Multi-scale investigation of the African lithosphere using GOCE gravity and gradiometric data

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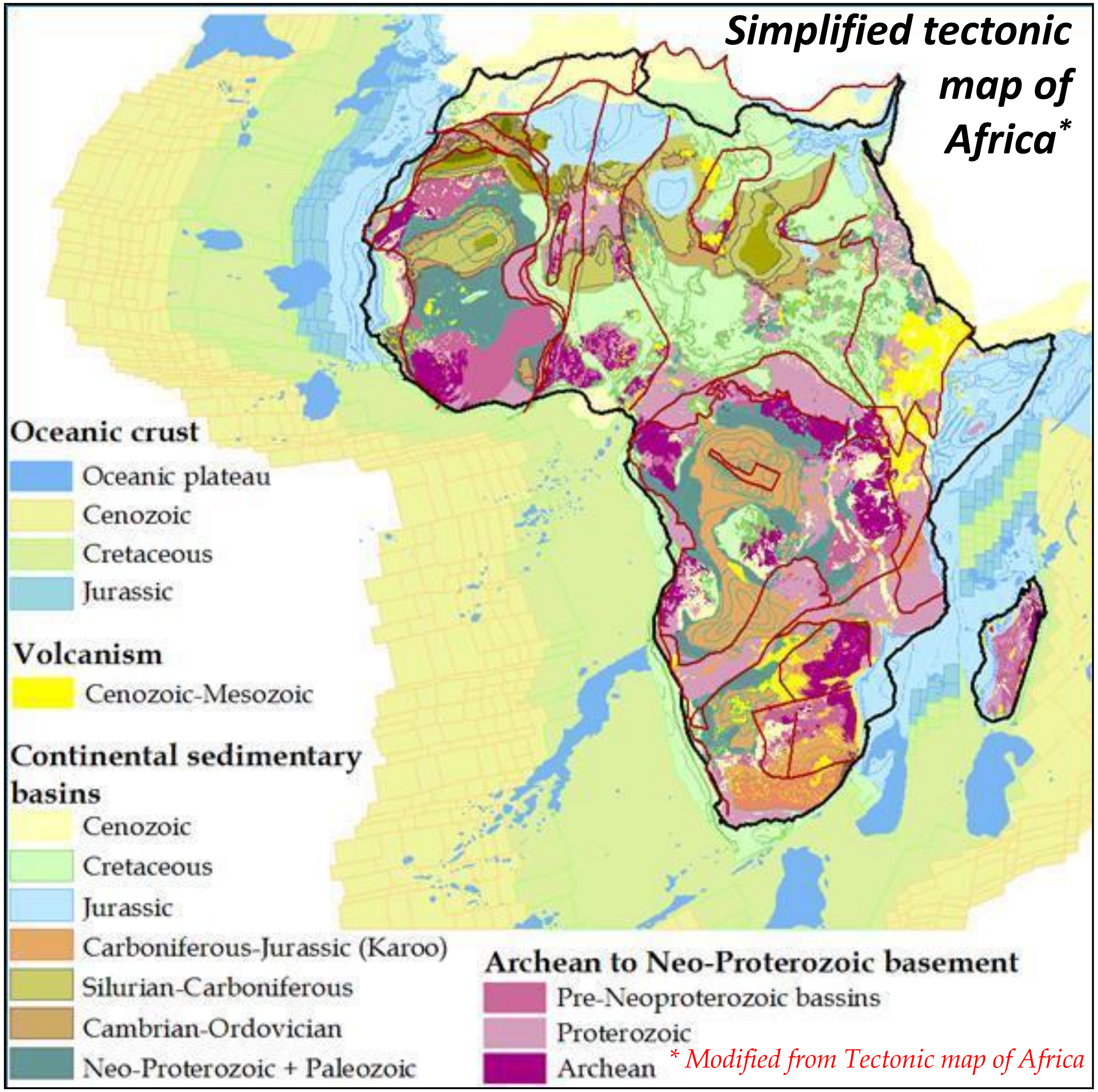
African geology



- **Geological structures**
  - Cratons
  - Orogenics belts
  - Sedimentary basins
  - Oceanic margins
- **From a tectonic point of view**
  - Intraplate volcanism
  - Rifting
  - Hot spots
- **Deeper phenomena**
  - African Superplume
  - Geodynamical processes

- **This complex geology finds expression in density variations inside the lithosphere**

Scientific objectives

- **Improve the knowledge of these large geological domains and their implications on the upper mantle structures**
  - Study the density variations in the African mantle using gravity data

- **Characterize the geometry and nature of the main crustal domains of the Africa**

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- **Characterize the geometry and nature of the main crustal domains of the Africa**

Working Guidelines

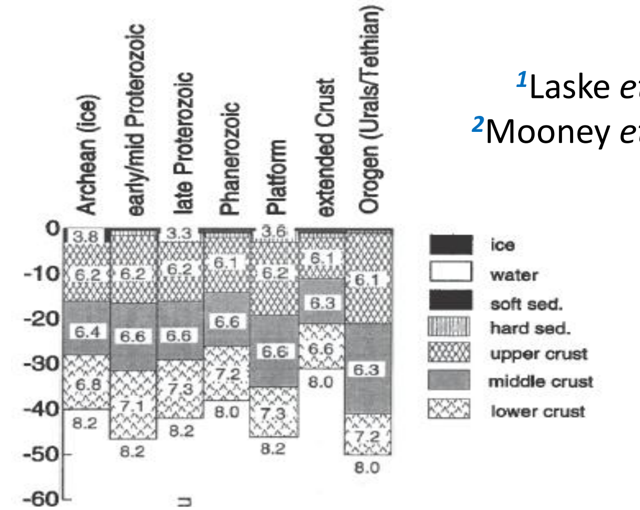
- **Two-scale study : Continental and Regional**
  - A lithospheric-scale study requires the availability of consistent data on a large scale
  - Using data from space missions dedicated to the study of the Earth gravity field

- **Three space missions were dedicated to the study of the Earth gravity field: CHAMP, GRACE and GOCE**

- **We choose to use data from the space mission GOCE**
  - The most recent
  - Aimed to provide an homogeneous and global model of the static gravity field with unprecedented high resolution and accuracy
  - For the first time, GOCE provides measurements of gravity gradients at a global scale

3D density modeling of the African plate

- **Combination of two global models mainly based upon seismology**
  - The Global Digital Map of Sediment Thickness[1]
  - CRUST2.0 [2]



MOONEY ET AL.: CRUST 5.1—A GLOBAL CRUSTAL MODEL AT 5° × 5°

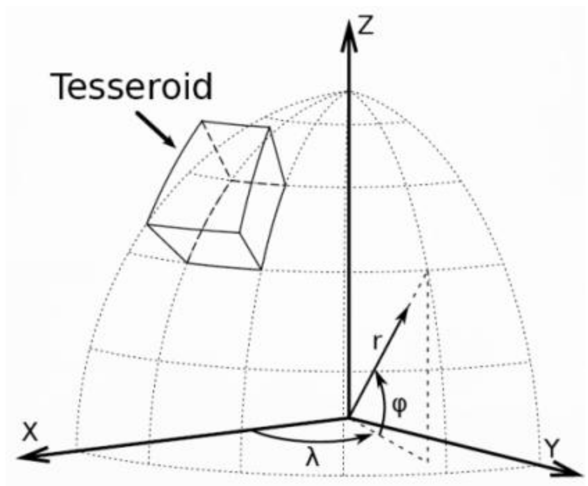
[1]Laske *et al*, 1997
[2]Mooney *et al*, 1998

- **We combine two models because:**
  - They were obtained independently from gravity data
  - GDMST more precise than CRUST2.0 for sedimentary layers
  - We used density variations converted from these seismological velocity models

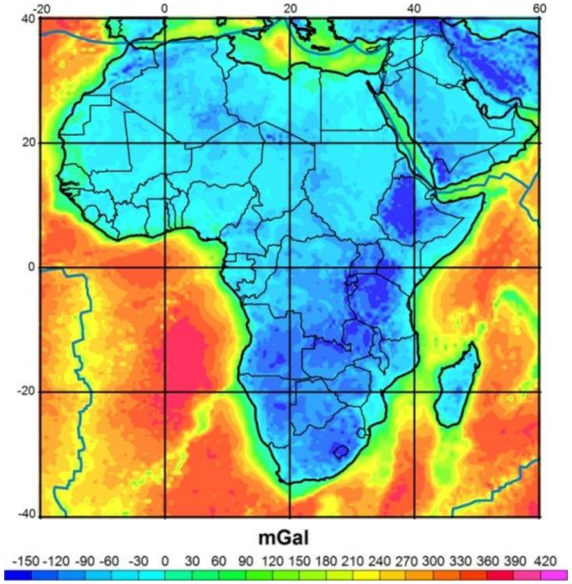
- **3 sedimentary and 3 cristalline crust layers**

- **Discretization using spherical prisms**
  - To consider the Earth curvature
  - Spatial resolution 1°x1°

