New national gravity reference frame in Sweden - RG2000

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ABSTRACT:

Sweden is located in the middle of the Fennoscandian postglacial rebound area. The postglacial rebound, or glacial isostatic adjustment (GIA), induces a temporal change in the gravity field varying from -0.1 to -1.7 µGal/yr on the Swedish mainland. This secular, GIA-induced gravity change has been studied since the 1960s, first by means of repeated relative observations and since the 1990s by repeated absolute gravity observations.

In early 2018, Sweden released the new gravity reference frame RG 2000. It is based on a large number of absolute and relative gravity observations. The foundation is 14 points where 190 repeated absolute gravity observations with two FG5 gravimeters (FG5-220 and FG5-233) have been conducted since 2004. In addition to that 95 points have been measured with an A10 gravimeter (A10-020). All absolute gravimeters participated in international comparisons.

Here we describe the realization of the new gravity reference frame; how the absolute gravity observations can be traced to international standards and conventions; how all gravity observations have been reduced, in terms of a linear relation between the land uplift model NKG2016LU and the gravity rate of change, to the reference epoch 2000.0; how all absolute and relative gravity observations have been adjusted to estimate gravity for a network consisting of the above mentioned absolute points and some 200 additional relatively connected points; how RG 2000 is related to older national gravity reference frames.

THE SITUATION BEFORE RG 2000:

The situation before RG 2000 is described in Engfeldt (2016a) and the strategy how to continue the work with a new gravity reference frame is described in Engfeldt (2016b). Below is brief summary.

- There are two old gravity systems which are somehow still in use in Sweden. **RG 82** was measured 1981-1982 with two LaCoste & Romberg gravimeters and is based on two absolute gravity observations in Sweden, one in Finland and one in Denmark (see Haller & Ekman 1988) by the Italian instrument IMGC in 1976. This absolute level differs about 30 µGal from RG 2000 after RG 82 has been reduced to the epoch 2000.0. **RG 62** was measured 1960-1966 with a Worden Master gravimeter and was connected to Potsdam via the European Calibration System 1962 (see Pettersson 1967). Due to the gross error in the absolute level of Potsdam and due to poor relative instruments, it differs from RG 2000 with about 14,6 mGal
- From the early 1990's to 2007, new absolute gravity points were established at totally 13 locations in Sweden. There are repeated observations on these points with FG5-233 (owned by Lantmäteriet) from 2007 until now, and on some of these points with FG5-220 (owned by LUH, Hanover) from 2004 to 2008.

DATA FROM THE FINAL ADJUSTMENT:

Total number of:

- Unknowns: 1405
- Equations: 4008
- Absolute instruments: 4
- Relative instruments: 14
- Gravity points: 329
- Absolute observations: 113
- Relative observations: 3721
- Precomputed differences: 174
- Unknown scale corrections: 9
- Unknown drift parameters: 213
- Unknown instrument levels: 854

STRATEGY:

- Use the FG5-observations as foundation
- Use the A-10 gravimeter to densify the network uniformly distributed over Sweden and at points in the old network(s), wherever possible
- Use the relative observations from the work with RG 82
- Use good relative observations from the NKG gravity land uplift lines, from 1975 to 2003
- Make new relative observations between the FG5-/A-10 points and other points in the network so that there are no stand-alone points = a real network. This also serves as a check for gross errors in the A-10 observations.
- All g-values refers to a point on the ground. This means that the gradient was measured and used at all Class A and B points.

