FATIANDO A TERRA: OPEN-SOURCE TOOLS FOR GEOPHYSICS

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About the speaker

- **Physicist** and **PhD in Geophysics** (Argentina)
  - Processing and analyzing **gravity and magnetic data**
  - Study **subduction zones** through **geodynamical modeling**

- Currently: **Researcher** in **SJ Geophysics** (Vancouver, Canada)
  - **Software development** of data processing tools
  - **Data processing** (gravity, MT, TDEM)
  - **Field work**

- Member of **Fatiando a Terra**’s Steering Council

- Member of **other communities**:
  - GeoLatinas, The Carpentries and Open Science Labs

Fatiando a Terra

Open-source Python tools for Geophysics

www.fatiando.org

A bit of history

- Started in 2010
- Part of PhD Thesis of Leonardo Uieda in Brazil
- Single Python library: **`fatiando`**
- Tools for:
  - Processing spatial data
  - Forward modelling gravity and magnetic fields
  - Geometry inversions
  - Toy problems for teaching

fatiando a terra

An open-source Python library for modeling and inversion in geophysics.

Our goal is provide a comprehensive and extensible framework for geophysical data analysis and the development of new methodologies.

Research

Make your research more **reproducible** by writing a Python script or Jupyter notebook instead of clicking through complicated menus.

Development

Don't start from scratch! Build upon the existing tools in Fatiando to develop new methods.

Teaching

Combine Fatiando with the Jupyter notebook to make rich, interactive documents. Great for teaching fundamental concepts of geophysics!

Overview

Gravity and magnetics

Modeling, inversion, and processing for potential field methods.

3D forward modeling with prisms, polygonal prisms, spheres, and tesseroids. Handles the potential, acceleration, gradient tensor, magnetic induction, total field magnetic anomaly.

Seismology and Seismics

Simple modeling functions for seismics and seismology.

Toy problems for: Cartesian straight-ray tomography, VSP, epicenter estimation. Experimental finite-difference wave propagation.

Grid manipulation

Functions for generating and operating on regular grids and data that is

Geometric objects and meshes

Classes that represent geometric objects (points, prisms, polyg

https://legacy.fatiando.org

Modernizing our tools

python™ 3 + Growing scientific Python ecosystem

GemPy

xarray

simpeg

PyVista

pyGIMLi
Geophysical Inversion & Modelling Library

scikit learn

GMT THE GENERIC MAPPING TOOLS

PyGMT

pandas

Modernizing our tools

- Santiago Soler:
  - joined during his PhD (Argentina)
  - leading the new developments
- Goals:
  - Move the project to **Python 3**
  - Create **new libraries** with very **specific scope and goal**
  - Improve **quality** of the **software**:
    - Better **design**
    - Better **tooling**
    - Better **tests**
    - **Best practices**

The Fatiando libraries

Verde

Spatial data processing and interpolation with a Machine Learning flavour

fatiando.org/verde

Harmonica

Processing and modelling potential field data

fatiando.org/harmonica

Choclo

Highly optimized forward modelling kernel functions

fatiando.org/choclo

Boule

Reference ellipsoids and normal gravity

fatiando.org/boule

Pooch

A friend to download and cache your data

fatiando.org/pooch

Ensaio

Curated open-licensed geophysical datasets

fatiando.org/ensaio

Example:
Processing gravity data

Download ground gravity data over Southern Africa

Fetch the data from the web

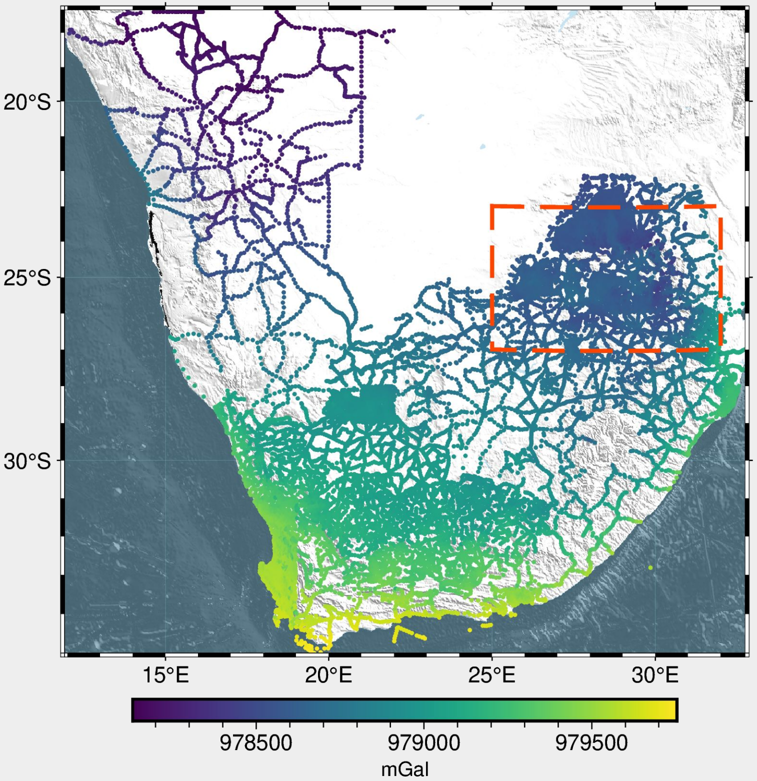
```python
import ensaio

fname = ensaio.fetch_southern_africa_gravity(version=1)
```

Load the data with Pandas

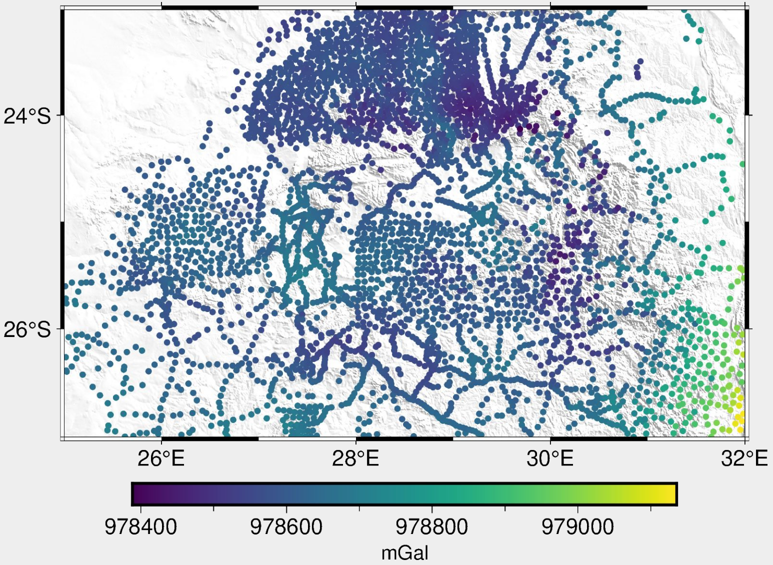
```python
import pandas as pd

data = pd.read_csv(fname)
```

Ensaio pandas (manage tabular data)

