 metre variations relative to the geoid. Importantly, the large-scale current systems flow along the lines of equal topography and are focused around the strongest gradients in sea-surface height.

Presently, the degree to which altimetry data can be used to make precise estimates of the transport of heat, salt and freshwater, is limited by the quality of the geoid at short length scales. It is therefore the combination of sea-surface height mapped by altimeters and the knowledge of the precise ocean geoid that will improve our understanding of surface currents and lead to a better knowledge of general ocean circulation patterns - crucial for understanding climate change.

Given the exciting possibility of the new GOCE 1-2 cm global geoid, satellite-altimetry data records spanning the last 15 years can be used to provide a detailed retrospective picture of ocean circulation patterns and variations, and their consequences for the global water and energy cycles.

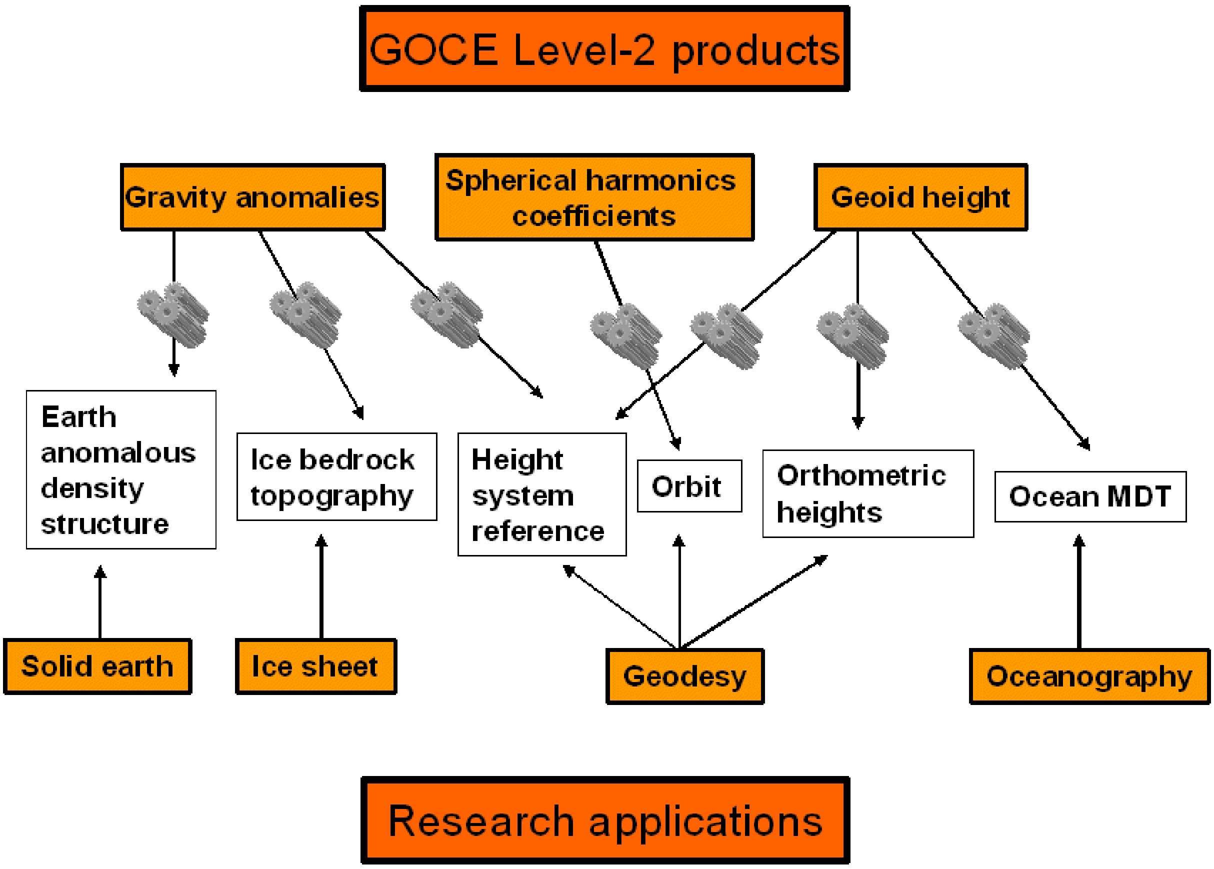
4. The GOCE data

The format and content of the GOCE Level-2 products delivered by the High Level Processing Facility (HPF) to the users are described in the GOCE Level-2 data handbook [RD2]. Among them, input to the GOCE User Toolbox are the GOCE Gravity Fields data including the spherical harmonic coefficients and error estimates as well as grids of geoid heights, gravity anomalies and deflection of the vertical.

The GOCE User Toolbox is a user friendly tool to handle and display the GOCE Level-2 products listed above.

In addition, it aims at helping, when feasible, to fill an existing gap between the GOCE Level-2 products delivered by HPF and the actual physical quantities relevant for the different research domain listed in section 3.

5. The GOCE User Toolbox rationale

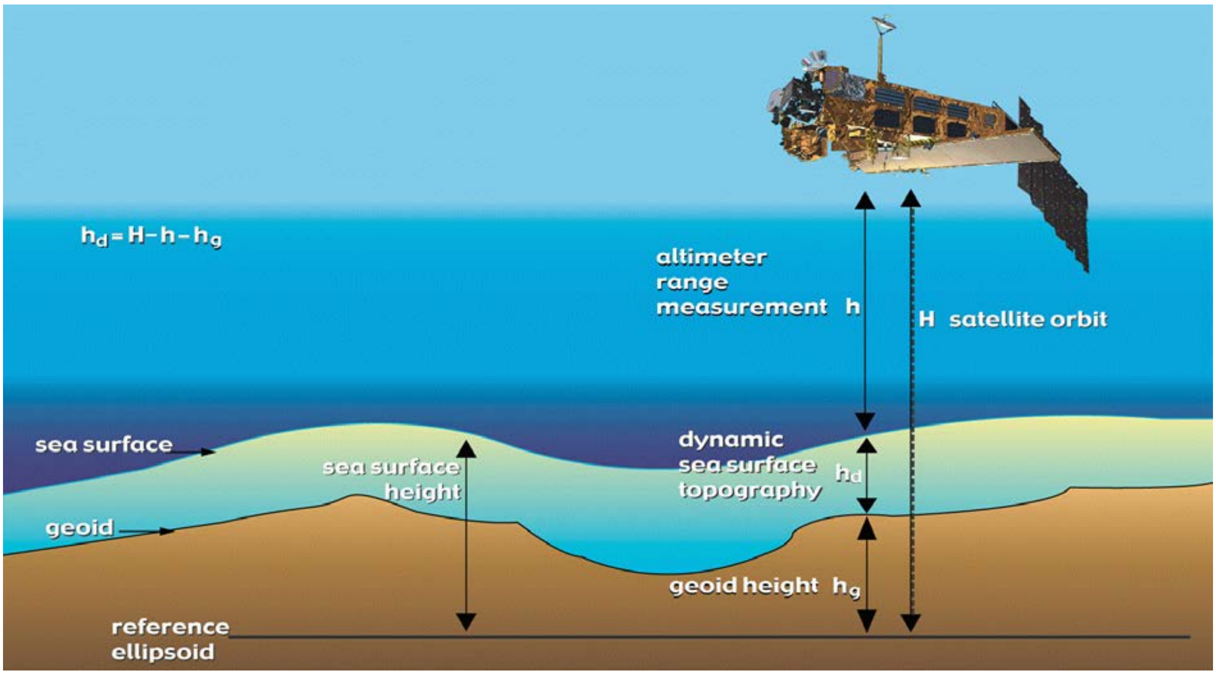


In particular, this is the case in oceanography, where the meaningful quantity is the ocean Mean Dynamic Topography (MDT), whose rigorous computation is doable using the GOCE User Toolbox, provided a number of recommendations are strictly followed.

6. Issues and recommendations for using GUT to compute the ocean Mean Dynamic Topography

6.1. Altimetry and the Mean Dynamic Topography issue

6.1.1. Radar altimetry principle



(Credits *ESA – J. Benveniste*)

Figure 1: Radar altimetry principle

Figure 1 is a schematic illustration of the radar altimetry principle: The combined knowledge of the satellite's orbit relative to a reference ellipsoid and the altimetric range (the distance between the satellite and the ocean surface) gives access to the sea level η above the reference ellipsoid: η=orbit-range

The shape of the sea level results from different forcing:

- Earth rotation

- Gravity

These two effects give shape to what is called the geoid: the ocean at rest

- External forcing from the atmosphere (winds, solar heating, precipitation) and gravitational effects from the moon and the sun (tides).

All these forcing generate motions of the ocean resulting in a sea level shape that differs from its shape at rest.

The sea level measured by altimetry therefore corresponds to the sum of the geoid height and the ocean dynamic topography, two terms from which only the second one is of interest for oceanographers and can be obtained from Eq. 1

$$h = \eta - N$$

Eq. 1

The use of altimetric data for oceanographic applications therefore depends on the capacity to separate the geoid height (that ranges between plus and minus 100 m) from the dynamic topography (that ranges between plus and minus 1m). In the open ocean, this implies to know the geoid with centimetre accuracy along the altimetric satellite track (one measure each 7 km)

At the time of the first altimetric missions (Seasat in 1978) the most accurate geoid models had a reasonable precision (for oceanography) at scales larger than 2500 km!

In the past decade, with the launch of dedicated gravity missions CHAMP (2000), GRACE (2002) and GOCE (2009), our knowledge of the geoid has drastically improved. The centimetre accuracy is now reached for scales greater than 100 km.

However this accuracy is still insufficient to directly apply Eq. 1 along altimetric tracks.

6.1.2. The repeat-track method

In order to make the best possible use of altimetric data, despite the large geoid uncertainties, the repetitivity of altimetric satellites was decided and the so-called "repetitive tracks" method was applied on the altimetric heights: Assuming a stationary geoid, the average of M altimetric measurements $\{\eta_i\}_{i=1,M}$ at a same geographical position (x,y) is the sum of the Geoid height and the average of the Dynamic Topography at that location for the time period P covering the M measurements.

$$\overline{\eta}_P(x,y) = \frac{1}{M}\sum_{i=1}^{M}\eta_i(t,x,y) = \frac{1}{M}\sum_{i=1}^{M}N(x,y) + h_i(t,x,y) = N(x,y) + \frac{1}{M}\sum_{i=1}^{M}h_i(t,x,y) = N(x,y) + \overline{h}_P(x,y)$$

Eq. 2

This mean altimetric height $\overline{\eta}_P(x,y)$ can be subtracted from any instantaneous altimetric height η(t,x,y). The resulting value is the variable part of the ocean dynamic topography, also called the Sea Level Anomaly (SLA)

$$\eta(t,x,y) - \overline{\eta}_P(x,y) = N(x,y) + h(t,x,y) - N(x,y) - \overline{h}_P(x,y) = h(t,x,y) - \overline{h}_P(x,y) = h'_P(t,x,y)$$

Eq. 3

Note: The Sea Level Anomaly is always referenced to a given period.

The time t at which the SLA is computed needs not to fall inside the chosen period P.

6.1.3. From altimetric anomalies to ocean surface currents

Absolute dynamic topography

In Eq. 3, the $\overline{h}_p$ term is the ocean Mean Dynamic Topography (MDT) for the time period P. It is the missing quantity needed to recover absolute dynamic topography values from sea level anomalies:

$$h(t,x,y) = \overline{h}_P(x,y) + h_P'(t,x,y)$$

Eq. 4

Along-track mean profiles $\overline{\eta}_P(x,y)$ from different inter-calibrated missions can be merged using optimal interpolation techniques. The resulting gridded field is the so-called altimetric Mean Sea Surface (MSS).

Subtracting the gridded geoid height N from the gridded MSS results in a grid of Mean Dynamic Topography (MDT) as given by Eq. 5 which corresponds to the gridded average of Eq. 1 over a chosen period P:

$$MDT_P = MSS_P - N$$

Eq. 5

The geostrophic surface currents

Under a number of hypotheses absolute dynamic heights are related to ocean surface currents through the geostrophic equations: The zonal (u) and meridional (v) geostrophic velocity components are proportional to height gradients, as expressed in Eq. 6 in a cartesian coordinate system fixed to the Earth.

$$u(t,x,y) = -\frac{g}{f}\frac{\partial h(t,x,y)}{\partial y} \qquad v(t,x,y) = \frac{g}{f}\frac{\partial h(t,x,y)}{\partial x}$$

Eq. 6

where f is the Coriolis parameter and g the acceleration of gravity.

6.1.4. Assimilation of altimetry into operational forecasting systems

Only the variable part of the ocean dynamic topography can be extracted with sufficient accuracy (few centimetres) for oceanographic applications. The estimation of an accurate Mean Dynamic Topography is mandatory for the correct interpretation of all past, present and future altimetric data and their use for oceanographic analyses. It has also proved to bring significant improvement for their assimilation into operational forecasting systems (RD5, RD6, results from the EU GOCINA project).

6.2. Recommendations to the GUT user

The objective of this section is to give a brief outline of the main issues a user has to keep in mind when using GOCE data for computing an ocean Mean Dynamic Topography. Further details on these issues can be found in (RD 4).

As described in the previous section, the ocean mean dynamic topography (MDT) for a chosen period is the difference between an altimetric mean sea surface (MSS, computed for the chosen period) and a geoid model N (Eq. 5).

This apparently very simple equation is actually quite intricate because of the following four main issues:

6.2.1. Reference ellipsoid issue:

Both altimetric mean sea surface heights and geoid heights are given relative to a reference ellipsoid, which corresponds to a theoretical shape of the Earth. The characteristics of different, currently used, reference ellipsoids are given in Table 1.

Before subtracting a geoid from a MSS, both fields have to be expressed relative to the same reference ellipsoid. If not, the impact on the resulting MDT is large: Figure 2 shows the height differences between the GRIM and Topex ellipsoids on a global grid.

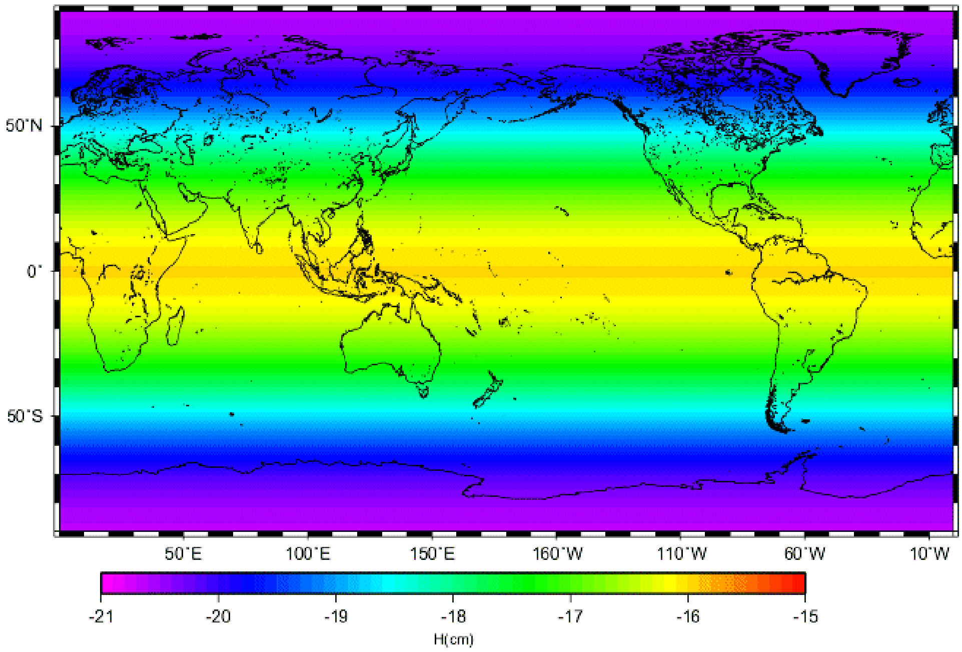


Figure 2: Height difference between the TOPEX and the GRIM ellipsoids.

Ellipsoid name	a (m)	1/f	Gm (m^3/s^2)
"GRIM"	6378136.46	298.25765	398600.4369e9
"TOPEX"	6378136.3	298.257	398600.4415e9
"GRS80"	6378137.	298.257222101	398600.5e9
"WGS84" WGS84 rev 1	6378137. 6378137.	298.257223563 298.257223563	398600.5e9 398600.4418e9

Table 1: The different reference ellipsoids and their characteristics

Altimetric Mean Sea Surfaces are most commonly computed relative to the TOPEX ellipsoid.

The GRACE geoid models provided by the GFZ are computed relative to the GRIM ellipsoid.

The **GOCE** geoid heights are computed relative to the **GRS80** reference ellipsoid [RD2].

Recommendations to users

MSS and the geoid must be defined in the same system if both are to be used jointly to compute a Mean Dynamic Topography (MDT).

This means that before computing the ocean MDT by subtracting the GOCE geoid from an altimetric Mean Sea Surface, the user must check that the MSS is defined in the same system. If not, the MSS must be computed relative to the GRS80 ellipsoid and in the tide-free system. Inversely, the user can decide to convert the GOCE geoid into the same system as the MSS before combining both fields.

Use GUT to change the reference ellipsoid of your geoid: GOTO 7.3.9

6.2.2. Tide system issue:

Geoid heights (and mean sea surface heights) also differ depending on what tidal system is implemented to deal with the permanent tide effects. In the MEAN TIDE system, the effects of the permanent tides are included in the definition of the geoid. In the ZERO TIDE system, the effects of the permanent tides are removed from the gravity field definition. In the TIDE FREE or NON-TIDAL system, not only the effects of the permanent tides are removed but the response of the Earth to that absence is also taken into account. Altimetric mean sea surfaces are usually expressed in the MEAN TIDE system. The GRACE GGM02 geoids from the CSR are defined relative to the ZERO TIDE system. The GRACE EIGEN geoids from the GFZ/GRGS are defined relative to the TIDE FREE system. When computing an ocean mean dynamic topography, the MSS and the geoid first have to be computed in the same system. If not, the impact on the resulting MDT is large: for instance, Figure 3 shows the difference between the TIDE FREE and the MEAN TIDE reference systems.

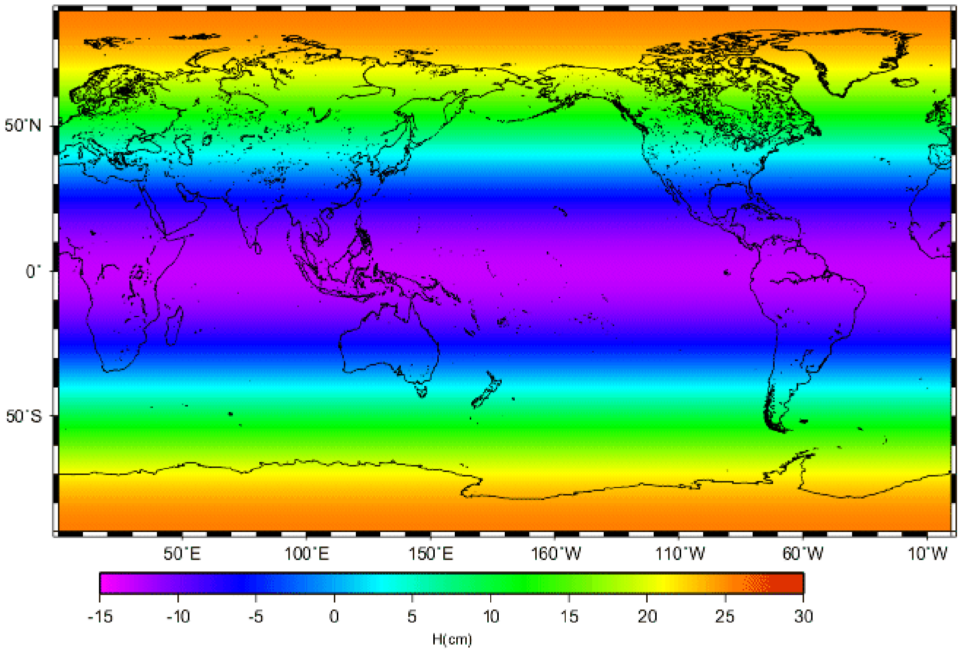


Figure 3: Height difference between the TIDE FREE and the MEAN TIDE reference systems

Recommendations to users

It is important for correct estimation of long-wavelength dynamic topography that the MSS and geoid are within the SAME tide system. The toolbox will ensure this happens when using the auxiliary data contained in the distribution, but users must check the tide system used in alternative data products is consistent,

Use GUT to change the tide system of your geoid: GOTO 7.3.8

6.2.3. Spectral content issue

Altimetric mean sea surfaces and geoid models don't have the same spectral content. Typically, mean sea surfaces are known with a centimetric accuracy at spatial scales down to a few kilometres. On the other hand, the same accuracy on the geoid is achieved using GRACE and GOCE data at scales down to around 100-200 km (RD1, RD2). If a simple difference of the two fields is calculated, the resultant dynamic topography will contain high spatial resolution geoid information, from the altimetric MSS, that is not included in the geodetic data, giving spurious circulation features. Hence, before subtracting a geoid from a MSS, the two fields have to be filtered in order to achieve from both of them a similar spectral content. The filtering can be done either in geographical space or in spectral (spherical harmonic) space. In the latter case, the MSS, which, by construction, is defined only over the oceans, needs to be completed over the continents in order to obtain a global field.

Use GUT to filter the geoid in geographical space: GOTO 7.3.10

Recommendations to users

When computing a MDT by subtracting a geoid model from an altimetric Mean Sea Surface, the user must check that the spectral content of the two fields are consistent and, if necessary, apply adequate filtering. A number of filter kernel are available for that purpose inside GUT.

Once these three points (ellipsoid, tide system, spectral content) have been taken into account and both the MSS and the geoid have been adequately processed, the mean dynamic topography can be computed. We will hereafter refer this MDT product to as a “Satellite-only” MDT or MDTS.

6.2.4. Time period issue:

The time period P over one chooses to compute the ocean MDT depends on the user's objective.
If the objective is to compute absolute dynamic topography values at time t from Eq. 4, one must be very careful that the averaging periods used to compute the Mean Dynamic Topography and the Sea Level Anomalies are the same.

Note: if altimetric anomalies are referenced to a period P and the MDT to a period P', one can easily change the reference period of the MDT to match the SLA reference period using the following equation:

$MDT_P = MDT_{P'} - \langle SLA_P \rangle_{P'}$

Eq. 7

Recommendations to users

It is important that the MSS used to generate the SLAs must be defined over the same averaging period as the MDT.

This means that before computing the absolute dynamic topography by adding an altimetric SLA to a MDT, the user must check that the SLA are defined relative to the same averaging period as used for the MDT. If not, the time period of the MSS must be changed and a consistent MDT computed.

6.2.5. Altimetric correction issue

Before subtracting the altimetric range from the satellite's orbit, a number of corrections have to be applied in order to take into account instrumental and geophysical effects that affect the range computation.

The following geophysical corrections are computed:

Ocean tides: Corrections for sea surface height variations due to the attraction of the Sun and Moon.

Solid earth tides: Corrections for solid earth variations due to the attraction of the Sun and Moon. Calculated by models.

Pole tides: The ocean pole tide is the ocean response to the variation of both the solid Earth and the oceans to the centrifugal potential that is generated by small perturbations to the Earth's rotation axis. Modelling the pole tide requires knowledge of proportionality constants, the so-called Love numbers, and a time series of perturbations to the Earth's rotation axis, a quantity that is now measured routinely with space techniques.

Tidal loading: Corrections for height variations due to changes in tide-induced forces acting on the Earth's surface.

Ionosphere: Correction for the path delay in the radar return signal due to the atmosphere's electron content. It is calculated by combining radar altimeter measurements acquired at two separate frequencies (C-band and K_u-band for Topex and Jason-1, K_u-band and S-band for Envisat).

Wet troposphere: Correction for the path delay in the radar return signal due to liquid water in the atmosphere. It is calculated from radiometer measurements and/or meteorological models.

Dry troposphere: Correction for the path delay in the radar return signal due to the dry gasses in atmosphere. It is calculated from meteorological models.

Inverse barometer: Correction for variations in sea surface height due to atmospheric pressure variations (atmospheric loading). It is calculated from meteorological models.

Electromagnetic bias: Correction for bias in measurements introduced by varying reflectivity of wave crests and troughs. It is calculated from models.

For all these corrections, different solutions exist. A number of standards are regularly decided and updated by the international scientific community. These standards are decided by the OSTST (Ocean Surface Topography Science Team) for the Topex and Jason missions and by the QWG (Quality Working Group) for the ERS and Envisat missions

Standards used for the computation of altimetric data provided with GUT

Different sets of altimetric products (SLA and MSS) are provided inside the toolbox.

The SLA products are gridded maps of intercalibrated, multimissions altimetric anomalies computed at CLS and distributed via AVISO. One year (2007) of weekly data in delayed mode is provided within GUT.

Several MSSs are provided inside GUT, either global (CLS01, CNES-CLS10 and DTU10 MSS) or regional (Ibiroos MSS, DNSC09 MSS). These MSS have been computed using slightly different standards.

Recommendations to users

The MDT computed from MSS minus Geoid is then added to altimetric anomalies (Level-3 products) and it is therefore recommended that the standards applied to the MSS are the same as those used to compute the altimetric anomalies. This means that before computing the absolute dynamic topography by adding the altimetric SLA to a MDT, the user must check that the SLA have been calculated using the same correction set as was used for the MDT. If not, merging the fields may provide erroneous results, caused by difference in corrections rather than ocean dynamic topography.

In practice, this is difficult to achieve since the standards used for the SLA computation are updated regularly (as improved corrections/models are made available) while the MSS are built using altimetric mean profiles computed using the standards available at the time of the MSS computation.

However, the impact on multi-years mean of using one altimetric correction instead of another does not exceed some centimetres, for an amplitude of the MSS signal ranging between + and - 100m.

7. Using the toolbox

7.1. A priori data delivered with GUT

In the following examples, we use a-priori files available to the user in the 'apriori' directories:

7.1.1. Mean Sea Surfaces (gut-apriori_MSS)

- MSS_DTU_10_2M.nc

DNSC-DTU 2010 MSS at 2min resolution
Coverage = Global
Conversion Notes: TOPEX Ellipsoid and Mean-Tide system metadata included.

- MSS_DTU_10_5M.nc

DNSC-DTU 2010 MSS at 5min resolution
Coverage = Global
Conversion Notes: TOPEX Ellipsoid and Mean-Tide system metadata included.

- MSS_DTU_10_10M.nc

DNSC-DTU 2010 MSS at 10min resolution
Coverage = Global
Conversion Notes: TOPEX Ellipsoid and Mean-Tide system metadata included.

- MSS_CNES_CLS_11_2M.nc

CNES-CLS 2011 MSS at 2min resolution
Coverage = Global
Conversion Notes: TOPEX Ellipsoid and Mean-Tide system metadata included. For any help desk request over the model, please refer to http://www.aviso.oceanobs.com.

- MSS_DNSC09_2M.nc

Danish National Space Center regional DNSC09 MSS at 2min resolution
Coverage = Regional (49d59'N to 80d01'N x -60d01E to +30d01'E)
Conversion Notes: TOPEX Ellipsoid and Mean-Tide system metadata included.

- MSS_CLS01_2M.nc

Mean Sea Surface CLS 2001 at 2min resolution
Coverage = Global

Conversion Notes: TOPEX Ellipsoid and Mean-Tide system metadata included.

- MSS_IBIROOS_CLS_1M.nc

IBIROOS CLS regional mean sea surface at 1min resolution
Coverage = Regional (30d00'N to 60d00'N x -30d00'E to +5d00'E)
Conversion Notes: TOPEX Ellipsoid and Mean-Tide system metadata included.

7.1.2. Mean Dynamic Topography (gut-apriori_MDT)

- MDT_DTU_10_2M.nc

DNSC-DTU 2010 MDT at 2min resolution
Coverage = Global
Conversion Notes: TOPEX Ellipsoid and Mean-Tide system metadata included.

- MDT_DTU_10_10M.nc

DNSC-DTU 2010 MDT at 10min resolution
Coverage = Global
Conversion Notes: TOPEX Ellipsoid and Mean-Tide system metadata included.

- MDT_DTU_10_5M.nc

DNSC-DTU 2010 MDT at 5min resolution
Coverage = Global
Conversion Notes: TOPEX Ellipsoid and Mean-Tide system metadata included.

- MDT_CNES_CLS_09_15M.nc

CNES-CLS 2009 MDT at 15min resolution
Coverage = Global
Conversion Notes: TOPEX Ellipsoid and Mean-Tide system metadata included. For any help desk request over the model, please refer to http://www.aviso.oceanobs.com/

- MDT_RIO05_30M.nc

CLS Synthetic Mean Dynamic Topography RIO-05 (June 05) at 30M resolution
Coverage = Global
Conversion Notes: TOPEX Ellipsoid and Mean-Tide system metadata

- MDT_OCCAM_5M.nc

OCCAM Mean Dynamic Topography 1989-2004 at 5min resolution
Coverage = Quasi-Global (78d07'30"S to 89d57'30"N)
Conversion Notes: TOPEX Ellipsoid and Mean-Tide system metadata included.

7.1.3. Terrain (gut-apriori_DTEM)

- GUT_ACE2_5M.nc

The De Monfort University (DMU) ACE2 DEM and EGM96 Geoid at 5M resolution
Coverage = Global
Conversion Notes : The original data are orthometric heights above EGM96 Geoid with the latitude and longitude coordinates in the GRS80/WGS84 datum. For use with GUT this data was converted to ellipsoid heights for the surface of the terrain and oceans by adding the orthometric height and geoid height and taking the maximum of this and the geoid height. Specifically:
-Merged the official DMU 5 Min tiles into one matrix.
-Interpolated the official 15 Min EGM96 Geoid on 5 Min ACE2 grid.
-Added the geoid and DEM if the DEM was positive, selecting the geoid otherwise.
-Exported in GUT netCDF format.

- GUT_ACE2_BATHY_5M.nc

The De Monfort University (DMU) ACE2 DEM (with Bathymetry) at 5min resolution
Coverage = Global
Conversion Notes : The original data are orthometric heights above EGM96 Geoid with the latitude and longitude coordinates in the GRS80/WGS84 datum. For use with GUT this data was converted to ellipsoid heights by adding the orthometric height and the geoid height. Specifically:
-Merged the official DMU 5 Min tiles into one matrix.
-Interpolated the official 15 Min EGM96 Geoid on 5 Min ACE2 grid.
- Added the geoid and DEM and exported in GUT netCDF format.

7.1.4. Topography and isostatic effect (gut-apriori_TOPO)

This data package includes global gravity field models related to Topography.

- dV_ELL_RET2014_with_GRS80_SHCto2190.dat and RWI_TOPO_2012_plusGRS80.gfc

These files contain the spherical harmonic coefficients of the gravity effect of topography estimated as described by Claessens and Hist (2013) [RD9] and Hirt and Rexer (2015) [RD11] for dV_ELL_RET2014_with_GRS80_SHCto2190.dat or by Grombein et al. (2014) [RD10] for RWI_TOPO_2012_plusGRS80.gfc.

- RWI_TOIS_2012_plusGRS80.gfc

This file contains the isostatic geopotential spherical harmonic coefficients estimated by Grombein et al. (2014) [RD10].

7.1.5. L2 Gravity gradient (gut-apriori_EGG)

- GO_CONS_EGG_TRF_2__20131002T000000_20131019T235959_0101.TGZ

This archive includes a file .HDR and a file .DBL. The .HDR is the description of the file .DBL that includes the data. The data are the GOCE gravity gradient EGG_TRF_2 Level-2 Product.

Archiving Notes: The user must decompress tgz archives before using it.

7.1.6. Spherical Harmonic Potential (gut-apriori_EGM_SHP)

- GOCE EGM_GOC_2 Level-2 Product File

There are several files corresponding to the different solutions (Time-wise, Space-wise and direct solution) and the different HPF deliveries:

File name	Solution	Delivery	Files included
GO_CONS_EGM_GOC_2_DIR_R2.TGZ	direct	2nd	.HDR, .DBL
GO_CONS_EGM_GOC_2_TIM_R2.TGZ	time-wise	2nd	.HDR, .DBL
GO_CONS_EGM_GOC_2_SPW_R2.TGZ	space-wise	2nd	.HDR, .DBL
GO_CONS_EGM_GOC_2_DIR_R3.TGZ	direct	3rd	.HDR, .DBL
GO_CONS_EGM_GOC_2_TIM_R3.TGZ	time-wise	3rd	.HDR, .DBL
GO_CONS_EGM_GOC_2_DIR_R5.zip	direct	5th	.HDR, .DBL, .IDF
GO_CONS_EGM_GOC_2_TIM_R5.zip	time-wise	5th	.HDR, .DBL, .IDF

All files have a global coverage.
The .HDR is the description of the file .DBL that includes the data. The data are geoid_height, gravity_anomaly, geoid_height_error, vertical_deflection_north and vertical_deflection_east.
The .IDF contains the spherical harmonic coefficients in ICGEM format.

Archiving Notes: The user must decompress tgz and zip archives before using it.

- EIGEN-5c.gfc

Global combined high-resolution GRACE-based gravity field model of the GFZ-GRGS cooperation in ICGEM format - Coverage = Global
Usage Notes: The reference epoch of this gravity field model is 01 Oct 2004.

❖ EIGEN-GRGS.RL02.MEAN-FIELD_2005.nc

Global satellite-only GRACE-based mean gravity field model (release 2) of the GRGS institute in netCDF format - Coverage = Global
Usage Notes: The EIGEN GRGS Release 2 mean-field model with time-dependent terms ignored. This references the field to the datum of 2005.0.

❖ EGM-96.nc

Global Combined geopotential model (1996 release) of the NIMA-GSFC-OSU cooperation in netCDF format.
Coverage = Global

7.1.7. Geoid Height Surface (gut-apriori_EGM_GRID)

❖ WW15MGH.GRD

Global gridded EGM96 geoid height surface at 15 minutes in GRAVSOFT format
Coverage = Global
Conversion Notes: The metadata information are not included in the GRAVSOFT format but it should be stated (ellipsoid WGS84 rev1 and tide-system tide-free) when the surface is imported by the command:

gut import_gf -InFile WW15MGH.GRD -Ellipse wgs84rev1 -T tide-free -PQ geoid

❖ corrcoef.nc

Spherical harmonic height correction coefficient set for the EGM-96 geoid height model in netCDF format
Coverage = Global

7.1.8. Land-Sea Mask (gut-apriori_LSM)

❖ GUT_LSM.nc

Land-Sea-Mask generated from ENVISAT DEM and Bathymetry data on 5min grid.
Coverage = Global

7.1.9. Sea Level Anomaly (gut-apriori_SLA)

- SLA/*.nc

This data is in original format. It can be exported to GUT netCDF format with the gut import_gf command.

7.1.10. Updated fields

Note that more updated fields are available at production centres. For instance

- MSS and MDT DTU13 (and next versions when available) can be found at ftp://ftp.space.dtu.dk/pub/DTU13/
- MDT CNES-CLS13 (and next versions when available) can be found at http://aviso.altimetry.fr/index.php?id=3122 (Note also that a future release of MSS CNES-CLS will be available on aviso website in 2016)

Also more geoid models can be downloaded here:

http://icgem.gfz-potsdam.de/ICGEM/

7.2. One toolbox for different user needs

The GOCE User Toolbox was designed so that it can be used at different levels, depending on the expertise and the needs of the user. The first level is the use of basic pre-defined workflows allowing the computation of geoid/gravity field/MDT in one single step, with few inputs required and a number of options.

The list of the existing workflows can be displayed using the following command (notice the double dash --):

```
gut --workflows
```

For each existing workflow ("workflow_name"), a brief description of functionality and options can be obtained using the following command (notice the double dash --):

```
gut --man workflow_name
```

Note that user that is not comfortable with command line can also use an interactive graphical user interface (GUI) that has exactly the same functionalities and will helps user to chose the parameters of each workflow (for more detail about GUI see part 8).

Example1:

User need:

Get a grid of geoid height developed to a given degree/order from a set of spherical harmonics coefficients → Use the "**geoidheight_gf**" workflow from GUT

Example 2:

User need:

Compute a MDT on a ¼° regular grid at 200 km resolution filtering the GUT default geoid and MSS using a gaussian filter → Use the "**spatialmdt_gf**" workflow from GUT

Example 3:

User need:

Interpolate a grid of geoid heights along an altimetric track → Use the "**transect_tf**" workflow from GUT

This is the **"single step"** approach for which different use cases are further described in section 7.3

Furthermore, single workflows may be called successively, providing an even more complex and flexible processing tool. For instance, when the grid of GOCE geoid heights at 100 km resolution will be available, a GUT user may want to compare it to the latest GRACE geoid model available [RD8]. He/She will be able to do it through the succession of four GUT functions.

Example 4:

User need:

Compare the grid of default GUT geoid heights with a user provided grid of geoid heights

Four steps:

1- Compute the GUT geoid relative to the same reference ellipsoid as the user provided geoid (**changeellipse_gf**)

2- Compute the GUT geoid relative to the same tide system as the user provided geoid (**changetide_gf**)

3- Compute the GUT geoid on the same grid as the user provided geoid (**adapt_gf**)

This is the “step by step” approach, for which different use cases are given in section 7.4.

