Considerations and National Preparation for the use of the Global Reference Frame in Sweden

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Traditionally, reference frames for geodetic purposes in Sweden have been the classical ones with the horizontal and vertical frames separated. We also have a large number of local networks used in the municipalities. To benefit for the introduction of GPS, a global reference frame for introduced in the mid 90's called SWEREF 93. However, a map projection was never connected to SWEREF 93. Having good transformation formulas between the national and local systems as well to our global reference frame has always been an important issue for users and this has increased with the increase of the use of GPS and GLONASS.

GPS, as well as GLONASS, has been included in many different applications in Sweden. The geodetic purposes are only a fraction of the total number of applications for GPS where navigation is the major part. To help the users, a global reference frame SWEREF 93 was introduced and transformation formulas to the national horizontal reference frame RT 90 and to the vertical reference frame RH 70 was published.

We now believe it is time to move a step further and to introduce a three dimensional reference frame in Sweden. An updated EUREF realisation for Sweden has been accepted by EUREF this year. EUREF is a sub-commission of IAG. We will start two major projects in connection with the introduction of the new realisation. First, we need to have a map projection connected to the realisation so that the global reference frame can be used in e.g. map production. Secondly, we need to create a model that can handle the land uplift. The land uplift is up to 1 cm per year in some parts of Sweden and effect the reference frames so that a high accuracy reference frame as the new solution would have a limited life span if it is not modelled.

The paper will discuss the present situation in Sweden concerning reference frames as well as try to look forward what we believe will be the main strategic works within reference frames in the next couple of years.

Reference Frames in use in Sweden

The horizontal component

The first triangulation of Sweden lasted from 1815-1890. The resulting co-ordinate system was used for topographic and economic mapping.

The second triangulation started 1903 and ended 1950. The resulting system, named RT 38, is based on the Bessel ellipsoid 1841. The definition of the system is somewhat complex, as there is no unique fundamental point. The defining latitude was originally taken from "Nikolai torn" in Copenhagen, while the longitude is related to the old astronomical observatory of Stockholm. The orientation comes from some ten Laplace stations and the scale is determined by five base lines measured by invar chains. No correction for the geoid is applied.

The configuration of the first order network in the second triangulation was closed chains of triangles. Concurrently with the topographic mapping, a second order net was measured, filling in the empty spaces of the network.

With the advent of EDM-technique, many towns and municipalities started to renovate their local networks. Trying to connect these networks to the national network caused a lot of trouble, as the RT 38 system was not accurate enough. For this reason a third systematic triangulation of Sweden started in 1967 based on EDM technique to almost one hundred percent. The average distance between stations is 10 km for most parts of the country. During the survey, most of the local networks were connected to the primary network.

The triangulation work lasted for about 15 years. In order to make the co-ordinates available to the users at earliest possible date, it was decided to divide the country into twelve regions and compute a separate solution for each region as soon as the fieldwork of the region was finished. To facilitate the transformation of co-ordinates, the regions are partly overlapping each other. The third triangulation thus resulted in twelve separate co-ordinate systems. These systems are designated RT R01, RT R02 etc, and are mainly used for cadastral surveying but also for different types of map projections in the municipalities.

For projects, like building roads, railways or pipelines, which often run through several regions, the regional systems are not so well adapted. The regional co-ordinate systems were not suitable for national mapping either. Therefore, in 1987, a least square adjustment was carried out, which included not only the data of the second and the third triangulation of Sweden, but also the first order networks of Denmark, Finland and Norway. The computation was done at the National Survey and Cadastre in Copenhagen.

As a conversion to a new geodetic datum would have been very costly and time wasting operation for the Swedish society, it was decided to transform the solution to the old Swedish datum. The co-ordinate system obtained this way is named RT 90. The largest difference between RT 38 and RT 90 is 4.8 meters (Reit, 1995). Studies of the internal accuracy of RT 90, using GPS, show that regional deformation of up to 15 cm exist. The relative accuracy is around 1-2 mm/km when the separation of the stations lies in the interval 10-30 km.

