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– 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 and positioning services are focused on the implementation of RH 2000 and SWEREF 99 – which are the Swedish national realizations of EVRS[1] and ETRS89[2], respectively – and the improvement of Swedish geoid models. Large efforts are also made concerning the operation, expansion and services of SWEPOS™, the Swedish network of permanent GNSS[3] stations. Some of the activities are done within the framework of NKG[4]. 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

Seven SWEPOS stations are included in EPN[5]. 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[6] network. All of the Swedish EPN/IGS stations are equipped with dual-frequency GPS[7]/GLONASS[8] receivers and antennas of Dorne Margolin choke ring design.

Lantmäteriet will offer another 20 stations to EPN. 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 existing Swedish EPN stations. Three of these new stations

[1] EVRS = European Vertical Reference System

[2] ETRS = European Terrestrial Reference System

[3] GNSS = Global Navigation Satellite Systems

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

[5] EPN = EUREF Permanent Network

[6] IGS = International GNSS Service

[7] GPS = Global Positioning System

[8] GLONASS = Globalnaya Navigatsionnaya Sputnikovaya Sistema

(KIR8, MAR7, ONS1) contribute to the IGS-MGEX[9] 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 IGS products. The EPN sub-network processed by NKG LAC consists of 52 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.

3 Network of Permanent Reference Stations (SWEPOS™)

SWEPOS™ is the Swedish network of permanent GNSS stations (Sunna et al., 2013 and Norin et al., 2012); see www.swepos.com. Since the first SWEPOS stations were established in 1993, the 20th anniversary of SWEPOS takes place in 2013. SWEPOS provides real-time services on both metre level (DGPS[10]/DGNSS[11]) and centimetre level (network RTK[12]), as well as data for post-processing. An automated post-processing service based on the Bernese GPS software is also available.

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.

A relocation of the SWEPOS control centre to new premises within Lantmäteriet's headquarters in Gävle took place during 2012.

3.1 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.

Figure 1: The SWEPOS network in May 2013. Squares indicate class A stations and dots indicate class B stations.

[9] MGEX = Multi-GNSS Experiment

[10] DGPS = Differential GPS

[11] DGNSS = Differential GNSS

[12] RTK = Real Time Kinematic

Today (May 2013) SWEPOS consists of totally 285 stations; 41 class A stations and 244 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 GPS/GLONASS receivers with antennas of Dorne Margolin design), but with somewhat less redundancy.

The 20 original class A stations have two kinds of monuments, both the original concrete pillars and 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. Local tie surveys were performed at the 20 stations during 2012.

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

3.2 *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 21 Norwegian SATREF stations, 5 Finnish Geotrim stations, 3 Danish Leica SmartNet stations and 2 Danish Geodatastyrelsen (Danish Geodata Agency) stations.

The service has supplied RTK data for both GPS and GLONASS since April 1, 2006 and has today (May 2013) approximately 2120 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 utilise, since June 2012, the network RTK/DGNSS software Trimble VRS3Net. The previous software used was GPSNet, also from Trimble. The software is working in virtual reference station mode, but an implementation of so-called network RTK correction messages as an additional service is planned. Test measurements with this technique have been performed, both as static field measurements and in dynamic applications on board a ship (Norin et al., 2012).

Absolute antenna models (igs08.atx) were implemented with the update of network RTK/DGNSS software to VRS3Net – see further section 5.2.

An ionosphere monitoring service can be accessed via the SWEPOS website and also downloaded as an application for Android smartphones, iPhone and iPad. The development of the monitoring service originates from the project "Close-RTK" which, among other things, studied how the ionosphere affects network RTK measurements (Emardson et al., 2009, Sunna et al., 2013 and Emardson et al., 2011).

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. 63 % 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 110 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[13].

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 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 remeasured in a yearly programme where 50 points are measured every year.

5.2 Adaptation of SWEREF 99 to igs08.atx

In connection to the upgrade of the network RTK software, cf. 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. The original SWEREF 99 coordinates were consistent with relative antenna models in igs_01.pcv.

5.3 Implementation of SWEREF 99

The work regarding implementation of SWEREF 99 among other authorities in Sweden, such as local ones, is in progress. 94 % of the 290 Swedish municipalities have started the process to replace their old reference frames with SWEREF 99. So far, 252 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.

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

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 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 have further been started in the Working Group of Geoid and Height System within NKG. The first one aims at computing a new common geoid model over the Nordic countries, while the second one investigates what is required to reach 5 mm uncertainty over the Nordic area; see www.nkg.fi.

