Case study:
Inversion and nullspace analysis in the Pyrenees

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Main sponsor for this work

Jeremie Giraud has received funding from the European Union's Horizon 2020 research and innovation programme[1] under the Marie Skłodowska-Curie grant agreement No. 101032994.

[1] for more info about project:
https://cordis.europa.eu/project/id/101032994

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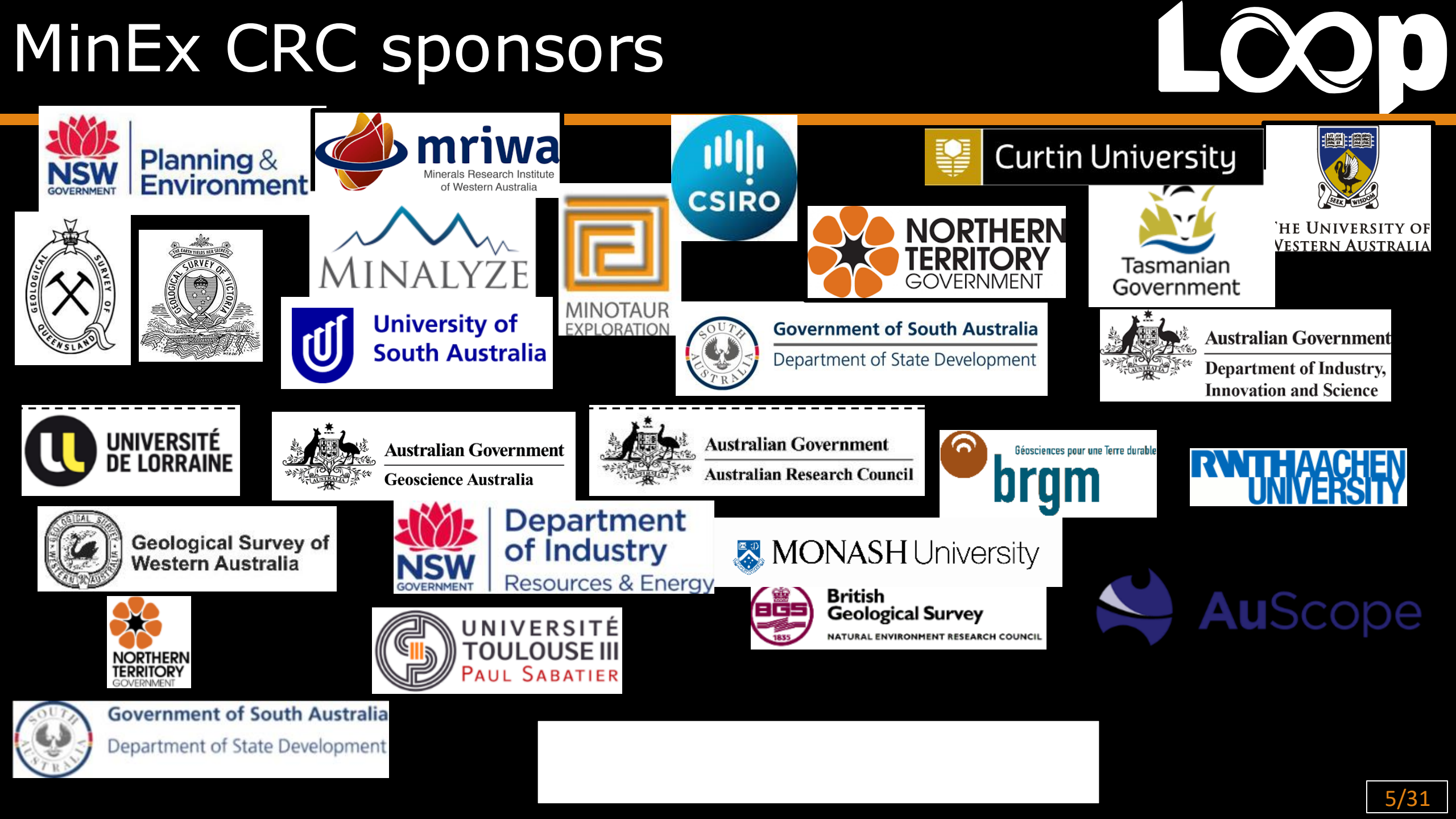
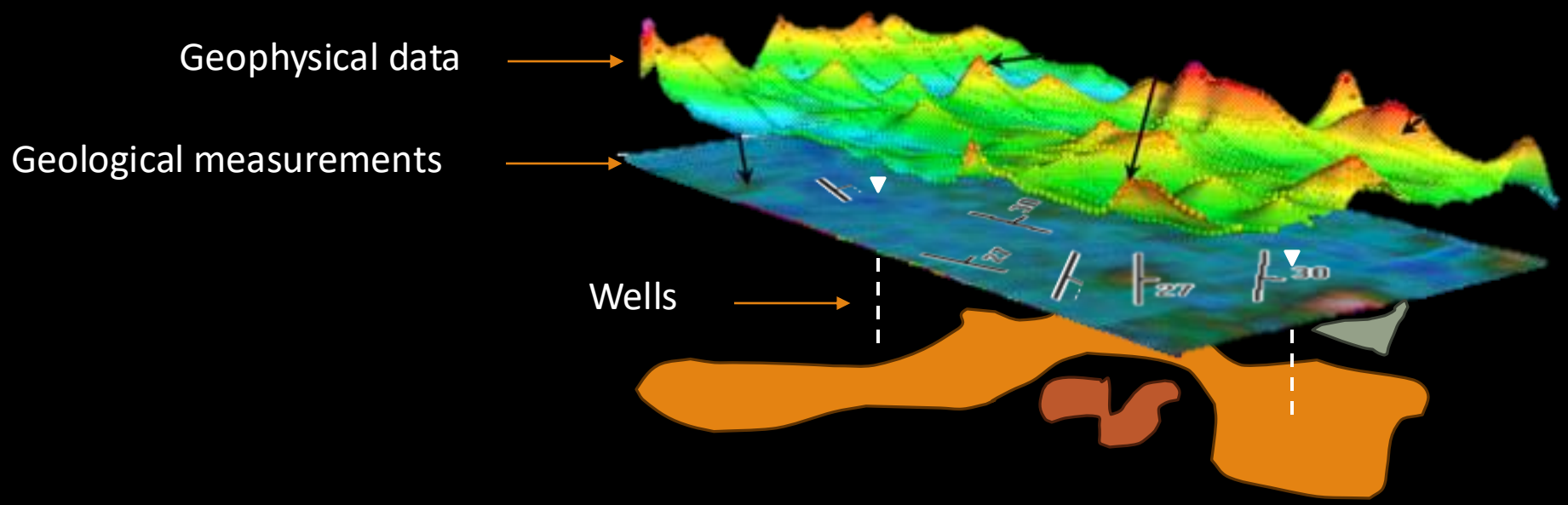


Motivation and Objectives



Exploration of alternative scenarios

Non-uniqueness: many models, same data!

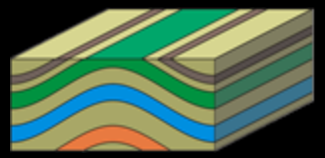
Overview

- Geological and geophysical context
  - Different scenarios investigated
- Geologically Constrained level-set inversion
- Nullspace analysis

Geometrical inversion

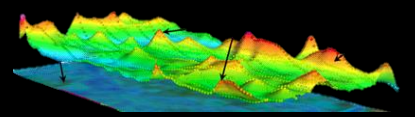
Geol.

Geological modelling
Direct observations
→ Modelling concepts valid everywhere



Geophysical (gravity) inversion
Indirect measurement of subsurface
→ Sensitivity to full study area, can image unseen geological features

Geophy



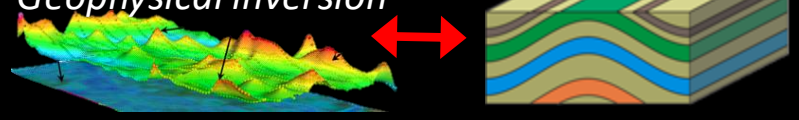
Petro

Populate structural model

Deform geological units using geophysical inversion <u>with geol. modelling component</u>[1]

Geological modelling

Geophysical inversion



[1]Giraud et al. 2022, 2023.

Inversion in a nutshell: cost functio

Iterative solver: at iteration *n…*

- Optimize implicit field $\boldsymbol{\phi}$, to reduce geophysical data misft
- Account for geological data $\boldsymbol{d}_{obs.}^{geol}$[1]

Geophysical data term

Geological model term

$$\min \quad \boldsymbol{W}_d^{-1} \left\| \boldsymbol{d}_{obs.}^{geophy} - \boldsymbol{d}_{calc.}^{geophy} \right\|_2^2 + \left\| \boldsymbol{W}_p^{-1} \left(\boldsymbol{\phi}^n - \boldsymbol{\phi}_{geol}^n \left(\boldsymbol{d}_{obs.}^{geol}, \boldsymbol{\phi}^{n-1} \right) \right) \right\|_2^2$$

Observations

Model response

Inverted. model

Geological projection (≈prior model)

[1]Giraud et al. 2022, 2023.

