→ 10th COASTAL ALTIMETRY WORKSHOP

SAR Altimetry Training Course

GUT Demo

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

- Launched in March 2009, end of mission in November 2013
- Dedicated to measure **Earth's static gravity field**, and by so allowing us to model the geoid
- Achieved a mean global accuracy of **2.4 cm** in terms of geoid heights and **0.7 mGal** for gravity anomalies at a spatial resolution of **100 km**.

goce

GOCE User Toolbox (GUT)

GUT is a toolkit to facilitate the use, viewing and post-processing of GOCE's Level 2 gravity field data products, applicable in the fields of **geodesy**, **solid Earth physics** and **oceanography**.

- Collection of command-line tools (C++) and graphical user interface (Python)
- Runs under Windows, Linux and Mac OS
- NetCDF (CF 1.6) used for final and intermediate products
- Fully open source software under GNU GPL license
- Extensible by means of three APIs in C, C++ and Fortran
- Current version **3.1**

GOCE User Toolbox (GUT)

- First public release (1.0) of GUT was in April 2009 (right after GOCE launch)
- The last one (3.1) was in December 2015
- There is an average of 2 to 3 downloads per week
- In the coming months, new work will be started around studying the error covariances structure associated with the MDT and also providing further user support

GUT v3.1

- Read **GOCE** Level 2 products and ancillary datasets, including a priori surfaces, calibrated gravity gradients and geoid height errors.
- Calculate the **error variance-covariance** matrix of GOCE's gravity models.
- Read **GRACE** Level 2 products.
- 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 **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 (CF 1.6).
- **Graphical User Interface**

Main concepts

GUT performs a series of processing steps as described in XML files called **workflows**.

```
<?xml version="1.0"?>
<workflow>
    <units>
        <CmdLineArgInputFileName name="InFile"></CmdLineArgInputFileName>
        <CmdLineArgReferenceEllipsoid name="RE" />
        <CmdLineArgGrid name="Grid">0.50 359.50 -89.50 89.50 1.0
1.0</CmdLineArgGrid>
        <CmdLineArgDegreeAndOrder name="DegreeAndOrder" />
        <CmdLineArgTideSystem name="TideSystem"></CmdLineArgTideSystem>
        <CreateReferenceEllipsoid name="DefaultRE" />
        <SphericalHarmonicPotentialImport name="DataShp" />
        <ChangePotentialDegreeAndOrder name="DegOrdSetShp" />
        <ChangePotentialTideSystem name="TideSetShp" />
        <GridFunctionGeoidHeight name="GeoidHeight" />
        <CmdLineArgOutputFileName
name="OutFile">geoid_height.nc</CmdLineArgOutputFileName>
        <GridFunctionExport name="Export" />
    </units>
    <connection>
        <socket unit="InFile" port="OutFileName" />
        <plug unit="DataShp" port="InFileName" />
    </connection>
    <connection>
        <socket unit="DefaultRE" port="OutReferenceEllipsoid" />
        <plug unit="RE" port="InReferenceEllipsoid" />
    </connection>
```

Main concepts

The **workflows** are defined by means of the **processing units** and the **connections** between them

```xml
<?xml version="1.0"?>
<workflow>
    <units>
        <CmdLineArgInputFileName
name="InFile"></CmdLineArgInputFileName>
        <CmdLineArgReferenceEllipsoid name="RE" />
        <CmdLineArgGrid name="Grid">0.50 359.50 -89.50 89.50 1.0
1.0</CmdLineArgGrid>
        <CmdLineArgDegreeAndOrder name="DegreeAndOrder" />
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        <CreateReferenceEllipsoid name="DefaultRE" />
        <SphericalHarmonicPotentialImport name="DataShp" />
        <ChangePotentialDegreeAndOrder name="DegOrdSetShp" />
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        <GridFunctionExport name="Export" />
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    <connection>
        <socket unit="InFile" port="OutFileName" />
        <plug unit="DataShp" port="InFileName" />
     </connection>
    <connection>
        <socket unit="DefaultRE" port="OutReferenceEllipsoid" />
        <plug unit="RE" port="InReferenceEllipsoid" />
    </connection>
```

Main concepts

GUT's basic algorithms are encapsulated within the **processing units (C, C++, Fortran)**

```
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    </units>
    <connection>
        <socket unit="InFile" port="OutFileName" />
        <plug unit="DataShp" port="InFileName" />
    </connection>
    <connection>
        <socket unit="DefaultRE" port="OutReferenceEllipsoid" />
        <plug unit="RE" port="InReferenceEllipsoid" />
    </connection>
```

```
#include "config.h"
#include "SphericalHarmonicPotentialImport.h"
#include "SphericalHarmonicPotentialExtraction.h"
#include "GutDebug.h"

//--------------------------------------------------------
// SphericalHarmonicPotentialImport
//--------------------------------------------------------

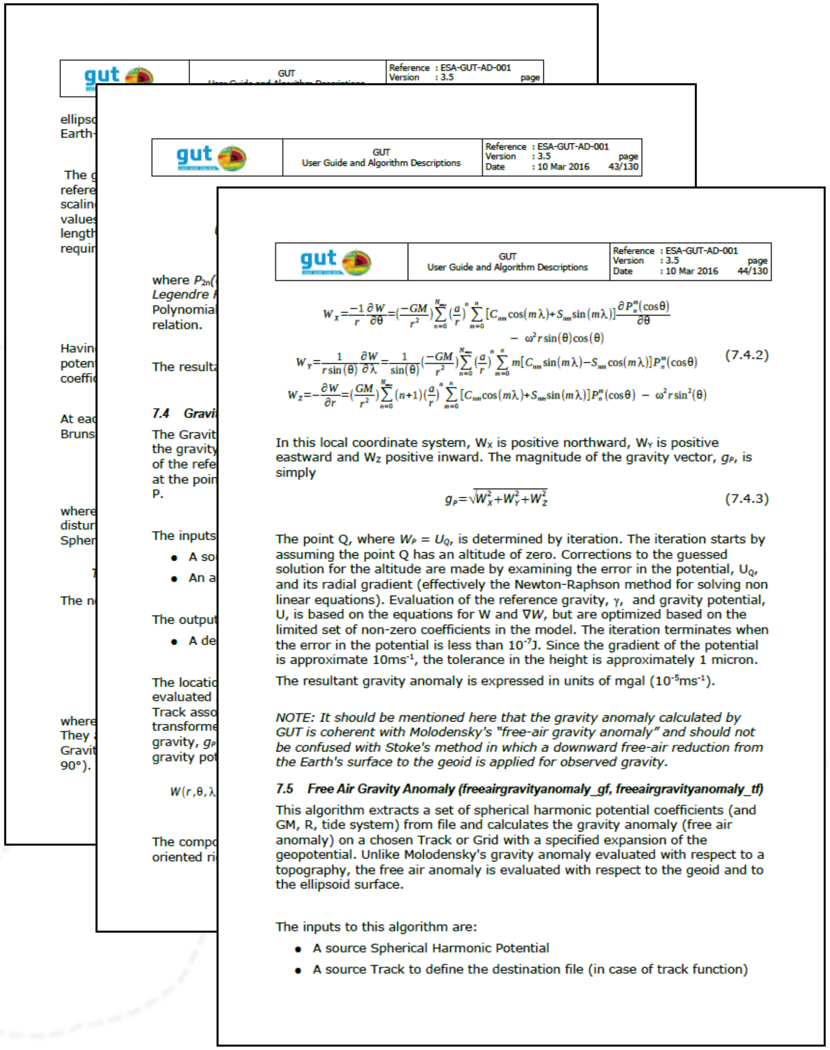
SphericalHarmonicPotentialImport::SphericalHarmonicPotentialImport(
WorkFlow &workflow, const std::string &name, const std::string
&parsableDefault) :
  ProcUnit(workflow, name),
  m_inFileName(*this, "InFileName"),
  m_outShp(*this, "OutSphericalHarmonicPotential")
{}

void SphericalHarmonicPotentialImport::calculate(LogSystem &log) {
  TRACE4("SphericalHarmonicPotentialImport::calculate");

  SphericalHarmonicPotential shp =
GUT::sphericalHarmonicPotentialImport(log, m_inFileName.data().c_str());
  if (shp.isValid())
    m_outShp.setData(shp);
}
```

Workflows and Processing Units Portfolio

- GUT offers to users a portfolio of more than **70 prebuilt workflows** and about **140 processing units** for the more general tasks in the fields of Geodesy and Oceanography
- These can be **extended by user-made workflows and processing units**



gut | GUT User Guide and Algorithm Descriptions | Reference : ESA-GUT-AD-001 Version : 3.5 Date : 10 Mar 2016 page 44/130

$$W_X = \frac{-1}{r}\frac{\partial W}{\partial\theta} = \left(\frac{-GM}{r^2}\right)\sum_{n=0}^{N_{max}}\left(\frac{a}{r}\right)^n\sum_{m=0}^{n}[C_{nm}\cos(m\lambda)+S_{nm}\sin(m\lambda)]\frac{\partial P_n^m(\cos\theta)}{\partial\theta} - \omega^2 r\sin(\theta)\cos(\theta)$$

$$W_Y = \frac{1}{r\sin(\theta)}\frac{\partial W}{\partial\lambda} = \frac{1}{\sin(\theta)}\left(\frac{-GM}{r^2}\right)\sum_{n=0}^{N_{max}}\left(\frac{a}{r}\right)^n\sum_{m=0}^{n} m[C_{nm}\sin(m\lambda)-S_{nm}\cos(m\lambda)]P_n^m(\cos\theta) \quad (7.4.2)$$

$$W_Z = -\frac{\partial W}{\partial r} = \left(\frac{GM}{r^2}\right)\sum_{n=0}^{N_{max}}(n+1)\left(\frac{a}{r}\right)^n\sum_{m=0}^{n}[C_{nm}\cos(m\lambda)+S_{nm}\sin(m\lambda)]P_n^m(\cos\theta) - \omega^2 r\sin^2(\theta)$$

In this local coordinate system, W_X is positive northward, W_Y is positive eastward and W_Z positive inward. The magnitude of the gravity vector, g_P, is simply

$$g_P = \sqrt{W_X^2 + W_Y^2 + W_Z^2} \quad (7.4.3)$$

The point Q, where $W_P = U_Q$, is determined by iteration. The iteration starts by assuming the point Q has an altitude of zero. Corrections to the guessed solution for the altitude are made by examining the error in the potential, U_Q, and its radial gradient (effectively the Newton-Raphson method for solving non linear equations). Evaluation of the reference gravity, γ, and gravity potential, U, is based on the equations for W and ∇W, but are optimized based on the limited set of non-zero coefficients in the model. The iteration terminates when the error in the potential is less than 10^{-7}J. Since the gradient of the potential is approximate $10ms^{-1}$, the tolerance in the height is approximately 1 micron.

The resultant gravity anomaly is expressed in units of mgal ($10^{-5}ms^{-1}$).

NOTE: It should be mentioned here that the gravity anomaly calculated by GUT is coherent with Molodensky's "free-air gravity anomaly" and should not be confused with Stoke's method in which a downward free-air reduction from the Earth's surface to the geoid is applied for observed gravity.

7.5 Free Air Gravity Anomaly (freeairgravityanomaly_gf, freeairgravityanomaly_tf)

This algorithm extracts a set of spherical harmonic potential coefficients (and GM, R, tide system) from file and calculates the gravity anomaly (free air anomaly) on a chosen Track or Grid with a specified expansion of the geopotential. 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.

The inputs to this algorithm are:

- A source Spherical Harmonic Potential
- A source Track to define the destination file (in case of track function)

Graphical User Interface

A user is no longer limited to editing XML files and executing command line tools.

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    <units>
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        <CmdLineArgGrid name="Grid">0.50 359.50 -89.50 89.50 1.0
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        <CmdLineArgDegreeAndOrder name="DegreeAndOrder" />
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        <CmdLineArgOutputFileName
name="OutFile">geoid_height.nc</CmdLineArgOutputFileName>
        <GridFunctionExport name="Export" />
    </units>
    <connection>
        <socket unit="InFile" port="OutFileName" />
        <plug unit="DataShp" port="InFileName" />
    </connection>
    <connection>
        <socket unit="DefaultRE" port="OutReferenceEllipsoid" />
        <plug unit="RE" port="InReferenceEllipsoid" />
    </connection>
```

Command Prompt

```
 effect. GUT specific options may be specified anywhere in the command-line
 except between a workflow flag and its argument.


C:\Documents and Settings\salvatore di nardo\Desktop\GUT 1.0\gut-1.0b\bin>gut --
help

 The GUT Command-Line Processor has several basic run-modes and precisely one
 of these is active for each invocation of GUT. Some run-modes do not require
 any additional input, but most require a workflow file and most workflows
 will require additional command-line flags and arguments. Command-line flags
 that start with -- are treated as GUT specific options. Flags with a single
 - are treated as workflow specific options. In general a workflow flag will
 be followed by an argument. The first command-line argument that is NOT a
 flag is interpretted as the workflow.
 The workflow name is used to locate a workflow definition file. The file
 search process is...

   * Treat the workflow name as a filename, as-is.
   * If not already present, append .xml to the name and treat as a filename.
   * Prepend the Standard Workflow Defintion directory to the name and append
       .xml if it is not already present.

 The minimal command-line required for each run-mode is shown below.

     --help            : Shows this help information.

     --version         : Shows the version and installation information.

     --workflows       : Shows the list of installed workflows. Note that a
                         file in the current directory may obscure these
                         workflows. The --man option can be used to determine
                         precisely which file is located.

     --man <workflow>  : Extracts the internal documentation from a workflow
                         definition and gives the full path of the workflow
                         file.

