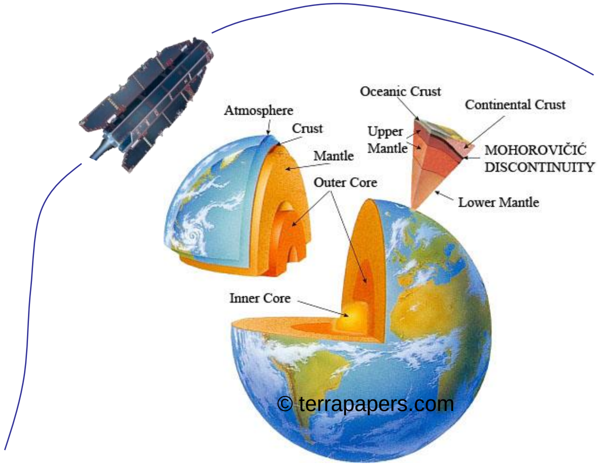
A Least Squares Collocation approach with GOCE gravity gradients for regional Moho-estimation



Daniel Rieser, Torsten Mayer-Guerr
Institute of Theoretical Geodesy and Satellite Geodesy
TU Graz

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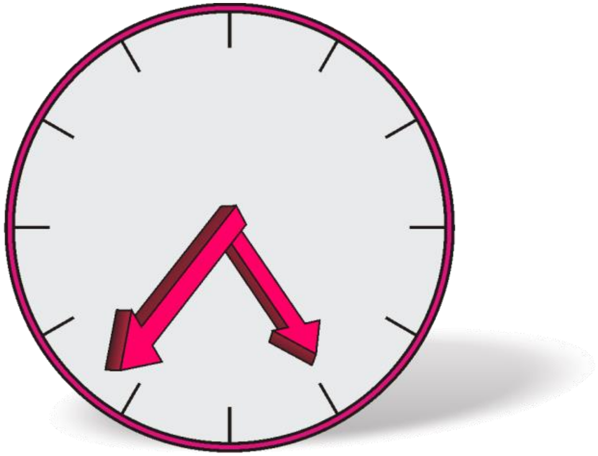
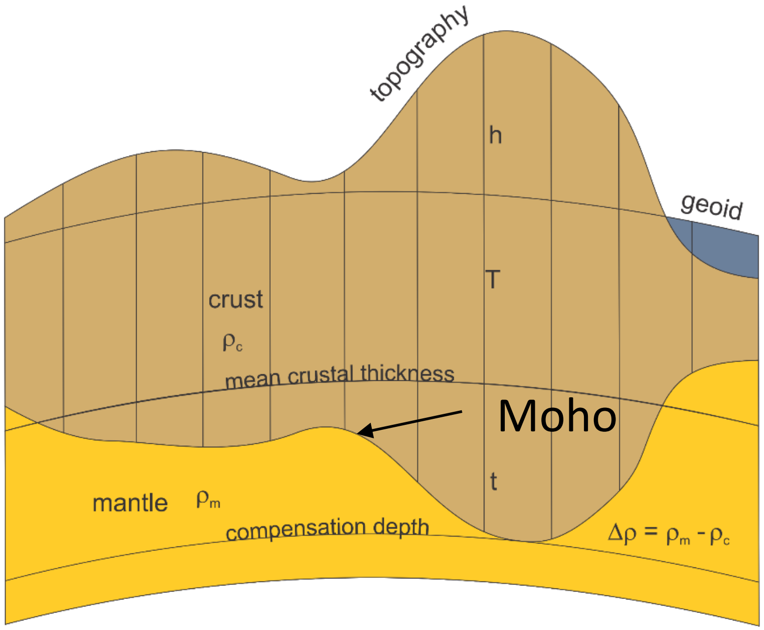


Introduction

A simplified concept:

- Isostatically compensated topography according to Airy-Heiskanen
- Remove gravitational effect of topography
- Density variations due to varying Moho remain
- Expression as density of a surface layer at certain depth

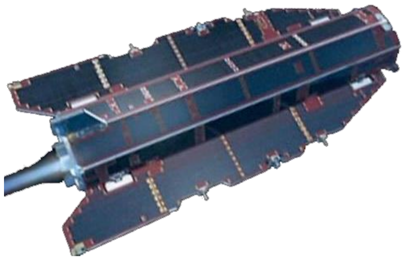


- Assumptions for gravity inversion
  - Constant mantle-crust density contrast
  - Evaluation with respect to a mean depth

Isostatic equilibrium

$$t\,\Delta\rho = h\,\rho_c$$

Introduction



- GOCE gravity gradients recover gravity signals in the medium spectral range
- Isostatic compensation is also expected to happen in the low to medium spectral range
- Use GOCE gradients as in-situ observations at orbit level
- Possible method for regional applications: Least Squares Collocation
- Difference to other studies: use gradients in all three dimensions

Least Squares Collocation for Moho estimation

- Least Squares Collocation

Prediction

$$s = C_{sl}\left(C_{ll} + C_{nn}\right)^{-1} l$$

Precondition: s , l functional of T

$$T_{xx} = \left(\frac{1}{r}\frac{\partial}{\partial r} + \frac{1}{r^2}\frac{\partial^2}{\partial \varphi^2}\right) T$$

Covariance propagation

$$cov(T_{xx}, T_{x'x'}) = \frac{1}{rr'}\frac{\partial^2 K}{\partial r \partial r'} + \frac{1}{rr'^2}\frac{\partial^3 K}{\partial r \partial \varphi'^2} + \frac{1}{r^2 r'}\frac{\partial^3 K}{\partial r' \partial \varphi^2} + \frac{1}{r^2 r'^2}\frac{\partial^4 K}{\partial \varphi^2 \partial \varphi'^2}$$

Covariance function

$$K = \sum_{n=2}^{\infty}\left(\frac{R^2}{rr'}\right) k_n P_n(\cos\psi)$$

Functional relationship between surface layer density and anomalous potential?

