GOCE gravity gradient data for lithospheric modelling

From well surveyed to frontier areas

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GOCE gravity gradient data for lithospheric modelling

• Project GOCE+ GeoExplore funded by ESA STSE (2011-2013)
• GOCE gravity gradient data may improve modelling of the Earth’s lithosphere and mantle composition and thereby contribute to a better understanding of the Earth’s dynamic processes

• Impact assessment for North-East Atlantic margin
  • Well surveyed area (gravity, seismics, magnetics, …)
  • Reliable lithospheric models exist

• Application to Rub’ al Khali (Saudi Arabia)
  • Frontier area
  • Knowledge transfer from NEA
Outline

• Density model
  – Setup
  – Comparison with GOCE

• Topography
  – Resolution
  – Planar versus spherical

• Moho depth

• GOCE and model gradients
  – Comparison at mean altitude
  – Tensor rotation

• Conclusions and outlook
Lithospheric model set-up

1st model: Topography only
Lithospheric model set-up

- Asthenosphere
- Lith. mantle
- Moho

Model Name: 3D_NEAtlantic.g3d
- Global Information
- Vertical Density Function
- Gravity
- Magnetic
- Layer 1: \3DMod_Topography10.grd(GRD)
  - Density: 2.67
  - Susc: Constant
- Layer 2: \Null10.grd(GRD)
  - Density: 1.03
  - Susc: Constant
- Layer 3: \3DMod_Bathymetry10.grd(GRD)
  - Density: Vertical Density Function
  - Susc: Constant
- Layer 4: \BaseSed_NGU_NOAA_Laske.grd
  - Density: \D_UC1.grd
  - Susc: Constant
- Layer 5: \JCMC.grd
  - Density: 2.8
  - Susc: Constant
- Layer 6: \JCLC.grd
  - Density: 2.95
  - Susc: Constant
- Layer 7: \3DMod_IsoTopLCBClipped.grd(GRD)
  - Density: 3.1
  - Susc: Constant
- Layer 8: \3DMod_Moho_Grad.grd
  - Density: \MantleDensityGP250km.grd
  - Susc: Constant
- Layer 9: \LAB_Artenui2a.grd
  - Density: 3.3
Lithospheric model set-up

- Asthenosphere
- Lith. mantle
- < Moho

Sediment compaction
Laterally temperature dependent
Comparison GOCE data and density model

Shape of anomalies similar
Amplitudes differ
Topographic reduction @ GOCE altitude

- Topographic effect is a few E
- GOCE accuracy 10 – 20 mE
- DEM with 10’ gives errors > 10 mE
- DEM with 4’ resolution sufficient to compute effect @ GOCE altitude
Flat Earth versus spherical calculations

View of a tesseract, the integration point Q, the global coordinate system, the computation P and its local coordinate system.

(Uieda 2011)
Topography: Grr spherical versus planar

Tesseroids
1 min ETOPO1

Flat Earth – GMSYS
1 km topography

Difference
(contours: 0.1 E)

Difference can be up to 0.5 E =>
Spherical computations are required
Moho depth and uncertainty (Grad et al. 2009)

Moho depth in km

Depth uncertainty in km
Effect of Moho depth uncertainty @ GOCE altitude

Grr @ GOCE altitude mean Moho depth

Uncertainty in Grr due to uncertainty in depth

Effect can be up to 2 E =>
GOCE gradients are sensitive to deep crustal/lithospheric structure
How high does GOCE fly?

Height above ellipsoid (mean = 270 km)

Height above sphere (mean = 260 km)

Reported GOCE altitude of 255 km is the perigee height
Mean height above ellipsoid is 270 km
Mean height varies for different regions
Height difference: does it matter?

Vertical gradient @ 255 km

Difference ellipsoid - sphere

Amplitudes may differ up to 20% using spherical or ellipsoidal height
Definition of “mean” altitude matters
Meridian convergence

Planar: UTM projection

Azimuth difference NEA: planar and spherical
Correction for meridian convergence increases with distance from central meridian
Amplitude of correction may reach 20% - 40% of total signal
Conclusions and outlook

• Comparison of calculated and observed GOCE gradients
  – Shape of anomalies similar
  – Amplitudes differ
    ✔ Flat Earth approximation
    ✔ Effect of model simplification and errors? (Constant density layers used in the model; Moho compilation 20% uncertainty)

• Preliminary sensitivity analysis
  – Large effect by topography, spherical computations needed
  – GOCE gradients sensitive to deep crustal/lithospheric structure
  – Height and tensor orientation: require proper definition to allow comparison

• Next step: Model optimization by inversion
  – Forward modelling of 5(9) tensor components is time-consuming
  – Depth weighted inversion
  – Sensitivity matrix for the entire lithospheric structure has to be developed
  – Knowledge transfer from North-East Atlantic margin to Rub’ al Khali
Project website

http://goce4interior.dgfi.badw.de