Furthermore, the user can create easily his/her own workflow to satisfy specific needs. Further details can be obtained in the user manual as well as in section 7.5.

The different use cases described in the following sections may be easily reproduced by the user. The different files needed to run the use cases or created by the use cases are provided in the tutorial package in the three following directories:

- tutorial/USE_CASE/SINGLE_STEP

for the single step approach use cases

- tutorial/USE_CASE/STEPBYSTEP

for the step by step approach use cases

- tutorial/USE_CASE/CREATE_YOUR_WORKFLOW

for the creation of your own workflow

The command lines given in the use cases can be copy and paste by the user provided that:

- The user has the GUT 'build' directory, that contains the GUT executable, in his/her system path
- The user makes the tutorial directory his/her current working directory

7.3. Using existing workflows: the 'single step' approach

7.3.1. verticaldeflectioneast_gf / verticaldeflectionnorth_gf: Compute a grid of deflection from the vertical

verticaldeflectioneast_gf (north_gf)	
Options	**Expected field**
-InFile input_file_name	Input File containing Spherical Harmonic Potential.
-Gf input_grid_file OR **-Af input_grid_file OR** **-R w:e,s:n** **-I dE:dN**	Specify file that defines output grid Read lon/lat axes of output grid from file Output Grid Region. (0.5:359.5,-89.5:89.5) Output Grid Spacing. (1.0,1.0)
-Ellipse ellipse	Reference Ellipsoid for Output Grid by one of name (ellipse is GRS80, TOPEX, or WGS84) parameters (ellipse is inverse_flattening:a:GM) file (ellipse is filename)
-DO degreeAndOrder OR **-Ddeg degrees OR** **-Dkm length**	Degree and Order of the SH expansion.
-T tide-system	Tide system (tide-free, mean-tide, zero-tide).
-InDemFile dem_file_name	Input DEM altitude grid function.
-OutFile output_file_name	Output File for resulting Grid Function.
Use the command: **gut verticaldeflectionnorth_gf --man** to get more information	

Use case n° 1: Compute and plot north deflection from the vertical in the Himalayas mountains area.

gut verticaldeflectionnorth_gf -InFile GO_CONS_EGM_GOC_2__20091101T000000_20100630T235959_0002.DBL **-InDemFile** GUT_ACE2_5M.nc **-R 60:100,10:60 -I 1.0:1.0 -Ellipse TOPEX -Dkm 100 -T mean-tide -OutFile** verticaldeflectionnorth_dir_hymalayas.nc

BratDisplay verticaldeflectionnorth_dir_hymalayas.nc

The two command lines above produced the following plot:

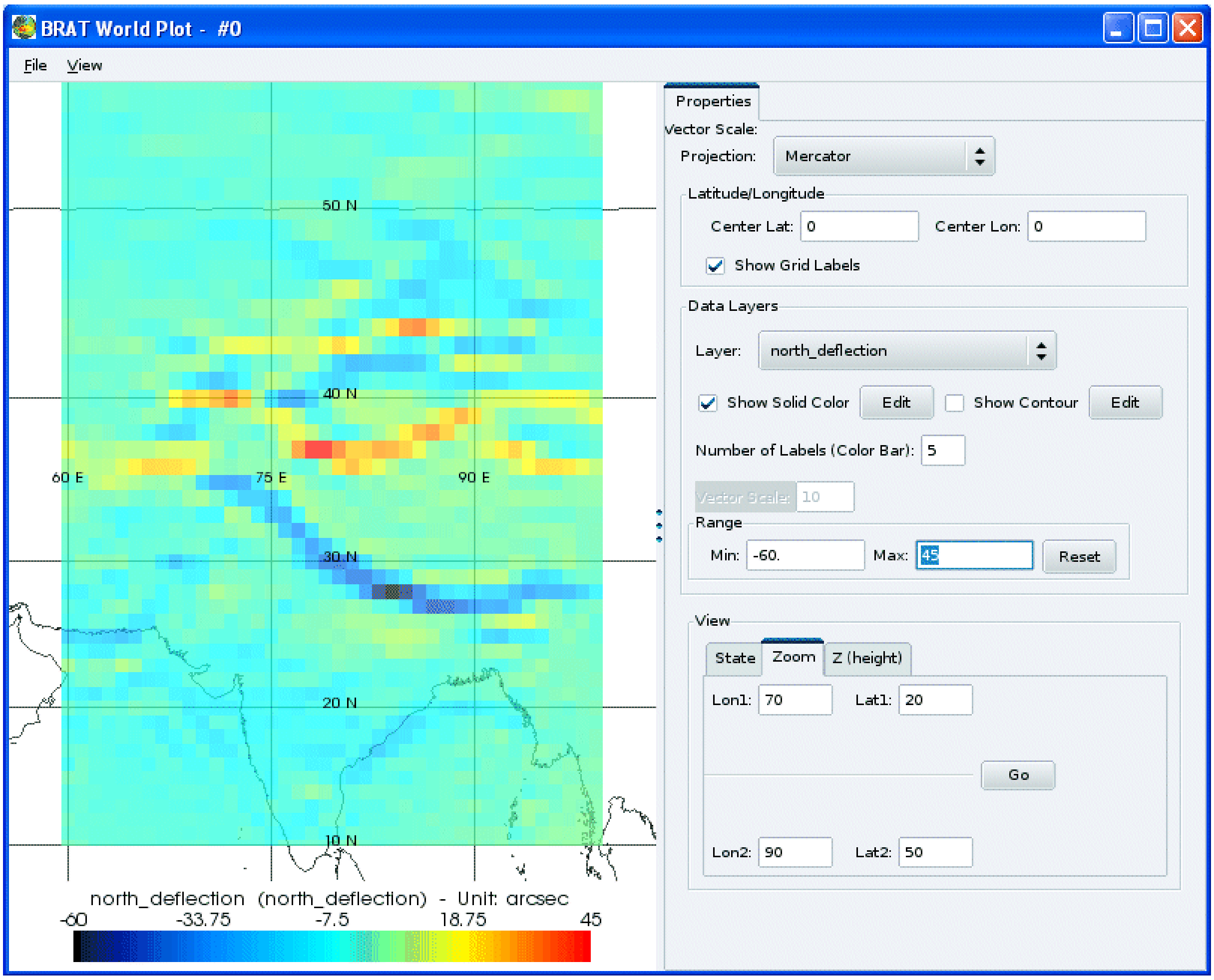


Figure 4: Map of north vertical deflections obtained over the Himalayas mountains using the verticaldeflectionnorth_gf workflow. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

7.3.2. gravityanomaly_gf: compute a grid of gravity anomalies

gravityanomaly_gf	
Options	**Expected field**
-InFile input_file_name	Input File containing Spherical Harmonic Potential.
-Gf input_grid_file OR **-Af input_grid_file OR** **-R w:e,s:n** **-I dE:dN**	Specify file that defines output grid Read lon/lat axes of output grid from file Output Grid Region. (0.5:359.5,-89.5:89.5) Output Grid Spacing. (1.0,1.0)
-Ellipse ellipse	Reference Ellipsoid for Output Grid by one of name (ellipse is GRS80, TOPEX, or WGS84) parameters (ellipse is inverse_flattening:a:GM) file (ellipse is filename)
-DO degreeAndOrder OR **-Ddeg degrees OR** **-Dkm length**	Degree and Order of the SH expansion.
-T tide-system	Tide system (tide-free, mean-tide, zero-tide).
-InDemFile dem_file_name	Input DEM altitude grid function.
-OutFile output_file_name	Output File for resulting Grid Function.
Use the command: **gut gravityanomaly_gf --man** to get more information	

Use case n° 2: Compute and plot gravity anomaly in the Alps mountains area from spherical harmonic potential in ICGEM format.

gut gravityanomaly_gf -InFile EIGEN-5C.gfc -InDemFile GUT_ACE2_5M.nc **-R 0:20,40:50 -I 0.1:0.1** -OutFile gravity_anomaly_eigen5c_alps.nc

BratDisplay gravity_anomaly_eigen5c_alps.nc

The two command lines above produced the following plot:

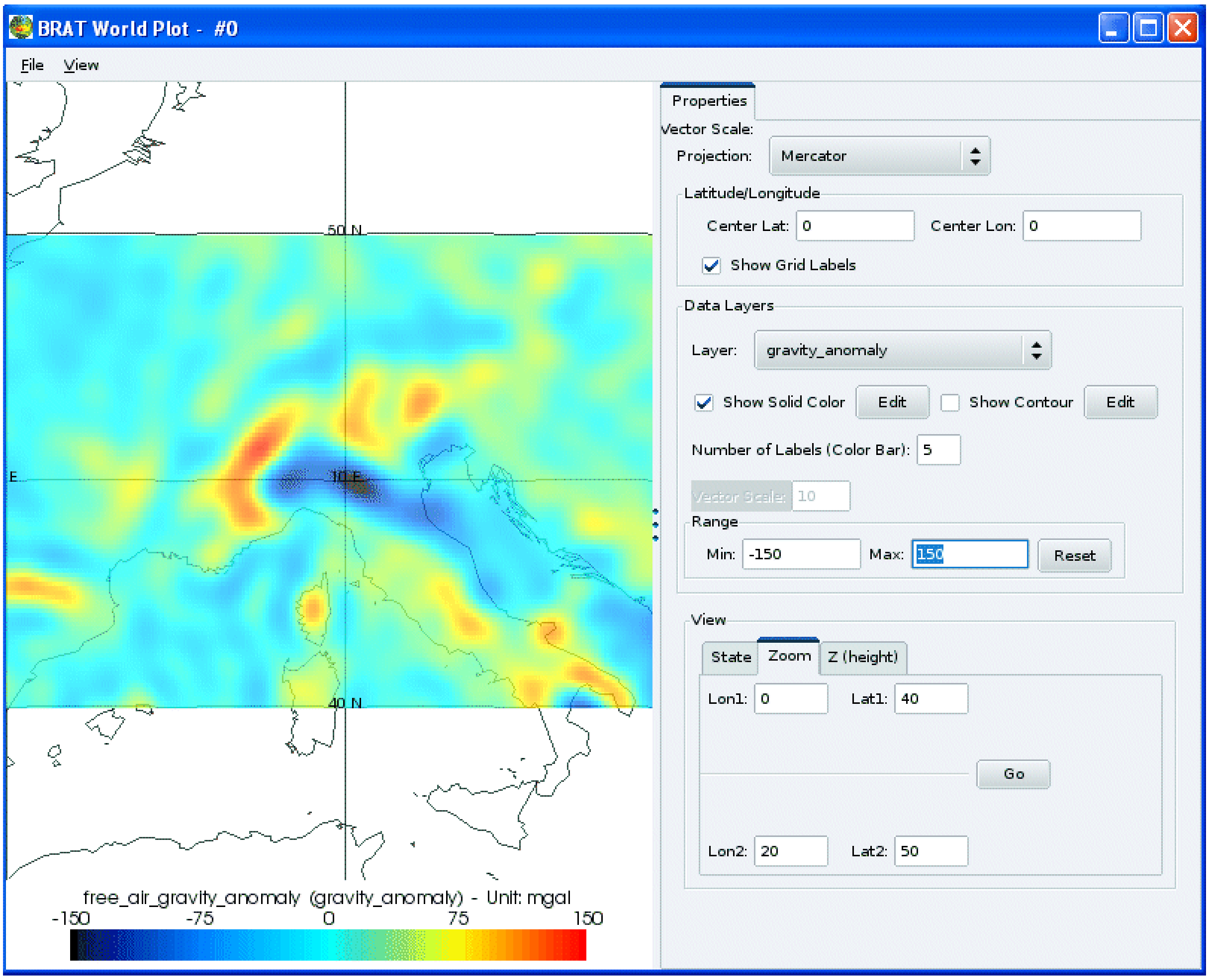


Figure 5: Map of gravity anomalies obtained over the Alps using the gravityanomaly_gf workflow. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

7.3.3. freeairgravityanomaly_gf: compute a grid of free air gravity anomalies

Unlike Molodensky's gravity anomaly evaluated with respect to a topography, the free air anomaly is evaluated with respect to the geoid and to the ellipsoid surface (see user manual for more information).

freeairgravityanomaly_gf	
Options	**Expected field**
-InFile input_file_name	Input File containing geopotential
-Gf input_grid_file OR	Specify file that defines output grid
-Af input_grid_file OR	Read lon/lat axes of output grid from file

-R w:e,s:n	Output Grid Region. (0.5:359.5,-89.5:89.5)
-I dE:dN	Output Grid Spacing. (1.0,1.0)
-Ellipse ellipse	Reference Ellipsoid for Output Grid by one of name (ellipse is GRS80, TOPEX, or WGS84) parameters (ellipse is inverse_flattening:a:GM) file (ellipse is filename)
-DO degreeAndOrder OR **-Ddeg degrees OR** **-Dkm length**	Degree and Order of the SH expansion.
-T tide-system	Tide system (tide-free, mean-tide, zero-tide).
-OutFile output_file_name	Output File for resulting Grid Function.
Use the command: **gut freeairgravityanomaly_gf --man** to get more information	

Use case n° 3: Compute and plot free air gravity anomaly in the Alps mountains area from spherical harmonic potential in ICGEM format.

gut freeairgravityanomaly_gf **-InFile** EIGEN-5C.gfc **-R 0:20,40:50 -I 0.1:0.1 -OutFile** free_air_gravity_anomaly_eigen5c_alps.nc

BratDisplay free_air_gravity_anomaly_eigen5c_alps.nc

The two command lines above produced the following plot:

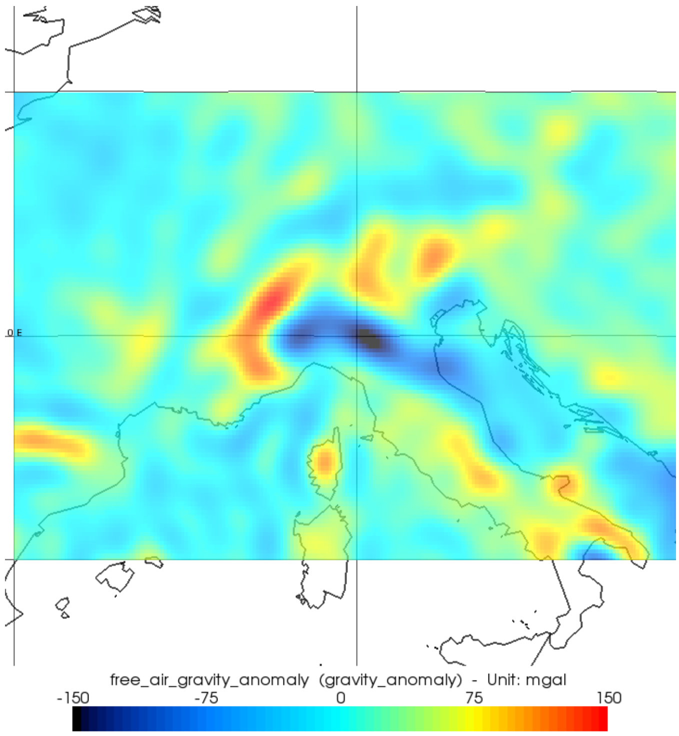


Figure 6: Map of free air gravity anomalies obtained over the Alps using the freeairgravityanomaly_gf workflow. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

Note that the result (Figure 6) is not the same than the one obtained with the workflow gravityanomaly_gf (Figure 5) as shown by the difference of the 2 figures (Figure 7).

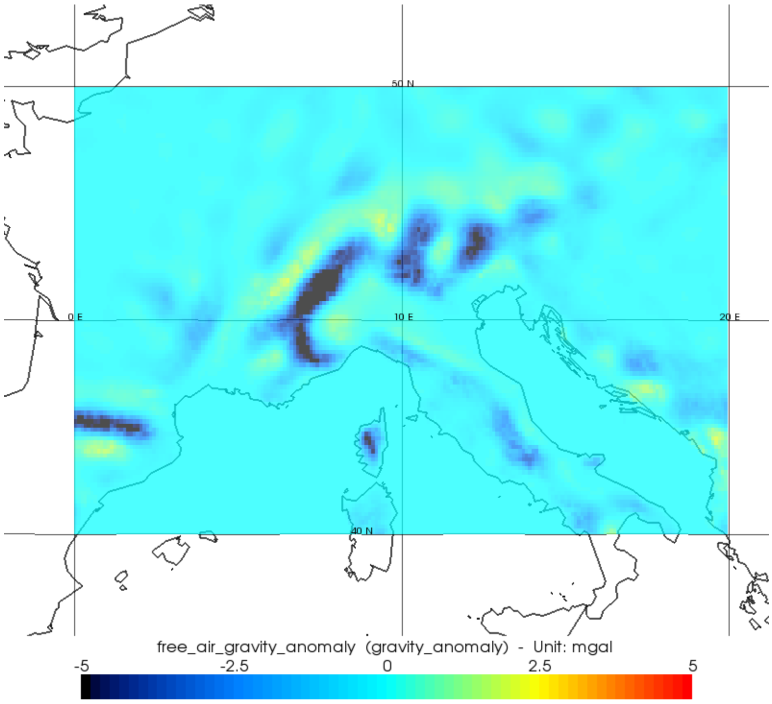


Figure 7: Difference between result from gravityanomaly_gf (Figure 5) and result form freeairgravityanomaly_gf (Figure 6) computing using the workflow subtract_gf (see section 7.3.6).The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

7.3.4. gravitydisturbance_gf/tf: Compute the gravity disturbance

gravitydisturbance_gf	
Options	**Expected field**
-InFile input_file_name	Input File containing the geopotential
-Gf input_grid_file **OR** **-Af input_grid_file** **OR** **-R w:e,s:n** **-I dE:dN**	Specify file that defines output grid Read lon/lat axes of output grid from file Output Grid Region. (0.5:359.5,-89.5:89.5) Output Grid Spacing. (1.0,1.0)
-Ellipse ellipse	Reference Ellipsoid for Output Grid by one of - name (ellipse is GRS80, TOPEX, or WGS84) - parameters (ellipse is inverse_flattening:a:GM) - file (ellipse is filename)
-DO degreeAndOrder **OR** **-Ddeg degrees** **OR** **-Dkm length**	Degree and Order of the SH expansion.
-T tide-system	Tide system (tide-free, mean-tide, zero-tide).

-InDemFile dem_file_name	Input DEM altitude grid function. This must provide the height of the terrain above the ellipsoid.
-OutFile output_file_name	Output File for resulting Grid Function.
Use the command: **gut gravitydisturbance_gf --man** to get more information	

gravitydisturbance_tf	
Options	**Expected field**
-InFile input_file_name	Input File containing the geopotential
-InAltFile input_alt_file	Input file containing the altitude track function. The altitudes must be heights above ellipsoid.
-T tide-system	Tide system (tide-free, mean-tide, zero-tide).
-OutFile output_file_name	Output File for resulting Grid Function.
Use the command: **gut gravitydisturbance_tf --man** to get more information	

Use case n° 4: Compute and plot gravity disturbance in the Alps mountains area from spherical harmonic potential in ICGEM format.

---

gut gravitydisturbance_gf **-InFile** EIGEN-5C.gfc **-R 0:20,40:50 -I 0.1:0.1 -InDemFile** GUT_ACE2_5M.nc **-OutFile** gravity_disturbance_eigen5c_alps.nc

BratDisplay gravity_disturbance_eigen5c_alps.nc

The two command lines above produced the following plot:

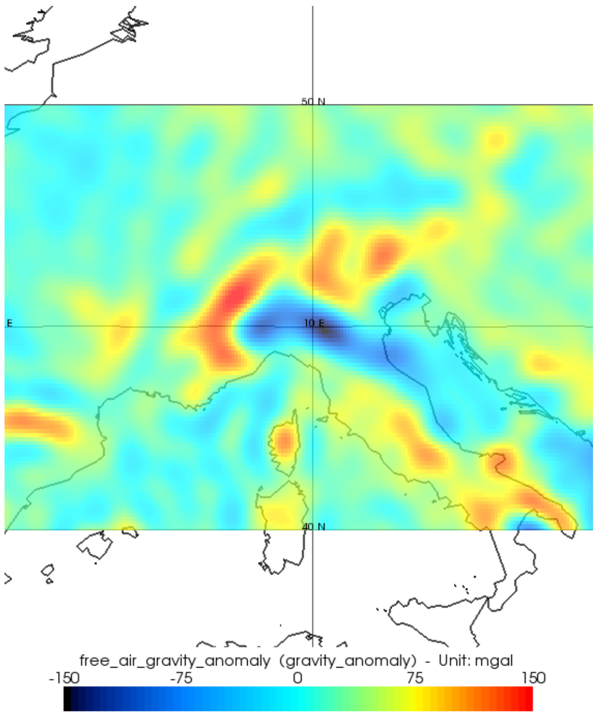


Figure 8: Map of gravity disturbance obtained over the Alps using the gravitydisturbance_gf workflow. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

Note that the result (Figure 8) is not the same than the one obtained with the workflow gravityanomaly_gf (Figure 5) as shown by the difference of the 2 figures (9).

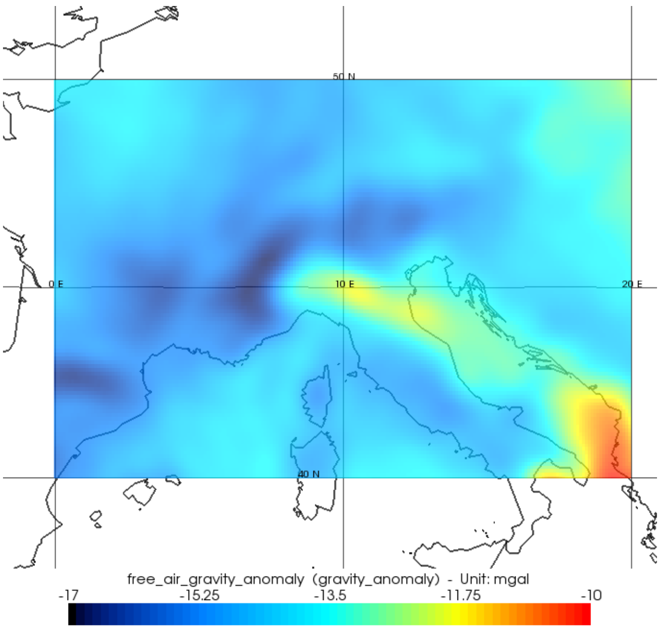


Figure 9: Difference between result from gravityanomaly_gf (Figure 5) and result from gravitydisturbance_gf (Figure 8) computing using the workflow subtract_gf (see section 7.3.6).The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

7.3.5. geoidheight_gf: Compute a grid of geoid heights

geoidheight_gf	
Options	**Expected field**
-InFile input_file_name	Input File containing Spherical Harmonic Potential.
-Gf input_grid_file OR	Specify file that defines output grid
-Af input_grid_file OR	Read lon/lat axes of output grid from file
-R w:e,s:n	Output Grid Region. (0.5:359.5,-89.5:89.5)
-I dE:dN	Output Grid Spacing. (1.0,1.0)
-Ellipse ellipse	Reference Ellipsoid for Output Grid by one of name (ellipse is GRS80, TOPEX, or WGS84) parameters (ellipse is inverse_flattening:a:GM)

	file (ellipse is filename)
-DO degreeAndOrder OR **-Ddeg degrees OR** **-Dkm length**	Degree and Order of the SH expansion.
-T tide-system	Tide system (tide-free, mean-tide, zero-tide).
-InDemFile dem_file_name	Input DEM altitude grid function.
-OutFile output_file_name	Output File for resulting Grid Function.
Use the command: **gut geoidheight_gf --man** to get more information	

Use case n° 5: Compute and plot a global grid of geoid heights at maximum degree/order of spherical harmonics expansion.

gut geoidheight_gf -InFile GO_CONS_EGM_GOC_2__20091101T000000_20100630T235959_0002.DBL -OutFile geoidheight_TW.nc

BratDisplay geoidheight_TW.nc

The two command lines above produced the following plot:

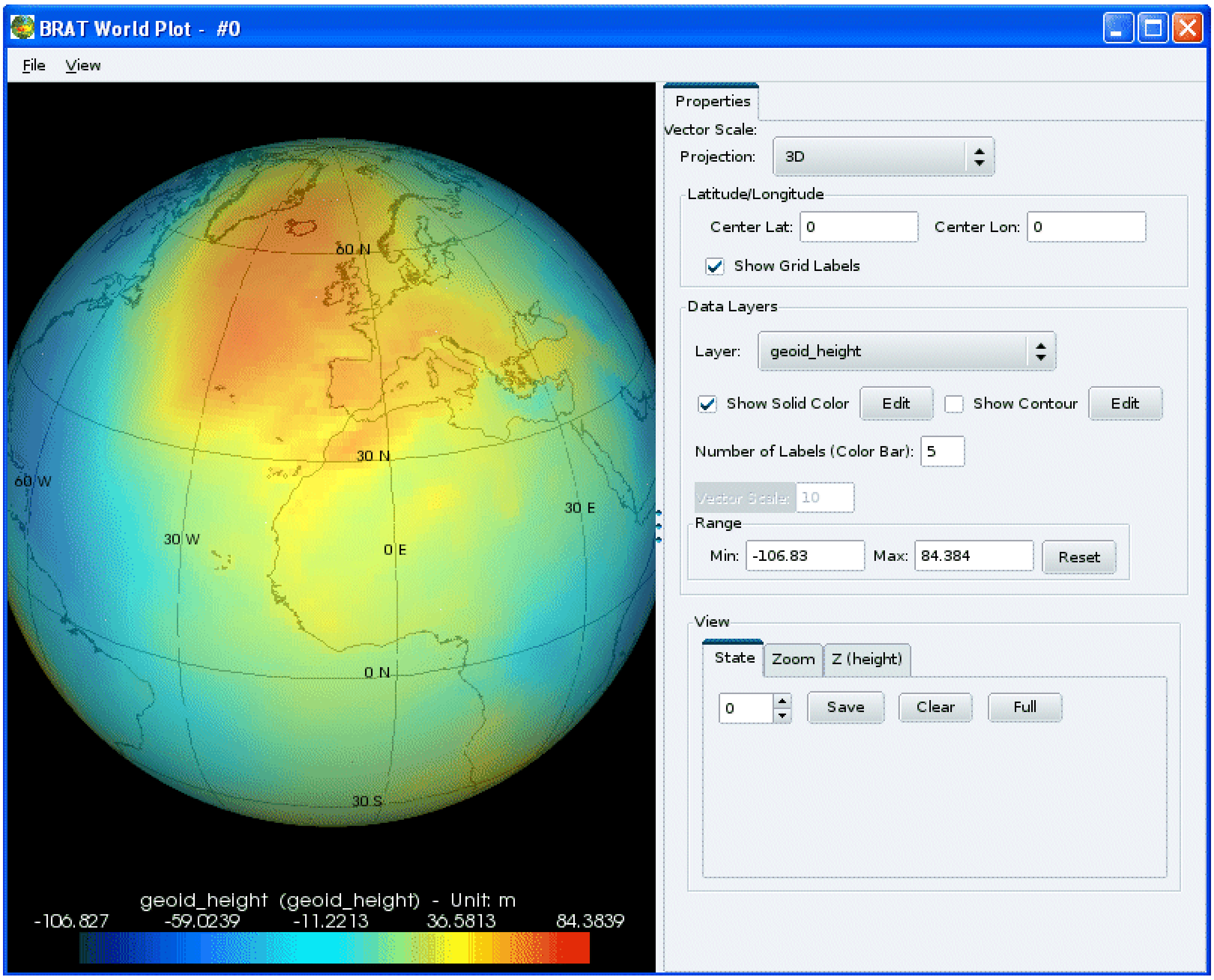


Figure 10: Map of geoid heights obtained using the geoidheight_gf command

The -T and -Ellipse options having not been set, the resulting geoid height was computed in its own reference system (tide-free and with respect to the GRS80 reference ellipsoid - see section 7.1).

Use case n° 6: Compute and plot a regional grid of geoid heights in the mean tide system and relative to the Topex ellipsoid over India and the North Indian ocean at degree/order 20 of spherical harmonics expansion.

gut geoidheight_gf -InFile GO_CONS_EGM_GOC_2__20091101T000000_20100705T235500_0002.DBL **-R 60:120,-30:30 -I 0.1:0.1 -DO 20 -T mean-tide -Ellipse TOPEX -OutFile** geoidheight_TW_MT_TOPEX_DO20_india.nc

BratDisplay geoidheight_TW_MT_TOPEX_DO20_india.nc

The two command lines above produced the following plot:

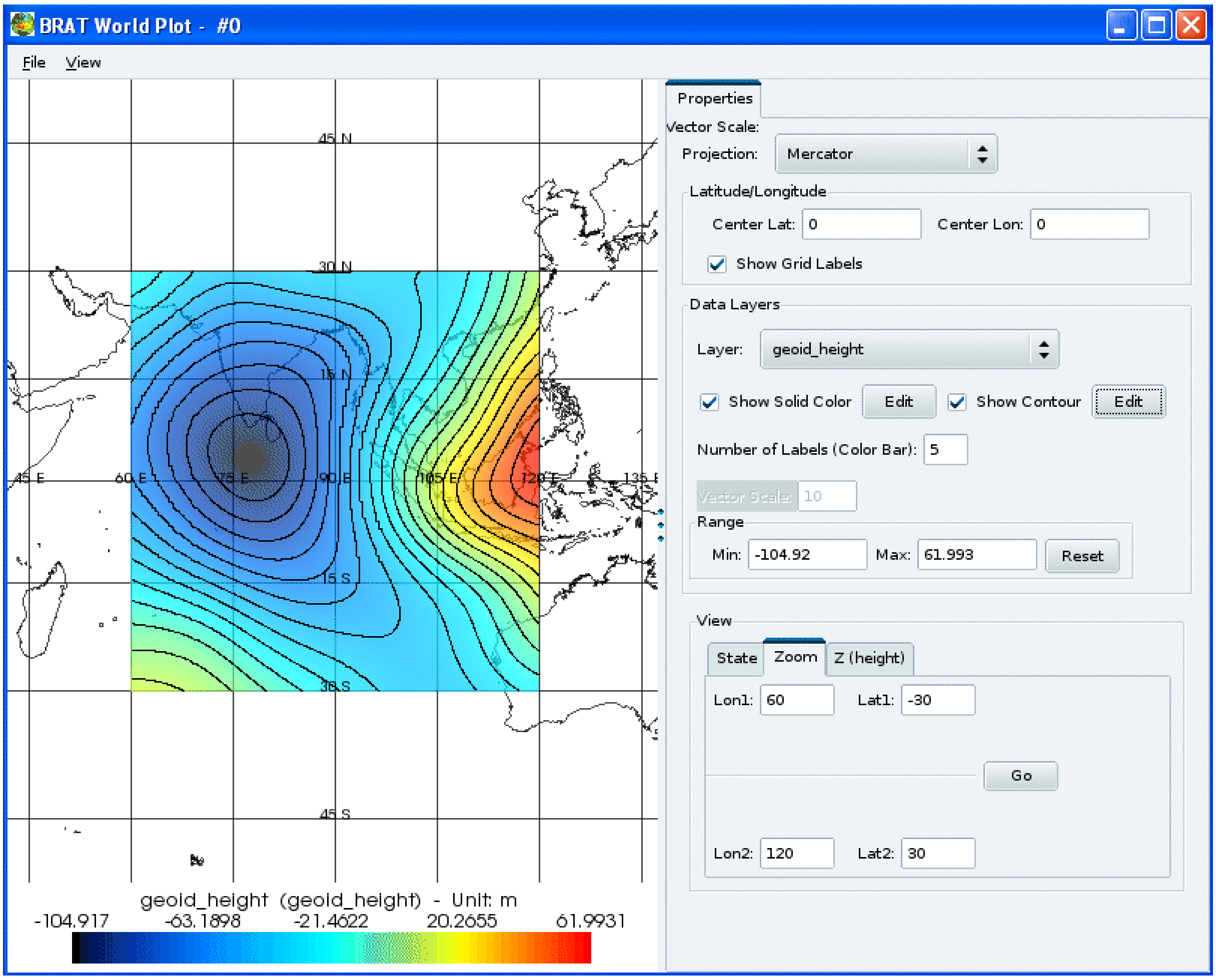


Figure 11: Map of geoid heights relative to the TOPEX ellipsoid and for the mean-tide system in the north-East Indian ocean developed at degree/order 20 using the geoidheight_gf workflow

7.3.6. subtract_gf: Compute the difference between two grid

subtract_gf	
Options	**Expected field**
-InFileLhs input_file_name	Input File containing the grid function of the Left Hand Side (LHS) operand
-InFileRhs input_file_name	Input File containing the grid function of the Right Hand Side (RHS) operand
-PQ1 physical quantity	Specifies the required data set for the LHS operand. If the input file lacks the meta-data to allow this to be used for selection of the data set, it is used to explicitly set the physical quantity of the LHS operand. (Accepted tokens are listed in Appendix A)
-PQ2 physical quantity	Specifies the required data set for the RHS operand. If the input file lacks the meta-data to

	allow this to be used for selection of the data set, it is used to explicitly set the physical quantity of the RHS operand. (Accepted tokens are listed in Appendix A)
-PQ physical quantity	Specifies the physical quantity of the output (Accepted tokens are listed in Appendix A)
-OutFile output_file_name	Output File for resulting Grid Function.
Use the command line: **gut subtract_gf -man** to get more information	

Use case n° 7: Compute the difference between the GOCE geoid (Time-Wise model) and the EIGEN-GRGS.RL02.MEAN-FIELD geoid both developed at degree/order 160 of spherical harmonic expansion.

gut subtract_gf -InFileLhs geoidheight_EIGEN_DO160_MT_TP.nc -InFileRhs geoidheight_TW_DO160_MT_TP.nc -OutFile Diff_geoidheight_EIGEN_TW_DO160.nc

BratDisplay Diff_geoidheight_EIGEN_TW_DO160.nc

The two command lines above produced the following plot:

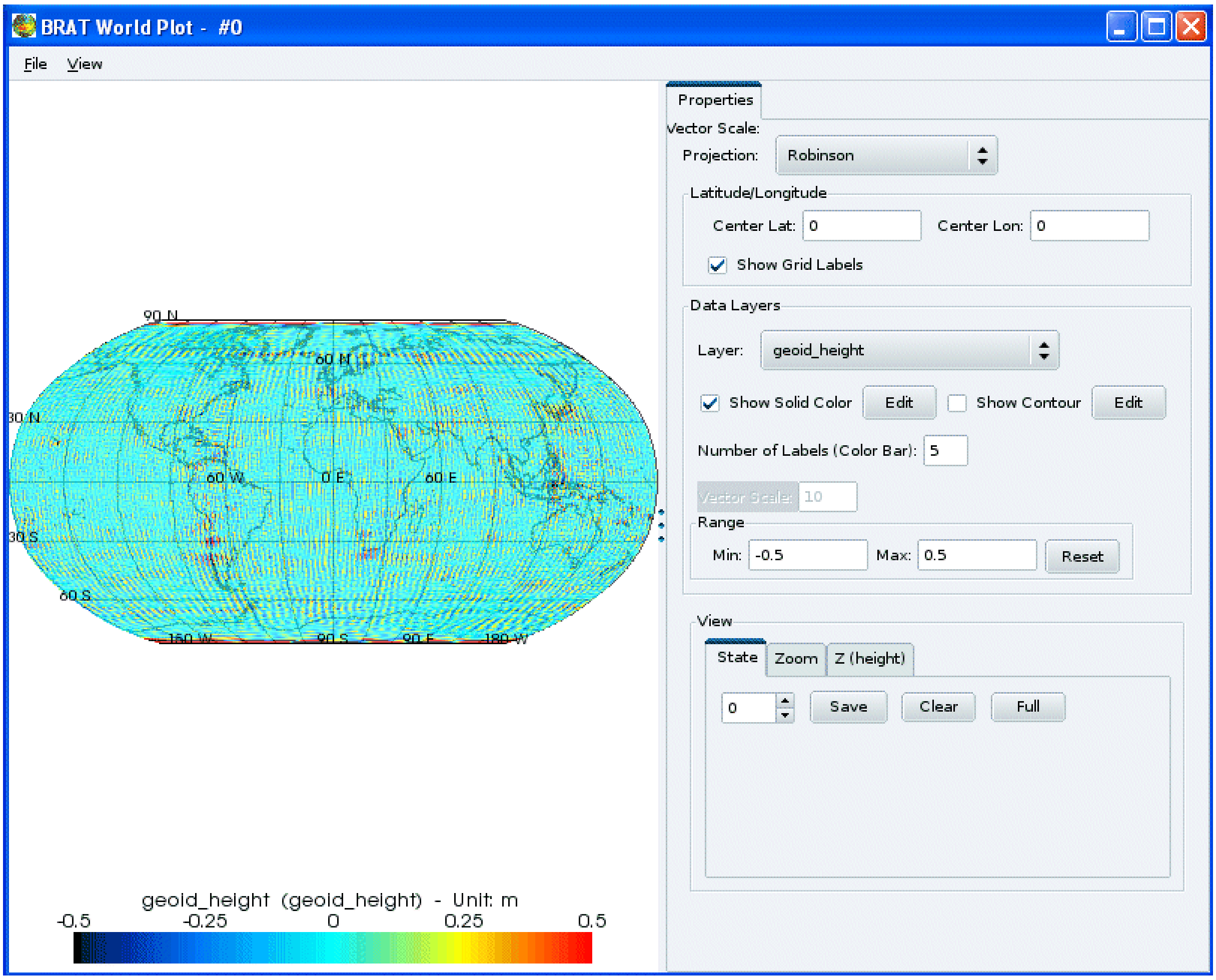


Figure 12: Map of differences between two different geoids computed using the subtract_gf workflow. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

