The Process of Changing from Local Systems into SWEREF 99

– *A Challenge for Lantmäteriet and a Great Step for the Municipalities*

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Abstract

Lantmäteriet has decided that SWEREF 99, the Swedish realisation of ETRS89, shall be the Swedish official reference frame. In the Swedish National Geodata Strategy formulated by the Geodata Advisory Board there is a strategic goal “all bodies that produce, manage, provide and use geodata should utilise the national geodetic reference systems, SWEREF 99 and RH 2000”.

Sweden consists of 290 municipalities; all of them have more or less used their own geodetic control networks. The local systems were usually old and not strongly linked to the national co-ordinate systems. Lantmäteriet has not the power to force the local authorities to adopt the national co-ordinate system also locally, why more or less every municipality has had its own system. Most of the local authorities are now in the process of changing system and today about 60% of the municipalities use the national reference system.

The paper describes the process of changing from a local system into SWEREF 99. The concept of direct projection used for transformation of coordinates, our analyzing tool and correction method of distorted coordinates will be presented.

1 Introduction

The implementation of SWEREF 99 as the national reference frame started in 2001, when it was introduced in SWEPOS[TM], the national network of permanent GNSS reference stations. Since 2007, Lantmäteriet has produced its maps and databases in SWEREF 99. The introduction and implementation of SWEREF 99 is also ongoing in other governmental authorities and agencies, as well as in the municipalities.

The Swedish Geodata Advisory Board has presented eight strategic goals in the Swedish National Geodata Strategy. One of them regards the geodetic reference frames: “*All bodies that produce, manage, provide and use geodata should utilise the national geodetic reference systems, SWEREF 99 and RH 2000*”. This is completely in line with the INSPIRE directive that prescribes that data exchange should be done using ETRS89 and EVRS.

2 The progress of implementing SWEREF 99

2.1 Governmental agencies

During the last four years, Lantmäteriet has – on behalf of the Swedish Geodata Advisory Board – performed a yearly inquiry among the Swedish governmental authorities and agencies, to find out the status of their introduction of SWEREF 99. Approximately 40 agencies were asked and generally around 30 of them answered that they are handling geodata. Most of them have earlier used the old national reference frame RT 90, sometimes in combination with local co-ordinate systems. Figure 1 below shows the progress of the implementation of SWEREF 99 in the governmental agencies.

During the last inquiry (performed in November 2010), 16 agencies replied that they are using SWEREF 99 as the main geodetic reference frame and five agencies answered that they are partly using SWEREF 99.

In the 2009 inquiry, several agencies replied that they were going to do the transition to SWEREF 99 during 2010, but when performing the 2010 inquiry, Lantmäteriet was informed that many of them had postponed their transition to 2011.

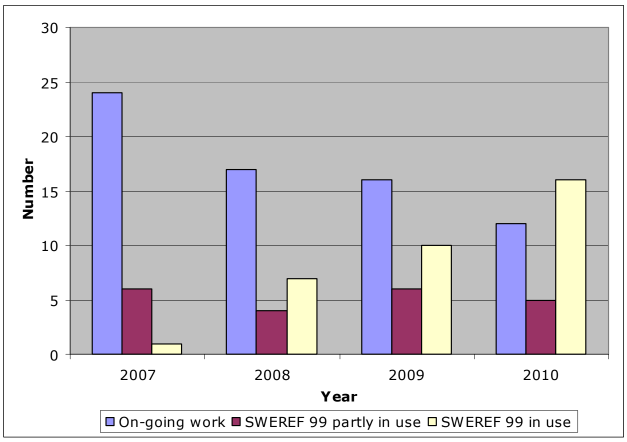

Figure 1: *Diagram showing the progress of the introduction of SWEREF 99 in the Swedish governmental agencies.*

2.2 Municipalities

The local authorities often have introduced GNSS surveying into their business and thus they have experienced the inconvenience of transforming data from SWEREF 99 to the old local co-ordinate systems. Using GNSS also reveals the distortions of the local system, which might be an important reason to do the transition to the new, homogeneous reference frame.

Lantmäteriet considers these factors to be some of the main reasons for the great acceptance of – and the relatively quick transition to – SWEREF 99 among the municipalities. Figure 2 shows the progress of the implementation of SWEREF 99 in the municipalities.

