Santiago Soler

Geophysical Inversion Facility
Earth, Ocean and Atmospheric Sciences
University of British Columbia

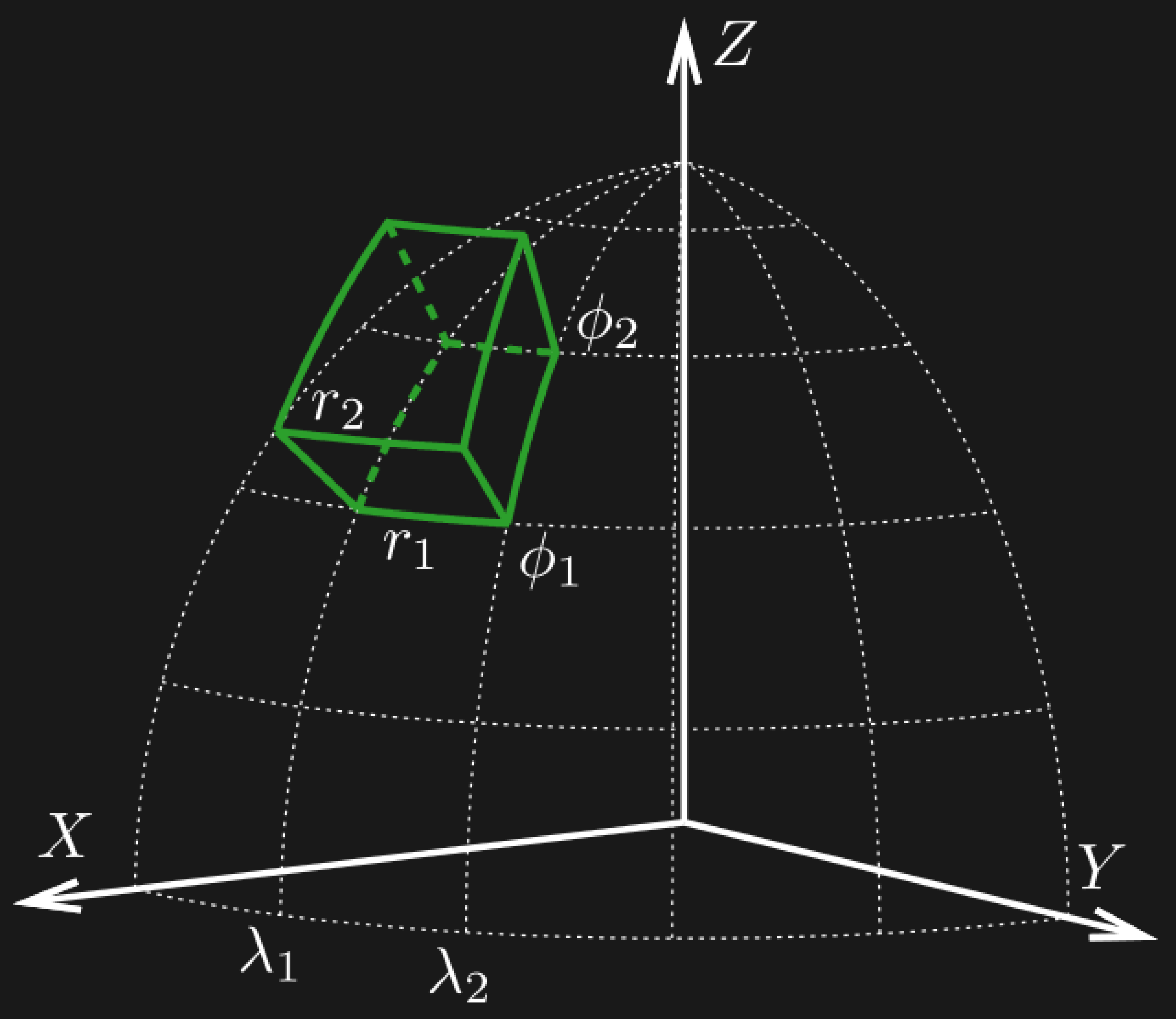
Background

- Licenciate in Physics (UNR, Argentina)
- PhD in Geophysics (CONICET & UNSJ, Argentina)
- Postdoc Researcher at UBC
- Former member of the Computer-Oriented Geoscience Lab
- Core developer of Fatiando a Terra

Past research

Gravitational fields in spherical coordinates

Tesseroids



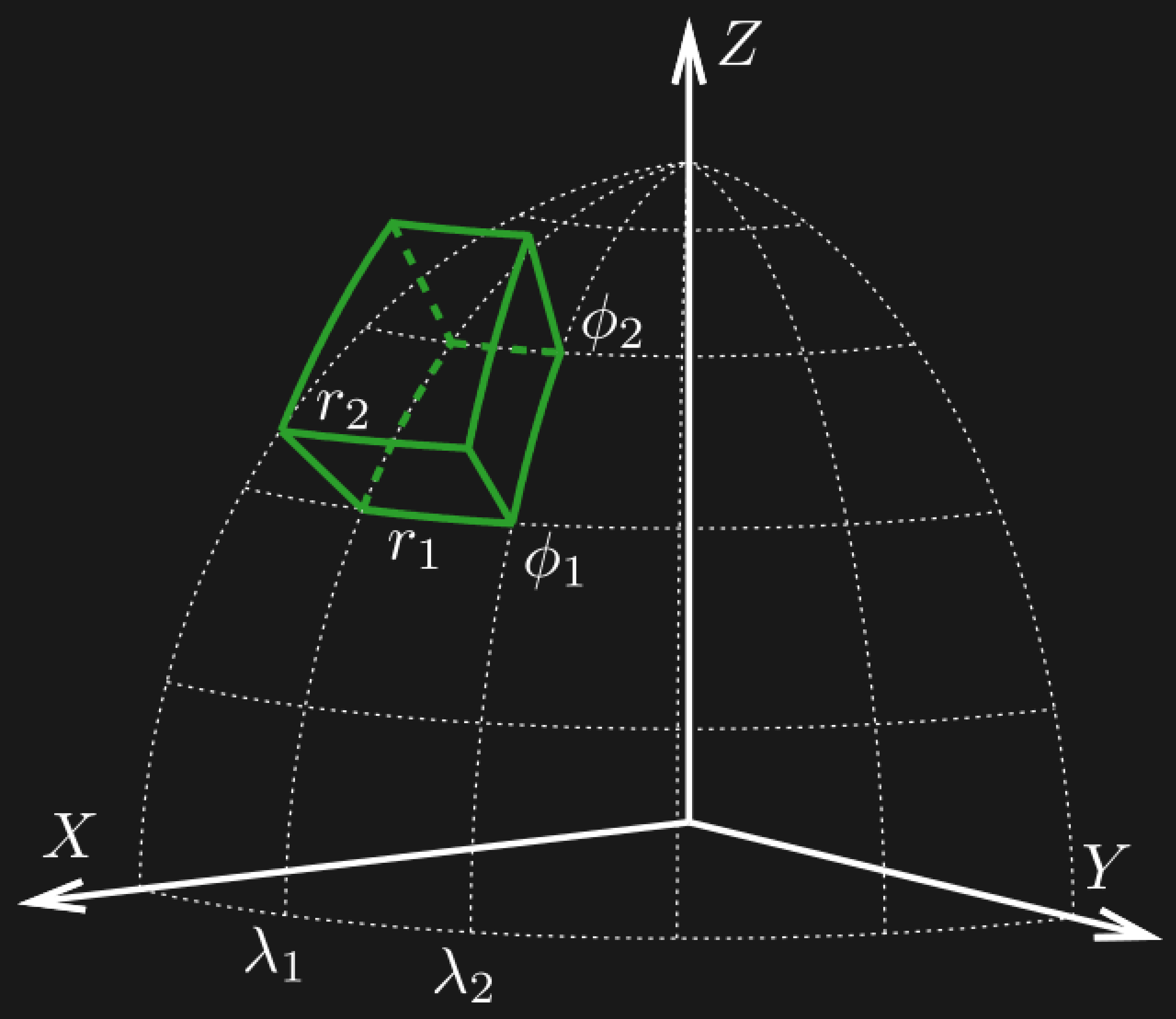
a.k.a. spherical prisms

Tesseroids' gravitational fields:

$$V(\mathbf{p}) = G\rho \iiint_V \frac{\kappa}{\|\mathbf{p} - \mathbf{q}\|} \mathrm{d}r' \mathrm{d}\lambda' \mathrm{d}\phi'$$

no analytical solution

Tesseroids



a.k.a. spherical prisms

Solution:

Numerical approximations

$$V(\mathbf{p}) \cong G\rho A \sum_{i=1}^{N_r} \sum_{j=1}^{N_\lambda} \sum_{k=1}^{N_\phi} W_{ijk} \frac{\kappa_{ik}}{\|\mathbf{p} - \mathbf{q}_{ijk}\|}$$