Download ground gravity data over Southern Africa



Observed gravity over the Bushveld Igneous Complex



Gravity disturbance

Normal gravity

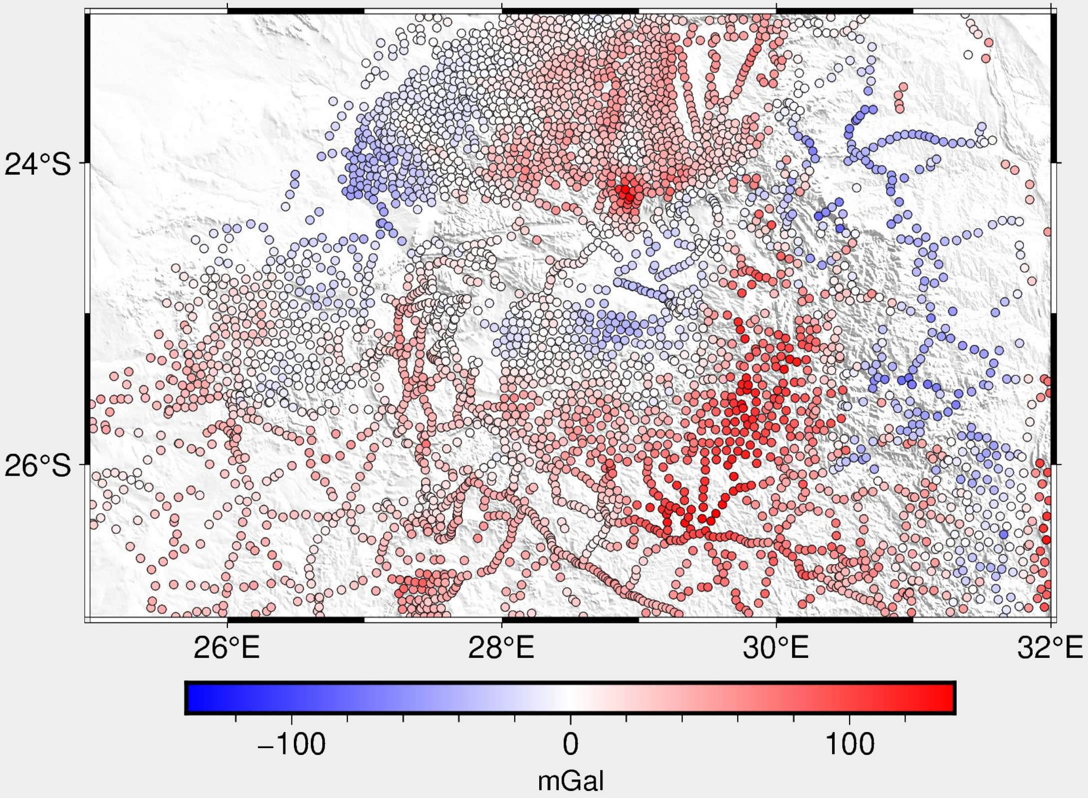
```
import boule as bl

ellipsoid = bl.WGS84
normal_gravity = ellipsoid.normal_gravity(
    data.latitude, data.height
)
```

Gravity disturbance

```
gravity_disturbance = data.gravity - normal_gravity
```

Boule

Gravity disturbance

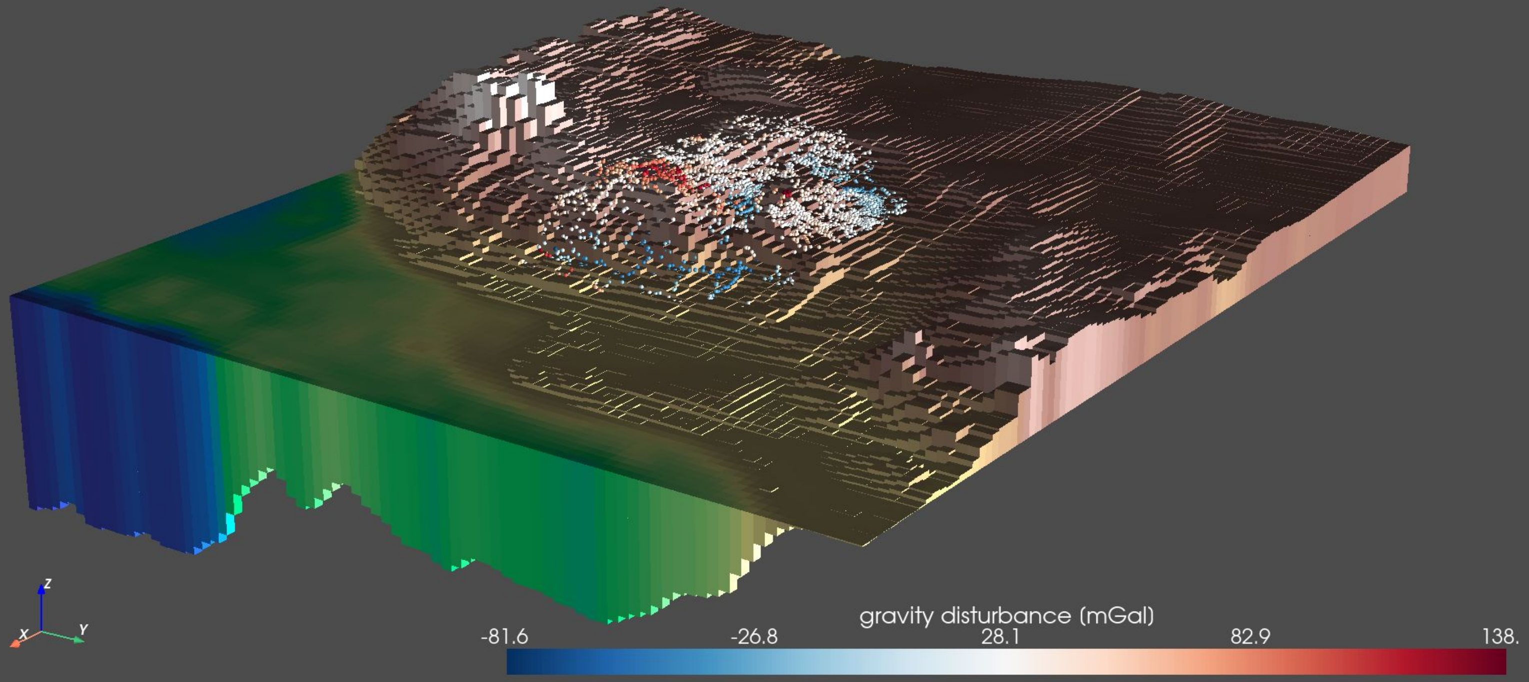


Terrain effect

Model the topography with prisms

```
import harmonica as hm

density = np.where(topography > 0, 2670, 1040 - 2670)

terrain_model = hm.prism_layer(
    coordinates=(topography.easting, topography.northing),
    surface=topography,
    reference=0,
    properties={"density": density},
)
```