- **Computation using Tesseroid software [3]**



[3]Uieda *et al*, 2010



Observed Bouguer anomaly map

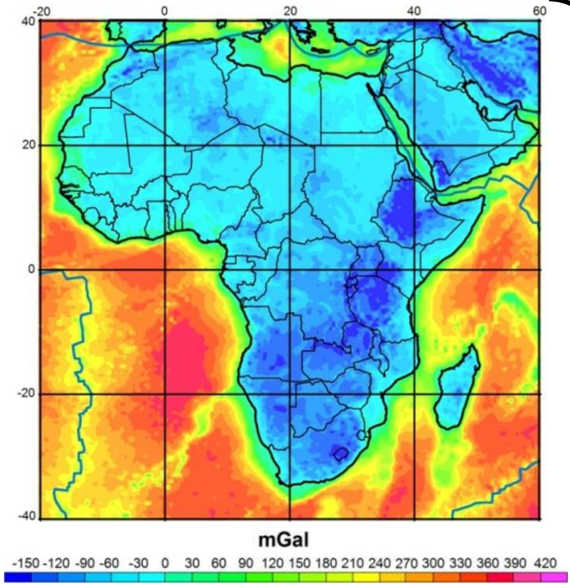
Observed Bouguer anomaly

-

Computed Bouguer anomaly map

=

Residual Anomaly



Observed Bouguer anomaly map

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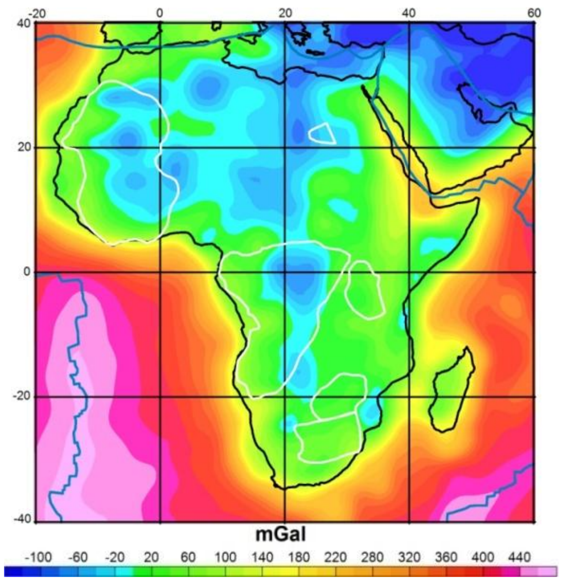

Computed Bouguer anomaly map

Observed Bouguer anomaly

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Computed Bouguer anomaly map

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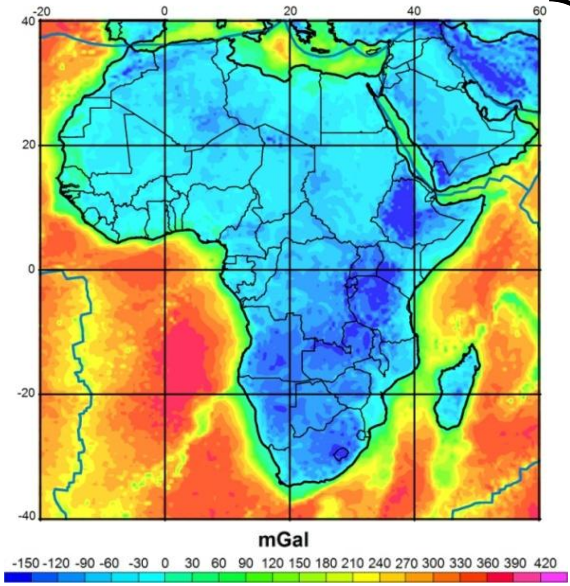
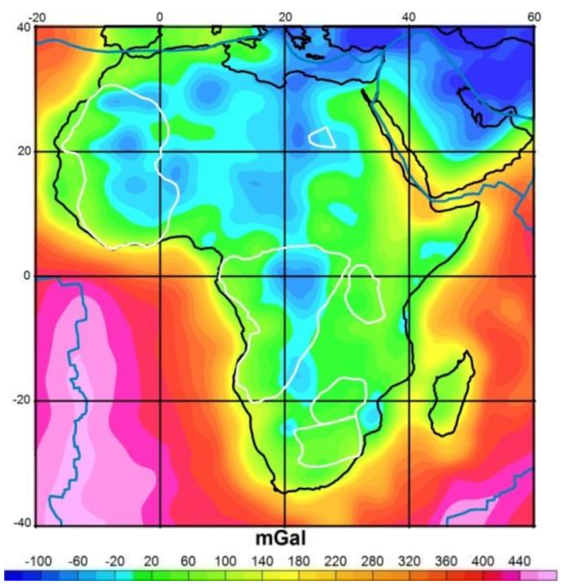
Residual Anomaly



Observed Bouguer anomaly map



Computed Bouguer anomaly map

Observed Bouguer anomaly

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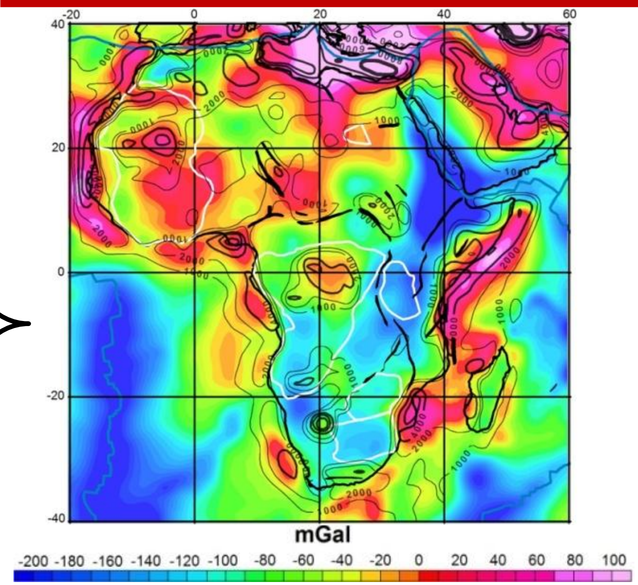
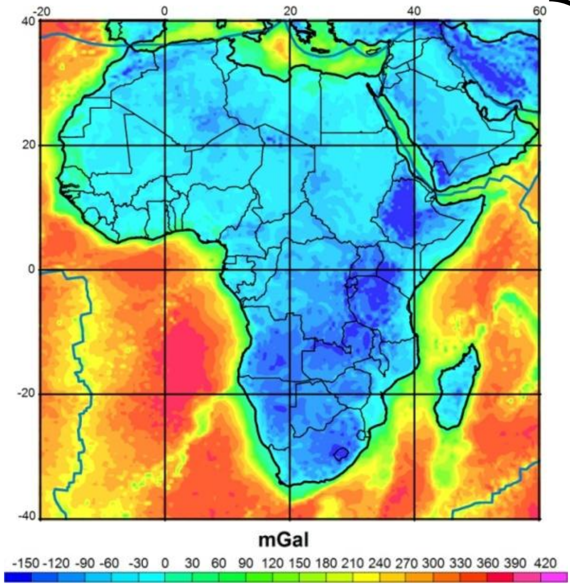
Computed Bouguer anomaly map

