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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 are focused on the implementation of the ETRS[1] 89 realisation SWEREF 99, the implementation of the national height system RH 2000 and the improvement of Swedish geoid models. Large efforts are also carried out concerning the operation, expansion and services of SWEPOS™, the Swedish network of permanent GNSS[2] stations. Some of the activities are done within the framework of NKG[3].

2 Contributions from Lantmäteriet to EPN[4], ECGN[5] and EUVN_DA[6]

Seven SWEPOS stations are included in EPN. These stations are Onsala, Mårtsbo, Visby, Borås, Skellefteå, Vilhelmina and Kiruna (ONSA, MAR6, VIS0, SPT0, SKE0, VIL0 and KIR0). Daily, hourly and real-time (EUREF-IP) data (1 second) are delivered for all stations, except for Vilhelmina, where just daily and hourly files are submitted.

Furthermore, Onsala, Mårtsbo, Visby, Borås and Kiruna are included in the IGS[7] network. Skellefteå (SKE0) is proposed to be a new IGS station. All the Swedish EPN/IGS stations are equipped with dual-frequency GPS[8]/GLONASS[9] receivers and antennas of Dorne Margolin Choke Ring design.

Lantmäteriet operates the NKG EPN Local Analysis Centre in co-operation with Onsala Space Observatory at Chalmers University of Technology. NKG EPN LAC contributes with weekly and daily solutions based on final IGS products. The EPN-subnetwork processed by NKG LAC consists of 50 stations concentrated to northern Europe. NKG LAC will contribute to the EPN reprocessing with solutions based on both the Bernese GPS Software and GAMIT. Bernese solutions

[1] ETRS = European Terrestrial Reference System

[2] GNSS = Global Navigation Satellite Systems

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

[4] EPN = EUREF Permanent Network

[5] ECGN = European Combined Geodetic Network

[6] EUVN_DA = European Vertical Network, Densification Action

[7] IGS = International GNSS Service

[8] GPS = Global Positioning System

[9] GLONASS = Globalnaya Navigatsionnaya Sputnikovaya Sistema

for the pilot processing of year 2006 have been submitted to BKG[10].

Sweden has, according to the co-ordination within the framework of NKG, offered all seven Swedish EPN stations except Vilhelmina for ECGN. These stations have been suggested for monitoring the time dependent changes of EVRS[11]2007. NKG has also created a Nordic densification called NGOS[12] (Lilje et al., 2008a).

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

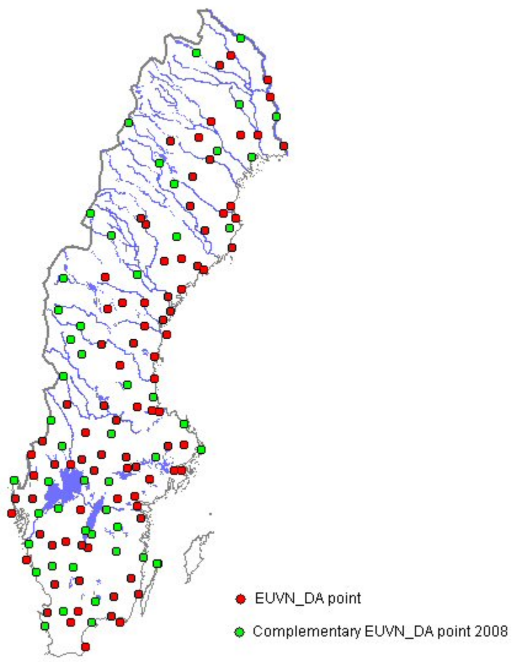

Figure 1: Swedish EUVN_DA sites (March, 2008).

The normal heights and geopotential numbers, as well as ellipsoidal heights, are given in epoch 2000.0 and are reduced for land-uplift using the model NKG2005LU, see Section 8. The estimated uncertainty of the given gravity values is generally about 1-2 mgal (68 % confidence level).