Constant density tesseroids

$$V(\mathbf{p}) = G\rho \iiint_V \frac{\kappa}{\|\mathbf{p} - \mathbf{q}\|} \mathrm{d}r' \mathrm{d}\lambda' \mathrm{d}\phi'$$

Variable density tesseroids

$$V(\mathbf{p}) = G \iiint_V \rho(r') \frac{\kappa}{\|\mathbf{p} - \mathbf{q}\|} \mathrm{d}r' \mathrm{d}\lambda' \mathrm{d}\phi'$$

Developed new method

- **Gravitational fields** of **variable density tesseroids**
- **Density**: continuous **function of depth**
- Open-source **Python** implementation

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- **Gravitational fields** of **variable density tesseroids**
- **Density**: continuous **function of depth**
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```python
from numba import njit
import harmonica as hm

@njit
def linear_density(radius):
    origin, slope = ...
    return slope * radius  + origin

gravity = hm.tesseroid_gravity(
    coordinates, tesseroids, linear_density, field="g_z"
)
```

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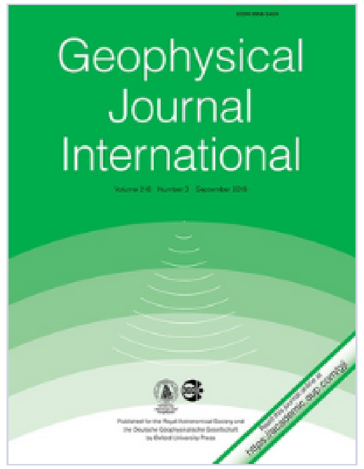

Volume 218, Issue 3

September 2019

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Gravitational field calculation in spherical coordinates using variable densities in depth

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

Geophysical Journal International, Volume 218, Issue 3, September 2019, Pages 2150–2164, https://doi.org/10.1093/gji/ggz277

Published: 11 June 2019 **Article history** ▾

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SUMMARY

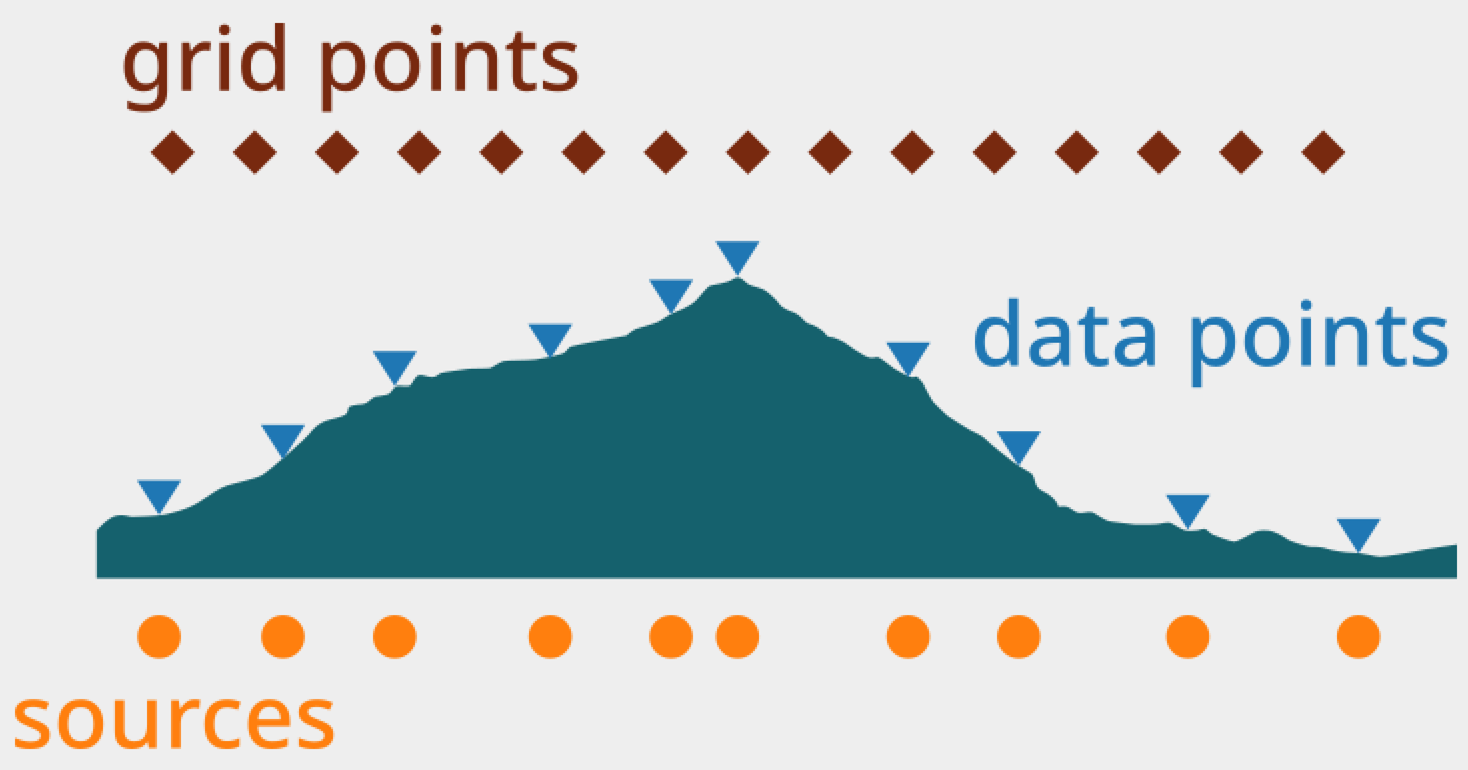
We present a new methodology to compute the gravitational fields generated by tesseroids

Soler et al. (2019). doi: 10.1093/gji/ggz277

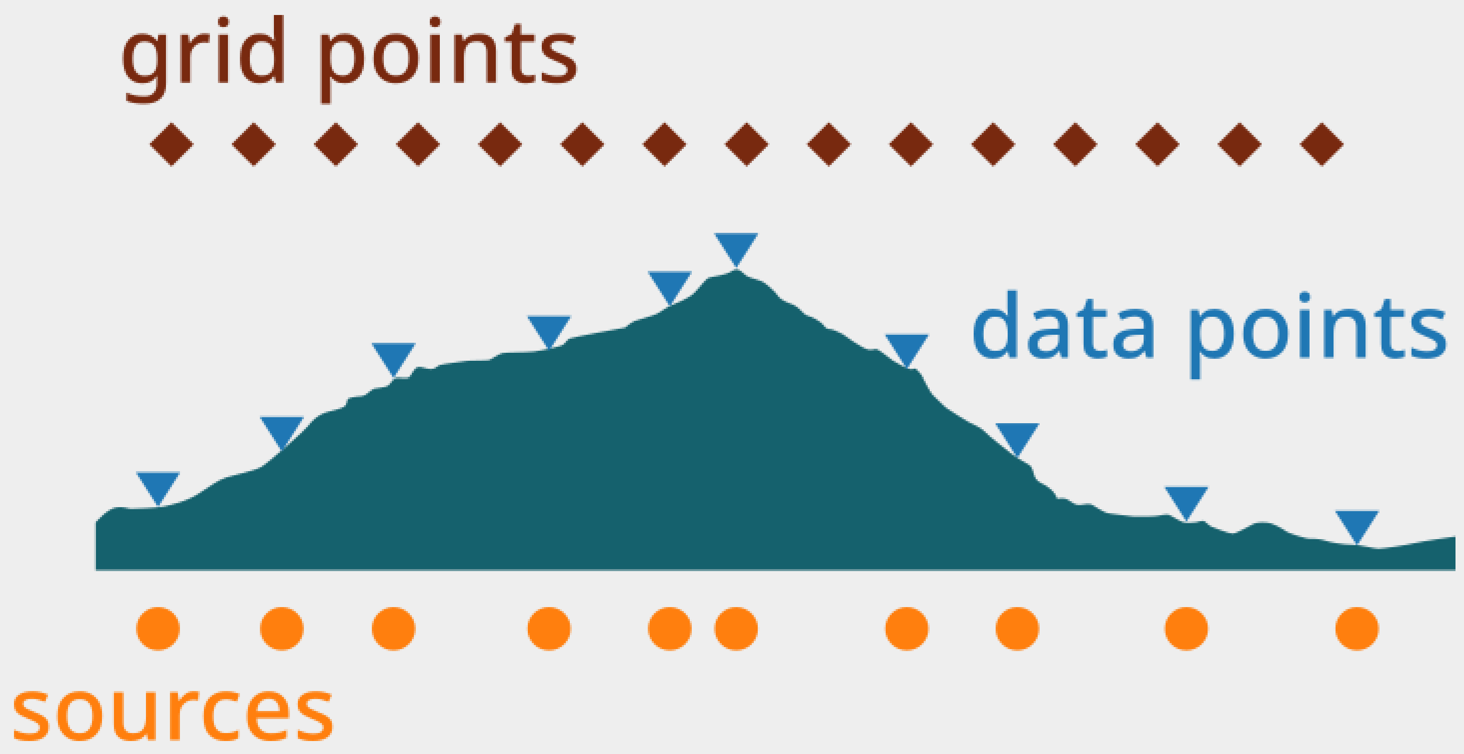
Preprint: 10.31223/osf.io/3548g

Gradient-boosted equivalent sources

