living planet symposium | BONN 23–27 May 2022

TAKING THE PULSE OF OUR PLANET FROM SPACE

MEDITERRANEAN CRUSTAL PROVINCES FROM GLOBAL GRAVITY FIELD MODELS

D. Sampietro, M. Capponi

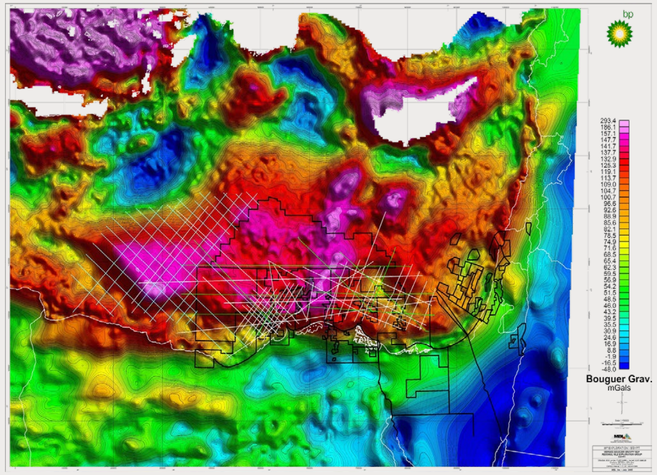
23.05.2022

THE GRAVITY INTERPRETATION PROBLEM

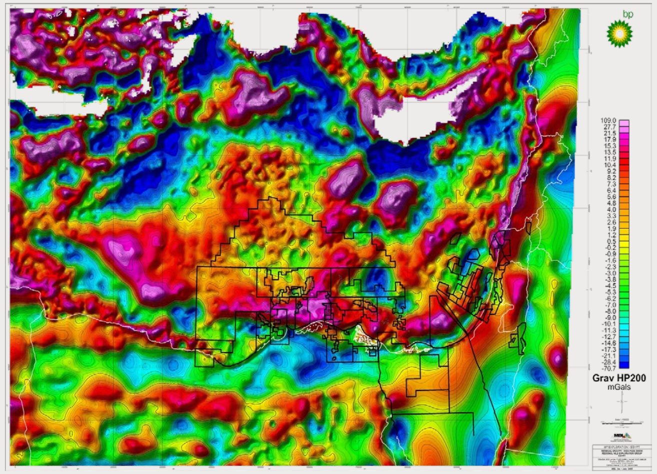
CLASSICAL SOLUTION

1. exploit gravity field in terms of Bouguer gravity anomalies;
2. apply to Bouguer anomalies proper filter to remove high-frequencies (due to sediments, etc.) and low frequencies (due to mantle);
3. Visual matching between filtered Bouguer anomaly and a priori geological map.

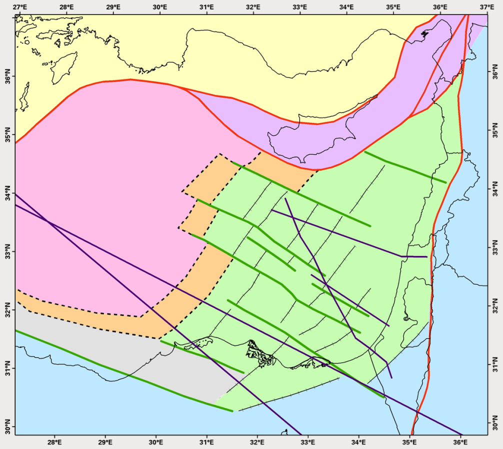
Merged Bouguer Gravity Data



Merged Residual Gravity – High-Pass 200km



Regional Crustal Architecture



From Longacre, M., et al. "New crustal structure of the Eastern Mediterranean basin: detailed integration and modeling of gravity, magnetic, seismic refraction, and seismic reflection data." EGM 2007 International Workshop: Innovation in EM, Grav and Mag Methods: A New Perspective for Exploration. Vol. 15. 2007.

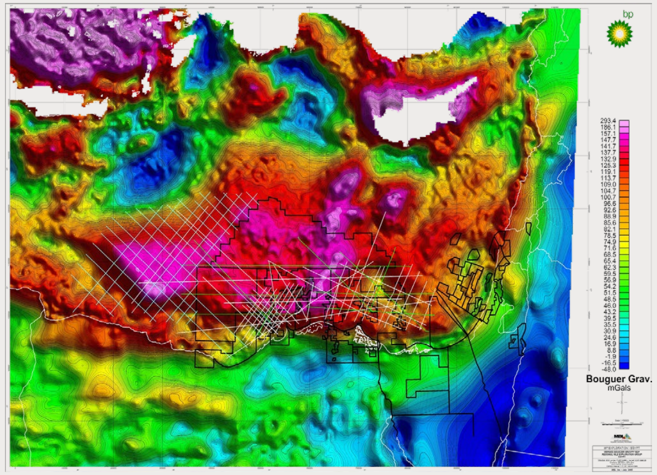
THE GRAVITY INTERPRETATION PROBLEM

CLASSICAL SOLUTION - drawbacks

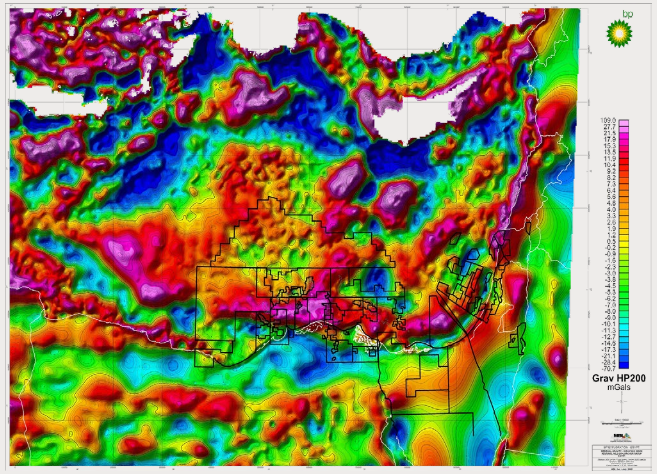
Results strongly depends on the operator experience:

- different filters can enhance different features
- different operators can perform different visual matching

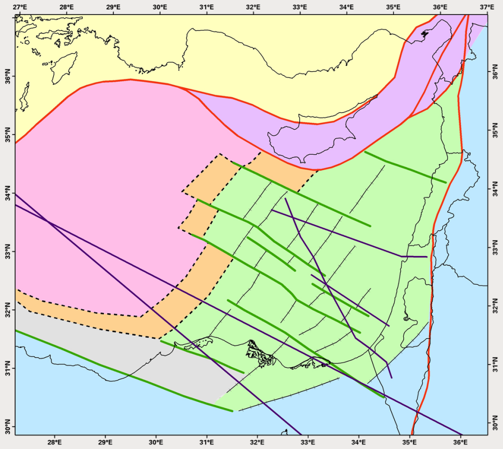
Merged Bouguer Gravity Data



Merged Residual Gravity – High-Pass 200km



Regional Crustal Architecture



From Longacre, M., et al. "New crustal structure of the Eastern Mediterranean basin: detailed integration and modeling of gravity, magnetic, seismic refraction, and seismic reflection data." EGM 2007 International Workshop: Innovation in EM, Grav and Mag Methods: A New Perspective for Exploration. Vol. 15. 2007.