3 Network of Permanent Reference Stations (SWEPOS™)

SWEPOS™ is the Swedish network of permanent GNSS stations (Norin et al., 2008, Hedling et al., 2009 and Jämtnäs et al., 2010), see www.swepos.com. It provides real-time services on both metre level (DGPS[13]/DGNSS[14]) and centimetre level (network RTK[15]), as well as data for post-processing. An automated processing service based on the Bernese GPS software is also available (Kempe & Jivall, 2002).

The purpose of SWEPOS is to:

- provide single- and dual-frequency data for relative GNSS measurements
- provide DGPS/DGNSS corrections and RTK data for distribution to real-time users
- act as the continuously monitored foundation of the Swedish geodetic reference frame SWEREF 99
- provide data for geophysical research
- monitor the integrity of the GNSS systems

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

Today (May 2010) SWEPOS consists of totally 189 stations, 35 class A stations and 154 class B ones, see Figure 2. The class A stations are built on bedrock and have redundant equipment for GNSS observations, communications, power supply, etc. They have also been connected by precise levelling to the national precise levelling network.

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

[11] EVRS = European Vertical Reference System

[12] NGOS = Nordic Geodetic Observing System

[13] DGPS = Differential GPS

[14] DGNSS = Differential GNSS

[15] RTK = Real Time Kinematic

Class B stations are mainly established on top of buildings for network RTK purposes. They have the same instrumentation as class A stations (dual-frequency GPS/GLONASS receivers with antennas of Dorne Margolin design), but with somewhat less redundancy.

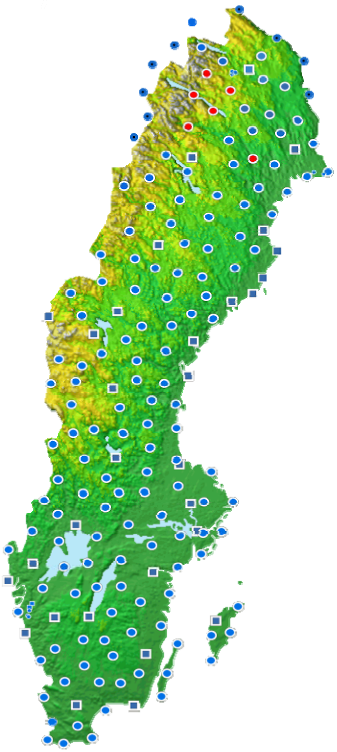

Figure 2: *The SWEPOS network in May 2010 with some bordering Norwegian and Finnish stations in the north. Squares are the 35 class A stations and blue dots are the rest of the existing stations (class B). Red dots are stations under construction.*

The SWEPOS Network RTK Service was launched on January 1st 2004 and it will during 2010 reach national coverage (a few stations are still under construction, see Figure 2). Since data from permanent GNSS stations is exchanged between the Nordic countries, good coverage of the network RTK service in border areas and along the coast has been obtained by the inclusion of 9 Norwegian SATREF stations, 7 Finnish Geotrim stations, 3 Danish Leica SmartNet stations and 1 Danish KMS[16] station.

The service broadcasts RTK data for both GPS and GLONASS with the VRS[17] technique and has today (May 2010) approximately 1400 subscriptions, which means approximately 200 new users since last year.

There is an increasing use of RTK for machine guidance. To meet this, some densifications of the SWEPOS network have been done. In these areas are SWEPOS Network RTK Service used as a flexible and redundant service, tailor-made for large-scale infrastructure projects (Hedling et al., 2009). Further densifications are during 2010 planned in the area around the Swedish capital Stockholm, in the Gothenburg area and in the southern part of Sweden.

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

A project called "Close-RTK" has also been performed during the last year, with an effort to assess the quality of the present network RTK technique, as well as future development scenarios of space (GNSS) and ground (SWEPOS) infrastructure (Emardson et al., 2009, Emardson et al., 2010 and Jämtnäs et al., 2010). The project was initiated by Lantmäteriet, SP Technical Research Institute of Sweden and Chalmers University of Technology. Parameters that were deeply studied were different sources of uncertainty in measurements (e.g. atmospheric and local effects), future satellite systems as Galileo and Compass and a general densification of the SWEPOS network (with 35 km between the stations).