=

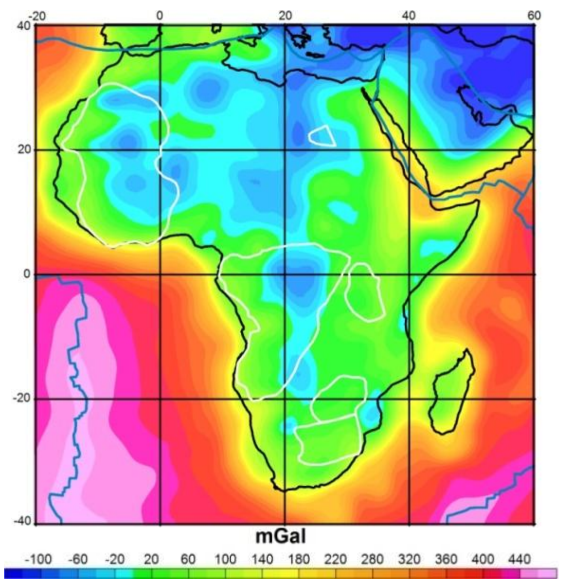
Residual Anomaly



Residual anomaly

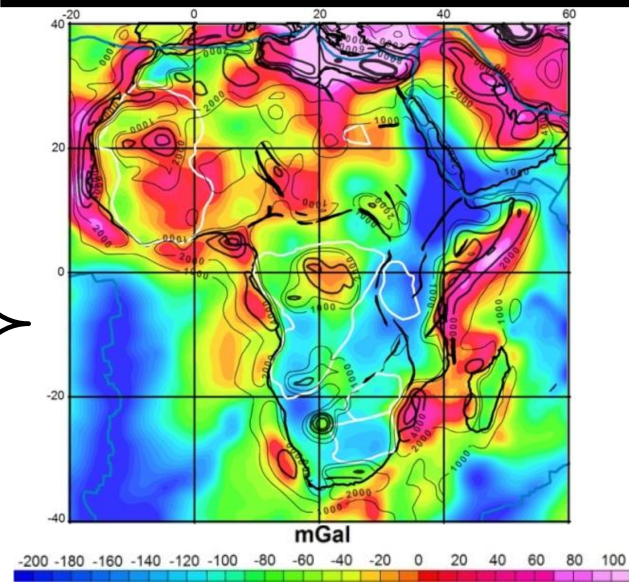


Observed Bouguer anomaly map



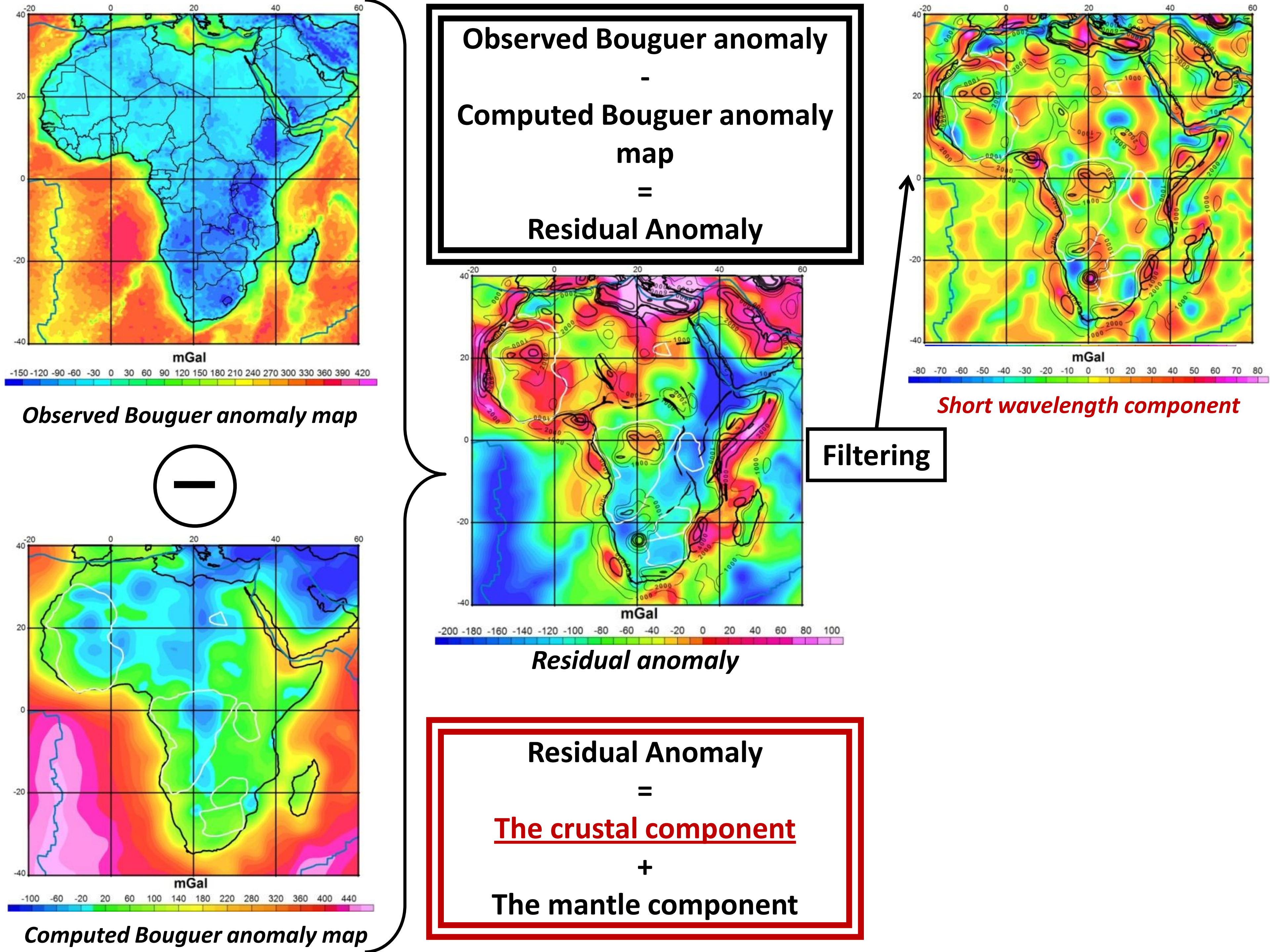
Computed Bouguer anomaly map

Observed Bouguer anomaly
-
Computed Bouguer anomaly map
=
Residual Anomaly

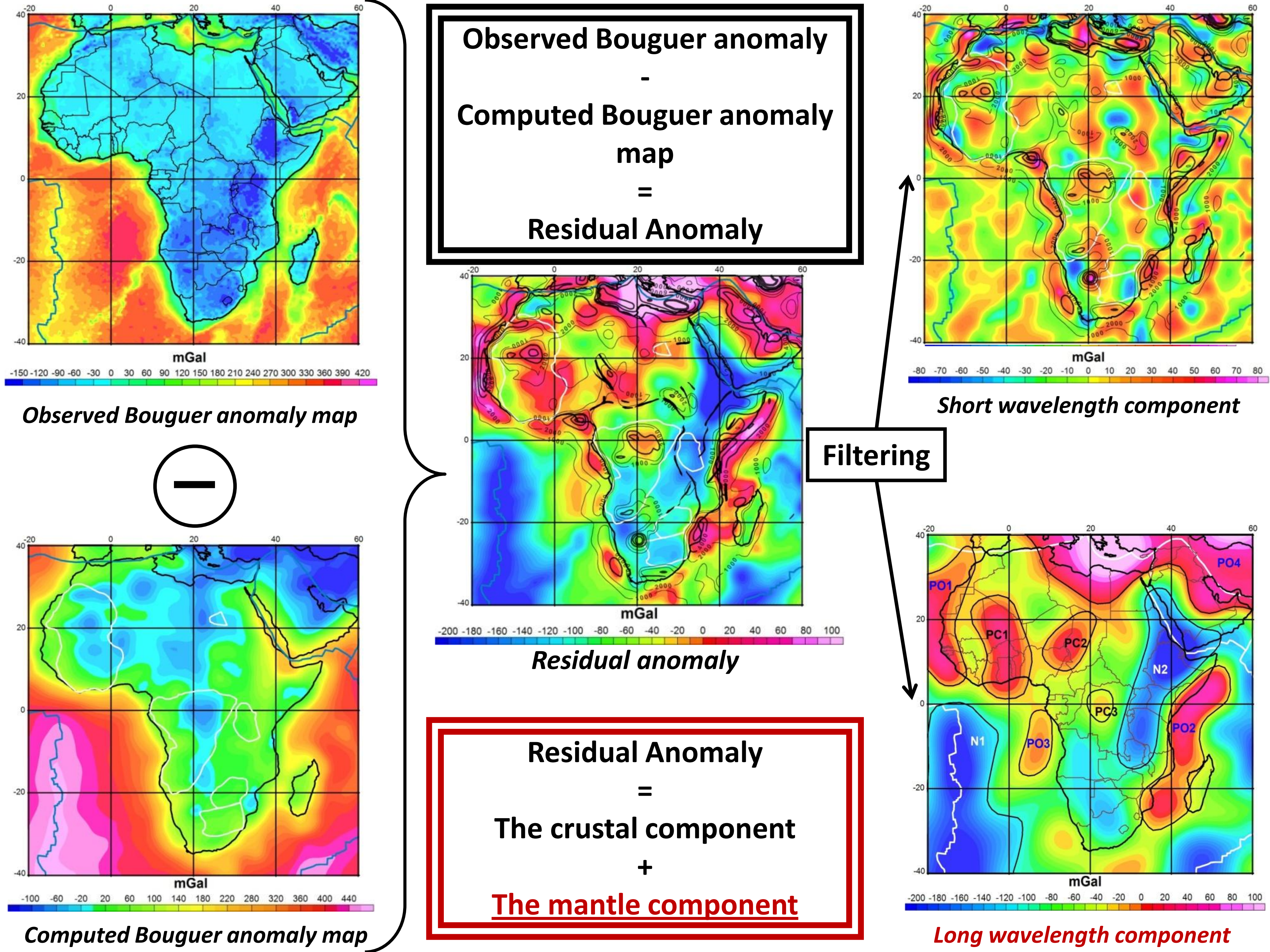


Residual anomaly

Residual Anomaly
=
The crustal component
+
The mantle component



Observed Bouguer anomaly
-
Computed Bouguer anomaly map
=
Residual Anomaly
mGal
-150 -120 -90 -60 -30 0 30 60 90 120 150 180 210 240 270 300 330 360 390 420
Observed Bouguer anomaly map
mGal
-100 -60 -20 20 60 100 140 180 220 280 320 360 400 440
Computed Bouguer anomaly map
mGal
-200 -180 -160 -140 -120 -100 -80 -60 -40 -20 0 20 40 60 80 100
Residual anomaly
Filtering
mGal
-80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80
Short wavelength component
Residual Anomaly
=
The crustal component
+
The mantle component


Observed Bouguer anomaly
-
Computed Bouguer anomaly map
=
Residual Anomaly
mGal
-150 -120 -90 -60 -30 0 30 60 90 120 150 180 210 240 270 300 330 360 390 420
Observed Bouguer anomaly map
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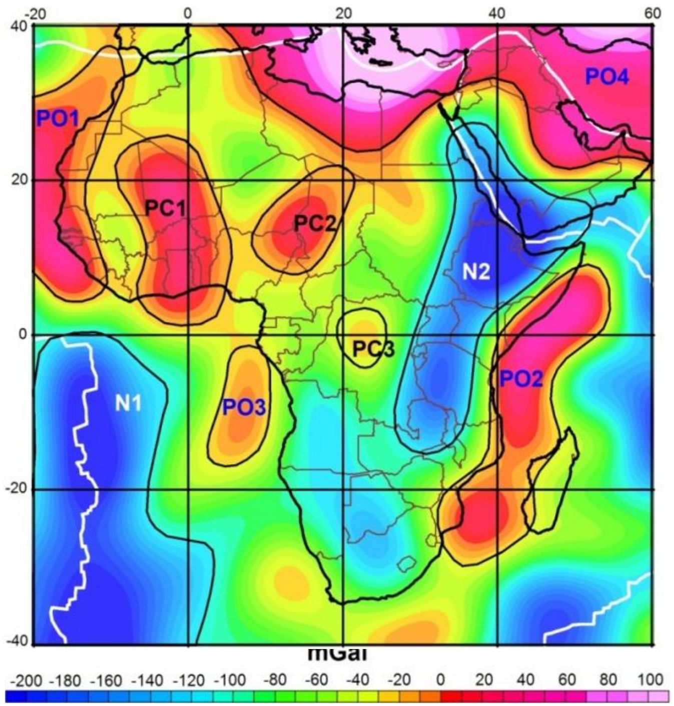
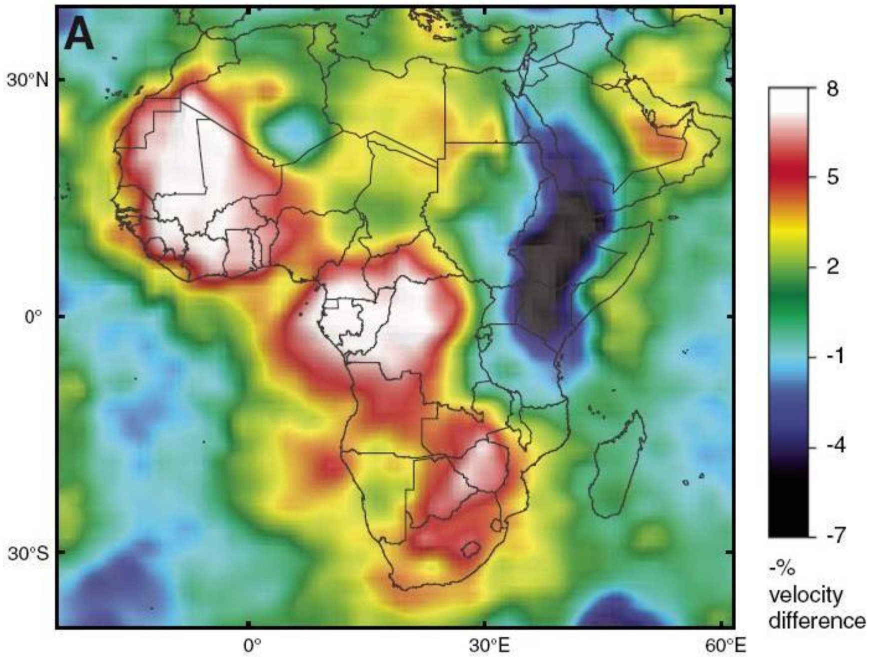
-80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80
Short wavelength component
PO1
PO4
PC1
PC2
N2
PC3
N1
PO3
PO2
mGal
-200 -180 -160 -140 -120 -100 -80 -60 -40 -20 0 20 40 60 80 100
Long wavelength component

