National Report of Sweden to the NKG General Assembly 2014
– geodetic activities in Sweden 2010–2014

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1. Geodetic activities at Lantmäteriet

1.1 Introduction

At Lantmäteriet (the Swedish mapping, cadastral and land registration authority) the geodetic activities during 2010–2014 have been focused on:

- The operation, expansion and services of SWEPOS™, the Swedish national network of permanent reference stations for GNSS[1].
- The implementation of the Swedish national reference frame SWEREF 99 and the national height system RH 2000 (ETRS89[2] and EVRS[3] realisations, respectively).
- The improvement of Swedish geoid models.

Some of the activities are performed within the framework of NKG[4]. Resources have also been allocated for the 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, which was released in 2011 (Lantmäteriet, 2011).

1.2 Satellite positioning (GNSS)

Lantmäteriet operates the NKG EPN[5] LAC[6] in co-operation with Onsala Space Observatory at Chalmers University of Technology. The NKG LAC contributes with weekly and daily solutions based on final CODE[7] products, using the Bernese GNSS Software. Since GPS[8] week 1765 (November 2013), version 5.2 is used. The EPN sub-network processed by NKG LAC consists of 68 reference stations (January 2015) concentrated to northern Europe, see Figure 1.1. This means that nineteen

[1] GNSS = Global Navigation Satellite Systems
[2] ETRS = European Terrestrial Reference System
[3] EVRS = European Vertical Reference System
[4] NKG = Nordiska Kommissionen för Geodesi (Nordic Geodetic Commission)
[5] EPN = EUREF Permanent Network
[6] LAC = Local Analysis Centre
[7] CODE = Centre for Orbit Determination in Europe, Switzerland
[8] GPS = Global Positioning System

stations have been added to and one station has been redrawn from the NKG LAC sub-network since the previous NKG General Assembly four years ago. Another four stations are expected to be added to the sub-network in the near future. The NKG LAC has also contributed to the EPN reprocessing activities. NKG has through Lantmäteriet been represented at the seventh and eighth EUREF[9] LAC's Workshops, which were held in 2010 and 2013.

Figure 1.1: *The NKG EPN LAC sub-network of 68 permanent reference stations for GNSS in January 2015. Source: www.epncb.oma.be.*

A GNSS analysis centre project has been started within NKG during the last four-year period 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 and the operational phase began during the summer 2014.

The EGNOS[10] RIMS[11] that was inaugurated at Lantmäteriet in Gävle already during 2003 has been successfully supported by Lantmäteriet since then.

During the years 2010–2012, Lantmäteriet chaired the Swedish Board of Radio Navigation (RNN).

1.3 Network of permanent reference stations for GNSS (SWEPOS)

SWEPOS™ is the Swedish national network of permanent GNSS stations (Lilje et al., 2014); see the new SWEPOS website available on swepos.se or through www.lantmateriet.se/swepos. SWEPOS is operated from the headquarters of Lantmäteriet in Gävle and a relocation of this control centre to new premises within the building took place during 2012, see Figure 1.2.

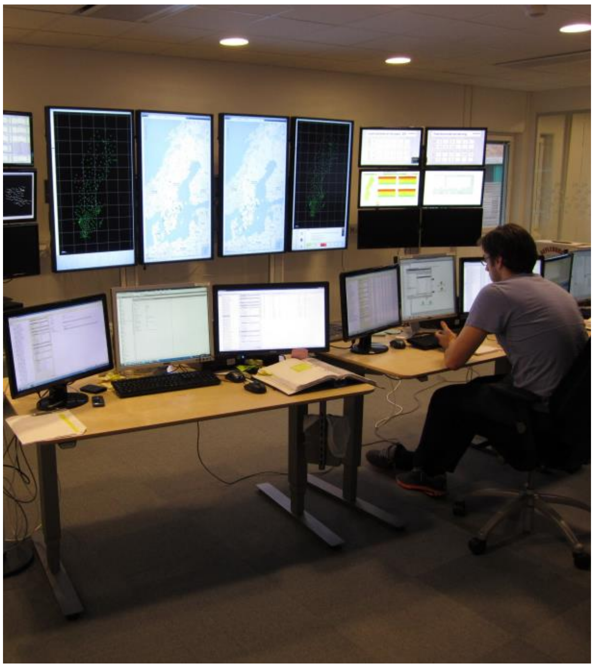

Figure 1.2: *The SWEPOS control centre.*

[9] EUREF = the IAG Reference Frame Subcommission for Europe

[10] EGNOS = European Geostationary Navigation Overlay System

[11] RIMS = Ranging and Integrity Monitoring Station

Since the first SWEPOS stations were established in 1993, the 20th anniversary of SWEPOS took place in 2013.