[16] KMS = Kort & Matrikelstyrelsen

[17] VRS = Virtual Reference Station

SWEPOS also offers a single frequency Network DGNSS Service that was launched on April 1st 2006. Both this service and the network RTK service are using the network RTK/DGNSS software GPSNet from Trimble and GSM[18] or GPRS[19] (i.e. mobile Internet connection) as the main distribution channels.

4 SWEREF 99, the National Reference Frame

SWEREF 99 was adopted by EUREF as the realisation of ETRS 89 in Sweden at the EUREF 2000 symposium in Tromsö (Jivall & Lidberg, 2000). It is used as the national geodetic reference frame for GNSS since 2001.

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

4.1 Consolidation points

By defining SWEREF 99 as an active reference frame we are exposed to rely on SWEPOS' positioning services like network RTK. All alterations of equipment and software as well as movements at the stations will in the end affect the coordinates. In order to be possible to keep a check on all these alterations we have introduced consolidation points (Engberg et al., 2010). For this purpose the SWEREF points from the RIX 95 project are used, see Figure 3. They are all marked in bedrock and most of them well suitable for GNSS measurements.

These points, about 300 in total, are remeasured in a yearly programme where 50 points are measured every year.

[18] GSM = Global System for Mobile communication

[19] GPRS = General Packet Radio Service

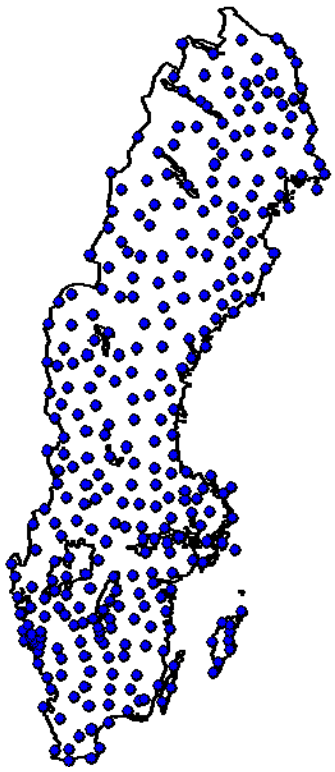

Figure 3: *The SWEREF points from the RIX 95 project.*

4.2 Implementation of SWEREF 99

A formal decision regarding map projections for national mapping, as well as for local surveying, was taken in 2003. All projections for SWEREF 99 are of the Transverse Mercator type. In January 2007, Lantmäteriet replaced RT 90 with SWEREF 99 TM in all databases and product lines.

A new map sheet division and a new index system have also been adopted.

The work regarding implementation of SWEREF 99 among other authorities in Sweden, such as local ones, is in progress. 85 % of the 290 Swedish municipalities have started the process to replace their old reference frames with SWEREF 99. So far, 184 of them have finalised the replacement.

To rectify distorted geometries of local reference frames, correction models used by the municipalities are together with the transformation parameters for direct projection (Engberg & Lilje, 2006) obtained from RIX 95. The models obtained are based on the residuals of the transformations and the rectification is made by a so-called rubber sheeting algorithm. The result will be that all geographical data are positioned in a homogenous reference frame, the national SWEREF 99.

5 RH 2000, the National Height System

The third precise levelling of the mainland of Sweden was finalised in 2003. The final adjustment of the new national height system was made early 2005. The name of the height system is RH 2000 and it has 2000.0 as epoch of validity (in the perspective of the Fennoscandian GIA[20]).

The work to define RH 2000 was made in co-operation with the other Nordic countries. It is defined as the Swedish realisation of EVRS (Ågren et al., 2007). The network consists of about 50 000 benchmarks, representing approximately 50 000 km double run precise levelling measured by the motorised levelling technique. The final computation was made using the land-uplift model NKG2005LU, see Section 8.

Figure 4: *The BLR data set.*

To connect the national network to NAP[21], the adjustment was made in a common adjustment of the nodal points in a data set called the BLR[22], see Figure 4. This set consists of data from mainly the Nordic countries, the Baltic states, Poland, Germany and Holland. The latter data has been provided by UELN[23]-database.

