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GRAVITY AND SEISMOLOGY

IS THERE ANY RELATION?

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Africa Array

ESTIMATING CRUSTAL THICKNESS

Starting point:

"simple" models that do not rely on *a priori* constraints or knowledge of area

Why gravity:

- Complete coverage
- Through validation at known crustal structure, reliability for other parts can be estimated

Validation through:

- Comparison with receiver function results (local estimates under seismic station)
- Comparison with global CRUST2
- Tomography based models

3D INVERSION – OLDENBURG-PARKER

Oldenburg-Parker defined (1974) the equation to compute the depth to the undulating interface from the gravity anomaly profile by means of an iterative process and is given by:

$$F[h(x)] = -\frac{F[\Delta g(x)]e^{(-kz_0)}}{2\pi G\rho} - \sum_{n=2}^{\infty} \frac{k^{n-1}}{n!} F[h^n(x)]$$

This expression allows us to determine the topography of the interface density by means of an iterative inversion procedure.

First, the first term is computed by assigning h(x)=0 and its inverse Fourier transform provides the first approximation of the topography interface, h(x).

h(x) is then used in the 2nd part to evaluate a new estimate of h(x).

This process is continued until a reasonable solution is achieved.

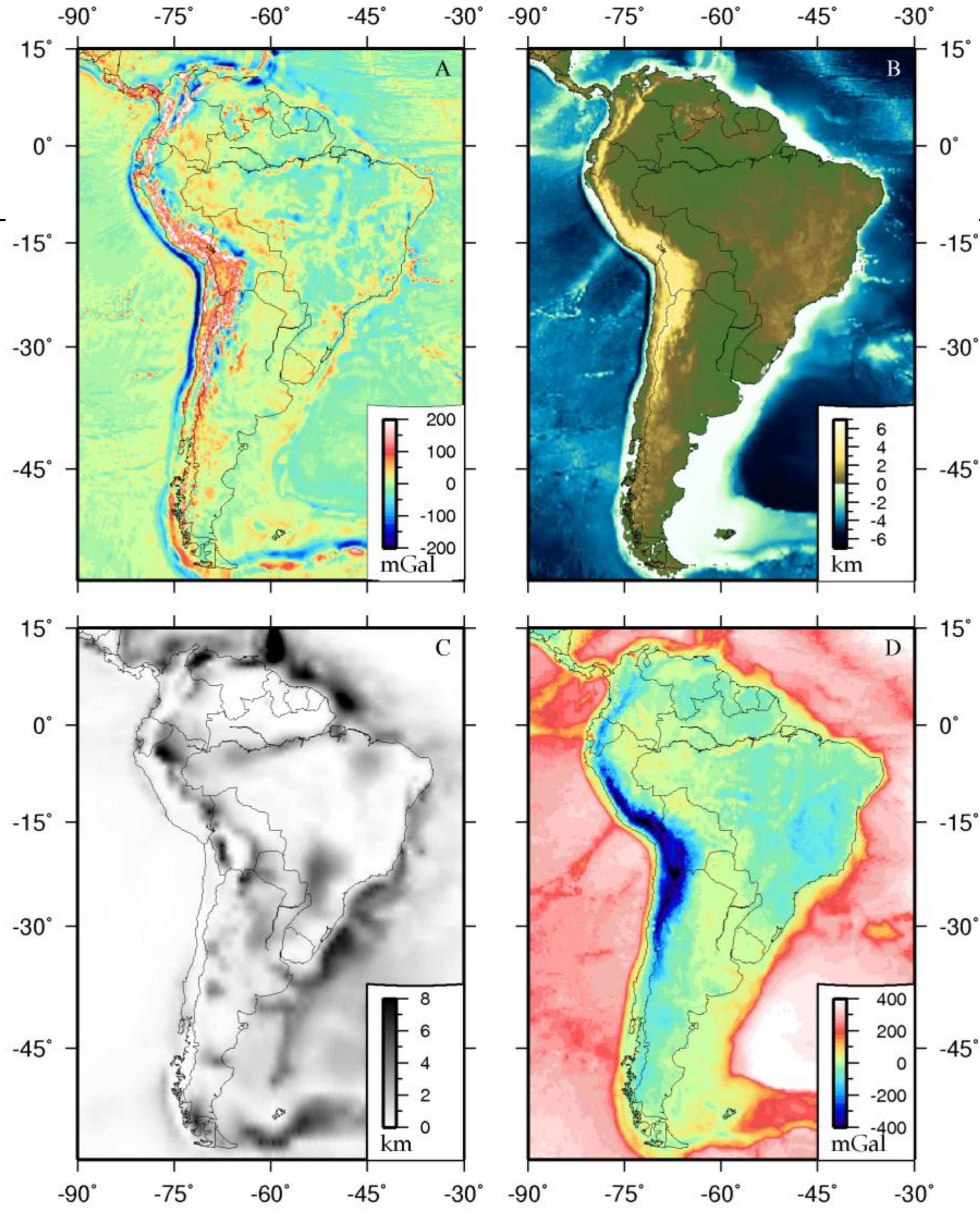
Source: Gomez-Ortiz & Agarwal, Computers and Geosciences, 2005

CRUSTAL MODEL SOUTH AMERICA

Input layers:

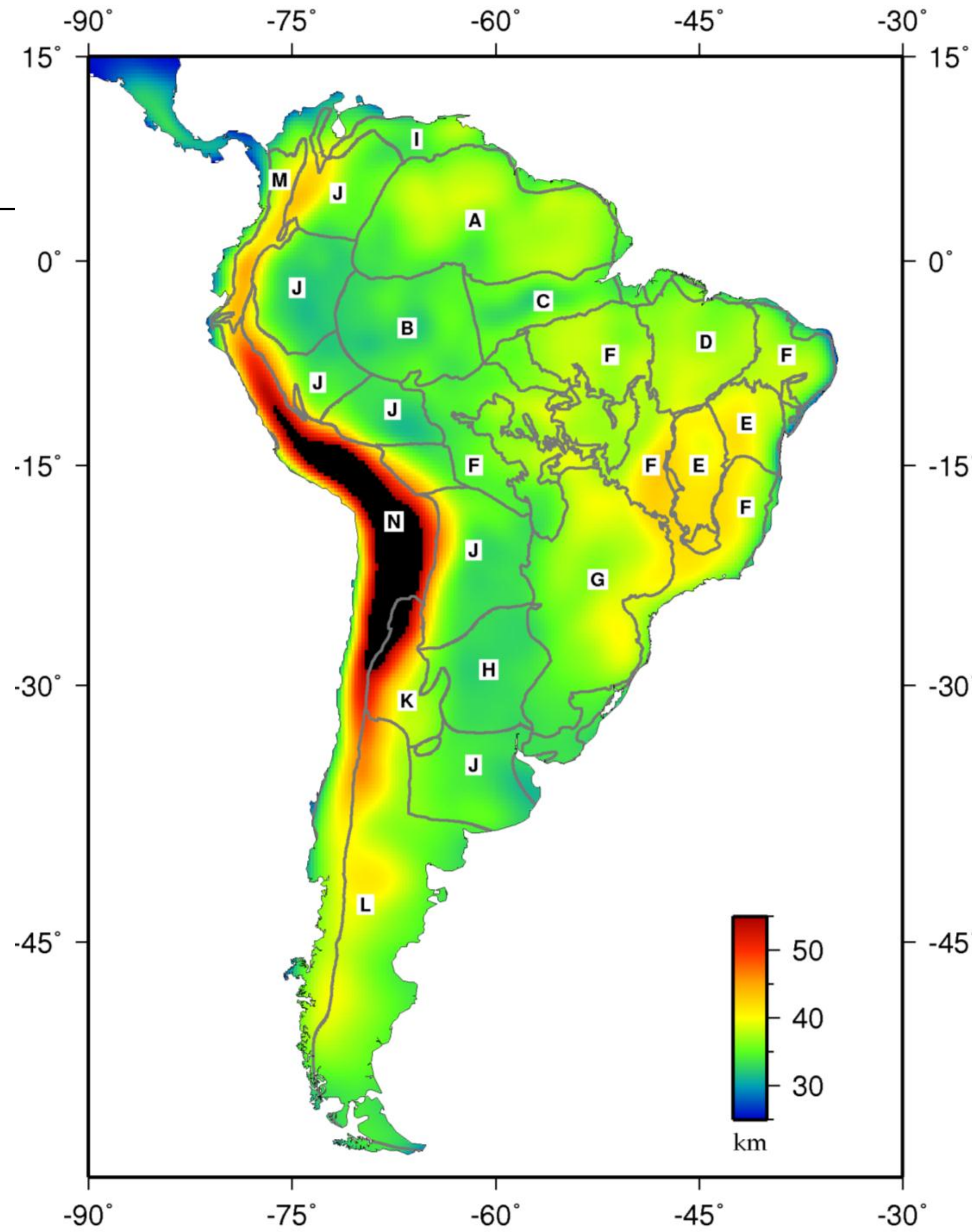
- Gravity anomaly
- Bouguer correction
- Sediment correction
    - Fixed contrast of 200 kg/m^3
    - no depth dependence

Final output for further processing



MOHO MODEL

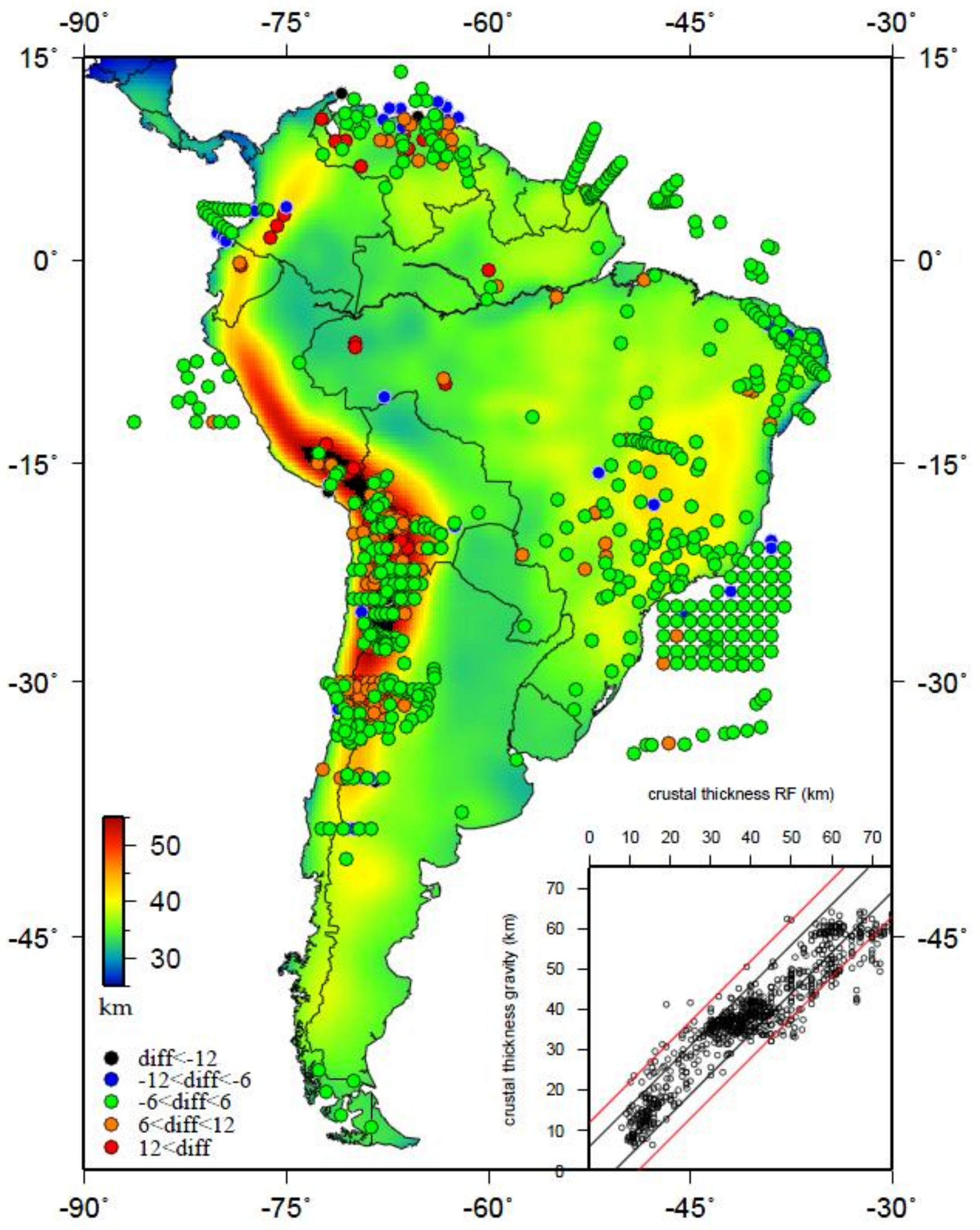
- Over 65 in Andes to less than 6 km in oceanic basins
- Thickest crust in central Andes
- Brazilian shield is thicker than Guyana shield
- Thinning (?) in basins along Andean Foreland as well as Solimoes and Amazon basins



