Tomofast-x-q

QGIS Plugin for Tomofast-x:

User Manual v0.2.10

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2 Introduction to Tomofast-x

Tomofast-x package solves constrained nonlinear (joint) inversion problems of gravity and magnetic data for rock density and magnetic susceptibility models [1-6]. While Tomofast-x is also capable of performing the Electrical Capacitance Tomography, for details see Ref. [7], in this manual we focus on gravity and magnetic inversions. To improve the final model, by adding geological and petrophysical information into inversion, the code supports several different constraints. Such constraints include cross-gradient constraints, “smart”-gradient, disjoint interval bound constraints, and clustering constraints. For more information on equations being solved and the type of constraints used, see reference [1], and references therein.

The model grid allows to accommodate an arbitrary surface topography. Unlike to other approaches, we do not need adding so-called “air cells” to model the topography. Thus adding topography does not involve additional computational cost.

The code with some examples can be downloaded from the following GitHub repository:

https://github.com/TOMOFAST/Tomofast-x

Please, feel free to commit your pull requests with new features, bugfixes, optimizations, new examples, etc.

If you are using this code or some of its parts, please cite references [1] and [2].

For detailed description of parameters, see the Tomofast-x user manual:

https://github.com/TOMOFAST/Tomofast-x/blob/master/docs/Tomofast-x%20User%20Manual.pdf

3 Introduction to Tomofast-x-q

Tomofast-x-q is the QGIS plugin to support the creation of the data, mesh, dtm and parameter files required by Tomofast-x, with the possibility on certain platforms (to be confirmed!) of launching Tomofast-x in the background.

The code with some examples can be downloaded from the following GitHub repository:

https://github.com/TOMOFAST/tomofast-x-q

Please, feel free to commit your pull requests with new features, bugfixes, optimizations, new examples, etc.

If you are using this code or some of its parts, please cite references [1] and [2].

4 Installation

Plugin Installation:

Install directly from the QGIS plugin manager OR download the zip file from the https://github.com/TOMOFAST/tomofast-x-q repository and install this using the QGIS Plugin Manager

WSL2 on Windows

1. **Open PowerShell or Command Prompt as administrator:**
   Search for "**PowerShell**" or "**Command Prompt**" in the Windows search bar, right-click, and select "**Run as administrator**".
2. **Run the installation command:**
   Type **wsl --install** and press Enter.
3. **Restart your computer:**
   After the installation is complete, restart your computer to apply the changes.
4. **Set up your distribution:**
   Once logged back into Windows, a console window for your chosen Linux distribution will open (Ubuntu by default). Follow the prompts to set up your username and password.
5. **Check your network:**
   Make sure you have network access in the Ubuntu system:
   ping google.com
   if you get a timeout warning then type:
   sudo bash -c 'echo "nameserver 8.8.8.8" > /etc/resolv.conf'
   restart a new console and try ping google.com again
6. **Update your distribution:**
   Inside the Linux distribution, run the following commands to update your packages: **sudo apt update && sudo apt upgrade.**
7. **Command to install OpenMPI**
   sudo apt-get install openmpi-bin openmpi-common libopenmpi-dev
8. **Command to install gfortran**
   sudo apt install gfortran
9. **Command to install make**
   sudo apt install make
10. **Download tomofast-x**
    Download the source code for Tomofast-x with:

    wget https://github.com/TOMOFAST/Tomofast-x/archive/refs/heads/master.zip

    then unzip the directory:

    unzip master.zip

    and rename the new directory:

    mv master Tomofast-x
11. **Compile Tomofast-x**
    Navigate to the tomofast-x home directory e.g. **\\wsl.localhost\Ubuntu-22.04\home\mark\Tomofast-x** and type **make**

This should compile the tomofast-x code and then you are ready to go with the plugin (within the plugin you will need to specify the path to the tomofast-x binary and the name of the distro (which is often just *Ubuntu*).

MacOS

1. Install OpenMPI

Install **homebrew** (**https://brew.sh/**) if not already installed, open a Terminal, and type: **brew install open-mpi**

2. Install gfortran

Type: **brew install gcc**

3 Install tomofast-x

Download and unzip the source code for Tomofast-x from **https://github.com/TOMOFAST/Tomofast-x** and install on your home directory with your user name e.g. **/Users/mark/**

4. Compile Tomofast-x

Navigate to the tomofast-x home directory e.g. **/Users/mark/Tomofast-x** and type **make**

This should compile the tomofast-x code and then you are ready to go with the plugin (within the plugin you will have to specify the paths to the tomofast-x and runmpi binaries).

