A New Co-ordinate System for Sweden

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Abstract

Sweden introduced the three-dimensional reference frame SWEREF 99 in May 2001. It is based on the permanent GPS stations that exist in Sweden, Norway, Finland and Denmark. The solution was adopted by the IAG subcommission of Europe (EUREF) as an ETRS 89 solution in 2000 and it is based on ITRF 97 epoch 1999.5.

SWEREF 99 will be the new national reference frame and hopefully it also will replace the local reference systems leaving us with more homogenous local reference systems. The situation today is that there exist several hundreds of more or less local reference systems based on various backgrounds. To do so, a map projection needs to be decided and this paper describes the work of introducing SWEREF 99 as well as working on the decision of a suitable map projection for users with demands from the mm-level to the m-level. Changing national and local reference frames affects all co-ordinate users from low-accuracy GIS-applications to high-accuracy scientific investigations.

1. Introduction

In Sweden, the responsibility for geodetic control networks is divided between local authorities and Lantmäteriet (National Land Survey). The main cause for this is mostly different aims. The responsibility for Lantmäteriet is to establish ground control for official mapping in small scales. The local authorities establish control networks for urban developments.

Lantmäteriet is the national geodetic authority but has no power against municipalities and other authorities. Lantmäteriet cannot do anything other than give proposal or advice to the local authorities concerning their reference systems.

Lantmäteriet is responsible for all national geodetic networks. The local authorities are responsible for their own networks. There is an on-going discussion at Lantmäteriet about replacing our national reference frame RT 90, which is based on the Bessel ellipsoid 1841, with a globally aligned reference frame. It is important that the new reference frame will be appropriate for a long time. The former three-dimensional reference frame SWEREF 93 did not fulfil this criterion perfectly. It was not officially approved by the IAG subcommission for Europe (EUREF) and it differs to the ETRS 89 realisations in the neighbouring countries. Furthermore, it represents the relations between the points, with respect to land uplift, at epoch 1993.6. Since then, we have had movements in the vertical component of c. 5-6 cm within the country.

Choosing an ETRS 89 solution approved by EUREF and originating from recent observation data, would give us good possibilities to get a reference frame that could last for a long time. Of course, the land uplift will continue, and even the new set of co-ordinates will be obsolete if we do not take the land uplift into account after some years. Starting from the land uplift epoch 1999.5, which is the epoch for SWEREF 99, will give us some more years to develop models for the movements within our country (and, not the least, methods to handle those models).

Continuing to work in the traditionally reference frames will force the users to use transformation formulae when using GPS effectively in Sweden, that means in connection to our permanent GPS reference network SWEPOS. Using transformation formulae will always result in distorting the quality of the collected data since no transformation formula is free from errors. Therefore, to benefit fully from satellite techniques and the high accuracy that the global reference frames have, the three-dimensional reference system SWEREF 99 should preferably be used nationally for both surveys and mapping. Lantmäteriet also recommends that SWEREF 99 should be introduced locally and together with the local authorities and others, we are currently working on finding a suitable set of map projections that will fulfil the needs both nationally and locally.

2. Why unified reference frame for all users

More and more users will be able to benefit from using geographical information for different types of analysis. The existence of positions in various forms for the spatial data is vital for the user. The use of modern technology as GPS and mobile telephones also gives private persons the possibility for accurate positioning in geographical reference systems. This will also put demand on interesting information used together with the positioning systems; the same geographical reference system must be used. Unification of the reference frames will be necessary. Many users of handhold GPS receivers have bad experience when trying to mark the position of the GPS on a printed map. If GPS gives co-ordinate in a global reference frame and the printed map is using a national reference frame, this would easily lead to errors in the order of 200-300 metres in Sweden.

The exchange of data both nationally and internationally will increase in the near future. Examples of such European project are CORINE Land Cover (Co-ordination of Information on the Environment), SABE (Seamless Administrative Boundaries of Europe) and the new initiative E-ESDI (the Environmental European Spatial Data Infrastructure). This type of project will benefit from homogenous reference systems over Europe. There are several international organisations working with these questions and in Europe this is mainly done by EuroGeographics and the IAG

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subcommission for Europe (EUREF).

3. Current situation nationally

3.1 Networks for horizontal control

In modern time, that means last century, we have carried out two national triangulation works in Sweden. The first started in 1903 and ended in 1951. The horizontal control system is called *The national triangulation network 1938* (RT 38). This system is still in use because many local networks are derived from it. The most modern triangulation took place between 1967 and 1982 and resulted in the horizontal control system called *The national triangulation network 1990* (RT 90). Associated to RT 90 are twelve regional subsystems, all of which were created for technical use.

