An integrated thermo-compositional model of the African cratonic lithosphere from gravity and seismic data

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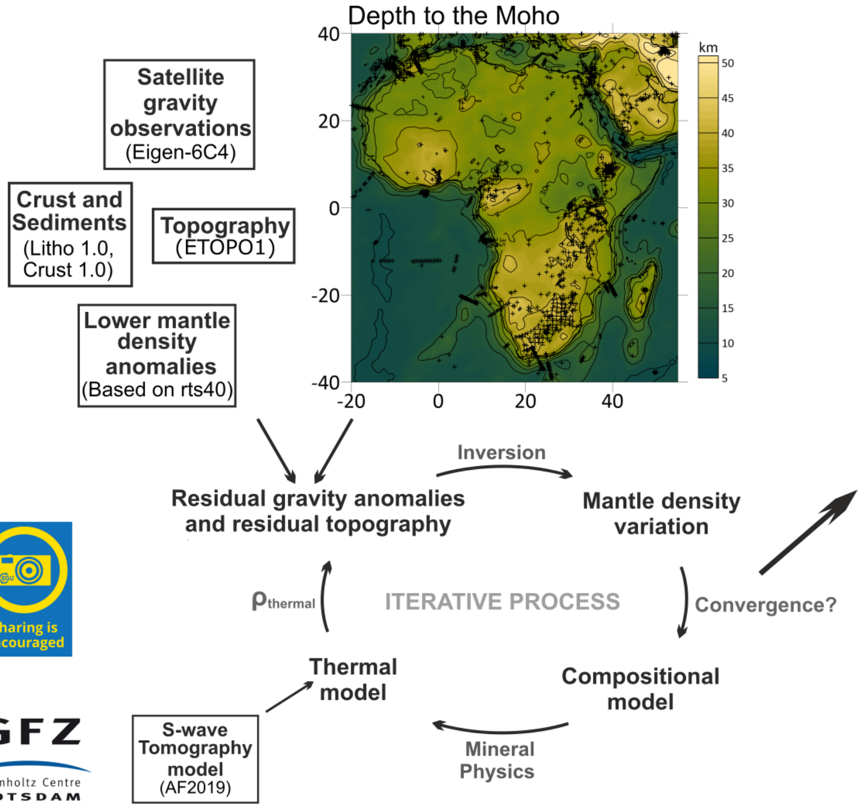
Inputs and Method



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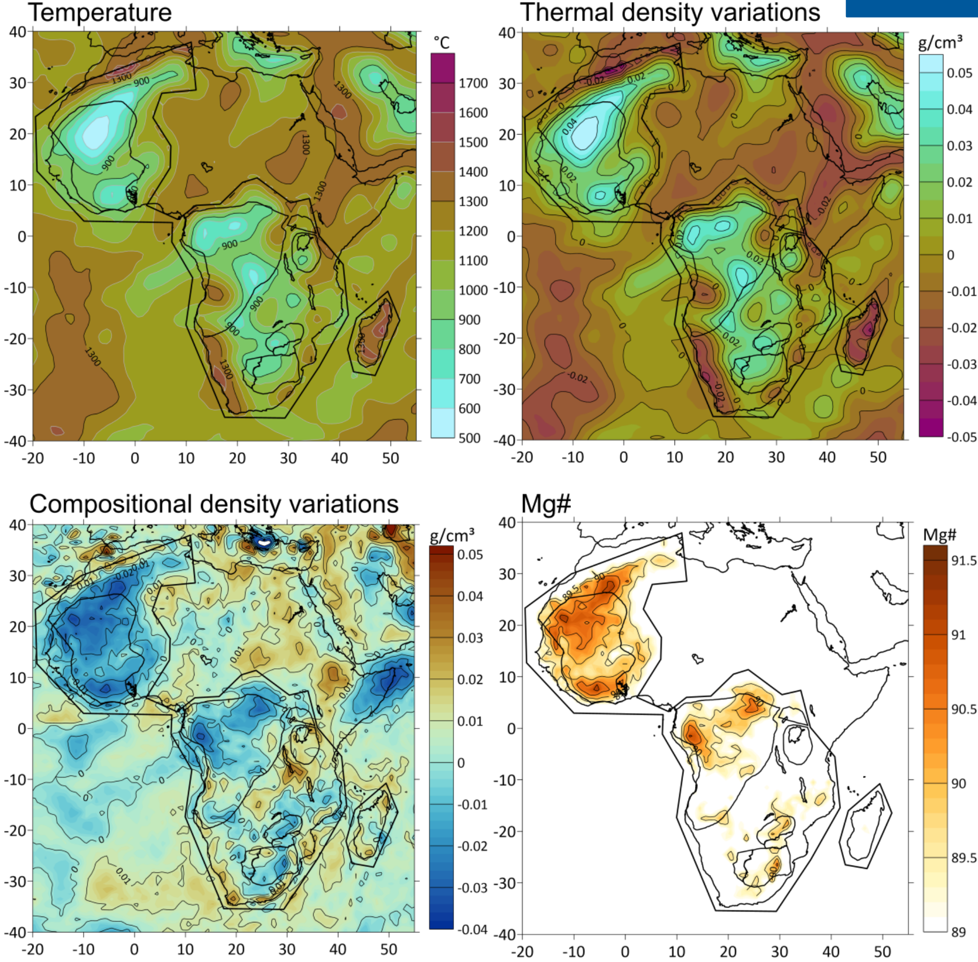
Results at 100 km