Ubuntu Linux

1. Update packages

Inside the Linux distribution, run the following commands to update your packages: **sudo apt update && sudo apt upgrade.**

2. Install OpenMPI

Type: **sudo apt-get install openmpi-bin openmpi-common libopenmpi-dev**

3. Install gfortran

Type: **sudo apt install gfortran**

4. Install tomofast-x

Download and unzip the source code for Tomofast-x from **https://github.com/TOMOFAST/Tomofast-x** and install on your home directory with your user name e.g. **/home/mark/**

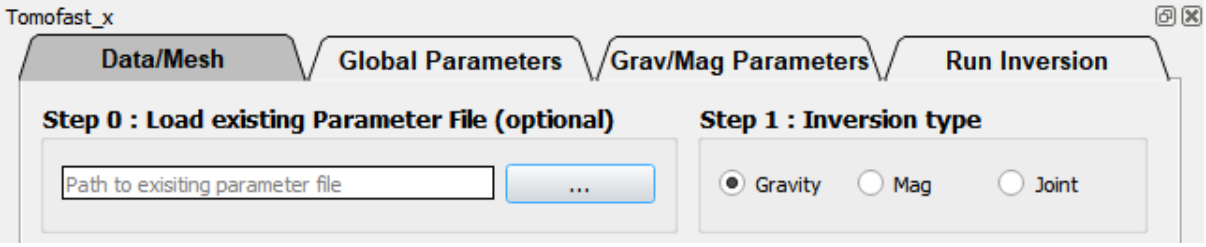
5. Compile Tomofast-x

Navigate to the tomofast-x home directory e.g. **/home/mark/Tomofast-x** and type **make**

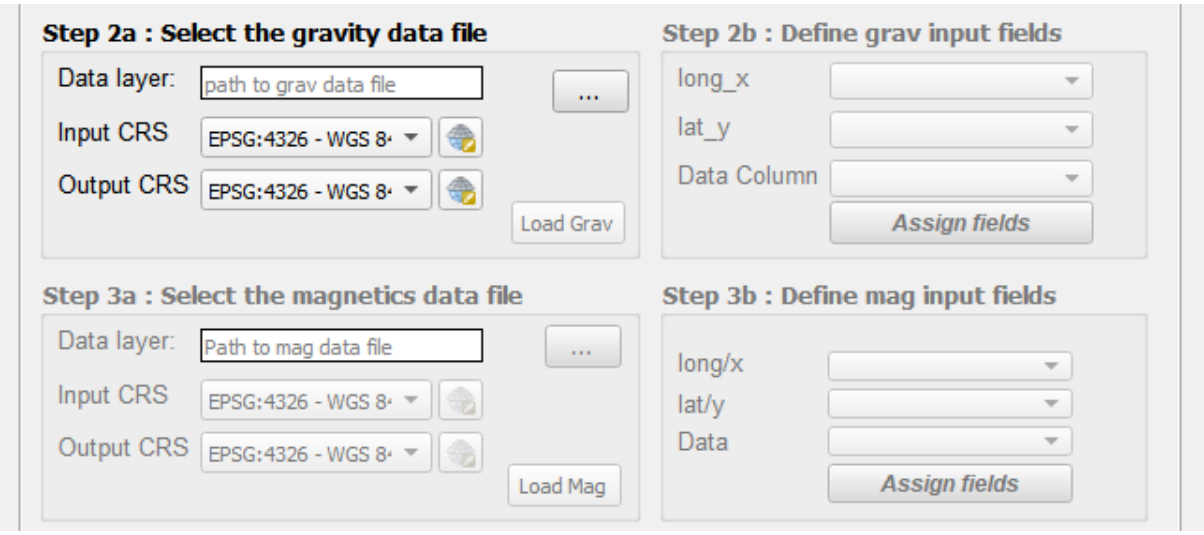
This should compile the tomofast-x code and then you are ready to go with the plugin (within the plugin you will have to specify the path to the tomofast-x binary)..