COMPARISON WITH SEISMOLOGICAL OBSERVATIONS

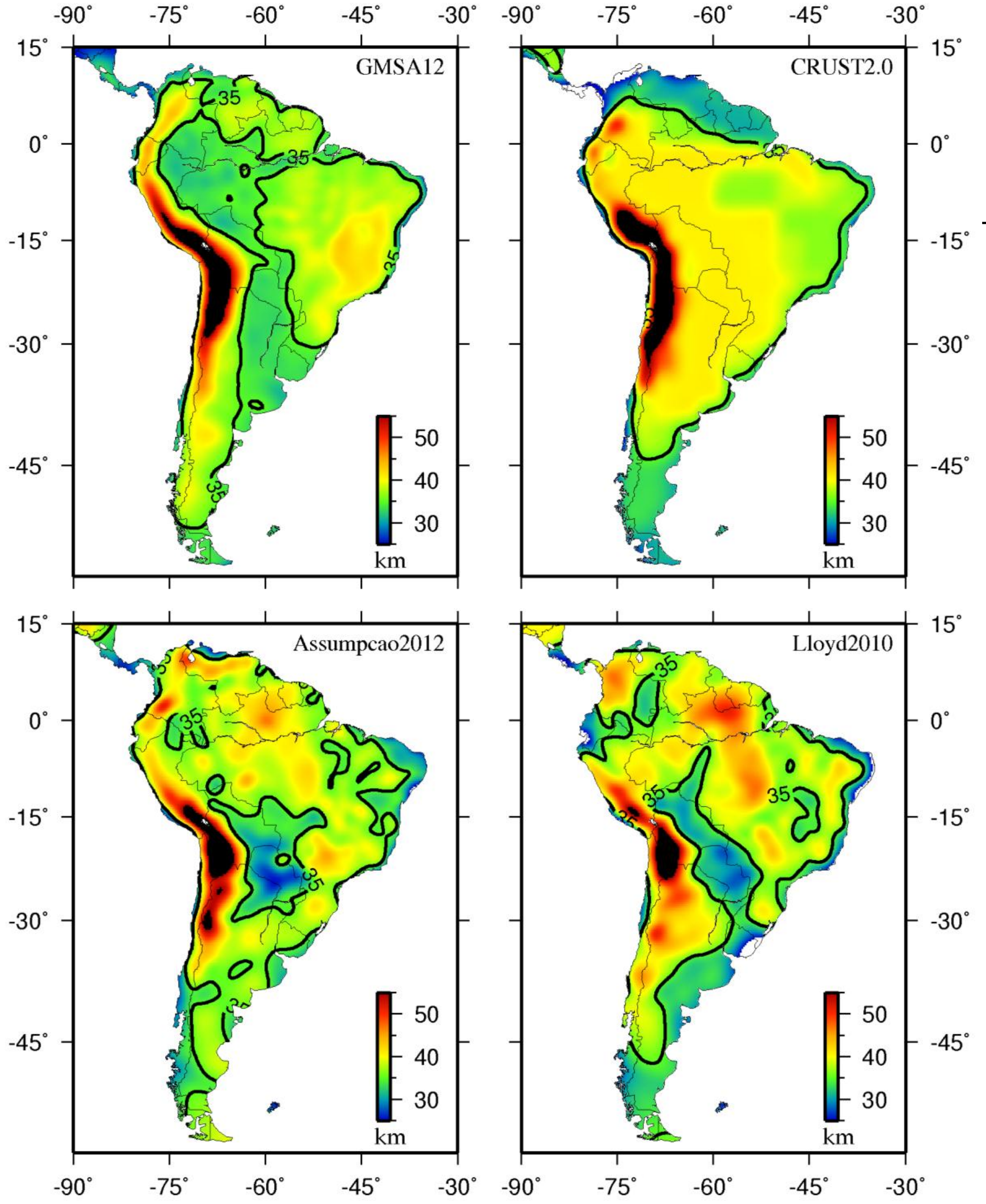
- Overall >70% similar

- Stable part 88%
- Andes 60% (especially underestimation)
- Caribbean orogenic zone shows scatter



COMPARISON

- good correlation with Assumpcao2012 and CRUST2.0 on the extent and thickness of the Andes region
- Brazilian shield is rather uniform for all models
- Thin crust behind Andes only partly seen in other models
- Thin crust in Venezuela in all models except Assumpcao



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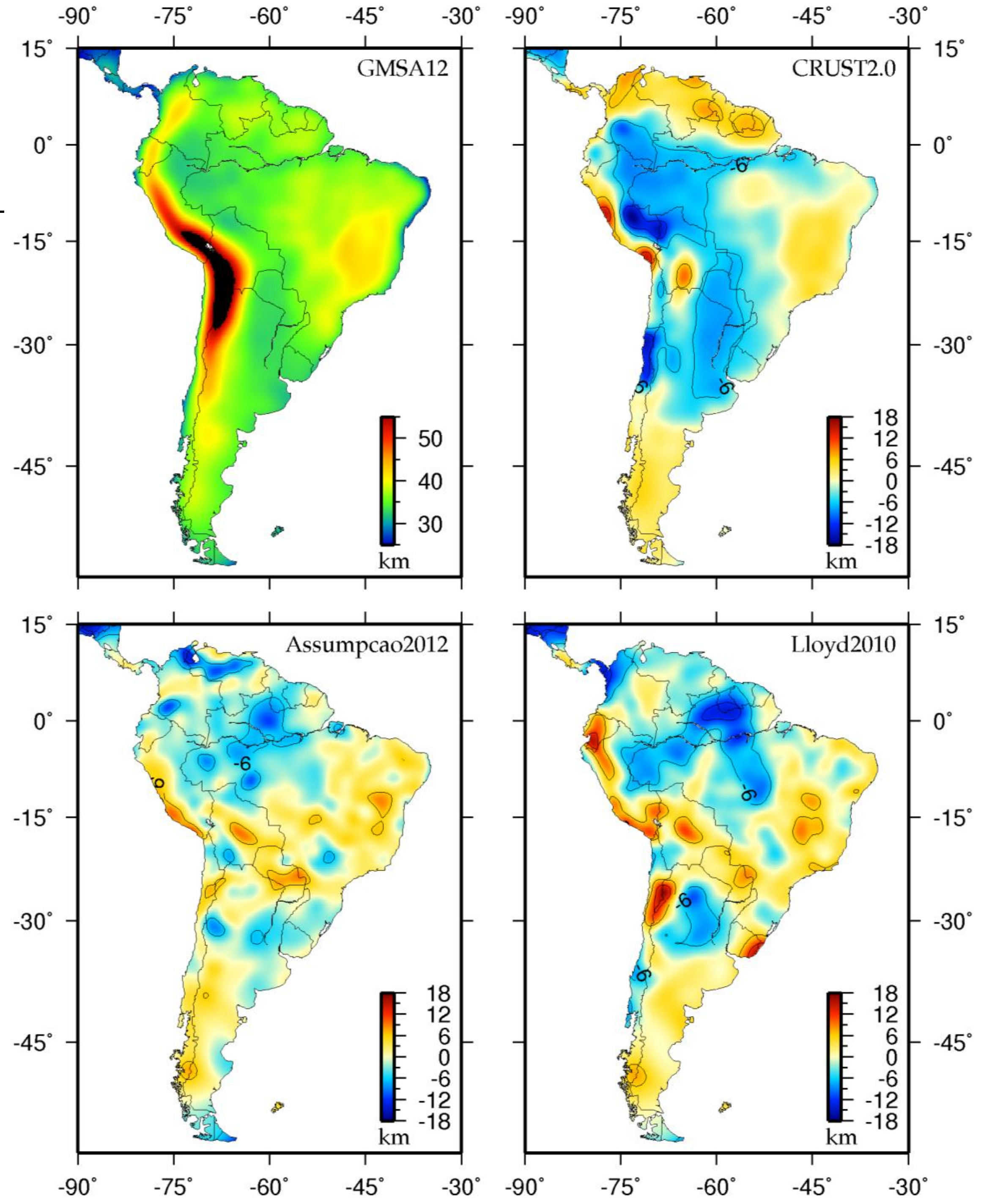
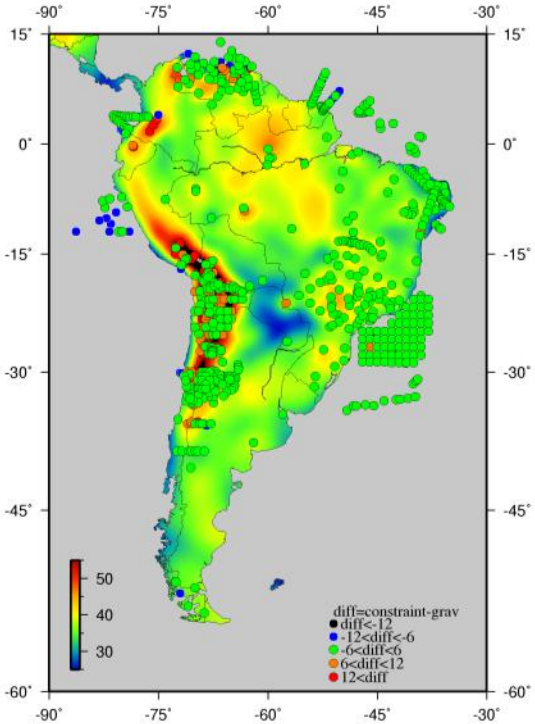
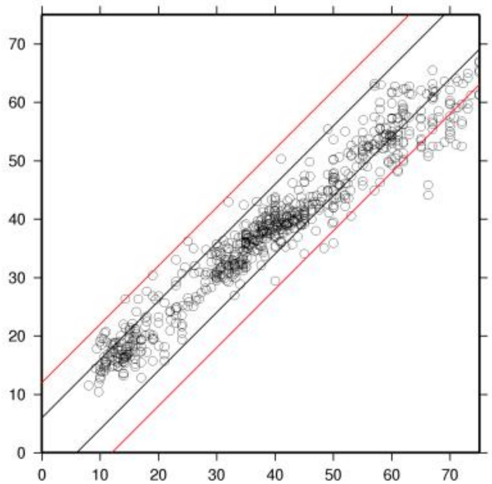
DIFFERENCES

- Best comparison with latest seismol. model
- CRUST2 shows largest differences
- Regions with few wavepaths and/or stations show largest differences
- Indication that satellite gravity data can be used for 1st order interpolation?