The vertical component

Precise levellings have been carried out since the end of 19th century. The first precise levelling of Sweden took place 1886-1905 and used the mean sea level in Stockholm year 1900 as the fundamental point. The levelling lines were running along railways, mostly at the coast of the Baltic Sea. The standard error after adjustment was 4.4 mm/$\sqrt{\text{km}}$. This height system is called RH 00.

The second precise levelling (1951 - 1967) had an extent of about twice the first (10 389 km) and included approximately 9 700 benchmarks. Most of the levelling (75%) were made along railways and the rest along roads. The standard error after the adjustment was 1.63 $mm/\sqrt{km}$. This height system is called RH 70. Zero point for RH 70 is Normaal Amsterdam Peil. This means that this system is connected to the European UELN-systems. The adjustment is calculated with the epoch 1960.0 and then changed to 1970.0 with the use of land uplift values.

A working group at the NLS studied the status of the second levelling network in the middle of the 1970s. Due to the suggestion from the working group it was decided that a new precise levelling of Sweden should be done and preparations started. (Becker, 1998)

The motorised levelling technique was presented to the world in the 1970s. Based on a report from Becker, it was decided that the technique should be tested in Sweden. The first motorised levelling in Sweden were made during the summer 1974 and the results achieved exceeded all expectations both concerning quality and production costs. More tests in 1975 confirmed the result from 1974.

The third precise levelling of Sweden started in the end of the 1970's. The total number of benchmarks in the new network will be around 50 000 covering the whole of Sweden and it is performed as one unified network and not as a network of two different orders (i.e. a primary network with subsequent densification). The new height network is expected to have an accuracy of 1 $mm/\sqrt{km}$. This has also been verified through several test adjustments.

The height network is based on closed loops along roads with a circumference of 80-120 km. The local needs are considered when planning the network and the distance between two benchmarks is about 1 km. The establishment of benchmark is done with great care to secure long term stability.

More details concerning the project can be found in e.g. Becker (1998) and Lilje (1999)

A final adjustment will be made when the network is completed and the data quality is checked. There are plans on a common Nordic adjustment since national precise levelling is done in Denmark and Finland at the moment. The height network will then also be distributed to be a part of the European height networks.

Figure 1. The third precise levelling of Sweden

Local co-ordinate systems

The first control networks for the municipalities were established in the beginning of this century. Nowadays we have 289 local authorities and almost every municipality has their own control network. The situation is the same for both horizontal as for vertical control networks, which means that there exist some 500 to 600 local control networks.

The National Land Survey, who are responsible for the national networks, has no power against the local municipalities and can therefore only give advise or propose action.

Much of the large scale mapping, and civil engineering work, is to a high degree based on a number of local reference systems. These are often only loosely connected to RT 90, to RT 38, or connected to one of the 12 regional systems that also origin from the third triangulation. The local authorities are responsible for these local networks.

In most cases there exist transformation formulas between the local systems and RT 90, useful for cartographic purposes at the "some dm level".

Since the introduction of RT 90 as well as the 12 regional co-ordinate systems, many municipalities have however realise the advantages there are in easily been able to share data with other municipalities and in this work use the regional or national co-ordinate system. Therefore a lot of effort has been put into trying to find good transformation formulas between the local and the national co-ordinate systems. Among the work, also a national project (RIX 95) can be mentioned where we are working us through all of Sweden trying to make the national triangulation network more accessible for GPS-users as well as connecting all the local horizontal co-ordinate systems. This project will also be a good base for the different local authorities to investigate the quality of their local co-ordinate systems and to help them to improve them if necessary.

SWEREF 93 – the Swedish version of EUREF 89

SWEREF 93, was determined 1993-94 before there were any official guidelines how to realise ETRS 89. SWEREF 93 was connected to EUREF by a 6-parameter transformation to the co-ordinates of 11 stations from the original EUREF 89-campaign. The rms-values of the residuals are 14, 14 and 23 mm for the north, east and height components respectively. SWEREF 93 has a high internal accuracy but differs on the 5 cm-level to the neighbouring ETRS 89-realisations in the Nordic countries. SWEREF 93 has mainly been used for intermediate steps in GPS-processing and the use of it for final presentation is so far limited, but this will very soon change. In the national project RIX95, which aims at getting transformation relations between different reference systems used in Sweden and to densify the national reference network, thousands of points have been preliminary determined in SWEREF 93.