Equivalent sources



Equivalent sources



- Always produce **harmonic fields**
- Consider the **observation heights**

THE PROBLEM

Require too much computational load

- 200.000 data points
- + 200.000 equivalent sources
- = **~300GB RAM**

THE SOLUTION

Gradient-boosted equivalent sources

- Interpolate **very large datasets**
- Significant **reduction** in required **memory**
- Open-source **Python** implementation

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import verde as vd
import harmonica as hm

eqs = hm.EquivalentSourcesGB(
    depth=depth, damping=damping, window_size=window_size
)
eqs.fit(coordinates, data)

grid_coords = vd.grid_coordinates(
    region, spacing, extra_coords=height
)
grid = eqs.grid(grid_coords)
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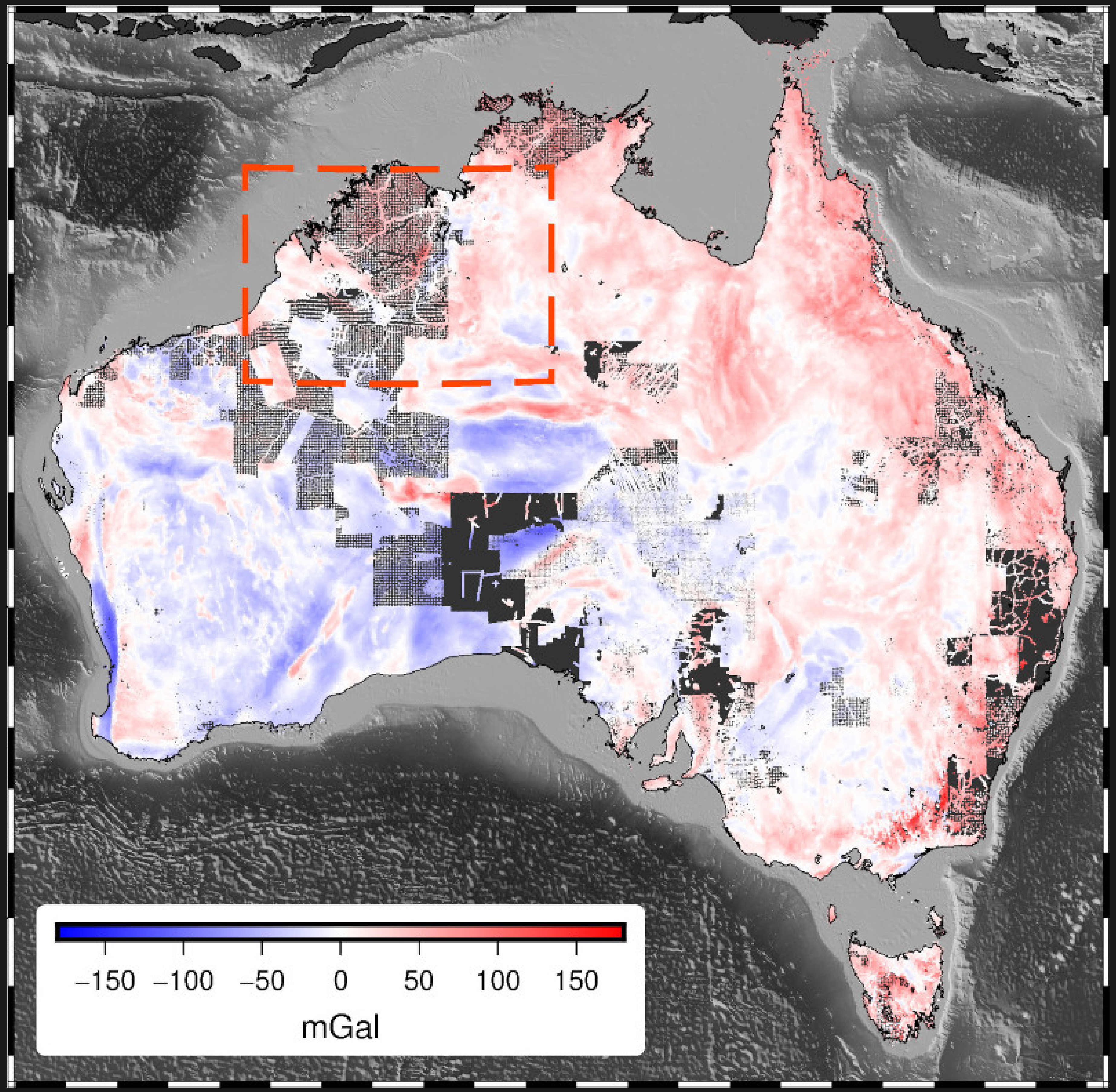
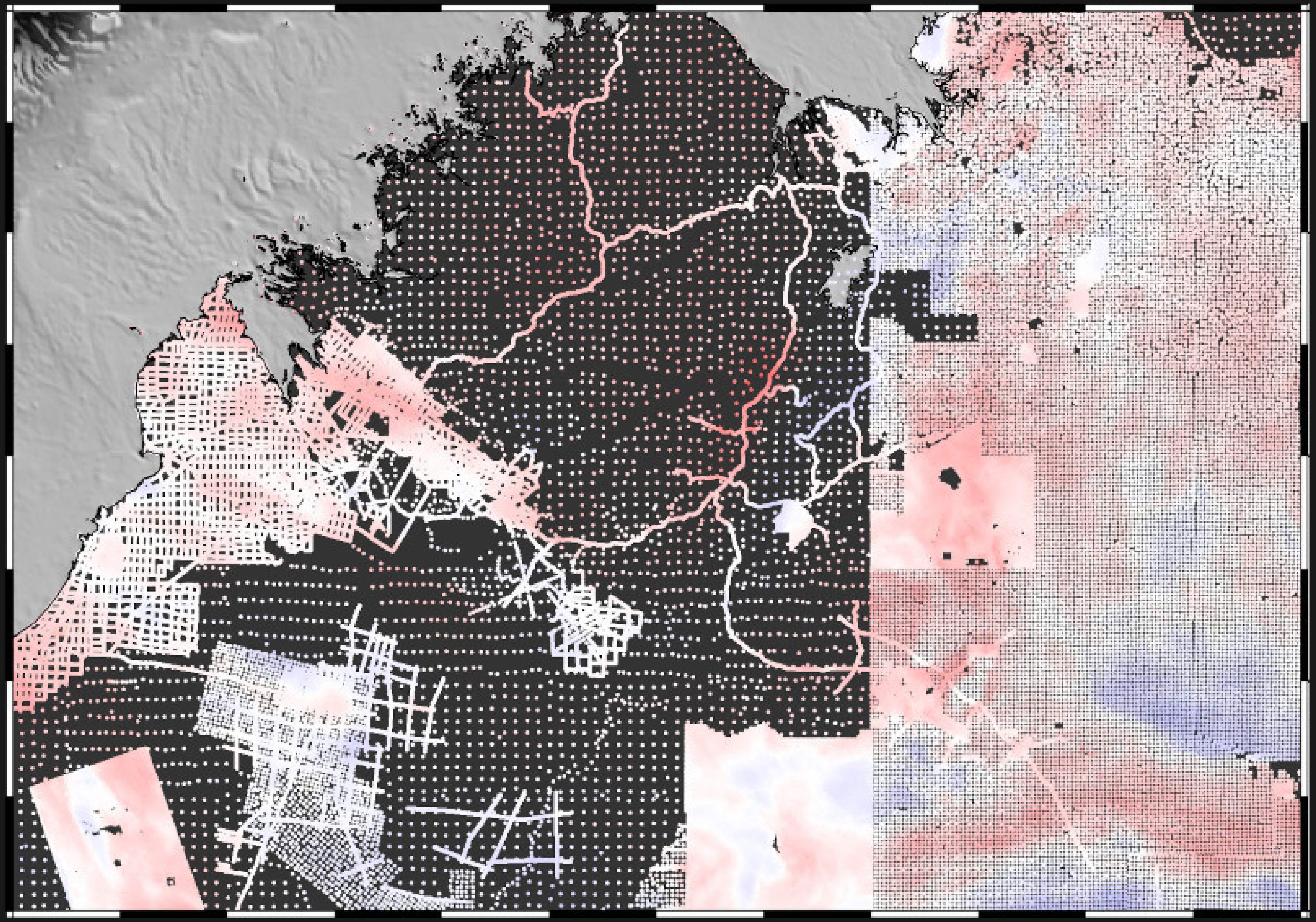
Gridding +1.7 million gravity data points





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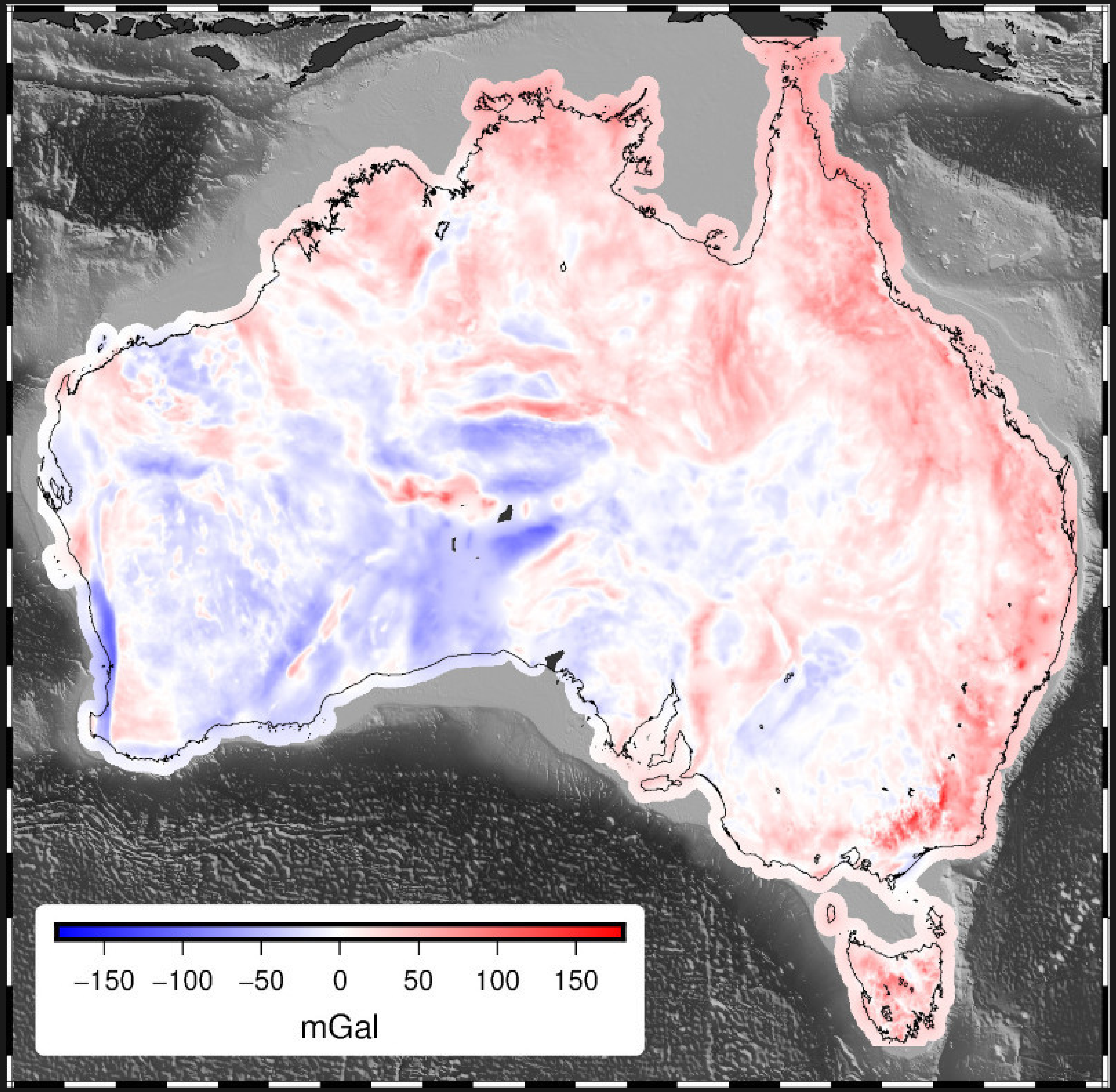

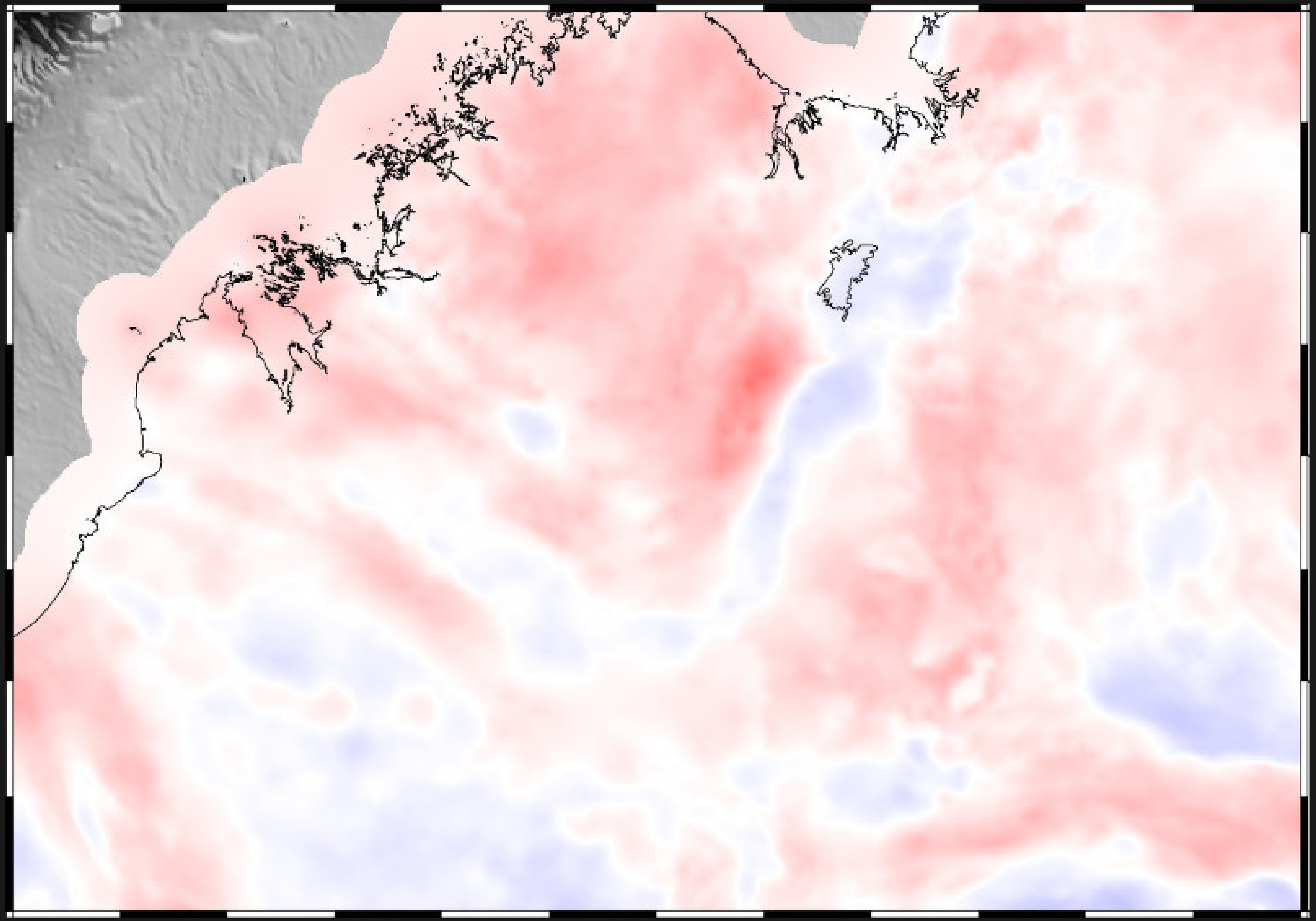

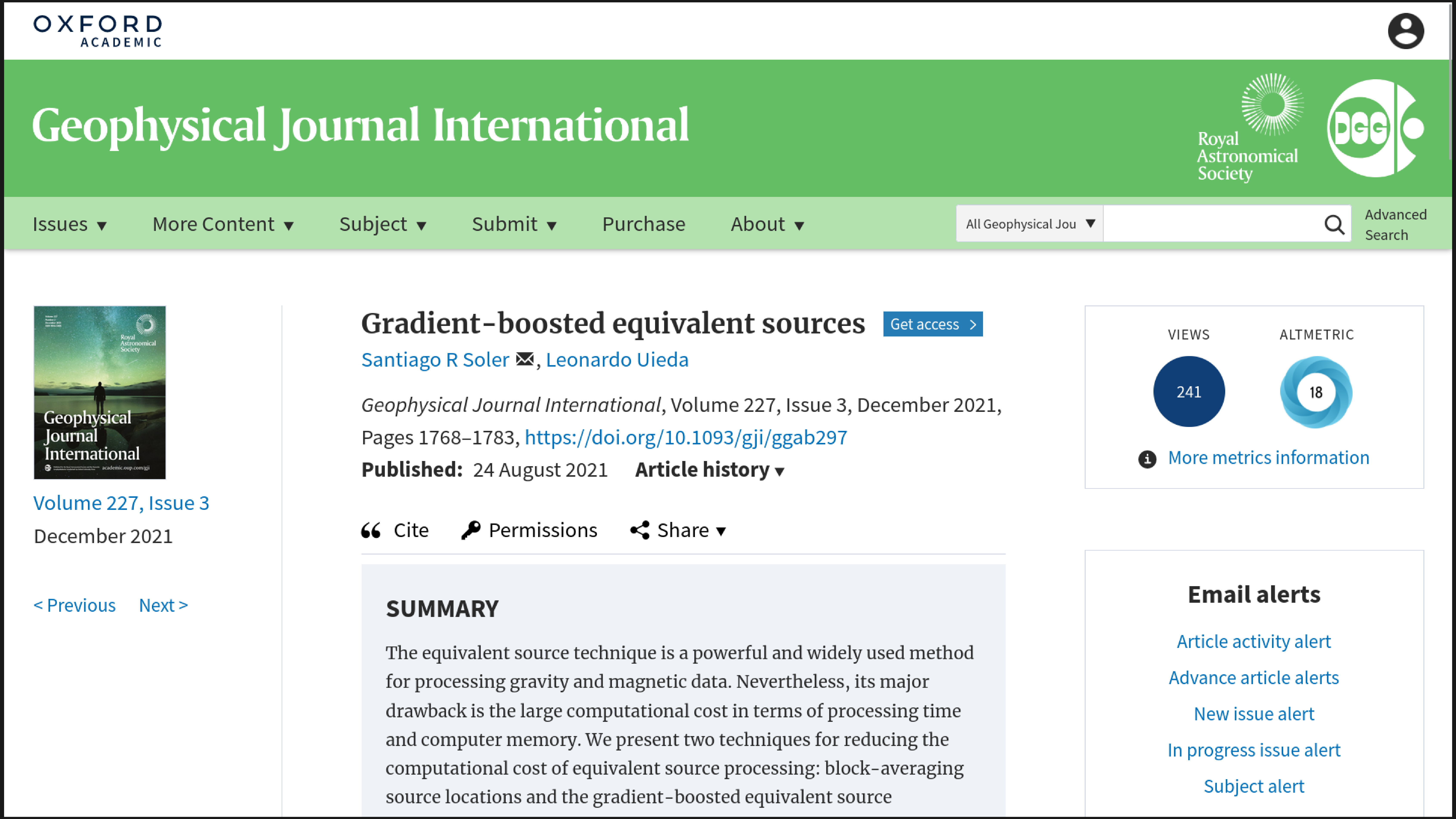
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Volume 227, Issue 3
December 2021

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Gradient-boosted equivalent sources

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Santiago R Soler ✉, Leonardo Uieda

Geophysical Journal International, Volume 227, Issue 3, December 2021, Pages 1768–1783, https://doi.org/10.1093/gji/ggab297

Published: 24 August 2021 **Article history** ▾

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SUMMARY