     --dot <workflow>  : Constructs the workflow and produces the file
                         <workflow>.dot in the current directory. This file
                         describes the structure of the workflow graph in the
                         DOT language, and can be visualized with OpenSource
                         tools (ie. Graphviz). Additional arguments, specific
                         to the workflow may be required for error-free
                         construction of the workflow.

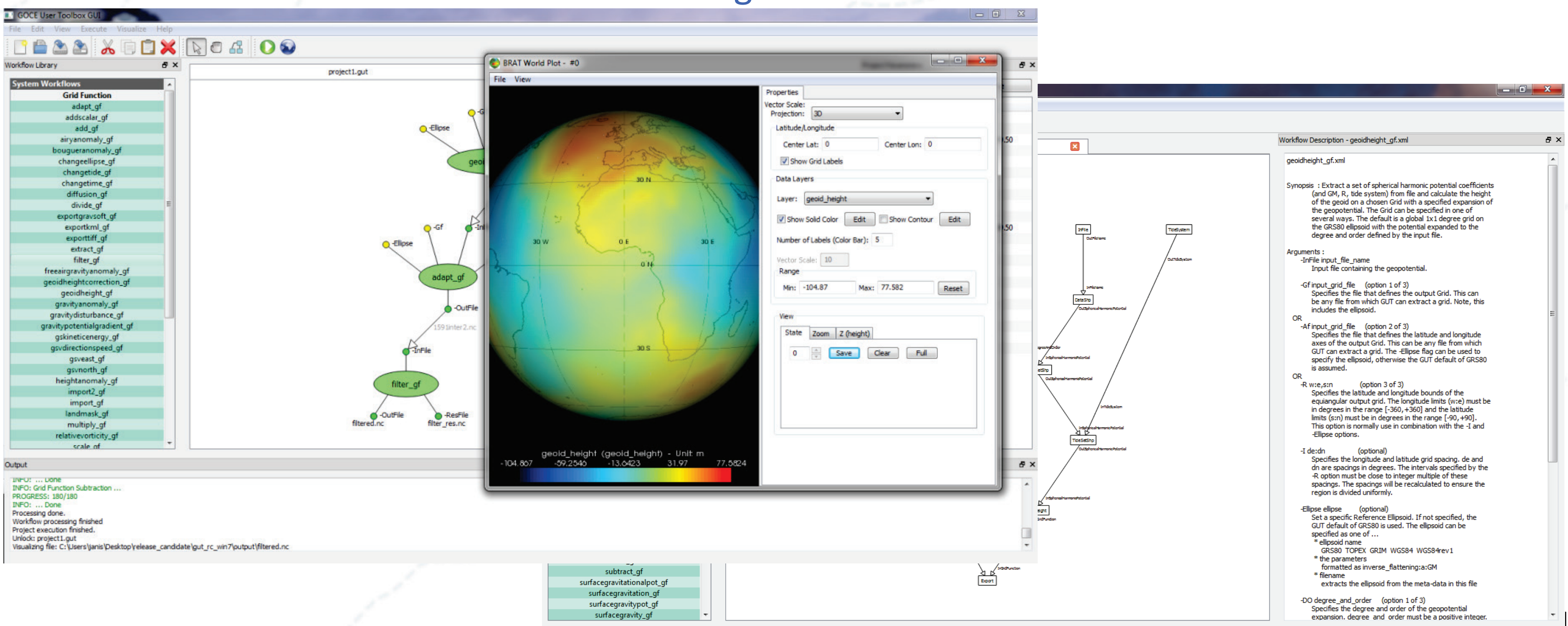
     --test <workflow> : Constructs the workflow to check that it is valid
                         and can be executed with the specified flags and
                         arguments.

     <workflow>        : Construct and execute a workflow. Additional command-
                         line arguments are usually required. The precise
                         nature of these arguments is defined by the content
                         of the workflow definition file.

