National Report of Sweden to the EUREF 2007 Symposium

– geodetic activities at Lantmäteriet, the National Land Survey of Sweden

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1. Introduction

At Lantmäteriet (the National Land Survey of Sweden) the activities in the fields of geodetic reference frames and geodetic reference networks are focused on introducing the ETRS 89[1] realisation SWEREF 99, introducing the national height system RH 2000, improving our geoid models and finalising of the project RIX 95. Large efforts are also carried out concerning the operation and expansion of the Swedish network of permanent reference stations SWEPOS™. Some of the activities are done within the framework of NKG[2].

[1] ETRS 89 = European Terrestrial Reference System 89

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

2. Contributions from Lantmäteriet to EPN[3], ECGN[4] and EUVN_DA[5]

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). Both daily and hourly data is delivered.

Furthermore, Onsala, Mårtsbo, Visby, Borås and Kiruna are included in the IGS[6] network. Skellefteå (SKE0) is proposed to be a new IGS station. All the Swedish EPN/IGS stations are equipped with dual-frequency GPS[7]/ GLONASS[8] receivers and Dorne Margolin Choke Ring antennas.

[3] EPN = EUREF Permanent Network

[4] ECGN = European Combined Geodetic Network

[5] EUVN_DA = European Vertical Network, Densification Action

[6] IGS = International GPS Service

[7] GPS = Global Positioning System

[8] GLONASS = Globalnaya Navigatsionnaya Sputnikovaya Sistema

Lantmäteriet operates the NKG EPN Local Analysis Centre in co-operation with Onsala Space Observatory. NKG EPN LAC contributes with weekly and daily solutions based on final IGS products. In addition, near-real time solutions based on hourly data and IGS ultra-rapid products are now being introduced.

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 EVRS2007. NKG has also created a Nordic densification called NGOS[9] (Poutanen et al, 2005).

Sweden has so far delivered 87 stations to the EUVN_DA, see figure 1. The normal heights and geopotential numbers are given in epoch 2000.0 and are reduced for land-uplift using the NKG2000LU model The estimated accuracy of the given gravity values is generally about 1-2 mgal (68 % conf. level). In 2007, the Swedish EUVN_DA contribution will be further densified with 42 points, including mountainous areas in the NW parts of the country.

3. Network of Permanent Reference Stations (SWEPOS™)

SWEPOS is the Swedish network of permanent GNSS[10] stations, providing real-time services on both meter level (DGPS/DGNSS) and centimeter level (Network RTK with regional coverage) as well as data for post-processing (Jonsson et al, 2006).

[9] NGOS = Nordic Geodetic Observing System

[10] GNSS = Global Navigation Satellite Systems

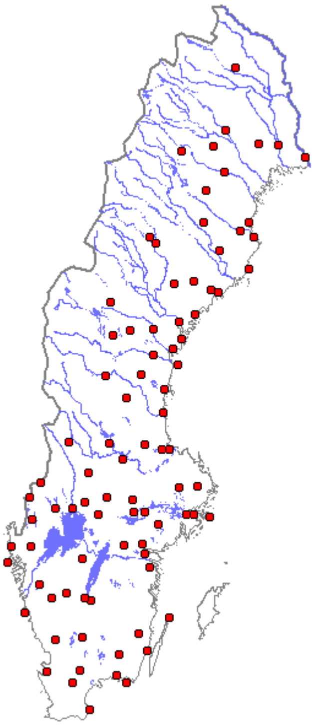

Figure 1: *Swedish EUVN_DA sites (May, 2007)*

SWEPOS also offers an automated post-processing service, based on the Bernese software (Kempe & Jivall, 2002), see www.swepos.com. The purpose of SWEPOS is to:

- provide single- and dual-frequency data for relative GNSS measurements
- provide DGPS[11]/DGNSS[12] corrections and RTK[13] 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.

[11] DGPS = Differential GPS

[12] DGNSS = Differential GNSS

[13] RTK = Real Time Kinematic

Within the framework of NKG, a subgroup of the project Nordic Positioning Service has developed a classification system of permanent reference stations for GNSS (Engfeldt et al, 2006a). This classification system has been adopted by Lantmäteriet and it includes four different classes: A (the best), B, C and D (the worst).