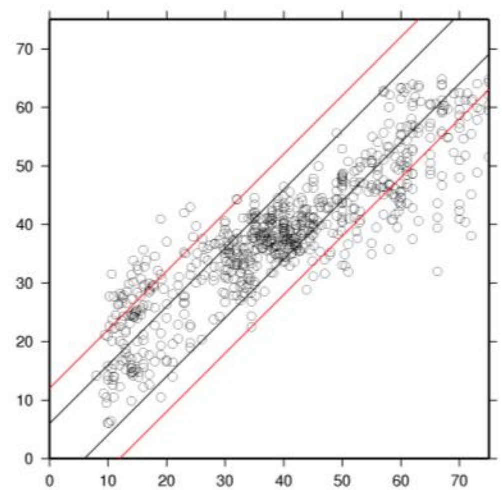
MISFITS OF SEISMOLOGICAL MODELS

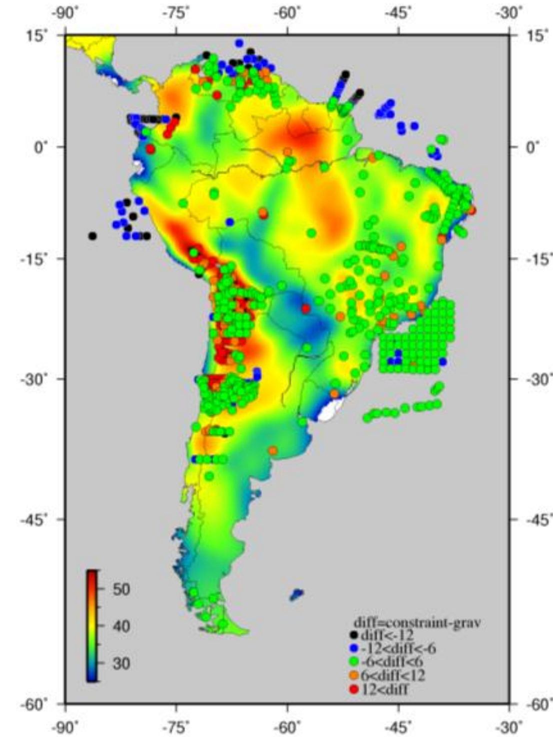




Although they used the constraints we observe that:

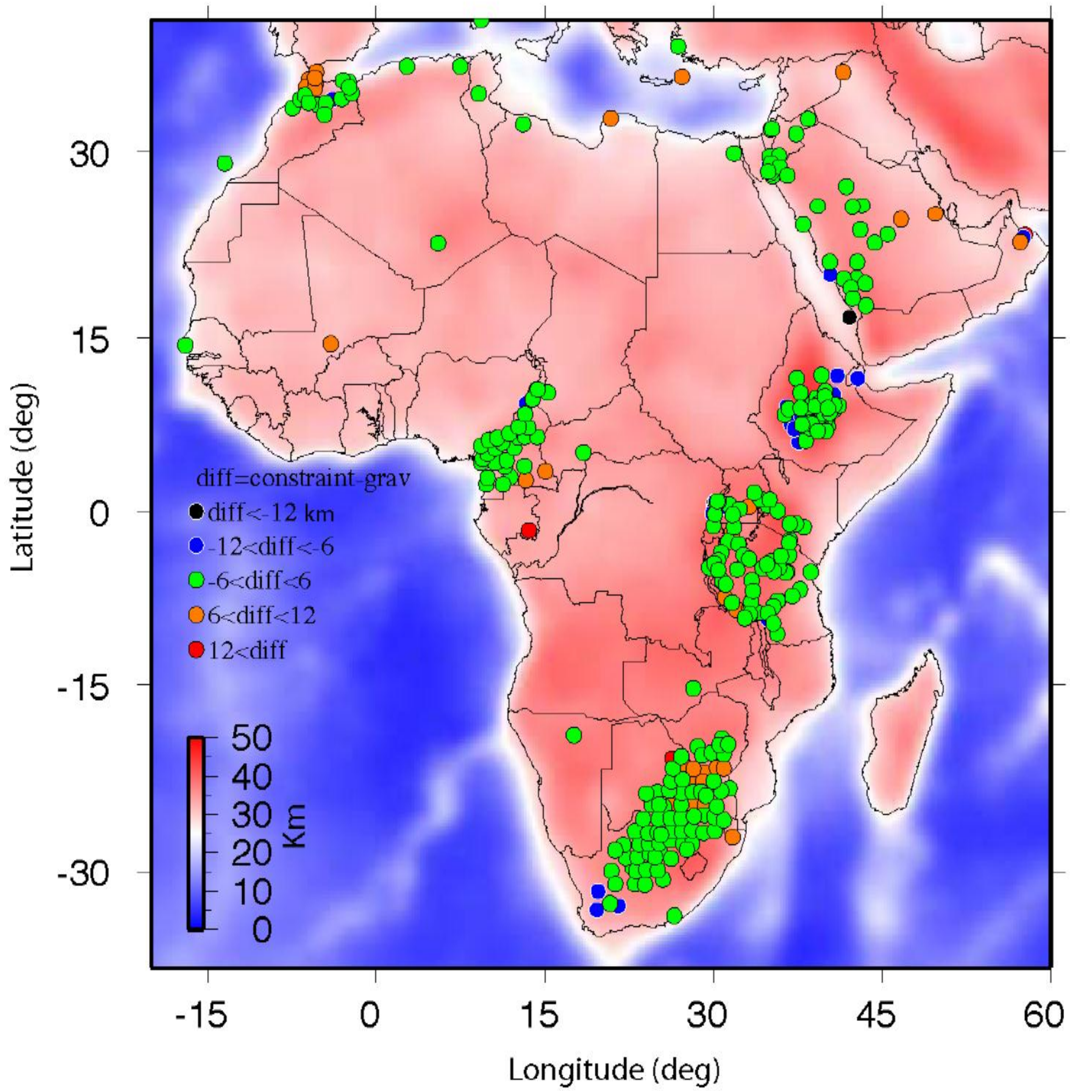
- Feng2007 similar
- Lloyd2010 worse





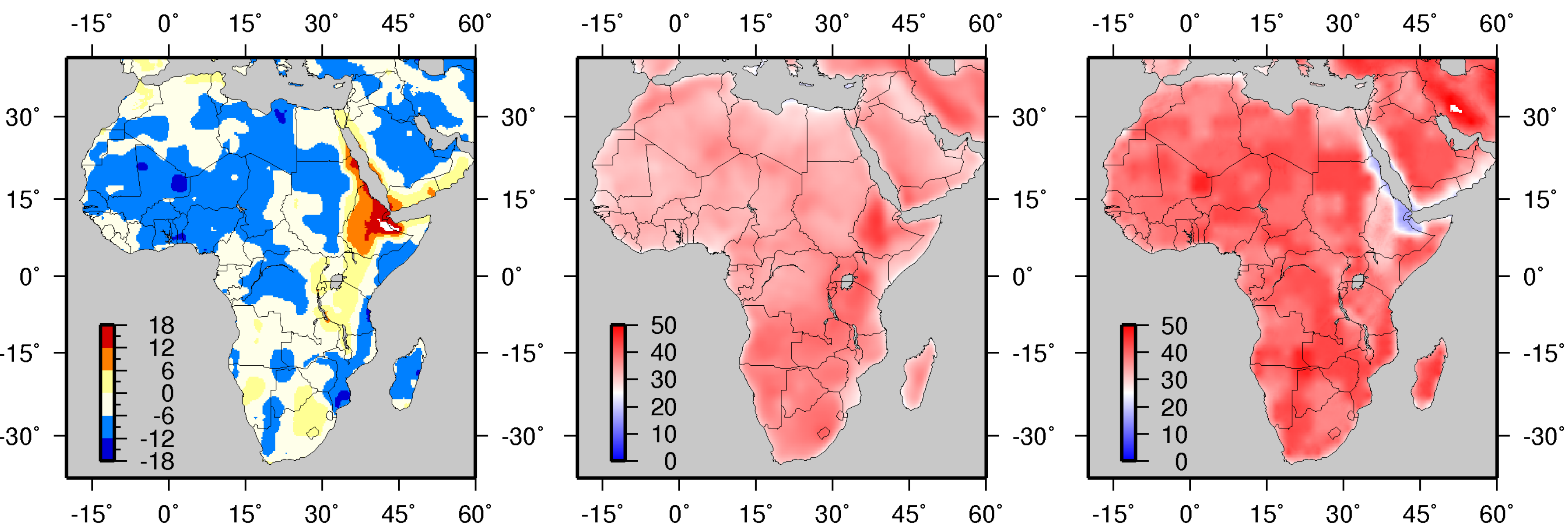
SIMILAR FOR AFRICA

- Good correlation
- (very) simple model
- Over 85% of data points significantly similar
- Small features not well imaged (Afar, ocean-continent boundaries)



COMPARISON WITH CRUST2

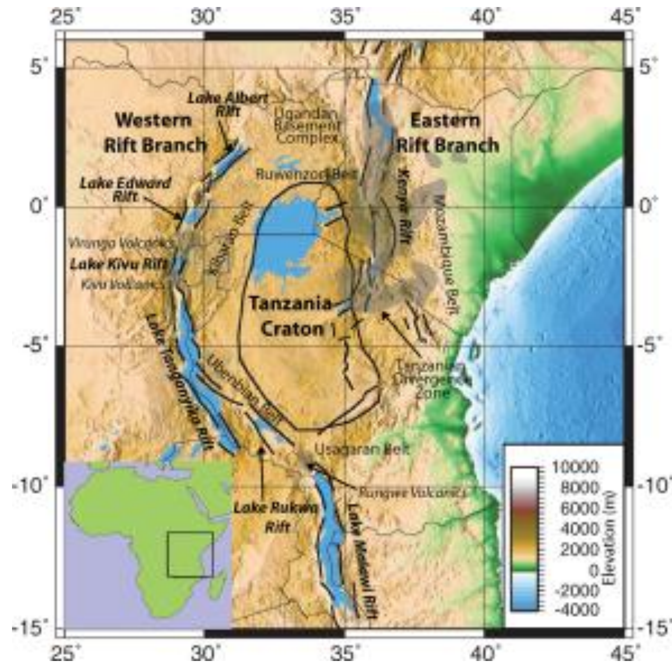
- Maybe some trend of geoid left?
- Overall better fit with seismological observations for satellite based model
- Larger discrepancies in areas without observations, meaning?