SWEREF 99 - an updated EUREF realisation for Sweden

In Sweden we are planing to replace our national reference frame RT 90, which is based on the Bessel ellipsoid, with a globally aligned reference system. It is important that the new reference system will be appropriate for a long time. SWEREF 93 does not fulfil this criterion perfectly. It is not officially accepted by the European community and it differs c. 5 cm to the ETRS 89 realisations in the neighbouring countries. Furthermore it represents the relations between the points with respect to the land uplift at epoch 1993. Since then we have changes of c. 5-6 cm within the country in the height component.

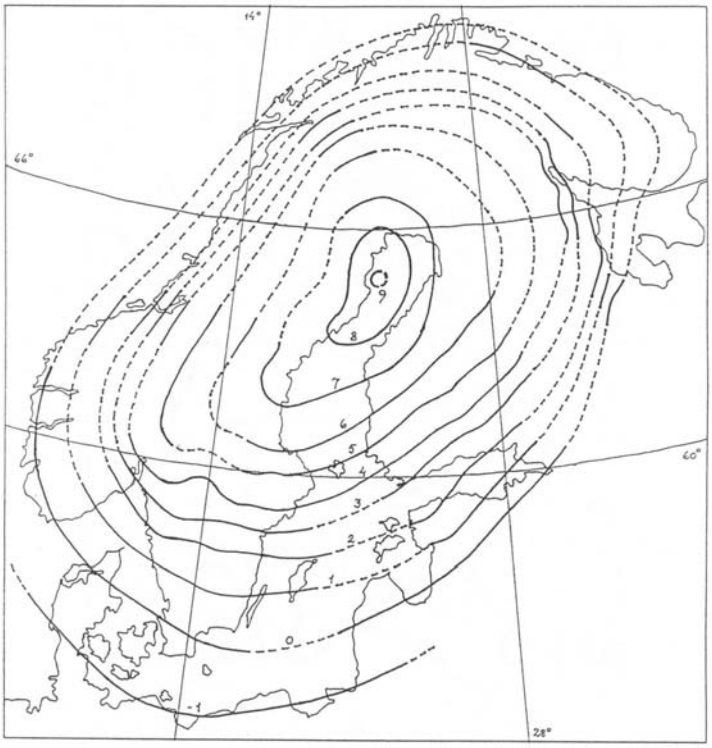

Figure 2. Apparent land uplift from the model by Ekman (1998).

Choosing an ETRS 89 solution accepted by EUREF and originating from recent observation data, would give us good possibilities to get a reference system, that could last for a long time. Of course the land uplift will continue and also the new set of co-ordinates will get obsolete if we do not take the land uplift into account after some years. The advantage with a newer reference system is that we will get some more years to develop models for the movements within our country and especially methods to handle those models in practical life (when needed).

The primary demand on the new Swedish ETRS 89 is that it should be accurate, homogeneous and consistent with normal GPS processing, so that a ordinary GPS user not will run into problems due to the reference system. The new Swedish ETRS 89 should also agree as well as possible with the ETRS 89 realisations used in our neighbouring countries – Denmark, Norway and Finland. It might also be an advantage if the new Swedish ETRS 89 has a specific epoch with respect to the land uplift, as we later on intend to model this kind of movements within Sweden.

More details concerning the campaign, processing and results can be found in Jivall (2000).

Figure 3: Stations included in the campaign in creating SWEREF 99.

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What do we expect from the future?

The vision we are working towards, is the availability of a nation wide RTK-service, with an accuracy at the 1 cm level (1D, 1σ) together with an increased used of GPS in the society for navigation and positioning.

In a network concept of Permanent GPS Stations, available data from several stations can be combined in an optimal way. A real time model for the ionosphere and the troposphere are computed based on the observations at the GPS stations. This model together with carrier phase data for RTK surveying will be distributed to the users in real time. For data distribution, the FM sub carrier DARC (Data Radio Channel) seems to be a promising alternative. The primary goal is not to reduce the need for a lot of geodetic points in a dense reference network. This is just a nice side effect. What is important is the possibility to make surveying of details and setting out more effective. The working hours can be used for surveying, and less time spent on searching for geodetic reference points, establishment of base station etc. The use of an active reference network will also reduce/eliminate possible errors connected to the set up of the local base station.