THE GRAVITY INTERPRETATION PROBLEM

PROPOSED INTERPRETATION ALGORITHM

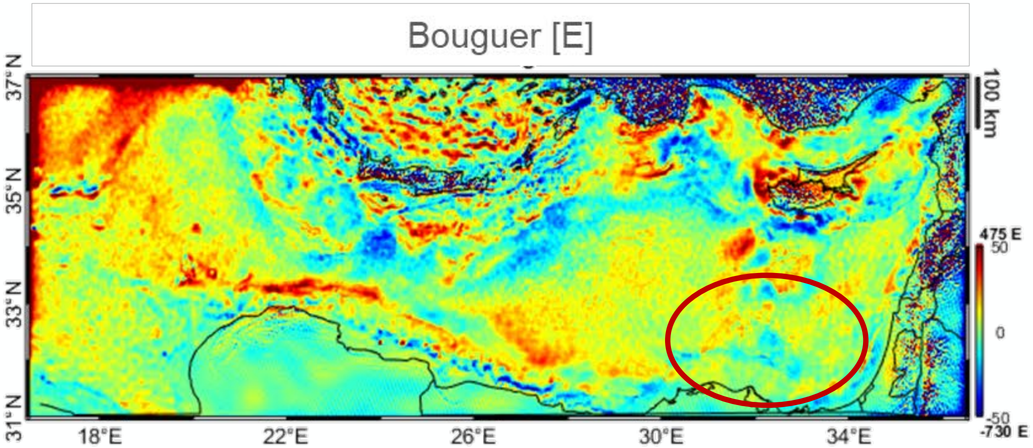
1) Bouguer anomalies	⟺	Second radial derivative (at ground level)
2) Filtering	⟺	Remove a Priori model
3) Visual Matching	⟺	Bayesian classification

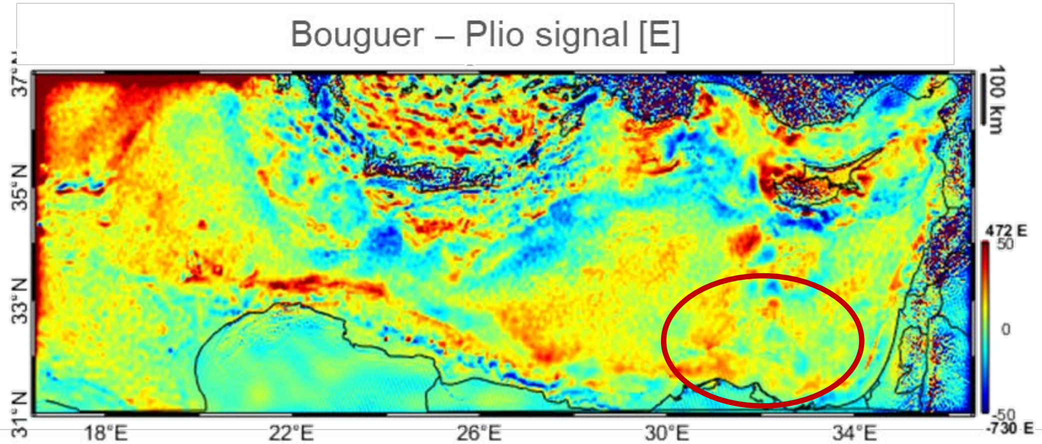
The effects of upper mantle and Moho can in general be disregarded

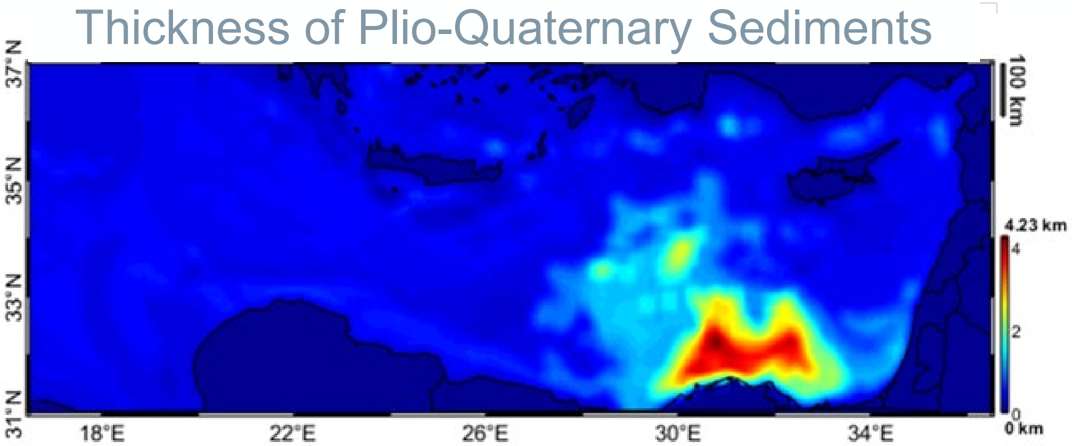
It does not involve arbitrary choices

It minimizes the residual gravity field and allows to insert proper constraints.

DATA REDUCTION T_{zz}





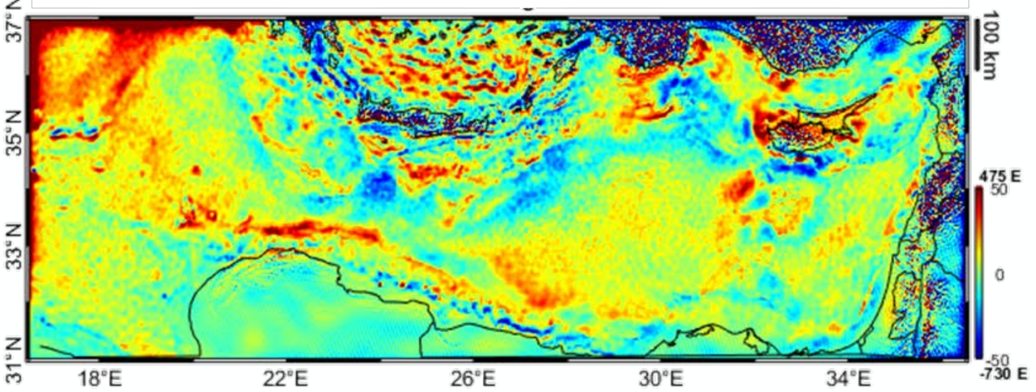


Main effect is to delineate the South-East part of the Herodotus signal, which was covered by the effect of the Nile delta sediments.

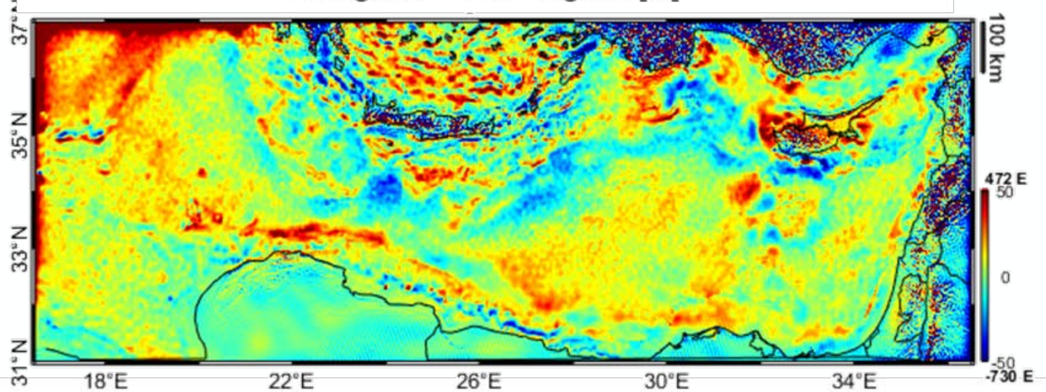
Capponi, M., E. Glavich, and D. Sampietro. "Map of Plio-Quaternary sediment depths in the Mediterranean Sea." Bollettino di Geofisica Teorica ed Applicata 61, no. 4 (2020).