Mantle Bouguer anomaly

Gravity effect of the African mantle



Tomographic image (S-wave velocity [Vs]) of Africa, 100 to 175 km depth slice [1]

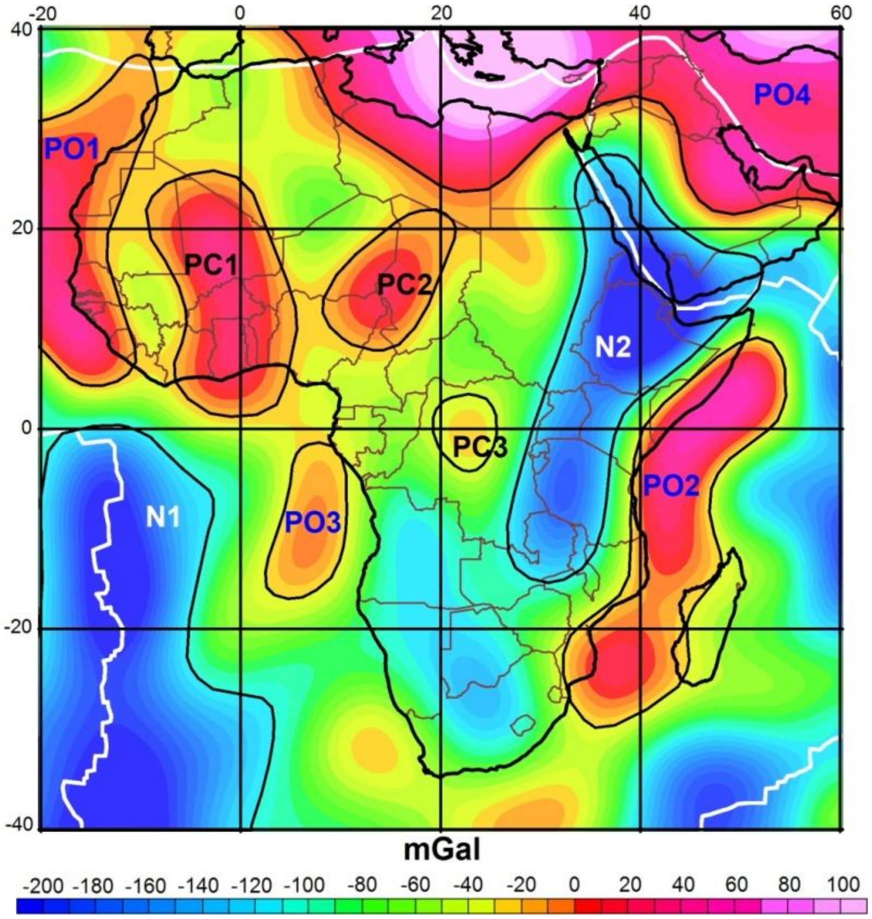


[1]Begg *et al.*, 2009

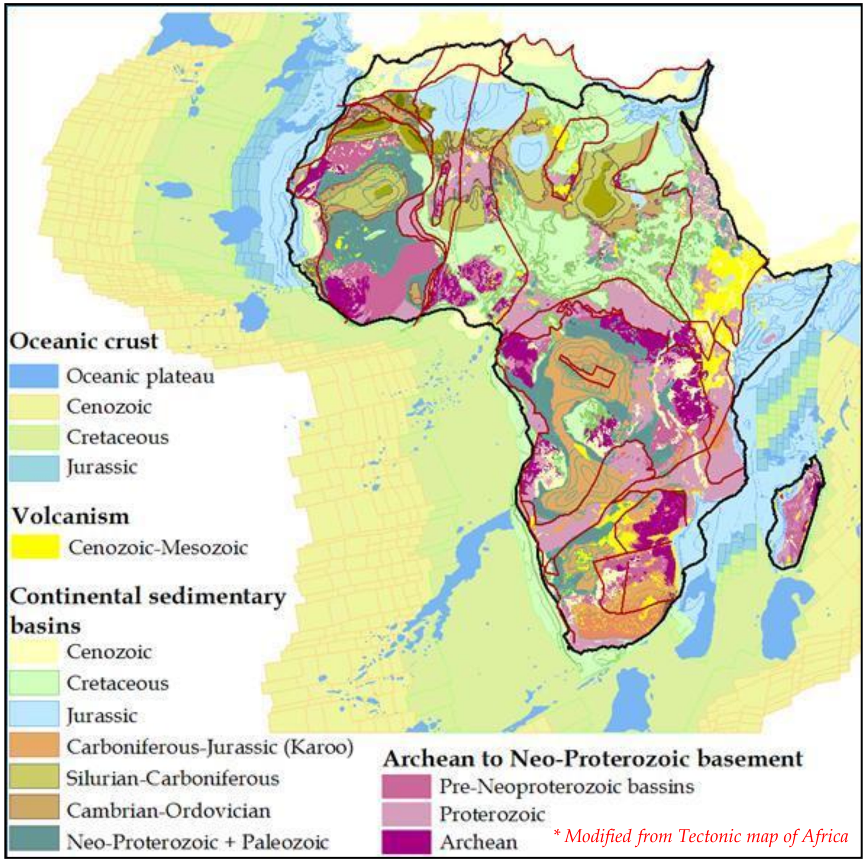
- **Comparison**
  - Good consistency for a large part of Africa
    - ✓ Rift / West African craton / Mid-Atlantic ridge / Arabia
  - Significant discrepancies over:
    - ✓ Congo craton and South Africa
- **Seismology and gravity do not have the same investigation depth**
  - Interferences between deep and shallow mantellic sources in gravity data

Mantle Bouguer anomaly

Gravity effect of the African mantle



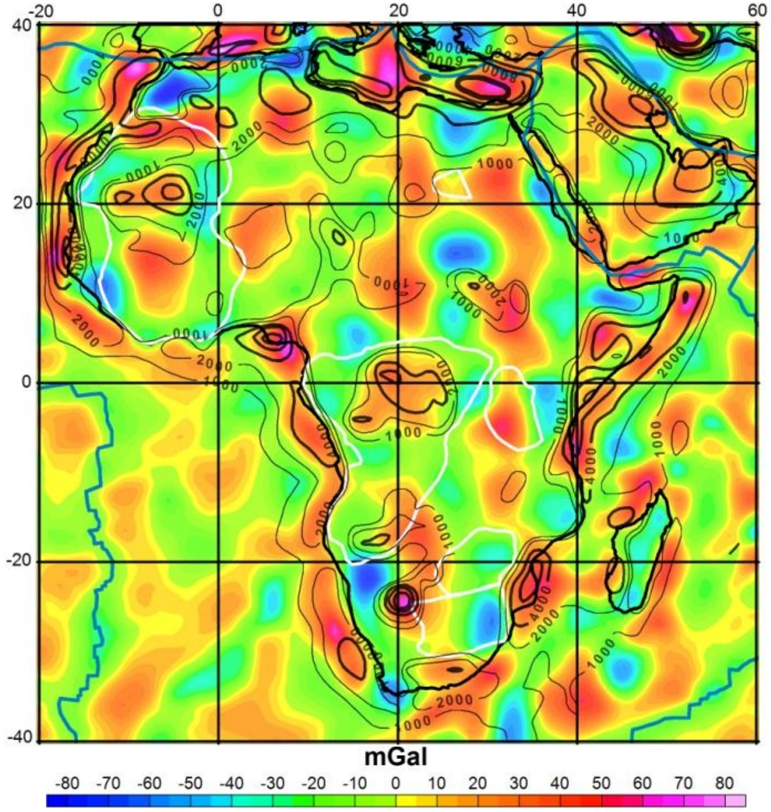
*Simplified geological map of Africa**



- **Main results:**
  - **Positive anomaly associated to the West African craton**
  - **Signature associated to Jurassic margins different from younger margins**

What about the crust? … shorter wavelengths

Short wavelength component of the Residual anomaly map



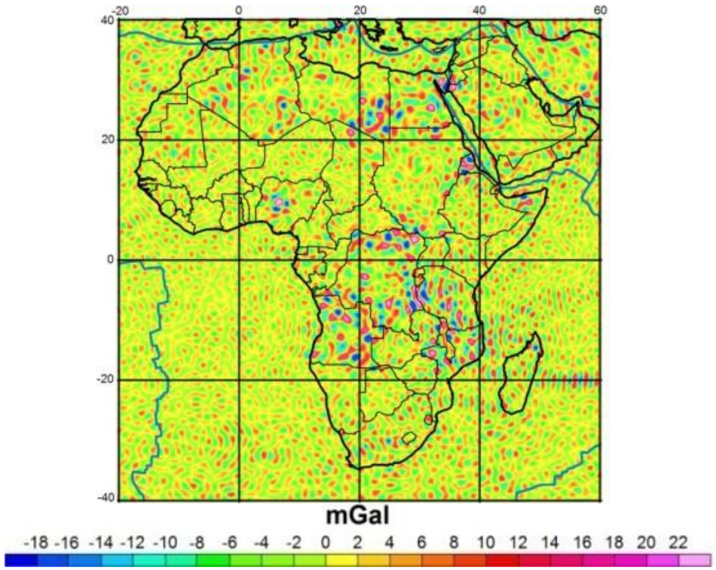
- **represents differences between our crustal model and the "real" African crust**
- **Sedimentary basins and oceanic margins clearly contribute to this residual**
- **started using the gradient data of GOCE mission**

- **Gravity gradients more sensitive to shallow structures than gravity data**

The regional scale study

- **Selection criteria**
  - Oceanic and continental domain
  - Reflect the complexity of the African geology
  - Area where the GOCE gravity model significantly improves the existing EGM2008.

