Postglacial rebound in Estonia: Constraints from the measurements of Estonian geodetic networks

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Introduction

Noticeable crustal movements in Estonia result mainly from the postglacial rebound (PGR) of northern Europe (fig. 1). The PGR has a clear impact on the maintenance of national geodetic networks (see fig. 2) because geodetic coordinates, gravity and geoid surface change in time.

Results. Part I: Observed gravity change

The observed rates of secular gravity change (network solution with measurement data from 1977 and from 1992-2004) and surfaces of the change are presented in fig. 3. Error estimations of observed rates stay between ±1.7 and ±3.3 µGal/yr.

Results. Part II: Gravity change and PGR

Gravity change is closely related to PGR because of the land uplift and mass redistribution inside the Earth. The contribution of both effects is efficiently described by the ratio \( \frac{\dot{h}}{H} \) (see Ekman and Mäkinen 1996) where \( \dot{h} \) is the absolute crustal uplift (m/yr) relative to the Earth’s centre of mass (radial velocity).

To interpolate uplift rates for the gravity points I select several published uplift maps (Randjärv 1993, Ekman 1996, Kakku 1997, Torim 1998) and predictions of two PGR models (Lambek et al. 1998 and Mäkinen et al. 2001). Apparent uplift rates were converted to absolute rates with formula

\[
\dot{h} = H \dot{h} + N
\]

where \( \dot{h} \) is absolute and \( H \dot{h} \) apparent uplift, \( H \) eustatic rate of mean sea level in this work, \( \pm 1.1 \) m/yr, \( N \) uplift of geoid (about 6% of \( H \)).

Based on observed gravity changes and various estimates of absolute uplift rates I compute the ratios \( \frac{\dot{h}}{H} \) for the points of Estonian gravity network (see table 1 and fig. 4).

Conclusions

Main results:

- Observed rates of secular gravity change in Estonia between -11.2 and 1.8 µGal/yr with average error ± 2.5 (1-sigma)
- Fitted linear surface of the gravity change correlates well with patterns of uplift
- The gravity changes combined with various estimates of uplift give ratios between 3...15 µGal/m above sea level
- Estimated ratios are mainly outside from the theoretical bounds
- Noise gravity data but also disagreement between observed/predicted uplift rates
- Observed gravity changes have better agreement with uplift rates introduced by Ekman (1996), Torim (1998), Lambek et al. (1998) and Mäkinen et al. (2001)

Discussion:

- The improvement of computational methods and software for gravity data processing
- More gravity data (from 1971/72, 1979/80 and 1986-87) into digital database
- Repeated and new absolute gravity measurements in the gravity network to constrain network solution
- New consistent uplift maps and constrained regional PGR models on the basis of repeated observations and time series of geodetic and sea level data in eastern Europe

Acknowledgements


Method

Several corrections to observed gravity data:

A) tidal correction applying tidal potential development and local parameters (gravity factor, phase lag)
B) atmospheric correction using local air pressure
C) free air correction
D) correction for polar motion

Gravity network adjustment:

New observation model with gravity change parameter \( \dot{g} \) is introduced to the gravity network adjustment

\[
y(t) - y = \sum_{i=1}^{n} D_i(t) - \sum_{i} A_i \sin(2\pi f_t + \phi_i)
\]

where

- \( y(t) \) is corrected reading of the gravimeter (mGal) at the observation time \( t \)
- \( \dot{g} \) is gravity value at the epoch \( T_0 \) and it’s rate of change (mGal per year, \( 1 \mu\text{Gal} = 10^{-5} \text{m/s}^2 \))

All observations are cast into the system of linear equations and solved by least-squares method:

\[
x = b \Rightarrow A^T A x = A^T b \Rightarrow x = (A^T A)^{-1} A^T b
\]

where \( x \) is vector of unknown parameters (includes \( \dot{g} \)).

Error estimations are obtained from covariance matrix

\[
\sigma_{xx} = \sigma_{g}^2 (A^T A)^{-1} \sigma_{g}^2 Q_{gg}
\]

References


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