The purposes of SWEPOS are:

- Providing single- and dual-frequency data for relative GNSS measurements.
- Providing DGPS[12]/DGNSS[13] corrections and RTK[14] 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 (Engfeldt et al., 2006). The system includes four different classes; A, B, C and D, where class A is the class with the highest demands.

Figure 1.3: *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).*

By the time for the 17th NKG General Assembly in September 2014 SWEPOS consisted of totally 305 stations, 38 class A stations and 267 class B ones, see Figures 1.3 and 1.4.

Figure 1.4: *Söderboda is a SWEPOS station with a roof-mounted GNSS antenna mainly established for network RTK purposes belonging to class B.*

This means that the total number of SWEPOS stations has increased with 120 stations since the previous NKG General Assembly, see Figure 1.5.

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.

[12] DGPS = Differential GPS

[13] DGNSS = Differential GNSS

[14] RTK = Real Time Kinematic

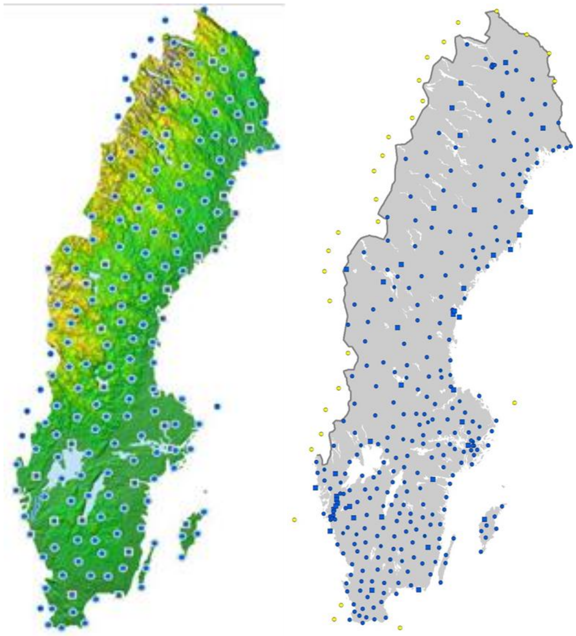

Figure 1.5: *The SWEPOS network by the time for the previous NKG General Assembly in 2010 to the left and by the time for the 17th NKG General Assembly in September 2014 to the right. Squares indicate class A stations and dots indicate class B ones. Stations in neighbouring countries used in the SWEPOS Network RTK Service are also marked, but stations from other service providers are not marked.*

The 20 original class A stations have two kinds of monuments; the original concrete pillars as well as newer steel grid masts established during 2011, see Figure 1.3. 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.

Seven SWEPOS stations have for a long time been included in EPN. These stations are Onsala, Mårtsbo, Visby, Borås, Skellefteå, Vilhelmina and Kiruna (ONSA, MAR6, VIS0, SPT0, SKE0, VIL0 and KIR0), which all are original class A stations. Daily, hourly and real-time (EUREF-IP) data (1 Hz) are delivered for all stations, except for Vilhelmina, where just daily and hourly files are submitted. Furthermore, Onsala, Mårtsbo, Visby, Borås and Kiruna are also included in the IGS[15] network.

The new monuments on all 20 original class A stations mentioned above are also expected to become EPN stations during 2014–2015 (16 of these 20 stations were included in January 2015). Three of the new stations (KIR8, MAR7 and ONS1) also contribute to the IGS-MGEX[16] campaign, which has been set-up to track, collate and analyse all available GNSS signals.

1.4 SWEPOS services

SWEPOS provides real-time services on both metre level (DGNSS) and centimetre level (network RTK), as well as data for post-processing in RINEX[17] format. An automated post-processing service based on the Bernese GNSS Software is also available, where version 5.0 has been used since 2008.

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

[15] IGS = International GNSS Service

[16] IGS-MGEX = IGS Multi-GNSS Experiment

[17] RINEX = Receiver Independent EXchange format

2006. By the time for the 17th NKG General Assembly in September 2014, it had approximately 2400 subscriptions, which means some 920 new users since the previous NKG General Assembly four years ago, see Figure 1.6.

Figure 1.6: *Personnel from Lantmäteriet introducing network RTK for Mr Stefan Attefall, the Swedish Minister for Public Administration and Housing. Photo: Anna Eklund.*

During the four past years, 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.

After the original Close-RTK project (Emardson et al., 2009), a second part of this project has investigated how network RTK measurements are affected by the ionosphere (Emardson et al., 2011). The investigation was done by analysing archived SWEPOS data from the previous solar maximum around 1999–2004. The project also included the development of an ionospheric monitoring service. The service can be accessed via the SWEPOS website and can also be downloaded as applications for smartphones.

