National Report of Sweden to the EUREF 2018 Symposium

– geodetic activities at Lantmäteriet

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1 Introduction

At Lantmäteriet (the Swedish mapping, cadastral and land registration authority) the activities in the fields of geodetic reference frames and positioning are focused on:

- The operation, expansion and services of SWEPOS™, the Swedish national network of permanent reference stations for GNSS[1].
- Contributions of SWEPOS data to international initiatives as EPN[2], IGS[3] and MGEX[4] and international analyses of GNSS data.
- The implementation of the Swedish national reference frame SWEREF 99 and the national height system RH 2000 (ETRS[5]89 and EVRS[6] realizations respectively).
- The sustainability of the Swedish reference frames.
- Improvements of Swedish geoid models and renovation of the gravity network.

The geodetic work within Lantmäteriet is presently based on a 10-year strategic plan for the years 2011–2020, which is called *Geodesy 2010* released in 2011 and updated in 2015 (Lantmäteriet, 2011, 2015), and some of the activities are performed within the framework of NKG[7]. A new strategic plan is planned to be released during 2018, initiated by the release of a new national Geodata Strategy in 2016.

To ensure a long term stable national geodetic infrastructure, Onsala Space Observatory initiated in 2017 discussions with Lantmäteriet concerning funding of the geodetic activities at the observatory. This will start from next year and is an important step in implementing the UN resolution *Global Geodetic Reference Frame for Sustainable Development* in Sweden.

2 Contributions from Lantmäteriet to EPN

The number of SWEPOS stations included in EPN is 27. Seven stations have been included since the very beginning of EPN and are all part of the 21 original SWEPOS stations. These stations are Onsala, Mårtsbo, Visby, Borås, Skellefteå, Vilhelmina and Kiruna (ONSA, MAR6, VIS0, SPT0, SKE0, VIL0 and KIR0). The other 20 stations also originate from the 21 original SWEPOS stations, but from an additional monument equipped with individually calibrated antennas/radomes (see chapter 4). Daily and hourly data are delivered for all stations. Real-time (EUREF-IP) data (1 Hz)

[1] GNSS = Global Navigation Satellite Systems

[2] EPN = EUREF Permanent Network

[3] IGS = International GNSS Service

[4] MGEX = Multi-GNSS Experiment

[5] ETRS = European Terrestrial Reference System

[6] EVRS = European Vertical Reference System

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

are delivered from seven stations. There is one new monument for the last original SWEPOS station that is expected to be included in EPN later on.

Lantmäteriet operates the NKG EPN AC[8] in co-operation with Onsala Space Observatory at Chalmers University of Technology. The NKG AC contributes with weekly and daily solutions based on final CODE[9] products, using the Bernese GNSS Software. The EPN sub-network processed by the NKG AC consists of 88 reference stations (May 2018) concentrated to northern Europe.

3 EPN related GNSS Analysis

The NKG GNSS analysis centre project is chaired by Lantmäteriet (Jivall et al., 2014; Lahtinen et al., 2018). The project aims at a dense and consistent velocity field in the Nordic and Baltic area. Consistent and combined solutions are produced based on national processing using the Bernese GNSS Software version 5.2, following the EPN Analysis guidelines. The project was declared fully operational in April 2017. A reprocessing, covering the years 1997–2016 with a processing setup consistent with EPN Repro2, of the full NKG network including all Nordic and Baltic countries has been completed and the time series analysis is well underway.

In June 2016 Lantmäteriet became one of the analysis centres in E-GVAP[10] (egvap.dmi.dk) and is in charge of the data processing in order to provide near-real-time (NRT) zenith total delay (ZTD). Currently two NRT hourly ZTD products (NGA1 and NGA2) are provided (Lindskog et al., 2017). The NGA1 product is obtained from the Bernese v.5.2 network solution while NGA2 is given by the GIPSY/OASIS II v.6.2 using the precise point processing (PPP) strategy. The NGA1 product is in an operational stage while the NGA2 product is provided for test purposes used by SMHI[11]. The Lantmäteriet GNSS data processing in total includes approximately 700 stations in Sweden, Finland, Norway, Denmark and some IGS stations outside of the Nordic area.

