

National Report of Sweden to the EUREF 2012 Symposium

– geodetic activities at Lantmäteriet

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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 are focused on the implementation of the ETRS¹ 89 realisation SWEREF 99, the implementation of the national height system RH 2000 and the improvement of Swedish geoid models. Large efforts are also carried out concerning the operation, expansion and services of SWEPOSTM, the Swedish network of permanent GNSS² stations. Some of the activities are done within the framework of NKG³. Resources have also been allocated for the renovation of the gravity network.

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

2 Contributions from Lantmäteriet to EPN⁴ and ECGN⁵

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 second) are delivered for all stations, except for Vilhelmina, where just daily and hourly files are submitted.

Furthermore, Onsala, Mårtsbo, Visby, Borås and Kiruna are included in the IGS⁶ network. All the Swedish EPN/IGS stations are equipped with dual-frequency GPS⁷/GLONASS⁸ receivers and antennas of Dorne Margolin Choke Ring design.

Lantmäteriet will offer another 20 stations to EPN, 7 of them are co-located with the existing Swedish EPN-stations. These new stations are equipped with individual calibrated antenna/radomes – see further Section 3. Three of these new stations

¹ ETRS = European Terrestrial Reference System

² GNSS = Global Navigation Satellite Systems

³ NKG = Nordic Geodetic Commission (Nordiska Kommissionen för Geodesi)

⁴ EPN = EUREF Permanent Network

⁵ ECGN = European Combined Geodetic Network

⁶ IGS = International GNSS Service

⁷ GPS = Global Positioning System

⁸ GLONASS = Globalnaya Navigatsionnaya Sputnikovaya Sistema

participate in IGS-MGEX⁹ (KIR8, MAR7, ONS1).

Lantmäteriet operates the NKG EPN Local Analysis Centre in co-operation with Onsala Space Observatory at Chalmers University of Technology. NKG EPN LAC contributes with weekly and daily solutions based on final IGS products. The EPN-subnetwork processed by NKG LAC consists of 52 stations concentrated to northern Europe. NKG LAC has contributed to the first EPN reprocessing and will also contribute to the next one with solutions based on the Bernese GPS Software.

Sweden has, according to the co-ordination within the framework of NKG, offered six Swedish EPN stations for ECGN. These stations have been suggested for monitoring the time dependent changes of EVRS¹⁰2007. NKG has also created a Nordic densification called NGOS¹¹ (Lilje et al., 2008a).

3 Network of Permanent Reference Stations (SWEPOS™)

SWEPOS™ is the Swedish network of permanent GNSS stations (Sunna et al., 2010), see www.swepos.com. It provides real-time services on both metre level (DGPS¹²/DGNSS¹³) and centimetre level (network RTK¹⁴), as well as data for post-processing. An automated processing service based on the Bernese GPS software is also available.

The purposes of SWEPOS are to:

- Provide single- and dual-frequency data for relative GNSS measurements.

- Provide DGPS/DGNSS corrections and RTK data for distribution to real-time users.
- Act as the continuously monitored foundation of the Swedish national geodetic reference frame SWEREF 99.
- Provide data for geophysical research.
- Monitor the integrity of the GNSS systems.