Note:

-The geoidheight_EIGEN_DO160_MT_TP.nc and geoidheight_TW_DO160_MT_TP.nc files were obtained using the geoidheight_gf workflow:

gut geoidheight_gf -InFile EIGEN-GRGS.RL02.MEAN-FIELD_2005.nc **-T mean-tide -Ellipse TOPEX -DO 160** -OutFile geoidheight_EIGEN_DO160_MT_TP.nc

gut geoidheight_gf -InFile GO_CONS_EGM_GOC_2__20091101T000000_20100705T235500_0002.DBL **-T mean-tide -Ellipse TOPEX -DO 160** -OutFile geoidheight_TW_DO160_MT_TP.nc

7.3.7. stats_gf: Compute basic statistics from a grid

stats_gf	
Options	**Expected field**
-InFile input_file_name	Input File containing Spherical Harmonic Potential.
-PQ physical quantity	Specify/set physical quantity of data set (Accepted tokens are listed in Appendix A)
-InMinLat minimum latitude	Specify the minimum latitude limit for values of the grid to be included in the statistics. Range [-90,90]
-InMaxLat maximum latitude	Specify the maximum latitude limit for values of the grid to be included in the statistics. Range [-90,90]
-InMinLon minimum longitude	Specify the minimum longitude limit for values of the grid to be included in the statistics. Range [0,360]
-InMaxLon maximum longitude	Specify the maximum longitude limit for values of the grid to be included in the statistics. Range [0,360]
-StepM step_value **OR** **-StepZ step_value**	Specify meridional bands or zonal bands every step_value degree
Use the command line: **gut stats_gf -man** to get more information	

Use case n° 8: Compute global basic statistics over 20° zonal bands

Typing

gut stats_gf -InFile MDT_DTU_10_10M.nc **-StepZ** 20

will give you:

```
INFO:    Extracted 'mdt'
INFO:    (Stats) Bounds [-89.9167, -69.9167] N,  [-0.0832562, 360.083] E
INFO:    (Stats) mdt
         Lon x Lat : 2160 x 121
         Maximum   : 0.035 m at (164.402 E, -80.0833 N)
         Minimum   : -1.919 m at (276.339 E, -75.4167 N)
         Mean      : -1.15216 m
         Variance  : 0.0774129  =>  RMS : 0.278232 m
         W-Mean    : -1.1626 m
         W-Var     : 0.0686116  =>  RMS : 0.261938 m
         Valid     : 63976 / 261360  (24.5%)

INFO:    (Stats) Bounds [-69.9167, -49.9167] N,  [-0.0832562, 360.083] E
INFO:    (Stats) mdt
         Lon x Lat : 2160 x 120
         Maximum   : 1.208 m at (287.182 E, -49.9167 N)
         Minimum   : -1.934 m at (295.69 E, -68.0833 N)
         Mean      : -0.814424 m
         Variance  : 0.269258  =>  RMS : 0.5189 m
         W-Mean    : -0.755343 m
         W-Var     : 0.289886  =>  RMS : 0.538411 m
         Valid     : 256638 / 259200  (99%)

INFO:    (Stats) Bounds [-49.9167, -29.9167] N,  [-0.0832562, 360.083] E
INFO:    (Stats) mdt
         Lon x Lat : 2160 x 120
         Maximum   : 1.33 m at (28.9436 E, -35.4167 N)
         Minimum   : -0.86 m at (352.91 E, -49.75 N)
         Mean      : 0.474862 m
         Variance  : 0.113564  =>  RMS : 0.336993 m
         W-Mean    : 0.493952 m
         W-Var     : 0.107465  =>  RMS : 0.327819 m
         Valid     : 251827 / 259200  (97.2%)

INFO:    (Stats) Bounds [-29.9167, -9.91667] N,  [-0.0832562, 360.083] E
INFO:    (Stats) mdt
         Lon x Lat : 2160 x 120
         Maximum   : 1.871 m at (37.4515 E, -15.4167 N)
         Minimum   : -0.645 m at (291.687 E, -23.0833 N)
         Mean      : 0.83141 m
         Variance  : 0.070305  =>  RMS : 0.265151 m
         W-Mean    : 0.832491 m
         W-Var     : 0.0707433  =>  RMS : 0.265976 m
         Valid     : 217556 / 259200  (83.9%)

INFO:    (Stats) Bounds [-9.91667, 10.0833] N,  [-0.0832562, 360.083] E
INFO:    (Stats) mdt
         Lon x Lat : 2160 x 120
         Maximum   : 1.804 m at (139.379 E, -3.75 N)
         Minimum   : -0.444 m at (125.7 E, 7.75 N)
         Mean      : 0.786359 m
         Variance  : 0.0619239  =>  RMS : 0.248845 m
         W-Mean    : 0.786399 m
         W-Var     : 0.0619124  =>  RMS : 0.248822 m
         Valid     : 220503 / 259200  (85.1%)
```

```
INFO:   (Stats) Bounds [10.0833, 30.0833] N,  [-0.0832562, 360.083] E
INFO:   (Stats) mdt
        Lon x Lat : 2160 x 120
        Maximum   : 1.916 m at (95.672 E, 20.25 N)
        Minimum   : -1.86 m at (31.4459 E, 26.5833 N)
        Mean      : 0.80574 m
        Variance  : 0.130442  =>  RMS : 0.361168 m
        W-Mean    : 0.806871 m
        W-Var     : 0.129108  =>  RMS : 0.359316 m
        Valid     : 204785 / 259200  (79%)

INFO:   (Stats) Bounds [30.0833, 50.0833] N,  [-0.0832562, 360.083] E
INFO:   (Stats) mdt
        Lon x Lat : 2160 x 120
        Maximum   : 1.633 m at (135.042 E, 31.0833 N)
        Minimum   : -1.924 m at (49.2958 E, 35.0833 N)
        Mean      : 0.32233 m
        Variance  : 0.216414  =>  RMS : 0.465204 m
        W-Mean    : 0.337296 m
        W-Var     : 0.220605  =>  RMS : 0.469686 m
        Valid     : 173150 / 259200  (66.8%)

INFO:   (Stats) Bounds [50.0833, 70.0833] N,  [-0.0832562, 360.083] E
INFO:   (Stats) mdt
        Lon x Lat : 2160 x 121
        Maximum   : 1.465 m at (229.296 E, 58.0833 N)
        Minimum   : -0.716 m at (233.967 E, 53.25 N)
        Mean      : 0.089287 m
        Variance  : 0.0879873  =>  RMS : 0.296627 m
        W-Mean    : 0.0940358 m
        W-Var     : 0.0895725  =>  RMS : 0.299287 m
        Valid     : 152925 / 261360  (58.5%)

INFO:   (Stats) Bounds [70.0833, 89.9167] N,  [-0.0832562, 360.083] E
INFO:   (Stats) mdt
        Lon x Lat : 2160 x 119
        Maximum   : 0.75 m at (143.383 E, 70.25 N)
        Minimum   : -1.39 m at (102.845 E, 75.0833 N)
        Mean      : 0.0363978 m
        Variance  : 0.0379125  =>  RMS : 0.194711 m
        W-Mean    : 0.023286 m
        W-Var     : 0.0477036  =>  RMS : 0.218412 m
        Valid     : 244467 / 257040  (95.1%)
```

Use case n° 9: Compute basic statistics from the grid above over the Himalayas.

Typing

gut stats_gf **-InFile** Diff_geoidheight_EIGEN_TW_DO160.nc **-InMinLon** 60 **-InMaxLon** 100 **-InMinLat** 10 **-InMaxLat** 60

Will give you:

```
INFO:   Extracted 'geoid_height'
INFO:   (Stats) Bounds [10, 60] N,  [60, 100] E
INFO:   (Stats) geoid_height
        Lon x Lat : 40 x 50
        Maximum   : 0.454165 m at (84.5 E, 46.5 N)
        Minimum   : -0.518059 m at (79.5 E, 47.5 N)
        Mean      : -0.00275741 m
        Variance  : 0.0208269  =>  RMS : 0.144315 m
        W-Mean    : -0.0018455 m
        W-Var     : 0.0210063  =>  RMS : 0.144935 m
        Valid     : 2000 / 2000  (100%)
```

You may use BratDisplay to plot the difference map over the Himalayas mountains region:

Typing

BratDisplay Diff_geoidheight_EIGEN_TW_DO160.nc

Will give you (after zooming on the Himalayas mountains area using the BratDisplay GUI):

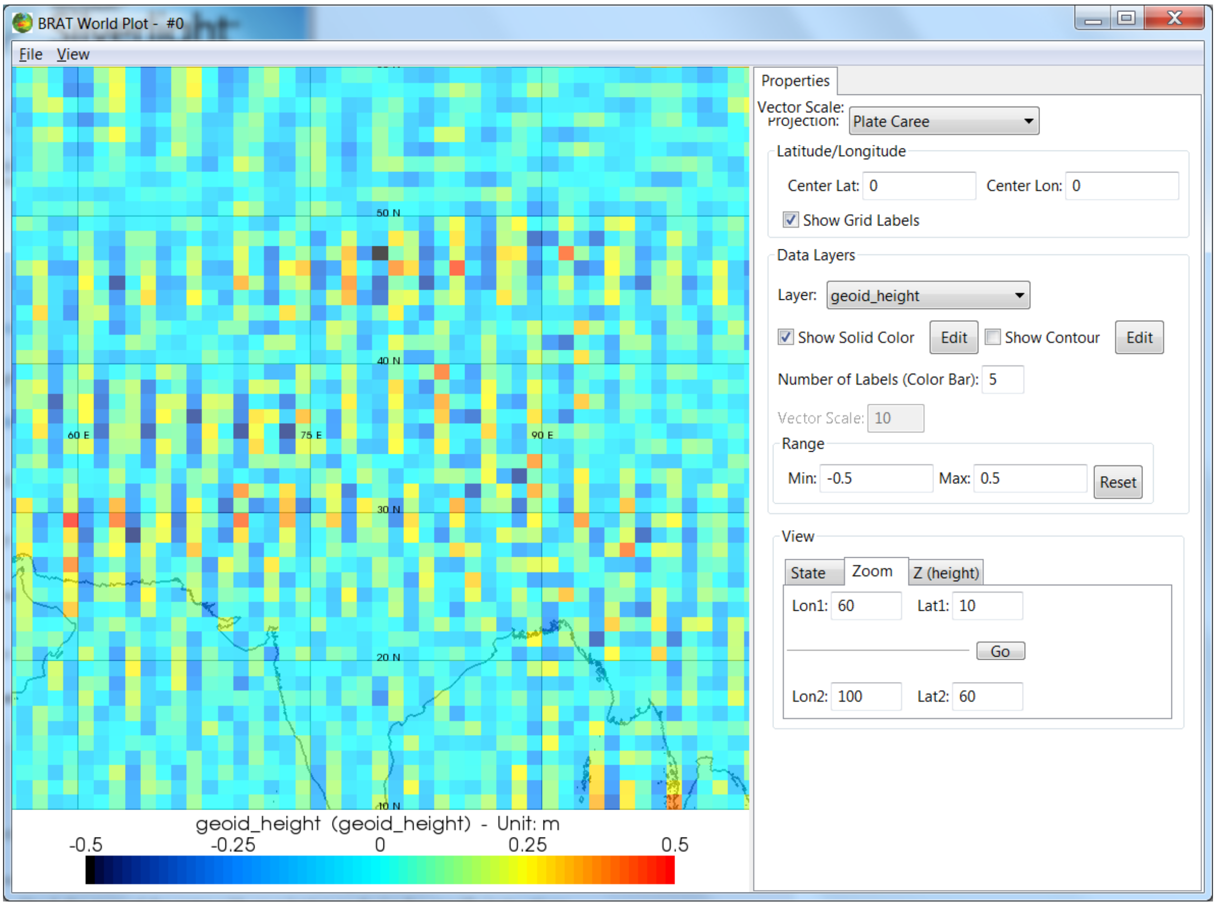


Figure 13: Maps of differences between the EIGEN-GRGS.RL02.MEAN-FIELD geoid and the GOCE time_wise geoid over the Hymalayas mountains. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

7.3.8. changetide_gf/ changetide_shf / changetide_tf : change tide system

changetide_gf/ changetide_shf / changetide_tf	
Options	Expected field
-InFile input_file_name	Input_file_name
-PQ physical_quantity*	Physical quantity (Accepted tokens are listed in Appendix A)
-T tide-system	Tide-system (tide-free, mean-tide, zero-tide)
-OutFile output file name	Output file name
* for changetide_gf and changetide_tf only	
Use the command: **gut -man changetide_shf (_gf or _tf)** to get more information	

WARNING: If the 'tide-system' attribute from InFile is not defined, this command will set the attribute to "mean-tide" but values of the grid will NOT be changed.

Use case n° 10: Transform the geoid height computed in use case n°5 from tide-free to mean-tide system

gut changetide_gf **-InFile** geoidheight_TW.nc **-OutFile** geoidheight_TW_MT.nc **-T mean-tide**

BratDisplay geoidheight_TW_MT.nc

The two command lines above produced the following plot:

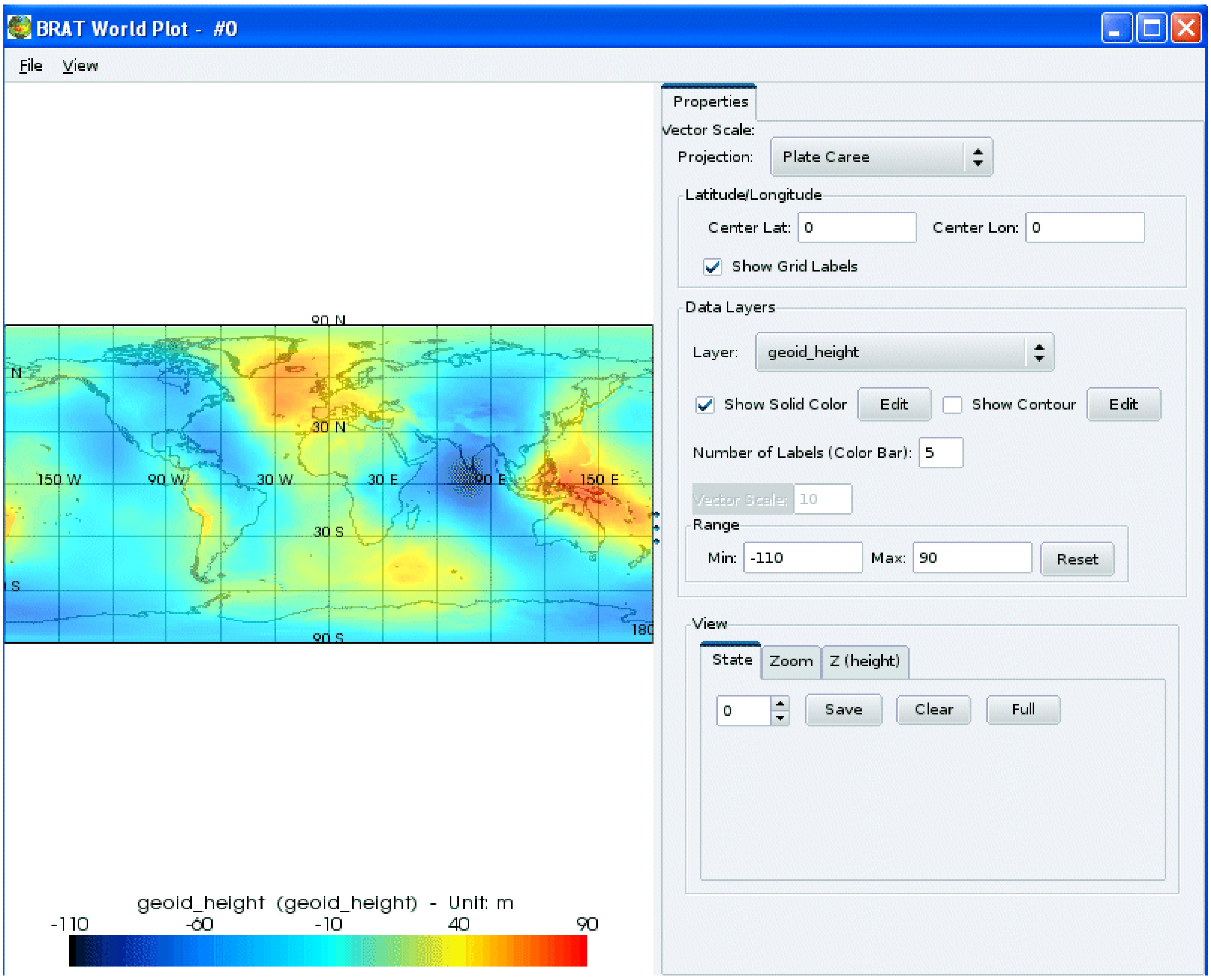


Figure 14: Map of geoid heights in the mean-tide system computed using the changetide_gf workflow. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

7.3.9. changeellipse_gf: Change reference ellipsoid

changeellipse_gf	
Options	Expected field
-InFile input_file_name	Input file containing grid function
-PQ physical_quantity	Specify/set the physical quantity of the data set (Accepted tokens are listed in Appendix A)
-Ellipse	Ellipsoid specified as one of ... * ellipsoid name GRS80 TOPEX GRIM WGS84 WGS84rev1 * the parameter inverse_flattening:a:GM * filename extracts the ellipsoid from the meta-data in this file
-OutFile output_file_name	Output file name
Use the command: **gut changeellipse -man** to get more information	

Use case n° 11: Compute the geoid height from Use case n° 6 in the TOPEX ellipsoid (see section 6.2.1 for the ellipsoid characteristics)

gut changeellipse_gf -InFile geoidheight_TW_MT.nc **-Ellipse TOPEX** -OutFile geoidheight_TW_MT_TP.nc

Below are displayed the headers of the NetCdf files (ellipsoid description given in the 'crs' variable) before (Figure 15) and after (Figure 16) the ellipsoid system transformation.

Note: Another possibility to transform a geoid height from the GRS80 ellipsoid to the TOPEX ellipsoid is to apply the geoidheight_gf workflow on the spherical harmonics potential typing:

gut geoidheight_gf -InFile GO_CONS_EGM_GOC_2__20091101T000000_20100630T235959_0002.DBL **-Ellipse TOPEX -T mean-tide** -OutFile geoidheight_TW_MT_TP_2.nc

However, the resulting grid is 23.2386 cm (+-5mm) higher than the previous geoidheight_TW_MT_TP.nc grid. The reason for this bias is that the changeellipse_gf is a purely geometric transformation that is applied to the geoid height. On the contrary, applying geoidheight_gf to a spherical harmonic potential results in calculating the geoid height as a first order approximation to finding the position where the 'real' potential is the same as the model potential defined by the ellipsoid.

For oceanographic applications, this bias is not an issue: Geostrophic ocean currents are proportional to the first derivative of the MDT (Eq. 6).

However, the 23.2386 cm bias can be added to the geoidheight_TW_MT_TP.nc grid function in order to match the geoidheight_TW_MT_TP_2.nc values using the addscalar_gf workflow (see use case n°9 below).

```
netcdf geoidheight_TW_MT {
dimensions:
        lat = 180 ;
        lon = 360 ;
variables:
        double lat(lat) ;
                lat:long_name = "latitude" ;
                lat:standard_name = "latitude" ;
                lat:units = "degrees_north" ;
        double lon(lon) ;
                lon:long_name = "longitude" ;
                lon:standard_name = "longitude" ;
                lon:units = "degrees_east" ;
        double geoid_height(lat, lon) ;
                geoid_height:standard_name = "geoid_height_above_reference_ellipsoid" ;
                geoid_height:long_name = "geoid_height" ;
                geoid_height:units = "m" ;
                geoid_height:tide_system = "mean_tide" ;
                geoid_height:grid_mapping = "crs" ;
                geoid_height:_FillValue = NaN ;
        int crs ;
                crs:semi_major_axis = 6378137. ;
                crs:inverse_flattening = 298.257222101004 ;
                crs:earth_gravity_constant = 398600500000000. ;
                crs:earth_rotation_rate = 7.292115e-05 ;
                crs:climatology_bounds = "2009-11-1 0:0:0, 2010-7-5 23:55:0" ;

// global attributes:
                :Conventions = "CF-1.1" ;
                :history = "gut changetide_gf -InFile ../tutorial/geoidheight_TW.nc -OutFile ../tutor
ial/geoidheight_TW_MT.nc -T mean-tide" ;
data:

 lat = -89.5, -88.5, -87.5, -86.5, -85.5, -84.5, -83.5, -82.5, -81.5, -80.5,
    -79.5, -78.5, -77.5, -76.5, -75.5, -74.5, -73.5, -72.5, -71.5, -70.5,
    -69.5, -68.5, -67.5, -66.5, -65.5, -64.5, -63.5, -62.5, -61.5, -60.5,
    -59.5, -58.5, -57.5, -56.5, -55.5, -54.5, -53.5, -52.5, -51.5, -50.5,
    -49.5, -48.5, -47.5, -46.5, -45.5, -44.5, -43.5, -42.5, -41.5, -40.5,
    -39.5, -38.5, -37.5, -36.5, -35.5, -34.5, -33.5, -32.5, -31.5, -30.5,
    -29.5, -28.5, -27.5, -26.5, -25.5, -24.5, -23.5, -22.5, -21.5, -20.5,
--Plus--
```

Figure 15: Header of the geoid height grid file referenced to the GRS80 ellipsoid

```
netcdf geoidheight_TW_MT_TP {
dimensions:
        lat = 180 ;
        lon = 360 ;
variables:
        double lat(lat) ;
                lat:long_name = "latitude" ;
                lat:standard_name = "latitude" ;
                lat:units = "degrees_north" ;
        double lon(lon) ;
                lon:long_name = "longitude" ;
                lon:standard_name = "longitude" ;
                lon:units = "degrees_east" ;
        double geoid_height(lat, lon) ;
                geoid_height:standard_name = "geoid_height_above_reference_ellipsoid" ;
                geoid_height:long_name = "geoid_height" ;
                geoid_height:units = "m" ;
                geoid_height:tide_system = "mean_tide" ;
                geoid_height:grid_mapping = "crs" ;
                geoid_height:_FillValue = NaN ;
        int crs ;
                crs:semi_major_axis = 6378136.3 ;
                crs:inverse_flattening = 298.257000000006 ;
                crs:earth_gravity_constant = 398600441500000. ;
                crs:earth_rotation_rate = 7.292115e-05 ;
                crs:climatology_bounds = "2009-11-1 0:0:0, 2010-7-5 23:55:0" ;

// global attributes:
                :Conventions = "CF-1.1" ;
                :history = "gut changeellipse_gf -InFile ../tutorial/geoidheight_TW_MT.nc -Ellipse TO
PEX -OutFile ../tutorial/geoidheight_TW_MT_TP.nc" ;
data:

 lat = -89.5, -88.5, -87.5, -86.5, -85.5, -84.5, -83.5, -82.5, -81.5, -80.5,
    -79.5, -78.5, -77.5, -76.5, -75.5, -74.5, -73.5, -72.5, -71.5, -70.5,
    -69.5, -68.5, -67.5, -66.5, -65.5, -64.5, -63.5, -62.5, -61.5, -60.5,
    -59.5, -58.5, -57.5, -56.5, -55.5, -54.5, -53.5, -52.5, -51.5, -50.5,
    -49.5, -48.5, -47.5, -46.5, -45.5, -44.5, -43.5, -42.5, -41.5, -40.5,
    -39.5, -38.5, -37.5, -36.5, -35.5, -34.5, -33.5, -32.5, -31.5, -30.5,
    -29.5, -28.5, -27.5, -26.5, -25.5, -24.5, -23.5, -22.5, -21.5, -20.5,
--Plus--
```

Figure 16: Header of the geoid height grid file referenced to the TOPEX ellipsoid

7.3.10. addscalar_gf: Adding a scalar to every point of a grid function

Use case n° 12: Add a 23.2386 cm bias to the geoidheight_TW_MT_TP.nc grid function computed previously to match the geoidheight_TW_MT_TP_2.nc values.

gut addscalar_gf **-InFile** geoidheight_TW_MT_TP.nc -InScalar 0.232386 **-OutFile** geoidheight_TW_MT_TP_p23cm.nc

The difference between the two grids can be computed and displayed typing (Figure 17):

gut subtract_gf **-InFileLhs** geoidheight_TW_MT_TP_p23cm.nc **-InFileRhs** geoidheight_TW_MT_TP_2.nc **-OutFile** Diff_geoidheight_TW_MT_TP_p23cm_2.nc

BratDisplay Diff_ geoidheight_TW_MT_TP_p23cm_2.nc

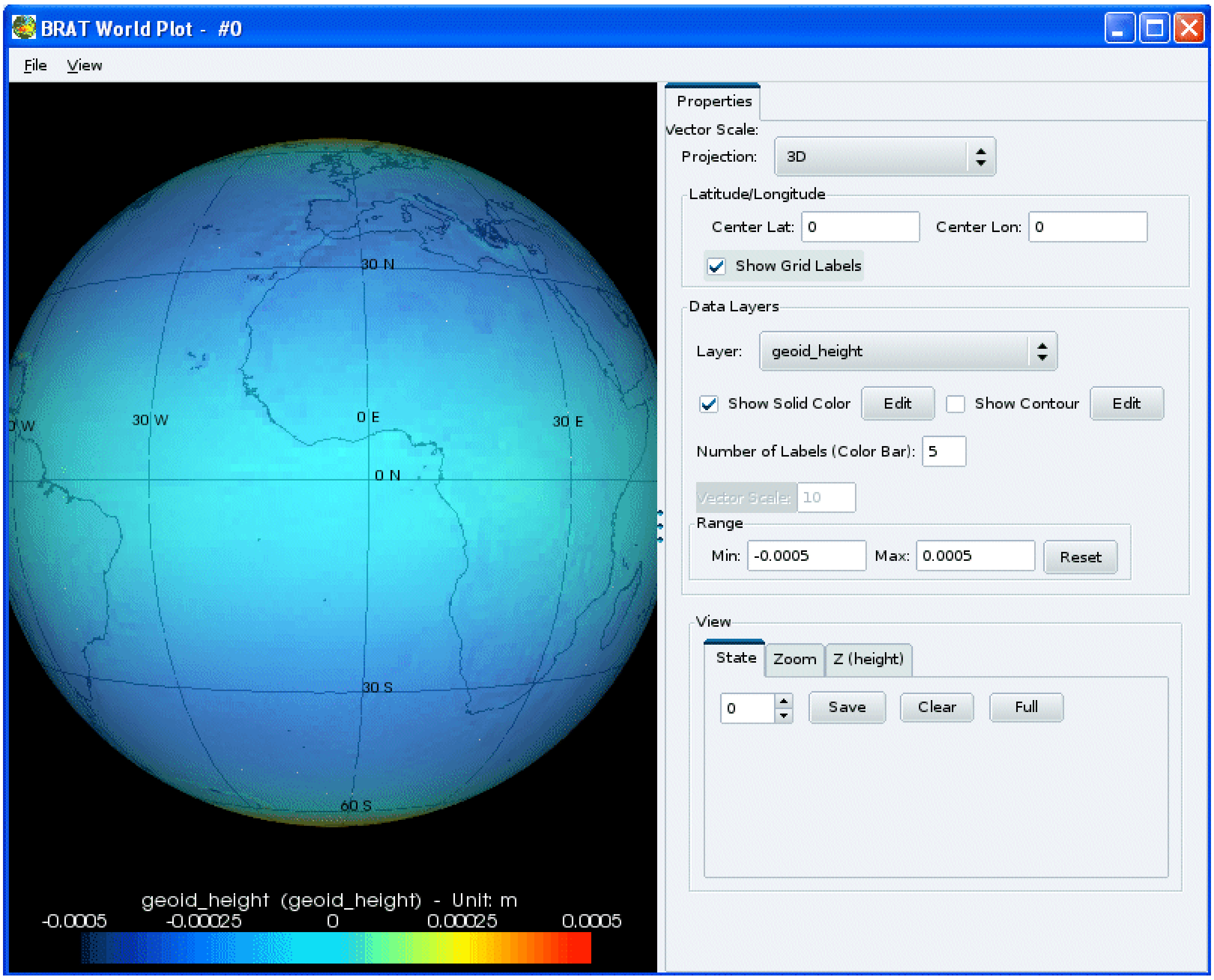


Figure 17: Map of differences between the geoidheight_TW_MT_TP_p23cm.nc and the geoidheight_MT_TP_2.nc grids. The colour range was set using the BratDisplay GUI.

7.3.11. spatialmdt_gf : Compute the Satellite-only MDT

spatialmdt_gf	
Options	**Expected field**
-InShpFile input_file_name	Input File containing the Potential.
-InSshFile input_file_name	Input File containing the sea surface height
-InLsmFile input_file_name	Input file containing the Land Sea Mask
-Gf input_grid_file OR	Specify file that defines output grid
-Af input_grid_file OR	Read lon/lat axes of output grid from file
-R w:e,s:n	Output Grid Region. (0.5:359.5,-89.5:89.5)
-I dE:dN	Output Grid Spacing. (1.0,1.0)
-Ellipse ellipse	Reference Ellipsoid for Output Grid by one of

	name (ellipse is GRS80, TOPEX, or WGS84) parameters (ellipse is inverse_flattening:a:GM) file (ellipse is filename)
-DO degreeAndOrder OR **-Ddeg degrees** OR **-Dkm length**	Degree and Order of the SH expansion.
-Substitute value	Value to substitute in masked region
-Thr lsm_threshold	Set the threshold for binary-mapping the value of the land-sea mask
-Op comparison_operator	Specify the logical operator that compares the mask value to the lsm_threshold
-F[filter_type] filter_scale_lat filter_scale_lon	Filter kernel type and scale length (in degrees)
-OutFile output_file_name	Output File for resulting NetCdf file.
Use the command line **gut spatialmdt_gf -man** for more information	

Use case n° 13: Compute a global grid of Satellite-only MDT in geographical space from the GUT apriori geopotential and Mean Sea Surface Height files, using a Hanning filter with a cut length of 3° in longitude and 2° in latitude.

gut spatialmdt_gf **-InShpFile** GO_CONS_EGM_GOC_2__20091101T000000_20100630T235959_0002.DBL **-InSshFile** MSS_CNES_CLS_11_2M.nc **-InLsmFile** GUT_LSM.nc **-Fhan 2,3 -Ellipse TOPEX -R 0.5:359.5,-89.5:89.5 -I 1:1** **-OutFile** SpatialMdt_fhan32.nc

BratDisplay SpatialMdt_fhan32.nc

The two command lines above produced the following plot:

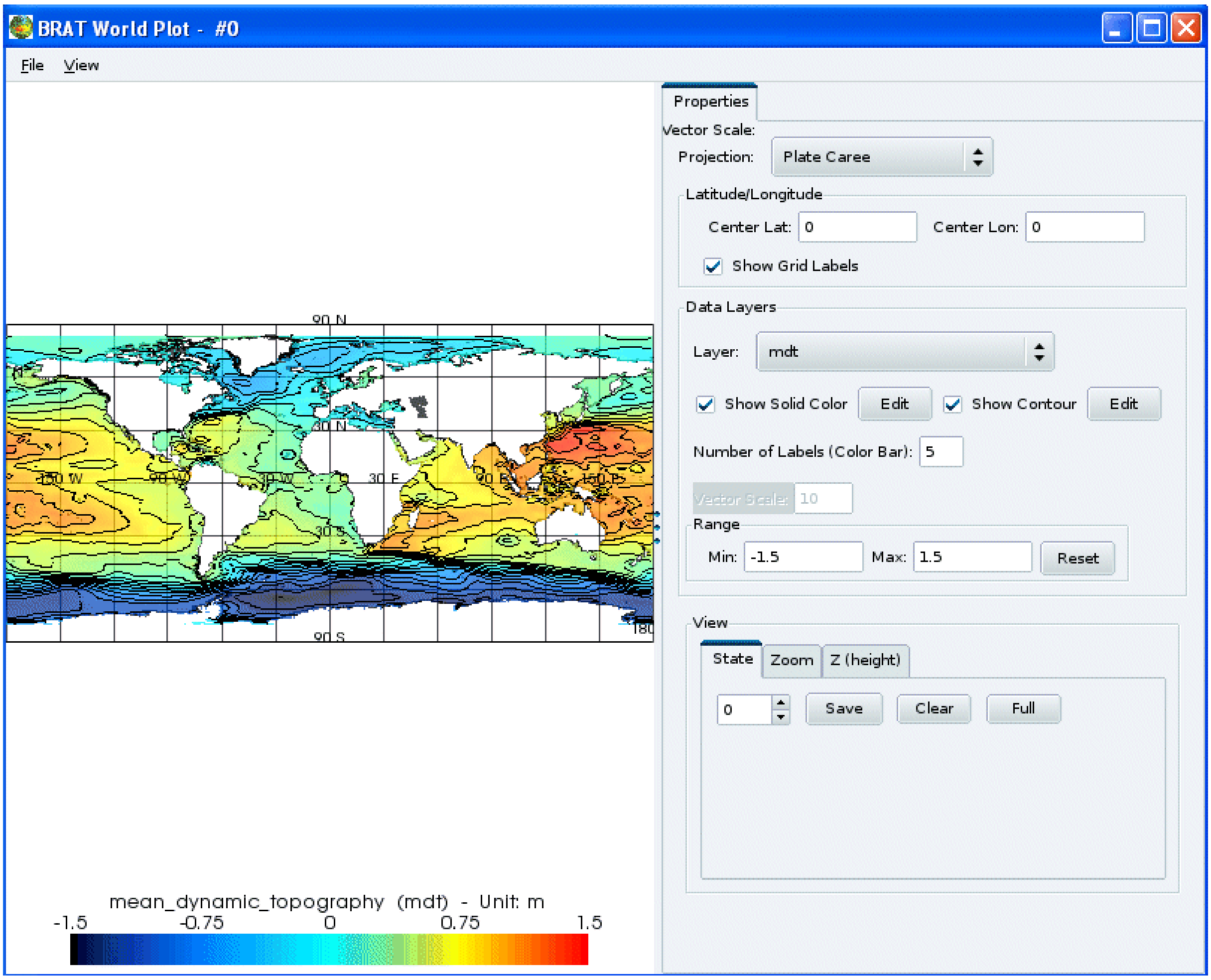


Figure 18: Map of Satellite-only MDT obtained using the Spatialmdt_gf workflow. The projection and the colour range were set using the BratDisplay GUI.