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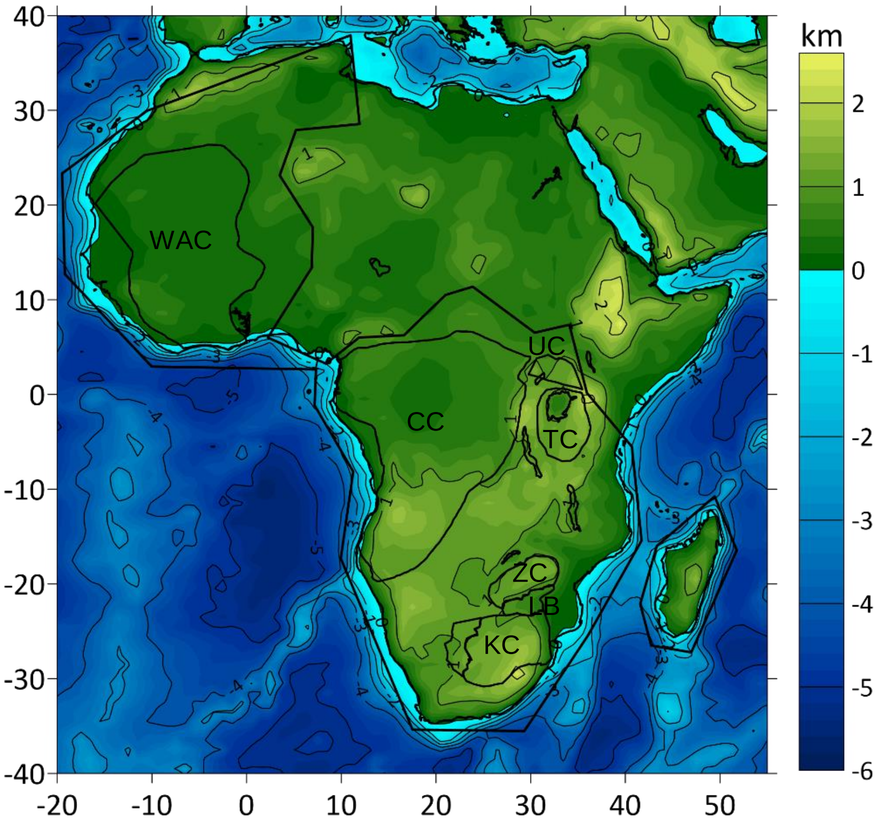
Introduction

- Cratons: ancient, stable parts of continental lithosphere
- Often buoyant despite low temperatures (density increase)
- Iso-pycnic hypothesis (Jordan et al., 1978): Fe depletion (compositional density decrease) balances effect of low temperatures (thermal density increase) in cratonic areas
- Just published: Integrated thermo-compositional model of the South American cratonic lithosphere (Finger et al., 2021; Model available here (external))
- New and extended datasets allow application of integrated iterative approach to Africa
- Presentation of current state of work
- Targets:
  - Assess density, temperature and composition (in terms of depletion) of African cratonic lithosphere and upper mantle
  - Also calculate Depth to the Moho and assess possible implied uncertainties
  - Compare to results from South America to link deep cratonic structures and their (different) evolution since break-up (future work)

Topography and Cratons



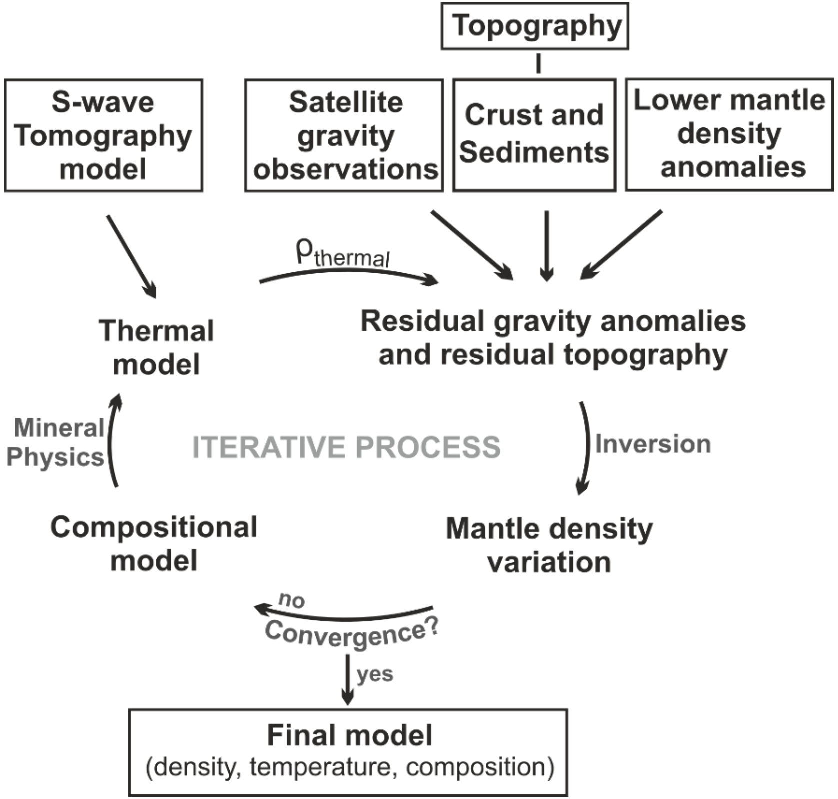
Cratons:

- CC – Congo
- KC – Kaapvaal
- LB – Limpopo Block
- UC – Uganda
- TC – Tanzania
- WAC – West African
- ZC – Zimbabwe

- Thick black polygon marks area where compositional changes in terms of Fe depletion are allowed in the integrated model

Cratons digitized from Begg et al. (2009) by N. Celli (pers. Communication)
Topography from ETOPO1 (Amante et Eakins, 2009)

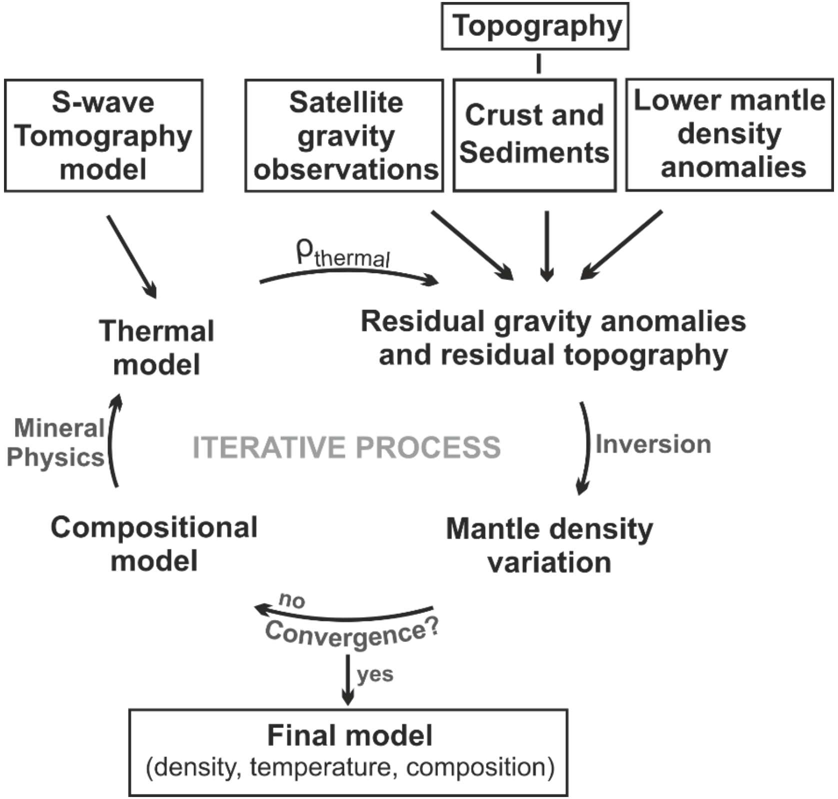
Method



Finger et al. (2021), modified from Haeger et al. (2019)

