National Report of Sweden to the NKG General Meeting 2006

- geodetic activities in Sweden 2002-2006

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1. Geodetic activities at Lantmäteriet (National Land Survey of Sweden)

LANTMÄTERIET

1.1 Introduction

At Lantmäteriet (the National Land Survey of Sweden) the geodetic activities during 2002-2006 have been focused on:

- The Swedish network of permanent reference stations (SWEPOS™) including development of SWEPOS services such as a network RTK[1] service.
- The ongoing project RIX 95 with development of transformation parameters between national reference frames and local ones.
- The finalisation of the third national precise levelling and the computation of the new national height system RH 2000.
- The development of the new geoid model SWEN 05LR.
- The introduction of new reference systems such as the ETRS 89[2] realisation SWEREF 99, the new national height system RH 2000 and also of transformation strategies.
- Absolute gravity measurements on the Swedish absolute gravity sites.

Other items to mention are the Lantmäteriet web page (www.lantmateriet.se/geodesi), which has been updated with extensive geodetic information and the work that has been done to make the geodetic archive digital.

1.2 Satellite positioning (GNSS[3])

1.2.1 GPS[4] campaigns

The 2002 NKG[5] GNSMART/GPSNet Test Campaign, planned within the NKG project Nordic Positioning Service, was carried out during one month in October-November 2002 at Lantmäteriet in Gävle (Engfeldt et al, 2003). The aim was to compare two

[1] RTK = Real-Time Kinematic

[2] ETRS 89 = European Terrestrial Reference System 1989

[3] GNSS = Global Navigation Satellite Systems

[4] GPS = Global Positioning System

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

different network RTK software and the work was performed by Lantmäteriet in collaboration with KMS[6] and the Norwegian Mapping Authority.

The processing of the NKG 2003 GPS Campaign has been co-ordinated from Lantmäteriet during 2004, with a final report completed in 2005 (Jivall et al, 2005 and Jivall et al, 2006). The purposes of the campaign were to develop a unified ETRS 89 reference frame on the cm level for the Nordic area and to develop transformation strategies between ITRF[7] and the national realisations of ETRS 89. The GPS observations were carried out from September 28th to October 4th 2003 on 133 stations in the Nordic and Baltic countries.

1.2.2 NKG EPN[8] LAC[9]

Lantmäteriet operates the NKG EPN LAC in co-operation with Onsala Space Observatory at Chalmers University of Technology. Since May 2005 (GPS week 1321) the daily processing has changed from version 4.2 to version 5.0 of the Bernese software. Since the last NKG General Meeting four years ago seven stations have been added to the NKG EPN LAC sub-network, which means that totally 42 stations are processed today (figure 1.1). Lantmäteriet has also represented NKG at the fourth and fifth EUREF[10] LACs Workshop, which were held in 2003 and 2006.

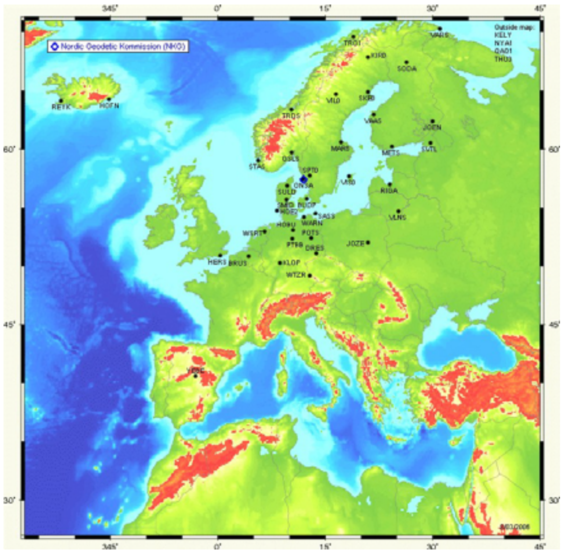

Figure 1.1: *The NKG EPN LAC sub-network.*

1.2.3 Galileo

Staff from Lantmäteriet have participated as experts in the definition of user requirements for Galileo and in the evaluation within EU[11] of proposals in FP6[12].

1.2.4 EGNOS[13]

During 2003 an EGNOS RIMS[14] was inaugurated at Lantmäteriet in Gävle. The station has been successfully supported by Lantmäteriet since that year.

1.2.5 Nordic Positioning Service

Lantmäteriet participates in the project Nordic Positioning Service (Engfeldt et al, 2006). The major purpose of Nordic Positioning Service is both to exchange data between the networks of permanent reference stations in Denmark, Norway and Sweden and to establish common positioning services. The project also implies exchange of knowledge in the fields of operation

6 KMS = Kort & Matrikelstyrelsen, Denmark

7 ITRF =International Terrestrial Reference Frame

8 EPN = EUREF Permanent Network

9 LAC = Local Analysis Centre

10 EUREF = the IAG Subcommission for Europe
IAG = International Association of Geodesy

11 EU = European Union

12 FP6 = Sixth Framework Programme

13 EGNOS = European Geostationary Navigation Overlay System

14 RIMS = Ranging and Integrity Monitoring Station

and applications of networks of permanent reference stations.

