National Report of Sweden to the EUREF 2015 Symposium

– geodetic activities at Lantmäteriet

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

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

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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 operation, expansion and services of SWEPOS™, the Swedish national network of permanent reference stations for GNSS[1].
- Contributions of SWEPOS data to international initiatives as EPN[2], IGS[3] and MGEX[4] and international analyses of GNSS data.
- The implementation of the Swedish national reference frame SWEREF 99 and the national height system RH 2000 (ETRS[5]89 and EVRS[6] realisations respectively).
- The sustainability in the Swedish reference frames.
- Improvements of Swedish geoid models and renovation of the gravity network.

The geodetic work within Lantmäteriet is based on a 10-year strategic plan for the years 2011–2020 called Geodesy 2010 released in 2011 (Lantmäteriet, 2011) and some of the activities are performed within the framework of NKG[7].

2 Contributions from Lantmäteriet to EPN

The total number of SWEPOS stations included in EPN has increase from 7 to 24 since the EUREF 2014 Symposium. The seven stations included prior to 2014 are all part of the 21 original SWEPOS stations. 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 Vilhelmina, where only daily and hourly files are submitted. The 17 new Swedish EPN stations also originate from the 21 original SWEPOS stations, but from an additional monument equipped with individually calibrated antennas/radomes (see Chapter 3). The new monuments at the four remaining original SWEPOS stations are also expected to be included in EPN, three in the near future and the last one later on.

Lantmäteriet operates the NKG EPN LAC[8] in co-operation with Onsala Space Observatory at Chalmers University of Technology. The NKG LAC contributes

[1] GNSS = Global Navigation Satellite Systems

[2] EPN = EUREF Permanent Network

[3] IGS = International GNSS Service

[4] MGEX = Multi-GNSS Experiment

[5] ETRS = European Terrestrial Reference System

[6] EVRS = European Vertical Reference System

[7] NKG = Nordic Geodetic Commission (Nordiska Kommissionen för Geodesi)

[8] LAC = Local Analysis Centre

with weekly and daily solutions based on final CODE[9] products, using the Bernese GNSS Software. Version 5.2 is used since GPS[10] week 1765 (November 2013). The EPN sub-network processed by NKG LAC consists of 70 reference stations (June 2015) concentrated to northern Europe. This means that 19 stations have been added to the NKG LAC sub-network since the previous EUREF Symposium in 2014. Another three stations are expected to be added to the sub-network in the near future.

A GNSS analysis centre project is going on within NKG and it is chaired by Lantmäteriet (Jivall et al., 2014). It is aiming at a dense and consistent velocity field in the Nordic and Baltic area. Consistent and combined solutions will be produced based on national processing using the Bernese GNSS Software version 5.2, following the new EPN Analysis guidelines. The operational phase of the project began during 2014, although all expected contributions are not yet included.

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

SWEPOS™ is the Swedish national network of permanent GNSS stations operated by Lantmäteriet (Lilje et al., 2014); see SWEPOS website available on www.swepos.se or through www.lantmateriet.se/swepos.

The purposes of SWEPOS are:

- Providing single- and dual-frequency data for relative GNSS measurements.
- Providing DGNSS[11] corrections and RTK[12] data for distribution to real-time users.
- Acting as the continuously monitored foundation of SWEREF 99.
- Providing data for geophysical research and for meteorological applications.
- Monitoring the integrity of the GNSS systems.

SWEPOS uses a classification system of permanent reference stations for GNSS 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.

By the time for the EUREF Symposium in June 2015 SWEPOS consisted of totally 355 stations, 38 class A stations and 317 class B ones, see Figures 3.1 and 3.2. This means that the total number of SWEPOS stations has increased with 46 stations since the previous EUREF Symposium one year ago, see Figure 3.3.