4 Network of Permanent Reference Stations for GNSS (SWEPOS™)

SWEPOS™ is the Swedish national network of permanent GNSS stations operated by Lantmäteriet (Lilje et al., 2014); see SWEPOS website www.swepos.se or http://swepos.lantmateriet.se.

The purposes of SWEPOS are:

- Providing single- and dual-frequency data for relative GNSS measurements.
- Providing DGNSS[12] corrections and RTK[13] 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. The system includes four different classes; A, B, C and D, where class A is the class fulfilling the highest demands.

By May 2018 SWEPOS consisted of totally 398 stations, 41 class A stations and 357 class B ones, see Figures 4.1 and 4.2. This means that the total number of SWEPOS stations has increased with 17 stations since the previous EUREF Symposium one year ago, see Figure 4.3.

[8] AC = Analysis Centre

[9] CODE = Centre for Orbit Determination in Europe

[10] E-GVAP = The EUMETNET GNSS water vapour programme

[11] Swedish Meteorological and Hydrological Institute

[12] DGNSS = Differential GNSS

[13] RTK = Real-Time Kinematic

The class A 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. 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.

Figure 4.1: *Sveg 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).*

Figure 4.2: *Vagnhärad is a class B SWEPOS station with a roof-mounted GNSS antenna mainly established for network RTK purposes.*

The 21 original class A stations have two kinds of monuments; the original concrete pillars as well as new steel grid masts, see Figure 4.1. The new monuments are equipped with individually calibrated antennas and radomes of the type LEIAR25.R3 LEIT.

Five of the original 21 SWEPOS stations (Onsala, Mårtsbo, Visby, Borås and Kiruna) are included in the IGS network, as well as three stations with the new monuments (ONS1, MAR7 and KIR8), which also are included in the IGS-MGEX pilot project.

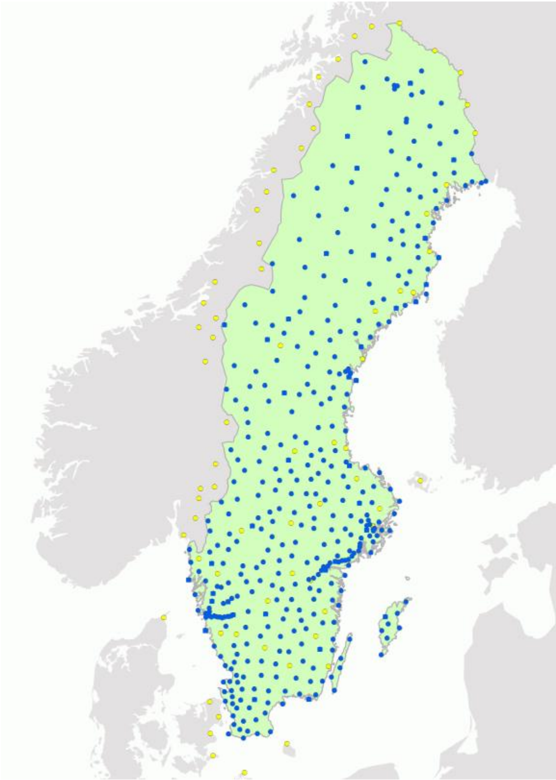

Figure 4.3: *The SWEPOS network in May 2018. Squares indicate class A stations and dots indicate class B ones. Stations in neighbouring countries as well as stations from other service providers in Sweden used in the SWEPOS Network RTK Service are also marked.*

All SWEPOS stations are upgraded to track the modernized GPS signals and the new GNSS systems. Galileo has been available in the SWEPOS services since February 1, 2018. The plan is to include Beidou in SWEPOS during 2020.

Previously, SWEPOS has been densified in co-operation with the Swedish Transport administration in areas of large infrastructure projects (highways, bridges and railways). A few municipalities have shown interest in densification of SWEPOS, to decrease the positional uncertainty of RTK surveys and to decrease their expenses for maintenance of local geodetic control networks. Such co-operational densifications can be implemented in areas where it is considered to give general socio-economic benefit, and has already been carried out in the south west area in the province of Skåne.