Terrain effect



Terrain effect

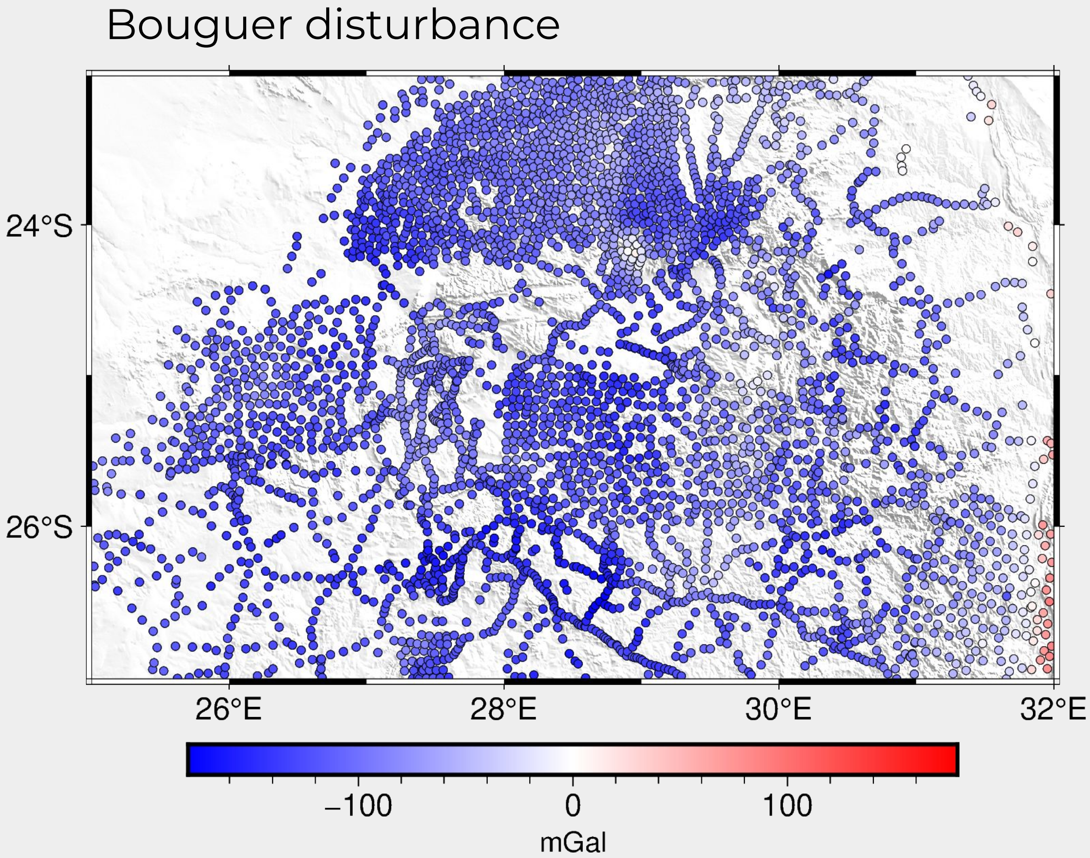
Forward model the terrain effect

```
terrain_effect = terrain_model.prism_layer.gravity(
    coordinates, field="g_z"
)
```

Compute Bouguer disturbance

```
bouguer = gravity_disturbance - terrain_effect
```

Terrain effect



Residual and regional field separation

Deep equivalent sources that reproduce the regional field

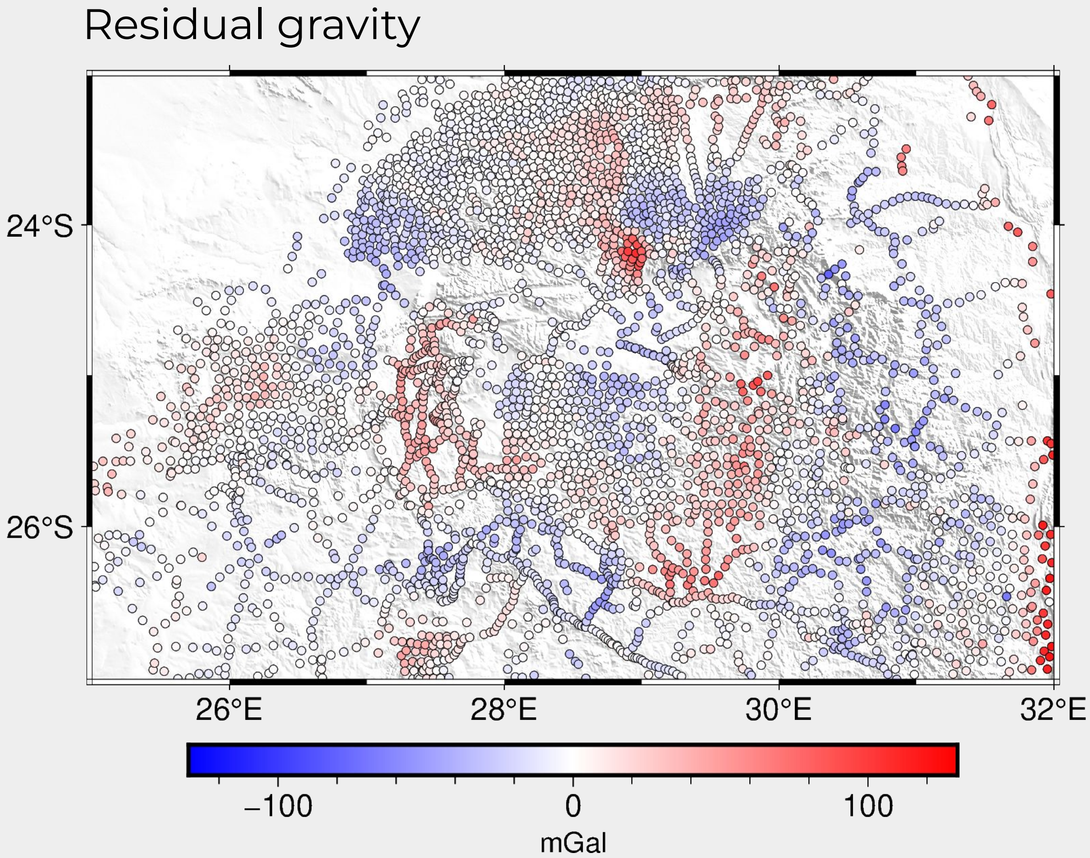
```
deep_sources = hm.EquivalentSources(damping=1000, depth=500e3)
deep_sources.fit(coordinates, gravity_bouguer)

gravity_regional = deep_sources.predict(coordinates)
```

Separate the residual field

```
gravity_residual = gravity_bouguer - gravity_regional
```

Harmonica

Residual and regional field separation



Grid with equivalent sources

Fit some equivalent sources

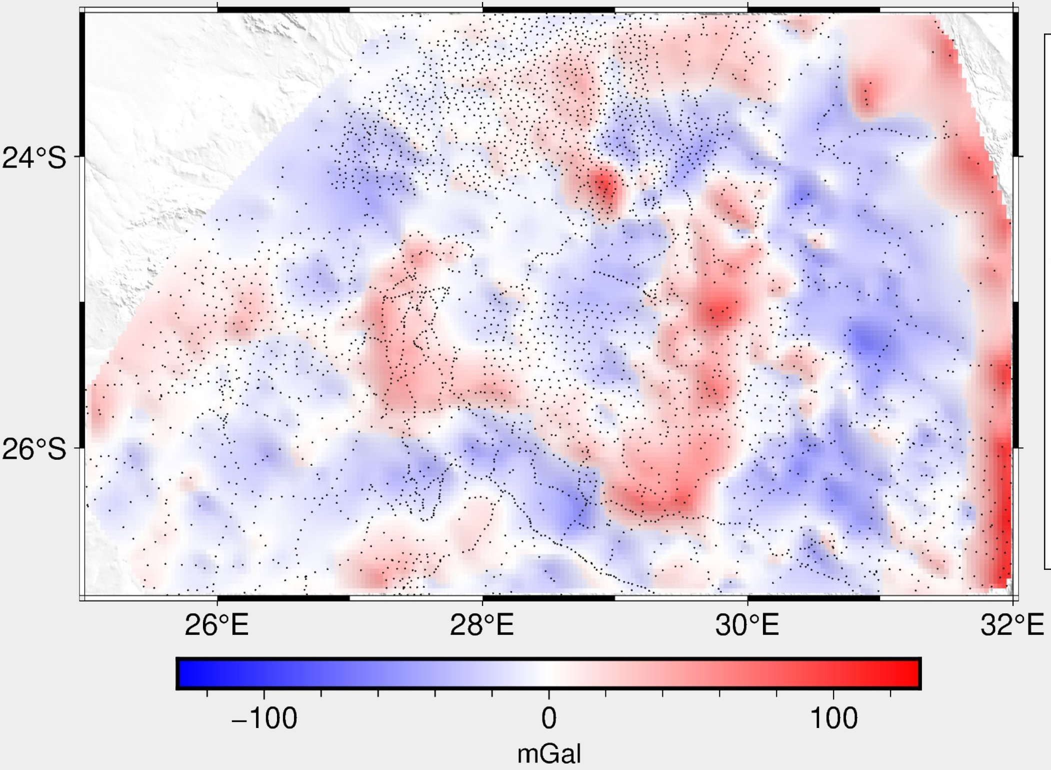
```
eq_sources = hm.EquivalentSources(damping=10, depth=10e3)
eq_sources.fit(coordinates, gravity_residual)
```