Figure 3.1: *Hässleholm is one of the SWEPOS stations belonging to class A. It has both a new monument (established in 2011) and an old monument (from 1993).*

[9] CODE = Centre for Orbit Determination in Europe

[10] GPS = Global Positioning System

[11] DGNSS = Differential GNSS

[12] RTK = Real-Time Kinematic

Figure 3.2: *Söderboda is a SWEPOS station with a roof-mounted GNSS antenna mainly established for network RTK purposes belonging to class B.*

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 21 original class A stations have two kinds of monuments; the original concrete pillars as well as newer steel grid masts, see Figure 3.1. The new monuments are equipped with individually calibrated antennas and radomes of the type LEIAR25.R3 LEIT.

Five of the original SWEPOS stations (Onsala, Mårtsbo, Visby, Borås and Kiruna) are included in the IGS network and the new monumentation on three of them (ONS1, MAR7 and KIR8) also contribute as stations in the IGS-MGEX campaign. This campaign has been set-up to track, collate and analyse all available GNSS signals.

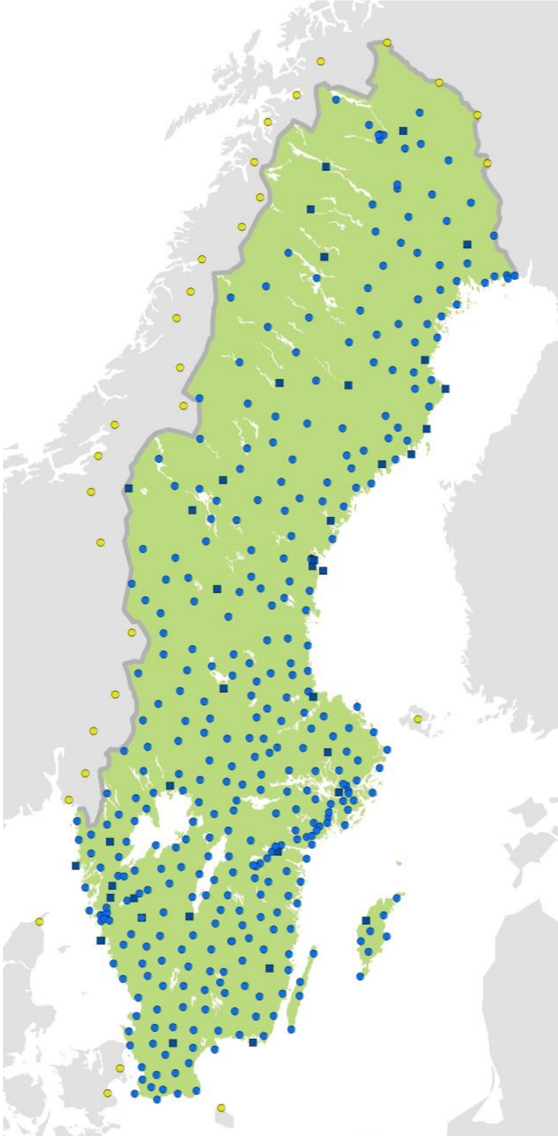

Figure 3.3: *The SWEPOS network in May 2015. Squares indicate class A stations and dots indicate class B ones. Stations in neighbouring countries used in the SWEPOS Network RTK Service are also marked, but stations from other service providers in Sweden are not marked.*

4 SWEPOS Services

SWEPOS provides real-time services on both metre level (network DGNSS) and centimetre level (network RTK), as well as data for post-processing in RINEX[13] format. An automated post-processing service is also available. This service utilises the Bernese GNSS Software, where version 5.0 has been used since 2008, but a

[13] RINEX = Receiver Independent EXchange format

transition to version 5.2 will soon be finalised.

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 twenty Norwegian SATREF stations, four Norwegian Leica SmartNet stations, five Finnish Geotrim stations, one Finnish Leica SmartNet station, three Danish Leica SmartNet stations and two Danish Geodatastyrelsen (Danish Geodata Agency) stations.

The service has supplied RTK data for both GPS and GLONASS since April 2006 and has today (May 2015) approximately 2670 subscriptions, which means some 330 new users since last year. Lantmäteriet has also signed cooperation agreements with three international GNSS service providers. This is done in order to increase the use of GNSS data from the SWEPOS stations and the providers are using the data for their own services.

