Validation and Preparation of Data for the Computation of a New Height System in Sweden

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ABSTRACT

The production work in the third precise levelling of Sweden is now completed after 25 years. Some 50 000 km has been levelled using the motorised levelling technique, and some 50 000 new benchmarks have been established. A lot of effort was put in to the project in the beginning to create a digital production line and the same production line as well as measuring technique has been used throughout the project. The main task now is to work towards the creation of a new height system in Sweden.

A project was organised in 2001 focused on validating the data and looking for systematic errors. This project has ended and a new project has started discussing how to model the land uplift that is affecting Sweden.

This paper will present some results from 25 years of motorised levelling. It will also discuss the major work of quality assurance of the levelling data and the problems that we have experienced. It will also discuss the necessary next steps in order to complete the new height system in Sweden.

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1. INTRODUCTION

1.1 Background

The fieldwork of the third precise levelling in Sweden started in 1979, and the last lines in the network were measured in 2001. From the beginning the project was scheduled for 10 years, but due to financial priorities the completion has been delayed. The first precise levelling performed 1886-1905 was replaced in 1951-1967 by the second one. The reason was that the network was not dense enough to meet the requirements from the users. The coverage of the country was very poor, and the quality of the heights was low. The reasons to perform the third levelling were mainly the same, even though the demands from the users for better coverage and accessibility were even stronger this time. The second levelling was mainly located along railroads, which made the benchmarks hard to reach. In course of time many benchmarks had also been destroyed. The aim of the new levelling was therefore to create a network covering the whole country, dense enough to allow all the local users to connect their measurements to easy accessible benchmarks. Another aim was to achieve a better estimation of the land uplift by comparing the new levelling with the old ones.

A very big advantage with the third precise levelling is that the whole work is carried out with the same technique and the same type of equipment, which gives a very good homogeneity to the network.

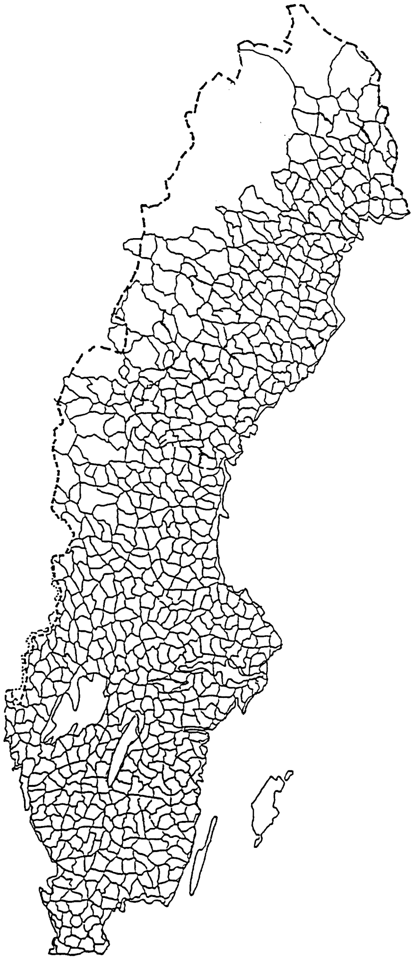

Fig 1. The net configuration of the third precise levelling of Sweden.

Since the field measurements are almost completed, the most effort is now concentrated on validation and preparation of data for the final adjustment.

1.2 The Network

The network consists of about 50 000 km double run levelling and the number of benchmarks is 50 800. The distance between the benchmarks is about 1 km. The network is covering the whole country with closed loops, with a circumference of approximately 120 km, except for the mountain areas in the north-west parts of the country, where the roads are very few and makes it impossible to achieve the same density (fig 1). In these parts of the country the population is also very sparse. Lines in our neighbouring countries Norway and Finland are included in the network, in order to get closed loops along the borders. Similar projects are going on in these countries, so their measurements can be used since the quality is comparable to the Swedish measurements. The network is in principle a relevelling of the second precise levelling, and in addition to that a considerably large expansion of the 10 000 km which was the extent of the second precise levelling. The network was planned in co-operation with the local users in order to increase the utility of the points for connections of local measurements.

2. PRODUCTION WORK

2.1 The Measurements

The measurements are carried out with the motorised levelling technique, using one instrument car and two rod cars (fig 2). The instrument is the Zeiss Jena NI002, with a 360 degree rotating eyepiece and a reversible pendulum giving a quasi absolute horizon. The rods are 3.5 m invar staffs with double scales. For connecting to the benchmarks, separate 3.0 m invar rods are used.