The work has been made within NKG. The Swedish network was then adjusted in a number of steps, keeping the nodal points from the BLR data set fixed. In 2007, the third precise levelling continued on the island of Gotland. The observations was adjusted and connected to RH 2000 on the mainland in 2008 through a combination of tide gauge and GNSS/levelling observations, complemented by geoid/oceanographic models.

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

5.1 Implementation of RH 2000

The work with implementing RH 2000 among other authorities in Sweden is in progress. Approximately 100 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 32 municipalities have finalised the replacement for all activities.

6 Geoid Models

The national Swedish geoid model, SWEN08_RH2000 was released in the beginning of 2009. It has been computed by adapting the Swedish gravimetric model KTH08 to the reference systems SWEREF 99 and RH 2000 by utilising a large number of geometrically determined

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[20] GIA = Glacial Isostatic Adjustment

[21] NAP = Normaal Amsterdam Peil

[22] BLR = Baltic Levelling Ring

[23] UELN = United European Levelling Network

geoid heights, computed as the difference between heights above the ellipsoid determined by GNSS and levelled normal heights above sea level. In this step, a correction has been applied for the postglacial land uplift and for differences in permanent tide systems. A smooth residual surface is used to model the GNSS/levelling residuals (residual interpolation).

The standard uncertainty of SWEN08_RH2000 has been estimated to 10-15 mm everywhere on the Swedish mainland with the exception of a small area to the north-west not covered by the third precise levelling (Ågren, 2009). The standard uncertainty is larger in the latter area and at sea, probably around 5-10 cm.

The underlying gravimetric model, KTH08, has been computed by the Least Squares Modification of Stokes formula with Additive corrections (LSMSA) (Sjöberg, 1991 and Sjöberg, 2003). This work has been made in cooperation between Lantmäteriet and Professor Sjöberg and his group at the Royal Institute of Technology (KTH) in Stockholm. The computation is described in detail in Ågren et al. (2009).

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

7 Gravity Activities

In the autumn of 2006, Lantmäteriet purchased a new absolute gravimeter (Micro-g Lacoste FG 5 - 233). The objective behind this investment is to ensure and strengthen the observing capability for long term monitoring of the changes in the gravity field due to the Fennoscandian GIA.

Absolute gravity observations have been carried out at 14 Swedish sites since the beginning of the 1990´s, see Figure 5. Since 2007, 12 of the sites have been observed by Lantmäteriet and observations have also been done on 1 Danish site, 1 Finnish site, 2 Norwegian sites, 3 Serbian sites and at two inter-comparisons, one with 19 other gravimeters in Luxembourg and one with 22 other gravimeters in Paris.