Example in the Pyrenees

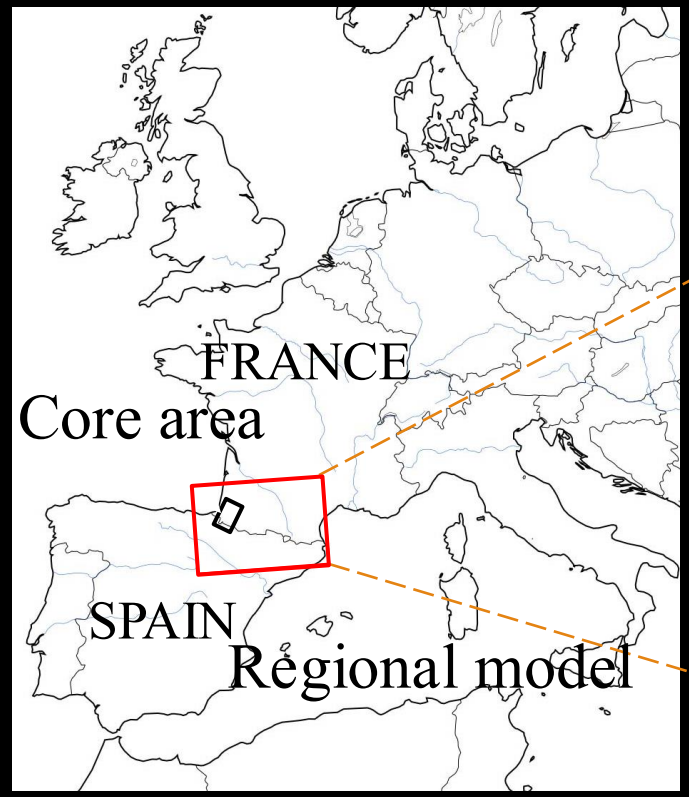
- Use of pre-existing regional geological model (PhD thesis of H. Wehr: Wehr 2017[1], Wehr et al. 2018[2])
- Comprehensive compilation of data
  - Seismic
  - Geological maps
  - Boreholes
  - Gravity
  - Previous interpretations

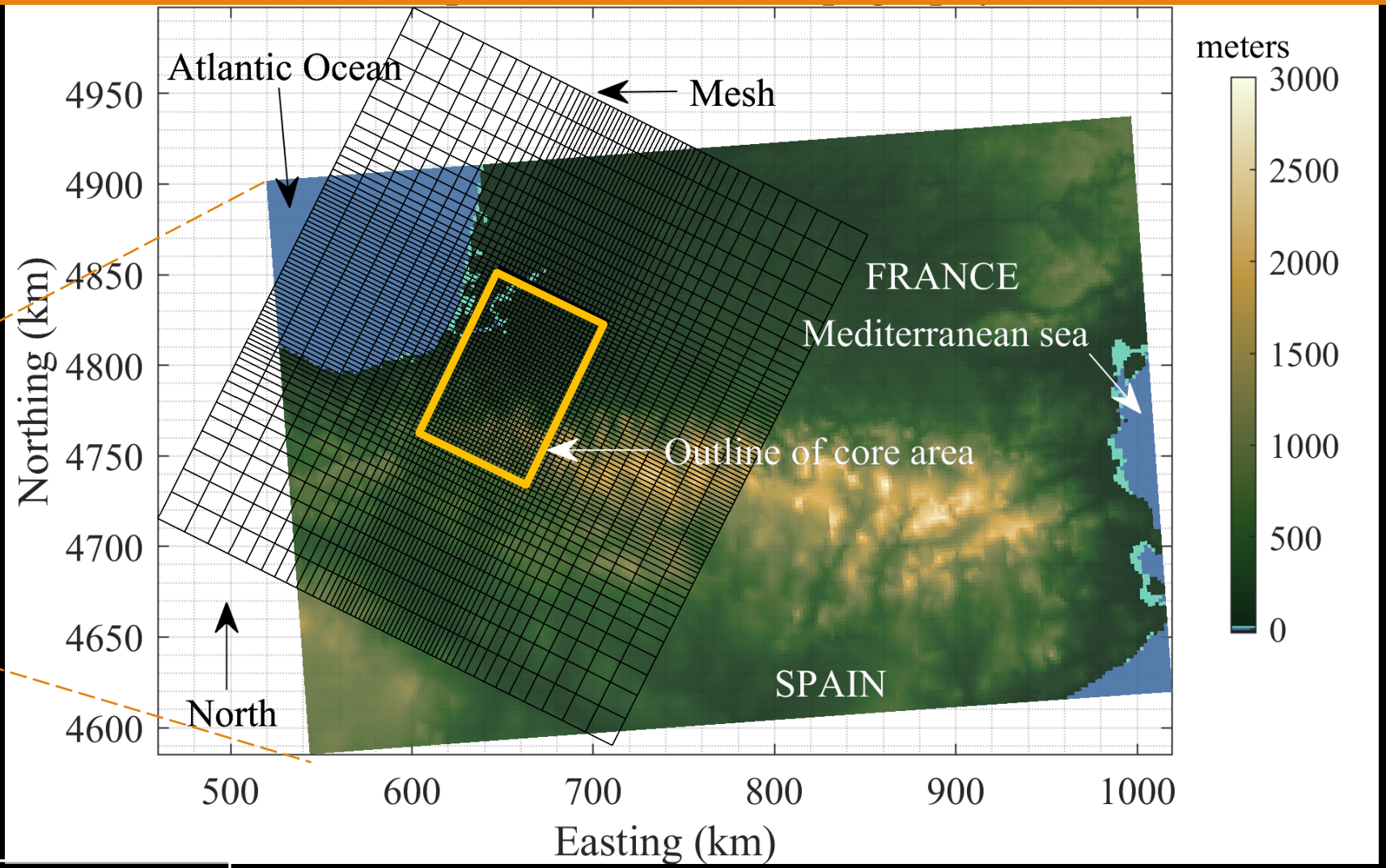
Q1: Can we improve gravity data misfit?

Q2: Are there other plausible scenarios?