Difference between EGM2008 and GOCE models



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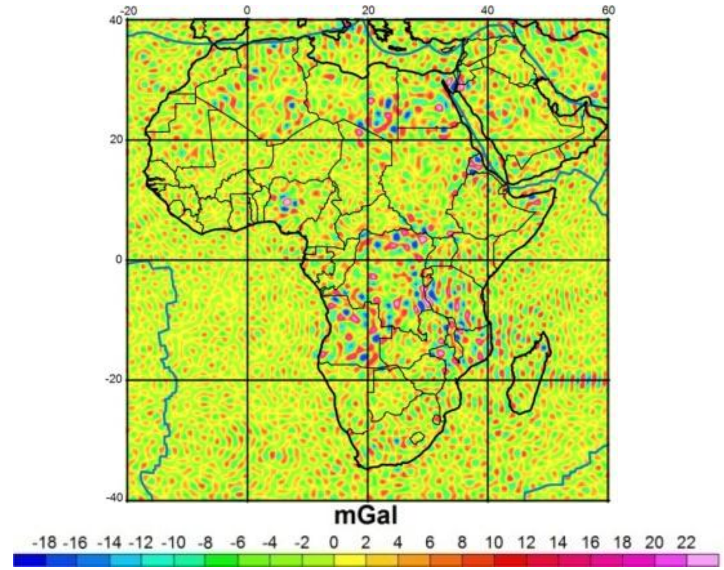
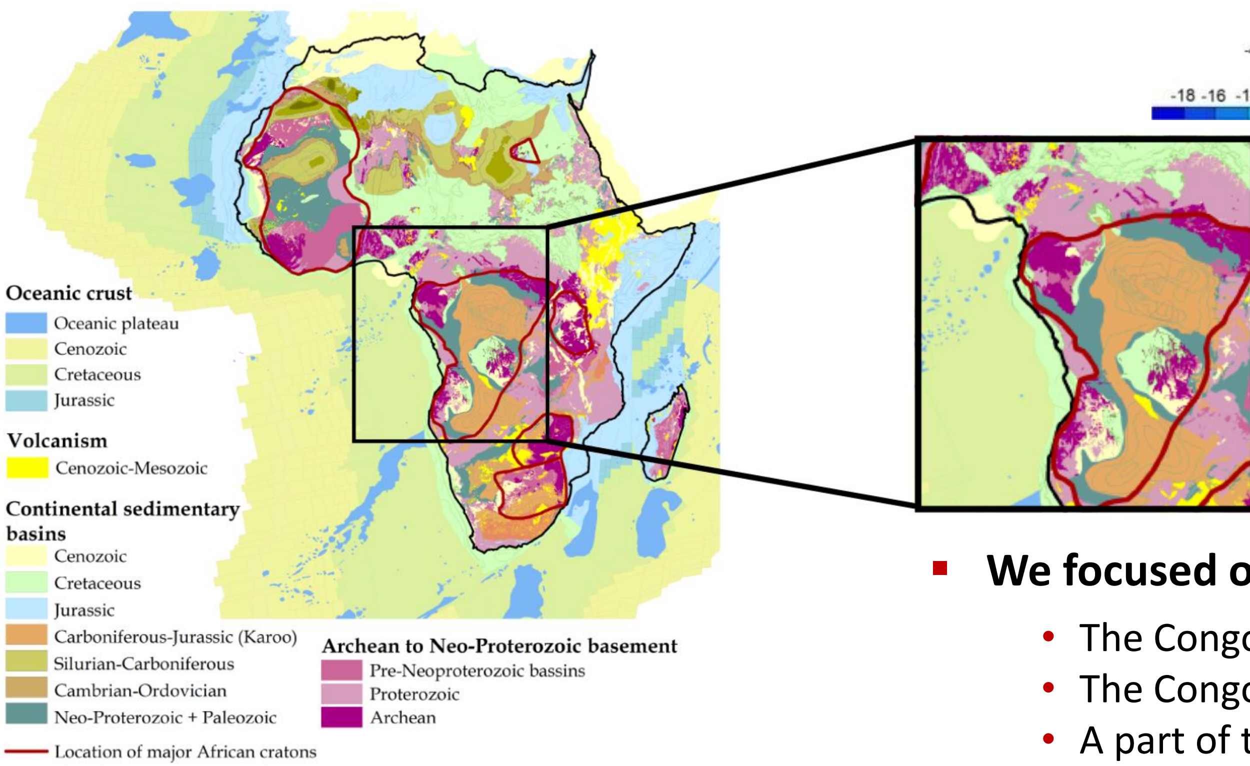




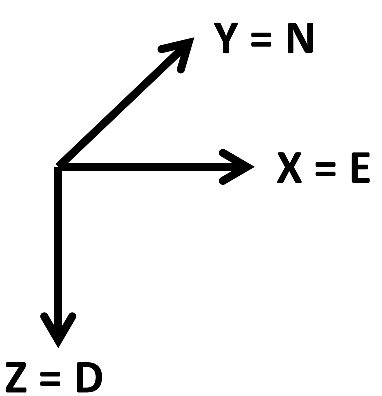
- **We focused our study on a 30°x30° area:**
  - The Congo craton
  - The Congo sedimentary basin
  - A part of the Cameroon volcanic line

3D density modeling

- **Combination of the same two global models**
  - The Global Digital Map of Sediment Thickness
  - CRUST2.0

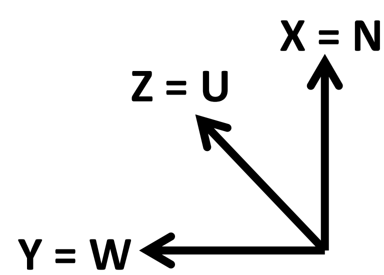
- **Modeling and computation using 3D Geomodeller software (©Intrepid-geophysics,BRGM)**
  - Allowed gravity and gradiometric forward modeling and inversion processes
  - Software dedicated to geological cartography
    - ✓ **Planar geometry approximation**

- **Geomodeller frame is different from LNOF**



X = east oriented
Y = north oriented
Z = down oriented

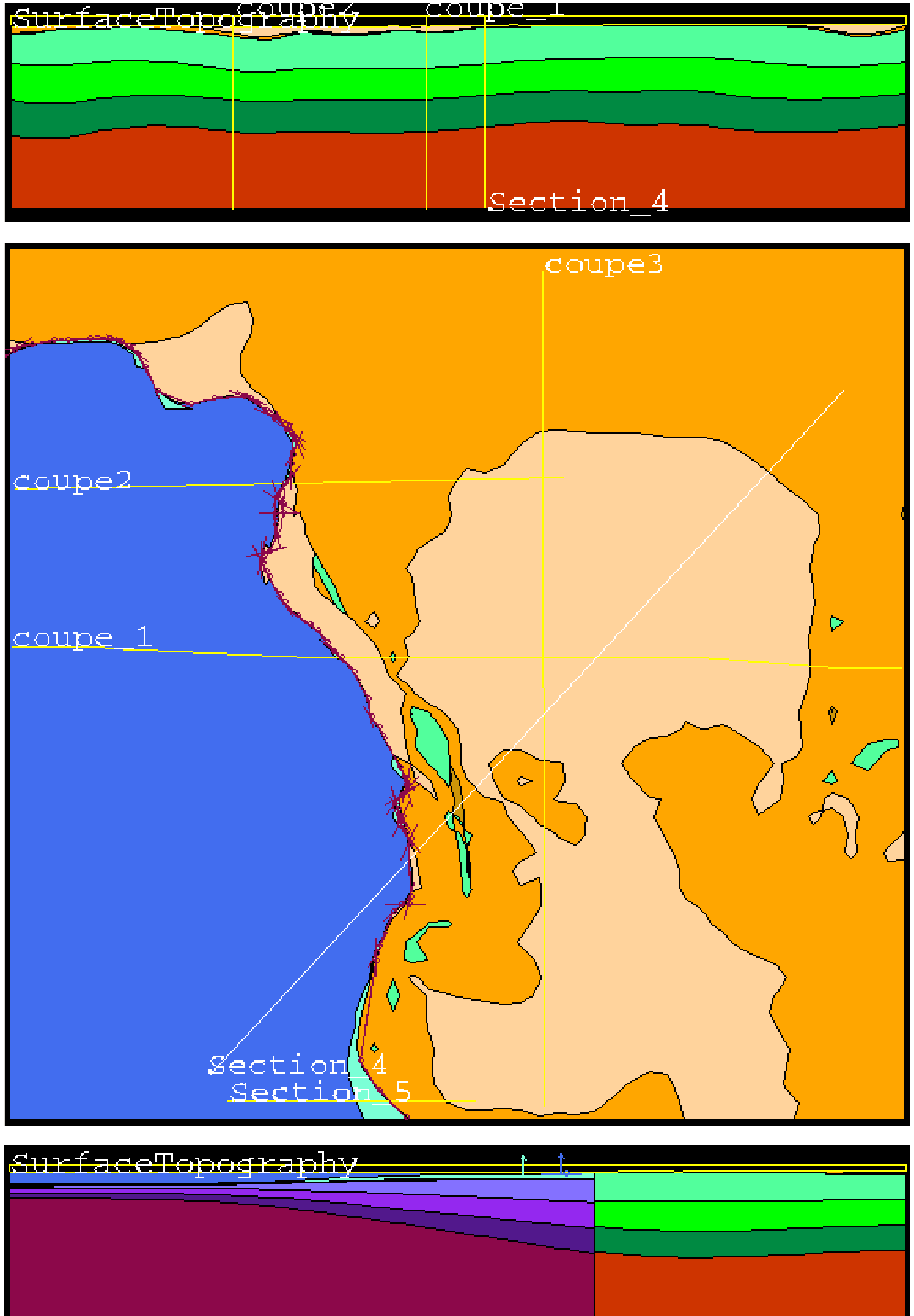
Geomodeller frame (E,N,D)