5 Workflow

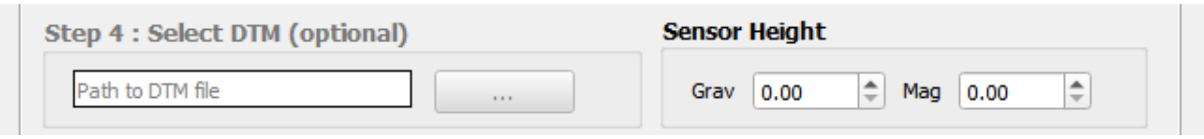
5.1 Data/Mesh Tab



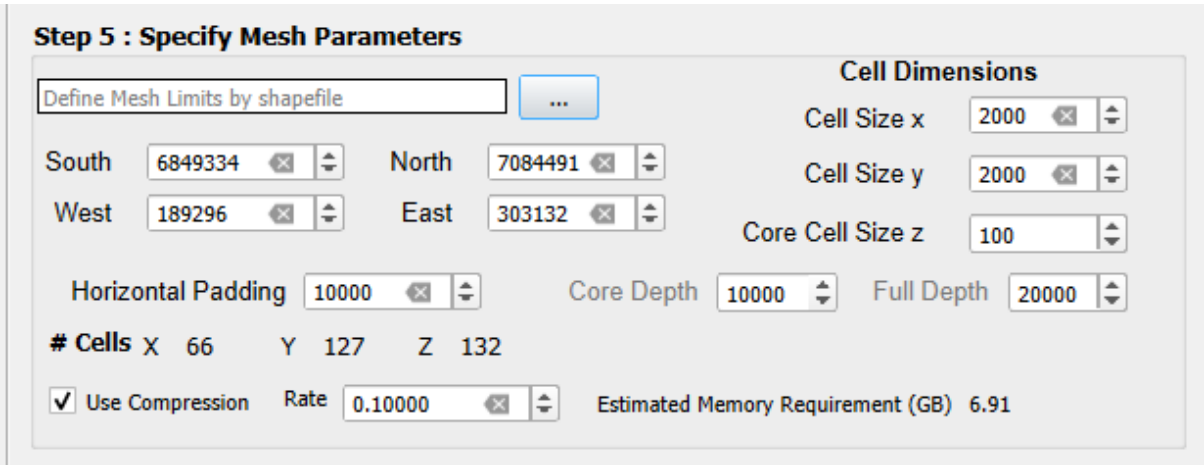
- [**Step 0**] Optionally pre-load an existing parameter file from disk
- [**Step 1**] Select **Grav**, **Mag** or **Joint** Inversion type



- [**Step 2a or Step 3a**] Select a grav or mag data layer (csv or tif format), define input and output projections systems (**CRS**), and Load data
- [**Step 2b or Step 3b**, data loaded to QGIS once Assign fields button selected] If csv data, select fields for **lat_x**, **long_y** & **data**



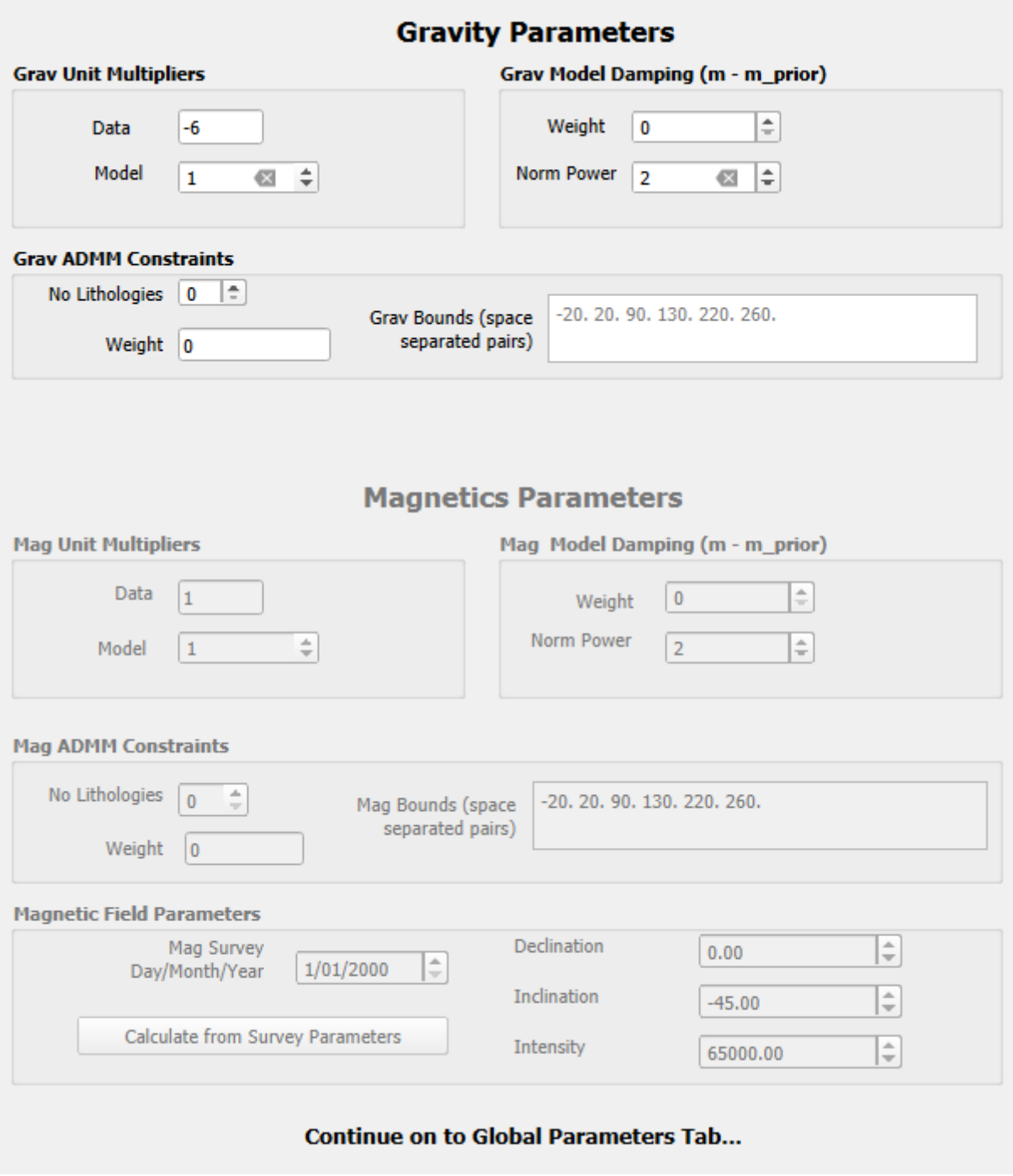
[Step 4 reprojected DTM loaded to QGIS] Select DTM tif file or use constant value. Specify **Sensor Height** for grav and mag surveys (above sea level or if DTM selected, above DTM)