All Swedish sites are co-located with per-

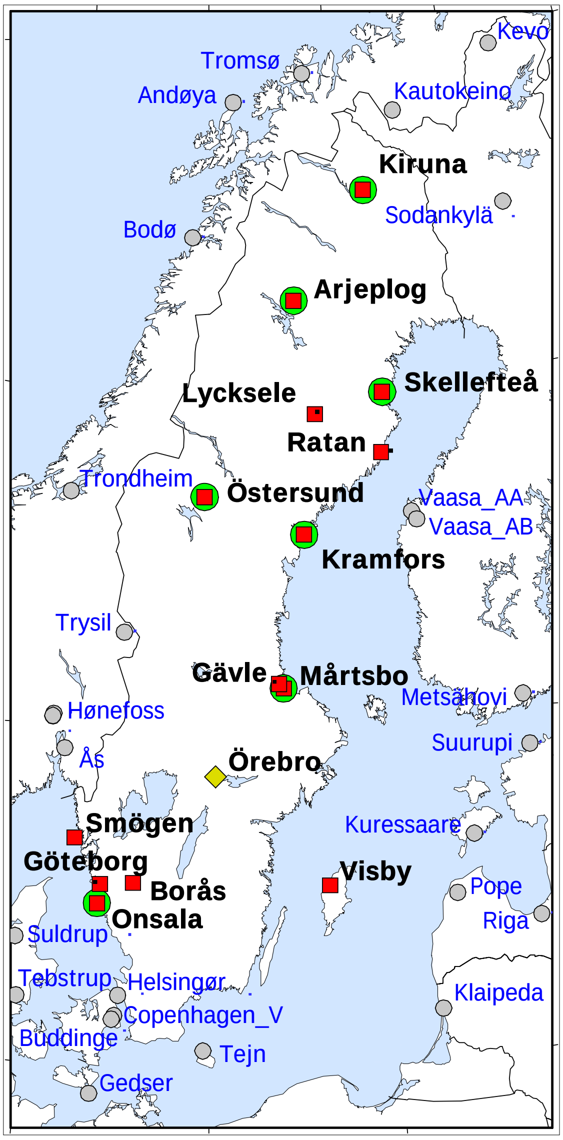

Figure 5: *Absolute gravity sites in Sweden (red squares), planned new site (yellow diamond) and sites in neighbouring countries (grey circles). Sites observed every year since 2003 have a green circle as background to the red square.*

manent reference stations for GNSS in the SWEPOS network (except for Göteborg (Gtbg) which is no longer in use). Onsala is also co-located with VLBI[24]. Skellefteå, Smögen, and Visby are co-located with tide gauges.

The absolute gravity observations are co-ordinated within the co-operation of NKG, and observations have been performed by several groups (BKG, IfE[25], UMB[26] and FGI[27]) together with Lantmäteriet (Lilje et al., 2008b). This arrangement has made it possible to observe 7 of the sites every year since 2003 (marked with green background circles in Figure 5).

At Onsala Space Observatory, a super-conducting gravimeter was installed during the summer last year. The investment should be seen as an additional important instrument at the Onsala geodetic station, but also in view of the efforts regarding absolute gravity for studying temporal variations in observed gravity.

8 Geodynamics

The purpose of the repeated absolute gravity observations is to support the understanding of the physical mechanisms behind the Fennoscandian GIA process, where the relation between gravity change and geometric deformation is a primary parameter.

Research regarding the 3D geometric deformation is foremost done within the BIFROST[28] effort. Reprocessing of all observations from continuously operating GPS stations since autumn 1993 up to autumn 2006 has been done (Lidberg, 2007, Lidberg et al., 2007a, Lidberg et al., 2009, Lidberg & Johansson, 2009 and Lidberg et al. 2010). The results agree with an updated geophysical, meaningful GIA model at the sub-mm/yr level.

NKG2005LU, a special land uplift model including the vertical component only, has been developed. It is based on a combination and modification of the mathematical model of Olav Vestøl and the geophysical model of Lambeck, Smither and Ekman (Ågren & Svensson, 2007).

A coordinate transformation scheme has been developed for high-precision survey applications using GNSS relative permanent reference stations. Internal deformations are accounted for in the scheme (Lidberg et al., 2007b and Nørbech et al., 2006). The used deformation model (NKG_RF03vel), which is based on the results from BIFROST and on NKG2005LU but adapted for GNSS applications, is now implemented in the automated post-processing service offered by SWEPOS, see Section 3.

9 A new Swedish Digital Elevation Model

The new Swedish digital elevation model, is based on airborne laser scanning (Klang & Burman, 2005). Irregular data will be acquired from approximately 3000 m and the orientation of each measured point will be calculated using an integrated concept of an INS[29] and GNSS, see Figure 6.

Verification of the geometrical correction procedures as well as the continuous surface of the DEM will be performed to meet the uncertainty requirements of < 50 cm. Quality control routines, including planimetric and vertical uncertainties as well a point density, will be used to detect gross errors as well as to describe local and global uncertainties.

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[24] VLBI = Very Long Baseline Interferometry