- Integrated iterative approach:
  - Recently applied to South America (Finger et al., 2021)
  - Based on Kaban et al. (2014), Tesauro et al. (2014)
  - For testing and uncertainties see Kaban et al. (2015), Finger et al. (2021)
  - Create self-consistent models of temperature, thermal and compositional density variations, and depletion in terms of Mg#
  - Mg# = %Mg / (%Mg + %Fe) in minerals

Method – Crust



Finger et al. (2021), modified from Haeger et al. (2019)

- Crustal model:
  - Interpolate Depth to Moho following Stolk et al. (2013) using topography (ETOPO1, Amante et Eakins, 2009), sediment thickness and density (Crust1.0, Laske et al., 2013) and available seismic data (Globig et al., 2012; Mooney et al., 2015 with updates up to 2019)
  - Calculate crustal gravity effect with densities from LITHO1.0 (Pasyanos et al., 2013)
  - Correct gravity observations (Eigen-6C4, Förste et al., 2014) for crustal effects and calculate residual topography
  - Correct residual fields for effects from the deep mantle based on rts40 (Ritsema et al., 2011)

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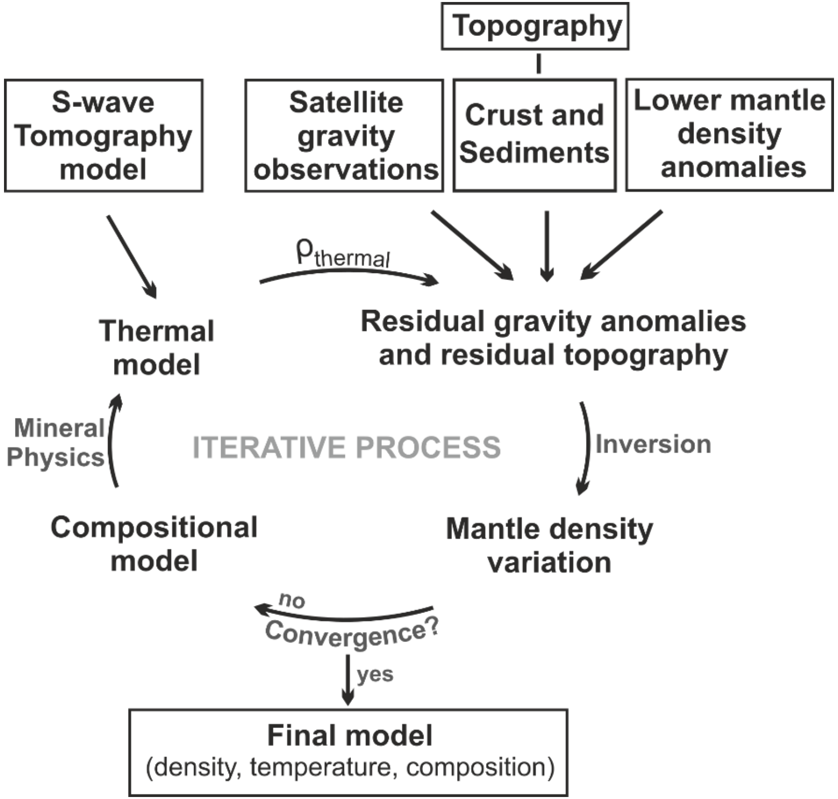
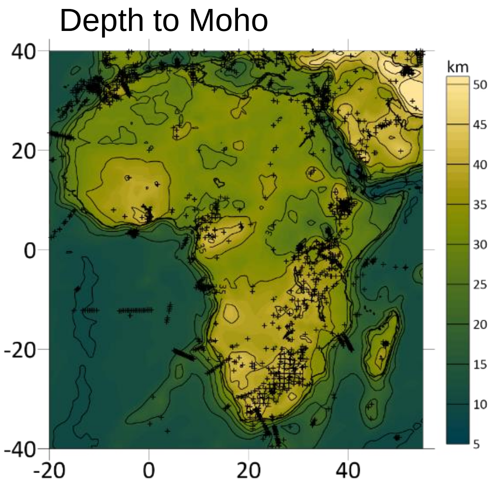
Method – Mantle

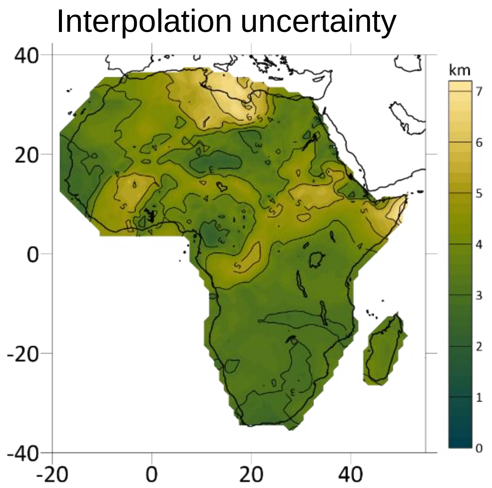


Finger et al. (2021), modified from Haeger et al. (2019)

- Upper mantle model:
  - Assume juvenile mantle composition with Mg# 89
  - Apply mineral physics approach (Tesauro et al., 2014) to S-wave tomography (AF2019, Celli et al., 2020) to obtain thermal model
  - Correct residual mantle gravity and residual topography for thermal variations
  - Jointly invert the two fields to assess compositional variations
  - Assign negative compositional variations in the cratonic area to Fe depletion
  - Increase Mg# accordingly and adapt mineral composition
  - Start over at step 2, iterate until convergence is reached (atmost 4 iterations)