- [**Step 5** after which mesh and data files written out and loaded to QGIS] Specify mesh geographic limits **South**, **North**, **West**, **East** (optionally defined from max/min extents of a polygon shapefile) and output directory for mesh and parameter files.
- Specify **Cell Size** in x,y and z directions for core of mesh, together with **Horizontal Padding** in the x & y directions, the depth of the core of the mesh in the z direction (**Core Depth**) and the depth of the extended mesh below core in the z direction (**Full Depth**). Padding and extended mesh size increases by a factor of 1.15 for each cell away from the cope of the mesh top reduce calculation time.
- **# Cells** is updated to reflect changes to mesh parameters.
- Define **Compression Rate** of Sensitivity Kernel. Check the **Estimated Memory Requirement (**in GB) to make sure you run the inversion on a computer with enough memory.
- Once relevant parameters have been defined, continue to the **Global Parameters Tab** of the plugin.

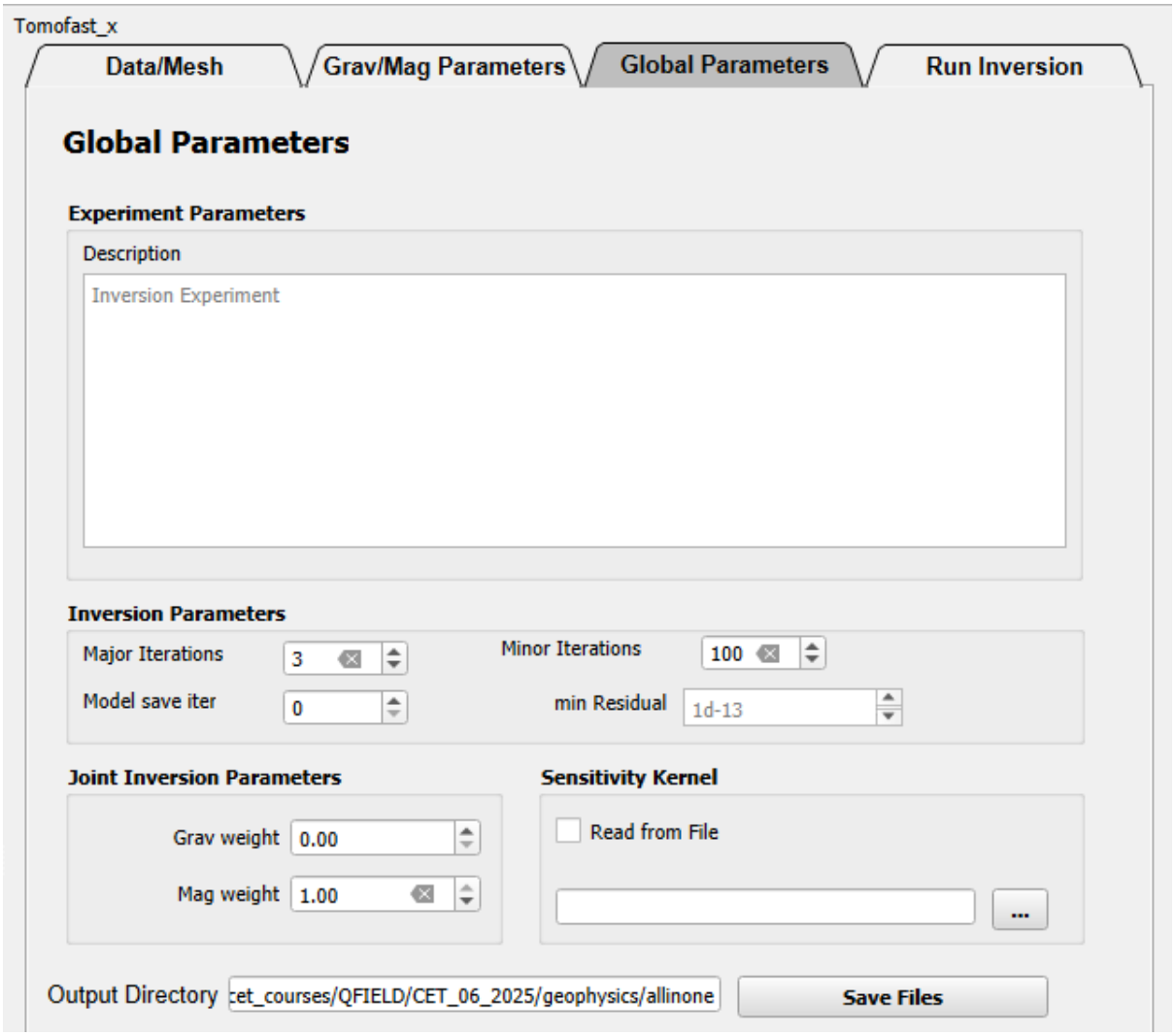
5.2 Grav/Mag Parameters Tab

The only field you need to worry about in this tab is -for Magnetic data inversion- for which you need to set the magnetic field at the time of the survey (set the date of the survey then click on Calculate from Survey Parameters). This tab should otherwise be ignored until you become familiar with the various parameters as described in the Tomofast-x Manual.



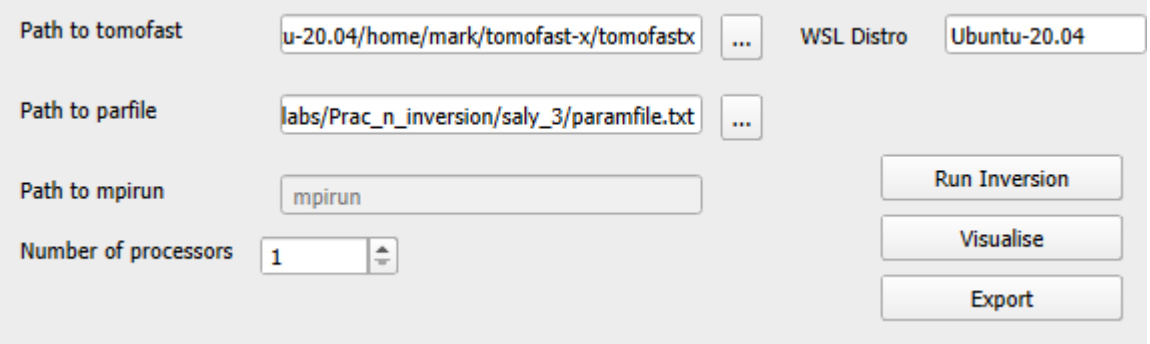
- **[Step 9]** For unconstrained inversions these parameters for Grav and Mag inversions can be left with the default values, except for Mag inversion the Magnetic Field parameters at the time of the survey must be defined.