ABSOLUTE INSTRUMENTS USED:

FG5-233: 10 years of repeated observations
FG5-220: 5 years of repeated observations
A10-020: Observations 2011-15 on totally 95 Class B points and 3 Class A points
A10-021: Observations 2012 on 2 Class B points

RELVATIVE INSTRUMENTS USED:

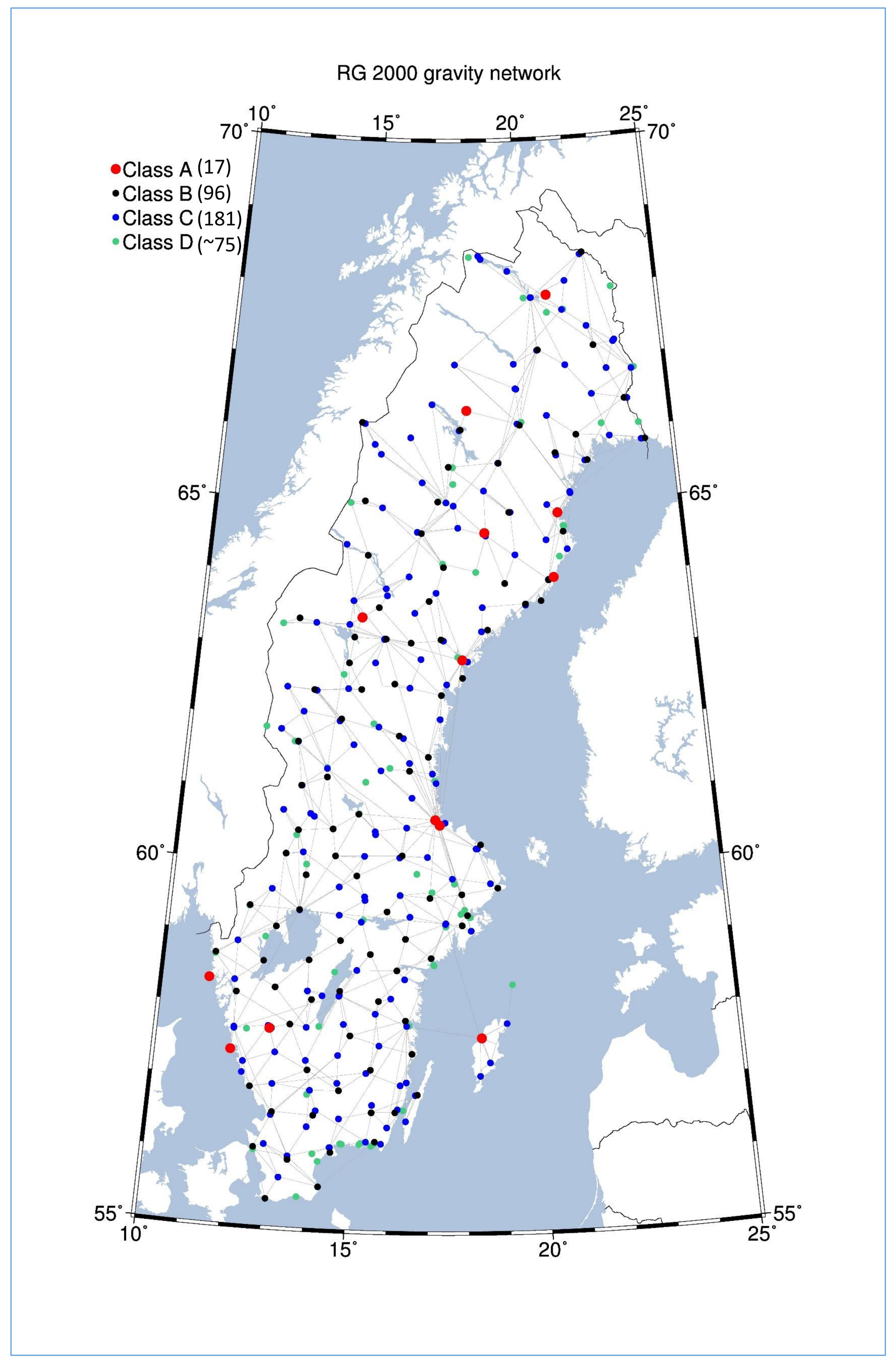
- LaCoste & Romberg G54: 1975-2017
- LaCoste & Romberg G290: 1975-2003
- Scintrex CG5-740: 2011-2014
- Scintrex CG5-1184: 2015-2017
- Several LCR instruments from other Nordic institutes, observed only on the gravity land uplift lines