7.3.12. filter_gf: filtering in geographical space

filter_gf	
Options	**Expected field**
-InFile input_file_name	Input File containing Spherical Harmonic Potential.
-PQ physical_quantity	Specify/set the physical quantity of the data set (Accepted tokens are listed in Appendix A)
-F[filter_type] filter_scale_lat filter_scale_lon	Filter kernel type and scale length
-OutFile output_file_name	Output File for resulting Grid Function.
-ResFile output_file_name	Output file name for residuals (=Input-filtered)
Use the command line gut **filter_gf -man** to get more information	

Use case n° 14: Filter the GUT apriori DTU10 MDT using the anisotropic capability of the Gaussian filter with a length scale of 1° in longitude and 0.5° in latitude.

gut filter_gf **-InFile** MDT_DTU_10_10M.nc **-Fg** **0.5,1.0** **-OutFile** MDT_DTU_10_10M_Fg105.nc

BratDisplay MDT_DTU_10_10M_Fg105.nc

The two command lines above produced the following plot (after zooming on the Gulfstream area using the BratDisplay GUI):

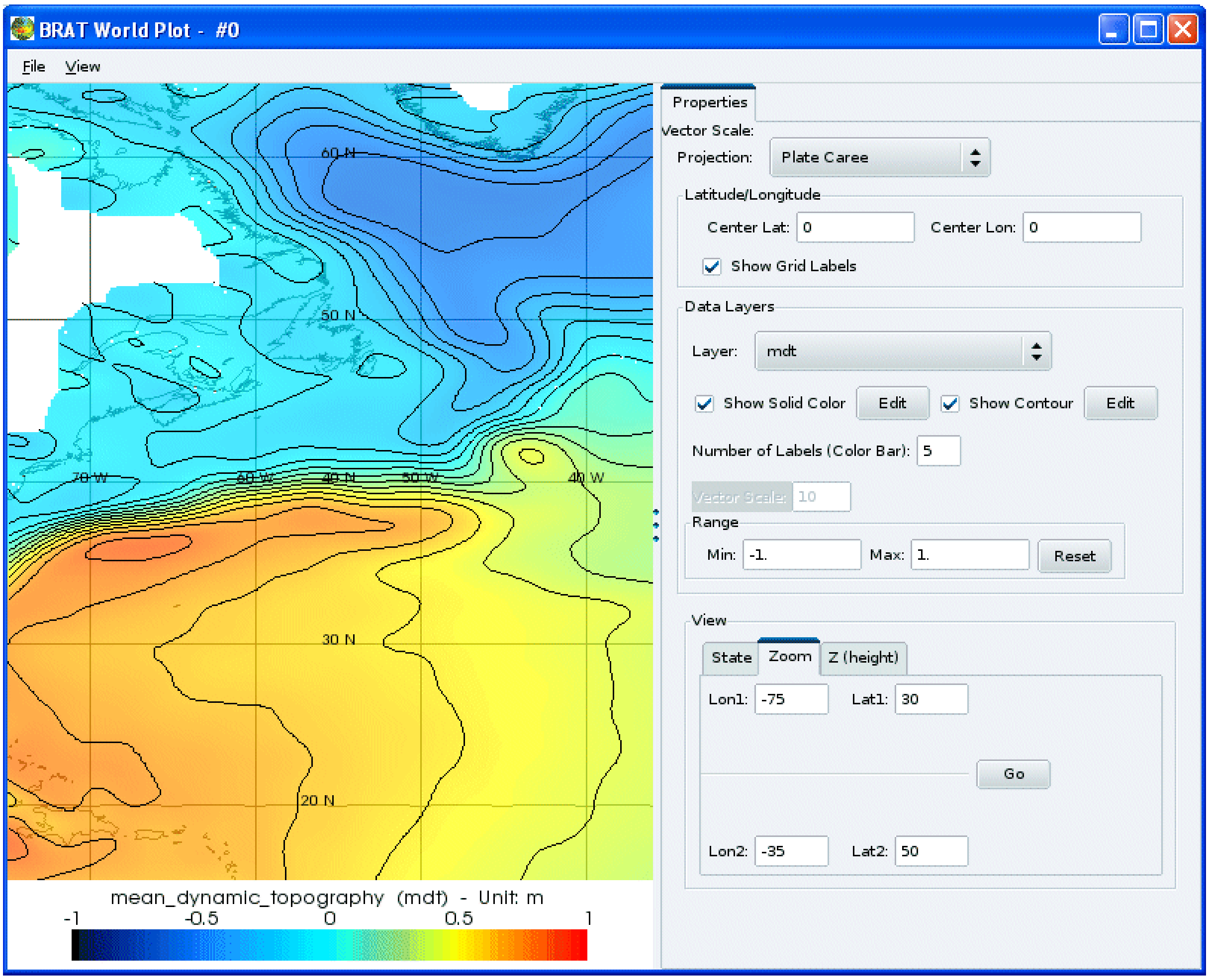


Figure 19: Map of filtered GUT apriori MDT obtained using the filter_gf workflow. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

7.3.13. diffusion_gf: filtering in geographical space with a diffusive filter

diffusion_gf	
Options	**Expected field**
-InFile input_file_name	Input File containing grid function(s)
-PQ physical_quantity	Specify/set the physical quantity of the data set (Accepted tokens are listed in Appendix A)
-Sensitivity	Sensitivity parameter (K) for the diffusive filter to gradients. Must be set such that the diffusion is blind to gradients associated to noise.

-DiffFunction	Function variant for diffusion. Options are: - exponential: exp(-(gradient/K)^2) - single: 1/(1+(gradient/K)^2) - sqrt: 1/sqrt(gradient^2)
-Iterations	The number of iterations for the filtering process.
-OutFile output_file_name	Output filename for resulting netCDF file.
Use the command line gut **diffusion_gf -man** to get more information	

Use case n° 15: Filter a MDT computed in the spectral domain (from Use case n° 39) using the diffusion filter

gut diffusion_gf **-InFile** MDT_DO200_qd.nc **-Sensitivity** 0.22 **-DiffFunction** single **-Iterations** 300 **-OutFile** MDT_DO200_qd_DiffusionFilter_K022_I300.nc

BratDisplay MDT_DO200_qd_DiffusionFilter_K022_I300.nc

The command lines above produced the following plot (after zooming in the North Atlantic area using the BratDisplay GUI):

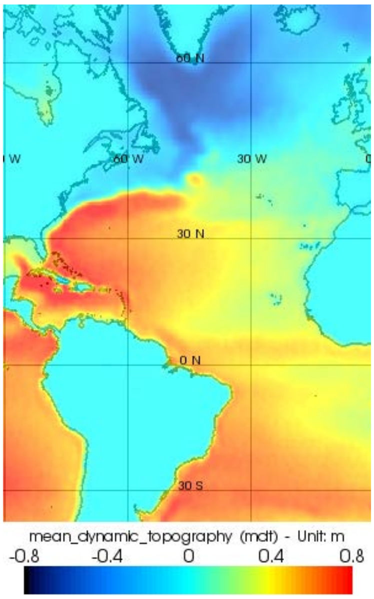


Figure 20: Map of filtered spectral MDT obtained using the diffusion_gf workflow. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

Note that the grid resolution of the input MDT has an impact on the result (a higher resolution grid need more iterations).

7.3.14. adapt_gf: Interpolate a grid function on a specified grid

adapt_gf	
Options	**Expected field**
-InFile input_file_name	Input File containing the grid function
PQ physical_quantity	Specify/set the physical quantity of the data set (Accepted tokens are listed in the GUT User Guide)
-Gf input_grid_file OR	Specify file that defines output grid
-Af input_grid_file OR	Read lon/lat axes of output grid from file
-R w:e,s:n	Output Grid Region. (0.5:359.5,-89.5:89.5)
-I dE:dN	Output Grid Spacing. (1.0,1.0)
-Ellipse ellipse	Reference Ellipsoid for Output Grid by one of name (ellipse is GRS80, TOPEX, or WGS84) parameters (ellipse is inverse_flattening:a:GM) file (ellipse is filename)
-IntAlg interpolation algorithm	Specify the interpolation algorithm for grid adaptation. Can be 'bilinear' (default) or 'spline'
-OutFile output_file_name	Output File for resulting Grid Function.
Use the command line **gut adapt_gf -man** to get more information	

Use case n° 16: Interpolate a 1/3° grid of SLA created using the BRAT toolbox over the Gulfstream current area on a ¼° regular grid.

gut adapt_gf -InFile BRAT_msla_gs.nc **-R 280.125:319.875,19.875:49.875 -I 0.25:0.25 -IntAlg spline -PQ sea_surface_height_above_sea_level -Ellipse TOPEX** -OutFile BRAT_msla_gs_025.nc

BratDisplay BRAT_msla_gs_025.nc

Note that since there is no information about the Physical Quantity in the input file BRAT_msla_gs.nc, you will get the following warning:

WARNING: The physical quantity in /homelocal/smulet/GUT2.2/DATA/TutorialData_GUT2.2/USE_CASE/SINGLE_STEP/BRAT_msla_gs.nc could not be determined and is assumed to be sea_surface_height_above_sea_level

This does not affect the result and the physical quantity is well informed in the output file BRAT_msla_gs_025.nc through the standard_name attribute.

The two command lines above produced the following plot:

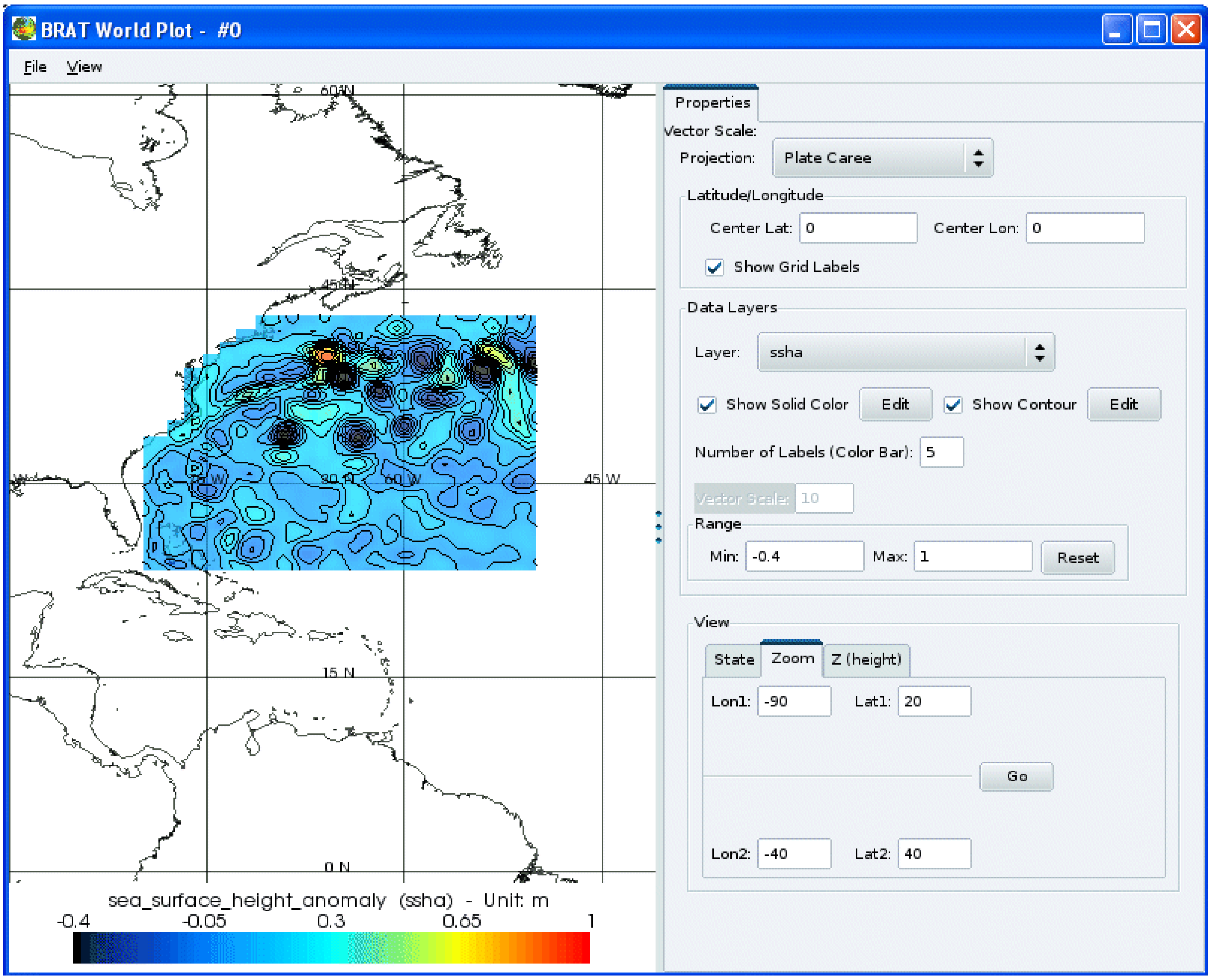


Figure 21: Map of Sea Level Anomaly in the Gulfstream current obtained using the adapt_gf workflow. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

Note: when using a file coming from BRAT, in order to be accepted by GUT, the data title name should be compliant with naming convention table as reported in the user guide.

Use case n° 17: Interpolate the grid of GUT apriori Sea Level Anomaly for December, 26th 2007 on a 0.25° grid over the Agulhas current area.

gut adapt_gf -InFile dt_upd_global_merged_msla_h_qd_20071226_20071226_20080516.nc **-R 10.125:39.875,-49.875:-29.875 -I 0.25:0.25 -IntAlg spline -PQ sea_surface_height_above_sea_level -Ellipse TOPEX -OutFile** sla_agulhas.nc

BratDisplay sla_agulhas.nc

The two command lines above produced the following plot:

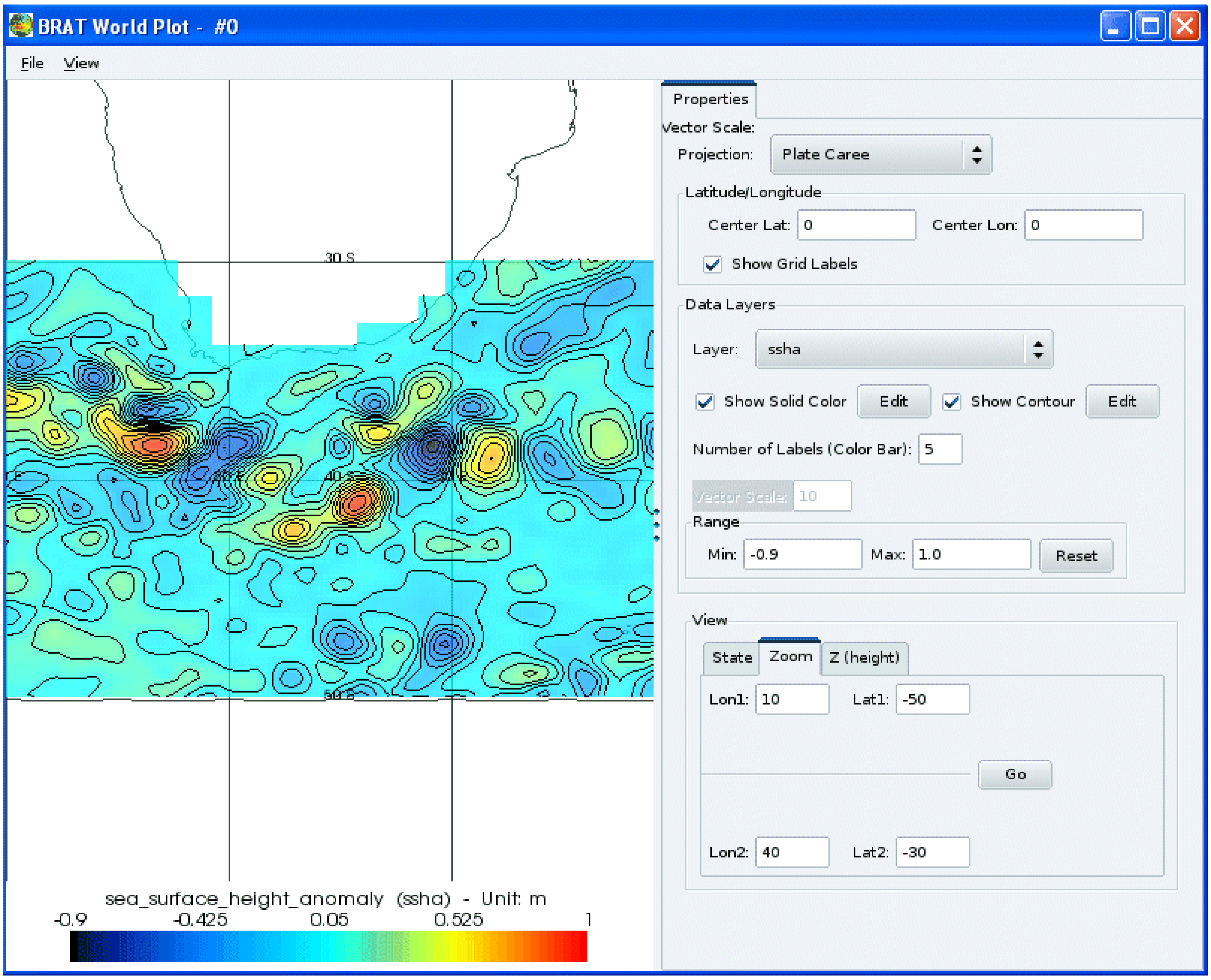


Figure 22: Map of Sea Level Anomaly in the Agulhas current on December 26th, 2007 obtained using the adapt_gf workflow. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

Note: Unit of the SLA files from the apriori GUT package is centimeter. Using the adapt_gf workflow with the **-PQ sea_surface_height_above_sea_level** option converts the grid values automatically into meters.

Values from the sla_agulhas.nc grid function may be converted back into centimetres using the scale_gf workflow (Use case n°14):

7.3.15. scale_gf: Extract a specific Grid Function from a file, scale the data and export the result in GUT netCDF format

scale_gf	
Options	**Expected field**
-InFile input_file_name	Input File containing the grid function
-PQ physical_quantity	Specify/set the physical quantity of the data set (Accepted tokens are listed in Appendix A)
-PQ0 physical_quantity	Specifies the physical quantity of the output dataset (Accepted tokens are listed in Appendix A)
-Scale scale_factor	Specify the scale factor
-OutFile output_file_name	Output File for resulting Grid Function.
Use the command line **gut scale_gf -man** to get more information	

Use case n° 18: Convert the values from the sla_agulhas.nc

gut scale_gf **-InFile** sla_agulhas.nc **-Scale 100** **-OutFile** sla_agulhas_cm.nc

Note: This operation however will not change the unit attribute of the NetCDF file.

7.3.16. add_gf, add_tf : sum in geographical space

add_gf, add_tf	
Options	**Expected field**
-InFileLhs input_file_name	Input File containing the grid function of the Left Hand Side (LHS) operand
-InFileRhs input_file_name	Input File containing the grid function of the Right Hand Side (RHS) operand
-PQ1 physical quantity	Specifies the required data set for the LHS operand. If the input file lacks the meta-data to allow this to be used for selection of the data set, it is used to explicitly set the physical quantity of

	the LHS operand. (Accepted tokens are listed in Appendix A)
-PQ2 physical quantity	Specifies the required data set for the RHS operand. If the input file lacks the meta-data to allow this to be used for selection of the data set, it is used to explicitly set the physical quantity of the RHS operand. (Accepted tokens are listed in Appendix A)
-PQ physical quantity	Specifies the physical quantity of the output (Accepted tokens are listed in Appendix A)
-OutFile output_file_name	Output File for resulting Grid Function.
Use the command line: **gut add_gf (add_tf) -man** to get more information	

Use case n° 19: Compute absolute dynamic height in the Agulhas current area from a GUT apriori MDT and a GUT apriori SLA file.

gut add_gf **-InFileLhs** MDT_CNES_CLS_09_15M_agulhas.nc **-InFileRhs** sla_agulhas.nc **-OutFile** adt_agulhas.nc

BratDisplay adt_agulhas.nc

The two command lines above produced the following plot:

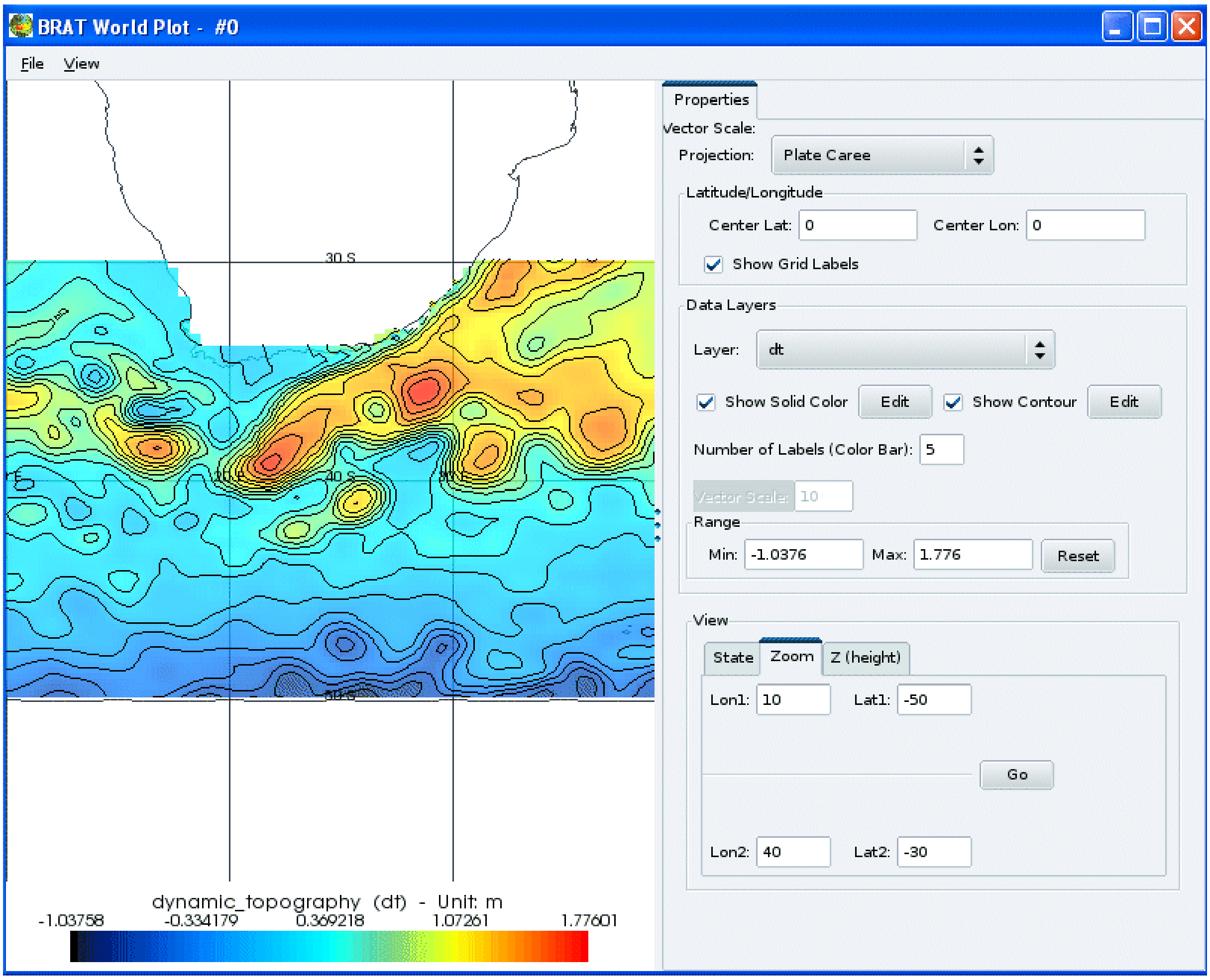


Figure 23: Map of absolute dynamic topography in the Agulhas current area computed using the add_gf workflow. The projection and the zoom parameters were set using the BratDisplay GUI.

Note: The MDT_CNES_CLS_09_15M_agulhas.nc grid file was obtained obtained using the adapt_gf workflow:

gut adapt_gf **-InFile** MDT_CNES_CLS_09_15M.nc **-R 10.125:39.875,-49.875:-29.875 -I 0.25:0.25** **-OutFile** MDT_CNES_CLS_09_15M_agulhas.nc

7.3.17. exporttiff_gf: create a quick look tiff image from a GUT output

exporttiff_gf	
Options	**Expected field**
-InFile input_file_name	Input File containing grid function
-Thr half_range	Scale of the colour bar (default is 120 units).

-OutFile output_file_name	Output File for resulting tiff image

Use case n° 20: Create a quick_look tiff image from the sla_agulhas.nc input file from USE CASE N°13

gut exporttiff_gf **-InFile** sla_agulhas.nc **-Thr 1** **-OutFile** sla_agulhas.tiff

display sla_agulhas.tiff

The two command lines above produced the following plot:

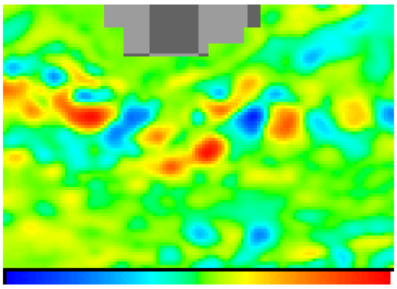


Figure 24: Tiff image of Sea Level Anomalies obtained using the exporttiff_gf workflow

7.3.18. exportkml_gf: Import a Grid Function from file and export as a TIFF image and creates a KML wrapper file.

exportkml_gf	
Options	**Expected field**
-InFile input_file_name	Input File containing grid function
-Thr half_range	Scale of the colour bar (default is 120 units).
-OutFile output_file_name	Output File for resulting tiff image and kml wrapper.

Use case n° 21: Use Google Earth to visualize the sla_agulhas.nc input file from USE CASE N°13

gut exportkml_gf **-InFile** sla_agulhas.nc **-Thr 1** **-OutFile** sla_agulhas.kml

The sla_agulhas.kml file can be displayed using the Google Earth application as shown on the Figure below:

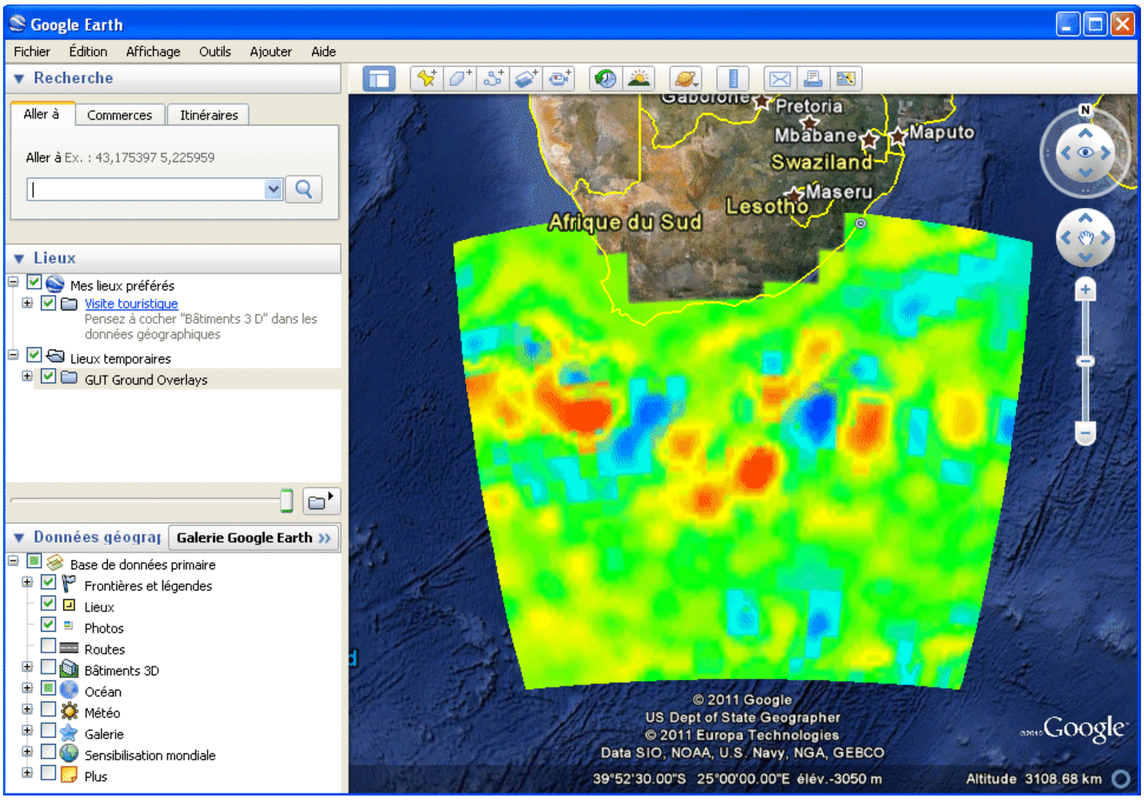


Figure 25: Tiff image of Sea Level Anomalies obtained using the exporttiff_gf workflow

7.3.19. changetime_gf: Set the time system for a grid function

changetime_gf	
Options	**Expected field**
-InFile input_file_name	Input File containing grid function
-PQ physical quantity	Specify/set physical quantity of data set (Accepted tokens are listed in Appendix A)
-TS Time-system	-TS 0: reference -TS YYYY:mm:dd:H:M:S: instantaneous -TS YYYY:mm:dd:H:M:S,YYYY:mm:dd:H:M:S: period
-OutFile output_file_name	Output File containing grid function

Use case n° 22: Set the time-system of the sla_agulhas grid function

gut changetime_gf **-InFile** sla_agulhas.nc **-TS 2007:12:26:0:0:0** **-OutFile** sla_agulhas_TS.nc

The command line above produced a NetCdf file whose content is partially displayed below:

```
netcdf sla_aghulas_TS {
dimensions:
        lat = 81 ;
        lon = 120 ;
variables:
        double lat(lat) ;
                lat:long_name = "latitude" ;
                lat:standard_name = "latitude" ;
                lat:units = "degrees_north" ;
        double lon(lon) ;
                lon:long_name = "longitude" ;
                lon:standard_name = "longitude" ;
                lon:units = "degrees_east" ;
        double ssha(lat, lon) ;
                ssha:standard_name = "sea_surface_height_above_sea_level" ;
                ssha:long_name = "sea_surface_height_anomaly" ;
                ssha:units = "m" ;
                ssha:grid_mapping = "crs" ;
                ssha:_FillValue = NaN ;
        int crs ;
                crs:semi_major_axis = 6378136.3 ;
                crs:inverse_flattening = 298.257000000006 ;
                crs:earth_gravity_constant = 398600441500000. ;
                crs:earth_rotation_rate = 7.292115e-05 ;
                crs:climatology_bounds = "2007-12-26 0:0:0" ;

// global attributes:
                :Conventions = "CF-1.1" ;
                :history = "../../../build/gut changetime_gf -InFile sla_aghulas.nc -TS 2007:12:26:0
:0:0 -OutFile sla_aghulas_TS.nc" ;
```

Figure 26: Setting the time system of the sla_agulhas.nc grid function using the changetime_gf workflow

7.3.20. transect_tf: Interpolate a grid on a track

transect_tf	
Options	**Expected field**
-InFile input_file_name	Input File containing Spherical Harmonic Potential.
-PQ physical_quantity	Specify/sets the physical quantity of the data set (Accepted tokens are listed in Appendix A)
-InTrack input_file_name	Input file containing the output track
-OutFile output_file_name	Output File for resulting NetCdf file.

Use case n° 23: Interpolate the Satellite-only Mean Dynamic Topography computed in Use case n° 13 along a track in the Drake passage and defined in the netCDF file below:

```
netcdf Drake_Track {
dimensions:
        station = 80 ;
variables:
        double lat(station) ;
                lat:long_name = "latitude" ;
                lat:standard_name = "latitude" ;
                lat:units = "degrees_north" ;
        double lon(station) ;
                lon:long_name = "longitude" ;
                lon:standard_name = "longitude" ;
                lon:units = "degrees_east" ;
        int crs ;
                crs:semi_major_axis = 6378137. ;
                crs:inverse_flattening = 298.257222101004 ;
                crs:earth_gravity_constant = 398600500000000. ;
                crs:earth_rotation_rate = 7.292115e-05 ;

// global attributes:
                :Conventions = "CF-1.1" ;
data:

 lat = -50.25, -50.5, -50.75, -51, -51.25, -51.5, -51.75, -52, -52.25, -52.5,
    -52.75, -53, -53.25, -53.5, -53.75, -54, -54.25, -54.5, -54.75, -55,
    -55.25, -55.5, -55.75, -56, -56.25, -56.5, -56.75, -57, -57.25, -57.5,
    -57.75, -58, -58.25, -58.5, -58.75, -59, -59.25, -59.5, -59.75, -60,
    -60.25, -60.5, -60.75, -61, -61.25, -61.5, -61.75, -62, -62.25, -62.5,
    -62.75, -63, -63.25, -63.5, -63.75, -64, -64.25, -64.5, -64.75, -65,
    -65.25, -65.5, -65.75, -66, -66.25, -66.5, -66.75, -67, -67.25, -67.5,
    -67.75, -68, -68.25, -68.5, -68.75, -69, -69.25, -69.5, -69.75, -70 ;

 lon = 290.125, 290.25, 290.375, 290.5, 290.625, 290.75, 290.875, 291,
    291.125, 291.25, 291.375, 291.5, 291.625, 291.75, 291.875, 292, 292.125,
    292.25, 292.375, 292.5, 292.625, 292.75, 292.875, 293, 293.125, 293.25,
    293.375, 293.5, 293.625, 293.75, 293.875, 294, 294.125, 294.25, 294.375,
    294.5, 294.625, 294.75, 294.875, 295, 295.125, 295.25, 295.375, 295.5,
    295.625, 295.75, 295.875, 296, 296.125, 296.25, 296.375, 296.5, 296.625,
    296.75, 296.875, 297, 297.125, 297.25, 297.375, 297.5, 297.625, 297.75,
    297.875, 298, 298.125, 298.25, 298.375, 298.5, 298.625, 298.75, 298.875,
    299, 299.125, 299.25, 299.375, 299.5, 299.625, 299.75, 299.875, 300 ;

 crs = _ ;
}
```

Figure 27: Content of the Drake_Track.nc NetCdf file

gut transect_tf **-InFile** SpatialMdt_fhan32.nc **-InTrack** Drake_Track.nc **-OutFile** SpatialMdt_fhan32_drake_track.nc

Note: The SpatialMdt_fhan32_drake_track.nc NetCdf file contains the MDT values interpolated along the track:

```
mdt = NaN, NaN, NaN, NaN, NaN, NaN, NaN, NaN, NaN, NaN, NaN, NaN, NaN, NaN, NaN, NaN,
NaN, NaN, NaN, NaN, NaN, 0.194381221992627l, 0.15509291500352268, 0.11538476536278833,
0.07525677307043896, 0.03470893522645923, -0.012637615864368148, -0.060261293959428086,
-0.10871740362591632, -0.15754488129948482, -0.2109507356814057, -0.26442574717011696,
-0.3179699157656346, -0.3715832421860998, -0.42667908764322204, -0.4813702039513983,
-0.5356475449521229, -0.5894992222446978, -0.6367786432601042, -0.6837485984459766,
-0.7304090878023357, -0.7767601071339638, -0.8127037566621279, -0.848186570054396,
-0.8826289290881598, -0.9166207416965011, -0.9479099324877905, -0.9788698670760227,
-1.0095005454612243, -1.0398019641147214, -1.061040075762595, -1.0821244184772838,
-1.1030341707228573, NaN, NaN, NaN, NaN, NaN, NaN, NaN, NaN, NaN, NaN, NaN, NaN,
-1.114025193644312, -1.1041900790647179, -1.0943038831317122, -1.0847845942337597,
-1.0752822859598132, -1.0724369967362606, -1.0698254664541722, -1.067447695113536,
-1.0653036851027877, -1.0703851021690483, -1.0753364836303012, -1.080293964541442,
-1.085200804508819, -1.0909976657229912, -1.096749812679236 ;
```

WARNING: BratDisplay's version shipped with GUT is not able to display tracks. Please check http://earth.eo.esa.int/brat for more recent versions.

7.3.21. gf2shf Compute spherical harmonics function from grid function

gf2shf	
Options	**Expected field**
-InFile input_file_name	Input File containing the geopotential
-PQ physical quantity	Specify/set the physical quantity of the data (Accepted tokens are listed in Appendix A)
-DO degreeAndOrder OR **-Ddeg degrees** OR **-Dkm length**	Degree and Order of the SH expansion.
-T tide-system	Tide system (tide-free, mean-tide, zero-tide).
-OutFile output_file_name	Output File for resulting NetCdf file.
Use the command line : **gut gf2shf -man** to get more information	

Use case n° 24: Create a NetCdf file of spherical harmonics function from the GUT apriori EGM96 geoid height (WW15MGH.GRD in Gravsoft format)

gut gf2shf **-InFile** WW15MGH.GRD **-OutFile** WW15MGH_shf.nc **-PQ geoid_height -T tide-free**

The command lines above produced a NetCdf file whose content is partially displayed below:

```
netcdf WW15MGH_shf2 {
dimensions:
        nm = 260281 ;
        coef = 2 ;
variables:
        double geoid_height(nm, coef) ;
                geoid_height:standard_name = "geoid_height_above_reference_ellipsoid" ;
                geoid_height:long_name = "geoid_height" ;
                geoid_height:units = "m" ;
                geoid_height:tide_system = "tide_free" ;
                geoid_height:grid_mapping = "crs" ;
        int crs ;
                crs:semi_major_axis = 6378137. ;
                crs:inverse_flattening = 298.257222101004 ;
                crs:earth_gravity_constant = 398600500000000. ;
                crs:earth_rotation_rate = 7.292115e-05 ;

// global attributes:
                :Conventions = "CF-1.1" ;
                :history = "../build/gut gf2shf -InFile WW15MGH.GRD -OutFile WW15MGH_shf2.n
c -PQ geoid_height -T tide-free"
data:

 geoid_height =
  -0.580276347077018, 0,
  0.0167697338816834, 0,
  0.0122202750092421, -0.0176921842251961,
  -0.0276152223165344, 0,
  -0.0084957113454072, -0.0212507748365563,
  15.6255962813056, -8.94786009200972,
  6.18985333218944, 0,
```

Figure 28: File of spherical harmonic coefficients computed using the gf2shf workflow

7.3.22. shf2gf: Expand spherical harmonic function on a grid

Shf2gf	
Options	**Expected field**
-InFile input_file_name	Input File containing the spherical harmonic function
-Gf input_grid_file **OR** **-Af input_grid_file** **OR** **-R w:e,s:n** **-I dE:dN**	Specify file that defines output grid Read lon/lat axes of output grid from file Output Grid Region. (0.5:359.5,-89.5:89.5) Output Grid Spacing. (1.0,1.0)
-Ellipse ellipse	Reference Ellipsoid for Output Grid by one of name (re is GRS80, TOPEX, or WGS84) parameters (ellipse is inverse_flattening:a:GM) file (ellipse is filename)
-DO degreeAndOrder OR **-Ddeg degrees** OR **-Dkm length**	Degree and Order of the SH expansion.
-OutFile output_file_name	Output File for resulting Grid Function.
Use the command line : **gut shf2gf -man** to get more information	

Use case n° 25: Create a grid from the spherical harmonics function computed in Use case n° 24

gut shf2gf -InFile WW15MGH_shf.nc -OutFile WW15MGH_shf2gf.nc

WARNING: The resulting WW15MGH_shf2gf.nc grid differs from the original WW15MGH.GRD grid. The non-closure of the Grid->SH->Grid is a known issue among the geodetic community (RD7).

