

GOCE User Toolbox and Tutorial

– An ESA effort to facilitate the use of GOCE Level-2 products

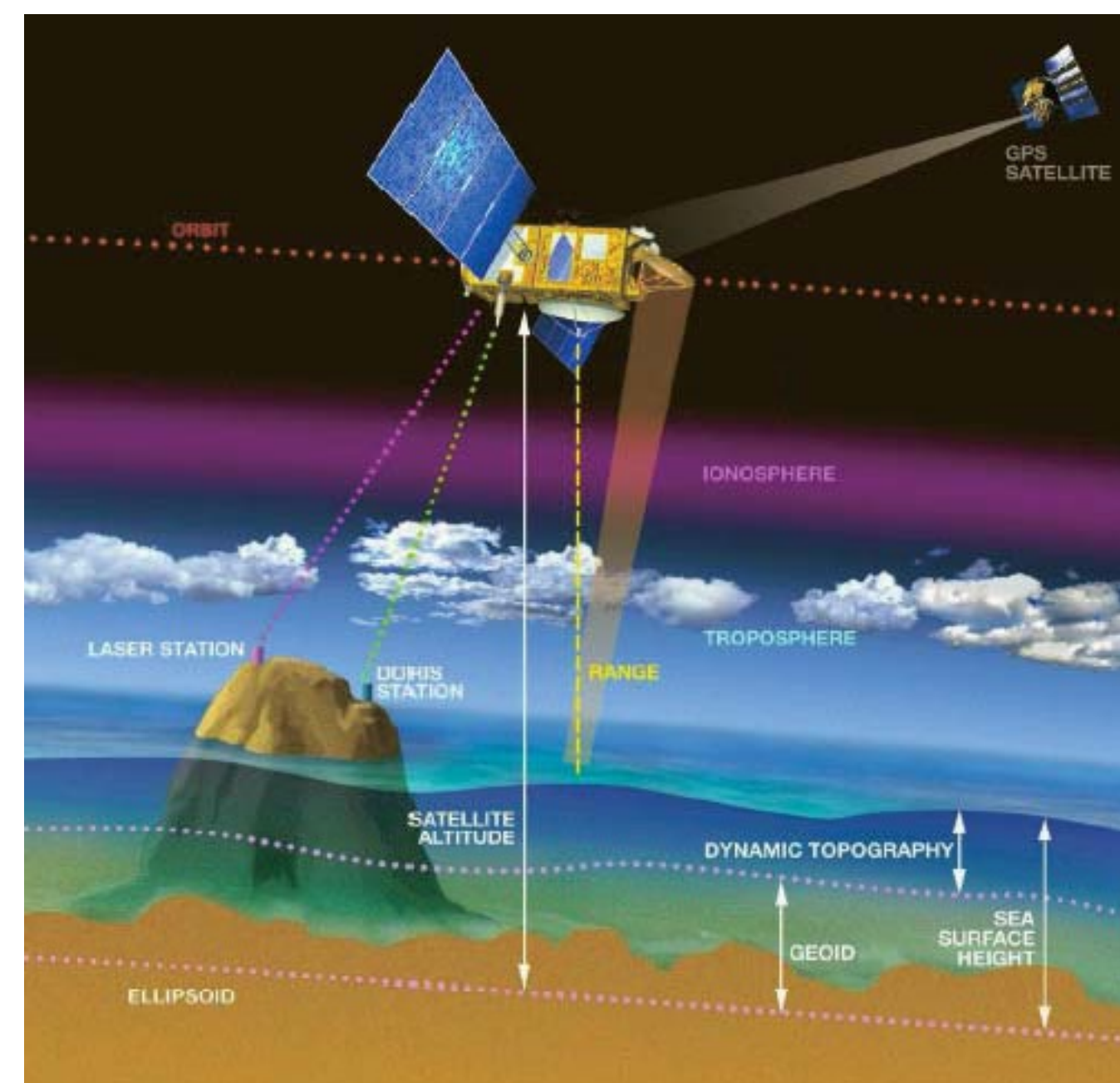
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Abstract
 The GOCE User Toolbox GUT is a compilation of tools for the utilisation and analysis of GOCE Level 2 products. GUT support applications in Geodesy, Oceanography and Solid Earth Physics. The GUT Tutorial provides information and guidance in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