Fig 2. Setup with the motorised levelling technique.

Accessible points from the former precise levellings are connected to the network in order to determine the land uplift. It has also been necessary to provide the users with heights from the third levelling as work goes on, since we cannot ask them to wait for more than 20 years for the new height system to be released. Those heights are preliminary heights in the existing height system, and they are calculated in blocks after each field season. The heights are considered as sufficient for local use until the new height system is released.

All measurements are double run levelling. The rejection limit is always 2√L (L in km). If the measurements of a section exceed this limit, the section is measured again. About 7 % of all sections have been remeasured for this reason. When connecting the measurements from one year to another the demands are even stronger.

2.2 Storing Data

The whole production line is digital, all the way from the observations to the archive. All the observations in the field are stored in data loggers together with other information concerning the measurements. After each day the data is checked and stored in a local database in the field. Every week the data is transferred to Lantmäteriet (National Land Survey of Sweden), and each single measurement is stored in the archive database. Graphical presentations of the measurements are made in the GIS software MapInfo. For each measured section there is about 50 different items stored in the database. The levelling database today contains more than 120 000 single run sections.

In addition to the levelling database there is a benchmark database, containing all information regarding the benchmarks such as type of marker, benchmark number, description of the location, a digital sketch, height and other information needed to find the point and to identify it and use it. All this information can be printed out on a form. A digital map can also be printed, showing all benchmarks and their numbers located on a specific map sheet.

3. VALIDATION AND PREPARATION OF DATA

A lot of effort is now put into preparing the data from the third precise levelling of Sweden for the final adjustment. The big amount of data, collected during more than 20 years of levelling (stored in a Microsoft Access database), has to be complete, well defined and structured in a way that makes it easy to handle. This chapter will give a short description of that work.

3.1 Observations with Different Purposes

One observation of a section is the mean value of the height difference from one forward and one backward measurement of that section. All observations are categorised according to why they have been measured. Except from the most common category, ordinary third precise levelling observations, there are for example control observations, observations commissioned by other organisations or observations made in purpose to replace destroyed benchmarks with new ones. This categorisation makes it easy to switch from one type of data to another when handling data for different purposes. In the final adjustment, for example, only “ordinary third precise levelling” observations will be used.

3.2 One Observation per Section

For different reasons some sections are observed more than one time. Since the adjustment model will give double weight to a section with two observations, the aim of this work is that for every section in the net should one and only one observation be used. If a section is observed more than one time, the reason for reobservation is investigated, cleared out and the first valid observation of that section is chosen. The other observations for that section get a mark that makes them not valid for the final adjustment. In some cases there are sections with no valid observation. That might be because of careless mistakes during the fieldwork or some other reason. In these cases a new observation has to be done. When this work is completed there will be one valid observation for every section in the net.

3.3 Corrections

All observations are corrected for temperature, earth curvature and earth tide. Before and after every field season the rods are calibrated. A linear interpolation is made between these calibrations and corrections are applied to all observations.

3.4 Systematic Errors

After having applied the corrections mentioned above, the production line we are using, built on the motorised levelling technique, is not supposed to leave many systematic errors in data. But nevertheless it is interesting to investigate this big amount of data, to see if it is possible to find anything that indicates systematic effects.

So far we have, for example, been studying sections that didn't make the rejection limit the first time they were observed. Do the conditions for these observations, with respect to for example the surface of the road, temperature, length of the section or height difference, differ significantly from the rest of the material? Maybe we could say that there is a bigger proportion remeasurement with increasing length of the section (fig 3) and increasing height difference. There also seems to be a slightly higher level of relevelling when the sun is present during one of the forward or backward levelling. The reasons for the relevelling are however not yet determined.