Existing guidelines concerning the use of the network RTK service have been improved, where also time correlation effects for points measured close to each other in time have been studied more in detail (Odolinski, 2012). Lantmäteriet is also working on a series of handbooks for mapping and surveying, see Section 1.10.7.

A SWEPOS user group exists with the main purpose to support the development of SWEPOS and its services. The user group consists of representatives from governmental and non-governmental organisations as well as from the private sector.

SWEPOS also offers a single frequency network DGNSS Service as a supplement to the network RTK service. Both services are since June 2012 utilising Trimble Pivot Platform GNSS Infrastructure Software. Together with the new software, absolute antenna models (igs08.atx) were implemented (implying that the SWEREF 99 coordinates of the SWEPOS stations were adjusted to comply with the new antenna models). The software is operating in virtual reference station mode, but so-called network RTK correction messages have been tested (Norin et al., 2012). An implementation of this as an additional service option, as well as options for new GPS signals, is planned.

The early Swedish DGPS service called EPOS, which used correction data from SWEPOS, ended its operation during 2012.

1.5 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 (Engberg et al., 2010). The approximately 300 so-called SWEREF points from the RIX 95 project are used for this purpose, see Figure 1.7, 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 (Norin et al., 2013).

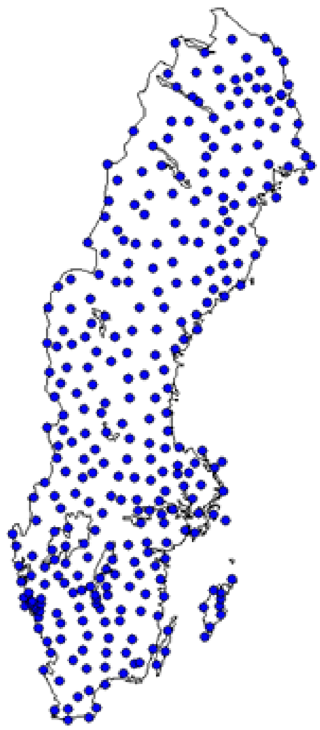

Figure 1.7: *The approximately 300 SWEREF points from the RIX 95 project, which totally included 9029 points.*

The work regarding the implementation of SWEREF 99 among different authorities in Sweden, such as local ones, is in progress (Kempe et al., 2010). 97 % of the 290 Swedish municipalities have started the process to replace their old reference frames with SWEREF 99. The number of municipalities that have finalised the replacement has increased from 192 to 264 during the past four years.

To rectify distorted geometries of local reference frames, the municipalities utilise correction models 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.

1.6 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. The network consists of about 50,000 bench marks, 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 new levelling is required, the work is done through procurement procedures. This is also the situation for the remeasurements of the 300 SWEREF points described in Section 1.5.

The work with implementing RH 2000 among different authorities in Sweden is in progress (Kempe et al., 2014). 70 % 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 159 municipalities have finalised the replacement for all activities, which is 126 more than by the time for the previous NKG General Assembly four years ago.

1.7 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 has been computed in cooperation between Lantmäteriet and Professor Lars E. Sjöberg and his group at KTH[18] in Stockholm. The adaption was done 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 and the Swedish detail gravity data set is improved by new gravity measurements, e.g. on Lake Vänern (Ågren et al., 2014a), see Figure 1.8.

Figure 1.8: *Relative gravity measurements in March 2011 on Lake Vänern, the largest lake in Sweden. Photo: Mikael Lindblom.*

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). Two projects are currently running in the NKG

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

Working Group of Geoid and Height Systems. The first aims at computing a new common geoid model over the Nordic countries (Ågren et al., 2014b), while the second investigates what is required to reach 5 mm uncertainty over the Nordic area.

In order to improve the Baltic Sea geoid model, Lantmäteriet is also engaged in the FAMOS[19] project.

1.8 Gravimetry

In the autumn of 2006, Lantmäteriet purchased a new absolute gravimeter (Micro-g LaCoste FG5 - 233). The objective behind this 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[20].

Absolute gravity observations have been carried out at 14 Swedish sites since the beginning of the 1990's, see Figure 1.9. This means that no sites have been added since the previous NKG General Assembly. Since 2007, 13 of these sites have been observed by Lantmäteriet. 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.

All Swedish sites are co-located with reference stations in the SWEPOS network (except for Göteborg (Gtbg), which no longer is in use). Onsala is also co-located with VLBI[21]. Skellefteå, Smögen, and Visby are co-located with tide gauges.