5 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[14] format. The DGNSS service is since 2016, in line with some other national geographical data from Lantmäteriet, available as open data. An automated post-processing service is also available. This service utilizes the Bernese GNSS Software version 5.2 and takes since 2016 advantage of both GPS and GLONASS.

Since the data from permanent GNSS stations are exchanged between the Nordic countries, good coverage of the network RTK service in border areas and along the coasts has been obtained. Several stations from SATREF in Norway and Danish Styrelsen for Dataforsyning of Effektivisering (Agency for Data Supply and Efficiency) as well as from private operators in Norway, Denmark, Finland and Germany are included. SWEPOS is also using data from 30 Trimble stations inside Sweden.

The service has today (May 2018) approximately 3760 subscriptions, which means some 440 new users since last year. Lantmäteriet has also signed cooperation agreements with four international GNSS service providers, using the data for their own services. This is done in order to increase the use of GNSS data from the SWEPOS stations as well as optimizing the benefit of the geodetic infrastructure.

With the main purpose to improve the performance of the network RTK service, a general densification of the SWEPOS network has been going on since 2010 by establishing around 40 new stations each year. The establishment of new stations is since a couple of years on a lower level. More comprehensive densifications have also been performed in some areas to meet the demands for machine guidance in large-scale infrastructure projects.

RINEX 3 is now stored in parallel with RINEX 2 and partly implemented, the plan is to have RINEX 3 fully implemented for all SWEPOS stations during 2018.

The real-time services are utilizing Trimble Pivot Platform GNSS Infrastructure Software and are operating in virtual reference station mode. Galileo network RTK test measurements have successfully been performed during 2016–2017. The implementation of Galileo in the software for the network RTK service as well as distribution of GPS L5 and L2C signals using RTCM MSM was done in February 1st 2018.

6 Implementation of SWEREF 99

SWEREF 99 was adopted by EUREF as the realization of ETRS89 in 2000 (Jivall & Lidberg, 2000) and is used as the national geodetic reference frame since 2007.

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 by Lantmäteriet (Engberg et al., 2010). The approximately 300 so-called SWEREF points are used for this purpose and 50 of them are re-measured each year following a yearly programme. Reprocessing of the measurements of SWEREF points performed during 1998–2017 has recently been done with both the GAMIT software and the Bernese GNSS Software. The outcome will be used to analyse the stability of SWEREF 99 and has been used to define the

[14] RINEX = Receiver Independent EXchange format

SWEREF 99 component in the fit of the NKG2015 geoid model to SWEREF 99 and RH 2000; see chapter 8.

The work regarding the implementation of SWEREF 99 among different authorities in Sweden, such as local ones, is in a final stage. Almost all of the 290 Swedish municipalities have started the process to replace their old reference frames with SWEREF 99 and actions are taken to start the transition in the remaining ones. The number of municipalities that have finalized the replacement has increased from 285 to 287 during the last year.

7 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 (Ågren et al., 2007).

Since the beginning of the 1990s, a systematic inventory/updating of the network is continuously performed. When an update is required, the new levelling is done through procurement procedures, which is also the situation for the remeasurements of the 300 SWEREF points described in chapter 6.

The work with implementing RH 2000 among different authorities in Sweden is in progress (Kempe et al., 2014). About 90% of the 290 Swedish municipalities have, mainly in co-operation with Lantmäteriet, started the replacement of their local height systems with RH 2000. So far approximately 245 municipalities have finalized the replacement for all activities, which is approximately 15 more than by the time for the previous EUREF Symposium.

8 Geoid Determination

According to Lantmäteriet's strategic plan for the time period 2010 to 2020, 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 – quite a lot of work is going on. A new gravity reference system/frame RG 2000 has recently been finalised (see chapter 10). Many new Swedish detail gravity observations are continuously being collected using Scintrex CG5 with the purpose to fill gaps or replace old data of bad quality. New measurements have for instance been made on the lake Vänern and in the rough Swedish mountains to the north-west. An important activity is further the work made in FAMOS to improve gravity and geoid in the Baltic Sea (see next section), which we can also benefit from on land, mainly in the coastal areas.