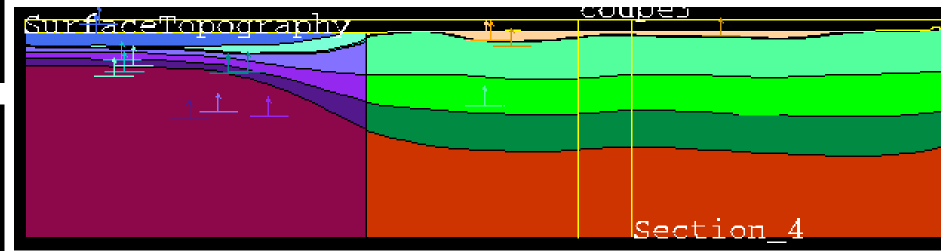


X = north oriented
Y = west oriented
Z = up oriented

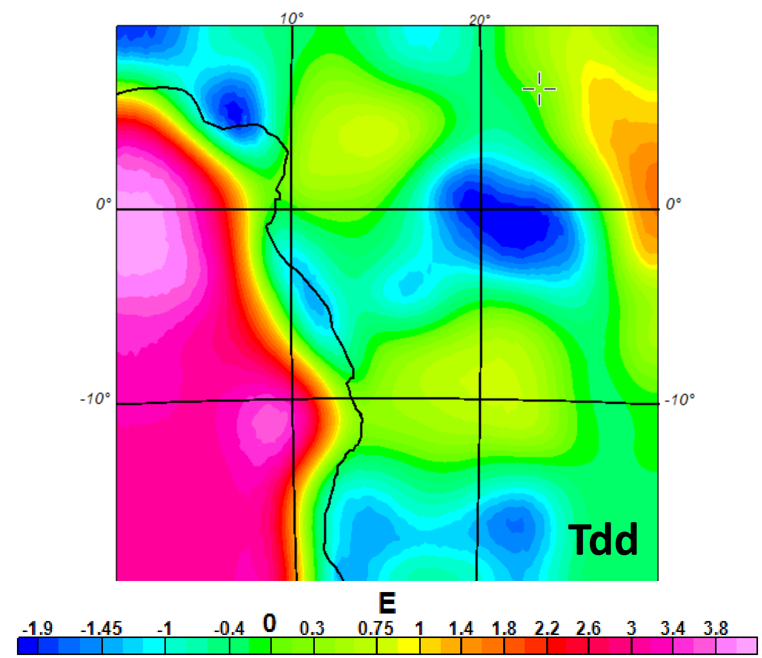
Local North Oriented Frame (X,Y,Z)

3D density modeling

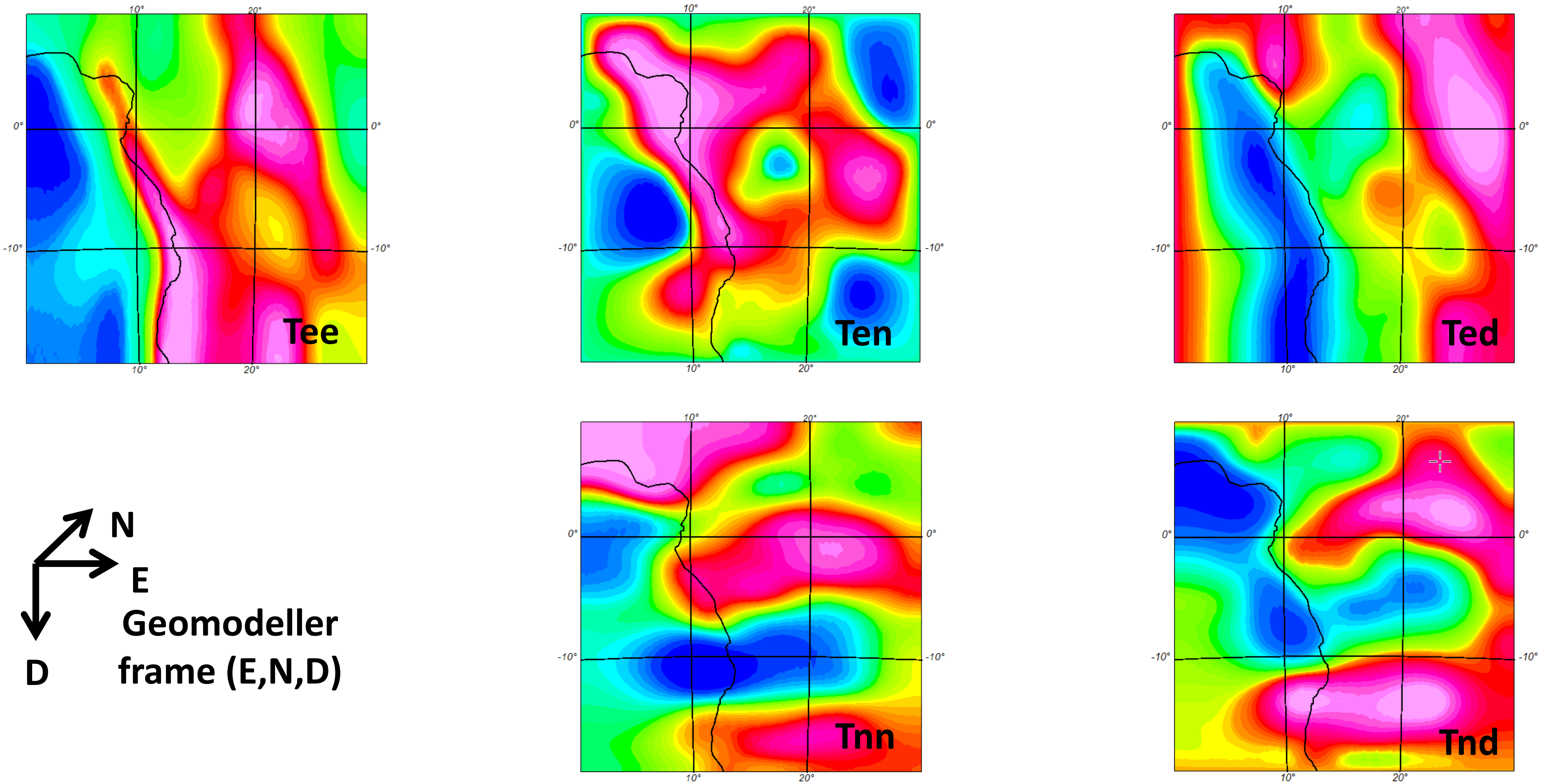


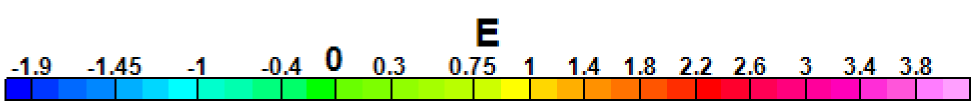


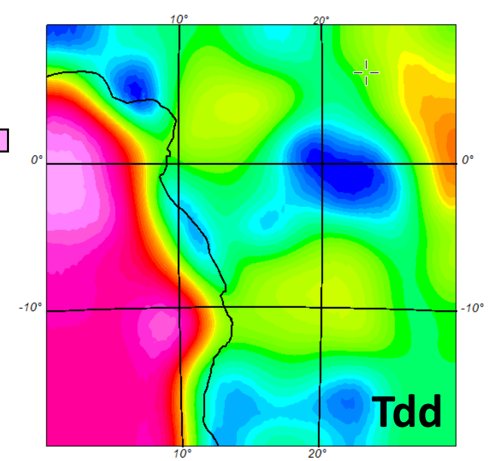
Computation of gradiometric effects generated by 3D model



Tdd gradient component







Gradiometric effect of 3D density model

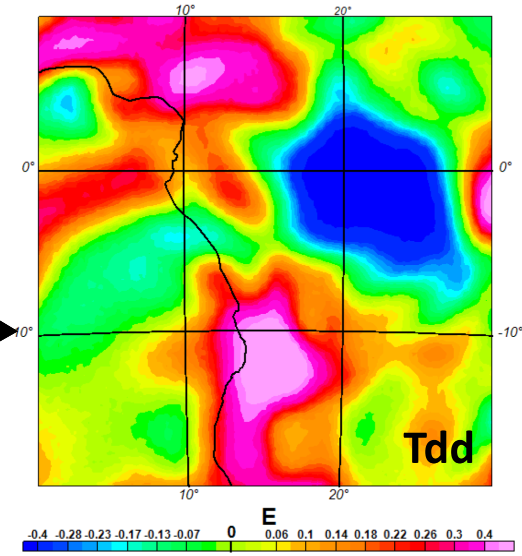
Gradiometric Bouguer anomalies

GOCE gravity gradients in spherical coordinates

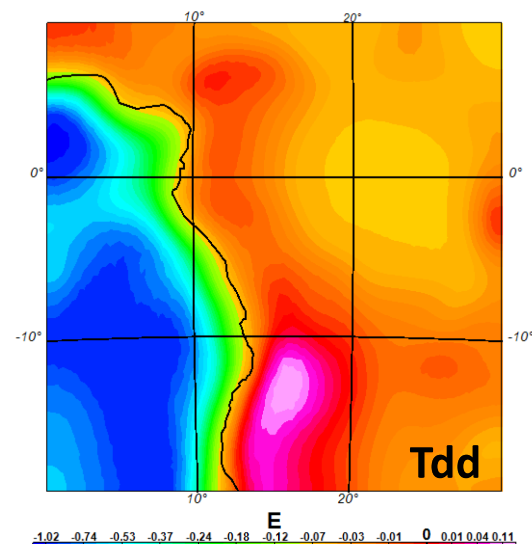
→

First step:
1- Relocate in geomodeller frame
2- Mercator projection using GEOSOFT