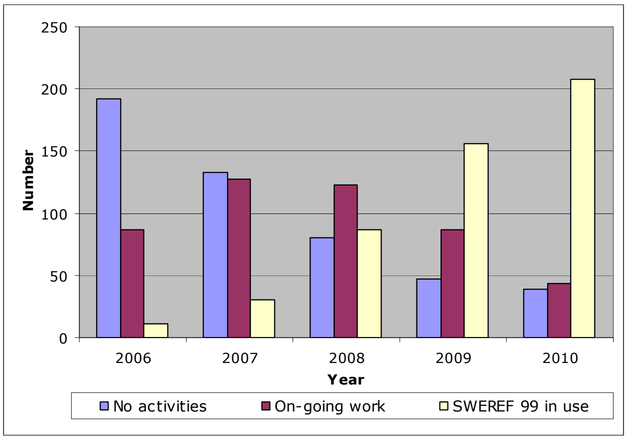

***Figure 2**: Diagram showing the progress of the introduction of SWEREF 99 in the municipalities.*

3 Background

3.1 History of the local co-ordinate systems

The first control networks for municipalities were established in the beginning of the last century. Most of them were connected to the national network prevailing at that time in Sweden, but often in a very weak way. Since then, control networks have been established in almost every urban area. Nowadays there are 290 local authorities and almost every municipality has their own control network. In some municipalities even more than one reference frame has been used, because a fusion of two or more municipalities into one has taken place.

In Sweden, the responsibility for geodetic control networks is divided between the local authorities and Lantmäteriet. The main cause for this is different aims of the systems. The responsibility for Lantmäteriet is to establish ground control for official mapping in small scales, while the local authorities establish control networks for urban development.

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

Lantmäteriet is responsible for all national geodetic networks, whereas the local authorities are responsible for their own networks. In 2003, a decision was made to replace the national reference frame RT 90, which is based on the Bessel 1841 ellipsoid, with a globally aligned reference frame, SWEREF 99, which will be appropriate for a long time. This replacement started a few years ago and is still on-going. Lantmäteriet did its official change in January 2007, meaning that e.g. all data stored in RT 90 were transformed into SWEREF 99 and all the official products, as public maps, now are produced in SWEREF 99.

3.2 Work done on national and local level

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

Locally, we have had several hundreds of different geodetic networks. Lantmäteriet recommends the local authorities to tie their local networks to the national reference frame or – preferably – to use the national reference frame. To help the users, a project called RIX 95 has been running from 1995 and ten years on. One of the outcomes of the project were transformation parameters between SWEREF 99 and the local co-ordinate systems, meaning that it locally will be easier to implement and utilize GNSS. One of the results from the development of the transformation parameters is a map of the residuals that exist. These residuals are then used when computing the correction model.

4 Transformation method

The RIX 95 transformation parameters are normally based on a so-called *direct projection* (see section 4.1), in some cases combined with a similarity transformation in two or three dimensions.

The direct projection approach means that the plane local co-ordinates can be transformed directly to geographic co-ordinates in e.g. SWEREF 99, using an ordinary Transverse Mercator projection.

As mentioned earlier, the residuals from this RIX 95 transformation form the basis for the correction model, used to rectify the distortions of the local co-ordinate system. Several rectifying methods were tested and the most suitable method appeared to be interpolation of residuals in Delaunay triangles (Svanholm 2000; Alfredsson, 2002).

Interpolation of residuals in Delaunay triangles has, so far, produced correction models well enough for their purposes. The method is quite easy to handle and it is possible to manipulate the correction model by using fictitious control points, if required. The natural neighbour method produces equally good results (Bosrup & Illerstam, 2009), but if a manipulation of the model is required it is more difficult to predict the result of the operation.

The correction model is used as figure 3 shows, in combination with the RIX 95 transformation parameters. As the arrows indicate, all of the transformation steps can be done in both directions.