- If magnetic data have been loaded, the IGRF estimates of the **Declination**, **Inclination** and **Intensity** of the Earth's field at a specified for a given **Mag Survey Day/Month/Year** by clicking on the **Calculate from Survey Parameters** button, that uses the centroid of the survey for the position of the calculation.
- All other parameters can be left as defaults or see Tomofast-x Manual for more details on usage.
- Now you can go to the **Global Parameters Tab**.

5.3 Global Parameters Tab



- **[Step 6]** Experiment Parameters The **Description** area is a free text field used to describe the inversion experiment
- **[Step 7]** The Inversion parameters can typically be left unchanged, see Tomofast-x Manual for more details
- **[Step 8]** Joint Inversion Parameters proves the relative **Weights** for **Grav** and **Mag** data, only relevant for joint inversions.
- **[Step 9]** The **Sensitivity Kernel** can be reread from a previous inversion ***only if*** the mesh parameters have not changed.
- **[Step 10]** Once relevant parameters have been defined, click on Save Files button and you will be asked to provide the path to a directory (best to create a new one) and then the data, mesh and ROI (if defined by shapefile) files are loaded to QGIS. The **paramfile.txt** file will be saved to the same directory as the data, mesh and dtm files.

5.4 Run Inversion Tab



- **[Step 12]** Depending on the Operating System you are running you may be able to run the Tomofast-x code directly from the QGIS Plugin.