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

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

[27] FGI = Finnish Geodetic Institute, Finland

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

[29] INS = Inertial Navigation System

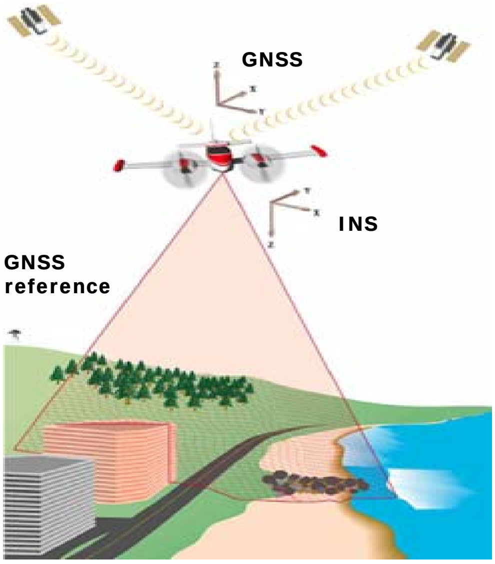

Figure 6: *Airborne laser scanning with registrations from INS and GNSS.*

The time schedule is estimated to 7 years and the production, 450,000 km², will be finished in 2015. The financing will be based on governmental founding and the products will be "free" available in accordance to INSPIRE[30] directives (Swedish interpretation).

The production volume year 2009 was 30,000 km² and for this year the planned production is 120,000 km².

10 References

Emardson R, Jarlemark P, Bergstrand S, Nilsson T, Johansson J (2009): *Measurement Accuracy in Network-RTK*. SP Technical Research Institute of Sweden, SP report 2009:23, http://www-v2.sp.se/publ/user/default.aspx?RapportId=10192 (cited May 2010).

Emardson R, Jarlemark P, Johansson J, Bergstrand S, Lidberg M, Jonsson B (2010): *Measurement Accuracy in Network-RTK*. Istituto Geografico Militare, Bulletin of Geodesy and Geomatics (in press).

Engberg L E & Lilje M (2006): *Direct Projection – an efficient approach for datum transformation of plane co-ordinates*. FIG[31], XXIII International Congress, October 8-13 2006, Proceedings, Munich, Germany.

Engberg L E, Lilje M, Ågren J (2010): *Is There a Need of Marked Points in Modern Geodetic Infrastructure?* FIG, XXIV International Congress, April 11-16 2010, Proceedings, Sydney, Australia.

Hedling G, Wiklund P, Lööf A, Lidberg M, Jonsson B (2009): *New Developments in the SWEPOS Network*. IAIN[32], 13th World Congress, October 27-30 2009, Stockholm, Sweden.

Jivall L & Lidberg M (2000): *SWEREF 99 – an updated EUREF realisation for Sweden*. In Torres & Hornik (eds): EUREF Publication No. 9, EUREF, 2000 Symposium, June 22-24 2000, pp. 167-175, Tromsö, Norway.

Jämtnäs L, Sunna J, Emardson R, Jonsson B (2010): *Quality Assessment of Network-RTK in the SWEPOS™ Network of Permanent GNSS Stations*. FIG, XXIV International Congress, April 11-16 2010, Proceedings, Sydney, Australia.

Kempe T & Jivall L (2002): *SWEPOS™ Automated Processing Service*. In Poutanen & Suurmäki (eds): Proceedings of the 14th General Meeting of the Nordic Geodetic Commission, NKG, October 1-5 2002, pp. 291-295, Espoo, Finland.

Klang D & Burman H (2005): *Airborne Laser Scanning, an Efficient Revision Procedure for the Swedish Digital Elevation Model*. Vienna University of Technology, 7th Conference on Optical 3-D Measurement Techniques, October 3-5 2005, Proceedings, Vienna, Austria.

Lidberg M, Johansson J M, Scherneck H-G (2007b): *Geodetic Reference Frames in the Presence of Crustal Deformations – with focus on Nordic conditions*. In Torres & Hornik (eds): EUREF Publication No. 16, EUREF, 2006 Symposium, June 14-16 2006, pp. 189-198, Riga, Latvia.

Lidberg M (2007): *Geodetic Reference Frames in Presence of Crustal Deformations*. Chalmers

30 INSPIRE = Infrastructure for spatial information in Europe

31 FIG = Fédération Internationale des Géomètres (International Federation of Surveyors)

32 IAIN = International Association of Institutes of Navigation

University of Technology, PhD Thesis, Doktorsavhandlingar vid Chalmers tekniska högskola Ny serie Nr 2705, Gothenburg, Sweden.