Depth to Moho





- Crosses mark data points
- Scarse data in Sahara, central CC and Horn of Africa
- 30-35 km in most of Sahara, East Africa and central CC
- > 35 km in southern Africa and WAC, northern CC

- Measurement uncertainty not always available → use interpolation uncertainy
- Interpolation uncertainty mostly below 4 km
- Higher in areas of scarse data
- Adding/subtracting and recalculation of results allows assessing effects of Depth to Moho uncertainties on mantle model

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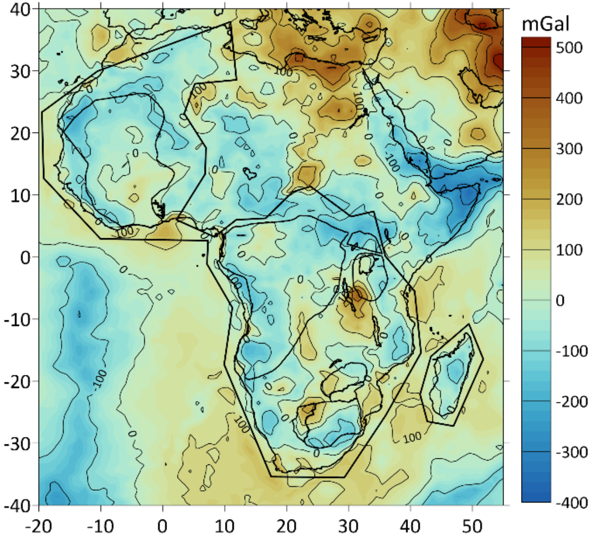
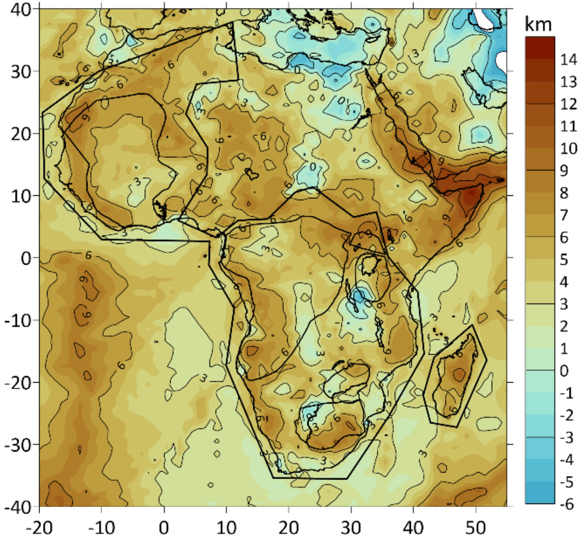
Mantle Residuals

Residual mantle gravity



Residual topography



- In most cratonic areas below 0 mGal
- Some small positive residuals (<100 mGal) in WAC and CC
- Positive residuals >100 mGal in parts of KC and ZC

- Note apparent anticorrelation to gravity residuals
- Allows to reduce bias and improve assessing depth of anomalies in joint inversion

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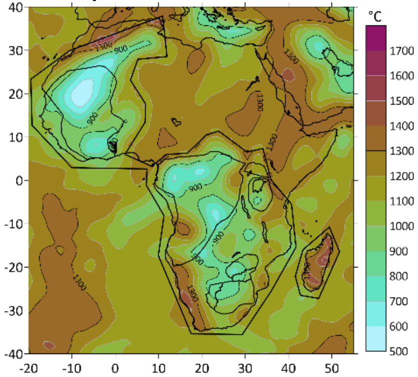
Mantle model results @100 km

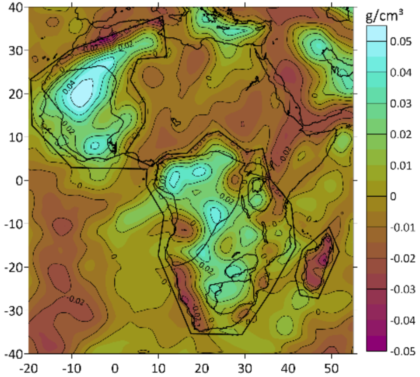
Temperature



- Low temperatures <1000° C in most cratonic areas
- Higher temperatures in TC and UC

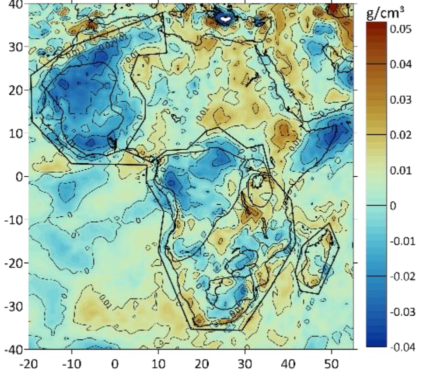
Single fields through depths

Thermal variations



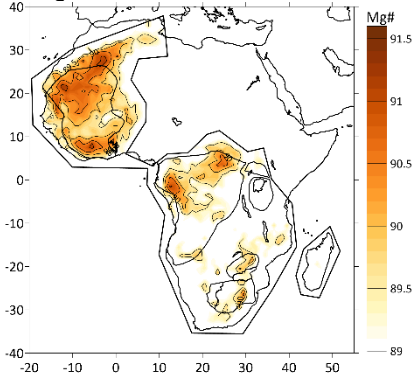
- Strong correlation to temperatures
- Positive thermal variations at most cratons except UC

Compositional variations



- Negative compositional variations in most cratonic areas
- Not in TC, parts of UC, and southern to eastern CC

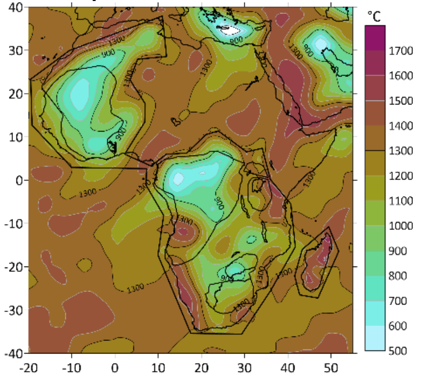
Mg#



- Highest depletion in WAC and northern CC (Mg# >91)
- Depletion in parts of KC, and ZC (up to Mg# 91)
- Minimal to no depletion (Mg# <89.5) in southern to eastern CC, TC, UC and wide parts of KC