Least Squares Collocation for Moho estimation

- Surface layer density (i.e. mass/area)

Disturbing potential T expressed as potential of surface layer S

$$T = G \iint_S \frac{\rho_s}{l} \mathrm{d}S$$

$$\rho_s = \frac{\mathrm{d}m}{\mathrm{d}S} \quad \text{... } surface\ density$$

Spherical approximation

$$T = \frac{2R}{3}\left(2\pi G \rho_s - \Delta g\right)$$

$$\Delta g = -\frac{\partial T}{\partial r} - \frac{2}{R} T$$

$$\rho_s = -\frac{1}{4\pi G}\left(2\frac{\partial T}{\partial r} + \frac{T}{R}\right)$$

Least Squares Collocation for Moho estimation

- Surface layer density and Moho-depth

Covariance propagation between density and all gravity gradients, e.g. T_{ZZ}

$$cov(\rho_s, T_{z'z'}) = -\frac{1}{4\pi G}\left(2\frac{\partial}{\partial r} + \frac{1}{r}\right)\frac{\partial^2 K}{\partial r'^2} = -\frac{1}{4\pi G}\left(2\frac{\partial^3 K}{\partial r \partial r'^2} + \frac{1}{r}\frac{\partial^2 K}{\partial r'^2}\right)$$

Moho-depth (variations to mean level)

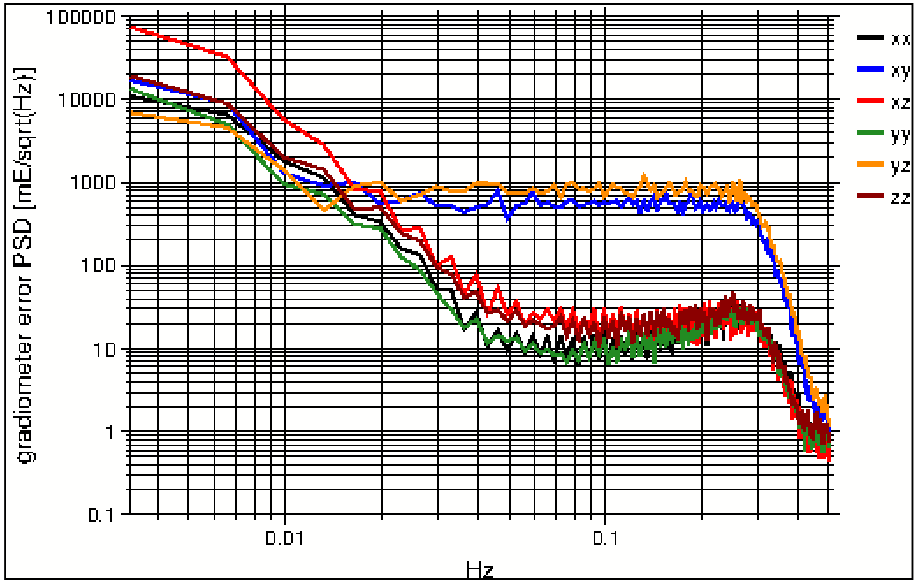
$$t = \frac{\rho_s}{\Delta\rho}$$

GOCE gravity gradients – preprocessing and filtering

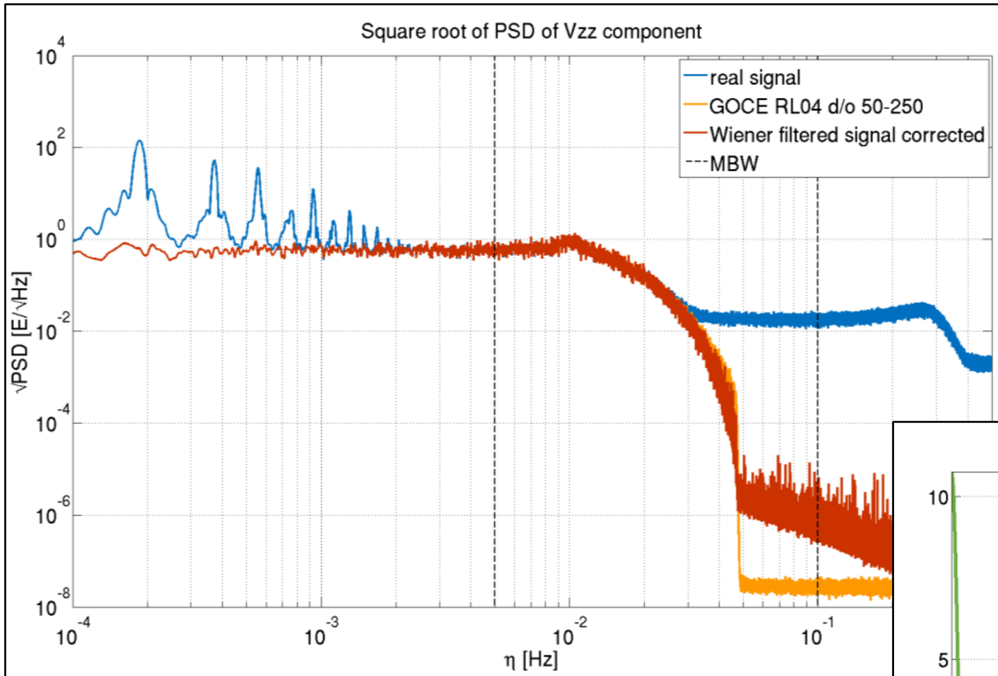
- GOCE Level 2 products
  - EGG_NOM_2 gradients (in GRF)
  - SST_PSO_orbits
  - Quaternions