[1] Wehr, 2017, PhD thesis [2] Wehr et al. 2018, Tectonophysics

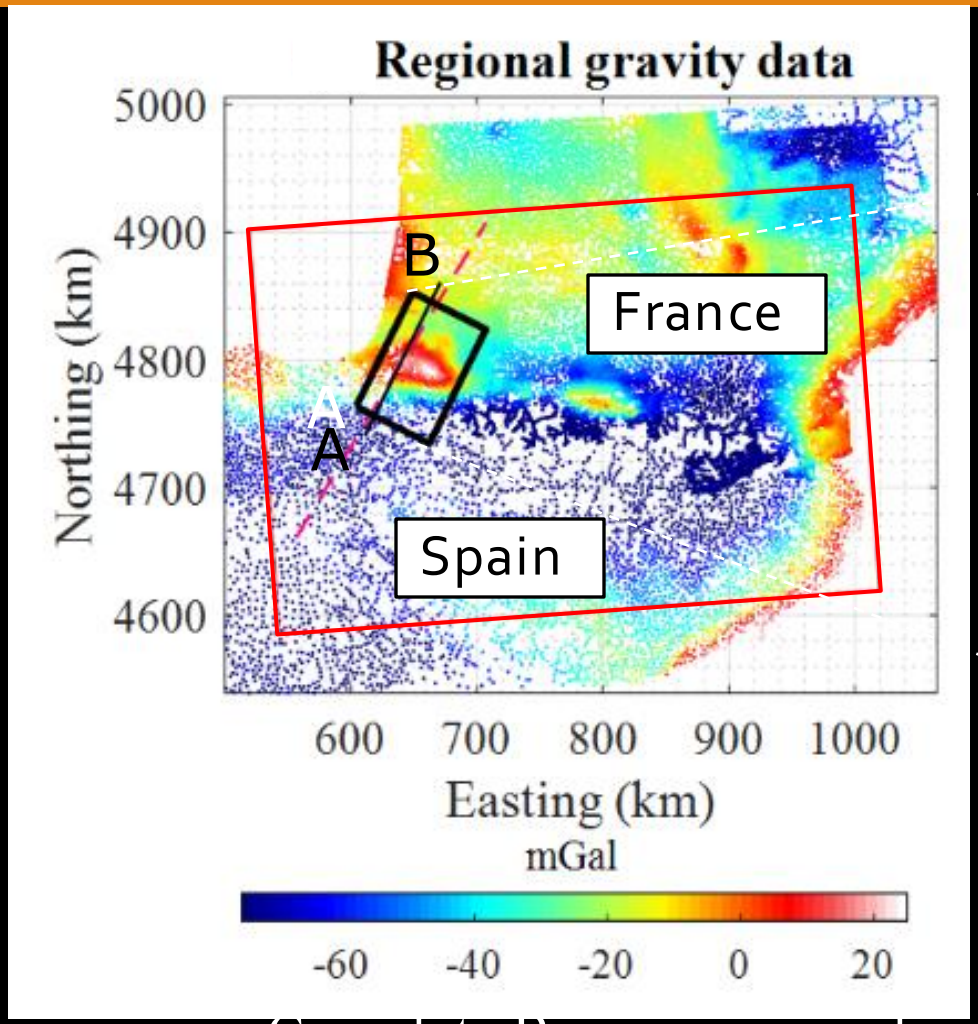
Example in the Pyrenees: generalities





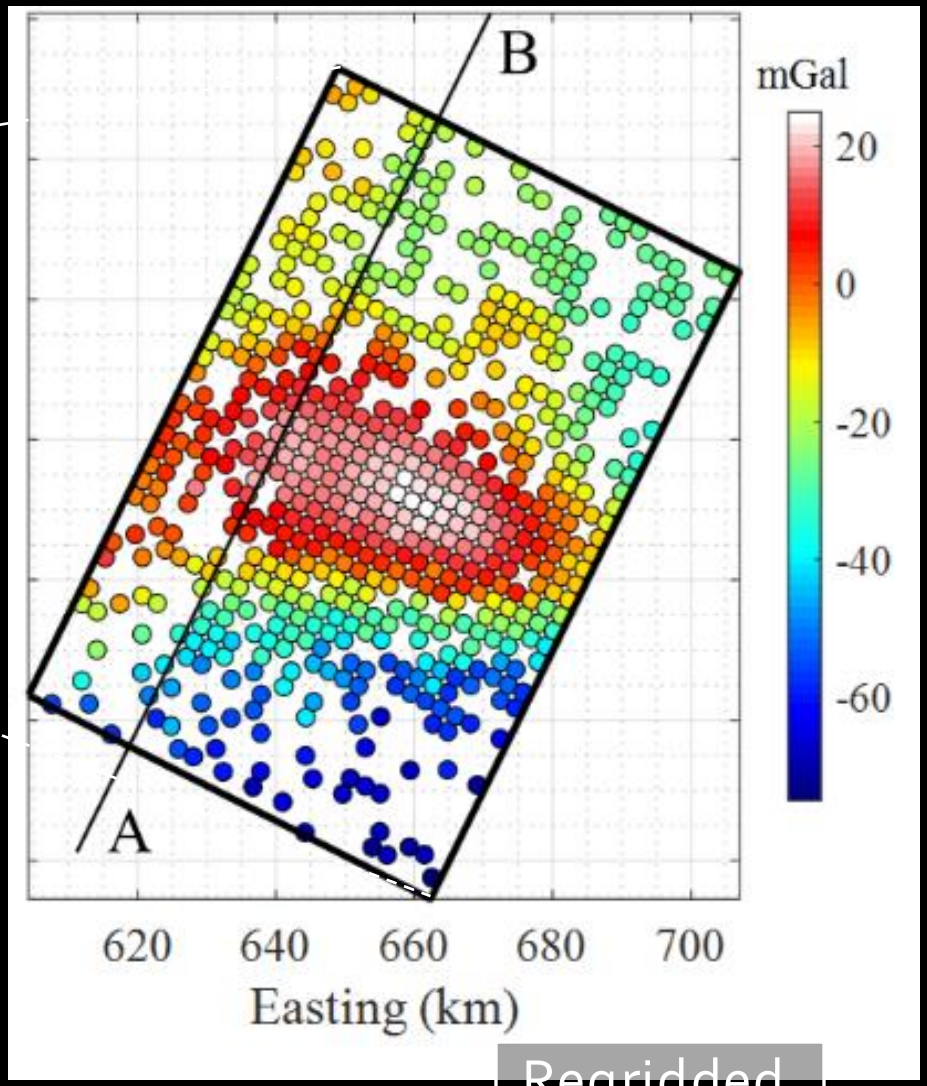
Area of interest: complex, H2 potential

Example in the Pyrenees: gravity data



Complete Bouguer anomaly

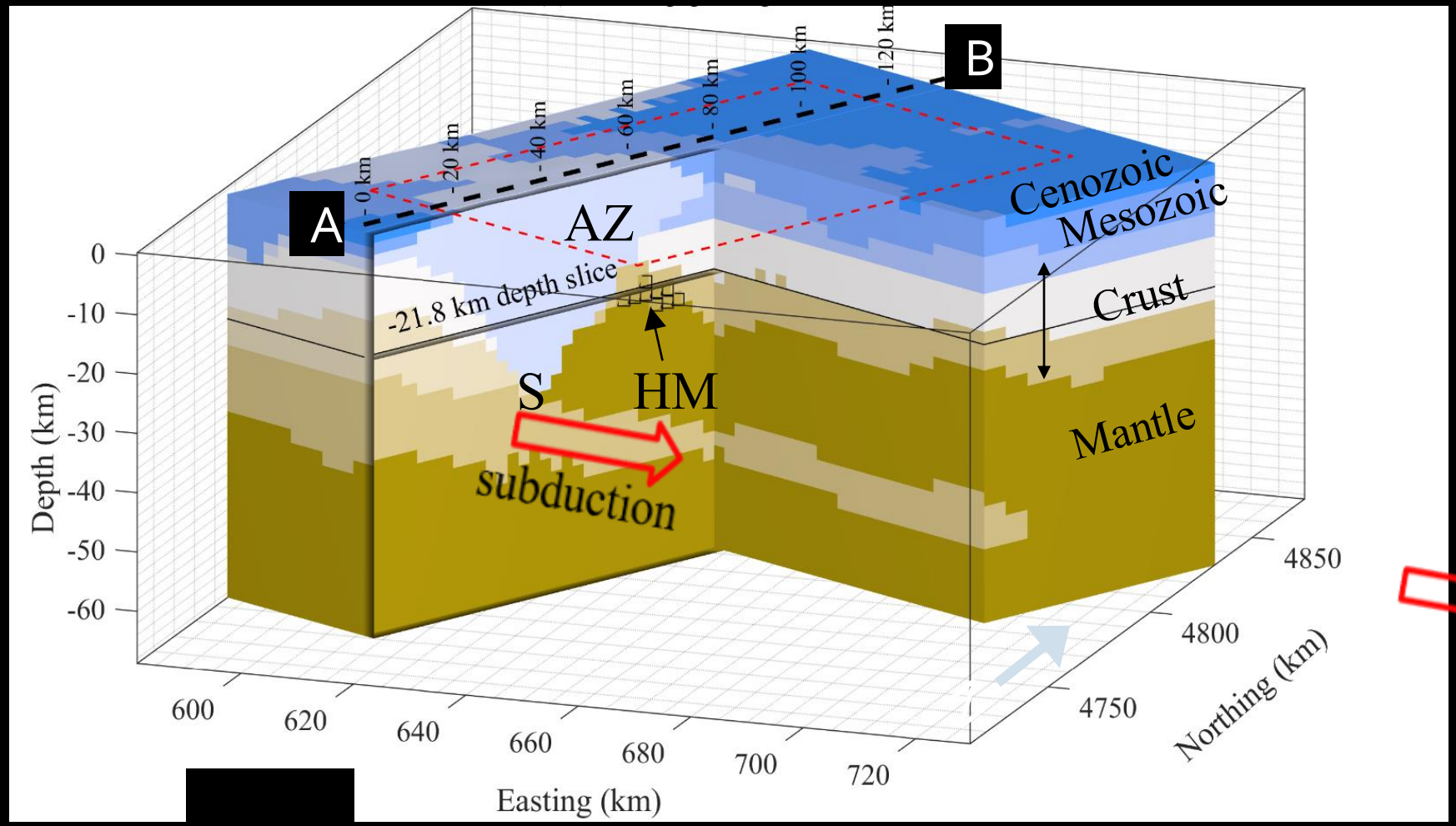
Inverted data



Regridded

Example in the Pyrenees: geological model

Original model



S: Singularity
(beginning of subduction)

