National Report of Sweden to the EUREF 2008 Symposium

– geodetic activities at Lantmäteriet, the National Land Survey of Sweden

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1 Introduction

At Lantmäteriet (the National Land Survey of Sweden) 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, the improvement of Swedish geoid models and the finalising of the project RIX 95. Large efforts are also carried out concerning the operation and expansion of the Swedish network of permanent reference stations SWEPOS™ and its services. Some of the activities are done within the framework of NKG[2].

[1] ETRS = European Terrestrial Reference System

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

2 Contributions from Lantmäteriet to EPN[3], ECGN[4] and EUVN_DA[5]

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[6] network. Skellefteå (SKE0) is proposed to be a new IGS station. All the Swedish EPN/IGS stations are equipped with dual-frequency GPS[7]/

[3] EPN = EUREF Permanent Network

[4] ECGN = European Combined Geodetic Network

[5] EUVN_DA = European Vertical Network, Densification Action

[6] IGS = International GNSS Service

[7] GPS = Global Positioning System

GLONASS[8] 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 in Gothenburg. NKG EPN LAC contributes with weekly and daily solutions based on final IGS products. In addition, near-real time solutions based on hourly data and IGS ultra-rapid products are now being introduced. The EPN-subnetwork processed by NKG LAC consists (June 2008) of 47 stations concentrated to northern Europe.

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[9]2007. NKG has also created a Nordic densification called NGOS[10] (Lilje et al., 2008a).

In 2007, the Swedish EUVN_DA contribution was further densified with 49 points, including mountainous areas in the north-west parts of the country.

So far Sweden has delivered 134 stations to the EUVN_DA, see Figure 1. 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 accuracy of the given gravity values is generally about 1-2 mgal (68 % confidence level).

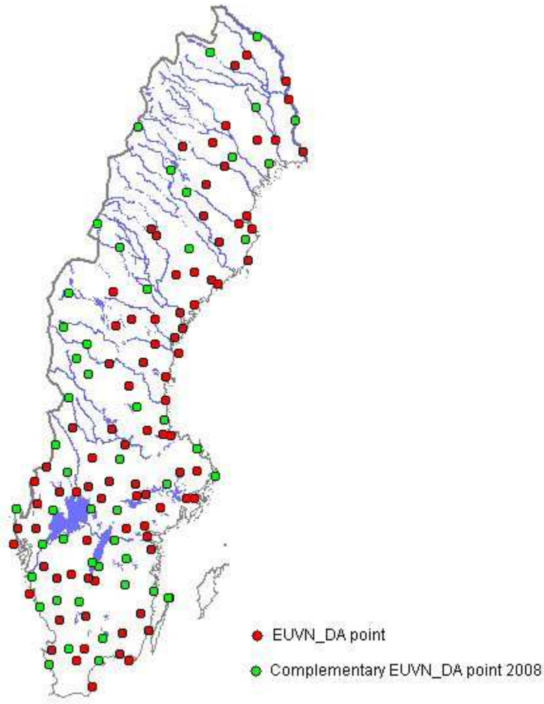

Figure 1: *Swedish EUVN_DA sites (March, 2008).*

3 Network of Permanent Reference Stations (SWEPOS™)

SWEPOS is the Swedish network of permanent GNSS[11] stations, providing real-time services on both metre level (DGPS[12]/DGNSS[13]) and centimetre level (network RTK[14]), as well as data for post-processing (Norin et al., 2008 and Jämtnäs et al., 2008), see www.swepos.com.

The purpose of SWEPOS is to:

- provide single- and dual-frequency data for relative GNSS measurements

[8] GLONASS = Globalnaya Navigatsionnaya Sputnikovaya Sistema

[9] EVRS = European Vertical Reference System

[10] NGOS = Nordic Geodetic Observing System

[11] GNSS = Global Navigation Satellite Systems

[12] DGPS = Differential GPS

[13] DGNSS = Differential GNSS

[14] RTK = Real Time Kinematic

- 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.

In August 1993, SWEPOS consisted of 20 stations and in 1996 a 21st one (Borås) was added. These 21 original SWEPOS stations together with 11 newer stations fulfil the requirements for class A type. These 32 stations are build 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.