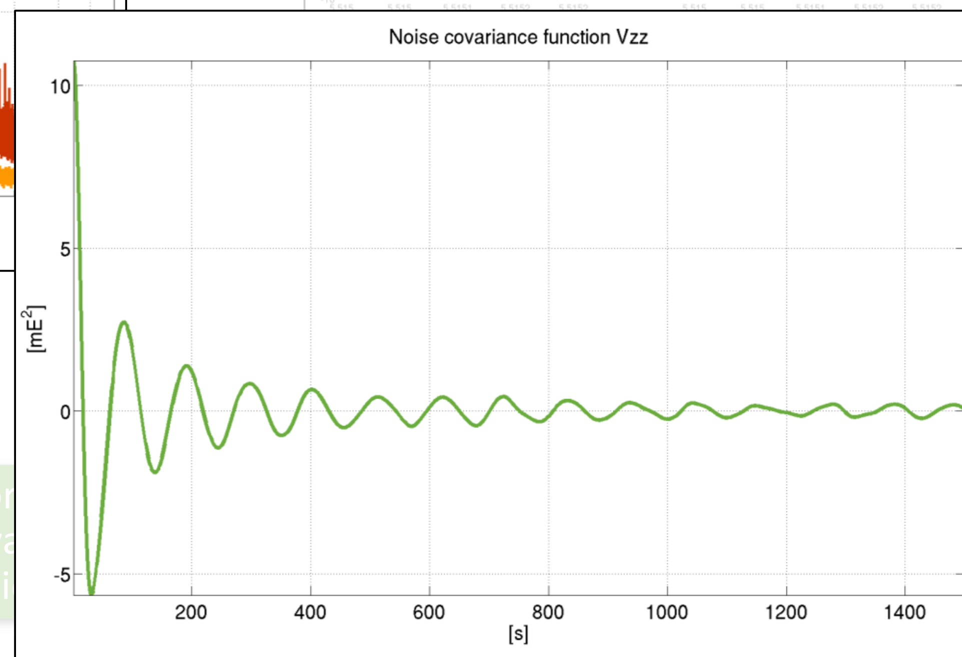
$$\nabla V = \begin{pmatrix} V_{xx} & V_{xy} & V_{xz} \\ V_{xy} & V_{yy} & V_{yz} \\ V_{xz} & V_{yz} & V_{zz} \end{pmatrix}$$

- Preprocessing due to
  - Large errors of Vxy and Vyz
    → only use main diagonal in GRF
  - Colored noise on measurements



GOCE gravity gradients – preprocessing and filtering





Wiener filter

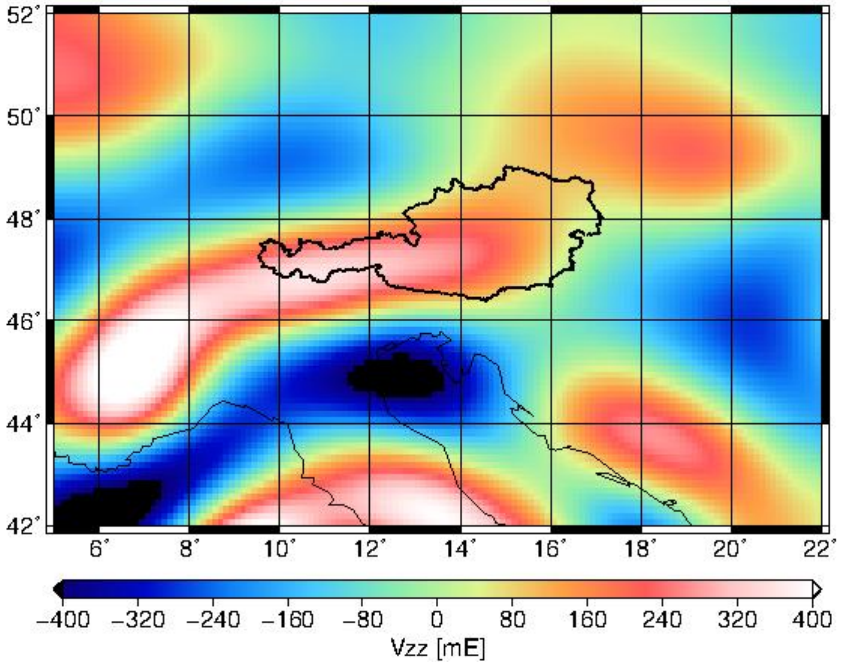
filtered GOCE gradient observations d/o 50 to 250