DATA REDUCTION T_{zz}

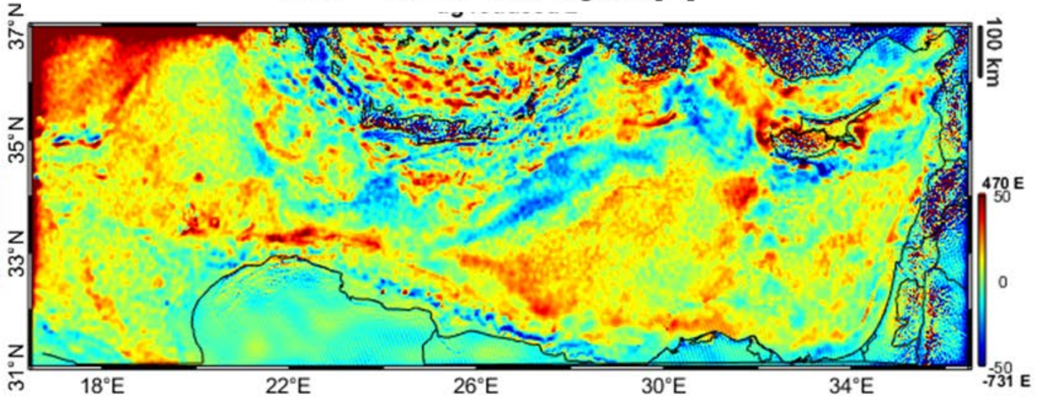
Bouguer [E]



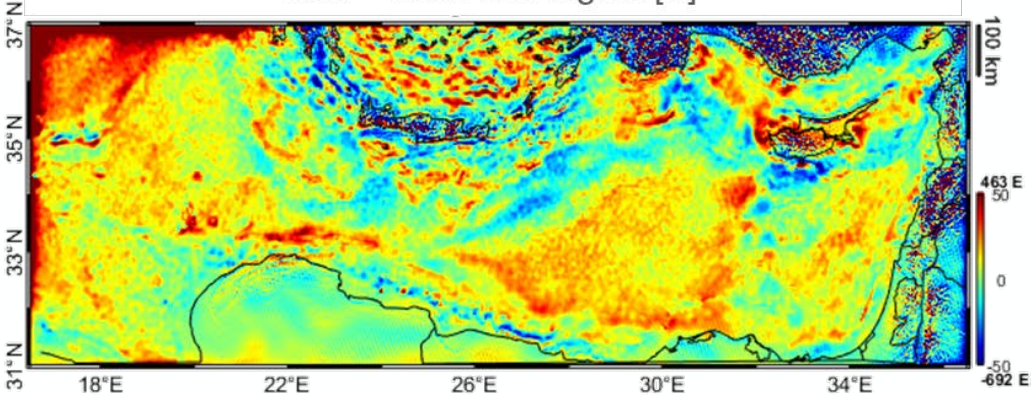
Bouguer – Plio signal [E]



Red – Mess salt signal [E]



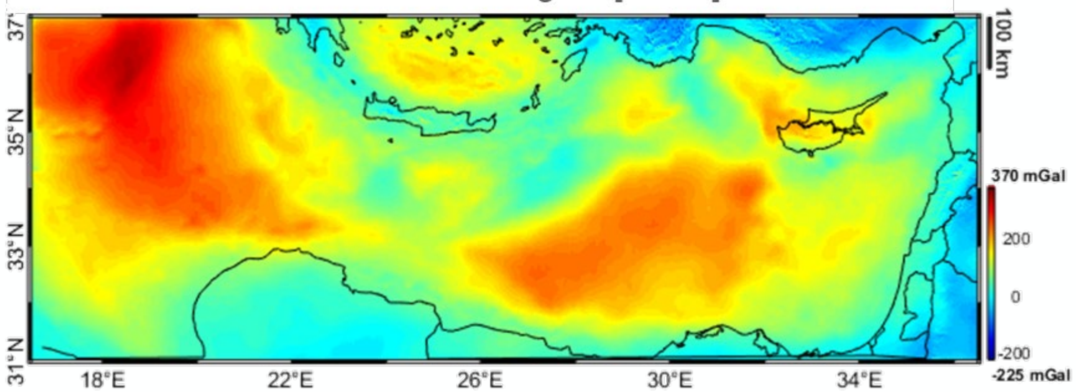
Red – Low. Sed signal [E]



DATA REDUCTION T_{zz}

PRE-MESSINIAN SEDIMENTS

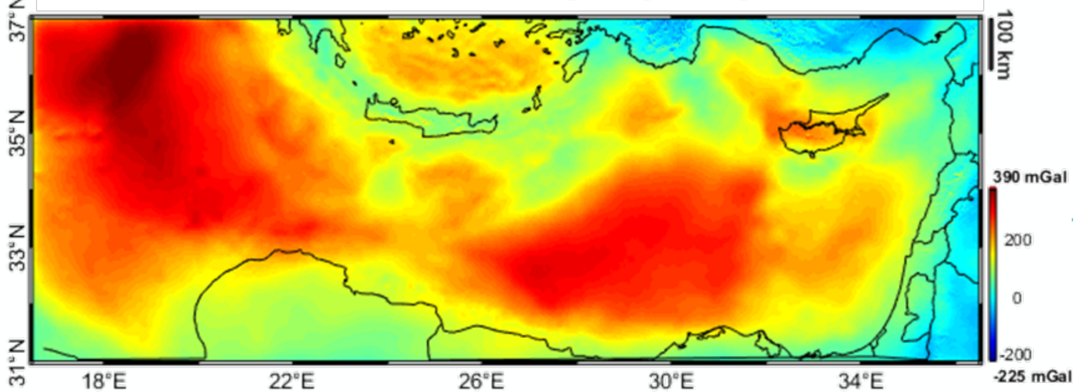
Red – Mess salt signal [mGal]



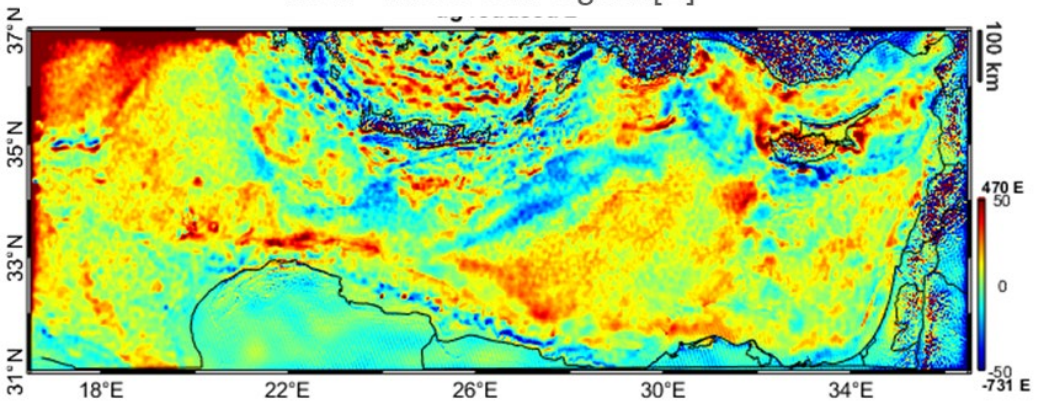
std~60 mGal

Remove Pre-Mess. sediments

Red – Low. Sed signal [mGal]



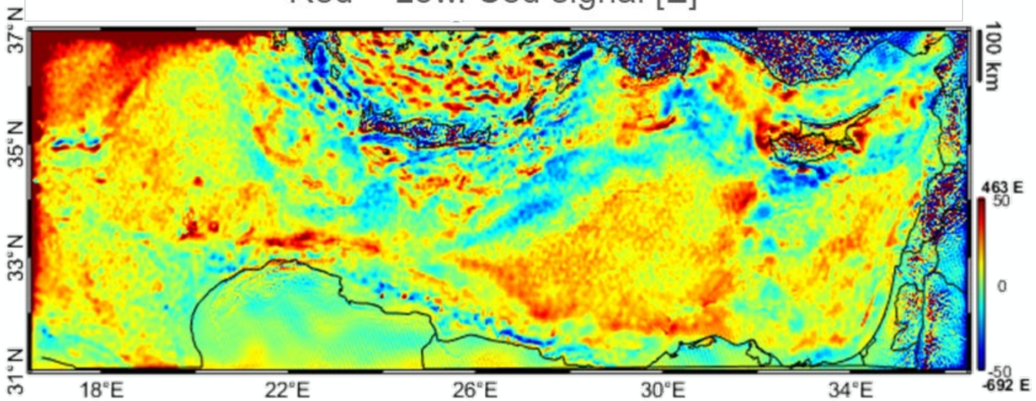
Red – Mess salt signal [E]



std~30 E

Remove Pre-Mess. sediments

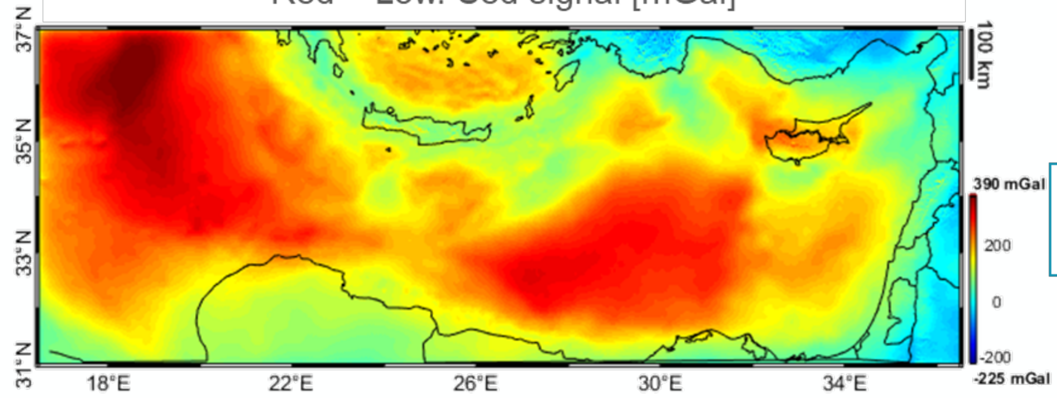
Red – Low. Sed signal [E]