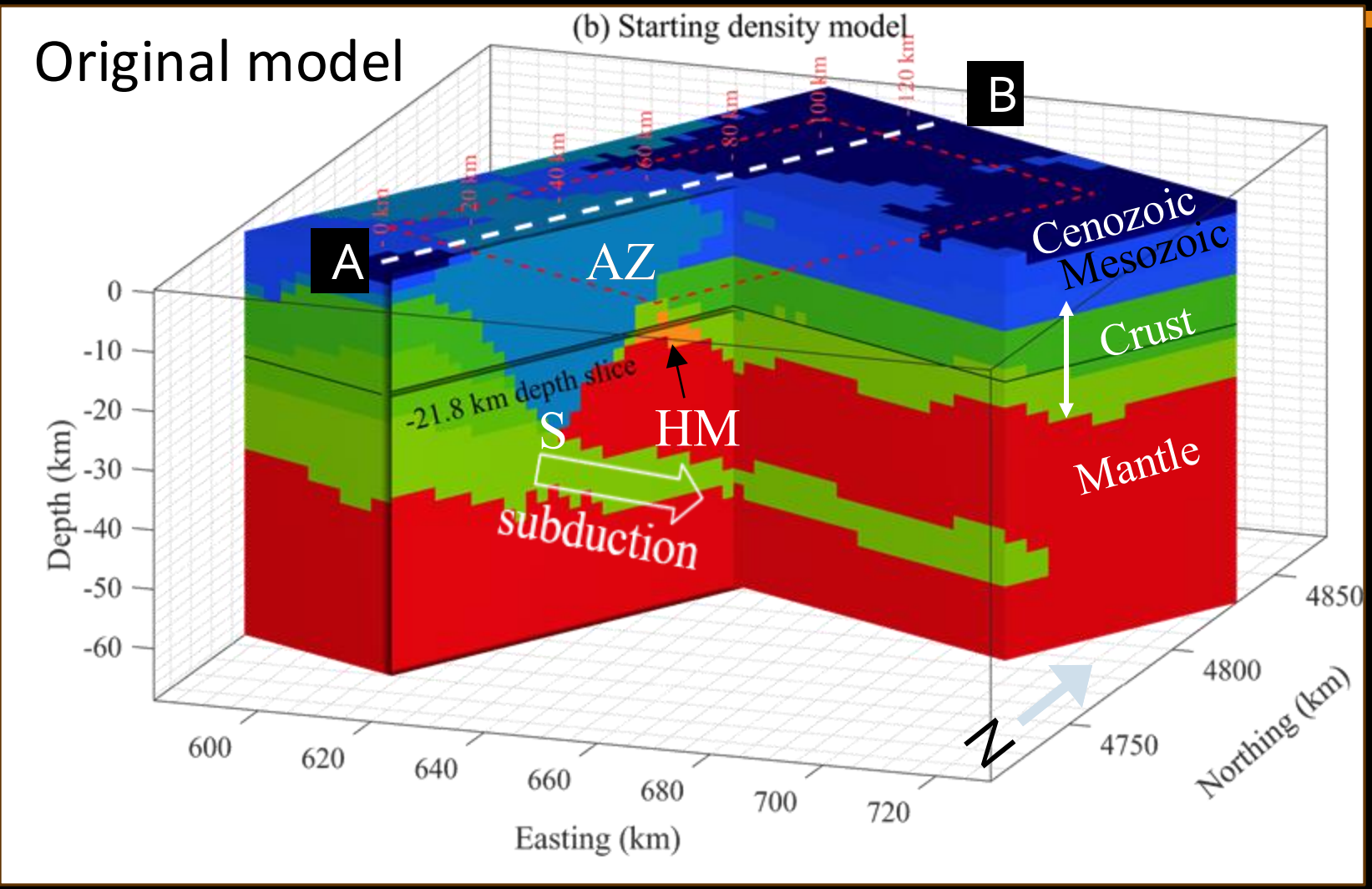
HM: Hydrated mantle.

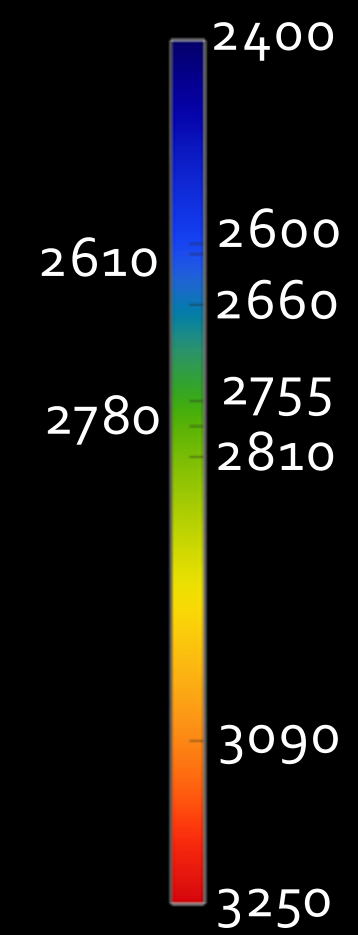
AZ: Axial Zone

Subduction

Geological modelling and data: Wehr et al. 2018, Wehr 2017. Model: courtesy of BRGM