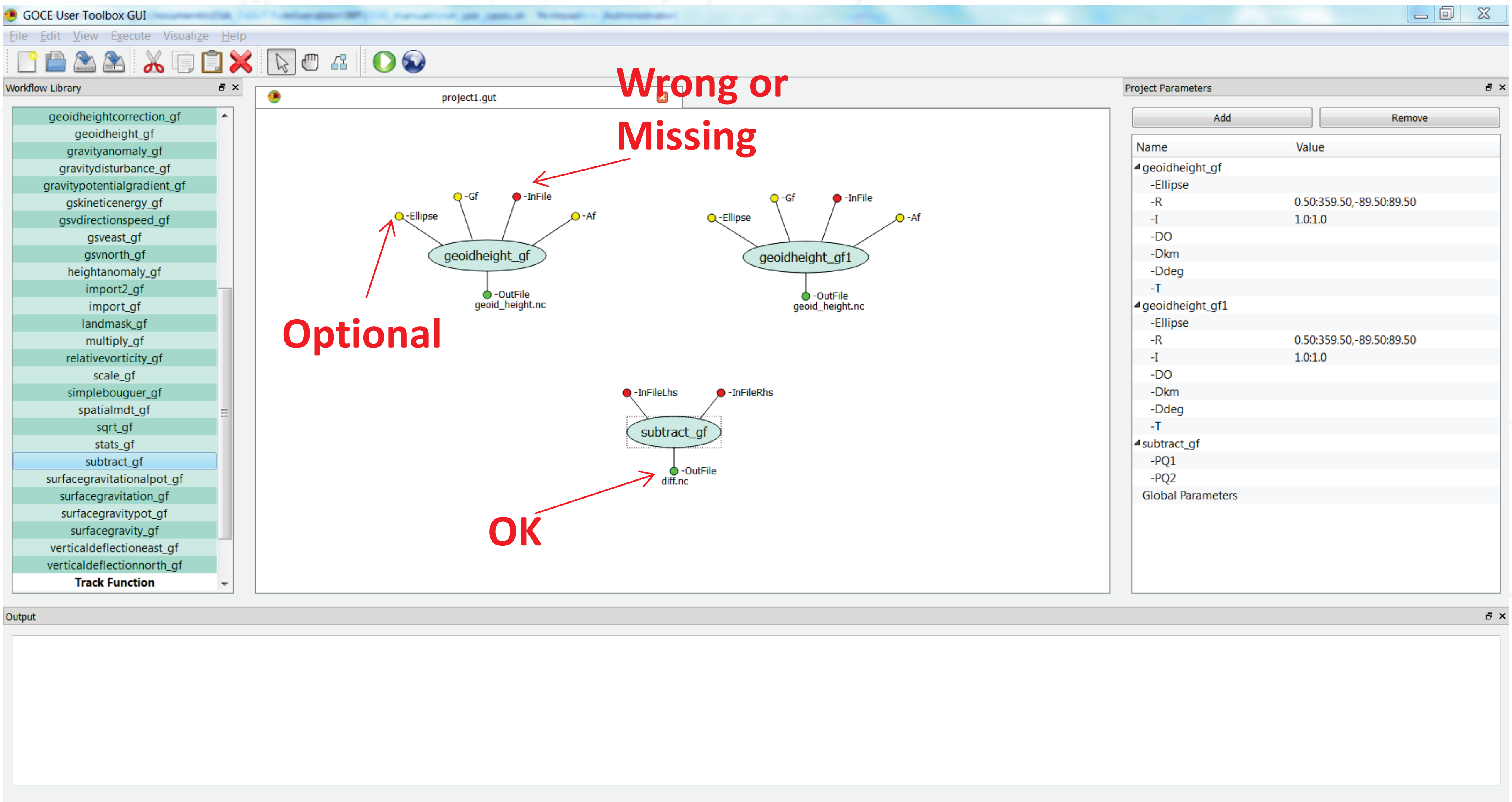
 For the workflow execution run-mode additional GUT options may be supplied.
 These are...
     --quiet           : Suppresses all error, warning, information and
                         progress messages.
```

Graphical User Interface

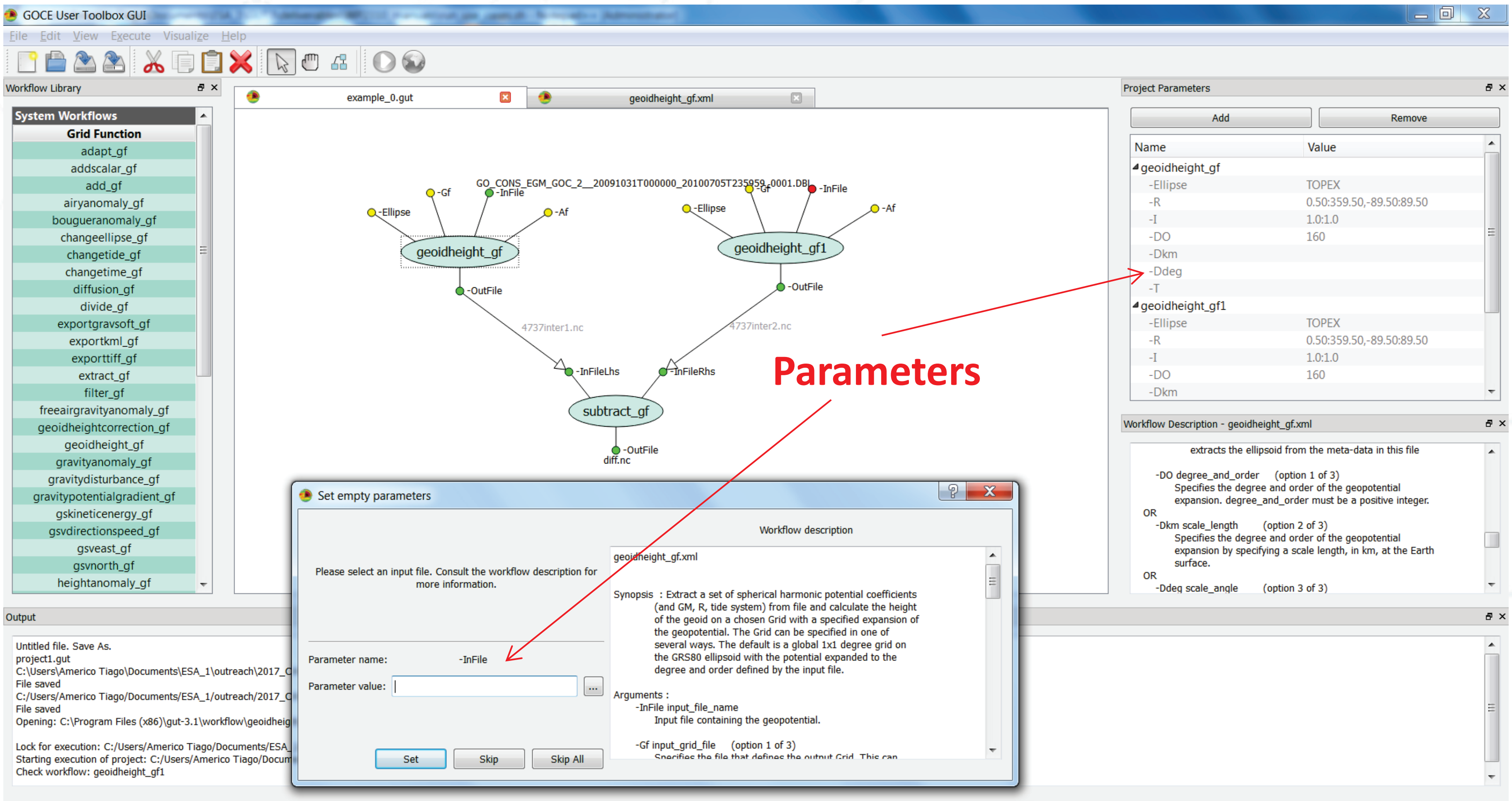
- Built with Python over the C++ command lines tools.
- Interaction by **dragging and dropping** workflow nodes, user-friendly **dialogs**, and **colour coded feedback**.
- Run and visualise results without leaving the GUI.



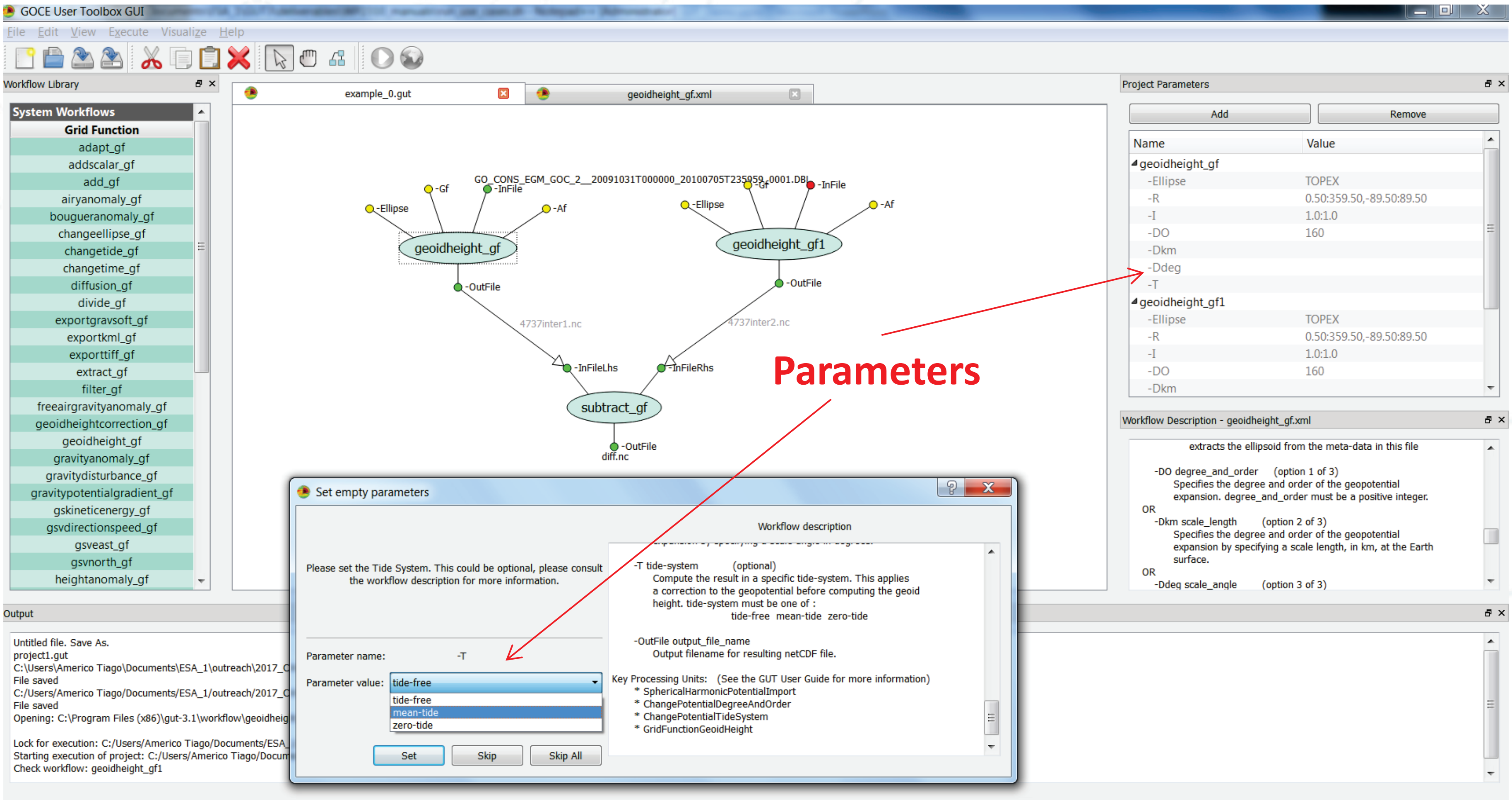
Graphical User Interface



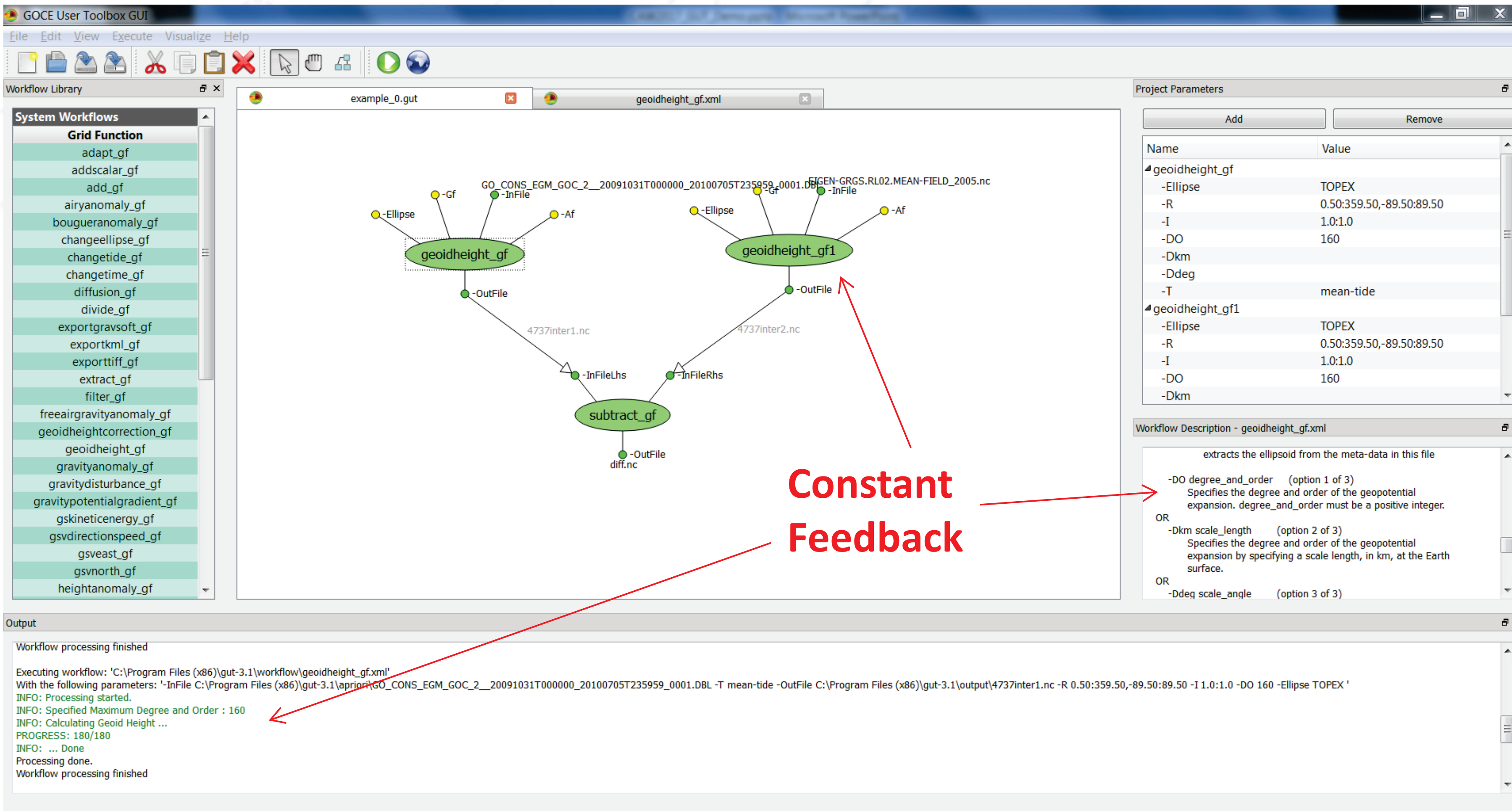
Graphical User Interface



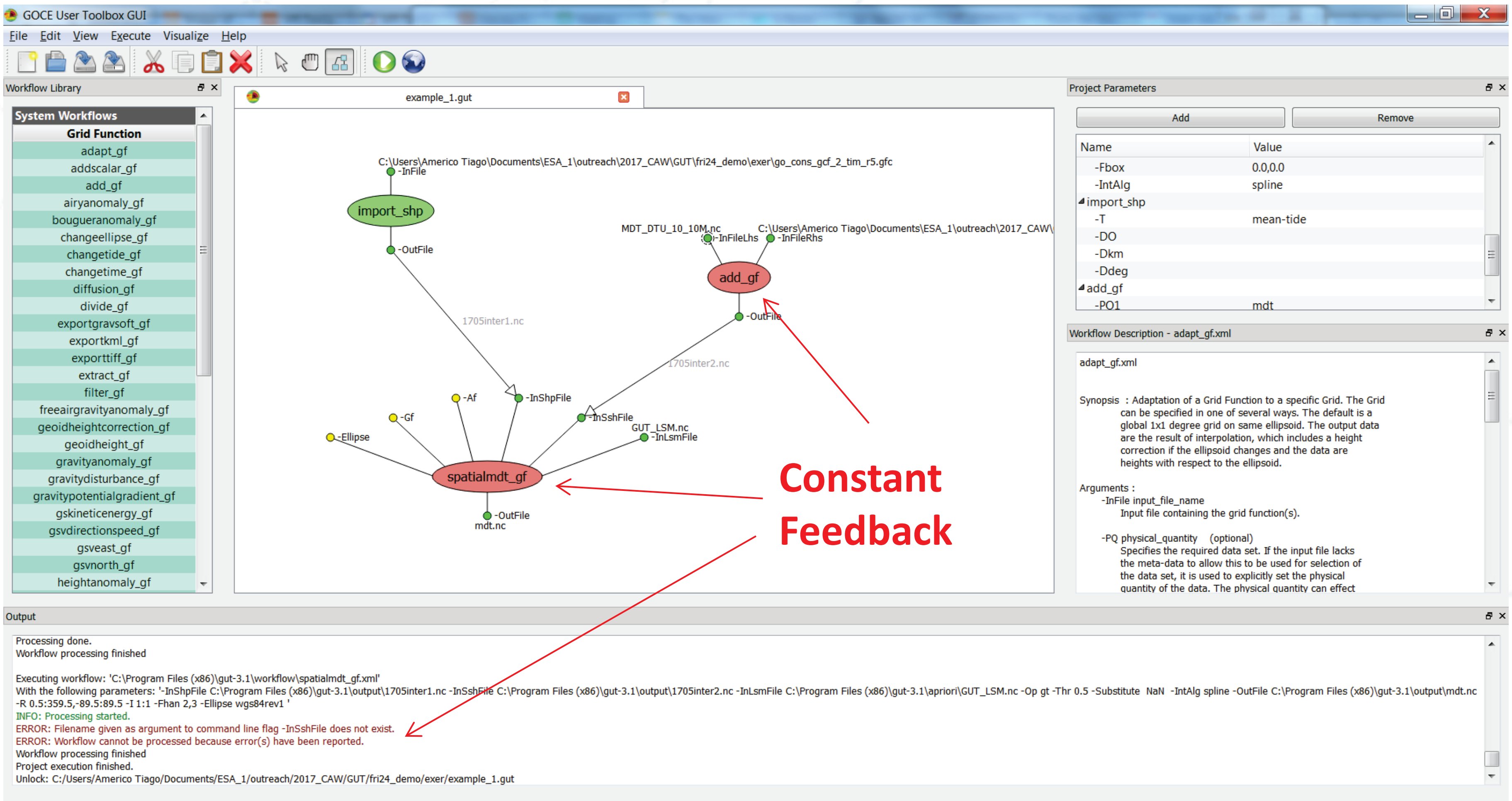
Graphical User Interface



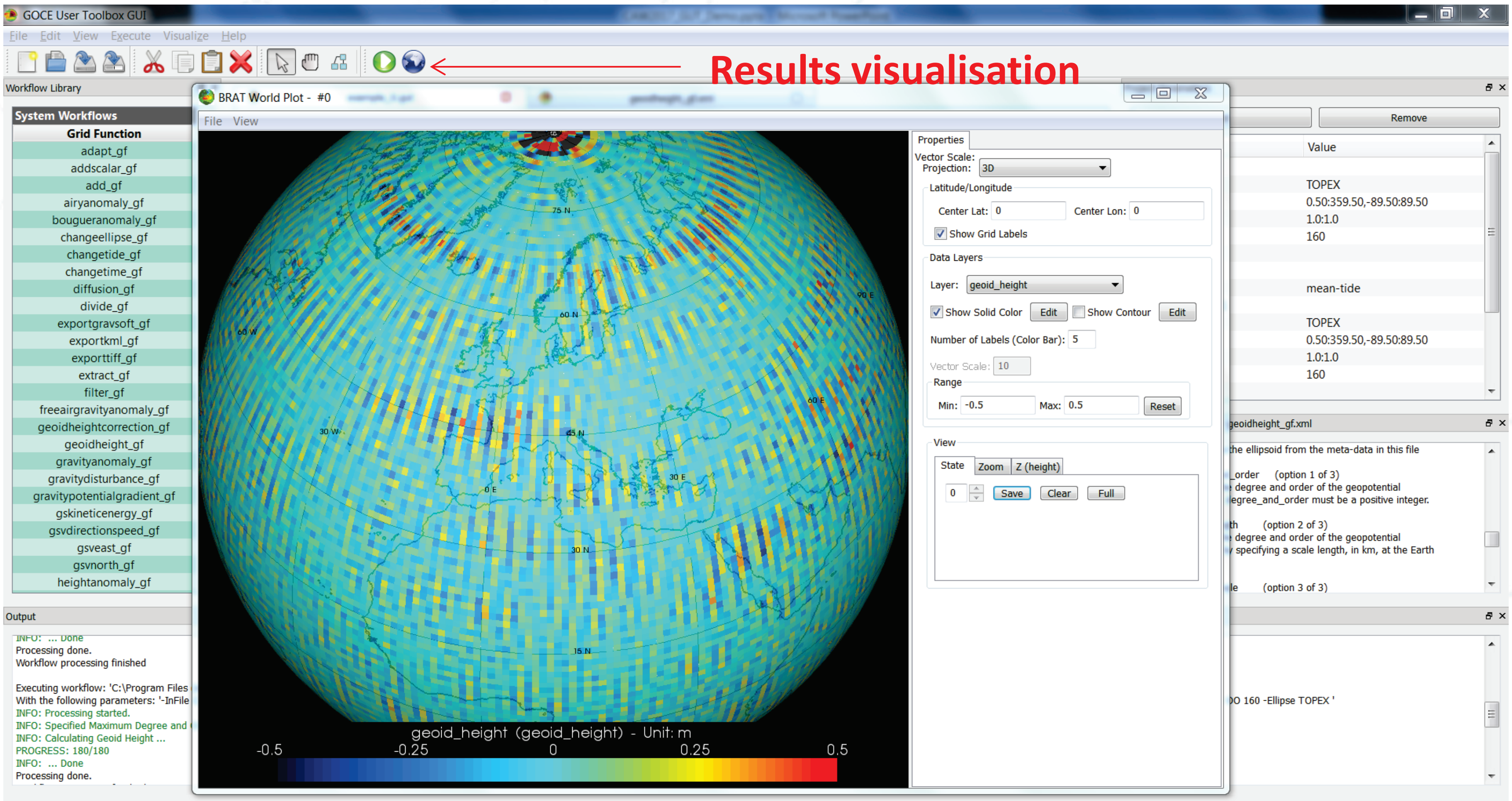
Graphical User Interface



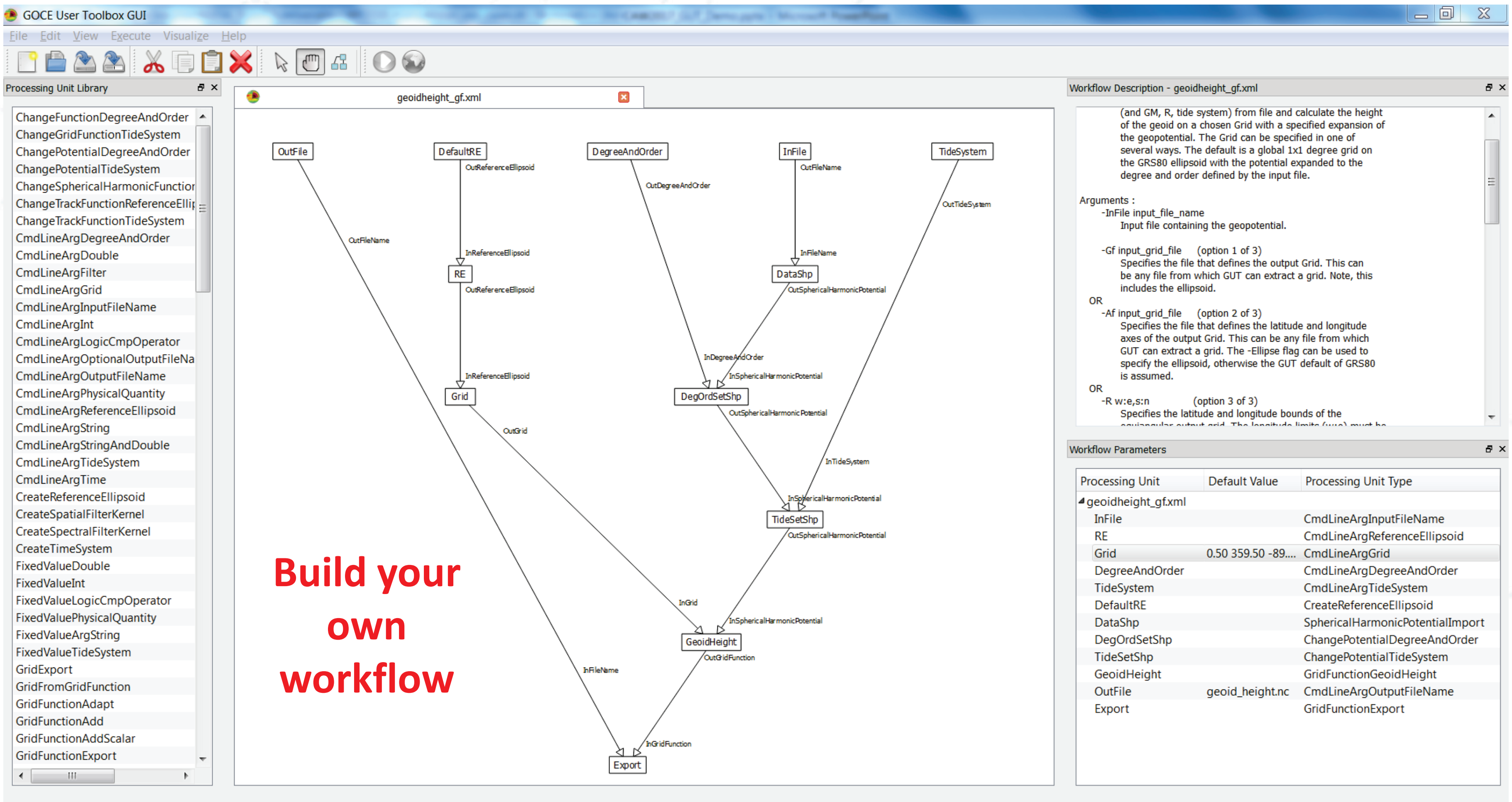
Graphical User Interface



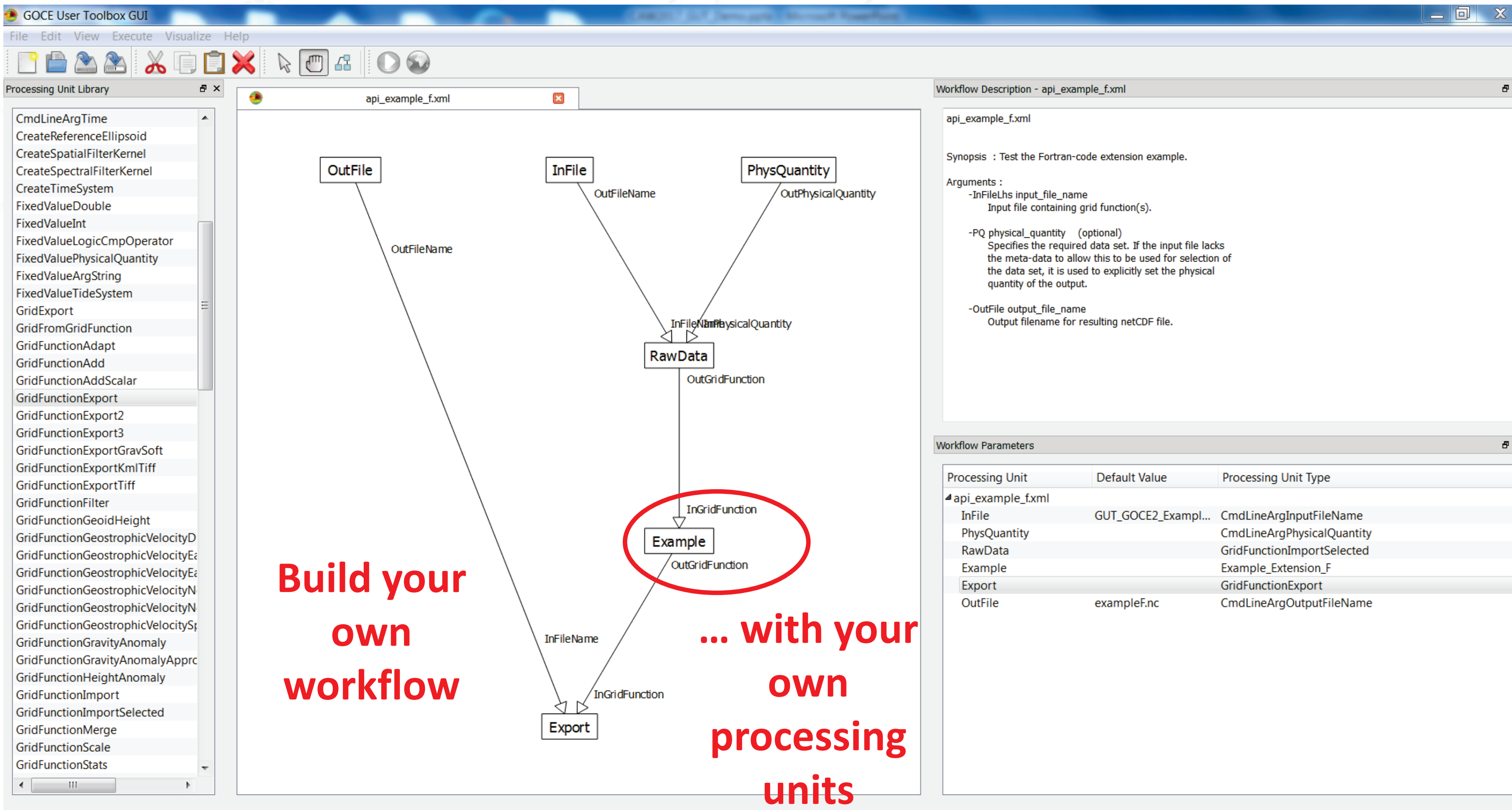
Graphical User Interface



Graphical User Interface

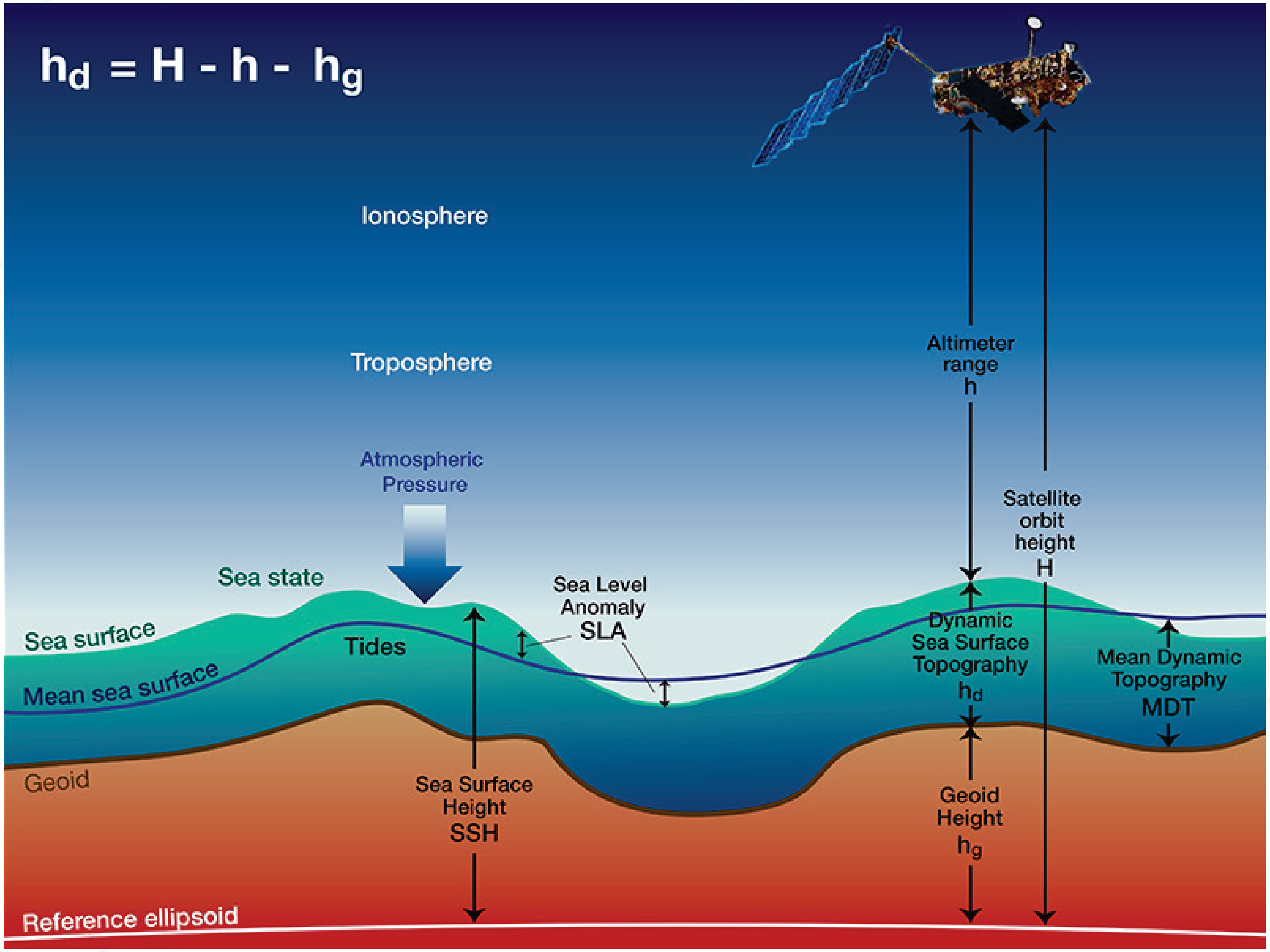


Graphical User Interface



Demo

How to calculate a **Mean Dynamic Topography** only from **GOCE**?



Demo

How to calculate a **Mean Dynamic Topography** only from **GOCE**?

Go to **http://icgem.gfz-potsdam.de/ICGEM/** and download a **geoid model** built using only GOCE data!

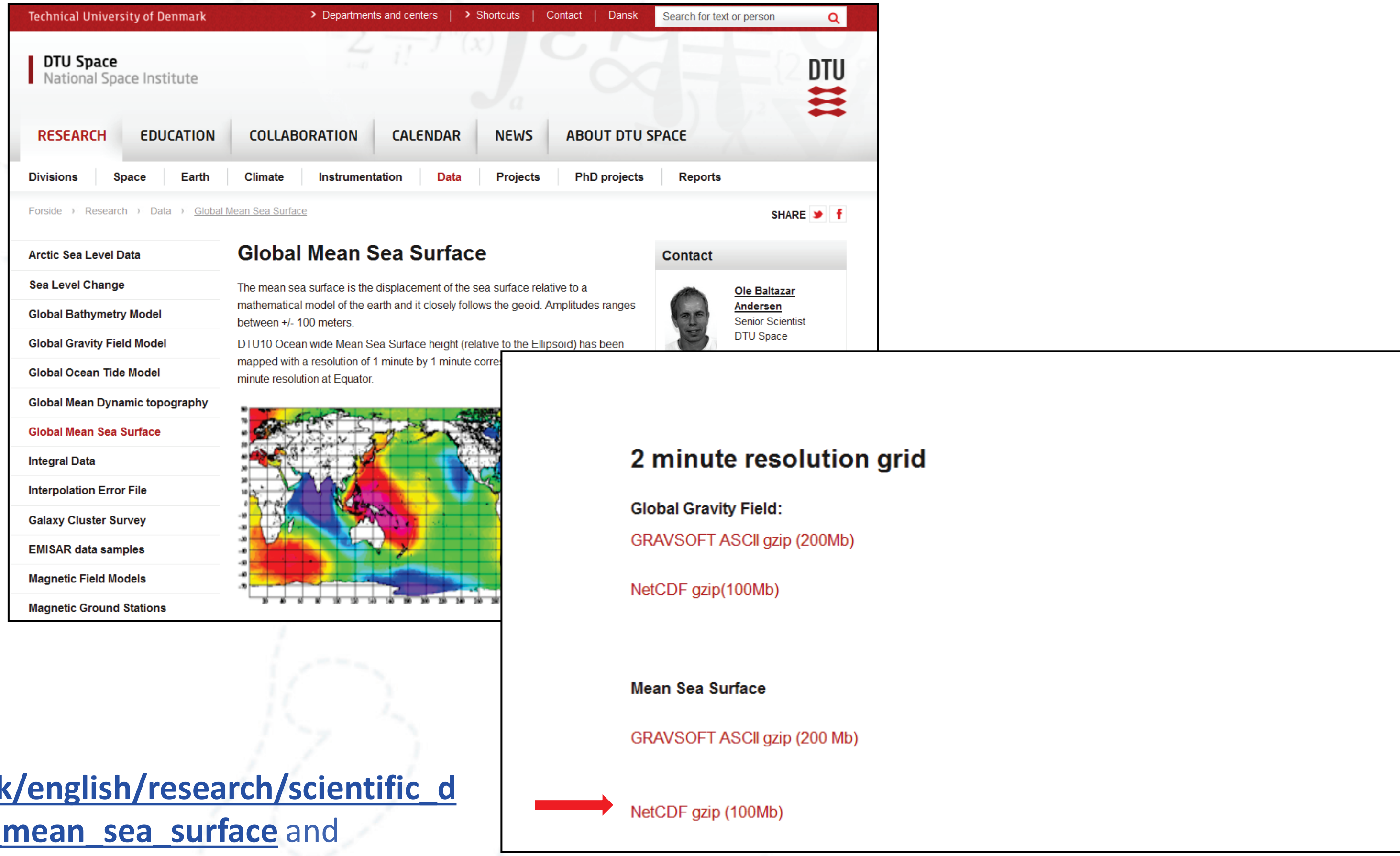
Global Gravity Field Models