The rest of the SWEPOS stations are classified as class B and are mainly established on top of buildings for network RTK purposes. They have the same instrumentation as class A stations, but with somewhat less redundancy. This means that the total number of SWEPOS stations is 161 (June 2008).

All SWEPOS stations are equipped with dual-frequency GPS/GLONASS receivers and with antennas of Dorne Margolin design.

The SWEPOS Network RTK Service was launched on January 1st 2004 and covers almost all the populated areas of Sweden. The service broadcasts RTK data for both GPS and GLONASS and has today (June 2008) approximately 1000 subscriptions.

The coverage in spring 2008 is shown as the green area in Figure 2 and the intended extended coverage for 2009 with about 20 new stations is shown as the yellow area in the same figure.

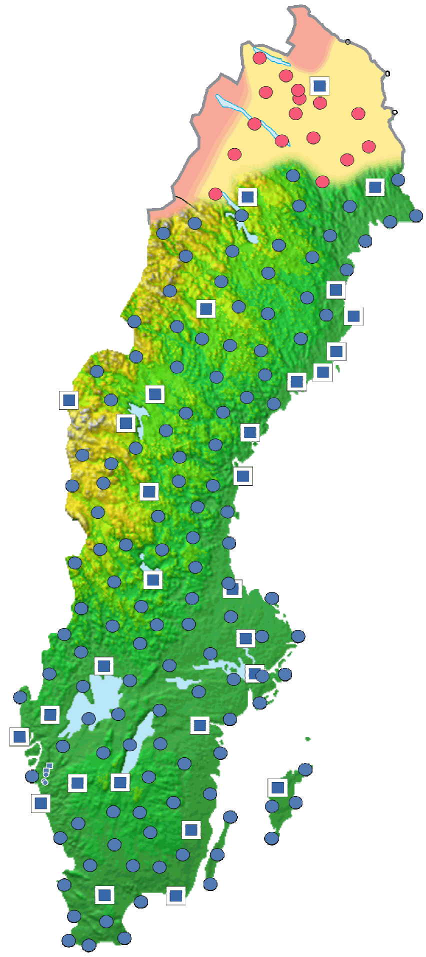

Figure 2: *The SWEPOS network in June 2008. Squares are the 32 class A SWEPOS stations. Blue dots are the rest of the existing stations. Red dots are stations that are planned to become operational during 2008-2009.*

So far the network RTK service is only using the VRS[15] technique. A diploma work has during the spring 2008

[15] VRS = Virtual Reference Station

compared the use of VRS and RTCM 3.1 network RTK messages in the service (Johansson & Persson, 2008).

A recent trend is the increasing use of the service for machine guidance and precision navigation, most notably in the form of flexible and redundant services that are tailor-made for large-scale projects.

During February 2008, a survey of the users of SWEPOS and its services was carried out by questionnaire. The survey had special focus on SWEPOS Network-RTK Service. Close to 400 answers were received from the 950 users that the service had at that point. Most of the users are very satisfied with the performance and "customer support" of the network RTK service and consider it to be worth its price.

SWEPOS also offers a single frequency Network DGNSS Service that was launched on April 1st 2006. Both services are using the network RTK/DGNSS software GPSNet from Trimble and GSM[16] or GPRS[17] (i.e. mobile Internet connection) as the main distribution channels. SWEPOS also offers an automated post-processing service, based on the Bernese software (Kempe & Jivall, 2002).

Through the work in NKG, NORPOS Web will soon be launched. It is a Nordic web portal for GNSS data for post-processing from the Danish, Norwegian and Swedish reference stations. Future plans are to facilitate the use of national positioning services in border areas, as well as the potential development of common Nordic positioning services (Engfeldt et al., 2006).

[16] GSM = Global System for Mobile communication

[17] GPRS = General Packet Radio Service

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 GPS 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 RIX 95

The national project RIX 95, involving GPS measurements on triangulation stations and selected local control points, is after 13 years almost finalized and will be completed this year.