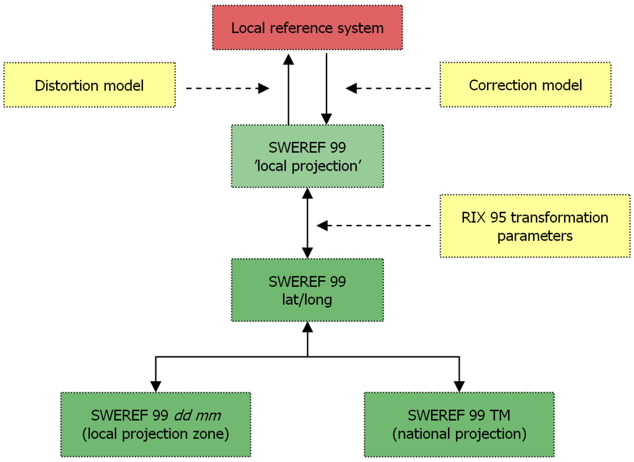

***Figure 3**: Transformation schedule for local reference systems to and from SWEREF 99.*

The production of the correction model is done in co-operation between Lantmäteriet and the municipality, and is normally an iterative process (Kempe, 2006).

4.1 The Direct projection approach

In 1997 B-G Reit proposed a method (Reit, 1997) that in most cases makes it possible to shorten the transformation sequence. This approach is based on the assumption that *"given a geodetic datum A and a plane rectangular system of another datum B, it is possible to find a set of projection parameters (using the same projection as used for the given plane coordinates of datum B) to define a plane system of datum A, which approximates the plane system of datum B"*. In strict mathematical sense the two systems will not be coincident, but the differences may be acceptable for some applications.

Projection fit based on Transverse Mercator projection with the formulas of Gauss-Krüger

The concept of the direct projection is to project the geodetic (global) system directly to the local system. The approach is as follows (from Reit, 2010):

Given: A number of points with known geodetic coordinates (φ, λ). We also know the coordinates (x, y) in a grid system.

Sought: A Transverse Mercator projection (TM projection) that converts the given (φ,λ) values into grid coordinates (x, y) that coincides with the given (x, y) values.

To perform a TM projection one needs to specify the semi-major axis (a) and flattening (f) of the ellipsoid used, the longitude of the central meridian (λ_0), the scale along the central meridian (k_0) and the false Northing and Easting (x_0) and (y_0). We assume that the ellipsoid parameters a and f are known.

Note that the ellipsoid parameters are always taken from the system with the given (φ, λ) values.

We regard x and y as functions of the projection parameters according to the following $x=x(\lambda_0, k_0, x_0, y_0)$ and $y=y(\lambda_0, k_0, x_0, y_0)$. As usual we do a Taylor series expansion around the approximate values (λ_0), (k_0), (x_0), (y_0). The observation equations then become

where $\Delta\lambda_0$, Δk_0, Δx_0 and Δy_0 are unknown corrections to the

$$x + v_x = x((\lambda_0),(k_0),(x_0),(y_0)) + (\frac{\partial x}{\partial \lambda_0})_0 \Delta\lambda_0 + (\frac{\partial x}{\partial k_0})_0 \Delta k_0 + (\frac{\partial x}{\partial x_0})_0 \Delta x_0 + (\frac{\partial x}{\partial y_0})_0 \Delta y_0$$

$$y + v_y = y((\lambda_0),(k_0),(x_0),(y_0)) + (\frac{\partial y}{\partial \lambda_0})_0 \Delta\lambda_0 + (\frac{\partial y}{\partial k_0})_0 \Delta k_0 + (\frac{\partial y}{\partial x_0})_0 \Delta x_0 + (\frac{\partial y}{\partial y_0})_0 \Delta y_0$$

approximate values and v_x and v_y are the residuals of the observed (known) values x and y.

The approximate values for the unknowns prior to the first iteration are set as follows:

Since the false northing and easting, x_0 and y_0, are linear parts of equations and the approximate values for them can be set to 0, but tests show that 0 is good enough also for λ_0. If one wishes to improve the convergence λ_0 can be set to the average of the smallest and the largest longitude of the common points. For k_0, a suitable choice is 1. The corrections of the parameters are solved for in the over-determined linear equation system with the method of least squares, after which they are added to the approximate values before the next iteration. Normally, the procedure has a rapid convergence.

Badly oriented networks

If the local co-ordinate systems are rotated compared to the global system, the projection must be done in combination with a transformation. There are basically two different methods that have been used due to the fact that different software can not use the same type of transformations, see figure 4. These two methods give almost the same accuracy but not the same co-ordinates. 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.