residuals for noise-cova functi

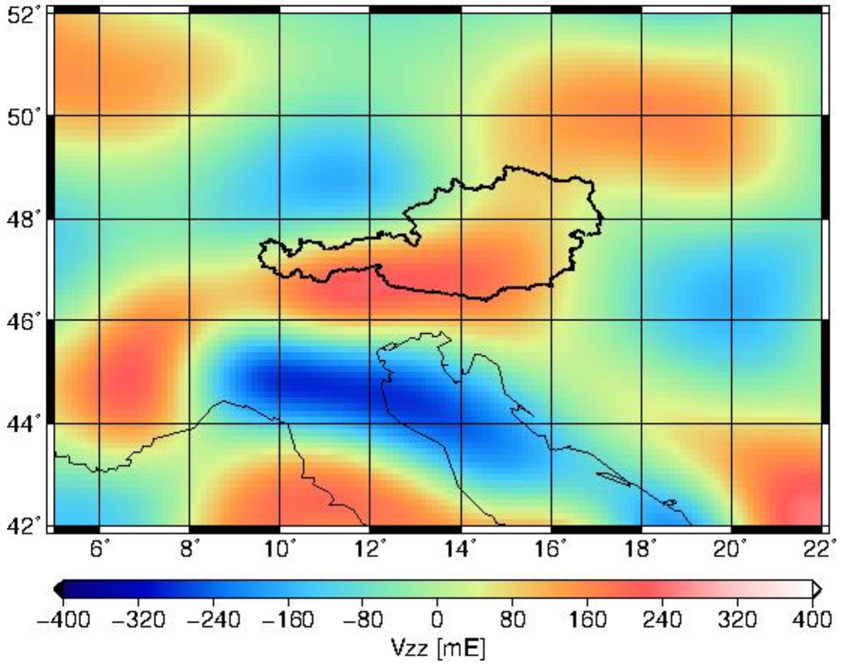
Moho estimation

- Topographic reduction
  - RWI TOPO, d/o 50-360 (Grombein et al., 2012)
  - Rotation to GRF
  - Reduction of preprocessed GOCE gradients

Topographic effect on Vzz at h=250 km (LNOF)



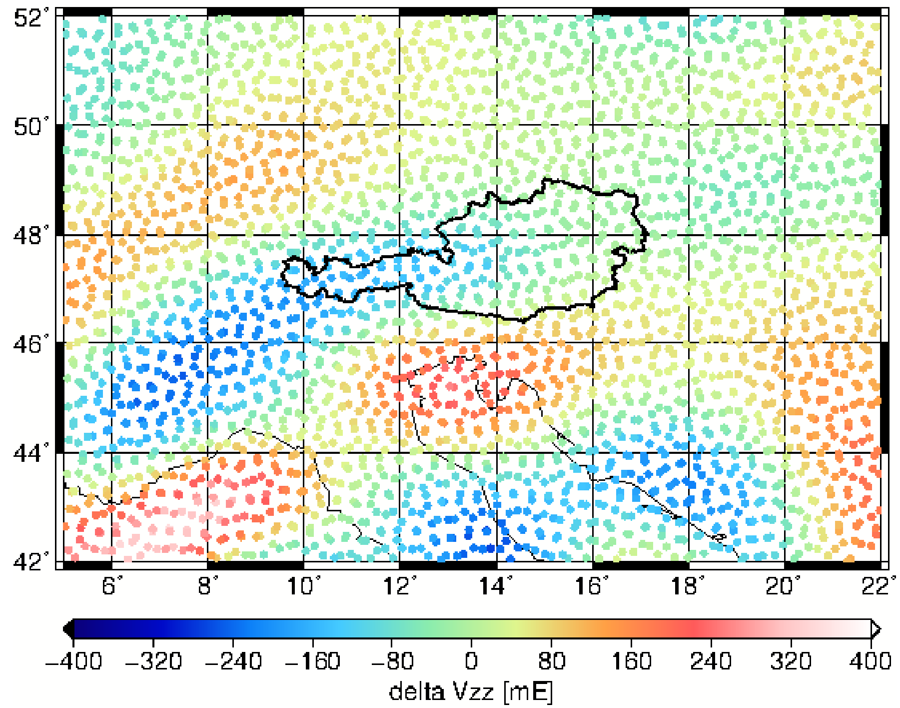
Vzz at h=250 km from TIM RL04 d/o 50-250 (LNOF)



