National Report of Sweden to the EUREF 2014 Symposium

– geodetic activities at Lantmäteriet

A. ALFREDSSON, L. E. ENGBERG, A. ENGFELDT, L. JIVALL, C. KEMPE, M. LIDBERG, C. LILJE, M. LILJE, D. NORIN, H. STEFFEN, P. WIKLUND, J. ÅGREN

Lantmäteriet, SE-801 82 Gävle, Sweden
geodesi@lm.se

Presented at the EUREF 2014 Symposium in Vilnius, Lithuania, June 4-6, 2014

1 Introduction

At Lantmäteriet, the Swedish mapping, cadastral and land registration authority, the activities in the fields of geodetic reference frames and positioning are focused on

- the implementation of RH 2000 and SWEREF 99 – which are the Swedish national realizations of EVRS[1] and ETRS89[2], respectively
- the improvement of Swedish geoid models
- the operation, expansion and services of SWEPOS™, the Swedish network of permanent GNSS[3] reference stations (including the contribution to international initiatives as EPN[4], IGS[5] and MGEX[6]).

Some of the activities are done within the framework of NKG[7]. Resources have also been allocated for the renovation of the gravity network.

The work within Lantmäteriet is following the 10-year strategic plan for Geodesy which was released in 2011 (Lantmäteriet, 2011).

2 Contributions from Lantmäteriet to EPN

Today seven SWEPOS stations are included in EPN. These stations are Onsala, Mårtsbo, Visby, Borås, Skellefteå, Vilhelmina and Kiruna (ONSA, MAR6, VIS0, SPT0, SKE0, VIL0 and KIR0). Daily, hourly and real-time (EUREF-IP) data (1 Hz) are delivered for all stations, except for Vilhelmina, where only daily and hourly files are submitted.

Furthermore, Onsala, Mårtsbo, Visby, Borås and Kiruna are included in the IGS network. All of the Swedish EPN/IGS stations are equipped with dual-frequency GPS[8]/GLONASS[9] receivers and antennas of Dorne Margolin choke ring design.

Another 20 stations are proposed EPN stations and are expected to get operational during the year. All of them are new monuments, co-located with existing SWEPOS stations, and equipped with individually calibrated antennas/ radomes; cf. Section 3.1. For seven of the 20 stations, the old monuments are the

[1] EVRS = European Vertical Reference System
[2] ETRS = European Terrestrial Reference System
[3] GNSS = Global Navigation Satellite Systems
[4] EPN = EUREF Permanent Network
[5] IGS = International GNSS Service
[6] MGEX = Multi-GNSS Experiment
[7] NKG = Nordic Geodetic Commission (Nordiska Kommissionen för Geodesi)
[8] GPS = Global Positioning System
[9] GLONASS = Globalnaya Navigatsionnaya Sputnikovaya Sistema

existing Swedish EPN stations. Three of these new stations (KIR8, MAR7, ONS1) contribute to the IGS-MGEX campaign.

Lantmäteriet operates the NKG EPN Local Analysis Centre (LAC) in co-operation with Onsala Space Observatory at Chalmers University of Technology. The NKG LAC contributes with weekly and daily solutions based on final CODE[10] products, using Bernese GNSS Software version 5.2 since GPS week 1765. The EPN sub-network processed by NKG LAC consists of 51 stations concentrated to northern Europe.

NKG have started a project aiming at a dense and consistent velocity field in the Nordic and Baltic area. Within the NKG GNSS AC project, consistent and combined solutions will be produced based on national processing using Bernese version 5.2 following the new EPN Analysis guidelines. The operational phase is expected to start during the year.

3 Network of Permanent Reference Stations for GNSS (SWEPOS™)

SWEPOS™ is the Swedish network of permanent GNSS stations (Sunna et al., 2013); see the new SWEPOS web-page on swepos.se. SWEPOS provides real-time services on both metre level (DGPS[11]/ DGNSS[12]) and centimetre level (network RTK[13]), as well as data for post-processing. An automated post-processing service based on the Bernese GNSS software is also available.

[10] CODE = Centre for Orbit Determination in Europe

[11] DGPS = Differential GPS

[12] DGNSS = Differential GNSS

[13] RTK = Real Time Kinematic

The purposes of SWEPOS are

- providing single- and dual-frequency data for relative GNSS measurements
- providing DGPS/DGNSS corrections and RTK data for distribution to real-time users
- acting as the continuously monitored foundation of the Swedish national geodetic reference frame SWEREF 99
- providing data for geophysical research
- monitoring the integrity of the GNSS systems.