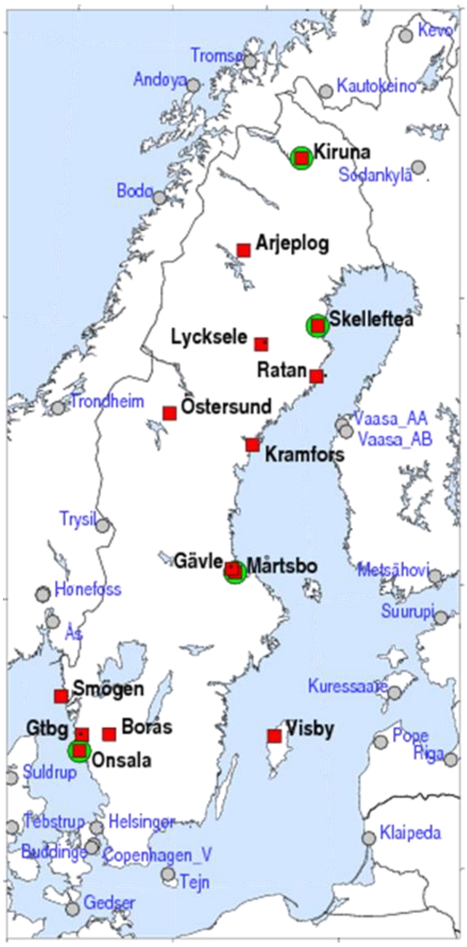

Figure 1.9: *The 14 absolute gravity sites in Sweden (red squares) and sites in neighbouring countries (grey circles). The four sites with time series more than 15 years long have a green circle as background to the red square.*

The absolute gravity observations are co-ordinated within NKG, and observations have also been performed by several groups (BKG[22], IfE[23], NMBU[24] and FGI[25]) together with Lantmäteriet.

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

[20] GIA = Glacial Isostatic Adjustment

[21] VLBI= Very Long Baseline Interferometry

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

[23] IfE = Institut für Erdmessung at Leibnitz University, Hannover, Germany

Within the coming three years, a new fundamental gravity network will be established in Sweden. The work started in 2011 in co-operation with IGiK[26] using their absolute gravimeter A-10 - 020. So far 83 sites have been measured in co-operation with IGiK.

At Onsala Space Observatory, 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 three times by Lantmäteriet's absolute gravimeter (FG5), latest in 2014.

1.9 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. GIA-induced gravity change was studied in a PhD project by Per-Anders Olsson, who successfully defended it in October 2013 (Olsson, 2013). One key parameter here is the relation between gravity change and geometric deformation (Olsson, 2015).

Research regarding the 3D geometric deformation in Fennoscandia and adjacent areas is foremost done within the BIFROST[27] effort (Lidberg et al., 2010). Reprocessing of all observations from permanent GPS stations is a continuous activity. In addition, another velocity field including a majority of Norwegian GNSS stations is published in a study introducing the GIA-reference frame (Kierulf et al., 2014). Using this method (named the GIA-frame approach) GIA models can 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. 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, 2014c). This improved geophysical model will deliver both vertical and horizontal motions, as well as gravity-rates-of-change and geoid change. 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. Parts of this database have already been beneficial in recent investigations (Steffen et al., 2014a,b).

Lantmäteriet is involved in the EUREF working group on "Deformation models", which 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 ETRS89 and also lead to a general understanding of the physics behind such a velocity field. An inventory of published velocity fields is established. The velocity model including deformations will be

[24] NMBU = Norges Miljø- og Biovitenskapelige Universitetet, Norway

[25] FGI = Finnish Geodetic Institute, Finland

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

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

developed once the densified EPN velocity field becomes available.

1.10 Further activities

1.10.1 Diploma works

During the period 2010–2014 totally nine diploma works have been performed at Lantmäteriet by students from KTH, Lund University, University of Gävle and University West in Trollhättan (not all published). Eight of the diploma works have mainly been focused on GNSS and to large extent the SWEPOS services. One of them has been focused on geodetic reference systems (vertical component).

1.10.2 Doctoral dissertation

One person from Lantmäteriet has performed doctoral studies at Chalmers University of Technology during the last four-year period (Olsson, 2013), see Section 1.9.

1.10.3 Arranged workshops and seminars

The yearly EUREF symposium was arranged in Gävle June 2nd–5th 2010 in co-operation with KTH and Chalmers University of Technology. It gathered 129 participants from 29 countries, see Figure 1.10.

Figure 1.10: *The EUREF 2010 symposium was held in Gävle. Photo: Örjan Zakrisson.*

In co-operation with Chalmers University of Technology, the 17th NKG General Assembly was arranged in Göteborg September 1st–4th 2014.