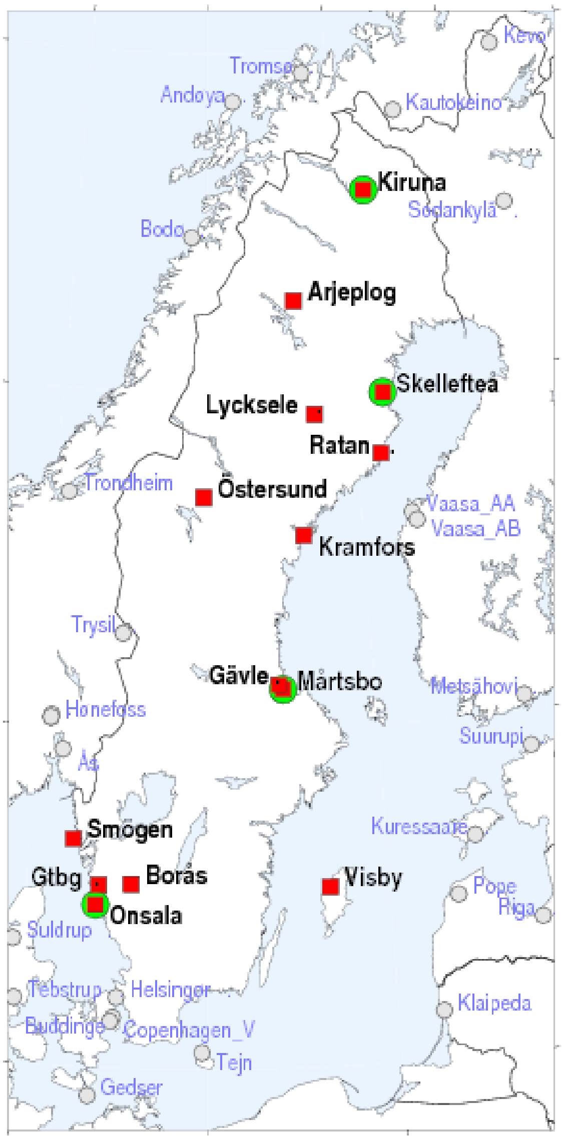

Figure 3: Absolute gravity sites in Sweden (red squares, and sites in neighbouring countries (grey circles). Sites with time series >15 years have a green circle as background to the red square.

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[14].

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 on 2 Danish sites, 1 Finnish site, 2 Norwegian sites, 3 Serbian sites and 3 sites in Rep. Macedonia. Furthermore, five inter-comparisons, one with 19 and one with 21 other gravimeters in Luxembourg, one with 22 other gravimeters in Paris and twice 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 3. Onsala is also co-located with VLBI[15]. 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[16], IfE[17], UMB[18] and FGI[19]) together with Lantmäteriet.

Within the coming three years, a new fundamental gravity network will be established in Sweden. The work started two years ago, when 12 sites were measured in co-operation with IGiK[20] using their absolute gravimeter A10 - 020. Last year 51 additional sites were 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 twice 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 is presently being studied in a PhD project (see e.g. Olsson et al., 2012). 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[21] effort, which celebrates its 20th anniversary in 2013. 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) and a new publication will accompany the forthcoming release. BIFROST results are frequently used in many scientific investigations (e.g. Zhao et al., 2012, Wang et al., 2013, Wu et al., 2013) as they among other things agree to current geophysical, meaningful GIA models at the sub-mm/yr level.

NKG2005LU is a Nordic land uplift model that includes the vertical component only. It has been developed as a combination

[14] GIA = Glacial Isostatic Adjustment

[15] VLBI = Very Long Baseline Interferometry

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

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

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

[19] FGI = Finnish Geodetic Institute, Finland

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

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

and modification of the mathematical model of Olav Vestøl and the geophysical model of Lambeck, Smither and Ekman (Ågren & Svensson, 2007). Work is presently going on to compute an improved GIA model in Nordic cooperation, intended to lead to a new and better NKG201XLU model. This new model 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[22] satellite mission as well as its follow-on. Additionally, error bars will be provided for all quantities. Geophysical model information will be derived from most recent GIA modelling techniques which rely on up-to-date ice models and earth parameters (see Steffen & Wu, 2011, for an overview). This information will be benchmarked within the Nordic co-operation similar to recent efforts by Spada et al. (2011).

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. First tests with the recent EPN velocity field, published results as well as selected model data already provide insight in the need of network densification but also inferences on the geodynamic situation in certain areas.

[22] GRACE = Gravity Recovery And Climate Experiment

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

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[24] ION = Institute of Navigation