We kindly ask the authors of the models to check the links to the original websites of the models from time to time.
Please let us know if something has changed.

The table can be interactively re-sorted by clicking on the column header fields (Nr, Model, Year, Degree, Data, Reference).
The buttons calculate and show in the last columns of the table directly invoke the Calculation Service and Visualization page for the selected model.
For models with a registered **doi** ("digital object identifier") the last column contains the symbol ✓, which directly opens the page on "http://dx.doi.org/".
The full reference of each model is displayed as 'tooltip' if you move the mouse over the table cell. The complete list of references can be found in the references section.

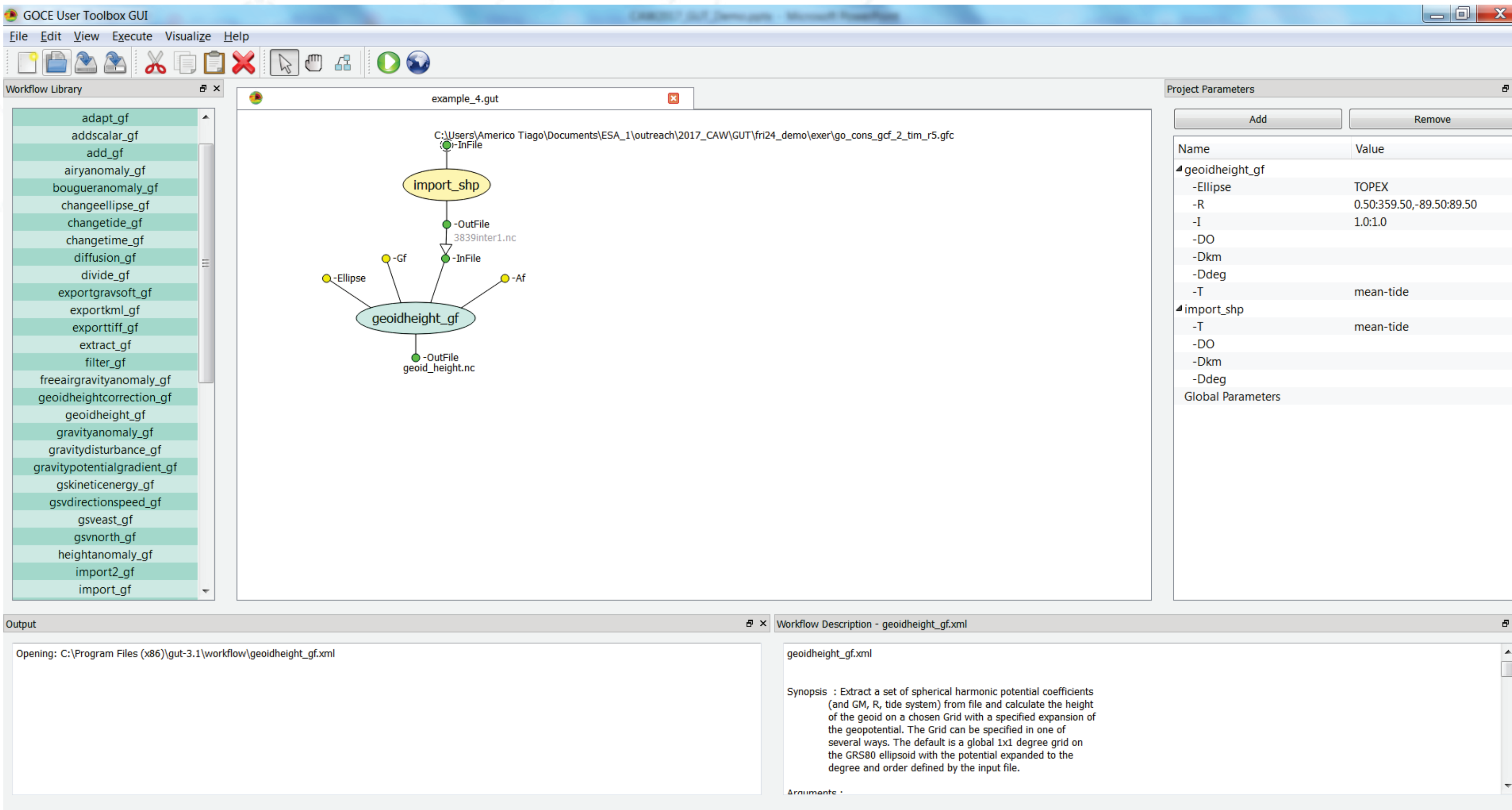
Nr ▲	Model ⇅	Year ⇅	Degree ⇅	Data ⇅	Reference ⇅	download	calculate	show	doi
158	HUST-Grace2016s	2016	160	S(Grace)	Zhou Hao et al, 2016	gfc zip	calculate	show	✓
157	ITU_GRACE16	2016	180	S(Grace)	Akyilmaz et al, 2016b	gfc zip	calculate	show	✓
156	ITU_GGC16	2016	280	S(Grace,Goce)	Akyilmaz et al, 2016a	gfc zip	calculate	show	✓
155	EIGEN-6S4v2	2016	300	S(Goce,Grace,Lageos)	Förste et al, 2016	gfc zip	calculate	show	✓
154	GOCO05c	2016	720	S,G,A (see model)	Pail, et al. 2016	gfc zip	calculate	show	✓
153	GGM05C	2016	360	S(Grace,Goce),G,A	Ries et al, 2016	gfc zip	calculate	show	✓