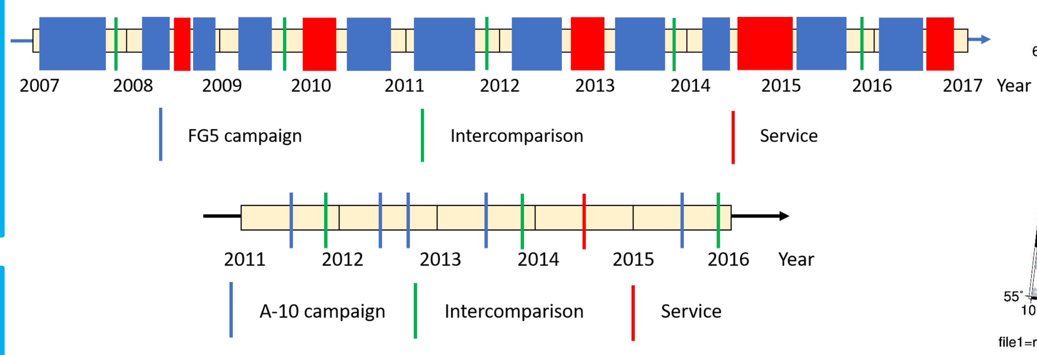
The scale factors for the instruments have been estimated using the Gad software. The observations of the G54 and G290 instruments have been divided into 4 and 3 different observation periods, respectively, and a scale factor for each period has been determined.

The scale factors of the Nordic LCR instruments were set to 1, since they were only used observing very small gravity differences.

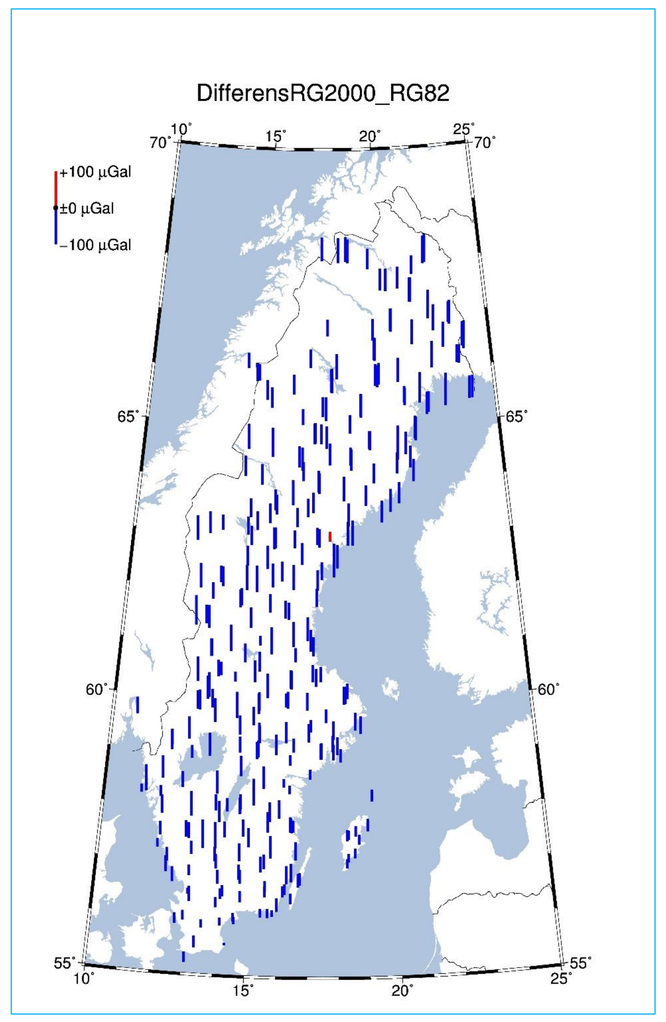
APRIORI STANDARD UNCERTAINTIES FOR THE DIFFERENT INSTRUMENTS:

- FG5: 1,0 µGal
- A10: 5,0 µGal
- Scintrex CG5-1184: 7,0 µGal
- LaCoste & Romberg G290: 11,0 µGal
- All other instruments: 9,0 µGal





Time line for the instrument FG5-233 and the instrument A10-020, showing when normal observations and intercomparisons have been performed and when the instrument has been on service. Between every service there has been one ICAG or ECAG. The observed FG5 and A10 data for these two instruments have been corrected with the result from the corresponding intercomparison.