The earth model (reference ellipsoid) for both RT 38 and RT 90 is Bessel's ellipsoid 1841.

3.2 Networks for vertical control

The first national precise levelling network was established for hundred years ago. Most of the benchmarks were situated along railways. The result of this levelling was *The national height system 1900* (RH 00). This system or systems derived from it are still in use. The second precise levelling started fifty years later and resulted in *The national height system 1970* (RH 70), which is the most modern national system and is used for national mapping. The third precise levelling is almost completed after 25 years of measurements and a new height system is expected in the beginning of 2004. This system will replace RH 00 and RH 70 as our national height system.

3.3 Networks for three dimensional control

Actually, we have introduced two three-dimensional reference frames in Sweden. These are SWEREF 93 and SWEREF 99. The latter one is based on ITRF 97 epoch 1999.5 and was accepted by EUREF in the summer of 2000. SWEREF 99 replaces SWEREF 93 as the national three-dimensional reference system. The reason is that SWEREF 93 (epoch 1993.6) was never accepted by EUREF. It was determined before EUREF had guidelines for how the realisation of ETRS 89 should be done nationally and SWEREF 99 agrees better with our neighbouring countries and the rest of Europe as well. GPS users in Sweden using data from our permanent GPS stations (SWEPOS) are automatically determining their position in SWEREF 99.

3.4 Geoid

Sweden uses geoid models calculated in co-operation with the Nordic countries in the framework of NKG (Nordic Geodetic Commission). Currently we are using two geoid models (NKG 89 and NKG 96) both fitted to the Swedish conditions.

The horizontal network in Sweden from the beginning of the 90's (RT 90) is using Bessels ellipsoid 1841 and the version of NKG 89 to be used in Sweden is therefore fitted to Bessels ellipsoid 1841. This version of the geoid model for Sweden is called RN 92.

NKG 96 is fitted to accurate determined GPS/levelling points in Sweden and corrected for the land uplift for the period 1970 to 1999.5 and the result is more correctly a height correction model. The model is called SWEN 01L.

GPS users in Sweden today are supposed to use SWEN 01L. RN 92 will not be used in the future.

A new Nordic geoid model in 2002 might result in a new height correction model for Sweden.

3.5 Map projection

Today, Sweden has a Gauss-Krüger projection. It was introduced for triangulation works in the southern part of the country in the first decade of the 20^{th} century. The table shows the chosen values for the projection-parameters.

Half major axis (a):	6 377 397.154 171 m
Half minor axis (b):	6 356 078.961 995 m
Central meridian (l_0):	15/ 48' 29.8" E*
Scale reduction factor (k_0):	1

* 2.5 gon W of the old Observatory in Stockholm

Table 1. Parameters chosen for Bessel's ellipsoid 1841 and Gaussian projection

Since 1946, the new topographical map in 1:50 000 and the economical map in 1:10 000 is produced in a grid system based on this Gaussian projection. The whole country of Sweden can be continuously mapped onto a plane with a maximum scale distortion of 1 700 ppm.

4. Current situation locally

4.1 Background

There were some attempts in the early part of the 20th century to establish a national cadastral system for rural areas. However, it was turned down because it would have been too costly in a sparsely populated country like Sweden.

The towns have always been responsible for their own networks. Since the merging of towns and rural areas in the 70's, all municipalities are in the same position.

4.2 Plane and height

The first horizontal control networks for towns were established in the beginning of the last century. Most of them are in a weak way connected to the national network prevailing at that time in Sweden. Since then, control networks have been established in almost every urban area. Nowadays we have 289 local authorities and almost everyone has their own control network. In some areas, there is more than one network because a forming of two or more municipalities into one has taken place.

In the 1920's, the projection mentioned above together with a system of six zones with 2.5 gon (2/ 15') between central meridians was also introduced for cadastral works in rural areas. The towns mostly had their own local systems.

The ellipsoid parameters as well as the projection parameters, see table 2 have been unchanged until 1993 when we did a slight change in the definition of the ellipsoid.