A training school on GIA modelling was held in Gävle in June 2011 within the ESSEM[28] COST[29] Action ES0701 "Improved constraints on models of glacial isostatic adjustment".

For Swedish GNSS users, seminars were arranged in Gävle in October 2011 and October 2013. The aim of these seminars held every second year is to highlight the development of GNSS techniques, applications of GNSS and experiences from the use of GNSS. Many locally organised seminars have also had key speakers from Lantmäteriet, who have informed about e.g. SWEPOS, SWEPOS services and the implementation of SWEREF 99 and RH 2000. Lantmäteriet is also giving courses in e.g. geodetic reference frames and GNSS positioning.

Among meetings which have taken place in Gävle, a meeting of the RTCM SC-104[30] in February 2010 and a meeting of the EUREF Technical Working group in March 2014 can be mentioned.

1.10.4 Participation in projects overseas

Lantmäteriet are involved (partly through the state-owned company Swedesurvey) in several projects abroad. Many projects have a geodetic

[28] ESSEM = Earth System Science and Environmental Management

[29] COST = European Cooperation in Science and Technology

[30] RTCM SC-104 = Radio Technical Commission for Maritime Services Special Committee No 104

part and typical components are the update of reference frames and the implementation of modern surveying techniques based on GNSS.

Countries which geodetic personnel have visited for assignments over the last four years are Albania, Belarus, Bosnia and Herzegovina, Botswana, Georgia, Ghana, Indonesia, Jamaica, Kenya, Mongolia, Namibia, Republic of Macedonia, Russia, Rwanda (see Figure 1.11) and Serbia.

Figure 1.11: *Personnel from Lantmäteriet introducing RTK surveying for RNRA*[31] *in Rwanda. Photo: Dan Norin.*

Besides the projects overseas, Lantmäteriet has also been represented and involved in different international seminars and working groups. Commission 5 (Positioning and Measurement) within FIG[32] has been chaired by Lantmäteriet during the period 2011–2014 and an article submitted to FIG was declared "Article of the Month January 2014" (Schwieger & Lilje, 2013).

[31] RNRA = Rwanda Natural Resources Authority

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

1.10.5 Website

The Lantmäteriet website (www.lantmateriet.se/geodesi) has extensive geodetic information. Here also transformation parameters and geoid models are easily and freely accessible.

1.10.6 Digital geodetic archive

Lantmäteriet has a digital geodetic archive with descriptions of national control points and their coordinates and heights etc., which has been accessible through a website since October 2007. The number of registered external users who pay a small yearly fee has since the previous NKG General Assembly four years ago increased from 109 to 191.

1.10.7 Handbooks for mapping and surveying

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.

1.10.8 National elevation model

Lantmäteriet is 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.

2. Geodetic activities at Chalmers University of Technology and Onsala Space Observatory

2.1 Introduction

Onsala Space Observatory is the Swedish national facility for radio astronomy. It is hosted by the Department of Earth and Space Sciences at Chalmers University of Technology, where the Space Geodesy and Geodynamics research group are focused on three techniques for geodetic, geophysical and other earth oriented applications:

- Geodetic VLBI.
- Gravimetry.
- GNSS.

The main interests in the work are geodynamic phenomena and atmospheric processes. The deformation of the Earth's crust due to mass redistribution, inter- and intra-plate tectonics, loading effects, and variations in the Earth's orientation and rotation are among others studied. The study of spatial and temporal variations of water vapour in the atmosphere can also be mentioned. The studied research topics are addressed using a variety of observational techniques together with theoretical work.

2.2 Geodetic VLBI

The Space Geodesy and Geodynamics research group has actively participated in the observing programme of IVS[33], where the 20 metre radio telescope and VLBI equipment at Onsala Space Observatory have been used. The work is part of IVS' earth rotation programme, terrestrial reference programme, celestial reference system programme, and the European geodetic VLBI series. Approximately 40–50 sessions per year are observed. Additionally, Onsala in 2011 and in 2014 participated in two 15-day long continuous VLBI campaigns named CONT11 and CONT14 organised by IVS. The CONT11 and CONT14 campaigns involved thirteen VLBI stations on five continents. Two of the stations (Onsala and the Japanese station Tsukuba) also sent the observational data from COST11 in real-time to the correlator station at the Geospatial Information Authority of Japan, where the data were analysed in near real-time. This unique setup resulted in near real-time observations of variations of the Earth rotation angle almost uninterruptedly during the whole campaign.