1.2.6 Combination of GPS and inertial technique

GSE[15] was a project that in 2004-2005 demonstrated the possibility for a combination of GPS in RTK mode and inertial technique. Lantmäteriet together with the company IMEGO AB and a group of Swedish municipalities and governmental organisations were involved in the project.

Figure 1.2: *Demonstration of a combination of GPS in RTK mode and inertial technique.*

1.3 Network of permanent reference stations (SWEPOS)

Since July 1st 1998 the Swedish network of permanent reference stations (SWEPOS) is operational in IOC[16] mode, i.e. for positioning in real-time on the metre level and by post-processing on the centimetre level. Positioning in real-time on the centimetre level is today (May 2006) also possible in large parts of Sweden.

The purposes of SWEPOS are to:

- Provide single- and dual-frequency data for relative GNSS measurements.
- Provide DGPS[17] corrections and RTK data for broadcasting 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 GPS system.

Data from SWEPOS are also used for on-going research projects for the use of GNSS in meteorological applications.

The same 21 fundamental stations that SWEPOS consisted of when it became operational in IOC mode are still in operation. 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.

[15] GSE = GPS Shadow Explorer

[16] IOC = Initial Operational Capability

[17] DGPS = Differential GPS

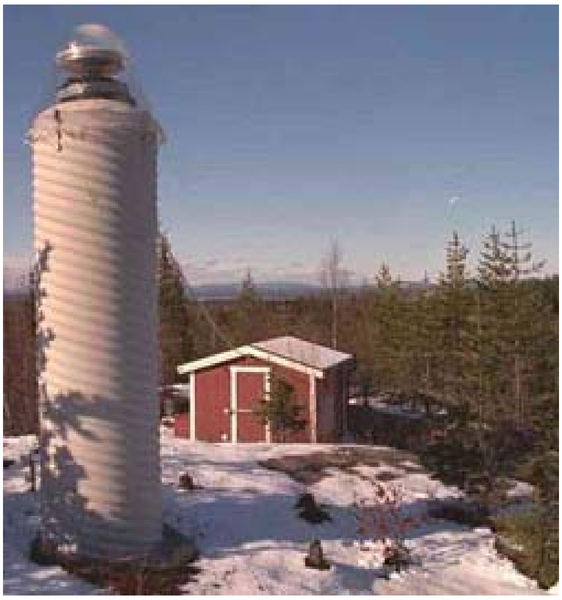

Figure 1.3: *The fundamental SWEPOS station Vilhelmina.*

The rest of the stations that SWEPOS consists of have a variety of instrumentations and monumentations, but are mainly established on top of buildings for network RTK purposes.

Figure 1.4: *The SWEPOS station Söderboda, monumented on top of a building.*

The total number of SWEPOS stations has since the last NKG General Meeting increased from 57 to 105 and another 16 stations will be operational during June 2006. A map with the location for all stations is shown in figure 1.6. All SWEPOS stations are equipped with dual-frequency GPS/ GLONASS[18] receivers and with antennas of Dorne Margolin type or similar.

During the four past years one more SWEPOS station (Skellefteå (SKE0)) has been included in EPN, which makes the total number of SWEPOS stations included seven (together with Onsala, Mårtsbo, Visby, Vilhelmina, Kiruna and Borås (ONSA, MAR6, VIS0, VIL0, KIR0 and SPT0)). Both daily and hourly data are delivered. Furthermore Onsala, Mårtsbo, Visby, Kiruna and Borås are included in the IGS[19] network and Skellefteå is proposed to be included.

Sweden has, according to a co-ordination done within NKG, offered all seven Swedish EPN stations except Vilhelmina for ECGN[20].

1.4 SWEPOS services

Quality checked SWEPOS data for post-processing on a WWW/FTP server in RINEX[21] format has been available for a long time. So has also an automated post processing service based on the Bernese software, which is available on www.swepos.com, the SWEPOS web page. This popular service makes it possible for GPS users to automatically determine their position with centimetre accuracy using only one GPS receiver and data from the SWEPOS network. Some developments have been done and during 2006 it is planned that the

[18] GLONASS = Globalnaya Navigatsionnaya Sputnikovaya Sistema

[19] IGS = International GNSS Service

[20] ECGN = European Combined Geodetic Network

[21] RINEX = Receiver Independent Exchange format

service will change from version 4.2 to version 5.0 of the Bernese software.

