National Report of Sweden to the EUREF 2016 Symposium

– geodetic activities at Lantmäteriet

L. JIVALL, D. NORIN, M. LILJE, M. LIDBERG, P. WIKLUND, L. E. ENGBERG, C. KEMPE, J. ÅGREN, A. ENGFELDT, H. STEFFEN

Lantmäteriet, SE-801 82 Gävle, Sweden
geodesi@lm.se

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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] realisations respectively).
- The sustainability in the Swedish reference frames.
- Improvements of Swedish geoid models and renovation of the gravity network.

The geodetic work within Lantmäteriet is based on a 10-year strategic plan for the years 2011–2020 called Geodesy 2010 released in 2011 and updated in 2015 (Lantmäteriet, 2011, 2015), and some of the activities are performed within the framework of NKG[7].

2 Contributions from Lantmäteriet to EPN

The total number of SWEPOS stations included in EPN has increased with three stations to 27 since the EUREF 2015 Symposium. 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). Daily, hourly and real-time (EUREF-IP) data (1 Hz) are delivered for all stations except Vilhelmina, where only daily and hourly files are submitted. 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). 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 LAC[8] in co-operation with Onsala Space Observatory at Chalmers University of Technology. The NKG LAC contributes

[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)

[8] LAC = Local Analysis Centre

with weekly and daily solutions based on final CODE[9] products, using the Bernese GNSS Software. Version 5.2 is used since GPS[10] week 1765 (November 2013). The EPN sub-network processed by NKG LAC consists of 74 reference stations (May 2016) concentrated to northern Europe. This means that 4 stations have been added to the NKG LAC sub-network since the previous EUREF Symposium in 2015.

3 EPN related GNSS Analysis

The NKG GNSS analysis centre project is chaired by Lantmäteriet (Jivall et al., 2014). The project aims at a dense and consistent velocity field in the Nordic and Baltic area. Consistent and combined solutions will be produced based on national processing using the Bernese GNSS Software version 5.2, following the EPN Analysis guidelines. The operational phase of the project began 2014, although all expected contributions are not yet included. A reprocessing consistent with EPN Repro2 of the full NKG-network including all Nordic and Baltic countries is in progress.

Lantmäteriet has taken over the GNSS water vapour analysis (LAC NGAA) for E-GVAP[11] from SMHI[12] and Chalmers. The work started in June 2015 by moving and modifying the GIPSY solution (NGA2) and preparing a new solution with the Bernese GNSS Software (NGA1). Since February 8th 2016 Lantmäteriet transfers estimated near real time zenith troposphere delay parameters from both the GIPSY and Bernese solutions to SMHI for operational purpose. The Bernese solution is further submitted to E-GVAP for validation. The solutions include approximately 680 stations in Sweden, Finland, Denmark and Norway as well as some IGS-sites outside 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 available on www.swepos.se or through www.lantmateriet.se/swepos.

The purposes of SWEPOS are:

- Providing single- and dual-frequency data for relative GNSS measurements.
- Providing DGNSS[13] corrections and RTK[14] data for distribution to real-time users.
- Acting as the continuously monitored foundation of SWEREF 99.
- Providing data for geophysical research and for meteorological applications.
- Monitoring the integrity of the GNSS systems.

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

By the time for the EUREF Symposium in May 2016 SWEPOS consisted of totally 370 stations, 39 class A stations and 331 class B ones, see Figures 4.1 and 4.2. This means that the total number of SWEPOS stations has increased with 15 stations since the previous EUREF Symposium one year ago, see Figure 4.3.

[9] CODE = Centre for Orbit Determination in Europe

[10] GPS = Global Positioning System

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

[12] SMHI = the Swedish Meteorological and Hydrological Institute

[13] DGNSS = Differential GNSS

[14] RTK = Real-Time Kinematic

Figure 4.1: *Hässleholm is one of the SWEPOS stations belonging to class A. It has both a new monument (established in 2011) and an old monument (from 1993).*

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

The class A stations are built on bedrock and have redundant equipment for GNSS observations, communications, power supply, etc. They have also been connected by precise levelling to the national precise levelling network. Class B stations are mainly established on top of buildings for network RTK purposes. They have the same instrumentation as class A stations (dual-frequency multi-GNSS receivers with antennas of Dorne Margolin choke ring design), but with somewhat less redundancy.