3.1 Stations

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

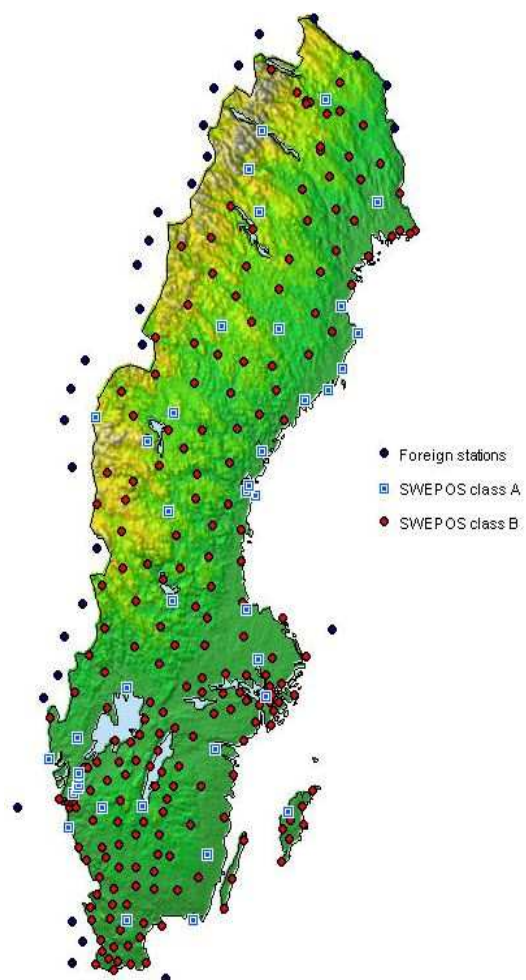


Figure 1: The SWEPOS-network and foreign border stations included in SWEPOS network RTK Service in May 2012.

⁹ MGEX=Multi-GNSS Experiment

¹⁰ EVRS = European Vertical Reference System

¹¹ NGOS = Nordic Geodetic Observing System

¹² DGPS = Differential GPS

¹³ DGNSS = Differential GNSS

¹⁴ RTK = Real Time Kinematic

Today (May 2012) SWEPOS consists of totally 249 stations, 40 class A stations and 209 class B ones, see 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 GPS/GLONASS receivers with antennas of Dorne Margolin design), but with somewhat less redundancy.

During 2011, new additional monuments have been established at the 20 original class A stations, see Figure 2. Several different designs were evaluated before finally choosing steel grid masts (Lehner, 2011). The new monuments are equipped with individual calibrated antennas and radomes of the type LEIAR25.R3 LEIT. Local surveys will be performed at the 20 stations during 2012.



Figure 2: The SWEPOS station Hässleholm with the new and the old monument.

3.2 Services

The SWEPOS Network RTK Service was launched with regional coverage on January 1st 2004, using the VRS¹⁵ technique. The service has been expanded with regional one-year-long establishment

projects and it reached national coverage during 2010. Since data from permanent GNSS stations is 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 KMS¹⁶ stations.

The service has broadcasted RTK data for both GPS and GLONASS since April 1st 2006 and has today (May 2012) approximately 1900 subscriptions, which means approximately 240 new users since last year.

There is an increasing use of RTK for machine guidance. To meet this, some densifications of the SWEPOS network have been done. In these areas are SWEPOS Network RTK Service used as a flexible and redundant service, tailor-made for large-scale infrastructure projects (Hedling et al., 2009). Since 2010, a general densification of the network is also going on with approximately 40 new stations each year.

SWEPOS also offers a single frequency Network DGNSS Service that was launched on April 1st 2006. Both this service and the network RTK service have since the start been using the network RTK/DGNSS software GPSNet from Trimble and during June 2012 an upgrade to Trimble VRS3Net will be done.

3.3 The CLOSE-RTK Project

A project called "Close-RTK" has been performed during the last years and it was initiated by Lantmäteriet, SP Technical Research Institute of Sweden and Chalmers University of Technology. The first part of the project had an effort to assess the quality of the present network RTK technique, as well as future development scenarios of space (GNSS) and ground (SWEPOS) infrastructure

¹⁵ VRS = Virtual Reference Station

¹⁶ KMS = Kort & Matrikelstyrelsen

(Emardson et al., 2009 and Sunna et al., 2010). Parameters that were deeply studied were different sources of uncertainty in measurements (e.g. atmospheric and local effects), future satellite systems as Galileo and Compass and a general densification of the SWEPOS network (with 35 km between the stations).

The second part of the Close-RTK project investigated how the ionosphere affects the measurements with network RTK by analysing archived SWEPOS data from last solar maximum around 1999–2004. It also included the development of an ionospheric monitoring service. The service can be accessed via the SWEPOS website and also be downloaded as an application for Android smartphones.

4 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 Tromsø (Jivall & Lidberg, 2000). It is used as the national geodetic reference frame for GNSS since 2001.

4.1 Consolidation points

By defining SWEREF 99 as an active reference frame we are exposed to rely on SWEPOS' positioning services 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 possible to keep a check on all these alterations we have introduced consolidation points (Engberg et al., 2010). For this purpose the SWEREF points from the RIX 95 project are used. They are all marked in bedrock and most of them well suitable for GNSS measurements.