The Swedish DGPS service EPOS is using correction data from SWEPOS. EPOS is using the RDS channel on the FM radio network for the distribution and is operated by Cartesia Informationsteknik AB. The wide-area differential GPS service Omnistar used correction data from SWEPOS until May 2006.

SWEPOS Network RTK service was launched on January 1st 2004. During 1999-2003, the service was preceded by both pre-study projects and projects with prototype production networks. The coverage of the service at the start is shown in figure 1.5.

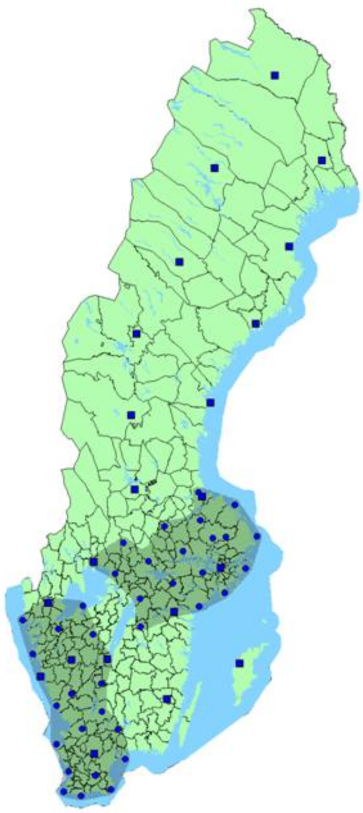

Figure 1.5: *The coverage of SWEPOS Network RTK Service at the start in January 2004.*

The service has since 2004 been expanded by five one-year-long regional establishment projects. Two of these projects ended during 2005 (Mitt-Ost-RTK and Ost-RTK) and three are still running (Position Mitt, Gute-RTK and Nordost-RTK). The intended coverage for SWEPOS Network RTK service for 2007 is shown as the green area in figure 1.6, which includes the stations for the planned establishment project Mellan-RTK (red dots). The stations for Nordost-RTK (orange dots) will be operational during June 2006.

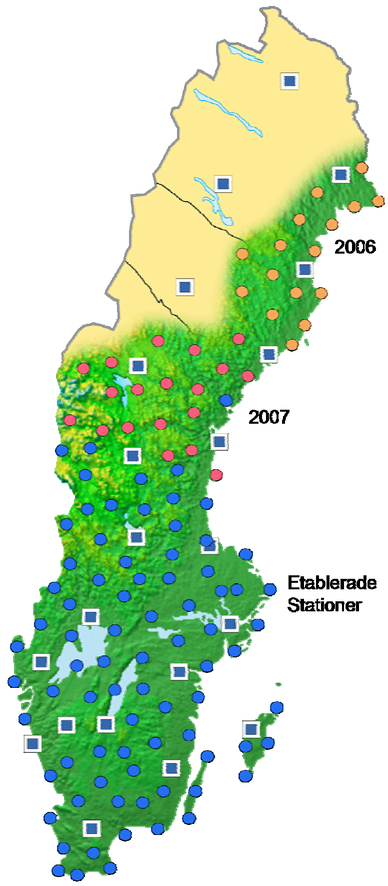

Figure 1.6: *The SWEPOS network in May 2006. Squares are the 21 fundamental SWEPOS stations. Blue dots are the rest of the existent stations (except for a few densifications). Orange dots are stations that will become operational during June 2006 and red dots are the plan for expansion during 2007.*

The total number of subscriptions for the service has since the start in January 2004 increased from approximately 180 to approximately 450, where the users in the on-going establishment projects are not included. The service uses the network RTK software GPSNet from Trimble. GSM[22] is used as distribution channel, but since November 1st 2005, also wireless Internet (mainly GPRS[23], but also UMTS[24] or WLAN[25]) can be used. Tests have also been made to broadcast the RTK data through satellite communication and this distribution channel is also possible to use.

The network RTK service was complemented with a service that broadcasts RTK data for both GPS and GLONASS on April 1st 2006. At this date a network DGPS service with nationwide coverage was also launched.

The use of SWEPOS services for construction projects has also been developed during the two past years. The SWEPOS network has been densified in two areas in the western part of Sweden for two road construction projects. Both SWEPOS Network RTK service and the post processing service have been adapted for these projects with the help of totally five new SWEPOS stations.

[22] GSM = Global System for Mobile communication
[23] GPRS = General Packet Radio Service
[24] UMTS = Universal Mobile Telecommunications System
[25] WLAN = Wireless Local Area Network

1.5 Development of reference systems

1.5.1 RIX 95

Since 1995, a project involving GPS measurements on triangulation stations and selected local control points called RIX 95 has been in operation. 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 GNSS measurements.

Concerning the connection of local coordinate systems, transformation parameters based on different transformation models are developed. The parameters are mainly based only on direct projection with Transverse Mercator, but in some cases also combined with similarity transformations in two or three dimensions. Now (June 2006) transformation parameters for 220 of the 290 Swedish municipalities are available.