TOMOGRAPHY AND GRAVITY

- To use gravity as a constraint in a combined inversion with seismic waves we need to establish the impact of composition on velocity and density

- Conversion of tomographic velocity model into densities using 3 different compositions

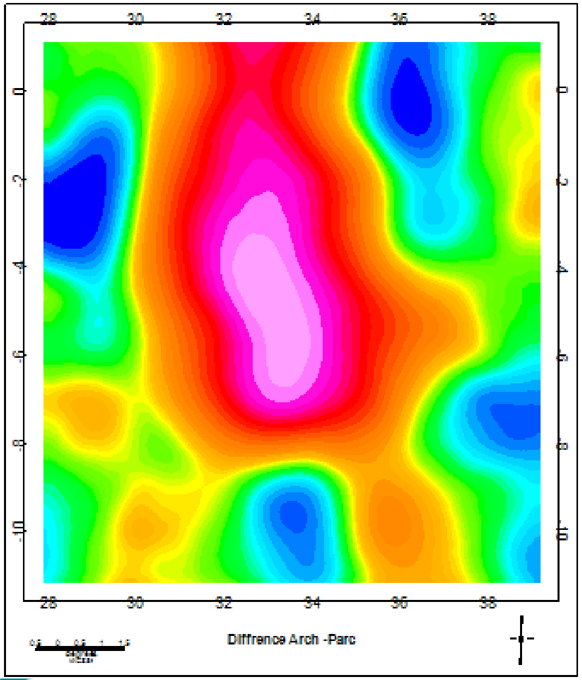


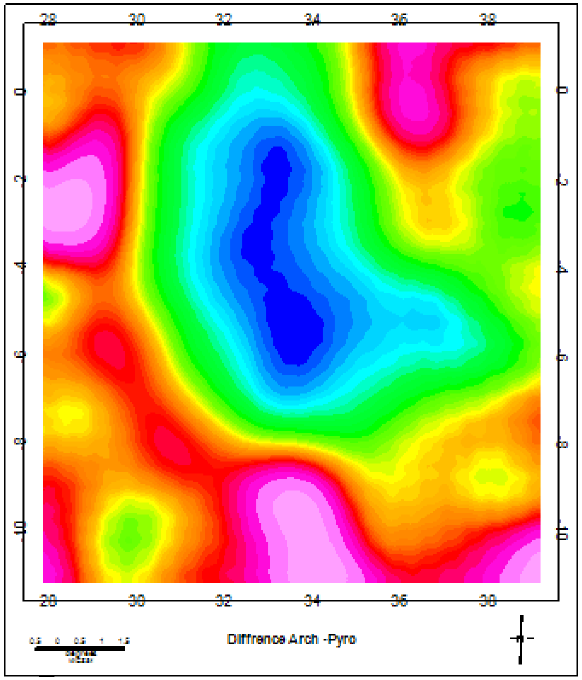
- Forward response calculated

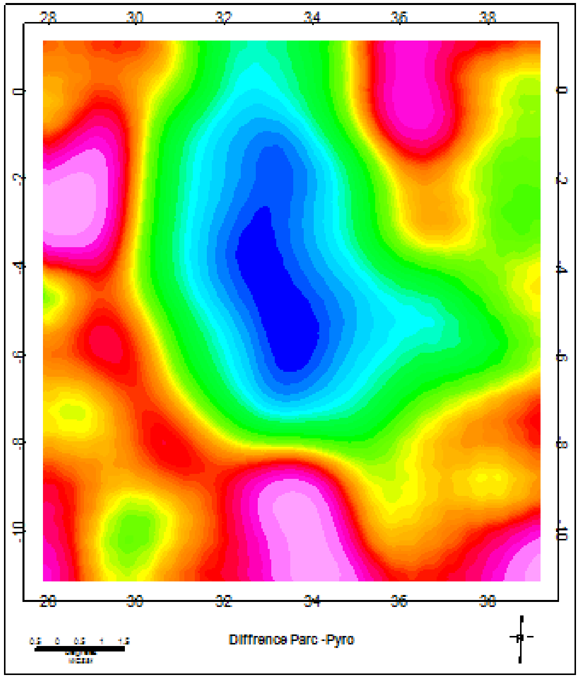
- Differences is significant

DIFFERENCES BETWEEN MODELS

- Variations significant, few hundreds of mgals, also spatially
- Using gravity field should provide better constraints
- Testing of more models will tell how much better it can be







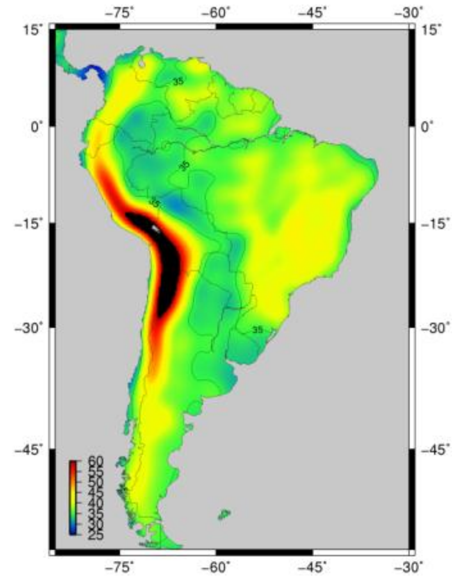
SUMMARIZING

- 3D modelling of gravity data provides unprecedented insights in African and South American crust → new structures found that deserve follow-up

- Comparison with seismological velocity models shows good general correlation

  → Does GOCE data provide details that are beyond seismological models, especially in spatial coverage?

- Integration with local tomography looks promising but more work is required



More info:

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SPARE SLIDES

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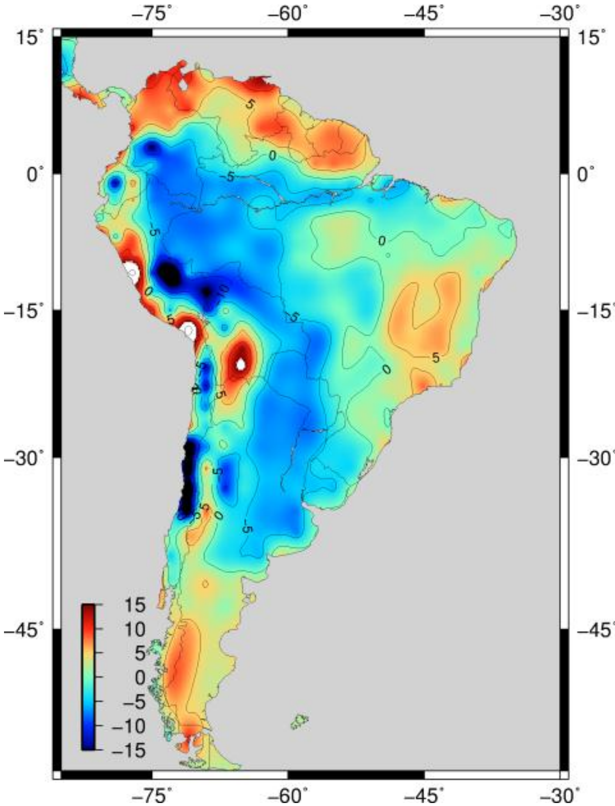
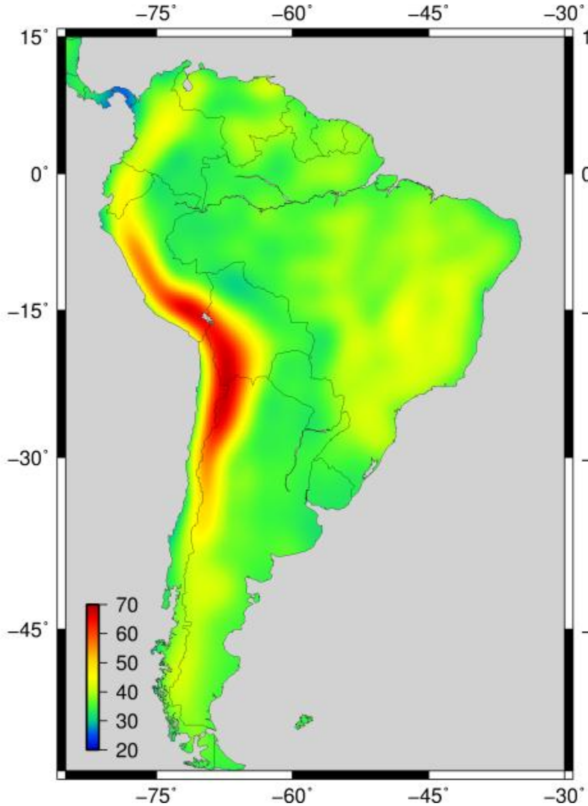
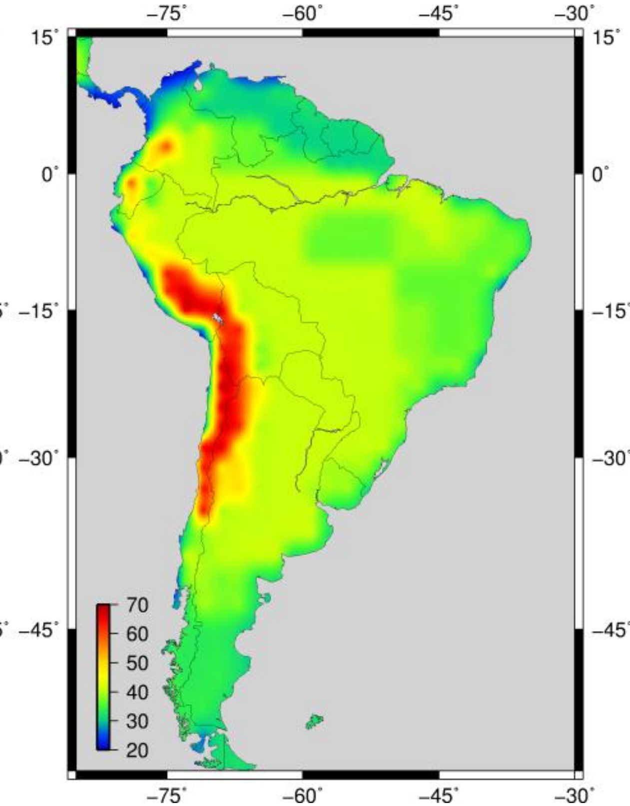
DIFFERENCE WITH CRUST2 GLOBAL MODEL



Difference 3D-crust2



model 3D

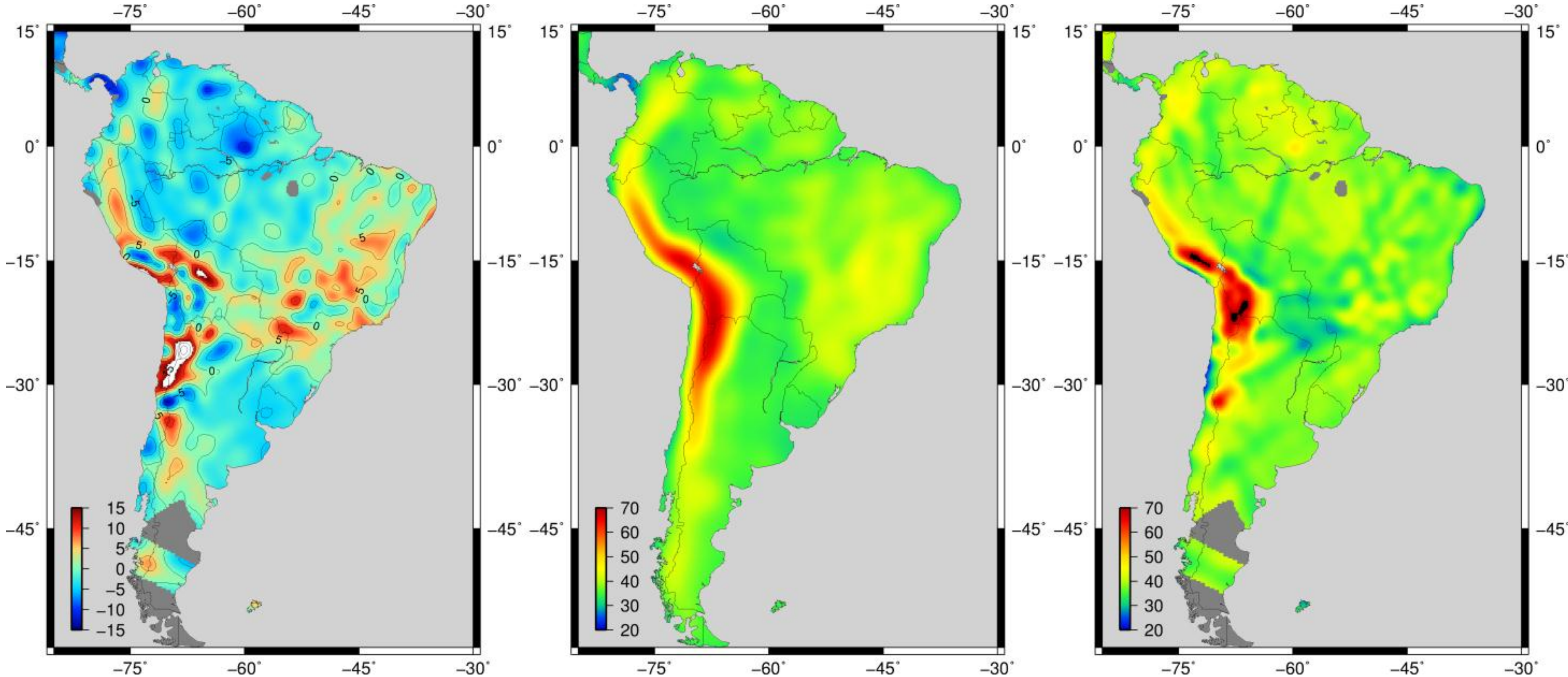


model crust2

Crust2: No thinning behind Andes, thin Guyana shield/Venezuela, thinner eastern part of craton