152	GECO	2015	2190	S(Goce),EGM2008	Gilardoni et al, 2015	gfc zip	calculate	show	
151	GGM05G	2015	240	S(Grace,Goce)	Bettadpur et al, 2015	gfc zip	calculate	show	
150	GOCO05s	2015	280	S(see model)	Mayer-Gürr, et al. 2015	gfc zip	calculate	show	
149	GO_CONS_GCF_2_SPW_R4	2014	280	S(Goce)	Gatti et al, 2014	gfc zip	calculate	show	
148	EIGEN-6C4	2014	2190	S(Goce,Grace,Lageos),G,A	Förste et al, 2015	gfc zip	calculate	show	✓
147	ITSG-Grace2014s	2014	200	S(Grace)	Mayer-Gürr et al, 2014	gfc zip	calculate	show	
146	ITSG-Grace2014k	2014	200	S(Grace)	Mayer-Gürr et al, 2014	gfc zip	calculate	show	
145	GO_CONS_GCF_2_TIM_R5	2014	280	S(Goce)	Brockmann et al, 2014	gfc zip	calculate	show	
144	GO_CONS_GCF_2_DIR_R5	2014	300	S(Goce,Grace,Lageos)	Bruinsma et al, 2013	gfc zip	calculate	show	
143	JYY_GOCE04S	2014	230	S(Goce)	Yi et al, 2013	gfc zip	calculate	show	

Demo: MDT from GOCE



Go to **http://www.space.dtu.dk/english/research/scientific_data_and_models/global_mean_sea_surface** and download a **Mean Sea Surface** grid

Demo: MDT from GOCE



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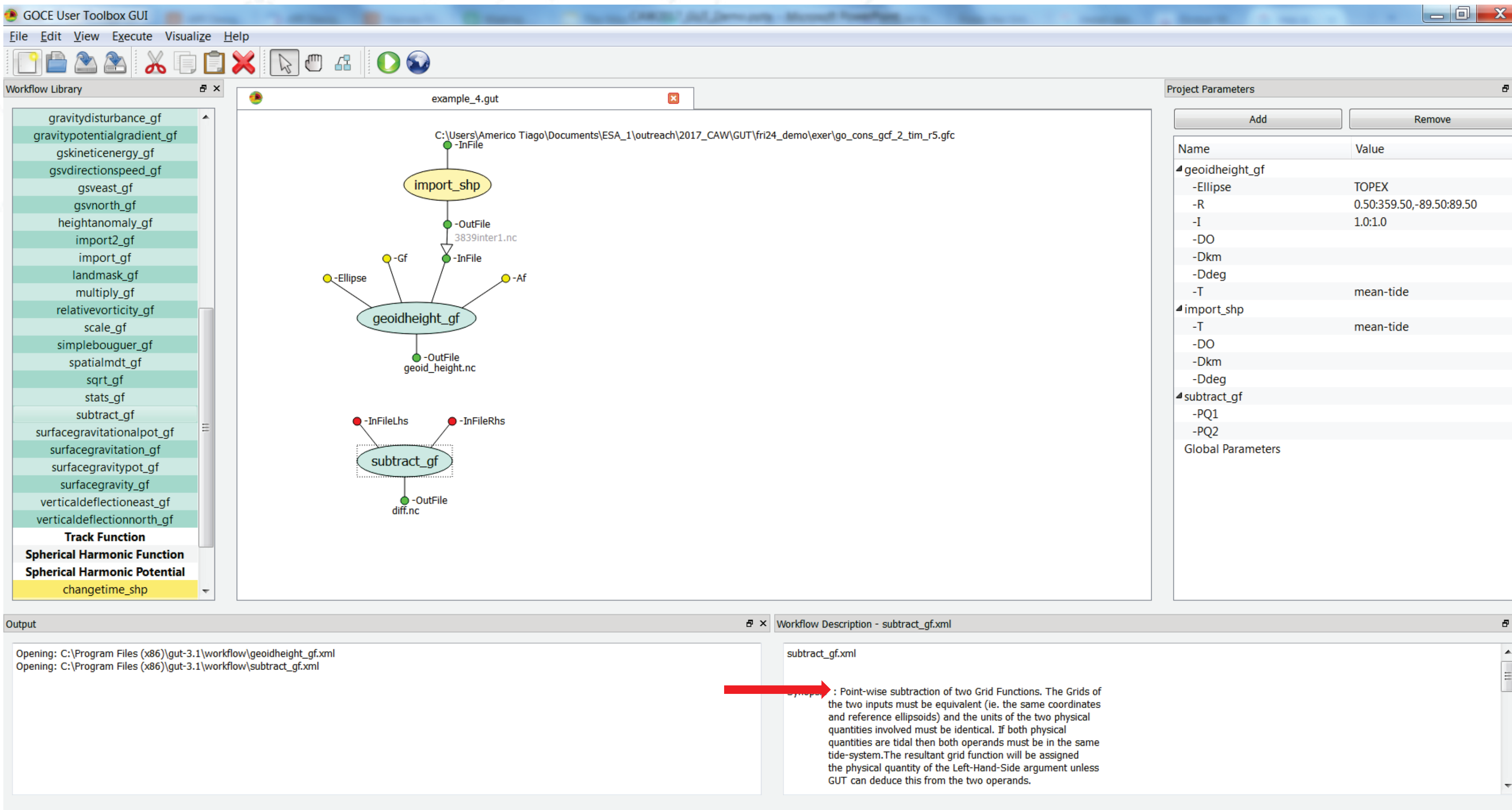

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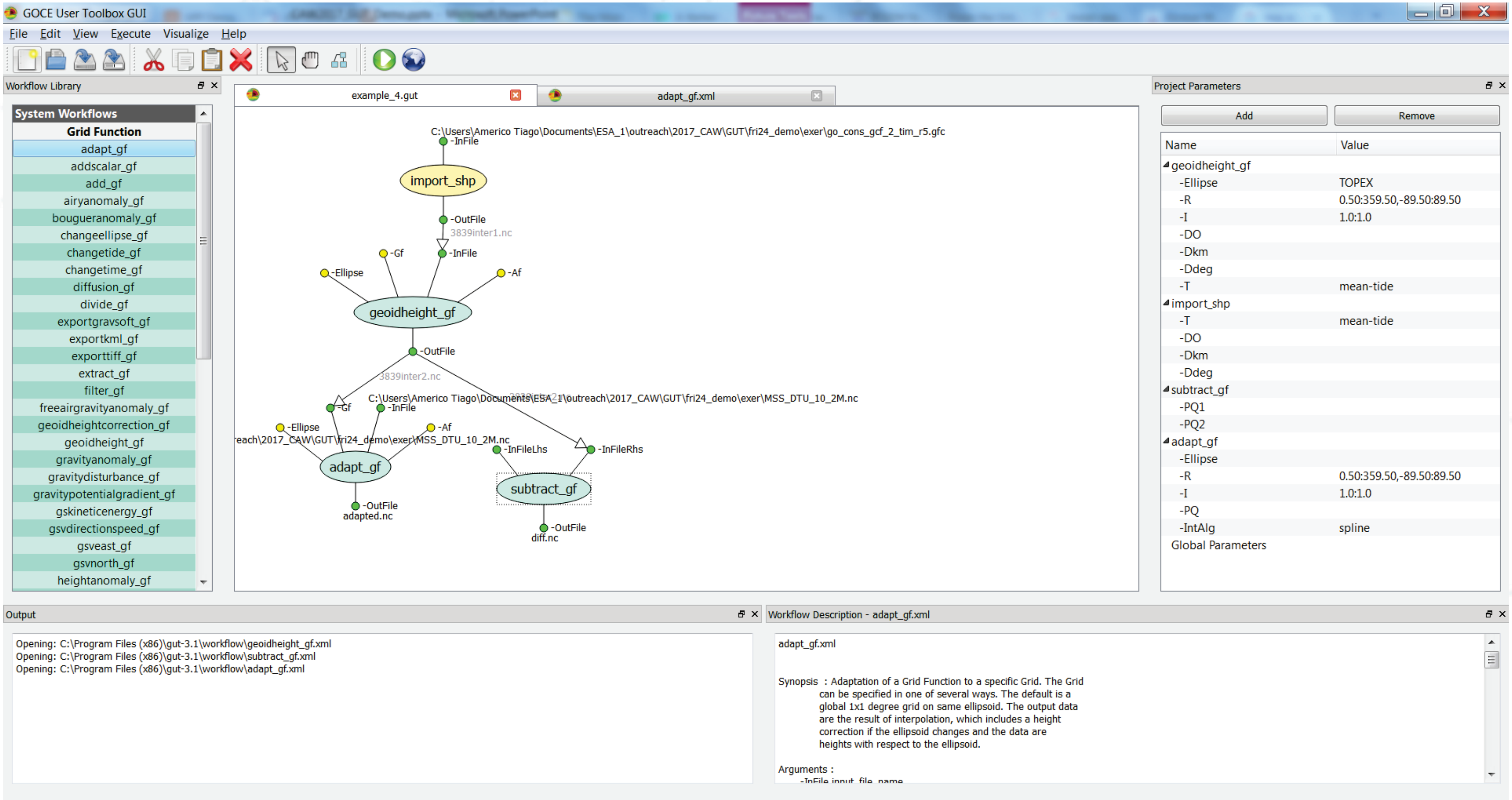

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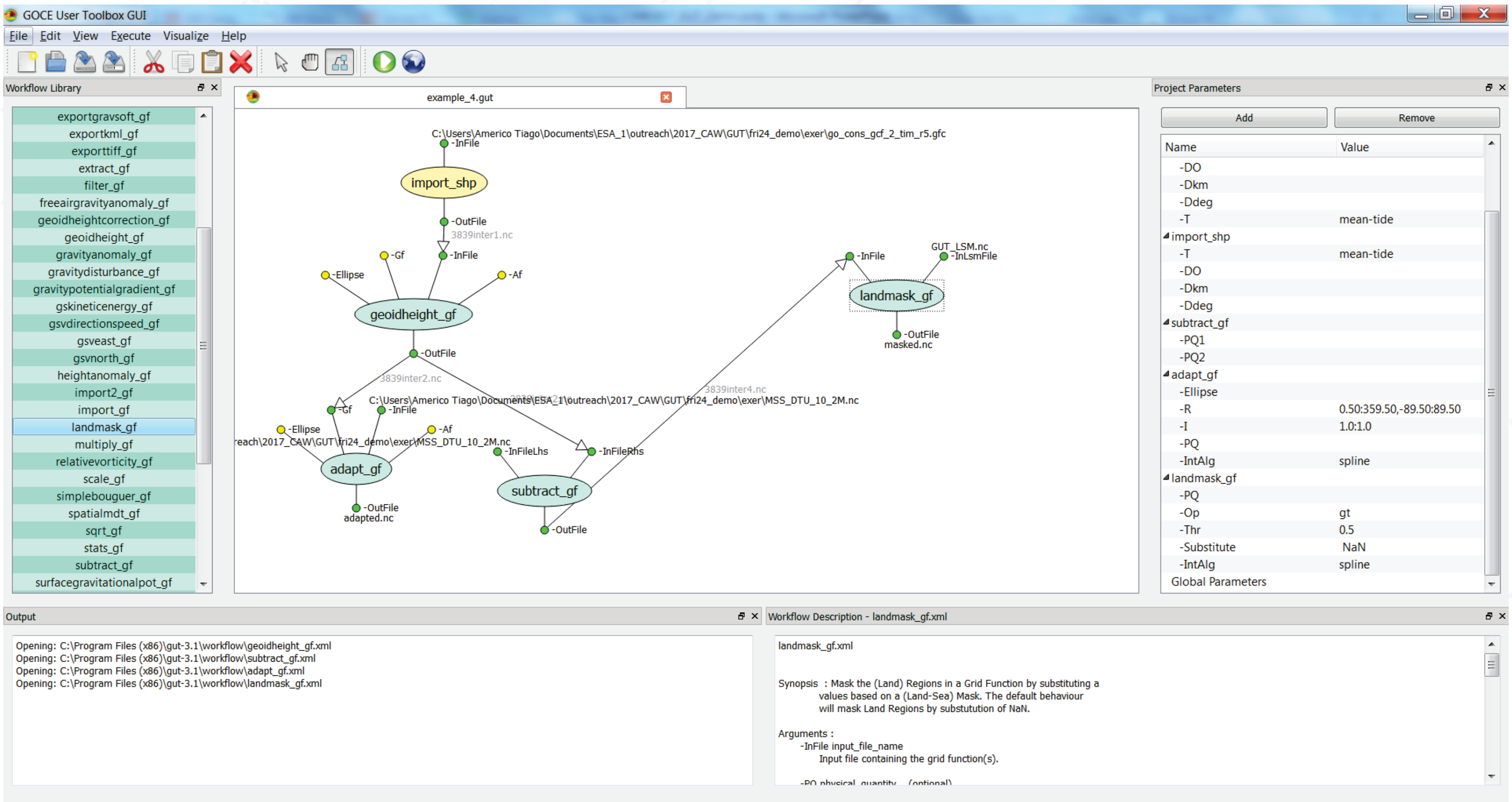