Grid residual field at a constant height

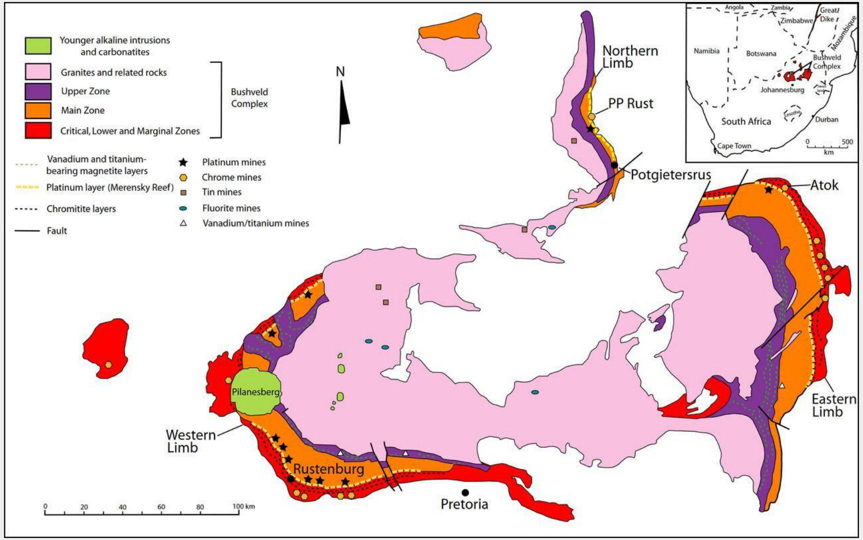
```
grid = eq_sources.grid(
    upward=2200,   # height in meters
    spacing=4000,  # grid spacing in meters
)
```

Grid with equivalent sources

Grid of residual gravity field



Geology of Bushveld Igneous Complex



Example:
Grid transformations

Download a magnetic data grid

Fetch the data from the web

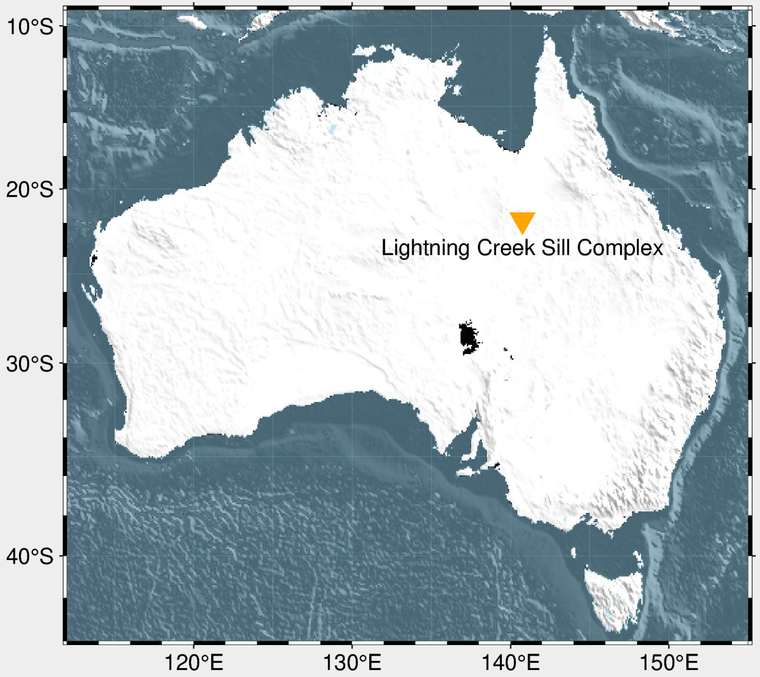
```python
import ensaio

fname = ensaio.fetch_lightning_creek_magnetic(version=1)
```

Load the grid with Xarray

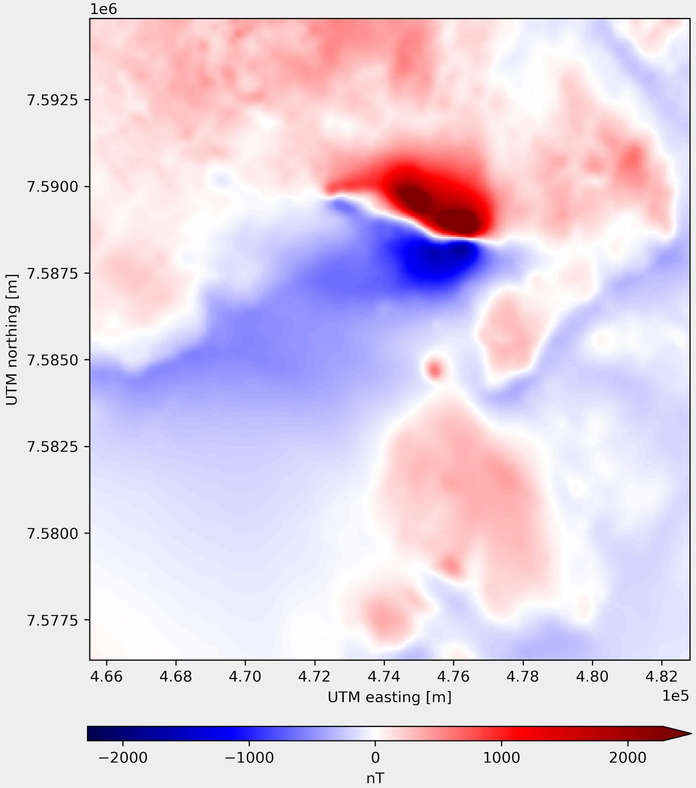
```python
import xarray as xr

magnetic_grid = xr.load_dataarray(fname)
```

Ensaio xarray (multidimensional arrays)