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

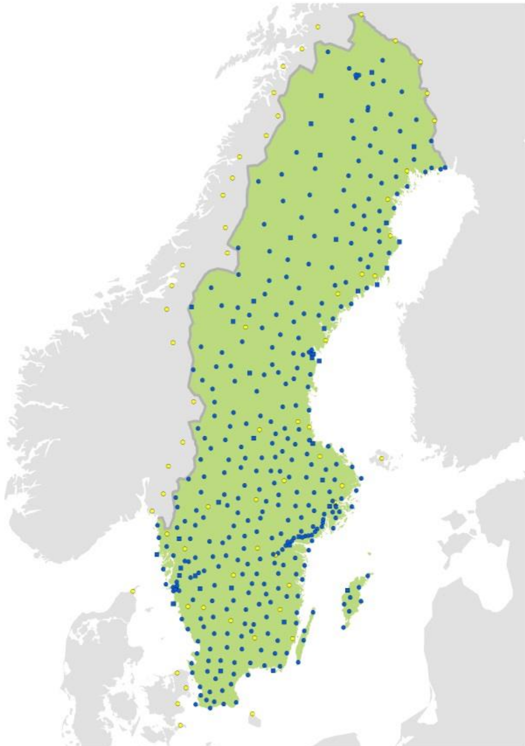

Figure 4.3: *The SWEPOS network in May 2016. Squares indicate class A stations and dots indicate class B ones. Stations in neighbouring countries as well as stations from other service providers in Sweden used in the SWEPOS Network RTK Service are also marked.*

Five of the original SWEPOS stations (Onsala, Mårtsbo, Visby, Borås and Kiruna) are included in the IGS network and the new monumentation on three of them (ONS1, MAR7 and KIR8) also contribute as stations in the IGS-MGEX campaign. This campaign has been set-up to track, collate and analyse all available GNSS signals. Today all SWEPOS stations are upgraded to track the modernized GPS signals and the new GNSS systems.

5 SWEPOS Services

SWEPOS provides real-time services on both metre level (network DGNSS) and centimetre level (network RTK), as well as data for post-processing in RINEX[15] format. An automated post-processing service is also available. This service utilises the Bernese GNSS Software version 5.2

The SWEPOS Network RTK Service reached national coverage during 2010. Since data from permanent GNSS stations are exchanged between the Nordic countries, good coverage of the service in border areas and along the coasts has been obtained by the inclusion of twenty Norwegian SATREF stations, four Norwegian Leica SmartNet stations, five Finnish Geotrim stations, one Finnish Leica SmartNet station, four Danish Leica SmartNet stations and two Danish Geodatastyrelsen (Danish Geodata Agency) stations. SWEPOS is also using data from 30 Trimble stations inside Sweden.

The service has supplied RTK data for both GPS and GLONASS since April 2006 and has today (May 2016) approximately 2960 subscriptions, which means some 290 new users since last year. Lantmäteriet has also signed cooperation agreements with three international GNSS service providers. This is done in order to increase the use of GNSS data from the SWEPOS stations and the providers are using the data for their own services.

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

The RINEX dataflow has been improved and the structure of the RINEX archive has been changed to better fit user needs. RINEX 3 is now stored in parallel with RINEX 2 on some stations and the plan is to have RINEX 3 available from all SWEPOS stations during 2016.

SWEPOS also offers a single frequency network DGNSS Service, which in line with some of the national geographical data from Lantmäteriet is available as open data from 2016. This service as well as the network RTK service are since June 2012 utilising Trimble Pivot Platform GNSS Infrastructure Software and operating in virtual reference station mode. Distribution of GPS L5 and L2C signals using RTCM MSM are planned during 2016. Galileo RTK tests with single station setup are ongoing and the implementation of Galileo in the software for the network RTK service is also discussed with the supplier.

6 Implementation of SWEREF 99

SWEREF 99 was adopted by EUREF as the realisation of ETRS89 in Sweden at the EUREF 2000 symposium in Tromsö (Jivall & Lidberg, 2000). It is used as the national geodetic reference frame since 2007 and has been used for Swedish GNSS services since 2001.