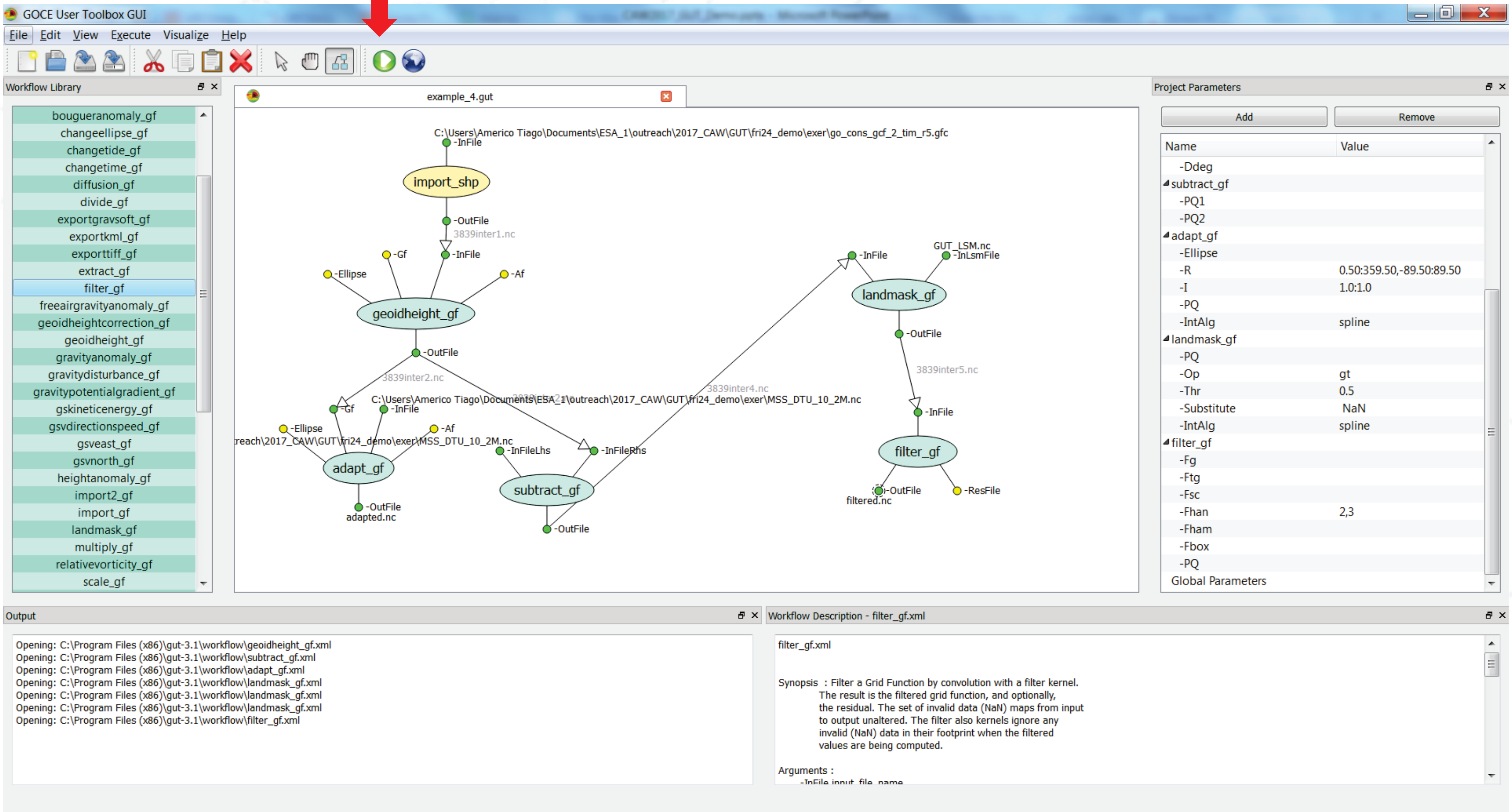


Demo: MDT from GOCE



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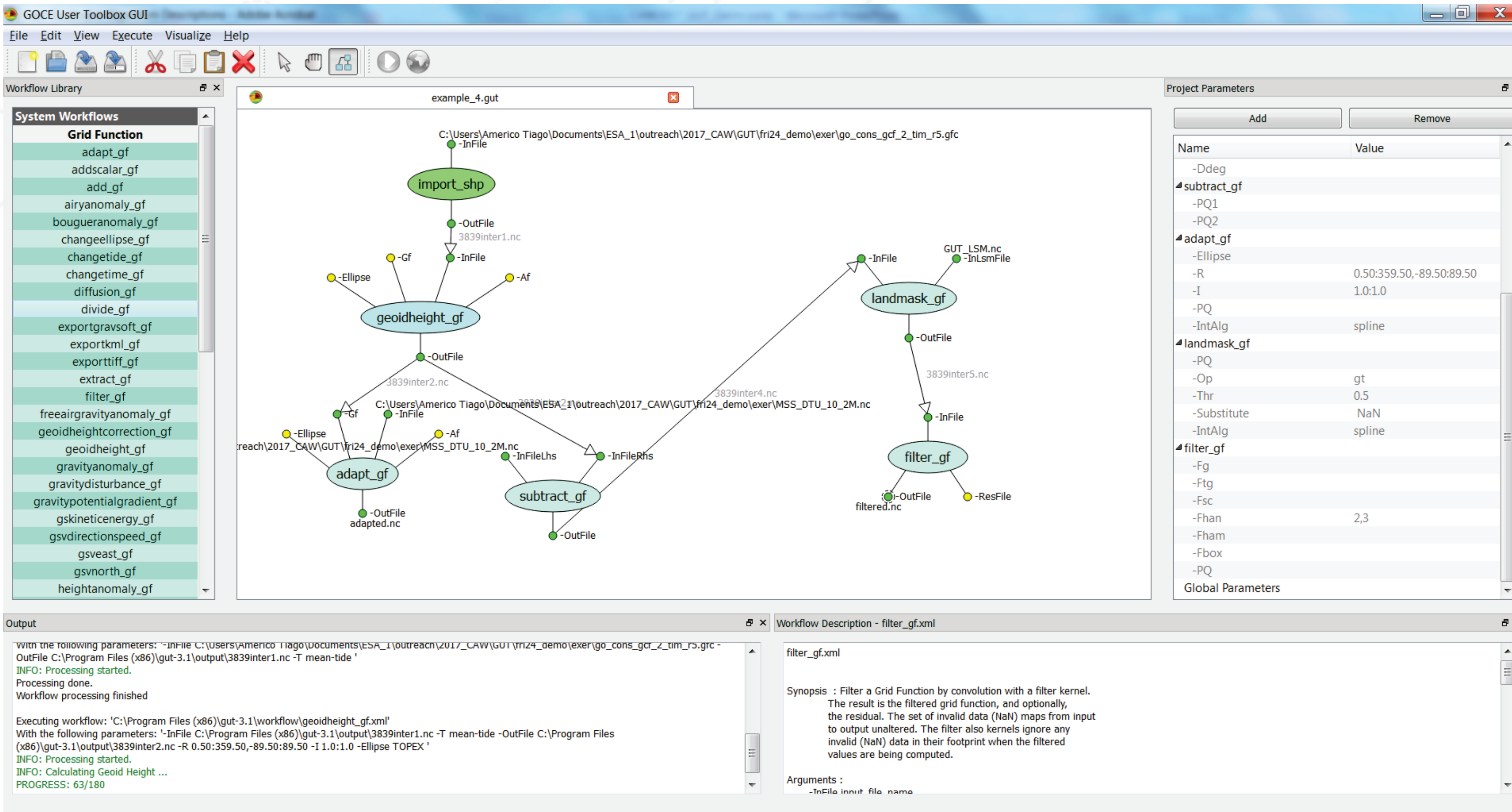
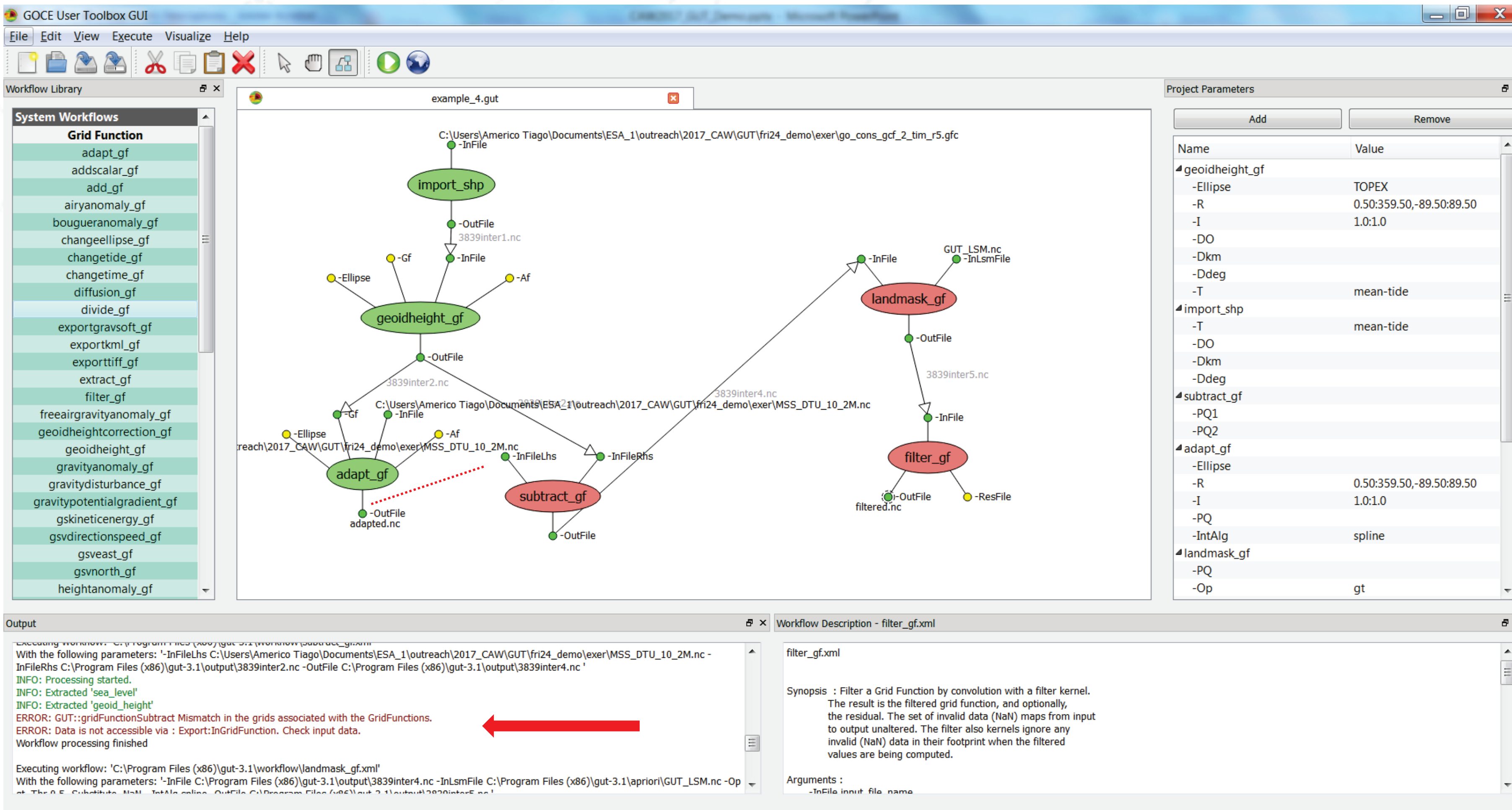


Demo: MDT from GOCE



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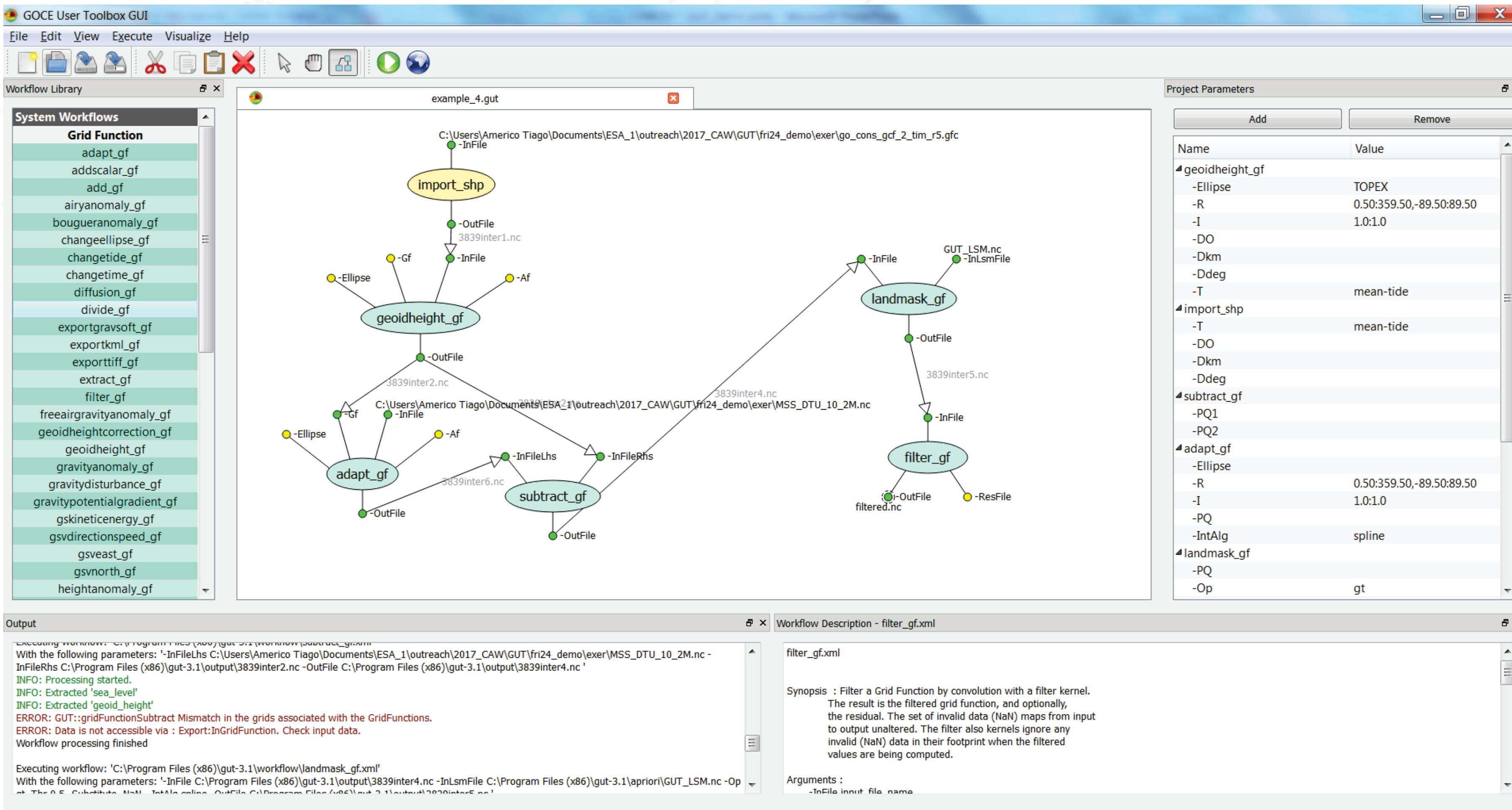

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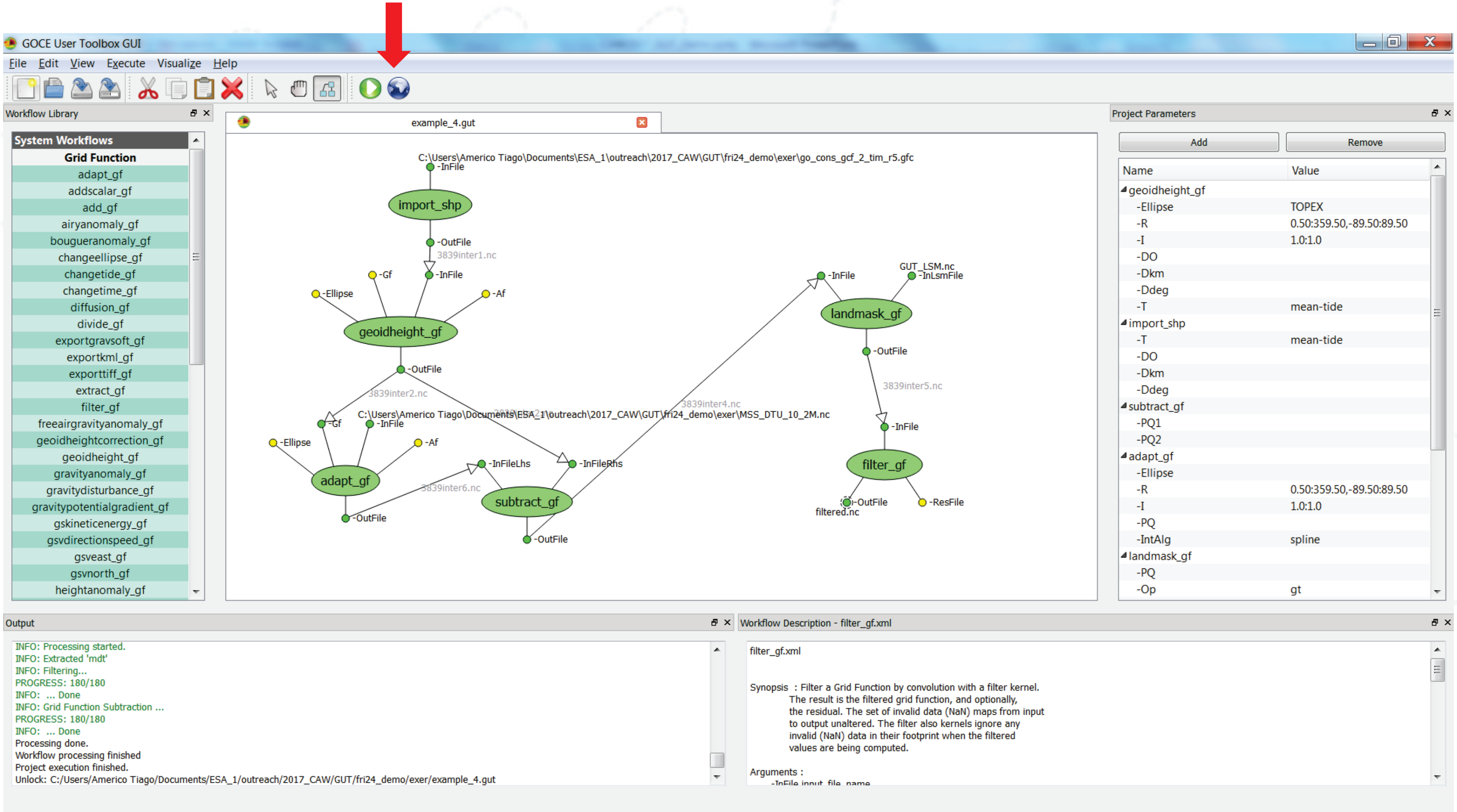

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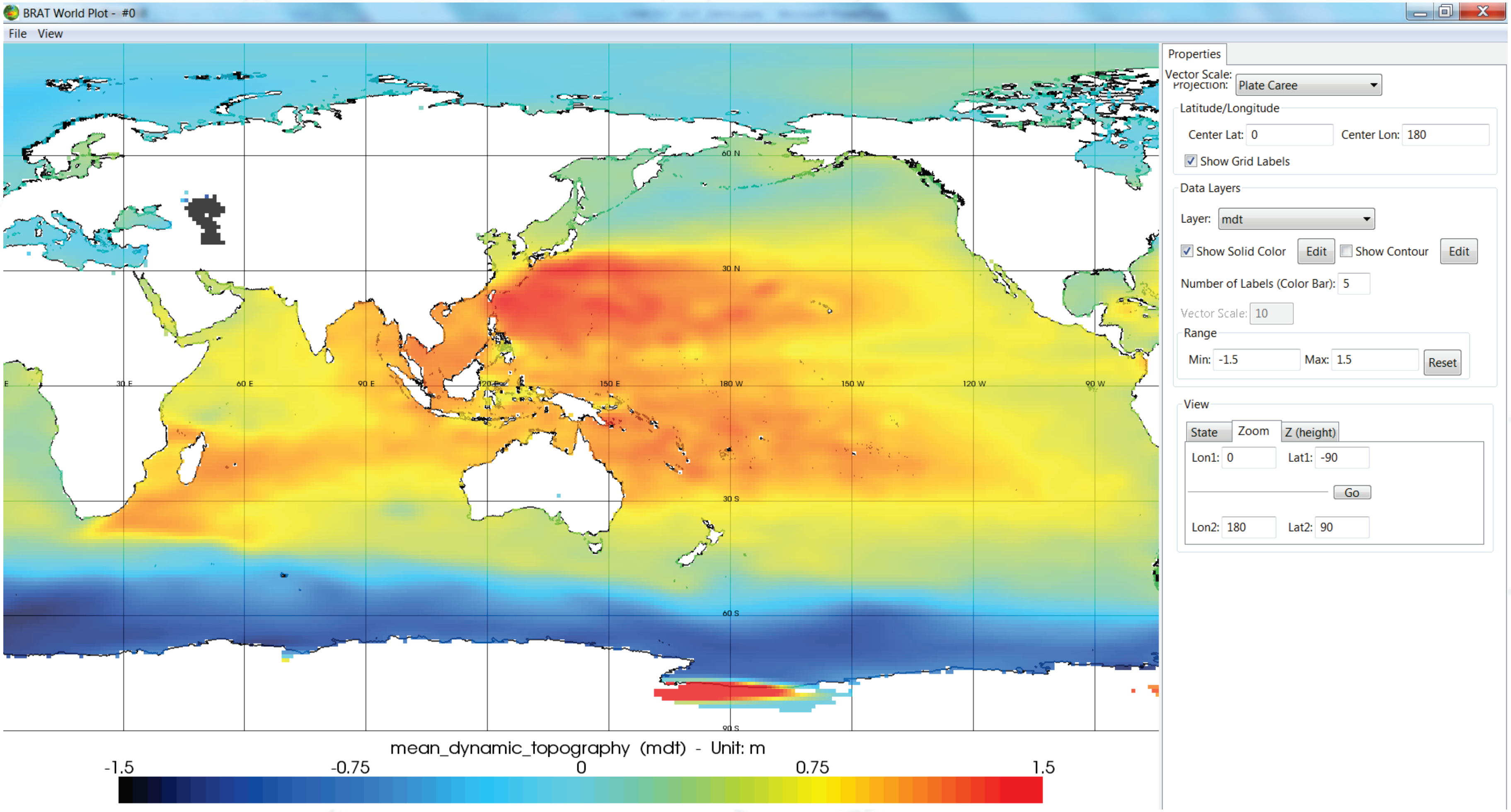
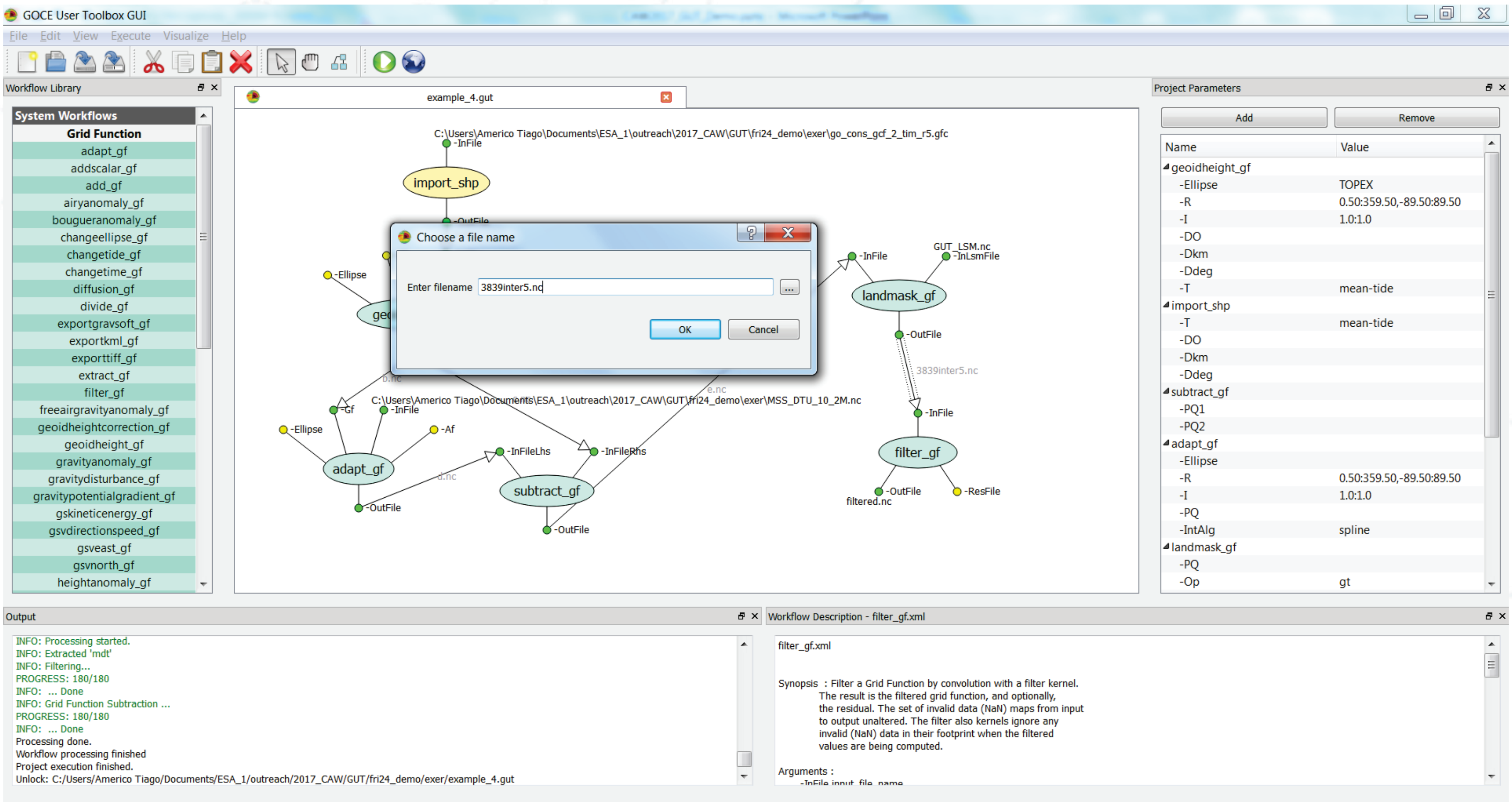


ANY QUESTIONS?

ANY QUESTIONS?

YES

Questions


GOCE User Toolbox GUI
File Edit View Execute Visualize Help
Workflow Library
System Workflows
Grid Function
adapt_gf
addscalar_gf
add_gf
airyanomaly_gf
bougueranomaly_gf
changeellipse_gf
changetide_gf
changetime_gf
diffusion_gf
divide_gf
exportgravsoft_gf
exportkml_gf
exporttiff_gf
extract_gf
filter_gf
freeairgravityanomaly_gf
geoidheightcorrection_gf
geoidheight_gf
gravityanomaly_gf
gravitydisturbance_gf
gravitypotentialgradient_gf
gskineticenergy_gf
gsvdirectionspeed_gf
gsveast_gf
gsvnorth_gf
heightanomaly_gf
example_4.gut
C:\Users\Americo Tiago\Documents\ESA_1\outreach\2017_CAW\GUT\fri24_demo\exer\go_cons_gcf_2_tim_r5.gfc
-InFile
import_shp
-OutFile
Choose a file name
Enter filename 3839inter5.nc
OK
Cancel
-Ellipse
GUT_LSM.nc
-InFile
-InLsmFile
landmask_gf
-OutFile