The outcome of the project is 9029 control points determined in SWEREF 99 and other existing national reference frames, see Figure 3. The outcome also consists of transformation relations between these reference frames as well as transformation relations to local reference frames used by the municipalities.

The GPS network is adjusted in the following national reference frames:

- SWEREF 99
- RT 90 (old national horizontal reference frame)
- RHB 70 (old national height system)
- RH 2000 (new national height system)

The horizontal transformation relations (SWEREF 99 - RT 90 and SWEREF 99 - local reference frames) are based on the so called direct projection with Transverse Mercator (Engberg & Lilje, 2006).

The vertical transformation relations (SWEREF 99 – RHB 70 and SWEREF 99 – RH 2000) are based on geoid models, see Section 6.

The remaining work to be completed this year is the adjustment of the GPS network in RH 2000 and to compute transformation parameters for the last 10-15 (out of totally 290) municipalities.

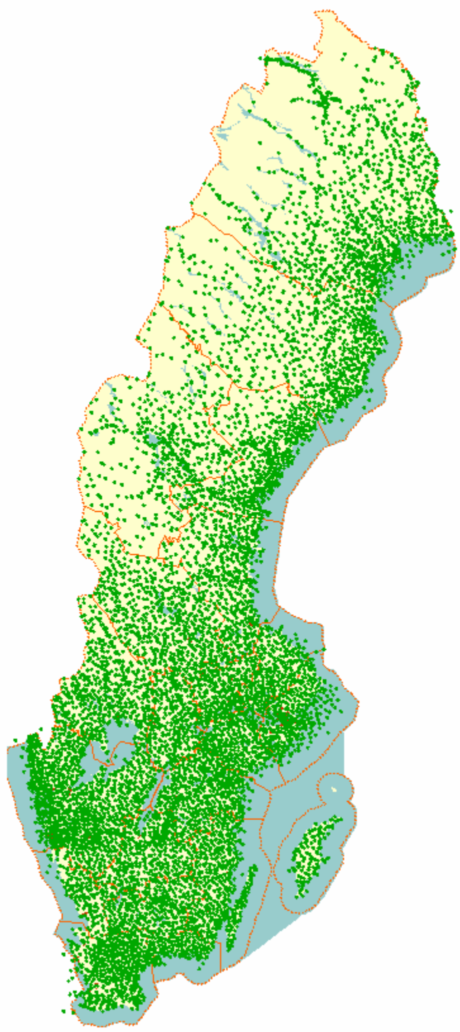

Figure 3: *9029 control points, determined within the RIX 95 project.*

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. Approximately 200 of the 290 Swedish municipalities have started the process to replace their old reference frames with SWEREF 99. So far, 55 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 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[18]).

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., 2006). 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.

To connect the national network to NAP[19], the adjustment was made in a common adjustment of the nodal points in a data set called the BLR[20], 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[21]-database.

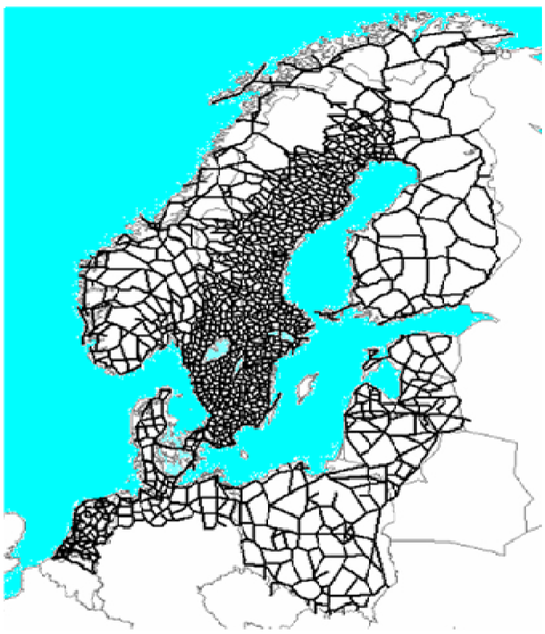

Figure 4: *The BLR data set.*

[18] GIA = Glacial Isostatic Adjustment

[19] NAP = Normaal Amsterdam Peil

[20] BLR = Baltic Levelling Ring

[21] UELN = United European Levelling Network

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 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 60 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 9 municipalities have finalised the replacement for all activities.