Moho estimation

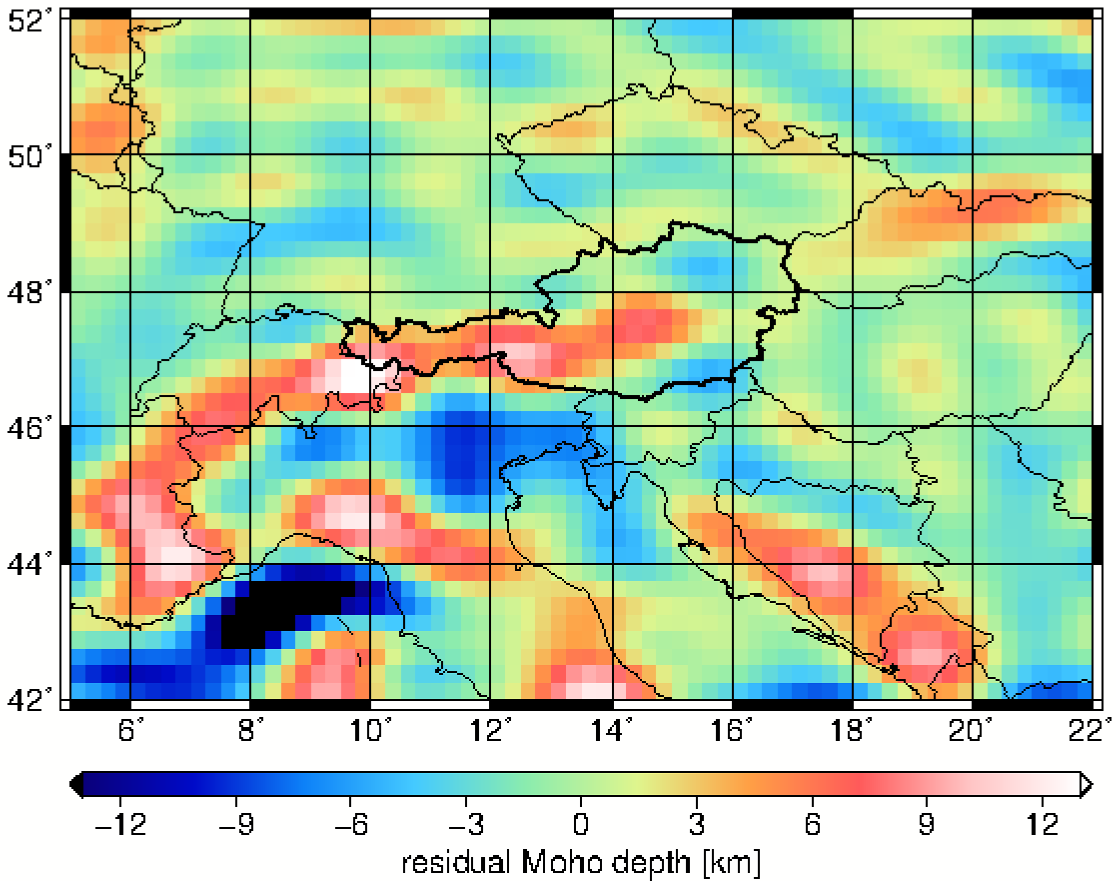
- Configuration
  - Input:
    - 6 months of preprocessed GOCE gradients reduced by topographic effect
    - 11/12 2009, 01/03/05/06 2010
    - 5 seconds sampling
    - → ~ 23500 observations
  - Output:
    - 0.25°x0.25° grid
    - Central Europe (5°-22° East, 42°-52° North)
  - Assumptions
    - mean Moho-depth 30 km
    - $\Delta\rho$ = 350 kg/m³ (according to literature)

GOCE Vzz gradients reduced by topography (GRF)



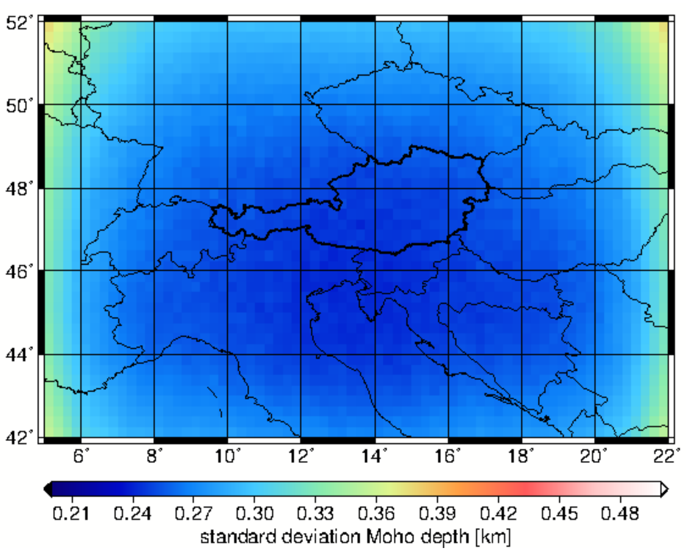
Moho estimation

- Moho-depth variation to mean depth of 30 km (spectral resolution according to input data d/o 50 to 250)



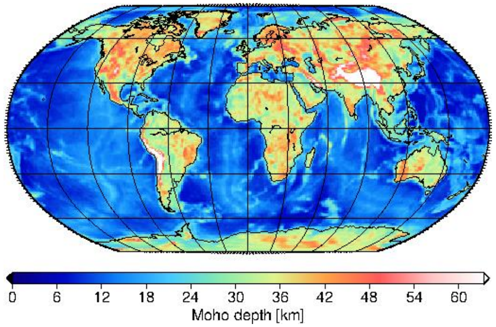
Statistics [km]		
min	max	rms
-20.0	13.6	4.0

Standard deviation from LSC in [km]

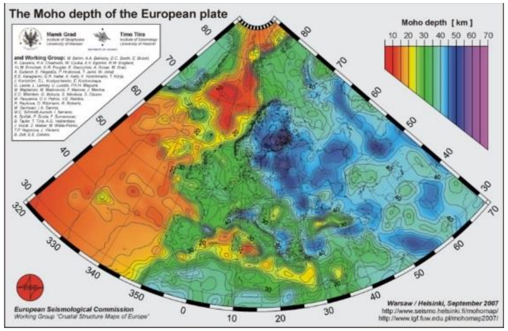


Comparison with other models

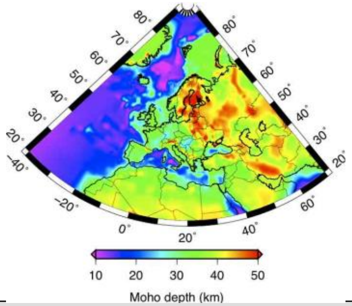
- GEMMA
  - Gravity inversion of gravitational potential and *Vzz* from Space-wise approach
  - Reference model Crust2.0
  - 0.5°x0.5° global grid