Crust2: Bassin et al, EOS, 2000

DIFFERENCE WITH MODEL FENG (2007)

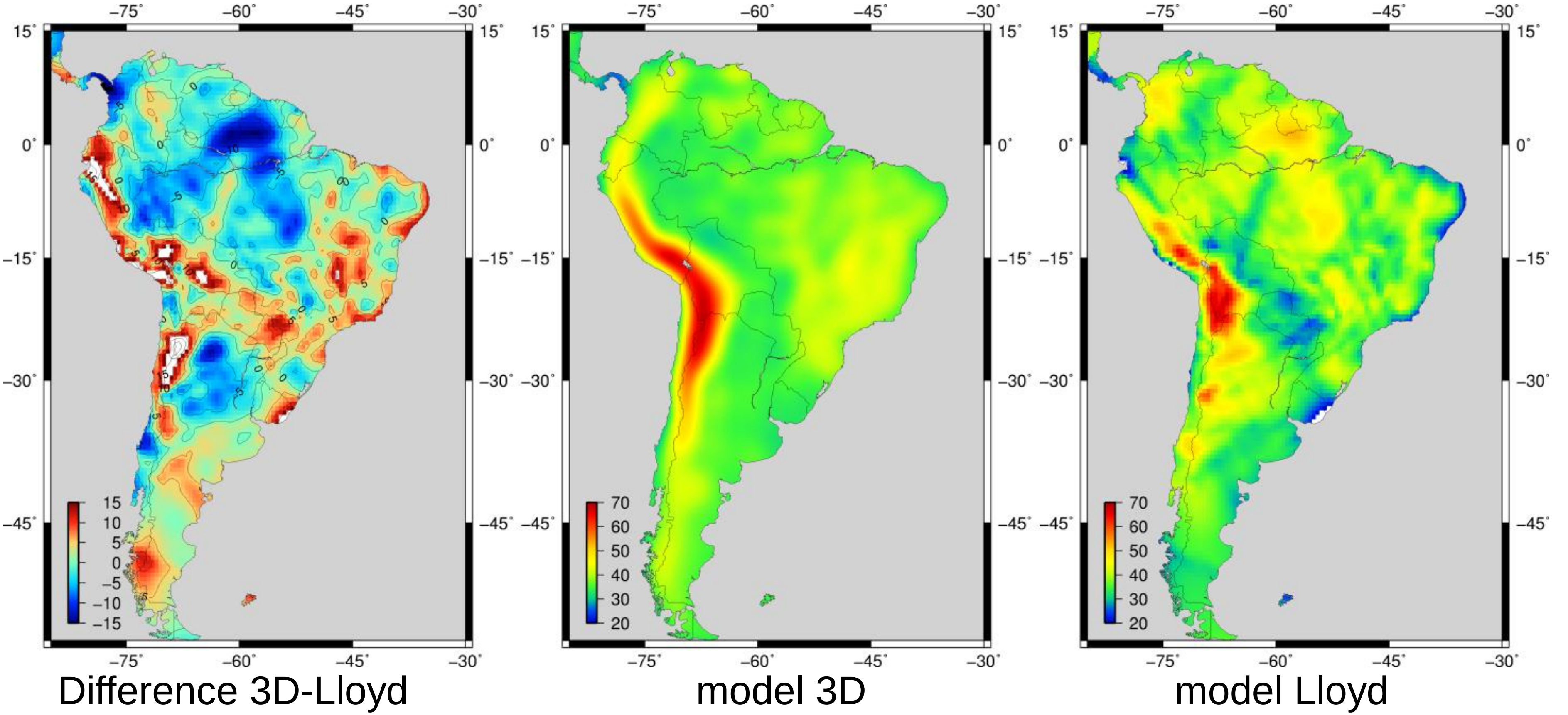


Difference 3D-Feng | model 3D | model Feng

Feng: partly thinning behind Andes (especially along wavepaths), thicker Guyana shield/Venezuela, thinner craton

Feng et al, JGR, 2007

DIFFERENCE WITH MODEL LLOYD(2010)



Lloyd: partly thinning behind Andes (especially along wavepaths), much thicker Guyana shield, thinner craton

→ overall: thinning seems to be there, need for more strategically located seismic stations

Lloyd et al, JGR, 2010

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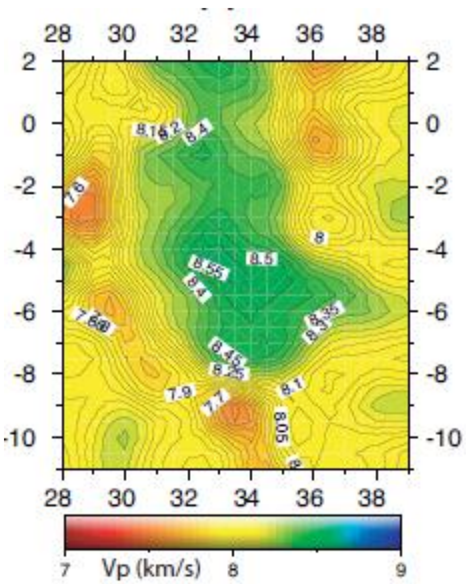
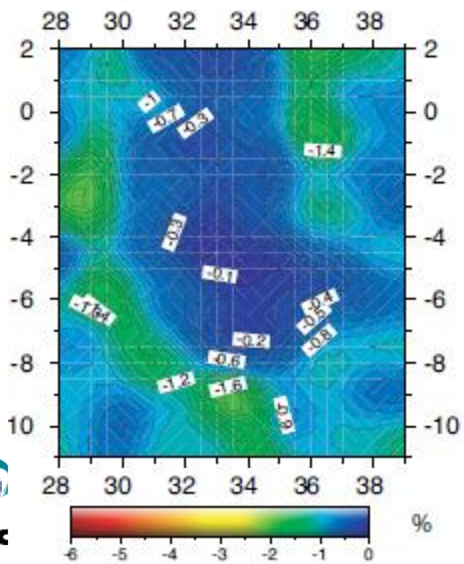
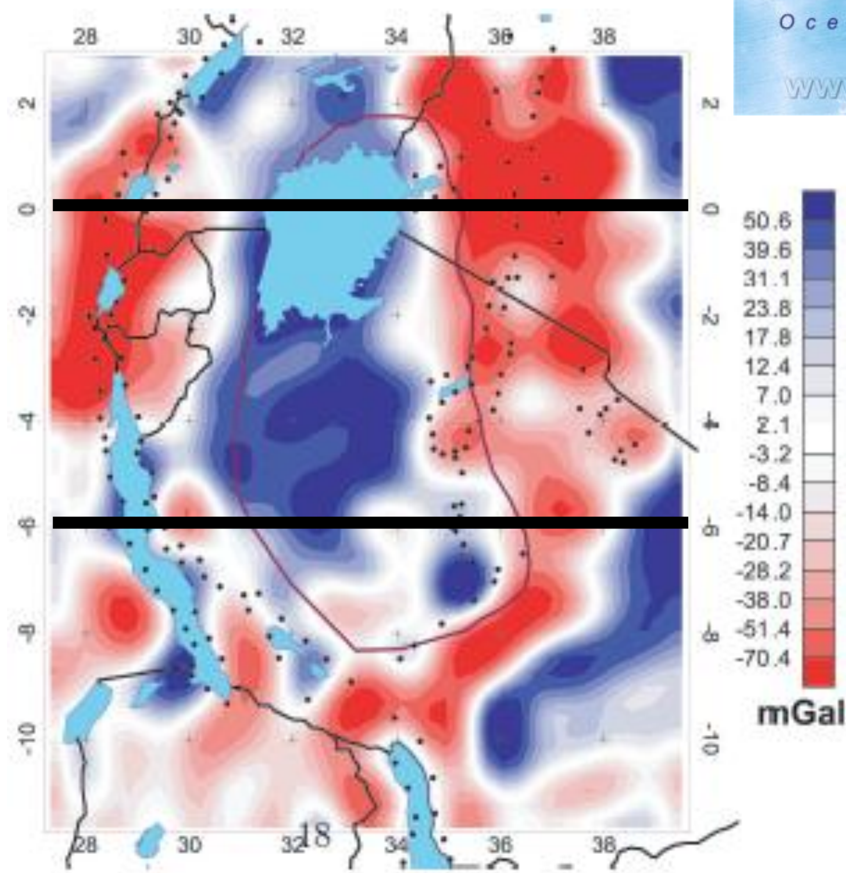
PROCESSING STEPS