The measurements in the project will be finalised in 2006. Each year about 350 triangulation stations and 500 new points (mainly existing local control points) has been measured. The present situation for the measurements is shown in figure 1.7.

To a large extent the measurements are made with standard equipment and procedures for static observations. Points with an approximate distance of 50 km are however measured in a way that very accurate coordinates in SWEREF 99 can be obtained. 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.

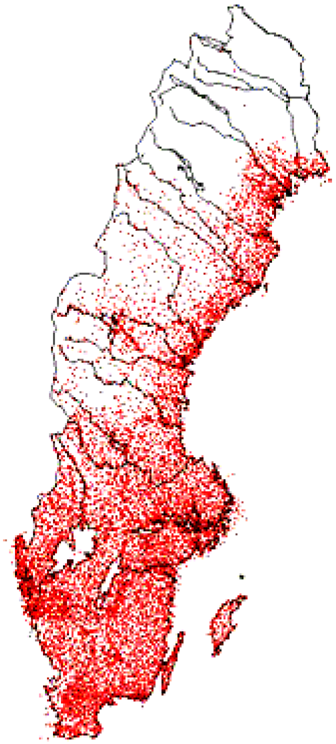

Figure 1.7: *Completed areas in RIX 95 (May 2006).*

1.5.2 Levelling and the new national height system RH 2000

The third precise levelling of Sweden was finalised in 2003. The final adjustment for the new national height system was done in the beginning of 2005. The name of the system is RH 2000 and has 2000.0 as epoch of validity (in the perspective of the Fennoscandian glacial isostatic adjustment).

The definition of RH 2000 is done according to EVRS[26] and in co-operation with the other Nordic countries. The network consists of about 50,000 bench marks, representing roughly 50,000 km double run precise levelling measured by motorised levelling technique.

[26] EVRS = European Vertical Reference System

The final computation has used 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 (Ågren & Svensson, 2006a and Ågren & Svensson, 2006b).

To get the national network connected to EVRS, the adjustment is done in a common adjustment of the nodal points in a data set called BLR[27]. The data set consists of data from mainly the Nordic countries, the Baltic states, Poland, Germany and Holland. The latter data has been provided by UELN[28]-database. The work has been done within NKG and will also give information about the closing error around the Baltic Sea. The Swedish network is then adjusted in a number of steps, keeping the nodal points from the BLR data set fixed.

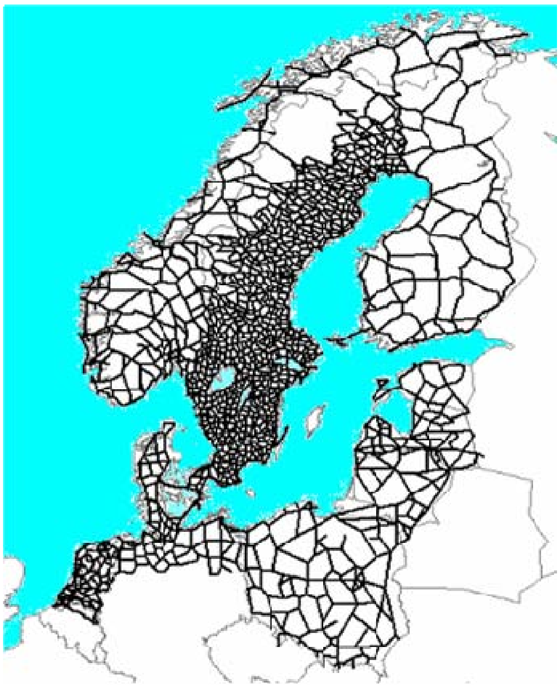

Figure 1.8: *The BLR data set.*

[27] BLR = Baltic Levelling Ring
[28] UELN = United European Levelling Network

1.5.3 Geoid model

A new geoid model to transform heights above ellipsoid in SWEREF 99 to heights in RH 2000 has been developed and introduced during 2005 (Ågren & Svensson, 2006c). The name of the geoid model is SWEN 05LR. The model is based on the geoid NKG 2004, calculated by the NKG working group on geoid determination. The model is then fitted on SWEREF 99 and RH 2000 using 1178 levelled points that have also been measured with GPS. Information about the residuals is also included in the model so that the users will receive heights as close as possible to RH 2000. The expected accuracy (rms) for a user is 1,5-2 cm (figure 1.9).