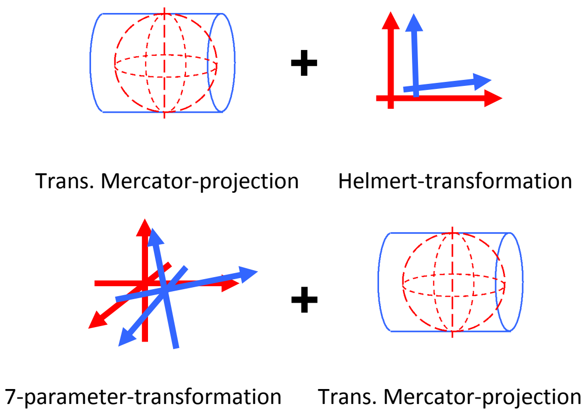

***Figure 4**: Different transformation combinations to handle rotated co-ordinate systems.*

4.2 Applications of the *Direct projection* method

Since the *direct projection* method was introduced it has been applied within Sweden. In the beginning it was seen as a complement to the 7-parameter transformation but in course of time it became more or less the main method in all cases.

Transformation of local systems

Changing from a local system into a SWEREF 99 system needs a transformation that includes a datum shift. Since on the one hand most of the control points in the local triangulation networks do not have heights and on the other many of the local systems do not have a rigorous geodetic definition it was obvious to use the direct projection approach. The result is very good and the RMS value for the residuals is normally between 0.01 and 0.08 m. The maximum residual is normally less than twice these values. Taking into account that the internal geometric quality in these local networks is of the same order we can not expect better results.

4.3 Direct projection vs 7-parameter transformation

The experiences from our work with transformation of local as well as national systems with the direct projection put up some questions. Is it possible to use direct projection elsewhere or are the conditions in Sweden special?

For Sweden and Finland we have compared results from 7-parameter transformation and direct projection. In table 1 the result from these tests and tests in Australia by Featherstone (Featherstone & Reit, 1998) are listed. It is obvious that the differences between the two methods relative the old co-ordinates are not so big. It means that the accuracy is almost the same but the figures are different.

***Table 1**: Statistics of the differences between transformed and projected co-ordinates. The number of points in Sweden was 185, in Finland 90 and in Australia 82.*

	Sweden		Finland		Australia	
	7-par transf.	Dir. proj.	7-par transf.	Dir. proj.	7-par transf.	Dir. proj.
RMS (m)	0.066	0.073	0.903	1.073	-	-
Max (m)	0.189	0.221	2.149	2.379	2.036	2.036
Min (m)	0.001	0.004	0.047	0.106	0.031	0.052
Mean (m)	0.055	0.063	0.806	0.970	0.630	0.663
Std (m)	0.038	0.040	0.408	0.462	0.340	0.444

5 Analysing the distortions

Lantmäteriet has developed a Matlab tool (Kempe et al., 2006) to analyse the variation of distortions of the local network. Where distortions vary a lot, more control points are needed to construct a high quality correction model than if the variations are continuous. The image map produced in Matlab (see figure 5) can aid the analysing, to see where more points need to be added to increase the quality of the correction model or to find deviant points to be removed from the correction model.

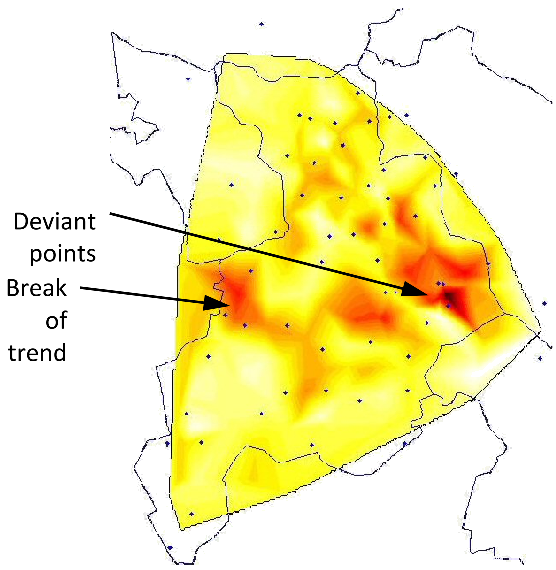

***Figure 5**: Red/dark colour indicates areas of large variations of the control network distortions. These areas are further investigated and more control points might be needed for the correction model.*

5.1 The correction model

To reduce the local distortions of the local co-ordinate systems, studies of several rectifying methods were carried out (Svanholm, 2000; Alfredsson, 2002). Four methods were tested and those were point-by-point transformation based on both Helmert transformation and Affine transformation, interpolation of residuals in triangles based on the common control points themselves and with fictitious common control points. Based on the results from the studies, we decided to use the method with interpolation of residuals in Delaunay triangles as our rubber sheeting algorithm.