Source: Tedla et al, in prep, 2011

PROFILE AT EQUATOR

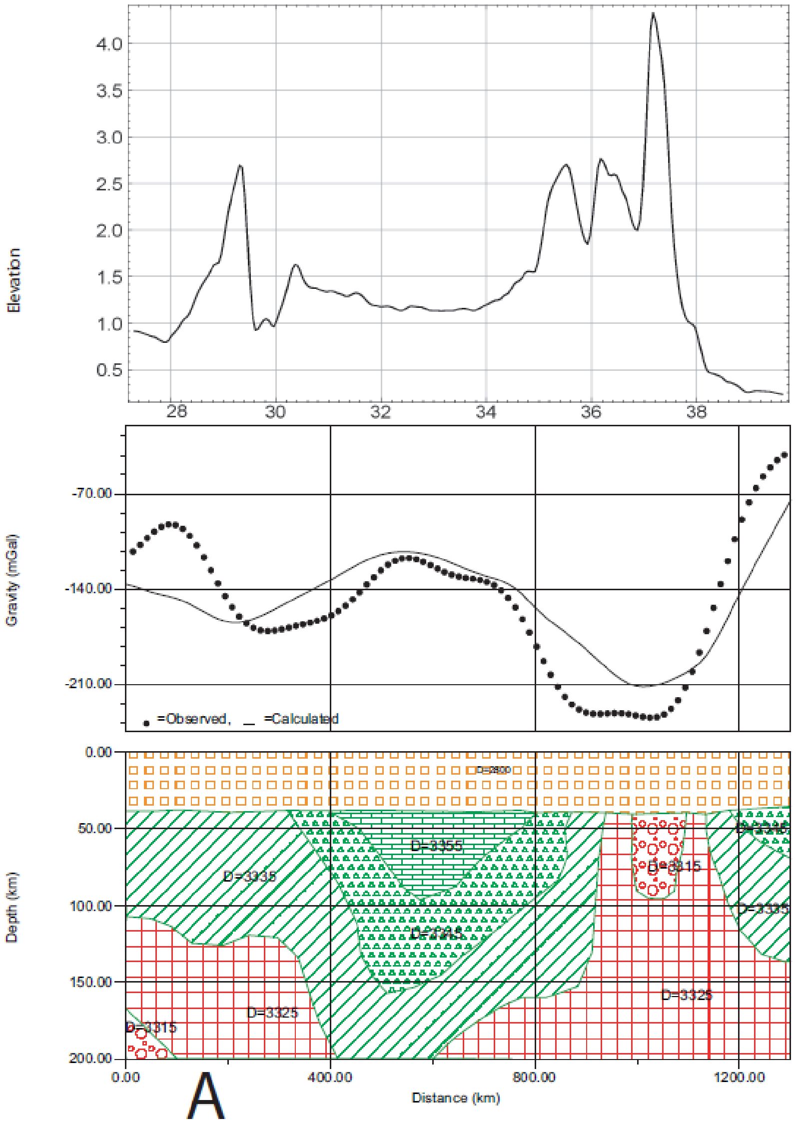
Density model at equator

Good fit with GOCE observations

Misfits at sides of craton at boundary with rift

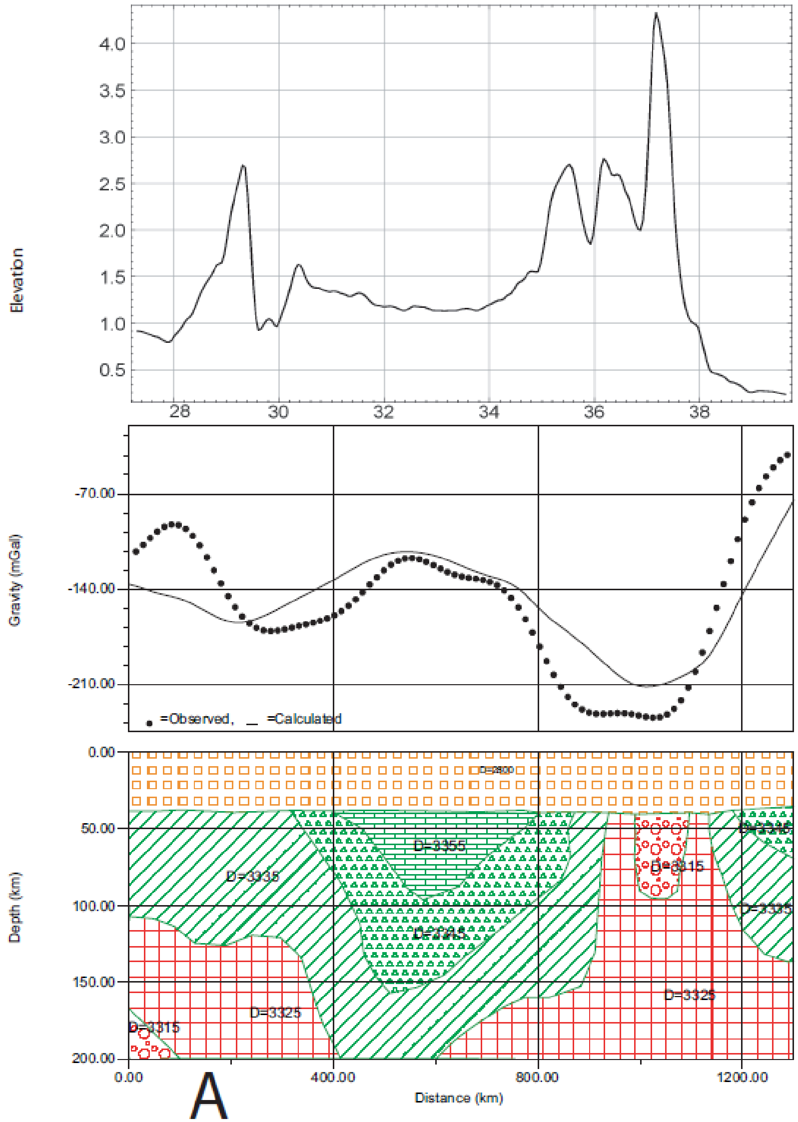
Standard velocity – density relation valid?

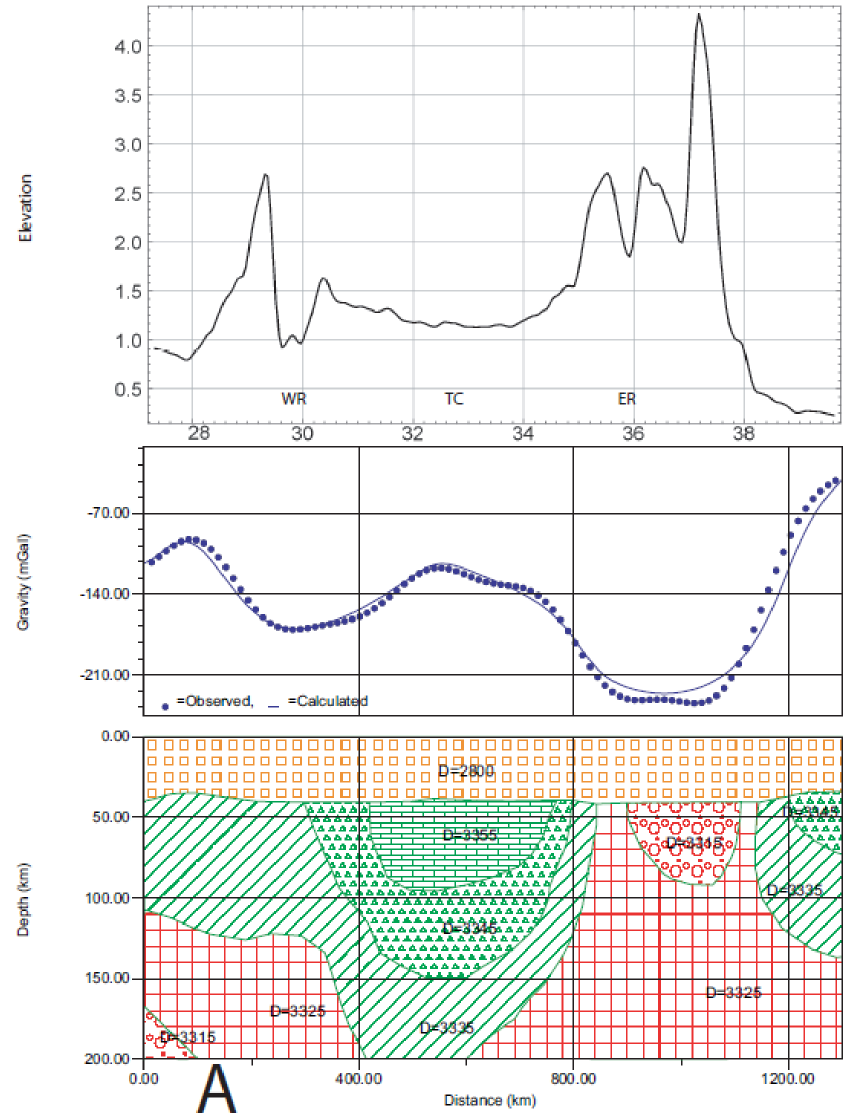
Sharp edges along craton creates problems



Source: Tedla et al, in prep, 2011

COMPARISON AT EQUATOR





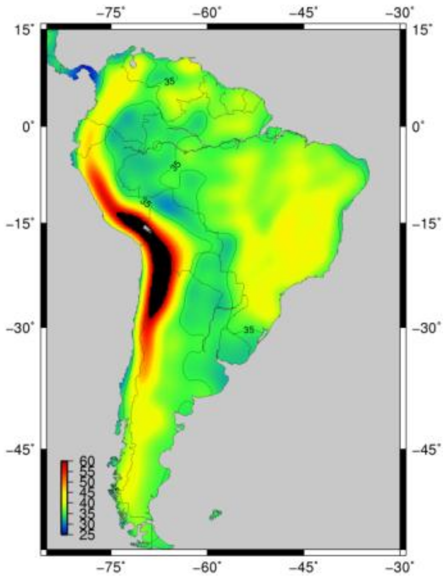
Source: Tedla et al, in prep, 2011

SUMMARIZING

- 3D modelling of GOCE data provides unprecedented insights in African and South American crust → new structures found that deserve follow-up

- Comparison of GOCE with seismological velocity models shows good general correlation

  → GOCE data provides details that are beyond seismological models, especially in spatial coverage



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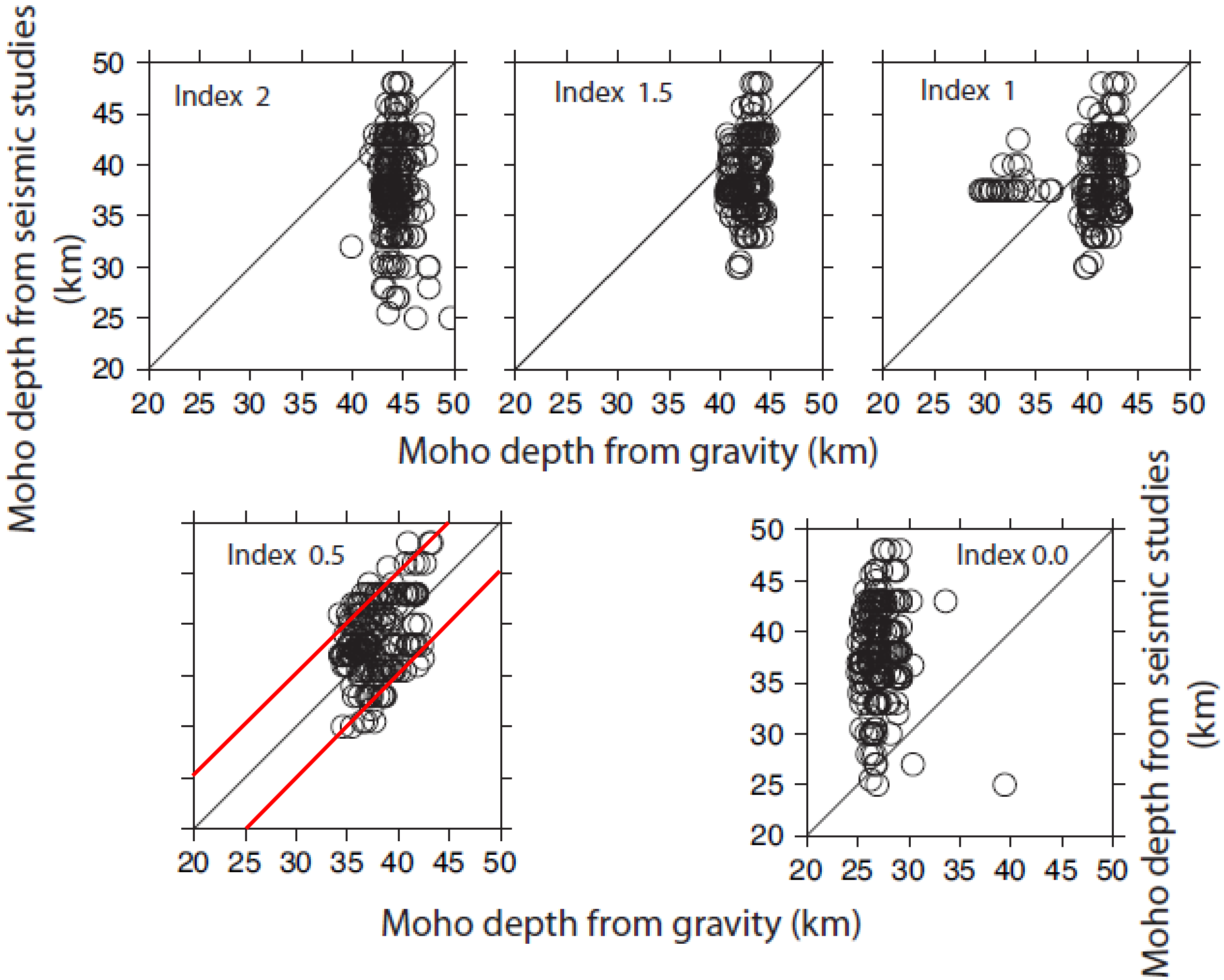
PROOF OF METHODOLOGY