Windows: If you have Windows Subsystem for Linux installed on your Windows computer, and you have compiled Tomofast-x in that environment:

- you can set the **Path to tomofast (it will start with \\wsl.localhost\ )**,
- the **Path to the parfile** should be preloaded if you have just created it or you can redefine it
- The **WSL Distro** should be the name of your Linux distro on WSL (check the windows path to the distro disk and use the second path of the path e.g. \\wsl.localhost**Ubuntu-20.04**
- You can define the **Number of processors** that will be used by tomofast-x to perform the inversion

MacOS: If you have a Macintosh computer, and you have compiled Tomofast-x in that environment:

- you can set the **Path to tomofast**,
- the **Path to the parfile** should be preloaded if you have just created it or you can redefine it
- you need to set the path to **mpirun** (perhaps it is at /opt/homebrew/bin/mpirun)
- The **WSL Distro** should be empty (i.e. no text)
- You can define the **Number of processors** that will be used by tomofast-x to perform the inversion

Linux: If you have a Linux computer, and you have compiled Tomofast-x in that environment:

- you can set the **Path to tomofast**,
- the **Path to the parfile** should be preloaded if you have just created it or you can redefine it
- you need to set the path to **mpirun** (perhaps it is at /usr/bin/mpirun)
- The **WSL Distro** should be empty (i.e. no text)

- You can define the **Number of processors** that will be used by tomofast-x to perform the inversion

Once these parameters have been set, you can run the inversion by clicking on the **Run Inversion** button.

To visualize the final model, open in Paraview the file Paraview/grav_final_model3D_full.vtk or Paraview/mag_final_model3D_full.vtk, located in the output folder.

- **[Step 12b]** Alternatively you can copy the data, mesh and paramfile to another computer, ***but then you will have to manually edit the paths in the paramfile before you run tomofast-x***.

1) Before you attempt to run the inversion, check the **Estimated Memory Requirements** in the **Data/Mesh Tab** (in the **Use Compression** area).

2) Once you have saved the parameter file in the previous tab, you can copy the entire directory that contains the paramfile to your machine ***but then you will need to update the paths in the paramfile to match the new machine***, with tomofast-x installed and from the tomofast-x directory you can run the inversion by entering either of the following lines on the command line:

a) For single node calculations type:

./tomofastx -p <Parfile path>

b) For multiprocessor calculations type:

mpirun -np <Number-of-cores> ./tomofastx -j <Parfile path>

3) If the code runs successfully you will see in the end of the screen log the messages "Writing the full model...", and "THE END".

[Step 13] To visualize the final model, click on the **Visualise button** if you have **pyvista** library installed, or open in **Paraview** the file Paraview/grav_final_model3D_full.vtk or Paraview/mag_final_model3D_full.vtk, located in the output folder.

[Step 14] You can also save the model out as a simple csv file by clicking on the **Export** button

6 References

All papers listed below are using Tomofast-x for performing inversions. For convenience, we split the papers to categories corresponding to the type of constraints they use.

- All types of constraints summary:

[1] J. Giraud, V. Ogarko, R. Martin, M. Lindsay, M. Jessell (2021): Structural, petrophysical and geological constraints in potential field inversion using the Tomofast-x open-source code, Geoscientific Model Development Discussions, https://doi.org/10.5194/gmd-2021-14

- Disjoint interval bound constraints:

[2] V. Ogarko, J. Giraud, R. Martin, and M. Jessell (2021), Disjoint interval bound constraints using the alternating direction method of multipliers for geologically constrained inversion: Application to gravity data, GEOPHYSICS 86: G1-G11, https://doi.org/10.1190/geo2019-0633.1

- Smart-gradient constraints:

[3] J. Giraud, M. Lindsay, M. Jessell, and V. Ogarko (2020), Towards plausible lithological classification from geophysical inversion: honouring geological principles in subsurface imaging, Solid Earth, 11: 419–436, https://doi.org/10.5194/se-11-419-2020

[4] J. Giraud, M. Lindsay, V. Ogarko, M. Jessell, R. Martin, and E. Pakyuz-Charrier (2019), Integration of geoscientific uncertainty into geophysical inversion by means of local gradient regularization, Solid Earth, 10: 193–210, https://doi.org/10.5194/se-10-193-2019

- Cross-Gradient constraints:

[5] R. Martin, J. Giraud, V. Ogarko, S. Chevrot, S. Beller, P. Gégout, M. Jessell (2021), Three-dimensional gravity anomaly data inversion in the Pyrenees using compressional seismic velocity model as structural similarity constraints, Geophysical Journal International 225(2): 1063–1085, https://doi.org/10.1093/gji/ggaa414

- Clustering constraints:

[6] J. Giraud, V. Ogarko, M. Lindsay, E. Pakyuz-Charrier, M. Jessell, R. Martin (2019), Sensitivity of constrained joint inversions to geological and petrophysical input data uncertainties with posterior geological analysis, Geophysical Journal International, 218(1): 666–688, https://doi.org/10.1093/gji/ggz152