The differences between the two grids are displayed Figure 29 running the following command lines:

gut adapt_gf -InFile WW15MGH.GRD **-Gf** WW15MGH_shf2gf.nc **-PQ** geoid_height -OutFile WW15MGH_adapt.nc

gut changetide_gf -InFile WW15MGH_adapt.nc **-T** tide-free -OutFile WW15MGH_tide.nc

gut subtract_gf -InFileLhs WW15MGH_tide.nc -InFileRhs WW15MGH_shf2gf.nc -OutFile Diff_WW15MGH_gf2shf2gf.nc

BratDisplay Diff_WW15MGH_gf2shf2gf.nc

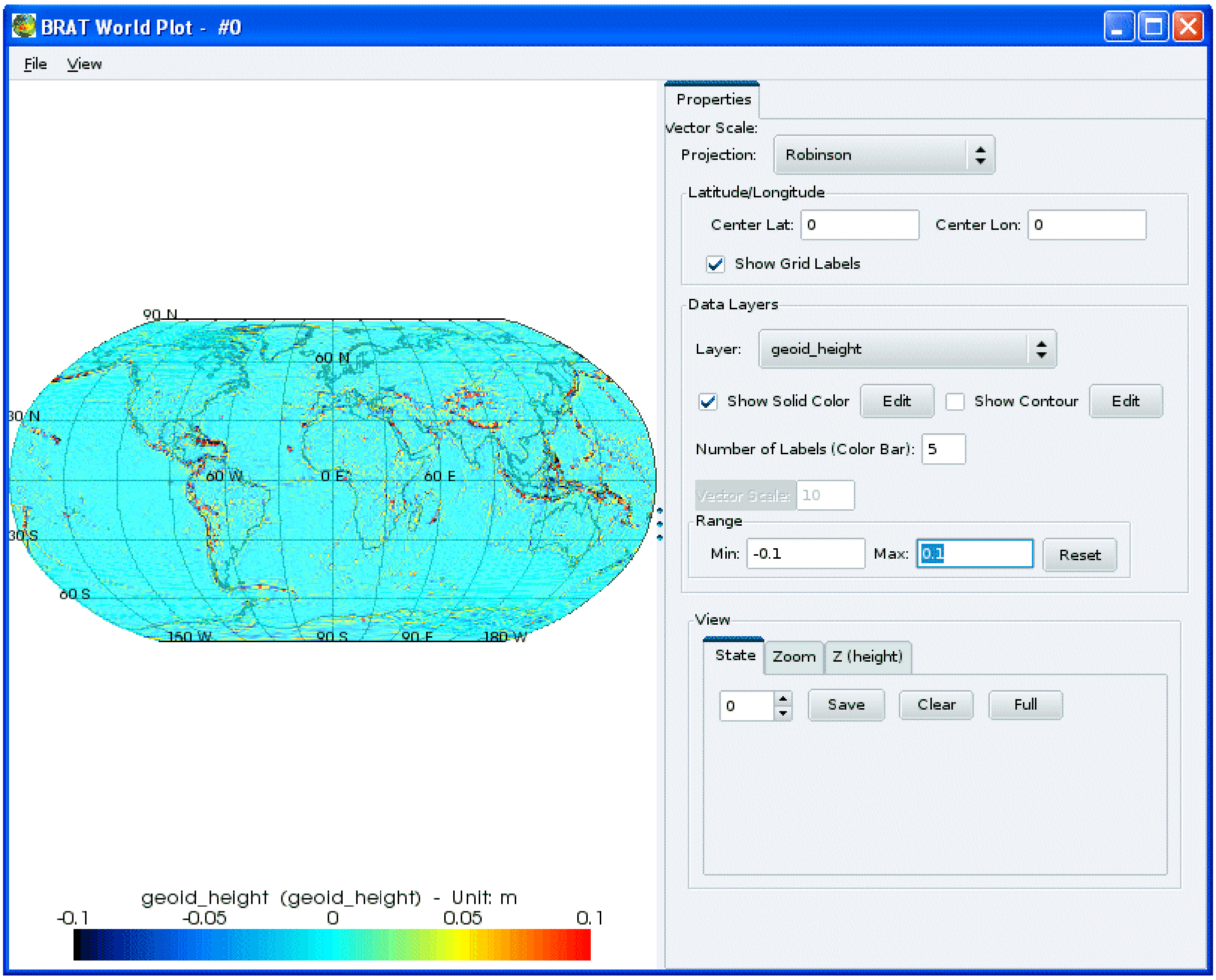


Figure 29: Differences between WW15MGH.GRD grid and WW15MGH_shf2gf.nc grid. The projection and the colour range were set using the BratDisplay GUI.

7.3.23. exportgravsoft_gf: Export a Grid function in Gravsoft grid format

Exportgravsoft_gf	
Options	**Expected field**
-InFile input_file_name	Input File in NetCdf format
-PQ physical quantity	Specify/set the physical quantity of the data (Accepted tokens are listed in Appendix A)
-OutFile output_file_name	Output File for resulting Gravsoft format.
Use the command line : **gut exportgravsoft_gf -man** to get more information	

Use case n° 26: Export a geoid grid in NetCdf format into a GRAVSOFT format file

gut exportgravsoft_gf **-InFile** WW15MGH_shf2gf.nc **-OutFile** WW15MGH_shf2gf.GRD

The command lines above produced a GRAVSOFT grid file whose content is partially displayed below:

```
-89.50000  89.50000  0.50000  359.50000  1.00000  1.00000
  14.40851  14.39996  14.39108  14.38187  14.37235  14.36251  14.35239  14.34199  14.33132  14
.32041  14.30925  14.29788  14.28629  14.27452  14.26258  14.25048  14.23824  14.22587  14.213
40  14.20084  14.18820  14.17550  14.16276  14.14999  14.13720  14.12442  14.11166  14.09893
14.08624  14.07360  14.06103  14.04854  14.03614  14.02384  14.01165  13.99958  13.98763  13.9
7581  13.96414  13.95260  13.94122  13.92999  13.91891  13.90800  13.89725  13.88666  13.87624
  13.86599  13.85590  13.84597  13.83621  13.82661  13.81717  13.80789  13.79876  13.78979  13
.78096  13.77229  13.76375  13.75535  13.74709  13.73896  13.73096  13.72308  13.71532  13.707
68  13.70015  13.69272  13.68540  13.67818  13.67105  13.66402  13.65708  13.65023  13.64346
13.63677  13.63015  13.62362  13.61715  13.61076  13.60444  13.59818  13.59199  13.58586  13.5
7980  13.57379  13.56785  13.56196  13.55614  13.55036  13.54465  13.53899  13.53338  13.52783
  13.52234  13.51689  13.51150  13.50616  13.50087  13.49564  13.49045  13.48531  13.48023  13
.47518  13.47019  13.46524  13.46033  13.45547  13.45065  13.44586  13.44112  13.43640  13.431
72  13.42707  13.42244  13.41784  13.41326  13.40870  13.40416  13.39963  13.39511  13.39059
13.38609  13.38158  13.37708  13.37258  13.36808  13.36357  13.35907  13.35456  13.35006  13.3
4556  13.34106  13.33657  13.33210  13.32764  13.32321  13.31880  13.31444  13.31012  13.30585
  13.30166  13.29754  13.29351  13.28958  13.28577  13.28209  13.27855  13.27517  13.27197  13
.26896  13.26615  13.26357  13.26123  13.25915  13.25733  13.25581  13.25459  13.25369  13.253
```

Figure 30: GRAVSOFT format grid file converted from NetCDF format using the exportgravsoft_gf workflow

7.3.24. geoidheightcorrection_gf : Extract a set of spherical harmonic potential coefficients from file and calculate the height of the geoid on a chosen Grid. Moreover, a set of height correction term is extracted from a file in the form of spherical harmonic coefficients and added to the resulting geoid heights.

Geoidheightcorrection_gf	
Options	**Expected field**
-InFile input_file_name	Input File containing the geopotential
-InFileCorr	Input file containing a spherical harmonic function with the geoid height correction coefficients
-Gf input_grid_file OR	Specify file that defines output grid
-Af input_grid_file OR	Read lon/lat axes of output grid from file
-R w:e,s:n	Output Grid Region. (0.5:359.5,-89.5:89.5)
-I dE:dN	Output Grid Spacing. (1.0,1.0)
-Ellipse ellipse	Reference Ellipsoid for Output Grid by one of name (re is GRS80, TOPEX, or WGS84) parameters (ellipse is inverse_flattening:a:GM) file (ellipse is filename)
-DO degreeAndOrder OR **-Ddeg degrees** OR **-Dkm length**	Degree and Order of the SH expansion.
-T tide-system	Tide system (tide-free, mean-tide, zero-tide).
-OutFile output_file_name	Output File for resulting netCDF file
-OutDiffsFile output_file_name	Output File for resulting differences between the calculated Geoid Heights and the original Heights from the spherical harmonic potential w/o corrections
Use the command line : **gut geoidheightcorrection_gf -man** to get more information	

Use case n° 27: Apply geoid height correction to the EGM96 geopotential and compute geoid height

gut geoidheightcorrection_gf **-InFile** EGM-96.nc **-InFileCorr** corrcoef.nc **-R 0:360,-90:90** **-I 0.25:0.25** **-Ellipse wgs84rev1** **-T tide-free** **-OutFile** EGM96_geoidheight_corr.nc

The difference between the corrected EGM96 geoid height and the geoid height stored in the file WW15MGH.GRD produced by NASA is a rigid bias of 53 cm that NASA added at posteriori (http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm96/egm96.html). This may be checked by computing the difference between the two grids:

gut subtract_gf **-InFileLhs** EGM96_geoidheight_corr.nc **-InFileRhs** WW15MGH.nc **-OutFile** Diff_EGM96_corr_WW15MGH.nc

Typing

BratDisplay Diff_EGM96_corr_WW15MGH.nc

Will produce the following plot (Figure 31):

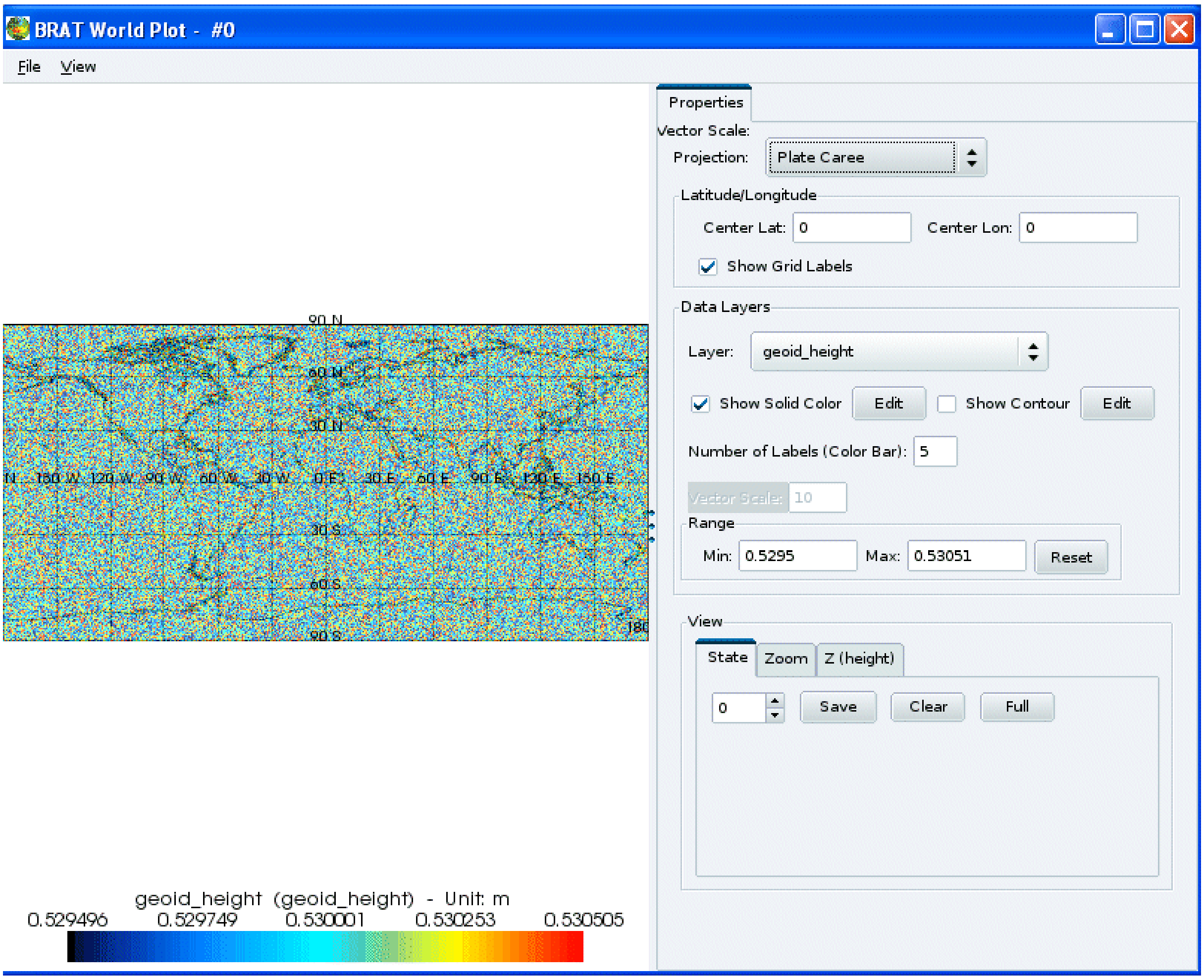


Figure 31: Map of differences between the EGM96_geoidheight_corr.nc obtained from the geoidheightcorrection_gf workflow and the WW15MGH.nc grids. The projection was set using the BratDisplay GUI.

Note: the WW15MGH.nc file was created using the following gut command:

gut import_gf **-InFile** WW15MGH.GRD **-PQ geoid_height -Ellipse wgs84rev1 -T tide-free** **-OutFile** WW15MGH.nc

7.3.25. gsveast_gf, gsvnorth_gf, gsveast_tf, gsvnorth_tf, gsvdirectionspeed_gf, gsvdirectionspeed_tf : Compute geostrophic velocities

gsveast_gf, gsvnorth_gf,gsveast_tf,gsvnorth_tf	
Options	**Expected field**
-InFile input_file_name	Input File containing the grid or the track function
-PQ physical_quantity	Specify/set the physical quantity of the data set (Accepted tokens are listed in Appendix A)
-EqMargin Scale	Specify extent of equatorial margin ([-4,+4] by default)
-OutFile output_file_name	Output File for resulting netCDF file
Use the command line : **gut gsvnorth_gf -man** to get more information	

Use case n° 28: Compute the zonal velocity component of the ocean geostrophic surface currents from the GUT apriori DTU10 MDT.

gut gsveast_gf **-InFile** MDT_DTU_10_10M.nc **-OutFile** MDT_DTU_10_10M_U.nc

BratDisplay MDT_DTU_10_10M_U.nc

The two command lines above produced the following plot (after zooming over the Gulfstream area using the BratDisplay GUI):

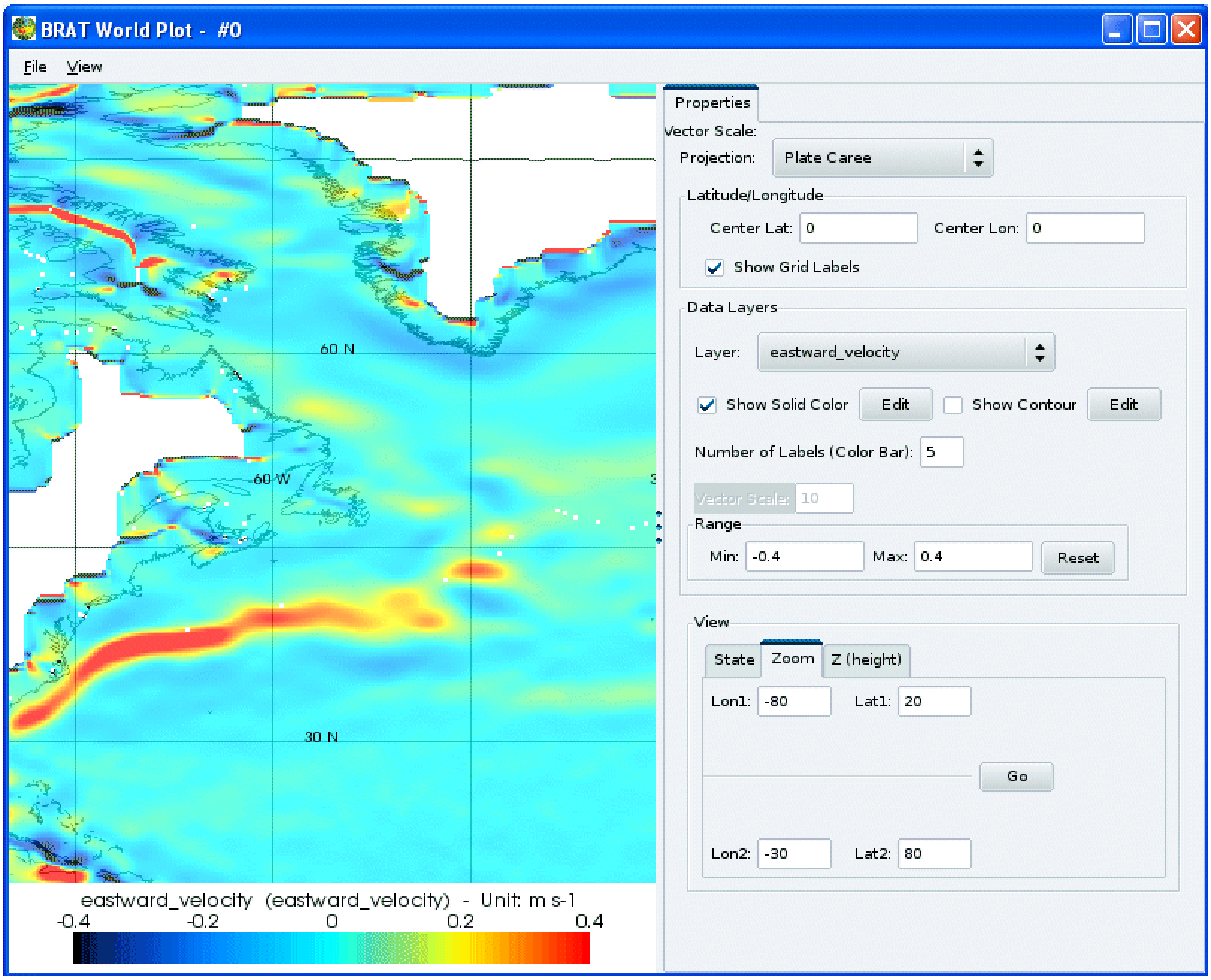


Figure 32: Map of eastward geostrophic velocities computed from the GUT apriori DTU10 MDT in the Gulfstream area. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

Use case n° 29: Compute the velocity speed of the ocean geostrophic surface currents from the GUT apriori RIO05 MDT.

gut gsvdirectionspeed_gf **-InFile** MDT_CNES_CLS_09_15M.nc **-OutFile** MDT_CNES_CLS_09_15M_Vit.nc

BratDisplay MDT_CNES_CLS_09_15M_Vit.nc

The two command lines above produced the following plot (zooming over the Agulhas current area using the BratDisplay GUI):

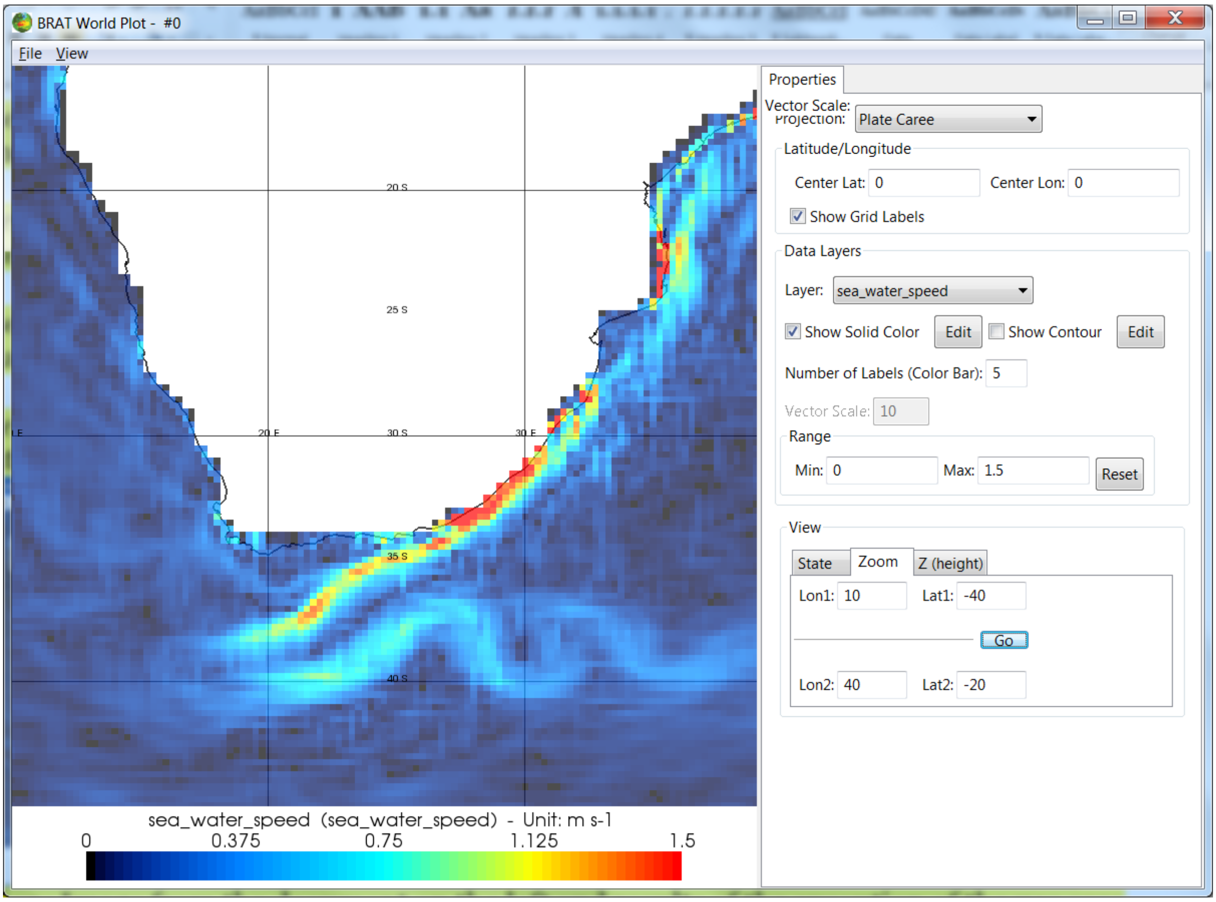


Figure 33: Map of geostrophic velocity speed computed from the GUT apriori CNES-CLS09 MDT in the Agulhas current area. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

Note: The MDT_CNES_CLS_09_15M_Vit.nc file contains two grids, the velocity speed and the direction. By default, the BratDisplay displays the first grid. In order to visualize the velocity direction, one must type:

BratDisplay -v direction_of_sea_water_velocity MDT_CNES_CLS_09_15M_Vit.nc

7.3.26. simplebouguer_gf: Compute simple Bouguer anomaly

simplebouguer_gf	
Options	**Expected field**
-InFile input_file_name	Input file containing the geopotential spherical harmonic coefficients
-Gf input_grid_file OR	Specify file that defines output grid
-Af input_grid_file OR	Read lon/lat axes of output grid from file
-R w:e,s:n	Output Grid Region. (0.5:359.5,-89.5:89.5)
-I dE:dN	Output Grid Spacing. (1.0,1.0)
-Ellipse ellipse	Reference Ellipsoid for Output Grid by one of name (GRS80 TOPEX GRIM WGS84 WGS84rev1) parameters (formatted as inverse_flattening:a:GM) file (extracts the ellipsoid from the meta-data in this file)
 -DO degreeAndOrder OR **-Ddeg degrees** OR **-Dkm length**	Degree and Order of the SH expansion. positive integer scale angle in degrees scale length in km
-T tide-system	Tide system (tide-free, mean-tide, zero-tide).
- InDemFile input_dem_file	Specifies the input DEM grid function. This must provide the height of the terrain above the ellipsoid
-IntAlg interpolation algorithm	Specifies the interpolation algorithm for grid adaptation. Can be 'spline' (default) or 'bilinear'.
-F[filter_type] filter_scale	Selects the filter kernel type and scale length for latitude and longitude in degrees to be applied to the topography. To specify the scale length in kilometers, add the suffix km. If only one value is supplied, it will be used for both latitude and longitude scales (isotropic kernel). The possible kernels and the interpretation of the scale lengths are: -Fg HWHM_lat,HWHM_lon: Gaussian with given Half-Width at Half-Maximum (HWHM = 1.1774 sigma) -Ftg HWHM_lat,HWHM_lon: Truncated Gaussian, with truncation at a radius of 3 sigma) -Fsc radius_lat, radius_lon : Spherical Cap -Fhan radius_lat, radius_lon : Hanning -Fham radius_lat, radius_lon : Hamming

	-Fbox radius_lat, radius_lon : Pill Box
-OutFile output_file_name	Output File for resulting netCDF file
Use the command line : **gut simplebouguer_gf -man** to get more information	

Use case n° 30: Compute Simple Bouguer Anomaly over Italy and Med sea

The simple Bouguer Anomaly is an approximation to the full Bouguer anomaly calculation and only valid in local areas and for low heights. A topography grid is filtered and multiplied by a factor to obtain a correction value (C_{BG}) and finally subtracted from the gravity anomaly evaluated at geoid height, g_{FA} (free air gravity anomaly). In the following we give the detailed steps that are fulfilled in the workflow:

1) Calculate the gravity anomaly up to degree N from a Earth Gravity Model at geoid height
2) Select the topography on the same geographic window augmented by the margin necessary for the low pass filter.
3) Apply the Gaussian low pass filter. The Gaussian filter shall reduce the topography at the spatial frequencies greater than the one corresponding to the maximum degree N of the gravity anomaly. In GUT the user defines the scale-length (R) of the Gaussian filter. The topography –reduction shall not introduce frequencies not contained in the band-limited gravity anomaly and therefore needs to be filtered.
   Given the maximum degree N, the shortest variations in degrees are *dPSI = 360°/N* (Jekeli,1981) [RD12]. Defining the Gaussian filter as

   $W(\psi) = e^{-\frac{1}{2}\left(\left(\frac{\psi}{a}\right)^2\right)}$,

   $\cos\psi = sin\varphi\ sin\varphi' + cos\varphi\ cos\varphi' \cos(\lambda - \lambda')$

   With φ , φ' the latitude and λ, λ' the longitude of the calculation point and point to be averaged, and ψ the spherical distance. The Filter parameter a should be:

   $$a = \frac{dPSI}{2} = 180° \frac{1}{N}$$

   In GUT the Gaussian filter is defined as:

   $W(\alpha_x, \alpha_y) = \frac{1}{\sqrt{2\pi\sigma_x\sigma_y}} e^{-\frac{1}{2}\left(\left(\frac{\alpha_x}{\sigma_x}\right)^2 + \left(\frac{\alpha_y}{\sigma_y}\right)^2\right)}$,

   the scale-length (R) in the two directions is related to the scaling parameters of the Gaussian function as:

   $R_x = \sigma_x\sqrt{2ln2}$ and $R_y = \sigma_y\sqrt{2ln2}$.

In analogy to what defined above we choose homogeneous scale-lengths in x and y, and define

$$\sigma_x = \sigma_y = \frac{dPSI}{2} = 180° \frac{1}{N}$$

The filter is evaluated at a distance of 10 *R for the Gaussian filter, and up to a distance 2*R for the truncated Gaussian filter.

4) The filtered topography is resampled to the same grid-size as the gravity anomaly grid. Then the scaling factor is applied to obtain the Bouguer plate correction.

The simple Bouguer plate correction is an approximation, as it calculates the effect of an infinite plate of a height equal to that of topography corresponding to the calculation point. Thus, the simple Bouguer plate correction is valid only over local areas where topography has low variability. If terrain gravity effect that takes into account the global effect of topography is significantly different to the simple Bouguer anomaly, the full terrain calculation has to be considered and the complete Bouguer correction is thus required. The validity of the simple Bouguer must be checked in each case and cannot be generalized.

In GUT we only apply it when gravity is calculated from a EGM at geoid height or at topography. It is only a crude approximation of the full Bouguer correction which calculates the exact contribution of the digital terrain model.

Given *t(i,j) , i=1:N; j=1:M* the digital terrain model in grid form, with N and M the size of the grid, the simple Bouguer correction is defined as:

$$C_{BG}(i,j) = 2\,\pi G\,\rho_c\,t(i,j) \qquad for\ \ t(i,j) \geq\ 0$$
$$C_{BG}(i,j) = 2\,\pi G\,(\rho_c - \rho_w\,)t(i,j) \qquad for\ \ t(i,j) <\ 0$$

With (from http://physics.nist.gov/cgi-bin/cuu/Value?bg|search_for=Newtonian)

Density of crust: ρ_c (standard value: 2670 kg/m3)
Density of water: ρ_w (standard value: 1020 kg/m3)
Gravitational Constant: $G = \mathbf{6.673\,84\ x\ 10^{-11}\,\frac{m^3}{kg\,s^2}}$

$$Units: density\ in \frac{kg}{m^3};\ gravity\ in\ \frac{m}{s^2}$$

5) The Simple Bouguer anomaly $g_{BG}(i,j)$ is then calculated as:

$$g_{BG}(i,j) = g_{FA}(i,j) - C_{BG}(i,j)$$

With g_{FA}(i,j) the gravity anomaly.

gut simplebouguer_gf -InFile GO_CONS_EGM_GOC_2__20091101T000000_20131020T235959_0001.IDF **-DO** 200 **-Ftg** 0.5 **-InDemFile** GUT_ACE2_BATHY_5M.nc **-R 0:20,40:50 -I 0.25:0.25 -OutFile** Simple_Bouguer_gravity_anomaly_GOCE5_alps.nc
BratDisplay Simple_Bouguer_gravity_anomaly_GOCE5_alps.nc

The two command lines above produced the following plot (using the BratDisplay GUI):

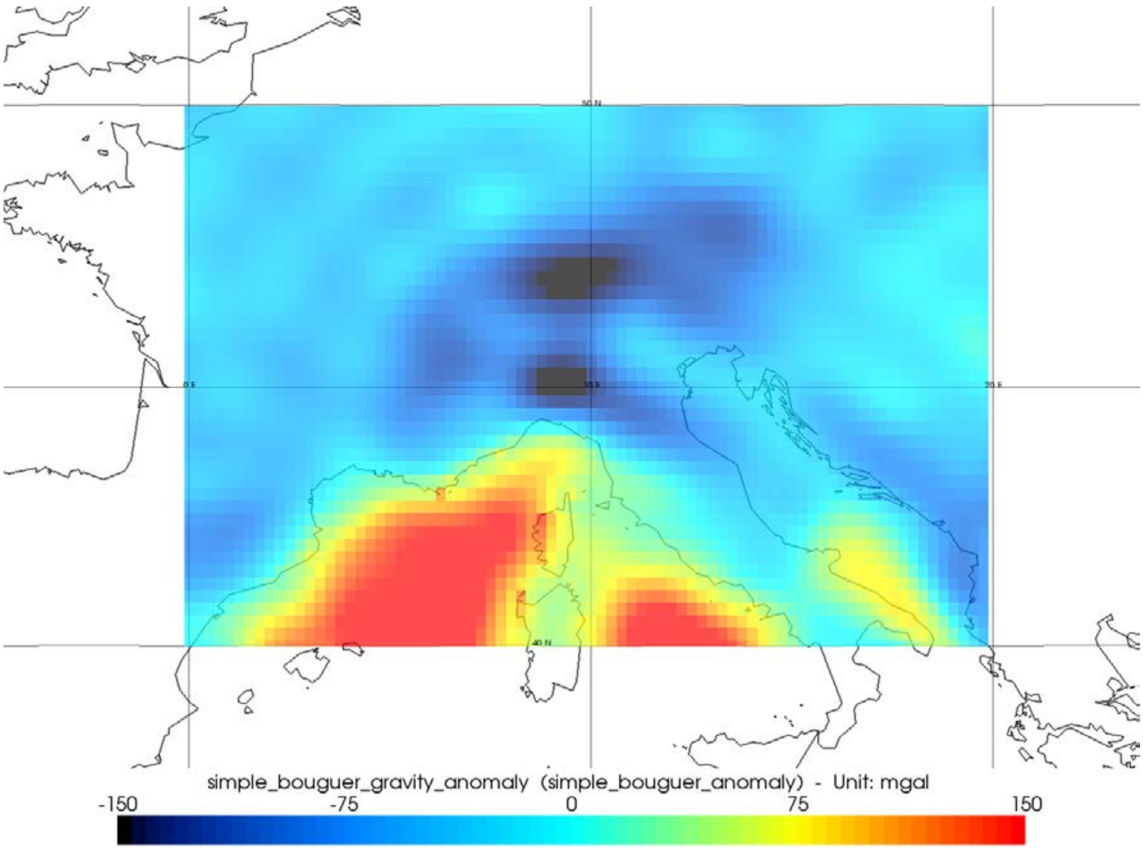


Figure 34: Map of simple Bouguer gravity anomalies (mgal) obtained over the Alps using the simplebouguer_gf workflow. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

7.3.27. bougueranomaly_gf: Compute the full Bouguer anomaly

Contrary with the previous section, in this algorithm the full Bouguer effect is computed from the synthesis of a set of pre-calculated spherical harmonic coefficients of this effect given by the *–InTopoFile* option (for more information see user guide).

bougueranomaly_gf	
Options	**Expected field**

-InFile input_file_name	Input file containing the geopotential spherical harmonic coefficients
-InTopoFile input_topo_file_name	Input file containing the spherical harmonic coefficients of the gravity effect of topography
-Gf input_grid_file OR	Specify file that defines output grid
-Af input_grid_file OR	Read lon/lat axes of output grid from file
-R w:e,s:n **-I dE:dN**	Output Grid Region. (0.5:359.5,-89.5:89.5) Output Grid Spacing. (1.0,1.0)
-Ellipse ellipse	Reference Ellipsoid for Output Grid by one of name (GRS80 TOPEX GRIM WGS84 WGS84rev1) parameters (formatted as inverse_flattening:a:GM) file (extracts the ellipsoid from the meta-data in this file)
 -DO degreeAndOrder OR **-Ddeg degrees** OR **-Dkm length**	Degree and Order of the SH expansion. positive integer scale angle in degrees scale length in km
-T tide-system	Tide system (tide-free, mean-tide, zero-tide).
- InDemFile input_dem_file	Specifies the input DEM grid function. which defines the height at which the Bouguer anomaly is calculated. These values should be on or above the Earth surface.
-OutFile output_file_name	Output File for resulting netCDF file
Use the command line : **gut bougueranomaly_gf -man** to get more information	

Use case n° 31: Compute and plot Full Bouguer Anomaly over Italy and Med sea

gut bougueranomaly_gf **-InFile** GO_CONS_EGM_GOC_2__20091101T000000_20131020T235959_0001.IDF **-InTopoFile** dV_ELL_RET2014_with_GRS80_SHCto2190.dat **-DO** 200 **-InDemFile** GUT_ACE2_BATHY_5M.nc **-R** **0:20,40:50** **-I** **0.25:0.25** **-OutFile** Full_Bouguer_gravity_anomaly_GOCE5_alps.nc
BratDisplay Full_Bouguer_gravity_anomaly_GOCE5_alps.nc

The two command lines above produced the following plot (using the BratDisplay GUI):

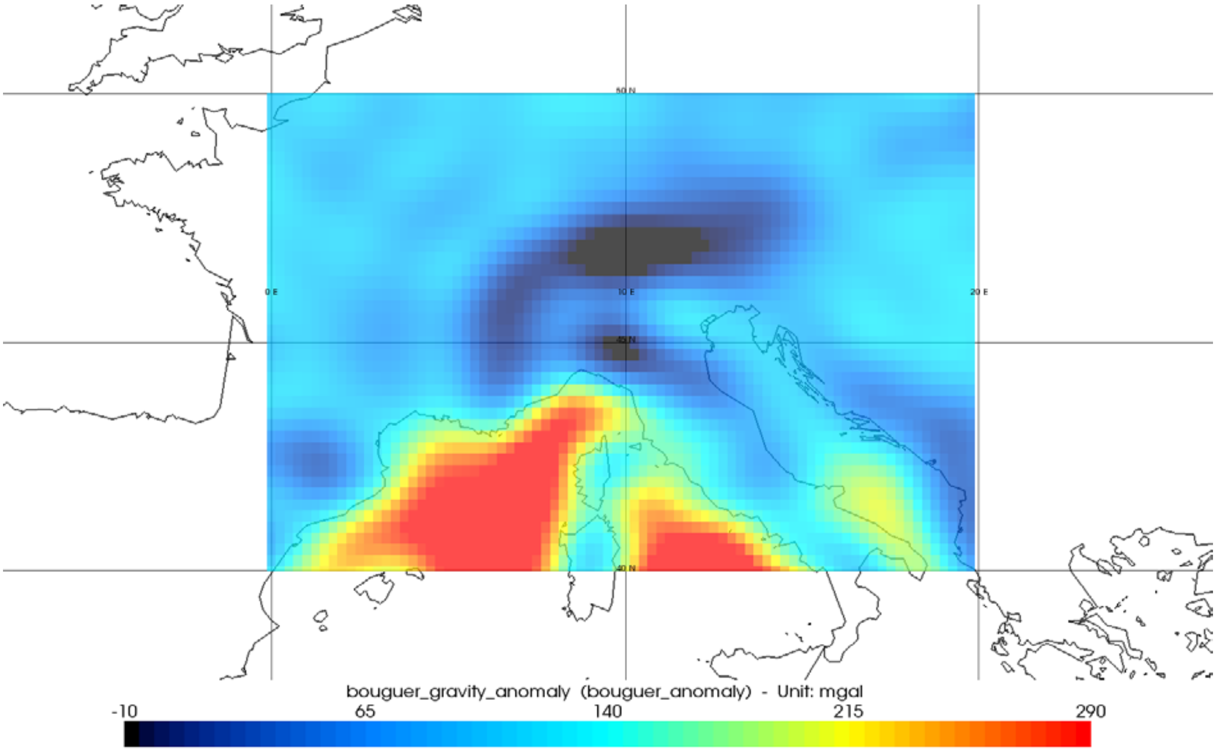


Figure 35: Map of full Bouguer gravity anomalies (mgal) obtained over the Alps using the bougueranomaly_gf workflow. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

Note that the patterns of Figure 35 are similar to those of Figure 34 (simple Bouguer anomaly), but that the values differ in their range. The full Bouguer values are upwards shifted by near to 140 mGal. Such a shift is possible due to the fact that the full Bouguer uses a global gravity effect model of terrain, without any distance limitations. In fact the spherical expansion used for the Bouguer correction, is based on the global gravity effect calculation over the entire Earth globe. The large masses, as is the Atlantic ocean, the Pacific ocean or the elevated land masses of the Eurasian plate contribute a non-negligible effect. The simple Bouguer calculation is only a local correction, approximating the gravity effect of the terrain to a flat plate of the same height as the calculated point. The entire Atlantic and the entire elevated landmasses in Northern Europe, produce a long-wavelength signal which is absent in the local reduction.