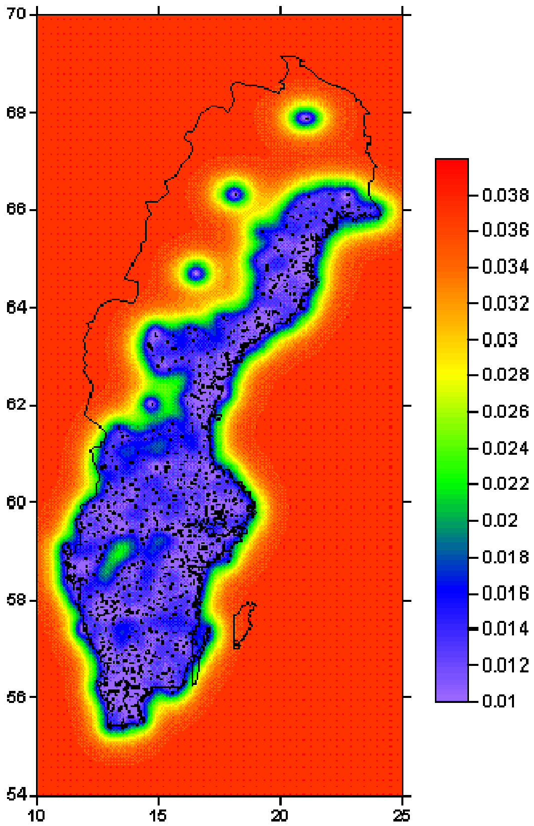

Figure 1.9: *Expected accuracy (rms) for the geoid model SWEN 05LR (m).*

1.5.4 Gravimetric geoid determination

Lantmäteriet and KTH[29] are engaged in a joint project concerning physical geodesy and gravimetric geoid determination (see section 2.3 for further information). The main purpose of the project is to evaluate the geoid determination methods developed at KTH numerically, to compute a gravimetric quasigeoid over Sweden and to publish software for geoid determination according to the KTH methods. Some results from the project are presented as a poster at the NKG General Meeting 2006 (Ågren et al, 2006).

1.6 Introduction of new reference systems

1.6.1 Introduction of the ETRS 89 realisation SWEREF 99

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

A formal decision regarding map projections for national mapping purposes as well as for local surveying was taken in 2003 (Lantmäteriet 2003). All the projections are of Transverse Mercator type and the chosen values for the defining parameters are shown in table 1.1. The introduction of SWEREF 99 in databases and in product lines at Lantmäteriet will take place in early 2007.

[29] KTH = Kungliga Tekniska Högskolan (Royal Institute of Technology), Stockholm

System	Projection parameters			
	central meridian, λ_0	scale reduction factor, k_0	false northing (m)	false easting (m)
SWEREF 99 TM	15° E	0,9996	0	500 000
SWEREF 99 12 00	12° 00' E	1	0	150 000
SWEREF 99 13 30	13° 30' E	1	0	150 000
SWEREF 99 15 00	15° 00' E	1	0	150 000
SWEREF 99 16 30	16° 30' E	1	0	150 000
SWEREF 99 18 00	18° 00' E	1	0	150 000
SWEREF 99 14 15	14° 15' E	1	0	150 000
SWEREF 99 15 45	15° 45' E	1	0	150 000
SWEREF 99 17 15	17° 15' E	1	0	150 000
SWEREF 99 18 45	18° 45' E	1	0	150 000
SWEREF 99 20 15	20° 15' E	1	0	150 000
SWEREF 99 21 45	21° 45' E	1	0	150 000
SWEREF 99 23 15	23° 15' E	1	0	150 000

Table 1.1: *Defining parameters for SWEREF 99 map projections.*

A proposal for a new map sheet division and index system has also been developed.

The work with the introduction of SWEREF 99 among other authorities in Sweden, such as local authorities, is in progress. Approximately 70 of the 290 Swedish municipalities have started the process to replace their old reference frames with SWEREF 99 and 11 have so far finalised the replacement.

To rectify distorted geometries of local reference frames, correction models can be used by the municipalities together with the transformation parameters from RIX 95. The models are based on residuals existing after transformation and the rectification is done by a so-called rubber sheeting algorithm. The result is a homogenous network in SWEREF 99 and geographical data with less deformations.

1.6.2 Introduction of the new national height system RH 2000

The work with the introduction of RH 2000 among other authorities in Sweden, such as municipalities, is in progress. Approximately 45 of the 290 Swedish municipalities have in co-operation with Lantmäteriet started the process with recalculation and analyse of their local networks, with the aim of replacing the local height systems with RH 2000. So far 4 municipalities have finalised the replacement for all activities.

1.6.3 Transformation strategies

In order to facilitate for users who still want to use local reference frames, both the transformation parameters derived from RIX 95 and the correction models mentioned in section 1.6.1 can be used. The transformation parameters are made easily accessible on the Lantmäteriet web page (www.lantmateriet.se/geodesi).

Also the geoid model SWEN 05LR used for transformation of heights above ellipsoid in SWEREF 99 to heights in RH 2000 is freely available through the Lantmäteriet web page. It is available as a grid file and also as files in both ASCII and binary formats.