By defining SWEREF 99 as an active reference frame we are exposed to rely on the positioning services of SWEPOS, like the network RTK service. All alterations of equipment and software as well as movements at the reference stations will in the end affect the coordinates. In order to be able to check all these alterations, so-called consolidation points have been introduced by Lantmäteriet (Engberg et al., 2010). The approximately 300 so-called SWEREF points from the RIX 95 project are used for this purpose and they are re-measured in a yearly programme with 50 points each year. The large project RIX 95 lasted 1995–2008 and involved GPS measurements on totally 9029 control points.

[15] RINEX = Receiver Independent EXchange format

Station dependent errors at the SWEPOS-stations are limiting factors for height estimation in SWEREF 99. In order to investigate such errors and find corrections for it, we have carried out station calibration campaigns, in situ calibrations, on a selection of the original SWEPOS stations. Last year (2015) six stations were measured including both the pillar and mast monuments and all campaigns have been analysed. The analysis revealed height errors of approximately 1 cm both for mast and pillars when not taking the station dependent effects into account in a solution based on ionosphere free linear combination with estimated troposphere parameters (Lidberg et al. 2016).

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 muni-ci-palities have started the process to replace their old reference frames with SWEREF 99 and actions are taken to start it in the remaining ones. The number of municipalities that have finalised the re-placement has increased from 276 to 282 during the last year.

To rectify distorted geometries of local reference frames, the municipalities utilise correction models created with the help of Lantmäteriet in combination with trans-formation parameters obtained from RIX 95. The rectification is made by a so-called rubber sheeting algorithm and the result will be that all geographical data are positioned in a homogenous reference frame, the national SWEREF 99.

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). The network consists of about 50,000 benchmarks, representing roughly 50,000 km double run precise levelling measured by motorised levelling technique.

Since the beginning of the 1990's, a syste-matic 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 re-measurements of the 300 SWEREF points described in Chapter 6. The levelling network has been slightly extended during 2015 with a new levelling line on the south part of the Öland island in the Baltic Sea.

The work with implementing RH 2000 among different authorities in Sweden is in progress (Kempe et al., 2014). More than 80 % of the 290 Swedish municipalities have, mainly 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 approximately 200 municipalities have finalised the re-placement for all activities, which is approximately 30 more than by the time for the previous EUREF Symposium.

8 Geoid Determination

The national Swedish geoid model SWEN08_RH2000 was released in the beginning of 2009. It was computed by adapting the Swedish gravimetric model KTH08 to SWEREF 99 and RH 2000. KTH08 was computed in cooperation between Lantmäteriet and Professor Emeritus Lars E. Sjöberg and his group at KTH[16] in Stockholm. The GNSS/levelling adaption was made by utilising a large number of geometrically determined geoid heights, computed as the difference between heights above the ellipsoid in SWEREF 99 determined by GNSS and levelled normal heights in RH 2000. The standard uncertainty of SWEN08_RH2000 has been estimated to 10–15 mm every-where on the Swedish mainland with the exception of a small mountainous area to the north-west, where the standard

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

uncertainty is larger, probably around 5–10 cm.

According to Geodesy 2010, the ultimate goal is to compute a 5 mm (68 %) geoid model by 2020. To reach this goal – to the extent that it is realistic – work is going on to establish a new gravity network/ system as well as to improve the Swedish detail gravity data by making new gravity measurements. New measurements have for instance been performed on Lake Vänern (Ågren et al., 2014a) and in the Swedish mountains to the north-west.

Another important geoid activity is the *NKG2015 geoid model project*, which is made in international cooperation under the umbrella of the NKG Working Group of Geoid and Height Systems. The goal is to compute a new common gravimetric (quasi)geoid model over the Nordic and Baltic countries (Ågren et al., 2015). The first major part of the work, which was to update the NKG gravity database including the whole area around the Baltic Sea, was finalised in 2014. A new GNSS/levelling database and a common DEM[17] have also been created. The computation was made independently by five computation centres, from Sweden, Denmark, Finland, Norway and Estonia, using different regional geoid computation methods, software and set-ups. At the NKG Working Group meeting in March 2016, the final computation method and set up was selected. The final quasigeoid model will now be computed as soon as possible, after correcting some recently discovered data problems. The final model is planned to be published during 2016, but the name will be NKG2015 (as the model only contains data collected up to 2015). The final NKG2015 geoid model is then planned to be used as underlying gravimetric model for the next Swedish geoid model SWEN16_RH2000, which will as before be especially adapted to the Swedish reference frames SWEREF 99 and RH 2000.