In 2012, the collaboration with the Japanese colleagues continued in order to improve the latency of Earth rotation parameters. Several so-called ultra-rapid dUT1-experiments were conducted, where the earth rotation angle (expressed as difference between astronomical time and UTC[34]) was determined in near real-time using the baseline Onsala-Tsukuba. The concept was extended to an ultra-rapid determination of all three Earth

[33] IVS= International VLBI Service for Geodesy and Astrometry

[34] UTC = Coordinated Universal Time

orientation parameters, i.e. two polar motion components and the earth rotation angle, with a network of four stations in Sweden, South Africa, Japan and Australia.

Observations of GLONASS satellites have been conducted through a number of experimental VLBI observations. The goal for these studies is to investigate whether it is possible to establish so-called space-ties between the different space geodetic techniques. While earlier experiments involved radio telescopes equipped with dedicated L-band systems, like the Onsala 25 metre and the Medicina 32 metre telescope, the experiments in 2013 and 2014 were conducted involving also the 20 metre geodetic radio telescope in Wettzell. A new L-band system have been developed and installed at Wettzell, which extracts the L-band signals from the S-band signal chain. It was verified that the Wettzell L-band system works fine and fringes were found successfully on the Onsala-Wettzell baseline. Total delay values agreed with rms 0.8–0.9 ns for group delays and 0.2–0.4 ns for phase delays (via integrated delay rates).

A new rack for VLBI was installed at Onsala in 2011, see Figure 2.1. An analogue Mark4 rack has operationally been used for more than 40 years for both astronomical and geodetic VLBI. The new rack is a modern digital backend/Mark5B+ system and it has been used in parallel with the old Mark4/Mark5A system since 2011.

Figure 2.1: *The new rack for VLBI at Onsala Space Observatory is a modern digital backend system.*

Tests with parallel recordings have been performed during numerous geodetic VLBI sessions and no significant differences have been found between the analogue and digital backends. The old analogue backend has now been phased-out and will be placed in the museum. A second digital backend was installed during autumn 2014 to work with Mark5C.

A proposal for a new Twin-Telescope for VLBI at Onsala Space Observatory was accepted for funding by Knut and Alice Wallenberg Foundation in April 2012. The project started in 2013 and includes the construction of two new radio telescopes. The telescopes will be part of the VGOS[35] network and are expected to contribute with a significant improvement in accuracy within the project.

2.3 Gravimetry

On June 10th 2009, a super-conducting gravimeter (SCG, series number GWR-054) was taken into operation at Onsala Space Observatory. Five years of gravity measurement with the instrument at one sample per second, of

[35] VGOS = VLBI2010 Global Observing System

which only 0.4 percent have been lost, have provided a rich data base. Of interest from the processing are tidal effects, annual perturbations, Kattegat basin oscillations, dynamic air pressure response and the background noise power spectrum. The instrument communicates one-second data to the world since January 2013. A link makes numeric data available for download with a latency of about one minute and other links allow to identify seismic events and the cause of microseismic noises.

The super-conducting gravimeter has been calibrated by absolute gravity measurements. Altogether six calibration campaigns have been carried out up to this date. Two different absolute gravimeters, one from Lantmäteriet and one from IfE in Hannover have been used (both Micro-g LaCoste FG5), see Figure 2.2.

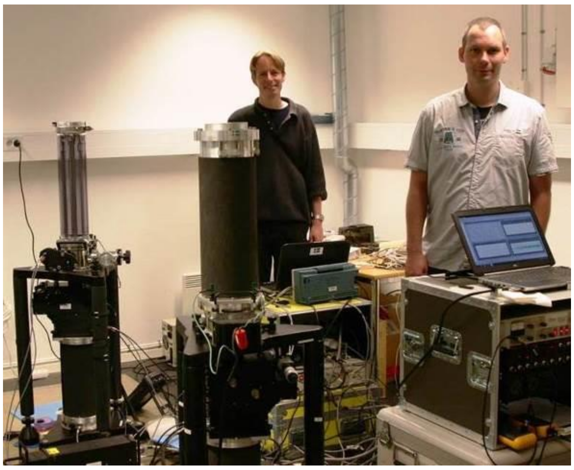

Figure 2.2: *Calibration of the super-conducting gravimeter with two absolute gravimeters (both Micro-g LaCoste FG5) in May 2014.*

2.4 GNSS

During 2008 a project started in order to measure local sea level and its variation using GNSS signals. The measurements are done using a GNSS-based tide gauge, which consists of two antennas mounted on a beam extending in southward direction over the coastline at Onsala Space Observatory (Löfgren & Hass, 2014), see Figure 2.3. The antennas are aligned along the local vertical with one antenna facing toward zenith direction and the other facing toward nadir. The zenith-looking antenna is Right-Hand-Circular-Polarized (RHCP) while the nadir-looking antenna is Left- Hand-Circular-Polarized (LHCP). The zenith-looking antenna receives predominantly the direct RHCP satellite signals, while the nadir looking antenna receives predominantly signals that are reflected off the sea surface and thus have changed polarization to LHCP in the reflection process. The GNSS receivers are connected to one antenna each and individually record multi-frequency signals of several GNSS. The analysis of phase measurements performed with the corresponding GNSS receivers allows to estimate the local sea surface height and its variation.