Table 2. Parameters chosen for Bessel's ellipsoid and Gaussian projection

Half major axis (a):	6 377 397.155 m
Flattening (f):	1:299.1528128
Central meridian (l_0):	15/ 48' 29.8" E
Scale reduction factor (k_0):	1

The situation for vertical control networks is similar. When the present height system RH 70 was introduced, most of the old municipalities decided not to change their height system. So we can, for excellent reasons, assume that we have at least 500 to 600 local control networks.

4.3 Three-dimensional

Three-dimensional reference frames are only used for GPS-measurements locally. The local users have been developed, often in collaboration with Lantmäteriet, good transformation formula between the three-dimensional reference system to the local two-dimensional plane system.

5. Suggestions nationally and locally

5.1 Reference system

The reference system used nationally must meet several criteria. It must be modern in such way that positioning using modern technologies should be possible without destroying the high accuracy that using modern instrument can achieve. It should make it possibly to exchange data with neighbouring countries and other users within the country easy and efficient, that means the connection must be well known or we should work in the same reference frame.

The introduction of SWEREF 99 as the national reference system for GPS was done during 2001. This means that positioning in relation to the SWEPOS stations is done in an accurate reference system well connected to our neighbouring countries and major part of Europe. This is not the case with RT 90.

Lantmäteriet has recommended to our government that SWEREF 99 is to be our official reference system for surveying and mapping. There has not been any decision yet but it will likely come during 2002. A decision that agrees with the proposal would mean that all data stored today in RT 90 in our databases should be transferred to SWEREF 99.

Locally, we have today several hundreds of different reference systems. Lantmäteriet recommends the local authorities to tie their local networks to the nationally or, preferably, change to use the national reference frame. To help the users today, we have a project running called RIX 95 that will calculate transformation parameters between the SWEREF 99 and the local networks meaning that GPS will locally be easier to implement.

5.2 Map projection

Before SWEREF 99 can replace the national reference system RT 90 and the local reference systems used in the municipalities, an official map projection has to be defined to SWEREF 99. An investigation of map projection to SWEREF 99 started during 2001.

A pre study has been carried out at Lantmäteriet, including both technical discussions of suitable map projections and an inventory on activities at Lantmäteriet dependent of co-ordinate or map projection. The outcome of the technical discussions was that the Transverse Mercator projection should be used and that several zones are needed for local surveying.

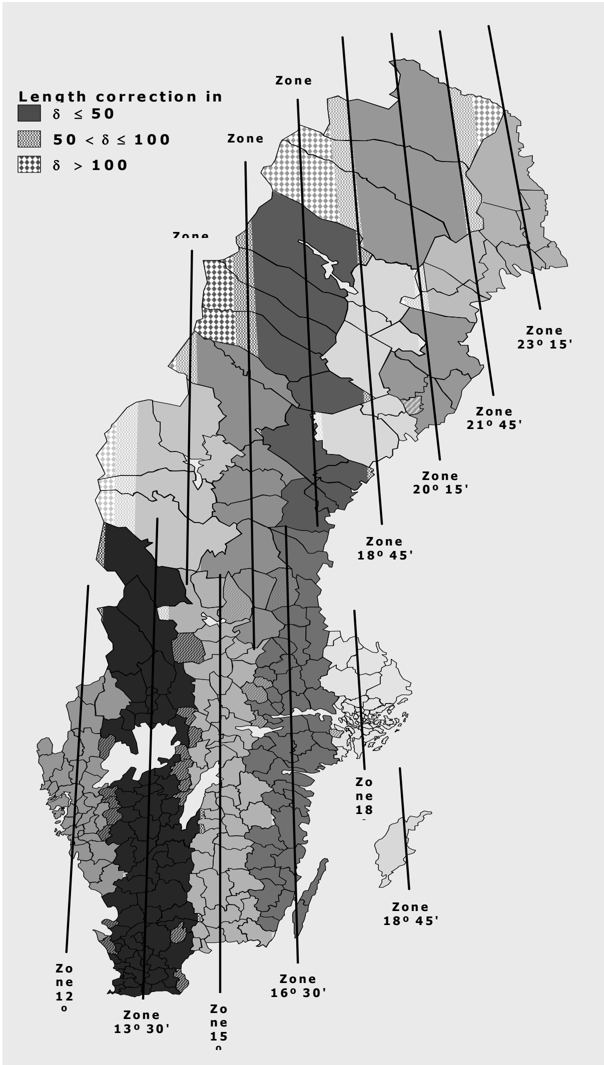


Figure 1. The proposed zone-system for local surveys

In a report to the government prepared during the autumn 2001 and after consultation with the Association of Local Authorities, Lantmäteriet proposed SWEREF 99 as a replacement of RT 90 in all official mapping activities. The proposal for the national map projection (small scale maps) is

– Transverse Mercator with central meridian, l_0=15°, and scale reduction factor, k_0 = 0.9996

– For local surveying, a system of zones with 1° 30' between central meridians and $k_0 = 1$ is recommended.