- L_p norm-based model damping:

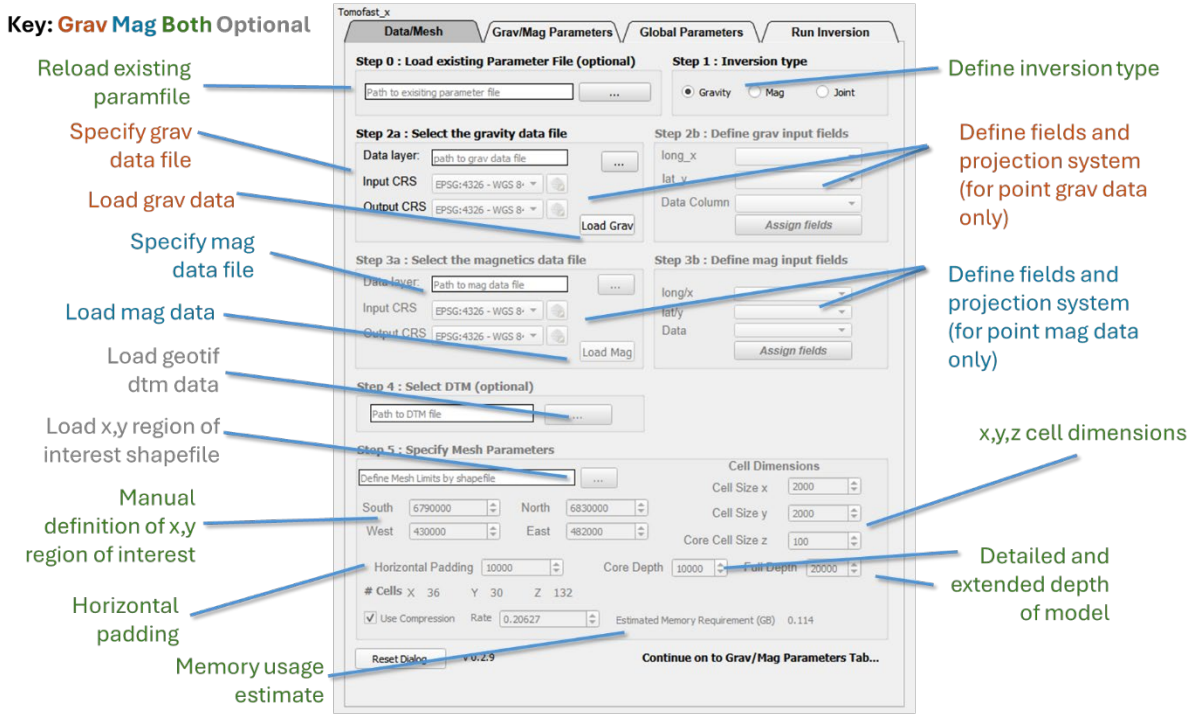
[7] R. Martin, V. Ogarko, D. Komatitsch, M. Jessell (2018), Parallel three-dimensional electrical capacitance data imaging using a nonlinear inversion algorithm and Lp norm-based model regularization, Measurement, 128: 428-445, https://doi.org/10.1016/j.measurement.2018.05.099