DATA REDUCTION

UPPER MANTLE/LITHOSPERIC MANTLE (FROM 55 – 200 KM)

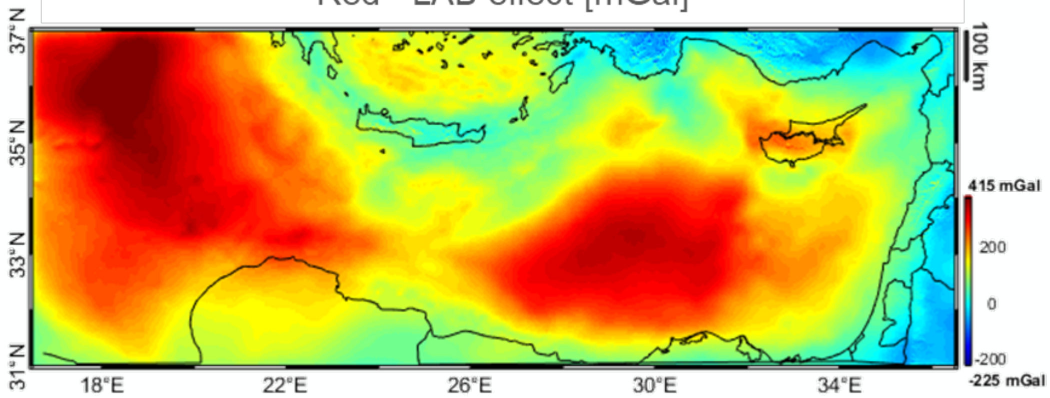
Red – Low. Sed signal [mGal]



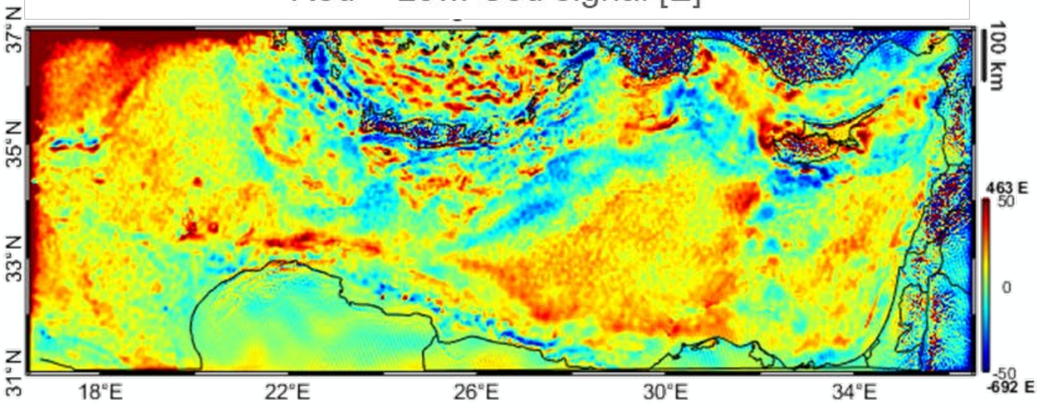
std~20 mGal

Remove LAB

Red - LAB effect [mGal]



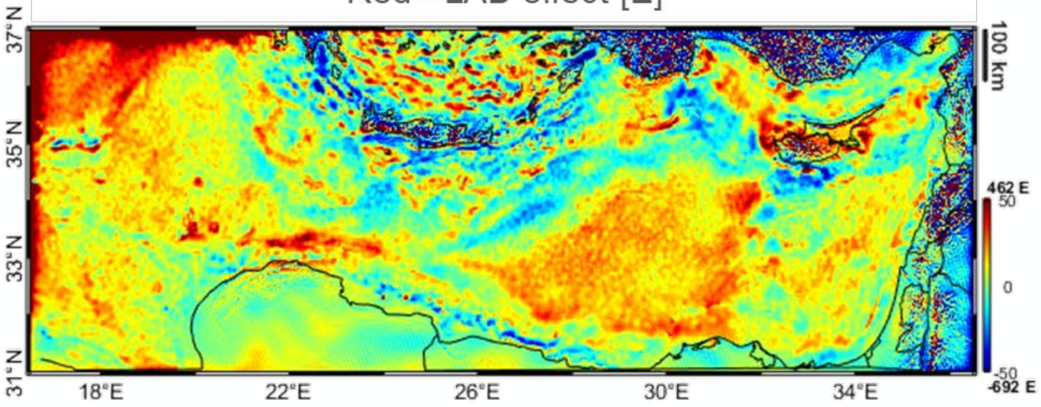
Red – Low. Sed signal [E]



std~2 E

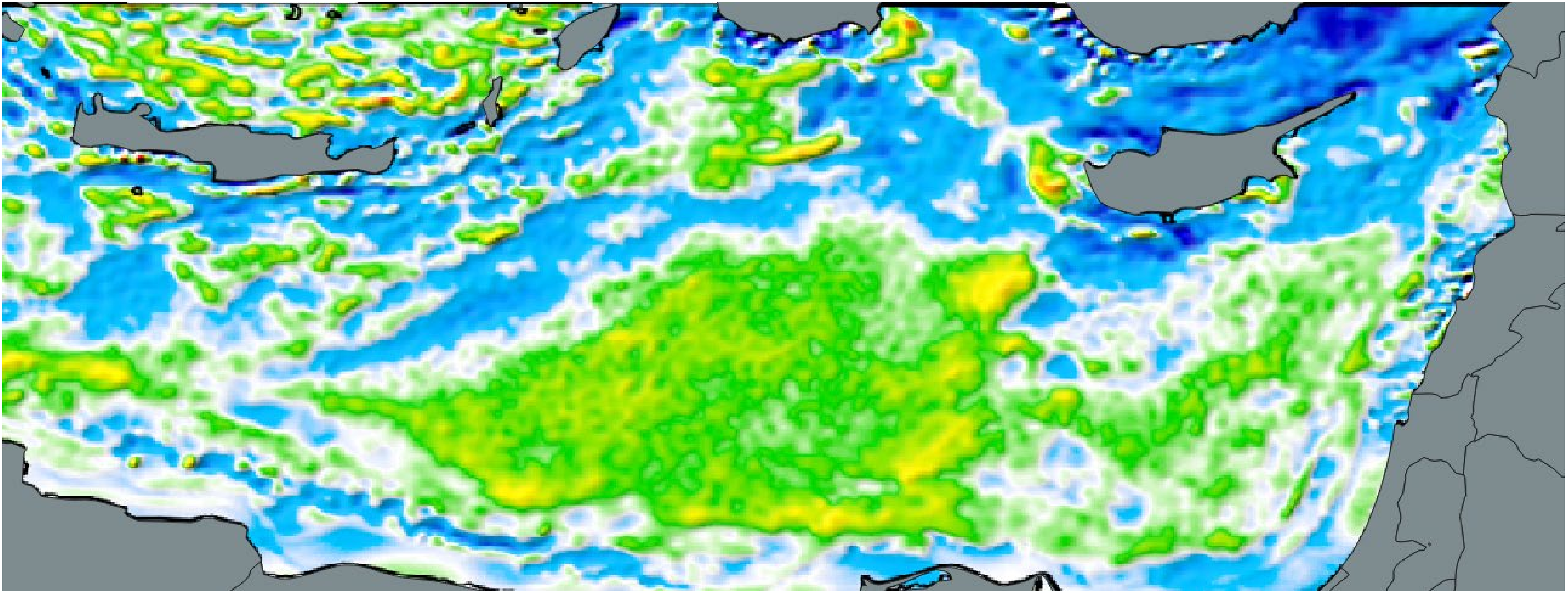
Remove LAB

Red - LAB effect [E]