It may be preferable to calculate the Bouguer anomaly at a constant height. For this we must prepare a grid with constant height. This can be accomplished with the following command lines.

gut scale_gf **-InFile** GUT_ACE2_5M.nc **-Scale** 0 **-PQ0** height_above_reference_ellipsoid **-OutFile** temp.nc
gut addscalar_gf **-InFile** temp.nc **-InScalar** 8000 **-OutFile** dem8km.nc

The calculation would be then:

gut **bougueranomaly_gf** -InFile GO_CONS_EGM_GOC_2__20091101T000000_20131020T235959_0001.IDF -InTopoFile dV_ELL_RET2014_with_GRS80_SHCto2190.dat -DO 200 -InDemFile dem8km.nc -R 0:20,40:50 -I 0.25:0.25 -OutFile Full_Bouguer_gravity_anomaly_GOCE5_alps_8km.nc

BratDisplay Full_Bouguer_gravity_anomaly_GOCE5_alps_8km.nc

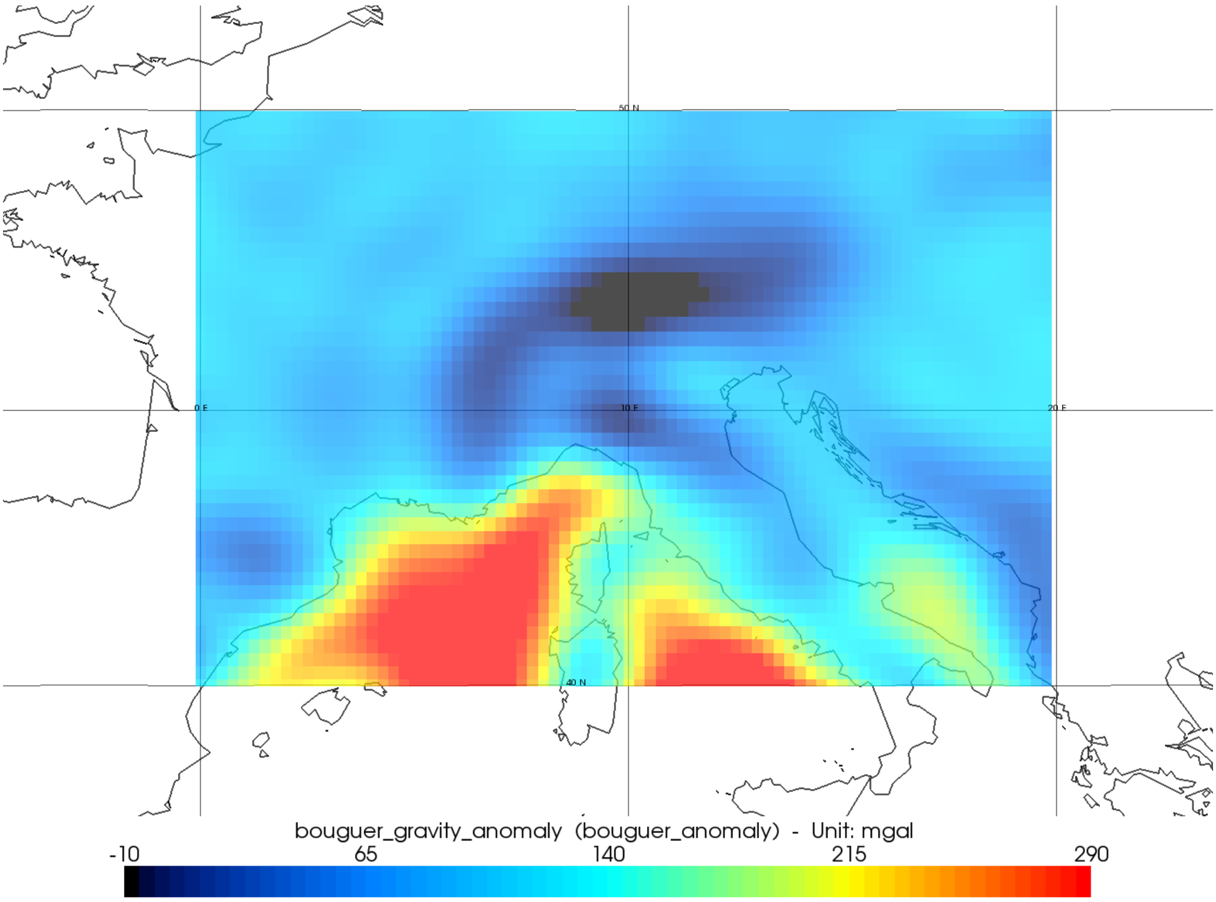


Figure 36: Map of full Bouguer gravity anomalies (mgal) calculated at 8000m height for the Alps using the bougueranomaly_gf workflow. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

7.3.28. airyanomaly_gf: Compute Airy anomaly

airyanomaly_gf	
Options	**Expected field**
-InFile input_file_name	Input file containing the geopotential spherical harmonic coefficients
-InIsoFile input_topo_file_name	Input file containing the isostatic geopotential spherical harmonic coefficients

-Gf input_grid_file **OR**	Specify file that defines output grid
-Af input_grid_file **OR**	Read lon/lat axes of output grid from file
-R w:e,s:n **-I dE:dN**	Output Grid Region. (0.5:359.5,-89.5:89.5) Output Grid Spacing. (1.0,1.0)
-Ellipse ellipse	Reference Ellipsoid for Output Grid by one of name (GRS80 TOPEX GRIM WGS84 WGS84rev1) parameters (formatted as inverse_flattening:a:GM) file (extracts the ellipsoid from the meta-data in this file)
 -DO degreeAndOrder OR **-Ddeg degrees** OR **-Dkm length**	Degree and Order of the SH expansion. positive integer scale angle in degrees scale length in km
-T tide-system	Tide system (tide-free, mean-tide, zero-tide).
- InDemFile input_dem_file	Specifies the input DEM grid function which defines the height at which the Bouguer anomaly is calculated. These values should be on or above the Earth surface.
-OutFile output_file_name	Output File for resulting netCDF file
Use the command line : **gut airynomaly_gf -man** to get more information	

Use case n° 32: Compute and plot the Airy gravity anomaly at 8000m height for the Alps

gut airyanomaly_gf **-InFile** GO_CONS_EGM_GOC_2__20091101T000000_20131020T235959_0001.IDF **-InIsoFile** RWI_TOIS_2012_plusGRS80.gfc **-DO** 200 **-InDemFile** dem8km.nc **-R** 0:20,40:50 **-I** 0.25:0.25 **-OutFile** Airy_gravity_anomaly_GOCE5_alps_8km.nc

BratDisplay Airy_gravity_anomaly_GOCE5_alps_8km.nc

Notice the file dem8km.nc has been built in the bouguer_anomaly workflow.

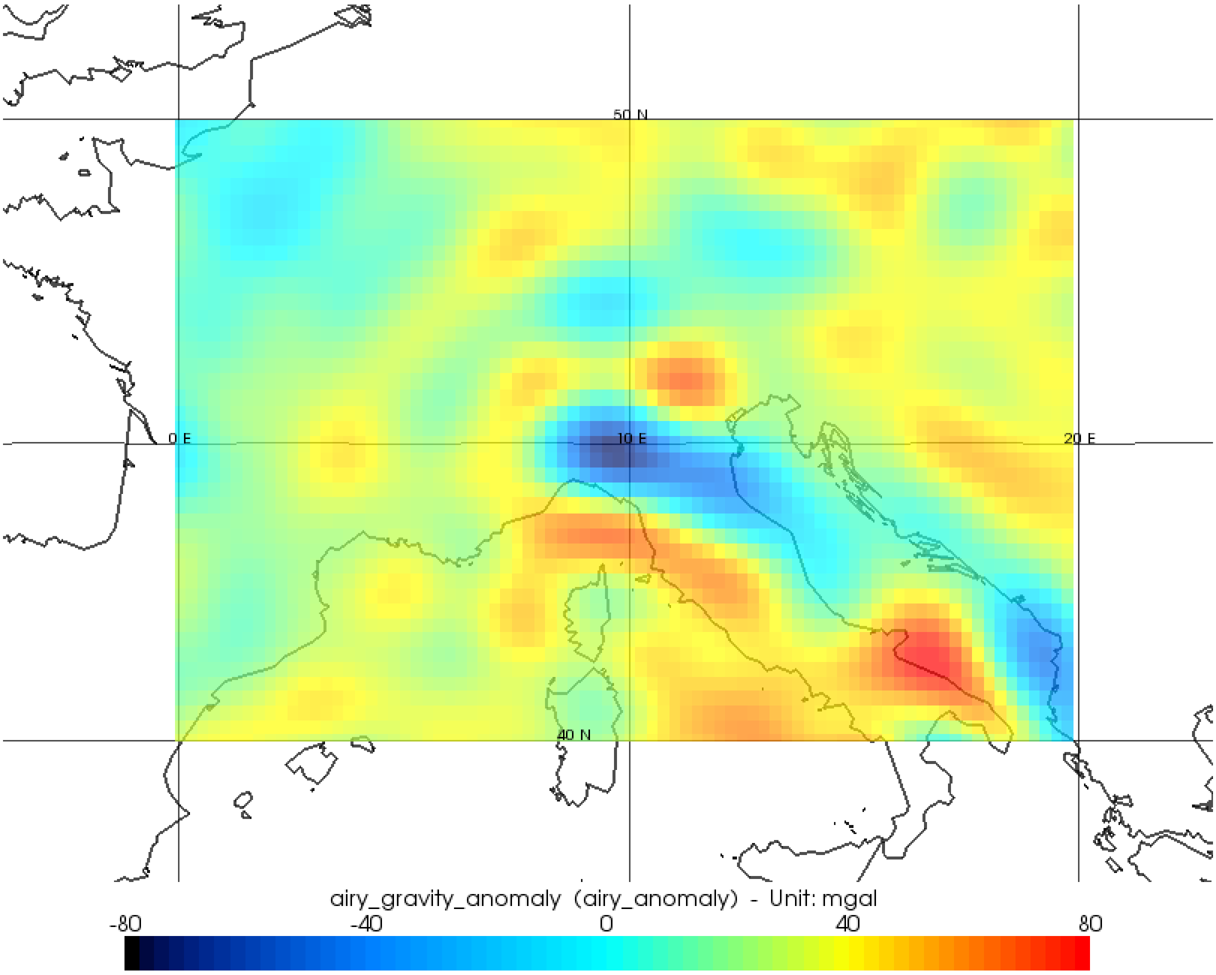


Figure 37: Map of Airy gravity residual (mgal) calculated at 8000m height for the Alps using the airyanomaly_gf workflow. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

7.3.29. gravitypotentialgradient_gf: Compute the second derivative of the disturbing gravity potential

gravitypotentialgradient_gf	
Options	**Expected field**
-Gradient gradient	Specifies the 2[d] derivative to be calculated. Can be any of: ZZ, XX, YY, XY, XZ, YZ where X-axis is pointing North, Y-axis is pointing West and Z-axis is pointing Up.
-InFile input_file_name	Input file containing the geopotential spherical harmonic coefficients
-Gf input_grid_file OR	Specify file that defines output grid
-Af input_grid_file OR	Read lon/lat axes of output grid from file
-R w:e,s:n **-I dE:dN**	Output Grid Region. (0.5:359.5,-89.5:89.5) Output Grid Spacing. (1.0,1.0)

-Ellipse ellipse	Reference Ellipsoid for Output Grid by one of name (GRS80 TOPEX GRIM WGS84 WGS84rev1) parameters (formatted as inverse_flattening:a:GM) file (extracts the ellipsoid from the meta-data in this file)
 -DO degreeAndOrder OR **-Ddeg degrees OR** **-Dkm length**	Degree and Order of the SH expansion. positive integer scale angle in degrees scale length in km
-T tide-system	Tide system (tide-free, mean-tide, zero-tide).
- InDemFile input_dem_file	Specifies the input DEM grid function. This must provide the height of the terrain above the ellipsoid
-OutFile output_file_name	Output File for resulting netCDF file
Use the command line : **gut gravitypotentialgradient_gf -man** to get more information	

Use case n° 33: Compute and plot the north-north derivative of the disturbing gravity potential over India

gut gravitypotentialgradient_gf -Gradient XX **-InFile** GO_CONS_EGM_GOC_2__20091101T000000_20131020T235959_0001.IDF **-R** 60:100,0:40 **-I** 0.1:0.1 **-DO** 260 **-InDemFile** GUT_ACE2_BATHY_5M.nc **-OutFile** gravitypotentialgradient_XX_GO_CONS_EGM_GOC_2_DIR5.nc

BratDisplay gravitypotentialgradient_XX_GO_CONS_EGM_GOC_2_DIR5.nc

The two command lines above produced the following plot (using the BratDisplay GUI):

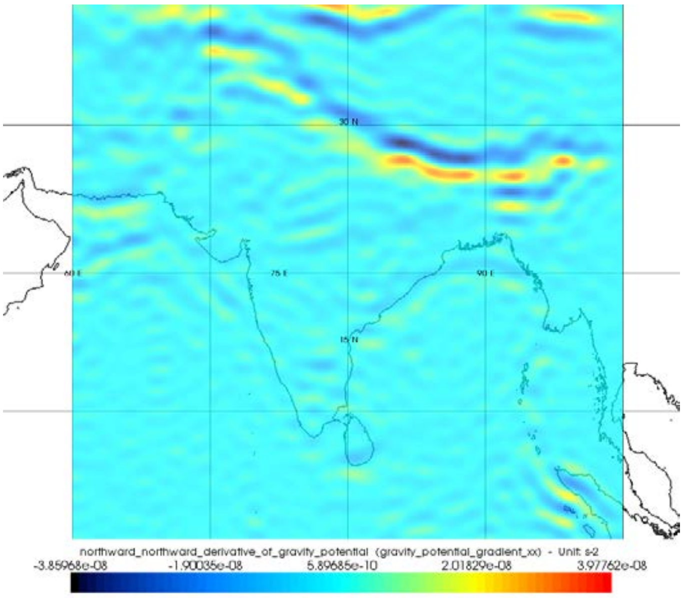


Figure 38: north-north derivative of disturbing gravity potential

7.3.30. gskineticenergy_gf: Compute geostrophic kinetic energy

gskineticenergy_gf	
Options	**Expected field**
-InFile input_file_name	Input file containing height grid
-PQ physical_quantity	Specifies the required data set. If the input file lacks the meta-data to allow this to be used for selection of the data set, it is used to explicitly set the physical quantity of the input data. Input data that are not a sea surface height above sea level are unlikely to yield sensible results (Accepted tokens are listed in Appendix A).
-EqMargin scale	Specifies the extent of the equatorial margin to be latitude range [-scale,+scale] degrees. The default is [-4,+4] degrees.
-OutFile output_file_name	Output File for resulting netCDF file
Use the command line : **gut gskineticenergy_gf -man** to get more information	

Use case n° 34: Compute kinetic energy from the mean dynamic topography DTU10 and plot it in the Agulhas current

gut gskineticenergy_gf -InFile MDT_DTU_10_10M.nc -OutFile MDT_DTU_10_10M_KE.nc

BratDisplay MDT_DTU_10_10M_KE.nc

The two command lines above produced the following plot (after zooming over the Agulhas area using the BratDisplay GUI):

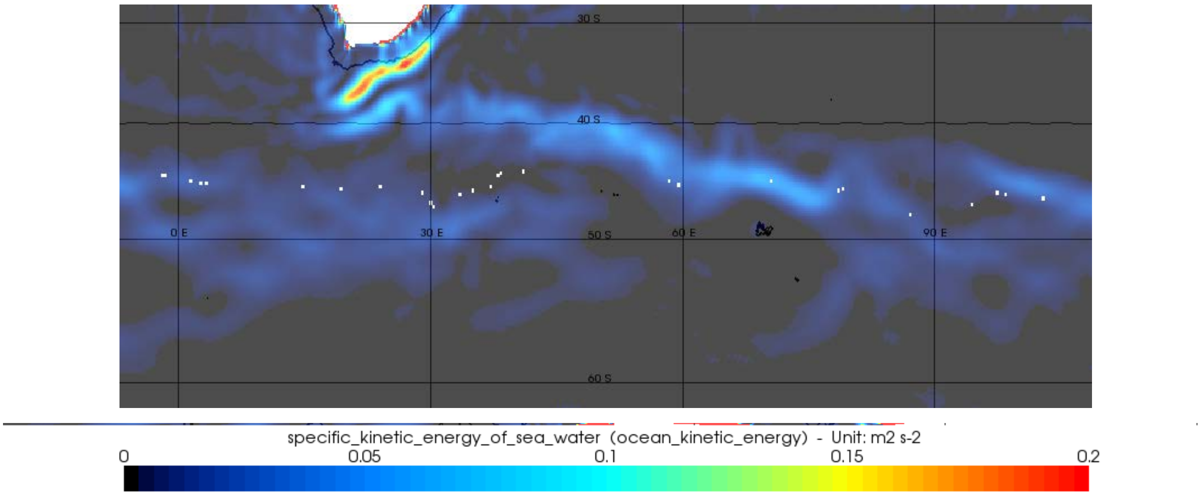


Figure 39: Mean Kinetic Energy computing through geostrophic approximation from the mean dynamic topography MDT DTU10

7.3.31. relativevorticity_gf: Compute the upward component of the relative vorticity from geostrophic velocity

relativevorticity_gf	
Options	**Expected field**
-InFile input_file_name	Input file containing height grid
-PQ physical_quantity	Specifies the required data set. If the input file lacks the meta-data to allow this to be used for selection of the data set, it is used to explicitly set the physical quantity of the input data. Input data that are not a sea surface height above sea level are unlikely to yield sensible results (Accepted tokens are listed in Appendix A).
-EqMargin scale	Specifies the extent of the equatorial margin to be latitude range [-scale,+scale] degrees. The default is [-4,+4] degrees.
-OutFile output_file_name	Output File for resulting netCDF file
Use the command line : **gut relativevorticity_gf -man** to get more information	

Use case n° 35: Compute upward relative vorticity from MDT CNES-CLS09 thought geostrophic approximation, filter it with a Gaussian Filter at 50km of resolution and plot it in the Agulhas current and its circumpolar current extension area

gut relativevorticity_gf -InFile MDT_CNES_CLS_09_15M.nc -OutFile MDT_CNES_CLS_09_15M_RelativeVorticity.nc

gut filter_gf -InFile MDT_CNES_CLS_09_15M_RelativeVorticity.nc -Fg 50km -OutFile MDT_CNES_CLS_09_15M_RelativeVorticity_Fg50km.nc

BratDisplay MDT_CNES_CLS_09_15M_RelativeVorticity_Fg50km.nc

The three command lines above produced the following plot (after zooming over the Agulhas area using the BratDisplay GUI):

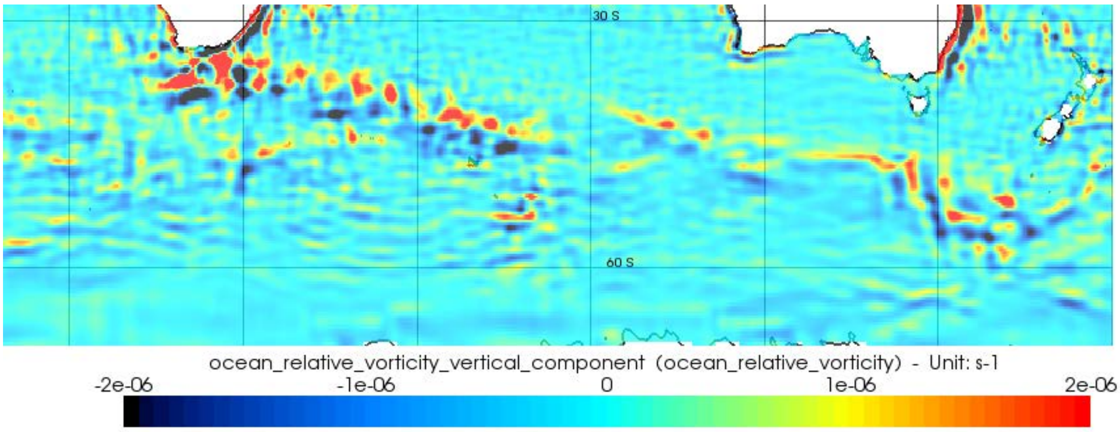


Figure 40: Upward component of the relative vorticity computing from the Mean Dynamic Topography MDT CNES-CLS09 through geostrophic assumption

7.3.32. Extract_gf: Extract a subset of a Grid Function within latitude and longitude bounds.

extract_gf	
Options	**Expected field**
-InFile input_file_name	Input file containing height grid
-PQ physical_quantity	Specifies the required data set. If the input file lacks the meta-data to allow this to be used for selection of the data set, it is used to explicitly set the physical quantity of the input data. Input data that are not a sea surface height above sea level are unlikely to yield sensible results (Accepted tokens are listed in Appendix A).
-R w:e,s:n	Specifies the latitude and longitude bounds of the equiangular output grid. The longitude limits (w:e) must be in degrees in the range [-360,+360] and the latitude limits (s:n) must be in degrees in the range [-90,+90].
Use the command line : **gut extract_gf -man** to get more information	

Use case n° 36: Extract geoid error over India

gut extract_gf

-InFile GO_CONS_EGM_GOC_2__20091101T000000_20131020T235959_0002.DBL

-R 55:90,0:40 **-PQ** geoid_height_error

-OutFile
GO_CONS_EGM_GOC_2__20091101T000000_20131020T235959_0002_ExtractErrorOverIndia.nc

BratDisplay
GO_CONS_EGM_GOC_2__20091101T000000_20131020T235959_0002_ExtractErrorOverIndia.nc

Note: The command line will give you the following warning: "WARNING: Product latitudes converted from geocentric to geodetic." This is only for your information but does not affect the result.

The two command lines above produced the following plot:

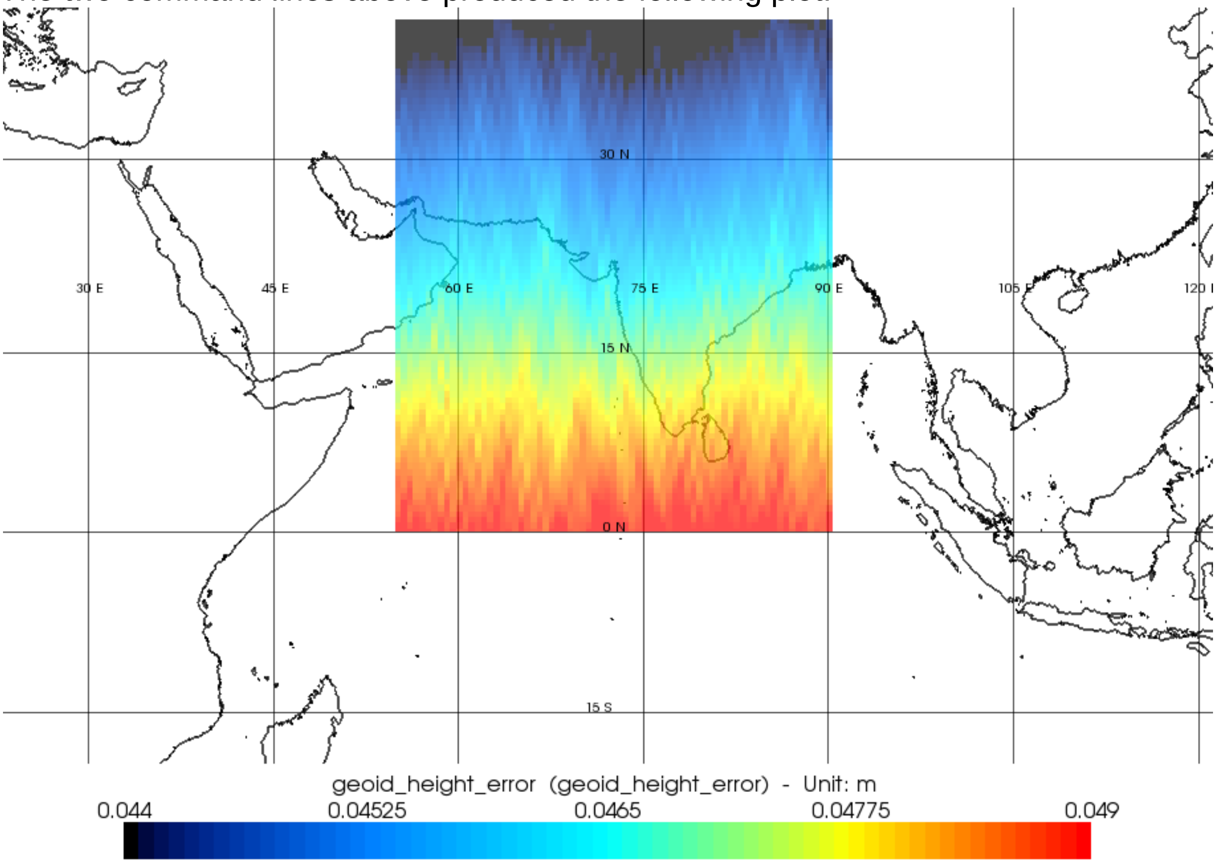


Figure 41: Geoid height error from GO_CONS_EGM_GOC_2__20091101T000000_20131020T235959_0002 extracted over India

7.3.33. Importegg_tf: Extract a specific Track Function from file and export it in GUT internal netCDF format

importegg_tf	
Options	**Expected field**
-InFile input_file_name	Input file containing height grid
-PQ physical_quantity	Specifies the required data set. If the input file lacks the meta-data to allow this to be used for selection of the data set, it is used to explicitly set the physical quantity of the input data. Input data that are not a sea surface height above sea level are unlikely to yield sensible results (Accepted tokens are listed in Appendix A).
-Gradient gradient	Specifies the 2[d] derivative to be extracted if the physical quantity is gravity_potential_gradient. Can be any of: ZZ, XX, YY, XY, XZ, YZ where X-axis is pointing North, Y-axis is pointing West and Z-axis is pointing Up.
-Ellipse ellipse	Set a specific Reference Ellipsoid. By default the reference ellipsoid extracted from the input file is preserved. For files that lack the meta-data that specifies the ellipsoid, GRS80 is assumed. The ellipsoid can be specified as one of: - ellipsoid name (GRS80 TOPEX GRIM WGS84 WGS84rev1) - the parameters formatted as inverse_flattening:a:GM - filename (extracts the ellipsoid from the meta-data in this file)
-T tide-system	Set (or transform to) a specific tide system. tide-system must be tide-free, mean-tide or zero-tide
-OutFile output_file_name	Output filename for resulting netCDF file
Use the command line : **gut importegg_tf -man** to get more information	

Use case n° 37: Export the north-east derivate of disturbance potential from GOCE data GO_CONS_EGG_TRF_2

gut importegg_tf -Gradient XY **-InFile** GO_CONS_EGG_TRF_2__20131002T000000_20131019T235959_0101.HDR **-OutFile** GO_CONS_EGG_TRF_2__20131002T000000_20131019T235959_0101_XY.nc

Figure 42 shows the reformatted file.

```
netcdf GO_CONS_EGG_TRF_2__20131002T000000_20131019T235959_0101_XY {
dimensions:
	station = 1518948 ;
variables:
	double lat(station) ;
		lat:long_name = "latitude" ;
		lat:standard_name = "latitude" ;
		lat:units = "degrees_north" ;
	double lon(station) ;
		lon:long_name = "longitude" ;
		lon:standard_name = "longitude" ;
		lon:units = "degrees_east" ;
	double alt(station) ;
		alt:long_name = "altitude" ;
		alt:standard_name = "altitude" ;
		alt:units = "m" ;
	double gravity_potential_gradient_xy(station) ;
		gravity_potential_gradient_xy:standard_name =
"northward_westward_derivative_of_gravity_potential" ;
		gravity_potential_gradient_xy:long_name =
"northward_westward_derivative_of_gravity_potential" ;
		gravity_potential_gradient_xy:units = "s-2" ;
		gravity_potential_gradient_xy:grid_mapping = "crs" ;
	int crs ;
		crs:grid_mapping_name = "latitude_longitude" ;
		crs:semi_major_axis = 6378137. ;
		crs:inverse_flattening = 298.257222101004 ;
		crs:earth_gravity_constant = 398600500000000. ;
		crs:earth_rotation_rate = 7.292115e-05 ;
		crs:climatology_bounds = "2013-10-2 0:0:0, 2013-10-19 23:59:59" ;

// global attributes:
		:Conventions = "CF-1.6" ;
		:history = "../../gut-3.0.0/bin/gut importegg_tf -Gradient XY -InFile
TO_BE_ADD/GO_CONS_EGG_TRF_2__20131002T000000_20131019T235959_0101.HDR -OutFile
GO_CONS_EGG_TRF_2__20131002T000000_20131019T235959_0101_XY.nc" ;
data:

 gravity_potential_gradient_xy = 1.22803778e-10, 1.1399427e-10,
   1.08946864e-10, 1.11790671e-10, 1.07801794e-10, 1.00357015e-10,
   9.90728936e-11, 9.63529201e-11, 9.34051386e-11, 9.78780515e-11,
   9.71790981e-11, 8.94127816e-11, 8.87736313e-11, 9.10815743e-11,
   8.71734287e-11, 8.66158616e-11, 8.67159657e-11, 7.80891188e-11,
   7.51746093e-11, 7.90227932e-11, 7.52258114e-11, 7.34054921e-11,
   7.54822553e-11, 6.96612095e-11, 6.75434517e-11, 6.97062553e-11,
   6.35319701e-11, 5.76225414e-11, 5.95709785e-11, 6.04172345e-11,
   5.55740518e-11, 5.13640907e-11, 5.17613171e-11, 5.12532013e-11,
   4.65996097e-11, 4.47930569e-11, 4.60428876e-11, 3.97056406e-11,
   3.54677945e-11, 3.80756608e-11, 3.48985719e-11, 3.09714287e-11,
   3.07514404e-11, 2.4718069e-11, 2.06353566e-11, 2.24115114e-11,
   2.10962849e-11, 1.74492264e-11, 1.59231223e-11, 1.63333359e-11,
   1.49468717e-11, 1.50828559e-11, 1.69364998e-11, 1.46340415e-11,
   9.65538726e-12, 5.52600963e-12, 2.55663025e-12, 4.45634995e-12,
   9.83317901e-12, 5.22562355e-12, -4.34359118e-12, 2.75509016e-12,
   1.14109768e-11, 8.42892567e-13, -4.1895243e-12, 5.15624606e-12,
   8.13538201e-12, 4.81960712e-12, 3.9273502e-12, 3.15271696e-12,
   4.8035655e-12, 9.34925299e-12, 8.8204606e-12, 8.20030643e-12,
   1.17236419e-11, 9.43328552e-12, 2.53947805e-12, 6.93583647e-12,…
```

Figure 42: Beginning of the file GO_CONS_EGG_TRF_2__20131002T000000_20131019T235959_0101_XY.nc as given by the

command line *ncdump -v gravity_potential_gradient_xy GO_CONS_EGG_TRF_2__20131002T000000_20131019T235959_0101_XY.nc*

7.4. Using existing workflows: the "step by step" approach

As already seen in the previous section, the "spatialmdt_gf" workflow can be used to compute the MDT filtered at the required resolution. The different steps of the computation can be visualized using the "gut -dot spatialmdt_gf" command followed by the 'dotty spatialmdt_gf.dot" command.

However, the intermediate files computed in the process are not stored on the computer, nor can be visualized. In order to create and keep on disk the different files produced in the MDT computation process, the user may want to proceed "step by step". We give hereafter an example of how this can be done:

WARNING: When working "step by step" the user must be careful to respect all the recommendations listed in section 6 "Issues and recommendation for using GUT to compute the ocean Mean Dynamic Topography". Any disregarding of the given recommendations will result in an erroneous MDT field.

Use case n° 38: Compute a satellite-only MDT with the same characteristics of Use case n° 13 without using the spatialmdt_gf workflow.

This can be done using the GUT toolbox in 5 steps:

Step 1: Put the geoid height into the same reference system as the MSS by typing:

gut geoidheight_gf -InFile GO_CONS_EGM_GOC_2__20091101T000000_20100630T235959_0002.DBL **-Ellipse TOPEX -T mean-tide** -OutFile GOCE_dir_MT_TP.nc

Step 2: Interpolate the MSS file onto the same grid as the geoid height

gut adapt_gf -InFile MSS_CNES_CLS_11_2M.nc **-Gf** GOCE_dir_MT_TP.nc -OutFile MSS_adapt.nc

Step 3: Subtract both files by typing:

gut subtract_gf -InFileLhs MSS_adapt.nc -InFileRhs GOCE_dir_MT_TP.nc -OutFile MSS_GOCE_dir.nc

Step 4: Remove the values on continents by typing:

gut landmask_gf -InFile MSS_GOCE_dir.nc -InLsmFile GUT_LSM.nc -OutFile MSS_GOCE_dir_lmsk.nc

Step 5: Filter the resulting file by typing:

gut filter_gf -InFile MSS_GOCE_dir_lmsk.nc **-Fhan 2,3 -OutFile** MSS_GOCE_dir_lmsk_fhan32.nc

Note that the resulting MDT is exactly the same as what was obtained using the 'spatialmdt_gf' workflow.

The user can check this by typing:

gut subtract_gf -InFileLhs MSS_GOCE_dir_lmsk_fhan32.nc **-InFileRhs** SpatialMdt_fhan32.nc **-OutFile** Diff_stepbystep_spatialmdt.nc

gut stats_gf -InFile Diff_stepbystep_spatialmdt.nc

He/she will get the following results:

```
INFO:    Extracted 'mdt'
INFO:    (Stats) Bounds [-89.5, 89.5] N,  [0.5, 359.5] E
INFO:    (Stats) mdt
          Lon x Lat : 360 x 180
          Maximum   : 4.78728e-13 m at (52.5 E, 47.5 N)
          Minimum   : -2.41585e-13 m at (53.5 E, 45.5 N)
          Mean      : 1.95619e-15 m
          Variance  : 1.36317e-28  =>  RMS : 1.16755e-14 m
          W-Mean    : 1.79931e-15 m
          W-Var     : 1.45923e-28  =>  RMS : 1.20799e-14 m
          Valid     : 40846 / 64800  (63%)
```

The advantage of working 'step by step' is that the user can then visualize the different steps of his/her computation.