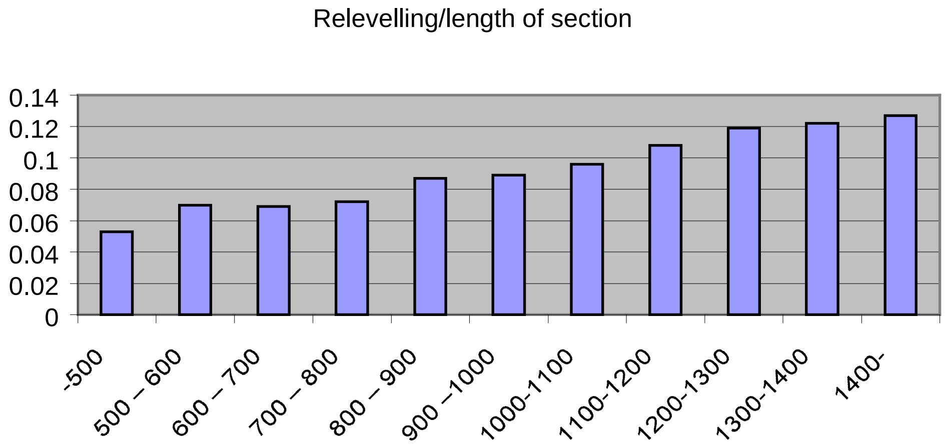

Fig 3. Percentage relevelling compared to length of section (meter).

Some investigations have also been done concerning the rods, for example how the moisture in the wooden frame of the rod varies during the field season, and how that effects the scale of the rod. For this experiment a rod was first put in a water bath for a couple of weeks. Then it was taken out from the bath and kept in the calibration room at Lantmäteriet. As the rod got dryer, measurements of the moisture in the wood and calibrations of the scale were performed simultaneously. This process showed how the length of the scale changed with the moisture in the wood (fig 4). After that the rod was put outdoors for one whole field season. About once a week the moisture in the wood was measured to see how “wet” the rods become during normal field conditions.

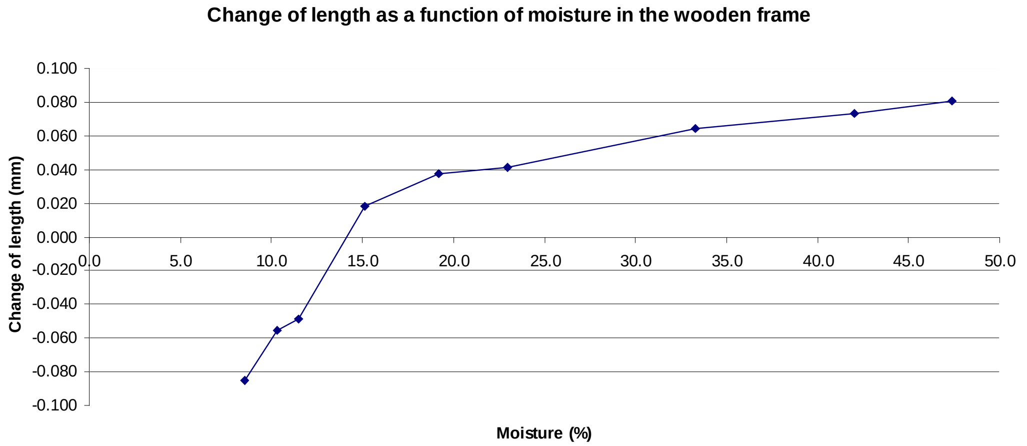

Fig 4. Change of length of the invar scale, as a function of the moisture in the wooden frame.

From these investigations came out that the scale of the rod became some 0,16 mm shorter as the rod went from ”very wet” to ”dry”. The moisture in the rod seems to increase quite linear during a field season, so our usual calibration procedure will compensate quite well for these variations in length.

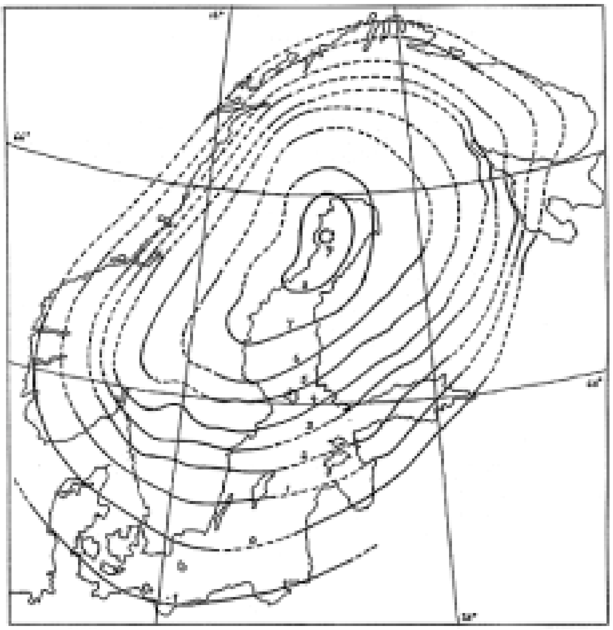

Fig 5. Apparent postglacial uplift of Fennoscandia 1892-1991 in mm/yr (Ekman, 1996).