The equivalent source technique is a powerful and widely used method for processing gravity and magnetic data. Nevertheless, its major drawback is the large computational cost in terms of processing time and computer memory. We present two techniques for reducing the computational cost of equivalent source processing: block-averaging source locations and the gradient-boosted equivalent source

Soler and Uieda (2021). doi: 10.1093/gji/ggab297
Preprint: 10.31223/X58G7C

Open-source software development

Fatiando a Terra

An open toolbox for the Geosciences

Fatiando provides **Python libraries** for data processing, modeling, and inversion across the Geosciences.

It is built by a **community** of geoscientists and software developers with a passion for well-designed tools and helping our peers.

All of our code is **free and open-source**, distributed under the permissive BSD 3-clause license.

Get started with Fatiando

www.fatiando.org

The libraries

Verde

Spatial data processing and **interpolation** with a **Machine Learning** flavour

fatiando.org/verde

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Verde

Spatial data processing and **interpolation** with a **Machine Learning** flavour

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Boule

Reference ellipsoids and **normal gravity** calculations

fatiando.org/boule

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Verde

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Harmonica

Processing and **modelling potential fields** data

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Pooch

A friend to **download** and **cache** your data

fatiando.org/pooch

fatiando/pooch

Who we are

Leonardo Uieda

Santiago Soler

Who is using Fatiando?

Journal of Applied Geophysics
Volume 193, October 2021, 104431

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

Lorenzo Perozzi, Luca Guglielmetti, Andrea Moscariello

Geophysical Journal International Advance Access published October 17, 2016