- ESC Moho depth map
  - Seismic data (gravity for validation)
  - 0.1°x0.1° regional grid (lowpass filtered at 100 km)

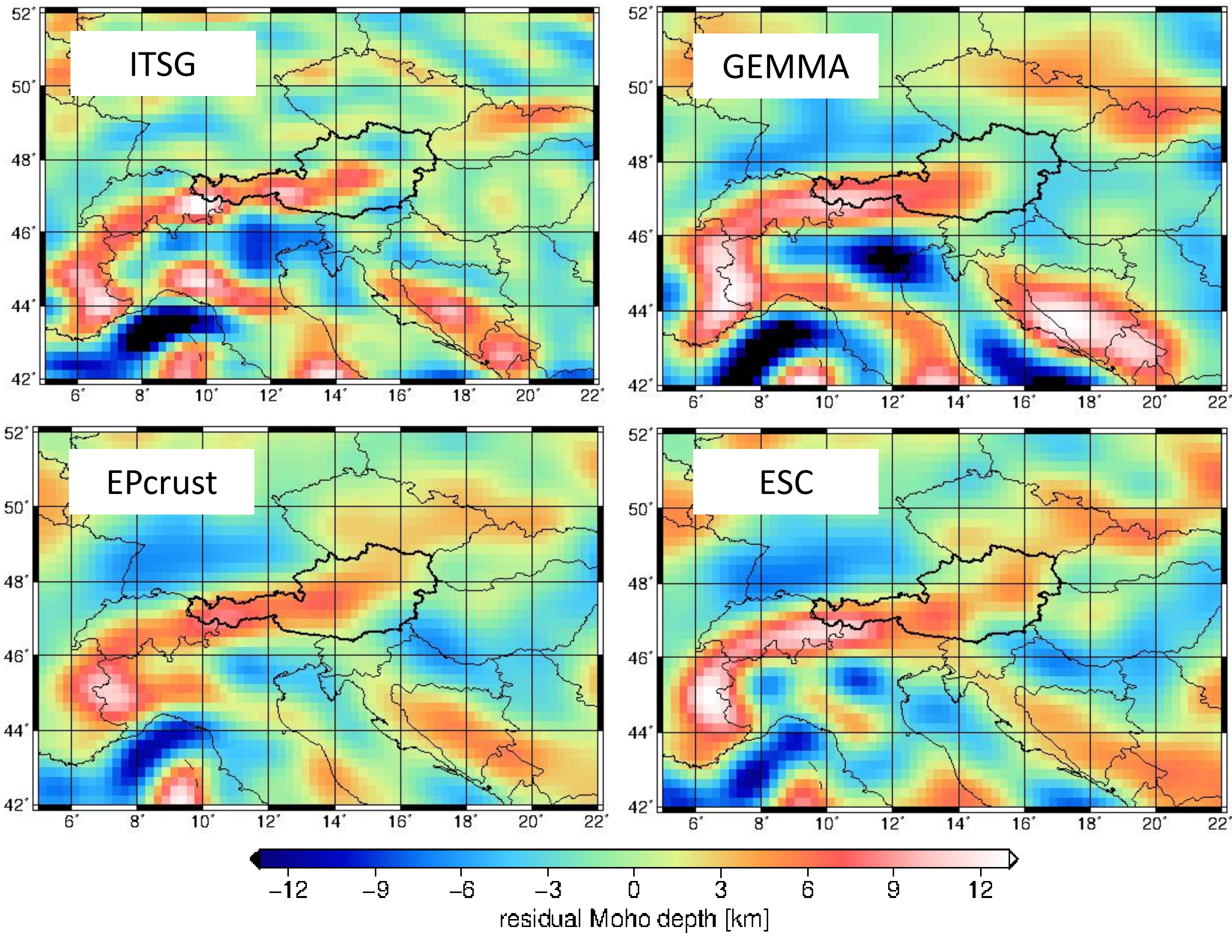


- EPcrust
  - Compilation of global and regional models (including ESC)
  - 0.5°x0.5° regional grid

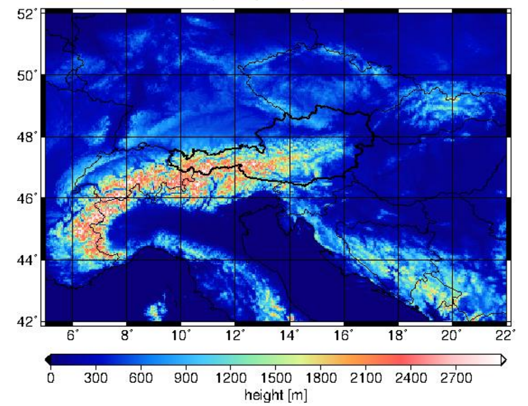


Comparison with other models

- Moho-depth variation to mean depth of 30 km (spectral resolution according to input data d/o 50 to 250)