1.7 Gravimetry and Geodynamics

Absolute gravity measurements in Sweden have been carried out at eleven sites (Onsala, Göteborg, Borås, Mårtsbo, Kramfors, Östersund, Arjeplog, Skellefteå (also known as Furuögrund), Kiruna (KIR0, also known as Esrange), Visby and Smögen). Totally 27 measurements on ten of the sites have been performed during the period 2002-2005 by BKG[30], IfE[31], UMB[32] and FGI[33] in co-operation with Lantmäteriet and often with field assistance from Lantmäteriet. All points are co-located with permanent reference stations for GNSS in the SWEPOS network except Göteborg. Onsala is also co-located with VLBI[34]. Smögen are co-located with a tide gauge and Visby and Skellefteå have tide gauges nearby.

In 2006 absolute gravity measurements will be carried out on the main part of the sites by IfE and on three sites by UMB (Kiruna, Onsala and Smögen).

Figure 1.10: *Absolute gravity sites in Sweden. The red stars (Kiruna, Arjeplog, Östersund, Mårtsbo, Skellefteå, Kramfors and Onsala) have been measured in 2003, 2004 and 2005 (Onsala twice in 2005). The purple stars (Visby and Smögen) have been measured in 2004 and 2005. The orange star (Borås) has been measured in 2003. The brown star (Göteborg) has not been measured during the period 2002-2005.*

Together with Onsala Space Observatory, a new tree dimensional velocity field for the Fennoscandian land uplift area has been computed (Lidberg 2004, Lidberg et al 2006a and Lidberg et al 2006b). It is derived from more than 3000 days of continuous observations at 53 permanent GPS stations. The results show a maximum vertical rate of 10.6 mm/yr at Umeå, which is somewhat south of current estimated location of the land uplift maximum. From internal and external

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30 BKG = Bundesamt für Kartographie und Geodäsie, Germany

31 IfE = Institut für Erdmessung, Universität Hannover, Germany

32 UMB = Universitetet for Miljø og Biovitenskap, Norway

33 FGI = Finnish Geodetic Institute, Finland

34 VLBI = Very Long Baseline Interferometry

accuracy assessment, the rate uncertainty for stations with the longest observation records is estimated to the 0.2 mm/yr level in horizontal components and 0.5 mm/yr for the vertical component (1σ level).

The 56° and 63° land uplift gravity lines were remeasured with relative gravimeters in a Nordic co-operation with participation from Lantmäteriet in 2003.

1.8 Further activities

1.8.1 Diploma works

During the period 2002-2006 totally 14 diploma works have been performed by students at Lantmäteriet. Ten of them have mainly been focused on GNSS and to large extend the SWEPOS services. For example have test measurements with network RTK and network DGPS been carried out to study accuracy and new distribution channels. Four of the diploma works have mainly been focused on reference systems, partly with the objective to support the introduction of new reference systems.

1.8.2 Workshops and seminars

An international workshop on network RTK was held in Gävle by Lantmäteriet in March 2004. The workshop was mainly focused on the use of the network RTK software GPSNet in different countries.

In March 2003 and 2005 seminars for Swedish GPS/GNSS users were arranged in Gävle by Lantmäteriet. The aim of these seminars was to highlight the development of GNSS techniques, applications of GNSS and experiences from the use of GNSS.

To inform and exchange knowledge between users in Sweden who are about to change to the new reference frame SWEREF 99 and the new height system RH 2000, a seminar was arranged in Gävle by Lantmäteriet in 2005.

Many locally arranged seminars have had key speakers from Lantmäteriet who informs about SWEPOS, SWEPOS services and the introduction of SWEREF 99 and RH 2000.

1.8.3 Participation in projects overseas

Lantmäteriet are through Swedesurvey involved in many projects abroad. Many projects have a geodetic part and typical components are first to update the reference frames and secondly to implement modern surveying techniques based on GNSS.

Figure 1.11: *Amasia, one of the stations in the zero-order geodetic network of Armenia. The reference frame ARMREF 02 was ratified as a ETRS 89 realisation at the*

2004 EUREF Symposium in Bratislava after presentations from personnel from Lantmäteriet.

Countries where geodetic personnel have had assignments over the last four years are Belarus, Moldova, Georgia, Armenia, Tajikistan, Kyrgyzstan, Mongolia, Bhutan, South Africa and Namibia.

Figure 1.12: *Personnel from Lantmäteriet introducing RTK surveying for* DSLR[35] in Bhutan.

2. Geodetic activities at the Royal Institute of Technology

The Division of Geodesy at the Royal Institute of Technology (KTH) in Stockholm offers graduate and postgraduate education as well as performs research in geodesy and surveying. Below we summarize these activities for the period 2002-2006.