3.1 SWEPOS Stations

SWEPOS uses a classification system of permanent reference stations for GNSS, which is developed within the NKG. The system includes four different classes; A, B, C and D, where class A is the class with the highest demands.

Today (May 2014) SWEPOS consists of totally 307 stations; 41 class A stations and 266 class B ones; cf. Figure 1.

The class A stations are built on bedrock and have redundant equipment for GNSS observations, communications, power supply etc. They have also been connected by precise levelling to the national precise levelling network. Class B stations are mainly established on top of buildings for network RTK purposes. They have the same instrumentation as class A stations (dual-frequency multi-GNSS receivers with antennas of Dorne Margolin choke ring design), but with somewhat less redundancy.

The 20 original class A stations have two kinds of monuments; the original concrete pillars as well as newer steel grid masts, see Figure 2. Steel grid masts were chosen after an evaluation of several different designs and they are equipped with individually calibrated antennas and radomes of the type LEIAR25.R3 LEIT.

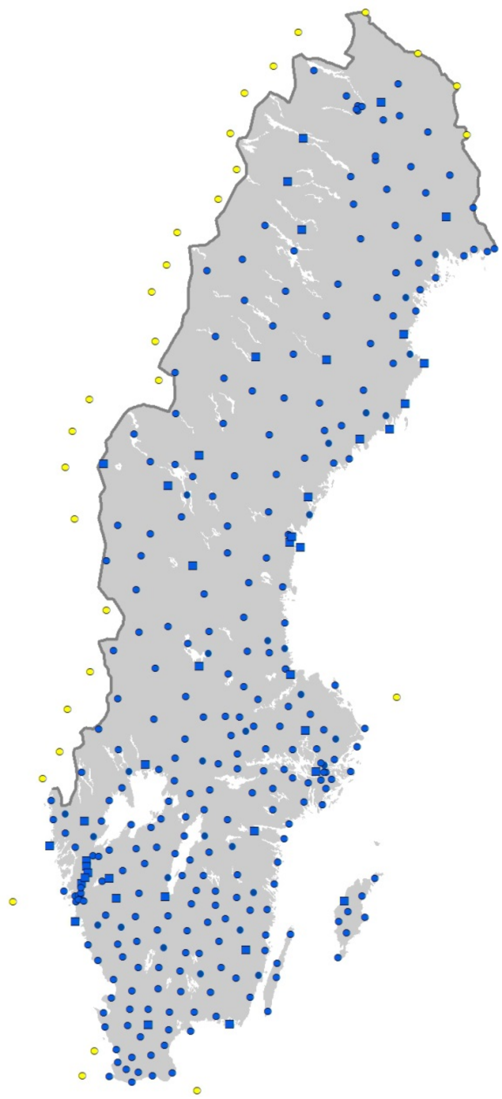

Figure 1: The SWEPOS network in May 2014. Squares indicate class A stations and dots indicate class B stations. Stations in neighbouring countries used in SWEPOS Network RTK Service are also marked on the map, but stations from other service providers have not been marked.

3.2 *SWEPOS Services*

The SWEPOS Network RTK Service reached national coverage during 2010. Since data from permanent GNSS stations are exchanged between the Nordic countries, good coverage of the service in border areas and along the coasts has been obtained by the inclusion of 20 Norwegian SATREF stations, 5 Finnish Geotrim stations, 3 Danish Leica SmartNet stations and 2 Danish Geodatastyrelsen (Danish Geodata Agency) stations.

Figure 2: The SWEPOS station Hässleholm with the new monument (established in 2011) and the old monument (established in 1993).

The service has supplied RTK data for both GPS and GLONASS since April 1, 2006 and has today (May 2014) approximately 2340 subscriptions, which means some 220 new users since last year.

With the main purpose to improve the performance of the network RTK service, a general densification of the SWEPOS network is going on since 2010, with approximately 40 new stations each year. More comprehensive densifications have also been performed in some areas to meet the demands for machine guidance in large-scale infrastructure projects.

SWEPOS also offers a single frequency Network DGNSS Service. Both this service and the network RTK service are since June 2012 utilising Trimble Pivot Platform GNSS Infrastructure Software. The software is operating in virtual reference station mode, but an implementation of so-called network RTK correction messages as an additional option is planned, as well as options for new GPS signals.