Fast non-linear gravity inversion in spherical coordinates with application to the South American Moho

Leonardo Uieda[1,2], Valéria C. F. Barbosa[2]
[1]Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil. e-mail: leouieda@gmail.com
[2]Observatório Nacional, Rio de Janeiro, Brazil.

doi:10.5194/egusphere-egu2020-15729

Evaluating the accuracy of equivalent-source predictions using cross-validation

Leonardo Uieda[1] and Santiago Soler[2]
[1] Department of Earth, Ocean and Ecological Sciences, SOES, University of Liverpool, UK
[2] CONICET, Argentina | Instituto Geofísico Sismológico Volponi, Universidad Nacional de San Juan, Argentina

@leouieda EGU 2020 COMPUTER-ORIENTED GEOSCIENCE LAB

JGR Solid Earth
Research Article Free Access

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

First published: 18 September 2018 | https://doi.org/10.1029/2018JB015634 |
Citations: 3

arXiv > cs > arXiv:2202.08869
Computer Science > Information Retrieval
[Submitted on 17 Feb 2022]

A recommender system for automatic picking of subsurface formation tops

Jesse R. Pisel, Joshua A. Dierker, Sanya Srivastava, Samira B. Ravilisetty, Michael J. Pyrcz

Geoscience domain experts traditionally correlate formation tops in the subsurface using geophysical well logs (known as well-log correlation) by-hand. Based on individual well log interpretation and well-to-well comparisons, these correlations are done in the context of depositional models within a stratigraphic framework. Recently, many researchers have focused on automatic well-log correlation using a variety of warping algorithms that measure well similarity, and both unsupervised and supervised machine learning methods that assign categorical labels based on known tops in many other wells. These