Future investigations (year 2002) will focus on settings and refraction. We think that the different readings from the left and the right scale during a set up can give some clues to the mystery of settings.

3.5 Land-Uplift

Since Sweden is located in an area with post-glacial rebound, this has to be considered in the computation work. The land uplift varies from 0 to 9 mm/year, relative the mean sea level, with the smallest values in the south and the biggest near the coast in Northern Sweden (fig 5). This means that the shape of Sweden is constantly changing with the northern parts ”coming up” relative the southern parts. A measured height difference is valid only for the time it is measured and then changes over time. Since the whole levelling net has been measured over a time of more than 20 years this effect from south to north is about 20 cm. This problem is dealt with by using a land uplift model to reduce all observations to a common epoch, as if they were all measured at the same time (more about land uplift models in chapter 4.1). The computed heights are then valid only for a certain epoch. With the land uplift model the height differences and heights can be recalculated to an optional (e.g. current) epoch.

3.6 Geopotentials

To reduce the effects of nonparallel level surfaces in the gravity potential field, all measured height differences are recalculated to geopotential differences. The gravity value for a section is the mean of the gravity values for the benchmarks at the ends of that section. The gravity value at each benchmark is determined by adding bouguer anomalies (from measured gravity data) to the normal gravity. The normal gravity is calculated with the International Gravity Formula 1930,

$$\gamma = 978049 \times \left(1 + 0{,}0052884 \times \sin^2 \Phi - 0{,}0000059 \times \sin^2 (2\Phi) \right) mgal$$

valid at the ellipsoid, and is then reduced to the approximate level of the bench marks. The bouguer anomalies are interpolated from the Swedish detail gravity net with a density of one station per 5×5 km.

3.7 Checking Loop Closing Errors

Common for all levelling networks is low redundancy (≈ 0,3). This makes the risk of accepting observations containing errors propagating into adjusted heights relatively high. To minimise that risk, it has been decided to relevel loops in the most ”high risk areas”. The smallest unit for this kind of remeasurement is one loop and the method for choosing loops to remeasure is by comparing the loop closing error with a rejection limit. By dividing the loop closing errors by $\sqrt{L}$ (L is the length of the loop in km) we get normalised loop closing errors. The distribution of normalised loop closing errors in the Swedish net is shown in figure 6.

This distribution seems to be close to the normal distribution from which it can be shown that a suitable rejection limit for remeasuring 5% of the net is:

$$1{,}96 \times \text{mean error in the whole net} \times \sqrt{L} \approx 1{,}96 \times 1{,}18 \times \sqrt{L} \approx 2{,}3\sqrt{L}.$$

Applying this rejection limit to the loop closing errors gives us 4.4 % of the loops (32 out of 735) to remeasure. Up till today about half of these loops have been remeasured and the results are what we hoped. Both the closing errors in the remeasured area and the mean error in the whole net are decreasing.