Assumption for horizontal layered earth (index 0.5) is correct

By far best fit, most points within 5 km

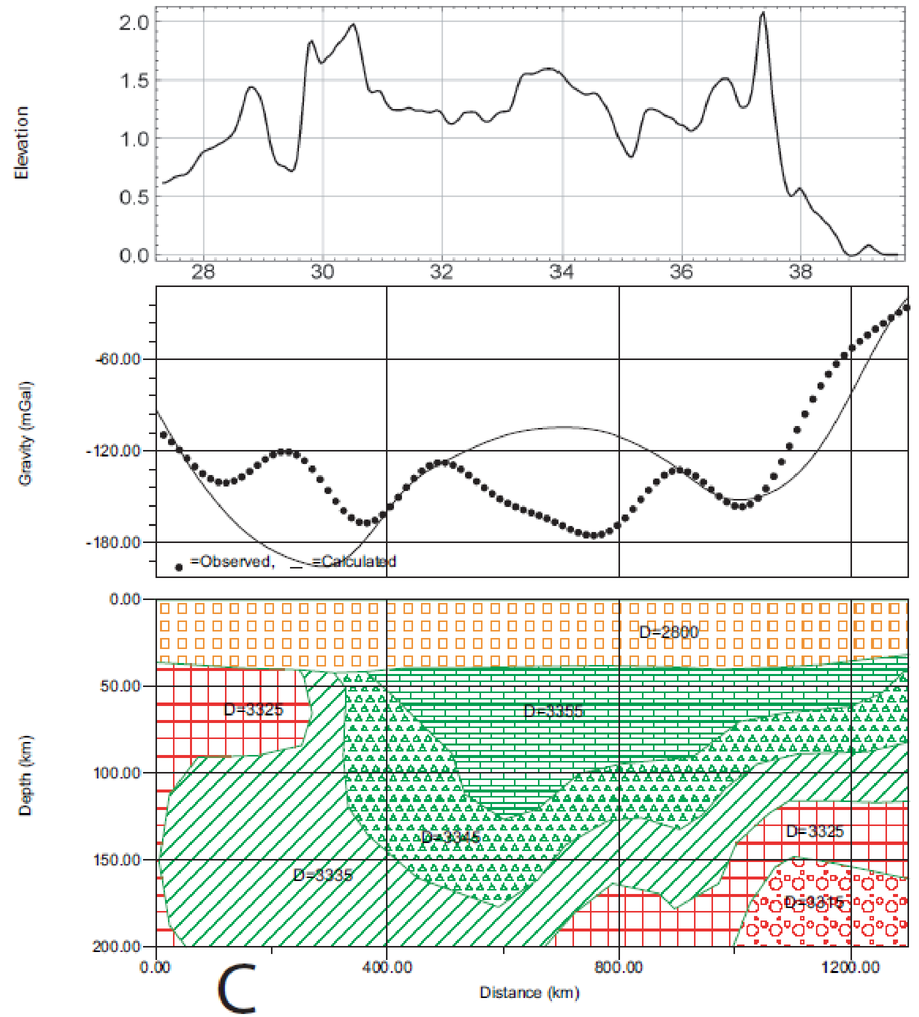
other index non-realistic results

Window size 20x20 also best, best fit with point constraints



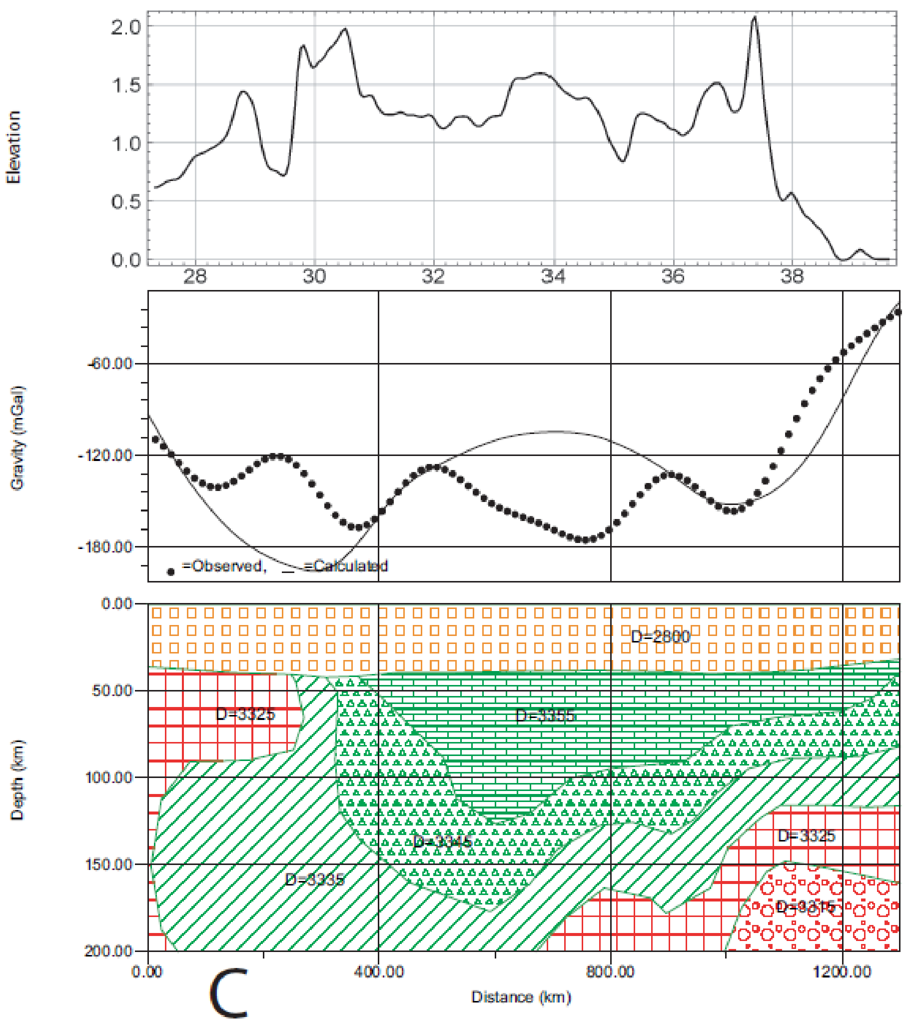
PROFILE AT 6 DEGREES SOUTH

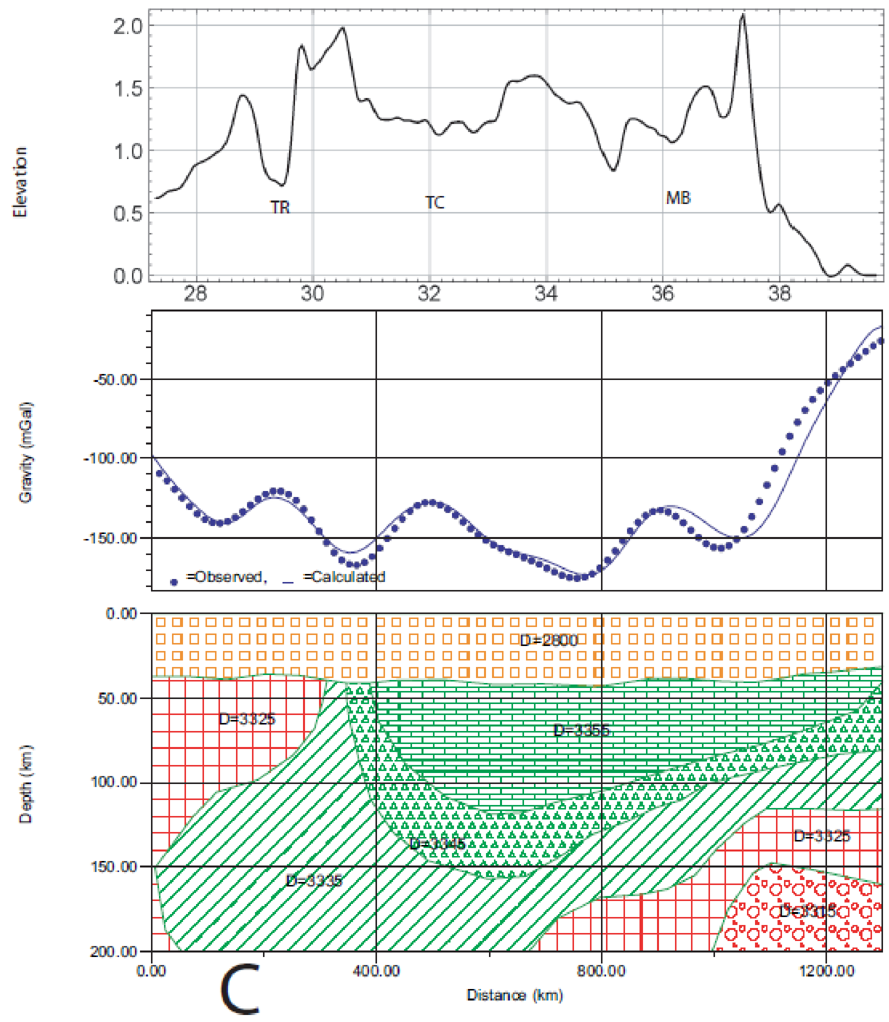
- Chaos inside craton
- Almost no fit except outside rift valley
- Maybe velocity-density relation doesn't always work?
- Will modifications solve this misfit…



Source: Tedla et al, in review, 2011

COMPARISON AT 6 DEGREES SOUTH





Source: Tedla et al, in review, 2011

WHY GRAVITY

- Does not rely on field observations, seismic stations, path coverage, etc → no instruments need to be installed.
- Has complete coverage → better than any other method
- Through validation at known crustal structure, reliability for other parts can be estimated

ESTIMATING CRUSTAL THICKNESS

Starting point:

"simple" models that do not rely on *a priori* constraints or knowledge of area

2 Different models:

- Euler Deconvolution
- 3D inversion

Validation through:

- Comparison with receiver function results (local estimates under seismic station)
- Comparison with global CRUST2
- Tomography based models

EULER DECONVOLUTION

- the gravity field due to a point source such as a pole at a position (x_0, y_0, z_0) is of the form:

$$\Delta T(x, y) = f((x - x_0), (y - y_0), z_0)$$

- If a function f is homogeneous of degree N then it satisfies Euler equation

$$x\frac{\partial f}{\partial x} + y\frac{\partial f}{\partial y} + z\frac{\partial f}{\partial z} = nf$$