6 Geoid Models

A new geoid model, to transform heights above the ellipsoid in SWEREF 99 to heights in RH 2000, was developed and introduced in 2005. The model was first called SWEN 05LR (Ågren & Svensson, 2006), but was later renamed SWEN05_RH2000.

The model was computed by adapting the gravimetric geoid model NKG 2004 to the reference systems SWEREF 99 and RH 2000 using 1178 GPS/levelling geoid heights. A representation of the fit residuals is also included in the model, so that the users will receive heights as close as possible to RH 2000. The expected standard error is 1.5-2 cm in most parts of the country and a little higher in the mountainous areas to the north-west.

The geoid model SWEN05_RH2000 has also been adapted to the old Swedish height system RH 70 by applying an accurate model for the height system difference. The resulting model is called SWEN05_RH70.

Since 2005 a considerable amount of work has been spend on developing a new national geoid model for Sweden. An improved gravimetric model has been computed by Lantmäteriet in cooperation with the Royal Institute of Technology (KTH[22]) in Stockholm using the method developed at KTH (Sjöberg, 1991 and Sjöberg, 2003). This work is presented in more detail in Ågren et al. (2008). The new gravimetric model is planned to be used later this year to compute the next Swedish geoid model pair SWEN08_RH2000 and SWEN08_RH70 by taking advantage of an updated and extended set of GPS/levelling observations.

The work to improve the gravimetric model is also meant to contribute to the on-going efforts of the NKG Working Group for Geoid Determination, to compare different geoid determination methods. The results for the KTH method are promising and a standard error as low as 2.0 cm is obtained in a 4-parameter fit (without residual interpolation) to GPS/levelling (Ågren et al., 2008).

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, 11 of the sites have been observed by Lantmäteriet and observations have also been done on 1 Finnish site, 2 Norwegian sites, 3 Serbian sites and at an intercomparison with 19 other gravimeters in Luxembourg. All Swedish sites are co-located with permanent 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[23]. 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[24], 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, efforts are currently made to obtain a superconducting gravimeter. The invest-

[22] KTH = Kungliga Tekniska Högskolan

[23] VLBI = Very Long Baseline Interferometry

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

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

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

[27] FGI = Finnish Geodetic Institute, Finland

ment 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.

