Using topographic-isostatic reductions to smooth GOCE gravity gradients

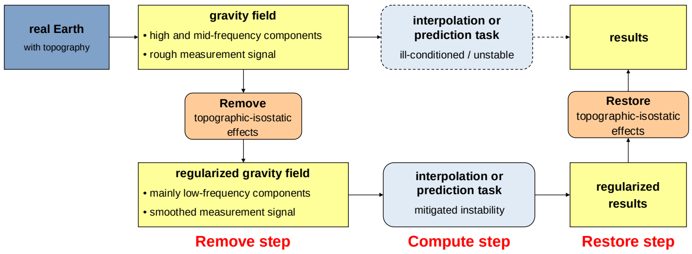
Thomas Grombein, Kurt Seitz and Bernhard Heck

REAL GOCE GERMANY

GEOTECHNOLOGIEN

Motivation and Introduction

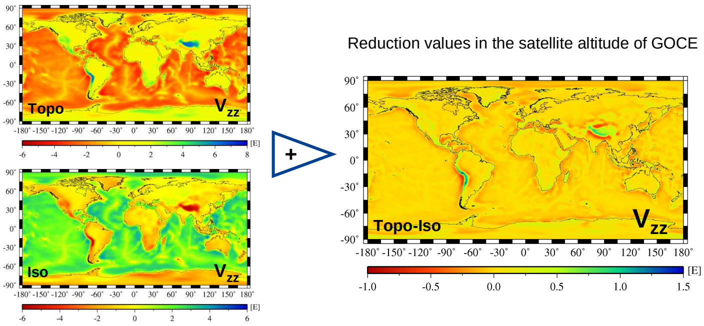
Analyzing the gravity gradients measured by ESA's satellite mission GOCE, high and mid-frequency components can be discriminated which are mainly caused by the attraction of the Earth's topographic and isostatic masses. Due to the induced rough measurement signal, interpolation or prediction tasks, such as a harmonic downward continuation of the gradients from satellite altitude to Mean Sea Level (MSL), are often ill-conditioned processes. Concerning the numerical stability of such tasks it is recommended to smooth the observed gradients by applying topographic-isostatic reductions using a Remove-Compute-Restore technique. The present research provides an overview of the newly developed and advanced concept used to generate suitable topographic-isostatic reduction values. Furthermore, results from the reduction of one week of real GOCE measurements are presented and a smoothing potential analysis is carried out.



Topographic-isostatic reduction concept

Topographic-isostatic reductions can be obtained by forward gravity modeling based on the numerical evaluation of Newton's integral extending over the domain of the Earth's topographic and isostatic masses. Thereby, global information on the geometry and density is required which have to be defined by a topographic model and an isostatic concept. Being advantageous over previous approaches the proposed concept of reduction is based on a three-layer Rock-Water-Ice decomposition of the topography and a modified Airy-Heiskanen isostatic concept introducing a Moho depth model. Geometry and density information is derived from the topographic data base DTM2006.0 and the global crust model CRUST2.0. Since this data is provided in geographical coordinates, tesseroid bodies are used for mass discretisation and arranged on an ellipsoidal reference surface (GRS80). The computation of topographic-isostatic reductions is performed by the self-developed C++ program TOISMAT (TOpographic-ISostatic MAss reductions using Tesseroids) which is designed for parallel computing on high-performance computer systems.

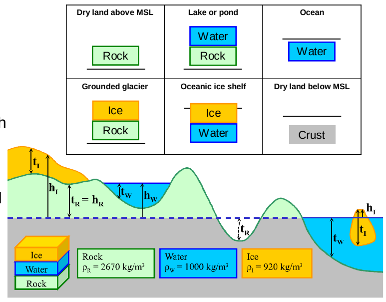
Reduction values in the satellite altitude of GOCE



Topographic model

Basic idea: Three-layer model

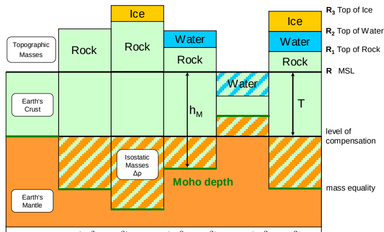
- Separate modeling of rock, water, and ice masses
- DTM2006.0 information is used to construct an own 5′ × 5′ vertical three-layer terrain and density model
- Each grid element consists of three components with different MSL-heights (h_R, h_W, h_I) and consistent thickness (t_R, t_W, t_I)
- Layer-specific density values (ρ_R, ρ_W, ρ_I) are derived from specified DTM2006.0 terrain types
- Topographic masses are represented by three tesseroids per grid element