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 by establishing 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.

Several IT improvements have been performed during the last year, e.g. redundant server solutions in different premises. For the moment are the possibilities to improve station calibrations and the installations of the stations studied.

SWEPOS also offers a single frequency network DGNSS Service, which in line with some of the national geographical data from Lantmäteriet will be available as open data from 2016. This service as well as 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 service option is planned, as well as options for new GNSS and the new GPS signals.

5 Implementation of SWEREF 99

SWEREF 99 was adopted by EUREF as the realisation of ETRS89 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.

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 reference stations will in the end affect the coordinates. In order to be able to check all these alterations, so-called consolidation points have been introduced by Lantmäteriet (Engberg et al., 2010). The approximately 300 so-called SWEREF points from the RIX 95 project are used for this purpose and they are remeasured in a yearly programme with 50 points each year. The large project RIX 95 lasted 1995–2008 and involved GPS measurements on totally 9029 control points.

The work regarding the implementation of SWEREF 99 among different authorities in Sweden, such as local ones, is in a final stage. 97 % of the 290 Swedish municipalities have started the process to replace their old reference frames with SWEREF 99 and actions are taken to start it in the remaining ones. The number of municipalities that have finalised the replacement has increased from 264 to 276 during the last year.

To rectify distorted geometries of local reference frames, the municipalities utilise correction models created with the help of Lantmäteriet in combination with transformation parameters obtained from RIX 95. The rectification is made by a so-called rubber sheeting algorithm and the result will be that all geographical data are positioned in a homogenous reference frame, the national SWEREF 99.

6 Implementation of RH 2000

The third precise levelling of the mainland of Sweden lasted 1978–2003, resulting in the new national height system RH 2000 in 2005 (Ågren et al., 2007). The network consists of about 50,000 benchmarks, representing roughly 50,000 km double run precise levelling measured by motorised levelling technique.

Since the beginning of the 1990's, a systematic inventory/updating of the network is continuously performed. When an update is required, the new levelling is done through procurement procedures, which is also the situation for the remeasurements of the 300 SWEREF points described in Chapter 5. The levelling network will also be slightly extended during 2015 with a new levelling line on the south part of the Öland island in the Baltic Sea.

The work with implementing RH 2000 among different authorities in Sweden is in progress (Kempe et al., 2014). 75 % 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 168 municipalities have finalised the replacement for all activities, which is 14 more than by the time for the previous EUREF Symposium.

7 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 SWEREF 99 and RH 2000. KTH08 was computed in cooperation between Lantmäteriet and former Professor Lars E. Sjöberg and his group at KTH[14] in Stockholm. The GNSS/levelling adaption was made 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. 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 in the north-west. The standard uncertainty is larger in the latter area and at sea, probably around 5–10 cm.

According to Geodesy 2010, the ultimate goal is to compute a 5 mm (68 %) 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 as well as to improve the Swedish detail gravity data by new gravity measurements. One region where such measurements have been performed is on Lake Vänern (Ågren et al., 2014a), see Figure 7.1.

Figure 7.1: *Relative gravity measurements in March 2011 on Lake Vänern, the largest lake in Sweden. Photo: Mikael Lindblom.*

[14] KTH = Kungliga Tekniska Högskolan (Royal Institute of Technology)

In cooperation with KTH, it is also investigated what is required of geoid determination data, method and theory to reach this uncertainty over Sweden (Ågren & Sjöberg, 2014).

A project within the NKG Working Group of Geoid and Height Systems is working with a new common geoid model over the Nordic countries (Ågren et al., 2014b). The first part of the work to update the NKG gravity database including the whole area around the Baltic Sea was finalised in 2014. A new GNSS/levelling database and a common DEM[15] have also been created. The project is currently in the computation phase. Preliminary computations have so far been submitted by the Swedish computation centre, which is expected to soon be followed by at least Denmark and Estonia, possibly also by Norway and Finland. The final model is planned to be published during 2015 with the name NKG2015.