9 FAMOS

Lantmäteriet is also engaged in the EU project FAMOS[18]. The main purpose of FAMOS is to increase the safety of navigation in the Baltic Sea, mainly by finalising hydrographic surveying in those areas that are of interest for commercial shipping. Another aim is to improve navigation and hydrographic surveying with GNSS based methods in the future. In activity 2 (*Harmonising vertical datum)* of the project, the main goal is to improve the geoid 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 from the hydrographic surveying vessels, both to check and improve the existing data as well as to fill in empty areas. According to the plan, a new validated FAMOS geoid model will be released by 2020. The first part of the project (FAMOS Freja) lasts from 2014 to 2016.

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

In FAMOS, Lantmäteriet has so far mainly been involved in coordination, planning and support of the marine gravity measurements, as well as with evaluation of existing gravity data, geoid computation and work with databases. Figure 9.1 illustrates a harbour tie measurement.

[17] DEM = Digital Elevation Model

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

During the coming years, Lantmäteriet will, in addition to the above, acquire a marine gravimeter, connect Swedish tide gauges to RH 2000 and contribute to the testing and evaluation of different real time GNSS navigation methods at 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 Göteborg (Gtbg) which no longer is in use, have been observed by Lantmäteriet since 2007. The observations have been carried out with an absolute gravimeter (Micro-g LaCoste FG5 - 233), which Lantmäteriet purchased in the autumn of 2006. 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[19].

All Swedish absolute gravity sites for FG5 (except for Göteborg) are co-located with reference stations in the SWEPOS network. Onsala is also co-located with VLBI[20], as well as a new installed tide gauge (in 2015). Skellefteå, Smögen and Visby are also co-located with tide gauges.

Absolute gravity observations have also been performed abroad, namely on two Danish sites, one Finnish site, two Norwegian sites, three Serbian sites, three sites in Republic of Macedonia and four sites in Bosnia and Herzegovina. Furthermore, seven inter-comparisons have been carried out; four times in Luxembourg with 17–25 other gravimeters, one time with 22 other gravimeters in Paris and twice with four other gravimeters in Wettzell.

The establishment of a new Swedish fundamental gravity network is going on (Engfeldt 2016a). The work started in 2011 in co-operation with IGiK[21], using their absolute gravimeter A-10 – 020 for the observations. 97 sites have been measured in co-operation with IGiK until 2015. Some relative measurements and some calculations concerning the land uplift for the FG5 sites remain until it is time to define the system (Engfeldt 2016b).

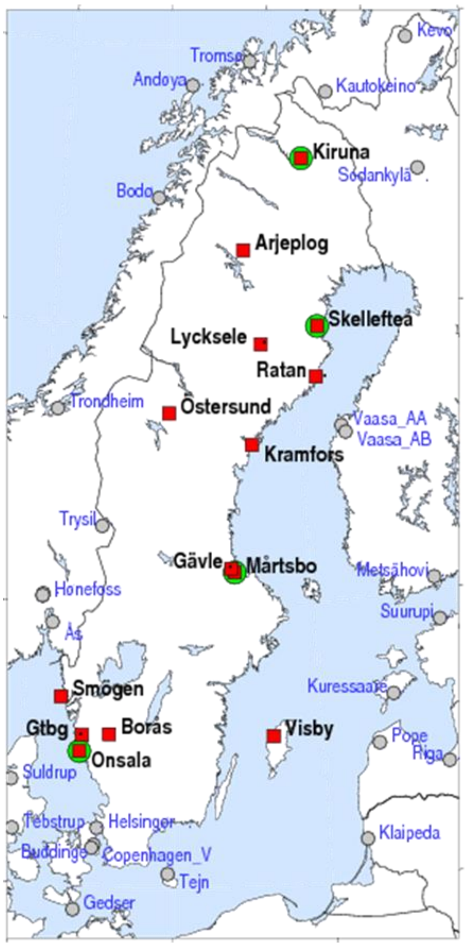

Figure 10.1: *The 14 absolute gravity sites (for FG5) in Sweden (red squares) and sites in neighbouring countries (grey circles). The four sites with time series more than 15 years long have a green circle as background to the red square.*

At Onsala Space Observatory of Chalmers University of Technology, a super-conducting gravimeter was installed during 2009. The investment should be seen as an additional important instrument at the Onsala geodetic station, but also in view of the efforts regarding absolute gravity for studying temporal

[19] GIA = Glacial Isostatic Adjustment

[20] VLBI = Very Long Baseline Interferometry

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

variations in observed gravity. This gravimeter has been calibrated four times by Lantmäteriet's FG5, latest in May 2015.