2.1 Graduate programme

Geodesy courses have been taught as a part of the Geomatics Engineering specialization. The number of students attending these courses varies greatly from 5 to about 40. The following courses have been given during the period 2002-2006:

- Geodetic surveying
- Analysis of measurements (Theory of errors)
- Map projections
- Reference systems
- Satellite positioning with GPS
- Physical geodesy
- Integrated navigation
- Engineering surveying

In the autumn of 2004, KTH started an international master programme "Geodesy and Geoinformatics". About 20 students, from Europe, Asia, Africa and Latin America, are recruited each year. From 2007, this programme will be extended to a 2-years programme in accordance with the Bologna process.

2.2 Postgraduate programme

Since 2002 two postgraduate students have completed their Ph.D.s in the field of the geoid determination (Ellmann, 2004 and Ågren, 2004). For the time being there are six active postgraduate students.

35 DSLR = Department of Surveying and Land Records, Thimphu, Bhutan

2.3 Physical geodesy and methods for geoid determination

This project is a continuation of a long-term research programme in physical geodesy at the Royal Institute of Technology (KTH) with the overall scientific objective of improving the theory and corrections needed in order to compute the geoid to 1 cm accuracy. So far most steps necessary to achieve this goal have been completed, and the developed methods seem promising. However, more tests are needed.

The main task of the current project is to carefully assess the quality of the methods. First, synthetic gravity field models were constructed and used for this purpose; they have the advantage that a true value is available. Second, a careful comparison is under way with the methods presently applied by the NKG, using both synthetic and real data. The third and fourth specific aims are to present a geoid model for Sweden, and to publish software for geoid determination according to the KTH methods. The geoid modelling runs as a joint project with Lantmäteriet. The project has a good progress both in theory and numerical view.

2.4 Technical aspects of the law of the sea

The Division of Geodesy has contributed to the work of the Advisory Board of the Law of the Sea (ABLOS; www.gmat.unsw.edu.au/ablos/), where L E Sjöberg is one of three geodesist - members.

The main task has been the revision of the Technical Aspects of the Law of the Sea (TALOS), and recently the 4th edition of TALOS was published. It is freely available for downloading at (www.iho.int; publ. # S-51). A publication was also prepared in the spirit of ABLOS (Sjöberg, 2006).

2.5 Geodetic monitoring of the Vasa Ship (since 2000)

The Swedish warship Vasa was lost on her maiden voyage in 1628. For more than 330 years, she was lying 30 m below the water until 1961. Today it is standing in the Vasa Museum and has become one of the greatest attractions in Stockholm.

Great efforts have been made to preserve the Vasa ship for future generations. One of these efforts is to monitor the changes in the form of the hull and other parts of the ship. The Division of Geodesy at KTH has established a geodetic system based on total station measurement of a set of points marked by reflective tape. The measurements are related to reference network realised by corner prisms firmly mounted on the walls of the building. The measurement procedure is automated with minimum input from operator. The system is able to detect millimetre-level changes.

The project began in 2000 and since that two epochs per year have been measured. The measurements are carried out by the museum's personnel and KTH students and processed by the Division of Geodesy at KTH. The results show slow "unfolding" motion of the hull.

2.6 TNK - Inertial camera (2002 – 2004)

The project initiated by prof. K. Torlegård, funded by TFR (Swedish Technical Foundation). The goal of the project was to develop a handheld mapping system consisting of a digital camera and inertial measurement unit (IMU). Using camera observations (image coordinates from multiple images), the position of the tracked features can be computed. IMU supports the tracking algorithms and the camera observations enable the estimation of the IMU errors.

This system can be used as a surveying tool for engineering measurements, creation of maps and plans, 3D models of various objects, virtual reality models and so on. The other possible use of the system is the navigation of industrial machines, robots or navigation in the virtual reality.

The software, which was the result of this project, is being used by the company VISIMIND in the processing module of their mobile mapping system.

2.7 Monitoring of constructions and detection of motions by GPS (since 2003)

This project is funded by the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas).

The goal of the project is to bring the ultimate precision of GPS into the application for monitoring measurements and for studying deformation of man-made constructions, e.g. buildings, bridges and dams and natural objects of moderate size (rock formations, slopes, atomic power plant stations and the bedrock in their surroundings). The project will focus on two components; to develop a system for monitoring and early detection of movements (section 2.7.1) and to analyse the data in various ways for an optimum detection of possible motions (section 2.7.2).

2.7.1 System development

The study will include monitoring using a single GPS receiver, a pair of receivers with one reference station and a rover and finally a rover and three reference stations. By setting up a network with one rover and three reference receivers all the above options can be studied. Controlled translations of the rover receiver will be performed by using a translation stage (device for controlled movement generation).