For instance, the following plot was produced by the command:

BratDisplay MSS_GOCE_dir.nc

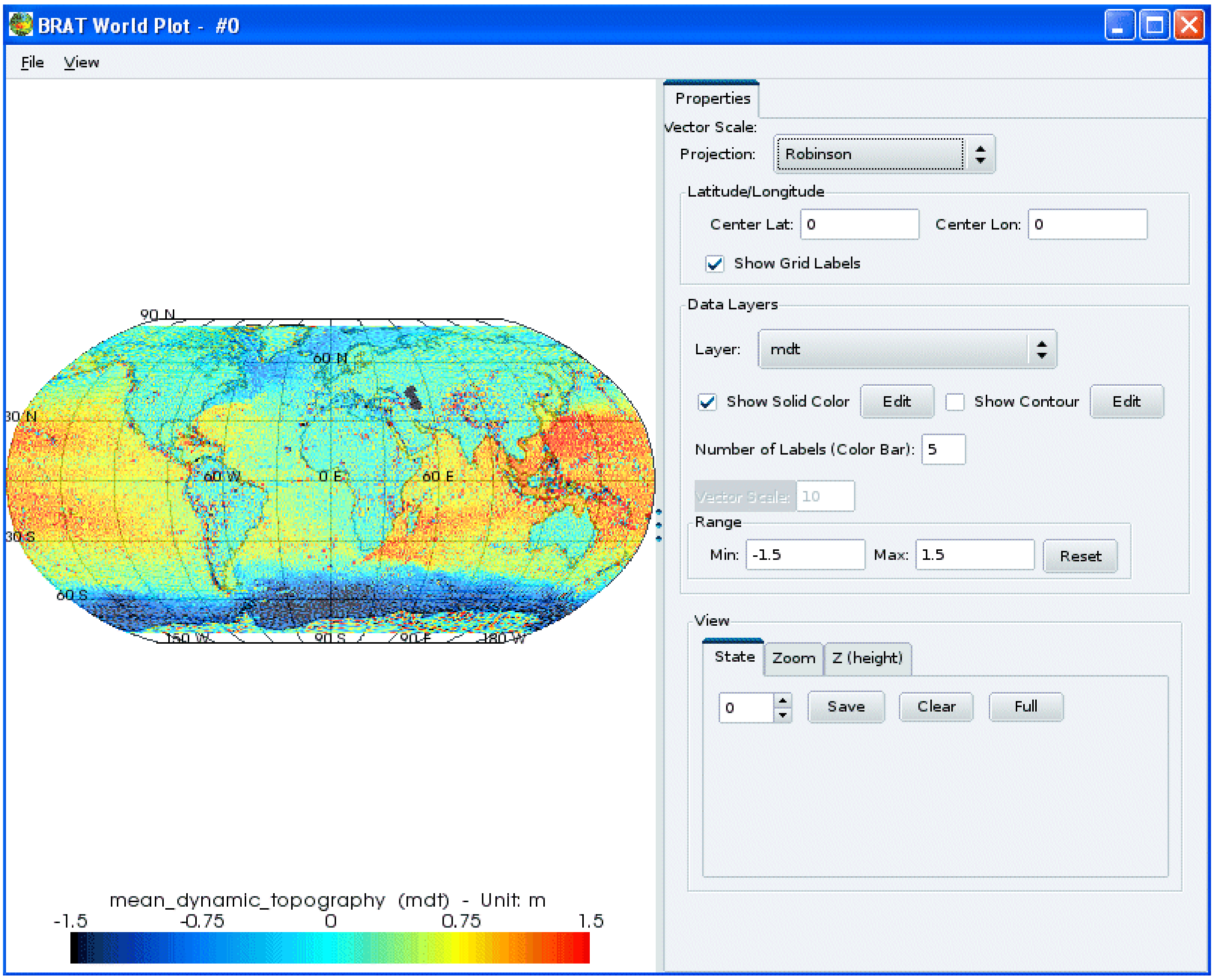


Figure 43: Map of unfiltered spatial MDT computed taking the difference between a MSS and a geoid. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

WARNING: The step n°4 is a crucial one, all the more than the GUT apriori MSS are completed on the continents with values from a geoid model. In that case, steps 1 and 2 will results in a full grid (with defined values on the continents). Further applying a filter will result near the coasts in a MDT that substantially differs from what is obtained by first removing the values on the continents.

Use case n° 39: Compute a satellite-only MDT in the spectral domain instead of the spatial domain

In the previous use case the MDT in computed in the spatial domain: The geoid height and the Mean Sea Surface (MSS) are first both defined by spatial gridded points associated with coordinates (longitude and latitude). Then the difference between MSS and geoid height is done by doing the difference at each gridded point.

It is also possible to compute a MDT in the spectral domain. In this case, the MSS and geoid model are defined by spherical harmonic coefficients and the MDT is computed by doing the difference between these coefficients.

Step 1: Complete the MSS over the continent with the geoid height values that will be used in the calculation of the MDT (to compute spherical harmonic function, the field should be defined everywhere, over both ocean and land):

a- First, under sample the MSS to reduce computation time:

gut adapt_gf -InFile MSS_DTU_10_2M.nc -I 0.1:0.1 -IntAlg spline -OutFile MSS_DTU_10_2M_10eme.nc

b- Then replace the initial value over the continents by “0”:

gut landmask_gf -InFile MSS_DTU_10_2M_10eme.nc -InLsmFile GUT_LSM.nc -Substitute 0. -OutFile MSS_DTU_10_2M_10eme_maskedLSM.nc

c- Compute the geoid height over the same grid than MSS:

gut geoidheight_gf -InFile GO_CONS_EGM_GOC_2__20091101T000000_20131021T000000_0001.IDF -Ellipse TOPEX -T mean-tide -I 0.1:0.1 -OutFile GOCE5_MT_TP_10eme.nc

d- Replace the geoid height value over the ocean by “0”:

gut landmask_gf -InFile GOCE5_MT_TP_10eme.nc -InLsmFile MSS_DTU_10_2M_10eme_maskedLSM.nc -Op ne -Thr 0.0 -Substitute 0. -OutFile GOCE5_MT_TP_10eme_maskedLSM.nc

e- Complete the MSS over the continent with the geoid height values

gut add_gf -InFileLhs MSS_DTU_10_2M_10eme_maskedLSM.nc -InFileRhs GOCE5_MT_TP_10eme_maskedLSM.nc -OutFile MSS_DTU_10_2M_10eme_GOCE5OnLand.nc

Step 2: Compute the spherical harmonic function associated with the geoid model

gut gf2shf -InFile GOCE5_MT_TP_10eme.nc -DO 300 -OutFile GOCE5_MT_TP_10eme_DO300_SH.nc

Step 3: Compute the spherical harmonic function associated with the MSS

gut gf2shf -InFile MSS_DTU_10_2M_10eme_GOCE5OnLand.nc -DO 300 -OutFile MSS_DTU_10_2M_10eme_GOCE5OnLand_DO300_SH.nc

Step 4: Compute Spectral MDT and coming back to the spatial domain

gut subtract_shf -InFileLhs MSS_DTU_10_2M_10eme_GOCE5OnLand_DO300_SH.nc -InFileRhs GOCE5_MT_TP_10eme_DO300_SH.nc -OutFile MDT_spectral.nc

gut shf2gf -InFile MDT_spectral.nc -DO 200 -R 0:359.75,-90:90 -I 0.25:0.25 -OutFile MDT_DO200_qd.nc

The following plot was produced by the command:

BratDisplay MDT_DO200_qd.nc

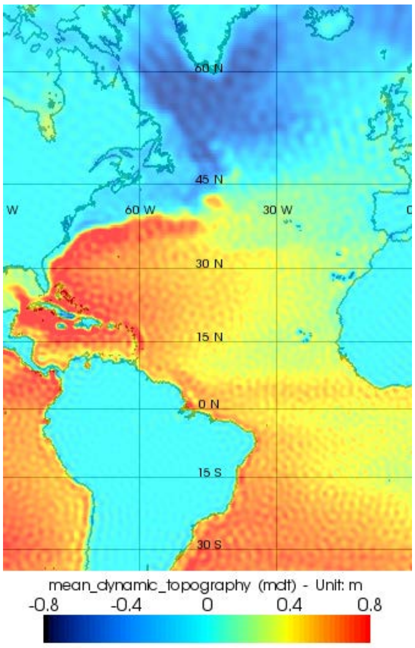


Figure 44: Map of the spectral MDT in the Atlantic Ocean. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

Use case n° 40: Compute a Combined MDT using a Remove-restore technique in the Gulfstream area

As explained in section 6.2, the spectral content of the 'Satellite_only' MDT is, by construction, limited by the spectral content of the geoid model. In the case of GOCE, the corresponding MDT will thus have a centimetric accuracy at a 100 km resolution. In some areas of the world ocean, notably coastal areas, straits, semi-enclosed seas such as the Mediterranean Sea and close to steep bottom topography, the MDT is expected to contain signals at shorter spatial scales.

In this context, one may want to compute a MDT containing spatial scales not resolved by the 'Satellite-only' MDT. This may be done for instance by completing the Satellite-only MDT with short scales MDT information from other, higher resolution MDT sources (hereafter called the a-priori MDT), through a so-called 'remove-restore' methodology:

First, a Satellite_only solution is computed using the previous use case. Then the high resolution a-priori MDT is filtered using the same filter than for the Satellite-only MDT computation. Residuals (Apriori MDT minus filtered Apriori MDT) are then added to the Satellite-only MDT.

The use case below is a description of how this can be achieved using the GOCE User Toolbox in 9 steps:

Step 1: Compute a grid of geoid height

gut geoidheight_gf -InFile GO_CONS_EGM_GOC_2__20091101T000000_20100630T235959_0002.DBL **-Ellipse TOPEX -T mean-tide -R 280:320,30:50 -I 0.25:0.25 -OutFile** GOCE_dir_TP_MT_gs.nc

Step 2: Interpolate the MSS file onto the same grid as the geoid height

gut adapt_gf -InFile MSS_CNES_CLS_11_2M.nc **-Gf** GOCE_dir_TP_MT_gs.nc **-OutFile** MSS_gs.nc

Step 3: Subtract both files by typing:

gut subtract_gf -InFileLhs MSS_gs.nc **-InFileRhs** GOCE_dir_TP_MT_gs.nc **-OutFile** MSS_GOCE_dir_TP_MT_gs.nc

Step 4: Remove the values on continents by typing:

gut landmask_gf -InFile MSS_GOCE_dir_TP_MT_gs.nc **-InLsmFile** GUT_LSM.nc **-OutFile** MSS_GOCE_dir_TP_MT_gs_lmsk.nc

Step 5 : Filter the resulting file by typing:

gut filter_gf -InFile MSS_GOCE_dir_TP_MT_gs_lmsk.nc **-Fg 1 -OutFile** SpatialMdt_gs_fg1.nc

Step 6: Interpolate the a-priori MDT on the same grid than the Satellite_only MDT

gut adapt_gf -InFile MDT_CNES_CLS_09_15M.nc **-Gf** SpatialMdt_gs_fg1.nc **-OutFile** MDT_CNES_CLS_09_15M_gs.nc

Step 7: Filter the a-priori MDT using the same filter used for step 5.

gut filter_gf -InFile MDT_CNES_CLS_09_15M_gs.nc **-Fg 1 -OutFile** MDT_CNES_CLS_09_15M_gs_fg1.nc

Step 8: Subtract the filtered a-priori MDT from the unfiltered a-priori MDT.

gut subtract_gf -InFileLhs MDT_CNES_CLS_09_15M_gs.nc **-InFileRhs** MDT_CNES_CLS_09_15M_gs_fg1.nc **-OutFile** MDT_CNES_CLS_09_15M_gs_hr.nc

Step 9: Add the resulting field to the Satellite-only MDT.

gut add_gf -InFileLhs SpatialMdt_gs_fg1.nc **-InFileRhs** MDT_CNES_CLS_09_15M_gs_hr.nc **-OutFile** RR_stepbystep_gs.nc

As for the previous use case, the different intermediate files can be stored and visualized.

For instance, the user may plot the spatial MDT computed at step 5 using the following command:

BratDisplay SpatialMdt_gs_fg1.nc

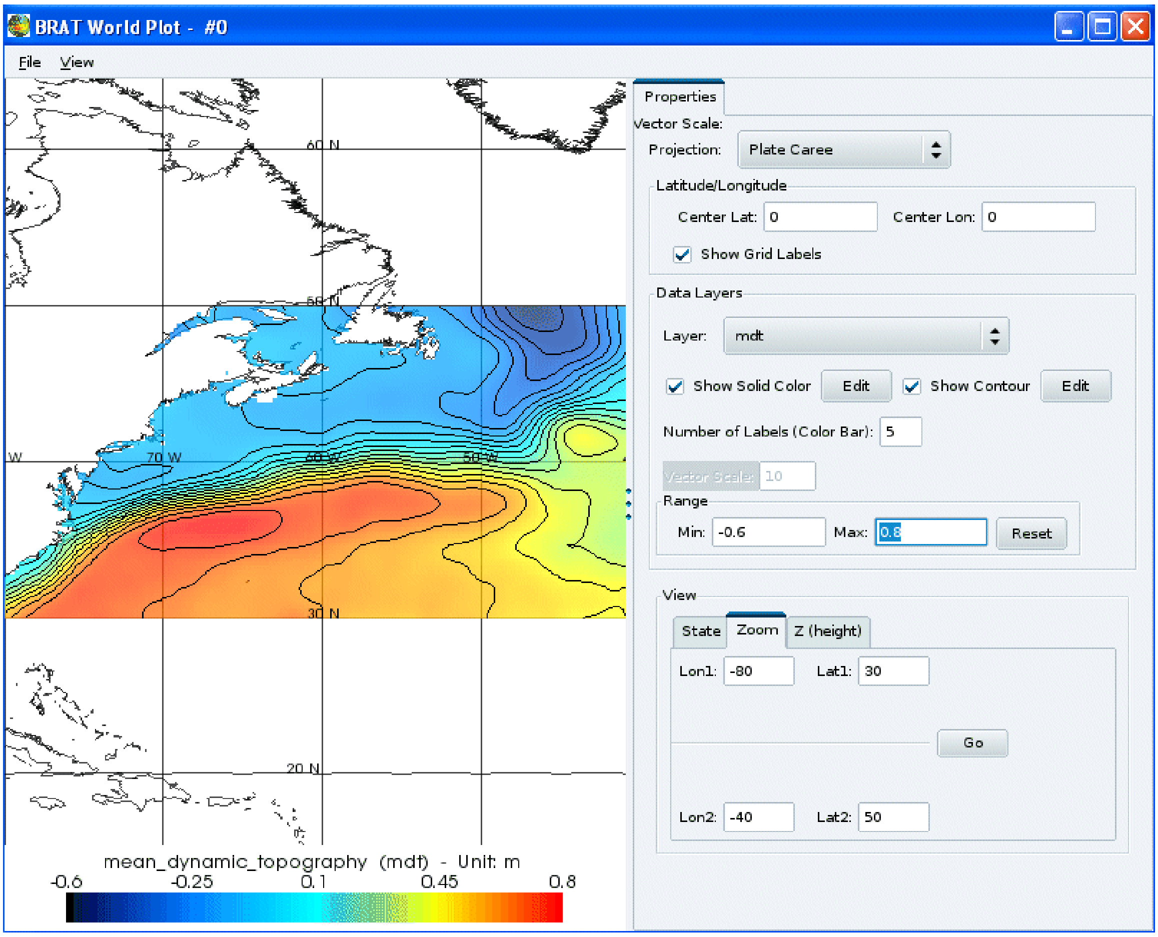


Figure 45: Map of MDT computed subtracting a geoid model from an altimetric MSS and applying a Gaussian low pass filter to remove scales shorter than 1°. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

The final 'combined' MDT may be displayed using the following command:

BratDisplay RR_stepbystep_gs.nc

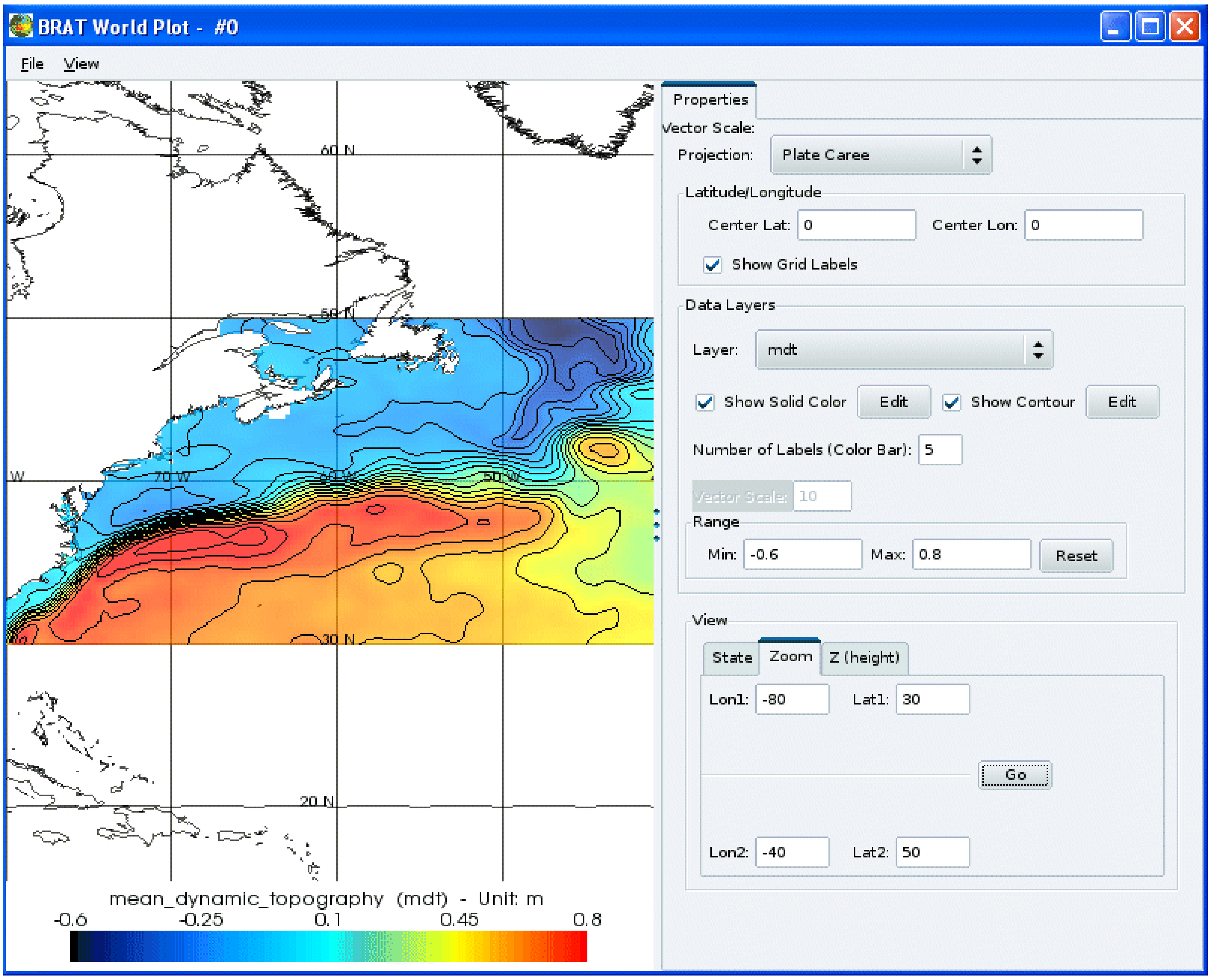


Figure 46: Map of Remove-Restore MDT computed step by step in the Gulfstream area. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

WARNING: In this example the apriori CNES-CLS09 MDT is used, which corresponds to the 1993-1999 averaging period, in consistency with the GUT apriori CNES-CLS10 MSS. When applying this method to his/her own apriori MDT field, the user must check that the time period of both the altimetric MSS and the apriori MDT used for the computation are consistent.

7.5. Creating his own workflow

A third way for the user to use the GOCE User Toolbox is to create his/her own workflow to fulfil specific needs.

Each workflow described above is an assembly of processing units. The different processing units are connected one to each other in the form of a 'directed acyclic graph' A complete description of all processing units available in GUT as well as a detailed explanation of how a workflow is structured are given in the User Guide (RD3). The user is strongly recommended to read the dedicated section (3.2) from the user guide before trying to create his/her own workflow.

We hereafter give an example of how this can be done.

Use case n° 41: Create a workflow allowing to compute a Combined MDT using a Remove-restore technique

To illustrate the 'step by step' approach, we have described in the previous section how a combined MDT can be computed by adding the short spatial scales from an apriori MDT to a filtered Satellite only MDT. In order not to repeat the 'step by step' approach each time a new combined field needs to be computed, the user may want to create a specific 'remove_restore_gf' workflow.

The use case described below shows how to proceed.

User need: give a MSS, a geoid model and an apriori MDT as input, as well as characteristics of the filter to apply, and compute a combined MDT using the remove-restore technique.

The structure of the created workflow can be conveniently visualized using the two following commands:

gut --dot remove_restore_gf (create the remove_restore_gf.dot file)

dotty remove_restore_gf.dot (display the remove_restore_gf.dot image on the screen)

The created workflow can then be used to compute combined MDT, as in the following example:

```
gut remove_restore_gf -InShpFile GO_CONS_EGM_GOC_2__20091101T000000_20100630T235959_0002.DBL -InSshFile MSS_CNES_CLS_11_2M.nc -InLsmFile GUT_LSM.nc -InAmdtFile MDT_CNES_CLS_09_15M.nc -R 280:320,30:50 -I 0.25:0.25 -Fg 1 -OutFile_Residuals ResidualMDT_gs.nc -OutFile_SMdt SpatialMdt_gs.nc -OutFile_RRMdt RR_workflow_gs.nc
```

The residual signal that has been added to the spatial MDT to compute the Remove-Restore solution may be visualized using the following command:

BratDisplay ResidualMDT_gs.nc

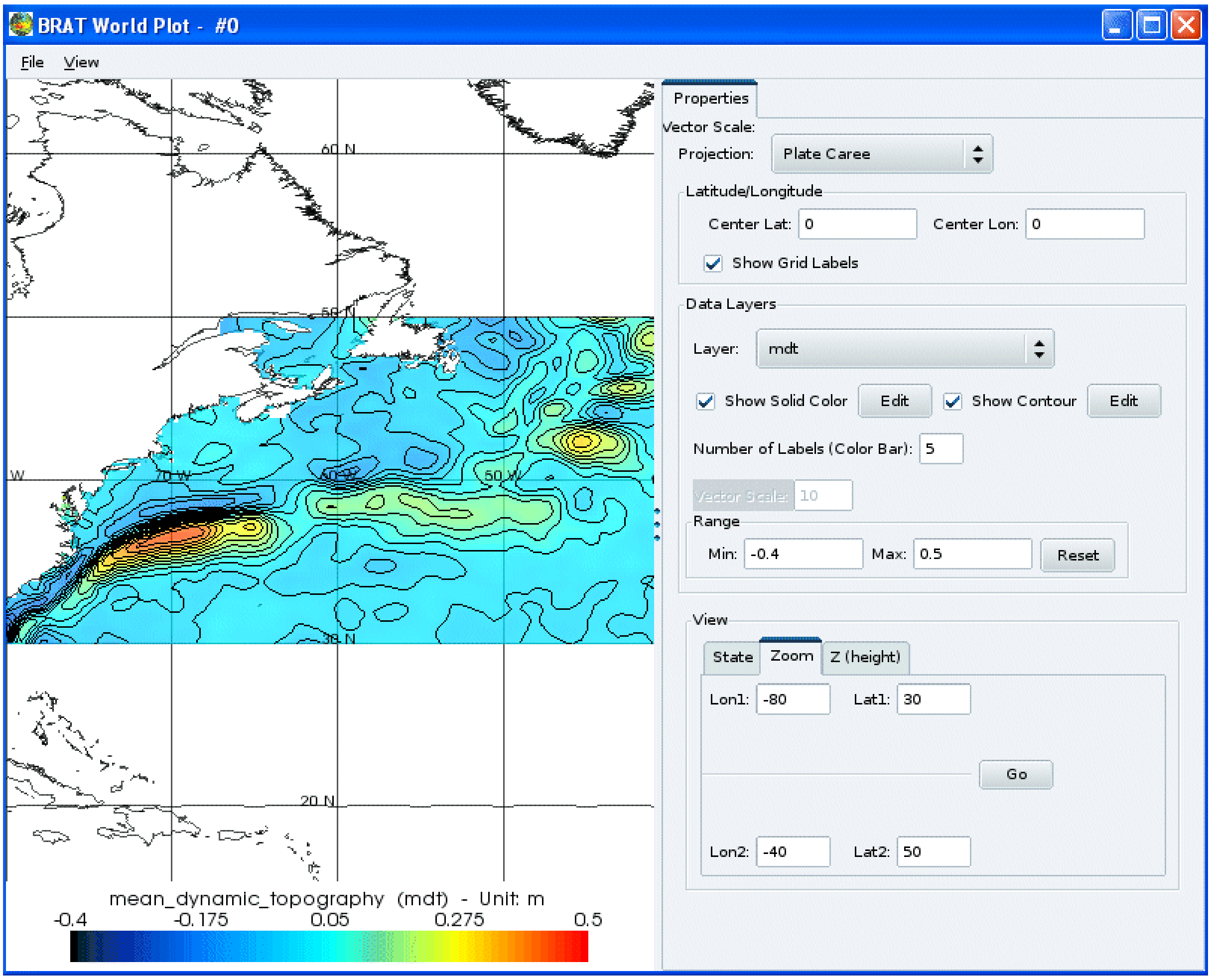


Figure 47: Map of the short scales from the apriori CNES-CLS09 MDT computed in the Gulfstream area using the remove_restore_gf workflow. The projection, the zoom parameters and the colour range were set using the BratDisplay GUI.

8. Use an interactive Graphical User Interface (GUI) instead of command line

The aim of this part is to help users to be familiar with the Graphical User Interface (GUI), which is an interactive interface to use the GOCE User Toolbox (GUT) instead of using command line.

However for general information about GUT and its philosophy, the user is invited to read the user guide (DR1). The user guide describes how to install GUT (included the GUI) and the algorithms offer by GUT. It also documents the fundamental data types, file formats and independent processing units implemented in the GUT Software.

The user is also invited to read the GUT tutorial (DR2) that described the usage of GUT and gives a lot of use cases (that use command line but same things can be done with GUI).

8.1. Open GUT gui

8.1.1. Windows

To open GUT gui you must

- go in the directory where you have installed GUT (Figure 48) - for installation procedure see the user guide DR1,
- open the "gui" directory (Figure 49)
- click on gutgui.exe

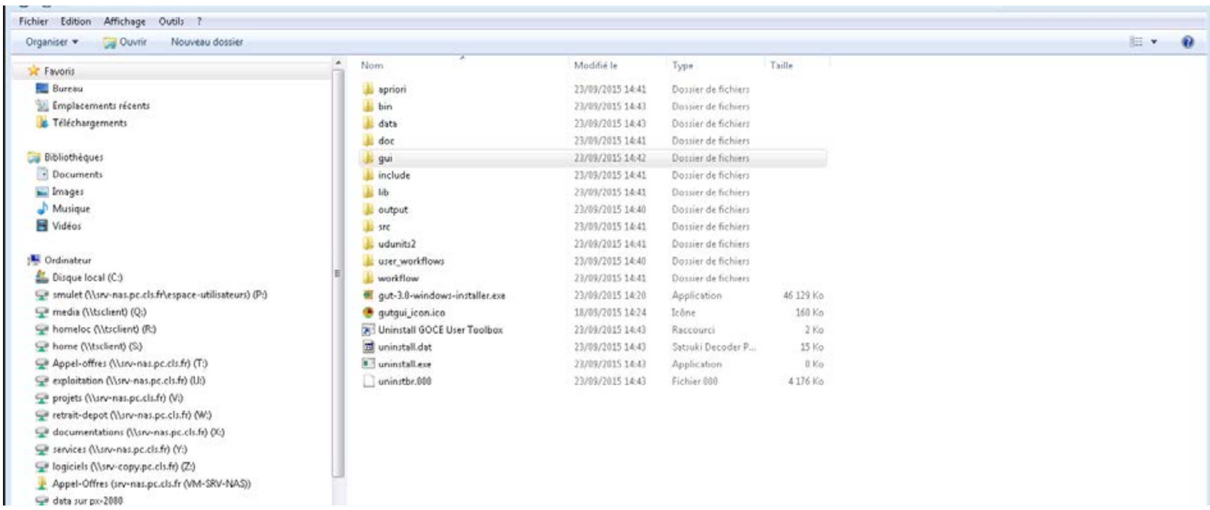


Figure 48: GUT directory

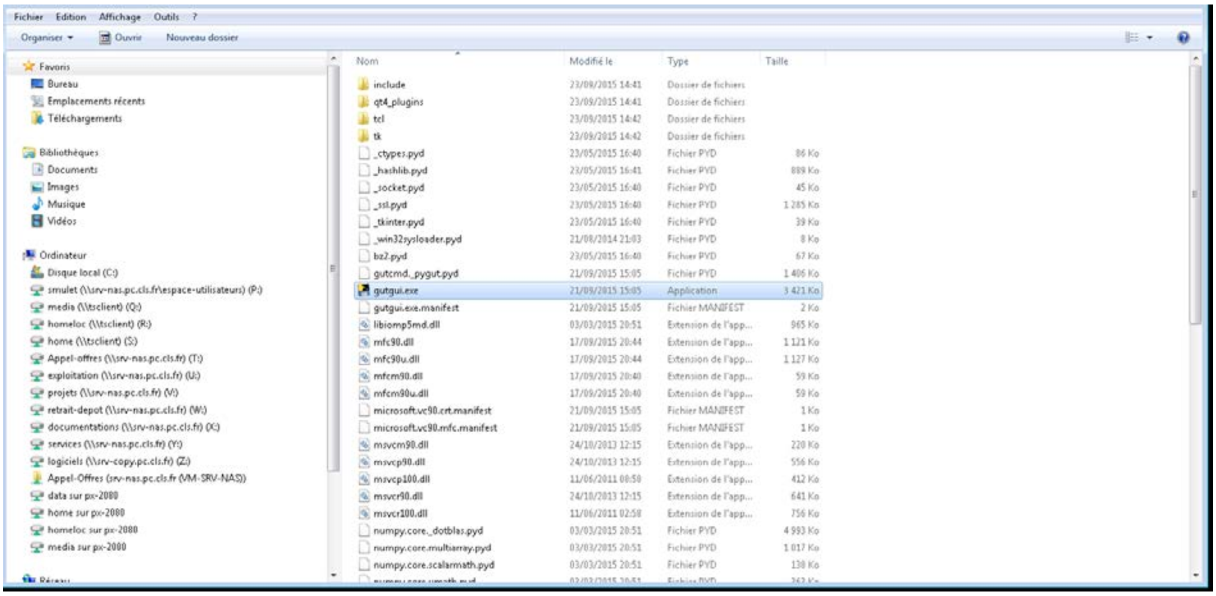


Figure 49: “gui” directory

8.1.2. Linux or Mac OS X

To open GUT gui you must

- go in the directory where you have installed GUT - for installation procedure see the user guide DR1,
- go in the binary directory

```
cd bin
```

- run gutgui

```
gutgui
```

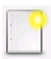
8.1.3. Use a desktop shortcut

You can also double click on the GUI desktop shortcut is you have chosen to create one when you have installed GUI. You can also easily create a shortcut by

- right clicking on gutgui.exe in the gui directory,
- select “create a shortcut” and
- drag and drop the shortcut on your desktop.

8.2. Create a new project

8.2.1. Open a new project

To create a new project, either you can open “New/Project” (Figure 50) in the “File” directory or click on the icon .

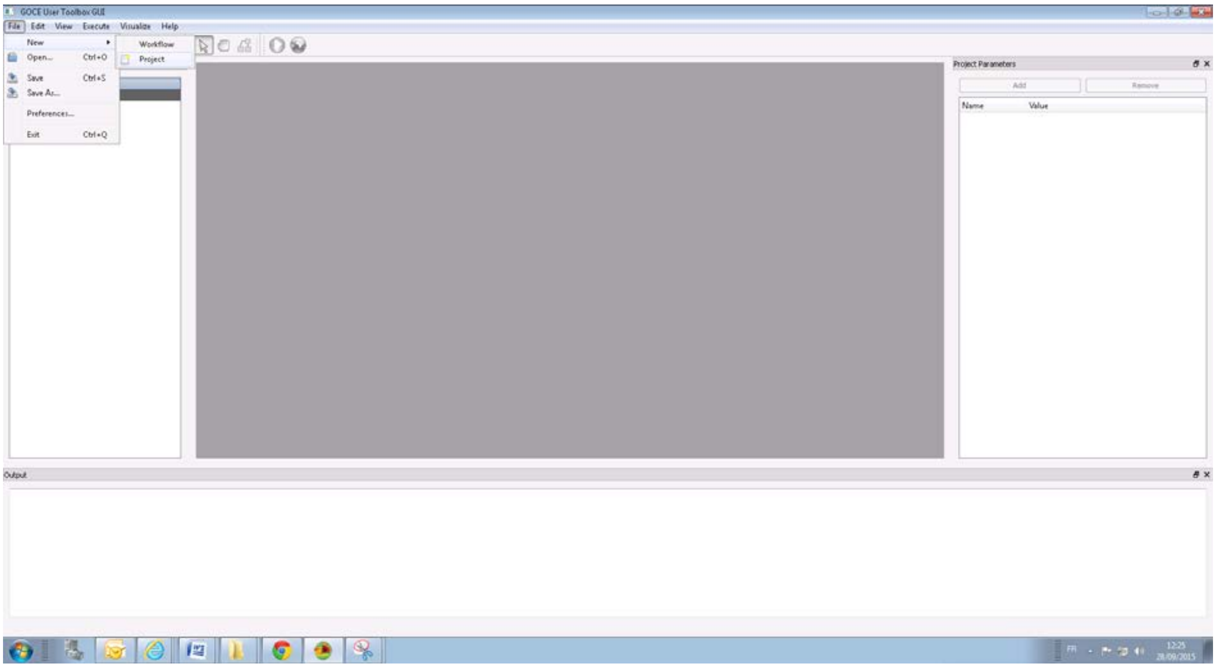


Figure 50: Open a new project

8.2.2. Add a workflow to the project

In the workflow library window on the left (to have information about the different windows: see section 8.4), you have 2 options (Figure 51):

1- Open an existing workflow in the "system workflows" directory. The algorithms associated with the workflows are described in the user guide DR1. They can be used to filter, compute geoid height, Bouguer anomaly and a lot of other things. The input of a workflow can be a grid function, a track function, a spherical harmonic function or a spherical harmonic potential.
2- Open a workflow created by user.

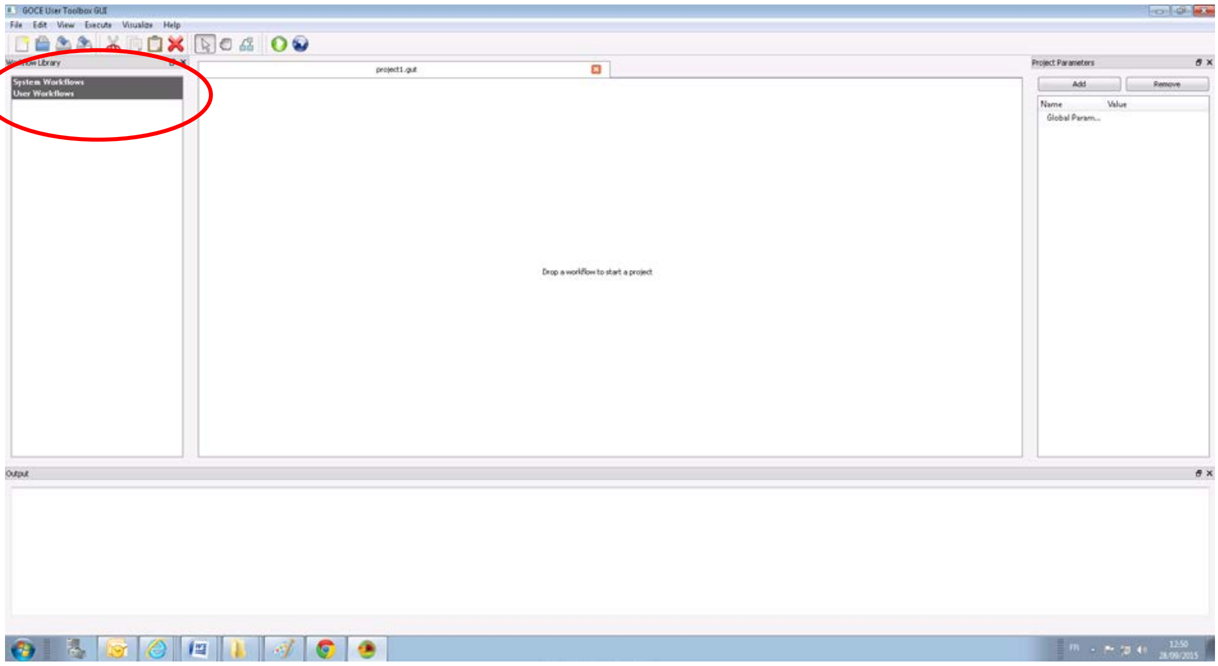


Figure 51: 2 options in the workflow library

To open a system workflow, double click on “system workflows” and then on the category of interest (grid, track, spherical harmonic...). Finally, drag and drop a workflow to the project window (Figure 52).