- Which leads to (in 2D case, with structure homogeneous along y):

$$x_0\frac{\partial T}{\partial x} + z_0\frac{\partial T}{\partial z} + N \cdot B = x\frac{\partial T}{\partial x} + N \cdot T.$$

after: Reid et al., Geophysics, 1990

CRUST GRACE – EULER DECONVOLUTION

Combination of GOCE-GRACE data

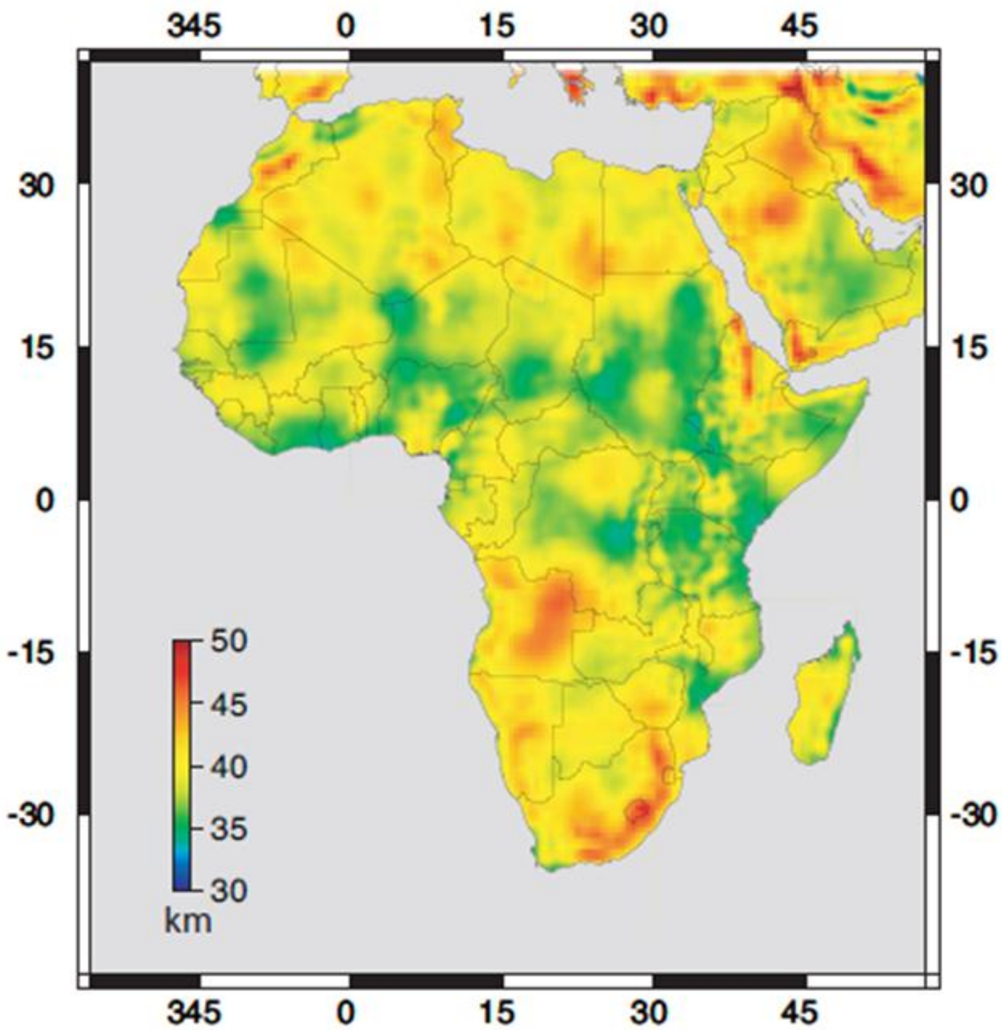
No *a priori* information

Structural index=0.5 → horizontal contrast

Result:

Good relation with tectonic provinces

<u>New satellite based findings</u> – interesting locations

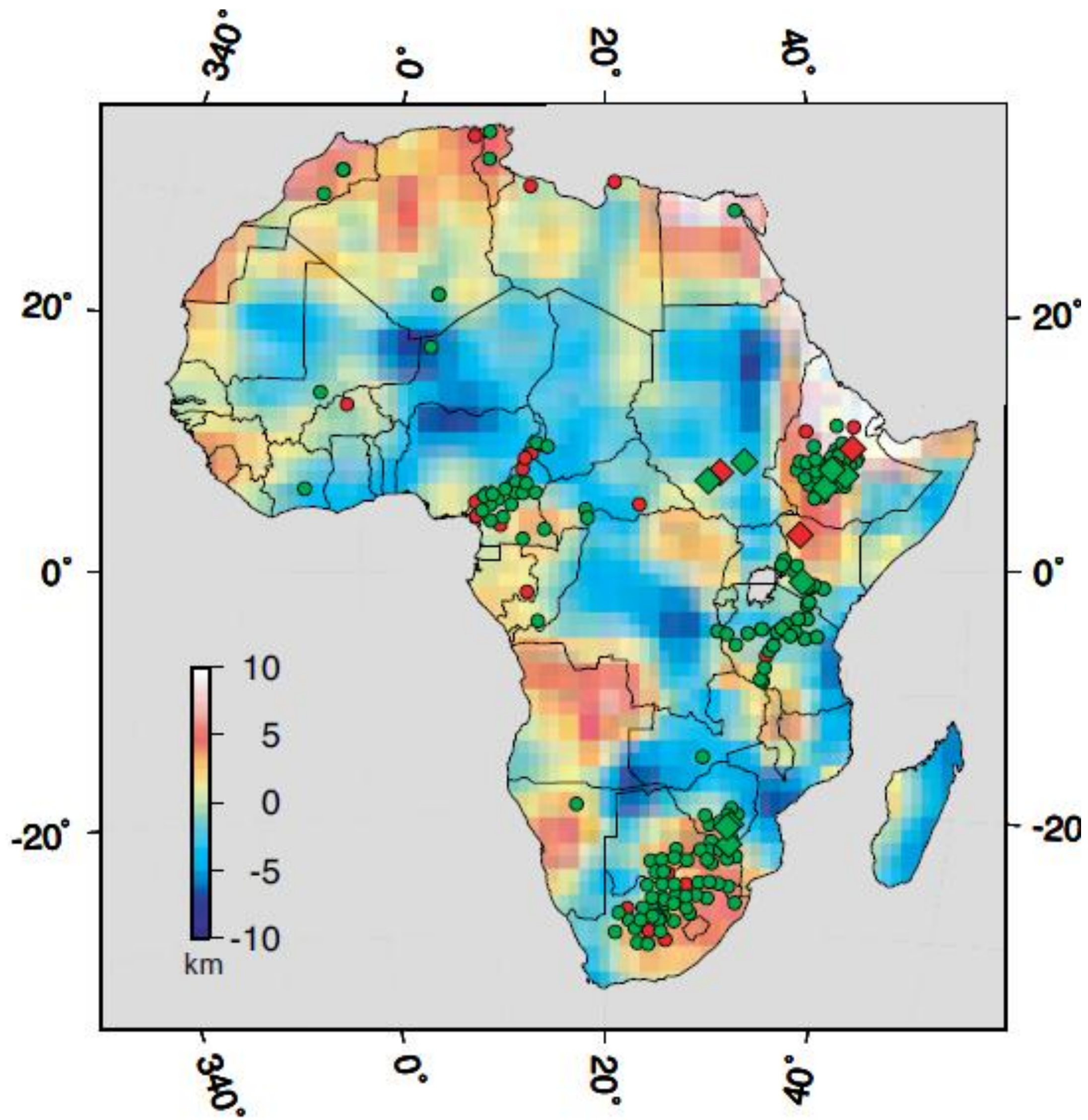


Source: Tedla et al., GJI, 2011

VALIDATION AND COMPARISON

estimates of Moho depth agree < 5 km of the seismic estimates at 86% of locations → model reliable!

Large variations with respect to CRUST2 model - many places improved



Source: Tedla et al., GJI, 2011

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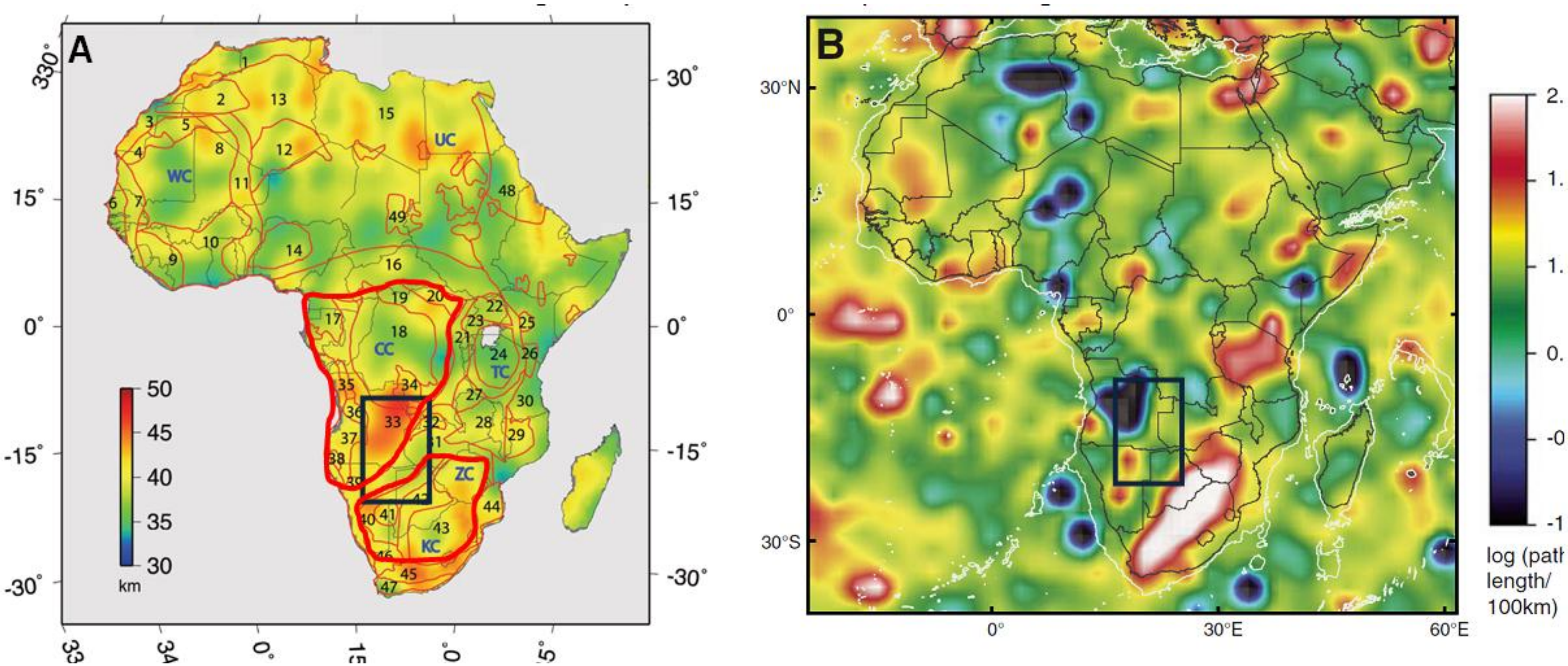
INTERESTING NEW FEATURE IN AFRICAN CRUST



Anomalous feature in southern part of Congo craton not supported by any other study. Tomographic models have no coverage for this area. Follow-up scheduled for 2012.

Source: left:Tedla et al., GJI, 2011
Right: Begg et al., Geosphere, 2009

BUT…

- Requires some data manipulation
  - Method gives also unrealistic values (too shallow, too deep)
  - These are manually removed
  - Requires a-priori knowledge
  - not feasible in areas with large contrast (shallow and deep values in one dataset)
- No optimal use of spatial content
  - Only strict x,y (east-west and north-south)
  - Better to use radial spatial information (3D analysis!)