1. Introduction
 Launched in March 2009, the Gravity field and steady-state Ocean Circulation Explorer (GOCE) satellite mission was an innovative Earth observation satellite that measured Earth's global gravity field with unprecedented spatial resolution. On 21 October 2013, the mission came to a natural end when it ran out of fuel. Three weeks later, on 11 November, the satellite disintegrated in the lower atmosphere. Over the course of the mission, 12 Earth gravity models (EGMs) were released, calculated by three approaches. The final solutions (TIM5 and DIR5) were based on 42 months of observations and achieved a geoid accuracy of approximately 2 cm at 100 km. Additional level 2 products released included the gravity gradients and the full error variance-covariance matrices for each EGM. GUT was developed to facilitate the use of these products by users working in fields including oceanography, geodesy and solid earth physics, without requiring expert knowledge of geodesy.

Figure 1: Sketch showing the relationship between the geoid, the Mean Dynamic Topography (MDT – the mean value of the Dynamic Topography) and the Mean Sea Surface (MSS – the mean value of the Sea Surface Height).
 The basic definition of the ocean dynamic topography is simply the difference between the sea surface height and the geopotential reference surface called the geoid. Hence, the topography is a geometrically surface that describes the shape of the Earth. Simultaneously the dynamic topography may be considered as a reference surface for the ocean circulation at the ocean surface.

2. The GOCE User Toolbox – GUT
 The GOCE User Toolbox (GUT) is a compilation of tools for the inspection and analysis of level 2 GOCE gravity field data products, including gravity field models, gravity gradients and error variance covariance information. It can compute and process a range of higher level products relevant to the fields of oceanography, solid earth physics and geodesy at global and regional scales. GUT can also process any global gravity model in the ICGEM format. GUT may be used on Windows PCs, UNIX/Linux workstations and Mac and comes as fully open source software under GNU GPL licence. GUT generates all output files in netCDF format in compliance with the CFConventions, and gridded results may be visualised using the BratDisplay tool from ESA's Broadview Radar Altimetry Toolbox (BRAT). Advanced users can easily extend the toolbox in accordance with the workflow based processing design principles, and contribute these enhancements to the GUT user community. Originally only a command line tool, the current version of GUT is 3.0. This version has been enhanced with a newly developed graphical user interface. This interface is built on top of the command-line interface, providing a more user-friendly alternative to it.



3. The GUT GUI
 A graphical user interface (GUI) is included with GUT 3.1 for increased usability. A user can drag and drop workflows from a workflow library to a project canvas, on which multiple workflows can be easily chained together, given inputs and executed (Figure 2). After execution, the output of the processing chain can be visualised by any netCDF viewer, right from the GUI. GUT is packaged with BratDisplay, which is used as the default visualiser (Figure 2). Individual workflows can be edited by manipulating automatically generated graphs, depicting structure and relations of processing units. Advanced users can create new workflows for their unique needs (Figure 3).

Figure 3 (to the right): An example of a custom workflows created by connecting multiple processing units of choice and linking the dependencies as specified by the user. (Credits S&T)

The Gravity field and steady-state Ocean Circulation Explorer (GOCE)

Its objectives are to improve understanding of:

- global ocean circulation and transfer of heat
- physics of the Earth's interior (lithosphere & mantle)
- topographic processes, ice sheets and sea level change