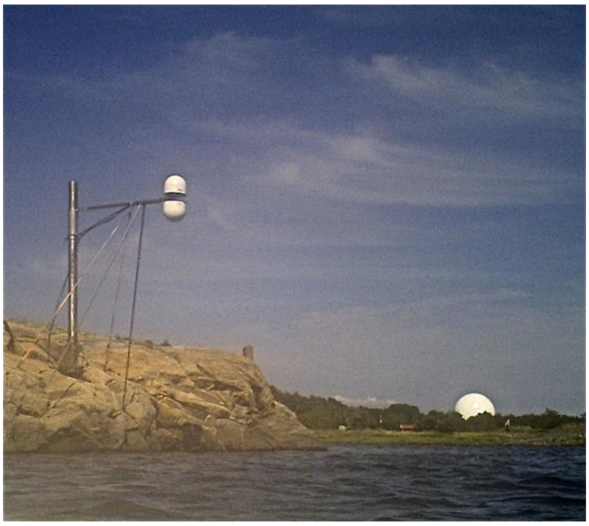

Figure 2.3: *The GNSS tide gauge installation, with one zenith-looking and one nadir-looking antenna (covered by hemispherical radomes), at the Onsala Space Observatory. The radome of the 20 metre radio telescope in the background.*

The BIFROST project was started in 1993. The first primary goal was to establish a new and useful three-dimensional measurement of the movements in the earth crust based on GNSS observations, able to constrain models of the GIA process in Fennoscandia. Data from about 40 permanent reference stations for GNSS has been used. In 2013, a new BIFROST GNSS solution was produced including GNSS data from 1993 to 2013. This solution is the most accurate BIFROST solution ever produced, and uses e.g. a consistent geodetic reference frame, models for absolute calibration of antenna phase centre variations and higher order ionospheric effects.

The long term stability in the atmospheric water vapour content has been studied using GPS together with VLBI, microwave radiometry and radiosondes using simultaneous measurements over a more than ten years long period. Water vapour is an effective green-house gas and accurate measurements over long time are of crucial importance when assessing possible global warming scenarios.

2.5 Further activities

2.5.1 Official tide gauge station at Onsala Space Observatory

The Swedish national network of tide gauge stations is operated by SMHI[36]. An agreement for a joint responsibility in constructing and operating a new station at Onsala Space Observatory was signed in 2013. The station is motivated by the fact that Onsala is located at the coast and loading effects on the Earth's crust are important. The modelling of the sea level in Kattegatt is complicated and the available tide gauge data today are at least 20 kilometres away. The new tide gauge will complement the existing GNSS-based tide gauge and also three pressure sensors submerged into the sea at the same location in the summer of 2011.

2.5.2 Doctoral dissertation

Three PhD theses have successfully been defended during 2010–2014 (Ning, 2012, Olsson, 2013 and Löfgren, 2014).

2.5.3 Arranged seminars

The yearly EUREF symposium was arranged in Gävle June 2nd–5th 2010 in co-operation with Lantmäteriet and KTH. It gathered 129 participants from 29 countries.

The European Frequency and Time Forum 2012 was arranged in Gothenburg April 23rd–27th 2012 in co-operation with SP Technical Research Institute of Sweden. The meeting had 320 participants and 20 exhibitors.

In co-operation with Lantmäteriet, the 17th NKG General Assembly was arranged in Göteborg September 1st–4th 2014.

[36] SMHI = Swedish Meteorological and Hydrological Institute

3. Geodetic activities at HiG, the University of Gävle

3.1 Introduction

The Department of Industrial Development, IT and Land Management at the University of Gävle (www.hig.se) offers graduate and postgraduate education as well as performs research in geodesy, engineering surveying and GIS[37].

3.2 The graduate programme in Land Management and Land Surveying

In 2009 the then existing graduate programme in Geomatics was comprehensively revised and at the same time renamed to the more appropriate Land Management/Land Surveying (LM/LS) programme. Thus two for the Swedish labour market demanded specialisations were offered. The two specialisations, LM and LS, share several courses which are of importance for both – like surveying courses.