Geological model



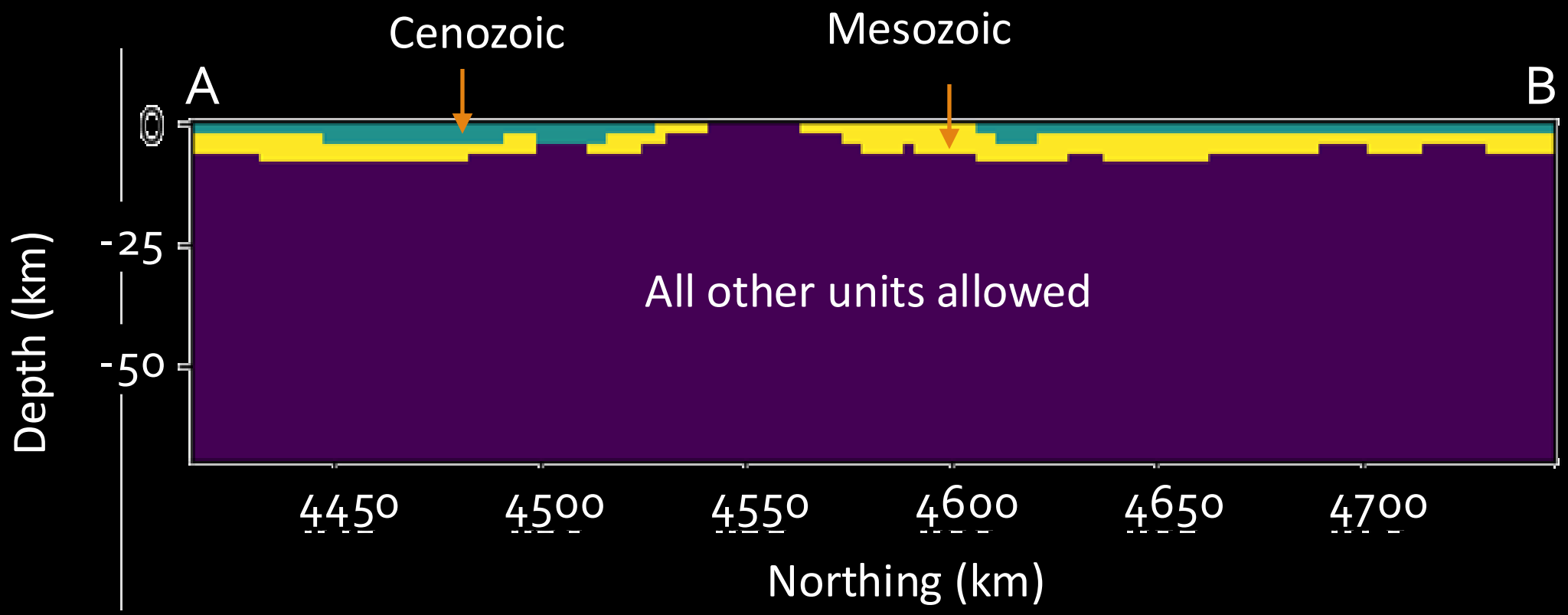


S: Singularity, beginning of subduction. HM: Hydrated mantle. AZ: Axial Zone

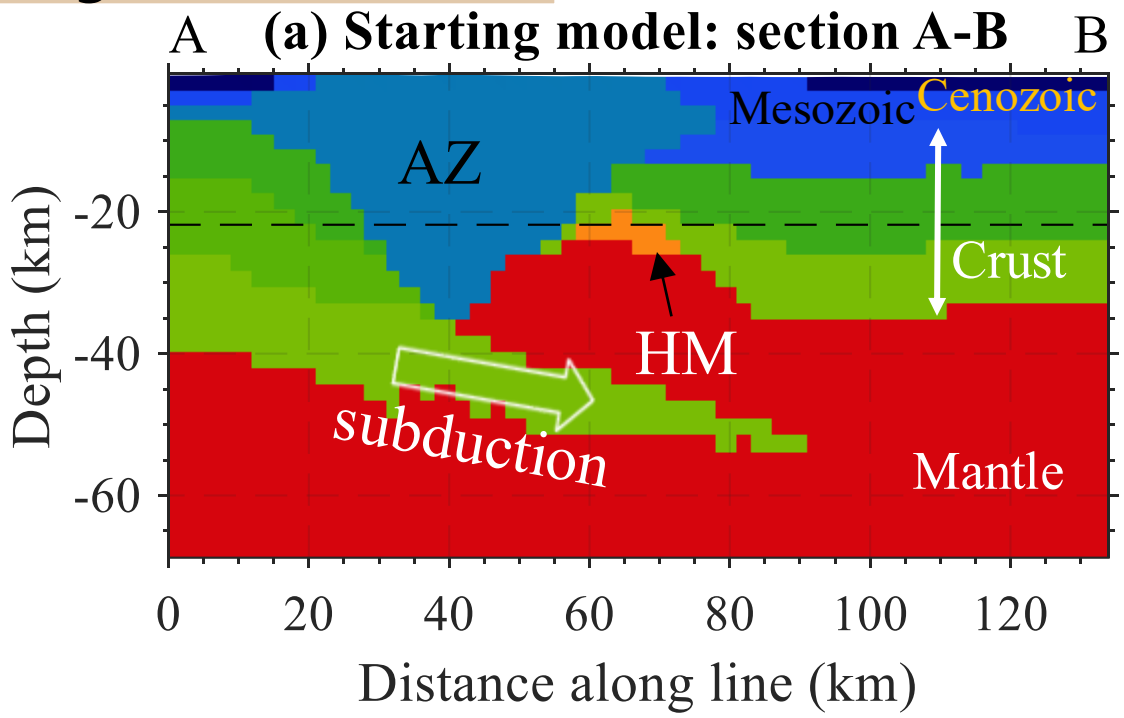
Geological modelling and data: Wehr et al. 2018, Wehr 2017. Model: courtesy of BRGM

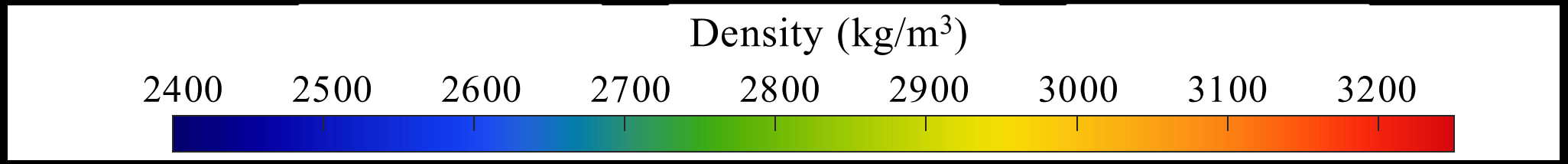
Pyrenees field application: geological data

- Contact and orientation data: mesozoic + cenozoic only in $\boldsymbol{d}_{obs.}^{geol}$
- Other units: deep and uncertain → free to evolve