3839inter5.nc
-InFile
filter_gf
-OutFile
-ResFile
filtered.nc
C:\Users\Americo Tiago\Documents\ESA_1\outreach\2017_CAW\GUT\fri24_demo\exer\MSS_DTU_10_2M.nc
-Gf
-InFile
-Ellipse
-Af
adapt_gf
-InFileLhs
-InFileRhs
subtract_gf
-OutFile
-OutFile
Project Parameters
Add
Remove
Name
Value
geoidheight_gf
-Ellipse TOPEX
-R 0.50:359.50,-89.50:89.50
-I 1.0:1.0
-DO
-Dkm
-Ddeg
-T mean-tide
import_shp
-T mean-tide
-DO
-Dkm
-Ddeg
subtract_gf
-PQ1
-PQ2
adapt_gf
-Ellipse
-R 0.50:359.50,-89.50:89.50
-I 1.0:1.0
-PQ
-IntAlg spline
landmask_gf
-PQ
-Op gt
Output
INFO: Processing started.
INFO: Extracted 'mdt'
INFO: Filtering...
PROGRESS: 180/180
INFO: ... Done
INFO: Grid Function Subtraction ...
PROGRESS: 180/180
INFO: ... Done
Processing done.
Workflow processing finished
Project execution finished.
Unlock: C:/Users/Americo Tiago/Documents/ESA_1/outreach/2017_CAW/GUT/fri24_demo/exer/example_4.gut
Workflow Description - filter_gf.xml
filter_gf.xml
Synopsis : Filter a Grid Function by convolution with a filter kernel.
The result is the filtered grid function, and optionally,
the residual. The set of invalid data (NaN) maps from input
to output unaltered. The filter also kernels ignore any
invalid (NaN) data in their footprint when the filtered
values are being computed.
Arguments :

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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