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

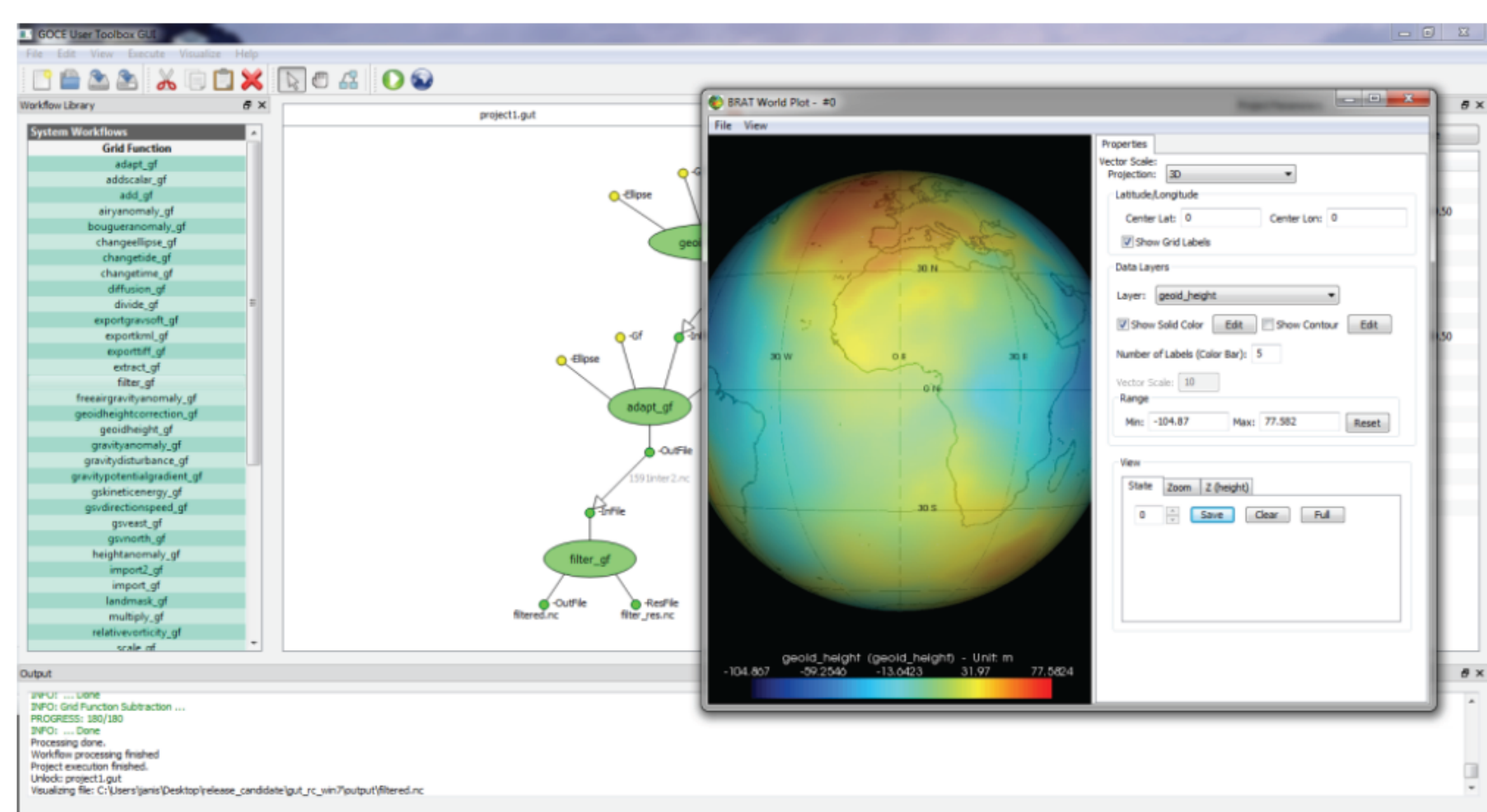
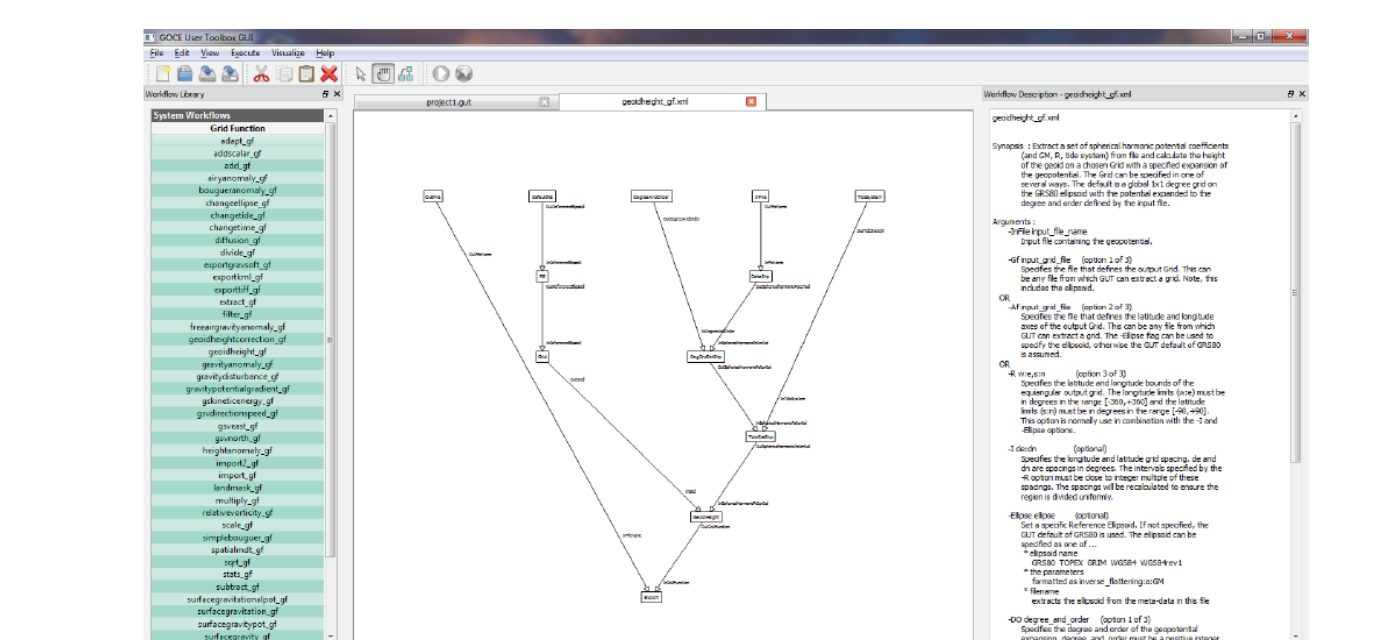