DATA REDUCTION

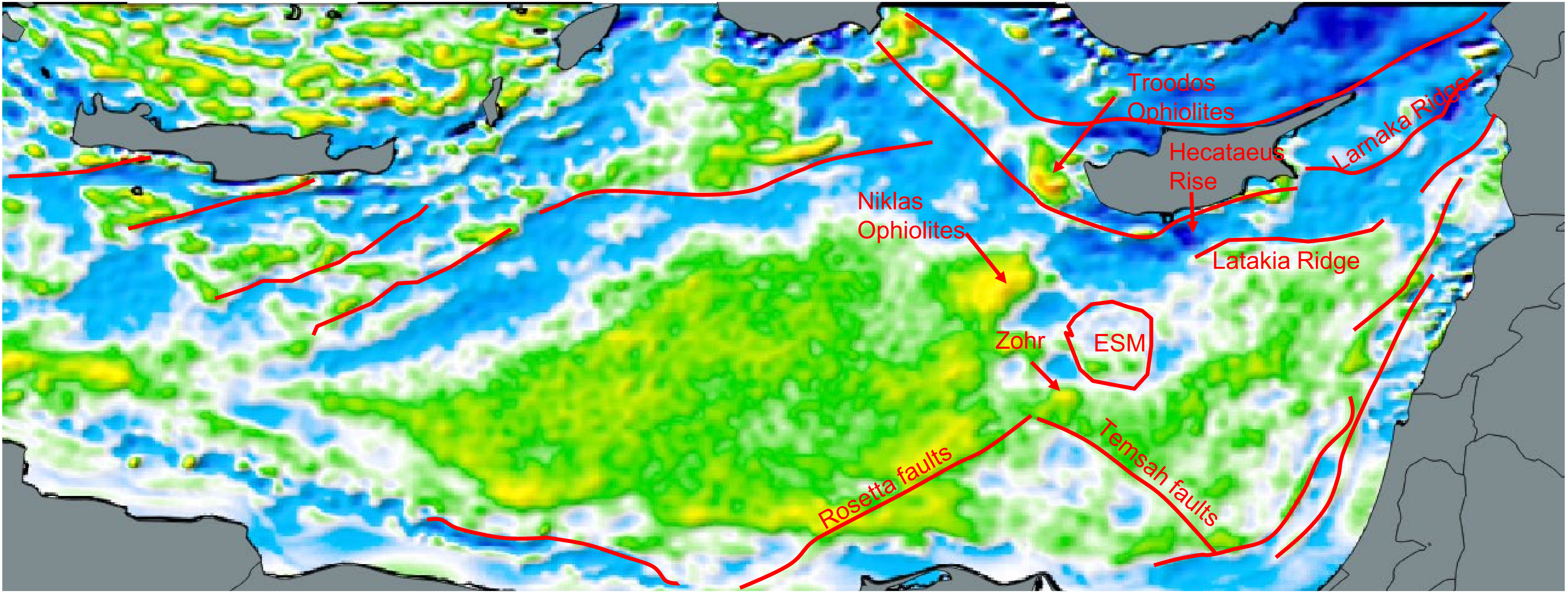
REDUCED SECOND RADIAL DERIVATIVES



Low frequencies are related to crustal domains, high frequency mainly related to local anomalies, faults,…

DATA REDUCTION

REDUCED SECOND RADIAL DERIVATIVES



Low frequencies are related to crustal domains, high frequency mainly related to local anomalies, faults,…

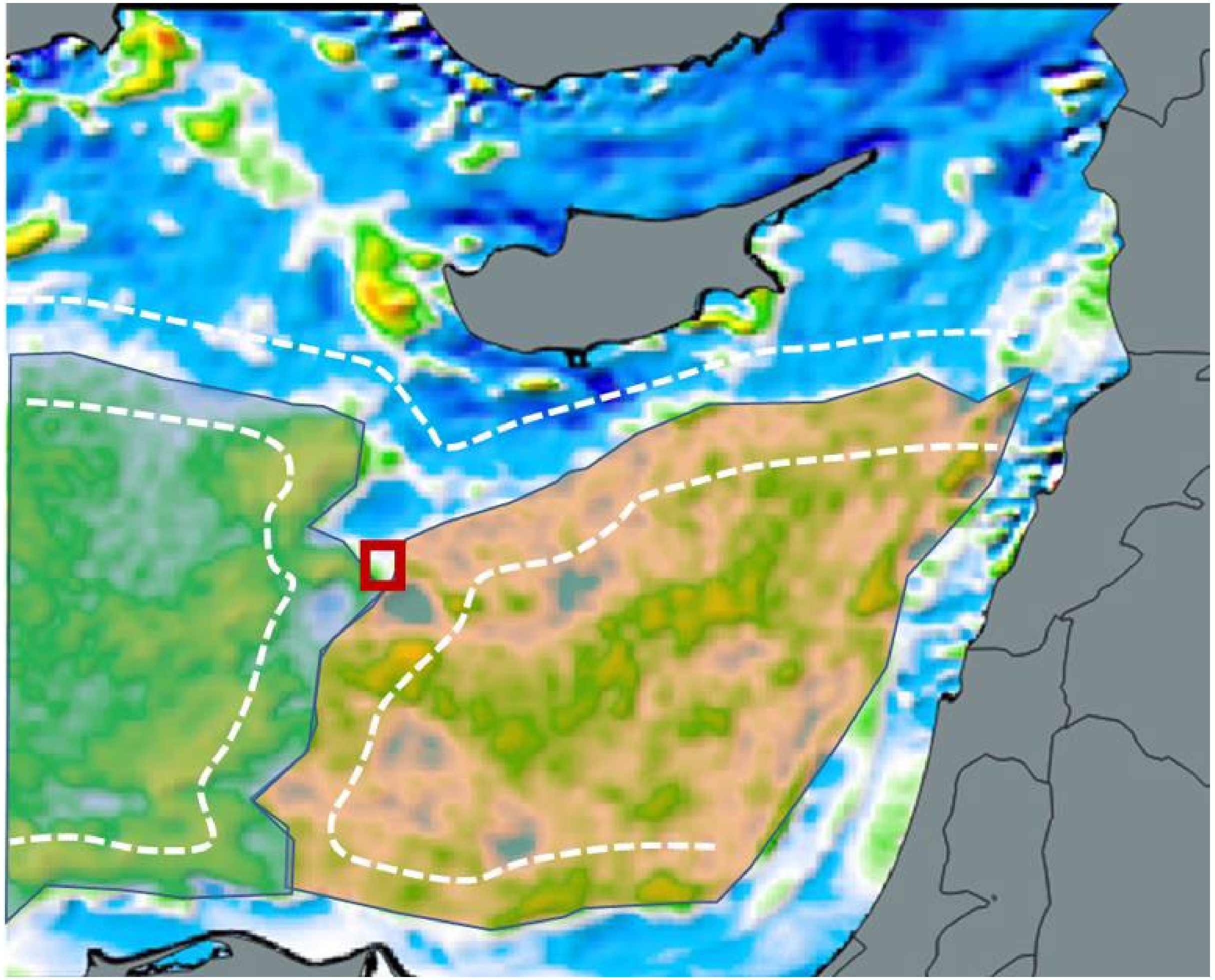
BAYESIAN CLASSIFICATION

1. We define rough a-priori homogeneous regions (e.g. yellow and green in the map);

2. We divide the study area in cells;

3. We define uncertainty regions;

4. We used similarity in gravity field and gravity fit to classify each cell in one of the given region (e.g. given the gravity in the red square we ask ourselves if it is more similar to the signal of the yellow or green region)