1

UES

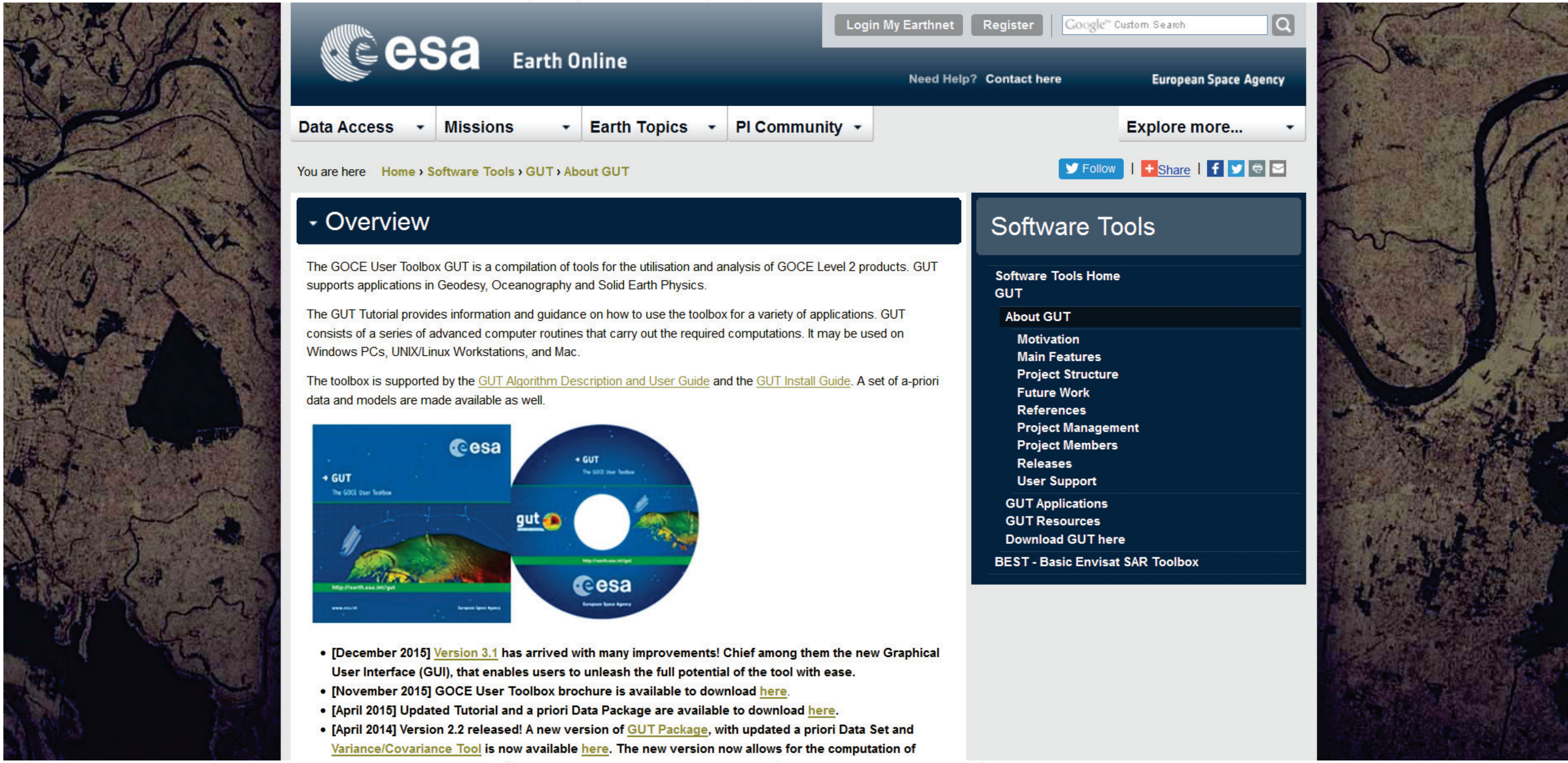
YES

gut	GUT User Guide and Algorithm Descriptions	Reference : ESA-GUT-AD-001 Version : 3.5 page Date : 10 Mar 2016 1/130

GUT

User Guide and Algorithm Descriptions

https://earth.esa.int/gut



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Overview

The GOCE User Toolbox GUT is a compilation of tools for the utilisation and analysis of GOCE Level 2 products. GUT supports applications in Geodesy, Oceanography and Solid Earth Physics.

The GUT Tutorial provides information and guidance on 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.

- **[December 2015] Version 3.1 has arrived with many improvements! Chief among them the new Graphical User Interface (GUI), that enables users to unleash the full potential of the tool with ease.**
- **[November 2015] GOCE User Toolbox brochure is available to download here.**
- **[April 2015] Updated Tutorial and a priori Data Package are available to download here.**
- **[April 2014] Version 2.2 released! A new version of GUT Package, with updated a priori Data Set and Variance/Covariance Tool is now available here. The new version now allows for the computation of**

Software Tools

gut.info@esa.int

Thank you!

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GOCE USER TOOLBOX

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