Figure 2: A user defined processing chain consisting of multiple workflows created using the GUT3 GUI, visualising the output using the BratDisplay tool from ESA's BRAT. (Credits S&T)

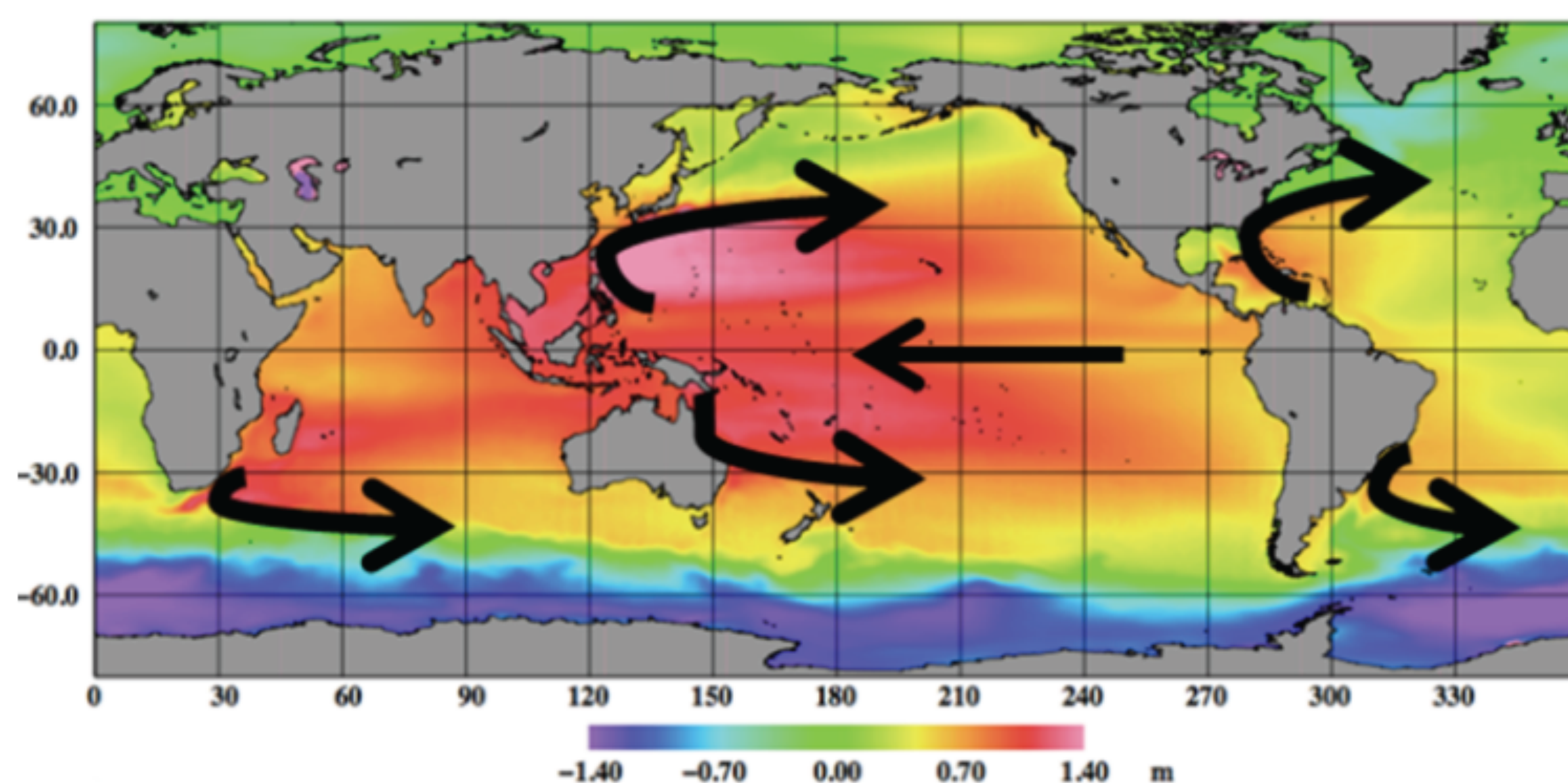


Figure 4: An MDT estimate (above) computed using GUT, overlain with a rough sketch of the currents following the gradient in the MDT (Credits DTU Space)