An important part of the geoid improvements efforts is the *NKG2015 geoid model project*, which was made in international cooperation under the umbrella of the NKG Working Group of Geoid and Height Systems. The goal has been to compute a new common *gravimetric quasigeoid model* over the Nordic and Baltic countries. The NKG gravity database for the whole Nordic-Baltic area has been updated and a new NKG GNSS/levelling database and a common DEM were also created. The computations were made independently by five computation centres, from Sweden, Denmark, Finland, Norway and Estonia, using different regional geoid computation methods, software and set-ups. The modelling method utilized for the final model, the Least Squares Modification of Stokes' formula with additive corrections, was chosen based mainly on the agreement to GNSS/levelling. The final NKG2015 quasigeoid model was released in October, 2016 (Ågren et al. 2016a). GNSS/levelling evaluations show that the model is a significant step forward, not only compared to previous NKG models, but also with respect to other state-of-the-art geoid models that cover the whole Nordic-Baltic area, as for instance EGM2008, EGG2015 and EIGEN-6C4.

In the last year much work has been made to improve the Swedish national GNSS/levelling dataset. The core of the new, updated dataset are the so-called SWEREF-points for which accurate levelled heights are available in RH 2000. These SWEREF-points have been measured for 2x24 hours using Choke ring antennas The processing has been made two times in the Bernese software (after the measurements and in a consistent way for all points in 2017) and once in the GAMIT software. A majority of these SWEREF-points are the consolidation points mentioned in chapter 6, which are re-determined every sixth years using the SWEREF-point methodology mentioned above. This makes it possible to detect and remove unstable points. The final GNSS heights above the ellipsoid were determined as the weighted mean of the different epochs (for consolidation points) and processing results (2 Bernese, 1 GAMIT).

The new Swedish national geoid model SWEN17_RH2000 was released in October 2017. It was computed by adapting the gravimetric NKG2015 geoid (slightly corrected over Sweden with some new Swedish data) to the above improved set of GNSS/ levelling observations by adding a smooth residual surface computed by Least Squares Collocation. The standard uncertainty of SWEN17_RH2000 is estimated by cross validation to 8-10 mm on the Swedish mainland and on the large Baltic Sea islands Öland and Gotland. This is a significant step forward compared to the old model SWEN08_RH2000, but still more work is required to reach the ultimate 5-mm goal.

9 FAMOS and Baltic Sea Chart Datum 2000

Lantmäteriet is also engaged in the EU project FAMOS[15]. The main purpose of FAMOS is to increase the safety of navigation in the Baltic Sea, mainly by finalizing hydrographic surveying in areas of interest for commercial shipping. Other important aims are to improve navigation and hydrographic surveying with GNSS based methods in the future and to support the introduction of the common Baltic Sea Chart Datum 2000 (EVRS with land uplift epoch 2000.0) in the Baltic Sea by 2020 (Ågren et al. 2016b). In FAMOS *activity 2* the main goal is to improve the geoid model in the Baltic Sea area, which will provide an important basis for future offshore navigation.

To reach the goal of an improved Baltic Sea geoid model, new marine gravity data are collected at the hydrographic surveying vessels, to check and improve the existing gravity data as well as to fill gaps. Figure 9.1 illustrates a harbour tie measurement. According to the plan, a new improved and validated FAMOS geoid model will be released by 2020, which will be used to realize the Baltic Sea Chart Datum 2000 out in the Baltic Sea.

In FAMOS, Lantmäteriet is working mainly with activity leading (of activity 2), marine gravimetry, evaluation of existing gravity data/databases and geoid computation. Lantmäteriet has recently procured a ZLS marine gravimeter, which was delivered in April 2017. We further work with connecting the Swedish tide gauges to RH 2000 as well as with evaluating different real-time GNSS navigation methods at sea.

Figure 9.1: *Harbour tie gravity measurement made by Lantmäteriet in the FAMOS project.*

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

10 Gravity Activities

Absolute gravity observations have been carried out at 14 Swedish sites since the beginning of the 1990's, see Figure 10.1. All sites, except for Gothenburg (Gtbg) which no longer is in use, have been observed by Lantmäteriet since 2007. The observations have been carried out with Lantmäteriet's absolute gravimeter (Micro-g LaCoste FG5X – 233, which was upgraded in the autumn 2016 to FG5X). The objective behind the 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[16].