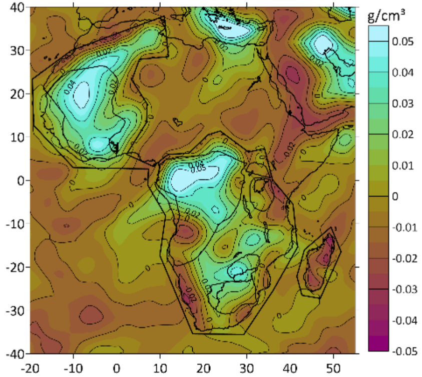
Mantle model results @150 km

Temperature



- Low temperatures <1000° C in most cratonic areas
- >1000° C in KC
- >1300° C in southern CC, TC, and UC → thin lithosphere

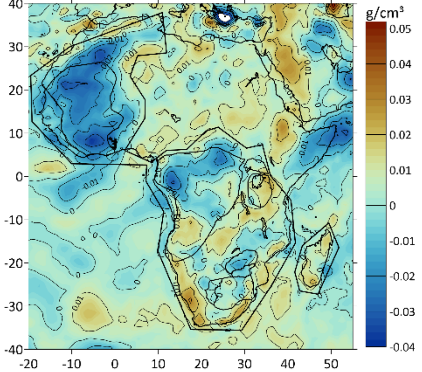
Thermal variations



- Strong correlation to temperatures
- Positive thermal variations where temperatures <1100° C

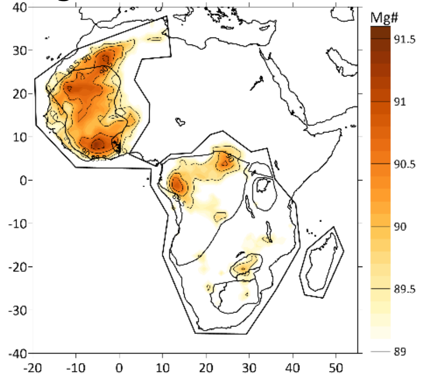
Single fields through depths

Compositional variations



- Negative compositional variations remain in most cratonic areas
- Positive variations in TC and UC, parts of KC, and southern to eastern CC

Mg#



- Depletion in WAC (Mg# >91)
- Less depletion in northern CC and ZC (up to Mg# 91)
- Absence of depletion in southern to eastern CC, most of KC, TC, and UC

Results @100 km

Results @200 km

Depth to Moho Uncertainties

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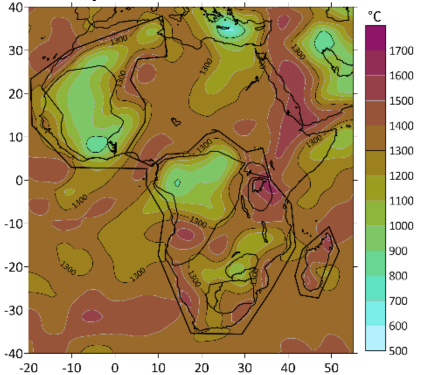
Mantle model results @200 km

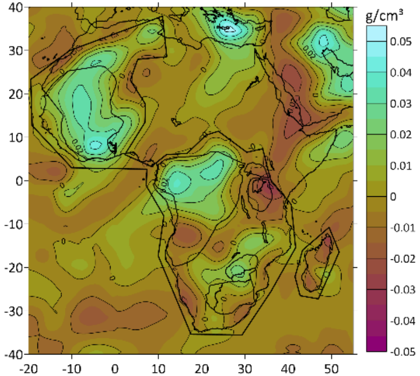
Temperature



- <1300° C in WAC, northern to eastern CC, LB, and parts of ZC → thick lithosphere
- >1300° C in TC, UC, and southern KC

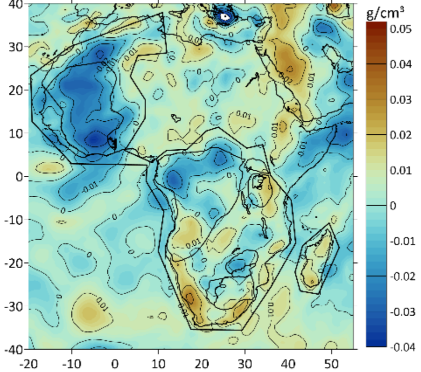
Single fields through depths

Thermal variations



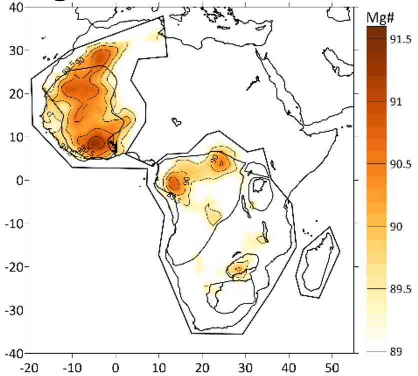
- Strong correlation to temperatures
- Positive thermal variations where temperatures <1300° C

Compositional variations



- Negative compositional variations remain in most areas
- Positive variations in TC and UC, wide parts of KC, and southern to eastern CC