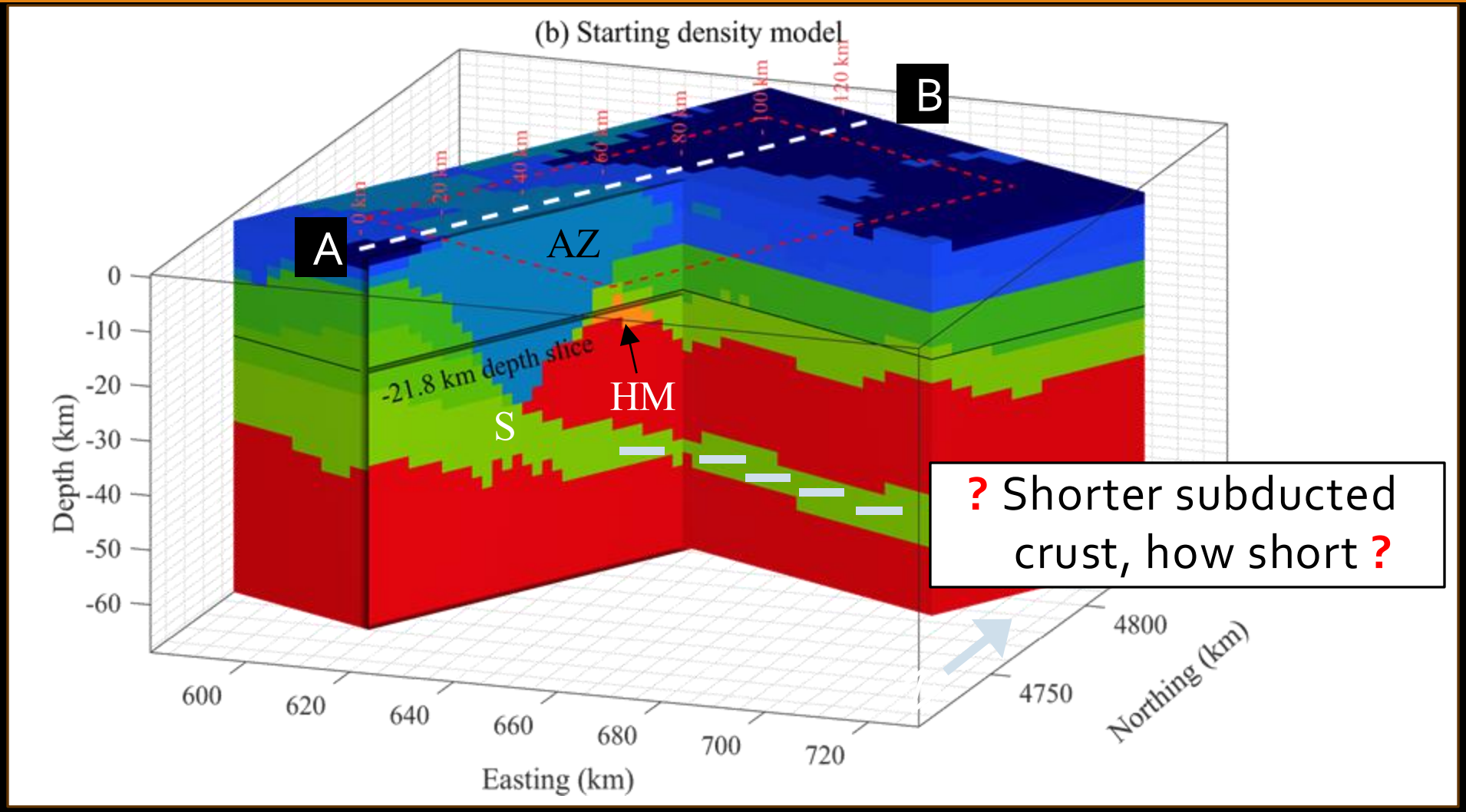


Original scenario





Geological questions



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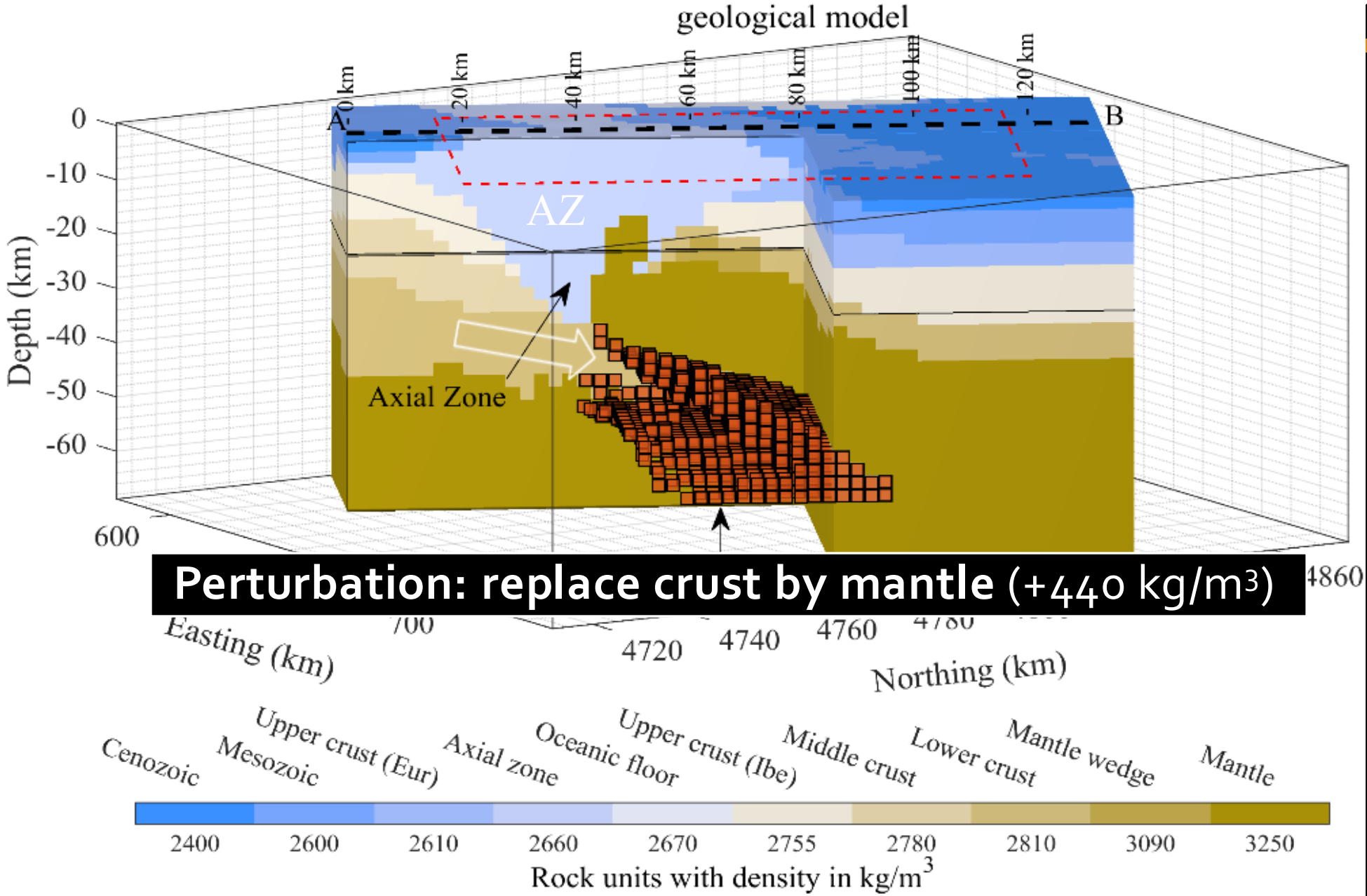
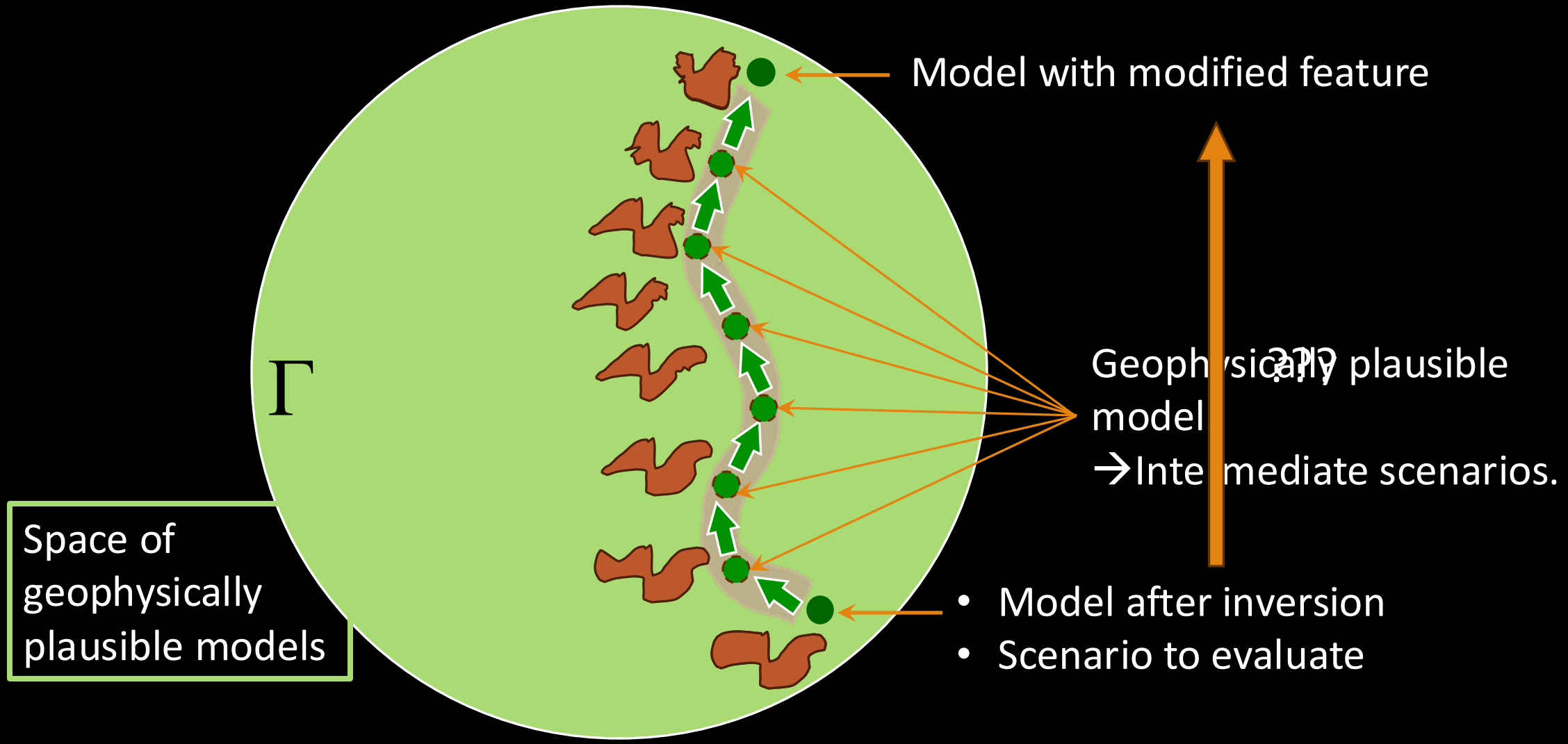
Geological modelling and data: Wehr et al. 2018, Wehr 2017. Model: courtesy of BRGM

Shortening the subducted crust



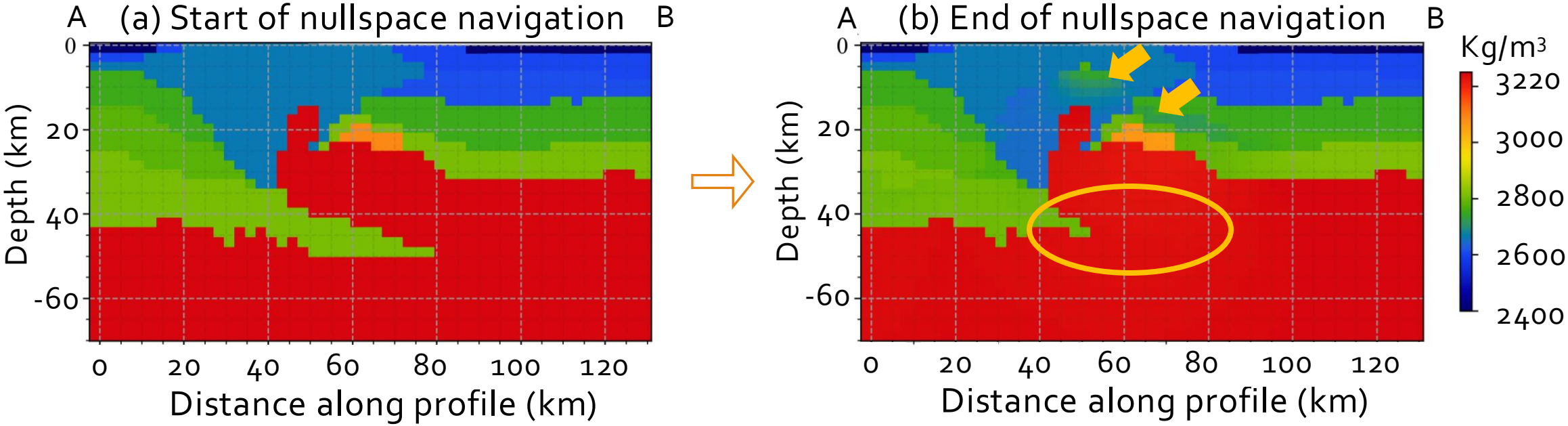
Perturbation: replace crust by mantle (+440 kg/m³)