→



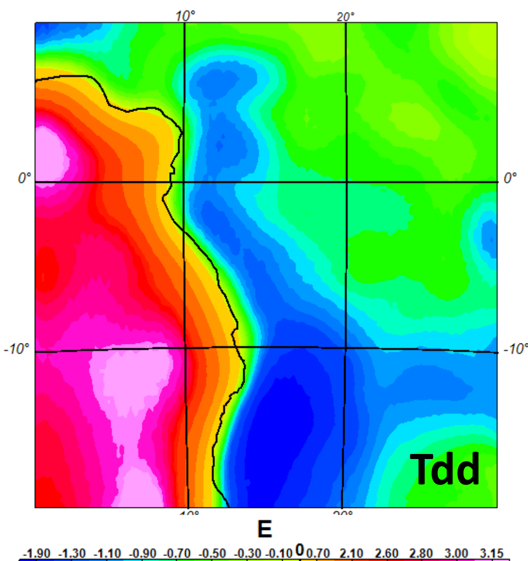
Free air gradient In projected coordinates



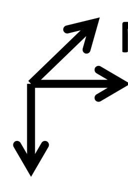
Gradiometric effect of bathymetry and topography

Second step:
Compute and remove the topographic and bathymetric effects

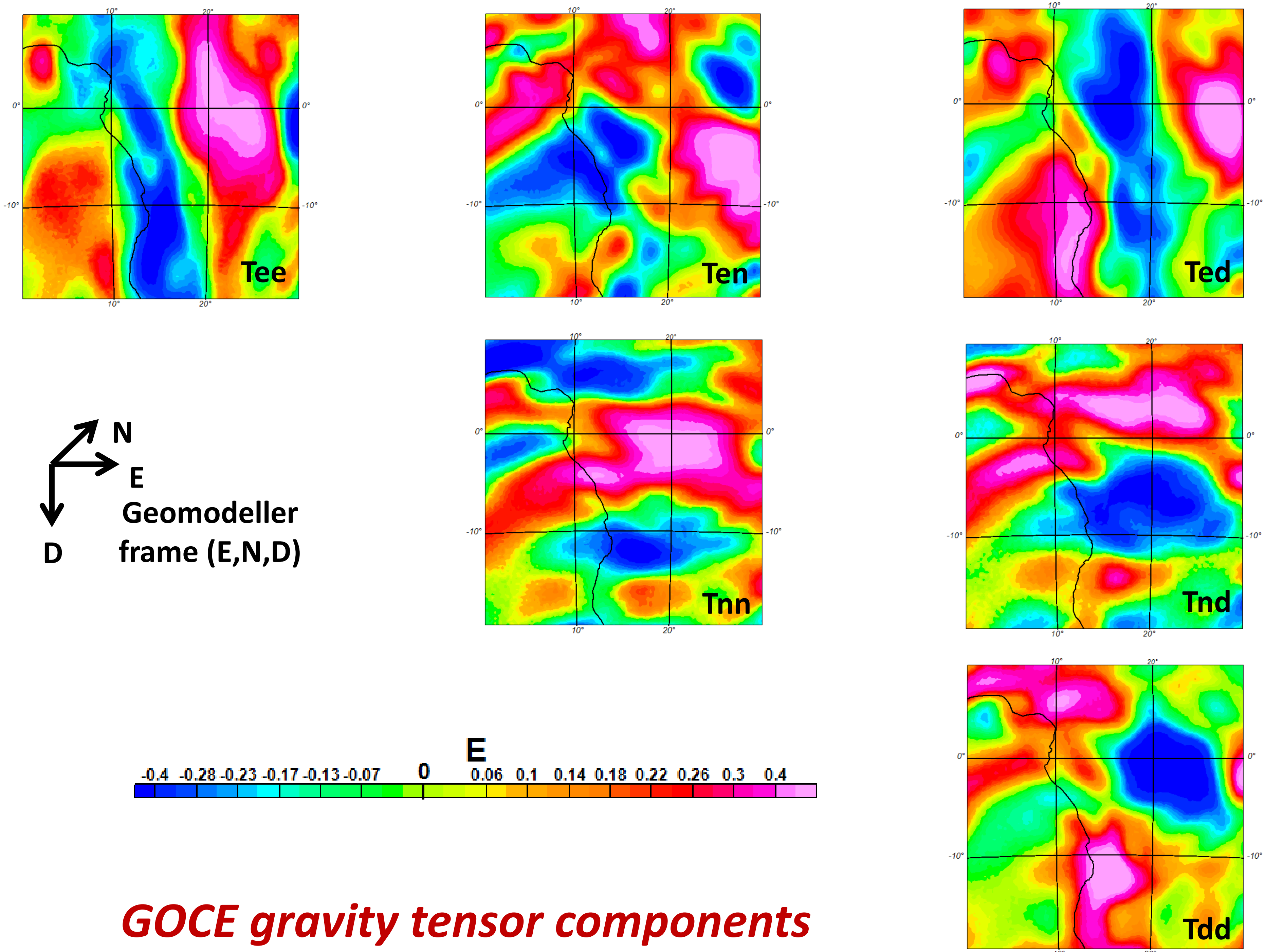
←



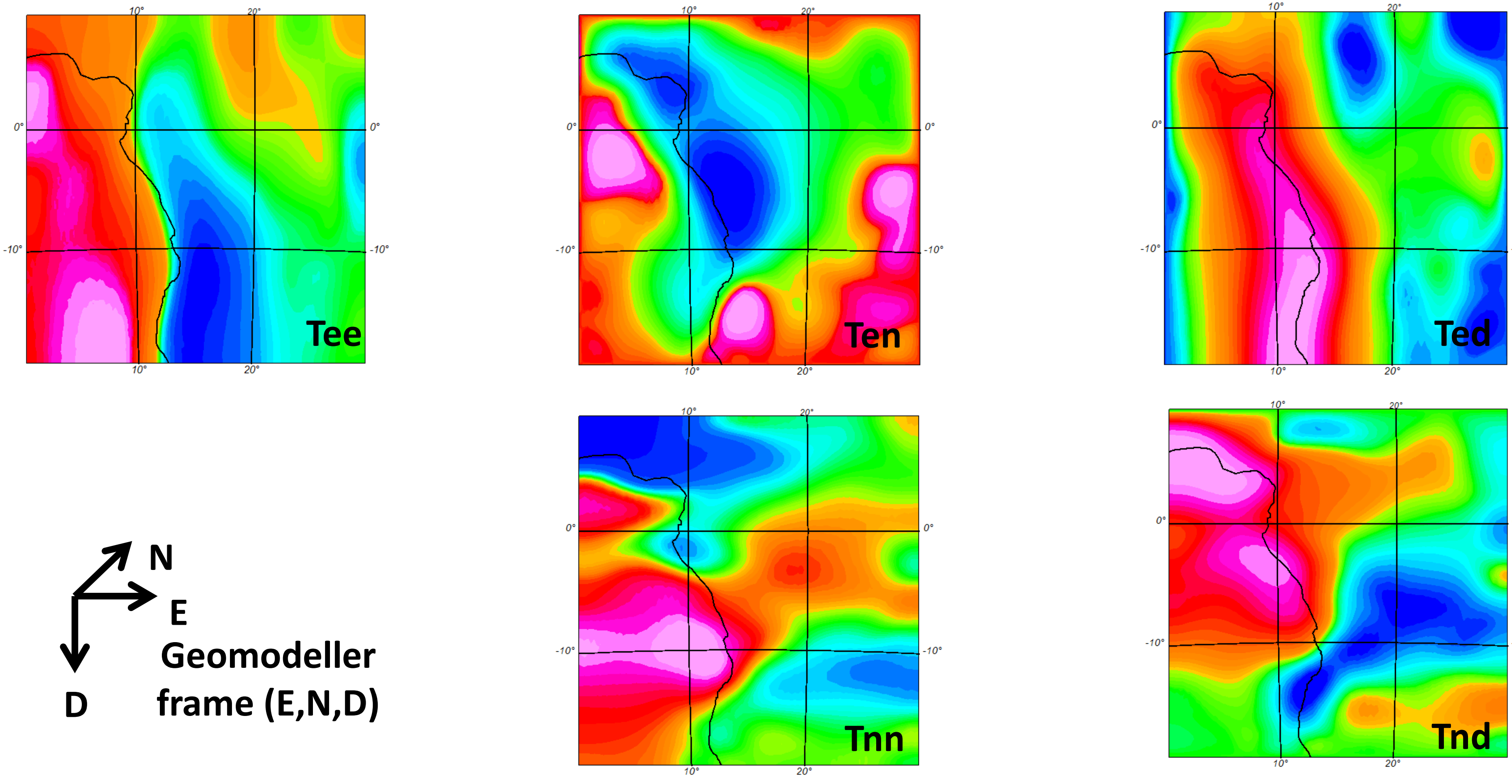
Bouguer gradient

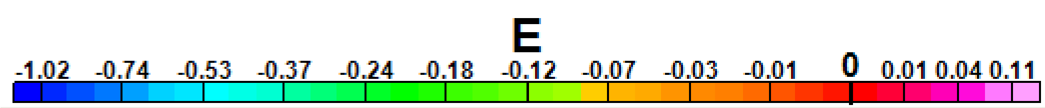


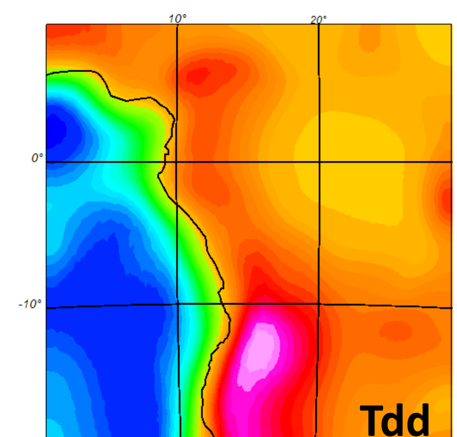
Geomodeller frame (E,N,D)