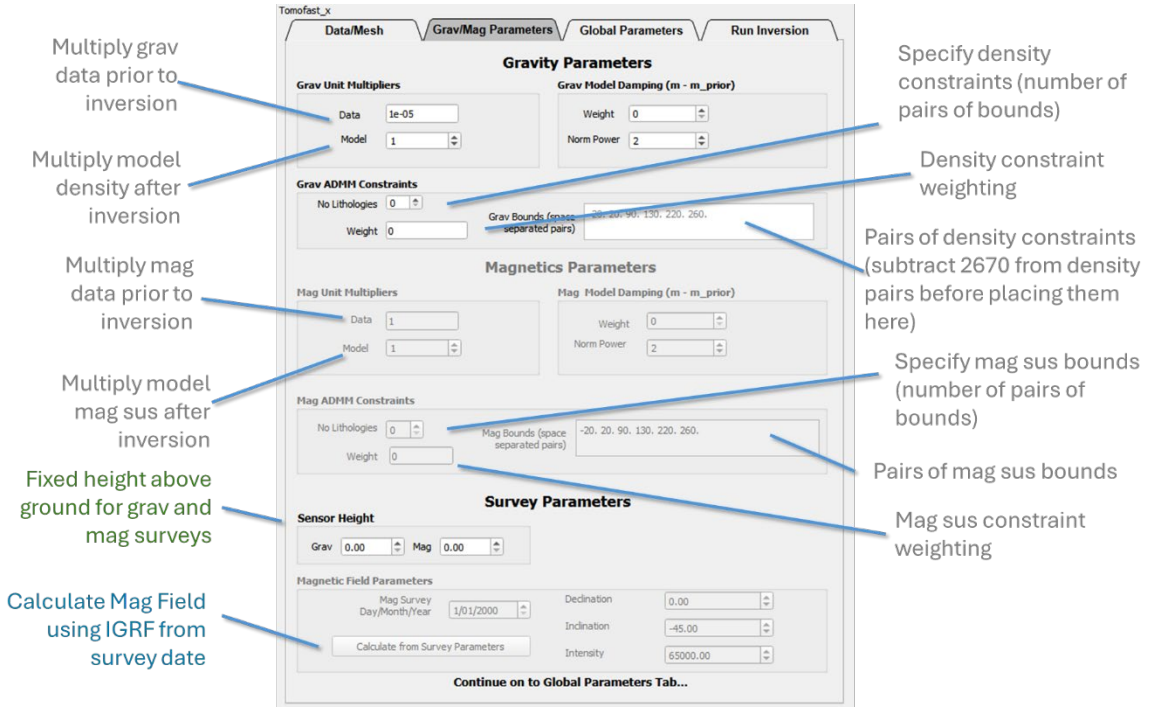
Plugin Cheat Sheet

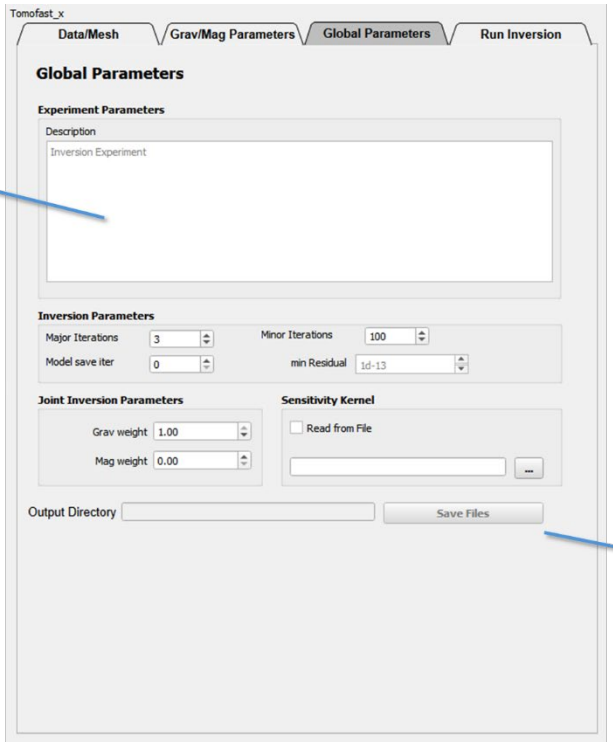
Tomofast-x-q Installation (the plugin)

Install directly from the QGIS plugin manager OR download the zip file from the https://github.com/TOMOFAST/tomofast-x-q repository and install this using the QGIS Plugin Manager

Quick Guide

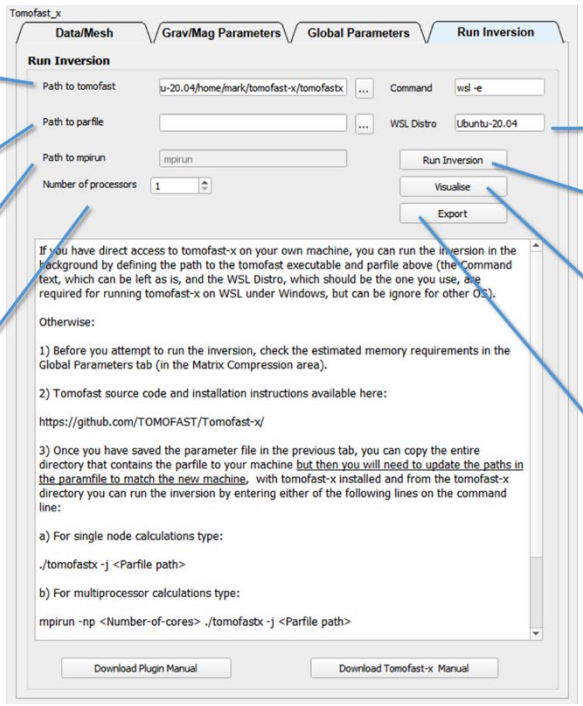






Provide inversion metadata

Create directory and save input files for inversion (extracted data, model mesh and paramfile)



On installation, find path to tomofast-x executable

Find path to paramfile (autoloaded if just created)

On installation, find path to mpirun ((MacOSX only)

Number of processors to use (1 less than you have on the machine)

Name of Linux Distribution (only for Windows/WSL)

Run inversion using current paramfile

Once inversion has been completed, simple visualisation of output for current paramfile

Export model to simple csv x,y,z,data format