Mg#

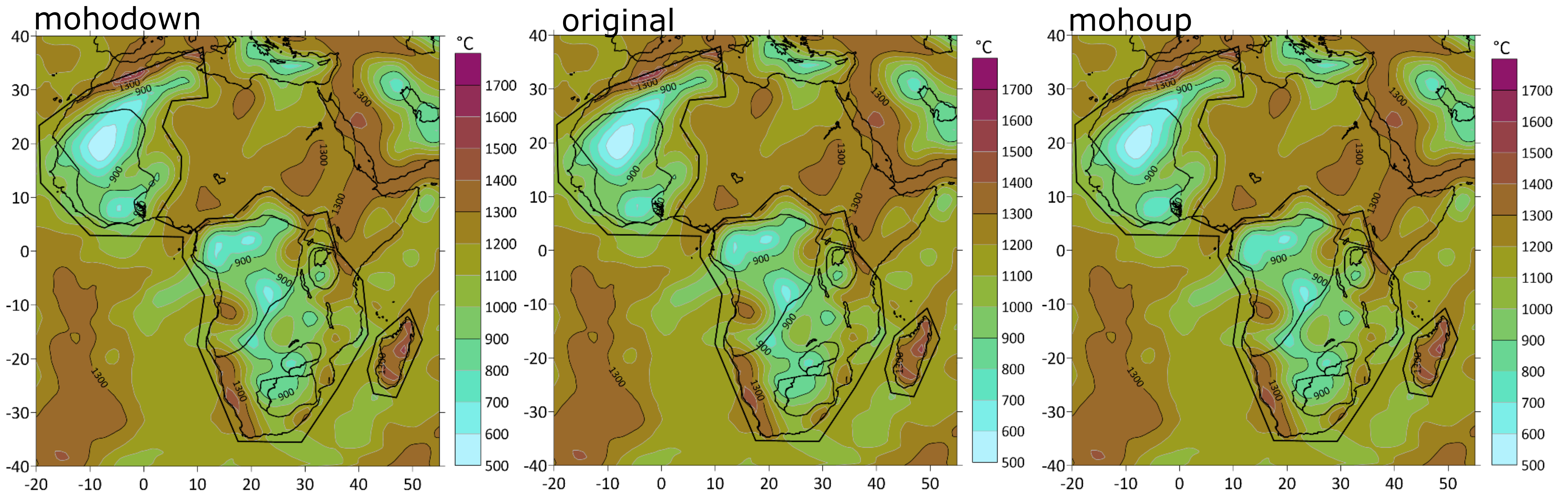


- Depletion in WAC (Mg# >91) and northern CC (Mg# up to 91)
- Less depletion in LB and ZC (up to Mg# 90)
- Absence of depletion in KC, TC and UC

Effect of Depth to Moho Uncertainties

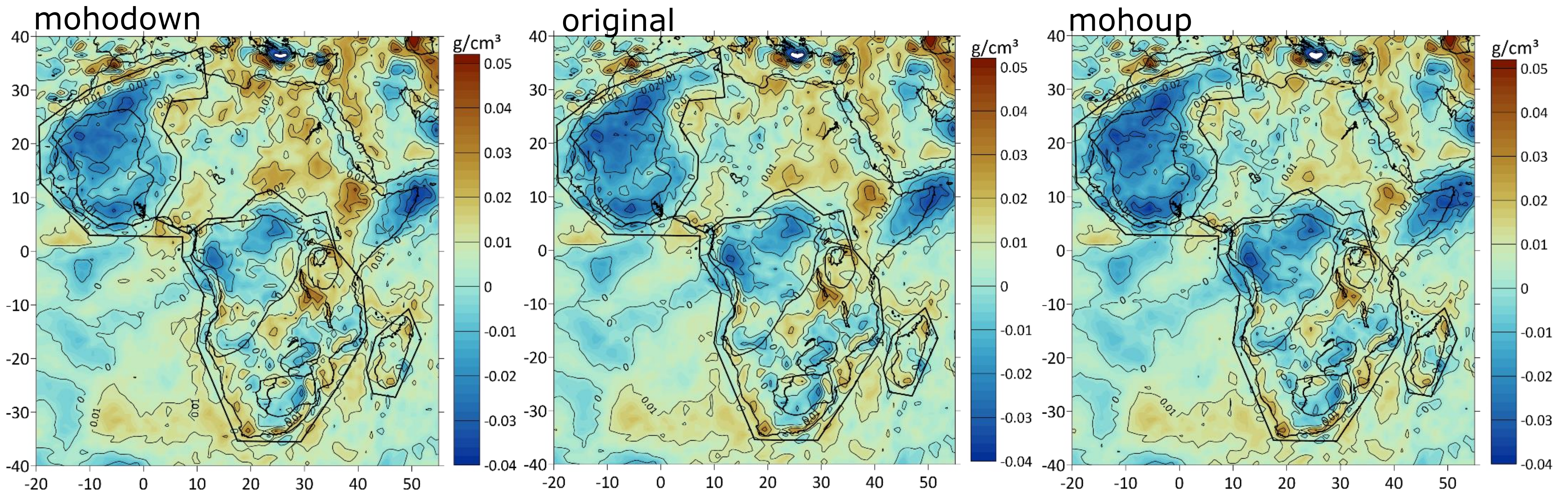
- Procedure:
  - ➢ Add (‟mohoup") / subtract (‟mohodown") interpolation uncertainties to / from interpolated Depth to Moho
  - ➢ Correct mantle gravity residual and residual topography accordingly
  - ➢ Recalculate resulting fields
- Expectations:
  - ➢ Only minimal changes in temperature or thermal density variations (tomography dependence of temperatures >> compositional dependence)
  - ➢ For upwards shift of Moho: More mass in crust → Lower residual mantle gravity and higher residual topography → Increase in area and amplitude of negative compositional variations and depletion
  - ➢ For downwards shift of Moho: Less mass in crust → Higher residual mantle gravity and lower residual topography → Decrease in area and amplitude of negative compositional variations and depletion