methods require a standardized suite of digital well logs (i.e. gamma ray logs for every well) along with the depth to the top of the formations, which might not be available in many cases. Herein, we propose a method that does not use geophysical well logs for correlation, but rather uses already picked tops in multiple wells to recommend the depth to

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

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Abstract

Presented here is a transfer-learning model for classifying basin-scale stratigraphic geometries from subsurface formation tops. Support vector, decision trees, random forests, AdaBoost and K-nearest neighbour classification models are evaluated to support this challenge. Each model is trained on labelled synthetic stratigraphic geometry data generated in Python using observable geological principles and concepts. Accuracy is measured using a weighted

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JOURNAL ARTICLE

Gradient-boosted equivalent sources

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Santiago R Soler, Leonardo Uieda

Geophysical Journal International, Volume 227, Issue 3, December 2021, Pages 1768–1783, https://doi.org/10.1093/gji/ggab297
Published: 24 August 2021 **Article history**

Pooch: A friend to fetch your data files

Leonardo Uieda[1], Santiago Rubén Soler[2,3], Rémi Rampin[4], Hugo van Kemenade[5], Matthew Turk[6], Daniel Shapero[7], Anderson Banihirwe[8], and John Leeman[9]

1 Department of Earth, Ocean and Ecological Sciences, School of Environmental Sciences, University of Liverpool, UK 2 Instituto Geofísico Sismológico Volponi, Universidad Nacional de San Juan, Argentina 3 CONICET, Argentina 4 New York University, USA 5 Independent (Non-affiliated) 6 University of Illinois at Urbana-Champaign, USA 7 Polar Science Center, University of Washington Applied Physics Lab, USA 8 The US National Center for Atmospheric Research, USA 9 Leeman Geophysical, USA

