

National Report of Sweden to the EUREF 2011 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.

A 10-year-strategic plan for the Geodesy-activities during the period 2011-2020 at Lantmäteriet has been developed. It is available and downloadable from the website

http://www.lantmateriet.se/upload/filer/kartor/geodesi_gps_och_detaljmatning/geodesi/Geodesy_2010.pdf or

<http://www.lantmateriet.se/geodesi>.

2 Contributions from Lantmäteriet to EPN⁴, ECGN⁵ and EUVN_DA⁶

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 IGS⁷ network. Skellefteå (SKE0) is proposed to be a new IGS station. All the Swedish EPN/IGS stations are equipped with dual-frequency GPS⁸/GLONASS⁹ receivers and antennas of Dorne Margolin Choke Ring design.

Lantmäteriet operates the NKG EPN Local Analysis Centre in co-operation with On-

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 EUVN_DA = European Vertical Network, Densification Action

⁷ IGS = International GNSS Service

⁸ GPS = Global Positioning System

⁹ GLONASS = Globalnaya Navigatsionnaya Sputnikovaya Sistema

sala 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 50 stations concentrated to northern Europe. NKG LAC has contributed to the first EPN reprocessing with solutions based on the Bernese GPS Software for the time interval 1996-2006.

Sweden has, according to the co-ordination within the framework of NKG, offered all seven Swedish EPN stations except Vilhelmina 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).

The Swedish contribution to the EUVN_DA is 134 stations, see Figure 1.

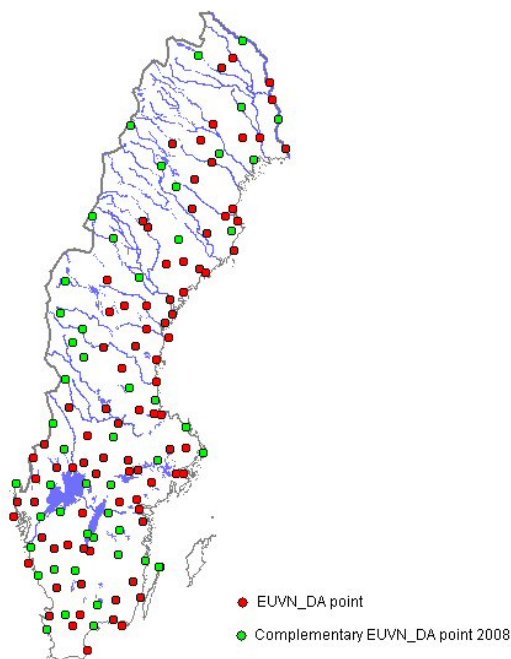


Figure 1: Swedish EUVN_DA sites (March, 2008).

The normal heights and geopotential numbers, as well as ellipsoidal heights, are given in epoch 2000.0 and are reduced for land-uplift using the model NKG2005LU,

¹⁰ EVRS = European Vertical Reference System

¹¹ NGOS = Nordic Geodetic Observing System

see Section 8. The estimated uncertainty of the given gravity values is generally about 1-2 mgal (68 % confidence level).

3 Network of Permanent Reference Stations (SWEPOS™)

SWEPOS™ is the Swedish network of permanent GNSS stations (Hedling et al., 2009, Jämtnäs et al., 2010 and 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 (Kempe & Jivall, 2002).

The purpose of SWEPOS is 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 geodetic reference frame SWEREF 99
- provide data for geophysical research
- monitor the integrity of the GNSS systems

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

Today (May 2010) SWEPOS consists of totally 215 stations, 39 class A stations and 176 class B ones, see Figure 2. The class A stations are built on bedrock and have redundant equipment for GNSS observations, communications, power supply, etc. They have also been

¹² DGPS = Differential GPS

¹³ DGNSS = Differential GNSS

¹⁴ RTK = Real Time Kinematic

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.

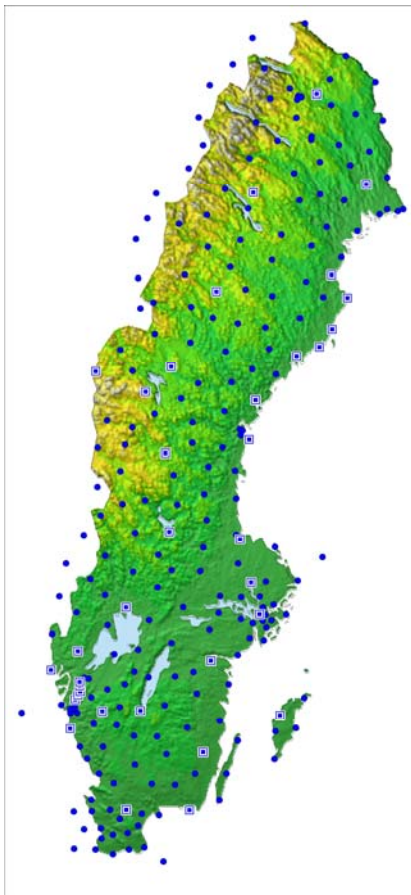


Figure 2. SWEPOS stations.

The SWEPOS Network RTK Service was launched on January 1st 2004 and it will during 2010 reach national coverage (a few stations are still under construction, see Figure 2). Since data from permanent GNSS stations is exchanged between the Nordic countries, good coverage of the network RTK service in border areas and along the coast has been obtained by the inclusion of 17 Norwegian SATREF stations, 7 Finnish Geotrim stations, 3

Danish Leica SmartNet stations and 2 Danish KMS¹⁵ stations.