Effect of Depth to Moho Uncertainties – Temperatures @100 km



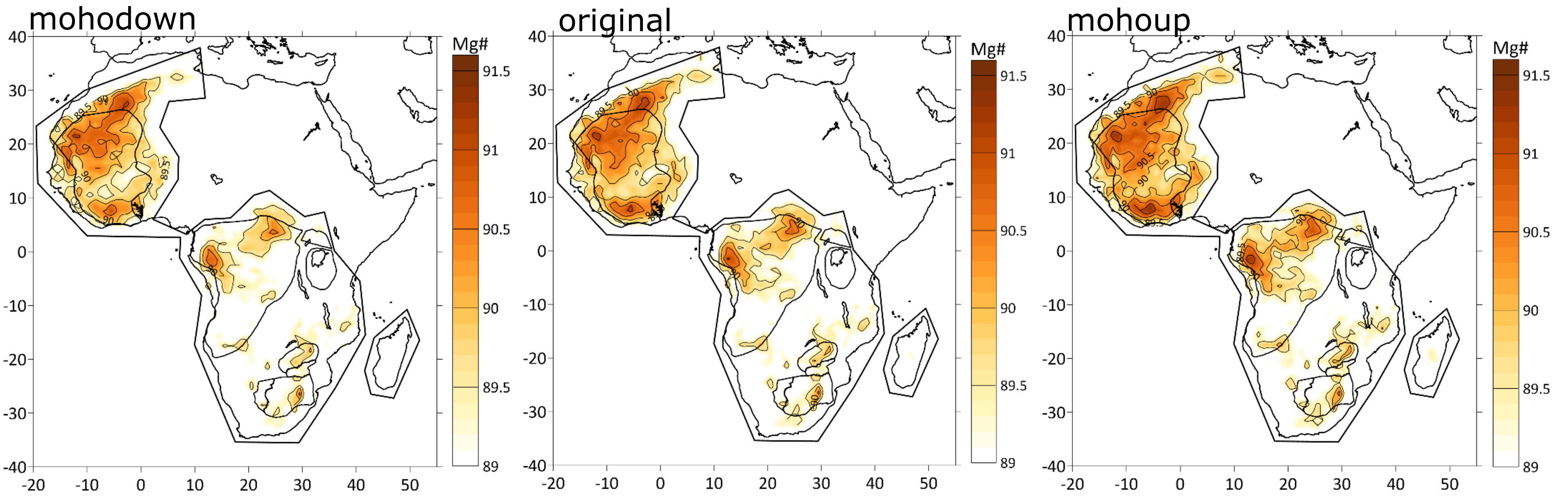
- As expected, almost no changes → almost no change in thermal density variations
- Change of thermal density variations not shown

Effect of Depth to Moho Uncertainties – Compositional variations @100 km



- As expected: Area and amplitude of negative compositional variations increase from "mohodown" to "mohoup"
- Minor amount of change → small effect of Depth to Moho interpolation uncertainty

Effect of Depth to Moho Uncertainties – Composition @100 km

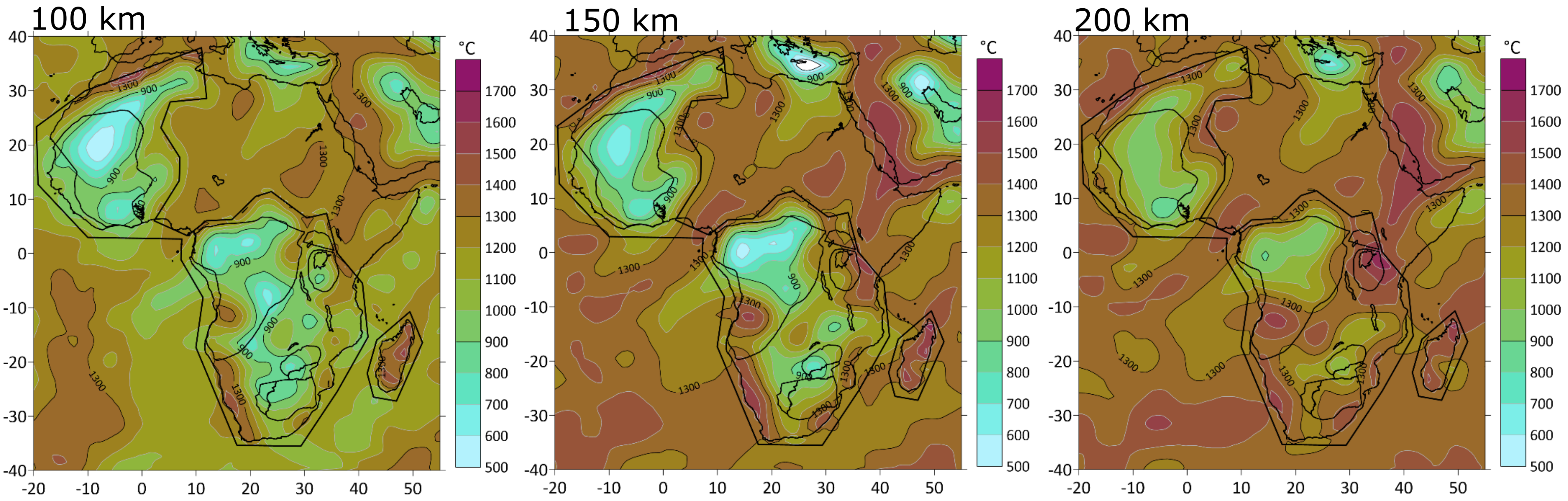


- As expected: Area and amplitude of Mg# increase from "mohodown" to "mohoup"
- Possible separation of depleted areas in NW and NE Congo Craton indicated
- No previous results overturned → Confirmation of results