Summary

Scientific software is usually created to acquire, analyze, model, and visualize data. As such, many software libraries include sample datasets in their distributions for use in documentation,

Verde: Processing and gridding spatial data using Green's functions

Leonardo Uieda[1]

1 Department of Earth Sciences, SOEST, University of Hawai'i at Mānoa, Honolulu, Hawaii, USA

Summary

Measurements made on the surface of the Earth are often sparse and unevenly distributed. For example, GPS displacement measurements are limited by the availability of ground stations and airborne geophysical measurements are highly sampled along flight lines

EGU21-3101
https://doi.org/10.5194/egusphere-egu21-3101
EGU General Assembly 2021

A comparison between sea-bottom gravity and satellite altimeter-derived gravity in coastal environments: A case study of the Gulf of Manfredonia (SW Adriatic Sea)

Luigi Sante Zampa[1,2], Emanuele Lodolo[1], Nicola Creati[1], Martina Busetti[1], Gianni Madrussani[1], Edy Forlin[1], and Angelo Camerlenghi[1]
[1]National Institute of Oceanography and Applied Geophysics - OGS - Italy
[2]Department of Mathematics and Geosciences - University of Trieste - Italy

In this study, we present a comparative analysis between two types of gravity data used in geophysical applications: satellite altimeter-derived gravity and sea-bottom gravity.

It is largely known that the marine gravity field derived from satellite altimetry in coastal areas is generally biased by signals back-scattered from the nearby

JGR Solid Earth
Research Article Free Access