In order to improve the Baltic Sea geoid model, Lantmäteriet is also engaged in the FAMOS[16] 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 collected in connection with the hydrographic surveying, both to check existing gravity data and to fill in empty areas. According to the plan, a new validated FAMOS geoid model will be calculated and ready by 2020. The first part of the project (FAMOS Freja) lasts from 2014 to 2016.

[15] DEM = Digital Elevation Model

[16] FAMOS = Finalising Surveys for the Baltic Motorways of the Sea

8 Gravity Activities

Absolute gravity observations have been carried out at 14 Swedish sites since the beginning of the 1990's, see Figure 8.1. All sites, except for Göteborg (Gtbg) which no longer is in use, have been observed by Lantmäteriet since 2007. The observations have been carried out with an absolute gravimeter (Micro-g LaCoste FG5 - 233), which Lantmäteriet purchased in the autumn of 2006. The objective behind the investment was to ensure and strengthen the observing capability for long-term monitoring of the changes in the gravity field due to the Fennoscandian GIA[17].

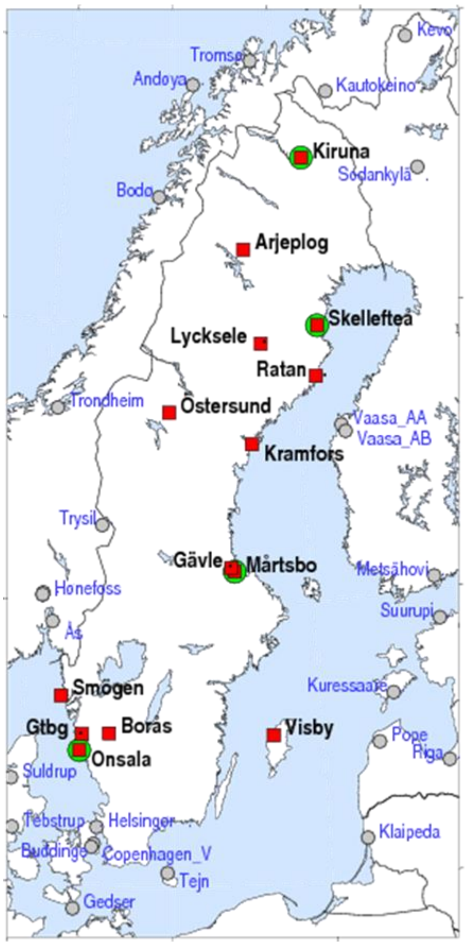

Figure 8.1: *The 14 absolute gravity sites in Sweden (red squares) and sites in neighbouring countries (grey circles). The four sites with time series more than 15 years long have a green circle as background to the red square.*

[17] GIA = Glacial Isostatic Adjustment

All Swedish absolute gravity sites (except for Göteborg) are co-located with reference stations in the SWEPOS network. Onsala is also co-located with VLBI[18]. Skellefteå, Smögen and Visby are co-located with tide gauges.

Absolute gravity observations have also been performed abroad, namely on two Danish sites, one Finnish site, two Norwegian sites, three Serbian sites, three sites in Republic of Macedonia and four sites in Bosnia and Herzegovina. Furthermore, six inter-comparisons have been carried out; three times in Luxembourg with 19–25 other gravimeters, one time with 22 other gravimeters in Paris and twice with four other gravimeters in Wettzell.

The establishment of a new Swedish fundamental gravity network is planned to be finalised in 2016. The work started in 2011 in co-operation with IGiK[19], using their absolute gravimeter A-10 – 020 for the observations. 83 sites have been measured in co-operation with IGiK until 2014 and the last A-10 tour is presently going on.

At Onsala Space Observatory of Chalmers University of Technology, a super-conducting 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 four times by Lantmäteriet's FG5, latest in May 2015.

9 Geodynamics

The main purpose of the repeated absolute gravity observations of Lantmäteriet is to support the understanding of the physical mechanisms behind the Fennoscandian GIA process. One key parameter is the relation between gravity change and geometric deformation (Olsson et al., 2015).