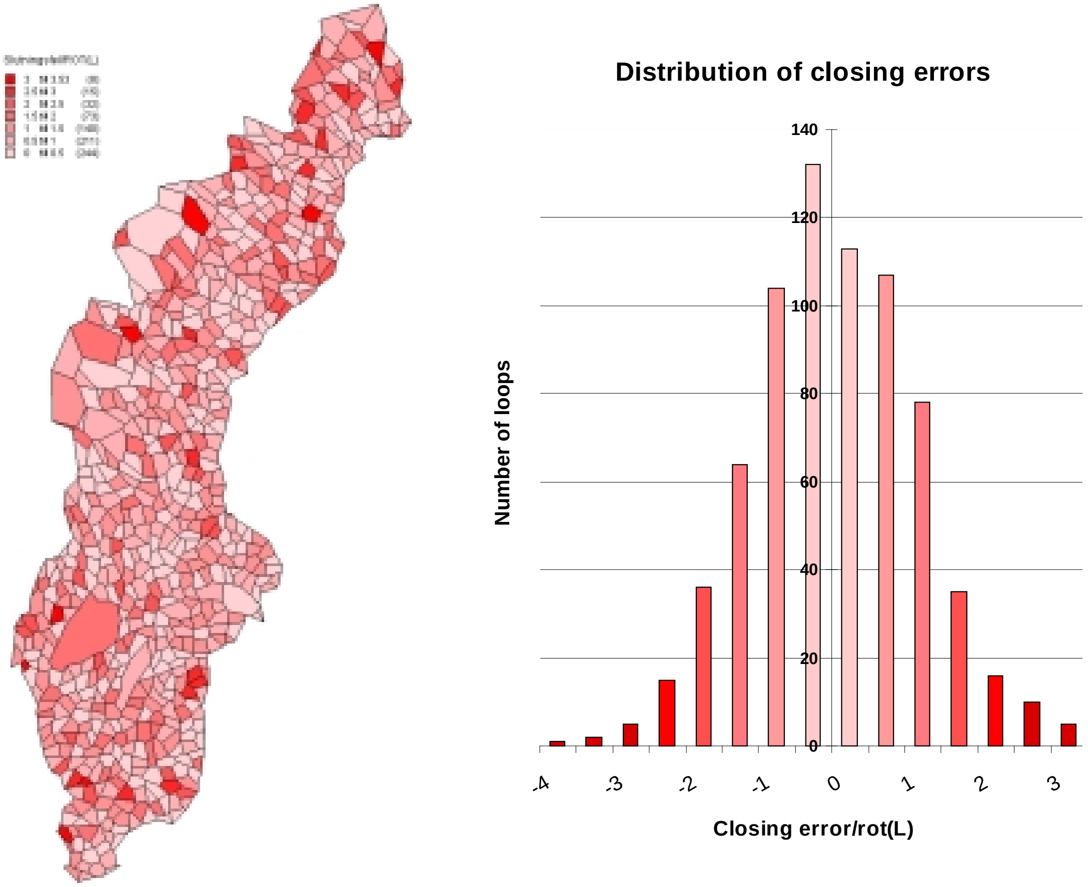

Fig 6. The distribution of normalised loop closing errors in the Swedish levelling net.

3.8 Preliminary Adjustment

As a last step of the validation and preparation of data, a preliminary adjustment has been performed. This gave us a first indication of how successful the validation and preparation has been and how well the whole project fits with its expectations. We can now be sure that all data ”runs smoothly” through the adjustment and that all benchmarks gets a calculated height. We also got an indication that the mean error in the observations (excluding the new measurements mentioned in chapter 3.7) seem to be around 1,18 mm/√km and the redundancy in the net 0,32. Including the new observations the mean error decreases a little.

4. TOWARDS A NEW HEIGHT SYSTEM

4.1 Modelling the Land-Uplift

As mentioned in chapter 3.5 it is important to have a model to describe the land uplift in Scandinavia. Modelling the uplift serves two purposes, it is needed to be able to reduce height measurements to a certain epoch and it is also of big importance for purely scientific purposes.

Today we are working with three different types of land uplift models:

- Land uplift model mainly based on geophysics and observations of historical seashores (Lambeck, 1998).
- Land uplift model mainly based on mareographs located along the seashore (Ekman, 1996).
- Land uplift model mainly based on repeated levellings.

The first two models mentioned are already available. The third type of uplift model, based on repeated levellings, is something that we are facing right now, as the third precise levelling of Sweden is becoming available. The greatest amount of work needed to create such a model is connected to validation and preparation of data from the first and second precise levellings of Sweden. It is of great importance that data from the three (or at least two) levellings are in the same data format and treated the same way with respect to reductions and corrections.

After evaluation of the three different types of models, the “best” one, or a combination of them will be chosen for the final adjustment

4.2 Choosing Parameters for the New Height System

Before introducing a new height system, some delicate choices have to be made:

- Reference (zero) point. Shall we choose Normaal Amsterdam Peil (NAP) as in our old height system and as parts of western Europe or shall we choose a zero level that, as good as possible, coincides with the mean sea level around Sweden?
- Kind of heights. Normal heights, as in big parts of Europe or orthometric heights with a clear physical meaning. There are also of course other height types but they are likely not to be interesting for the new height system.
- Permanent earth tides. Shall we choose a mean-, zero- or non-tidal geoid?
- Epoch for the new height system.

These choices have to be made before the final adjustment.