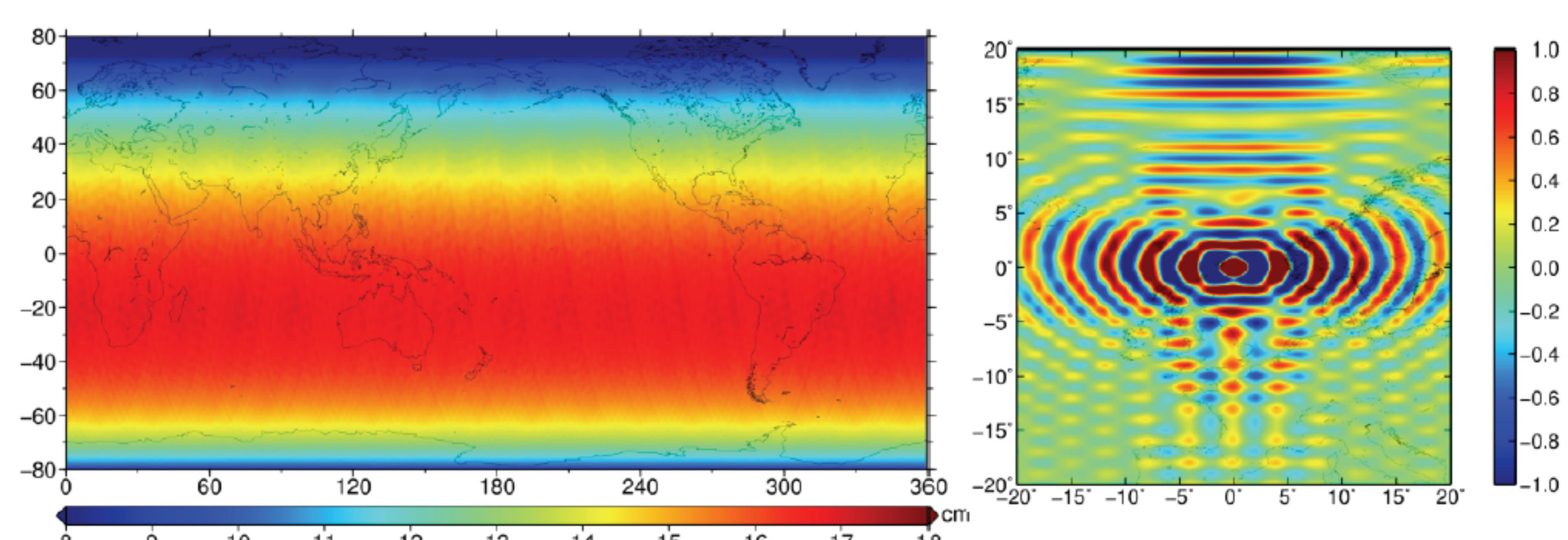
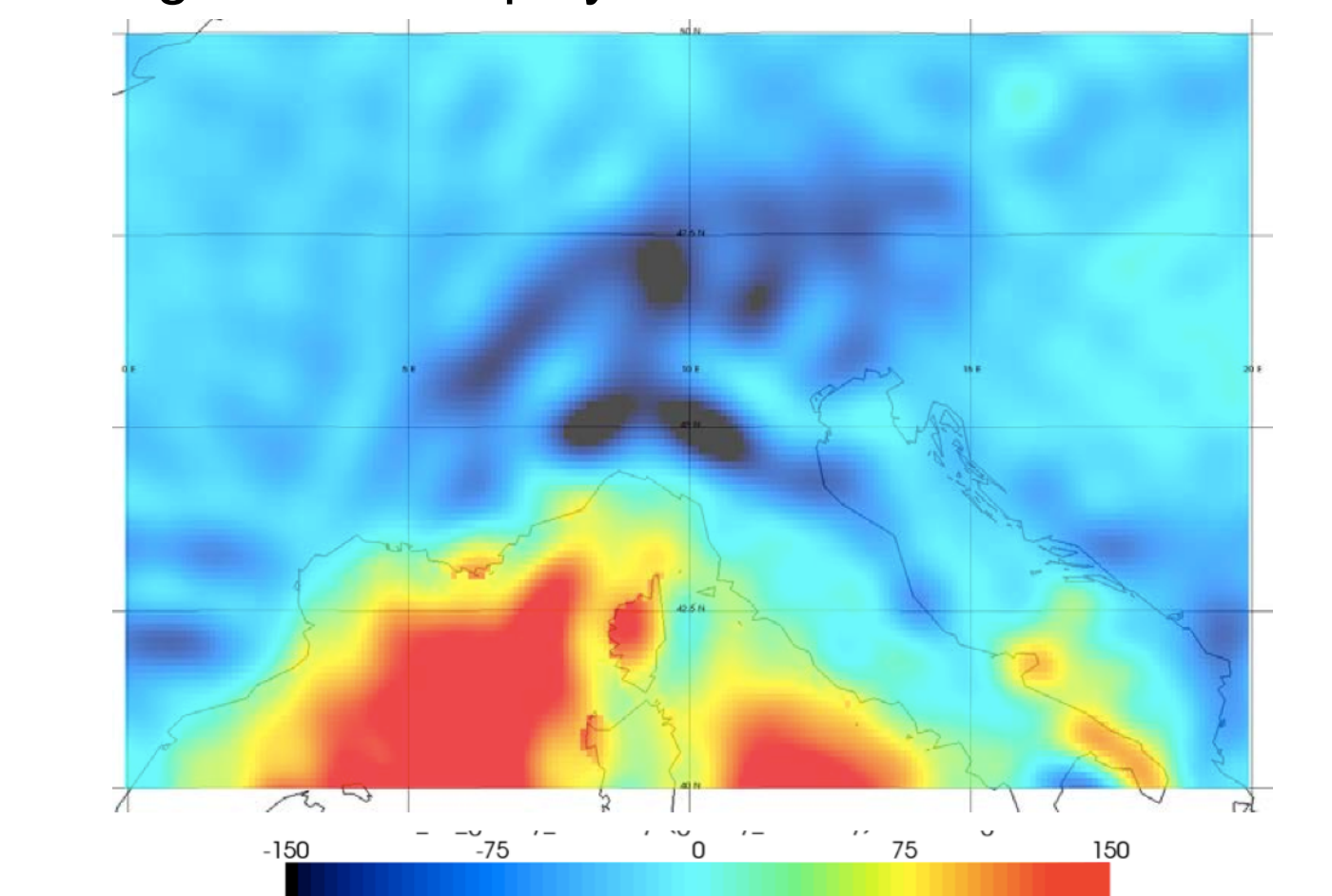