The 21 fundamental SWEPOS stations, which have been in operation since autumn 1993 (the last one was added in 1996) and 6 more stations fulfil the requirements for class A stations. These stations are monumented 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.

The rest of the SWEPOS stations are mainly established on top of buildings for Network RTK purposes; they have a variety of instrumentation and monumentation. Those stations are all classified as class B. This means that the total number of SWEPOS stations is 125. Another 28 stations will become operational during August/September 2007.

All SWEPOS stations are equipped with dual-frequency GPS/GLONASS[14] receivers and with antennas of Dorne Margolin type.

The SWEOS Network RTK Service was launched on January 1st 2004. This service will soon cover almost all the populated areas of Sweden and has today (June 2007) approximately 800 subscriptions.

[14] GLONASS = Globalnaya Navigatsionnaya Sputnikovaya Sistema

The coverage in spring 2007 is shown as the green area in figure 2 and the intended new coverage for autumn 2007 is shown as the yellow area in the same figure. This includes the stations from the establishment project XYZ-RTK (red dots), which will be operational during August/September 2007, and four new stations from last years establishment project Nordost-RTK (the four most northern red dots, in operation since late May).

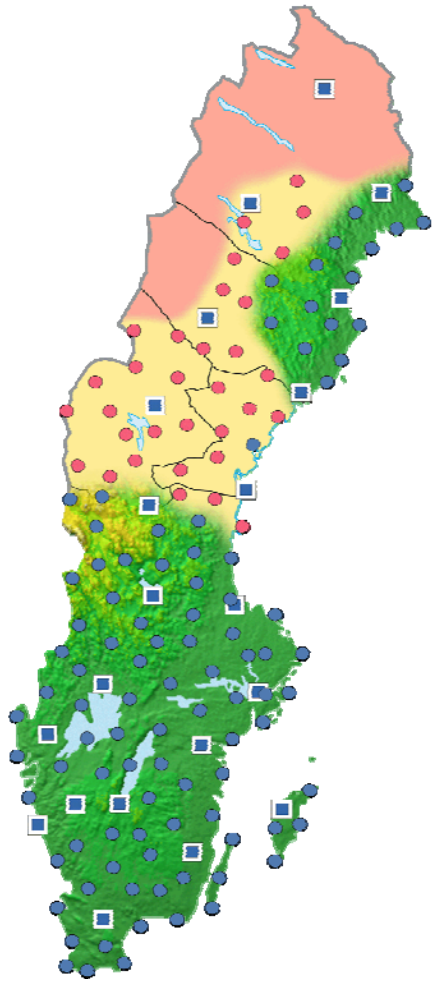

Figure 2: *The SWEPOS network in June 2007. Squares are the 21 fundamental SWEPOS stations. Blue dots are the rest of the existing stations (except for a few densifications in the Gothenburg area). Red dots are stations that will become operational during 2007.*

Originally the Network RTK service was for GPS use only, but on April 1st 2006 it was complemented with a service that broadcasts RTK data for both GPS and GLONASS. At this date, a Network DGPS service with nationwide coverage was launched.

A diploma work has during the winter 2007 compared the use of only GPS to the use of the combination GPS-/GLONASS for Network RTK in areas with different degrees of visual obstacles. With the combination GPS-/GLONASS, the possibility in these measurements to get a fixed solution increased from 81 to 88 % (Johnsson & Wallerström, 2007).

The service uses the Network RTK software GPSNet from Trimble. GSM[15] is used as distribution channel, but since November 1st 2005, also wireless Internet (mainly GPRS[16], but also UMTS[17] or WLAN[18]) can be used. In addition, tests have been made to distribute RTK data through satellite phone communication and this distribution channel is also possible to use.

The establishment of a Nordic Positioning Service based on Network DGPS is in progress within the framework of the NKG project Nordic Positioning Service. Actions that have been carried out through that project are the establishment of a computer network between the national control centres, the classification system of permanent reference stations for GNSS (see above), the development of a Nordic web-portal for post-processing data and test measurements with Network DGPS (Engfeldt et al, 2006b).