4 RH 2000, the National Height System

The third precise levelling of the mainland of Sweden was finalised in 2003, resulting in the new national height system RH 2000 in 2005 (Ågren et al., 2007).

Since the beginning of the 1990's, a systematic inventory/updating of the network is continuously performed.

4.1 *Implementation of RH 2000*

The work with implementing RH 2000 among other authorities in Sweden is in progress. 69 % of the 290 Swedish municipalities have, in co-operation with Lantmäteriet, started the process of analysing their local networks, with the aim of replacing the local height systems with RH 2000. So far 154 municipalities have finalised the replacement for all activities. Initiatives to speed up the work with implementation of the new system have been taken together with SALAR[14].

5 SWEREF 99, the National Reference Frame

SWEREF 99 was adopted by EUREF as the realisation of ETRS 89 in Sweden at the EUREF 2000 symposium in Tromsö (Jivall & Lidberg, 2000). It is used as the national geodetic reference frame since 2007 and has been used for Swedish GNSS services since 2001.

5.1 *Consolidation Points*

By defining SWEREF 99 as an active reference frame we are exposed to rely on the positioning services of SWEPOS, like the network RTK service. All alterations of equipment and software as well as movements at the stations will in the end affect the coordinates. In order to be able to check all these alterations we have introduced consolidation points (Engberg et al., 2010). For this purpose the so-called SWEREF points from a project called RIX 95 are used. They are all marked in bedrock and most of them well suitable for GNSS measurements.

These points, about 300 in total, are remeasured in a yearly programme where 50 points are measured every year.

[14] SALAR = Swedish Association of Local Authorities and Regions

5.2 *Implementation of SWEREF 99*

The work regarding implementation of SWEREF 99 among other authorities in Sweden, such as local ones, is in progress. 96 % of the 290 Swedish municipalities have started the process to replace their old reference frames with SWEREF 99. So far, 264 of them have finalised the replacement. Actions aimed to start the process also in the last municipalities have been taken together with SALAR.

To rectify distorted geometries of local reference frames, correction models used by the municipalities are together with the transformation parameters for direct projection (Engberg & Lilje, 2006) obtained from RIX 95. The models obtained are based on the residuals of the transformations and the rectification is made by a so-called rubber sheeting algorithm. The result will be that all geographical data are positioned in a homogenous reference frame, the national SWEREF 99.

6 Geoid Models

The national Swedish geoid model, SWEN08_RH2000 was released in the beginning of 2009. It has been computed by adapting the Swedish gravimetric model KTH08 to the reference systems SWEREF 99 and RH 2000 by utilising a large number of geometrically determined geoid heights, computed as the difference between heights above the ellipsoid determined by GNSS and levelled normal heights above sea level. In this step, a correction has been applied for the post-glacial land uplift and for differences in permanent tide systems. A smooth residual surface is used to model the GNSS/levelling residuals (residual interpolation).

The standard uncertainty of SWEN08_RH2000 has been estimated to 10-15 mm everywhere on the Swedish mainland with the exception of a small area to the north-west not covered by the third precise levelling (Ågren, 2009). The standard uncertainty is larger in the latter area and at sea, probably around 5-10 cm.

The underlying gravimetric model, KTH08, has been computed by the Least Squares Modification of Stokes formula with Additive corrections (LSMSA) (Sjöberg, 1991 and Sjöberg, 2003). This work has been made in cooperation between Lantmäteriet and Professor Lars E Sjöberg and his group at the Royal Institute of Technology (KTH) in Stockholm. The computation is described in detail in Ågren et al. (2009).

According to Lantmäteriet's 10-year plan, Geodesy 2010, the ultimate goal is to compute a 5 mm (1 sigma) geoid model by 2020. To reach this goal – to the extent that it is realistic – work is going on to establish a new gravity network/system and the Swedish detail gravity data set is improved by new gravity measurements (Ågren et al., 2013). In cooperation with the Royal Institute of Technology (KTH) in Stockholm, it is also investigated what is required of geoid determination data, method and theory to reach this uncertainty over Sweden (Ågren and Sjöberg, 2013). Two projects are currently running under the umbrella of NKG, in the Working Group of Geoid and Height System. The first aims at computing a new common geoid model over the Nordic countries, while the second investigates what is required to reach 5 mm uncertainty over the Nordic area.