Lidberg M, Johansson J M, Scherneck H-G, Davis J L (2007a): *An Improved and Extended GPS-derived 3D Velocity Field of the Glacial Isostatic Adjustment (GIA) in Fennoscandia.* Springer, Journal of Geodesy, 81: 213-230.

Lidberg M & Johansson J M (2009): *New Velocity Solutions from 13 Years of BIFROST Activities.* In Torres et al. (eds): EUREF Publication No. 17, EUREF, 2007 Symposium, June 6-9 2007, pp. 155-163, London, Great Britain.

Lidberg M, Johansson J M, Scherneck H-G, Milne G A, Davis J L (2009): *New results based on reprocessing of 13 years continuous GPS observations of the Fennoscandia GIA process from BIFROST.* In Sideris (ed.): Observing our changing earth, IAG[33], General Assembly, July 2-13, 2007, pp. 557-568, Perugia, Italy.

Lidberg M, Johansson J M, Scherneck H-G, Milne G A (2010) *Recent results based on continuous GPS observations of the GIA process in Fennoscandia from BIFROST*. Elsevier, Journal of Geodynamics, Volume 50, Issue 1, pp. 8-18. doi:10.1016/j.jog.2009.11.010

Lilje M, Poutanen M, Knudsen P, Scherneck H-G, Skei I, Thorsen S O (2008a): *NGOS, the Nordic Geodetic Observing System*. FIG, Working Week 2008, June 14-19 2008, Proceedings, Stockholm, Sweden.

Lilje M, Ågren J, Engfeldt A, Olsson P-A (2008b): *One Year with our Absolute Gravimeter*. FIG, Working Week 2008, June 14-19 2008, Proceedings, Stockholm, Sweden.

Norin D, Jonsson B, Wiklund P (2008): *SWEPOS and its GNSS-based Positioning Services.* FIG, Working Week 2008, June 14-19 2008, Proceedings, Stockholm, Sweden.

Nørbech T, Engsager K, Jivall L, Knudsen P, Koivula H, Lidberg M, Ollikainen M, Weber M (2006): *Transformation from a Common Nordic Reference Frame to ETRF89 in Denmark, Finland, Norway, and Sweden – Status Report.* In Andersen & Bahl (eds): Proceedings of the 15th General Assembly of the Nordic Geodetic Commission. NKG, May 29 - June 2 2006, Copenhagen, Denmark (in press).

Odolinski R (2010a): *Swedish User Guidelines for Network-RTK*. FIG, XXIV International Congress, April 11-16 2010, Proceedings, Sydney, Australia.

Odolinski R (2010b): *Checklista för nätverks-RTK*. Lantmäteriet, Reports in Geodesy and Geographical Information Systems, LMV-Rapport 2010:3 (in Swedish).

Sjöberg L E (1991): *Refined Least Squares Modification of Stokes' Formula.* Springer, Manuscripta Geodaetica, 16:367-375.

Sjöberg L E (2003): *A Computational Scheme to Model the Geoid by the Modified Stokes' Formula without Gravity Reductions.* Springer, Journal of Geodesy, 77: 423-432.

Ågren J, Svensson R, Olsson P-A, Eriksson P-O, Lilje M (2007): *The Swedish Height System as a National Realization of EVRS.* In Torres & Hornik (eds): EUREF Publication No. 16, EUREF, 2006 Symposium, June 14-16 2006, pp. 65-73, Riga, Latvia.

Ågren J & Svensson R (2007): *Postglacial Land Uplift Model and System Definition for the new Swedish Height System RH 2000.* Lantmäteriet, Reports in Geodesy and Geographic Information Systems, 2007:4, Gävle, Sweden.

Ågren J, Sjöberg L E & Kiamehr R (2009): *The New Gravimetric Quasigeoid Model KTH08 over Sweden*. deGruyter, Journal of Applied Geodesy 3 (2009) pp. 143-153.

Ågren J (2009): *Beskrivning av de nationella geoidmodellerna SWEN08_RH2000 och SWEN08_RH70.* Lantmäteriet, Reports in Geodesy and Geographic Information Systems, 2009:1, Gävle, Sweden (in Swedish).

[33] IAG = International Association of Geodesy