BAYESIAN CLASSIFICATION

LIKELIHOOD

$$P(\rho, L|y)=\frac{1}{A}exp\left\{-\frac{1}{2}(\delta g - F_g\rho)^T C_{gg}^{-1}(\delta g - F_g\rho) - \eta\sum_{i=1}^{n}\frac{\left(\delta g_i - \mu_{\delta g}(L_i)\right)^2}{\sigma^2_{\delta g}(L_i)} - \frac{\gamma}{2}\sum_{i=1}^{n} s_i^2(L_i) - \frac{\lambda}{2}\sum_{i=1}^{n}\sum_{j\in\Delta_i} q^2(L_i, L_j)\right\}$$

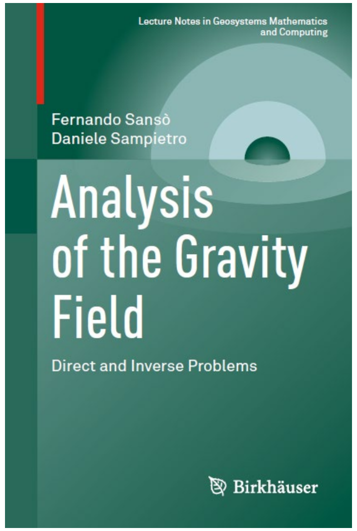
Gravity residual	similarity in gravity field	"distance" from the initial geometries	Neighbors clustering

PRIOR

Unknown:

- 1 density for each province;
- 1 label for each cell;

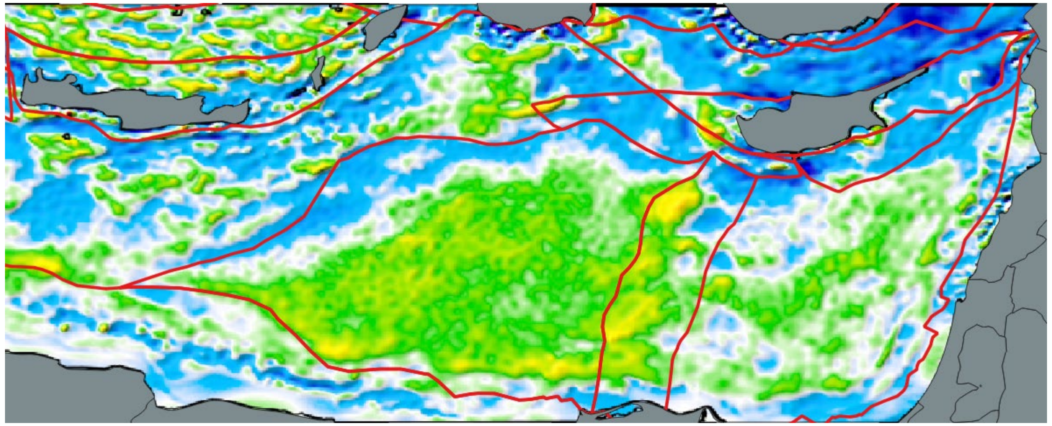
The solution is found by looking for the Maximum a Posteriori by means of a Simulating Annealing combined with a Gibbs sampler



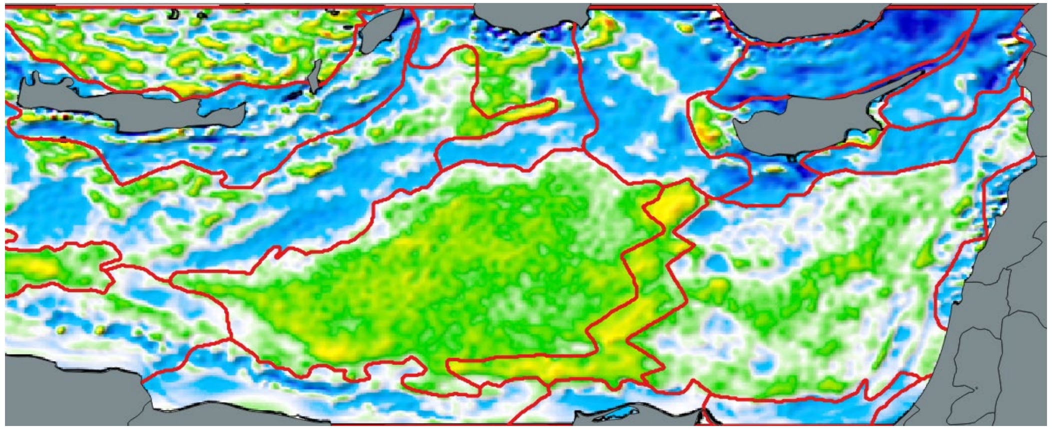
BAYESIAN CLASSIFICATION

MAIN GEOLOGICAL CRUSTAL PROVINCES IN THE EASTERN MEDITERRANEAN AREA

A-priori model



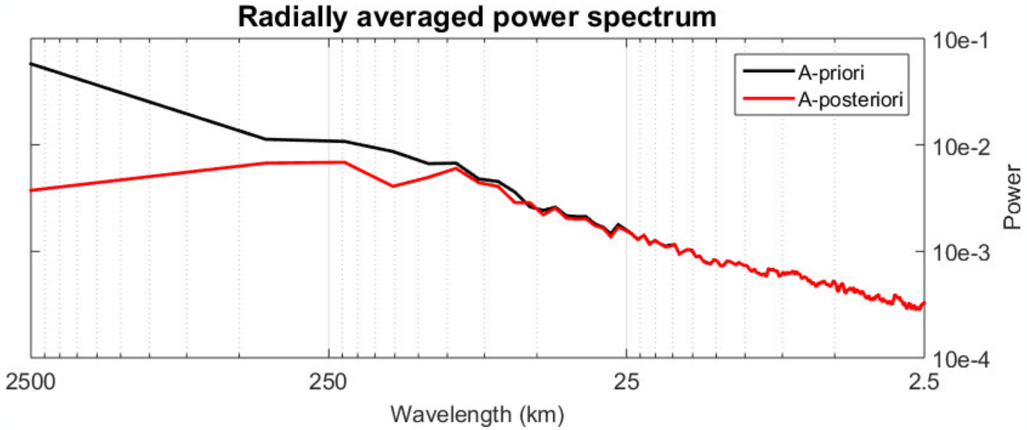
GReD geological crustal provinces



A detailed analysis of the gravitational field can help in defining the boundaries of main geological crustal provinces.

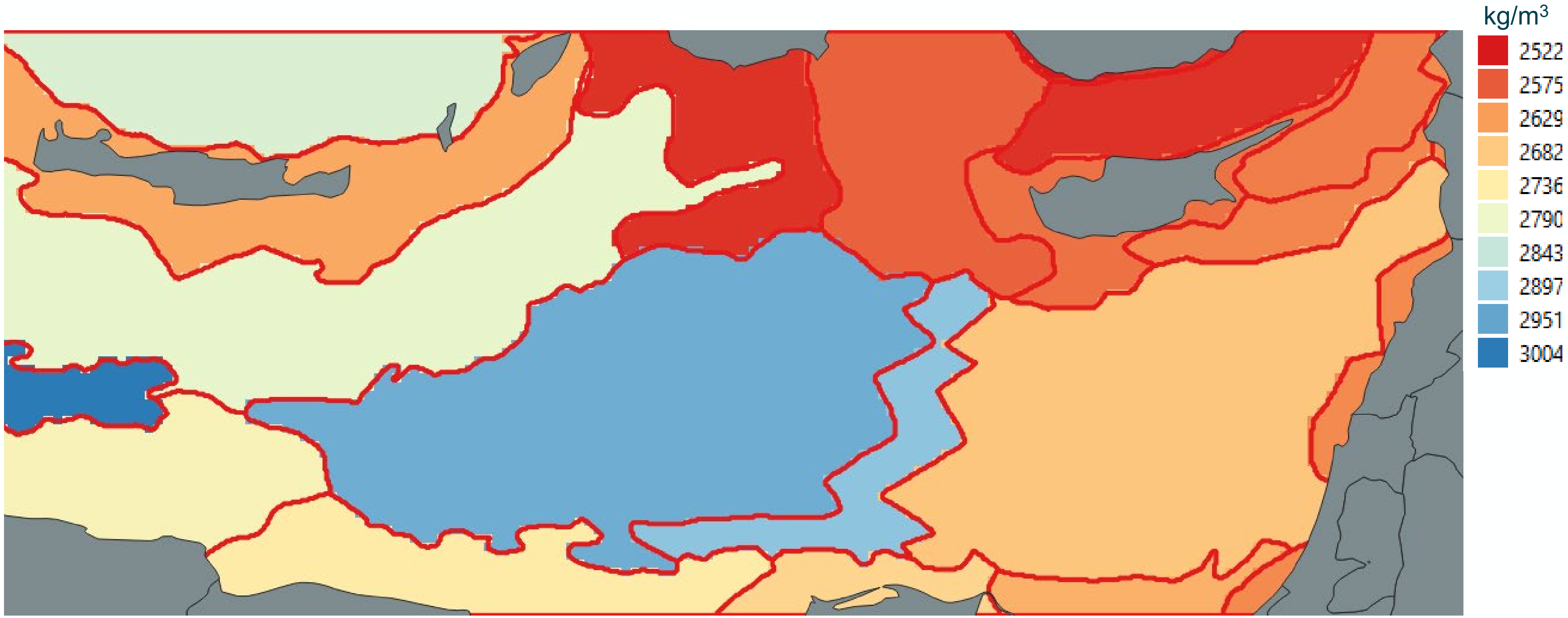
GReD interpretation algorithm has been applied to automatically determine geological crustal provinces in the Mediterranean Sea.