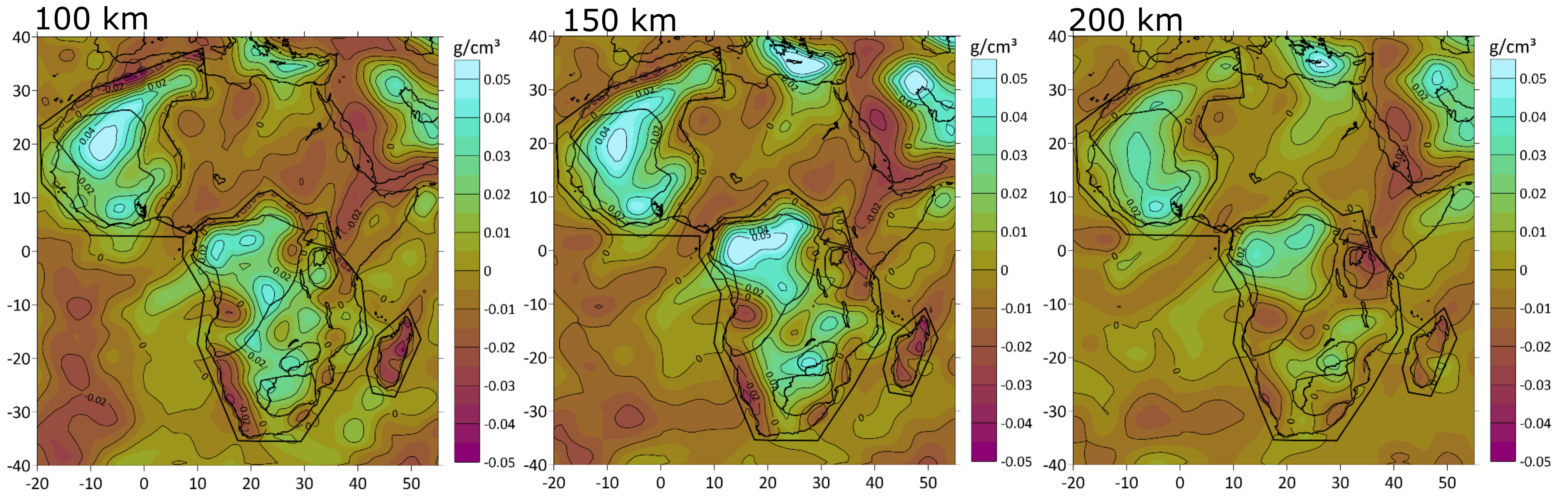
Conclusions

- New model of Depth to Moho
- New upper mantle model of temperatures, thermal and compositional variations, and composition
- Temperatures <1300° C in WAC, northern to eastern CC, LB, and parts of ZC indicate thick lithosphere
- Deep depleted cratonic roots in WAC, northern CC, LB and ZC
- Thinner lithosphere (Temperatures >1300° C @200 km) in southern to eastern CC, KC, TC, and UC
- Low to no depletion in these areas indicates removal or refertilization of cratonic roots
- Small effect of Depth to Moho interpolation uncertainty confirms results
- Article in preparation

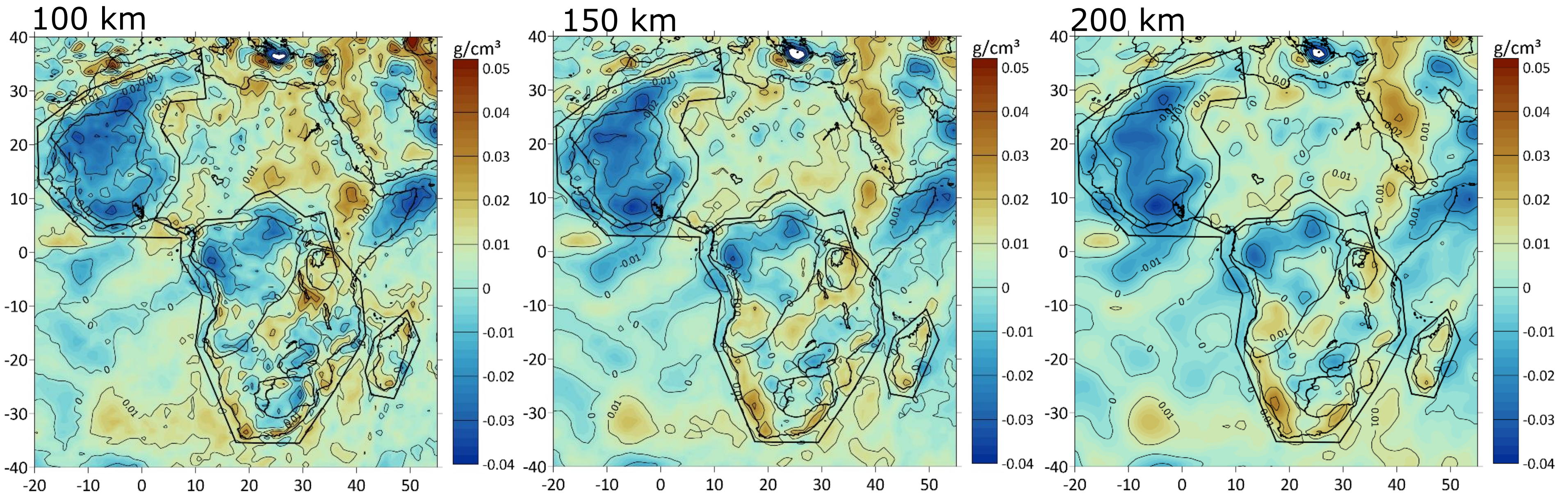
Temperatures through depths



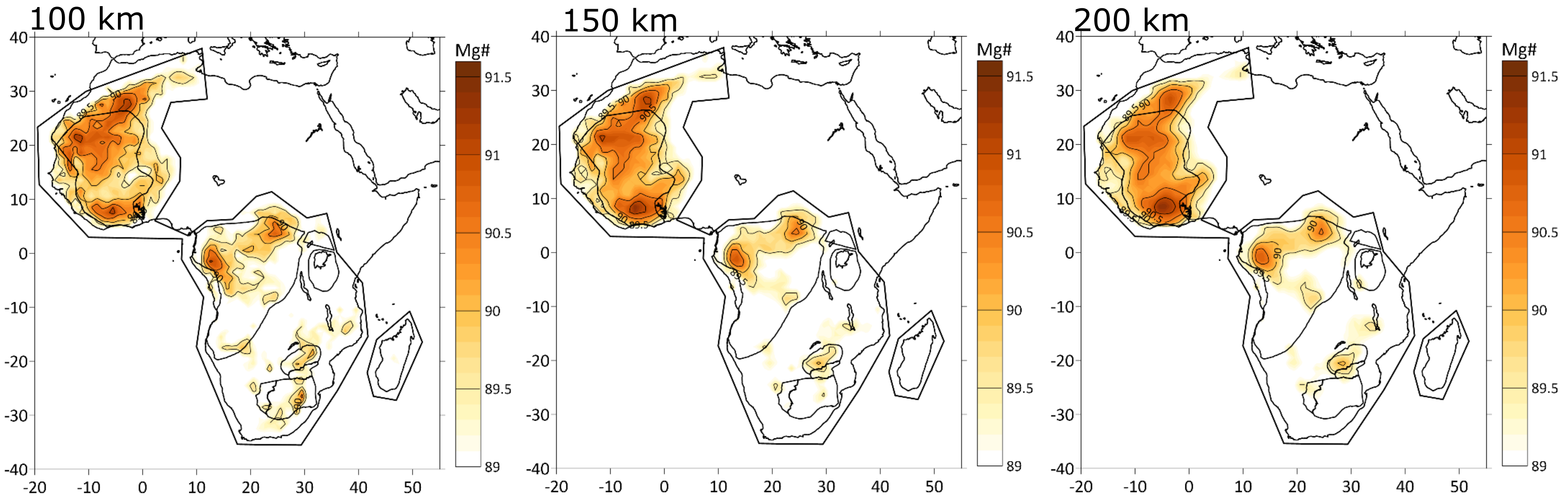
Thermal density variations through depths



Compositional variations through depths



Depletion through depths



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