4. RIX 95

The RIX 95 project involves GPS measurements on triangulation stations and selected local control points. It has been running since 1995 and will be finished this year (2007). The work is financed by a group of national agencies. The principal aims are to connect local coordinate systems to the national reference frames (SWEREF 99 and RT 90) and to establish new points easily accessible for local GPS measurements.

Concerning the connection of local coordinate systems, transformation parameters based on different transformation models are developed. The parameters are mainly based on direct projection with Transverse Mercator, in some cases also combined with similarity transformations in two or three dimensions (Engberg & Lilje 2006). Transformation parameters will be available for all 290 Swedish municipalities by the end of the year.

The measurements on totally 9029 control points were finalised in 2006. Definitive coordinates for the northern most part are to be calculated during 2007.

To a large extent the measurements are made with standard equipment and procedures for static observations (8704 points).

[15] GSM = Global System for Mobile communication

[16] GPRS = General Packet Radio Service

[17] UMTS = Universal Mobile Telecommunications System

[18] WLAN = Wireless Local Area Network

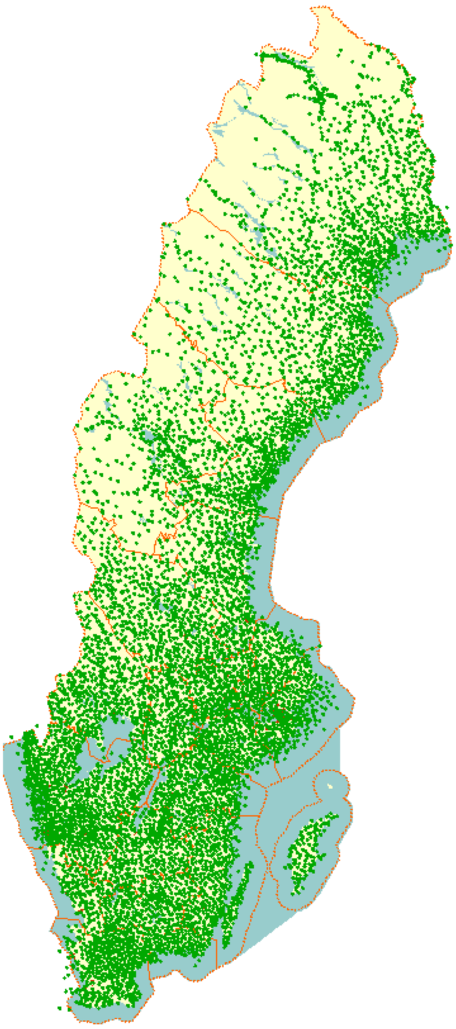

Figure 3: 9029 control points, determined within the RIX 95 project.

However, more accurate coordinates in SWEREF 99 are determined for one point every 50 km (325 points). These points are observed for 2x24 hours with a new set-up between the sessions. The observations for these points are made with Dorne Margolin T-type antennas, and the Bernese software is used for the processing.

5. Implementation of SWEREF 99

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 for GPS since 2001.

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

A formal decision regarding map projections for national mapping, as well as for local surveying, was taken in 2003. All projections 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 index system has also been adopted.

The work regarding implementation of SWEREF 99 among other authorities in Sweden, such as local ones, is in progress. Approximately 100 of the 290 Swedish municipalities have started the process to replace their old reference frames with SWEREF 99. Fourteen of them have so far 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 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 is a national, homogenous network in SWEREF 99 and geographical data with less deformation.

6. The National Height System RH 2000

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 the beginning of 2005. The name of the system is RH 2000 and it has 2000.0 as epoch of validity (in the perspective of the Fennoscandian 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[19] (Ågren et al, 2006). The network consists of about 50 000 benchmarks, representing appr. 50 000 km double run precise levelling measured by the motorised levelling technique.

The final computation was made using a land uplift model based on a combination and modification of the mathematical model of Olav Vestøl and the geophysical model of Lambeck, Smither and Ekman, named NKG2005LU(APP) (Ågren & Svensson, 2007).