GReD interpretation is well coherent with the observed gravity field.



BAYESIAN CLASSIFICATION

CRUSTAL DENSITY MAP

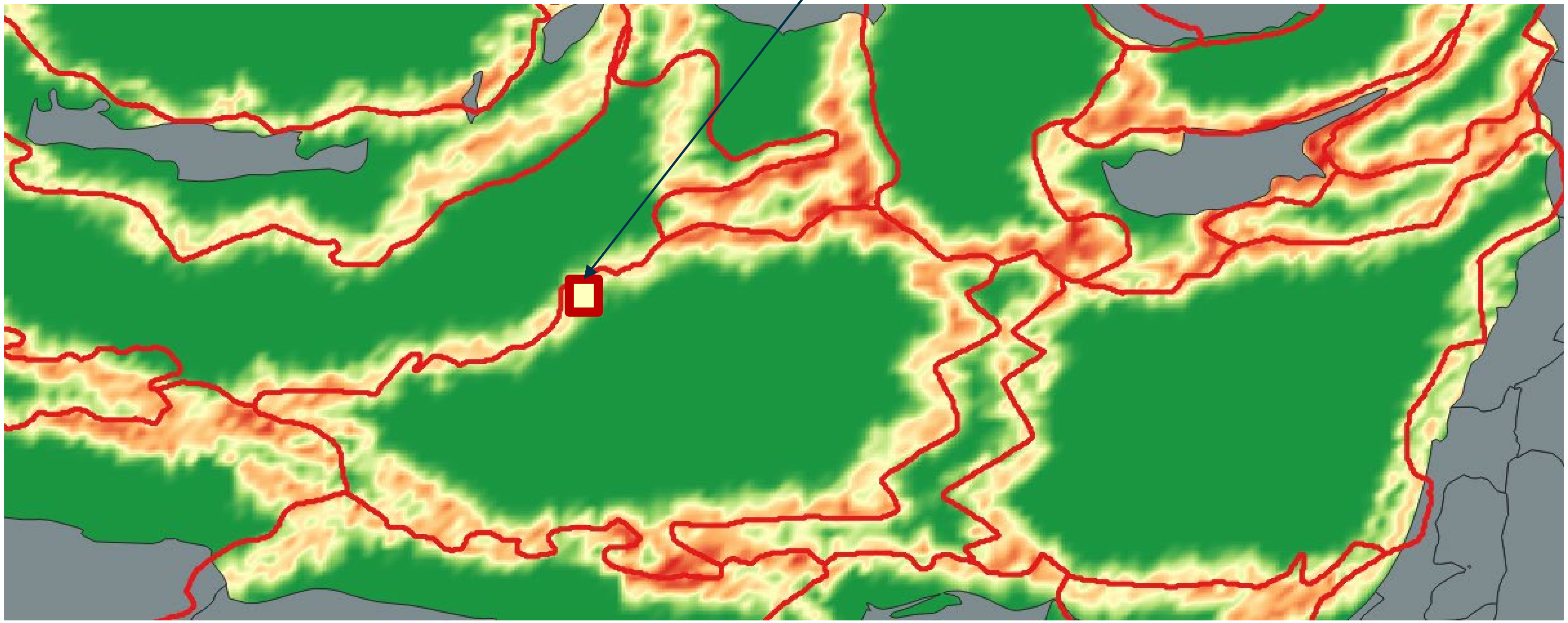


We can also estimate an average crustal density for each province. This is a quite approximate estimate, which however gives hints on the nature of the crust.

BAYESIAN CLASSIFICATION

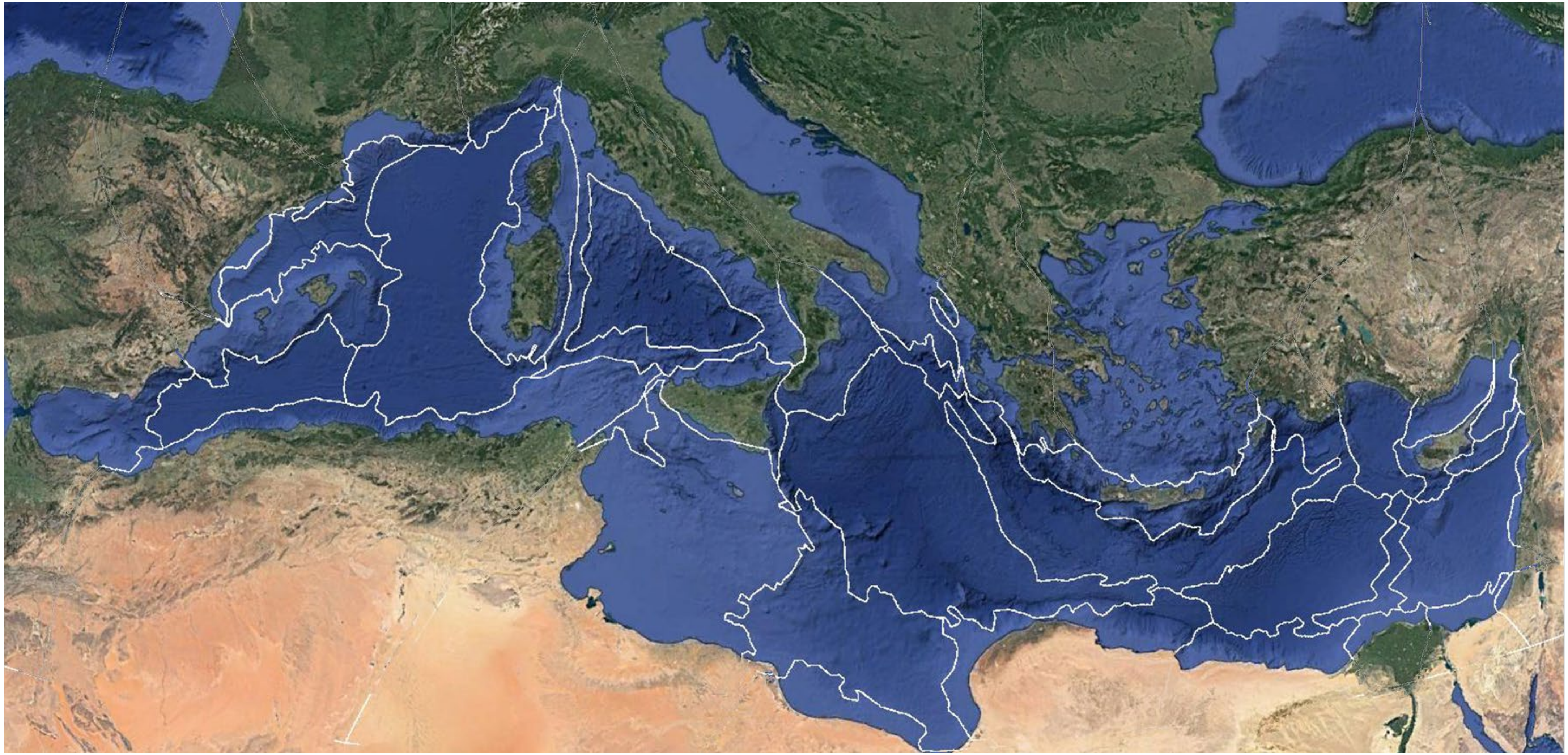
CLASSIFICATION RELIABILITY

Here the algorithm can choose between two regions. 64% of the extractions the cell has been classified as Herodotus basin, 46 % as Mediterranean Ridge.