Figure 4: SWEPOS-net

It can not be told whether the 1 cm accuracy can be achieved or not, using current stations in the SWEPOS© network (200 km between stations). Densification in areas with high activity would be a possible alternative. A co-ordination on a regional or national level should be done to achieve optimal efficiency.

Requirements on the reference frame

The reference system needed to support the vision on RTK on the centimetre level must have equal or better accuracy compared to the possible internal accuracy in the network RTK service. This means that accuracy at the 1 cm level at least for areas of the size equal to the distance between the reference stations, and preferably for the whole network.

The internal processing within the RTK service, to determine the ionosphere/ troposphere error model, can use latest ITRF in actual epoch. However, for practical use, the reference frame must be stable also in time, e.g. co-ordinates for rail tracks need to be stable from day to day. This is a problem in Scandinavia, where the post glacial land uplift (maximum about 1 cm/year) cause deformations in the vertical as well as the horizontal components.

The RTK service will deliver heights above the ellipsoid. For practical use, height above the geoid will be most suitable. Therefore, a geoid model at the 1 cm level is needed if we want to take full advantage of the possibility from the network RTK concept.

Further activities needed

To be able to change reference frame, and to transform spatial information into a new system, the relation between the two systems RT 90 and SWEREF 93 (shortly SWEREF 99) as well as possible deformations must be known. The RIX95 project provides a foundation to investigate regional deformations in the RT90 reference frame. To be able to take full advantage from RIX95 and the RTK-service that we are developing, the local authorities must go on with evaluating and improving the local reference systems, until sufficient accuracy in the transformation to RT90 and SWEREF93 (shortly SWEREF 99) have been reached. Our aim is to change from RT 90 to a global three dimensional reference system as SWEREF 99 both for the daily work of the surveyor but also as reference frame for our spatial data.

The active reference net, SWEPOS, must continue to be developed and the aim is to make it possible to conduct RTK measurements on the cm/dm-level nation wide. For this purpose it will be necessary to have a co-operation with the local municipalities so that we co-ordinate the location of the permanent GPS stations.

It is not easy to perform height measurements with GPS comparable with precise levelling on short/medium distances. One of the problems is the fact that we do not have a geoid that is accurate enough. Therefore, it will be important to complete the ongoing precise levelling and also to connect local height networks to the national one. For the latter part, some densification of the height network will be needed as well as some investigations on the quality of the local height networks. We will also need an improved geoid model as well as improved model for land uplift.

It will be necessary for the local municipalities to investigate the quality of the local networks, both the horizontal and the height networks. We even suggest that a global 3D-reference frame should replace the number of reference frames that can be found on national and local level. It will therefore also be necessary to connect the global 3D-reference frame with a map projection. Traditionally, we have been using a Gauss-Krüger projection and there is a lot saying that we should continue to do so.

With the introduction of SWEREF 99 we now have a geodetic reference frames accepted by EUREF. We needed this upgraded SWEREF because SWEREF 93 was eight years old and was distorted due to the land uplift that we have. There is no component today in SWEREF 99 to handle this problem but we will work hard the next years on trying to find a suitable model for the land uplift. The usage of GPS today and the introduction of RTK and especially network RTK is important for the introduction of the new reference frame but the most important reason for the change is probably that all our spatial data will after the change be based on a modern reference frame that is accurately connected to Europe. This will increase the value of the spatial data and our databases.

Conclusions

Our vision for the future is an increased use of active reference networks based on permanent stations for GPS (and other global satellite navigation systems like GLONASS and Galileo). The vision requires the introduction of the global reference frame as well as model for land uplift and a high accuracy geoid.

However, large amount of spatial data has been collected during the years. This information has a very high value, and it should not be lost or degraded when changing reference system. Our beliefs are the opposite. With a new high accurate reference frame that is strongly connected to other reference frames in our neighbouring countries, the value of the data in our databases will increase. The transition from the use of local and national reference systems, to the introduction of the global reference frame, will therefore require much effort spent on investigating the reference systems currently in use.

We also believe that GPS will not be compared to levelling when accomplishing a new height network which mean that we must fulfil the third precise levelling of Sweden as well as try to connect the local height networks.

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