Selection of control points

Common control points are selected in the areas where a correction is needed. As the rubber sheeting algorithm used is a triangular model it is important that the control points surround the area. Otherwise the control points in one community can affect the correction values in another community. In the smallest communities or local control network parts it is recommended that at least 3-6 common control points are selected for use in the correction model. For larger control networks a densification of the common control points of course is needed. We recommend a control point spacing of 500-700 metres, but from the beginning a more sparse distribution of control points can be used. The distortion analysis will show if a densification of the control point distribution is needed in some areas. The objective is to map the distortions of the local control networks. Lantmäteriet recommends mainly two methods for surveying of these control points, namely rapid static GNSS survey or RTK survey. The co-ordinates of the control points must be determined in a controlled way, as the future control network accuracy is directly dependent of these control points. The errors to be modeled by the correction model shall ideally concern system errors only and not errors from the survey.

Evaluation of local control network distortions

The GNSS-surveyed common control point co-ordinates are transformed to the local co-ordinate system using direct projection approach. The residuals from the comparison of these co-ordinated to the "true" local co-ordinates are then analysed.

To facilitate the analysis of the variations of the distortions of the local control network, a Matlab tool has been developed.

- One of the two residual vectors along a side of the Delaunay triangulation is moved to the other one.
- A vector subtraction is done to get a resulting vector of length *d*.
- The *d* value is then handled as a scalar and is moved to the middle of the triangle side. The *d* values are normally weighted inversely to the square of the point distance or absolute, i.e. no weighting. The first case is most often used, but the latter case is a useful complement in some cases.
- Perform the vector subtraction and transfer of the *d* values for all triangle sides.
- The *d* values can then be plotted as an image map (for an example, see figure 8) using e.g. Matlab.

Figure 6 below will illustrate how the analysis tool works.

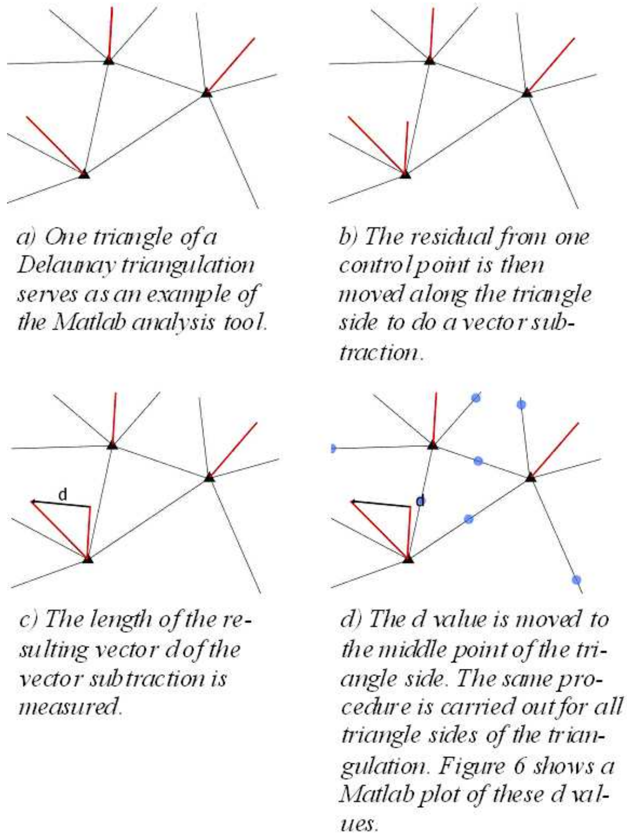

Figure 6: *Illustration of the Matlab tool.*

An example can further illustrate the procedure of analysing the distortions of the local control network. Figure 7 shows the common control point residuals after transformation with the direct projection. There are 24 control points and the size of the largest vector is a little more than 10 centimetres. The Matlab plot is shown in figure 8 below. The red (dark) colour shows areas with large variations in the distortions where there might be a need to have a further look into the distortions, whereas the bright colour are areas of higher homogeneity. The next step is to further map the variations and thus another six common control points were included (see figure 9). At the same time the two deviant control points in figure 8 were excluded, as they did not represent the local control network very well.