All Swedish absolute gravity sites for FG5 (except for Gtbg) are co-located with reference stations in the SWEPOS network. Ratan, Skellefteå, Smögen, Visby and Onsala are co-located with tide gauges. Onsala is also co-located with VLBI[17].

Absolute gravity observations have also been performed abroad, mainly in the Nordic countries but also in Serbia, the Republic of Macedonia and in Bosnia and Herzegovina. Furthermore, seven inter-comparisons have been carried out; in Luxembourg, Paris and Wettzell.

In the beginning of 2018 the new Swedish gravity reference frame, RG 2000, became official. The reference level is as obtained by absolute gravity observations according to international standards and conventions. It is a zero permanent tide system in post glacial rebound epoch 2000. RG 2000 is realized by the 14 FG5 stations (see above), 96 A10 stations (measured by IGiK[18]) and some 200 stations observed with relative gravimeters.

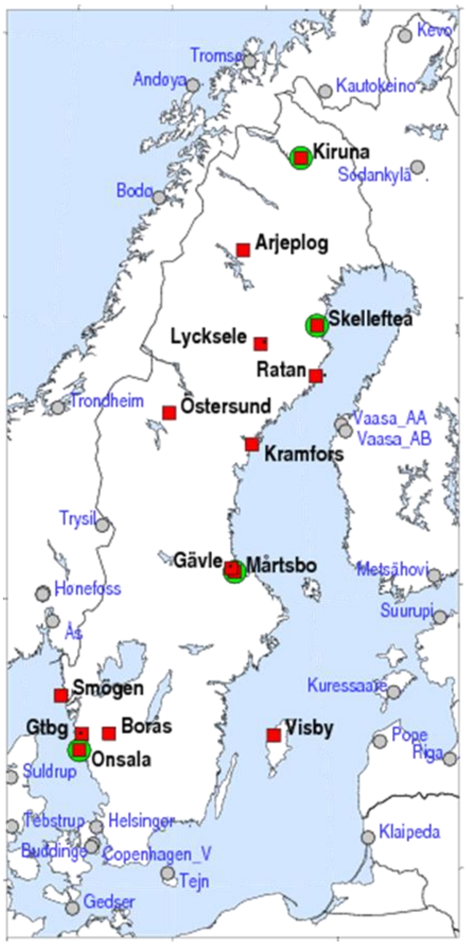

Figure 10.1: *The 14 absolute gravity sites (for FG5) in Sweden (red squares) and sites in neighbouring countries (grey circles). The four sites with time series more than 15 years long have a green circle as background to the red square.*

At Onsala Space Observatory of Chalmers University of Technology, a superconducting gravimeter was installed during 2009. This 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 six times by Lantmäteriet's FG5, latest in July 2017.

[16] GIA = Glacial Isostatic Adjustment

[17] VLBI = Very Long Baseline Interferometry

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

11 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. One key parameter is the relation between gravity change and geometric deformation. A theoretical determination of the relation in Fennoscandia has been done by Olsson et al. (2015) which was verified by comparison of the first complete collection of absolute gravity observations in northern Europe to the latest uplift velocity field (see below). A manuscript to an open access journal about the combined database, its analysis and its geoscientific implications is close to submission.

Research regarding the 3D geometric deformation in Fennoscandia and adjacent areas is foremost done within the BIFROST[19] effort (Lidberg et al., 2015). Reprocessing of all observations from permanent GPS stations is a continuous activity. A velocity field based on 170 stations using the GAMIT/GLOBK software is currently subject to publication. Works towards a new velocity field based on more than 200 stations are underway using the GAMIT/GLOBK, GIPSY and Bernese software.

The land uplift model NKG2016LU was released on 30 June 2016. Current efforts aim at providing reliable uncertainty estimates and submission of a final publication for peer review. Uncertainty of the geophysical model is calculated based on the spread of well-fitting GIA models to the observations within the 1-sigma range of the best-fitting GIA model. The range of GIA models tested include more than 400 different Earth models and 33 different ice history models.

The new 3D velocity model NKG_RF17vel for northern Europe is currently in preparation. The uplift part is based on NKG2016LU while the horizontal motions are generated from an updated four-layer GIA model that reduces the misfit in the horizontals. This GIA model includes a sub-lithospheric high-viscosity layer.