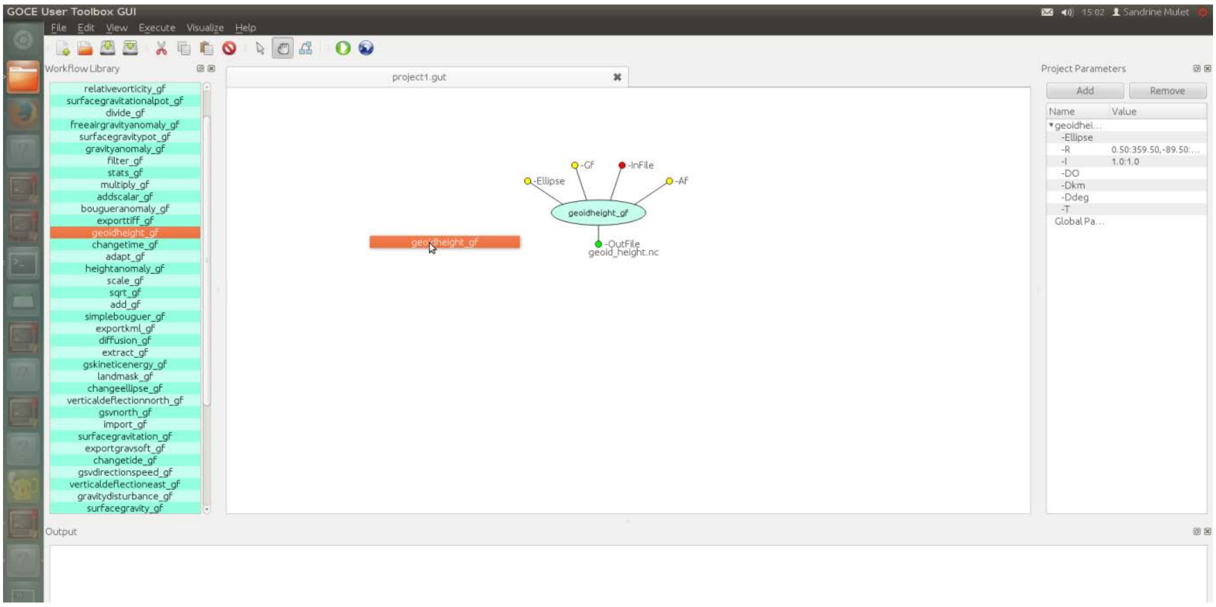


Figure 52: Drag and drop the “geoidheight_gf” workflow

The workflow is represented by an oval with the name of the workflow inside. Around this oval, the lines ended by little circles symbolize input files (on the top) and output files (below): the optional files are associated with yellow circles and the defined files with green ones. Red circles indicate that user has to specify the file name by double-clicking on the circles.

8.2.3. Run the project

To run a project you can either open “Execute” directory and click on “Project…” or click on the icon  (Figure 53). Then a window appears to ask the user to choose the parameters of the workflow (Figure 54). On the right, the different options are described. Finally, if the workflow has run successfully, the oval become green (Figure 55) otherwise an error message is written in red in the Output window at the bottom of the screen (see section 8.4).

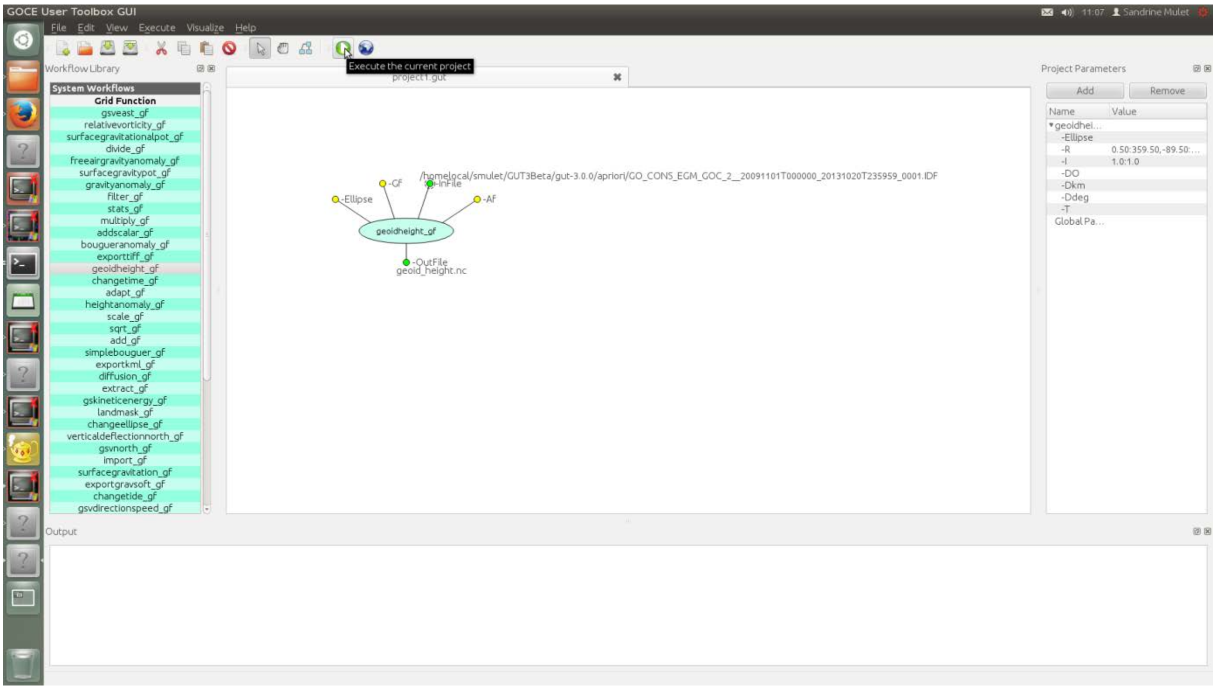


Figure 53: Start a run

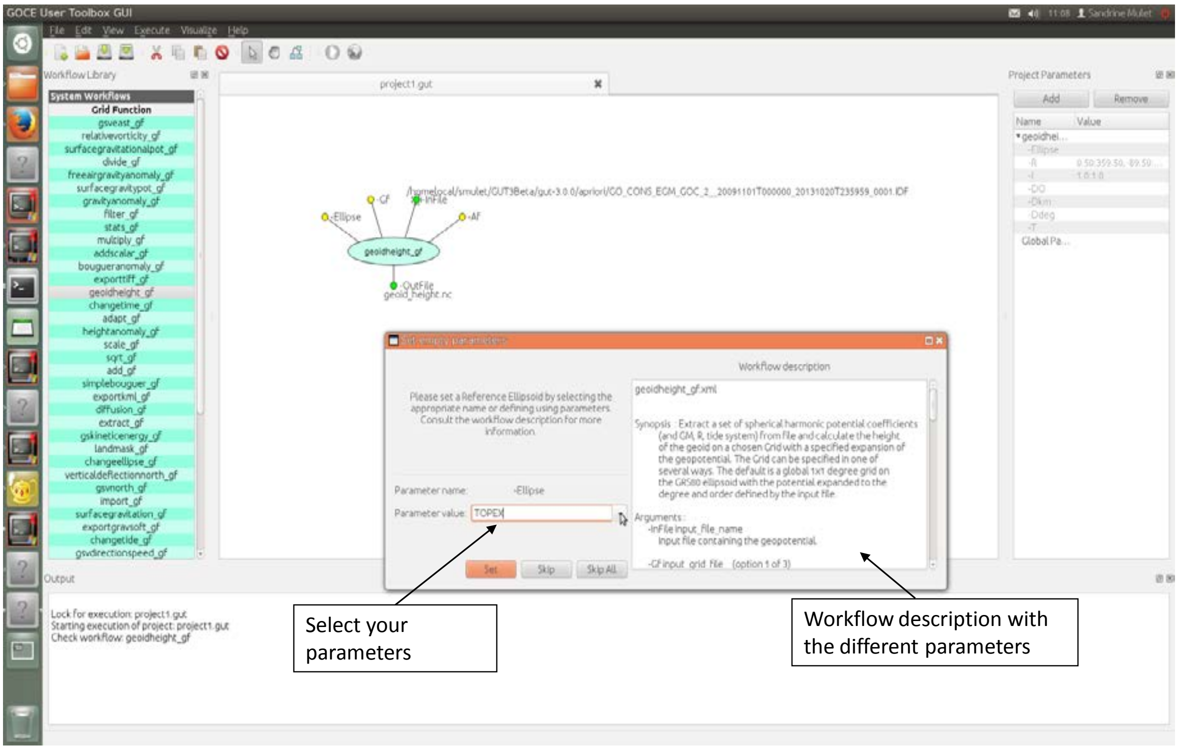


Figure 54: interactive window to select the parameters of the workflow

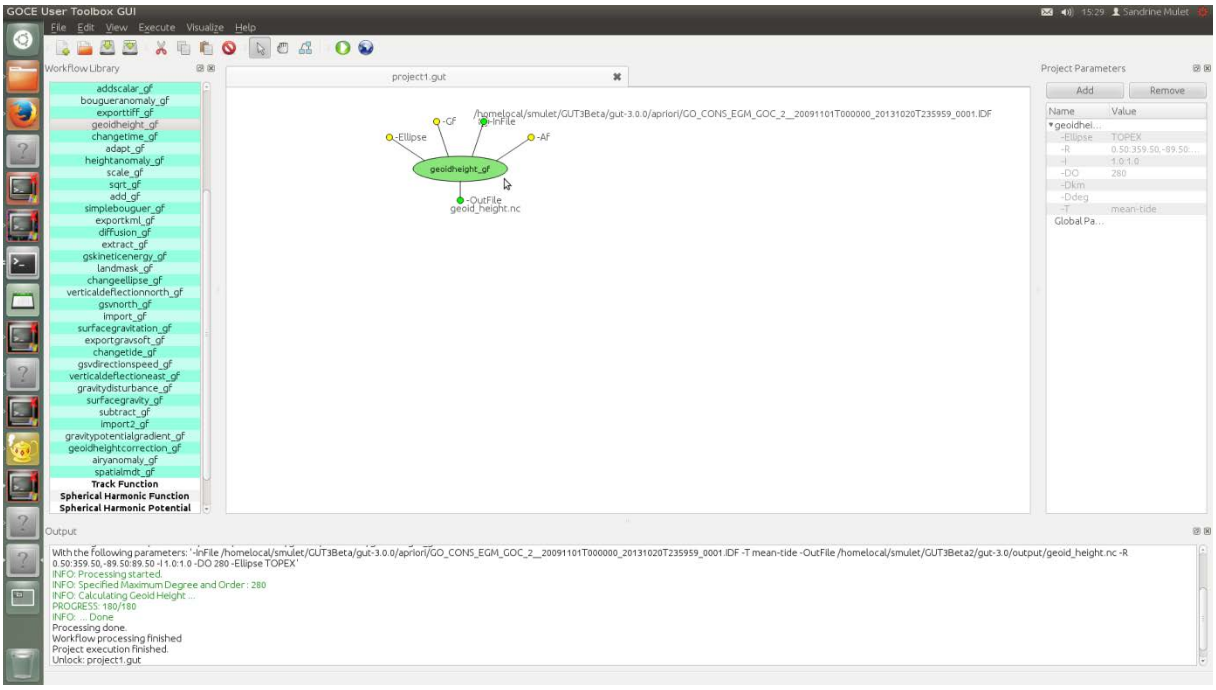


Figure 55: The workflow has run with success

8.2.4. Change parameters of the workflow

The parameters of the workflow(s) used in the project are listed in the “project parameters” window on the right. These parameters can be changed by double-clicking (Figure 56). Also, the unused parameters can be removed by selecting them and press “Remove” (Figure 57).

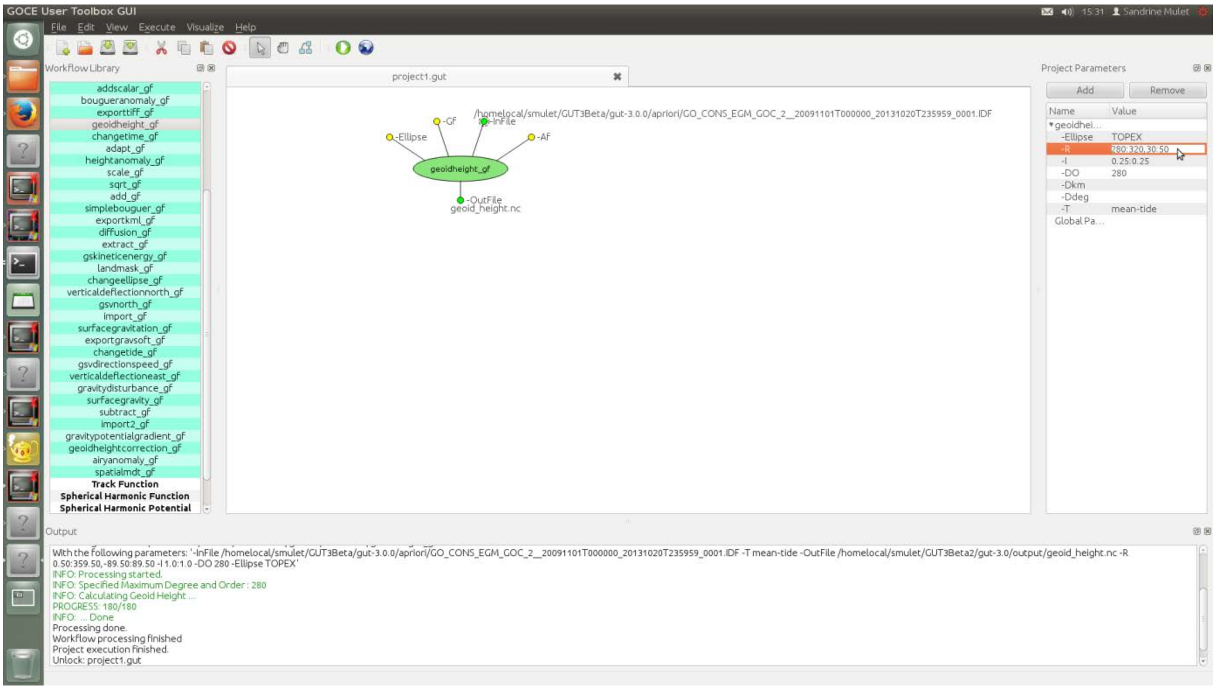


Figure 56: Change parameters of a workflow

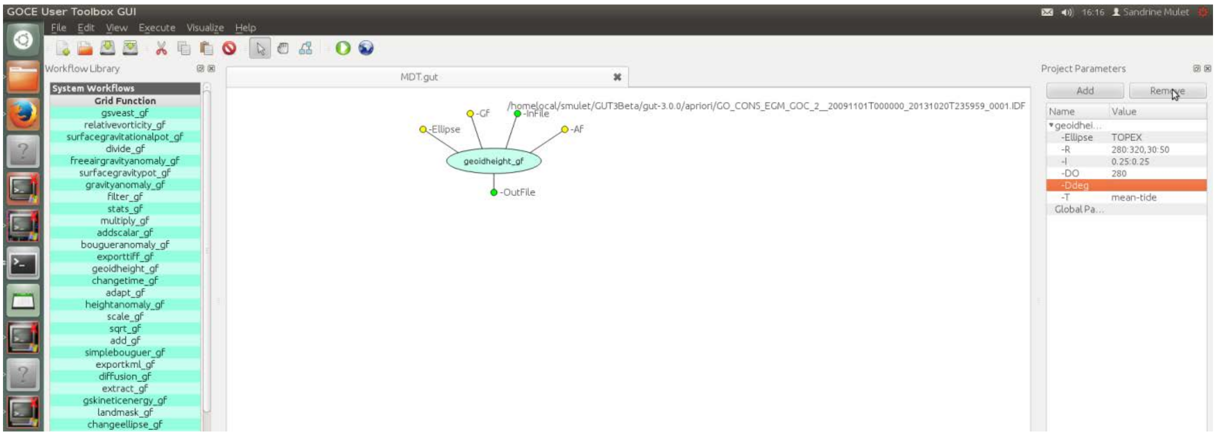


Figure 57: Remove unused parameters

8.2.5. Visualize the output

The output can be visualized by clicking on the icon  (Figure 58). By default GUI used the Broadview Radar Altimetry Toolbox (BRAT). This can be changed in the "Preferences" in the "File" directory.

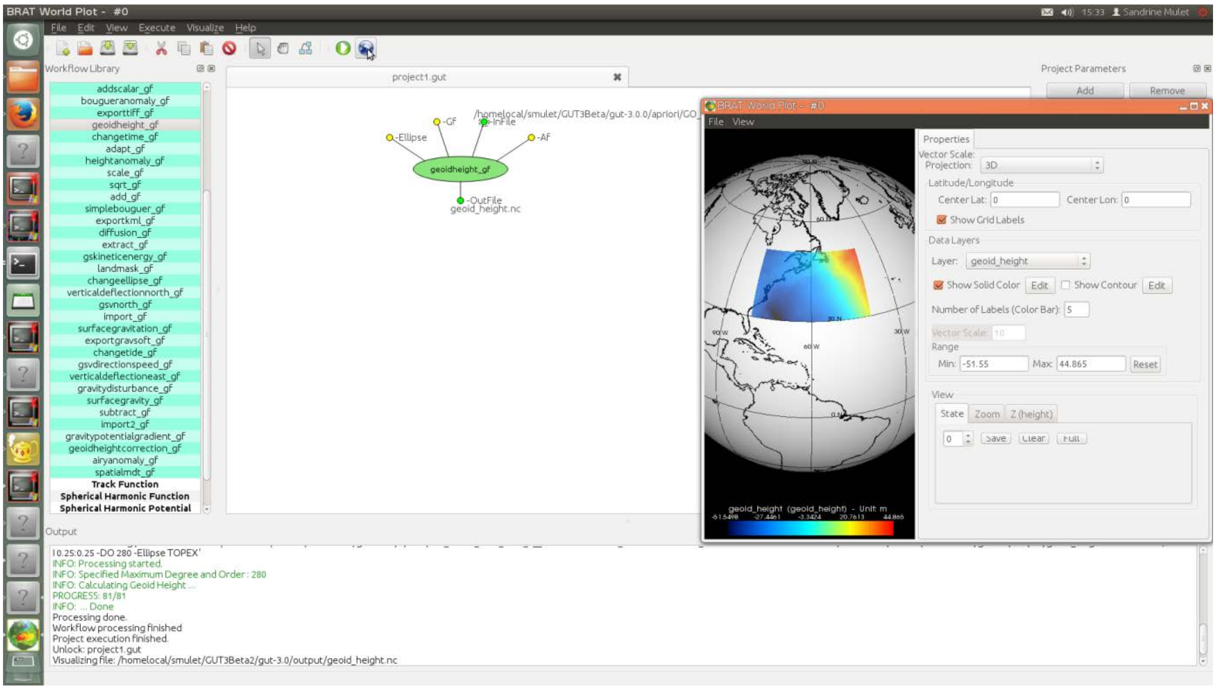


Figure 58: Visualize the output

8.3. Linked several workflows

Use case n° 42: compute a Mean Dynamic Topography with GUI

This part explains how to link several workflows to build a more complex project. This use case is similar to Use case n° 38 but it uses the GUI instead of the command lines, also it uses a more recent GOCE geoid model from release5.

To compute a filtered GOCE satellite only Mean Dynamic Topography, user should

1- Compute a geoid height from a GOCE geoid model (use geoidheight_gf workflow)
2- Subtract it from a Mean Sea Surface computed on the same grid (use subtract_gf and adapt_gf workflows)
3- Remove the values on continents (use landmask_gf)
4- Filtered the difference (use filter_gf).

8.3.1. Link two workflows

Once you have dragged and dropped all the needed workflows and choose the parameters (Figure 59), you should link them together. For that used the icon (Figure 60).

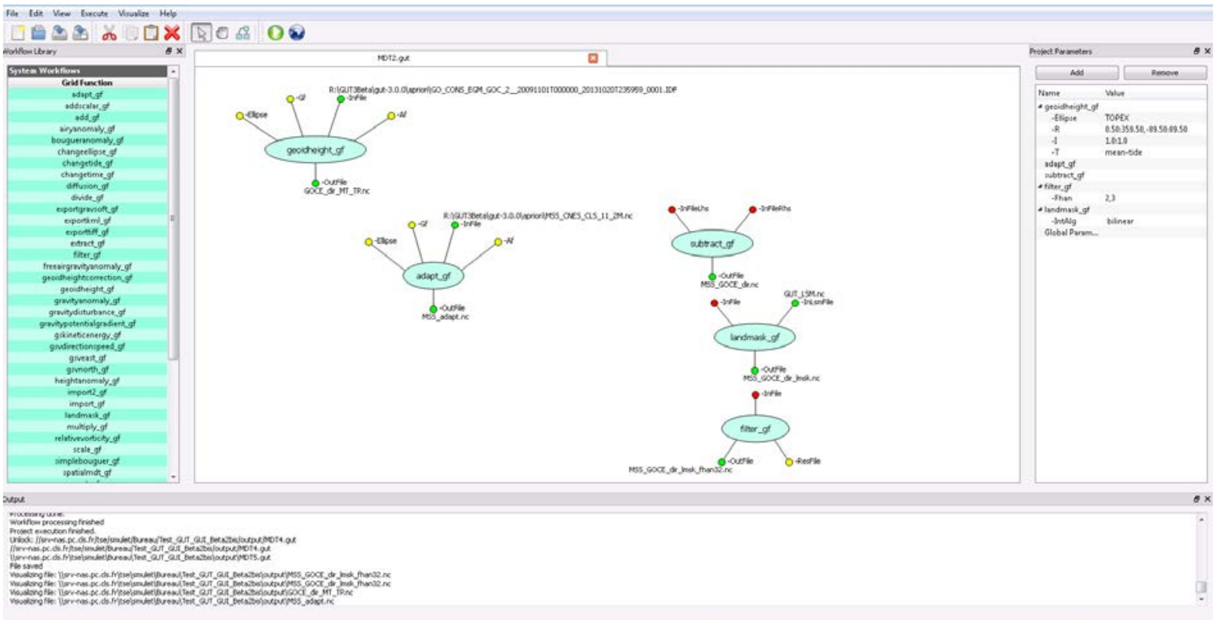


Figure 59: All needed workflows to compute a filtered GOCE satellite only Mean Dynamic Topography

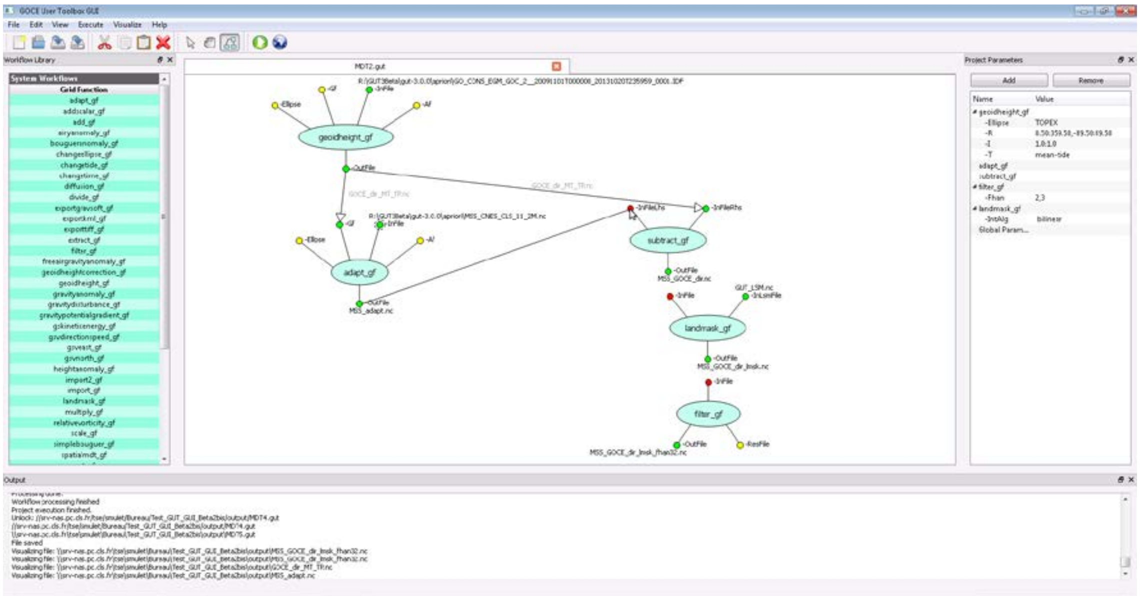


Figure 60: how to link the adapt_gf and substract_gf workfows

8.3.2. Change intermediate file name

When you link two workflows, an intermediate file name is given by default and written in light grey; this file is the output of the upstream workflow and an input of the downstream workflow. To change the name, double click on the link (Figure 61).

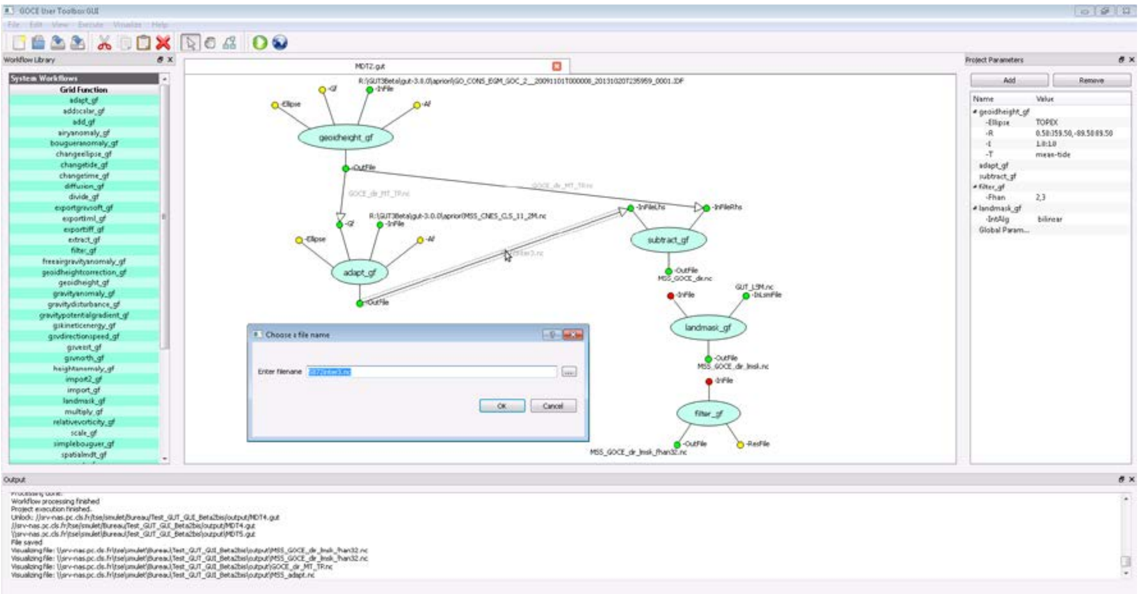


Figure 61: Change intermediate file name

8.3.3. Save the project

To save the project, go to “Save As…” in the “File” directory (Figure 62).

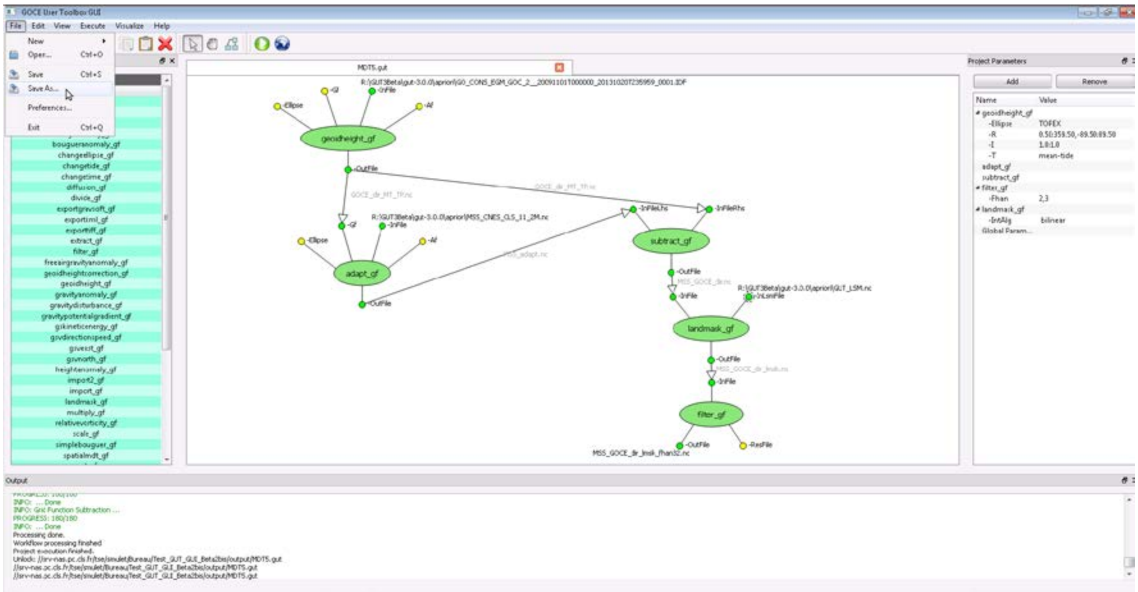


Figure 62: save the MDT project

8.4. The different windows/views

8.4.1. Windows open by default

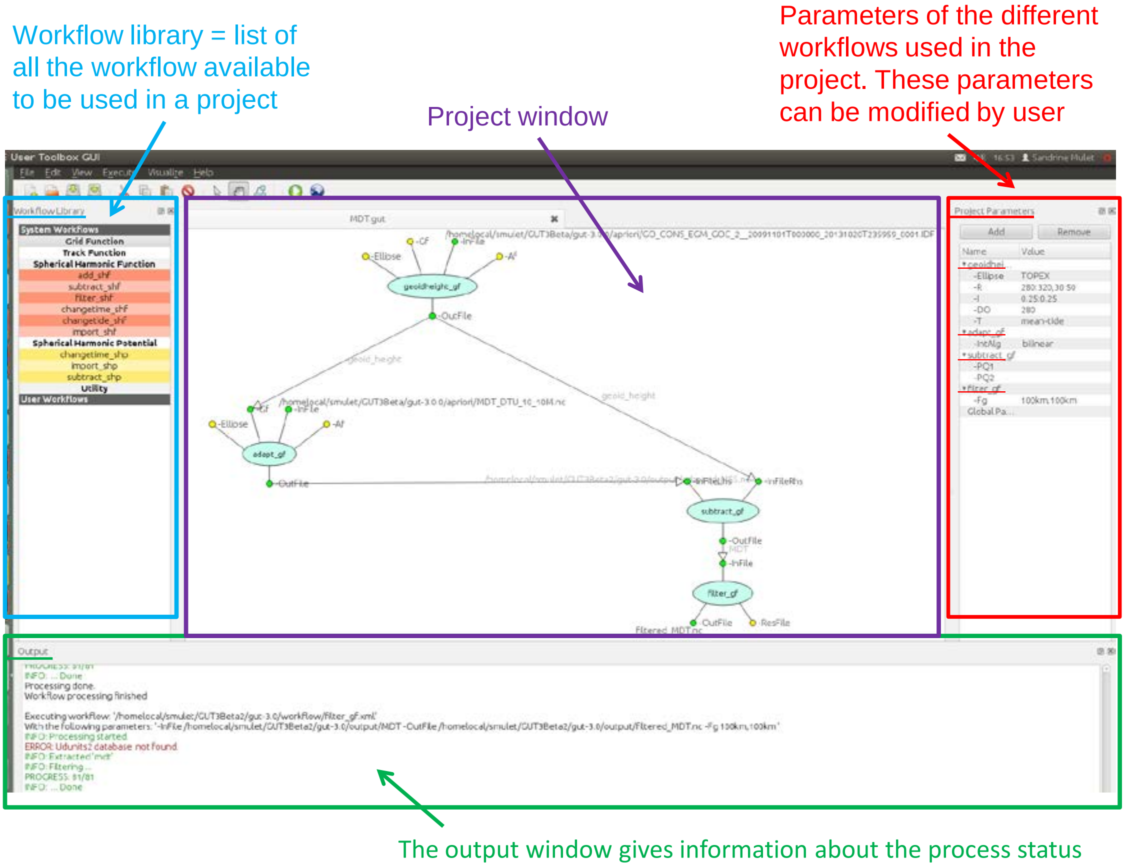
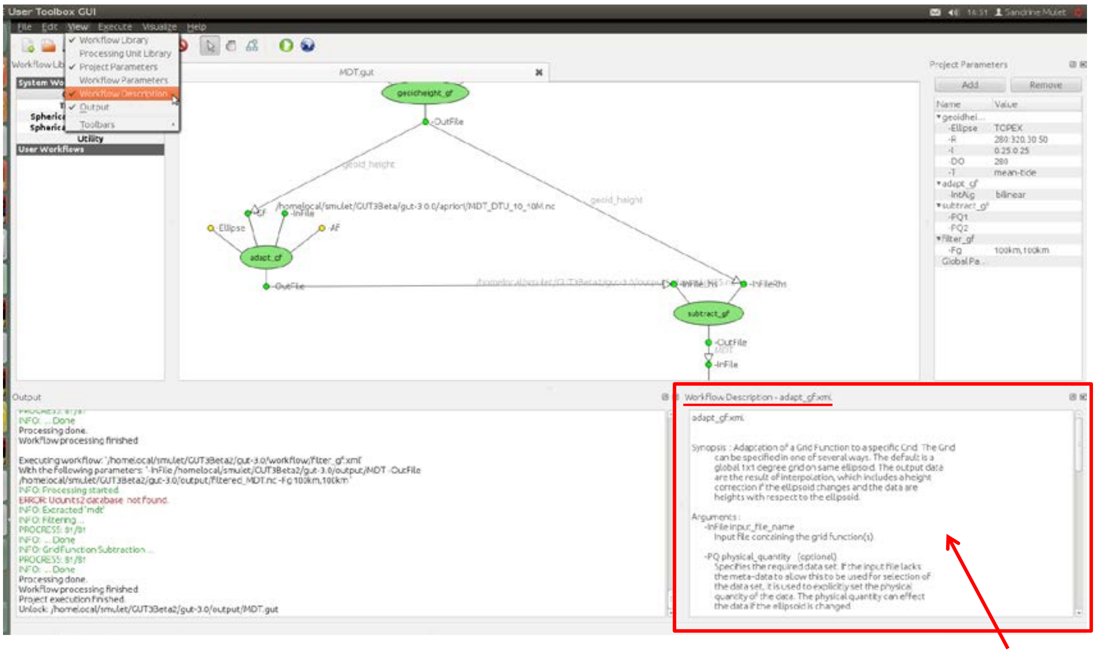


Figure 63: The different windows open by default

8.4.2. Add new window/view

To add other window/view open the “View” directory (Figure 64).



Description of the workflow on which user has click in the project window.
The parameters of the workflow are also described.

Figure 64: Open the workflow description window

Appendix A. List of supported Physical Quantity (PQ)

The argument of the flag -PQ is one of a predefined set of tokens, each of which represents a distinct physical quantity. These tokens correspond with variable, standard or long names used for data in GUT internal data files (netCDF), and follow existing naming conventions where appropriate. The list of tokens and common aliases is shown in the following table.

Physical Quantity	Token
Land Mask	land_binary_mask land_mask mask
Height	height height_above_reference_ellipsoid
Orthometric Height	orthometric_height
Normal Height	normal_height
Geoid Height	geoid_height geoid_height_above_reference_ellipsoid geoid (alias)
Gravity gradient in Local North Oriented Frame (LNOF)	gravity_potential_gradient_xx = northward_northward_derivative_of_gravity_potential gravity_potential_gradient_yy = westward_westward_derivative_of_gravity_potential gravity_potential_gradient_zz = upward_upward_derivative_of_gravity_potential gravity_potential_gradient_xy = northward_westward_derivative_of_gravity_potential gravity_potential_gradient_yz = westward_upward_derivative_of_gravity_potential gravity_potential_gradient_xz = northward_upward_derivative_of_gravity_potential
Sea Surface Height Above Sea Level	ssha sea_surface_height_above_sea_level sea_level_anomaly (alias) sea_surface_height (alias)
Sea Surface Height Above Reference Ellipsoid	ssh sea_surface_height_above_reference_ellipsoid
Sea Level	sea_level sea_level_above_reference_ellipsoid sea_level_height mssh (alias) mss (alias)
Dynamic Topography	dt dynamic_topography sea_surface_height_above_geoid sea_surface_elevation (alias) sea_surface_elevation_anomaly (alias)
Mean Dynamic Topography	mdt sea_level_above_geoid mean_dynamic_topography

Height Anomaly	height_anomaly
Gravity Anomaly	gravity_anomaly free_air_gravity_anomaly bouguer_anomaly airy_anomaly
Vertical Deflection North	north_deflection gravity_vector_vertical_northward_deflection
Vertical Deflection East	east_deflection gravity_vector_vertical_eastward_deflection
Gravity	gravity magnitude_of_gravity
Gravity Potential	gravity_potential
Gravitational Potential	gravitational_potential
Geoid Height Error	geoid_height_error geoid_height_above_reference_ellipsoid_error
Geostrophic Velocity North	northward_velocity surface_geostrophic_northward_sea_water_velocity surface_northward_geostrophic_sea_water_velocity
Geostrophic Velocity East	eastward_velocity surface_geostrophic_eastward_sea_water_velocity surface_eastward_geostrophic_sea_water_velocity
Geostrophic Velocity North Anomaly	northward_velocity_anomaly surface_geostrophic_northward_sea_water_velocity_assuming_sea_level_for_geoid surface_northward_geostrophic_sea_water_velocity_assuming_sea_level_for_geoid
Geostrophic Velocity East Anomaly	eastward_velocity_anomaly surface_geostrophic_eastward_sea_water_velocity_assuming_sea_level_for_geoid surface_eastward_geostrophic_sea_water_velocity_assuming_sea_level_for_geoid