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 \(^2\)

- 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 crystalline crust layers

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

- Computation using Tesseroid software \(^3\)

\(^1\)Laske et al, 1997
\(^2\)Mooney et al, 1998
\(^3\)Uieda et al, 2010
Observed Bouguer anomaly -
Computed Bouguer anomaly map
= Residual Anomaly
Observed Bouguer anomaly - Computed Bouguer anomaly map = Residual Anomaly
Observed Bouguer anomaly map
- Computed Bouguer anomaly map = Residual Anomaly
Observed Bouguer anomaly map
- Computed Bouguer anomaly map = Residual Anomaly

Residual Anomaly = The crustal component + The mantle component
Observed Bouguer anomaly map

- Computed Bouguer anomaly map
  = Residual Anomaly

Filtering

Residual Anomaly

= The crustal component
+ The mantle component
Observed Bouguer anomaly map

- Computed Bouguer anomaly map

= Residual Anomaly

Filtering

Residual Anomaly

= The crustal component

+ The mantle component

Observed Bouguer anomaly map

Computed Bouguer anomaly map

Short wavelength component

Long wavelength component
**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

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1. Begg et al., 2009
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.
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.

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

\[\begin{align*}
X &= \text{east oriented} \\
Y &= \text{north oriented} \\
Z &= \text{down oriented}
\end{align*}\]

\[\begin{align*}
X &= \text{north oriented} \\
Y &= \text{west oriented} \\
Z &= \text{up oriented}
\end{align*}\]

Geomodeller frame \((E,N,D)\)  
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**

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

**Second step:**
Compute and remove the topographic and bathymetric effects

GOCE gravity gradients in spherical coordinates

Free air gradient in projected coordinates

Bouguer gradient

Gradiometric effect of bathymetry and topography
GOCE gravity tensor components
Topographic and bathymetric reduction for GOCE gravity tensor components
GOCE Bouguer anomaly tensor

E

Tee; Tnn; Tdd

Ten; Ted; Tnd

Geomodeller frame (E,N,D)
Comparison between observed and computed gradients

- 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