Download a magnetic data grid



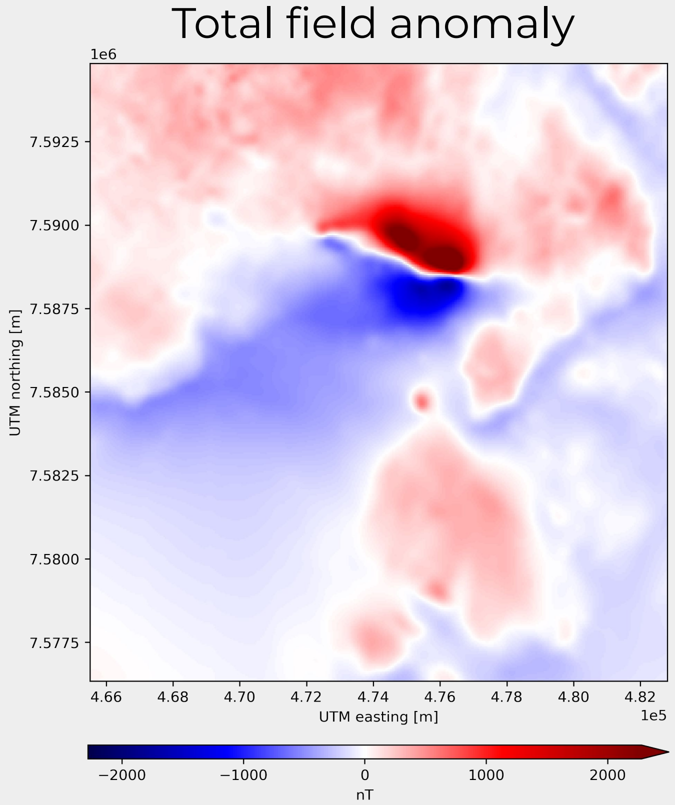
Total field magnetic anomaly

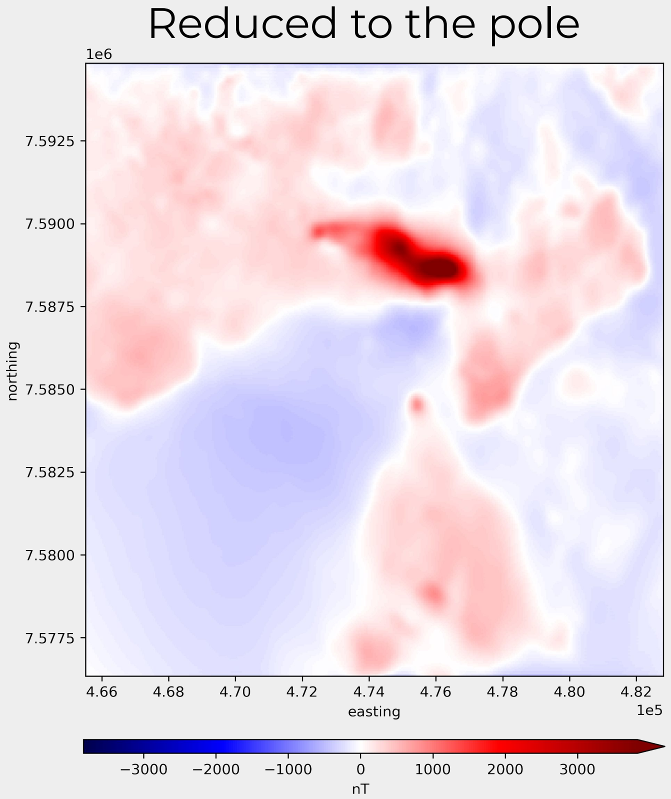


Reduction to the pole

```
import harmonica as hm

reduced_to_pole = hm.reduction_to_pole(
    magnetic_grid,
    inclination=-53.0,
    declination=6.5,
)
```

Reduction to the pole

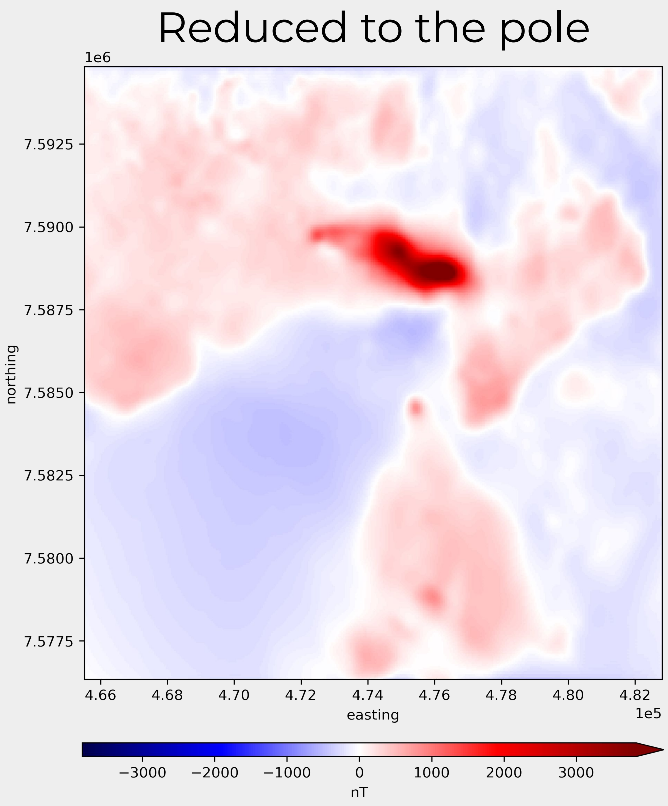


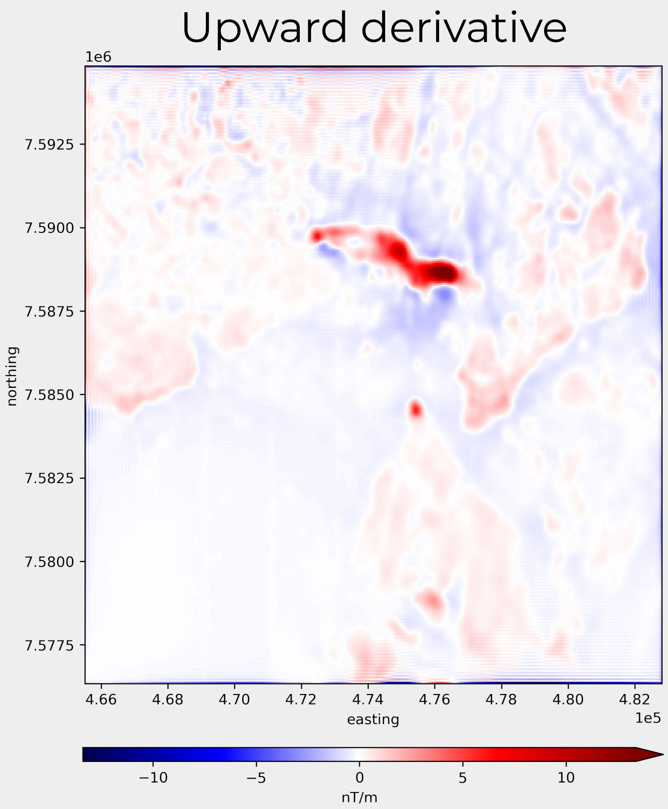


Upward derivative

```python
import harmonica as hm

deriv_upward = hm.derivative_upward(reduced_to_pole)
```

