VALIDATION OF THE GOCE LEVEL 2 GRAVITY GRADIENTS BY UPWARD CONTINUATION: SOFTWARE TESTING AND PRELIMINARY RESULTS FOR NORWAY

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INTRODUCTION:
The GOCE satellite gradiometry mission represents an important tool for improved knowledge of the Earth’s gravity field. Since launch, measurement phases and calibration processes have been performed successfully. Moreover, results in the form of Level 1b and Level 2 data have been made available by the European Space Agency. It is expected that especially Level 2 data will be exploited in many scientific disciplines studying our planet by different approaches and for different purposes. An important task is to validate Level 2 data.

In general, validation is defined as an application of methods to compare data products derived from measurements with existing independent data or knowledge in order to assess the quality of the data products and to make sure that the measurement process, error estimation and calibration have been performed well (Koop et al., 2001). Several mathematical methods have been proposed for validation of Level 2 data of the GOCE gradiometry mission depending on products tested. In this contribution, upward continuation of terrestrial gravity measurements into gravitational tensor components at GOCE satellite orbit is considered. For this purpose new computational software has been developed. Its numerical performance has been tested by a synthetic Earth gravity model. In a next step, gravitational tensor components available from EGG_TRF_2 product have been validated for this purpose. Therefore, terrestrial gravity data in Norway and a global gravity model have been combined in the remove-compute-reprocess procedure.

UPWARD CONTINUATION OF GRAVITY DATA INTO Gravitational Tensor Components:
Gravitational tensor components are defined in an arbitrary reference frame. Originally, they are measured in a gradiometer reference frame respecting the orbit of the GOCE satellite. Such components have been corrected, calibrated and made available in the form of EGG_NOM_2 product. For geophysical or oceanographic applications, gravitational tensor components in an Earth related frame, i.e. in a north-oriented reference frame (LNOFR), are more suitable. In the LNOFR, x is axis points to the north, y axis points to the west and z axis has the direction of the geocentric radius vector. Fig. 1. By a transformation of EGG_NOM_2 product, gravitational tensor components have been obtained in the LNOFR and made available in the EGG_TRF_2 product. Validation of EGG_TRF_2 product may be performed by upward continuation, see Fig. 2. Disturbing potential tensor components Tr at the GOCE orbit are evaluated by the following integral transformations:

\[
\psi_{ij}(0,0,0) = \int_{-R}^{R} \int_{-R}^{R} \int_{-R}^{R} \frac{1}{(R + \rho)^2} \frac{\rho dx dy dz}{\rho \rho R} \nabla^2 T_{ij}(\rho, \theta, \phi)
\]

where \( T_{ij} \) are the integral kernels and A4p are the terrestrial gravity anomalies.

In practice, gravity anomalies and a global gravity model (GGM) are combined in a remove-compute-reprocess (RCP) approach.

BEHAVIOR OF INTEGRAL KERNELS:
Integral kernels \( S_{ij} \) in the upward continuation formulas (1) depend on the geocentric radius \( r \) of an evaluation point, spherical azimuth \( \phi \) and distance \( \chi \) of an integration point, see Fig. 2. Considering first and second derivatives of the extended Stokes' function with respect to \( r \), \( \phi \) and \( \chi \), integral kernels for the upward continuation (1) are defined as follows (Wölfi, 2007):

\[
S_{ij}(r) = \frac{1}{r^2} \left( \frac{\partial^2}{\partial r^2} T_{ij}^{GR} + \frac{\partial}{\partial r} T_{ij}^{GR} + \frac{\partial}{\partial \phi} T_{ij}^{GR} \right)
\]

where \( T_{ij}^{GR} \) are the disturbing potential tensor components.

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PRELIMINARY RESULTS FOR NORWAY:
Terrestrial gravity data over Nordic countries has been continued upwards by formulas (1) and combined in the RCP approach with satellite-only GGM EIGEN-CHAOS5P (Estepnik et al., 2009). In a next step, the results have been compared with GOCE gravity data from EGG_TRF_2 product file, see Tab. 2. Differences reach up to 0.036E and change slightly depending on integration radius and the degree of the low-frequency gravity field. Fig. 2. Differences show low-frequency behavior of differences with patterns similar to topographic and atmospheric effects for the gravitational gradient components (Eshagh, 2009).

CONCLUSIONS:
- software for upward continuation of terrestrial gravity data and its combination with a GGM has been developed;
- numerical precision of the software is on the level of several mGal;
- kernel functions have to be modified in order to accelerate the convergence of the truncation error;
- gravity data over Nordic countries and EIGEN-CHAOS5P model have been compared with EGG_TRF_2 product;
- topographic and atmospheric corrections have to be considered;
- propagation of errors due to erroneous gravity data and geopotential coefficients have to be studied.

REFERENCES:
- Meissl P (1971) Preparation for the numerical evaluation of the second disturbing tensor components. Methods of Geodesy, Geodynamics and Geoinformatics, 1 project 4294 Application and Validation of GOCE and remote sensing data with focus on Nordic countries and EIGEN-CHAOS5P

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Fig. 1: Geocentric Cartesian (X, Y, Z), geodetic spherical (r, \( \phi \), \( \lambda \)), local north-oriented (x, y, z), r = geocentric radius, \( \phi \) = geodetic latitude, \( \lambda \) = geodetic meridian.

Fig. 3: Values of integral kernels \( S_{xx} \), \( S_{yy} \), \( S_{zz} \), \( S_{xy} \), \( S_{yz} \), \( S_{xz} \).

Fig. 4: Differences between disturbing potential tensor components \( T_{ij} \) on the GOCE satellite orbit and corresponding GOCE gravity data from EGG_TRF_2 product.

Fig. 2: Geometry of upward continuation: \( P(x,y,z) \) being its projection on a reference sphere, \( Q(x,y,z) \) is the integration point.

Fig. 6(a): Differences between disturbing potential tensor components \( T_{ij} \) on the GOCE satellite orbit and corresponding GOCE gravity data from EGG_TRF_2 product, see Fig. 5. Differences reach up to 0.036E and change slightly depending on integration radius and the degree of the low-frequency gravity field.