Topography

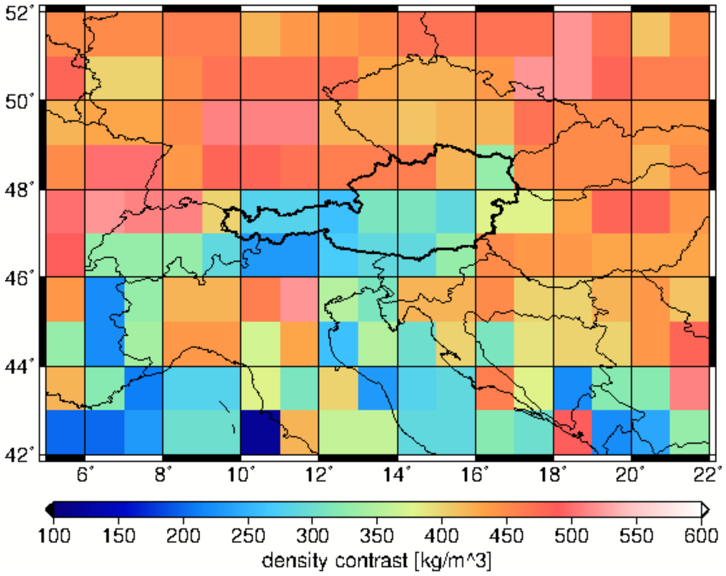


	Statistics [km]		
Model	min	max	rms
ITSG	-20.0	13.6	4.0
EPcrust	-11.6	12.4	3.5
ESC	-12.0	13.5	4.0
GEMMA	-17.6	13.6	5.2

Summary and conclusions

- Conclusions
  - Reasonable agreement with other models
    - Amplitudes comparable to GEMMA
    - Better resolution than other models
    - Clearer footprint of mountainous regions (Alps, Apennines, Dinaric Alps, Tatra)
- Open issues
  - Use a variable density contrast, e.g. From CRUST1.0?

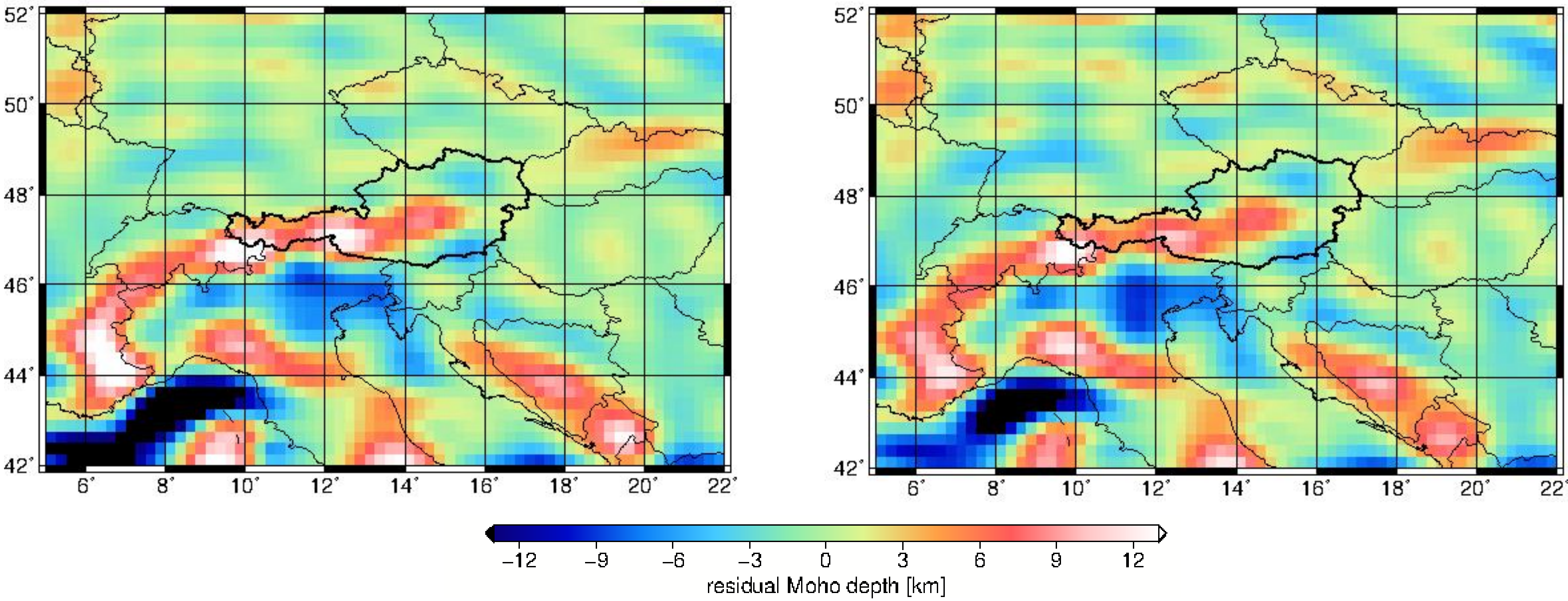
Variable density contrast CRUST1.0



Summary and conclusions

Moho from variable density contrast

Moho from constant density contrast (350 kg/m³)



Statistics [km]		
min	max	rms
-26.3	16.6	4.6

Statistics [km]		
min	max	rms
-20.0	13.6	4.0

Summary and conclusions

- Conclusions
  - Reasonable agreement with other models
    - Amplitudes comparable to GEMMA
    - Better resolution than other models
    - Clearer footprint of mountainous regions (Alps, Apennines, Dinaric Alps, Tatra)
- Open issues
  - Use a variable density contrast, e.g. From CRUST1.0?
  - No consideration of density variations in crust (sediments)
  - Gradients are only covering spectral range from ~ d/o 50 to 250
  - Recovery of the long-wavelength part d/o 0-49:
    - Do mantle density anomalies affect this wavelengths?