In order to improve the Baltic Sea geoid model, Lantmäteriet is also engaged in the FAMOS (Finalising Surveys for the Baltic Motorways of the Sea) project. The main purpose of FAMOS is to finalise hydrographic surveying in those areas of the Baltic Sea that are of interest for commercial shipping. In the *Harmonising vertical datum* activity of the project, the main goal is to improve the geoid over the Baltic Sea area, to provide an important basis for future offshore navigation. To reach the goal of an improved geoid model, new marine gravity data will be

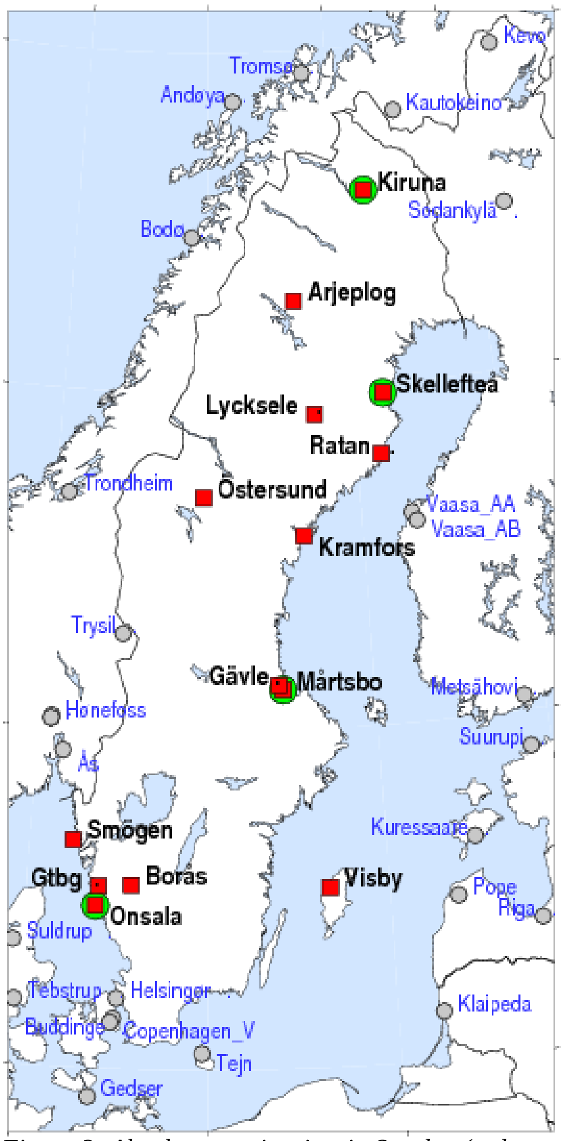

Figure 3: Absolute gravity sites in Sweden (red squares, and sites in neighbouring countries (grey circles). Sites with time series >15 years have a green circle as background to the red square.

collected in connection with the hydrographic surveying, both to check existing gravity data and to fill in empty areas. The activity also includes computation of a geoid model. According to the plan, the validated FAMOS geoid model will be ready by 2020.

7 Gravity Activities

In 2006, Lantmäteriet purchased a new absolute gravimeter (Micro-g Lacoste FG5 - 233). The objective behind this investment is to ensure and strengthen the observing capability for long-term monitoring of the changes in the gravity field due to the Fennoscandian GIA[15].

Absolute gravity observations have been carried out at 14 Swedish sites since the beginning of the 1990's, cf. Figure 3. Since 2007, 13 of the sites have been observed by Lantmäteriet and observations have also been done abroad, on 2 Danish sites, 1 Finnish site, 2 Norwegian sites, 3 Serbian sites, 3 sites in Rep. Macedonia and 4 sites in Bosnia-Hercegovina. Furthermore, six inter-comparisons have been carried out; three times in Luxembourg with 19-25 other gravimeters, one with 22 other gravimeters in Paris and twice with 4 other gravimeters in Wettzell.

All Swedish sites are co-located with permanent reference stations for GNSS in the SWEPOS network (except for Göteborg (Gtbg) which is no longer in use). On four of the sites there are more than 15 years long GNSS time series, see Figure 3. Onsala is also co-located with VLBI[16]. Skellefteå, Smögen, and Visby are co-located with tide gauges.

The absolute gravity observations are coordinated within the co-operation of NKG, and observations have been performed by several groups (BKG[17], IfE[18], NMBU[19] and FGI[20]) together with Lantmäteriet.

Within the coming three years, a new fundamental gravity network will be established in Sweden. The work started in 2011 in co-operation with IGiK[21] using their absolute gravimeter A-10 - 020. So far 83 sites have been measured in co-operation with IGiK.