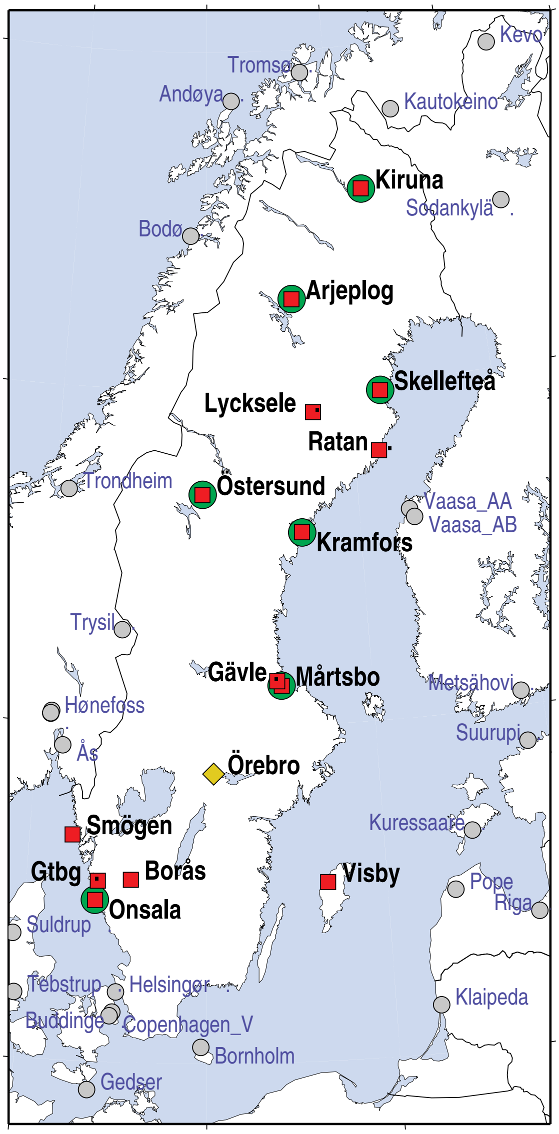

Figure 5: *Absolute gravity sites in Sweden (red squares), planned new site (yellow diamond) and sites in neighbouring countries (grey circles). Sites observed every year since 2003 have a green circle as background to the red square.*

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 & Johansson, 2007, Lidberg et al., 2007 and Lidberg et al., 2008). The results agree with an updated geophysical, meaningful GIA model at the sub-mm/yr level, see Figure 6.

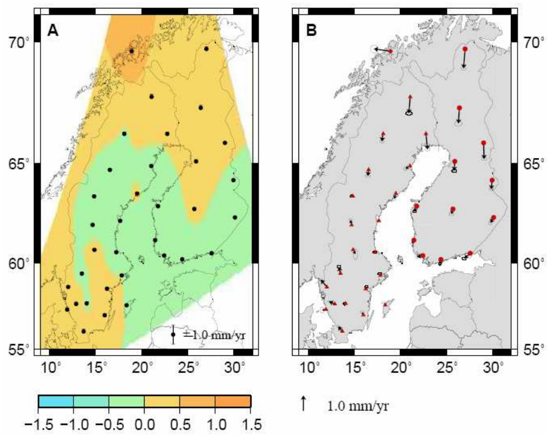

Figure 6: *Residuals in vertical (left) and horizontal rates (right), determined by subtracting predictions obtained by the best fit model from the observations.*

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

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

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., 2006 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 present Swedish digital elevation model, 50 metre grid, was established during a period of 12 years, 1982-1994. An inventory of the DEM[29] accuracy was performed 2001. The results, about 2 m RMS against check points, clearly indicated a need for an improvement of the DEM accuracy to meet requirements from governmental as well as commercial organisation.

The revision concept is based on airborne laser scanning (Klang & Burman, 2005). Irregular data will be acquired from app. 3000 m and the orientation of each measured point will be calculated using an integrated concept of an INS[30] and GNSS, see Figure 7.

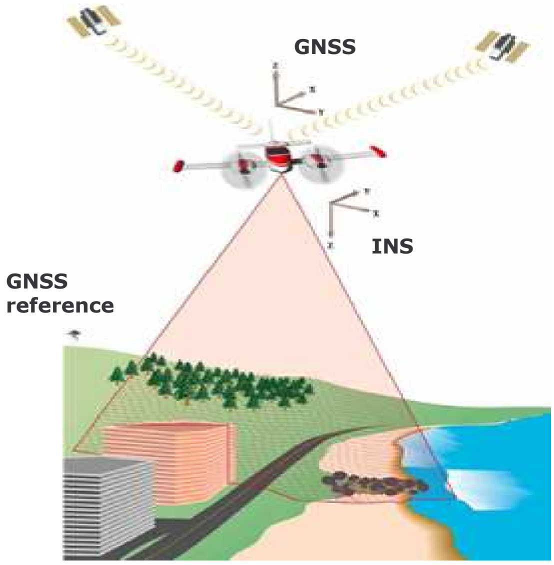

Figure 7: *Airborne laser scanning with registrations from INS and GNSS.*

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

The time schedule is estimated to 7 years and the production, 450,000 km^2, will be finished in 2015. The financing will be based on governmental founding and the products will be "free" available in accordance to INSPIRE[31] directives (Swedish interpretation).

[29] DEM = Digital Elevation Model

[30] INS = Inertial Navigation System

[31] INSPIRE = Infrastructure for spatial information in Europe

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

[33] EUGIN = European Group of Institutes of Navigation

[34] ENC = European Navigation Conference

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[35] IAG = International Association of Geodesy

[36] IUGG = International Union of Geodesy and Geophysics

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