2.7.2 Analyses

The analyses will be both theoretical and with real data. The theoretical studies will focus on the error propagation of the measurement error into the estimated rover positioning error. In the analyses both Kalman filtering and moving averages of position will be studied. The goal is, of course, to detect a possible motion of the rover. This detection is related with the size of the motion vs. the precision of the observations as well as the time elapsed from an episodic motion, or from the time a more or less continuous motion started. If a movement larger than a certain limit is detected, the system turns on an alarm. Such system will work properly only if the limit is sufficiently large compared to precision of the monitoring sensor. Otherwise it can happen that the measurement noise can cause false alarm. How small movement can be detected depends on the precision of the measurements.

Currently, the precision (standard error) of epoch-wise GPS solution is about 1 cm in horizontal and 2 cm in vertical position. If there are just random errors in the GPS measurements, 64 % of errors are less than standard error. That is, 1 cm horizontal movement can be detected with GPS only with 64 % probability, 2 cm movement with 95.45 % and 4 cm with 99.99 % probability. So if we want to be 99 % sure that we do not set a false alarm, only movements larger than 4 cm can be detected. Such precision is often not sufficient. The GPS precision given above is usually stated by manufacturers and it is assumed, that one reference station is used and the roving receiver is close enough to the reference so that atmospheric (troposphere and ionosphere) and orbital errors are negligible.

2.8 Oskarshamn site investigation by GPS

During the period June 2000 to March 2004 KTH monitored crustal motions by 7, and later 11, GPS control points with baselines of 2-7 km in the vicinity of Äspö Hard Rock Laboratory near Oskarshamn in south-east Sweden.

This work, conducted on behalf of the Swedish Nuclear Fuel and Waste Management Company, was performed by repeated GPS observations 3 times per year and in total 11 campaigns. As a result of the study, 3 baselines could not be excluded from possible crustal motions of the order of 1 mm/yr, but, unfortunately, the data was collected during a period with solar maximum in 2002, and the severe ionosphere disturbances could have had some impact on the results (Sjöberg et al, 2002 and Sjöberg et al, 2004).

2.9 An un-manned GPS station at Svea, Antarctica

Since December 2004 KTH runs an automatic GPS reference station of type Trimble R7 24 channel GPS receiver (Sjöberg & Asenjo, 2006). The needed electric power of 1.8-2.3 W is generated by solar panels and a small wind generator, and the dual frequency data, recorded at a sampling rate of 15 s, is stored in a 1 GB compact flash (CF) memory. The data storage is limited by 512 (days of) observation files. The CF memory is specified to function down to – 40 degrees Celsius. So far data must be picked at Svea once per year. After the first year of monitoring at Svea, all daily data files were complete and in order. Except for being a regional reference station for all kinds of expeditions around Svea, all the GPS data recorded will contribute to the joint SCAR crustal movement GPS investigations as a link to the international reference frame ITRF.

2.10 3D laser scanning of engineering constructions and historical monuments

Terrestrial laser scanning (TLS), or 3D laser scanning, is an innovative surveying technology allowing direct and fast acquisition of high-resolution 3D images ("point clouds") of any object or environment, reflecting their existing condition.

The purpose of this project is to develop an integrated survey system consisting of a laser scanner, GPS-receiver and inertial navigation system (INS), for the implementation in engineering, architectural and cultural heritage documentation projects. The work is conducted within the framework of PhD training, which is preceded by the licentiate studies. The aim of the licentiate thesis is to investigate the factors influencing TLS accuracy and develop calibration model(s) and procedures available for users.

Knowledge of the accuracy of a surveying instrument is inevitable for achieving the expected results in a project. This knowledge is obtained from calibration. Standardized calibration procedures exist for all traditional surveying instruments, and they should also be developed for terrestrial laser scanners.

During 2004-2006 we investigated three modern laser scanners – Callidus 1.1, Leica HDS 3000 and Leica HDS 2500 – at the indoor 3D calibration field established at KTH. The first two scanners have been provided by the vendors, and the scanner Leica HDS 2500 is owned by the Division of Geodesy. Based on the results of the tests, we have identified significant systematic errors in the scanners and estimated the target coordinate accuracy achieved with these instruments. We have also investigated the following issues: behavior of the range measurements over time, angular precision and accuracy and influence of the surface reflectance of different materials on the range measurements. Finally, we have proposed two simple procedures for the determination of some systematic errors in laser scanners, which might be used for in-field calibration. The results of our research are believed to improve the knowledge of the performance of laser scanners. They also create a good base for the comparison of different scanning systems and development of calibration model(s) and procedures for TLS.

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40 KIF = Kartteknisk Intresseförening

41 SLF = Sveriges Lantmätareförening

42 KS = Kartografiska Sällskapet (Swedish Cartographic Society)

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

44 ULI = Utvecklingsrådet för Landskapsinformation

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