At Onsala Space Observatory, a superconducting gravimeter was installed during 2009. The investment should be seen as an additional important instrument at the Onsala geodetic station, but also in view of the efforts regarding absolute gravity for studying temporal variations in observed gravity. This gravimeter has been calibrated three times by Lantmäteriet's FG5, latest in 2013.

8 Geodynamics

The purpose of the repeated absolute gravity observations is to support the understanding of the physical mechanisms behind the Fennoscandian GIA process, where the relation between gravity change and geometric deformation is a primary parameter. The latter was studied in a PhD project by Per-Anders Olsson, who successfully defended in October 2013 (Olsson, 2013). Knowledge of the spatial variation of the change in gravity is also needed while determining the new gravity system at a specific epoch in time.

Research regarding the 3D geometric deformation in Fennoscandia and adjacent areas is foremost done within the BIFROST[22] effort. Reprocessing of all observations from continuously operating GPS stations is a continuous activity. A new publication will accompany the forthcoming release to be presented at the NKG General Assembly 2014. In addition, another velocity field including a majority of Norwegian GNSS stations will be published in a study introducing the GIA-reference frame (Kierulf et al., submitted).

[15] GIA = Glacial Isostatic Adjustment

[16] VLBI = Very Long Baseline Interferometry

[17] BKG = Bundesamt für Kartographie und Geodäsie, Germany

[18] IfE = Institut für Erdmessung, Universität Hannover, Germany

[19] NMBU = Norges Miljø- og Biovitenskapelige Universitetet, Norway

[20] FGI = Finnish Geodetic Institute, Finland

[21] IGiK = Institute of Geodesy and Cartography, Poland

[22] BIFROST = Baseline Inferences for Fennoscandian Rebound Observations Sea level and Tectonics

Using this method (named the GIA-frame approach) GIA models can be constrained with minimal influence of errors in the global reference frame or biasing signals from plate tectonics.

NKG2005LU, the Nordic land uplift model that includes the vertical component only, will be substituted with a new model. A first new model version (NKG2014LU_Up_test) will be introduced at the NKG General Assembly 2014. It is developed as a combination and modification of the mathematical model of Vestøl (2006) and a new geophysical model developed within a NKG activity. Work is presently going on to compute this improved GIA model, which will not only deliver vertical and horizontal motions, but also gravity-rates-of-change and geoid change, i.e. for comparison and/or usage to/in absolute gravimetry and the GRACE[23] satellite mission as well as its follow-on. Additionally, uncertainty estimates will be provided for all fields. Geophysical model information will be derived from most recent GIA modelling techniques which rely on up-to-date ice models such as GLAC (Tarasov et al. 2012) and reliable earth parameters. Within this NKG modelling activity, a database of relative sea level will be made publicly available. Parts of this database already helped in recent investigations (Steffen et al. 2014a,b).

The IAG Reference Frame Sub-Commission for Europe (EUREF) working group on "Deformation models" aims at obtaining a high resolution velocity model for Europe and adjacent areas and significantly improving the prediction of the time evolution of coordinates. This will help in overcoming the limitations in the use of the ETRS89 and also lead to a general understanding of the physics behind such a velocity field. An inventory of published velocity field is established. A deformation model will be developed once the densified EPN velocity field becomes available.

9 Handbooks for Mapping and Surveying

Lantmäteriet is working on a revised series of handbooks for mapping and surveying. The old versions of the handbooks were published in the mid-1990's, why there has been a request for revised handbooks including new technologies, e.g. RTK surveying and laser data. The revised handbooks will be published as digital documents.

Presently, there are three projects going on:

- Introduction, containing e.g. a glossary, is common for all sub-projects.
- Geodata collection, covering image data, laser data, height data, orthophoto, photogrammetry etc.
- Geodesy, covering GNSS as well as terrestrial surveying.

The geodesy handbook will comprise a main document – including a reference frame section – as well as GNSS and terrestrial survey sections.

The document is aimed at two purposes, according to the need of the users: Either it can be used as a handbook, or as a support for those preparing tender invitations.

The introduction, as well as the geodata collection and geodesy documents are planned to be published during 2014.

[23] GRACE = Gravity Recovery And Climate Experiment

10 References

Engberg L E & Lilje M (2006): *Direct Projection – an efficient approach for datum transformation of plane co-ordinates.* FIG[24], XXIII International Congress, October 8–13 2006, Proceedings, Munich, Germany.