The success of the new programme is shown in Table 3.1 in form of number of applicants (students' first choice) since its establishment.

Table 3.1: *The number of applicants at the LM/LS programme at HiG from 2009.*

Academic year	*LM*	*LS*	*Total*
2009/10	17	34	51
2010/11	34	29	63
2011/12	25	42	67
2012/13	56	62	118
2013/14	65	80	145
2014/15	55	81	136

3.3 Staff, research and quality in geodesy and engineering surveying

The increasing number of applicants to the LM/LS programme has involved an increasing number of enrolled students. Consequently, the number of staff has increased. By the time for the 17th NKG General Assembly in September 2014 there were four highly qualified (PhDs) lecturers/researchers in geodesy/surveying employed. Their main task is lecturing, with research up to approximately 20–30 %. An increase in research is expected, particularly since an application for the entitlement of awarding postgraduate and PhD qualifications has been approved with effect from January 1st 2015. The research area has been defined as "Geospatial Information Science" and comprise besides LM and LS also Spatial Planning and Computer Science.

Research has primarily been focused on applied geodesy and presently monitoring movements on the surface of the Earth by different platforms, such as UAS[38], is of increasing interest. A main project has been running during 2014 aiming at evaluating the ultimate uncertainty of UAS-produced terrain models. The latter has been evaluated

[37] GIS = Geographic Information Systems

[38] UAS = Unmanned Aircraft Systems

with respect to newly, by SIS[39], issued specifications for producing and control of digital ground models.

The geodetic research activities at HiG also include:

- Gravity inversion.
- Crustal thickness determination using gravimetric-isostatic methods.
- Study on upper-mantle parameters for GIA modelling using land uplift data and Moho.
- Deformation monitoring using geodetic sensors.

The LM/LS graduate programme was during 2013 reviewed by UKÄ[40]. It received, as the only Swedish programme within the area, the highest rank "Very high quality".

[39] SIS = Swedish Standards Institute

[40] UKÄ = Universitetskanslersämbetet (Swedish Higher Education Authority)

4. Geodetic activities at University West (UW)

HÖGSKOLAN VÄST

4.1 Introduction

The surveying engineering programme at University West (UW) is under the Department of Engineering Science. This programme offers graduate education and performs research in geodesy and geodetic surveying.

4.2 Surveying engineering programme

The surveying engineering programme of UW is the most popular engineering programme of the university and offers only the graduate training in this subject. This programme has not different directions like other Swedish universities and the degree that the students will receive is not specified whether it is in the Land Management (LM) or the Land Surveying (LS). During the first 2.5 years of studies, all courses are compulsory for the students. In the second half of the third year, when they have to select the subject for their thesis, they are free to work either on LM or LS. The programme offers 6 geodetic courses, which amongst them, three are obligatory and the rest of them are optional for those who are interested to learn more about geodesy.

During the last four years, the programme has been successful and served more than 50 students per year. The result of the review by UKÄ was "High quality" for this programme at UW.

4.3 Staff and research in Geodesy

Being the only university in the western part of Sweden which has this programme and having capacity of training more than 50 students per year, has increased the capability of UW to hire more experts. So far, UW has been successful to employ two professors (one in geodesy and one in LM), one associate professor in GIS, and three instructors in construction, LM and geodetic measurements.

Most of the geodetic activities of UW are related to the researches of its professor in geodesy. One geodetic PhD students from KTH has been at UW for six months and worked under the professor in geodesy (his supervisor) for optimisation of the Lilla Edet GNSS deformation monitoring network. In June 2014, the university hosted a guest researcher from the Czech Republic for a study about satellite gravimetric missions with the professor in geodesy. In September 2014, a Spanish professor of geodesy visited the university for initiating possible collaborations in geodesy and geophysics.

The geodetic research activities of UW, which started after employing the professor in geodesy in 2013, include:

- Optimisation and design of geodetic monitoring networks.
- Gravity field recovery from satellite missions.
- Geophysical studies using satellite data, like Moho and sub-crustal stress determination.
- Geoid and applications of gravity data.

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[41] ION = Institute of Navigation, USA

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[42] IAG = International Association of Geodesy

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[46] DGMK = Deutsche Wissenschaftliche Gesellschaft für Erdöl, Erdgas und Kohle e.V.

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[48] DVW = Deutscher Verein für Vermessungswesen

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[49] UN-GGIM = United Nations Committee of Experts on Global Geospatial Information Management

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[51] IGFS = International Gravity Field Service

[52] UNESCO = United Nations Educational Scientific and Cultural Organisation

[53] AGU = American Geophysical Union

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