The selection of common control points and analysis of the variations of the distortions is an iterative process that continues until the accuracy is adequate for rectifying of the local control network.

Figure 7: *The residuals after transformation of control points with direct projection.*

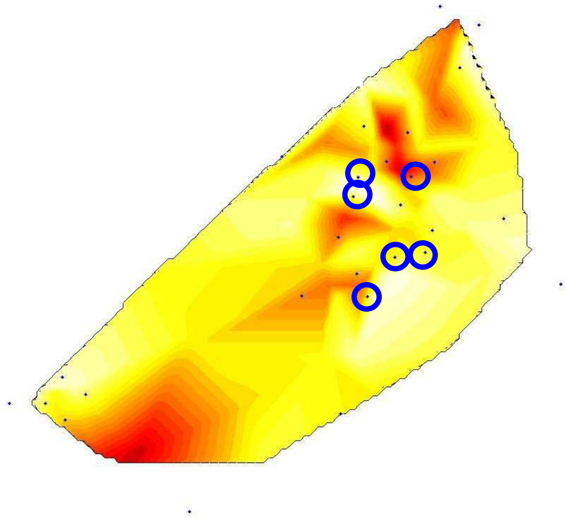

Figure 9: *The variations of distortions of the local control network, after inclusion of six supplementary common control points and exclusion of the two deviant points shown in figure 8.*

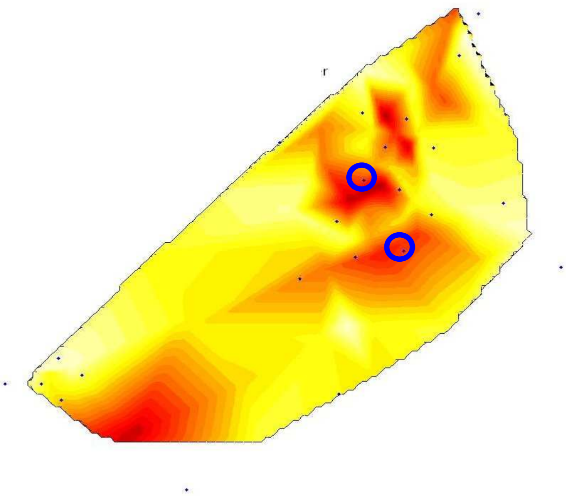

Figure 8: *The variations of distortions of the local control network, based on the residuals shown in figure 7. The distortions are weighted inversely to the square of the point distance. The two marked common control points were deviant, and finally excluded.*

6 Concluding remarks

SWEREF 99 seems to be more quickly accepted by the municipalities (local authorities) than by the governmental agencies. Probable reasons could be

- the local authorities have utilized distorted local co-ordinate systems to a larger extent than the governmental agencies, which mainly have been using the old national reference frame,
- the municipalities have been using GNSS surveying more frequently than the governmental agencies,
- the governmental agencies are mainly producing and handling small-scale geodata, implying that high quality transformation results might not be crucial.

Altogether this could indicate that co-ordinate transformations and distorted local co-ordinate systems have been worse problems to handle for the municipalities than for the governmental agencies.

Finally, it can be mentioned that the introduction of the new height system, RH 2000, also is ongoing but at a slower pace.

There has been a growing demand for a high quality national elevation model during the last few years. The production of such a model started in 2009, and it will be produced using RH 2000. To get the most benefit from this model the users will have to utilise RH 2000, so we hope that this shortly will increase the interest in analysing the local height systems and doing the transition to RH 2000.

The direct projection offers a simple and efficient method to transform co-ordinates between the existing and new reference frame (datum) and map projection. The accuracy is commensurable with the 7-parameter transformation and much more easy to use. When using some GIS software that have implemented the 7-parameter transformation for transformation of the 2D-position (horizontal) also the heights will be altered and special arrangements have to be inaugurated. Using direct projection no such problem will occur.

Our experiences are that the approach with simple interpolation in Delaunay triangles has turned out to produce correction models good enough for their purposes. As an example, the correction model covering five municipalities (600 km^2) in southern Sweden gives results better than 2 cm. That is the same level of accuracy as both the RTK measurements and the position in the old network.

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