Motivation and Objectives



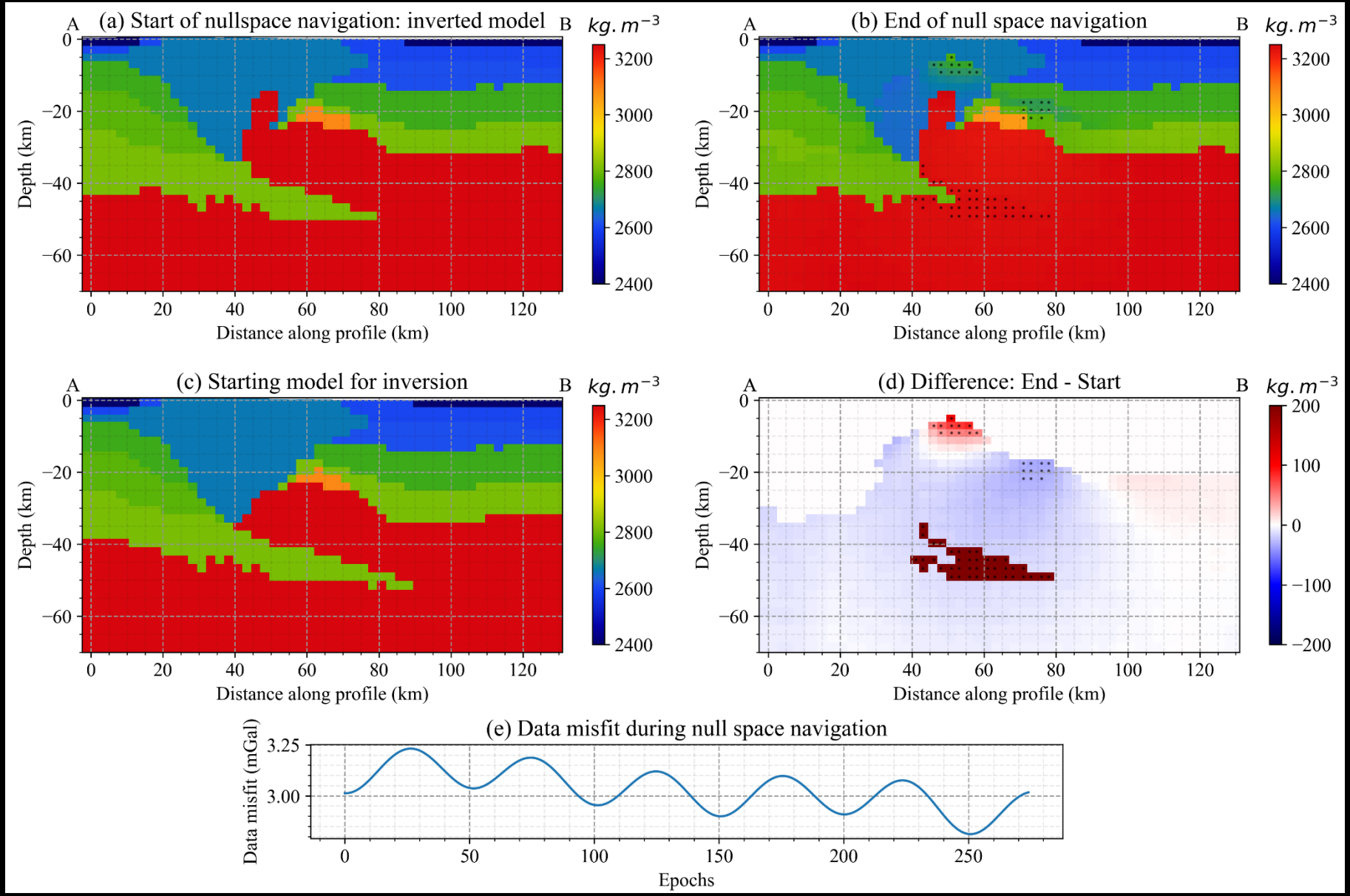
Question: what if a given feature is added or removed?