To connect the national network to the Normaal Amsterdam Peil (NAP), the adjustment was made in a common adjustment of the nodal points in a data set called the BLR[20] (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 UELN[21]-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 continues on the island of Gotland and, in parallel, work is in progress considering the connection of the island to RH 2000 on the mainland.

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

7. Implementation of RH 2000

The work with implementing RH 2000 among other authorities in Sweden is in progress. Approximately 50 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 6 municipalities have finalised the replacement for all activities.

8. Geoid Models

A new geoid model, to transform heights above the ellipsoid in SWEREF 99 to heights in RH 2000, has been developed and introduced. The model was first called SWEN 05LR (Ågren & Svensson, 2006), but was later renamed SWEN05_RH2000.

It has been computed by adapting the gravimetric geoid model NKG 2004 to the reference systems SWEREF 99 and RH 2000 using 1178 GPS/levelling geoid heights. A representation of the fit residuals is also included in the model, so that the users will receive heights as close as possible to RH 2000. The expected standard error is 1.5-2 cm in most parts of the country and a little higher in the mountainous areas to the north-west.

The geoid model SWEN05_RH2000 has also been adapted to the old Swedish height system RH 70 by applying an accurate model for the height system difference. The resulting model is called SWEN05_RH70.

[19] EVRS = European Vertical Reference System

[20] BLR = Baltic Levelling Ring

[21] UELN = United European Levelling Network

Since 2005 Lantmäteriet is engaged in a joint project together with the Royal Institute of Technology in Stockholm (KTH). The main purpose is to evaluate the gravimetric geoid determination methods developed at KTH (Sjöberg 1991, 2003) and to compute a new gravimetric geoid (quasigeoid) model over Sweden.

This work is also meant to contribute to the on-going efforts of the NKG Working Group for Geoid Determination, to compare different geoid determination methods. The results for the KTH method are promising and a good fit has been obtained to Swedish GPS/levelling, see Ågren et al. (2006).

9. Gravity Activities

Figure 4: *The new FG5 absolute gravimeter and the observer team during the on-site training course.*

A new absolute gravimeter (FG5) was purchased by Lantmäteriet in the autumn of 2006. 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 Glacial Isostatic Adjustment (GIA). The new instrument, together with the appointed observer team, is illustrated in figure 4.

Absolute gravity observations have been carried out at 12 sites since the beginning of the 1990:s, see figure 5. All sites are co-located with permanent reference stations for GNSS in the SWEPOS network (except for Gtbg which is no longer in use). Onsala is also co-located with VLBI[22]. 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[23], IfE[24], UMB[25] and FGI[26]) together with Lantmäteriet (Engfeldt et al, 2006c). This arrangement has made it possible to observe 7 of the sites every year since 2003 (marked with green background circles in figure 5).

At the Onsala Space Observatory, efforts are currently made to obtain a superconducting gravimeter. 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.

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[22] VLBI = Very Long Baseline Interferometry