This report will be referred for consideration to different users outside Lantmäteriet, e.g. the municipalities, Swedish Defence, Statistics Sweden, Swedish Maritime Administration, National Rail Administration, National Road Administrations. A decision for the future is expected during 2002.

6. Connecting local co-ordinate systems to SWEREF 99 and RT 90

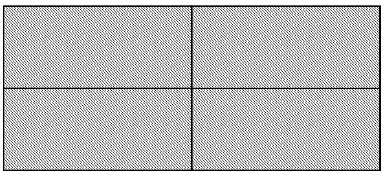
RIX 95 is a national project, which aims at creating high quality connections between local, national and global reference frames. With these connections we can study different transformation formulae and determine appropriate parameter-values. This project will also give us a mapping of RT 90 onto SWEREF 99 and that give us the opportunity to study local deformations of RT 90. This knowledge will be useful when we have to decide upon a new horizontal co-ordinate system.

The project started in 1994 and expects to be finished in 2005.

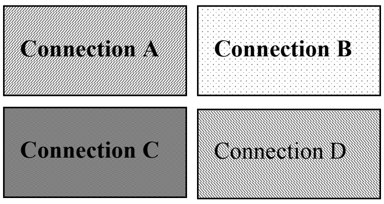
The production of high quality connections started during the spring 2002. As mentioned, we have in Sweden several hundreds of local systems, both horizontal and vertical. The discussion below will concern the horizontal co-ordinate systems.

Even though most of the local systems in one way or another are connected to RT 38 or RT 90, the systems are considered to be local in the work of producing the connections. Most local systems are only weakly connected to RT 38 or RT 90 giving them a different origin or scale than the national systems. In several areas of Sweden, the local systems in neighbouring municipalities are connected to each other which means that we must take this into consideration when calculating the transformation parameters. There are mainly three different cases:

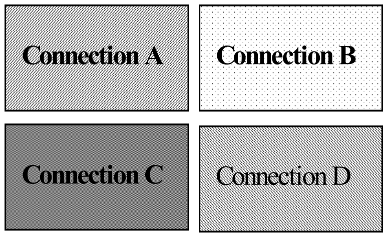
Case 1: One connection for several municipalities



Case 2: Separate connections for each municipality



Case 3: Separate connections but with jointly borders.



Going for case 1 would mean that municipalities who are tied to more or less the same co-ordinate system would get a connection that would give a homogeneity in the border areas. The disadvantage though is that the connection for each municipality will be of lower accuracy than if a separate connection would have been derived (e.g. case 2). On the other hand, the risk with case two is that there will be a discrepancy between the different municipalities is the border area. We are also the third method meaning that we calculate separate connections but by weighting we can control the connections so that they can give the same co-ordinates in the border area.

In the end it is up to the local authorities to decide which method that should be the official one in their area and the decision is made in discussion with Lantmäteriet.

The connections that we calculate are from RT 90 and SWEREF 99 to the local co-ordinate system. It is necessary to use both systems since the data in our databases are in RT 90 but GPS-users, especially in the ongoing Network-RTK projects, are using SWEREF 99. For the planned transition to SWEREF 99, we also need to calculate connections to SWEREF 99 with central meridian 15° as well as the proposed central meridian in the area for local surveying, see 6.2.

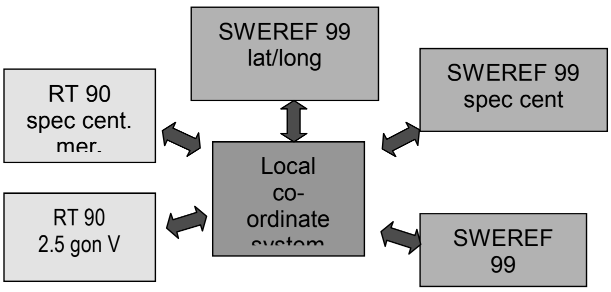


Figure 2: Different types of connections needed to be calculated.

The transformation between RT 90 and the local system, if the systems are in the same projection, is done by using a Helmert-transformation. Otherwise a conversion is also connected to the transformation.