Upward derivative

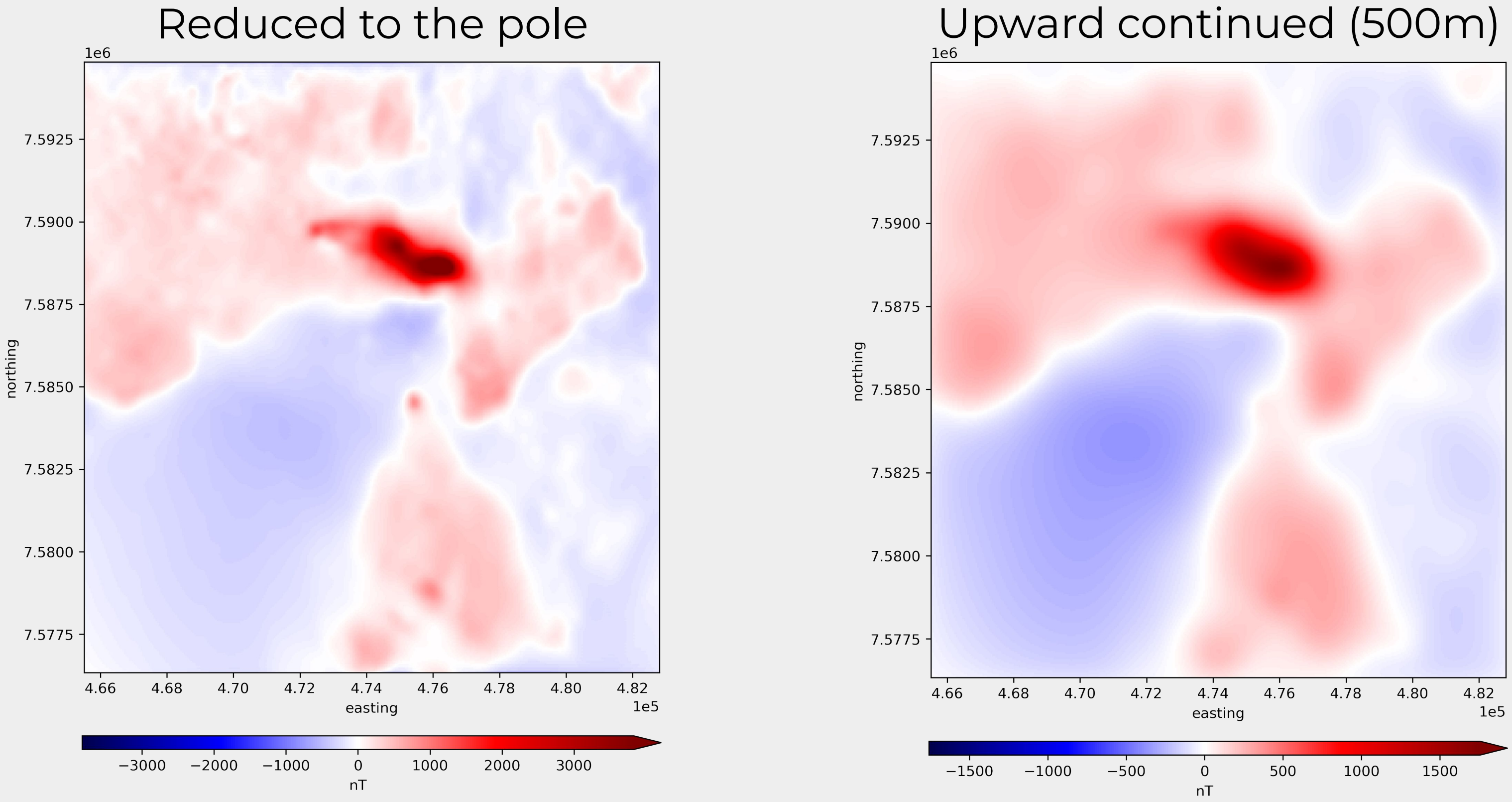




Upward continuation

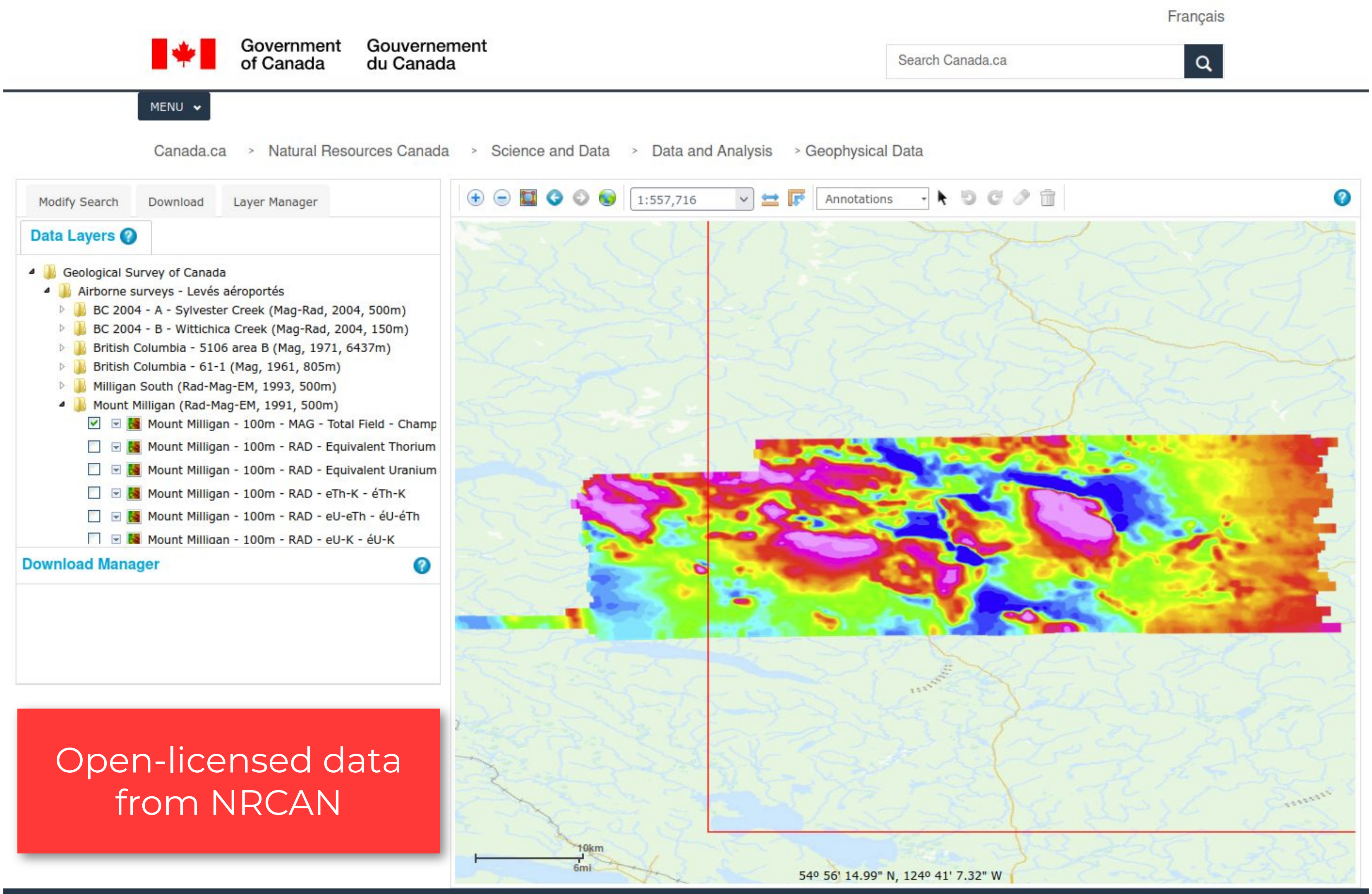
```python
import harmonica as hm

upward_cont = hm.upward_continuation(
    reduced_to_pole,
    height_displacement=500,
)
```

Upward continuation



Example:
Oasis Montaj® GRD files in Python

Mt. Milligan, British Columbia



Open-licensed data from NRCAN

Français

Government of Canada | Gouvernement du Canada

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MENU

Canada.ca > Natural Resources Canada > Science and Data > Data and Analysis > Geophysical Data