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

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

[25] UMB = Universitetet for Miljø og Biovitenskap, Norway

[26] FGI = Finnish Geodetic Institute, Finland

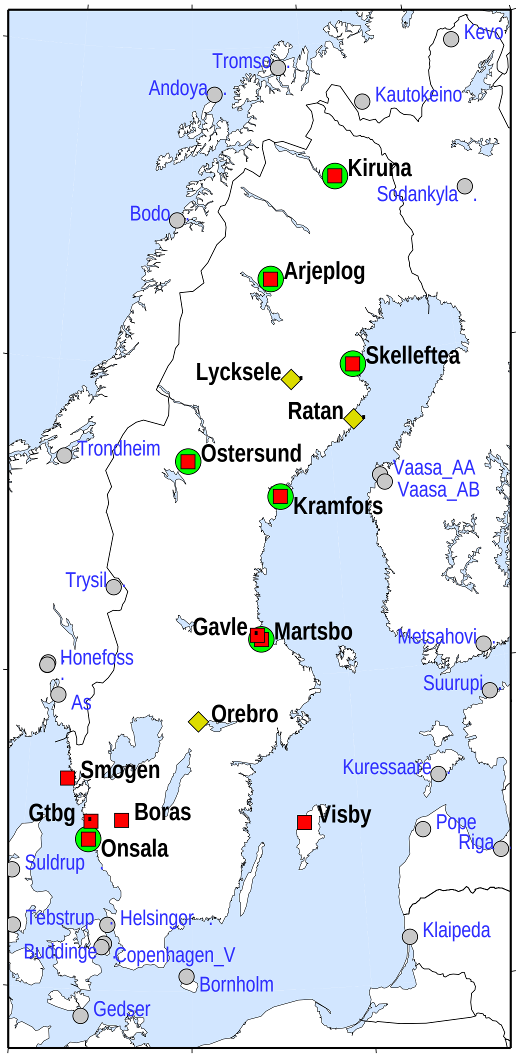

Figure 5: Absolute gravity sites in Sweden (red squares), planned new sites (yellow diamonds) and sites in neighbouring countries (grey circles). Sites observed every year since 2003 have a green circle as background to the red square.

10. 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 BIFROST effort. Reprocessing of all observations from continuously operating GPS stations since fall 1993 is in finalising stage. Preliminary results agree with an updated geophysical, meaningful GIA model at the sub-mm/yr level, see figure 6.

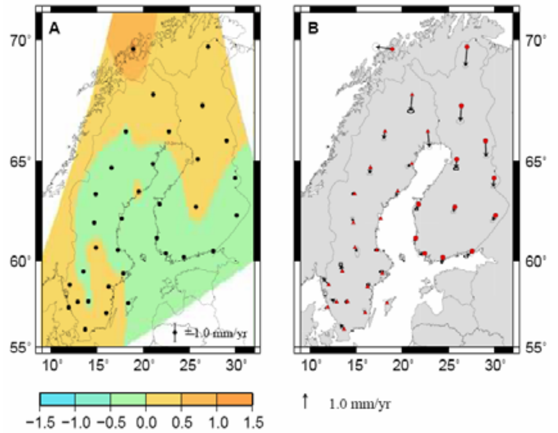

Figure 6: Residuals in vertical (left) and horizontal rates (right), determined by subtracting predictions obtained by the best fit model from the observations.

NKG2005LU, a special land uplift model including the vertical component only, has also been developed together with the new height system RH 2000, see section 6.

For survey applications, a velocity model has been developed in order to account for internal deformations, including co-ordinate transformations (NKG_RF03vel). The north and east components origin from the Glacial Isostatic Adjustment (GIA) model presented in Milne 2001. The velocity field from this model has been transformed to the GPS-derived velocity field in Lidberg et al (2007).

Thus, the horizontal velocity field in the grid files describe horizontal displacements relative to the stable Eurasia, as defined by the ITRF2000 and its rotation pole for Eurasia (Altamimi et al, 2003).

NKG2005LU(ABS) has been used as the up-component. This model origins from the model NKG2005LU(APP), see section 6.

11. The Swedish GI Strategy

The Swedish Government and Parliament has given Lantmäteriet an outspoken role as co-ordinator of the national SDI[27]. The responsibility comprises co-ordination of production as well as co-operation, dissemination and R&D.

This responsibility includes co-ordination of the implementation of EC directives related to geographic information (GI), such as INSPIRE[28], PSI[29] and GMES[30]. The government has also established a high level advisory board (Geodatarådet) to support Lantmäteriet in its co-ordination role.

Furthermore, a national GI strategy has been developed, covering all strategic issues related to geographic information in Sweden. The strategy was presented by the end of March 2007 and will be annually updated.

The strategic goal "Geodetic Reference Frame" states that all actors dealing with building-up, processing and use of geographic information shall apply SWEREF 99 as the common geodetic reference frame, normally without any previous transformations.

[27] SDI = Spatial Data Infrastructure

[28] INSPIRE = Infrastructure for Spatial Information in Europe

[29] PSI = Public Sector Information

[30] GMES = Global Monitoring of Environment and Security

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