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

4.2 Adaptation of SWEREF 99 to igs08.atx

Up to now, mainly the same options and processing strategies, when determining new SWEREF 99 coordinates with low uncertainty, have been used as for the original SWEREF 99 campaign. This also includes the used antenna models, which by that time was in agreement with the igs_01.pcv, i.e. a relative antenna table.

In connection to the upgrade of the network RTK software, see Section 3.2, the coordinates of the SWEPOS stations (and stations with SWEREF 99 coordinates in neighbouring countries), have been adjusted to comply with the antenna models in igs08.atx.

4.3 Implementation of SWEREF 99

A formal decision regarding map projections for national mapping, as well as for local surveying, was taken in 2003. All projections for SWEREF 99 are of the Transverse Mercator type. In January 2007, Lantmäteriet replaced RT 90 with SWEREF 99 TM in all databases and product lines.

A new map sheet division and a new index system have also been adopted.

The work regarding implementation of SWEREF 99 among other authorities in Sweden, such as local ones, is in progress. 93 % of the 290 Swedish municipalities have started the process to replace their old reference frames with SWEREF 99. So far, 242 of them have finalised the replacement.

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.

5 RH 2000, the National Height System

The third precise levelling of the mainland of Sweden was finalised in 2003. The final adjustment of the new national height system was made in 2005. The name of the height system is RH 2000 and it has 2000.0 as epoch of validity (in the perspective of the Fennoscandian GIA¹⁷).

The work to define RH 2000 was made in co-operation with the other Nordic countries. It is defined as the Swedish realisation of EVRS (Ågren et al., 2007). The network consists of about 50 000 benchmarks, representing approximately 50 000 km double run precise levelling measured by the motorised levelling technique. The final computation was made using the land-uplift model NKG2005LU, see Section 8.

To connect the national network to NAP¹⁸, the adjustment was made in a common adjustment of the nodal points in a data set called the BLR¹⁹, see Figure 3. This set consists of data from mainly the Nordic countries, the Baltic states, Poland, Germany and Holland. The latter data has been provided by UELN²⁰-database.



Figure 3: The BLR data set.

The work has been made within NKG. The Swedish network was then adjusted in a number of steps, keeping the nodal points from the BLR data set fixed.

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

5.1 Implementation of RH 2000

The work with implementing RH 2000 among other authorities in Sweden is in progress. 53 % 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 67 municipalities have finalised the replacement for all activities.

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 postglacial 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 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, a new gravity network/system will be established and the Swedish detail gravity data set will be improved by new gravity measurements. One example here is the gravity measurements made on the ice of lake Vänern during 2011. In cooperation with the Royal Institute of Technology (KTH) in Stockholm, it is also investigated what is required of geoid determination method and theory to reach this uncertainty over Sweden. Two projects have further been started in the Working Group of Geoid and Height System within NKG. 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; see www.nkg.fi.

7 Gravity Activities

In the autumn of 2006, Lantmäteriet purchased a new absolute gravimeter (Microg 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.

Absolute gravity observations have been carried out at 14 Swedish sites since the beginning of the 1990's, see Figure 4. Since 2007, 12 of the sites have been observed by Lantmäteriet and observations have also been done on 1 Danish site, 1 Finnish site, 2 Norwegian sites, 3 Serbian sites and 3 sites in Rep. Macedonia. Furthermore, four inter-comparisons, one with 19 and

one with 21 other gravimeters in Luxembourg, one with 22 other gravimeters in Paris and one with 4 other gravimeters in Wettzell have been carried out.

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 4. Onsala is also co-located with VLBI²¹. Skellefteå, Smögen, and Visby are co-located with tide gauges.