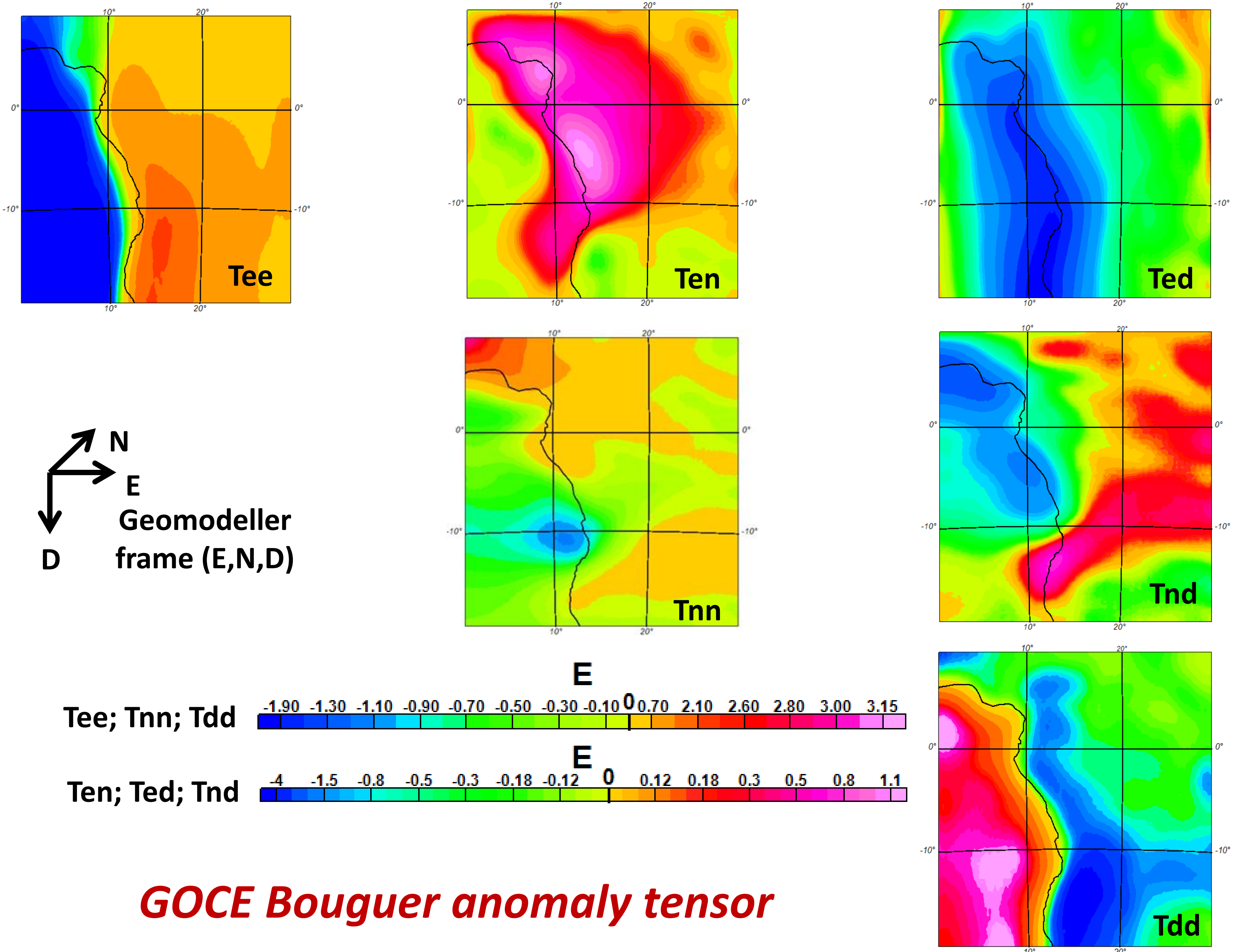
GOCE gravity tensor components





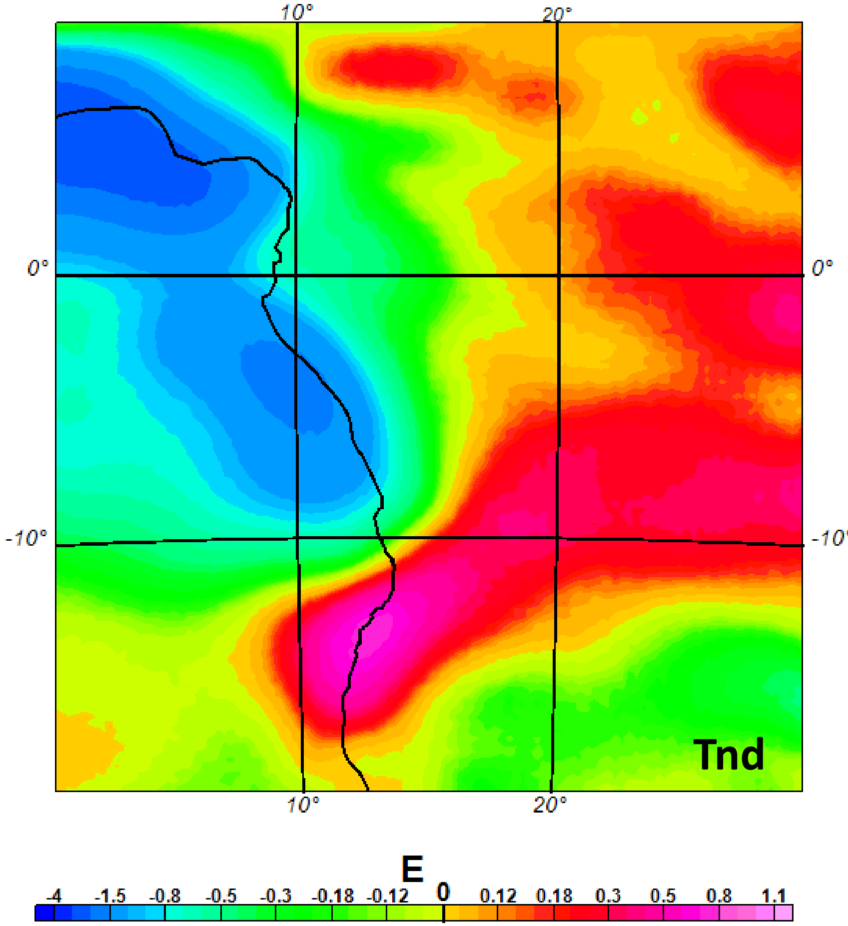


Topographic and bathymetric reduction for GOCE gravity tensor components

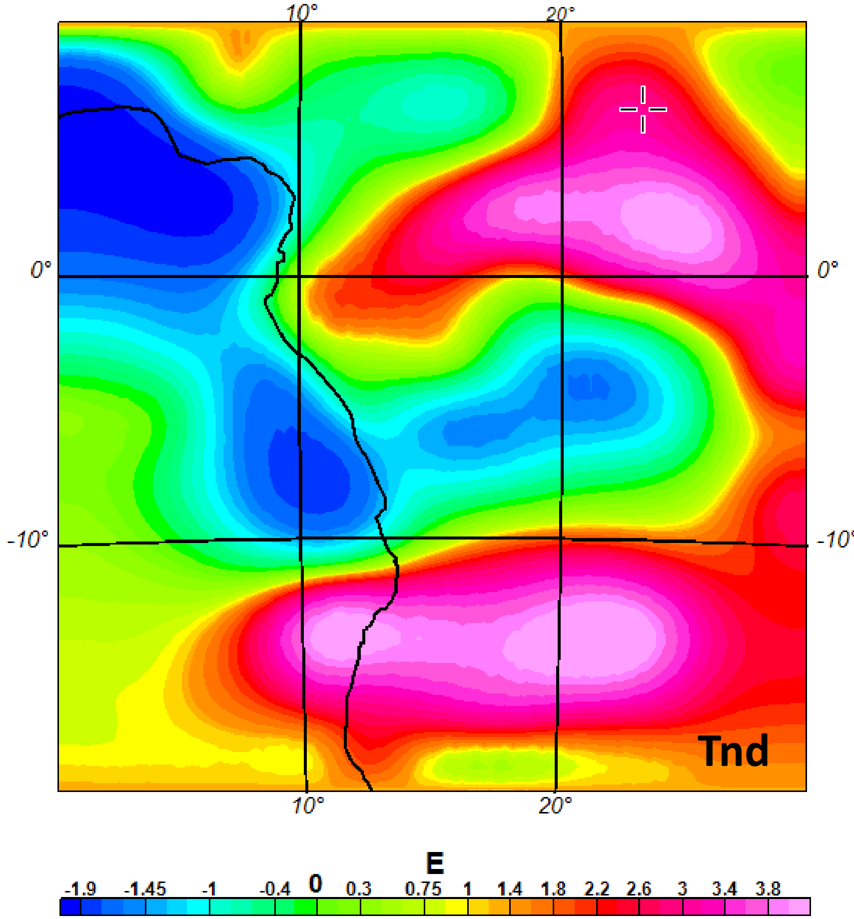


GOCE Bouguer anomaly tensor

Comparison between observed and computed gradients



Observed Bouguer gradient



Computed Bouguer gradient

- **Good consistency between these two gradients**
  - **We can introduce GOCE gradients in inversion processes in order to improve our crustal model**

Summary of the different results presented

- **We compute the gravity anomaly of a spherical crustal 3D model of the entire African plate**

- **We derive the first map of the African mantle gravity response**
  - New gravity information on the African mantle is compatible and complementary to previous seismological results
  - We observe interesting mantellic signatures for West African and Jurassic oceanic margins

- **We computed the gradiometric effects of a planar 3D model of the craton and the sedimentary basin of Congo**

- **We derived from GOCE gravity tensor the different Bouguer gradients**
  - Currently improve the 3D model through inversion processes
    - ✓ Using gravity data
    - ✓ Using gradiometric data

    - ✓ Gradiometric data should allowed us to better characterize the poorly known geometry of the Congo sedimentary basin

Thank you for your attention