Engberg L E, Lilje M, Ågren J (2010): *Is There a Need of Marked Points in Modern Geodetic Infrastructure?* FIG, XXIV International Congress, April 11–16 2010, Proceedings, Sydney, Australia.

Jivall L & Lidberg M (2000): *SWEREF 99 – an updated EUREF realisation for Sweden.* In Torres & Hornik (eds): EUREF Publication No. 9, EUREF, 2000 Symposium, June 22–4 2000, pp. 167–175, Tromsö, Norway.

Kierulf, H. P., Steffen, H., Simpson, M. J. R., Lidberg, M., Wu, P. and Wang, H. (submitted). *A GNSS velocity field for Fennoscandia and a consistent comparison to glacial isostatic adjustment models.* J. Geophys. Res., 38 pp.

Lantmäteriet (2011): *A strategic plan for Lantmäteriet's geodetic activities 2011–2020,* Lantmäteriet, http://www.lantmateriet.se/Global/Kartor%20och%20geografisk%20information/GPS%20och%20m%c3%a4tning/Geodesi/Rapporter_publikationer/Publikationer/Geodesy_2010.pdf (cited April 2013).

Olsson P-A (2013) *On modelling of postglacial gravity change.* Doktorsavhandlingar vid Chalmers tekniska högskola. Ny serie nr 3583, ISSN 0346-718X.

Sjöberg L E (1991): *Refined Least Squares Modification of Stokes' Formula.* Springer, Manuscripta Geodaetica, 16:367–375.

Sjöberg L E (2003): *A Computational Scheme to Model the Geoid by the Modified Stokes' Formula without Gravity Reductions.* Springer, Journal of Geodesy, 77: 423–432.

Steffen H, Kaufmann G, Lampe R (2014a). *Lithosphere and upper-mantle structure of the southern Baltic Sea estimated from modelling relative sea-level data with glacial isostatic adjustment.* Solid Earth 5, 17 pp.

Steffen H, Wu P, Wang H (2014b). *Optimal locations of sea-level indicators in glacial isostatic adjustment investigations.* Solid Earth 5, 17 pp.

Sunna J, Jämtnäs L, Jonsson B (2013): *Improving RTK positioning with SWEPOS™ – lessons from theory and practice.* In Henriksen & Jørgensen (eds): Proceedings of the 16th General Assembly of the Nordic Geodetic Commission, NKG, September 27–30 2010, pp. 124–128, Sundvollen, Norway.

Tarasov L, Dyke A S, Neal R M, Peltier W R (2012): *A data-calibrated distribution of deglacial chronologies for the North American ice complex from glaciological modelling.* Earth Planet Sci. Lett. 315–316: 30–40.

Vestøl O (2006): *Determination of postglacial land uplift in Fennoscandia from leveling, tide-gauges and continuous GPS stations using least squares collocation.* J. Geod. 80: 248–258.

Ågren J, Svensson R, Olsson P-A, Eriksson P-O, Lilje M (2007): *The Swedish Height System as a National Realization of EVRS.* In Torres & Hornik (eds): EUREF Publication No. 16, EUREF, 2006 Symposium, June 14–16 2006, pp. 65–73, Riga, Latvia.

Ågren J (2009): *Beskrivning av de nationella geoidmodellerna SWEN08_RH2000 och SWEN08_RH70.* Lantmäteriet, Reports in Geodesy and Geographic Information Systems, 2009:1, Gävle, Sweden (in Swedish).

Ågren J, Sjöberg L E & Kiamehr R (2009): *The New Gravimetric Quasigeoid Model KTH08 over Sweden.* de Gruyter, Journal of Applied Geodesy 3 (2009) pp. 143–153.

Ågren J, Engberg L E, Alm L, Dahlström F, Engfeldt A, Lidberg M (2013) *Improving the Swedish quasigeoid by gravity observations on the ice of Lake Vänern.* International Symposium on Gravity, Geoid and Height Systems GGHS2012, October 9-12, 2012, Venice. Accepted for publication in Springer, IAG Symposia.

Ågren J & Sjöberg L E (2013) *Investigation of gravity data requirements for a 5 mm-quasigeoid model over Sweden.* International Symposium on Gravity, Geoid and Height Systems GGHS2012, October 9-12, 2012, Venice. Accepted for publication in Springer, IAG Symposia.

[24] FIG = Fédération Internationale des Géomètres (International Federation of Surveyors)