Isostatic concept

Basic idea: Mass equality condition

- Isostatic masses are derived from topographic load
- Different classical isostatic concepts have been adopted to the Rock-Water-Ice approach
- Development of a modified Airy-Heiskanen concept, which is improved by introducing a Moho depth model obtained from CRUST2.0
- (Anti-)root depths are replaced by the Moho depths
- Mantle-Crust density contrast Δρ is kept variable
- Normal compensation depth is set to T = 31 km



$$\Delta\rho = \frac{\rho_R\,(R_1^3 - R^3) + \rho_W\,(R_2^3 - R_1^3) + \rho_I\,(R_3^3 - R_2^3)}{(R-T)^3 - (R-h_M)^3}$$

Numerical Investigations

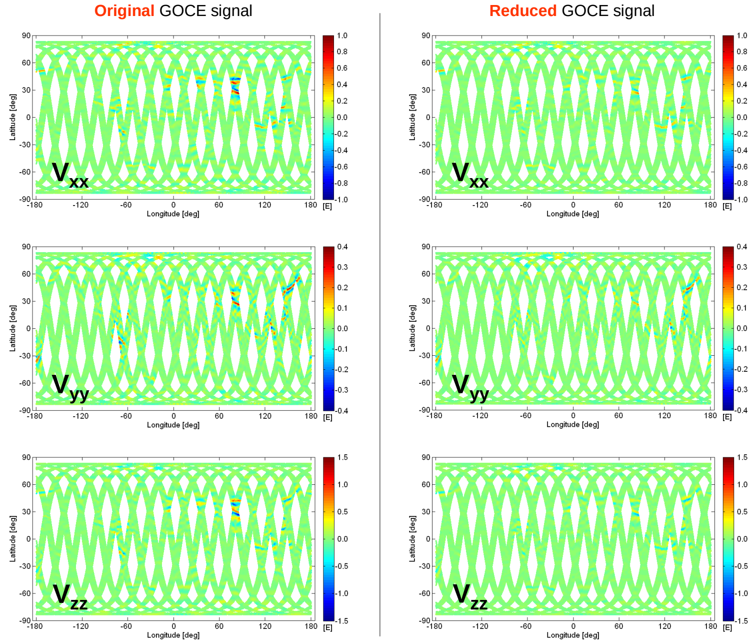
Reduction of GOCE measurements

- Reduction concept is used to smooth a GOCE data set measured from Oct. 27 - Nov. 02, 2010
- Topographic-isostatic reductions are calculated along the orbit of the GOCE satellite, which requires four hours run-time using parallel computing on 560 processors (Intel Xeon 2.53 GHz)
- Reduction values have to be rotated from the Local North Oriented Frame (LNOF) to the Gradiometer Reference Frame (GRF) before they can be applied to the gradient measurements

Smoothing potential analysis

- Comparison of original and reduced GOCE signals in the high and mid-frequency components
- Signals are bandpass-filtered to the measurement bandwidth of the gradiometer (5 to 100 mHz)
- Degree of smoothing is quantified by percentage change in standard deviation and range

Results



[%]	V_{xx}	V_{yy}	V_{zz}	V_{xy}	V_{xz}	V_{yz}
STD	31.8	27.7	31.5	0.7	31.5	0.7
Range	43.1	22.0	40.4	3.4	43.8	0.0

Percentage improvements in standard deviation and range before and after reduction

Conclusions

- Smoothing behavior has a dominant regional character and is strongly dependent on the actual topographic surface that is crossed by the satellite
- Significant smoothing effects can be detected in regions with strongly variable topography (e.g. the Himalayas, the Andes), while other areas seem to remain uncompensated (e.g. Japan Trench)
- The use of topographic-isostatic reductions is particularly suitable for regional applications

- Significant smoothing potential for V_{xx}, V_{yy}, V_{zz}, and V_{xz} gradient components
- Degree of smoothing quantified by changes in standard deviation amounts to about 30%
- Range can be reduced by about 40% in comparison to the original signal
- V_{xy} and V_{yz} cannot be smoothed due to high-frequency noise in the original measurements

Acknowledgements

The authors would like to thank N.K. Pavlis for providing the global topographic data base DTM2006.0. The Bundesministerium für Bildung und Forschung (BMBF, German Federal Ministry of Education and Research) is acknowledged for the financial support of this research within the REAL GOCE project of the GEOTECHNOLOGIEN Programme. Finally, the Steinbuch Centre for Computing at the Karlsruhe Institute of Technology (KIT) is acknowledged for the allocation of computing time on the high performance parallel computer system HC3.

KIT – University of the State of Baden-Wuerttemberg and National Research Center of the Helmholtz Association

Thomas Grombein, thomas.grombein@kit.edu
Kurt Seitz, kurt.seitz@kit.edu
Bernhard Heck, bernhard.heck@kit.edu

Englerstraße 7
D-76131 Karlsruhe
www.gik.kit.edu

Geodetic Institute