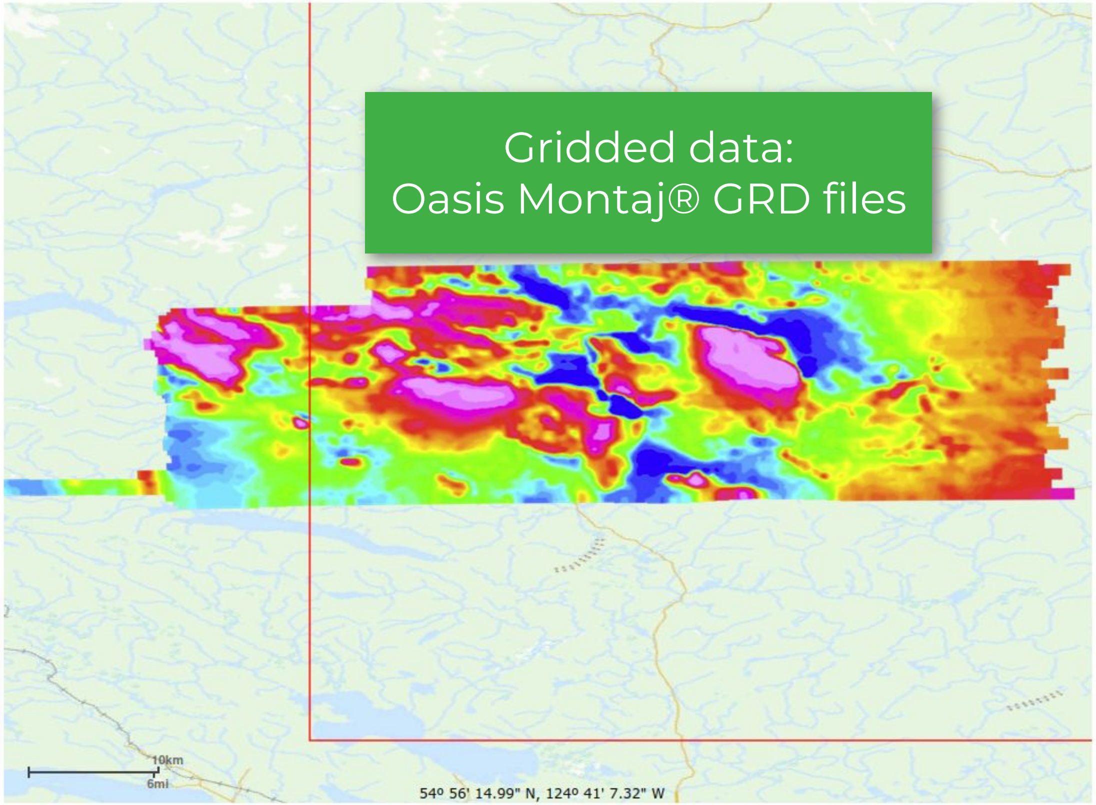
Modify Search | Download | Layer Manager

Data Layers

- Geological Survey of Canada
  - Airborne surveys - Levés aéroportés
    - BC 2004 - A - Sylvester Creek (Mag-Rad, 2004, 500m)
    - BC 2004 - B - Witticha Creek (Mag-Rad, 2004, 150m)
    - British Columbia - 5106 area B (Mag, 1971, 6437m)
    - British Columbia - 61-1 (Mag, 1961, 805m)
    - Milligan South (Rad-Mag-EM, 1993, 500m)
    - Mount Milligan (Rad-Mag-EM, 1991, 500m)
      - [x] Mount Milligan - 100m - MAG - Total Field - Champ
      - [ ] Mount Milligan - 100m - RAD - Equivalent Thorium
      - [ ] Mount Milligan - 100m - RAD - Equivalent Uranium
      - [ ] Mount Milligan - 100m - RAD - eTh-K - éTh-K
      - [ ] Mount Milligan - 100m - RAD - eU-eTh - éU-éTh
      - [ ] Mount Milligan - 100m - RAD - eU-K - éU-K

Download Manager

1:557,716 | Annotations



Gridded data:
Oasis Montaj® GRD files

Open-licensed data
from NRCAN

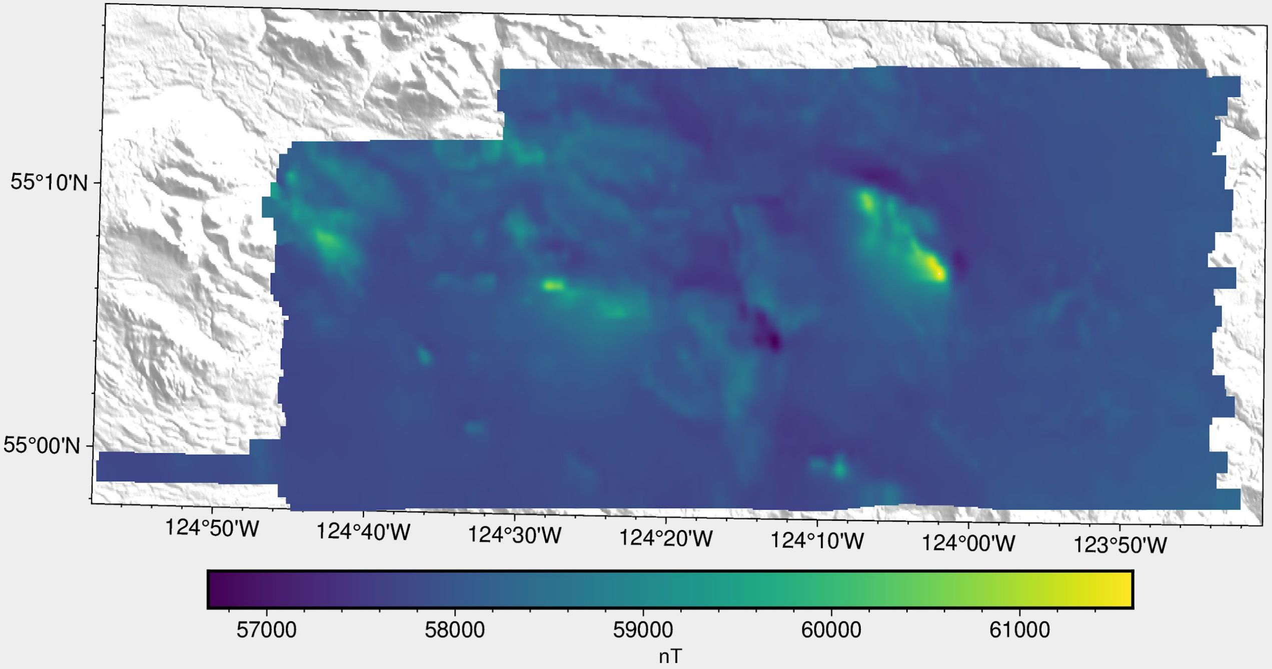
Reading GRD files in Python

```python
import harmonica as hm

grid = hm.load_oasis_montaj_grid("Mount_Milligan_MTF.GRD")
```