The classification is a non-linear algorithm. Here it is performed by means of a simulated annealing system. The algorithm allows to estimate also a map of the reliability of the classification.

BAYESIAN CLASSIFICATION



BAYESIAN CLASSIFICATION

Results of the interpretation can be used as input for further detailed analysis/inversion.

XORN objectives:

- Develop an integrated approach, to perform 3D joint inversion of gravity and magnetic fields data, constrained by seismic and geological a-priori information.

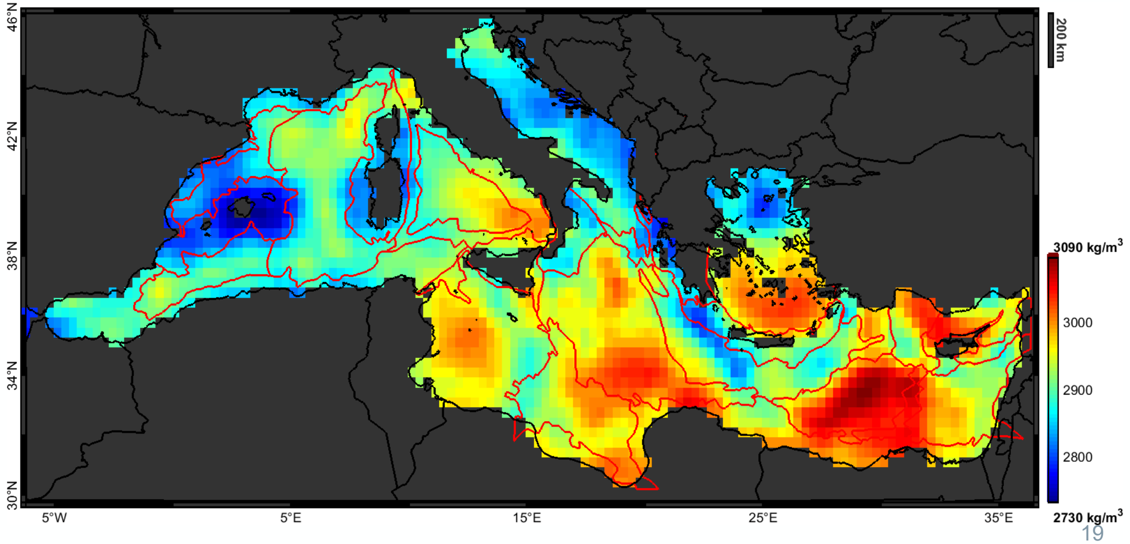
- Study the crust in the Mediterranean Sea area.

Partners:

Laboratoire Magma et Volcans, Université Clermont Auvergne (Dr. Erwan Thébault)

XORN

https://xorn-project.eu/



BAYESIAN CLASSIFICATION

Results of the interpretation can be used as input for ... ana

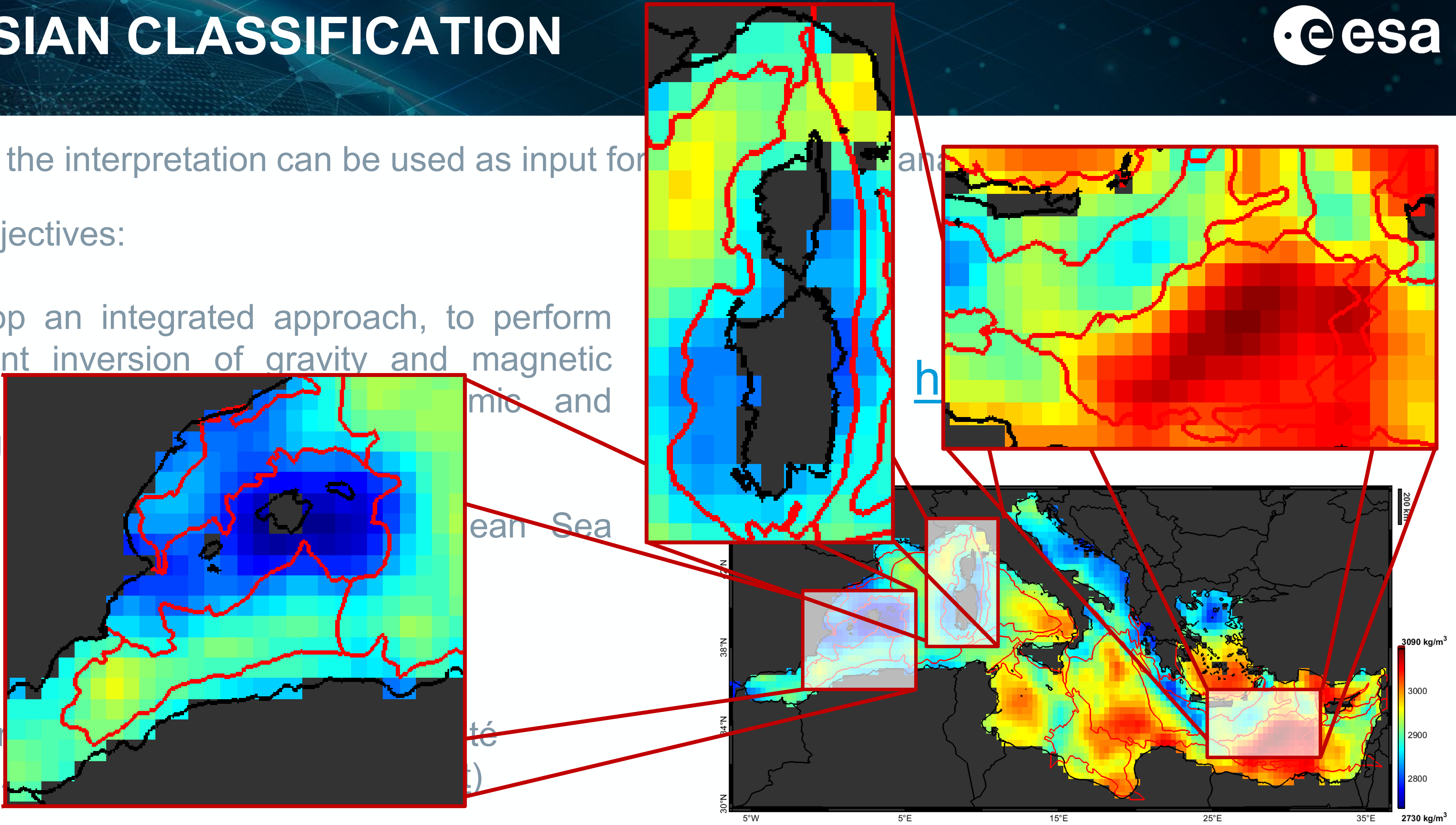
XORN objectives:

- Develop an integrated approach, to perform 3D joint inversion of gravity and magnetic fields ... mic and geolog...

- Study ... ean Sea area.

Partners:

Laboratoi... té Clermont ... t)



h

CONCLUSIONS AND FUTURE DEVELOPMENTS

The gravity field contains reliable information to identify the shape of main crustal provinces;

The identification of the homogenous provinces of the crust can be carried out almost automatically (even on a global level) starting from a rough a-priori model;

The proposed algorithm is able to correct the shape of the main crustal provinces, also estimating a map of uncertainty and an average value of the mass density of each province;

We would like to extend the algorithm to use different gravity functionals and or magnetic field;

We would like to optimize the algorithm to identify/delineate sedimentary basins (this problem is more complex e.g. because the same basin is made up of different units that are not all homogeneous from the point of view of density - think for example of the salt in the Nile delta).

Thank you for your kind attention

Geomatics Research & Development s.r.l.
Phone: +39 02 36714448
https://www.g-red.eu/
daniele.sampietro@g-red.eu

https://xorn-project.eu/