Lantmäteriet is involved in the EUREF working group on *Deformation models* (www.lantmateriet.se/en/Maps-and-geographic-information/GPS-and-geodetic-surveys/Reference-systems/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 overcome the limitations in the use of ETRS89 and also lead to a general understanding of the physics behind such a velocity field. A test deformation model is under development based on a preliminary version of the densified EPN velocity field that was recently provided.

Another major activity is the generation of the strain-rate product within the European Plate Observing System (EPOS[20]). The project is currently in the implementation phase and is expected to be operational from 2020 onwards. In cooperation with a few institutes in Europe, Lantmäteriet will calculate strain-rate grids for Europe targeted in resolution due to GNSS station distribution and area of interest.

In 2015-2017, Lantmäteriet contributed via a Service Level Agreement to the EU-financed Horizon 2020 project EGSIEM[21]. The global GIA correction for gravity missions such as GRACE was provided by Lantmäteriet. The first official version LM17.3, yet without uncertainty estimates, was implemented in the EGSIEM service in October 2017 and is adequately filtered available under http://plot.egsiem.eu/index.php?p=times

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

[20] EPOS (https://www.epos-ip.org/)

[21] EGSIEM = European Gravity Service for Improved Emergency Management

eries (search for GIA LM17.3 DDK5). This correction is based on a combination of several regional ice history models with a standard Earth model. An updated version is planned for this year, based on a slightly refined ice model and a laterally varying Earth model.

In a geodynamic study regarding the reactivation of faults due to GIA, modelling results from Lantmäteriet were among others used to classify the Børglum Fault in northern Denmark as so-called glacially induced fault (Brandes et al. 2018). This study filled a geographical gap of such faults in the formerly glaciated area.

12 Further Activities

The regulatory documents for Lantmäteriet states that one of its responsibilities is to contribute to efficient and standardized surveying and mapping in Sweden. One of the means to accomplish this is through a series of best-practice guidelines called HMK (a Swedish acronym roughly translated as "Guidelines for mapping and surveying"). HMK covers a wide variety of methods for geodata capture (e.g. laser scanning, aerial photography, geodetic surveying) as well as more general information about quality parameters and how they should be specified. Updates are published on an annual basis, and additional guidelines are added as new techniques emerges. Geodetic applications are covered in five documents:

- Geodetic infrastructure
- Control surveying
- Terrestrial detail surveying
- GNSS-based detail surveying
- Support for tendering and choice of surveying methods

All HMK guidelines are published online at www.lantmateriet.se/hmk. The five documents covering geodesy were updated during 2017 and can be downloaded free of charge.

13 References

Alfredsson A., Sunna J., Persson C.-G., Jämtnäs L. (2014): *HMK – Swedish handbook in surveying and mapping*. FIG[22], XXV International Congress, June 16–21 2014, 8 pp., Kuala Lumpur, Malaysia. Also in NKG, 17th General Assembly, September 1–4 2014, Göteborg, Sweden (slightly updated).

Brandes C., Steffen H., Sandersen P., Wu P., Winsemann J. (2018): Glacially induced faulting along the NW segment of the Sorgenfrei-Tornquist Zone, northern Denmark: Implications for neotectonics and Lateglacial fault-bound basin formation. Quaternary Science Reviews, Vol. 189, 149-168.

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, 7 pp., Sydney, Australia.

Engfeldt A. (2016a): *RG 2000 – status*. Lantmäteriet, Lantmäterirapport 2016:1. www.lantmateriet.se/globalassets/kartor-och-geografisk-information/gps-och-matning/geodesi/rapporter_publikationer/rapporter/lantmaterirapport-2016-1.pdf (cited May 2016).

Engfeldt A. (2016b): *Preparations and plans for the new national gravity system, RG 2000*. Lantmäteriet, Lantmäterirapport 2016:2. www.lantmateriet.se/globalassets/kartor-och-geografisk-information/gps-och-matning/geodesi/rapporter_publikationer/rapporter/lantmaterirapport-2016-2.pdf (cited May 2016).