Figure 5: The formal geoid error for one of the GOCE gravity model (TIM5) expanded to degree and order 280 – the maximum degree and order to which the model is defined (left) and the correlation between the TIM5 geoid error at one location (0E, 60N) and the error at surrounding points (right). (Credits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

4. An example application in oceanography
 A primary objective of the GOCE mission was to map the ocean's time mean circulation globally in unprecedented detail. Figure 4 shows the ocean's mean dynamic topography (MDT) obtained by subtracting the final GOCE geoid, based on 42 months of gravity observations, from the DTU13 altimetric mean sea surface. This MDT is used to determine a global map of the ocean's time-mean geostrophic surface circulation as shown in Figure 4. The MDT and associated currents were calculated using GUT, taking advantage of the diffusive filter to remove residual noise while preserving the gradients associated with oceanographic structures. Large-scale currents such as the North Atlantic's Gulf Stream, the North Pacific's Kuroshio Current and the Southern Ocean's Antarctic Circumpolar Current, as well as finer-scale structures such as the Brazil-Malvinas Confluence and the Agulhas Retroflection, are revealed in remarkable clarity. This demonstrates the success of the GOCE mission and serves as the basis for on-going efforts to understand the ocean and its central and complex role in Earth's changing climate.

5. GOCE errors
 The GUT package also includes additional tools for fully exploiting the error variance-covariance matrix of each GOCE gravity model. They allow both the magnitude and correlation structure of the formal errors for the geoid, or other derived quantities, to be rigorously determined from the error variance-covariance matrices on a standard desktop PC. For example, Figure 5 (left) shows a global map of the formal geoid error magnitudes calculated using the error tools for one of the GOCE gravity models (TIM5) expanded to degree and order 280 – the maximum degree and order to which the model is defined. Meanwhile, Figure 5 (right) shows how the geoid error at one location (0E, 60N) is correlated to the error at surrounding points. Such information is essential for optimal filtering, data assimilation and for rigorously combining the GOCE gravity observations with other data types.

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



6. Obtaining GUT
 GUT and associated data cant be downloaded from: <http://earth.esa.int/gut> The GUT package includes:

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

For potential users with limited internet connection a DVD with the GUT software and associated data can be requested at the above link.

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