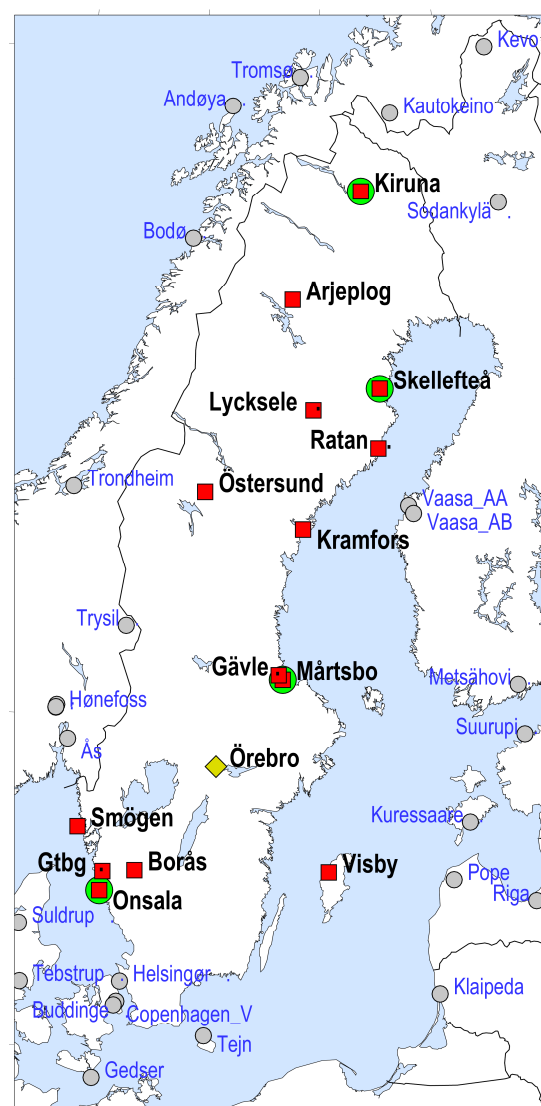


Figure 4: Absolute gravity sites in Sweden (red squares), planned new site (yellow diamond) and sites in neighbouring countries (grey circles). Sites with time series >15 years have a green circle as background to the red square.

The absolute gravity observations are coordinated within the co-operation of NKG, and observations have been performed by several groups (BKG²², IfE²³, UMB²⁴ and FGI²⁵) together with Lantmäteriet (Lilje et al., 2008b).

Within the upcoming five years, a new fundamental gravity network will be established in Sweden and the work started one year ago, when 12 sites were measured in co-operation with IGIK²⁶ using their absolute gravimeter A10 - 020.

At Onsala Space Observatory, a superconducting gravimeter was installed during the summer 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.

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. Knowledge of the spatial variation of the change in gravity is also needed while determine the new gravity system at a specific epoch in time.

Research regarding the 3D geometric deformation is foremost done within the BIFROST²⁷ effort. Reprocessing of all observations from continuously operating GPS stations is a continuous activity. The

most recent publication including site velocities is Lidberg et al. (2010). The results agree with an updated geophysical, meaningful GIA model at the sub-mm/yr level.

NKG2005LU, a special land uplift model including the vertical component only, has been developed. It is based on a combination and modification of the mathematical model of Olav Vestøl and the geophysical model of Lambeck, Smither and Ekman (Ågren & Svensson, 2007).

A coordinate transformation scheme has been developed for high-precision survey applications using GNSS relative permanent reference stations. Internal deformations are accounted for in the scheme (Lidberg et al., 2007 and Nørbech et al., 2006). The used deformation model (NKG_RF03vel), which is based on the results from BIFROST and on NKG2005LU but adapted for GNSS applications, is now implemented in the automated post-processing service offered by SWEPOS, see Section 3.

²¹ VLBI = Very Long Baseline Interferometry

²² BKG=Bundesamt für Kartographie und Geodäsie, Germany

²³ IfE = Institut für Erdmessung, Universität Hannover, Germany

²⁴ UMB = Universitetet for Miljø og Biovitenskap, Norway

²⁵ FGI = Finnish Geodetic Institute, Finland

²⁶ IGIK = Institute of Geodesy and Carthography, Poland

²⁷ BIFROST = Baseline Inferences for Fennoscandian Rebound Observations Sea level and Tectonics

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²⁸ FIG = Fédération Internationale des Géomètres (International Federation of Surveyors)

²⁹ IAIN = International Association of Institutes of Navigation

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