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 (Olsson et al., 2015).

Research regarding the 3D geometric deformation in Fennoscandia and adjacent areas is foremost done within the BIFROST[22] effort (Johansson et al., 2015; Lidberg et al., 2015). Reprocessing of all observations from permanent GPS stations is a continuous activity. A new velocity field based on at least 150 stations is currently under preparation using both the GAMIT/GLOBK and GIPSY software.

NKG2005LU, the Nordic land uplift model that includes the vertical component only, will be substituted with the new model NKG2016LU. This new land uplift model is developed as a combination and modification of the mathematical (empirical) model of Olav Vestøl and a new geophysical model currently developed within an NKG activity (Steffen et al., 2014). This improved geophysical model (NKG201xGIA) will deliver both vertical and horizontal motions, as well as gravity-rates-of-change and geoid change. Current work focused on the search for the best ice and earth model combinations to be used as underlying geophysical model for NKG2016LU. This geophysical model is called NKG2016GIA_prel0306 and fits both the recent BIFROST uplift velocity field as well as relative sea-level data equally well. It consists of 1D spherical earth model with 160 km lithospheric thickness, $7x10^{20}$ Pa s upper mantle viscosity and $7x10^{22}$ Pa s lower mantle viscosity together with an ice model provided by Lev Tarasov from Memorial University of Newfoundland, Canada. This model will be developed into a 3D GIA model that shall also fit the horizontal velocity field as well as gravity observations. In future, uncertainty estimates will be provided for all fields of interest. Within this NKG modelling activity, a database of relative sea levels in northern Europe will be made publicly available.

Lantmäteriet is involved in the EUREF working group on "Deformation models", which aims at obtaining a high resolution velocity model for Europe and adjacent areas and significantly improving the prediction of the time evolution of coordinates. This will help overcome the limitations in the use of ETRS89 and also lead to a general understanding of the physics behind such a velocity field. An inventory of published velocity fields as well as a website (www.lantmateriet.se/en/Maps-and-geographic-information/GPS-and-geodetic-surveys/Reference-systems/EUREF-working-group-on-Deformation-models) are established. The velocity model including deformations will be developed once the densified EPN velocity field becomes available.

Since January 2015, Lantmäteriet contributes via a Service Level Agreement to the EU-financed Horizon 2020 project EGSIEM[23]. Here, the global GIA correction for gravity missions such as GRACE will be provided by Lantmäteriet. This work commenced in November 2015. Several regional ice history models have been provided by various colleagues from all over the world. A test version of the GIA correction is planned for January 2017.

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

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

12 Further Activities

Lantmäteriet is working on a series of handbooks for mapping and surveying called HMK ("Handbok i mät- och kartfrågor"), with the aim to contribute to an efficient and standardised handling of surveying and mapping issues in Sweden (Alfredsson et al., 2014). The handbooks are, together with three introduction documents, divided into two main parts, geodesy and geodata capture. The geodetic part was published as four documents in February 2016 and will be supplemented with a fifth document in late autumn 2016. The first document contains information about the Swedish geodetic infrastructure and the other three are guidelines in different topics; control networks, RTK and terrestrial surveying. The fifth document will support the procurement process and guide the users into the surveying methods in the guidelines. All documents can be downloaded free of charge from www.lantmateriet.se/hmk.

Sweden (and Lantmäteriet) will organise NKG Summer School in Båstad starting 29th August to 1st September. Last time we arranged the Summer school, it is organised every fourth year and moves between the Nordic countries, the theme was GPS. This happened in 1996 with prominent speakers as Marcus Rothacher, Geff Blewitt, Elizabeth Cannon and more. The theme this time will be GNSS. More information can be found at www.lantmateriet.se/nkg2016.

Lantmäteriet is also responsible for the production of a new Swedish national elevation model. The mainly used method for the data capture is airborne laser scanning and the production started in July 2009. 95 % of the Swedish territory has so far been scanned, where the remaining part is mostly in the mountainous part of Sweden. The scanning is expected to be finalised during 2016.

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

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[25] IAG = International Association of Geodesy