Raw difference between the new gravity frame RG 2000 and the previous gravity frame RG 82. Most of the difference is due to GIA.

RG 2000 – DEFINITION

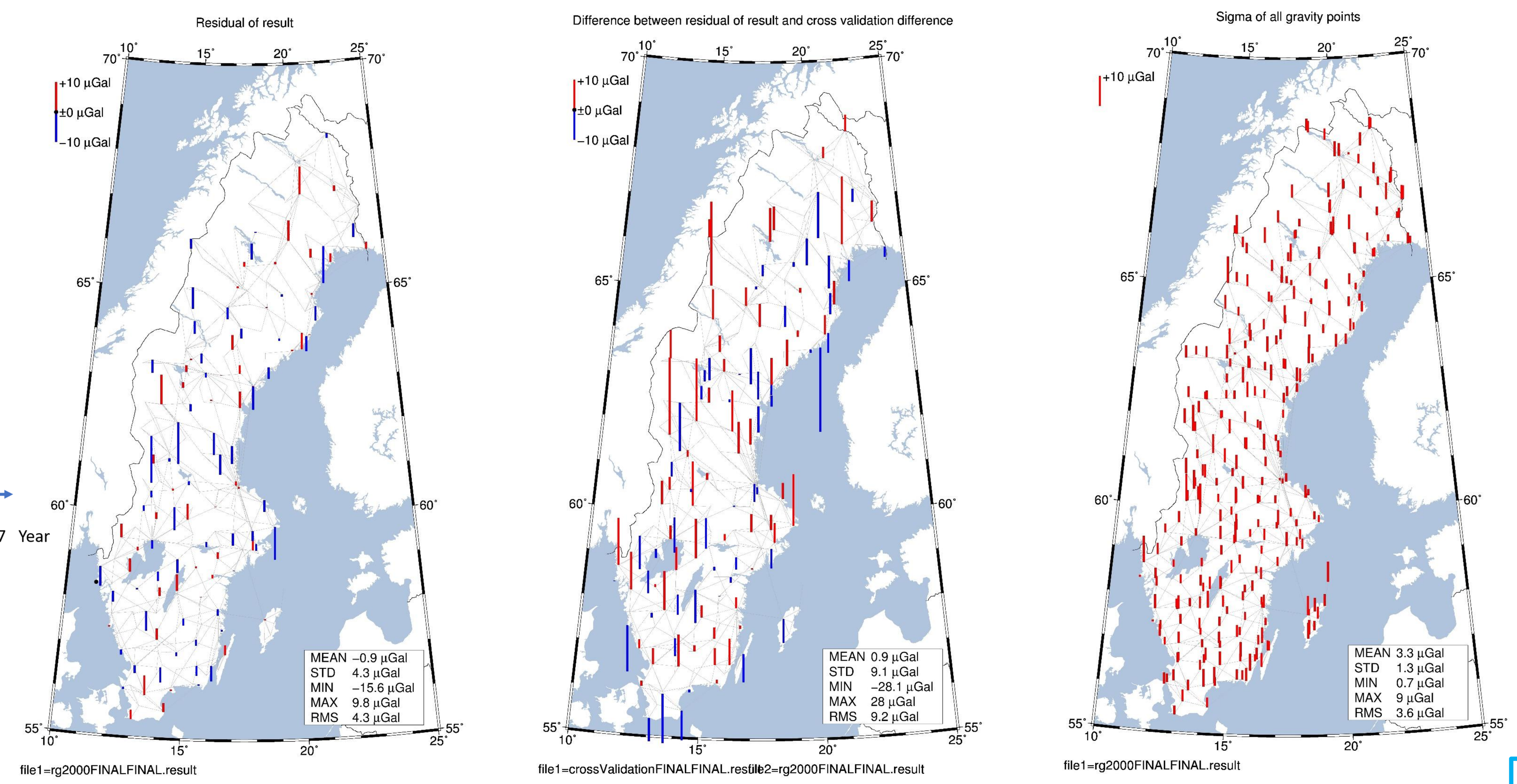
- The gravity reference level as obtained by absolute gravity observations according to international standards and conventions
- The post glacial rebound epoch is 2000.0
- It is a zero permanent tide system