Shortening the subducted crust



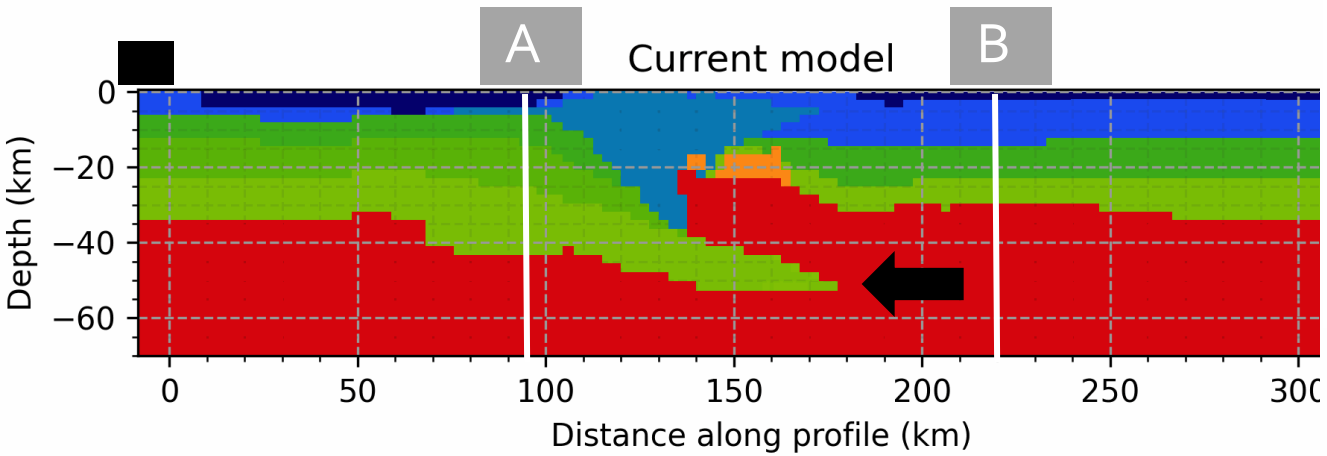
Perturbation

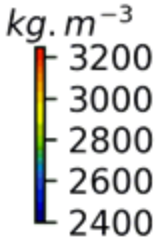
Shortening the subducted crust



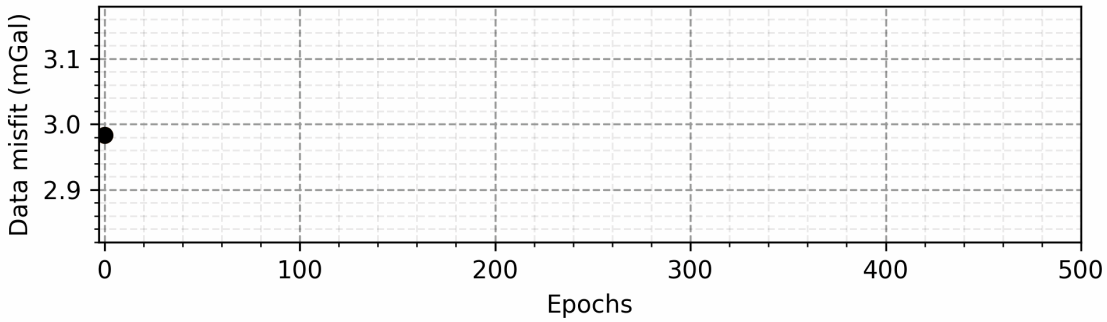
Giraud et al. 2024

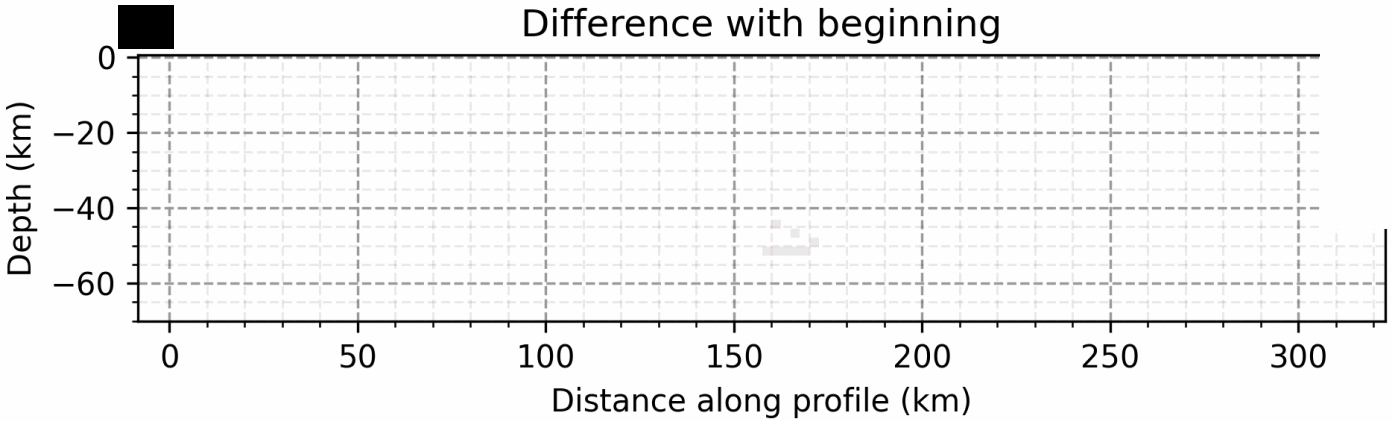
Shortening the subducted crust

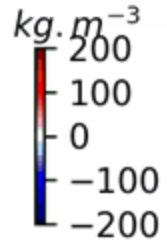




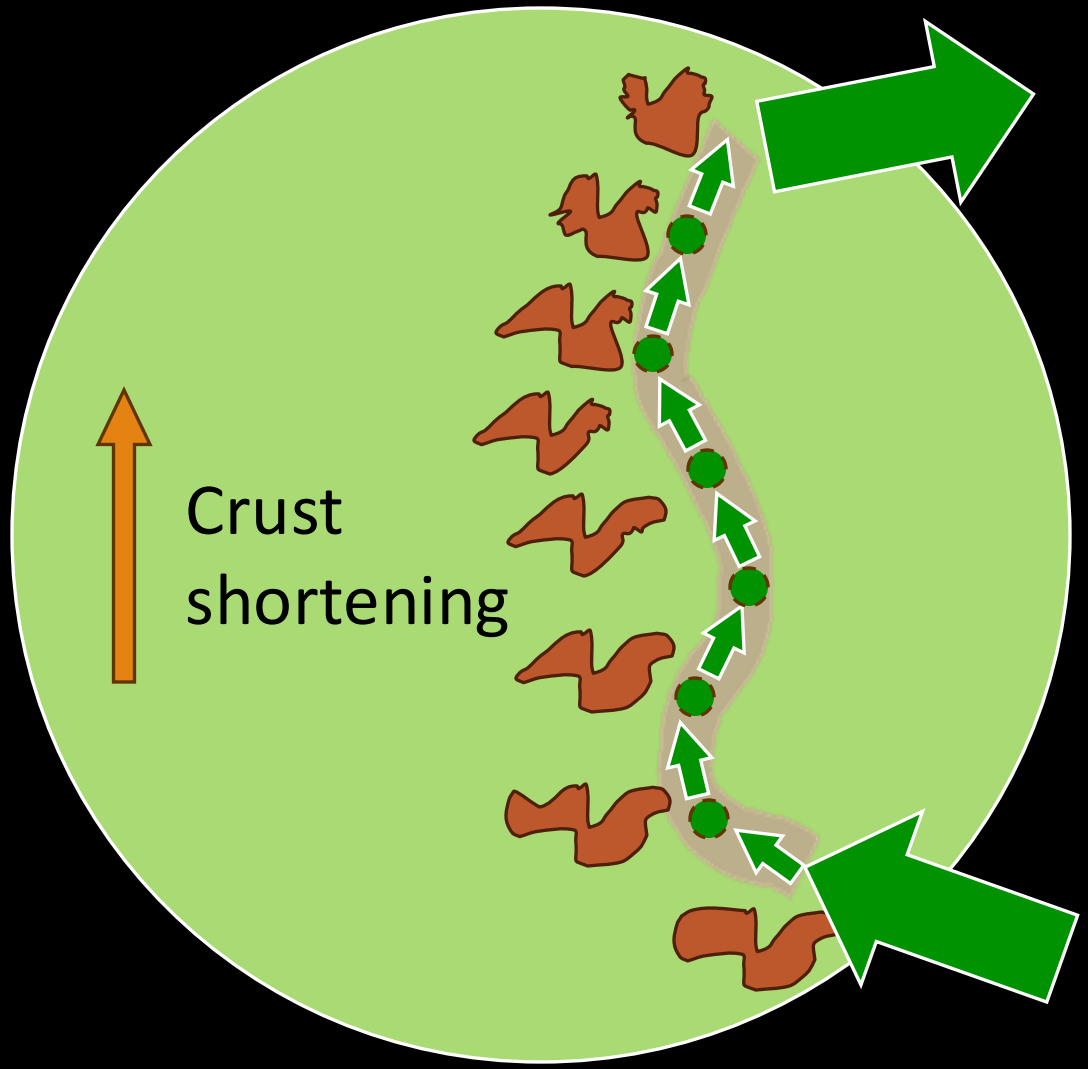
- Step-by-step pertubation
- Intermediate models
- Similar data misfit

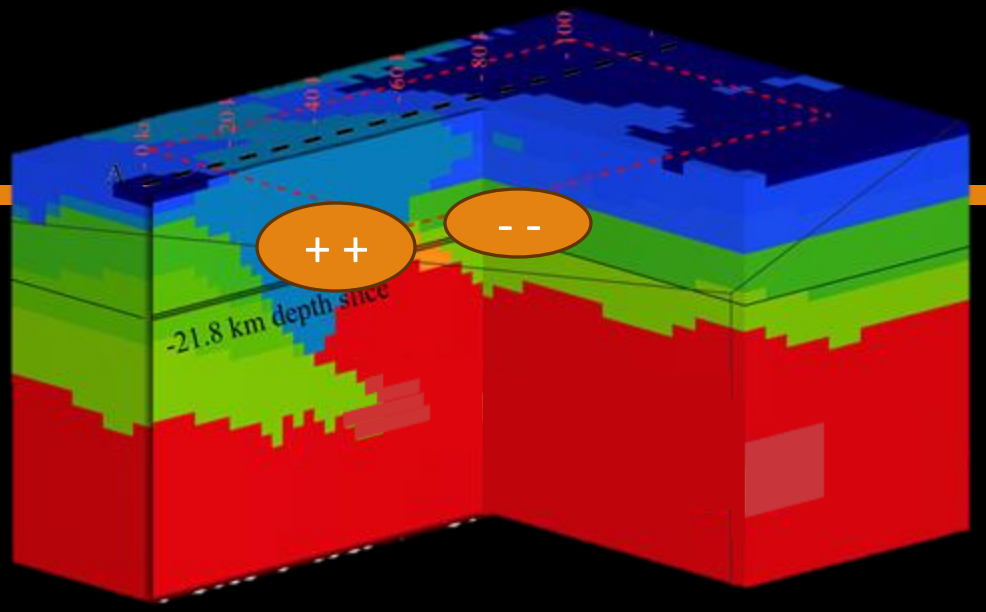


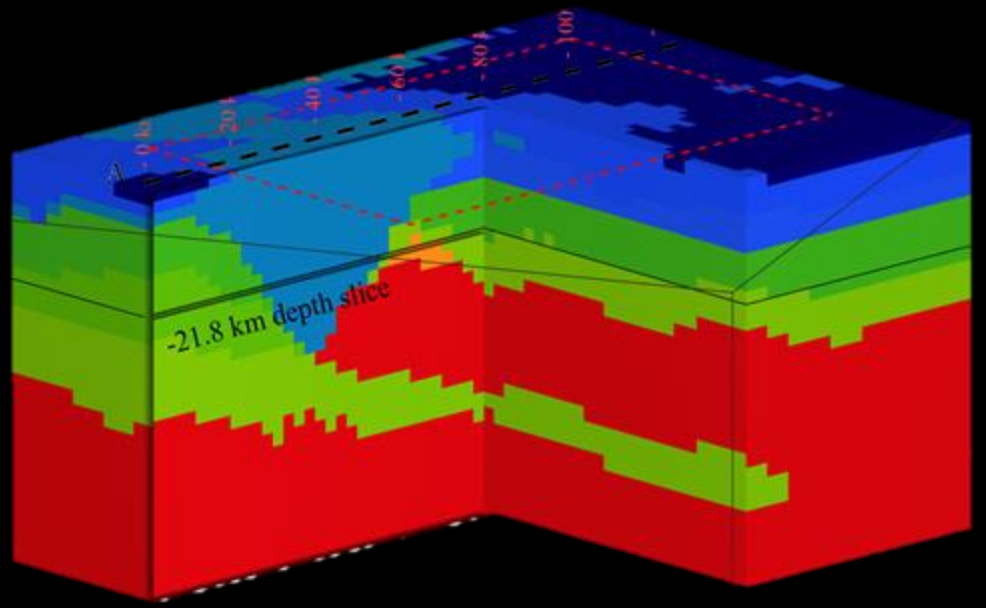




Navigation







Demo?

References

JOURNAL ARTICLE

Geologically constrained geometry inversion and null-space navigation to explore alternative geological scenarios: a case study in the Western Pyrenees

Jérémie Giraud ✉, Mary Ford, Guillaume Caumon, Vitaliy Ogarko, Lachlan Grose, Roland Martin, Paul Cupillard

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Repository

GeoMos-nullspace Public

Scripts for null space exploration using gravity data with application to the Western Pyrenees and synthetic examples.

Python 1

References

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- Deal , M.M. & Nolet, G., 1996. Nullspace shuttles, Geophys. J. Int., 124, 372–380.
- Fichtner , A. & Zunino, A. 2019. Hamiltonian nullspace shuttles. Geophys. Res. Lett., 46, 644–651.

Questions?