Håkansson M., Jensen A. B. O., Horemuz M., Hedling G. (2016): *Review of code and phase biases in multi-GNSS positioning.*

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

GPS Solutions (in print, published online October 21, 2016).

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.

Jivall L., Kempe T., Lilje C., Nyberg S., Häkli P., Kollo K., Pihlak P., Weber M., Kosenko K., Sigurðsson Þ., Valsson G., Prizginiene D., Paršeliūnas E., Tangen O. (2014): *Report from the project NKG GNSS AC*. NKG, 17th General Assembly, September 1–4 2014, Göteborg, Sweden.

Kempe C., Alm L., Dahlström F., Engberg L. E., Jansson J. (2014): *On the transition to the new Swedish height system RH 2000.* FIG, XXV International Congress, June 16–21 2014, 9 pp., Kuala Lumpur, Malaysia. Also in NKG, 17th General Assembly, September 1–4 2014, Göteborg, Sweden (slightly updated, with the title "*Swedish municipalities implementing the new national height system RH 2000*").

Lahtinen S., Häkli P., Jivall L., Kempe C., Kollo K., Kosenko K., Pihlak P., Prizginiene D., Tangen O., Weber M., Paršeliūnas P., Baniulis R., Galinauskas K. (2018): *First results of the Nordic and Baltic GNSS Analysis Centre*, J. Geod. Sci. 2018; 8:34–42. https://doi.org/10.1515/jogs-2018-0005

Lantmäteriet (2011): *Geodesy 2010 – a strategic plan for Lantmäteriet's geodetic activities 2011–2020*, Lantmäteriet, 16 pp., Gävle, Sweden. www.lantmateriet.se/globalassets/kartor-och-geografisk-information/gps-och-matning/geodesi/rapporter_publikationer/publikationer/geodesy_2010.pdf (cited May 2015).

Lantmäteriet (2015): *Geodesi 2010 – Nyckelaktiviteter 2016-2017*, Lantmäteriet, 4 pp., Gävle, Sweden. www.lantmateriet.se/globalassets/kartor-och-geografisk-information/gps-och-matning/geodesi/rapporter_publikationer/publikationer/geodesi_2010_folder.pdf (cited May 2016)

Lidberg M., Steffen H., Johansson J., Kierulf H. P., Kristiansen O. (2015): *The BIFROST project: 21 years of search for the true crustal deformation in Fennoscandia*. EUREF, 2015 Symposium, June 3–5 2015, Leipzig, Germany.

Lidberg M., Jarlemark P., Ohlsson K., Johansson J. (2016): *Station calibration of the SWEPOS GNSS Network*. FIG, Working Week 2016, Christchurch, New Zeeland.

Lilje M., Wiklund P., Hedling G. (2014): *The use of GNSS in Sweden and the national CORS network SWEPOS*. FIG, XXV International Congress, June 16–21 2014, 11 pp., Kuala Lumpur, Malaysia.

Lindskog M., Ridal M., Thorsteinsson S., Ning T. (2017): *Data assimilation of GNSS zenith total delays from a Nordic processing centre*. Atmos. Chem. Phys., 17, 13983–13998, 2017.

Olsson P.-A., Milne G., Scherneck H.-G., Ågren J. (2015): *The relation between gravity rate of change and vertical displacement in previously glaciated areas*. Journal of Geodynamics, Vol. 83, pp. 76–84.

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., Strykowski G., Bilker-Koivula M., Omang O., Märdla S., Forsberg R., Ellmann A., Oja T., Liepins I., Parseliunas E., Kaminskis J., Sjöberg L., Valsson G. (2016a): *The NKG2015 gravimetric geoid model for the Nordic-Baltic region.* 1st Joint Commission 2 and IGFS Meeting International Symposium on Gravity, Geoid and Height Systems, 19-23 September 2016, Thessaloniki, Greece.

Ågren J., Liebsch G., Mononen J., Jakobsson L., Hell B., Schwabe J., Ellmer W. (2016b) *On the definition and realisation of the Baltic Sea Chart Datum 2000.* 1st Joint Commission 2 and IGFS Meeting International Symposium on Gravity, Geoid and Height Systems, 19-23 September 2016, Thessaloniki, Greece.