Research regarding the 3D geometric deformation in Fennoscandia and adjacent areas is foremost done within the BIFROST[20] effort (Johansson et al., 2015). Reprocessing of all observations from permanent GPS stations is a continuous activity. A new velocity field based on more than 200 stations is currently under preparation.

In addition, another velocity field including the majority of Norwegian GNSS stations is published in a study introducing the GIA-reference frame approach (Kierulf et al., 2014). GIA models can by using this method 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 (NKG201xLU). The new land uplift model will be developed as a combination and modification of the mathematical model of Olav Vestøl and a new geophysical model currently developed within an NKG activity (Steffen et al., 2014). This improved geophysical model (NKG201xGIA) will deliver both vertical and horizontal motions, as well as gravity-rates-of-change and geoid change. Currently the work is focused on the search for the best ice and earth model combinations, where a set of ice models is provided by Lev Tarasov from Memorial University of Newfoundland, Canada. Additionally, uncertainty estimates will be provided for all fields. Within this NKG modelling activity, a database of relative sea levels will be made publicly available.

Lantmäteriet is involved in the EUREF working group on "Deformation models", which aims at obtaining a high resolution velocity model for Europe and adjacent

[18] VLBI = Very Long Baseline Interferometry

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

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

areas and significantly improving the prediction of the time evolution of coordinates. This will help overcome the limitations in the use of ETRS89 and also lead to a general understanding of the physics behind such a velocity field. An inventory of published velocity fields as well as a website (www.lantmateriet.se/en/Maps-and-geographic-information/GPS-and-geodetic-surveys/Reference-systems/EUREF-working-group-on-Deformation-models) are established. The velocity model including deformations will be developed once the densified EPN velocity field becomes available.

Since January 2015, Lantmäteriet contributes via a Service Level Agreement to the EU-financed Horizon 2020 project EGSIEM[21]. Here, the global GIA correction for gravity missions such as GRACE will be provided by Lantmäteriet.

10 Further Activities

Lantmäteriet is working on a series of handbooks for mapping and surveying called HMK ("Handbok i mät- och kartfrågor"), with the aim to contribute to an efficient and standardised handling of surveying and mapping issues in Sweden (Alfredsson et al., 2014). The handbooks are divided into two main parts, geodesy and geodata capture, together with an introduction document. The geodetic part will comprise a main document – including a reference frame section – as well as GNSS and terrestrial survey sections. The geodetic documents exist as working drafts and the first valid versions are expected to be published by the end of 2015.

An NKG General Assembly is arranged every fourth year. The 17th NKG General Assembly was arranged by Lantmäteriet in Göteborg September 1st–4th 2014 in co-operation with Chalmers University of Technology. It had key note speakers as Ignacio Fernández-Hernández from the European Commission and Zuheir Altamimi from IGN[22] and it gathered around 110 participants from 10 countries, see Figure 10.1.

Figure 10.1: *At the 17th NKG General Assembly, which was held in Göteborg in 2014, former and new professor in Geodesy at KTH Lars E. Sjöberg (left) and Anna Jenson (right) were honoured by Jan Johansson of Chalmers University of Technology. Photo: Holger Steffen.*

At KTH, where the geodetic activities are carried out at the Division for Geodesy and Satellite Positioning under the School of Architecture and the Built Environment, Anna Jensen was appointed as new full professor in Geodesy on September 1st 2014. She succeeded Lars E. Sjöberg who has held this position since 1984, see Figure 10.1.

Lantmäteriet is also responsible for the production of a new Swedish national elevation model. The mainly used method for the data capture is airborne laser scanning and the production started in July 2009. 82 % of the Swedish territory has so far been scanned, where the remaining part is mostly in the mountainous part of Sweden. The scanning is expected to be finalised during 2015.

21 EGSIEM = European Gravity Service for Improved Emergency Management

22 IGN = Institut Géographique National, France

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

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[24] IAG = International Association of Geodesy