4.3 Software for the Adjustment

During the process of validation and preparation of data we have tested some different software for the adjustment. One software tested is X-net by X-position. We have also run the whole net through adjustment programs developed and maintained by the Swedish and Danish mapping authorities. The resulting heights of the benchmarks coincide very well between the different software. They all have different characteristics speaking for or against them when it comes to choose the software for the final adjustment. These characteristics can be for example the amount of statistics coming out from the adjustment, error control and graphical support. In the end probably a combination of two software with different characteristics will be used.

4.4 Final Adjustment

As there are at least two more field seasons left of remeasuring loops with big closing errors, the final adjustment can not be performed before the autumn 2003. When the fieldwork is finished though, everything else will be ready too, and the only thing left to do is to “press the button”.

5. AFTER THE FINAL ADJUSTMENT

5.1 Maintenance of the Network

A lot of money is invested in the production of the new height system. The whole investment is actually put in the benchmarks and their heights. If benchmarks are destroyed, the value of the network will decrease and if all benchmarks disappear the new height system is worthless. It is therefore of great importance that destroyed benchmarks, on a regular basis, are replaced with new ones. The maintenance of the network is performed according to a plan, where different parts of the network are maintained each year. This process has already started.

5.2 Introduction of the New Height System

Sweden consists of 289 municipalities. Most of the practical geodetic activities in Sweden (field measurements) are performed within their local networks. To get full benefit of the new national height system it is important that the municipalities connect their height systems to the national system. The benefits that this will lead to is for example:

- “stronger” local height systems,
- possibility to measure accurate heights with GPS,
- co-operation between neighbouring municipalities benefits if they work in the same height system,
- actors working over more than one municipality (e.g. road or railway authorities) has to deal with less co-ordinate systems.

The local authorities are responsible for their height networks and Lantmäteriet has no influence in their decision more than as advisor. However, there will probably be a lot of work for Lantmäteriet in terms of advice and help to local authorities when implementing the new height system. Preparations for this process will start in 2002 and hopefully accelerate in 2004.

5.3 Documentation

As we have been working with data from the first and the second precise levelling during the land uplift modelling, we have realised the big value of a good documentation. Therefore we will perform a documentation that, as good as possible, describes the whole process from planning the network via the measurements to the work with the final adjustment. As a good example serves the documentation of the Danish third precise levelling (Schmidt, 2000).

6. CONCLUSIONS

The measurements in the third precise levelling of Sweden are now completed after 22 seasons of fieldwork. During that period more than 120 000 single run sections have been measured for various purposes. In order to compile all those measurements relevant for computation of the new height system, a strict categorisation and valuation of all the measurements has been carried out. Thus we are sure to use the right observations. Corrections have also been applied to the observations.

Weak parts in the network are identified. Remeasurement of those areas is going on and will be completed within the next two years.

Possible systematic errors affecting the measurements have in some sense been investigated, and further investigations will be done, mainly concerning effects from refraction and settings.

Furthermore evaluation of different software has been carried out in order to find the best software appropriate for the task.

So after the remaining measures e g to decide the parameters for the height system, all the preparations should be complete in order to establish the new height system as soon as the weak parts are remeasured.

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BIOGRAPHICAL NOTES

Per-Ola Eriksson

Mr Eriksson graduated as a Survey Engineer from the Technical Institute in Härnösand, Sweden in 1966. Since then he has worked at the Geodetic Production Division at Lantmäteriet and its corresponding organisations with the national geodetic networks. He has participated in the development of the motorised levelling technique in Sweden from the early 1970s, and since 1988 he is responsible for the production of the whole precise levelling project in Sweden.

Mikael Lilje

Mr Lilje graduated in 1993 from the Royal Institute of Technology as a land surveyor with emphasis on Geodesy and Photogrammetry. He is working at Lantmäteriet since 1994 with various topics, mainly at the Geodetic Research Division. Currently he is the head of a group working with reference frame and co-ordinate system questions.

Mr Lilje is a member of the Swedish Map and Measuring Technique Society and the Nordic Geodetic Commission. Within the Nordic Geodetic Commission he is the chair of the working group for determining a Nordic Height Block.

Mr Lilje was secretary for FIG Commission 5 during the period 1998 – 2002.

Per-Anders Olsson

Mr Olsson works since 2000 as a research geodesist at the Geodetic Research Division at Lantmäteriet. His main task is validation and preparation of data for the third precise levelling of Sweden.

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