The service broadcasts RTK data for both GPS and GLONASS with the VRS¹⁶ technique and has today (May 2011) approximately 1700 subscriptions, which means approximately 300 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). Further densifications with 40 stations during 2011 are planned in mainly the southern part of Sweden.

Existing guidelines concerning the use of the network RTK service have been improved during the last year (Norin et al 2010). Several parameters have been handled as well as time correlation effects for points measured close to each other in time.

SWEPOS also offers a single frequency Network DGNSS Service that was launched on April 1st 2006. Both this service and the network RTK service are using the network RTK/DGNSS software GPSNet from Trimble and GSM¹⁷ or GPRS¹⁸ (i.e. mobile Internet connection) as the main distribution channels.

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 Tromsö (Jivall & Lidberg, 2000). It is used as the national

¹⁵ KMS = Kort & Matrikelstyrelsen

¹⁶ VRS = Virtual Reference Station

¹⁷ GSM = Global System for Mobile communication

¹⁸ GPRS = General Packet Radio Service

geodetic reference frame for GNSS since 2001.

Lantmäteriet has further decided that SWEREF 99 shall be the official reference frame and replace the old national reference frame RT 90 for surveying and mapping.

4.1 Consolidation points

By defining SWEREF 99 as an active reference frame we are exposed to rely on SWEPOS' positioning services like network RTK. 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, see Figure 3. 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.

4.2 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. 88 % of the 290 Swedish municipalities have started the process to replace their old reference frames with SWEREF 99. So far, 223 of them have finalised the replacement.

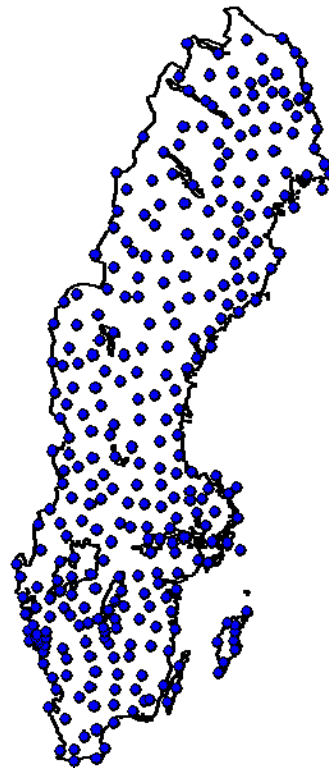


Figure 3: The SWEREF points from the RIX 95 project.

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 early 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 GIA¹⁹).

¹⁹ GIA = Glacial Isostatic Adjustment

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-uptift model NKG2005LU, see Section 8.



Figure 4: The BLR data set.

To connect the national network to NAP²⁰, the adjustment was made in a common adjustment of the nodal points in a data set called the BLR²¹, see Figure 4. This set consists of data from mainly the Nordic countries, the Baltic states, Poland, Germany and Holland. The latter data has been provided by UELN²²-database.

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. In 2007, the third precise levelling continued on the island of Gotland. The observations was adjusted and connected to RH 2000 on the mainland in 2008 through a

combination of tide gauge and GNSS/levelling observations, complemented by geoid/oceanographic models.

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. Approximately 45 % 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 46 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.

²⁰ NAP = Normaal Amsterdam Peil

²¹ BLR = Baltic Levelling Ring

²² UELN = United European Levelling Network

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).

Presently Lantmäteriet investigates what is required of the national gravity system and the gravity data to be able to compute a more accurate geoid model in the future (with standard uncertainty of the order 5 mm). Two preliminary conclusions from this ongoing project (not yet published) are that a new gravity system is needed and that 5 km resolution is sufficient for the detail gravity in case a dense, high quality Digital Elevation Model (DEM) is used for the topographic corrections. Besides, a significant amount of new observations are required and the old data need to be checked and updated in various ways.

7 Gravity Activities

In the autumn of 2006, Lantmäteriet purchased a new absolute gravimeter (Micro-g Lacoste FG 5 - 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 5. 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, two inter-comparisons, one with 19 other gravimeters in Luxembourg and one with 22 other gravimeters in Paris 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). Onsala is also co-located with VLBI²³. Skellefteå, Smögen, and Visby are co-located with tide gauges.

The absolute gravity observations are co-ordinated within the co-operation of NKG, and observations have been performed by several groups (BKG, IfE²⁴, UMB²⁵ and FGI²⁶) together with Lantmäteriet (Lilje et al., 2008b). This arrangement has made it



² Figure 5: Absolute gravity sites in Sweden (red squares), planned new site (yellow diamond) and sites in neighbouring countries (grey circles). Sites² observed every year since 2003 have a green circle as background to the red square.

possible to observe 7 of the sites every year since 2003 (marked with green background circles in Figure 5).

Within the upcoming five years, a new fundamental gravity network will be established in Sweden and the work has started this spring.

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.

Research regarding the 3D geometric deformation is foremost done within the BIFROST²⁷ effort. Reprocessing of all observations from continuously operating GPS stations since autumn 1993 up to autumn 2006 has been done (Lidberg, 2007, Lidberg et al., 2007a, Lidberg et al., 2009, Lidberg & Johansson, 2009 and 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 perma-

nent reference stations. Internal deformations are accounted for in the scheme (Lidberg et al., 2007b 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.

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

³⁰ IAG = International Association of Geodesy

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