Crustal Structure of the Andean Foreland in Northern Argentina: Results From Data-Integrative Three-Dimensional Density Modeling

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

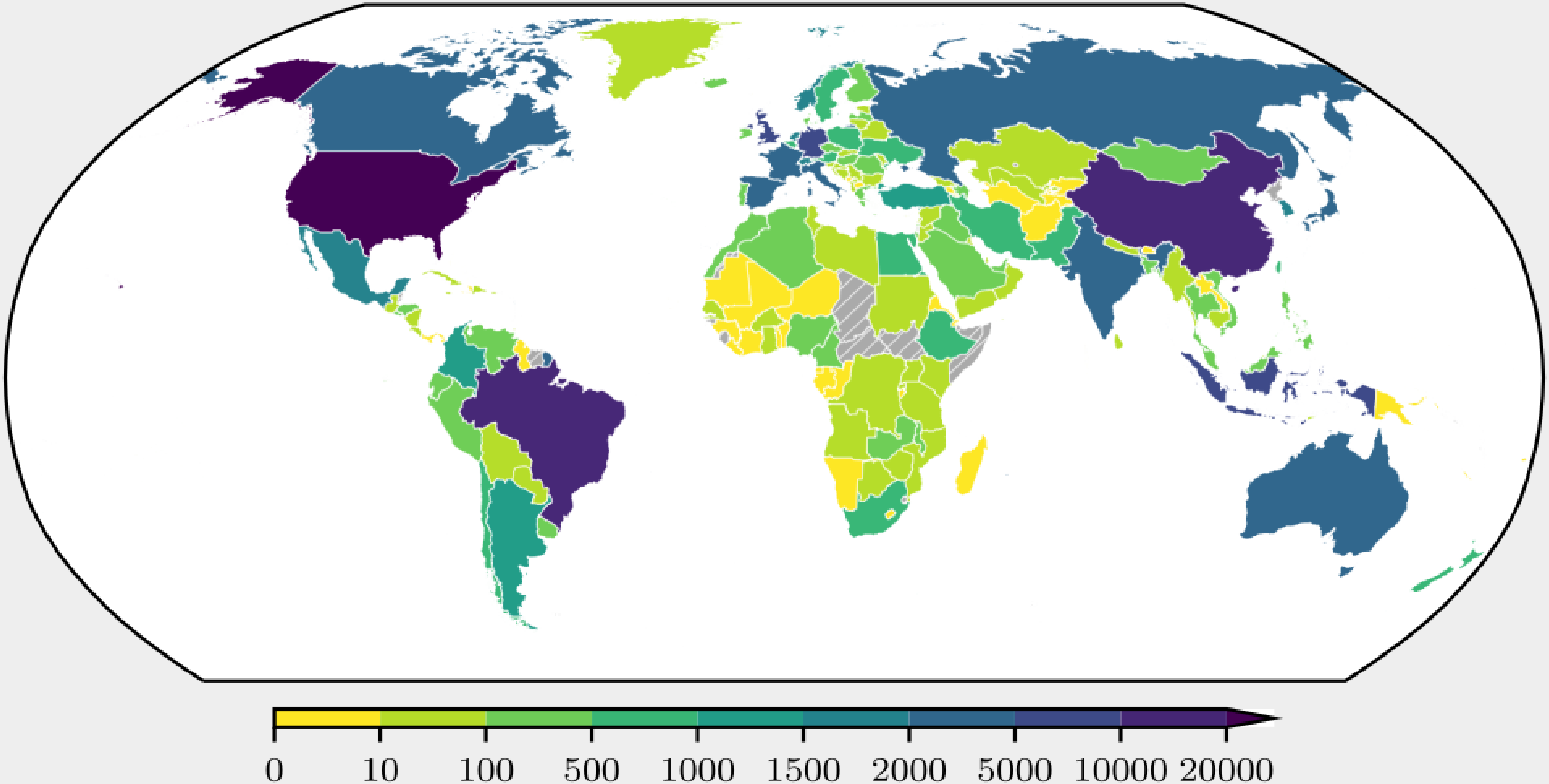
First published: 19 January 2018 | https://doi.org/10.1002/2017JB014296 |
Citations: 6

ELSEVIER
Journal of Volcanology and Geothermal Research
Volume 427, July 2022, 107555

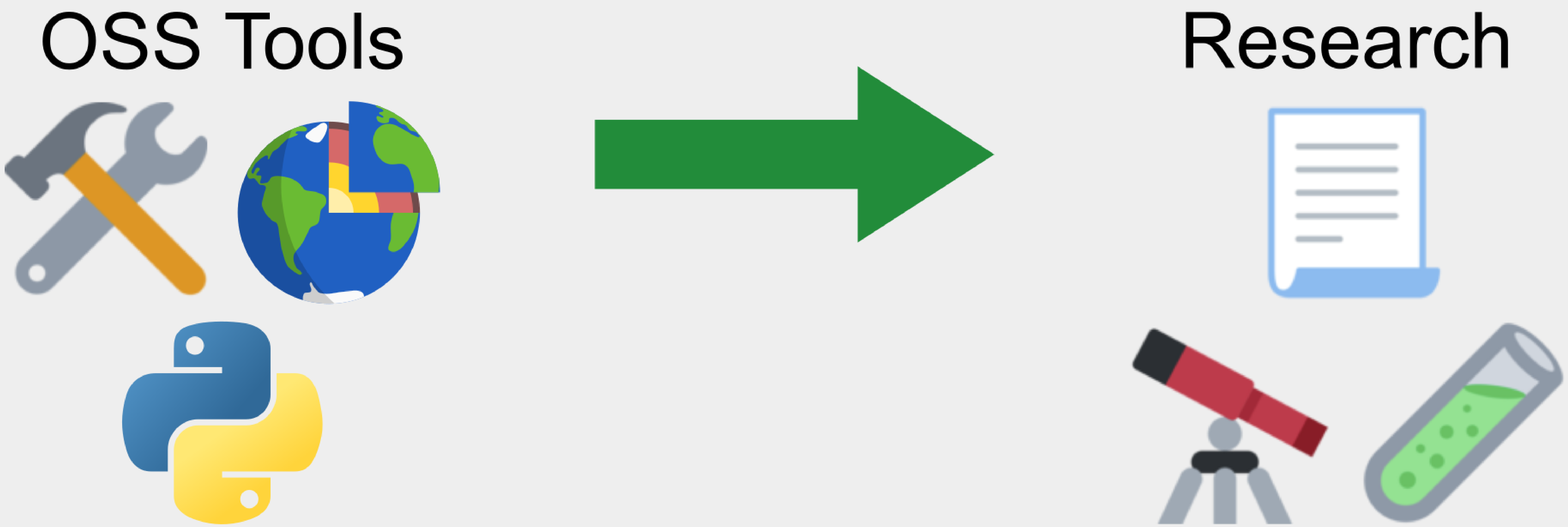
The integrated history of repeated caldera formation and infill at the Okataina Volcanic Centre: Insights from 3D gravity and magnetic models

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

Visits to fatiando.org (2017-04 - 2021-09)



Research and open-source software



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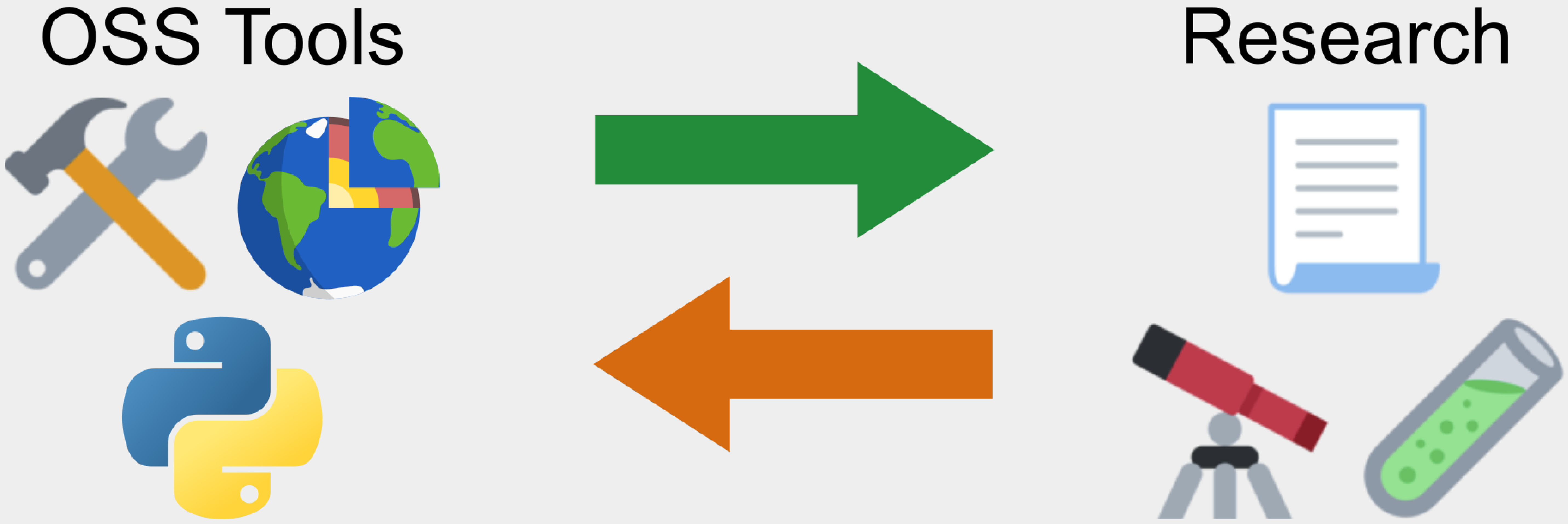
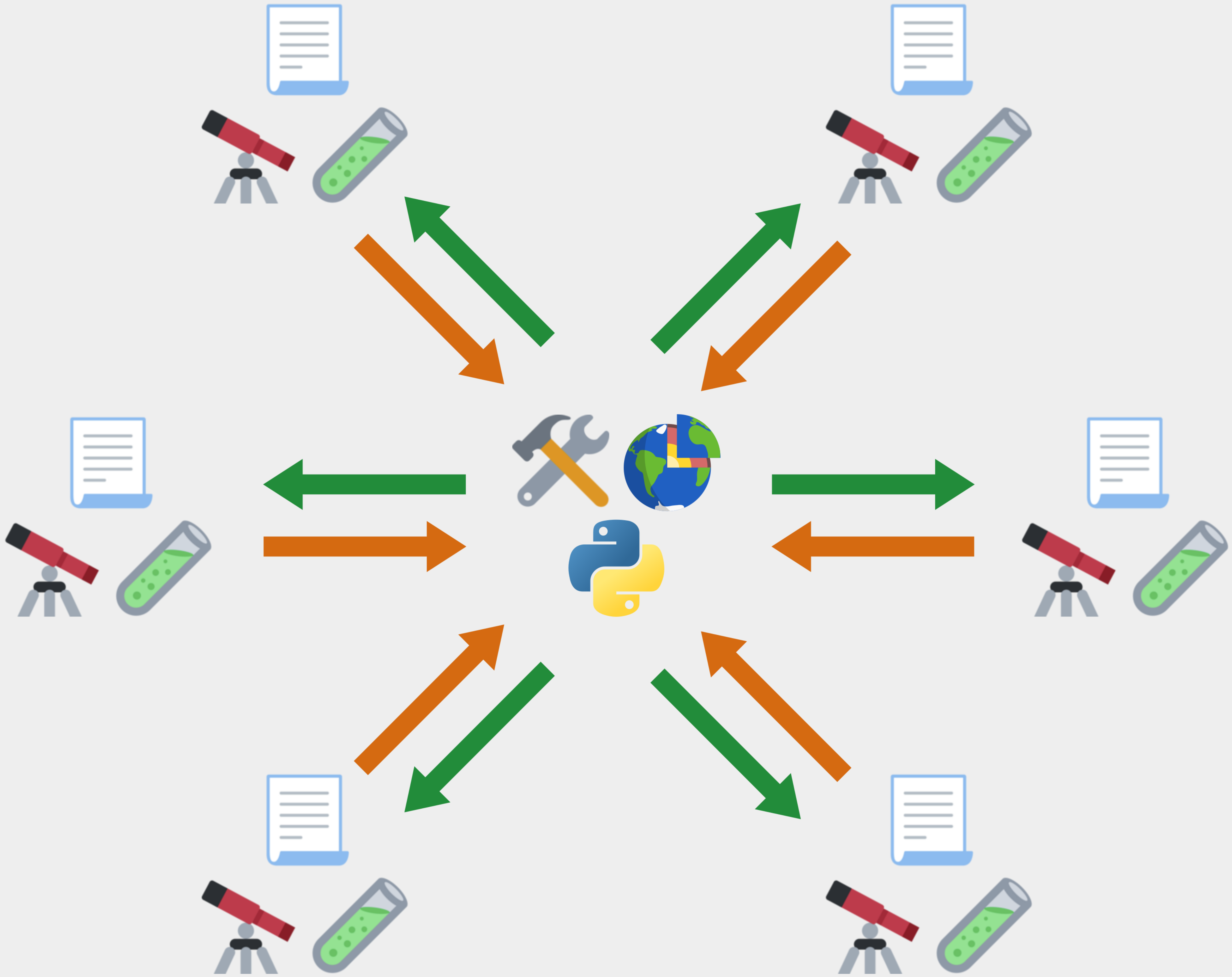
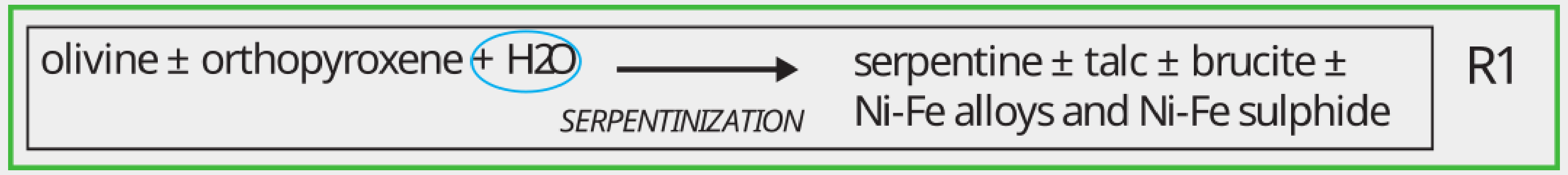




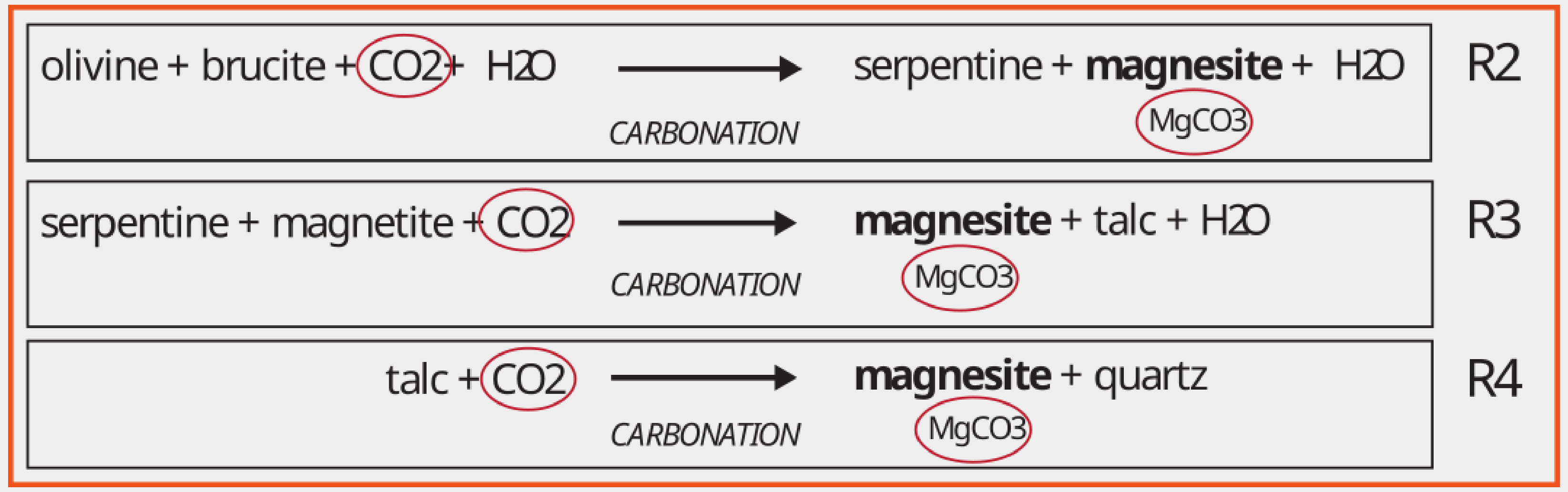
Current research

Carbon mineralization

Serpentinization



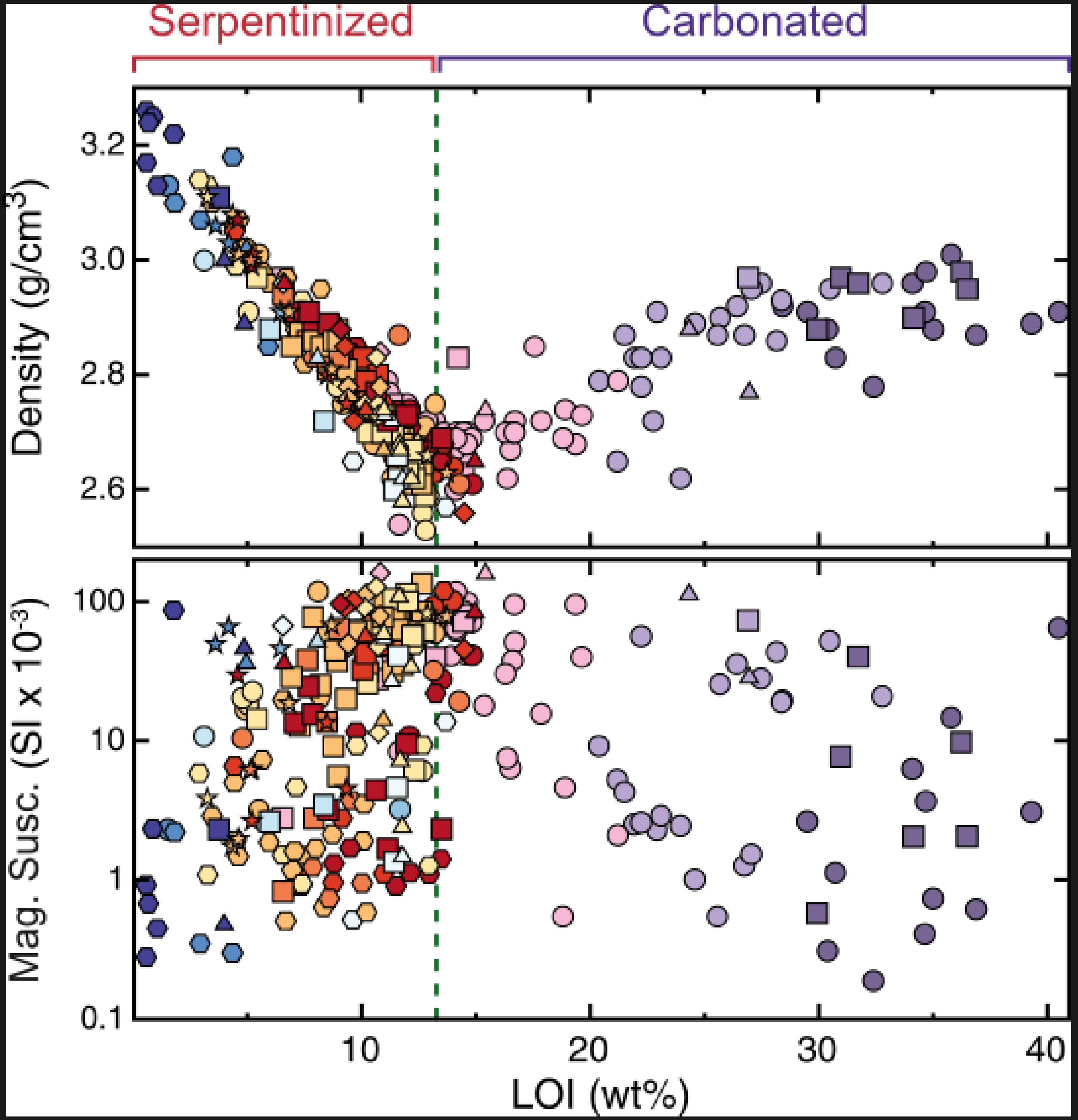
Carbonation



- **Serpentinized** rocks react with **CO_2**
- Mineralize in **carbonated** rocks
- **Carbon sequestration** with **ultramafic rocks**

Cutts et al. (2021). doi: 10.1029/2021GC009989
Mitchinson et al., (2020). ISBN: 978-0-88865-470-0

Physical properties



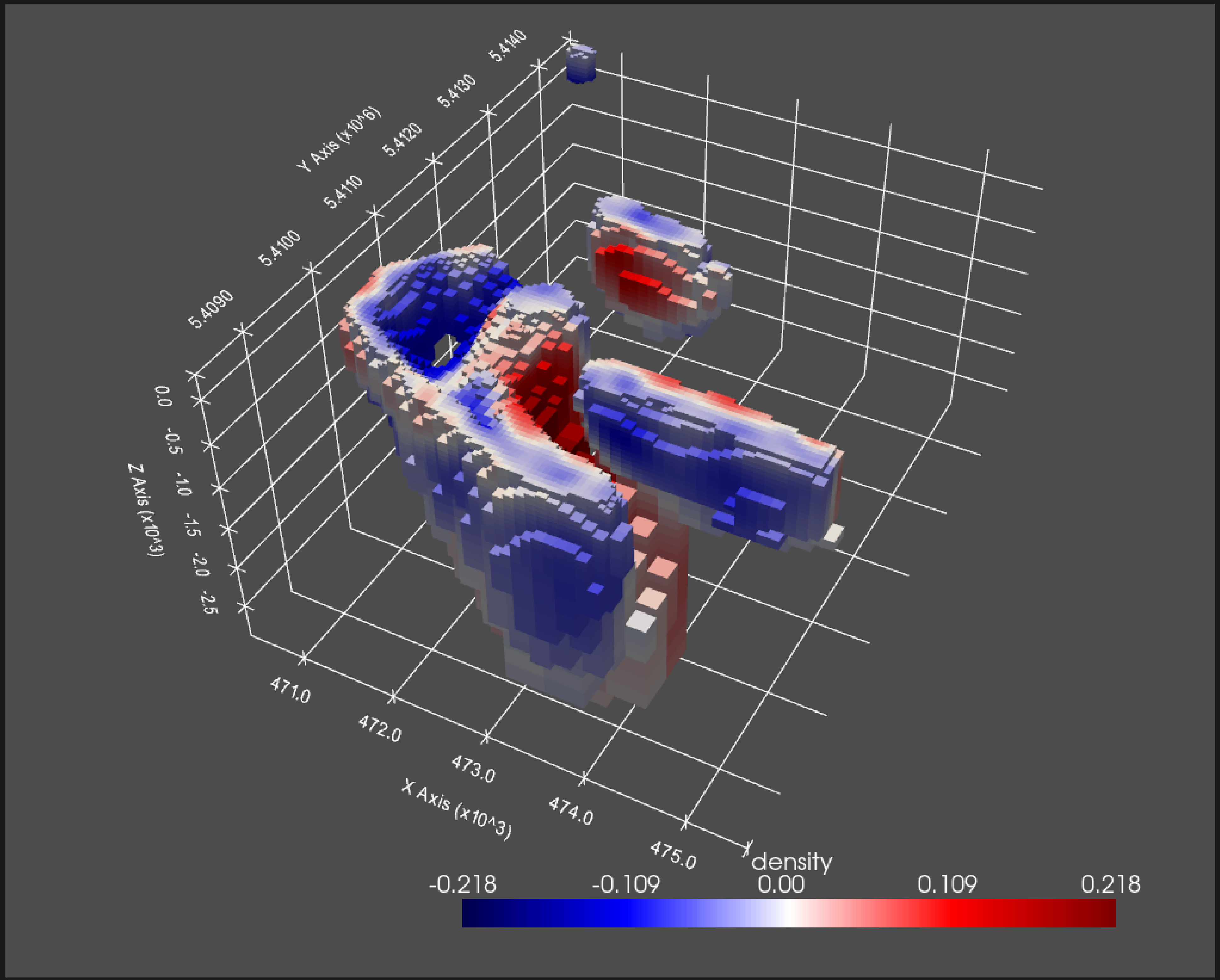
Density and susceptibility change with alteration

Research opportunity:

Geophysical inversion for assessing carbonation potential

Goals

- **Gravity** + **magnetic** data
- 3D joint **inversions**
- Characterize **volume** and **depth** of rocks with **carbonation potential**



Contact

ssoler@eoas.ubc.ca

www.santisoler.com

@santisoler

@santisoler@scicomm.xyz

Muchas gracias | Thank you

Slides: www.santisoler.com/2022-ubc-open-house