A method has been developed at the Geodetic Research Division of Lantmäteriet to compute projection parameters which maps the latitudes and longitudes of one geodetic datum to Transverse Mercator northings and eastings of another datum. The method is used to map SWEREF 99 on the local co-ordinate system If the local co-ordinate systems are rotated compared to the national systems, the projection must be done in combination with a transformation. There are basically two different methods that we are using due to the fact that different software's can not use the same type of transformations see figure 3.

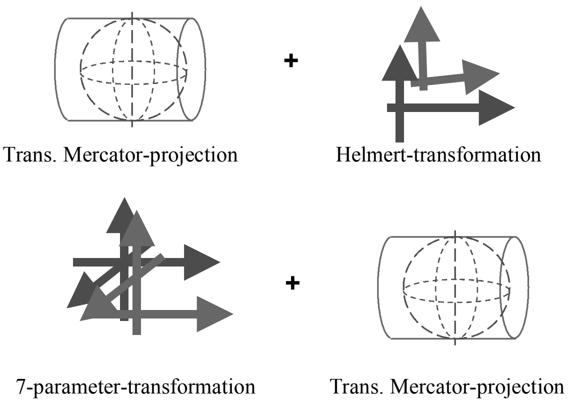


Figure 3. Different transformation combinations to handle rotated co-ordinate systems

Lantmäteriet calculates both combinations and the final decision on which combination that should be the official one is done by the local authorities in the municipality.

7. The future

New techniques and new methods give rise to new type of control networks. Will the use of GPS-techniques imply that we have no need for dense control networks? How shall we handle heights in new three-dimensional reference frames? These are questions that we have to deal with and there are no simple answers.

Up to now our control networks have been what we can characterise as ”passive” networks. In the future, we may have what we can call ”active” networks. If we have passive networks the user normally doesn't pay for using them but if we have active networks, the user will have to pay for them in some way. This situation is completely new and leads us beside technical problems into financial problems.

The height problem or can we get accurate heights above the geoid from GPS-measurements? The situation in Sweden is lucky because within a few years we will have a new height system. Our main problem in this area is to harmonise the new height system, the model of the geoid and the three-dimensional reference frame. A lot of effort is put on all these areas.

The financial problem, which was mentioned above, may lead us into different solutions for urban and rural areas.

In urban areas, exclusive the inner cities, we can introduce RTK-techniques with permanent reference stations. In rural areas on the other hand, it will be too expensive to establish permanent reference stations.

A possible solution for the future geodetic networks is some kind of active networks for urban areas, passive networks in the inner cities and in rural areas but of cause with different density.

8. Conclusion

Lantmäteriet has experienced that there is a need to minimise the large number of local systems in plane and height. Lantmäteriet has also realised that the reference frame used nationally should be closely aligned to what Europe is using. The same goes for the situation locally. The users can no longer ignore what the neighbouring municipality is doing regarding co-ordinate system. There is a large benefit from working together in co-ordinate systems that are tightly connected. More and more local authorities are also realising this and the process has started in a number of municipalities with the investigation of the quality of their local networks.

Our experience from the work that is done so far regarding introducing a common reference frame including map projections nationally and locally is that it is vital to have the users involved in the process early. In the end, it is their work that we are trying to change. It is easy to specify a very scientific approach of the problem but we always must have the usefulness of the result in mind, otherwise there is a risk that our efforts will not be used. As mentioned in the paper, there exist a large number of more or less local systems both in plane and height. What we are suggesting is that this number should be decreased to a handful. The best would be if all local users would change to the suggested new national reference frame (SWEREF 99) and use the central meridian that fits best to the area. The utopia would also include that all users would change their local height system to the new national height system, which should be released early 2004.

There is nothing at present foreseeing any measuring technique that is not working globally as GPS is doing. There is also more and more suggestions that the work conducted both on national level and on local level also can be used in the neighbourhood, region or Europe. Therefore, it is important that the reference frame and map projection that is being introduced should fit globally. Lantmäteriet is suggesting that SWEREF 99 (ETRS 89) should be used as the new reference frame in all applications together with a new map projection.

Lantmäteriet, together with other governmental agencies as well as local authorities are working extensively to connect local co-ordinate systems to the national reference frame and also to SWEREF 99. Lantmäteriet are presently calculating transformation formulaes between RT 90 and SWEREF 99 to the local systems in different ways trying to find the optimal solution for the specific region. This work is done in the project RIX 95.

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