RG 2000 - REALIZATION

- The epoch 2000.0 is chosen in order to harmonize this network with the national height system, RH 2000, and 3D system, SWEREF 99.
- The land uplift model NKG2016LU_abs was used to get the right post glacial rebound epoch. The factor -0,163 µGal/mm was used to convert the absolute land uplift to gravity change (Olsson et al 2018).
- The FG5-233 observations are corrected after results from international comparisons (ICAG and ECAG, see Olsson et al 2015)

Östersund AA (Class A point) from outside, with co-located GNSS.

FG5-233 at Ratan AA (Class A point).



Results from the calculation and adjustment of RG 2000. On the left and the middle graph, only the points measured by absolute gravimeters are included (Class A and B points). Cross validation means that the absolute observation of one certain point was excluded in one solution and the g value for the point of that solution was substracted from the g value of the same point with the absolute observation included. The largest residuals here are caused by the relative observations rather than the absolute observations. On the right graph all the 326 points included in the main adjustement are shown. The least good point here was destroyed the year after it was measured and is only included in the adjustment since it is connected to other points as a link in a chain.

A10 measurements in rain, at Säffle (Class B-site). The tent protects the instrument from sun, wind and rain. This tent was though broken at the top, thus an umbrella was needed.

WHY A NEW GRAVITY REFERENCE FRAME?:

- Today we can see an increased need for improved geoid models for GNSS height determination, which calls for additional gravity observations and quality assurance of existing gravity data. In this perspective, a new modern gravity system and the renovation of the high order gravity network is considered as a moderate strategic investment, which will provide a firm foundation for further activities.
- Lantmäteriet owns an absolute gravimeter since 2006 and have 10 years of state-of-the-art observations with todays technique at 13 places all over Sweden.
- The previous Swedish gravity frame, RG 82 (Haller & Ekman 1988), was based on four absolute gravity observations in Scandinavia in 1976 by the Italian absolute gravimeter IMGC. Although the gravity level of this system in land uplift epoch 1982.0 agrees surprisingly well with RG 2000 (some 30 µGal difference), a considerable improvement is possible with modern instruments.
- About 75% of the gravity measurements for geoid determination are in the even earlier gravity frame RG 62 and the transformation between these two frames is not the best. When making a new frame and new relative observations between points in the old frames, a new better transformation can be developed.
- To harmonize the reference frames in Sweden. The land uplift epoch (2000.0) of the new gravity system is in agreement with the Swedish height reference frame RH 2000 and 3D reference frame SWEREF 99.
- The coordination aspect. All different organizations working with gravity in Sweden need a common well-defined high quality reference frame.

SOFTWARE FOR LEAST SQUARES ADJUSTMENT:

- The software that was used for RG 82 is not available anymore, so we decided to write a new software
- The same observation equations and adjustment theory is used as in our old RG 82 software, see e.g. Koch (2000) or Fan (2010)
- It contains three parts: Gprep, Gad and Gcross
- *Gprep* prepares the data from different instruments to several input files in the land uplift epoch 2000.0
- *Gad* is the main software and makes the least squares adjustment
- *Gcross* is used to make cross validations for the AG observations

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