Harmonica

Reading GRD files in Python

Total magnetic field data

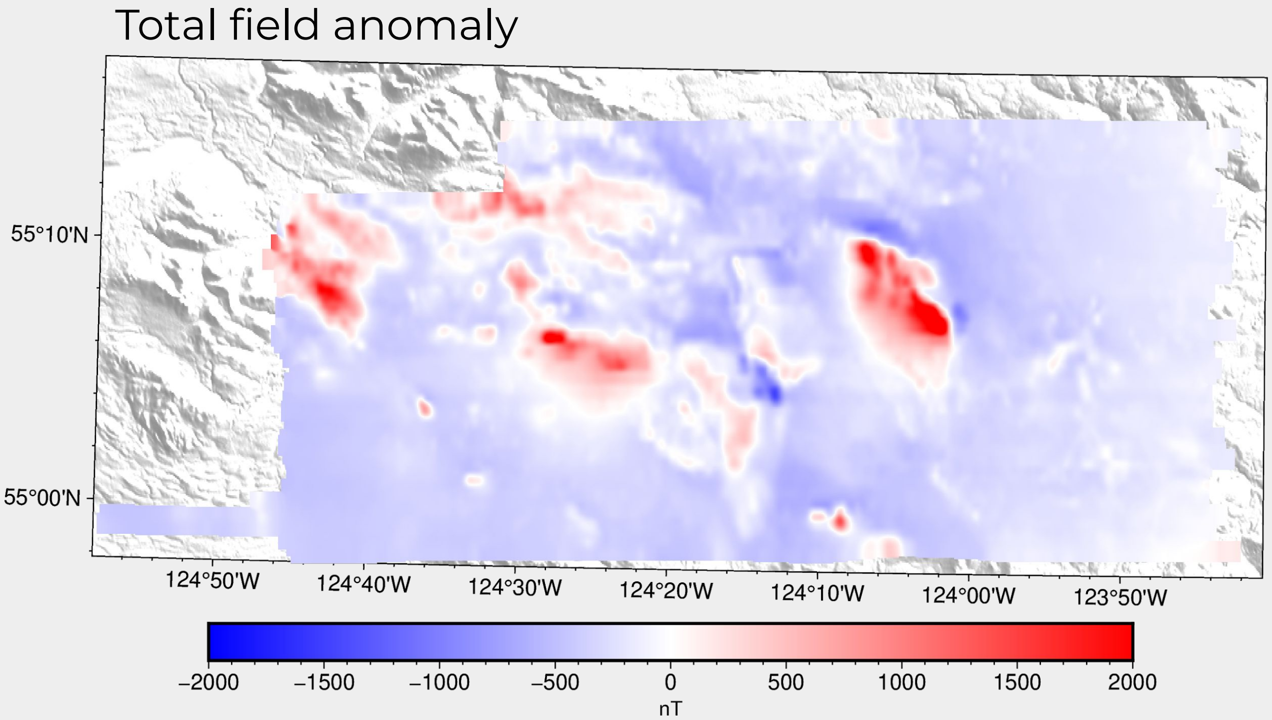


Total field anomaly

```python
import ppigrf
from datetime import datetime

date = datetime(year=1991, month=9, day=14)
height_km = 0.120

igrf = ppigrf.igrf(
    longitude, latitude, height_km, date
)
igrf = np.sqrt(igrf[0]**2 + igrf[1]**2 + igrf[2]**2)

tf_anomaly = grid - igrf
```

klaundal/ppigrf (compute International Geomagnetic Reference Field)

Total field anomaly



Who uses Fatiando a Terra tools?

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The integrated history of repeated caldera formation and infill at the Okataina Volcanic Centre: Insights from 3D gravity and magnetic models

Craig A. Miller [a], Jenny Barretto [b], Vaughan Stagpoole [b], Fabio Caratori-Tontini [c], Thomas Brakenrig [a], Edward Bertrand [b]

Classifying basin-scale stratigraphic geometries from subsurface formation tops with machine learning

Jesse R. Pisel, Michael J. Pyrcz

First published: 03 November 2020 | https://doi.org/10.1002/dep2.129 | Citations: 1

Lithospheric Control on Asthenospheric Flow From the Iceland Plume: 3-D Density Modeling of the Jan Mayen-East Greenland Region, NE Atlantic

Pingchuan Tan, Judith Sippel, Asbjørn Johan Breivik, Christian Meeßen, Magdalena Scheck-Wenderoth

Research Article | Open Access

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L. S. Zampa, E. Lodolo, N. Creati, M. Busetti, G. Madrussani, E. Forlin, A. Camerlenghi

Fast nonlinear gravity inversion in spherical coordinates with application to the South American Moho

Leonardo Uieda, Valéria C.F. Barbosa

Geophysical Journal International, Volume 208, Issue 1, January 2017, Pages

Multiple, Coeval Silicic Magma Storage Domains Beneath the Laguna Del Maule Volcanic Field Inferred From Gravity Investigations

Sarah F. Trevino, Craig A. Miller, Basil Tikoff, Dominique Fournier, Brad S. Singer

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Use of the "shape-of-anomaly" data misfit in 3D inversion by planting anomalous densities

Authors:

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C. Meeßen, J. Sippel, M. Scheck-Wenderoth, C. Heine, M. R. Strecker

Gradient-boosted equivalent sources

Santiago R Soler, Leonardo Uieda

Geophysical Journal International, Volume 227, Issue 3, December 2021, Pages

Fast nonlinear gravity inversion in spherical coordinates with application to the South American Moho

Leonardo Uieda, Valéria C.F. Barbosa

Geophysical Journal International, Volume 208, Issue 1, January 2017, Pages

Gravitational field calculation in spherical coordinates using variable densities in depth

Santiago R Soler, Agustina Pesce, Mario E Gimenez, Leonardo Uieda

Geophysical Journal International, Volume 218, Issue 3, September 2019, Pages

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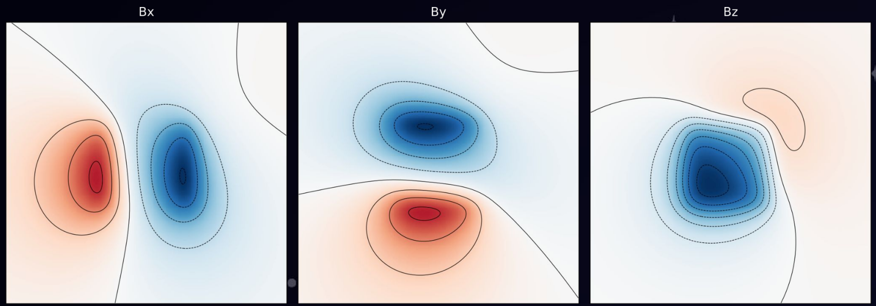
Quantitative uncertainty analysis of gravity disturbance. The case of the Geneva Basin (Switzerland)

Lorenzo Perozzi, Luca Guglielmetti, Andrea Moscariello

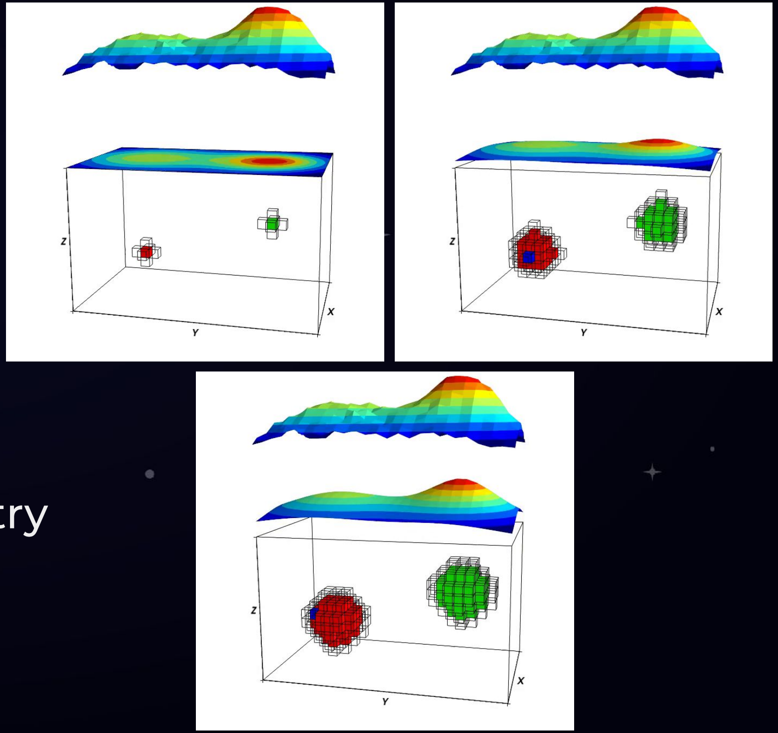
Future roadmaps

Current and future developments

Efficient magnetic forwards



Planting inversions



Complete gravity data processing workflow

Non-linear geometry inversions

Extended FFT grid filters

Collaborations with other OSS communities

Joint BIRS Workshop (July 2023)

Banff International
Research Station

Enhancing our tools

Speed up SimPEG forward
models with Choclo

Who makes Fatiando possible?

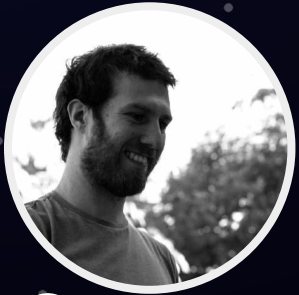
Steering Council


aguspesce


leouieda


LL-Geo


MGomezN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Thank you