For absolute Moho-depths, validation and integration of other techniques is compulsory!

Thank you for your attention!

Daniel Rieser, Torsten Mayer-Gürr

Institute of Theoretical Geodesy and Satellite Geodesy
TU Graz

Graz University of Technology

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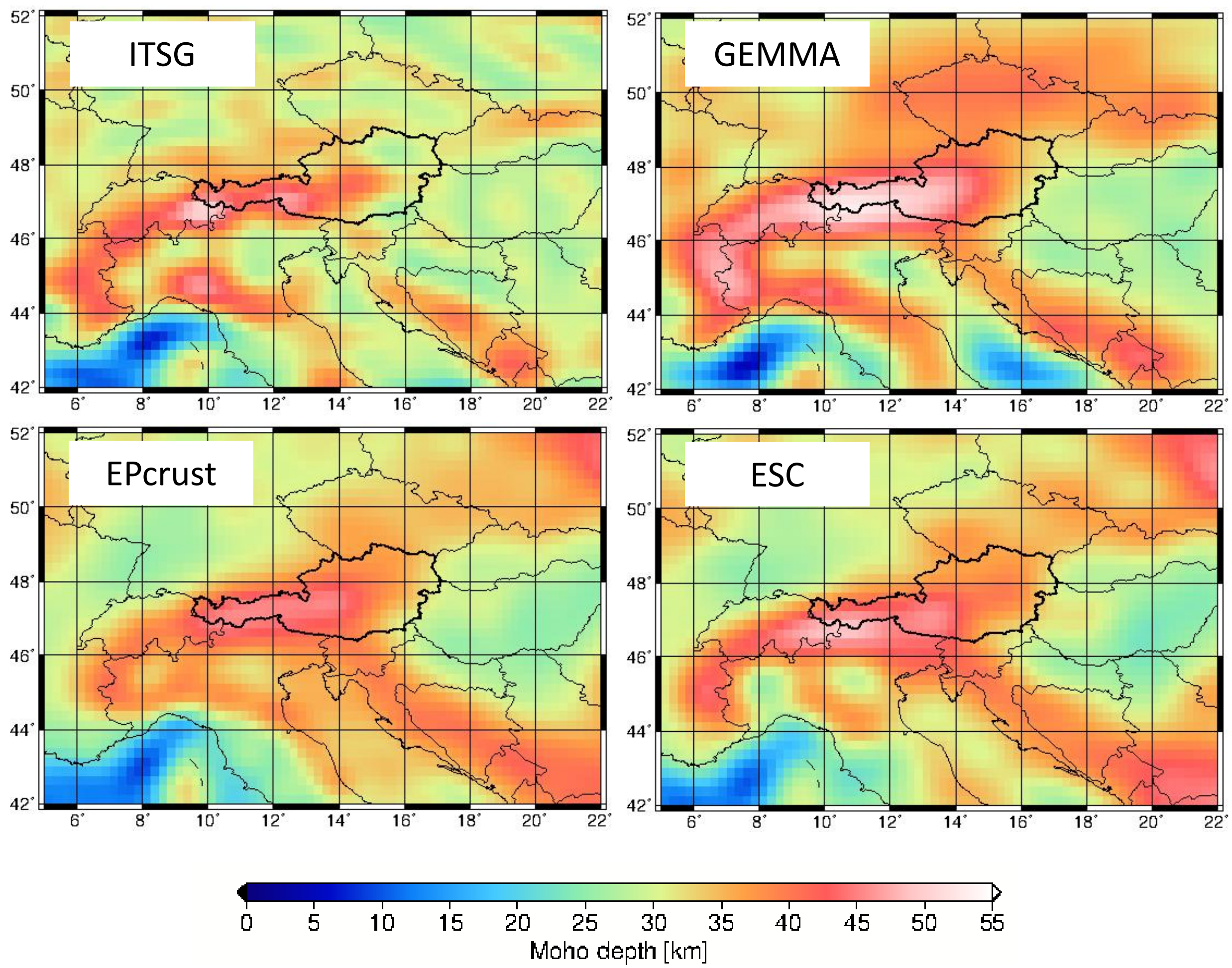
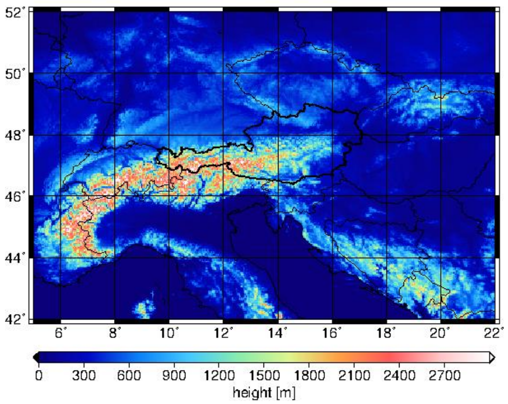
FWF
Der Wissenschaftsfonds.

Application: Moho estimation

- „Absolute“ Moho-depths (d/o 250)



Topography



	Statistics [km]		
Model	min	max	avg
ITSG	7.1	50.5	31.1
EPcrust	9.2	45.7	32.1
ESC	9.9	49.1	32.6
GEMMA	4.8	53.2	34.6